



Cisco Networking Academy Program CCNA 1 and 2 Companion Guide Third Edition

Cisco Systems, Inc.
Cisco Networking Academy Program

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Cisco Systems, Inc.

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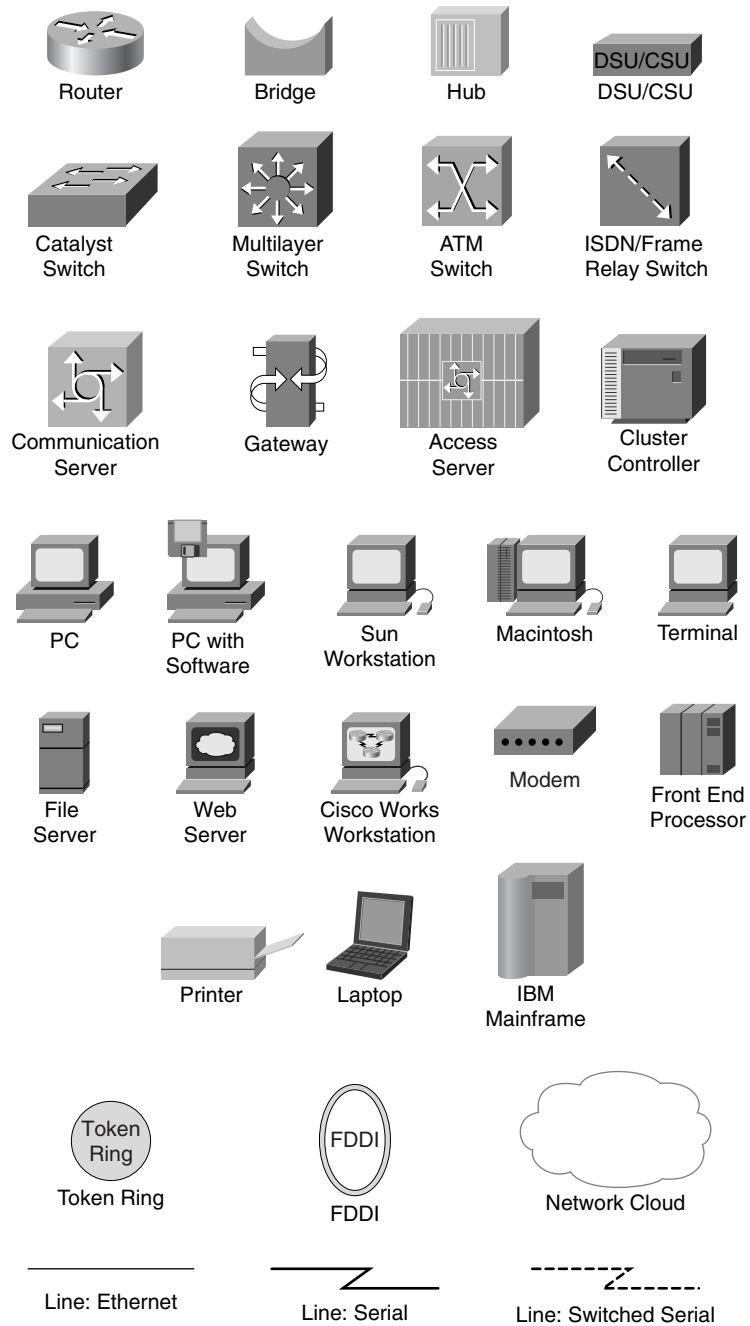
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Cisco Systems Networking Icon Legend

Cisco Systems, Inc., uses a standardized set of icons to represent devices in network topology illustrations. The following icon legend shows the most commonly used icons that you might encounter throughout this book.



Command Syntax Conventions

The conventions used to present command syntax in this book are the same conventions used in the Cisco IOS Software Command Reference. The Command Reference describes these conventions as follows:

- Vertical bars (|) separate alternative, mutually exclusive elements.
- Square brackets ([]) indicate optional elements.
- Braces ({ }) indicate a required choice.
- Braces within brackets ([{ }]) indicate a required choice within an optional element.
- **Boldface** indicates commands and keywords that are entered exactly as shown.
- *Italic* indicates arguments for which you supply values.

Foreword

Throughout the world, the Internet has brought tremendous new opportunities for individuals and their employers. Companies and other organizations are seeing dramatic increases in productivity by investing in robust networking capabilities. Some studies have shown measurable productivity improvements in entire economies. The promise of enhanced efficiency, profitability, and standard of living is real and growing.

Such productivity gains aren't achieved by simply purchasing networking equipment. Skilled professionals are needed to plan, design, install, deploy, configure, operate, maintain, and troubleshoot today's networks. Network managers must assure that they have planned for network security and for continued operation. They need to design for the required performance level in their organization. They must implement new capabilities as the demands of their organization, and its reliance on the network, expands.

To meet the many educational needs of the internetworking community, Cisco Systems established the Cisco Networking Academy Program. The Networking Academy is a comprehensive learning program that provides students with the Internet technology skills essential in a global economy. The Networking Academy integrates face-to-face teaching, web-based content, online assessment, student performance tracking, hands-on labs, instructor training and support, and preparation for industry-standard certifications.

The Networking Academy continually raises the bar on blended learning and educational processes. The Internet-based assessment and instructor support systems are some of the most extensive and validated ever developed, including a 24/7 customer service system for Networking Academy instructors. Through community feedback and electronic assessment, the Networking Academy adapts the curriculum to improve outcomes and student achievement. The Cisco Global Learning Network infrastructure designed for the Networking Academy delivers a rich, interactive, and personalized curriculum to students worldwide. The Internet has the power to change the way people work, live, play, and learn, and the Cisco Networking Academy Program is in the forefront of this transformation.

This Cisco Press title is one of a series of best-selling companion titles for the Cisco Networking Academy Program. Designed by Cisco Worldwide Education and Cisco Press, these books provide integrated support for the online learning content that is made available to Academies all over the world. These Cisco Press books are the only authorized books for the Networking Academy by Cisco Systems, and provide print and CD-ROM materials that ensure the greatest possible learning experience for Networking Academy students.

I hope you are successful as you embark on your learning path with Cisco Systems and the Internet. I also hope that you will choose to continue your learning after you complete the Networking Academy curriculum. In addition to its Cisco Networking Academy Program titles, Cisco Press also publishes an extensive list of networking technology and certification publications that provide a wide range of resources. Cisco Systems has also established a network of professional training companies—the Cisco Learning Partners—who provide a full range of Cisco training courses. They offer training in many formats, including e-learning, self-paced, and instructor-led classes. Their instructors are Cisco certified, and Cisco creates their materials. When you are ready, please visit the Learning & Events area on Cisco.com to learn about all the educational support that Cisco and its partners have to offer.

Thank you for choosing this book and the Cisco Networking Academy Program.

Kevin Warner
Senior Director, Marketing
Worldwide Education
Cisco Systems, Inc.

Introduction

Cisco Networking Academy Program CCNA 1 and 2 Companion Guide, Third Edition, supplements your classroom and laboratory experience with the Cisco Networking Academy Program, whose curriculum is designed to empower you to enter employment or further education and training in the computer networking field.

This book trains you beyond the online materials that you already have used in this program, and introduces you to topics pertaining to the Cisco Certified Network Associate (CCNA) certification exam. This book closely follows the style and format that Cisco Systems has incorporated into the curriculum.

This book introduces and extends your knowledge and practical experience with the design, configuration, and maintenance of local-area networks (LANs). The concepts covered in this book enable you to develop practical experience in skills related to cabling, routing, IP addressing, routing protocols, and network troubleshooting. This book introduces the OSI model, discusses collisions and segmentations, and includes a new chapter on Ethernet technologies and Ethernet switching. This *Companion Guide* also features greatly enhanced chapters on IOS and TCP/IP and an additional chapter on access control lists.

This book not only prepares you for the CCNA certification exam, but also for the CompTIA Network+ certification exam.

The Goal of This Book

The goal of this book is to educate you about Cisco supported networking technologies, and to help you understand how to design and build networks and to configure Cisco routers. It is designed for use in conjunction with the Cisco Networking Academy Program online curriculum.

The Audience for This Book

This book's main audience is students interested in networking technologies. In particular, it is targeted toward students in the Cisco Networking Academy Program. In the classroom, this book can serve as a supplement to the online curriculum.

This book is also appropriate for corporate training faculty and staff members, as well as general users. The book's user-friendly, nontechnical approach is ideal for readers who prefer to stay away from technical manuals.

Book Features

Many of this book's features help facilitate a full understanding of the networking and routing covered in this book:

- **Objectives**—Each chapter starts with a list of objectives that should be mastered by the end of the chapter. The objectives provide a reference of the concepts covered in the chapter.
- **Figures, examples, tables, and scenarios**—This book contains figures, examples, and tables that help explain theories, concepts, commands, and setup sequences that reinforce concepts and help visualize the content covered in the chapter. In addition, the specific scenarios provide real-life situations that detail the problem and the solution.
- **Chapter summaries**—At the end of each chapter is a summary of the concepts covered in the chapter. It provides a synopsis of the chapter and serves as a study aid.
- **Key terms**—Each chapter includes a list of defined key terms that are covered in the chapter. These terms serve as a study aid. In addition, the key terms reinforce the concepts introduced in the chapter and help you understand the chapter material before you move on to new concepts. You can find the key terms highlighted in blue throughout the chapter where they are used in practice.
- **Check Your Understanding questions**—Review questions, presented at the end of each chapter, serve as an assessment. In addition, the questions reinforce the concepts introduced in the chapter and help test your understanding before you move on to new chapters.
- **Lab Activity references**—Throughout the book are references to worksheet and lab activities found in *Cisco Networking Academy Program CCNA 1 and 2 Lab Companion*, Third Edition. These labs help you make a connection between theory and practice.

How This Book Is Organized

This book is divided into 20 chapters and 3 appendixes:

- **Chapter 1, “Introduction to Networking,”** presents the basics of connecting to the Internet. It also introduces different number systems and the processes used to convert a number from one number system to another. This chapter corresponds to the Module 1 content from the CCNA 1 online curriculum.

- **Chapter 2, “Networking Fundamentals,”** introduces some of the terminology used by networking professionals and various types of computer networks. It also describes how the OSI reference model networking scheme supports networking standards. In addition, this chapter describes the basic functions that occur at each layer of the OSI model. Finally, this chapter describes various network devices and networking topologies. This chapter corresponds to the Module 2 content from the CCNA 1 online curriculum.
- **Chapter 3, “Networking Media,”** introduces the basic theory of electricity, which provides a foundation for understanding networking at the physical layer of the OSI model. This chapter also discusses different types of networking media that are used at the physical layer, including shielded twisted-pair cable, unshielded twisted-pair cable, coaxial cable, and fiber-optic cable, as well as wireless media. This chapter corresponds to the Module 3 content from the CCNA 1 online curriculum.
- **Chapter 4, “Cable Testing and Cabling LANs and WANs,”** describes issues related to the testing of media used for physical layer connectivity in local-area networks (LANs). Networking media is literally and physically the backbone of a network. Inferior quality of network cabling results in network failures and in networks with unreliable performance. The equipment used to perform these tests involves certain electrical and mathematical concepts and terms, such as signal, wave, frequency, and noise. Understanding this vocabulary is helpful when learning about networking, cabling, and cable testing. This chapter corresponds to the Module 4 and 5 content from the CCNA 1 online curriculum.
- **Chapter 5, “Ethernet Fundamentals,”** discusses the operation of Ethernet, Ethernet framing, error handling, and the different type of the collisions on Ethernet networks. In addition, this chapter introduces the collision domains and broadcast domains. Finally, this chapter describes segmentation and the devices used to create the network segments. This chapter corresponds to the Module 6 content from the CCNA 1 online curriculum.
- **Chapter 6, “Ethernet Technologies and Ethernet Switching,”** introduces Layer 2 bridging and switching techniques. It introduces the Spanning Tree Protocol (STP), tells how STP works, and covers the STP switch port states. This chapter corresponds to the Module 7 and 8 content from the CCNA 1 online curriculum.

- **Chapter 7, “TCP/IP Protocol Suite and IP Addressing,”** presents an overview of the TCP/IP protocol suite. It starts with the history and future of TCP/IP, compares the TCP/IP protocol model to the OSI model, and identifies and describes each layer of the TCP/IP protocol suite. This chapter corresponds to the Module 9 content from the CCNA 1 online curriculum.
- **Chapter 8, “Routing Fundamentals and Subnets,”** covers the topics related to the Internet Protocol (IP). This chapter also discusses the difference between routing and routed protocols, and tells how routers track distance between locations. Finally, this chapter introduces the distance vector, link-state, and hybrid routing approaches, as well as how each resolves common routing problems. This chapter corresponds to the Module 10 content from the CCNA 1 online curriculum.
- **Chapter 9, “TCP/IP Transport and Application Layer,”** covers the issues related to the transport layer and how it uses the services provided by the network layer, such as best path selection and logical addressing, to provide end-to-end communication between source and destination. This chapter describes how the transport layer regulates the flow of information from source to destination reliably and accurately. This chapter corresponds to the Module 11 content from the CCNA 1 online curriculum.
- **Chapter 10, “WANs and Routers,”** introduces WAN devices, technologies, and standards. In addition, it discusses the function of a router in a WAN. This chapter corresponds to the Module 1 content from the CCNA 2 online curriculum.
- **Chapter 11, “Router Fundamentals,”** describes how to start a router for the first time by using the correct commands and startup sequence to do an initial configuration of the router. This chapter also explains the startup sequence of a router and the setup dialog that the router uses to create an initial configuration file using current versions of Cisco IOS Software. This chapter corresponds to the Module 2 content from the CCNA 2 online curriculum.
- **Chapter 12, “Router Configuration,”** discusses the router modes and configuration methods for updating a router’s configuration file. It is important that a firm understand Cisco IOS Software and know the procedures for starting a router. In addition, this chapter describes the tasks necessary for password recovery. This chapter corresponds to the Module 3 content from the CCNA 2 online curriculum.
- **Chapter 13, “Learning About Neighboring and Remote Devices,”** covers how to implement, monitor, and maintain Cisco Discovery Protocol by using the correct router commands. In addition, this chapter explains the three most used commands. This chapter corresponds to the Module 4 content from the CCNA 2 online curriculum.

- **Chapter 14, “Managing Cisco IOS Software,”** examines the stages of the router boot sequence. It also covers how to use a variety of Cisco IOS Software source options, execute commands to load Cisco IOS Software onto the router, maintain backup files, and upgrade Cisco IOS Software. In addition, this chapter discusses the functions of the configuration register and tells how to determine the version of the IOS file. Finally, this chapter describes how to use a TFTP server as a software source. This chapter corresponds to the Module 5 content from the CCNA 2 online curriculum.
- **Chapter 15, “Routing and Routing Protocols,”** covers the router’s use and operations in performing the key internetworking function of the Open System Interconnection (OSI) reference model’s network layer, Layer 3. In addition, this chapter discusses the difference between routing and routed protocols and tells how routers track distance between locations. Finally, this chapter introduces distance vector, link-state, and hybrid routing approaches and details how each resolves common routing problems. This chapter corresponds to the Module 6 content from the CCNA 2 online curriculum.
- **Chapter 16, “Distance Vector Routing Protocols,”** covers the initial configuration of the router to enable the Routing Information Protocol (RIP) and the Interior Gateway Routing Protocol (IGRP). In addition, this chapter describes how to monitor IP routing protocols. This chapter corresponds to the Module 7 content from the CCNA 2 online curriculum. This chapter corresponds to the Module 7 content from the CCNA 2 online curriculum.
- **Chapter 17, “TCP/IP Error and Control Messages,”** covers ICMP, the ICMP message format, ICMP error message types, potential causes of specific ICMP error messages, a variety of ICMP control messages used in networks today, and the causes for ICMP control messages. This chapter corresponds to the Module 8 content from the CCNA 2 online curriculum.
- **Chapter 18, “Basic Router Troubleshooting,”** provides an introduction to network testing. It emphasizes the necessity of using a structured approach to troubleshooting. Finally, this chapter describes the fundamentals of troubleshooting routers. This chapter corresponds to the Module 9 content from the CCNA 2 online curriculum.
- **Chapter 19, “Intermediate TCP,”** describes TCP/IP operation to ensure communication across any set of interconnected networks. In addition, this chapter covers the TCP/IP protocol stack components, such as protocols to support file transfer, e-mail, remote login, and other applications. This chapter also introduces

reliable and unreliable transport layer protocols and details connectionless datagram (packet) delivery at the network layer. Finally, it explains how ARP and RARP work. This chapter corresponds to the Module 10 content from the CCNA 2 online curriculum.

- **Chapter 20, “Access Control Lists,”** includes tips, considerations, recommendations, and general guidelines on how to use ACLs, and includes the commands and configurations needed to create ACLs. Finally, this chapter provides examples of standard and extended ACLs and tells how to apply ACLs to router interfaces. This chapter corresponds to the Module 11 content from the CCNA 2 online curriculum.
- **Appendix A, “Structured Cabling,”** includes coverage of structured cabling systems, standards, and codes. In addition, this appendix provides coverage of cabling safety, tools of the trade, installation process, finish phase, overview of the cabling business. This appendix also provides a cabling case study that covers how to apply all of the information in this chapter to a real-world scenario. The material in this appendix does not appear in the online curriculum, but provides some valuable information that you will need to know as a CCNA.
- **Appendix B, “Glossary of Key Terms,”** provides a compiled list of all the key terms that appear throughout this book.
- **Appendix C, “Check Your Understanding Answer Key,”** provides the answers to the Check Your Understanding questions that you find at the end of each chapter.

About the CD-ROM

A CD-ROM accompanies this book to further enhance your learning experience. The CD contains additional chapters not found online, a test engine with CCNA practice exam questions, interactive e-Lab Activities, PhotoZooms of networking equipment and hardware, and instructional Videos and animations that highlight potentially difficult concepts. These materials support self-directed study by allowing you to engage in learning and skill building exercises outside of the classroom. The CD also provides the following:

- An easy-to-use graphical user interface
- Chapter-by-chapter activities and resources
- Information and activities not found online

- Accurate and concise feedback on practice exam questions
- Learner-directed practice and study
- Flexibility for learners of all levels

Finally, these learning tools emphasize not only conceptual material, but also the importance of practicing what you have learned. The CD helps you understand routing and switching, and make the connection between theory and practice.



Part I

CCNA 1: Networking Basics

- Chapter 1** Introduction to Networking
- Chapter 2** Networking Fundamentals
- Chapter 3** Networking Media
- Chapter 4** Cable Testing and Cabling LANs and WANs
- Chapter 5** Ethernet Fundamentals
- Chapter 6** Ethernet Technologies and Ethernet Switching
- Chapter 7** TCP/IP Protocol Suite and IP Addressing
- Chapter 8** Routing Fundamentals and Subnets
- Chapter 9** TCP/IP Transport and Application Layer



Objectives

Upon completion of this chapter, you will be able to

- Identify the requirements for Internet connection
- Identify the major components of a personal computer
- Name the Ethernet adapter used for a laptop computer
- State the functions of network interface cards (NICs)
- List the components needed for NIC installation
- Identify the functions of the **ping** command
- Identify the features of web browsers
- Describe the units used to measure the size of digital data
- Convert a decimal number to a binary number
- Convert a binary number to a decimal number
- Convert a hexadecimal number to a binary number
- Convert a binary number to a hexadecimal number

Chapter 1

Introduction to Networking

This chapter presents the basics of computers and connection to the Internet. It also introduces different number systems and the processes used to convert a number from one number system to another.

Please be sure to look at this chapter's associated e-Lab Activities, Videos, and Photo-Zooms that you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

The Fundamentals of Internet Connectivity

To understand the role that computers play in a networking system, consider the *Internet*. The Internet can be thought of as a tree with computers as leaves. Computers are the sources and receivers of information by way of the Internet. Computers can function without the Internet, but the Internet cannot exist without computers. The Internet is growing rapidly, and users are becoming increasingly dependent on it for a myriad of services.

Computers, along with being an integral part of a network, also play a vital role in the world of work. Businesses use their computers for a variety of purposes, but they also use them in some common ways. They use servers to store important data to manage customer and employee accounts. They use spreadsheet software to organize financial information, word processor software to maintain records and correspondence, and browsers to access internal and external websites.

High-speed accesses to the Internet, such as cable modem and DSL services, are now available to the home and small office, which is increasing the demand for support services. No longer satisfied with a single computer connected to the Internet, the consumer needs the tools to be able to share the connection.

6 Chapter 1: Introduction to Networking

The Internet is the largest data network in the world. The Internet consists of a multitude of interconnected networks, both large and small. At the edge of this giant network is the individual consumer computer.

Connection to the Internet can be broken down into the following components:

- The *physical connection*—A physical connection to a network is made by connecting a specialized expansion card, such as a modem or a network interface card (NIC), to a PC with a cable. The physical connection is used to transfer signals between PCs in the local network and remote devices on the Internet.
- The *logical connection*—The logical connection uses standards called protocols. A *protocol* is a formal description of a set of rules and conventions that govern how devices on a network communicate. Connections to the Internet may use multiple protocols. The *Transmission Control Protocol/Internet Protocol (TCP/IP)* suite is the primary protocol used on the Internet. TCP/IP is a suite of protocols that work together to send and receive data. You learn more about TCP/IP in Chapter 7, “TCP/IP Protocol Suite and IP Addressing.”
- *Applications*—The application that interprets the data and displays the information in a comprehensible format is the last part of the connection. Applications work with protocols to send and receive data across the Internet. A *web browser* displays HTML as a web page. *File Transfer Protocol (FTP)* is used to download files and programs from the Internet. Web browsers also use proprietary plug-in applications to display special data types such as video, audio, and animation.

This introductory view might make the Internet seem like an overly simple process. However, as this topic is explored in greater depth later in this book, it will become apparent that sending data across the Internet is a complicated task.

PC Basics

Because computers are important building blocks in a network, it is important to be able to recognize and name the major components of a PC. Think of the internal components of a PC as a network of devices, all attached to the system bus. In a sense, a PC is a small computer network.

Many networking devices, such as routers and switches, are special-purpose computers and have many of the same parts as normal PCs. For a computer to be a reliable means of obtaining information, it must be in good working order. You should be able to recognize, name, and state the purpose of the PC components (this information pertains to laptops as well) described in the following sections.

Electronic Components

Electronic components are unique in that they are designed to conduct or transmit data or signals in electronic form. Most electronic components are found on the motherboard and expansion cards that plug into the motherboard. Here are some of the parts that commonly are found on electronic components:

- **Transistor**—A device that amplifies a signal or opens and closes a circuit. Microprocessors can have millions of transistors.
- **Integrated circuit (IC)**—A device made of semiconductor material. It contains many transistors and performs a specific task.
- **Resistor**—A device that is made of material that opposes the flow of electric current.
- **Capacitor**—An electronic component that stores energy in the form of an electrostatic field. It consists of two conducting metal plates separated by an insulating material.
- **Connector**—A port or interface that a cable plugs into. Examples include serial, parallel, USB, and disk drive interfaces.
- **Light emitting diode (LED)**—A semiconductor device that emits light when a current passes through it. These are commonly used as indicator lights.

PC Components

PC components are typically thought of as packaged or add-on parts that provide additional functionality to a PC. This is in contrast to vital electronic components that are necessary in every PC. These include things such as media drives, memory, hard drives, processors, and the power supply. Here are some of the most common PC components:

- **Printed circuit board (PCB)**—A thin plate on which chips (integrated circuits) and other electronic components are placed. Examples include the motherboard and various expansion adapters.
- **CD-ROM drive**—An optical drive that can read information from a CD-ROM. This can also be a CD-RW (compact disc read-write) drive or a DVD (digital video disc) drive or a combination of all three in one drive.
- **Central processing unit (CPU)**—The “brain” of the computer, where most of the calculations take place (see Figure 1-1).
- **Floppy disk drive**—Can read and write to floppy disks (see Figure 1-2).
- **Hard disk drive**—Reads and writes data on a hard disk. The primary storage device in the computer.

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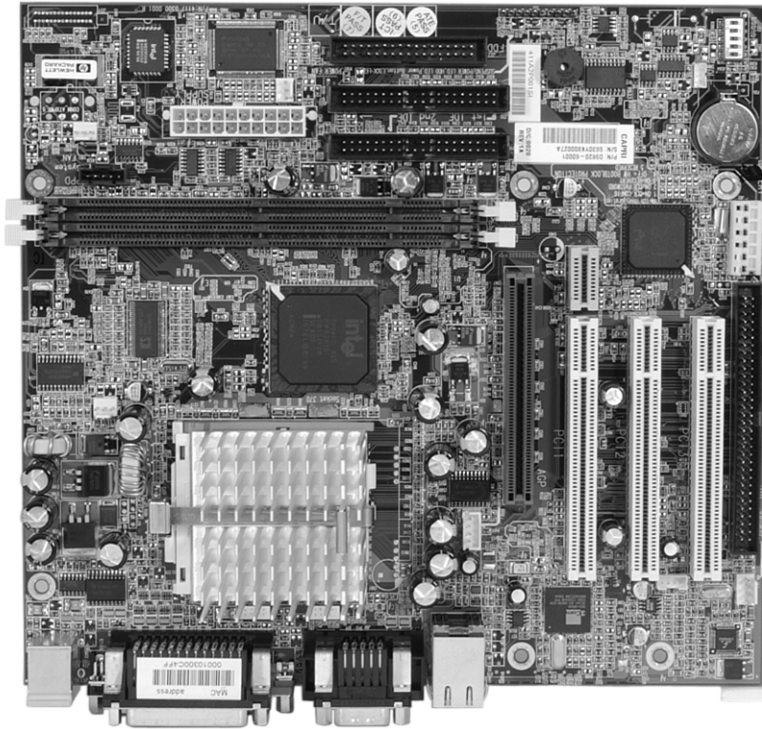
Figure 1-1 Central Processing Unit



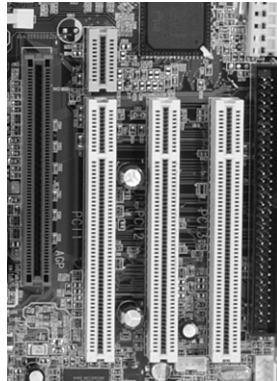
Figure 1-2 Floppy Disk Drive



- **Microprocessor**—A silicon chip that contains a CPU. A typical PC has a number of microprocessors, including the main CPU.
- **Motherboard**—The computer's main circuit board (see Figure 1-3). The motherboard is crucial because it is the computer's nerve center. Everything else in the system plugs into it, is controlled by it, and depends on it to communicate with other devices in the system.
- **Bus**—A collection of circuits through which data is transmitted from one part of a computer to another. The bus connects all the internal computer components to the CPU. The Industry-Standard Architecture (ISA) and the peripheral component interconnect (PCI) are two types of buses.
- **Random-access memory (RAM)**—Also known as read-write memory, RAM can have new data written to it and can have stored data read from it. RAM is the main working area used by the CPU for most processing and operations. A drawback of RAM is that it requires electrical power to maintain data storage. If the computer is turned off or loses power, all data stored in RAM is lost unless the data was previously saved to disk. Memory boards with RAM chips plug into the motherboard.

Figure 1-3 Motherboard

- **Read-only memory (ROM)**—A type of computer memory in which data has been prerecorded. After data has been written onto a ROM chip, it cannot be removed and can only be read. A version of ROM known as EEPROM (electronically erasable programmable read-only memory) can be written to. It is called Flash memory or firmware. The basic input/output system (BIOS) in most PCs is stored in EEPROM.
- **Expansion slot**—An opening in a computer, usually on the motherboard, where an expansion card can be inserted to add new capabilities to the computer (see Figure 1-4).
- **System unit**—The main component of the PC system. It includes the case, chassis, power supply, microprocessor, main memory, bus, expansion cards, disk drives (floppy, CD hard disk, and so on), and ports. The system unit does not include the keyboard, the monitor, or any other external devices connected to the computer.
- **Power supply**—Supplies power to a computer.

Figure 1-4 Expansion Slot**NOTE**

Some computers have a network card, sound card, video card, and other cards integrated into the motherboard.

Motherboard Components

The motherboard is the computer's main circuit board. It is crucial because it is the nerve center of the computer system. Everything else in the system plugs into it, is controlled by it, and depends on it to communicate with other devices in the system. The following list describes the motherboard's various components:

- **Backplane**—A large circuit board that contains sockets for expansion cards.
- **Memory chips**—RAM chips on memory cards plug into the motherboard.
- **Network interface card (NIC)**—A printed circuit board that provides network communication capabilities to and from a PC. Many newer desktop and laptop computers have an Ethernet NIC built into the motherboard.
- **Video card**—A board that plugs into a PC to give it display capabilities. Video cards typically include onboard microprocessors and additional memory to speed up and enhance graphics display.
- **Sound card**—An expansion board that handles all sound functions.
- **Parallel port**—An interface that can transfer more than 1 bit at a time. It is used to connect external devices, such as printers.
- **Serial port**—An interface used for serial communication in which only 1 bit is transmitted at a time. The serial port can connect to an external modem, plotter, or serial printer. It can also be used to connect to networking devices such as routers and switches as a console connection.
- **Mouse port**—Connects a mouse to a PC.
- **Keyboard port**—Connects a keyboard to a PC.

- **Power cord**—Connects an electrical device to an electrical outlet to provide power to the device.
- **Universal Serial Bus (USB) port**—This interface lets peripheral devices such as mice, modems, keyboards, scanners, and printers be plugged in and unplugged without resetting the system. USB ports eventually might replace serial and parallel ports.



Lab Activity PC Hardware

This lab helps you become familiar with the basic peripheral components of a PC system and their connections, including network attachment. You examine the internal PC configuration and identify major components. You also observe the boot process for the Windows operating system and use the Control Panel to find out information about the PC hardware.

Desktop Versus Laptop

Laptop and notebook computers are becoming increasingly popular. The main difference between desktop PCs and laptops, other than the fact that laptop components are smaller than those found in a PC, is that laptops offer more mobility and portability than desktop PCs. The expansion slots are called **Personal Computer Memory Card International Association (PCMCIA) card** slots or PC card slots in laptop computers. The PC card slots are where devices such as NICs, modems, hard drives, and other useful devices (usually the size of a thick credit card) are connected. Figure 1-5 shows a PC card adapter for a wireless local-area network (WLAN).

Figure 1-5 PC Card



Network Interface Cards

As shown in Figure 1-6, a NIC is a printed circuit board that provides network communication capabilities to and from a PC. Also called a LAN adapter, a NIC plugs into a motherboard and provides a port for connecting to the network. The NIC constitutes the computer interface with the LAN.

Figure 1-6 Network Interface Card



The NIC communicates with the network through a cable and with the computer via an expansion slot. When a NIC is installed in a computer, it requires an interrupt request (IRQ) for service from the CPU, as well as an input/output (I/O) address, a memory space for the operating system (such as Linux or Windows), and drivers to perform its function. An IRQ is a signal that informs a CPU that an event needing its attention has occurred. An IRQ is sent over a hardware line to the microprocessor. An example of an interrupt being issued is a key being pressed on the keyboard. The CPU must move the character from the keyboard to RAM. An I/O address is a location in memory used to enter data into or retrieve data from a computer using an auxiliary device.

When selecting a NIC for a network, consider the following:

- **Type of network**—Different types of networks use different types of NICs. For example, Ethernet NICs are designed for Ethernet LANs. Some other types of networks include Token Ring and Fiber Distributed Data Interface (FDDI). Ethernet is by far the most common.
- **Type of medium**—The type of port or connector used by the NIC for network connection is specific to the medium type, such as twisted-pair, coaxial, fiber-optic, or wireless. Coaxial is becoming increasingly rare.

- **Type of system bus**—There are different types of system buses, such as PCI and ISA. Because PCI slots are faster than ISA slots, the latter are being phased out.

NIC and Modem Installation

Connectivity to the Internet requires an adapter card, which might be a modem or NIC.

A *modem* is an electronic device that is used for computer communications through telephone lines. It allows data transfer between one computer and another over the Public Switched Telephone Network (PSTN). Figure 1-7 shows an example of an external modem. Typically, modems send data in blocks of bytes. After each block, basic math is performed to analyze the block, and the computer on the receiving end is asked whether it agrees with the results. If any differences appear, the block is sent again. The modems convert digital data to analog signals for transmission over the PSTN and then convert analog signals back to digital data on the receiving end.

Figure 1-7 External Modem



The term *modem* derives from the function of this device. The process of converting digital signals to analog and back again is called *modulation/demodulation* (hence the term *modem*). Modems can be installed internally or attached to the computer via a serial or USB interface externally. Modems connect a computer to the network by dialing the telephone number of another computer's modem, typically that of the Internet service provider (ISP).

The NIC lets hosts connect to the network. The NIC is considered a key component. NICs are available in different types, depending on the individual device configuration. Notebook computers can have a built-in interface or use a PCMCIA card. Desktop systems can use a built-in or adapter card-type NIC.

Situations that require NIC installation include the following:

- Adding a NIC to a PC that does not already have one
- Replacing a bad or damaged NIC
- Upgrading from a 10-megabits per second (Mbps) NIC to a 10/100-Mbps NIC

To install a NIC, as shown in Figure 1-8, you need the following resources:

- Knowledge of how the adapter is configured, including jumpers and plug-and-play software. Most modern NICs do not require jumpers and are plug-and-play, requiring little or no configuration. They can be configured using software that comes with the NIC if necessary.
- Use of network card diagnostics, including the vendor-supplied diagnostics and loopback test (see the card's documentation).
- The ability to resolve hardware resource conflicts, including IRQ, I/O base address, and direct memory address (DMA), which is used to transfer data from RAM to a device without going through the CPU.

Figure 1-8 Installing a NIC



Overview of High-Speed and Dialup Connectivity

In the early 1960s, modems were introduced to provide data communications connectivity for dumb terminals to a centrally based computer. Many companies rented computer time because owning an onsite system was cost-prohibitive. The connection rate was very slow—300 bits per second (bps), which translates to about 30 characters per second.

As PCs became affordable in the 1970s, Bulletin Board Systems (BBSs) appeared, allowing users to connect and post or read messages on a discussion board. Running at 300 bps was acceptable, because this exceeds the speed at which most people can read or type. BBSs did not become widely used until the early 1980s, and the transfer of

files and graphics began to be desirable. The 300 bps speed quickly became intolerable, and modem speeds started to increase. By the 1990s, modems were running at 9600 bps. They reached the current standard of 56 kbps (56,000 bps) by 1998.

Inevitably, the high-speed services used in the corporate environment, such as digital subscriber line (DSL) and cable modem access, migrated to the consumer market. These services no longer required expensive equipment or a second phone line. They are also *always-on* services and therefore provide instant access that does not require a connection to be established for each session. This results in greater reliability and flexibility. It has also led to the ease of Internet connection sharing and small office and home networks.

TCP/IP Configuration

TCP/IP is a set of protocols or rules developed to allow cooperating computers to share resources across a network. A computer must be running the TCP/IP protocol suite to access the Internet. To enable TCP/IP on the workstation, it must be configured using the operating system tools. The PC requires an IP address, subnet mask, default gateway, DNS (domain name server) information. These can be assigned manually or obtained from a Dynamic Host Configuration Protocol (DHCP) server. The information necessary to configure TCP/IP on a computer is typically obtained from a network administrator or an ISP. The process is similar whether you're using a Windows or Apple Macintosh operating system. TCP/IP, DHCP, and DNS are covered in subsequent chapters.



Lab Activity PC TCP/IP Network Settings

This lab introduces you to the methods of discovering your computer's network connection, host name, MAC (Layer 2) address, and network (Layer 3) address.

Testing Connectivity with Ping

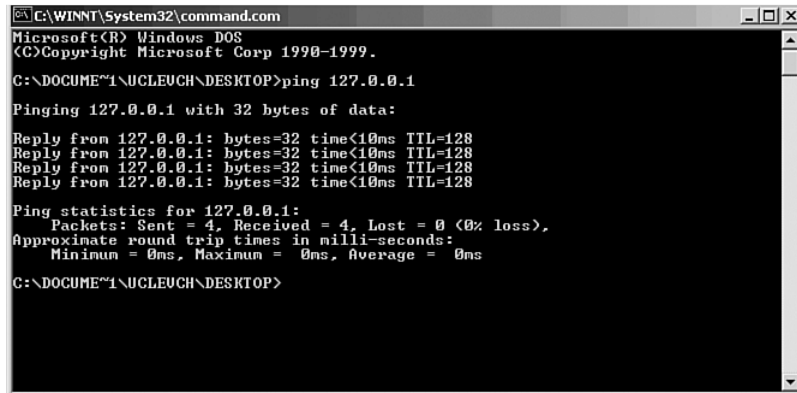
Ping is a program that is useful for verifying a successful TCP/IP installation. It is named after the sonar operation used to locate and determine the distance to an underwater object. Ping stands for Packet Internet Groper.

The **ping** command works by sending multiple IP packets to a specified destination. Each packet sent is a request for a reply. The output response for a ping contains the success ratio and round-trip time to the destination. From this information, you can

determine if there is connectivity to a destination. The **ping** command is used to test the NIC transmit/receive function, the TCP/IP configuration, and network connectivity. The following are some usages of the **ping** command:

- **ping 127.0.0.1** (internal loopback test)—This verifies the operation of the TCP/IP stack and NIC transmit/receive function. Figure 1-9 shows the **ping 127.0.0.1** test.
- **ping IP address of host computer**—Verifies the TCP/IP address configuration for the local host.
- **ping default-gateway IP address**—Verifies whether the router that connects the local network to other networks can be accessed.
- **ping remote destination IP address**—Verifies connectivity to a remote host.

Figure 1-9 ping 127.0.0.1



```
C:\WINNT\System32\command.com
Microsoft(R) Windows DOS
(C) Copyright Microsoft Corp 1990-1999.

C:\DOCUMENT1\UCLEUCH\DESKTOP>ping 127.0.0.1

Pinging 127.0.0.1 with 32 bytes of data:

Reply from 127.0.0.1: bytes=32 time<10ms TTL=128
Reply from 127.0.0.1: bytes=32 time<10ms TTL=128
Reply from 127.0.0.1: bytes=32 time<10ms TTL=128
Reply from 127.0.0.1: bytes=32 time<10ms TTL=128

Ping statistics for 127.0.0.1:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
    Approximate round trip times in milli-seconds:
        Minimum = 0ms, Maximum = 0ms, Average = 0ms

C:\DOCUMENT1\UCLEUCH\DESKTOP>
```



Lab Activity Using ping and tracert

In this lab, you learn to use the TCP/IP **ping** and **tracert** commands to test connectivity in a network. In the process, you see name resolution occur.

Web Browsers and Plug-Ins

A web browser acts on a user's behalf by

- Contacting a web server
- Requesting information
- Receiving information
- Displaying the results on the screen

A web browser is software that interprets *Hypertext Markup Language (HTML)*, one of the languages used to code web page content. Other markup languages, such as SGML and XML, provide more advanced features for creating dynamic and interactive web pages than does HTML. HTML, the most common markup language, can display graphics and play sound, movies, and other multimedia files. *Hyperlinks* are computer program commands that point to other HTML files on a web server or other places in the same documents, which provide shortcuts to other web pages and files.

Two of the most popular web browsers are Internet Explorer (IE) and Netscape. Although they are identical in the task they perform, there are differences between them. Some websites might not support the use of one or the other, so it can be beneficial to have both programs installed on the computer.

Table 1-1 compares the characteristics of these two web browsers.

Table 1-1 Microsoft Internet Explorer Versus Netscape Communicator

IE	Communicator
Integrated with other Microsoft products	First popular browser
Takes up more disk space	Takes up less disk space
Displays HTML files and performs e-mail, file transfers, and other functions	Displays HTML files and performs e-mail, file transfers, and other functions

Standard web browsers cannot display many special, or proprietary, file types. To view these files, the browser must be configured to use *plug-in* applications. These applications work in conjunction with the browser to launch the program required to view the special files. Here are some of the more popular proprietary plug-ins:

- **Flash Player/Shockwave Player**—A plug-in that plays multimedia files created by Macromedia Flash.
- **Adobe Acrobat Reader**—A software program that allows the user to view and print Adobe Portable Document Format (PDF) files.
- **Windows Media Player**—A software program that allows the user to play audio and video files.
- **Quicktime**—A software program created by Apple that allows the user to play video and audio files.
- **Real Player**—A software program that allows the user to play audio files.

**Lab Activity** Web Browser Basics

In this lab, you learn how to use a web browser to access Internet sites, become familiar with the concept of a URL, and use a search engine to locate information on the Internet. You access selected websites to learn the definitions of networking terms and use hyperlinks to jump from the current website to other websites.

Other Common Computer Applications

Computers perform many other useful tasks. In business, employees regularly use a set of applications that come in the form of an *office suite*, such as Microsoft Office or Lotus Smart Suite. Office applications typically include the following:

- **Spreadsheet software**—An application that lets users construct spreadsheets consisting of columns and rows. It is often used with formulas to process and analyze data.
- **A word processor**—An application that lets users create and edit text documents. Modern word processors allow the user to create sophisticated documents that include graphics and richly formatted text.
- **Database software**—An application that lets users store, maintain, organize, sort, and filter records. A *record* is a collection of information identified by a common theme, such as a customer name.
- **Presentation software**—An application that lets users design and develop presentations to deliver at meetings, classes, or sales presentations.
- **Personal information managers**—Applications that can include features such as e-mail, contact lists, a calendar, and a to-do list.

**Lab Activity** The Basic PC/Network Troubleshooting Process

In this lab, you apply the basic troubleshooting model to simple and common network problems. You also become familiar with the more common hardware and software problems.

Binary Numbers

This section introduces the way in which data is represented inside a computer and the form in which it is transmitted across a network. You also learn about the various number systems and logic used with computers.

Binary Representation of Data

Computers are electromechanical devices made up of electronic switches. At the lowest levels of computation, computers depend on these electronic switches to make decisions. As such, computers react only to electrical impulses. These impulses are understood by the computer as either *on* or *off* states (1s or 0s).

Computers work with and store data using electronic switches that are either on or off. Computers can only understand and use data that is in this two-state (binary) format. 1 represents an on state, and 0 represents an off state. These 1s and 0s represent the two possible states of an electronic component in a computer. These 1s and 0s are called binary digits or *bits*.

The *American Standard Code for Information Interchange (ASCII)*, the most commonly used code for representing alphanumeric data in a computer, uses binary digits to represent the symbols typed on the keyboard. When computers send on/off states over a network, electricity, light, or radio waves represent the 1s and 0s. Each character has a unique pattern of eight binary digits assigned to represent the character.

Bits, Bytes, and Measurement Terms

Bits are binary digits. They are either 0s or 1s. In a computer, they are represented by on/off switches or the presence or absence of electrical charges, light pulses, or radio waves.

For example:

- A binary 0 might be represented by 0 volts of electricity (0 = 0 volts).
- A binary 1 might be represented by +5 volts of electricity (1 = +5 volts).

Computers are designed to use groupings of 8 bits. This grouping of 8 bits is called a *byte*. In a computer, 1 byte represents a single addressable storage location. These storage locations represent a value or a single character of data, such as an ASCII code. The total number of combinations of the eight switches being turned on and off is 256 (or 2^8). The value range of a byte is from 0 to 255. So, a byte is an important concept to understand when working with computers and networks.

Most computer coding schemes use 8 bits to represent each number, letter, or symbol. A series of 8 bits is called a byte; 1 byte represents a single addressable storage location (see Table 1-2).

NOTE

It is common to confuse KB with Kb and MB with Mb. Remember to do the proper calculations when comparing transmission speeds that are measured in KB with those measured in Kb. For example, modem software usually shows the connection speed in *kilobits* per second (for example, 45 kbps). However, popular browsers display file-download speeds in *kilobytes* per second. This means that with a 45-kbps connection, the download speed would be a maximum of 5.76 kBps. In practice, this download speed cannot be reached because of other factors that consume bandwidth at the same time. Also, file sizes are typically expressed in bytes, whereas LAN bandwidth and WAN links are typically expressed in kilobits per second (kbps) or Megabits per second (Mbps). You must multiply the number of bytes in the file by 8 to determine the amount of bandwidth consumed in bps.

Table 1-2 Units of Information

Unit	Bytes*	Bits*
Bit (b)	1/8 byte	1 bit
Byte (B)	1 byte	8 bits
Kilobyte (KB)	1000 bytes	8000 bits
Megabyte (MB)	1 million bytes	8 million bits
Gigabyte (GB)	1 billion bytes	8 billion bits
Terabyte (TB)	1 trillion bytes	8 trillion bits

*Common or approximate bytes or bits

The following are commonly used computer measurement terms:

- **Bit**—The smallest unit of data in a computer. A bit equals 1 or 0, and it is the binary format in which data is processed, stored, and transmitted by computers.
- **Byte**—A unit of measure used to describe the size of a data file, the amount of space on a disk or another storage medium, or the amount of data being sent over a network. 1 byte equals 8 bits of data.
- **Kb (kilobit)**—Approximately 1000 bits.
- **KB (kilobyte)**—Approximately 1000 bytes (1024 bytes exactly).
- **Mb (megabit)**—Approximately 1 million bits.
- **MB (megabyte)**—Approximately 1 million bytes (1,048,576 bytes exactly). A megabyte is sometimes called a “meg.” The amount of RAM in most PCs is typically measured in MB. Large files are often some number of MB in size.
- **GB (gigabyte)**—Approximately 1 billion bytes. A gigabyte is sometimes called a “gig.” Hard drive capacity on most PCs is typically measured in GB.
- **TB (terabyte)**—Approximately 1 trillion bytes. Hard drive capacity on some high-end computers is measured in TB.
- **kbps (kilobits per second)**—One thousand bits per second. This is a standard measurement of the amount of data transferred over a network connection.
- **kBps (kilobytes per second)**—One thousand bytes per second. This is a standard measurement of the amount of data transferred over a network connection.

- **Mbps (megabits per second)**—One million bits per second. This is a standard measurement of the amount of data transferred over a network connection. Basic Ethernet operates at 10 Mbps.
- **MBps (megabytes per second)**—One million bytes per second. This is a standard measurement of the amount of data transferred over a network connection.
- **Gbps (gigabits per second)**—One billion bits per second. This is a standard measurement of the amount of data transferred over a network connection. 10G or 10 Gigabit Ethernet operates at 10 Gbps.
- **Tbps (terabits per second)**—One trillion bits per second. This is a standard measurement of the amount of data transferred over a network connection. Some high-speed core Internet routers and switches operate at more than Tbps.
- **Hz (hertz)**—A unit of frequency. It is the rate of change in the state or cycle in a sound wave, alternating current, or other cyclical waveform. It represents one cycle per second.
- **MHz (megahertz)**—One million cycles per second. This is a common measurement of the speed of a processing chip, such as a computer microprocessor. Some cordless phones operate in this range (for example, 900 MHz).
- **GHz (gigahertz)**—One thousand million, or 1 billion (1,000,000,000), cycles per second. This is a common measurement of the speed of a processing chip, such as a computer microprocessor. Some cordless phones and wireless LANs operate in this range (for example, 802.11b at 2.4 GHz).

Because computers are designed to work with on/off switches, binary digits and binary numbers are natural to them. However, humans use the decimal number system in their daily lives. It is hard to remember the long series of 1s and 0s that computers use. Therefore, the computer's binary numbers need to be converted to decimal numbers.

Sometimes, binary numbers need to be converted to hexadecimal (hex) numbers. This is done because hex numbers can represent a long string of binary digits with just a few hexadecimal digits. This makes it easier to remember and work with the numbers.

Base 10 Number System

A number system consists of symbols and rules for using those symbols. Many number systems exist. The number system used most frequently is the decimal, or Base10, number system. It is called Base10 because it uses ten symbols. These ten symbols are the digits 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9. Combinations of these digits can represent all possible numeric values, as documented in Table 1-3.

NOTE

PC processors are getting faster all the time. The microprocessors used in PCs in the 1980s typically ran at less than 10 MHz (the original IBM PC was 4.77 MHz). Currently, PC processors are pushing speeds up to 3 GHz, with faster processors being developed for the future.

Table 1-3 Base 10 Number System

Number of Symbols	Ten			
Symbols	0, 1, 2, 3, 4, 5, 6, 7, 8, 9			
Base Exponent	10^3	10^2	10^1	10^0
Place Value	1000	100	10	1
Example: 2,134	$2 * 10^3$	$1 * 10^2$	$3 * 10^1$	$4 * 10^0$

The decimal number system is based on powers of 10. The value of each column position from right to left is multiplied by the number 10 (the base number) raised to a power (exponent). The power that 10 is raised to depends on its position to the left of the decimal point. When a decimal number is read from right to left, the first (right-most) position represents 10^0 (1), and the second position represents 10^1 ($10 * 1 = 10$). The third position represents 10^2 ($10 * 10 = 100$). The seventh position to the left represents 10^6 ($10 * 10 * 10 * 10 * 10 * 10 = 1,000,000$). This is true no matter how many columns the number has.

For example:

$$2134 = (2 * 10^3) + (1 * 10^2) + (3 * 10^1) + (4 * 10^0)$$

There is a 4 in the ones position, a 3 in the tens position, a 1 in the hundreds position, and a 2 in the thousands position. This example seems obvious when the decimal number system is used. Seeing exactly how the decimal system works is important, because it is needed for you to understand two other number systems, binary (Base2) and hexadecimal (Base16). These systems use the same methods as the decimal system. Human-readable IP addresses are expressed in Base10 (decimal). The IP address 172.16.14.188 is made up of four decimal numbers separated by dots or periods.

Base 2 Number System

Computers recognize and process data using the *binary*, or Base2, number system. The binary number system uses only two symbols (0 and 1) instead of the ten symbols used in the decimal, or Base10, number system. The position, or place, of each digit represents the number 2 (the base number) raised to a power (exponent) based on its position (2^0 , 2^1 , 2^2 , 2^3 , 2^4 , and so on), as documented in Table 1-4.

Table 1-4 Base 2 Number System

Number of Symbols	Two							
Symbols	0, 1							
Base Exponent	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Place Value	128	64	32	16	8	4	2	1
Example: 10110	0	0	0	1	0	1	1	0

Example:

$$\begin{aligned}
 10110 &= (1 * 2^4 = 16) + (0 * 2^3 = 0) + (1 * 2^2 = 4) + (1 * 2^1 = 2) + (0 * 2^0 = 0) \\
 &= (16 + 0 + 4 + 2 + 0) = 22
 \end{aligned}$$

If the binary number (10110) is read from left to right, there is a 1 in the 16s position, a 0 in the 8s position, a 1 in the 4s position, a 1 in the 2s position, and a 0 in the 1s position, which adds up to decimal number 22. Machine-readable IP addresses are expressed as a string of 32 bits (binary).

Base 16 Number System

The Base 16, or hexadecimal (hex), number system is used frequently when working with computers because it can represent binary numbers in a more readable form. The computer performs computations in binary, but there are several instances in which a computer's binary output is expressed in hexadecimal form to make it easier to read.

The hexadecimal number system uses 16 symbols. Combinations of these symbols can represent all possible numbers. Because only ten symbols represent digits (0, 1, 2, 3, 4, 5, 6, 7, 8, and 9) and because Base 16 requires six more symbols, the extra symbols are the letters A, B, C, D, E, and F. The A represents the decimal number 10, B represents 11, C represents 12, D represents 13, E represents 14, and F represents 15, as shown in Table 1-5.

The position of each symbol (digit) in a hex number represents the base number 16 raised to a power (exponent) based on its position. Moving from right to left, the first position represents 16^0 (or 1), the second position represents 16^1 (or 16), the third position represents 16^2 (or 256), and so on. Network adapter or NIC addresses are expressed as a string of 12 hexadecimal characters.

Table 1-5 Base 16 Number System

Number of Symbols	16			
Symbols	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F			
Base Exponent	16^3	16^2	16^1	16^0
Place Value	65536	256	16	1
Example: 1A2C	1	A	2	C

Example:

$$1A2C = (1 * 16^3 = 65536) + (10(A) * 16^2 = 2560) + (2 * 16^1 = 32) + (12(C) * 16^0 = 12) = (65536 + 2560 + 32 + 12) = 68144$$

Decimal-to-Binary Conversion

You can convert decimal numbers to binary numbers in many different ways. The flowchart shown in Figure 1-10 describes one method. This process involves trying to figure out which values of the power of 2 are added together to get the decimal number being converted. This method is one of several that can be used. It is best to select one method and practice with it until it always produces the correct answer.

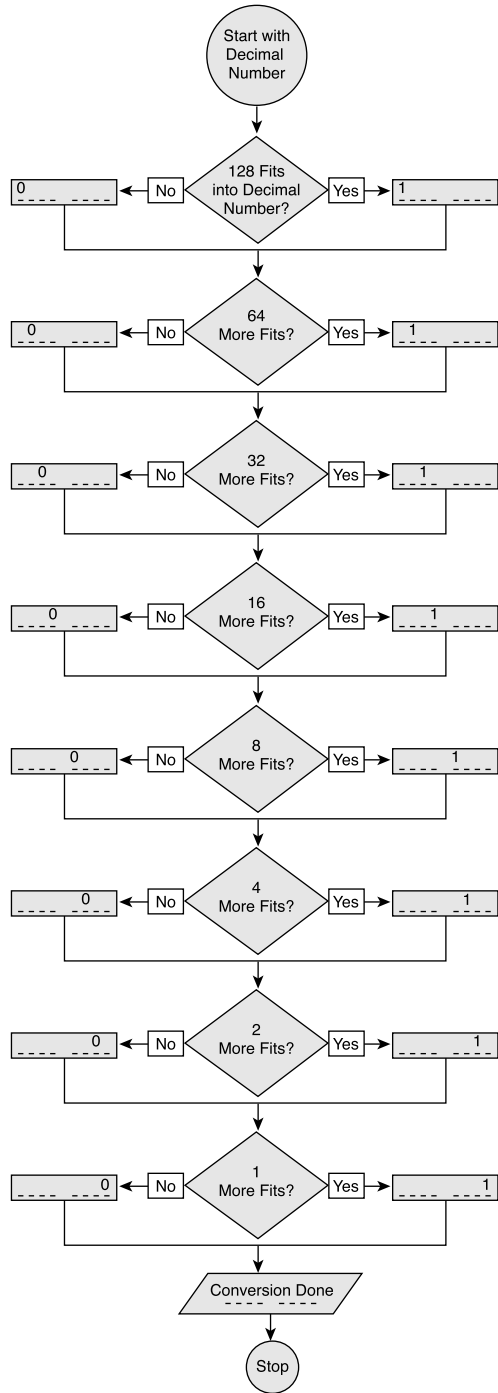
Here's an example:

These steps convert the decimal number 168 to binary:

- Step 1** 128 fits into 168, so the leftmost bit in the binary number is a 1.
 $168 - 128 = 40$
- Step 2** 64 does not fit into 40, so the second bit from the left is a 0.
- Step 3** 32 fits into 40, so the third bit from the left is a 1.
 $40 - 32 = 8$
- Step 4** 16 does not fit into 8, so the fourth bit from the left is a 0.
- Step 5** 8 fits into 8, so the fifth bit from the left is a 1.
 $8 - 8 = 0$, so the remaining bits to the right are all 0s.
- Step 6** As a result, the binary equivalent of the decimal value 168 is 10101000.

For more practice, try converting decimal 255 to binary. The answer should be 11111111.

Figure 1-10 Decimal-to-Binary Conversion Process



This flowchart works for decimal numbers of 255 or less. It yields an eight-digit binary number. This is appropriate for translating decimal IP addresses. Larger numbers can be converted by starting with the highest power of 2 that fits. For example, the number 650 can be converted by first subtracting 512. This yields a ten-digit binary number.



Decimal-to-Binary Conversion

In this exercise, you practice converting decimal values to binary values.

Binary-to-Decimal Conversion

As with decimal-to-binary conversion, there is usually more than one way to solve the conversion. The flowchart in Figure 1-11 shows one example.

Binary numbers can also be converted to decimal numbers by multiplying the binary digits by the base number of the system (Base2) raised to the exponent of its position.

Here's an example:

NOTE

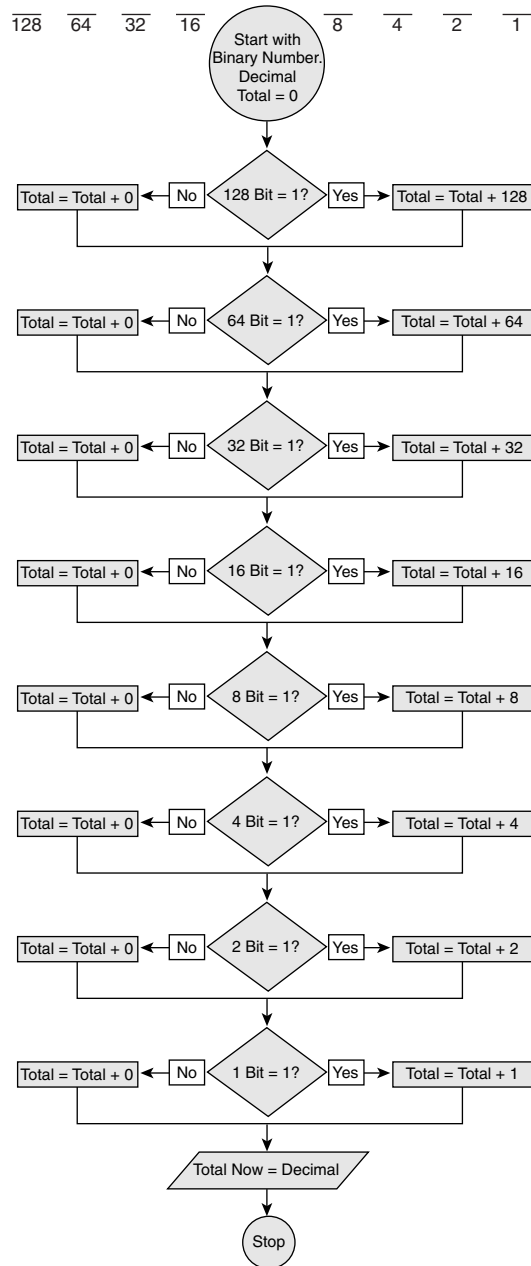
Work from right to left. Remember that anything raised to the 0 power is 1; therefore, $2^0 = 1$.

Convert the binary number 01110000 to a decimal number.

$$\begin{array}{r}
 0 * 2^0 = 0 \\
 + \\
 0 * 2^1 = 0 \\
 + \\
 0 * 2^2 = 0 \\
 + \\
 0 * 2^3 = 0 \\
 + \\
 1 * 2^4 = 16 \\
 + \\
 1 * 2^5 = 32 \\
 + \\
 1 * 2^6 = 64 \\
 + \\
 0 * 2^7 = 0 \\
 \hline
 112
 \end{array}$$

(The sum of the powers of 2 that have a 1 in their position)

Figure 1-11 Binary-to-Decimal Conversion Process



As with the flowchart shown in Figure 1-10, the flowchart shown in Figure 1-11 also works for decimal numbers of 255 or less that start with an eight-digit binary number. Larger binary numbers can be converted by increasing the power of 2 for each bit on the right. For example, if you have a ten-digit binary number, the tenth digit is worth 512, and the ninth is worth 256 if they are turned on (have a value of 1).



Binary-to-Decimal Conversion

In this exercise, you practice converting binary values to decimal values.

Hexadecimal and Binary Conversion

Converting a hexadecimal number to binary form and vice versa is a common task when dealing with the configuration register in Cisco routers. Cisco routers have a configuration register that is 16 bits long. That 16-bit binary number can be represented as a four-digit hexadecimal number. For example, 0010000100000010 in binary equals 2102 in hex.

Layer 2 *Media Access Control (MAC) addresses* are typically written in hex. For Ethernet and Token Ring, these addresses are 48 bits, or six *octets* (one octet is 1 byte). (“Oct” comes from the Greek word for eight.) Because these addresses consist of six distinct octets, they can be expressed as 12 hex numbers instead. Every 4 bits is a hex digit ($2^4 = 16$), as you will see in Table 1-6 in a moment.

Instead of writing

```
10101010.11110000.11000001.11100010.01110111.01010001
```

you can write the much-shorter hex equivalent:

```
AA.F0.C1.E2.77.51.
```

To make handling hex versions of MAC addresses even easier, the dots are placed only after every four hex digits, as in AAF0.C1E2.7751.

The most common way for computers and software to express hexadecimal output is by using 0x in front of the hexadecimal number. Thus, whenever you see 0x, you know that the number that follows is a hexadecimal number. For example, 0x1234 means 1234 in base 16.

Like the binary and decimal number systems, the hexadecimal system is based on the use of symbols, powers, and positions. The symbols that hex uses are 0 through 9 and A through F. Table 1-6 shows the binary and decimal equivalents of hex digits.

Table 1-6 Binary and Decimal Equivalents of Hexadecimal Digits

Binary	Hexadecimal	Decimal
0000	0	0
0001	1	1
0010	2	2
0011	3	3
0100	4	4
0101	5	5
0110	6	6
0111	7	7
1000	8	8
1001	9	9
1010	A	10
1011	B	11
1100	C	12
1101	D	13
1110	E	14
1111	F	15

To convert from hexadecimal to binary, convert every hex digit into 4 bits. For example, to convert hex AC (0xAC) to binary, you first convert hex A, which is 1010 binary, and then you convert hex C, which is 1100 binary. So hex AC is 10101100 in binary.

Notice that all possible combinations of four binary digits have only one hexadecimal symbol, whereas two symbols are required for decimal. The reason why hex is used is that two hexadecimal digits can efficiently represent any combination of eight binary digits (as opposed to decimal, which would require up to four digits). In allowing two decimal digits to represent 4 bits, using decimal could also cause confusion in reading a value. For example, the eight bit binary number 01110011 would be 115 if converted to decimal digits. Does this represent 11-5 or 1-15? If 11-5 is used, the binary number would be 10110101, which is not the number originally converted. Using hexadecimal, the conversion is 1F, which always converts back to 00011111.

The best way to think about hexadecimal is to think of it as a shorthand way of reading binary. It reduces an 8-bit number to just two hex digits. This reduces the confusion of reading long strings of binary numbers and the amount of space it takes to write them. Remember that hexadecimal is sometimes abbreviated as 0x, so hex 5D might be written as 0x5D.

To convert from hex to binary, simply expand each hex digit into its 4-bit binary equivalent.



Hexadecimal Conversion

In this exercise, you practice converting hexadecimal values to decimal and binary values.

Four-Octet Dotted-Decimal Representation of a 32-Bit Binary Number

Currently, addresses assigned to computers on the Internet (IP addresses) are 32-bit binary numbers. To make it easier to work with these addresses, the 32-bit binary number is broken into a series of decimal numbers. To do this, split the binary number into four groups of eight binary digits. Then convert each group of 8 bits (an octet) into its decimal equivalent. Do this conversion exactly as was shown in the section, “Binary-to-Decimal Conversion.”

When written, the complete decimal number is represented as four groups of decimal digits separated by periods, such as 10.15.129.201. This is called *dotted-decimal notation* and provides a compact, easy-to-remember way of referring to 32-bit addresses. This representation is used frequently later in this course, so be sure to understand it. When converting to binary from dotted decimal, remember that each group of from one to three decimal digits represents a group of eight binary digits. If the decimal number you are converting is less than 128, you need to add 0s to the left of the equivalent binary number until you have a total of 8 bits.

For example, to convert the dotted-decimal value 10.15.129.201 to its binary equivalent, you should write the number as 00001010.00001111.10000001.11001001.

Boolean Logic

Boolean logic is based on digital circuitry that accepts one or two incoming voltages and, based on these input voltages, generates an output voltage. For the purpose of computers, the voltage difference is associated with two states, on and off. These two states are in turn represented by a 1 or a 0, which are the two digits in the binary number system.

Boolean logic is a binary logic that allows two numbers to be compared, and then a choice based on those two numbers is generated. These choices are the logical AND, OR, and NOT. With the exception of the NOT, Boolean operations have the same function. They accept two numbers (1 or 0) and generate a result based on the logic rule.

This section presents the operations, starting with the NOT operation. The next section provides an example of directly applying Boolean logic in networking—network masking. This example covers the AND operation.

The NOT operation, as shown in Table 1-7, simply takes whatever value is presented (0 or 1) and inverts it. A 1 becomes a 0, and a 0 becomes a 1. Remember that the logic gates are electronic devices built specifically for this purpose. This is the logic rule that they follow; whatever is input, the opposite is output.

Table 1-7 NOT Operation

Input	Output
0	1
1	0

The AND operation, as shown in Table 1-8, takes two input values. If both values are 1, the logic gate generates a 1 output; otherwise, it outputs a 0. There are four combinations of input values. Three combinations generate a 0, and one combination generates a 1. The AND operation is used extensively with IP addressing and subnet masks.

Table 1-8 AND Operation

AND	0	1
0	0	0
1	0	1

The OR operation, as shown in Table 1-9, also takes two input values. If one value is 1 or both values are 1, the output is 1. Just like the AND operation, there are four combinations of input values. However, in an OR operation, three of the combinations generate a 1 output, and one combination generates a 0 output.

The two networking operations that use Boolean logic are subnetwork masking and wildcard masking. Masking operations provide a way to filter addresses. The addresses identify the devices on the network. Masking allows the addresses to be grouped or controlled by other network operations.

Table 1-9 OR Operation

OR	0	1
0	0	1
1	1	1

IP Addresses and Subnet Masks

The 32-bit binary addresses used on the Internet are called *Internet Protocol (IP)* addresses. This section covers the relationship between IP addresses and network masks. You learn more about IP addresses in Chapter 7.

When IP addresses are assigned to computers, some of the bits on the left side of the 32-bit IP number are used to represent a network. The number of bits designated depends on the address class. The bits left over in the 32-bit IP address identify a particular computer on the network. A computer is called a host. So a computer's IP address usually consists of a network portion and a host portion that represents a particular computer on a particular network.

For the computer to know how the 32-bit IP address has been split, a second 32-bit number called a *subnet mask* is used. This mask is a guide that indicates how the IP address should be interpreted by identifying how many of the bits identify the computer's network. The network mask sequentially fills in the 1s from the left side of the mask. A subnet mask is always all 1s until the network address is identified. Then it is all 0s from there to the mask's rightmost bit. The bits in the IP address that are 0 identify the computer (host) on that network. Some examples of subnet masks follow.

Example 1:

11111111.00000000.00000000.00000000 written in dotted decimal is 255.0.0.0.

Example 2:

11111111.11111111.00000000.00000000 written in dotted decimal is 255.255.0.0.

In the first example, the first 8 bits from the left are the network address, and the last 24 bits are the host address. In the second example, the first 16 bits are the network address, and the last 16 bits are the host address.

Converting the IP address 10.34.23.134 to binary results in the following:

00001010.00100010.00010111.10000110

To determine the network portion of the IP address, compare the subnet mask bits to all 32 bits of the IP address 1 bit at a time, using the AND process, and record the result. The combination of a 0 IP address bit and a 0 mask bit is a 0. The combination of a 0 and a 1 is a 0. The combination of a 1 and a 1 is a 1. To better demonstrate, consider the following examples:

Example 1: Using the first mask (255.0.0.0):

00001010.00100010.00010111.10000110: IP address

11111111.00000000.00000000.00000000: network mask

00001010.00000000.00000000.00000000 is the network part of the address. In dotted-decimal format, 10.0.0.0 is the network portion of the IP address.

Example 2: Using the second mask (255.255.0.0):

00001010.00100010.00010111.10000110: IP address

11111111.11111111.00000000.00000000: network mask

00001010.00100010.00000000.00000000 is the network part of the address. In dotted-decimal format, 10.34.0.0 is the network portion of the IP address.

The importance of subnetwork masking will become much clearer as you work more with IP addresses. For now, it is only important that you understand the concept of the network mask.

Summary

In this chapter, you learned the following key points:

- Computers are vital components of every network. The more you know about computers, the easier it is to understand networks.
- Knowing how a computer functions makes it easier to understand networks.
- TCP/IP is the protocol of the Internet.
- The **ping** command is a simple way of testing connectivity.
- Software allows the user to interface with the hardware. In networking, web browsers and e-mail are the most commonly used software programs.
- Troubleshooting PCs is a necessary skill when working on networks.
- It is important to be familiar with the components of a computer and to understand the functions of a NIC. It is also important to be able to install a NIC.
- Bits are binary digits. 8 bits equals 1 byte.

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- Computers can recognize and process data only by using the binary number system. The binary number system is made up of 0s and 1s.
- The hexadecimal number system is used frequently at higher levels of computation. The hexadecimal number system uses 16 symbols: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, and F.
- Boolean logic is a binary logic that allows two numbers to be compared. An operation is created based on the two numbers. Three common Boolean logic operators are NOT, AND, and OR.
- IP addresses are the 32-bit binary addresses used on the Internet.

To supplement all you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab Activities on the CD-ROM accompanying this book.

Key Terms

American Standard Code for Information Interchange (ASCII) The most commonly used code for representing alphanumeric data in a computer. Uses binary digits (bits) to represent the symbols typed on the keyboard.

application Interprets the data and displays the information in a comprehensible format as the last part of an Internet connection. Applications work with protocols to send and receive data across the Internet.

backplane A large circuit board that contains sockets for expansion cards.

binary A number system characterized by 1s and 0s (1 = on, and 0 = off).

bit The smallest unit of data in a computer. A bit equals 1 or 0. It is the binary format in which data is processed, stored, and transmitted by computers. In a computer, bits are represented by on/off switches or the presence or absence of electrical charges, light pulses, or radio waves.

Boolean logic In computer operation with binary values, Boolean logic can describe electromagnetically charged memory locations or circuit states that are either charged (1 or true) or not charged (0 or false). The computer can use an AND gate or an OR gate operation to obtain a result that can be used for further processing.

bus A collection of circuits through which data is transmitted from one part of a computer to another.

byte A unit of measure that describes the size of a data file, the amount of space on a disk or another storage medium, or the amount of data being sent over a network. 1 byte equals 8 bits of data.

CD-ROM drive An optical drive that can read information from a CD-ROM.

central processing unit (CPU) The computer's "brain," where most of the calculations take place.

dotted-decimal notation A syntactic representation for a 32-bit integer that consists of four 8-bit numbers written in base 10 with periods (dots) separating them. Used to represent IP addresses on the Internet, as in 192.67.67.20.

expansion slot An opening in a computer, usually on the motherboard, where an expansion card can be inserted to add new capabilities to the computer.

File Transfer Protocol (FTP) An application protocol, part of the TCP/IP protocol suite, used to transfer files between network hosts.

floppy disk drive Reads and writes to floppy disks.

GB (gigabyte) Approximately 1 billion bytes. Sometimes called a “gig.” Hard drive capacity on most PCs is typically measured in GB.

Gbps (gigabits per second) One billion bits per second. A standard measurement of the amount of data transferred over a network connection. 10G or 10 Gigabit Ethernet operates at 10 Gbps.

hard disk drive Reads and writes data on a hard disk. The primary storage device in the computer.

hyperlink A computer program command that points to other HTML files on a web server or other places on the same documents. Provides shortcuts to other web pages and files.

Hypertext Markup Language (HTML) A simple hypertext document-formatting language that uses tags to indicate how a given part of a document should be interpreted by a viewing application, such as a web browser.

Internet The largest global internetwork, connecting tens of thousands of networks worldwide and having a culture that focuses on research and standardization based on real-life use.

Internet Protocol (IP) A network layer protocol in the TCP/IP protocol suite offering a connectionless internetwork service.

Kb (kilobit) Approximately 1000 bits.

KB (kilobyte) Approximately 1000 bytes (1024 bytes exactly).

kbps (kilobits per second) One thousand bits per second. A standard measurement of the amount of data transferred over a network connection.

kBps (kilobytes per second) One thousand bytes per second. A standard measurement of the amount of data transferred over a network connection.

keyboard port Connects a keyboard to a PC.

logical connection Uses standards called protocols.

Mb (megabit) Approximately 1 million bits.

MB (megabyte) Approximately 1 million bytes (1,048,576 bytes exactly). A megabyte is sometimes called a “meg.” The amount of RAM in most PCs is typically measured in MB. Large files are typically some number of MB in size.

Mbps (megabits per second) One million bits per second. A standard measurement of the amount of data transferred over a network connection. Basic Ethernet operates at 10 Mbps.

Mbps (megabytes per second) One million bytes per second. A standard measurement of the amount of data transferred over a network connection.

Media Access Control (MAC) address A standardized data link layer address that is required for every port of devices that connect to a LAN. Other devices in the network use these addresses to locate specific ports in the network and to create and update routing tables and data structures. MAC addresses are 6 bytes long and are controlled by the IEEE.

memory chips RAM chips on memory cards plug into the motherboard.

microprocessor A silicon chip that contains a CPU.

modem A device that converts digital and analog signals. At the source, a modem converts digital signals to a form suitable for transmission over analog communication facilities. At the destination, the analog signals are returned to their digital form.

motherboard A computer's main circuit board.

mouse port Connects a mouse to a PC.

network interface card (NIC) A printed circuit board that provides network communication capabilities to and from a PC.

network interface card (NIC) A printed circuit board that provides network communication capabilities to and from a PC.

octet Eight bits. In networking, the term octet often is used (rather than byte) because some machine architectures employ bytes that are not 8 bits long.

parallel port An interface that can transfer more than 1 bit simultaneously. It connects external devices, such as printers.

Personal Computer Memory Card International Association (PCMCIA) An organization that has developed a standard for small credit card-sized devices called PCMCIA cards (or PC cards). Originally designed to add memory to portable computers, the PCMCIA standard has been expanded several times and is now suitable for many types of devices.

physical connection A connection to a network that is made by connecting a specialized expansion card, such as a modem or NIC, from a PC with a cable to a network.

ping Stands for Packet Internet Groper. Often used in IP networks to test the reachability of a network device.

plug-in Software or a program that can easily be installed and used as part of a web browser.

power cord Connects an electrical device to an electrical outlet to provide power to the device.

power supply Supplies power to a computer.

printed circuit board (PCB) A thin plate on which chips (integrated circuits) and other electronic components are placed.

protocol A formal description of a set of rules and conventions that govern how devices on a network exchange information.

random-access memory (RAM) Also known as read-write memory. Can have new data written to it as well as stored data read from it.

read-only memory (ROM) A type of computer memory in which data has been prerecorded.

serial port Can be used for serial communication in which only 1 bit is transmitted at a time.

sound card An expansion board that handles all sound functions.

subnetwork In IP networks, a network that shares a particular subnet address. Subnetworks are networks arbitrarily segmented by a network administrator to provide a multilevel, hierarchical routing structure while shielding from the addressing complexity of attached networks. Sometimes called a subnet.

subnetwork mask A 32-bit address mask used in IP to indicate the bits of an IP address that are being used for the subnet address.

system unit The main component of a PC system.

TB (terabyte) Approximately 1 trillion bytes. Hard drive capacity on some high-end computers is measured in TB.

Tbps (terabits per second) One trillion bits per second. A standard measurement of the amount of data transferred over a network connection. Some high-speed core Internet routers and switches operate at more than Tbps.

Transmission Control Protocol/Internet Protocol (TCP/IP) A common name for the suite of protocols developed by the U.S. DoD in the 1970s to support the construction of worldwide internetworks. TCP and IP are the two best-known protocols in the suite.

universal serial bus (USB) port Lets peripheral devices such as mice, modems, keyboards, scanners, and printers be plugged in and unplugged without resetting the system.

video card A board that plugs into a PC to give it display capabilities.

web browser A graphical user interface (GUI)-based hypertext client application, such as Internet Explorer or Netscape Navigator, used to access hypertext documents and other services located on remote servers throughout the WWW and the Internet.

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. The connection to the Internet can be broken down into which of the following?
 - A. Physical connection
 - B. Logical connection
 - C. Applications
 - D. All of the above
2. What is the main circuit board of a computer?
 - A. PC subsystem
 - B. Motherboard
 - C. Backplane
 - D. Computer memory
3. What are PCMCIA slots?
 - A. Slots used in laptops
 - B. Slots used as expansion slots in all computers
 - C. Expansion slots for a NIC
 - D. Slots for certain specialized devices
4. What is a NIC?
 - A. A WAN adapter
 - B. A printed circuit board that provides network communication
 - C. A card used only for Ethernet networks
 - D. A standardized data link layer address

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5. Which of the following is/are the resource(s) you need before you install a NIC?
 - A. Knowledge of how the network card is configured
 - B. Knowledge of how to use the network card diagnostics
 - C. Capability to resolve hardware resource conflicts
 - D. All of the above
6. Which number system is based on powers of 2?
 - A. Octal
 - B. Hexadecimal
 - C. Binary
 - D. ASCII
7. Match the following terms with their definitions:
 1. Bit
 2. Byte
 3. kbps
 4. MHz
 - a. The smallest unit of data in a computer
 - b. A standard measurement of the rate at which data is transferred over a network connection
 - c. A unit of frequency; the rate of change in the state or cycle in a sound wave, alternating current, or another cyclical waveform
 - d. A unit of measure that describes the size of a data file, the amount of space on a disk or another storage medium, or the amount of data being transferred over a network
8. What is the largest decimal value that can be stored in 1 byte?
 - A. 254
 - B. 256
 - C. 255
 - D. 257

9. What is the decimal number 151 in binary?
- A. 10100111
 - B. 10010111
 - C. 10101011
 - D. 10010011
10. What is the binary number 11011010 in decimal?
- A. 186
 - B. 202
 - C. 218
 - D. 222
11. What is the binary number 0010000100000000 in hexadecimal?
- A. 0x2100
 - B. 0x2142
 - C. 0x0082
 - D. 0x0012
12. What is the hexadecimal number 0x2101 in binary?
- A. 0010 0001 0000 0001
 - B. 0001 0000 0001 0010
 - C. 0100 1000 0000 1000
 - D. 1000 0000 1000 0100
13. Which of the following statements is true of ping?
- A. The **ping** command is used to test a device's network connectivity.
 - B. Ping stands for packet Internet groper.
 - C. The **ping 127.0.0.1** command is used to verify the operation of the TCP/IP stack and the NIC transmit/receive function.
 - D. All of the above



Objectives

Upon completion of this chapter, you will be able to

- Describe networking history
- Define and describe the features of a LAN, WAN, MAN, SAN, and data center technology
- Define and describe the functions, benefits, and technologies of VPNs
- Define physical and logical topologies
- Describe the benefits of the OSI reference model
- Discuss the functions of each of the seven layers of the OSI reference model
- Describe the basic process of communication among the layers of the OSI reference model
- Name the layers of the TCP/IP protocol model
- Describe the function of a repeater, hub, NIC, bridge, switch, and router
- Describe the function of a voice gateway, DSLAM, CMTS, and optical platform
- Describe the function of a firewall, AAA server, and VPN concentrator
- Describe the function of a wireless adapter, wireless access point, and wireless bridge
- Define the bus, star, extended-star, ring, hierarchy, mesh, and partial-mesh topologies

Chapter 2

Networking Fundamentals

This chapter introduces some of the terminology used by networking professionals and various types of computer networks. It explains how standards ensure greater compatibility and interoperability among various types of network technologies. It also describes how the OSI reference model networking scheme supports networking standards. In addition, this chapter describes the basic functions that occur at each layer of the OSI model. As you work through this chapter, you learn about the basic functions that take place at each layer of the OSI model, which will serve as a foundation as you begin to design, build, and troubleshoot networks.

Finally, this chapter describes various network devices as well as cabling physical and logical layouts.

Be sure to look at this chapter's associated e-Labs, Videos, and PhotoZooms, which you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

Networking Terminology

This section introduces the concept and history of the data network. It also discusses the basic features of the following types of networks:

- Local-area networks (LANs)
- Wide-area networks (WANs)
- Metropolitan-area networks (MANs)
- Storage-area networks (SANs)
- Data centers
- Intranets
- Extranets
- Virtual private networks (VPNs)

Data Networks

Data networks developed as a result of businesses and government agencies needing to exchange electronic information across long distances. At the time, microcomputers were not connected as mainframe computer terminals were, so there was no efficient way of sharing data between multiple microcomputers. Figure 2-1 illustrates a company with many microcomputers without a network connection.

NOTE

In the early days, a company invested in computers as stand-alone devices that sometimes had printers attached. When employees who didn't have a printer wanted to print documents, they had to copy a file to a floppy disk, carry it over and load it on to a coworker's PC that was connected to a printer, and print it from there. This rather crude version of a network became known as *sneakernet* (see Figure 2-2).

Figure 2-1 Company with Many Standalone Computers

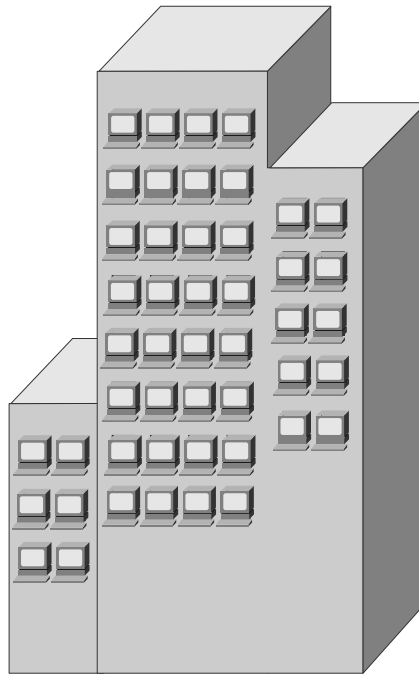
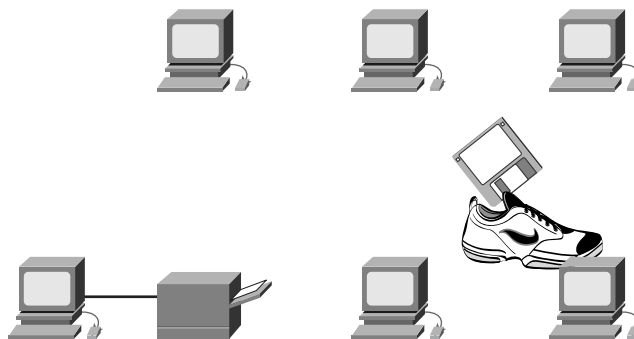


Figure 2-2 Sneakernet



It became apparent that sharing data through the use of floppy disks was not an efficient or cost-effective manner in which to conduct business. Each time a file was modified, it had to be shared again with all the other people who needed it. If two people modified the file and then tried to share it, one of the sets of changes would be lost.

Businesses needed a solution that would address the following concerns:

- How to avoid duplication of equipment and resources
- How to communicate efficiently
- How to set up and manage a network

Businesses realized that networking technology could increase productivity while saving money. Networks were added and expanded almost as rapidly as new network technologies and products were introduced. In the early 1980s, networking saw a tremendous expansion, even though the early development of networking was chaotic.

The network technologies that emerged in the mid-1980s were created with a variety of hardware and software. Each company that created network hardware and software used its own company standards that were developed because of competition with other companies. Consequently, many new network technologies were incompatible with each other. It became increasingly difficult for networks that used different specifications to communicate with each other. This often required the old network equipment to be removed to implement the new equipment.

One early solution was the creation of *local-area network (LAN)* standards. Because LAN standards provided an open set of guidelines for creating network hardware and software, the capability to mix and match different equipment manufactured by different companies facilitated stability in LAN implementation. Figure 2-3 shows a simple LAN.

As the use of computers in businesses grew, it soon became obvious that even LANs were insufficient. In a LAN system, each department or company is a kind of electronic island, as shown in Figure 2-4.

Before LANs were created, there was a need for information to move efficiently and quickly—not only within a company, but also from one business to another. The solution was the creation of *metropolitan-area networks (MANs)* and *wide-area networks (WANs)*. Because WANs could connect user networks over large geographic areas, they made it possible for businesses to communicate with each other across great distances, as shown in Figure 2-5.

Figure 2-3 A Simple LAN

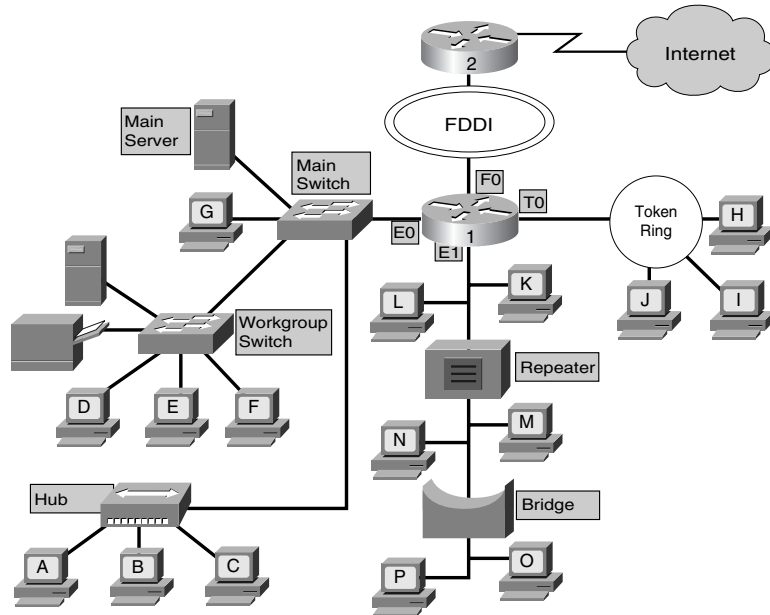


Figure 2-4 LAN

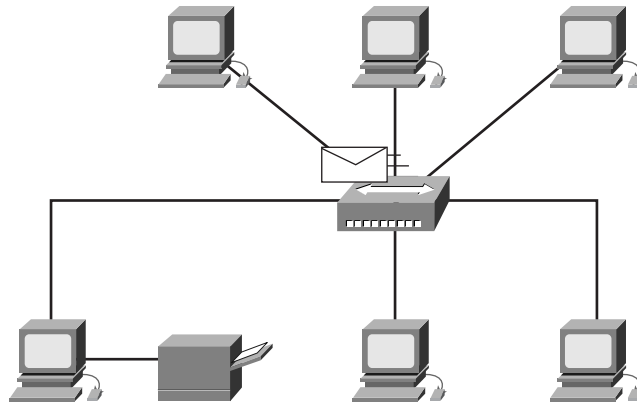
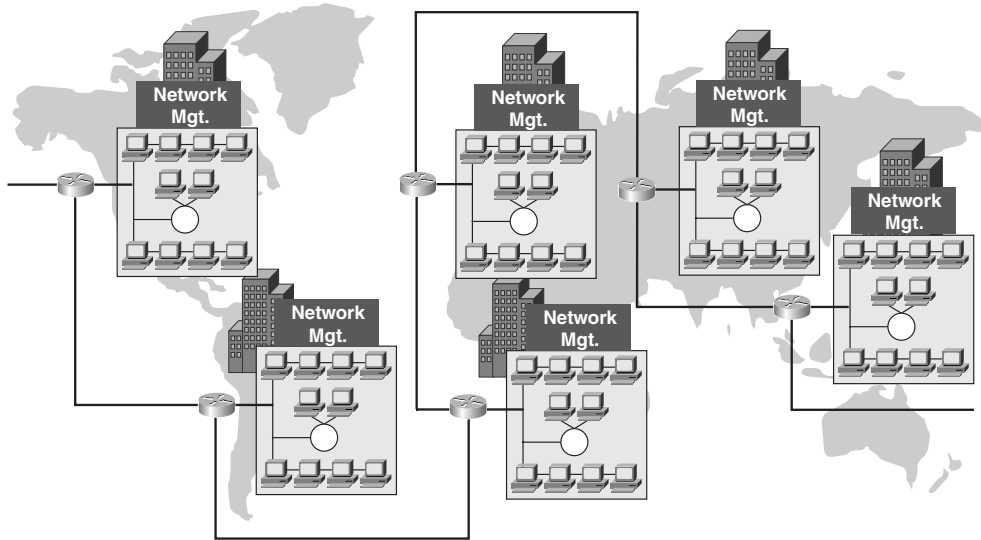


Figure 2-5 WAN



Computer Networking History

The history of computer networking is complex, involving many people from all over the world over the past 35 years. Table 2-1 presents a simplified view of how the Internet evolved. The processes of invention and commercialization are far more complicated, but it is helpful to look at the fundamental development.

Table 2-1 Microcomputer Development Timeline

Time Period	Development
Early 1940s	Large electromechanical devices that were prone to failure.
1947	The invention of the semiconductor transistor opened up many possibilities for making smaller, more reliable computers.
1950s	The integrated circuit was invented. It combined several—and then many, and now millions—of transistors on one small piece of semiconductor.
1960s	Mainframes with terminals were commonplace, and integrated circuits were widely used.

continues

Table 2-1 Microcomputer Development Timeline (Continued)

Time Period	Development
Late 1960s and 1970s	Smaller computers called minicomputers came into existence.
1977	Apple Computer introduced the microcomputer, also called the personal computer (PC).
1981	IBM introduced its first PC.
Mid-1980s	Computer users using standalone computers started sharing data (files) through the use of modems connected to another computer. This was called point-to-point or dialup communication.

In the 1940s, computers were large electromechanical devices that were prone to failure. In 1947, the invention of a semiconductor transistor opened up many possibilities for making smaller, more-reliable computers. In the 1950s, mainframe computers, run by punched-card programs, began to be used by large institutions. In the late 1950s, the integrated circuit was invented. It combined several—and then many, and now millions—of transistors on one small piece of semiconductor. Through the 1960s, mainframes with terminals were commonplace, and integrated circuits were widely used.

In the late 1960s and 1970s, smaller computers called minicomputers (even though they were still very large by today's standards) came into existence. In 1977, Apple Computer introduced the microcomputer, also known as the personal computer (PC). In 1981, IBM introduced its first PC. The user-friendly Apple Macintosh, the open-architecture IBM PC, and the further microminiaturization of integrated circuits led to widespread use of PCs in homes and businesses.

In the mid-1980s, computer users using standalone computers started sharing data (files) through the use of a modem connected to another computer. This was called *point-to-point* or *dialup* communication. This concept was expanded by the use of computers that were the central point of communication in a dialup connection. These computers were called *bulletin boards*. Users would connect to the bulletin board, leave and pick up messages, and upload and download files. The drawback of this type of system was that there was very little, if any, direct communication, and then only with those who knew about the bulletin board. Another limitation was that the bulletin board computer required one modem per connection. If five people connected simultaneously, five modems connected to five separate phone lines were required. Imagine if 500 people wanted to connect at the same time!

Starting in the 1960s and continuing through the 1990s, the U.S. Department of Defense (DoD) developed large, reliable WANs for military and scientific reasons. This technology was different from the point-to-point communication used in bulletin boards. It allowed multiple computers to be connected using many different paths. The network itself determined how to move data from one computer to another. Instead of being able to communicate with only one other computer at a time, many computers could be reached using the same connection. The DoD's WAN eventually became the Internet.

Network Protocols

Protocol suites are collections of protocols that enable network communication from one host through the network to another host. A *protocol* is a formal description of a set of rules and conventions that govern a particular aspect of how devices on a network communicate. Protocols determine the format, timing, sequencing, and error control in data communication. Without protocols, the computer cannot create or rebuild the stream of incoming bits from another computer into the original data.

Protocols control all aspects of data communication. They determine how the physical network is built, how computers connect to the network, how the data is formatted for transmission, and how that data is sent. These network rules are created and maintained by many different organizations and committees:

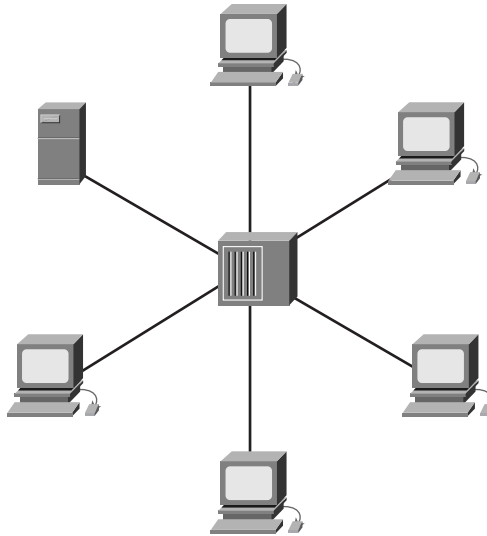
- Institute of Electrical and Electronic Engineers (IEEE)
- American National Standards Institute (ANSI)
- Telecommunications Industry Association (TIA)
- Electronic Industries Alliance (EIA)
- International Telecommunications Union (ITU), formerly known as the CCITT (Comité Consultatif International Téléphonique et Télégraphique)

Local-Area Networks (LANs)

LANs consist of computers, network interface cards, peripheral devices, networking media, and network devices. Figure 2-6 illustrates a LAN.

LANs make it possible for businesses that use computer technology to locally share files and printers efficiently and make internal communications possible, such as e-mail. LANs tie together data, local communications, and computing equipment.

Figure 2-6 LAN



LANs are designed to do the following:

- Operate within a limited geographic area
- Allow many users to access high-bandwidth media
- Provide full-time connectivity to local services
- Connect physically adjacent devices

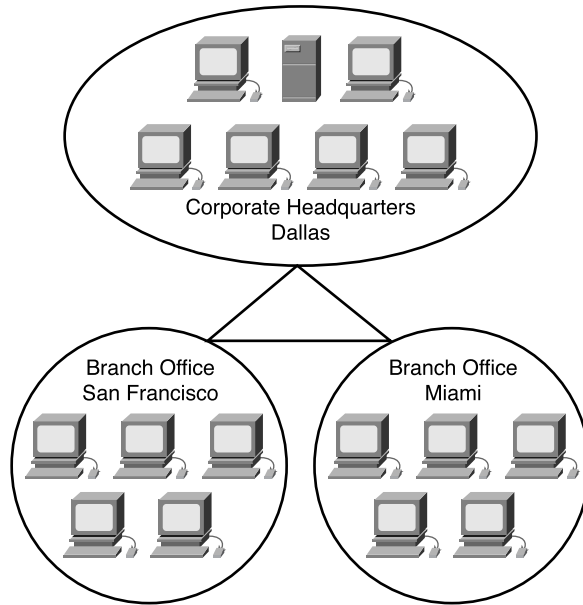
Some common LAN technologies are

- Ethernet
- Token Ring
- FDDI

Wide-Area Networks (WANs)

WANs interconnect LANs, which then provide access to computers or file servers in other locations. Because WANs connect user networks over a large geographic area, as shown in Figure 2-7, they make it possible for businesses to communicate across great distances.

Figure 2-7 WAN



Using WANs allows computers, printers, and other devices on a LAN to share and be shared with distant locations. WANs provide instant communications across large geographic areas. The ability to send an instant message (IM) to someone anywhere in the world provides the same communication capabilities that used to be possible only if people were in the same physical office. Collaboration software provides access to real-time information and resources that allow meetings to be held remotely instead of in person. Wide-area networking has also created a new class of workers called *tele-commuters*—people who never have to leave home to go to work.

WANs are designed to do the following:

- Operate over large, geographically separated areas
- Allow users to engage in real-time communication with other users
- Provide full-time remote resources connected to local services
- Provide e-mail, World Wide Web, file transfer, and e-commerce services

Here are some common WAN technologies:

- Modems
- Integrated Services Digital Network (ISDN)
- Digital Subscriber Line (DSL)

- Frame Relay
- T (U.S.) and E (Europe) carrier series—T1, E1, T3, E3, and so on
- Synchronous Optical Network (SONET)—Synchronous Transport Signal level 1 (STS-1) (Optical Carrier [OC]-1), STS-3 (OC-3), and so on

More Information: Emerging Home Networking Applications

People now design and build their homes to be Internet homes, wiring them for Ethernet connectivity. People integrate their computer(s) with their phone system, security system, home theater system, heating and air conditioning, lighting, and other electronic components to be able to control them all with the click of a mouse or even via a voice command.

Service providers have built cellular- and satellite-based carrier networks that offer sophisticated services, such as wireless Internet access. Local exchange carriers (LECs) (commonly known as local telephone companies) are implementing high-speed services for data transfer, such as DSL services, at a cost low enough to market to home users. Many cable operators, in addition to cable TV, now provide high-speed Internet access that can be shared among networked home computers. Cisco products support the latest wireless, DSL, and cable technologies.

People also are integrating PC, telephone, and fax capabilities, allowing for automatic answering and message storage and retrieval via computer. In addition, the Internet phone, which uses IP telephony technology and Voice over IP (VoIP), allows people to bypass telephone lines entirely with an Internet connection through cable, wireless, or some other medium to make long distance calls without paying long distance charges.

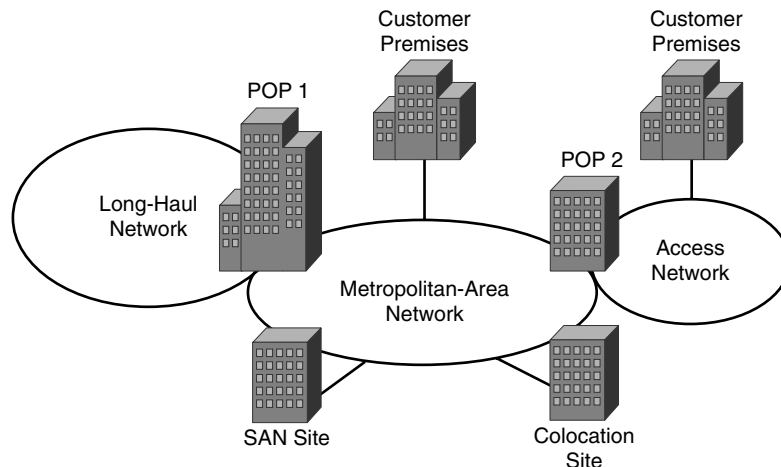
Metropolitan-Area Networks (MANs)

A MAN is a network that spans a metropolitan area, such as a city or a suburban area. MANs are networks that connect LANs separated by distance and that are located within a common geographic area, as shown in Figure 2-8. For example, a bank with multiple branches might use a MAN. Typically, a service provider connects two or more LAN sites using private communication lines or optical services. A MAN also can be created using wireless bridge technology by beaming signals across public areas. The higher optical bandwidths that are currently available make MANs a more functional and economically feasible option than in the past.

The following features differentiate MANs from LANs and WANs:

- MANs interconnect users in a geographic area or region larger than that covered by a LAN but smaller than the area covered by a WAN.
- MANs connect networks in a city into a single larger network (which can then also offer efficient connection to a WAN).
- MANs also are used to interconnect several LANs by bridging them with backbone lines.

Figure 2-8 MAN



Specialized Networks Located Within the LAN

There are times when smaller and more specialized networks might reside within the LAN. Most notably, these specialized networks are used for access to storage systems, data center technology systems and devices, intranets or extranets, and VPNs. These various specialized networks are covered in this section.

Storage-Area Networks (SANs)

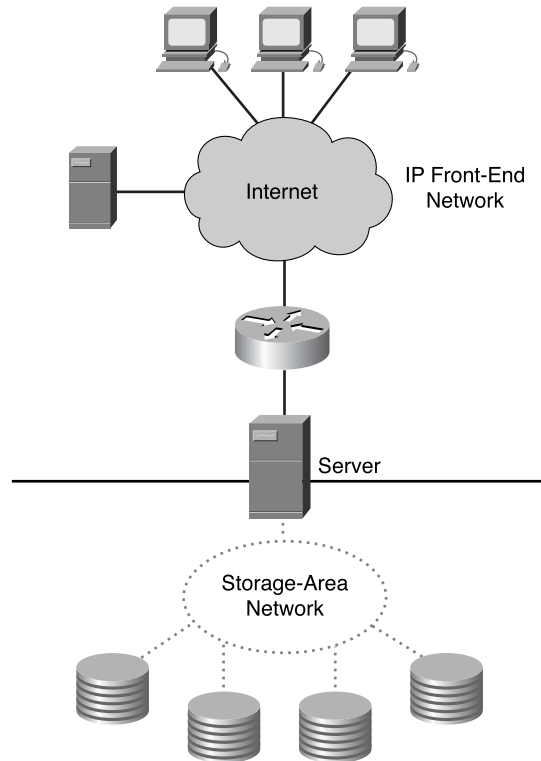
A *storage-area network (SAN)* is a dedicated, high-performance network that moves data between servers and storage resources. Because it is a separate dedicated network, it avoids any traffic conflict between clients and servers, as shown in Figure 2-9.

SAN technology allows high-speed server-to-storage, storage-to-storage, or server-to-server connectivity. This method uses a separate network infrastructure that relieves any problems associated with existing network connectivity.

SANs offer the following features:

- **Performance**—SANs enable concurrent access to disk or tape arrays by two or more servers at high speeds, providing enhanced system performance.
- **Availability**—SANs have disaster tolerance built in, because data can be mirrored using a SAN up to 10 kilometers (km) (6.2 miles) away.
- **Scalability**—Like a LAN/WAN, a SAN can use a variety of technologies. This allows easy relocation of backup data operations, file migration, and data replication between systems.

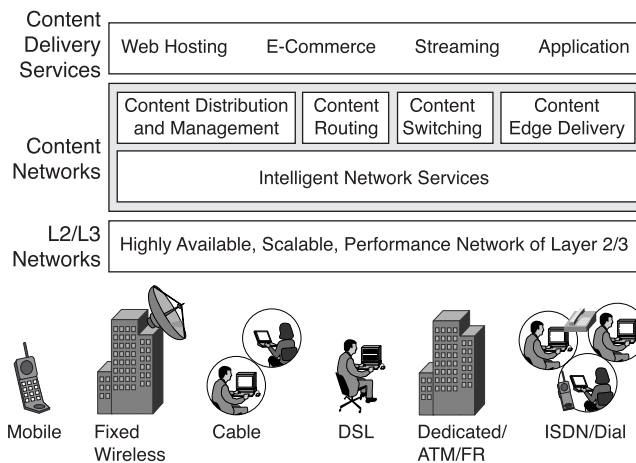
Figure 2-9 SAN



Data Center Technology

A *data center*, as shown in Figure 2-10, is a globally coordinated network of devices designed to accelerate the delivery of information over the Internet infrastructure. By taking advantage of services in the core IP network, enterprises and service providers can accelerate and improve the use of rich content such as broadband streaming media. Data center technology improves network performance and eliminates the need to stream media on the infrastructure.

A data center bypasses potential sources of congestion by distributing the load across a collection of content engines that are located close to the viewing audience. Rich web and multimedia content is copied to the content engines, and users are routed to an optimally located content engine.

Figure 2-10 Data Center

For example, when downloading a movie from an Internet service provider (ISP), instead of waiting for hours for the big movie file to download, the same movie might take only minutes to download if the ISP is using data center technology, because a data center can accelerate the delivery of information.

Intranets and Extranets

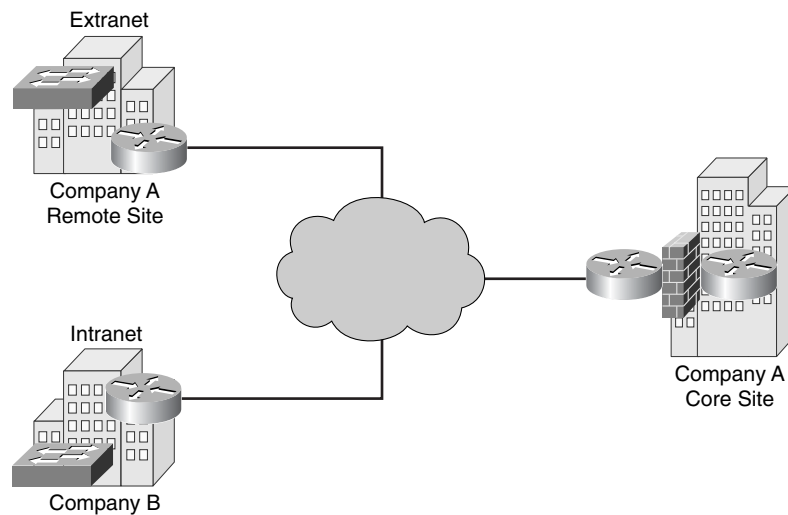
One common configuration of a LAN is an *intranet*. Intranet web servers differ from public web servers in that the public does not have access to an organization's intranet without the proper permissions and passwords. Intranets are designed to be accessed by users who have access privileges to an organization's internal LAN. Within an intranet, web servers are installed in the network, and browser technology is used as the common front end to access information such as financial data or graphical, text-based data stored on those servers.

An *extranet* is an intranet that is partially accessible to authorized outsiders. Whereas an intranet resides behind a firewall and is accessible only to people who are members of the same company or organization, an extranet provides various levels of accessibility to outsiders. You can access an extranet only if you have a valid username and password, and your identity determines which parts of the extranet you can view. Extranets help extend the reach of applications and services that are intranet-based but that employ extended, secure access to external users or enterprises. This access is usually accomplished through passwords, user IDs, and other application-level security. Therefore, an extranet is the extension of two or more intranet strategies with a secure interaction between participant enterprises and their respective intranets. The extranet

maintains control of access to the intranets within each enterprise in the deployment. Extranets link customers, suppliers, partners, or communities of interest to a corporate intranet over a shared infrastructure using dedicated connections.

Figure 2-11 illustrates an intranet and an extranet.

Figure 2-11 Intranet and Extranet



Virtual Private Networks

A *virtual private network (VPN)* is a private network that is constructed within a public network infrastructure such as the global Internet. For example, using a VPN, a telecommuter can access the company headquarters' network through the Internet by building a secure tunnel between the telecommuter's PC and a VPN router in the headquarters.

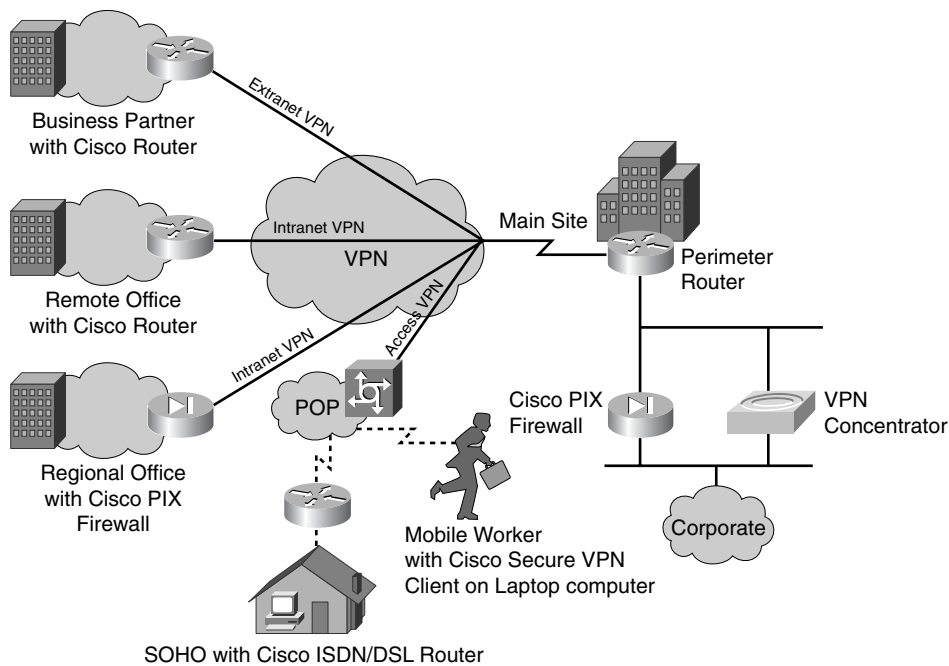
Cisco products support the latest in VPN technology. A VPN is a service that offers secure, reliable connectivity over a shared public network infrastructure such as the Internet. VPNs maintain the same security and management policies as a private network. They are the most cost-effective method of establishing a point-to-point connection between remote users and an enterprise customer's network.

Three main types of VPNs exist, as shown in Figure 2-12:

- **Access VPNs** provide remote access for a mobile worker and small office/home office (SOHO) to the headquarters' intranet or extranet over a shared infrastructure. Access VPNs use analog dialup, ISDN, DSL, mobile IP, and cable technologies to securely connect mobile users, telecommuters, and branch offices.

- **Intranet VPNs** link regional and remote offices to the headquarters' internal network over a shared infrastructure using dedicated connections. Intranet VPNs differ from extranet VPNs in that they allow access only to the enterprise customer's employees.
- **Extranet VPNs** link business partners to the headquarters' network over a shared infrastructure using dedicated connections. Extranet VPNs differ from intranet VPNs in that they allow access to users outside the enterprise.

Figure 2-12 VPN Technologies



VPNs have the following advantages:

- A single VPN technology can provide privacy for multiple TCP/IP applications. Providing privacy for multiple TCP/IP applications is especially important in environments in which you want to provide secure access for partners or telecommuters.
- Encryption services can be provided for all TCP/IP communications between the trusted client and the VPN server. This scenario has the advantage of being transparent to the end user. Because encryption is turned on, the server can enforce it.
- VPN provides mobility to employees and allows employees to access the corporate network securely.

Digital Bandwidth

LANs and WANs have always had one thing in common: the use of the term *bandwidth* to describe their capabilities. This term is essential to understanding networks, but it can be confusing at first. The following sections take a detailed look at this concept before delving too far into networking.

The Importance of Bandwidth

Bandwidth is defined as the amount of information that can flow through a network connection in a given period of time. This definition might seem simple, but you must understand the concept of bandwidth when studying networking. Why is it so important to understand bandwidth?

- **Bandwidth is finite**—Regardless of the medium used to build the network, there are limits on that network's capacity to carry information. Bandwidth is limited both by the laws of physics and by the technologies employed to place information on the medium. For example, a conventional modem's bandwidth is limited to about 56 kilobits per second (kbps) by both the physical properties of twisted-pair phone wires and by voice modem technology. The technologies employed by DSL also use the same twisted-pair phone wires, yet DSL provides much greater bandwidth than is available with conventional modems. The frequency range (bandwidth) that DSL uses is much wider than the frequency range used for voice (and used by the POTS modem). That is why you can send more bits per second (bps) over DSL. Optical fiber has the physical potential to provide virtually limitless bandwidth. Even so, the bandwidth of optical fiber cannot be fully realized until technologies are developed to take full advantage of its potential.
- **Bandwidth is not free**—It is possible to buy equipment for a LAN that will provide nearly unlimited bandwidth over a long period of time. For WAN connections, it is almost always necessary to buy bandwidth from a service provider. In either case, an understanding of bandwidth, and changes in demand for bandwidth over a given time, can save an individual or business a significant amount of money. A network manager needs to make the right decisions about the kinds of equipment and services to buy.
- **Bandwidth is a key factor in analyzing network performance, designing new networks, and understanding the Internet**—A networking professional must understand the tremendous impact of bandwidth and throughput on network performance and design. Information flows as a string of bits from computer to computer throughout the world. The Internet is trillions upon trillions of bits,

representing massive amounts of information flowing back and forth across the globe in seconds or less. In a sense, it might be appropriate to say that the Internet is bandwidth.

- **The demand for bandwidth is ever-increasing**—As soon as new network technologies and infrastructures are built to provide greater bandwidth, new applications are created to take advantage of the greater capacity. The delivery over the network of rich media content, including streaming video and audio, requires tremendous amounts of bandwidth. IP telephony systems are now commonly installed in place of traditional voice systems, adding further to the need for bandwidth. The successful networking professional must anticipate the need for increased bandwidth and plan accordingly.

Analogies That Describe Digital Bandwidth

The idea that information flows suggests two analogies that might make it easier to visualize bandwidth in a network. Because both water and traffic are said to *flow*, consider the following:

- **Bandwidth is like the width of a pipe, as shown in Figure 2-13**—A network of pipes brings fresh water to homes and businesses and carries wastewater away. This water network is made up of pipes with different diameters. A city's main water pipe might be 2 meters in diameter, whereas a kitchen faucet might have a diameter of only 2 centimeters. The width of the pipe determines the pipe's water-carrying capacity. Thus, the water is analogous to data, and pipe width is analogous to bandwidth. Many networking experts say they need to "put in bigger pipes" when they want to add more information-carrying capacity.
- **Bandwidth is like the number of lanes on a highway, as shown in Figure 2-14**—A network of roads serves every city or town. Large highways with many traffic lanes are joined by smaller roads with fewer traffic lanes. These roads lead to even smaller, narrower roads, and eventually to the driveways of homes and businesses. When very few automobiles use the highway system, each vehicle can move freely. When more traffic is added, each vehicle moves more slowly, especially on roads with fewer lanes for the cars to occupy. Eventually, as even more traffic enters the highway system, even multilane highways become congested and slow. A data network is much like the highway system, with data packets analogous to automobiles, and bandwidth analogous to the number of lanes on the highway. When a data network is viewed as a system of highways, it is easy to see how low-bandwidth connections can cause traffic to become congested all over the network.

Figure 2-13 Pipe Analogy for Bandwidth

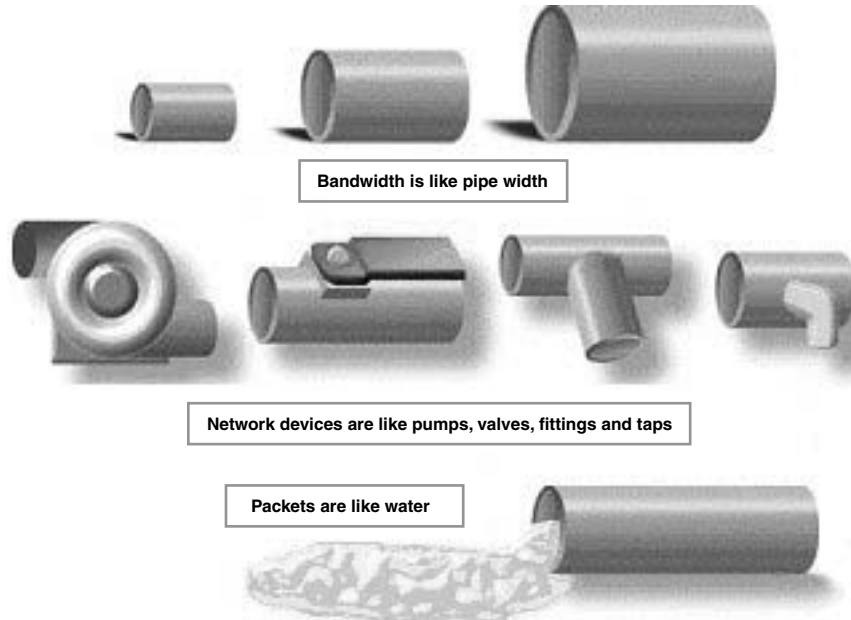
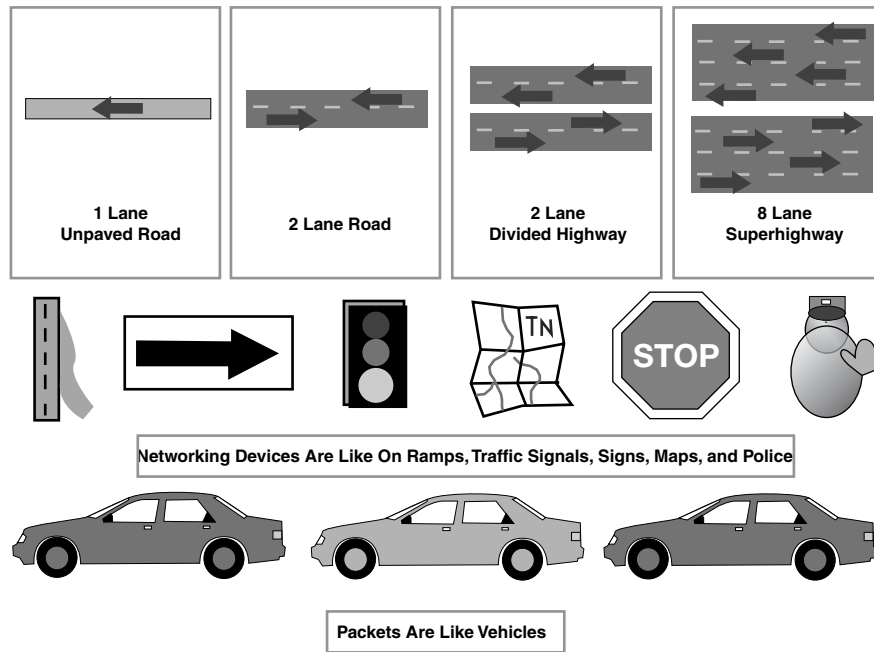


Figure 2-14 Highway Analogy for Bandwidth



Keep in mind that the true, actual meaning of bandwidth, in this context, is the maximum number of bits that theoretically can pass through a given area of space in a specified amount of time (under the given conditions). These analogies are only to make it easier to understand the concept of bandwidth.

Digital Bandwidth Measurements

In digital systems, the basic unit of bandwidth is bits per second (bps). Bandwidth is the measure of how much information, or bits, can flow from one place to another in a given amount of time, or seconds. Although bandwidth can be described in bits per second, usually some multiple of bits per second is used. In other words, network bandwidth is typically described as thousands of bits per second, millions of bits per second, and even billions of bits per second.

Although the terms *bandwidth* and *speed* are often used interchangeably, they are not exactly the same thing. You might say, for example, that a T3 connection at 45 megabits per second (Mbps) operates at a higher speed than a T1 connection at 1.544 Mbps. However, if only a small amount of their data-carrying capacity is being used, each of these connection types carries data at roughly the same speed, just as a small amount of water flows at the same rate through a small pipe as through a large pipe. Therefore, it is usually more accurate to say that a T3 connection has greater bandwidth than a T1, because it can carry more information in the same period of time, not because it has a higher speed.

Table 2-2 summarizes the various units of bandwidth.

Table 2-2 Units of Bandwidth

Unit of Bandwidth	Abbreviation	Equivalent
Bits per second	bps	1 bps = fundamental unit of bandwidth
Kilobits per second	kbps	1 kbps = 1000 bps = 10^3 bps
Megabits per second	Mbps	1 Mbps = 1,000,000 bps = 10^6 bps
Gigabits per second	Gbps	1 Gbps = 1,000,000,000 bps = 10^9 bps

Bandwidth Limitations

Bandwidth varies depending on the type of medium as well as the LAN and WAN technologies used. The physics of the medium account for some of the difference. Physical differences in the ways signals travel through twisted-pair copper wire, coaxial cable, optical fiber, and even air result in fundamental limitations on the information-carrying

capacity of a given medium. However, a network's actual bandwidth is determined by a combination of the physical medium and the technologies chosen for signaling and detecting network signals.

For example, current understanding of the physics of unshielded twisted-pair (UTP) copper cable puts the theoretical bandwidth limit at more than 1 Gbps. But in actual practice, the bandwidth is determined by the use of a particular technology, such as 10BASE-T, 100BASE-TX, or 1000BASE-TX Ethernet. Bandwidth is also determined by other varying factors, such as the number of users in the network, the equipment being used, applications, the amount of broadcast, and so on. In other words, the actual bandwidth is determined not by the medium's limitations, but by the signaling methods, NICs, and other items of network equipment that are chosen.

Table 2-3 lists some common networking media types, along with their limits on distance and bandwidth.

Table 2-3 Maximum Bandwidths and Length Limitations

Medium	Maximum Theoretical Bandwidth	Maximum Physical Distance
50-ohm coaxial cable (10BASE2 Ethernet, Thinnet)	10 Mbps	185 m
50-ohm coaxial cable (10BASE5 Ethernet, Thicknet)	10 Mbps	500 m
Category 5 UTP (10BASE-T Ethernet)	10 Mbps	100 m
Category 5 UTP (100BASE-TX Ethernet)	100 Mbps	100 m
Category 5 UTP (1000BASE-TX Ethernet)	1000 Mbps	100 m
Multimode optical fiber (62.5/125 μm) (100BASE-FX Ethernet)	100 Mbps	2000 m
Multimode optical fiber (62.5/125 μm) (1000BASE-SX Ethernet)	1000 Mbps	220 m

Table 2-3 Maximum Bandwidths and Length Limitations (Continued)

Medium	Maximum Theoretical Bandwidth	Maximum Physical Distance
Multimode optical fiber (50/125 μm) (1000BASE-SX Ethernet)	1000 Mbps	550 m
Single-mode optical fiber (9/125 μm) (1000BASE-LX Ethernet)	1000 Mbps	5000 m

Table 2-4 summarizes common WAN services and the bandwidth associated with each.

Table 2-4 WAN Services and Bandwidths

WAN Service	Typical User	Bandwidth
Modem	Individuals	56 kbps = 0.056 Mbps
DSL	Individuals, telecommuters, and small businesses	12 kbps to 6.1 Mbps = 0.128 Mbps to 6.1 Mbps
ISDN	Telecommuters and small businesses	128 kbps = 0.128 Mbps
Frame Relay	Small institutions (schools) and medium-sized businesses	56 kbps to 44.736 Mbps (U.S.) or 34.368 Mbps (Europe) = 0.056 Mbps to 44.736 Mbps (U.S.) or 34.368 Mbps (Europe)
T1	Larger entities	1.544 Mbps
T3	Larger entities	44.736 Mbps
STS-1 (OC-1)	Phone companies, data- comm company backbones	51.840 Mbps
STS-3 (OC-3)	Phone companies, data- comm company backbones	155.251 Mbps
STS-48 (OC-48)	Phone companies, data- comm company backbones	2.488 Gbps

Data Throughput

Bandwidth is the measure of the amount of information that can move through the network in a given period of time. Therefore, the amount of available bandwidth is a

critical part of the network's specification. A typical LAN might be built to provide 100 Mbps to every desktop workstation, but this does not mean that each user can actually move one hundred megabits of data through the network for every second of use. This is true only under the most ideal circumstances. The concept of throughput can help explain why this is so.

Throughput refers to actual measured bandwidth at a specific time of day, using specific Internet routes, and while a specific set of data is transmitted on the network. Unfortunately, for many reasons, throughput is often far less than the maximum possible digital bandwidth of the medium that is being used. The following are some of the factors that determine throughput:

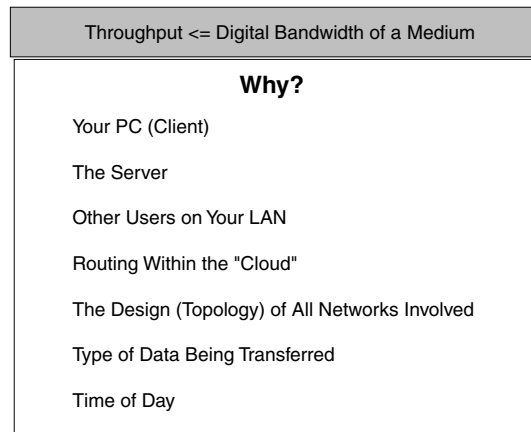
- Internetworking devices
- Type of data being transferred
- Network topology
- Number of users on the network
- User's computer
- Server computer
- Power conditions
- Congestion

A network's theoretical bandwidth is an important consideration in network design, because network bandwidth is never greater than the limits imposed by the chosen medium and networking technologies. Figure 2-15 lists some of the variables that affect throughput. However, it is just as important for a network designer and administrator to consider the factors that might affect actual throughput. By measuring throughput on a regular basis, a network administrator will be aware of changes in network performance and changes in the needs of network users. The network can then be adjusted accordingly.

Data Transfer Calculation

Network designers and administrators are often called on to make decisions regarding bandwidth. Should the size of the WAN connection be increased to accommodate a new database? Is the current LAN backbone of sufficient bandwidth for a streaming-video training program? The answers to questions like these are not always easy to find, but one place to start is with a simple data transfer calculation.

Using the formula $T = S / BW$ (transfer time = size of file / bandwidth) lets a network administrator estimate several of the important components of network performance. If the typical file size for a given application is known, dividing the file size by the network bandwidth yields an estimate of the fastest time that the file can be transferred.

Figure 2-15 Throughput Variables

Two important points should be considered when doing this calculation:

- The result is an estimate only, because the file size does not include any overhead added by the process that takes place to prepare data to be transferred over the network. This process is called encapsulation. Encapsulation is covered in more detail in later chapters.
- The result is likely to be a best-case transfer time, because available bandwidth is almost never at the theoretical maximum for the network type. (A more accurate estimate can be attained if throughput is substituted for bandwidth in the equation.)

Although the data transfer calculation is quite simple, it can be tricky if you are not careful to use the same units throughout the equation. In other words, if the bandwidth is measured in Mbps, the file size must be in megabits (Mb), not megabytes (MB). Because file sizes are typically given in megabytes, you might need to multiply the number of megabytes by 8 to convert to megabits.

Try to answer the following question using the formula $T = S / BW$. (Be sure to convert units of measurement as necessary.)

Would it take less time to send the contents of a floppy disk full of data (1.44 MB) over an ISDN line or to send the contents of a 10-GB hard drive full of data over an OC-48 line?

Figure 2-16 summarizes a simple formula for file transfer time calculations.

Figure 2-16 File Transfer Time Calculation

Best Download $T = \frac{S}{BW}$	Typical Download $T = \frac{S}{P}$
BW =	Maximum theoretical bandwidth of the "slowest link" between the source host and the destination host (measured in bits per second).
P =	Actual throughput at the moment of transfer (measured in bits per second).
T =	Time for file transfer to occur (measured in seconds).
S =	File size in bits.

Digital Bandwidth Versus Analog Bandwidth

Until recently, radio, television, and telephone transmissions were sent through the air and over wires using electromagnetic waves. These waves are called *analog* because they have the same shapes as the light and sound waves produced by the transmitters. As light and sound waves change size and shape, the electrical signal that carries the transmission changes proportionately. In other words, the electromagnetic waves are *analogous* to the light and sound waves.

Analog bandwidth is measured by how much of the electromagnetic spectrum is occupied by each signal. The basic unit of analog bandwidth is *hertz* (Hz), or cycles per second. Typically, multiples of this basic unit of analog bandwidth are used, just as with digital bandwidth. Units of measurement that are commonly seen are kilohertz (kHz), megahertz (MHz), and gigahertz (GHz). These are the units used to describe the bandwidth of cordless telephones (which usually operate at either 900 MHz or 2.4 GHz). 802.11a and 802.11b wireless network frequencies usually operate at 5 GHz and 2.4 GHz.

Although analog signals can carry a variety of information, they have some significant disadvantages compared to digital transmissions. The analog video signal that requires a wide frequency range for transmission cannot be squeezed into a smaller band. Therefore, if the necessary analog bandwidth is unavailable, the signal cannot be sent. The same goes for digital bandwidth; however, it is less common for digital bandwidth to experience this because of its much-larger bandwidth capabilities.

In digital signaling, all information is sent as bits, regardless of the kind of information it is. Voice, video, and data all become streams of bits when they are prepared for transmission over digital media, which gives digital bandwidth an important advantage over analog bandwidth. Unlimited amounts of information can be sent over the smallest (lowest-bandwidth) digital channel. Regardless of how long it takes, when the digital

information arrives at its destination and is reassembled, it can be viewed, listened to, read, or processed in its original form.

It is important to understand the differences and similarities between digital and analog bandwidth. Both types of bandwidth are regularly encountered in the field of information technology. However, because this course is concerned primarily with digital networking, the term *bandwidth* refers to digital bandwidth.

Networking Models

Learning about networking is easier when you start with theory and concepts and then move on to the more concrete aspects of implementation. As a network professional, you need to learn the theory of how networks communicate before you design, build, and maintain networks. Learning the concept of layers can help you understand the action that occurs during communication from one computer to another.

This section covers the concepts of layering and how it applies specifically to communication models. Two specific models, OSI and TCP/IP, are described, as well as peer-to-peer layer communication and encapsulation.

Using Layers to Analyze Problems in a Flow of Materials

The concept of layers helps you understand the action that occurs during communication from one computer to another. The following questions involve the movement of physical objects, such as highway traffic or electronic data:

- What is flowing?
- What are the different forms of the object that is flowing?
- What rules govern flow?
- Where does the flow occur?

This motion of objects, whether physical or logical, is called *flow*. Layers help describe the details of the flow process. Examples of systems that flow are the public water system, the highway system, the postal system, and the telephone system.

Now examine Table 2-5. What network is being examined? What is flowing? What are the different forms of the object that is flowing? What are the rules for flow? Where does the flow occur? The networks listed in this chart give analogies to help you understand data flow in computer networks.

Table 2-5 Network Comparisons

Network	What Is Flowing	Different Forms	Rules	Where
Water	Water	Hot, cold, drinkable, wastewater/ sewer	Access rules (turning taps), flushing, not putting certain things in drains	Pipes
Highway	Vehicles	Trucks, cars, cycles	Traffic laws and common courtesy	Roads and highways
Postal	Objects	Letters (written information), packages	Rules for packaging and attaching postage	Postal service boxes, offices, trucks, planes, delivery people
Telephone	Information	Spoken languages	Rules for accessing phone and rules for politeness	Phone system wires, EM waves, and so on

The network communication process is complex. The data, in the form of electronic signals, must travel across media to the correct destination computer and then be converted back into its original form to be read by the recipient. Several steps are involved in this process. For this reason, the most efficient way to implement network communications is a layered process. In a layered communication process, each layer performs a specific task.

In the next few sections, you'll see how the network communication process is broken down using a layered model. You'll also see how data is sent over the network and how it reaches its intended destination. As you learn about the network communication process, it is important for you to understand the various steps, components, and protocols of the network communication process. This understanding provides you with valuable troubleshooting information when the communications process does not proceed smoothly.

Using Layers to Describe Data Communication

The difficulty in dealing with network communications is that it is a very complex process. It would be extremely difficult for someone to understand this process if he or she looked only at network communication as a whole. The solution to this issue was to break down the total network communication system into a series of layers. Each layer

is responsible for a specific part of network communication. These layers interact with the layer above and below them only. This interaction very narrowly defines a layer's purpose. The two common network models that use layers are the Open System Interconnection (OSI) reference model and the TCP/IP reference model.

The OSI Reference Model

The early development of LANs, MANs, and WANs was chaotic in many ways. The early 1980s saw tremendous increases in the number and size of networks. As companies realized the money they could save and the productivity they could gain by using networking technology, they added networks and expanded existing networks almost as rapidly as new network technologies and products were introduced.

By the mid-1980s, these companies began to experience difficulties from all the implemented expansions. It became more difficult for networks that used different specifications and implementations to communicate with each other. These companies realized that they needed to move away from *proprietary* networking systems. Proprietary systems are privately developed, owned, and controlled. In the computer industry, proprietary is the opposite of open. Proprietary means that one company or a small group of companies controls all usage of the technology. *Open* means that free usage of the technology is available to the public.

To address the problem of network incompatibility and the inability to communicate with one another, the International Organization for Standardization (ISO) researched different network schemes, such as DECnet, Systems Network Architecture (SNA), and TCP/IP, to find a set of rules. As a result of this research, the ISO created a network model that would help vendors create networks that would be compatible and operate with other networks.

The process of breaking down complex communications into smaller discrete tasks can be compared to the process of building an automobile. When taken as a whole, the design, manufacture, and assembly of an automobile is a highly complex process. It is unlikely that a single person would know how to perform all the required tasks to build a car from scratch. This is why mechanical engineers design the car, manufacturing engineers design the molds to make the parts, and assembly technicians each assemble a part of the car.

The *OSI reference model*, released in 1984, was the descriptive scheme that the ISO created. This reference model provided vendors with a set of standards that ensured greater compatibility and interoperability among the various types of network technologies that were produced by many companies around the world.

The OSI reference model is the primary model used as a guideline for network communications. Although other models exist, most network vendors today relate their products to the OSI reference model, especially when they want to educate users on the use of their products. The OSI reference model is considered the best tool available for teaching people about sending and receiving data on a network.

The OSI reference model defines the network functions that occur at each layer. More importantly, it is a framework that facilitates an understanding of how information travels throughout a network. In addition, the OSI reference model describes how information, or data packets, travels from application programs (such as spreadsheets and documents) through a network medium (such as wires) to another application program that is located in another computer on a network, even if the sender and receiver have different types of network media.

The OSI reference model has seven numbered layers, each of which illustrates a particular network function:

- Layer 7—Application layer
- Layer 6—Presentation layer
- Layer 5—Session layer
- Layer 4—Transport layer
- Layer 3—Network layer
- Layer 2—Data link layer
- Layer 1—Physical layer

This separation of networking functions is called *layering*. Dividing the network into seven layers provides the following advantages:

- It breaks network communication into smaller, simpler parts.
- It standardizes network components to allow multiple-vendor development and support.
- It allows different types of network hardware and software to communicate.
- It prevents changes in one layer from affecting the other layers so that they can be developed more quickly.
- It breaks network communication into smaller components to make learning easier.

By working through the layers of the OSI reference model, you will understand how data packets travel through a network and what devices operate at each layer. As a result, you will understand how to troubleshoot network problems if they occur during data packet flow.

OSI Layers and Functions

Each OSI layer has a set of functions that it must perform for data packets to travel from a source to a destination on a network. The following sections briefly describe each layer in the OSI reference model.

Layer 7: The Application Layer

The *application layer* is the OSI layer that is closest to the user. It provides network services to the user's applications. It differs from the other layers in that it does not provide services to any other OSI layer; instead, it provides services only to applications outside the OSI model. Examples of such applications are spreadsheet programs and word-processing programs. The application layer establishes the availability of intended communication partners and also synchronizes and establishes agreement on procedures for error recovery and control of data integrity. Examples of the Layer 7 applications include Telnet and HTTP.

Layer 6: The Presentation Layer

The *presentation layer* ensures that the information that the application layer of one system sends out can be read by the application layer of another system. If necessary, the presentation layer translates among multiple data formats by using a common format. One of the more important tasks of this layer is encryption and decryption. The common Layer 6 graphic standards are PICT, TIFF, and JPEG. Examples of Layer 6 standards that guide the presentation of sound and movies are MIDI and MPEG.

Layer 5: The Session Layer

As its name implies, the *session layer* establishes, manages, and terminates sessions between two communicating hosts. The session layer provides its services to the presentation layer. It also synchronizes dialogue between the two hosts' presentation layers and manages their data exchange. In addition to handling session regulation, the session layer offers provisions for efficient data transfer, class of service, and exception reporting of session layer, presentation layer, and application layer problems. Examples of Layer 5 protocols are the Network File System (NFS), X-Window System, and AppleTalk Session Protocol (ASP).

Layer 4: The Transport Layer

The *transport layer* segments data from the sending host's system and reassembles it into a data stream on the receiving host's system. The boundary between the transport layer and the session layer can be thought of as the boundary between application protocols and data-flow protocols. Whereas the application, presentation, and session

layers are concerned with application issues, the lowest four layers are concerned with data-transport issues.

The transport layer attempts to provide a data-transport service that shields the upper layers from transport-implementation details. Specifically, issues such as reliability of transport between two hosts are the concern of the transport layer. In providing communication service, the transport layer establishes, maintains, and properly terminates virtual circuits. Transport error detection and recovery and information flow control are used to provide reliable service. Examples of Layer 4 protocols are Transmission Control Protocol (TCP), User Datagram Protocol (UDP), and Sequenced Packet Exchange (SPX).

Layer 3: The Network Layer

The *network layer* is a complex layer that provides connectivity and path selection between two host systems that might be located on geographically separated networks. Additionally, the network layer is concerned with logical addressing. Examples of Layer 3 protocols are Internet Protocol (IP), Internetwork Packet Exchange (IPX), and AppleTalk.

Layer 2: The Data Link Layer

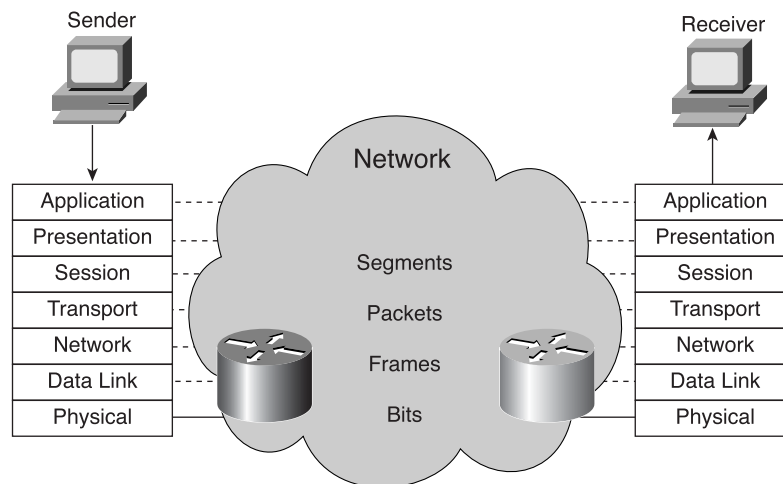
The *data link layer* provides reliable transit of data across a physical link. In so doing, the data link layer is concerned with physical (as opposed to logical) addressing, network topology, network access, error notification, ordered delivery of frames, and flow control.

Layer 1: The Physical Layer

The *physical layer* defines the electrical, mechanical, procedural, and functional specifications for activating, maintaining, and deactivating the physical link between end systems. Such characteristics as voltage levels, timing of voltage changes, physical data rates, maximum transmission distances, physical connectors, and other similar attributes are defined by physical layer specifications.

Peer-to-Peer Communications

For data packets to travel from the source to the destination, each layer of the OSI model at the source must communicate with its peer layer at the destination. This form of communication is called *peer-to-peer communication*. During this process, the protocols at each layer exchange information, called *protocol data units (PDUs)*, between peer layers. Each layer of communication on the source computer communicates with a layer-specific PDU and with its peer layer on the destination computer, as shown in Figure 2-17.

Figure 2-17 Peer-to-Peer Communication

Data packets on a network originate at a source and then travel to a destination. Each layer depends on the service function of the OSI layer below it. To provide this service, the lower layer uses encapsulation to put the PDU from the upper layer into its data field. Each layer then adds whatever headers it needs to perform its function. As the data moves through the layers of the OSI model, additional headers are added. The grouping of data at the Layer 4 PDU is called a *segment*.

The network layer provides a service to the transport layer. The network layer moves the data through the internetwork by encapsulating the data and attaching a header to create a *packet* (the Layer 3 PDU). The header contains information required to complete the transfer, such as source and destination logical addresses.

The data link layer provides a service to the network layer. It encapsulates the network layer information in a *frame* (the Layer 2 PDU). The frame header contains the physical addresses required to complete the data link functions, and the frame trailer contains the frame check sequence (FCS), which is used by the receiver to detect whether the data is in error. This then becomes the data that is passed down to the physical layer.

The physical layer provides a service to the data link layer. The physical layer encodes the data link frame into a pattern of 1s and 0s (bits) for transmission on the medium (usually a wire) at Layer 1.

Network devices such as hubs, switches, and routers work at the lowest three layers. Hubs operate at Layer 1, switches operate at Layer 2, and routers at Layer 3. The first layer that deals with the end-to-end transport between end users is the transport layer (Layer 4).

DoD (TCP/IP) Model

Although the OSI reference model is universally recognized, the historical and technical open standard of the Internet is Transmission Control Protocol/Internet Protocol (TCP/IP). The TCP/IP reference model and the TCP/IP protocol suite make data communication possible between any two computers anywhere in the world at nearly the speed of light. The TCP/IP model has historical importance, just like the standards that allowed the telephone, electrical power, railroad, television, and videotape industries to flourish.

The U.S. DoD provided funding for the invention of the TCP/IP reference model because it wanted a network that could survive any conditions, even a nuclear war. To illustrate further, imagine a world at war, criss-crossed by different kinds of connections, including wires, microwaves, optical fibers, and satellite links. Then imagine that information/data (in the form of packets) must flow, regardless of the condition of any particular node or network on the internetwork (which, in this case, might have been destroyed by the war). The DoD wants its packets to get through every time, under any conditions, from any one point to any other point. This very difficult design problem brought about the creation of the TCP/IP model, which has since become the standard on which the Internet has grown.

When reading about the TCP/IP model layers, remember the original intent of the Internet; it helps explain why certain things are as they are. The TCP/IP model, as shown in Figure 2-18, has four layers:

- The application layer
- The transport layer
- The Internet layer
- The network access layer

Figure 2-18 The TCP/IP Model

OSI	TCP/IP
Application (Layer 7)	Application
Presentation (Layer 6)	
Session (Layer 5)	
Transport (Layer 4)	Transport
Network (Layer 3)	Internet
Data Link (Layer 2)	Network Access
Physical (Layer 1)	

It is important to note that some of the layers in the TCP/IP model have the same names as layers in the OSI model. However, do not confuse the layers of the two models. Even with the same name, most the layers have the same functions in each model, but some do not.



Lab Activity OSI Model and TCP/IP Model

In this exercise, you describe and compare the layers of the OSI and TCP/IP models. You also name the TCP/IP protocols and utilities that operate at each layer.

Detailed Encapsulation Process

All communications on a network originate at a source and are sent to a destination. The information that is sent on a network is called data or data packets. If one computer (Host A) wants to send data to another computer (Host B), the data must first be packaged by a process called *encapsulation*.

Encapsulation

Encapsulation wraps data with the necessary protocol information before network transit. Therefore, as the data moves down through the layers of the OSI model, each OSI layer adds a header (and also a trailer at Layer 2) to the data before passing it down to a lower layer. The headers and trailers contain control information for the network devices and receiver, to ensure proper delivery of the data and to ensure that the receiver can properly interpret the data. For example, think of a header as an address on an envelope. An address is required on the envelope so that the letter inside the envelope can be delivered to the desired recipient.

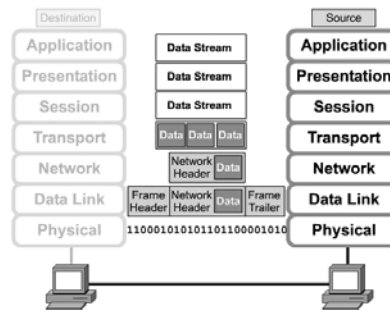
To see how encapsulation occurs, examine the manner in which data travels through the layers, as illustrated in Figure 2-19. After the data is sent from the source, it travels through the application layer down through the other layers. The packaging and flow of the data that is exchanged go through changes as the layers perform their services for end users.

The data, in the form of electronic signals, must travel across a cable to the correct destination computer and then be converted to its original form to be read by the recipient. As you can imagine, several steps are involved in this process. For this reason, developers of hardware, software, and protocols recognized that the most efficient way to implement network communications would be as a layered process.

NOTE

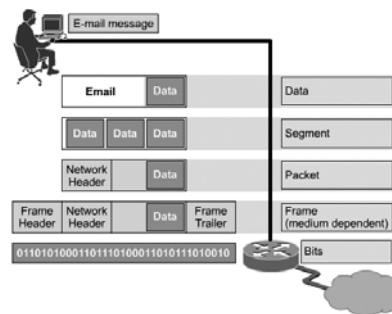
The word *header* means that information was added to the front of the packet, just as trailers are added to the end. In addition, an address is an important piece of information that gets added.

Figure 2-19 Encapsulation



As illustrated in Figure 2-20, networks must perform the following five conversion steps to encapsulate data:

- Step 1 Build the data**—As a user sends an e-mail message, its alphanumeric characters are converted to data that can travel across the internetwork.
- Step 2 Package the data for end-to-end transport**—The data is packaged for internetwork transport. By using segments, the transport function ensures that the message hosts at both ends of the e-mail system can communicate reliably.
- Step 3 Append (add) the network address to the header**—The data is put into a packet or datagram that contains a network header with source and destination logical addresses. These addresses help network devices send the packets across the network along a chosen path.
- Step 4 Append (add) the local address to the data link header**—Each network device must put the packet into a frame. The frame allows connection to the next directly-connected network device on the link. Each device in the chosen network path requires framing to be connected to the next device.
- Step 5 Convert to bits for transmission**—A clocking function lets the devices distinguish these bits as they travel across the medium. The medium on the physical internetwork can vary along the path used. For example, the e-mail message can originate on a LAN, cross a campus backbone, and go out a WAN link until it reaches its destination on another remote LAN. Headers and trailers are added as data moves down through the layers of the OSI model.

Figure 2-20 Data Encapsulation Process

De-Encapsulation

When the remote device receives a sequence of bits, the physical layer at the remote device passes the bits to the data link layer for manipulation. The data link layer does the following:

- Step 1** Verifies that the MAC destination address matches this station's address or is an Ethernet broadcast. If neither of these situations is true, the frame is discarded.
- Step 2** If the data is in error, it can be discarded, and the data link layer might ask for the data to be retransmitted. If the data is not in error, the data link layer reads and interprets the control information in the data link header.
- Step 3** The data link layer strips the data link header and trailer and then passes the remaining data up to the network layer based on the control information in the data link header.

This process is called *de-encapsulation*. Each subsequent layer performs a similar de-encapsulation process. Think of the de-encapsulation process as the process of reading the address on a letter to see if it is for you and then removing the letter from the envelope if the letter is addressed to you.

More Information: Cyclical Redundancy Check

Each data packet has information added to the raw data itself, in the form of packet headers. The headers contain addressing information so that the packets reach the correct destination. They also contain sequencing information so the data can be reassembled accurately when all packets reach the receiving computer.

continues

More Information: Cyclical Redundancy Check (Continued)

Header information is placed at the head of the packet, in front of the original data. Packets also can include trailer information, which is appended to the back of the packet, following the original data.

The error-checking component in the trailer is called a cyclical redundancy check (CRC). The CRC performs calculations on the packet before it leaves the source computer and again when it reaches the destination. If the results of these calculations are different, the data has changed. This can occur because of a disruption of the electrical signals that represent the 0s and 1s making up the data. If a discrepancy is found, that packet can be resent.

Networking Devices

Equipment that connects directly to a network segment is called a *device*. These devices are broken into two classifications:

- **End user devices**—Include computers, printers, scanners, and other devices that provide services directly to the user.
- **Network devices**—Include all devices that connect the end-user devices to allow them to communicate.

End-user devices that provide users with a connection to the network are also called *hosts*. Figure 2-21 shows an example of an end-user device—a workstation.

Figure 2-21 End-User Device: Workstation



These devices allow users to share, create, and obtain information. Host devices can exist without a network, but without a network, host capabilities are greatly reduced. Host devices are physically connected to the network media using a *network interface card (NIC)*. They use this connection to perform the tasks of sending e-mails, printing reports, scanning pictures, or accessing databases. A NIC is a printed circuit board that fits into the expansion slot of a bus on a computer motherboard, or it can be a peripheral device. It is also called a network adapter. Laptop or notebook computer NICs are usually the size of a PCMCIA card.

Each NIC carries a unique code called a MAC address. MAC addresses are covered more in a moment. As the name implies, the NIC controls host access to the medium.

There are no standardized symbols for end-user devices in the networking industry. They bear a resemblance to the real device to allow for quick recognition.

Network devices provide transport for the data that needs to be transferred between end-user devices. Network devices extend cable connections, concentrate connections, convert data formats, and manage data transfers. Examples of devices that perform these functions are repeaters, hubs, bridges, switches, and routers. The following sections provide an overview of some common networking devices.

Repeaters

Repeaters are networking devices that exist at Layer 1, the physical layer, of the OSI reference model. To understand how a repeater works, it is important to understand that as data leaves a source and goes out over the network, it is transformed into either electrical or light pulses that pass along the networking medium. These pulses are called *signals*. When signals leave a transmitting station, they are clean and easily recognizable. However, the longer the cable length, the weaker and more deteriorated the signals become as they pass along the networking medium. The purpose of a repeater is to regenerate and retime network signals at the bit level, allowing them to travel a longer distance on the medium.

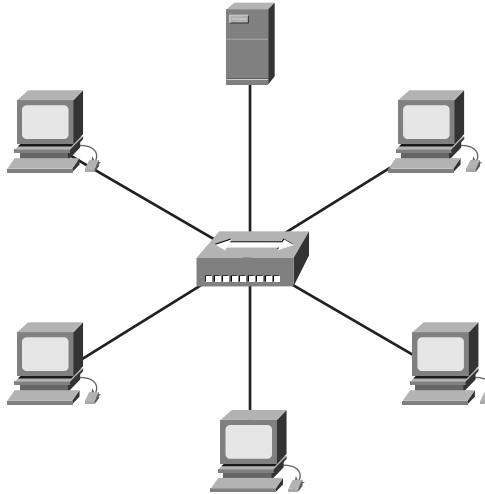
The term *repeater* originally meant a single port “in” device and a single port “out” device. Today multiple-port repeaters also exist. Repeaters are classified as Layer 1 devices in the OSI model because they act only on the bit level and look at no other information.

Hubs

The purpose of a *hub* is to regenerate and retime network signals. The characteristics of a hub are similar to those of a repeater. A hub is a common connection point for

devices in a network, as shown in Figure 2-22. Hubs commonly connect segments of a LAN. A hub contains multiple ports. When a packet arrives at one port, it is copied to the other ports so that all the LAN's segments can see all the packets.

Figure 2-22 Hub



Because hubs and repeaters have similar characteristics, a hub is also called a *multiport repeater*. The difference between a repeater and a hub is the number of cables that connect to the device. Whereas a repeater typically has only two ports, a hub generally has from four to 20 or more ports, as shown in Figure 2-23. Whereas a repeater receives on one port and repeats on the other, a hub receives on one port and transmits on all the other ports.

Figure 2-23 Hubs Have Several Ports



The following are the most important properties of hubs:

- Hubs amplify signals.
- Hubs propagate signals through the network.
- Hubs do not require filtering.

- Hubs do not require path determination or switching.
- Hubs are used as network-concentration points.

Hubs are commonly used in Ethernet 10BASE-T or 100BASE-T networks. (You will learn more about Ethernet networks in Chapter 6, “Ethernet Technologies and Ethernet Switching.”) Hubs create a central connection point for the wiring medium. They also increase the network’s reliability by allowing any single cable to fail without disrupting the entire network. This feature differs from the bus topology, in which the failure of one cable disrupts the entire network. (Network topology is discussed later in this chapter.) Hubs are considered Layer 1 devices because they only regenerate the signal and repeat it out all their ports (network connections).

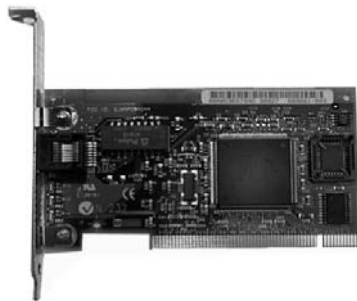
In Ethernet networks, all the hosts are connected to the same physical medium. Signals that are sent out across the common medium are received by all devices. A *collision* is a situation that can occur when 2 bits propagate at the same time on the same network. The area within the network from where the data packets originate and collide is called a *collision domain*. All shared-media environments are collision domains, or *bandwidth domains*. You learn more about collision domains in Chapter 5, “Ethernet Fundamentals.”

As previously mentioned in this section, the function of Layer 1 devices is simply to facilitate the transmission of signals. The devices recognize no information patterns in the signals, no addresses, and no data. When two wires are connected using hubs or repeaters, all the interconnections are part of a collision domain.

Network Interface Cards

Network interface cards (NICs) are considered Layer 2 devices because each NIC throughout the world carries a unique code, called a *Media Access Control (MAC)* address. This address controls data communication for the host on the LAN. The NIC controls the access of the host to the medium. Figure 2-24 shows a NIC.

Figure 2-24 Network Interface Card



Bridges

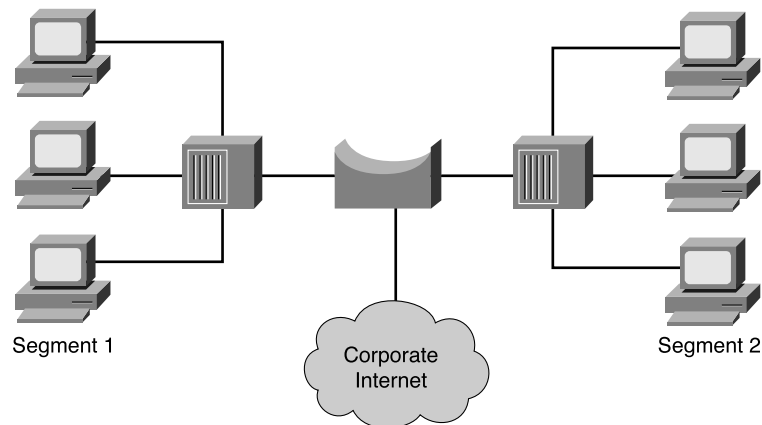
A *bridge* is a Layer 2 device designed to create two or more LAN segments, each of which is a separate collision domain. In other words, bridges were designed to create more usable bandwidth. The purpose of a bridge is to filter traffic on a LAN to keep local traffic local yet allow connectivity to other parts (segments) of the LAN for traffic that is directed there. Every networking device has a unique MAC address on the NIC. The bridge keeps track of which MAC addresses are on each side of the bridge and makes forwarding decisions based on this MAC address list.

Bridges filter network traffic by looking only at the MAC address. Therefore, they can rapidly forward traffic representing any network layer protocol. Because bridges look only at MAC addresses, they are not concerned with network layer protocols. Consequently, bridges are concerned only with passing or not passing frames, based on their destination MAC addresses. The following are the important properties of bridges:

- Bridges are more “intelligent” than hubs. That is, they can analyze incoming frames and forward (or drop) them based on addressing information.
- Bridges collect and pass packets between two or more LAN segments.
- Bridges create more collision domains, allowing more than one device to transmit simultaneously without causing a collision.
- Bridges maintain MAC address tables.

Figure 2-25 shows how a bridge is used. The appearances of bridges vary greatly, depending on the type.

Figure 2-25 Bridge



What defines a bridge is its Layer 2 filtering of frames and how this is accomplished. To filter or selectively deliver network traffic, bridges build tables of all MAC addresses located on a network segment and other networks and then map them to associated ports. The process is as follows:

- Step 1** If data comes along the network medium, a bridge compares the destination MAC address carried by the data to MAC addresses contained in its tables.
- Step 2** If the bridge determines that the data's destination MAC address is from the same network segment as the source, it does not forward the data to other segments of the network. This process is known as *filtering*. By performing this process, bridges can significantly reduce the amount of traffic between network segments by eliminating unnecessary traffic.
- Step 3** If the bridge determines that the data's destination MAC address is not from the same network segment as the source, it forwards the data to the appropriate segment.
- Step 4** If the destination MAC address is unknown to the bridge, the bridge broadcasts the data to all devices on a network except the one on which it was received. This process is known as *flooding*.

A *broadcast* is a data packet that is sent to all nodes on a network. A *broadcast domain* consists of all the devices connected to a network that receive the data packet broadcast by a node to all other nodes on the same network. Because every device on the network must pay attention to broadcasts, bridges always forward them. Therefore, all segments in a bridged environment are considered to be in the same broadcast domain.

As was the case in the repeater/hub combination, another device, called a *switch*, is used for multiple bridge connections. The next section discusses switches in greater detail.

Layer 2 Switches

Layer 2 switches, also called LAN switches or workgroup switches, often replace shared hubs and work with existing cable infrastructures to ensure that the switches are installed with minimal disruption of existing networks. Figure 2-26 shows a switch.

Figure 2-26 Switch



Like bridges, switches connect LAN segments, use a table of MAC addresses to determine the segment on which a frame needs to be transmitted, and reduce traffic. Switches operate at much higher speeds than bridges.

Switches are data link layer devices that, like bridges, let multiple physical LAN segments be interconnected into single larger networks. Similar to bridges, switches forward and flood traffic based on MAC addresses. Because switching is performed in hardware, it is significantly faster than the switching function performed by a bridge using software. Think of each switch port as a microbridge. Each switch port acts as a separate bridge and gives each host the medium's full bandwidth. This process is called microsegmentation.

Microsegmentation allows the creation of private or dedicated segments—one host per segment. Each host receives instant access to the full bandwidth and does not have to compete for available bandwidth with other hosts. In full-duplex switches, because only one device is connected to each switch port, collisions do not occur.

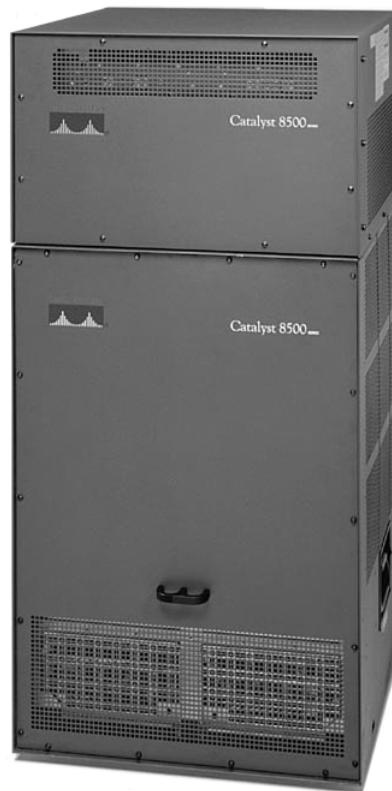
However, as with a bridge, a switch forwards a broadcast message to all the segments on the switch. All segments in a switched environment are therefore considered to be in the same broadcast domain.

Some switches—mainly high-end and enterprise-level switches—perform multilayer functioning. For example, the Cisco 6500 and 8500 series perform some Layer 3 functions. The Cisco Catalyst 8500, shown in Figure 2-27, is a Layer 3-enhanced ATM switch that seamlessly integrates wire-speed Layer 3 switching and ATM switching. The Catalyst 8500 family delivers campus and MAN solutions with scalable performance, lower cost of ownership, and intranet-based application features to deliver increased business productivity. Unlike old first- or second-generation ATM switches, which force customers to have a costly, inefficient, multisystem solution, the Catalyst 8500 switch provides an integrated ATM and Gigabit Ethernet solution in a single chassis.

Routers

A *router*, as shown in Figure 2-28, is a type of internetworking device that passes data packets between networks based on Layer 3 addresses. A router can make decisions regarding the best path for delivery of data on the network.

Working at Layer 3 allows the router to make decisions based on network addresses instead of individual Layer 2 MAC addresses. Routers also can connect different Layer 2 technologies, such as Ethernet, Token Ring, and Fiber Distributed Data Interface (FDDI). Routers also commonly connect Asynchronous Transfer Mode (ATM) and serial connections. However, because of their capability to route packets based on Layer 3 information, routers have become the backbone of the Internet and run the IP protocol.

Figure 2-27 Cisco Catalyst 8500 Switch**Figure 2-28** Router

The purpose of a router is to examine incoming packets (Layer 3 data), choose the best path for them through the network, and then switch them to the proper outgoing port. Routers are the most important traffic-regulating devices on large networks. Routers let virtually any type of computer communicate with any other computer anywhere in the world.

Voice, DSL, Cable Modem, and Optical Devices

Recent networking demands of voice and data network integration and fast data transmission for end users and network backbones have resulted in the development of the following new networking devices:

- Voice gateways for handling converged packetized voice and data traffic
- DSLAMs used at the service provider's central office for concentrating DSL modem connections from hundreds of homes
- Cable Modem Termination System (CMTS) used at a cable operator's headend or central location to concentrate connections from many cable modem subscribers.
- Optical platforms for sending and receiving data over fiber-optic cable, providing high-speed connection

Voice Gateway

A *gateway* is a special-purpose device that converts information from one protocol stack to another. The Cisco AS5400 Series Universal Access Server provides cost-effective platforms that combine routing, remote access, voice gateway, firewall, and digital modem functionality. Figure 2-29 shows a Cisco AS5400 Series Universal Gateway, which offers universal port data, voice, wireless, and fax services on any port at any time.

Figure 2-29 Cisco AS5400 Series Universal Gateway



DSLAM

A digital subscriber line access multiplexer (DSLAM) is a device used in a variety of DSL technologies. A DSLAM serves as the interface point between a number of subscriber premises and the carrier network. Figure 2-30 shows a Cisco 6100 Series Advanced DSL Access Multiplexer.

Figure 2-30 Cisco DSLAM 6100

CMTS

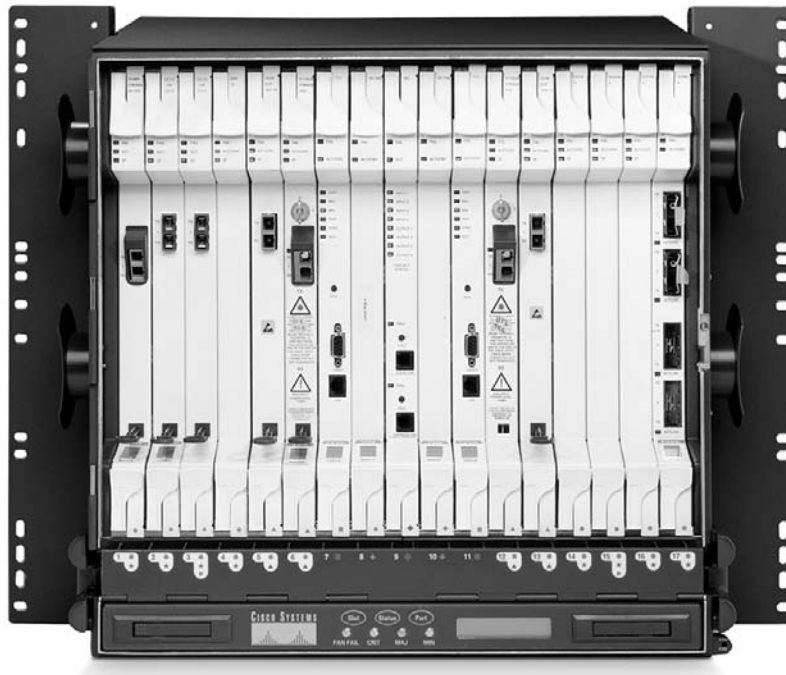
Cable operators use a Cable Modem Termination System (CMTS) at various concentration points or hubs in the cable network to provide high-speed Internet access, voice, and other networking services to home and business subscribers. The Cisco uBR7100 (Universal Broadband Router) CMTS series is designed for MTUs (multitenant units) such as apartment buildings and hotels. High-capacity models such as the uBR10012 series, shown in Figure 2-31, can handle thousands of subscribers.

Figure 2-31 Cisco CMTS uBR10012

Optical Platforms

Several optical platforms are available for optical networking, which is primarily a backbone, wide-area technology. Figure 2-32 shows a Cisco ONS 15454 dense wavelength division multiplexing (DWDM) optical network system (ONS). The Cisco ONS 15454 provides the functions of multiple network elements in a single platform.

Figure 2-32 Optical Platform—The Cisco ONS 15454 DWDM Optical Network System



Security Devices

Because of increased Internet and extranet connections, as well as more telecommuters and mobile users accessing enterprise networks from remote sites, the importance of network security increases. Firewalls, AAA servers, and VPN concentrators are components or devices related to network security.

Firewalls

The term *firewall* refers to either a firewall program running on a router or server or a special standalone hardware component of a network. A firewall protects a private network's resources from users in other networks.

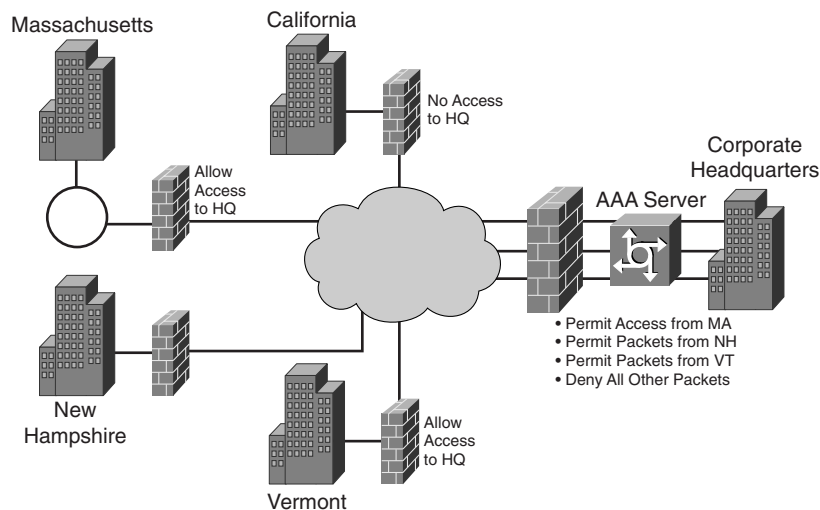
Working closely with a router program, a firewall examines each network packet to determine whether to forward it to its destination. Using a firewall is like using a traffic officer to ensure that only valid traffic can enter or leave certain networks. Figure 2-33 shows a Cisco PIX Firewall 535 series, which is a dedicated network device.

Figure 2-33 Cisco PIX Firewall

AAA Servers

An *AAA server* is a server program that handles user requests for access to computer and network resources. An AAA server provides authentication, authorization, and accounting services for an enterprise. The AAA server ensures that only authentic users can get into the network (authentication), that the users are allowed access only to the resources they need (authorization), and that records are kept of everything they do after they are allowed entry (accounting).

An AAA server is like the credit card system. To put charges on a credit card, the merchant must verify that the credit card actually belongs to the person using it (authentication). The merchant must also check that the credit card has enough credit left for the requested charge amount (authorization), and then the merchant must record the charge to the user's account (accounting). Figure 2-34 shows an example of where an AAA server is used.

Figure 2-34 AAA Server

VPN Concentrators

A VPN concentrator offers powerful remote access and site-to-site VPN capability, an easy-to-use management interface, and a VPN client. The Cisco VPN 3000 Concentrator Series is a family of purpose-built, remote-access VPN platforms and client software that incorporates high availability, high performance, and scalability with the most advanced encryption and authentication techniques available today. Figure 2-35 shows a VPN 3000 Concentrator.

Figure 2-35 Cisco VPN 3000 Concentrator

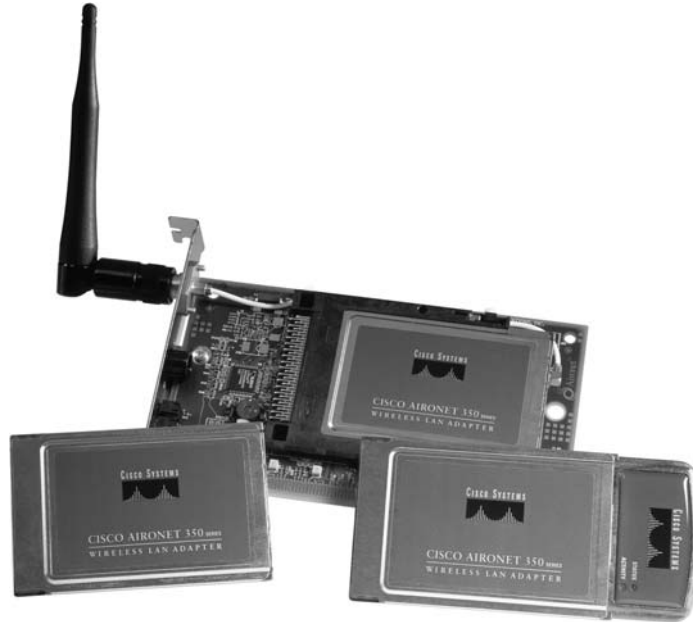


Wireless Devices

A wireless LAN (WLAN) provides all the features and benefits of traditional LAN technologies, such as Ethernet, without the limitations of wire or cables. Some common wireless networking devices include wireless NICs, wireless access points, and wireless bridges. The following sections briefly describe these wireless networking devices.

Wireless NICs

Each wireless client requires a wireless NIC or client adapter. These are available as PCMCIA and PCI cards to provide wireless connectivity for both laptop and desktop workstations. Laptops or notebook PCs, with wireless NICs, can move freely throughout a campus environment while maintaining connectivity to the network. Wireless PCI and ISA adapters (for desktop workstations) allow end stations to be added to the LAN quickly, easily, and inexpensively without the need for additional cabling. All adapters feature antennas—the PCMCIA card with a built-in antenna and the PCI card with an external antenna. The antennas provide the range required for data transmission and reception. Figure 2-36 shows wireless adapters.

Figure 2-36 Wireless Adapters

Wireless Access Points

The access point (AP) or base station (see Figure 2-37) is a wireless LAN transceiver that can act as a hub—the center point of a standalone wireless network—or as a bridge—the connection point between wireless and wired networks. Multiple APs can provide roaming functionality, allowing wireless users freedom to roam throughout a facility while maintaining uninterrupted connectivity to the network.

Figure 2-37 Wireless Access Point

Wireless Bridges

A wireless bridge, shown in Figure 2-38, provides high-speed (11 Mbps), long-range (up to 2.5 miles), line-of-sight wireless connectivity between Ethernet networks. Any Cisco AP can be used as a repeater (extension point) for the wireless network.

Figure 2-38 Wireless Bridge



Lab Activity OSI Model Encapsulation and Devices

In this lab, you describe layers and characteristics of the OSI model. You also identify the encapsulation units and devices that operate at each layer.

Network Topologies

A network topology defines how computers, printers, network devices, and other devices are connected. In other words, a network topology describes the layout of the wire and devices as well as the paths used by data transmissions. The topology greatly influences how the network works.

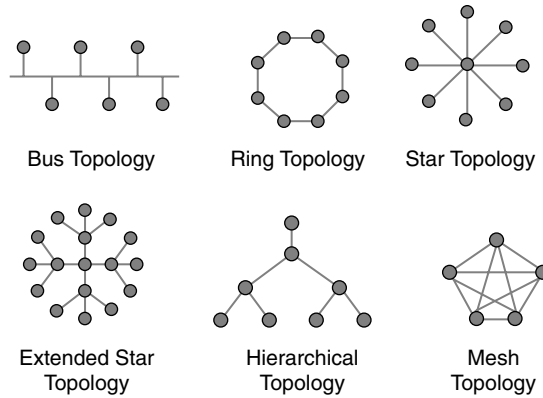
Networks can have both a physical and a logical topology. *Physical topology* refers to the physical layout of the devices and media. Physical topologies that are commonly used are

- Bus
- Ring
- Star
- Extended star

- Hierarchical
- Mesh

Figure 2-39 illustrates the different physical topologies.

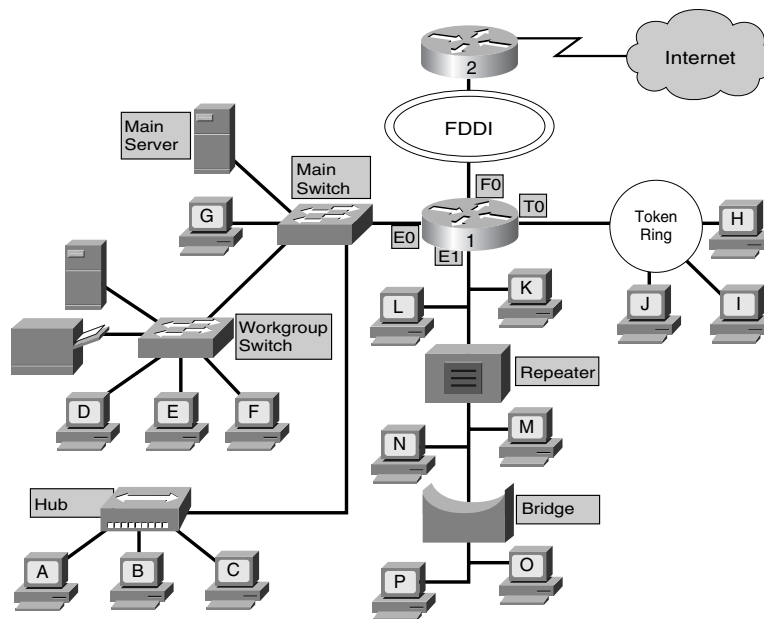
Figure 2-39 Physical Topologies



Logical topology defines how the medium is accessed by the hosts for sending data. The following sections describe different types of physical and logical topologies.

Figure 2-40 shows many different topologies connected by networking devices. It shows a network of moderate complexity that is typical of a school or small business.

Figure 2-40 Networking Topologies

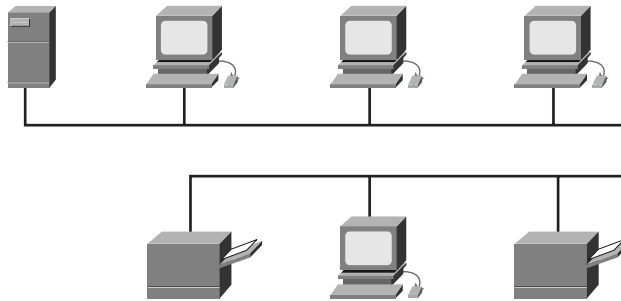


The following sections describe the different networking topologies in more detail.

Bus Topology

Commonly called a linear bus, a *bus topology* connects all the devices using a single cable (see Figure 2-41). This cable proceeds from one computer to the next like a bus line going through a city.

Figure 2-41 Bus Topology



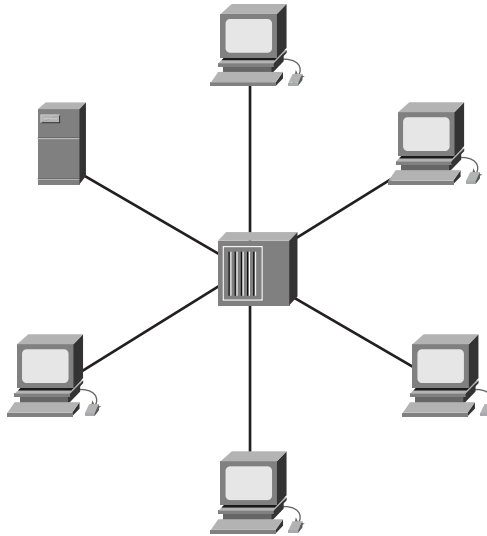
With a physical bus topology, the main cable segment must end with a terminator that absorbs the signal when it reaches the end of the line or wire. If there is no terminator, the electrical signal representing the data bounces back at the end of the wire, causing errors in the network.

Star and Extended-Star Topologies

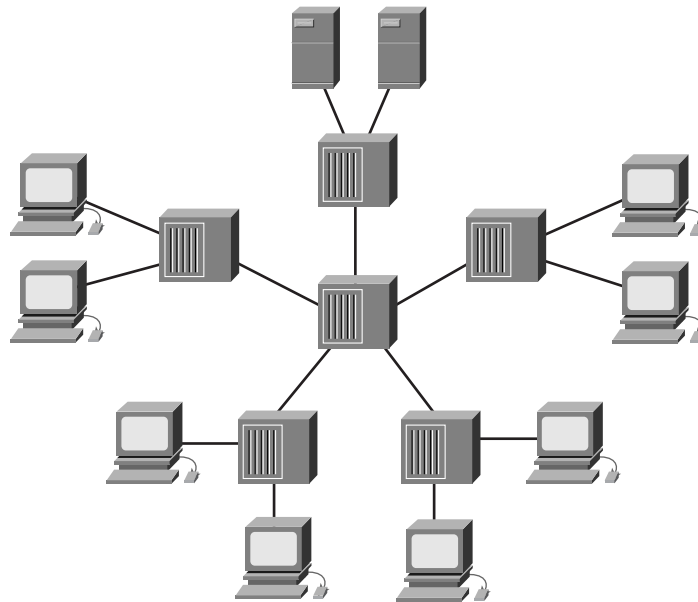
The *star topology*, shown in Figure 2-42, is the most commonly used physical topology in Ethernet LANs. When installed, the star topology resembles spokes in a bicycle wheel. The star topology is made up of a central connection point that is a device such as a hub, switch, or router, where all the cabling segments meet. Each host in the network is connected to the central device with its own cable.

Although a physical star topology costs more to implement than the physical bus topology, the advantages of a star topology make it worth the additional cost. Because each host is connected to the central device with its own cable, when that cable has a problem, only that host is affected; the rest of the network remains operational. This benefit is extremely important and is why virtually every newly designed Ethernet LAN has a physical star topology.

A central connection point might be desirable for security or restricted access, but this is also a main disadvantage of a star topology. If the central device fails, the whole network becomes disconnected.

Figure 2-42 Star Topology

When a star network is expanded to include an additional networking device that is connected to the main networking device, it is called an *extended-star topology*, as shown in Figure 2-43.

Figure 2-43 Extended-Star Topology

Ring Topology

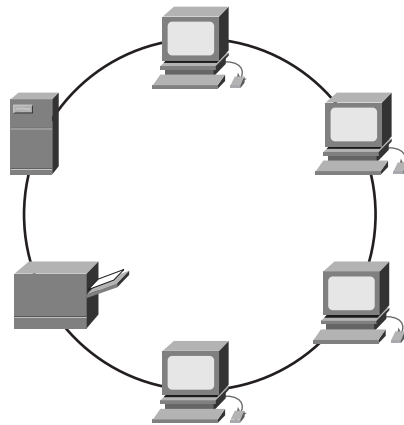
The logical *ring topology* is another important topology in LAN connectivity. As the name implies, hosts are connected in the form of a ring or circle. Unlike the physical bus topology, the ring topology has no beginning or end that needs to be terminated. Data is transmitted in a way unlike the logical bus topology. A frame travels around the ring, stopping at each node. If a node wants to transmit data, it is permitted to add that data as well as the destination address to the frame. The frame then continues around the ring until it finds the destination node, which takes the data out of the frame. The advantage of using this type of method is that there are no collisions of data packets.

Two types of rings exist:

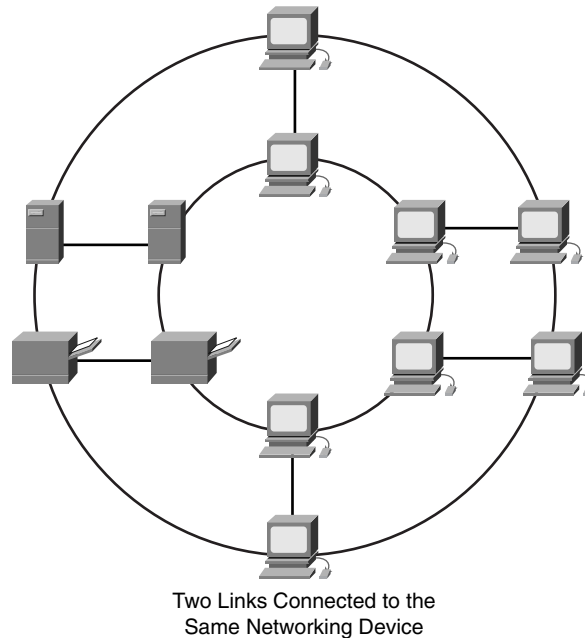
- Single ring
- Dual ring

In a single ring, as shown in Figure 2-44, all the devices on the network share a single cable, and the data travels in one direction only. Each device waits its turn to send data over the network. Most single-ring topologies are actually wired as a star.

Figure 2-44 Ring Topology



In a dual ring, two rings allow data to be sent in both directions, as shown in Figure 2-45. This setup creates redundancy (fault tolerance), meaning that if one ring fails, data can be transmitted on the other ring. Also, if both rings fail, a “wrap” at the fault can heal the topology back into a ring.

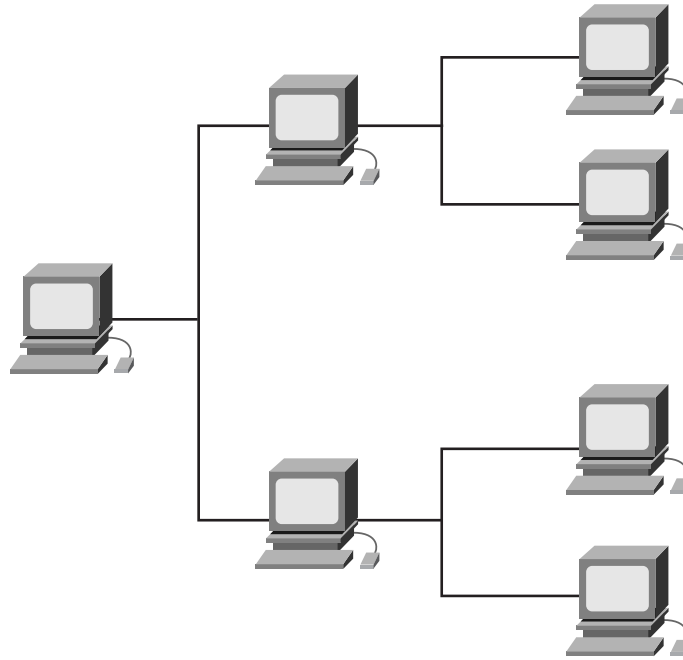
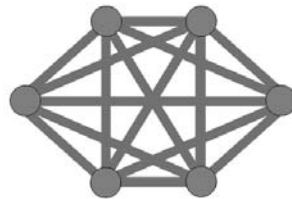
Figure 2-45 Dual-Ring Topology

Hierarchical Topology

A *hierarchical topology* is created similar to an extended-star topology. The primary difference is that it does not use a central node. Instead, it uses a trunk node from which it branches to other nodes, as shown in Figure 2-46. Two types of tree topologies exist: the binary tree (each node splits into two links) and the backbone tree (a backbone trunk has branch nodes with links hanging from it).

Full-Mesh and Partial-Mesh Topologies

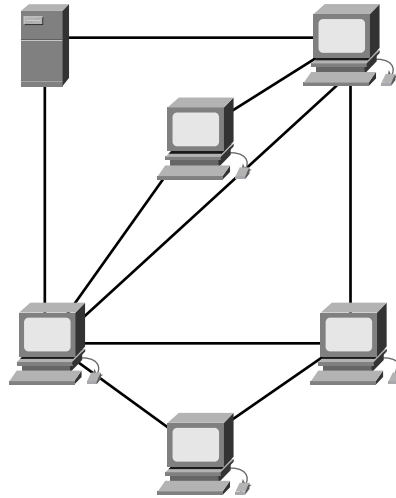
The *full-mesh topology* connects all devices (nodes) to each other for redundancy and fault tolerance, as shown in Figure 2-47. The wiring in a full-mesh topology has very distinct advantages and disadvantages. The advantage is that every node is connected physically to every other node, which creates a redundant connection. If any link fails, information can flow through many other links to reach its destination. The primary disadvantage is that for anything more than a small number of nodes, the amount of media for the links and the number of the connections on the lines becomes overwhelming. Implementing a full-mesh topology is expensive and difficult. The full-mesh topology is usually implemented in WANs between routers.

Figure 2-46 Hierarchical Topology**Figure 2-47** Full-Mesh Topology

In a *partial-mesh topology*, at least one device maintains multiple connections to others without being fully meshed, as shown in Figure 2-48. A partial-mesh topology still provides redundancy by having several alternative routes. If one route cannot be used, the data takes another route, even if it is longer. The partial-mesh topology is used for many telecommunications backbones, as well as the Internet.

Logical Topology

A network's logical topology is how the hosts communicate across the medium. The two most common types of logical topology are broadcast and *token passing*.

Figure 2-48 Partial-Mesh Topology

Broadcast topology simply means that each host addresses its data to a particular NIC, to a multicast address, or to a broadcast address on the network medium. There is no order that the stations must follow to use the network. It is first come, first serve. Ethernet also works this way, as explained later in this course.

The second logical topology is token passing. Token passing controls network access by passing an electronic token sequentially to each host. When a host receives the token, it can send data on the network. If the host has no data to send, it passes the token to the next host, and the process repeats itself. Two examples of networks that use token passing are Token Ring and FDDI, both of which are examples of token passing on a physical ring topology.

Summary

In this chapter, you learned the following key points:

- Historic reasons for the development of LANs and WANs
- A LAN consists of computers, NICs, peripheral devices, networking media, and network devices.
- A WAN consists of two or more LANs spanning two or more geographically separate areas.
- A MAN spans a metropolitan area, such as a city or a suburban area.

- A SAN provides enhanced system performance, is scalable, and has disaster tolerance built in.
- A data center is a globally coordinated network of devices designed to accelerate the delivery of information over the Internet infrastructure.
- Intranets are designed to be accessed by users who have access privileges to an organization's internal network. Extranets are designed to deliver applications and services that are intranet-based but that employ extended, secured access to external users or enterprises.
- A VPN is a private network that is constructed within a public network infrastructure. Three main types of VPNs are access, intranet, and extranet.
- Bandwidth and throughput are measures of a network's speed or capacity.
- Breaking a complex problem into smaller units helps you understand the larger problem.
- Communication is a complex problem that can be broken into a series of layers. Multiple systems can be used for the breakdown.
- The ISO created and released the OSI model in 1984 to provide vendors with a set of standards to ensure greater compatibility and interoperability among various types of network technologies.
- The OSI reference model is a descriptive network scheme whose standards ensure greater compatibility and interoperability between various types of network technologies.
- Each OSI layer has a specific function and protocols to support it. The seven layers of the OSI model are application, presentation, session, transport, network, data link, and physical.
- Each layer in a sending device's communication protocol communicates with its peer layer in the receiving device.
- The TCP/IP model has four layers: application, transport, Internet, and network access.
- All communications on a network originate at a source and are sent to a destination. That encapsulation wraps data with the necessary protocol information before network transit.
- Networking devices are products that connect networks. Hubs, switches, and routers interconnect devices within LANs, MANs, and WANs. Networking devices function at different layers of the OSI model.
- Repeaters regenerate, amplify, and retime signals before sending them along the network.

- The term *hub* is used instead of *repeater* when referring to the device that serves as the center of a network. Hubs (also known as multiport repeaters) work at Layer 1 only and make no decisions. A hubs-only environment is a shared-access environment within which collisions occur. As devices are added to the network, more collisions occur, and performance declines dramatically.
- LAN switches work at Layer 2 and make limited MAC hardware address decisions. Ethernet switches provide dedicated LAN connections.
- Working at Layers 2, 3, and 4, multilayer switches enable the implementation of Layer 3 quality of service and security functionality. Multilayer switches perform many of the same functions as routers do, but they do so in hardware.
- Routers can make decisions regarding the best path for delivery of data on the network.
- Various types of servers provide services to computers and users accessing the network. Firewalls, AAA servers, and VPN concentrators provide security to the network.
- Various types of wireless networking devices provide services to computers and users accessing the network. Common wireless networking devices include wireless adapters, wireless access points, and wireless bridges.
- A physical topology describes the plan for wiring the physical devices. A logical topology describes how information flows through a network.
- In a physical bus topology, a single cable connects all the devices.
- The most commonly used architecture in Ethernet LANs is the physical star topology. In a star topology, each host in the network is connected to the central device with its own cable. When a star network is expanded to include additional networking devices that are connected to the main networking device, it is called an extended-star topology.
- In a ring topology, all the hosts are connected in the form of a ring or circle.
- A full-mesh topology connects all devices to each other.

To supplement all you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab Activities on the CD-ROM accompanying this book.

Key Terms

application layer Layer 7 of the OSI reference model. This layer provides services to application processes (such as e-mail, file transfer, and terminal emulation) that are outside the OSI reference model.

bandwidth The amount of information that can flow through a network connection in a given period of time.

bridge A Layer 2 device designed to create two or more LAN segments, each of which is a separate collision domain.

broadcast A data packets that is sent to all nodes on a network. Broadcasts are identified by a broadcast address.

broadcast domain The set of all devices that receive broadcast frames originating from any device in the set.

bus topology Commonly called a linear bus, this topology connects all the devices with a single cable. This cable proceeds from one computer to the next like a bus line going through a city.

collision In Ethernet, the result of two nodes transmitting simultaneously. The frames from each device impact and are damaged when they meet on the physical medium.

collision domain In Ethernet, the network area within which frames that have collided are propagated. Repeaters and hubs propagate collisions; LAN switches, bridges, and routers do not.

data center A globally coordinated network of devices designed to accelerate the delivery of information over the Internet infrastructure.

data link layer Layer 2 of the OSI reference model. Provides transit of data across a physical link. The data link layer is concerned with physical addressing, network topology, line discipline, error notification, ordered delivery of frames, and flow control.

de-encapsulation Unwrapping data in a particular protocol header.

encapsulation Wrapping data in a particular protocol header.

extended-star topology A network in which a star network is expanded to include an additional networking device that is connected to the main networking device.

extranet Intranet-based applications and services that employ extended, secure access to external users or enterprises.

firewall A router or access server designated as a buffer between any connected public networks and a private network.

flooding A traffic-passing technique used by switches and bridges in which traffic received on an interface is sent out all that device's interfaces except the interface on which the information was received originally.

frame A logical grouping of information sent as a data link layer unit over a transmission medium.

full-mesh topology Connects all devices (nodes) to each other for redundancy and fault tolerance.

hierarchical topology Created similar to an extended-star topology. The primary difference is that it does not use a central node. Instead, it uses a trunk node from which it branches to other nodes.

hub A common connection point for devices in a network. Hubs commonly connect segments of a LAN. A hub contains multiple ports. When a packet arrives at one port, it is copied to the other ports so that all the segments of the LAN can see all the packets.

intranet A common LAN configuration. Intranets are designed to be accessed by users who have access privileges to an organization's internal LAN.

local-area network (LAN) A high-speed, low-error data network covering a relatively small geographic area (up to a few thousand meters). LANs connect workstations, peripherals, terminals, and other devices in a single building or another geographically limited area.

Media Access Control (MAC) A hardware address that uniquely identifies each node of a network. This address controls data communication for the host on the network.

metropolitan-area network (MAN) A network that spans a metropolitan area. Generally, a MAN spans a larger geographic area than a LAN but a smaller geographic area than a WAN.

microsegmentation Allows the creation of private or dedicated segments—one host per segment. Each host receives instant access to the full bandwidth and does not have to compete for available bandwidth with other hosts.

network interface card (NIC) A printed circuit board that fits into the expansion slot of a bus on a computer motherboard. Also can be a peripheral device.

network layer Layer 3 of the OSI reference model. This layer provides connectivity and path selection between two end systems. The network layer is the layer at which routing occurs.

Open System Interconnection (OSI) reference model A network architectural model developed by the ISO. This model consists of seven layers, each of which specifies particular network functions, such as addressing, flow control, error control, encapsulation, and reliable message transfer. The OSI reference model is used universally as a method for teaching and understanding network functionality.

packet A logical grouping of information that includes a header containing control information and (usually) user data. Packets most often refer to network-layer units of data.

partial-mesh topology At least one device maintains multiple connections to others without being fully meshed. A partial-mesh topology still provides redundancy by having several alternative routes.

peer-to-peer communication A form of communication in which each layer of the OSI model at the source must communicate with its peer layer at the destination.

physical layer Layer 1 of the OSI reference model. The physical layer defines the electrical, mechanical, procedural, and functional specifications for activating, maintaining, and deactivating the physical link between end systems.

presentation layer Layer 6 of the OSI reference model. This layer ensures that information sent by the application layer of one system can be read by the application layer of another.

protocol A formal description of a set of rules and conventions that govern how devices on a network exchange information.

protocol suite A set of related communications protocols that operate together and, as a group, address communication at some or all of the seven layers of the OSI reference model. Not every protocol stack covers each layer of the model, and often a single protocol in the suite addresses a number of layers at once. TCP/IP is a typical protocol suite.

repeater A networking device that exists at Layer 1, the physical layer, of the OSI reference model. The purpose of a repeater is to regenerate and retime network signals at the bit level, allowing them to travel a longer distance on the medium.

ring topology A topology in which hosts are connected in the form of a ring or circle. Unlike the physical bus topology, the ring topology has no beginning or end that needs to be terminated.

router A type of internetworking device that passes data packets between networks based on Layer 3 addresses. A router can make decisions regarding the best path for delivery of data on the network.

segment In the TCP specification, a logical information group at transport layers of the OSI reference model.

session layer Layer 5 of the OSI reference model. This layer establishes, manages, and terminates sessions between applications and manages data exchange between presentation layer entities.

star topology The most commonly used physical topology in Ethernet LANs. The star topology is made up of a central connection point that is a device such as a hub, switch, or router, where all the cabling segments meet.

storage-area network (SAN) A dedicated, high-performance network that moves data between servers and storage resources.

switch A device that connects LAN segments, uses a table of MAC addresses to determine the segment on which a frame needs to be transmitted, and reduces traffic. Switches operate at much higher speeds than bridges.

throughput The rate of information arriving at or passing through a particular point in a network system.

token passing An access method by which network devices access the physical medium in an orderly fashion based on possession of a small frame called a token.

transport layer Layer 4 of the OSI reference model. This layer is responsible for reliable network communication between end nodes. The transport layer provides mechanisms to establish, maintain, and terminate virtual circuits, transport fault detection and recovery, and information flow control.

virtual private network (VPN) A private network constructed within a public network infrastructure such as the global Internet.

wide-area network (WAN) A data communications network that serves users across a broad geographic area and often uses transmission devices provided by common carriers.

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. What was the first type of microcomputer network to be implemented?
 - A. MAN
 - B. WAN
 - C. LAN
 - D. PAN
2. Using modem connections, how many modems would it take to allow connections from ten computers?
 - A. One
 - B. Five
 - C. Ten
 - D. Fifteen
3. What is a code that is “burned in” to a network interface card?
 - A. NIC
 - B. MAC address
 - C. Hub
 - D. LAN
4. Which topology has all its nodes connected directly to one center point and has no other connections between nodes?
 - A. Bus
 - B. Ring
 - C. Star
 - D. Mesh
5. What do TIA and EIA stand for?
 - A. Television Industry Association, Electronic Industries Association
 - B. Telecommunications Industry Association, Electronic Industries Alliance
 - C. Telecommunications Industry Alliance, Electronic Industries Association
 - D. Téléphonique International Association, Elégraphique Industries Alliance
6. LANs are designed to do which of the following? (Select all that apply.)
 - A. Operate within a limited geographic area
 - B. Allow many users to access high-bandwidth media
 - C. Connect to the Internet
 - D. Provide full-time connectivity to local services

7. Which of the following statements best describes a WAN?
 - A. It connects LANs that are separated by a large geographic area.
 - B. It connects workstations, terminals, and other devices in a metropolitan area.
 - C. It connects LANs within a large building.
 - D. It connects workstations, terminals, and other devices within a building.
8. Which of the following statements correctly describes a MAN?
 - A. A MAN is a network that connects workstations, peripherals, terminals, and other devices in a single building.
 - B. A MAN is a network that serves users across a broad geographic area. It often uses transmission devices provided by common carriers.
 - C. A MAN is a network that spans a metropolitan area such as a city or suburban area.
 - D. A MAN is a network that is interconnected by routers and other devices and that functions as a single network.
9. Which of the following is *not* one of the features of a SAN?
 - A. SANs enable concurrent access of disk or tape arrays, providing enhanced system performance.
 - B. SANs provide a reliable disaster recovery solution.
 - C. SANs are scalable.
 - D. SANs minimize system and data availability.
10. What service offers secure, reliable connectivity over a shared public network infrastructure?
 - A. Internet
 - B. Virtual private network
 - C. Virtual public network
 - D. WAN
11. What links enterprise customer headquarters, remote offices, and branch offices to an internal network over a shared infrastructure?
 - A. Access VPN
 - B. Intranet VPN
 - C. Extranet VPN
 - D. Internet VPN

12. What is the name of the part of a company's LAN that is made available to select parties such as employees, customers, and partners?
- A. The Internet
 - B. The extranet
 - C. The intranet
 - D. The LAN
13. What is the movement of objects through layers?
- A. Wrapping
 - B. Flow
 - C. Traveling
 - D. Transmission
14. The OSI model has how many layers?
- A. Four
 - B. Five
 - C. Six
 - D. Seven
15. What is the OSI model?
- A. A conceptual framework that specifies how information travels through networks
 - B. A model that describes how data makes its way from one application program to another throughout a network
 - C. A conceptual framework that specifies which network functions occur at each layer
 - D. All of the above
16. Which of the following is the correct order of the network layers?
- A. 1: Physical
2: Data link
3: Transport
4: Network
5: Presentation
6: Session
7: Application

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- B.** 1: Physical
2: Data link
3: Network
4: Transport
5: Session
6: Presentation
7: Application
 - C.** 1: Physical
2: Data link
3: Network
4: Session
5: Transport
6: Application
7: Presentation
 - D.** 1: Physical
2: Network
3: Session
4: Data link
5: Transport
6: Application
7: Presentation
- 17.** Which layer of the OSI model handles physical addressing, network topology, network access, and flow control?
- A.** The physical layer
 - B.** The data link layer
 - C.** The transport layer
 - D.** The network layer
- 18.** Which of the following best defines encapsulation?
- A.** Segmenting data so that it flows uninterrupted through the network
 - B.** Compressing data so that it moves faster
 - C.** Moving data in groups so that it stays together
 - D.** Wrapping data in a particular protocol header

19. An e-mail message is sent from Host A to Host B on a LAN. Before this message can be sent, the data must be encapsulated. Which of the following best describes what happens after a packet is constructed?
- A. The packet is transmitted along the medium.
 - B. The packet is put into a frame.
 - C. The packet is segmented into frames.
 - D. The packet is converted to binary format.
20. In the TCP/IP model, which layer deals with reliability, flow control, and error correction?
- A. Application
 - B. Transport
 - C. Internet
 - D. Network access
21. Repeaters can provide a simple solution for what problem?
- A. Too many types of incompatible equipment on the network
 - B. Too much traffic on a network
 - C. Too-slow convergence rates
 - D. Too many nodes or not enough cable
22. Which of the following is true of a bridge and its forwarding decisions?
- A. Bridges operate at OSI Layer 2 and use IP addresses to make decisions.
 - B. Bridges operate at OSI Layer 3 and use IP addresses to make decisions.
 - C. Bridges operate at OSI Layer 2 and use MAC addresses to make decisions.
 - D. Bridges operate at OSI Layer 3 and use MAC addresses to make decisions.
23. Which of the following is true of a switch's function?
- A. Switches increase the size of collision domains.
 - B. Switches combine the connectivity of a hub with the traffic regulation of a bridge.
 - C. Switches combine the connectivity of a hub with the traffic direction of a router.
 - D. Switches perform Layer 4 path selection.

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- 24.** What does a router route?
- A.** Layer 1 bits
 - B.** Layer 2 frames
 - C.** Layer 3 packets
 - D.** Layer 4 segments
- 25.** Which of the following statements is true?
- A.** A gateway is a special-purpose device that performs an application layer conversion of information from one protocol stack to another.
 - B.** The Cisco AS5400 Series Universal Gateway offers universal port data, voice, wireless, and fax services on any port at any time.
 - C.** A DSLAM serves as the interface point of between a number of subscriber premises and the carrier network.
 - D.** All of the above
- 26.** What is/are the function(s) of an AAA server? (Select all that apply.)
- A.** To ensure that only authenticated users can get into the network
 - B.** To ensure that the users are allowed access to only the resources they need
 - C.** To ensure that records are kept of everything the authentic users do after they are allowed entry
 - D.** All of the above
- 27.** What is/are the function(s) of a firewall? (Select all that apply.)
- A.** Software-based
 - B.** Hardware-based
 - C.** Filter traffic
 - D.** Layer 2 devices
 - E.** None of the above



Objectives

Upon completion of this chapter, you will be able to

- Describe the main parts of an atom
- Describe the terms used to measure electricity
- Be familiar with the organizations developing standards for wired and wireless networking
- Describe the primary types and uses of twisted-pair cables
- Describe the primary types and uses of coaxial cables
- Describe the primary types and uses of fiber-optic cables
- Describe the primary types and uses of wireless media
- Describe different types of wireless data communications and their advantages and drawbacks
- Describe different modulation techniques
- Describe radio frequency modulation
- Describe the benefits of spread-spectrum technology
- Describe frequency-hopping spread spectrum and direct-sequence spread spectrum
- Explain the importance of encryption and security in a wireless environment

Chapter 3

Networking Media

The function of the physical layer is to transmit data by defining the electrical, wireless, or light specifications between the source and destination. After it reaches a building, low-voltage electricity is carried to workstations, servers, and network devices via wires concealed in walls, floors, and ceilings. Data, which can consist of such things as text, pictures, audio, or video, travels through the wires and is represented by the presence of either electrical pulses on copper conducting wires or light pulses in optical fibers.

This chapter introduces the basic theory of electricity, which provides a foundation for understanding networking at the physical layer of the OSI model. This chapter also discusses different types of networking media that are used at the physical layer, including shielded twisted-pair cable, unshielded twisted-pair cable, coaxial cable, and fiber-optic cable, as well as wireless media.

Please be sure to look at this chapter's associated e-Labs, Videos, and PhotoZooms that you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

Electricity Basics

This section discusses the basic theory of electricity, which provides a foundation for understanding networking at the physical layer (Layer 1) of the OSI reference model.

Atoms and Molecules

The basic unit of all matter in the universe is the atom. The atom is made of three tiny parts: protons, neutrons, and electrons. The protons and neutrons are lumped together in a small grouping called a nucleus. The electron flows freely around this nucleus. When

these three parts come together, they form an atom. The Periodic Table of Elements, as shown in Figure 3-1, lists all known types of atoms and their properties. Atoms are made up of three basic particles:

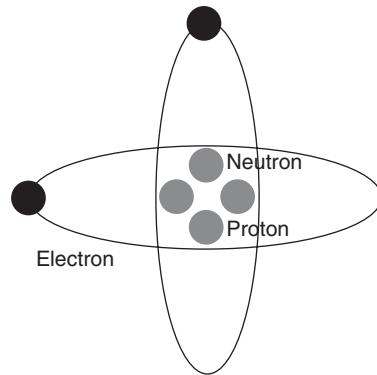
- **Protons**—Particles that have a positive charge
- **Neutrons**—Particles that have no charge
- **Electrons**—Particles that have a negative charge

Figure 3-1 Periodic Table of Elements

Main Groups		Main Groups																
1A	2A	Transition Metals										3A	4A	5A	6A	7A	8A	
1 H												5 B	6 C	7 N	8 O	9 F	10 Ne	
3 Li	4 Be											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar	
11 Na	12 Mg	3B	4B	5B	6B	7B	8B				1B	2B	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn	
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110	111	112	114	116	118				
Lanthanide Series		58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tm	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu			
Actinide Series		90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr			

Atoms normally have equal numbers of protons and electrons. Because the positive and negative charges are equal, atoms have no net charge.

Niels Bohr, a Danish physicist, developed a simplified model to illustrate atoms, as shown in Figure 3-2. This illustration shows the Bohr model for a helium atom, which has two protons, two neutrons, and two electrons. The protons and neutrons form the nucleus at the center of the atom, and the electrons are shown in orbit around the nucleus. The diagram is not drawn to scale, but if the protons and neutrons of this atom were the size of soccer balls in the middle of a soccer field, the electrons would be the size of cherries, and would be orbiting near the outer-most seats of the stadium. The electrons are quite small compared to the nucleus, and the orbit is quite large compared to the size of the particles, even though the atoms themselves are microscopic.

Figure 3-2 Bohr Model of a Helium Atom

Atoms bond together in different combinations to form molecules of various types of matter. For example, hydrogen and oxygen atoms bond to form water molecules.

Electrical Properties of Matter

The nucleus of an atom is bound together by a very powerful force. Electrons are bound to their orbit around the nucleus by a much weaker force. Electrons in certain atoms can be pulled away from their orbit and go into orbit around nearby atoms. This movement of electrons is defined as electric current.

If an atom loses or gains an electron, it no longer has the same number of electrons and protons. Such an atom is called an ion, and it has a net charge since the number of protons and electrons is not equal. The charge of an ion exerts a force on nearby atoms that can cause them to lose or gain electrons. Thus, as electrons of nearby atoms move, current flows through a material.

Atoms and molecules can be classified as belonging to one of three groups, depending on how easily electrons are pulled out of their orbit. These three groups are insulators, conductors, and semiconductors. See Table 3-1 for a summary.

Electrical Insulators

Insulators are materials made of atoms or molecules that require a great deal of force to remove their electrons from orbit. Examples of electrical insulators include plastic, glass, air, dry wood, paper, rubber, helium gas, and pure water (whose atoms are not ions).

Table 3-1 Summary of the Three Main Types of Electrical Materials

Material	Flow	Examples
Insulator	Electrons flow poorly.	Plastic, paper, rubber, dry wood, air, pure water, and glass.
Conductors	Electrons flow well.	Copper (Cu), silver (Ag), gold (Au), solder, water with ions, and the human body.
Semiconductors	Electrons flow can be controlled precisely.	Carbon (C), germanium (Ge), gallium arsenide (GaAs), and silicon (Si).

Electrical Conductors

Conductors are materials made of atoms or molecules with electrons that are bound very loosely to the nucleus and require little force to remove them from orbit. The Periodic Table categorizes groups of atoms, listing them by columns. The best conductors are located in one particular column of Table 3-1: copper (Cu), silver (Ag), and gold (Au). Other conductors include lead solder, which is a mixture of lead (Pb) and tin (Sn), and water in which some atoms are ions. Because the human body is made of approximately 70 percent ionized water, it is also a conductor.

Electrical Semiconductors

Semiconductors are materials made of atoms or molecules with electrons whose movement can be precisely controlled. The most important semiconductor is silicon (Si). Other examples from the same column of the Periodic Table include carbon (C) and germanium (Ge). Gallium arsenide (GaAs), a molecule, is also a common semiconductor.

Silicon is common and can be found in sand, glass, and many types of rocks. The region around San Jose, California, is known as Silicon Valley because the computer industry, which depends on silicon microchips, started in that area. The switches, or gates, inside a microprocessor are made up of semiconductors.

Measuring Electricity

As with any other physical process or concept, you need to be able to measure electricity to make use of it. You can measure electricity in numerous ways, but in this section, you focus on voltage, current, resistance, and impedance.

Voltage

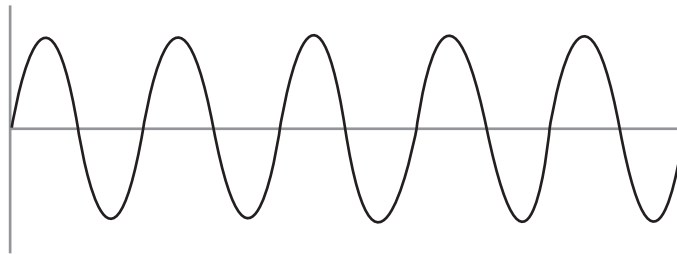
Because electrons and protons have opposite charges, they are attracted to each other with a force similar to the attractive force of the north and south poles of two magnets. When the charges are separated, this separation creates an attractive force or pressure field between the charges. This force is voltage. The force that is created pulls toward the opposite charge and pushes away from the like charge. This process occurs in a battery, where chemical action causes electrons to be freed from the battery's negative terminal and to travel to the opposite, or positive, terminal through an external circuit—not through the battery itself. The separation of charges results in voltage. Voltage can also be created by friction (static electricity), by magnetism (electric generator), or by solar energy.

Voltage is represented by the letter V . The unit of measurement for voltage is the volt, and it is also represented with the letter V (for example, $12\text{ V} = 12\text{ volts}$).

Two kinds of voltage exist:

- **Direct-current (DC) voltage**—A battery is an example of a DC voltage source. The movement of electrons in a DC circuit is always in the same direction, from negative to positive.
- **Alternating-current (AC) voltage**—In an AC circuit, the positive and negative terminals of the AC voltage source regularly change to negative and positive and back again, as shown in Figure 3-3. This change makes the direction of electron movement change, or alternate, with respect to time.

Figure 3-3 Alternating Current



Lab Activity Safe Handling and Use of a Multimeter

In this lab, you learn how to use or handle a multimeter correctly.



Lab Activity Voltage Measurements

In this lab, you demonstrate the ability to measure voltage with the multimeter.

Current

Electrical current is the flow of charges that is created when electrons move. When voltage (electrical pressure) is applied and a path for the current exists, electrons move from the negative terminal (which repels them), along the path, to the positive terminal (which attracts them).

Current is represented by the letter *I*. The unit of measurement for current is the ampere, and it is represented by the letter *A*, or by the abbreviation *amp*. An amp is defined as the number of charges per second that pass by a point along a path. It can be thought of as the amount of electron traffic that is flowing through a circuit; the more electrons that pass by any given point in a circuit, the higher the current.

Current that results from DC voltage always flows in the same direction, from negative to positive. Current that results from AC voltage flows in one direction, then changes direction, and then alternates back to the original direction, and so on.

Wattage

If amperage or current can be thought of as the amount or volume of electron traffic that is flowing, then voltage can be thought of as the speed of the electron traffic. The combination of amperage (quantity of electrons past a given point) and voltage (pressure or speed of electrons) equals *wattage* or electrical power. A watt (W) is the basic unit of electrical power or work done by electricity. Wattage equals voltage times amperage ($W = V \times I$). Electrical devices such as light bulbs, motors, and computer power supplies are rated in terms of watts, which is how much power they consume or produce. It is the current or amperage in an electrical circuit that really does the work. As an example, static electricity has very high voltage, so much that it can jump a gap of an inch or more. However, it has very low amperage and as a result can create a shock but not injure someone. The starter motor in an automobile operates at a relatively low 12 volts but requires very high amperage to generate enough energy to turn over the engine. Lightning has very high voltage and high amperage and can cause severe damage or injury.

Resistance and Impedance

Conductors exchange electrons very easily, so it does not take much voltage to cause electrons to move through them. Conversely, the electrons in insulators are bound to their orbits much more tightly, so they oppose the movement of electrons. *Resistance* is the property of a material that resists electron movement. Conductors have low resistance, and insulators have high resistance.

Resistance is represented by the letter R . The unit of measurement for resistance is the ohm, and it is represented by the Greek letter, omega (Ω), because omega sounds like ohm.

The term *resistance* is generally used when referring to DC circuits. The resistance to the movement of electrons in an AC circuit is called *impedance*. Impedance is represented by the letter Z . Like resistance, its unit of measurement is the ohm, represented by Ω .



Lab Activity Resistance Measurements

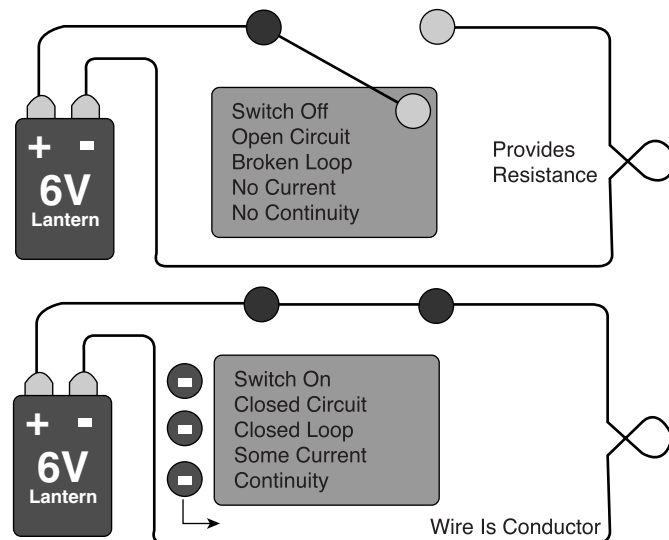
In this lab, you demonstrate the ability to measure resistance and continuity with the multimeter.

Circuits

Electrons move best through conductive materials. Although air in a dry climate can be conductive, as noticed through shocks of static electricity, electrons cannot jump across air from a battery to an unconnected, nearby piece of copper wire. Current, or electron movement, occurs only in circuits that form complete loops. These circuits are known as closed circuits.

Figure 3-4 shows a simple circuit, typical of a lantern-style flashlight. The switch is like two ends of a single wire that can be opened (or broken) and then closed (or shorted) to prevent or allow current.

Figure 3-4 Serial Circuit—Flashlight

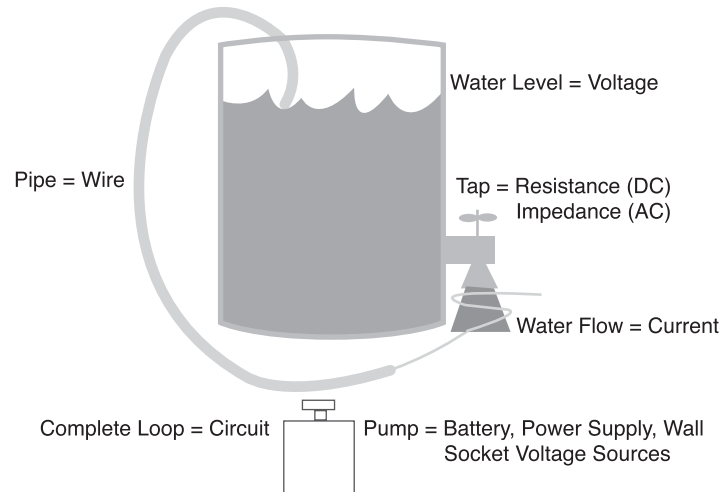


The top of Figure 3-4 illustrates the flashlight with its switch turned off. The chemical processes in the battery cause charges to be separated, which provides voltage. However, because no complete path for electron movement exists, there is no current, and the bulb will not be lit.

As shown in the bottom of Figure 3-4, the switch is turned on, and a complete path of conductive wire for current exists. The bulb provides resistance to the flow of electrons, causing the current to release energy in the form of light.

The circuits involved in networking use the same concepts as this very simple circuit, but networking circuits are much more complex. When you are learning a new concept, it is often helpful to relate the concept to a familiar example. The circuit discussed previously can be compared to a water circuit, as illustrated in Figure 3-5. The pressure that causes water flow comes from the weight of the water in the tank. The tap can be compared with the switch in the previous example. When the tap is turned off, it blocks water from moving. When the tap is turned on, it allows water to move and also provides resistance to the flow of water, because a small tap will allow a lesser flow than a large tap. Finally, the pipe provides a closed path for the flow of water to cycle back into the tank.

Figure 3-5 Water Circuit Analogy for Flowing Electrons



Lab Activity Communications Circuits

In this lab, you build series circuits and explore their basic properties.

Copper Media

Copper is the most common medium for signal wiring. Copper wires are the components of a cable that carry the signals from the source computer to the destination computer. Copper has several important properties that make it well suited for electronic cabling:

- **Conductivity**—Copper is perhaps best known for its ability to conduct electric current. Copper is also an excellent conductor of heat. This property makes it useful in cooking utensils, radiators, and refrigerators.
- **Corrosion resistance**—Copper does not rust and is fairly resistant to corrosion; the copper corrodes as copper oxide at a somewhat slower pace than other metals.
- **Ductility**—Copper possesses great ductility, the ability to be drawn into thin wires without breaking. For example, copper rod that is 1 centimeter (cm) in diameter can be heated, rolled, and drawn into a wire that is thinner than a human hair.
- **Malleability**—Pure copper is highly malleable (easy to shape). It does not crack when hammered, stamped, forged, or spun into unusual shapes. Copper can be worked (shaped) when it is hot or cold.
- **Strength**—Cold-rolled copper has a tensile strength 3500 to 4900 kilograms per square centimeter. Copper keeps its strength and toughness up to about 400° Fahrenheit (F) (204° Celsius [C]).

This section focuses on two types of copper cable used for networks:

- **Twisted-pair**—Twisted-pair cables are composed of one or more pairs of copper wires. Most data and voice networks use twisted-pair cabling.
- **Coaxial**—*Coaxial cable* has one center conductor of either solid or stranded copper wire. Coaxial cable, once the choice for local-area network (LAN) cabling, is now used primarily for video connections, high-speed connections such as T3 (or E3) lines, and cable television.

American Wire Gauge System

The diameter of cable wires or conductors is commonly measured using the American wire gauge (AWG) system. AWG is a U.S. standard for measuring the diameter of primarily copper and aluminum cable. Typical residential wiring is AWG 12 or 14. The conductor or wire size used in the UTP in most telephone local loops (from the central office to a home or residence) is between 19 and 26 AWG. Most newer telephone wire is from 22 to 26 gauge with 24 gauge being the most common. The lower the gauge number the thicker the wire. Thicker wire has less resistance and can carry more current resulting in a better signal over longer distances. A wire with an AWG size of 24 would be 1/24th of an inch in diameter.

Twisted-Pair Cable

Twisted-pair cable is a type of cabling that is used for telephone communications and most modern Ethernet networks. A pair of wires forms a circuit that can transmit data. The pairs are twisted to provide protection against *crossstalk*, the noise generated by adjacent pairs.

The wire pairs are twisted for two reasons. First, when a wire is carrying a current, that current creates a magnetic field around the wire. This field can interfere with signals on nearby wires. To combat this, pairs of wires carry signals in opposite directions, so that the two magnetic fields also occur in opposite directions and cancel each other out. This process is known as *cancellation*. Twisting the pairs holds the two wires closer together and helps to ensure effective cancellation within the cable.

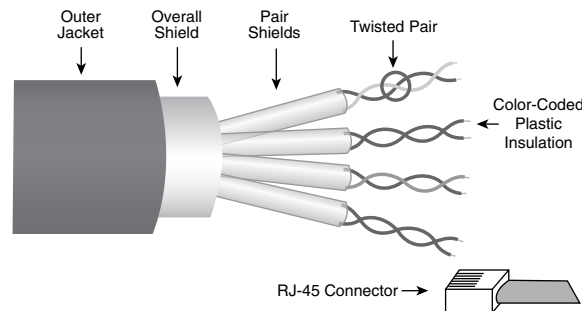
Second, network data is sent using two wires in a twisted pair. One copy of the data is sent on each wire, and the two copies are mirror images of each other. These signals are called *differential signals*. If the two wires are twisted together, noise seen on one wire is also be seen on the other wire. When the data is received, one copy is inverted, and the two signals are then compared. In this manner the receiver can filter out noise because the noise signals cancel each other.

Two basic types of twisted-pair cable exist: shielded twisted-pair (STP) and unshielded twisted-pair (UTP). The following sections discuss UTP and STP cable in more detail.

Shielded Twisted-Pair Cable

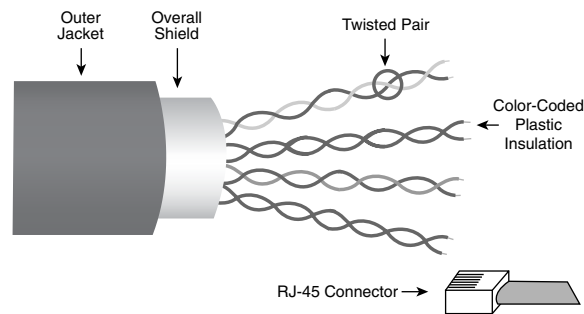
Shielded twisted-pair (STP) cable contains four pairs of thin, copper wires covered in color-coded plastic insulation that are twisted together. Each pair is wrapped in metallic foil, and then the four pairs are collectively wrapped in another layer of metallic braid or foil. This layer is wrapped with a plastic outer jacket. Figure 3-6 illustrates an example of STP.

Figure 3-6 Shielded Twisted-Pair Cable



Screened twisted-pair (ScTP), also known as foil twisted-pair (FTP), is a variation of STP. ScTP is essentially STP with just one layer of foil shielding around the set of all four-wire pairs, as shown in Figure 3-7. The shielding in both STP and ScTP reduces unwanted electrical noise. This noise reduction provides a major advantage of STP over unshielded cable.

Figure 3-7 Screened Twisted-Pair Cable



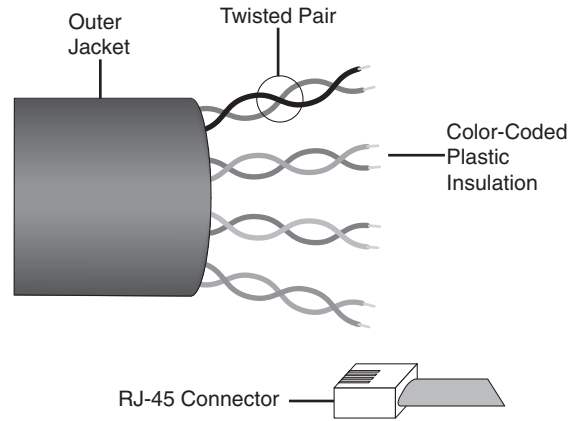
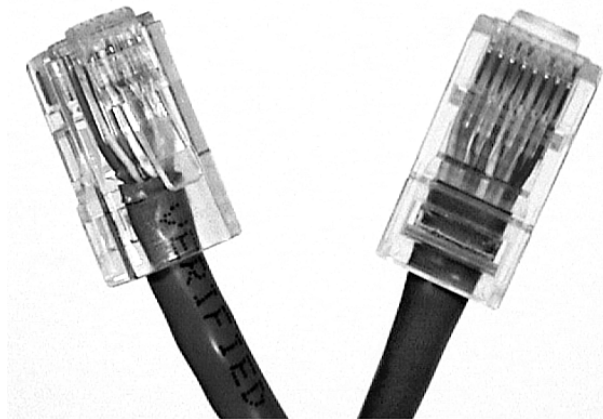
However, shielded cable is more difficult to install than unshielded cable because the metallic shielding needs to be grounded. If improperly installed, STP and ScTP become very susceptible to noise problems because an ungrounded shield acts like an antenna, picking up unwanted signals. STP and ScTP cable cannot be run as far as coaxial and fiber-optic cable without the use of repeaters. The insulation and shielding considerably increase the size, weight, and cost of the cable. Despite these disadvantages, shielded copper cable is still used as networking media today, especially in Europe.

The following summarizes the features of STP cable:

- **Speed and throughput**—10 to 100 Mbps
- **Average cost per node**—Moderately expensive
- **Media and connector size**—Medium to large
- **Maximum cable length**—100 meters (m) (short)

Unshielded Twisted-Pair Cable

Unshielded twisted-pair (UTP) cable is a common networking *media*. It consists of four pairs of thin, copper wires covered in color-coded plastic insulation that are twisted together, as shown in Figure 3-8. The wire pairs are then covered with a plastic outer jacket. The connector used on a UTP cable is called a registered jack 45 (RJ-45) connector, as shown in Figure 3-9.

Figure 3-8 Unshielded Twisted-Pair Cable**Figure 3-9** RJ-45 Connector

UTP cable has many advantages. It has a small diameter and does not require grounding, so it is the easiest type of cable to install. Its size provides an additional advantage because more UTP cable can fit in a given area than other copper media. It is also the least expensive type of networking media, and the connector is the easiest to build. It supports the same data speeds as other copper media.

The primary disadvantage to UTP is that it is more susceptible to electrical noise and interference than any other type of networking media. Because it has no shielding, it relies solely on the cancellation and differential signals to reduce the effects of noise. The other main disadvantage is that its maximum run length is less than that allowed for coaxial and fiber-optic cables.

Although UTP was once considered to be slower at transmitting data than other types of cable, this is no longer true. In fact, UTP is considered the fastest copper-based medium today. The following summarizes the features of UTP cable:

- **Speed and throughput**—10 to 1000 Mbps
- **Average cost per node**—Least expensive
- **Media and connector size**—Small
- **Maximum cable length**—100 m (short)

Commonly used types of UTP cabling are as follows:

- **Category 1 (CAT 1)**—Used for telephone communications. Not suitable for transmitting data.
- **Category 2 (CAT 2)**—Capable of transmitting data at speeds up to 4 Mbps.
- **Category 3 (CAT 3)**—Used in 10BASET Ethernet networks. Can transmit data at speeds up to 10 Mbps.
- **Category 4 (CAT 4)**—Used in Token Ring networks. Can transmit data at speeds up to 16 Mbps.
- **Category 5 (CAT 5)**—Can transmit data at speeds up to 100 Mbps. Used in Fast Ethernet networks.
- **Category 5e (CAT 5e)**—Used in networks running at speeds up to 1000 Mbps (1 Gbps). Used in Gigabit Ethernet (GigE) networks.
- **Category 6 (CAT 6)**—The specification for CAT 6 is new, was released on February 3, 2003, and is currently available for installation and use. Used in Gigabit Ethernet (GigE) networks.

Typically, CAT 5 and higher network cable consists of four pairs of 24 AWG multi-strand copper wires. Older cabling installations run CAT 3 for voice and CAT 5 for data. Most new installations run a minimum of CAT 5e for voice and data. Although CAT 5e costs a little more it is worth it in the long run.

When comparing UTP and STP, keep the following points in mind:

- The speed of both types of cable is usually satisfactory for local-area distances.
- These are the least-expensive media for data communication. UTP is less expensive than STP.
- Because most buildings are already wired with UTP, many transmission standards are adapted to use it to avoid costly rewiring with an alternative cable type. You must take care to ensure that the category level of the cable is adequate to handle the bandwidth desired. As an example, a building wired with CAT 3 cable cannot support Fast Ethernet, which requires at least CAT 5.

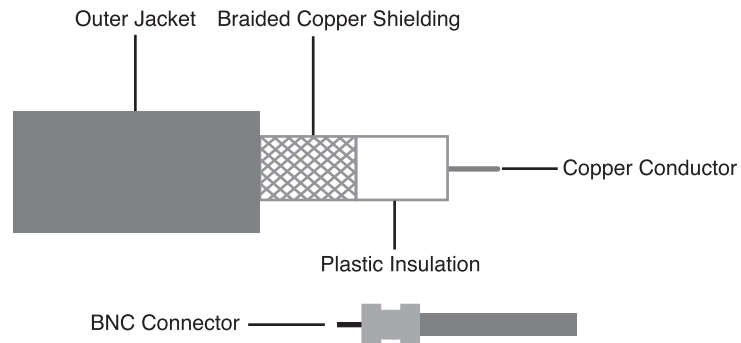
Coaxial Cable

Coaxial cable, as shown in Figure 3-10, consists of four main parts:

- Copper conductor
- Plastic insulation
- Braided copper shielding
- Outer jacket

At the center of the cable is a solid copper conductor. Surrounding that conductor is a layer of flexible plastic insulation. A woven copper braid or metallic foil is wrapped around the insulation. This layer acts as the second wire in the cable. It also acts as a shield for the inner conductor and helps reduce the amount of outside interference. Covering this shield is the outer cable jacket. The connector used on coaxial cable is called a BNC, short for British Naval Connector or Bayonet Neill Concelman, connector.

Figure 3-10 Coaxial Cable



Coaxial cable was a popular choice with LANs in the past. It offered several advantages. It can be run with fewer boosts from repeaters for longer distances between network nodes than either STP or UTP cable. Although more expensive than UTP, coaxial cable is less expensive than fiber-optic cable. The technology is well known, because it has been used for many years in various types of data communication. For example, coaxial cable is commonly used in homes to deliver cable television signals and high-speed Internet access. For cable TV, RG-59 is commonly used inside the home and has a center conductor of 20 AWG. RG-6 is most often used from the street pedestal to the home due to heavier shielding and a larger center conductor of 18 AWG. RG-11 cable is heavier still with a center conductor of 14 AWG and is used to bring cable into neighborhoods.

When working with cable, consider its size. As the diameter of the cable increases, so does the difficulty in working with it because cable must be pulled through existing conduits that are limited in size. Coaxial cable comes in several sizes. The largest diameter (1 cm) was once specified for use as Ethernet *backbone* cable because it had a greater transmission length and better noise rejection characteristics than other types of cable. This type of coaxial cable is frequently referred to as *thicknet*, as shown in Figure 3-11. As its nickname suggests, thicknet cable can be too rigid to install easily in some situations because of its thickness. The general rule is that the more difficult the network medium is to install, the more expensive it is to install. Coaxial cable is more expensive to install than twisted-pair cable. Thicknet cable is almost never used except for special-purpose installations.

Figure 3-11 Coaxial Cable—Thicknet



Coaxial cable with a diameter of 0.35 cm, sometimes referred to as *thinnet*, was also frequently used in Ethernet networks at one time. Thinnet, as shown in Figure 3-12, was especially useful for cable installations that required the cable to make many twists and turns. Because it was easier to install, it was also cheaper to install. Thus, it was sometimes referred to as *Cheapernet*.

Figure 3-12 Coaxial Cable—Thinnet



However, in both types of coaxial cable, the outer conductor must be carefully and properly grounded, which increases the complexity of the installation. It is for this reason that, despite its advantages, coaxial cable is no longer commonly used in Ethernet networks.

Although many bus topology networks still utilize coaxial cable in use throughout the world, the IEEE no longer recommends this cable or topology as a standard for use with Ethernet. Nearly all new LANs use Ethernet extended star topology and a combination of UTP and fiber.

The following summarizes the features of coaxial cables:

- **Speed and throughput**—10 to 100 Mbps
- **Average cost per node**—Inexpensive
- **Media and connector size**—Medium
- **Maximum cable length**—500 m (medium)

More Information: Plenum Cable

Plenum cable is the cable that runs in plenum spaces of a building. In building construction, a plenum (pronounced PLEH-nuhm, from Latin meaning “full”) is a separate space provided for air circulation for heating, ventilation, and air-conditioning (sometimes referred to as HVAC), typically in the space between the structural ceiling and a drop-down ceiling. In buildings with computer installations, the plenum space often is used to house connecting communication cables. Because ordinary cable introduces a toxic hazard in the event of fire, special plenum cabling is required in plenum areas.

Plenum cable sheathing is often made of Teflon and is more expensive than ordinary cabling. Its outer material is more resistant to flames and, when burning, produces less smoke than ordinary cabling. Both twisted-pair and coaxial cable are made in plenum cable versions.

Cable Specification and Termination

Specifications, or *standards*, are sets of rules or procedures that are widely used and serve as the accepted method of performing a task. For example, the OSI reference model standards help to ensure that networking devices around the world are compatible and will work together. Many specifications exist for cabling to ensure interoperability, safety, and performance.

The *Institute of Electrical and Electronic Engineers (IEEE)* has outlined LAN cabling specifications. IEEE 802.3 is a standard for Ethernet networks, and IEEE 802.5 is a Token Ring network standard. The Underwriters Laboratories issues standards that are primarily concerned with safety.

The *Telecommunications Industry Association (TIA)* and the *Electronic Industries Association (EIA)* have jointly issued cabling standards often called TIA/EIA standards. The list that follows describes some of the TIA/EIA standards:

- **TIA/EIA-568-B**—This is a commercial building telecommunication cabling standard.
- **TIA/EIA-569-B**—Formerly the TIA/EIA-568-A standard. This is a commercial building standard for telecommunications pathways and spaces.
- **TIA/EIA-570-A**—This is a residential and light commercial telecommunications wiring standard.
- **TIA/EIA-606**—This is an administration standard for the telecommunications infrastructure of commercial buildings.
- **TIA/EIA-607**—This is a commercial building grounding and bonding requirement for telecommunications.

The specifications created by this organization have had the greatest impact on networking media standards and include standards for horizontal and backbone (vertical) cabling, wiring closets and equipment rooms, work areas, and entrance facilities. The TIA/EIA standards allow for the planning and installation of LAN equipment in a way that allows network designers the freedom to choose the devices needed while assuring the operability of the LAN design.

The TIA/EIA-568-B standard focuses on horizontal cabling, which is cabling that runs from a wall outlet at a work area to a wiring closet. There are five historic categories for cable (CAT 1 through CAT 5), and of these, only CAT 3, CAT 4, and CAT 5 meet the TIA/EIA-568-B standard. CAT 5 cable is the most frequently installed. Recent standards have been developed for CAT 5e and CAT 6, and a new standard for CAT 7 cabling is also underway. These new standards offer improvements to CAT 5 and are becoming more common.

TIA/EIA-568-B calls for two cables to each work area outlet:

- A telephone cable for voice
- A network cable for data

The voice cable must be a 2-pair UTP cable with its correct connectors, or terminators. The network cable must be one of the following and must include the correct connectors, or terminators:

- 150 ohm STP 2-pair cable (Token Ring LANs)
- 100 ohm UTP 4-pair cable (Ethernet LANs)
- 62.5/125 μ fiber-optic cable (Ethernet LANs)

- Coaxial cable (rarely used for new installations and expected to be removed from this list the next time the standard is updated)

Although not part of the standard, a coaxial 75 ohm RG-6 cable can also be run for cable TV connection, in addition to the minimum voice and data connections if desired.

The standard also specifies the maximum length of each cabling run from the wall outlet to the wiring closet connections for UTP cabling. A 3-meter patch cord is specified from the workstation to the wall outlet. A 90-meter cable run is allowed from the wall outlet to the *patch panel* in the wiring closet. A 6-meter patch cord is permitted from the patch panel to the horizontal cross connect in the wiring closet. This standard ensures that the entire cable run does not exceed 100 meters.

**Lab Activity Basic Cable Testing**

In this lab, you use a simple cable tester to verify whether a straight-through or crossover cable is good or bad. You also use the Fluke 620 advanced cable tester to test cables for length and connectivity.

**Lab Activity Making a Straight-Through Cable**

In this lab, you build a CAT 5 or CAT 5e UTP Ethernet network patch cable (or patch cord). You also test the cable for good connections (continuity) and correct pinouts (correct color of wire on the right pin).

**Lab Activity Making a Rollover Cable**

In this lab, you build a CAT 5 or CAT 5e UTP console rollover cable. You also test the cable for good connections (continuity) and correct pinouts (correct wire on the right pin).

**Lab Activity Making a Crossover Cable**

In this lab, you build a CAT 5 or CAT 5e UTP Ethernet crossover cable to TIA-568-B and TIA-568-A standards. You also test the cable for good connections (continuity) and correct pinouts (correct wire on the right pin).



Lab Activity UTP Cable Purchase

In this lab, you are introduced to the variety and prices of network cabling and related components in the market. This lab looks specifically at patch cables and bulk cable.

Optical Media

Optical fiber is the most frequently used medium for the longer, high bandwidth, point-to-point transmissions required on LAN backbones and on wide-area networks (WANs). Very good reasons exist for the popularity of fiber.

Optical fiber is used in networks because

- Fiber is not susceptible to lightning, *electromagnetic interference (EMI)*, or *radio frequency interference (RFI)*, and it does not generate EMI or RFI.
- Fiber has much greater bandwidth capabilities than other media.
- Fiber allows significantly greater transmission distances and excellent signal quality because very little signal attenuation occurs.
- Fiber is more secure than other media because it is difficult to tap into a fiber and easy to detect someone's placing a tap on the fiber.
- Current fiber transmitter and receiver technologies can be replaced by newer, faster devices as they are developed so that greater transmission speeds can be achieved over existing fiber links with no need to replace the fiber.
- Fiber costs less than copper for long distance applications.
- The raw material that fiber is made from is sand, a plentiful substance.
- With fiber, you have no grounding concerns as you have when signaling using electricity.
- Fiber is light in weight and easily installed.
- Fiber has better resistance to environmental factors, like water, than copper wire.
- Lengths of fiber can easily be spliced together for very long cable runs.

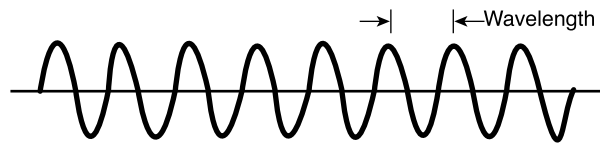
For these reasons, when very large numbers of bits need to be sent over distances greater than 100 meters, fiber-optic fiber is often used.

This section explains the basics of *fiber-optic cable*. You learn about how fibers can guide light for long distances. You also learn about the types of cable used, how fiber is installed, the type of connectors and equipment used with fiber-optic cable, and how fiber is tested to ensure that it functions properly.

The Electromagnetic Spectrum

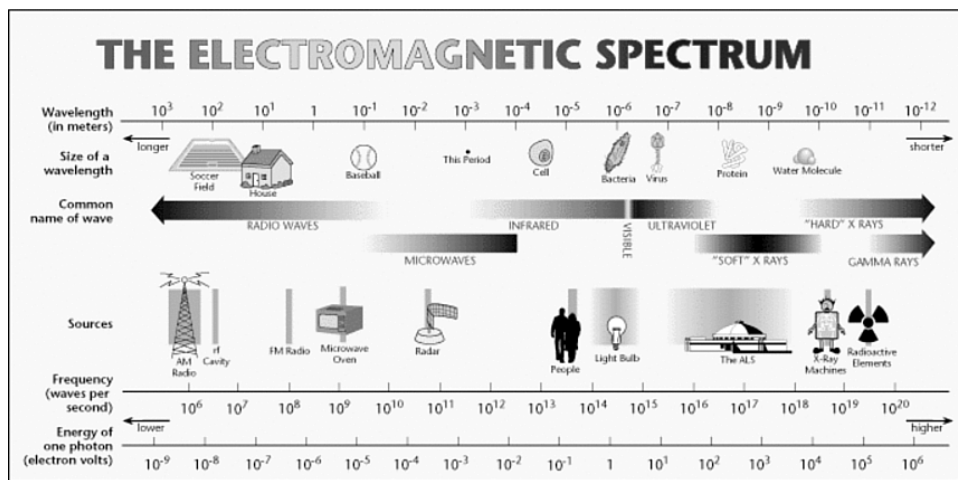
The light used in optical fiber networks is one type of electromagnetic energy. When an electric charge moves back and forth or accelerates, a type of energy called electromagnetic energy is produced. This energy, in the form of waves, can travel through a vacuum, the air, and through some materials like glass. An important property of any energy wave is its *wavelength*, as shown in Figure 3-13.

Figure 3-13 Wavelength



To human beings, radio, microwaves, radar, visible light, X rays, and gamma rays seem to be very different things, but they are all types of electromagnetic energy. If all the types of electromagnetic waves are arranged in order from waves with the longest wavelength down to those waves with the shortest wavelength, it creates a continuum called the *Electromagnetic Spectrum*, as shown in Figure 3-14.

Figure 3-14 Electromagnetic Spectrum



The wavelength of an electromagnetic wave is determined by how frequently the electric charge that generates the wave moves back and forth. For example, if the charge moves back and forth slowly, it generates a long wavelength. Visualize the movement of the electric charge as like that of a stick in a pool of water. If the stick is moved back

and forth slowly, it generates ripples in the water with a long wavelength between the tops of the ripples. If the stick is moved back and forth more rapidly, the ripples have a shorter wavelength.

Because electromagnetic waves are all generated in the same way, all electromagnetic waves share many of the same properties. For example, they all travel at the same rate of speed through a vacuum, about 300,000 kilometers per second or 186,000 miles per second or the speed of light.

Human eyes can sense electromagnetic energy only with wavelengths between 700 nanometers and about 400 nanometers. A nanometer is one billionth of a meter (0.000000001 m) in length and is abbreviated nm. Electromagnetic energy with wavelengths between 700 nm and 400 nm is called *visible light*. The longer wavelengths of light (those around 700 nm) are seen as the color red. The shortest wavelengths (around 400 nm) appear as the color violet. This part of the electromagnetic spectrum is seen as the colors in a rainbow.

To transmit data over optical fiber, wavelengths that are not visible to the human eye are used. These wavelengths are slightly longer than red light and are called *infrared light*. Infrared light is used in TV remote controls. The wavelength of the light in optical fiber is one of the following wavelengths:

- 850 nm
- 1310 nm
- 1550 nm

These wavelengths were selected because they travel better through optical fiber than other wavelengths.

The Ray Model of Light

When electromagnetic waves, including light, travel out from the source, they travel in straight lines. These straight lines pointing out from the source are called *rays*.

Think of light rays as narrow beams of light like those produced by lasers. In the vacuum of empty space, light travels continuously in a straight line at 300,000 kilometers per second. However, light travels at different, slower speeds through other materials like air, water, and glass. When a light ray (called the *incident ray*) crosses the boundary from one material (air, for example) to another (glass, for example), some of the light energy in the ray is reflected back. That is why you can see yourself in a mirror. The light that is reflected back is called the *reflected ray*.

The light energy in the incident ray that is not reflected enters the glass. The entering ray is usually bent at an angle from its original path. This ray is called the *refracted ray*. How much the incident light ray is bent depends on two factors:

- The angle at which the incident ray strikes the surface of the glass
- The different rates of speed at which light travels through the two substances (air and glass in this example)

The bending of light rays at the boundary of two substances is the reason why light rays are able to travel through an optical fiber even if the fiber curves in a circle.

How much rays of light in glass bend is determined by the optical density of the glass. Optical density refers to how much a light ray is slowed down by passing through a substance. The greater the optical density of a material, the more it slows light down from its speed in a vacuum. The ratio of the speed of light in a material to the speed of light in a vacuum is called the material's index of refraction (IR) and is expressed as follows:

$$\text{IR} = \frac{\text{Speed of light in a vacuum}}{\text{Speed of light in a material}}$$

Therefore, the measure of a material's optical density is that material's index of refraction. A material with a large index of refraction is more optically dense and slows light down more than a material with a smaller index of refraction.

Table 3-2 shows the IR of air, glass, diamond, and water.

Table 3-2 Index of Refraction

Substance	Index of Refraction
Air	1.000
Glass	1.523
Diamond	2.419
Water	1.333

For a substance like glass, the index of refraction (the optical density) can be made larger by adding chemicals to the glass. The index of refraction can be made smaller by making the glass very pure.

In the next two sections, you learn more about the *reflection* and refraction that help you to understand the design and operation of optical fibers.

The Law of Reflection

When light travels through a medium like air and strikes another medium like glass, the light either reflects off the surface or passes into or through the second medium, as shown in Figure 3-15. It depends on the angle it strikes the surface. The angle between the incident ray and a line perpendicular to the surface of the glass at the point where the incident ray strikes the glass is called the *angle of incidence*. When this angle of incidence reaches a certain point, called the critical angle, all the light is reflected back into the original medium, as illustrated in Figure 3-16.

Figure 3-15 Reflection

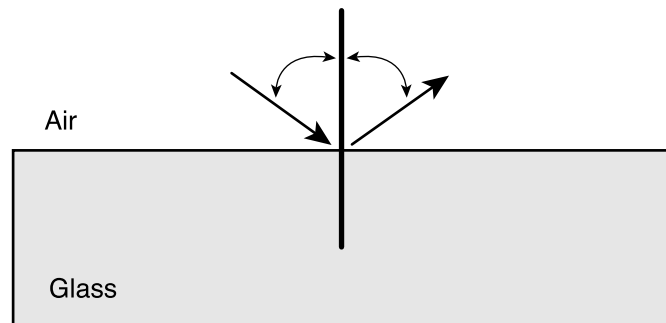
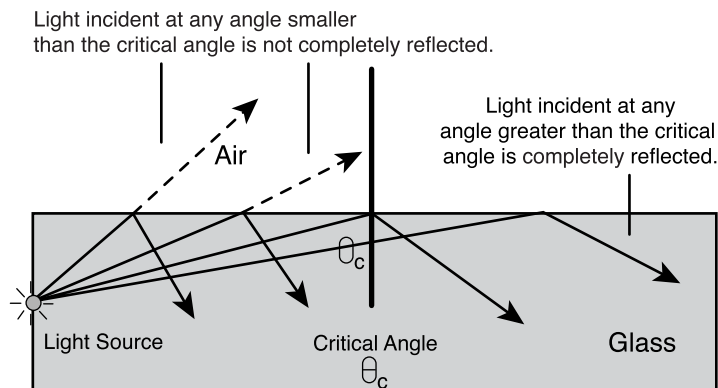


Figure 3-16 Critical Angel



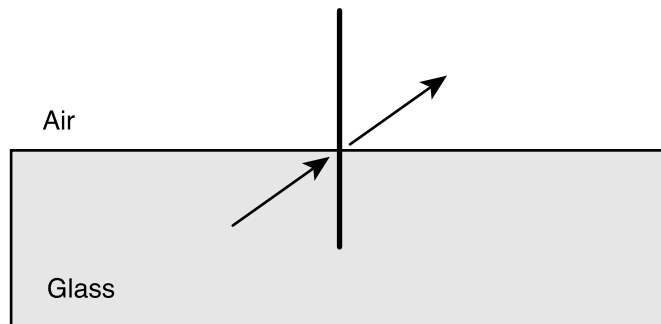
The perpendicular line is called the *normal*. It is not a light ray but a tool to allow the measurement of angles. The angle between the reflected ray and the normal is called the angle of reflection. The Law of Reflection states that the *angle of reflection* of a light ray is equal to its angle of incidence. In other words, the angle at which a light ray strikes a reflective surface determines the angle that the ray reflects off the surface.

The Law of Refraction (Snell's Law)

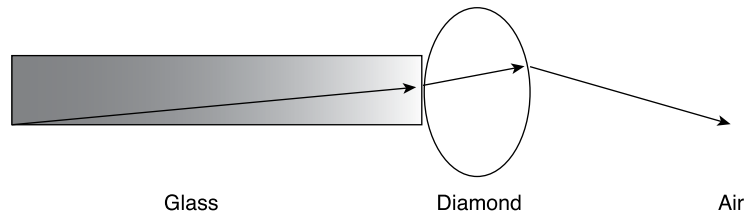
When light strikes the interface between two transparent materials like air and glass, the light divides into two parts. Part of the light ray is reflected back into the first substance (the air), with the angle of reflection equaling the angle of incidence. The remaining energy in the light ray crosses the interface and enters into the second substance (the glass).

If the incident ray strikes the glass surface at exactly a 90-degree angle, the ray goes straight into the glass. The ray is not bent. But, if the angle of incidence is not exactly 90 degrees, then the ray that enters the glass (the transmitted ray) is bent. We call this bending of the entering ray *refraction*. How much the ray is bent (refracted) depends on the index of refraction of the two transparent materials. If the light ray travels from a substance whose index of refraction is smaller into a substance where the index of refraction is larger, the refracted ray is bent towards the normal. If the light ray travels from a substance where the index of refraction is larger into a substance where the index of refraction is smaller, the refracted ray is bent away from the normal. Figure 3-17 illustrates an example of refraction.

Figure 3-17 Refraction

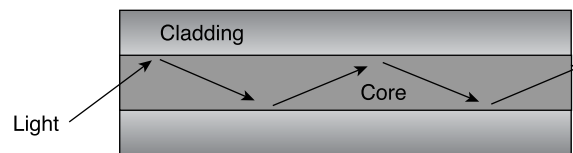


For example, consider a light ray moving at some angle other than 90 degrees through the boundary between glass and a diamond, as shown in Figure 3-18. The glass has an index of refraction of about 1.523. The diamond has an index of refraction of about 2.419. Therefore, the ray that continues into the diamond is bent towards the normal. When that light ray crosses the boundary between the diamond and the air at some angle other than 90 degrees, it is bent away from the normal. The reason for this is that air has a lower index of refraction (about 1.000) than does diamond.

Figure 3-18 Refraction Example

Total Internal Reflection

A light ray that is being turned on and off to send data 1s and 0s into an optical fiber must stay inside the fiber until it reaches the far end. The ray must not refract into the material wrapped around the outside of the fiber because such refraction causes the loss of part of the ray's light energy. A design for the fiber that makes the outside surface of the fiber act like a mirror to the light ray moving through the fiber must be achieved. If any light ray that tries to move out through the side of the fiber is reflected back into the fiber at an angle that sends it towards the far end of the fiber, this is a good *pipe* or *wave guide* for the light waves, as illustrated in Figure 3-19.

Figure 3-19 Total Internal Reflection

The laws of reflection and refraction tell how to design a fiber that guides the light waves through the fiber with a minimum energy loss. Two conditions are needed to cause light rays in a fiber to be reflected back into the fiber with out any loss due to refraction. These two conditions are as follows:

- The core (the inside) of the optical fiber has to have a larger (a higher) index of refraction than the material that surrounds it. The material that surrounds the core of the fiber is called the cladding.
- The angle of incidence of the light ray is greater than the critical angle for the core and its cladding.

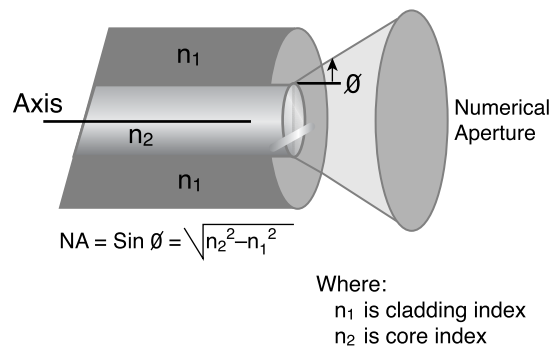
When both of these conditions are met, all the incident light in the fiber is reflected back inside the fiber. This condition is called *total internal reflection*, which is the foundation on which optical fiber is constructed. Total internal reflection causes the light rays in the

fiber to bounce off the core-cladding boundary and continue their journey toward the far end of the fiber. The light follows something of a zigzag path through the core of the fiber.

A fiber that meets the first condition (a core with a higher index of refraction than the cladding) can be easily created. Also, the angle of incidence of the light rays that enter the core can be controlled. Restricting two factors controls the angle of incidence:

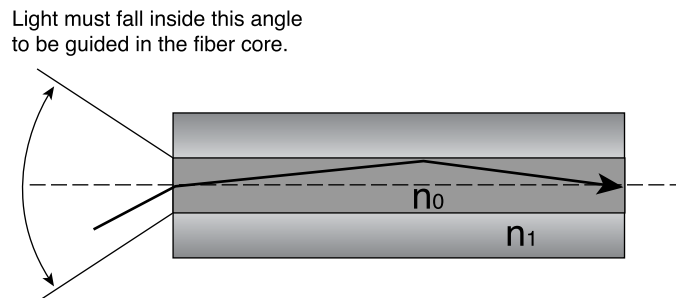
- The numerical aperture of the fiber. The numerical aperture of a core is the range of angles of incident light rays entering the fiber that are totally internally reflected, as illustrated in Figure 3-20.
- The paths (called the modes) that a light ray can follow when traveling down a fiber.

Figure 3-20 Numerical Aperture



Controlling conditions 1 and 2 creates a fiber with total internal reflection, consequently giving a light wave path that can be used for data communications, as shown in Figure 3-21.

Figure 3-21 Light Wave Path



Fiber-Optic Cables

Fiber-optic cable is a networking medium that uses modulated light for data transmissions through thin strands of glass. Signals that represent data bits are converted into beams of light. It is important to recognize that while electricity is required to generate and interpret the fiber-optic signals at the end devices, no electricity is in the cable itself as there is with copper media. In fact, fiber-optic cable components are very good insulators. Many characteristics of fiber-optic media are superior to copper.

Every fiber-optic cable used for networking consists of two glass fibers encased in separate sheaths. One fiber carries transmitted data from device A to device B; the second fiber carries data from device B to device A. A fiber for data goes in each direction, similar to two one-way streets going in opposite directions. This arrangement provides a full-duplex communication link. Just as copper twisted-pair uses separate wire pairs to transmit (Tx) and receive (Rx), fiber-optic circuits use one fiber strand to transmit and one to receive, as illustrated in Figure 3-22. Typically, these two fiber cables are in a single outer jacket until they reach the point at which connectors are attached.

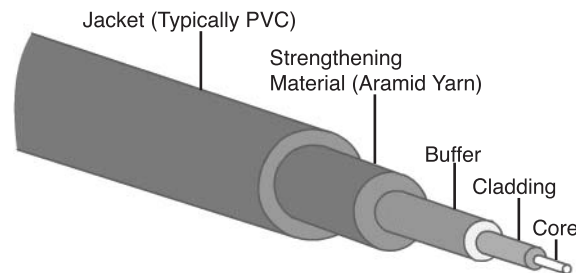
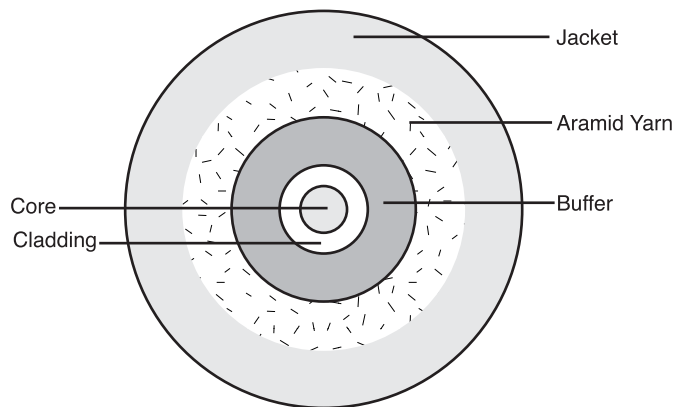
Figure 3-22 Duplex Fiber



At this point, the two fiber cables are separated. No need for twisting or shielding exists because no light escapes when it is inside a fiber, which means no crosstalk issues exist with fiber. It is common to see multiple fiber pairs encased in the same cable. This arrangement allows a single cable to be run between data closets, floors, or buildings. One cable can contain 2, 4, 8, 12, 24, 48, or more separate fibers. With copper, one UTP cable has to be pulled for each circuit. Fiber can carry many more bits per second and carry them farther than copper can.

As illustrated in Figure 3-23 and Figure 3-24, five parts typically make up each fiber-optic cable:

- The core
- The cladding
- A buffer
- A strengthening material
- An outer jacket

Figure 3-23 Five Elements of a Fiber-Optic Cable**Figure 3-24** Cross Section Showing the Five Elements of a Fiber-Optic Cable

The core is the light transmission element at the center of the optical fiber, and all the light signals travel through the core. This core is typically glass made from a combination of silica (silicon dioxide) and other elements. Surrounding the core is the cladding, also made of silica but with a lower index of refraction than the core. Light rays traveling through the fiber core reflect off this core-to-cladding interface where the core and cladding meet, which keeps light in the core as it travels down the fiber.

Surrounding the cladding is a buffer material, usually plastic, that helps shield the core and cladding from damage.

The strengthening material surrounds the buffer, preventing the fiber cable from being stretched when installers pull it. The material used is often Kevlar, the same material used to produce bulletproof vests. The final element, the outer jacket, surrounds the cable to protect the fiber against abrasion, solvents, and other contaminants. This outer jacket composition can vary depending on the cable usage.

The part of an optical fiber through which light rays travel is called the *core* of the fiber. Light rays cannot enter the core of an optical fiber at all angles. The rays can enter the core only if their angle is inside the fiber's numerical aperture. Likewise, once the rays have entered the fiber's core, a limited number of optical paths exist that a light ray can follow through the fiber. These optical paths are called modes. If the diameter of a fiber's core is large enough so that many paths exist that light can take as it passes through the fiber, the fiber is called *multimode* fiber. *Single-mode* fiber has a much smaller core that allows light rays to travel along only one path (one mode) inside the fiber. Figure 3-25 illustrates the differences between multimode and single-mode fibers.

Figure 3-25 Single-Mode Versus Multimode

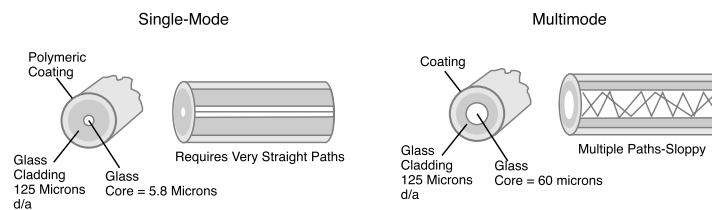


Table 3-3 compares the features of single-mode and multimode fiber.

Table 3-3 Features of Single-Mode and Multimode Fiber

	Single-Mode Fiber	Multimode Fiber
Core Features	Small core (10 microns or less)	Larger core than single-mode cable (50 or 62.5 microns or greater)
Dispersion Characteristics	Less dispersion	Allows greater dispersion and, therefore, loss of signal
Distance Characteristics	Suited for long-distance applications (up to 3 kilometers [9,842 feet])	Used for long-distance application, but shorter than single-mode (up to 2 kilometers [6,560 feet])
Light Source	Uses lasers as the light source often within campus backbones for distances of several thousand meters	Uses LEDs as the light source, often within LANs or distances of a couple hundred meters within a campus network

The next two sections cover the two basic types of optical fiber, multimode and single-mode, in more detail.

Multimode Fiber

Multimode fiber allows multiple modes (paths) of light to propagate through the fiber-optic core, as compared to single-mode fiber, which allows only one mode. Multiple modes of light propagating through fiber might travel different distances, depending on their entry angles. This angle causes them to arrive at the destination (receiving end of the cable) at slightly different times—a phenomenon called *modal dispersion*. Multimode uses a type of glass, called *graded index glass*, which has a lower index of refraction towards the outer edge of the core. This glass causes the light to slow down when passing through the center of the core and accelerate when passing through the outer areas of the core, ensuring that all modes of light reach the end at approximately the same time. This design is used because a light ray following a mode that goes straight down the center of the core does not have to go as far as a ray following a mode that bounces around in the fiber. All rays should arrive at the end of the fiber together. Then, the receiver at the end of the fiber receives a strong flash of light rather than a long, dim pulse.

A standard multimode fiber-optic cable (the most common type of fiber-optic cable used in LANs) uses an optical fiber with either a 62.5- or a 50-micron core and a 125-micron diameter cladding. This cable is commonly designated as 62.5/125 or 50/125 micron optical fiber. A micron is one millionth of a meter. Because the diameter of the cladding is considerably larger than the wavelength of the light being transmitted, the light bounces around (reflects) inside the core as it is propagated along the transmission line.

Infrared light emitting diodes (LEDs) or vertical cavity surface emitting lasers (VCSELs) are usually the light source used with multimode fiber. LEDs are a little cheaper to build and require somewhat less safety concerns than lasers. However, LEDs cannot transmit light over cable as far as the lasers. Multimode fiber (62.5/125) can carry data distances of up to 2000 meters (6560 feet). Multimode fiber is mainly used in LAN applications including backbone cabling.



Lab Activity Optical Fiber Purchase

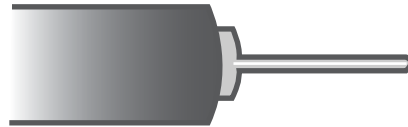
In this lab, you are introduced to the variety and prices of network cabling and related components in the market. This lab looks specifically at fiber-optic patch cables and bulk fiber cable.

Single-Mode Fiber

Single-mode fiber uses only one mode of light to propagate through the fiber-optic core. In single-mode fiber-optic cabling, the core is much smaller than in multimode. The single-mode core is 8 to 10 microns in diameter. Nine micron cores are the most common. A 9/125 marking on a single-mode fiber's jacket indicates that the core fiber has a diameter of 9 microns and the surrounding cladding is 125 microns in diameter.

The size of the core in single-mode fiber leaves very little room for light to bounce around. Furthermore, a very focused infrared laser is used as the light source in single-mode fiber. The ray of light it generates enters the core at a 90-degree angle. As a result the data carrying light ray pulses in single-mode fiber are essentially transmitted in a straight line right down the middle of the core, as shown in Figure 3-26. This greatly increases both the speed and the distance that data can be transmitted.

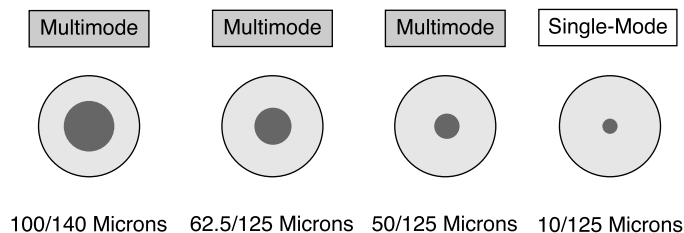
Figure 3-26 Single-Mode Fiber



Because of its design, single-mode fiber is capable of higher rates of data transmission (bandwidth) and greater cable run distances than multimode fiber. Single-mode fiber can carry LAN data up to 3000 meters. Multimode is only capable of up to 2000 meters. Lasers and single-mode fibers are more expensive than LEDs and multimode fiber. Because of these characteristics, single-mode fiber is often used for interbuilding connectivity or WANs (for example, telephone company network connections).

Figure 3-27 compares the relative sizes of the core and cladding for both types of fiber-optic cable in different sectional views. The much smaller and more refined fiber core in single-mode fiber, although it entails more manufacturing costs, is the reason single-mode has a higher bandwidth and cable run distance than multimode fiber.

Figure 3-27 Single-Mode and Multimode Fiber



WARNING

Be aware that the laser light used with single-mode has a longer wavelength than can be seen, and it is so strong that it can seriously damage eyes. Never look at the end of a fiber that is connected to a device at its far end. Never look into the transmit port on a NIC, switch, or router. There is nothing that can be seen anyway. Remember to keep protective covers over the ends of fiber and inserted into the fiber-optic ports of switches and routers. Be very careful!

The following summarizes the features of fiber-optic cables:

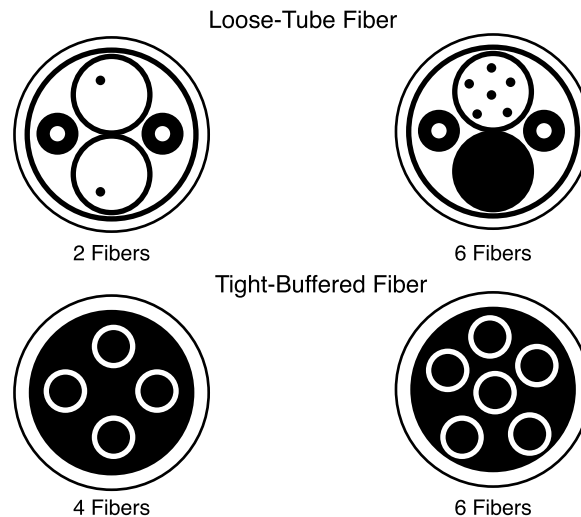
- **Speed and throughput**—More than 1 Gbps
- **Average cost per node**—Expensive
- **Media and connector size**—Small
- **Maximum cable length**—More than 10 kilometers (km) for single mode; up to 2 km for multimode

Cable Designs

As illustrated in Figure 3-28, two basic cable designs exist:

- Loose-tube
- Tight-buffered

Figure 3-28 Loose-Tube Versus Tight-Buffer Construction



Tight-buffered cables have the buffering material that surrounds the cladding in direct contact with the cladding. The main practical difference between the two designs is the applications for which they are used. Loose-tube cable is primarily used for outside-building installations, while tight-buffered cable is used inside buildings. Most of the fiber used in LANs is tight-buffered multimode cable.

Other Optical Networking Components

Most of the data sent over a LAN is in the form of electrical signals. But, optical fiber links use light to send data. So, something is needed to convert the electricity to light and, at the other end of the fiber, convert the light back to electricity. This situation means that two devices are always required: a transmitter and a receiver.

In addition to transmitters and receivers, this section also discusses different types of fiber-optic cable connectors as well as devices used in optical networking.

Transmitters

The transmitter receives data to be transmitted from switches and routers. This data is in the form of electrical signals. The transmitter converts the electronic signals into their equivalent light pulses. Two types of light sources encode and transmit the data through the cable. These two sources are

- **Light emitting diodes (LEDs)**—An LED produces infrared light with wavelengths of either 850 or 1310 nm. These are used with multimode fiber in LANs. Lenses are used to focus the infrared light on the end of the fiber. LEDs have fewer safety concerns.
- **Light amplification by stimulated emission radiation (Laser)**—Laser is a light source producing a thin beam of intense infrared light usually with wavelengths of 1310 or 1550 nm. Lasers are used with single-mode fiber over the longer distances involved in WANs or campus backbones. Exercise extra care to prevent eye injury.

Each light source can be lighted and darkened quickly to send data 1s and 0s at a high number of bits per second.

Receiver

At the other end of the optical fiber from the transmitter is the receiver. It functions something like the photoelectric cell in a solar-powered calculator. When light strikes the receiver, it produces electricity. The first job of the receiver is to detect a light pulse that arrives from the fiber. Then the receiver converts the light pulse back into the original electrical signal that first entered the transmitter at the far end of the fiber. Now the signal is again in the form of voltage changes. The signal is ready to be sent over copper wire into any receiving electronic device such as a computer, switch, or router. The semiconductor devices that are usually used as receivers with fiber-optic links are called p-intrinsic-n diodes (PIN photodiodes).

PIN photodiodes are manufactured to be sensitive to the particular wavelength of light (850, 1310, or 1550 nm) generated by the transmitter at the far end of the fiber. When

struck by a pulse of light at the proper wavelength, the PIN photodiode quickly produces an electric current of the proper voltage for the network. It instantly stops producing the voltage when no light strikes the PIN photodiode. This process generates the voltage changes that represent the data 1s and 0s on a copper cable.

Connectors

Connectors are attached to the fiber ends so that the fibers can be connected to the ports on the transmitter and receiver. The most common type of connector used with multi-mode fiber is the subscriber connector (SC), as shown in Figure 3-29. On single-mode fiber, the straight tip (ST) connector, as shown in Figure 3-30, is frequently used. With SC and ST, there is one connector for each fiber. Newer connectors combine the send and receive fibers into one modular connector, comparable in size to an RJ-45, to save space.

Figure 3-29 SC Connector

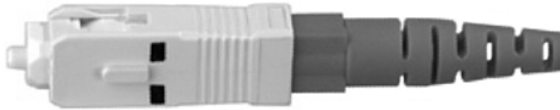


Figure 3-30 ST Connector



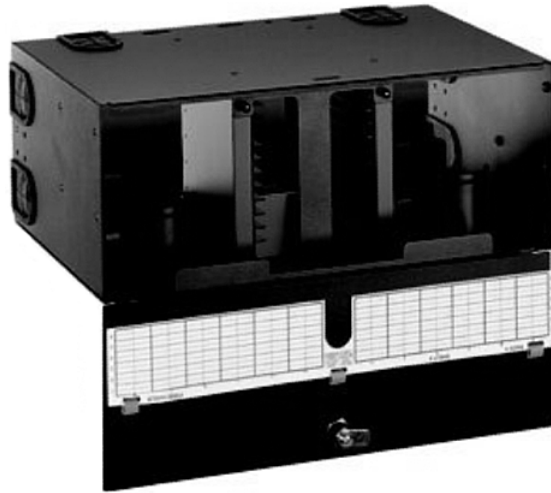
Optical Amplifiers and Fiber Patch Panels

In addition to the transmitters, receivers, connectors, and fibers that are always required on an optical network, you can sometimes see several other devices on an optical fiber network.

Repeaters are optical amplifiers that receive attenuating light pulses traveling long distances and restore them to their original shapes, strengths, and timings. Then the restored signals can be sent on along the journey to the receiver at the far end of the fiber.

Fiber-optic patch panels, as shown in Figure 3-31, are similar to the patch panels used with copper cable. These panels increase the flexibility of an optical network by allowing quick changes to the connection of devices like switches or routers with various available fiber runs (cable links).

Figure 3-31 Fiber-Optic Patch Panels



Signals and Noise in Optical Fiber

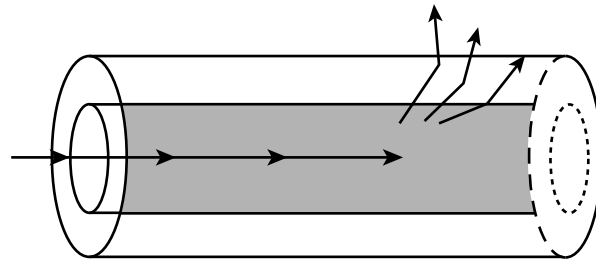
Fiber-optic cable is not affected by the sources of external *noise* that cause problems on copper media. Why? Because external light cannot enter the fiber except at the transmitter end. The cladding is covered by a buffer and an outer jacket that stops light from entering or leaving the cable.

Furthermore, the transmission of light on one fiber in a cable does not generate interference that disturbs transmission on any other fiber, which means that fiber does not have the problem with crosstalk that copper media does. In fact, the quality of fiber-optic links is so good that the recent standards for Gigabit and 10-Gigabit Ethernet specify transmission distances that far exceed the traditional 2-kilometer reach of the original Ethernet. (You learn more about the Ethernet technologies in Chapter 6, “Ethernet Technologies and Ethernet Switching”.) Fiber-optic transmission allows the Ethernet protocol to be used on metropolitan-area networks (MANs) and WANs.

Although fiber is the best of all the transmission media at carrying large amounts of data over long distances, fiber is not without problems. When light travels through fiber, some of the light energy is lost. The farther a light signal travels through a fiber,

the more it loses strength. This *attenuation* of the signal is due to several factors involving the nature of fiber itself. The most important factor is *scattering*. The scattering of light in a fiber is caused by microscopic non-uniformity (distortions) in the fiber that reflects and scatters some of the light energy, as shown in Figure 3-32.

Figure 3-32 Scattering

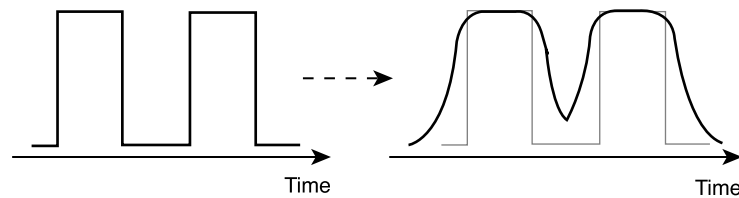


Absorption is another cause of light energy loss. When a light ray strikes some types of chemical impurities in a fiber, the impurities absorb part of the ray's energy. This light energy is converted to a small amount of heat energy. Absorption makes the light signal a little dimmer.

Another factor that causes attenuation of the light signal is manufacturing irregularities or roughness in the core-to-cladding boundary. Power is lost from the light signal as a result of the less than perfect total internal reflection in that rough area of the fiber. If there are any microscopic imperfections in the thickness or symmetry of the fiber, it cuts down on total internal reflection, and some light energy is absorbed by the cladding.

Dispersion of a light flash limits transmission distances on a fiber. Dispersion is the technical term for the spreading of pulses of light as they travel down the fiber, as shown in Figure 3-33.

Figure 3-33 Dispersion



Graded index multimode fiber is designed to compensate for the different distances the various modes of light have to travel in the large diameter core. Single-mode fiber does not have the problem of multiple paths that the light signal can follow. Chromatic

dispersion, however, is a characteristic of both multimode and single-mode fiber. Some wavelengths of light travel at slightly different speeds through glass than do other wavelengths. This discrepancy causes chromatic dispersion. That is why a prism separates the wavelengths of light. Ideally, an LED or laser light source emits light of just one frequency. Then, chromatic dispersion is not a problem.

Unfortunately, lasers and, especially, LEDs generate a range of wavelengths so chromatic dispersion limits the distance you can transmit on a fiber. If you try to transmit a signal too far, what started as a bright pulse of light energy is spread out, separated, and dim when it reaches the receiver. The receiver is not able to distinguish a 1 from a 0.

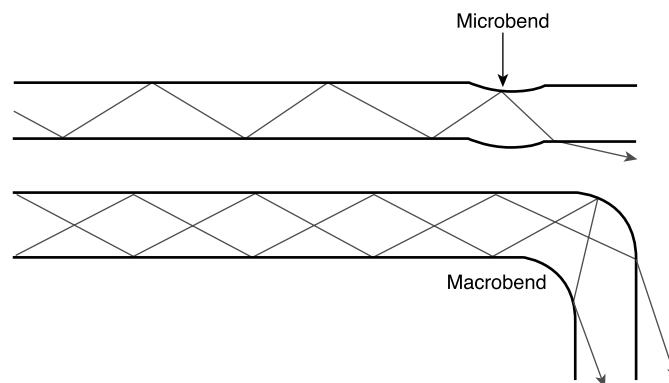
Installation, Care, and Testing of Optical Fiber

A major cause of too much attenuation in fiber-optic cable is improper installation. If the fiber is stretched or curved too tightly, it can cause tiny fissures (cracks) in the core that scatter the light rays. Bending the fiber in too tight a curve can change the incident angle of light rays striking the core-to-cladding boundary. Then, the ray's incident angle becomes less than the critical angle for total internal reflection. Instead of reflecting around the bend, some light rays refract into the cladding and are lost.

There are two types of bending:

- **Macrobending**—A macrobend is a bend you can see. When you bend fiber, you can cause some of the light rays to exceed the critical angle, allowing light to leak out of the core and into the cladding. When light is in the cladding, it cannot easily get back into the core; it then leaks out through the buffer, as shown in Figure 3-34.
- **Microbending**—Microbending produces the same effect as macrobending; it causes the light to exceed the critical angle and leak out of the core, as shown in Figure 3-34. It occurs on a microscopic scale and is not visible to the eye.

Figure 3-34 Macrobending and Microbending



NOTE

Microbending can also be caused by extreme temperature swings in installed cable when the different materials in the cable structure expand and contract at different rates. This expansion and contraction causes the fiber to be squeezed or stretched, which causes microbending.

To prevent fiber bends that are too sharp, fiber is usually pulled through a type of installed pipe called *interducting*. The interducting is much stiffer than fiber and cannot be bent so sharply that the fiber inside the interducting has too tight a curve. The interducting protects the fiber, makes it easier to pull the fiber, and ensures that the bending radius (curve limit) of the fiber is not exceeded.

When the fiber has been pulled, the ends of the fiber must be cleaved (cut) and properly polished to ensure that the ends are smooth. Figure 3-35 illustrates the problems with improper fiber end face finishes, and Figure 3-36 illustrates the proper fiber end face polishing techniques.

Figure 3-35 Fiber End Face Finishes

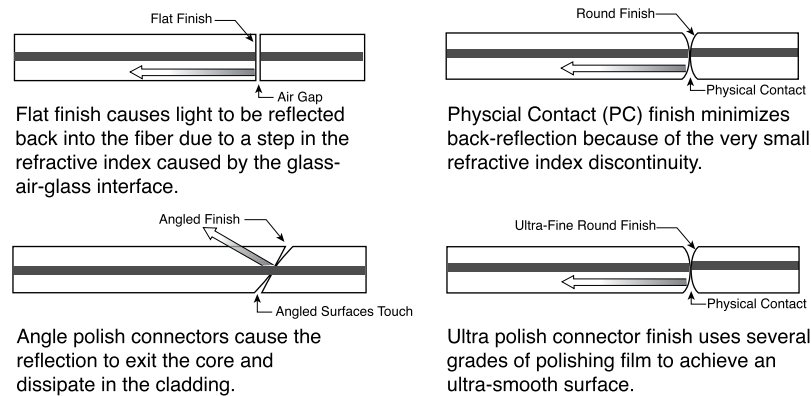
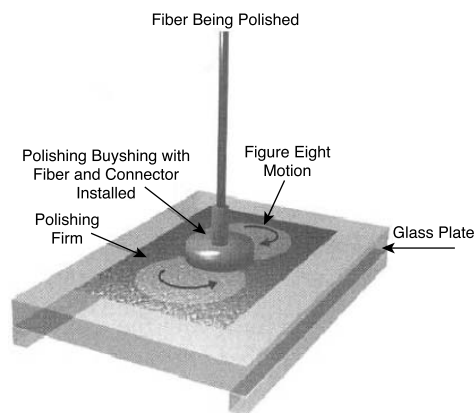
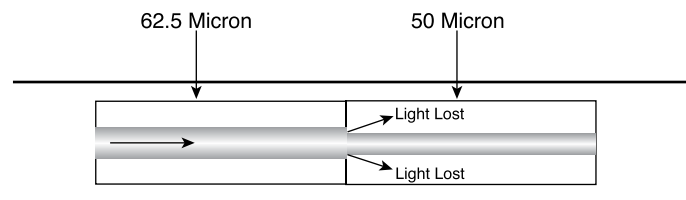


Figure 3-36 Fiber End Face Polishing Techniques



A microscope or test instrument with a built-in magnifier is used to examine the end of the fiber and verify that it is properly polished and shaped. Then, the connector is carefully attached to the fiber end. Improperly installed connectors, improper splices, or the splicing of two cables with different core sizes dramatically reduces the strength of a light signal. Figure 3-37 illustrates the splicing of a 62.5 micron fiber to a 50 micron fiber.

Figure 3-37 Splicing of Different Types of Fiber



After the fiber-optic cable and connectors are installed, the connectors and the ends of the fibers must be kept spotlessly clean. The ends of the fibers should be covered with protective covers to prevent damage to the fiber ends. When these covers are removed prior to connecting the fiber to a port on a switch or router, the fiber ends must be cleaned. Clean the fiber ends with lint-free lens tissue moistened with pure isopropyl alcohol. The fiber ports on a switch or router should also be kept covered when not in use and cleaned with lens tissue and isopropyl alcohol before a connection is made. Dirty ends on a fiber cause a big drop in the amount of light that reaches the receiver.

All these factors, scattering, absorption, dispersion, improper installation, and dirty fiber ends diminish the strength of the light signal and are referred to as fiber noise. Before using a fiber-optic cable, it must be tested to ensure that enough light actually reaches the receiver for it to detect the 0s (off) and 1s (on) in the signal.

When a fiber-optic link is being planned, the amount of signal power loss that can be tolerated must be calculated. This tolerance is referred to as the *optical link loss budget*. It is like your monthly financial budget. After all your expenses (attenuations) are subtracted from your initial income, enough money must be left to get you through the month.

The *decibel (dB)* is the unit used to measure the amount of power loss. It tells what percent of the power that leaves the transmitter actually enters the receiver.

Testing fiber links is extremely important, and records of the results of these tests must be kept. Several types of fiber-optic test equipment are used. Two of the most important instruments are Optical Loss Meters and Optical Time Domain Reflectometers (OTDRs).

These meters both test optical cable to ensure that the cable meets the TIA standards for fiber. They also test to verify that the link power loss does not fall below the optical link loss budget. OTDRs can provide a lot of detailed diagnostic information about a fiber link and can be used to troubleshoot a link when problems occur.

**Lab Activity** Fiber Optic Purchase

In this lab, you are introduced to the variety and prices of cabling and related components in the market. This lab looks specifically at fiber-optic patch cables and bulk fiber cable.

Wireless Communications

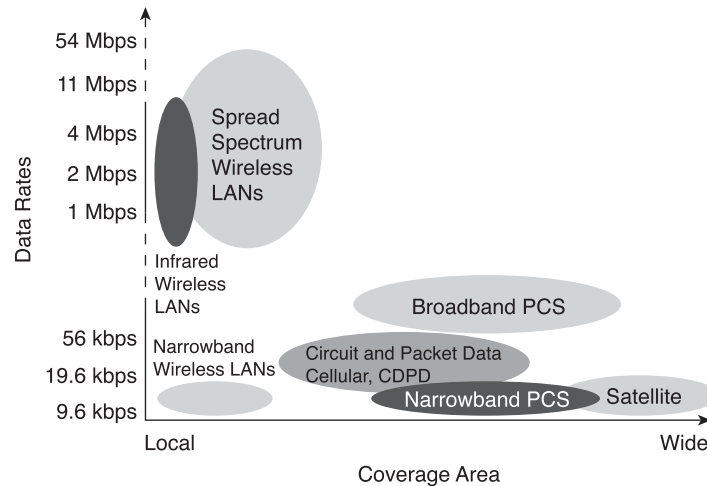
Wireless signals are electromagnetic waves that can travel through the vacuum of outer space or through a medium such as air. No physical copper-based or fiber-optic medium is necessary for wireless signals, which makes utilizing wireless signals a very versatile way to build a network. Wireless transmissions can cover large distances by using high-frequency signals. Each signal uses a different frequency measured in hertz so that they remain unique from one another.

Wireless technologies have been around for many years. Satellite TV, AM/FM radio, cellular phones, remote-control devices, radar, alarm systems, weather radios, cordless phones, and retail scanners are integrated into everyday life. Today, wireless technologies are a fundamental part of business and personal life.

Wireless Data Communications

The radio spectrum is the part of the electromagnetic spectrum used to transmit voice, video, and data. It uses frequencies from 3 kilohertz (kHz) to 300 gigahertz (GHz). This section considers only the part of the radio spectrum that supports wireless data transmission.

Many different types of wireless data communications exist, as illustrated in Figure 3-38.

Figure 3-38 Wireless Data Networks

Each type of wireless data communication has its advantages and drawbacks, as follows:

- **Infrared (IR)**—Very high data rates and lower cost, but very short distance.
- **Narrowband**—Low data rates and medium cost. Requires a license and covers a limited distance.
- **Spread spectrum**—Medium cost and high data rates. Limited to campus coverage. Cisco Aironet products are spread spectrum.
- **Broadband personal communications service (PCS)**—Low data rates, medium cost, and citywide coverage. Sprint is an exception; Sprint PCS provides nationwide and international coverage.
- **Circuit and packet data (cellular data and Cellular Digital Packet Data [CDPD])**—Low data rates, high packet fees, and national coverage.
- **Satellite**—Low data rates, high cost, and nationwide or worldwide coverage.

Wireless Signal

When a signal is transmitted in a data format, you must consider the following three parameters:

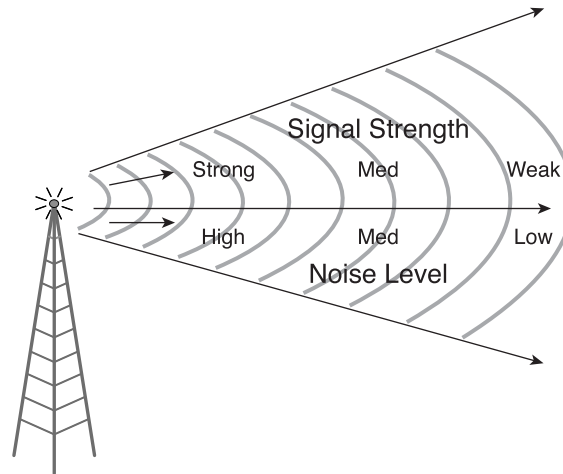
- **How fast**—What data rate can be achieved?
- **How far**—How far can wireless LAN (WLAN) units be placed apart and still get the maximum data rate?
- **How many**—How many users can exist without slowing the data rate?

These parameters all relate to the ability to receive a good signal as far away as possible. Increasing the amount of data requires the use of more frequency spectra or a different method of placing the data on the radio frequency (RF) signal.

RF efficiency is affected by the following three factors, as shown in Figure 3-39:

- **Type of modulation used**—More complex modulation techniques provide greater throughput.
- **Distance**—The farther the signal must be transmitted, the weaker the signal becomes.
- **Noise**—Electronic noise and barriers negatively affect RF.

Figure 3-39 Factors Affecting RF Efficiency



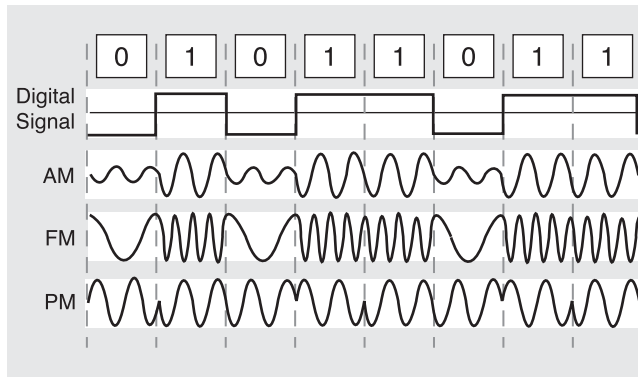
The following sections discuss these three factors in greater detail.

Modulation

Modulation is the process by which the amplitude, frequency, or phase of an RF or light wave is altered to transmit data. The characteristics of the carrier wave instantaneously are varied by another modulating waveform. Modulation blends a data signal (text, voice, and so on) into a carrier for transmission over a network.

The most common methods of modulation are as follows (see Figure 3-40):

- **Amplitude modulation (AM)**—Modulates the height of the carrier wave
- **Frequency modulation (FM)**—Modulates the frequency of the wave
- **Phase modulation (PM)**—Modulates the polarity (phase) of the wave

Figure 3-40 Modulation

Effects of Distance on a Signal

As a receiver moves farther from a transmitter, the signal gets weaker, and the difference between the signal and noise becomes less. Eventually, the signal cannot be distinguished from the noise, and loss of communication occurs. The amount of compression (or modulation scheme) at which the signal is transmitted determines the amount of signal needed to be heard through the noise. As transmission, or modulation schemes (compression), becomes more complex and data rates increase, immunity to noise lessens. Therefore, the distance is reduced.

Effects of Noise on a Signal

Electronic noise and barriers negatively affect RF efficiency. An exact transmission distance for WLAN products cannot be provided without going to the site and actually testing the environment. Walls with internal metal structures, for example, greatly limit RF transmission range.

Radio Frequency Bands

Most radio frequencies are licensed by government agencies, such as the Federal Communications Commission (FCC) in the United States. To broadcast over these frequencies, you need to have a license and to pay a fee.

Unlicensed frequency bands are easier to implement and cost less over time because they do not require licenses. Three unlicensed bands exist, as illustrated in Figure 3-41:

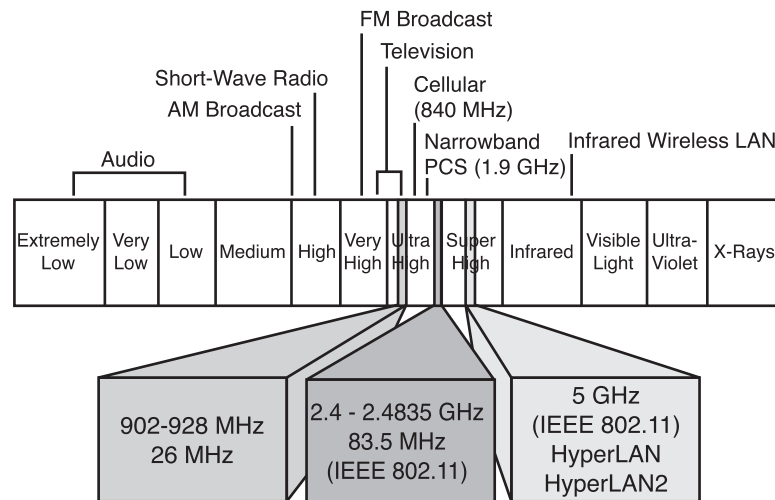
- **900 megahertz (MHz)**—The 900-MHz band carries cordless and cellular phones.
- **2.4 gigahertz (GHz)**—The 802.11b standard, the most widely deployed wireless standard, operates in the 2.4-GHz unlicensed radio band, delivering a maximum data rate of 11 Mbps.

NOTE

To be received correctly, complex modulation schemes require optimal signal-to-noise ratios (more signal with less noise). If there is noise on the channel, the line speed is reduced. Noise, speed, and distance are all interrelated.

- **5 GHz**—Recently, the FCC opened up the 5-GHz band for unlicensed use by high-speed data communications devices. Cisco has acquired 5-GHz technology and uses this frequency in new products, such as Cisco Aironet 1200 series, which is dual band, delivering support for both 2.4 GHz (802.11b) and 5 GHz (802.11a) standards. The 802.11a standard can deliver a maximum data rate of 54 Mbps.

Figure 3-41 Unlicensed Frequency Bands



A relationship exists between the frequency and the amount of data that can be sent. The concept is like that of a pipe. The wider the bandwidth is, the more frequencies are available. The wider the spectrum is, the higher the data rate can be transmitted. The amount of spectrum available determines the data rate.

Because the 900-MHz band supports cellular phones and other consumer products, the band has become overcrowded. As a result, users often experience interference or cannot access the network. As a benefit, 900 MHz offers longer range (for the same gain antennas) than 2.4 GHz. The drawback of 900 MHz is that the fastest, most reliable data rate is only 1 Mbps because of its limited frequency range.

The 2.4-GHz frequency range is much wider than 900 MHz, allowing higher data rates with a reliable range of up to 25 miles. The Cisco Aironet 340 Wireless LAN Series can deliver 11-Mbps throughput because it operates in the 2.4-GHz frequency.

Cisco has acquired 5-GHz technology and will deliver products for the 5-GHz frequency range because its wider bandwidth allows for faster throughput of data. The Cisco Aironet 5 GHz 54 Mbps Wireless LAN client adapter is an IEEE 802.11a-compliant CardBus adapter that operates in the UNII-1 and UNII-2 bands. The client adapter

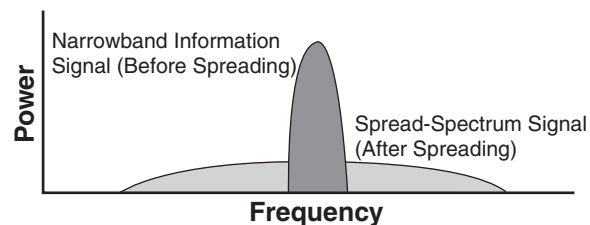
complements the Cisco Aironet 1200 Series 802.11a Access Point, providing a solution that combines performance and mobility with the security and manageability that enterprises require. It will be possible to achieve data rates of greater than 20 Mbps in this frequency range. The drawback of the 5-GHz frequency, however, is its limited range. The typical range for 5 GHz inside is about 50 feet; outside poses a limitation of approximately 2500 feet.

Spread-Spectrum Technology

Just as the radio in your car has AM and FM bands, other radios use certain bands, frequencies, and types of modulation. *Spread spectrum (SS)* is a modulation technique developed in the 1940s that spreads a transmission signal over a broad band of radio frequencies. The term *spread spectrum* describes a modulation technique that sacrifices bandwidth to gain signal-to-noise performance. This technique is ideal for data communications because it is less susceptible to radio noise and creates little interference.

Spread spectrum, as illustrated in Figure 3-42, is a system in which the transmitted signal is spread over a frequency much wider than the minimum bandwidth required to send the signal. The fundamental premise is that in channels with narrowband interference increasing the transmitted signal bandwidth results in an increased probability that the received information is correct.

Figure 3-42 Spread-Spectrum Technology



To use the unlicensed radio bands, you have to use spread-spectrum techniques. Frequency-hopping spread spectrum (FHSS) and direct-sequence spread spectrum (DSSS) are two ways of doing spread spectrum. These spread-spectrum techniques spread the RF energy over the available band. The next sections describe FHSS and DSSS in more detail.

FHSS Versus DSSS

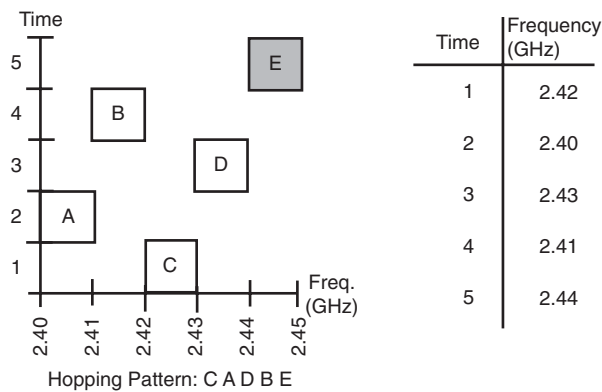
As modulation techniques, both *frequency-hopping spread spectrum (FHSS)* and *direct-sequence spread spectrum (DSSS)* have advantages and limitations.

NOTE

Narrowband interference occurs when two signals are broadcasting at the same frequency in the same geographic area. The term *band* refers to a grouping of frequencies; narrowband would mean a relatively smaller range of frequencies. Narrowband noise might disrupt certain channels or spread-spectrum components.

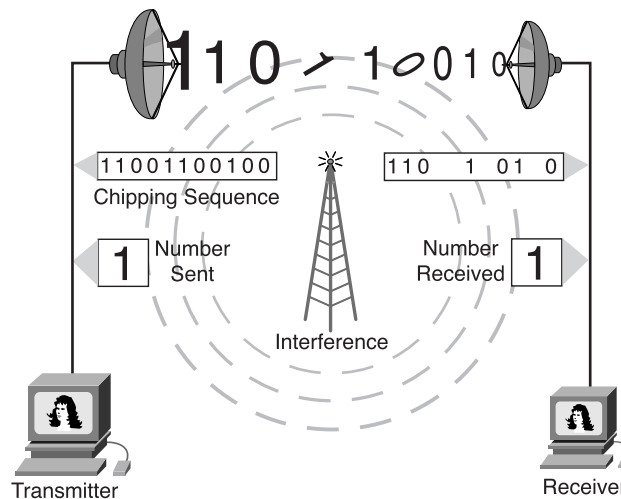
With FHSS technology, transmissions hop from one frequency to another in random patterns. Figure 3-43 illustrates an example of a FHSS. In this example, the transmission hops from C (2.42 GHz), to A (2.40 GHz), to D (2.43 GHz), then to B (2.41 GHz), and finally to E (2.44 GHz). This technique enables the transmissions to hop around narrow-band interference, resulting in a clearer signal and higher reliability of the transmission. However, FHSS technology is slower, and the receiver must use the same pattern to decode.

Figure 3-43 Frequency-Hopping Spread Spectrum



DSSS technology transmissions, as illustrated in Figure 3-44, are more reliable because each bit (1 or 0) is represented by a string of 1s and 0s called a *chipping sequence*. Even if up to 40 percent of the string is lost, the original transmission can be reconstructed. DSSS technology also enables high throughput of data and longer-range access.

Figure 3-44 Direct-Sequence Spread Spectrum



Limited to a 2-Mbps data-transfer rate, FHSS is recommended for only very specific applications such as for certain types of watercraft. For all other wireless LAN applications, DSSS is the better choice. The recently released evolution of the IEEE standard, 802.11b, provides for a full Ethernet-like data rate of 11 Mbps over DSSS. FHSS does not support data rates greater than 2 Mbps.

Wireless Networking

When the computer was first introduced to the world, it was affordable by only large corporations, governments, and universities. From the first building-sized devices with minimal computing power to those that fit in the palm of a person's hand, huge leaps in technology have occurred. The same is true on the connectivity side of the industry.

The various types of networking discussed earlier in this chapter have all involved physical connectivity. The advantages are speed, reliability, and to a certain extent convenience. Physical connectivity allows an increase in productivity by allowing the sharing of printers, servers, and software. However, networked systems require that the workstation remain stationary, permitting moves only within the limits of the media and office area.

The introduction of wireless technology removes these restraints and brings true portability to the computing world. While the current state of wireless technology does not provide the high-speed transfers of cabled networks nor the security and uptime reliability, the flexibility justifies the trade off.

When considering the installation of a network in an existing facility, wireless is at the top of many an administrator's lists of options. A simple wireless network can be up and running in just a few minutes after the workstations are turned on. Connectivity to the Internet is provided through a wired connection, router, cable modem, or Digital Subscriber Line (DSL) modem, and a wireless access point that acts as a hub for the wireless nodes. In a residential or small office environment these devices might be combined into a single unit.

Wireless LAN Organization and Standards

An understanding of the regulations and standards that apply to wireless technology ensures that deployed networks are interoperable and in compliance. Just as in cabled networks, IEEE is the prime issuer of standards for wireless networks. The standards have been created within the framework of the regulations set forth by the FCC.

A key technology contained within the IEEE 802.11 standard is DSSS. DSSS applies to wireless devices operating within a 1 to 2 Mbps range. A DSSS system can operate at

up to 11 Mbps but is not considered compliant above 2 Mbps. The next standard approved was IEEE 802.11b, which increased transmission capabilities to 11 Mbps. Even though DSSS WLANs are able to interoperate with the FHSS WLANs, problems developed prompting design changes by the manufacturers. In this case, IEEE's task was simply to create a standard that matched the manufacturer's solution.

IEEE 802.11b, called Wi-Fi or high-speed wireless, refers to DSSS systems that operate at 1, 2, 5.5, and 11 Mbps. All 802.11b systems are backward-compliant in that they also support 802.11 for 1- and 2-Mbps data rates for DSSS only. This backward compatibility is extremely important because it allows upgrading of the wireless network without replacing the network interface cards (NICs) or access points.

IEEE 802.11b devices achieve the higher data throughput rate by using a different coding technique from 802.11, allowing for a greater amount of data to be transferred in the same time frame. The majority of 802.11b devices still fail to match the 10 Mbps throughput of wired Ethernet and generally function in the 2–4 Mbps range.

802.11a covers WLAN devices operating in the 5-GHz transmission band. Using the 5-GHz range disallows interoperability of 802.11b devices as they operate within 2.4 GHz. 802.11a is capable of supplying data throughput of 54 Mbps and with proprietary technology known as *rate doubling* has achieved 108 Mbps. In production networks a more standard rating is 20 to 26 Mbps.

802.11g provides the same throughput as 802.11a but with backwards compatibility for 802.11g devices using Orthogonal Frequency Division Multiplexing (OFDM) modulation technology. Cisco has developed an access point that permits 802.11b and 802.11a devices to coexist on the same WLAN. The access point supplies gateway services allowing these otherwise incompatible devices to communicate.

Wireless Devices and Topologies

A wireless network can consist of as few as two devices, two nodes with wireless NICs. Figure 3-45 shows an internal wireless NIC, and Figure 3-46 shows an external USB wireless NIC. The nodes can be desktop workstations or notebook computers. Equipped with wireless NICs, an *ad hoc* network can be established that equates to a peer-to-peer wired network. Both devices act as servers and clients in this environment, and although it does provide connectivity, security is at a minimum along with throughput. Another problem with this type of network is compatibility; oftentimes, NICs from different manufacturers do not interoperate.

Figure 3-45 Internal Wireless NIC

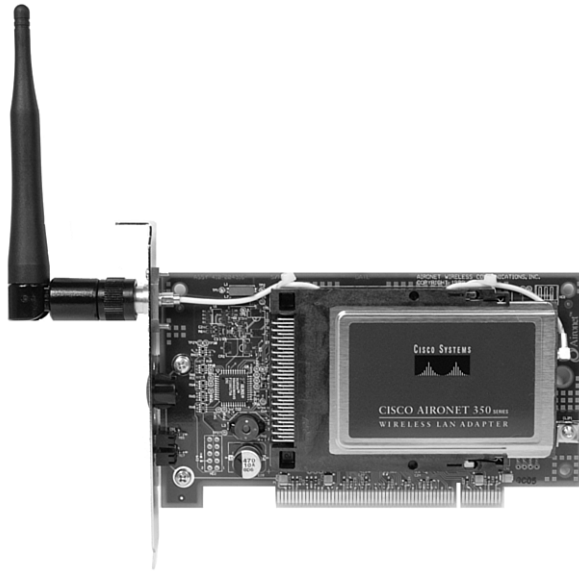


Figure 3-46 External USB Wireless NIC



More commonly, an access point (AP), as shown in Figure 3-47, is installed acting as a central hub for the WLAN *infrastructure mode*. The AP is hard wired to the cabled LAN to provide Internet access and connectivity to the wired network. APs are equipped with antennae and provide wireless connectivity over a specified area referred to as a cell.

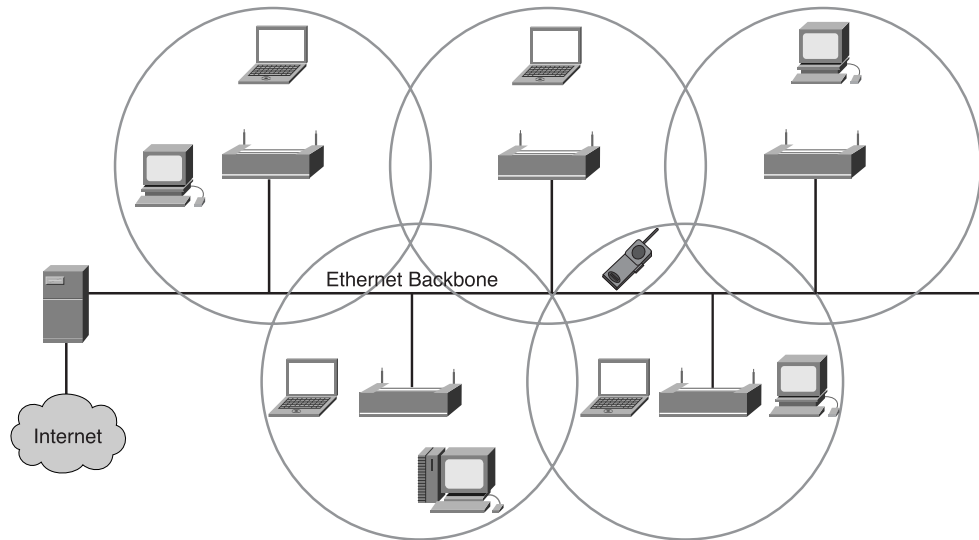
Figure 3-47 Access Point



Depending on the structural composition of the location in which the AP is installed and the size and gain of the antennae, the size of the cell can range from a few dozen feet to 25 miles. More commonly the range is from 300 to 500 feet. To service larger areas multiple APs can be installed with a degree of overlap, permitting *roaming* between cells, as illustrated in Figure 3-48. This roaming is very similar to the services provided by cellular phone companies. Overlap on multiple AP networks is critical to allow for movement of devices within the WLAN, and although it is not addressed in the IEEE standards, a 20–30 percent overlap is desirable. This rate of overlap permits roaming between cells, allowing for the disconnect/reconnect activity to occur seamlessly without service interruption.

When a client is activated within the WLAN, it starts listening for a compatible device with which to associate. This process is referred to as *scanning* and can be active or passive.

Active scanning causes a probe request to be sent from the wireless node seeking to join the network. The probe request contains the Service Set Identifier (SSID) of the network it wants to join. When an AP with the same SSID is found, the AP issues a probe response, and the authentication and association steps are completed.

Figure 3-48 Roaming

Passive scanning nodes listen for beacon management frames (beacons), which are transmitted by the AP (infrastructure mode) or peer nodes (ad hoc). When a node receives a beacon that contains the SSID of the network it is trying to join, an attempt is made to join the network. Passive scanning is a continuous process and nodes can associate or disassociate with APs as signal strength changes.

How Wireless LANs Communicate

After establishing connectivity to the WLAN, a node passes frames similarly to any other 802 network. WLANs do not use a standard 802.3 frame. Therefore, using the term *wireless Ethernet* is misleading. There are three types of frames: control, management, and data. The following lists the frames that are included in each type of frame:

- Management frames
 - Association request frame
 - Association response frame
 - Probe request frame
 - Probe response frame
 - Beacon frame
 - Authentication frame

- Control frames
 - Request to send (RTS)
 - Clear to send (CTS)
 - Acknowledgment
- Data frames

Only the data frame type is similar to 802.3 frames. However, the payload of wireless and 802.3 frames is 1500 bytes, and an Ethernet frame cannot exceed 1518 bytes. On the other hand, a wireless frame can be as large as 2346 bytes. Usually the WLAN frame size is limited to 1518 bytes because it is most commonly connected to a wired Ethernet network.

Because RF is a shared medium, collisions can occur just as they do on wired shared medium. The significant difference is that there is no method by which the source node is able to detect that a collision has occurred. In view of this, WLANs use carrier sense multiple access with collision avoidance (CSMA/CA). This feature is somewhat like Ethernet carrier sense multiple access collision detect (CSMA/CD). Chapter 5, “Ethernet Fundamentals,” discusses CSMA/CD in greater detail.

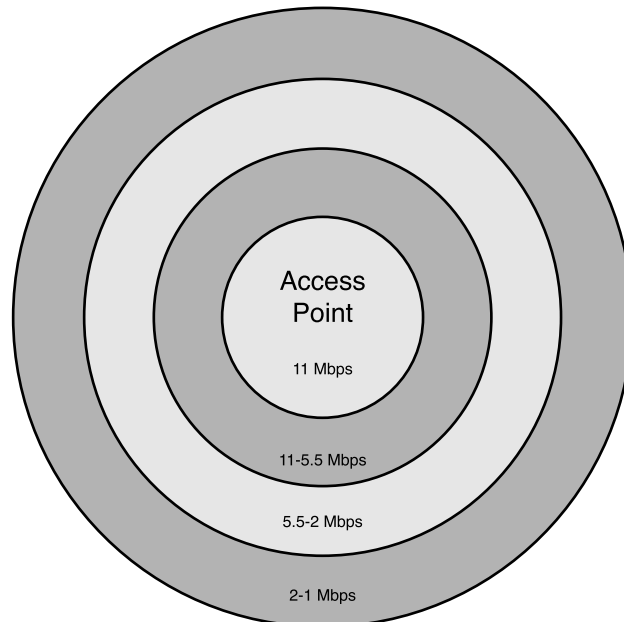
When a source node sends a frame, the receiving node returns a positive acknowledgment (ACK); which can consequently cause consumption of 50 percent of the available bandwidth. This overhead, when combined with the collision avoidance protocol overhead, reduces the actual data throughput to a maximum of 5.0 to 5.5 Mbps on an IEEE 802.11b wireless LAN rated at 11 Mbps.

Performance of the network will also be affected by signal strength and degradation in signal quality due to distance or interference. As the signal becomes weaker, Adaptive Rate Selection (ARS) can be invoked, and the transmitting unit drops the data rate from 11 Mbps to 5.5 Mbps, from 5.5 Mbps to 2 Mbps, or 2 Mbps to 1 Mbps, as illustrated in Figure 3-49.

Authentication and Association

WLAN authentication occurs at Layer 2 and is the process of authenticating the device, not the user. This point is a critical one to remember when considering WLAN security, troubleshooting, and overall management.

Authentication might be a null process, as in the case of a new AP and NIC with default configurations in place. The client sends an authentication request frame to the AP, and the frame is accepted or rejected by the AP. The client is notified of either course of action via an authentication response frame. The AP might also be configured to hand off the authentication task to an authentication server, which performs a more thorough credentialing process.

Figure 3-49 Adaptive Rate Selection

Association, performed after authentication, is the state that permits a client to use the AP's services to transfer data.

Authentication and Association Types

The authentication and association types are as follows:

- **Unauthenticated and unassociated**—The node is disconnected from the network and not associated to an access point.
- **Authenticated and unassociated**—The node has been authenticated on the network but has not yet associated with the access point.
- **Authenticated and associated**—The node is connected to the network and able to transmit and receive data through the access point.

Methods of Authentication

IEEE 802.11 lists two types of authentication processes:

- **Open system**—This process is an open connectivity standard in which only the SSID must match. It can be used in a secure or non-secure environment, although the ability of low-level network sniffers to ascertain the SSID of the WLAN is fairly high.

- **Shared key**—This process requires the use of Wired Equivalent Privacy (WEP) encryption. WEP is a fairly simple algorithm using 64- and 128-bit keys. The AP is configured with an encrypted key, and nodes attempting to access the network through the AP must have a matching key. Statically assigned WEP keys provide a higher level of security than the open system but are definitely not hack proof.

The susceptibility to unauthorized entry into WLANs is being addressed by a number of emerging security solution technologies.

The Radio Wave/Microwave Spectrum

Computers send data signals electronically. Radio transmitters convert these electrical signals to radio waves. The radio waves are generated by changing electric currents in a transmitter's antenna. These radio waves radiate out in straight lines from the antenna. However, radio waves weaken (attenuate) as they move out from the transmitting antenna. In a WLAN, a radio signal measured at a distance of just 10 meters (30 feet) from the transmitting antenna is only 1/100th of its original strength. Like light, radio waves can be absorbed by some materials and reflected by others. When passing from one material like air into another material like a plaster wall, radio waves are refracted (bent). Radio waves are also scattered and absorbed by water droplets in the air.

These qualities of radio waves are important to remember when a WLAN is being planned for a building or for a campus. The process of evaluating a location for the installation of a WLAN is called making a site survey.

Because radio signals weaken as they travel away from the transmitter, the receiver must also be equipped with an antenna. When radio waves hit a receiver's antenna, weak electric currents are generated in that antenna. These electric currents, caused by the received radio waves, are equal to the currents that originally generated the radio waves in the transmitter's antenna. The receiver amplifies the strength of these weak electrical signals.

In a transmitter, the electrical (data) signals from a computer or a LAN are not sent directly into the transmitter's antenna. Rather these data signals are used to alter a second, strong signal called the carrier signal.

A receiver demodulates the carrier signal that arrives from its antenna. The receiver interprets the phase changes of the carrier signal and reconstructs from it the original electrical data signal.

Signals and Noise on a WLAN

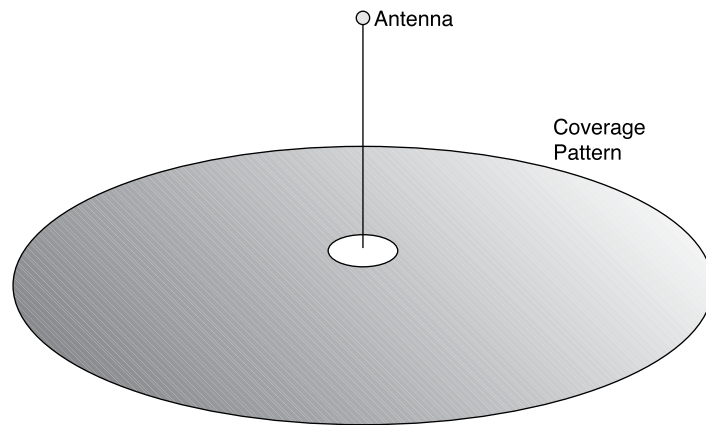
On a wired Ethernet network, it is usually a fairly simple process to diagnose the cause of interference. When using RF technology, you must take into account many kinds of interference:

- **Narrowband**—This is the opposite of spread spectrum technology. As the name implies, narrowband does not affect the entire frequency spectrum of the wireless signal. One solution to a narrowband interference problem is simply changing the channel that the AP is using. Actually, diagnosing the cause of narrowband interference can be a costly and time-consuming experience. To identify the source requires a spectrum analyzer and even a low cost model can cost \$3000 to \$4000 in the U.S. Examples of narrowband interference include CB radios and ham radios.
- **All band**—All band interference affects the entire spectrum range. Bluetooth technologies hop across the entire 2.4 GHz many times per second and can cause significant interference on an 802.11b network. It is not uncommon to see signs in facilities that use wireless networks requesting that all Bluetooth devices be shut down before entering. In homes and offices, a device that is often overlooked as causing interference is the standard microwave oven. Leakage from a microwave of as little as 1 watt into the RF spectrum can cause major network disruption. Wireless phones operating in the 2.4-GHz spectrum can also cause network degradation.
- **Weather**—Generally, the RF signal is not affected by even the most extreme weather conditions. However, fog or very high moisture conditions can and do affect wireless networks. Lightning can also charge the atmosphere and alter the path of a transmitted signal.

Signal Range Concerns

The first and most obvious source of a signal problem is the transmitting station and antenna type. A higher output station transmits the signal further, and a parabolic dish antenna that concentrates the signal increases the transmission range.

In a small office, home office (SOHO) environment, most access points utilize twin omnidirectional antennae that transmit the signal in all directions, thereby reducing the range of communication. Figure 3-50 illustrates an omnidirectional antenna.

Figure 3-50 Omnidirectional Antenna

Wireless Security

The exponential growth of networking, including wireless technologies, has led to increased security risks. Increasing the security means increasing the time spent managing the system.

The first level of security in a wireless LAN consists of protecting the radio frequency waveform itself. Wireless access points radiate radio waves over a large area that is not contained in a physical building, which makes the radio waves accessible to eavesdroppers and thus increases vulnerability. The radio waves of wireless bridges are concentrated in a beam. An eavesdropper must get into the beam path to intercept the communication. Therefore, wireless access points usually require better security than wireless bridges.

WEP

Wired equivalent privacy (WEP) is a security mechanism, defined within the 802.11 standard, that is designed to protect the over-the-air transmission between wireless LAN access points and NICs. The IEEE 802.11b requires 40-bit encryption keys. However, many vendors, such as Cisco, support the optional 128-bit standard.

The main goals with WEP follow:

- Deny access to the network by unauthorized users who do not possess the appropriate WEP key
- Prevent the decoding of captured WLAN traffic that is WEP-encrypted without the possession of the WEP key

WEP uses the RC4 stream cipher that was invented by Ron Rivest of RSA Data Security, Inc., (RSADSI) for encryption. The RC4 encryption algorithm is a symmetric-stream cipher that supports a variable-length key. A symmetric cipher uses the same key for both encryption and decryption. The key is the one piece of information that must be shared by both the encrypting and decrypting endpoints.

Recently, encryption analysts have reported weaknesses in the authentication and WEP encryption schemes in the IEEE 802.11 WLAN standard. Improvements on WEP have been developed to address the weaknesses found by encryption analysts. However, it is not recommended to use WEP as a sole security mechanism for a WLAN. WEP should be supplemented with additional higher-level security mechanisms, such as a VPN or firewalls.

VPN, EAP, and LEAP

A number of new security solutions and protocols, such as Virtual Private Network (VPN) and Extensible Authentication Protocol (EAP) are evolving. Using EAP, the access point does not provide authentication to the client but passes the duties to a more sophisticated server designed for that purpose. Using an integrated VPN server, VPN technology creates a tunnel on top of an existing protocol such as IP. This tunnel is a Layer 3 connection as opposed to the Layer 2 connection between the AP and the sending node.

The following list briefly describes EAP and LEAP:

- **EAP-MD5 Challenge**—EAP is the earliest authentication type, which is very similar to Challenge Handshake Authentication Protocol (CHAP) password protection on a wired network. EAP allows wireless client adapters that can support different authentication types to communicate with different back end servers, such as Remote Authentication Dial-In User Service (RADIUS).
- **Lightweight Extensible Authentication Protocol (LEAP)**—Cisco has developed a derivation of EAP based on mutual authentication called LEAP. Mutual authentication means that both the user and the access point to which the user is attempting to connect must be authenticated before access onto the corporate network is allowed. Mutual authentication protects enterprises from unauthorized APs serving as a potential entrance into the network. LEAP is the type of authentication primarily used on Cisco WLAN access points. LEAP provides security during credential exchange, encrypts using dynamic WEP keys, and supports mutual authentication.

VPN security levels include the following:

- **User authentication**—Allows only authorized users to connect, send, and receive data over the wireless network.

- **Encryption**—Provides encryption services, further protecting the data from intruders.
- **Data authentication**—Ensures the integrity of the data, authenticating source, and destination devices.

VPN technology effectively closes the wireless network because an unrestricted WLAN automatically forwards traffic between nodes that appear to be on the same wireless network. WLANS often extend outside the perimeter of the home or office in which they are installed, and without security, intruders can infiltrate the network with little effort. Conversely, it takes minimal effort on the part of the network administrator to provide low-level security to the WLAN.

Summary

In this chapter, you learned the following key points:

- Electricity is based on the ability of electrons of certain types of atoms to separate, or flow, from the confines of their atoms.
- Opposite charges attract and like charges repel. Electricity flows from negative to positive within electrical circuits.
- Materials can be classified as insulators, conductors, or semiconductors, depending on their ability to allow electrons to flow.
- The concepts of voltage, current, resistance, and impedance provide a means of measuring electricity, which is required to be able to design and manufacture electronic devices.
- Alternating current and direct current are the two types of current. AC provides power to our homes, schools, and work places. DC is used with electrical devices that depend on a battery to function.
- STP cable combines the techniques of shielding, cancellation, and twisting of wires. ScTP cable is essentially a twisted pair wrapped in a metallic foil shield.
- UTP cable is a four-pair wire medium used in a variety of networks.
- Coaxial cable consists of four main parts: copper conductor, plastic insulation, braided copper shielding, and outer jacket.
- Specifications or standards are sets of rules or procedures that are widely used and serve as the accepted method of performing a task.
- Optical fiber is a good transmission medium when it is properly installed, tested, and maintained.

- Light energy, a type of electromagnetic energy wave, is used to transmit large amounts of data securely over relatively long distances.
- Light rays obey the laws of reflection and refraction as they travel through a glass fiber, which allows fibers with the property of total internal reflection to be manufactured. Total internal reflection makes light signals stay inside the fiber, even if the fiber is not straight.
- Attenuation of a light signal becomes a problem over long cables, especially if sections of cable are connected at patch panels or spliced. Therefore, cable and connectors must be properly installed and thoroughly tested with high-quality optical test equipment before their use.
- In wireless data communication, the radio spectrum is the part of the electromagnetic spectrum used to transmit voice, video, and data.
- Modulation is the process by which the amplitude, frequency, or phase of a radio frequency or lightwave is changed to transmit data.
- To take advantage of unlicensed radio bands, you have to use spread-spectrum techniques. Two important modulation technologies are frequency-hopping spread spectrum (FHSS) and direct-sequence spread spectrum (DSSS). DSSS offers greater reliability and more throughput than FHSS.
- The wireless signal deteriorates with distance. A wireless device connects at a slower speed if it is moved out of optimal range.
- Noise can be caused through structures (walls with metal) or by electrical equipment. Both adversely affect the range of wireless communications.
- Wireless standards include IEEE 802.11, IEEE 802.11a, IEEE 802.11b, and IEEE 802.11g.
- Wired equivalent privacy (WEP) is a security mechanism, defined within the 802.11 standard, that is designed to protect the over-the-air transmission between wireless LAN APs and NICs.
- A number of new security solutions and protocols, such as VPN, EAP, and LEAP, are emerging.

To supplement all that you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab Activities on the CD-ROM accompanying this book.

Key Terms

AM (amplitude modulation) Modulates the height of the carrier wave.

angle of incidence The angle at which the ray hits the glass surface.

angle of reflection The angle between the reflected ray and the normal.

attenuation Loss of communication signal energy.

backbone The part of a network that acts as the primary path for traffic that is most often sourced from, and destined for, other networks.

coaxial cable A cable consisting of a hollow outer cylindrical conductor that surrounds a single inner wire conductor.

crosstalk The unwanted reception of electromagnetic signals on a wire from a nearby wire.

dispersion The broadening of light signals along the length of the fiber.

DSSS (direct-sequence spread spectrum) A technology in which transmissions are more reliable because each bit (1 or 0) is represented by a string of 1s and 0s, called a chipping sequence.

EIA (Electronic Industries Association) A group that specifies electrical transmission standards. The EIA and TIA have developed numerous well-know communication standards.

EMI (electromagnetic interference) An electromagnetic field that has the potential to disrupt the operation of electronic components, devices, and systems in its vicinity.

FHSS (frequency-hopping spread spectrum) A technology in which transmissions hop from one frequency to another in random patterns. This feature enables the transmissions to hop around narrowband interference, resulting in a clearer signal and higher reliability of the transmission.

fiber-optic cable A physical medium capable of conducting modulated light transmission. Compared with other transmission media, fiber-optic cable is more expensive but is not susceptible to electromagnetic interference. Sometimes called optical fiber.

FM (frequency modulation) Modulates the frequency of the wave.

IEEE (Institute of Electrical and Electronic Engineers) A professional organization whose activities include the development of communications and network standards. IEEE LAN standards are the predominant LAN standards.

impedance The resistance to the movement of electrons in an AC circuit.

media The plural of medium. Media refers to various physical environments through which transmission signals pass. Common network media include twisted-pair, coaxial, fiber-optic cable, and the atmosphere (through which microwave, laser, and infrared transmission occurs).

modal dispersion When multiple modes of light propagating through fiber travel different distances, depending on their entry angles, which causes them to arrive at the destination (receiving end of the cable) at slightly different times.

multimode A type of fiber-optic cable that transmits more than one light path.

noise An unwanted electrical signal on a wire that interferes with the quality of the signal by altering its shape.

patch panel An assembly of pin locations and ports that can be mounted on a rack or wall bracket in the wiring closet. Patch panels act like switchboards that connect workstations' cables to each other and to the outside.

PM (phase modulation) Modulates the polarity (phase) of the wave.

reflection The photons of light striking a surface and leaving that surface in an equal but opposite direction.

refraction The change in direction of a beam of light when it enters another medium.

resistance The property of a material that resists electron movement.

RFI (radio frequency interference) The noise on wires caused by radio signals.

single-mode An optical fiber that has only one mode of light transmission. Contrast with multimode.

SS (spread spectrum) A modulation technique developed in the 1940s that spreads a transmission signal over a broad band of radio frequencies. The term spread spectrum describes a modulation technique that sacrifices bandwidth to gain signal-to-noise performance.

standard A set of rules or procedures that are either widely used or officially specified.

STP (shielded twisted-pair) A two-pair wiring medium used in a variety of network implementations. STP cabling has a layer of shielded insulation to reduce EMI.

thicknet An early form of coaxial cable using 10BASE5 for networking. Thicknet was once desirable because it could carry signals up to 500 meters.

thinnet A simple, thin, coaxial network cable for the 10BASE2 system. Thinnet can carry a signal only 185 meters, but was much easier to work with than thicknet.

TIA (Telecommunications Industry Association) A standards association that publishes standards for telecommunications.

UTP (unshielded twisted-pair) A four-pair wire medium used in a variety of networks.

wavelength The length of a wave measured from any point on one wave to the corresponding point on the next wave. The wavelength of light is usually measured in nanometers (nm).

WEP (wired equivalent privacy) A security mechanism, defined within the 802.11 standard, that is designed to protect the over-the-air transmission between wireless LAN APs and NICs.

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. Match the columns:
 - 1) Neutrons
 - 2) Protons
 - 3) Electrons
 - A) Particles that have a negative charge
 - B) Particles that have no charge (neutral)
 - C) Particles that have a positive charge
 - A. 1-C, 2-B, 3-A
 - B. 1-A, 2-C, 3-B
 - C. 1-B, 2-C, 3-A
 - D. 1-B, 2-A, 3-C
2. Which of the following regarding electricity is untrue?
 - A. Opposite charges react to each other with a force that causes them to be attracted to each other.
 - B. Like charges react to each other with a force that causes them to repel each other.
 - C. In the case of opposite and like charges, the force increases as the charges move closer to each other.
 - D. None of the above.

3. Match the following to their respective units of measurement:

- 1) Voltage A) Ohm
- 2) Current B) Ampere
- 3) Resistance C) Volt

A. 1-C, 2-B, 3-A

B. 1-B, 2-C, 3-A

C. 1-A, 2-C, 3-B

D. 1-C, 2-B, 3-A

4. Electrons flow in _____ loops called _____.

- A. Open; voltage
- B. Closed; voltage
- C. Open; circuits
- D. Closed, circuits

5. What is the maximum cable length for STP?

- A. 100 feet
- B. 150 feet
- C. 100 meters
- D. 1000 meters

6. How many pairs of wires make up a UTP cable?

- A. 2
- B. 4
- C. 6
- D. 8

7. Which connector does UTP use?

- A. STP
- B. BNC
- C. RJ-45
- D. RJ-69

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8. What is an advantage that coaxial cable has over STP or UTP?
 - A. It is capable of achieving 10 Mbps to 100 Mbps.
 - B. It is inexpensive.
 - C. It can run for a longer distance unboosted.
 - D. None of the above.
9. What does the twisting of the wires do in a twisted-pair cable?
 - A. It makes it thinner.
 - B. It makes it less expensive.
 - C. It reduces noise problems.
 - D. It allows six pairs to fit in the space of four pairs.
10. What is the importance of the EIA/TIA standards? Select all that apply.
 - A. They provide a framework for the implementation of the OSI reference model.
 - B. They provide guidelines for manufacturers to follow to ensure compatibility.
 - C. They provide the minimum media requirements for multiproduct and multi-vendor environment.
 - D. None of the above.
11. A _____ fiber-optic cable transmits multiple streams of LED-generated light.
 - A. Multimode
 - B. Multichannel
 - C. Multiphase
 - D. None of the above
12. What is one advantage of using fiber-optic cable in networks?
 - A. It is inexpensive.
 - B. It is easy to install.
 - C. It is an industry standard and is available at any electronics store.
 - D. It is capable of higher data rates than either coaxial or twisted-pair cable.

13. Which fiber-optic cable type is typically used for outside installations?
- A. Tight-buffered
 - B. Tight-tube
 - C. Loose-buffered
 - D. Loose-tube
14. What is the light source typically used in single mode fiber optics?
- A. Photo transistor
 - B. Laser
 - C. Photo resistor
 - D. LED
15. Which term describes the angle at which a ray hits a glass surface?
- A. Angle of reflection
 - B. Angle of refraction
 - C. Angle of incidence
 - D. Angle of attack
16. Modulation is a process of changing amplitude, frequency, or phase. Which acronym does *not* represent a type of modulation?
- A. AM
 - B. FM
 - C. PM
 - D. RM
17. Which range does *not* correctly identify an unlicensed wireless frequency?
- A. 2.4 GHz
 - B. 5 GHz
 - C. 9 GHz
 - D. 900 MHz
18. Which statement does *not* describe a benefit of spread spectrum?
- A. Spread-spectrum transmissions are transmitted at high speeds.
 - B. Spread spectrum is less susceptible to radio noise.
 - C. Spread spectrum has a higher probability of correct reception.
 - D. Spread spectrum creates little interference.

19. Which statement does *not* describe the features of direct-sequence spread spectrum (DSSS)?
- A. DSSS is reliable because each bit is represented by a string of 1s and 0s.
 - B. If up to 40 percent of the string is lost, the original transmission can be reconstructed.
 - C. DSSS technology has low throughput of data and short-range access.
 - D. The recently released evolution of the IEEE standard, 802.11b, provides for a full Ethernet-like data rate of 11 Mbps over DSSS.
20. Which of the following is *not* a feature of wired equivalent privacy (WEP)?
- A. WEP uses the RC4 stream cipher for encryption.
 - B. WEP is a security mechanism defined within in the 802.3 standards.
 - C. One of the goals of WEP is to deny access to the network by unauthorized users who do not possess the appropriate WEP key.
 - D. None of the above.



Objectives

Upon completion of this chapter, you will be able to

- Become familiar with the basic terminology used for frequency-based cable testing
- Understand what signals and noise impact networking media
- Properly cable a LAN
- Properly cable a WAN



Chapter 4

Cable Testing and Cabling LANs and WANs

This chapter describes issues relating to the testing of media used for physical layer connectivity in local-area networks (LANs). In order for the LAN or WAN to function properly, the physical layer medium must meet the industry standards specified for the data rate used to transmit signals over Ethernet (10, 100, 1000, or 10,000 Mbps). The use of *signals* in this text refers to the data signals that move from the transmitter to the receiver. The signals weaken (attenuate) traveling over the physical media; however, the receiver must still be able to clearly determine the state of each bit of the data (one or zero). Otherwise, the error rate on the network will be too high for the LAN or WAN connections to be useful.

Networking media is literally and physically the backbone of a network. Inferior quality network cabling results in network failures and in networks with unreliable performance. All three categories of networking media (copper-based, optical fiber, and wireless) require testing and measurement to determine their quality, and this testing is the primary subject of this chapter.

Please be sure to look at this chapter's associated e-Lab Activities, Videos, and PhotoZooms that you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.



Background for Studying Frequency-Based Cable Testing

The equipment used to perform quality testing and measurement of copper-based, optical fiber, and wireless networking media involves certain electrical and mathematical concepts and terms, such as signal, wave, frequency, and noise. Understanding this vocabulary is helpful when learning about networking, cabling, and cable testing.

Waves

A *wave* is energy traveling from one place to another. Many types of waves exist, but all can be described with similar vocabulary.

It is helpful to think of waves as disturbances. A bucket of water that is completely still, with no disturbances, does not have waves. Conversely, the ocean always has some sort of detectable waves due to disturbances such as wind and tide.

Ocean waves can be described in terms of their height, or amplitude, which can be measured in meters. They can also be described in terms of how frequently the waves reach the shore. This feature can be described in two similar ways: period and frequency. The period of the waves is the amount of time between each wave and is measured in seconds. The *frequency* is the number of waves that reach the shore each second.

The *amplitude* of an electrical signal represents its height just as in ocean waves, but it is measured in volts instead of meters. If the signal repeats itself regularly, then the period of the signal is the amount of time to complete one cycle of the signal, and is measured in seconds, just as the period of ocean waves is the amount of time for one wave to complete. The frequency of an electrical signal is the number of complete cycles (or waves) per second and is measured in *hertz*.

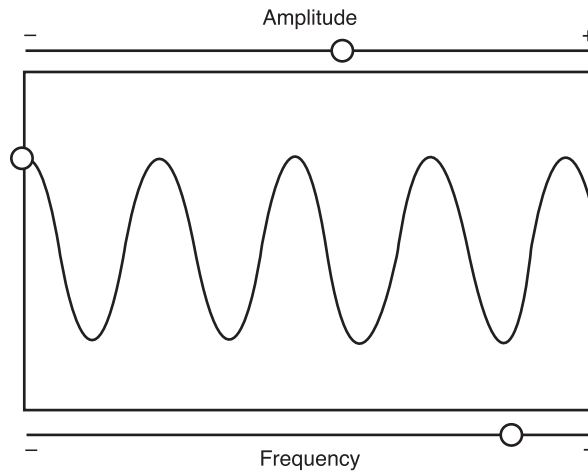
If a disturbance is deliberately caused and involves a fixed, predictable duration, it is called a *pulse*. Pulses are important in electrical signals because they determine the value of the data being transmitted.

Figure 4-1 shows a representation of the concepts of amplitude and frequency.

Networking professionals are interested in specific types of waves:

- Voltage waves on copper media
- Light waves in optical fiber
- Alternating electric and magnetic fields called electromagnetic waves used in the wireless environment

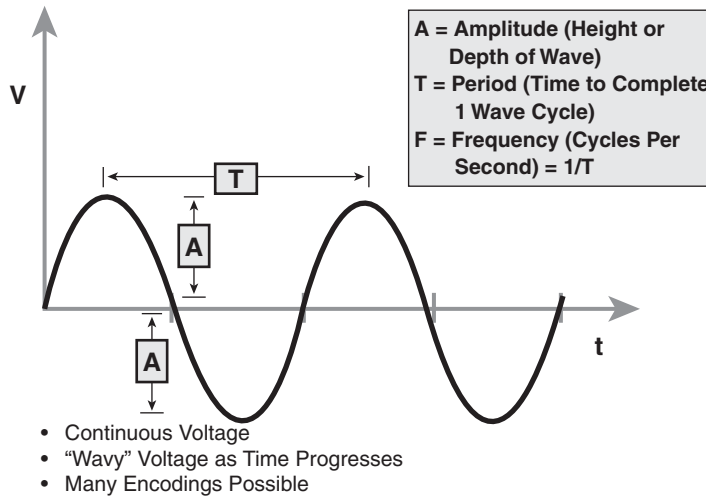
Figure 4-1 Amplitude and Frequency



Sine Waves and Square Waves

Sine waves, or sinusoids, are graphs of mathematical functions as shown in Figure 4-2.

Figure 4-2 Analog Signals



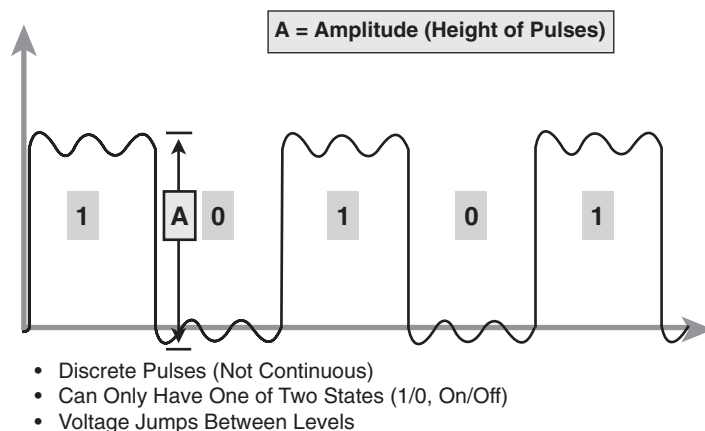
Sine waves have certain characteristics:

- They are periodic (which means that they repeat the same pattern at regular intervals).
- They are continuously varying (which means that no two adjacent points on the graph have the same value).

Sine waves are graphical representations of many natural occurrences that change regularly over time, such as the distance from the earth to the sun, the distance from the ground while riding a Ferris wheel, and the time of day that the sun rises. Since sine waves are continuously varying, they are examples of analog waves.

Square waves, like sine waves, are periodic. However, square wave graphs do not continuously vary with time. The values remain the same for some time, then suddenly change, then remain the same, and then suddenly return to the initial value, as shown in Figure 4-3. Square waves represent digital signals, or pulses. Square waves, like all waves, can be described in terms of amplitude, period, and frequency.

Figure 4-3 Digital Signals



Exponents and Logarithms

As discussed in Chapter 1, “Introduction to Networking,” in networking, remember three important number systems:

- Base 2 (binary)
- Base 10 (decimal)
- Base 16 (hexadecimal)

Recall that the base of a number system refers to the number of different symbols that can occupy one place. For example, binary numbers have only two different placeholders (the numbers 0 and 1), decimal numbers have 10 different place holders (the numbers 0–9), and hexadecimal numbers have 16 different placeholders (the numbers 0–9 and the letters A through F).

Remember that $10 * 10$ can be written as 10^2 (10 “squared,” or 10 raised to the second power, or 10 multiplied by itself 2 times. $10 * 10 * 10$ can be written as 10^3 (ten “cubed,”



or 10 raised to the third power, or 10 multiplied by itself 3 times). When written this way, you say that 10 is the base of the number and 2 or 3 is the exponent of the number. The following example demonstrates the preceding concepts.

$y = 10^x$	$y = 10^x$
x: 2	x: 3
y: 100	y: 1000

The base of a number system also refers to the value of each digit. The least significant digit has a value of $base^0$ (base raised to the zero power), or one. The next digit has a value of $base^1$. This is equal to 2 for binary numbers, 10 for decimal numbers, and 16 for hexadecimal numbers.

Numbers with exponents are used to more easily represent very large numbers. It is much easier and less error prone to represent one billion numerically as 10^9 than as 1,000,000,000. Many calculations involved in cable testing involve numbers that are very large, so exponents are the preferred format.

Decibels

An important way of describing networking signals is a unit of measure called the *decibel* (dB). The decibel is related to the exponents and logarithms described in prior sections. The formulas for calculating decibels are as follows:

$$\text{dB} = 10 \log_{10} (P_{\text{final}} / P_{\text{ref}})$$

or

$$\text{dB} = 20 \log_{10} (V_{\text{final}} / V_{\text{reference}})$$

Typically, light waves on optical fiber and radio waves in the air are measured using the power formula, and electromagnetic waves on copper cables are measured using the voltage formula. In these formulas,

- dB measures the loss or gain of the power of a wave. Decibels are usually negative numbers representing a loss in power as the wave travels, but can also be positive values representing a gain in power if the signal is amplified.
- \log_{10} indicates that the number in parenthesis is transformed using the base 10 logarithm rule.
- P_{final} is the delivered power measured in watts.
- P_{ref} is the original power measured in watts.



- V_{final} is the delivered voltage measured in volts.
- V_{ref} is the original voltage measured in volts.

The following example illustrates how the dB value is calculated:

$$P_{\text{final}} = P_{\text{ref}} * 10^{(\text{dB}/10)}$$

$$\text{dB} = 20$$

$$P_{\text{ref}} = 2 \text{ kilowatts}$$

$$P_{\text{final}} = 200 \text{ kilowatts}$$

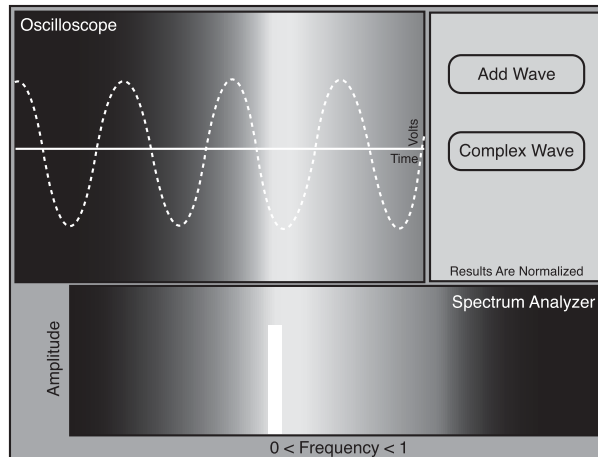
When you enter values for dB and P_{ref} , the resulting power changes. This calculation can be used to see how much power is left in a radio wave after it has traveled over a distance, through different materials, and through various stages of electronic systems such as a radio.

Viewing Signals in Time and Frequency

One of the most important facts of the “information age” is that data symbolizing characters, words, pictures, video, or music can be represented electrically by voltage patterns on wires and in electronic devices. The data represented by these voltage patterns can be converted to light waves or radio waves and back to voltage waves. Consider the example of an analog telephone. The sound waves of the caller’s voice enter a microphone in the telephone. The microphone converts the patterns of sound energy into voltage patterns of electrical energy that represent the voice.

If the voltage patterns are graphed over time, the distinct patterns representing the voice are displayed. An *oscilloscope* is an important electronic device used to view electrical signals, such as voltage waves and pulses. The x-axis on the display represents time, and the y-axis represents voltage or current. There are usually two y-axis inputs, so two waves can be observed and measured at the same time.

Analyzing signals using an oscilloscope is called time-domain analysis because the x-axis or domain of the mathematical function represents time. Engineers also use frequency-domain analysis to study signals. In frequency-domain analysis, the x-axis represents frequency. An electronic device called a *spectrum analyzer* creates graphs for frequency-domain analysis. Figure 4-4 illustrates several signals of how the output looks on both the oscilloscope and the spectrum analyzer.

Figure 4-4 Fourier Synthesis

Electromagnetic signals use different frequencies for transmission so that different signals do not interfere with each other. For example, frequency modulation (FM) radio signals use frequencies that are different than television or satellite signals. When listeners change the station on a radio, they are changing the frequency that the radio is receiving.

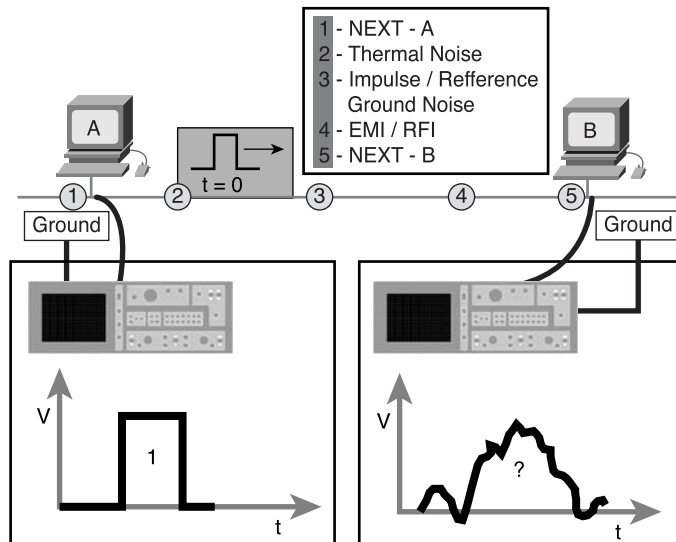
Noise in Time and Frequency

An important concept in communications systems, including LANs, is *noise*, as shown in Figure 4-5. Although noise usually signifies undesirable sounds, the definition of noise that is related to communications is undesirable signals. Noise can originate from natural and technological sources and is added to the data signals in communications systems.

All communications systems have noise. Even though noise cannot be completely eliminated, its effects can be minimized if the sources of the noise are understood. Sources of noise include the following:

- Nearby cables that carry data signals
- **Radio frequency interference (RFI)**, which is noise from other signals being transmitted nearby
- **Electromagnetic interference (EMI)**, which is noise from nearby sources such as motors and lights
- Laser noise at the transmitter or receiver of an optical signal

Figure 4-5 Recognizing and Defining Noise



Noise that affects all transmission frequencies equally is called *white noise*. Noise that affects only small ranges of frequencies is called *narrowband interference*. When detected on a radio receiver, white noise interferes with all radio stations, while narrowband interference affects only a few stations whose frequencies are close together. When detected on a LAN, white noise affects all data transmissions, but narrowband interference might disrupt only certain signals. However, if the band of frequencies affected by the narrowband interference included all frequencies transmitted on the LAN, the performance of the entire LAN is compromised.

Analog and Digital Bandwidth

Bandwidth is an extremely important concept in communications systems. For your study of LANs, two ways of considering bandwidth are important: analog bandwidth and digital bandwidth.

Analog bandwidth typically refers to the frequency range of an analog electronic system. Analog bandwidth can be used to describe the range of frequencies transmitted by a radio station or an electronic amplifier. The units of analog bandwidth are the units of frequency; cycles per second, or hertz. Examples of analog bandwidth values are 3 kilohertz (kHz) for telephony, 20 kHz for audible signals, 5 kHz for AM radio stations, and 200 kHz for FM radio stations.

Digital bandwidth measures how much information can flow from one place to another in a given amount of time. The fundamental unit of measurement for digital bandwidth is bits per second (bps). However, because LANs are capable of speeds of millions of bits per second, the unit is often expressed in kilobits per second (kbps) or megabits per second (Mbps), as shown in Table 4-1. Bandwidth is limited by physical media, current technologies, and the laws of physics.

Table 4-1 Units of Digital Bandwidth

Digital Units of Bandwidth	Abbreviation	Equivalence
Bits per second	bps	1 bps = fundamental unit of bandwidth
Kilobits per second	kbps	1 kbps = 1000 bps = 10^3 bps
Megabits per second	Mbps	1 Mbps = 1,000,000 bps = 10^6 bps
Gigabits per second	Gbps	1 Gbps = 1,000,000,000 bps = 10^9 bps

During cable testing, analog bandwidth is used to determine the digital bandwidth of a copper cable. Analog frequencies are transmitted from one end and received on the opposite end. The two signals are then compared, and the amount of attenuation of the signal is calculated. In general, media that supports higher analog bandwidths without high degrees of attenuation will also support higher digital bandwidths.

Signals and Noise on Networking Media

Noise refers to any interference on the physical medium that makes it difficult for the receiver to detect the data signal. Copper cabling is susceptible to many sources of noise, but far fewer sources of noise are possible when optical fiber is used as the transmission medium. Some level of noise on the medium is inevitable, but that acceptable level of noise must be kept as low as possible. Just as it is difficult to carry on a conversation when the background noise of the room is high compared to the volume of the participant's voices, data signals can be overwhelmed by the strength of noise to the point that the desired signal cannot be interpreted.

Proper cable installation techniques and proper attachment of connectors at both ends of a cable are vital. If standards are followed, the data signal experiences less attenuation, and noise levels are kept at a minimum.

Once the cable has been installed, it must be tested and meet the specifications of the Telecommunications Industry Association/Electronics Industries Association TIA/EIA-568-B standards. Problems must be identified and corrected prior to further installation of network hardware. Installed cable should also be tested periodically after the installation to determine if it still meets specifications. Cable and connectors experience wear and deterioration over a period of time, and potential problems must be identified and corrected to ensure reliable network operation. For all cable testing and troubleshooting, quality cable testers must be properly used.

Signaling over Copper and Fiber-Optic Cabling

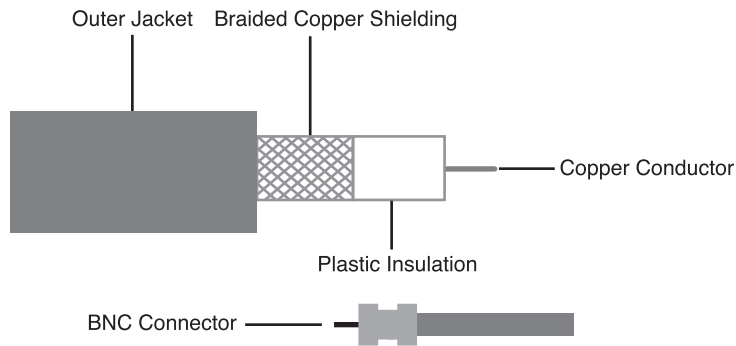
On copper cable, the data signals are represented by voltage changes that depict binary ones and zeros. At the transmitter and receiver the voltage levels are measured with respect to the signal ground. The signal ground provides a reference level of zero volts. The transmitting and receiving device must be properly grounded so that this zero volt reference point is accurate.

For the LAN to operate properly, the receiving device must be able to accurately interpret the binary ones and zeros transmitted as voltage levels. The signals use very low voltages; less than 5 volts. Because current Ethernet technology supports data rates of billions of bits per second, each bit must be recognized even though its duration is very small. The voltage level cannot be amplified at the receiver, nor the bit duration extended, to recognize the data. Therefore, as much of the original signal strength as possible must be retained as the signal moves through the cable and passes through the connectors. In anticipation of ever-faster Ethernet protocols, new cable installations should be made with the best available Category 5 (CAT 5) unshielded twisted-pair (UTP) or higher rated cable, connectors, and interconnect devices such as, punch-down blocks and patch panels.

Two basic types of copper cable exist, shielded and unshielded. In shielded cable, some types of shielding protect the data signal from external sources of noise. Other types of shielding protect one pair of wires in a cable from noise generated by electrical signals on another pair of wires within the same cable.

Coaxial cable is a type of shielded cable, as shown in Figure 4-6. It consists of a solid copper conductor surrounded, first, by an insulating material and, then, by a braided conductive shielding. In LAN applications, the braided shielding is electrically grounded, protecting the inner conductor from external electrical noise. The shielding also helps eliminate signal loss by keeping the transmitted signal confined to the cable, which helps make coaxial cable less “noisy” than twisted pair; however, coaxial cable is also more expensive. The need to ground the shielding and the bulky size of coaxial cable also make it more difficult to install than other types of copper cabling.

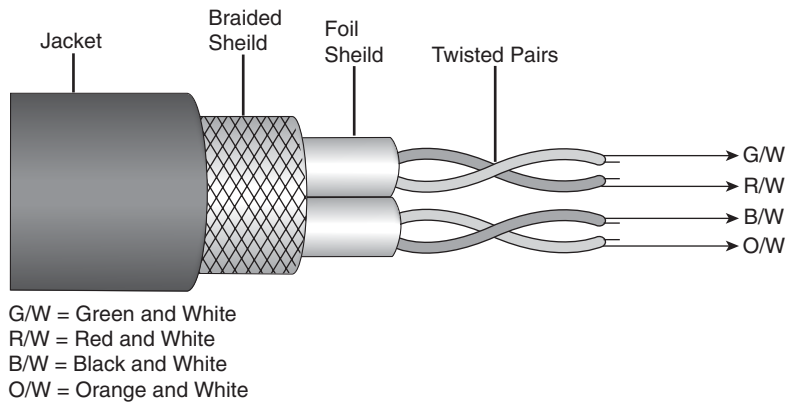
Figure 4-6 Coaxial Cable



There are two types of twisted pair cable:

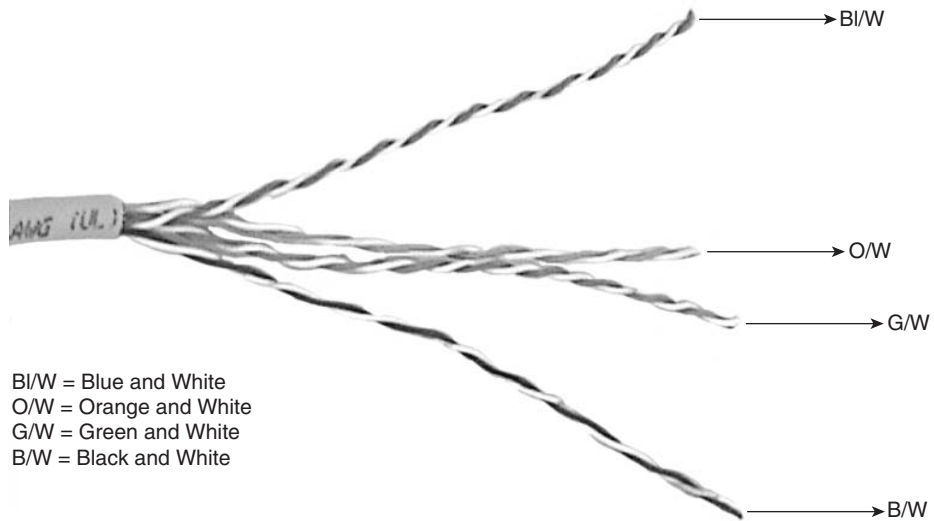
- Shielded twisted-pair (STP) (see Figure 4-7)
- Unshielded twisted-pair (UTP) (see Figure 4-8)

Figure 4-7 Shielded Twisted-Pair Cable



STP cable, which can also be referred to as screened twisted-pair (ScTP) or foil twisted pair (FTP), contains an outer conductive shield that is electrically grounded to insulate the signals from external electrical noise. STP also uses inner foil shields to protect each wire pair from noise generated by the other pairs. STP cable is more expensive, more difficult to install, and less frequently used than UTP. UTP contains no shielding and is the noisiest copper cabling, but it is the most frequently used because it is inexpensive and easier to install.

Figure 4-8 Unshielded Twisted-Pair Cable



Fiber-optic cable, shown in Figures 4-9 and 4-10, transmits data signals by increasing and decreasing the intensity of light to represent binary ones and zeros. The strength of a light signal does not diminish like the strength of an electrical signal does over an identical run length. Optical signals are not affected by electrical noise, and optical fiber does not need to be grounded. Therefore, optical fiber is often used between buildings and between floors within the building. As costs decrease and demand for speed increases, optical fiber may become a more commonly used LAN media.

Figure 4-9 Fiber Connector



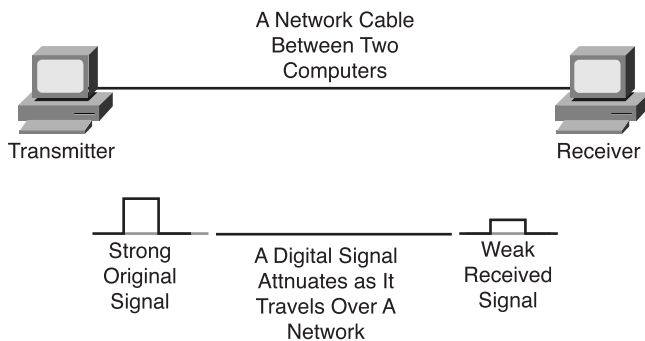
Figure 4-10 Fiber-Optic Cable



Attenuation and Insertion Loss on Copper Media

Attenuation is the decrease in signal amplitude over the length of a link, as shown in Figure 4-11. Long cable lengths and high signal frequencies contribute to greater signal attenuation. For this reason, attenuation on a cable is measured by a cable tester using the highest frequencies that the cable is rated to support.

Figure 4-11 Attenuation



Attenuation is expressed in decibels (dB) using negative numbers. Smaller negative dB values are an indication of better link performance.

Several factors contribute to attenuation:

- The resistance of the copper cable converts some of the electrical energy of the signal to heat.
- Signal energy is also lost when it leaks through the insulation of the cable and by impedance caused by defective connectors.

Impedance is a measurement of the resistance of the cable to alternating current (AC) and is measured in ohms. The normal (characteristic) impedance of a CAT 5 cable is 100 ohms. If a connector is improperly installed on CAT 5, it has a different impedance value than the cable. This difference is called an *impedance discontinuity* or an *impedance mismatch*.

Impedance discontinuities cause attenuation because a portion of a transmitted signal is reflected back to the transmitting device rather than continuing to the receiver, much like an echo. This effect is compounded if multiple discontinuities cause additional portions of the remaining signal to be reflected back to the transmitter. When this returning reflection strikes the first discontinuity, some of the signal rebounds in the direction of the original signal, creating multiple echo effects. The echoes strike the receiver at different intervals making it difficult for the receiver to accurately detect data values on the signal. This effect is called jitter and results in data errors.

The combination of the effects of signal attenuation and impedance discontinuities on a communications link is called *insertion loss*. Proper network operation depends on constant characteristic impedance in all cables and connectors, with no impedance discontinuities in the entire cable system.

Source of Noise on Copper Media

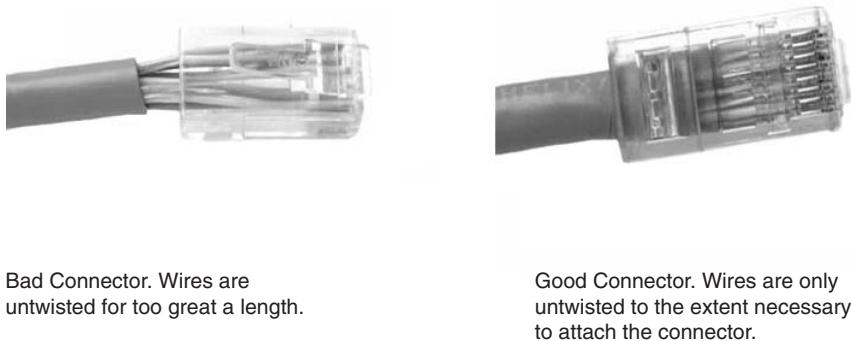
Noise is any electrical energy on the transmission cable that makes it more difficult for a receiver to interpret the data sent from the transmitter. TIA/EIA-568-B certification of a cable now requires testing for a variety of types of noise. UTP does not have any shielding from external sources of noise such as nearby motors or fluorescent lights or sources inside the cable.

Crosstalk involves the transmission of signals from one wire pair to nearby pairs. When voltages change on one pair of wires, electromagnetic energy is generated. This energy radiates outward from the transmitting wire pair like a radio signal from a transmitter. Adjacent wire pairs in the cable act like antennas generating a weaker but similar electrical signal onto the nearby wire pairs. Crosstalk can cause interference with data that might be present on the adjacent wires. Crosstalk can also be caused by signals from a completely separate nearby cable. When crosstalk is caused by a signal on another cable, it is called *alien crosstalk*. Crosstalk is more destructive at higher transmission frequencies.

Cable testing instruments measure crosstalk by first applying a test signal to one wire pair. The cable tester then measures the amplitude of the unwanted crosstalk signals induced on the other wire pairs in the cable. At higher transmission frequencies, crosstalk increases and is more destructive to data signals.

Undesired crosstalk occurs when the wire pairs are untwisted and thus subject to data crosstalk from another wire pair, as shown in Figure 4-12. Therefore, crosstalk can be minimized by twisting the wire pairs. The higher the category of UTP, the more twists in the cable are necessary to minimize crosstalk even at high transmission frequencies. To ensure reliable LAN communications the untwisting of wire pairs must be kept to an absolute minimum. This point is especially important to remember when attaching connectors to the ends of UTP cable.

Figure 4-12 Connector Vulnerable to Crosstalk

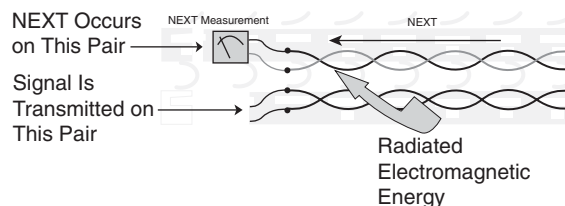


There are three distinct types of crosstalk:

- Near-end crosstalk (NEXT)
- Far-end crosstalk (FEXT)
- Power sum near-end crosstalk (PSNEXT)

Near-end crosstalk (NEXT), shown in Figure 4-13, is computed as the ratio in voltage amplitude between the test signal and the crosstalk signal when measured from the same end of the link. This difference is expressed in a negative value of decibels (dB). Low negative numbers indicate more noise, and large negative numbers indicate less noise, just as low negative temperatures indicate more heat than large negative temperatures. By tradition, cable testers do not show the minus sign indicating the negative NEXT values. A NEXT reading of 30 dB (really -30) indicates less NEXT noise and a better cable than does a NEXT reading of 10 dB (really -10.)

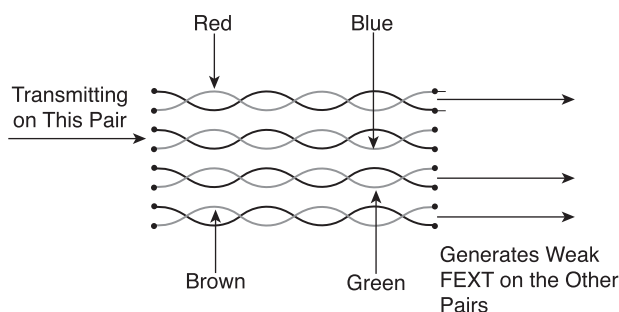
Figure 4-13 Near-End Crosstalk (NEXT)



NEXT needs to be measured from every pair to every other pair in a UTP link and from both ends of the link. To shorten test times, some cable test instruments allow the user to test the NEXT performance of a link by using larger frequency step sizes than specified by the TIA/EIA standard. The resulting measurements might not comply with TIA/EIA-568-B and might overlook link faults. To verify proper link performance, NEXT should be measured from both ends of the link with a high-quality test instrument. This verification is also a requirement for complete compliance with high-speed cable specifications.

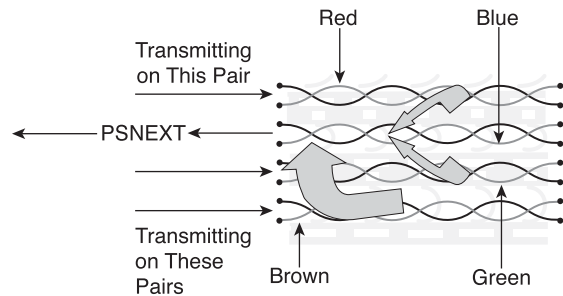
Because of attenuation, crosstalk occurring further away from the transmitter (*far-end crosstalk [FEXT]*) creates less noise on a cable than NEXT, as shown in Figure 4-14. The noise caused by FEXT still travels back to the source, but the noise is attenuated as it returns. Thus, FEXT is not as significant a problem as NEXT.

Figure 4-14 Far-End Crosstalk (FEXT)



Power sum near-end crosstalk (PSNEXT), shown in Figure 4-15, measures the cumulative effect of NEXT from all wire pairs in the cable. For each wire pair in the four-pair cable, PSNEXT is computed from three pair-to-pair NEXT test results. The combined effect of crosstalk from multiple simultaneous transmission sources can be very detrimental to the signal. TIA/EIA-568-B certification now requires this PSNEXT test.

Figure 4-15 Power Sum Near-End Crosstalk (PSNEXT)



Some Ethernet standards, such as 10BASE-T and 100BASE-TX, receive data from only one wire pair in each direction. However, for newer technologies such as 1000BASE-T that receive data simultaneously from multiple pairs in the same direction, power sum measurements are important tests.

Cable Testing Standards

The *TIA/EIA-568-B* standard specifies ten tests that a copper cable must pass if it is to be used for modern, high-speed Ethernet LANs. All cable links should be tested to the maximum rating that applies for the category of cable being installed.

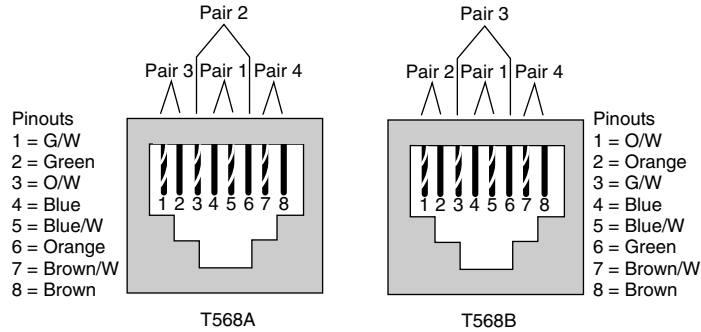
The primary test parameters that must be verified for a cable link to meet TIA/EIA-568-B standards are as follows:

- Wire map
- Insertion loss
- Near-end crosstalk (NEXT)
- Power sum near-end crosstalk (PSNEXT)
- Equal-level far-end crosstalk (ELFEXT)
- Power sum equal-level far-end crosstalk (PSELFEXT)
- Return loss
- Propagation delay
- Cable length
- Delay skew

The Ethernet standard specifies that each of the pins on an RJ-45 connector has a particular purpose, as shown in Figure 4-16. A network interface card (NIC) transmits signals on pins 1 and 2, and it receives signals on pins 3 and 6. The wires in UTP cable must be connected to the proper pins at each end of a cable. The wire map test insures

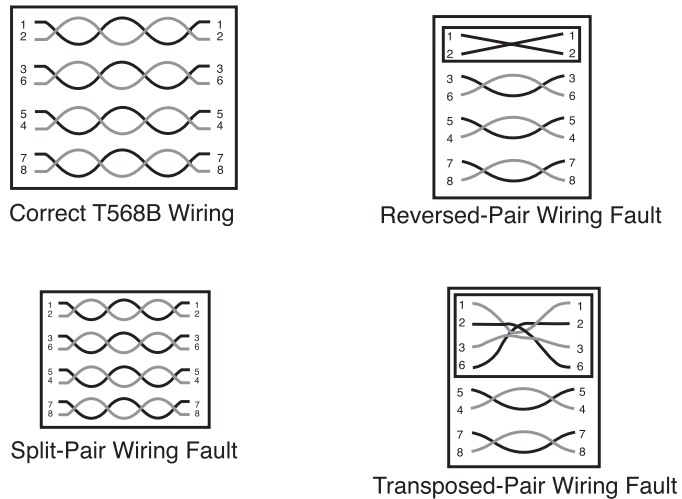
that no open or short circuits exist in the cable. An open circuit occurs if the wire does not attach properly at the connector. A short circuit occurs if two wires are connected to each other.

Figure 4-16 Ethernet Standards for RJ-45 Connectors



The wire map test also verifies that all eight wires are connected to the correct pins on both ends of the cable. The wire map test can detect several different wiring faults. The reversed-pair fault occurs when a wire pair is correctly installed on one connector, but reversed on the other connector. If the orange striped wire is on pin 1 and the orange wire is on pin 2 at one end, but the orange striped wire is on pin 2 and the orange wire is on pin 1 at the other end, then the cable has a reversed-pair fault, as demonstrated in Figure 4-17.

Figure 4-17 Cable Wire Map Problems



A split-pair wiring fault occurs when two wires from different wire pairs are connected to the wrong pins on both ends of the cable. Look carefully at the pin numbers in Figure 4-17 to detect the wiring fault. A split pair creates two transmit or receive pairs each with two wires that are not twisted together.

Transposed-pair wiring faults occur when a wire pair is connected to completely different pins at both ends. Contrast this with a reversed-pair where the same pair of pins is used at both ends. Transposed pairs also occur when two different colors codes on punch-down blocks (representing T568A and T568B) are used at different locations on the same link.



Lab Activity Fluke 620 Cable Tester: Wire Map

In this lab, you learn the wire mapping features of the Fluke 620 LAN CableMeter.



Lab Activity Fluke 620 Cable Tester: Faults

In this lab, you learn the Cable Fault Test—Pass/Fail features of the Fluke 620 LAN CableMeter.



Lab Activity Fluke 620 Cable Tester: Length

In this lab, you learn the cable length feature of the Fluke 620 LAN CableMeter.



Lab Activity Fluke LinkRunner: LAN Tests

In this lab, you use the Fluke LinkRunner to determine whether a cable drop is active and identify its speed, duplex capabilities, and service type. You also verify network layer connectivity with **ping**.



Lab Activity Fluke LinkRunner: Cable and NIC Tests

In this lab, you use the Fluke LinkRunner to verify cable length and integrity and determine where a cable terminates. You also verify PC NIC functionality.

Other Test Parameters

The combination of the effects of signal attenuation and impedance discontinuities on a communications link is called *insertion loss*. Insertion loss increases as data transmission speeds and frequencies increase. Insertion loss is measured in decibels. The TIA/EIA-568-B standard requires that a cable and its connectors pass an insertion loss test before the cable can be used as a communications link in a LAN.

Crosstalk is measured in four separate tests:

- NEXT
- ELFEXT
- PSELFEXT
- Return loss

A cable tester measures NEXT by applying a test signal to one cable pair and measuring the amplitude of the crosstalk signals received by the other cable pairs. The NEXT value, expressed in decibels, is computed as the difference in amplitude between the test signal and the crosstalk signal measured at the same end of the cable. Remember, because the number of decibels that the tester displays is a negative number, the larger the number, the lower the NEXT on the wire pair.

The *equal-level far-end crosstalk (ELFEXT)* test measures FEXT. Pair-to-pair ELFEXT is expressed in dB as the difference between the measured FEXT and the insertion loss of the wire pair whose signal is disturbed by the FEXT. ELFEXT is an important measurement in Ethernet networks using 100BASE-T technologies.

Power sum equal-level far-end crosstalk (PSELFEXT) is the combined effect of ELFEXT from all wire pairs.

Return loss is a measure in decibels of reflections that are caused by the impedance discontinuities at all locations along the link. Recall that the main impact of return loss is not on loss of signal strength. The significant problem is that signal echoes caused by the reflections from the impedance discontinuities strike the receiver at different intervals causing signal jitter.

Time-Based Parameters

Propagation delay is a simple measurement of how long it takes for a signal to travel along the cable being tested. The delay in a wire pair depends on its length, twist rate, and electrical properties. Delays are measured in the hundredths of nanoseconds (one nanosecond is one-billionth of a second, or 0.000000001 second). The TIA/EIA-568-B standard sets a limit for propagation delay for the various categories of UTP.



Propagation delay measurements are the basis of the cable length measurement. TIA/EIA-568-B-1 specifies that the physical length of the link is calculated using the wire pair with the shortest electrical delay. Testers measure the length of the wire based on the electrical delay as measured by a Time Domain Reflectometry (TDR) test, not the physical length of the cable jacket. Because the wires inside the cable are twisted, signals actually travel farther than the physical length of the cable. When a cable tester makes a TDR measurement it sends a pulse signal down a wire pair and measures the amount of time required for the pulse to return on the same wire pair.

The TDR test is used not only to determine length, but also to identify the distance to wiring faults such as shorts and opens. When the pulse encounters an open, short, or poor connection, all or part of the pulse energy is reflected back to the tester, which can calculate the approximate distance to the wiring fault. This calculation can be helpful in locating a faulty connection point, such as a wall jack, along a cable run.

The propagation delays of different wire pairs in a single cable can differ slightly because of differences in the number of twists and electrical properties of each wire pair. The delay difference between pairs is called *delay skew*. Delay skew is a critical parameter for high-speed networks in which data is simultaneously transmitted over multiple wire pairs, such as 1000BASE-T Ethernet. If the delay skew between the pairs is too great, the bits arrive at different times, and the data cannot be properly reassembled. Even though a cable link might not be intended for this type of data transmission, testing for delay skew helps ensure that the link supports future upgrades to high-speed networks.

All cable links in a LAN must pass all of the tests covered in the preceding text as specified in the TIA/EIA-568-B standard to ensure that they function reliably at high speeds and frequencies. Perform cable tests when the cable is installed, and afterward on a regular basis to ensure that LAN cabling meets industry standards. Use high-quality cable test instruments correctly to ensure that the tests are accurate. Carefully document test results.

Testing Fiber-Optic Cables

A fiber link consists of two separate glass fibers functioning as separate and independent data pathways. One fiber carries transmitted signals in one direction, while the second carries signals in the opposite direction. Each glass fiber is surrounded by a sheath that light cannot pass through, so no crosstalk problems exist on fiber-optic cable. The jacket, external EMI or noise has no effect on fiber cabling. Attenuation does occur on fiber links, but to a lesser extent than on copper cabling.



Fiber links are subject to the optical equivalent of UTP impedance discontinuities. When light encounters an optical discontinuity, some of the light signal is reflected back in the opposite direction with only a fraction of the original light signal continuing down the fiber towards the receiver. This results in a reduced amount of light energy arriving at the receiver making signal recognition more difficult. Just as with UTP cable, improperly installed connectors are the main cause of light reflection and signal strength loss in optical fiber.

Because noise is not an issue when transmitting on optical fiber, the main concern with a fiber link is the strength of the light signal that arrives at the receiver. If attenuation weakens the light signal at the receiver, then data errors result. Testing fiber-optic cable primarily involves shining a light down the fiber and measuring whether a sufficient amount of light reaches the receiver.

On a fiber-optic link, the acceptable amount of signal power loss that can occur without dropping below the requirements of the receiver must be calculated. This calculation is referred to as the optical link loss budget. A fiber test instrument checks whether the optical link loss budget has been exceeded. If the fiber fails the test, the cable test instrument indicates where the optical discontinuities occur along the length of the cable link. Usually, the problem is one or more improperly attached connectors. The cable test instrument indicates the location of the faulty connections that must be replaced. When the faults are corrected, the cable must be retested.

A New Cabling Standard

On June 20, 2002, the Category 6 (CAT 6) addition to the TIA-568 standard was published. The official title of the standard is ANSI/TIA/EIA-568-B.2-1. This new standard specifies the original set of ten tests for Ethernet cabling and the passing scores for each of these tests. Cables certified as CAT 6 cable must pass all ten tests.

Although the CAT 6 tests are essentially the same as the CAT 5 standard specifies, CAT 6 cable must pass the tests with higher scores to be certified. CAT 6 cable must be capable of carrying frequencies up to 250 MHz and must have lower levels of crosstalk and return loss.

A quality cable tester similar to the Fluke DSP-4000 series or Fluke OMNIScanner2 can perform all the test measurements required for CAT 5, CAT 5e, and CAT 6 cable certifications of both permanent links and channel links.

Cabling the LANs

The cabling aspect of the LAN exists at Layer 1 of the OSI reference model. To understand the types of cabling used to cable networking devices, you need to understand the LAN physical layer implementation of Ethernet, which is a LAN technology specified at the data link layer.

It is important that you be able to identify the usages of different types of cable and to differentiate among the types of connectors that can be used to connect Ethernet.

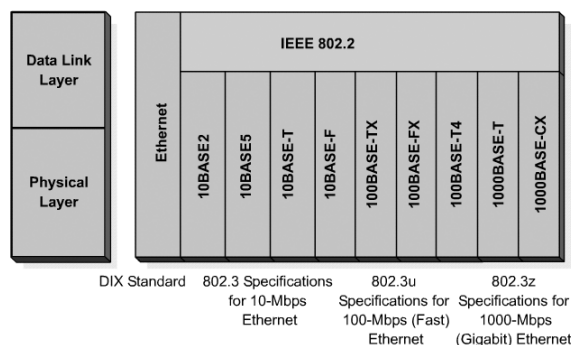
This section addresses the LAN physical layer implementation and the main principle of implementing Ethernet in a campus LAN. This chapter also discusses the different types of connectors specified for Ethernet use as well as the UTP wiring standards.

LAN Physical Layer

Ethernet is the most widely used LAN technology. Ethernet was first implemented by a group called DIX (Digital, Intel, and Xerox). DIX created and implemented the first Ethernet LAN specification, which was used as the basis for the Institute of Electrical and Electronics Engineer (IEEE) 802.3 specification released in 1980. Later, the IEEE extended the 802.3 committee to three new committees known as 802.3u (Fast Ethernet), 802.3z (Gigabit Ethernet over Fiber), and 802.3ab (Gigabit Ethernet over UTP).

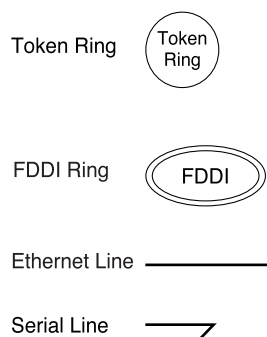
The cabling aspect of the LAN exists at Layer 1 of the Open System Interconnection (OSI) reference model. Many topologies support LANs, as well as different physical media. Figure 4-18 shows a subset of physical layer implementations that you can deploy to support Ethernet.

Figure 4-18 LAN Physical Layer Implementation



The symbols for media vary. For example, the symbol for a serial line looks an elongated letter z or a lightning bolt; the Ethernet symbol is typically a straight line with perpendicular lines projecting from it; the Token Ring network symbol is a circle with hosts attached to it; and for FDDI, the symbol is two concentric circles with attached devices, as shown in Figure 4-19.

Figure 4-19 LAN Physical Layer Media Symbols



The basic functions of media are to carry a flow of information, in the form of bits and bytes, through a LAN. Other than wireless LANs (that use the atmosphere, or space, as the medium), networking media confines network signals to a wire, cable, or fiber. Networking media are considered Layer 1 components of LANs.

Computer networks can be built with many different media types. Each media has advantages and disadvantages. What is an advantage for one media (CAT 5 cost) might be a disadvantage for another (fiber-optic cost). The primary advantage and disadvantage comparison categories are as follows:

- Cable length
- Cost
- Ease of installation

Coaxial cable, optical fiber, and even free space can carry network signals. However, the principal medium that is studied is called Category 5 unshielded twisted-pair cable (CAT 5 UTP).

Ethernet in the Campus

Given the variety of Ethernet speeds that you can deploy in the campus, you need to determine when, if, and where to upgrade to one or more of the Fast Ethernet implementations. With the correct hardware and cabling infrastructure, 10- or 100-Mbps

Ethernet can be run anywhere in the network. As noted in Table 4-2, 10-Mbps Ethernet typically is implemented at the end-user level to connect to desktops, and faster technologies are used to interconnect to servers and network devices, such as routers and switches.

Table 4-2 Ethernet Connectivity Recommendations

	Ethernet 10BASE-T Position	Fast Ethernet Position	Gigabit Ethernet Position
End-User Level (End-user device to workgroup device)	Provides connectivity between the end-user device and the user-level switch.	Gives high-performance PC workstations 100-Mbps access to the server.	Not typically used at this level.
Workgroup Level (Workgroup device to backbone)	Not typically used at this level.	Provides connectivity between the end user and workgroups. Provides connectivity from the workgroup to backbone. Provides connectivity from the server block to the backbone.	Provides high-performance connectivity from the workgroup to backbone. Provides high-performance connectivity to the enterprise server block.
Backbone Level	Not typically used at this level.	Provides connectivity for low- to medium-volume applications.	Provides high-speed backbone and network device connectivity.

In today's installations, although customers are providing Gigabit Ethernet from the backbone to the end user, costs for cabling and switch ports can make this prohibitive. Before making this decision, you must determine network requirements. For example, a network running at traditional Ethernet speeds of 10 Mbps can be easily overwhelmed with the new generation of multimedia, imaging, and database products.

In general, you can use Ethernet technologies in a campus LAN in several different ways:

- An Ethernet speed of Fast Ethernet can be used at the user level to provide good performance. Also, Fast Ethernet or Gigabit Ethernet can be used for clients or servers that consume high bandwidth.

- Fast Ethernet is often used as the link between the user-level and network devices, supporting the aggregate traffic from each Ethernet segment on the access link.
- Many client/server networks suffer from too many clients trying to access the same server, creating a bottleneck where the server attaches to the LAN. To enhance client/server performance across the campus LAN and avoid bottlenecks at the server, you can use Fast Ethernet or Gigabit Ethernet links to connect enterprise servers. Fast Ethernet or Gigabit Ethernet creates an effective solution for avoiding slow networks.
- You also can use Fast Ethernet links to provide the connection between the workgroup level and the backbone. Because the campus LAN model supports dual links between each workgroup router and backbone switch, you can load balance the aggregate traffic from multiple-access switches across the links.
- You can use Fast Ethernet (or Gigabit Ethernet) between switches and the backbone. Implement the fastest medium affordable between backbone switches.

Ethernet Media and Connector Requirement

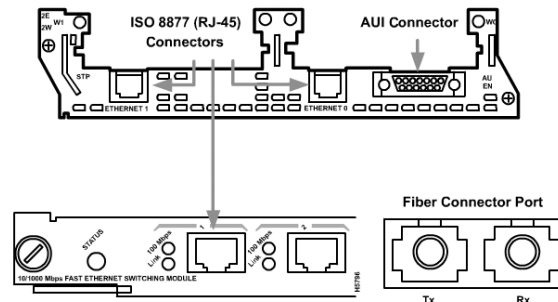
In addition to network need, and before selecting an Ethernet implementation, you must consider the media and connector requirements for each implementation. The cables and connector specifications used to support Ethernet implementations are derived from the Electronic Industries Association and (newer) Telecommunications Industry Association (EIA/TIA) standards body. The categories of cabling defined for the Ethernet are derived from the EIA/TIA-568 (SP-2840) Commercial Building Telecommunications Wiring Standards. The EIA/TIA specifies an **RJ-45** connector for UTP cable. The letters *RJ* stand for *registered jack*, and the number 45 refers to the physical connector that has eight conductors.

Table 4-3 compares the cable and connector specifications for the most popular Ethernet implementations. The important difference to note is the medium used for 10-Mbps Ethernet versus 100-Mbps and 1000-Mbps Ethernet. In today's networks, in which you see a mix of 10- and 1000-Mbps requirements, you must be aware of the need to change over to UTP CAT 5 to support Fast Ethernet.

Figure 4-20 illustrates some of different connection types used by the physical layer implementation.

Table 4-3 Comparing Ethernet Media Requirements

	Media	Maximum Segment Length	Topology	Connector
10BASE2	50-ohm coaxial (thinnet)	185 m (606.94 feet)	Bus	British Naval Connector (BNC)
10BASE5	50-ohm coaxial (thicknet)	500 m (1640.4 feet)	Bus	Attachment unit interface (AUI)
10BASE-T	EIA/TIA CAT 3, 4, 5 UTP, two pair	100 m (328 feet)	Star	ISO 8877 (RJ-45)
100BASE-TX	EIA/TIA CAT 5 UTP, two pair	100 m (328 feet)	Star	ISO 8877 (RJ-45)
100BASE-FX	62.5/125 multimode fiber	400 m (1312.3 feet)	Star	Duplex media interface connector (MIC) straight tip (ST) connector or subscriber connector (SC)
1000BASE-CX	STP	2.5 m (82 feet)	Star	ISO 8877 (RJ-45)
1000BASE-T	EIA/TIA CAT 5 UTP, four pair	100 m (328 feet)	Star	ISO 8877 (RJ-45)
1000BASE-SX	62.5/50 micro multimode fiber	275 m (853 feet) for 62.5 micro fiber; 550 m (1804.5 feet) for 50 micro fiber	Star	SC
1000BASE-LX	62.5/50 micro multimode fiber; 9-micron single-mode fiber	440 m (1443.6 feet) for 62.5 micro fiber; 550 m (1804.5 feet) for 50 micro fiber; 3 to 10 km (1.86 to 6.2 miles) on single-mode fiber	Star	SC

Figure 4-20 Differentiating Among Connections

Connection Media

This section briefly discusses the connection types used by physical layer implementation and an interface device, Gigabit Interface Converter (GBIC), used between the Ethernet and fiber-optic systems. This section covers the following topics:

- **RJ-45**—A connector commonly used for finishing a twisted-pair cable
- **AUI**—A connector that interfaces between a computer’s NIC or router interface and an Ethernet cable
- **GBIC**—A device used as an interface between the Ethernet and fiber-optic systems

RJ-45

The RJ-45 connector and jack are the most prevalent. RJ-45 connectors are discussed in more detail in the section, “UTP Implementation” later in the chapter.

Attachment Unit Interface

In some cases, the type of connector on a NIC does not match the type of media that it needs to connect to. An interface exists for the AUI connector. The AUI is the 15-pin physical connector interface between a computer’s NIC and Ethernet cable. On 10BASE5 (thicknet) Ethernet, a short cable is used to connect the AUI on the computer with a transceiver on the main cable. In 10BASE2 (thinnet) Ethernet networks, the NIC connects directly to the Ethernet coaxial cable at the back of the computer.

Gigabit Interface Converter

A *Gigabit Interface Converter (GBIC)* is a hot-swappable input/output device that plugs into a Gigabit Ethernet port. A key benefit of using a GBIC is that GBICs are interchangeable. This feature gives users the flexibility to deploy other 1000BASE-X technology without needing to change the physical interface/module on the router or switch.



The fiber-optic GBIC is a transceiver that converts serial electric currents to optical signals and that also converts optical signals to digital electric currents. Some of the optical GBICs include the following:

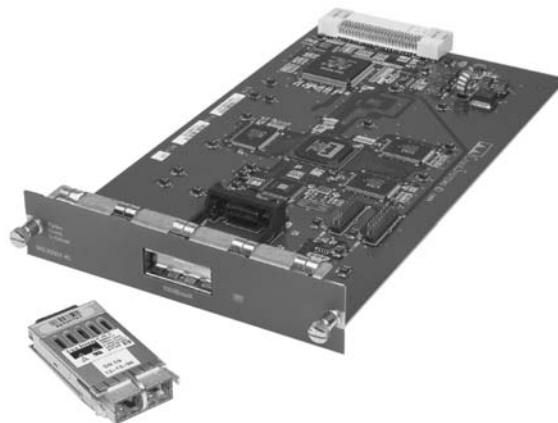
- Short wavelength (1000BASE-SX)
- Long wavelength/long haul (1000BASE-LX/LH)
- Extended distance (1000BASE-ZX)

Typically, the GBIC is used as an interface between the Ethernet and fiber-optic systems, such as Fiber Channel and Gigabit Ethernet. Figure 4-21 shows a GBIC, and Figure 4-22 shows a Cisco WS-X2931 Gigabit Ethernet Module with the GBIC out.

Figure 4-21 Gigabit Interface Converter (GBIC)



Figure 4-22 Cisco WS-X2931 Gigabit Ethernet Module with GBIC Out

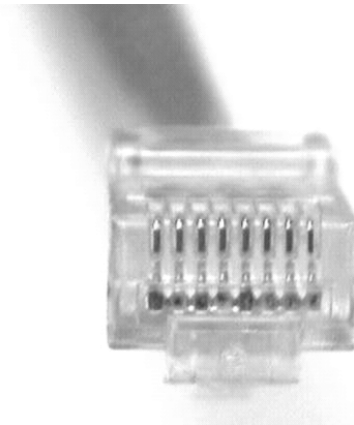


UTP Implementation

If you look at the RJ-45 transparent end connector, you can see eight colored wires. These wires are twisted into four pairs. Four of the wires (two pairs) carry the positive, or true, voltage and are considered “tip” (T1 through T4); the other four wires carry the inverse, or false, voltage grounded and are called “ring” (R1 through R4). *Tip* and *ring* are terms that originated in the early days of the telephone. Today, these terms refer to the positive and the negative wire in a pair. The wires in the first pair in a cable or a connector are designated as T1 and R1, the second pair is T2 and R2, and so on.

The RJ-45 plug is the male component, crimped at the end of the cable. As you look at the male connector from the front, with the clip facing down, the pin locations are numbered from 8 on the left down to 1 on the right, as shown in Figure 4-23. The jack, shown in Figure 4-24, is the female component in a network device, wall or cubicle partition outlet, or patch panel. As you look at the device port, the corresponding female pin locations are 1 on the left up to 8 on the right.

Figure 4-23 Pin Locations on the RJ-45 Connector



For electricity to run between the connector and the jack, the order of the wires must follow EIA/TIA-568-A and EIA/TIA-568-B standards, as shown previously in Figure 4-16.

In addition to identifying the correct EIA/TIA category of cable to use for a connecting device (which depends on what standard is being used by the jack on the network device), you need to determine which of the following to use:

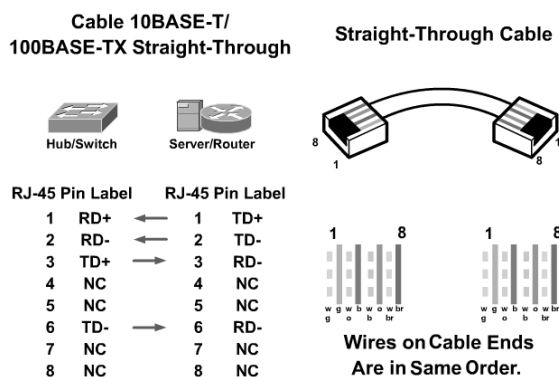
- A **straight-through cable**—A cable that maintains the pin connection all the way through the cable. Thus, the wire connected to pin 1 is the same on both ends of the cable.
- A **crossover cable**—A cable that crosses the critical pair to properly align, transmit, and receive signals on the device with line connections.

Figure 4-24 RJ-45 Jack and Wire Order



If the two RJ-45 ends of a cable are held side by side in the same orientation, the colored wires (or strips or pins) are seen at each connector end. If the order of the colored wires is the same at each end, the cable is straight-through. Figure 4-25 illustrates that the RJ-45 connectors on both ends show all the wires in the same order.

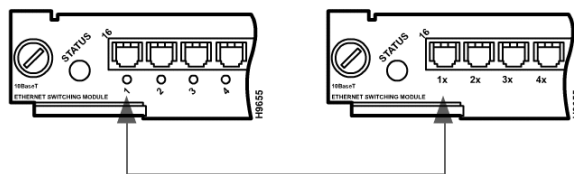
Figure 4-25 UTP Implementation: Straight-Through Cable



Specified for Ethernet, in a CAT 5 UTP cable, only wires 1, 2, 3, and 6 are used for transmit (TD) and receive (RD) signals. The other four wires are not used. As shown on the left of Figure 4-25, in a straight-through cable, the RJ-45 pins 1, 2, 3, and 6 at one end are connected to pins 1, 2, 3, and 6 at the other end of the connection. Gigabit Ethernet, however, uses all eight wires.

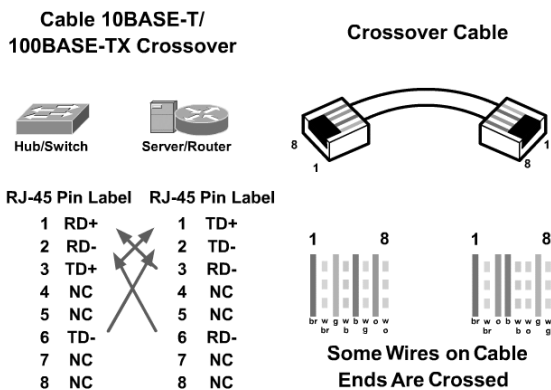
You can use a straight-through cable to connect devices such as PCs or routers to other devices used as hubs or switches. As Figure 4-26 shows, you should use straight-through when only one port is designated with an *x*.

Figure 4-26 Interconnecting Devices Using Straight-Through Cable



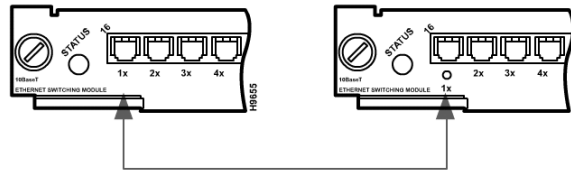
With crossover cable, the RJ-45 connectors on both ends show that some of the wires on one side of the cable are crossed to a different pin on the other side of the cable. Specifically for Ethernet, pin 1 at one RJ-45 end should connect to pin 3 at the other end. Pin 2 at one end should connect to pin 6 at the other end, as shown in Figure 4-27.

Figure 4-27 UTP Implementation—Crossover



You can use a crossover cable to connect similar devices, switch to switch or switch to hub. Figure 4-28 shows that you use a crossover cable when both ports are designated with an *x* or when neither port is designated with an *x*.

Figure 4-28 Interconnecting Devices Using Crossover Cable



The following are the guidelines for the type of cable to use when interconnecting networking devices.

Use straight-through cables for the following cabling:

- Switch to router
- Switch to PC or server
- Hub to PC or server

Use crossover cables for the following cabling:

- Switch to switch
- Switch to hub
- Hub to hub
- Router to router
- PC to PC
- Router to PC



Lab Activity Punch-Down Jacks

In this lab, you learn to wire an RJ-45 data jack for installation in a wall plate using a punch-down tool.

LAN Connection Devices

Many types of devices are connected to make up a LAN. These are called the LAN hardware components. This section discusses some of the common hardware components that are used in a LAN environment. LAN devices can include repeaters, hubs, bridges, switches, and routers with switches being the most prevalent device in modern LANs.

Repeaters

As mentioned in the section, “LAN Physical Layer” and shown in Figure 4-19, many types of media exist, and each one has advantages and disadvantages. One of the disadvantages of the CAT 5 UTP cable that is primarily used is cable length. The maximum length for UTP cable in a network is 100 meters (approximately 333 feet). If you have to expand the network beyond that limit, you need to add a repeater. In most Ethernet networks this repeater normally takes the form of hub, which is a multiport repeater, or a newer technology switch.

The term *repeater* comes from the early days of visual communication when a person situated on a hill would repeat the signal that was just received from the person on the previous hill to communicate the signal to the person on the next hill. Telegraph, telephone, microwave, and optical communications all use repeaters to strengthen their signals over long distances.

The purpose of a repeater, shown in Figures 4-29 and 4-30, is to regenerate and retime network signals at the bit level to allow them to travel a longer distance on the media. Repeaters are commonly used if too many network nodes exist or the number of cables is insufficient. The Four Repeater Rule for 10 Mbps bus-based Ethernet, also known as the 5-4-3 Rule, is used as a standard when extending LAN segments. This rule states that no more than five network segments can be connected end-to-end using four repeaters, but only three segments can have hosts (computers) on them. Although the 5-4-3 rule is important when applied to bus-based networks, it does not have much validity with switches and extended star topologies.



Figure 4-29 Repeaters

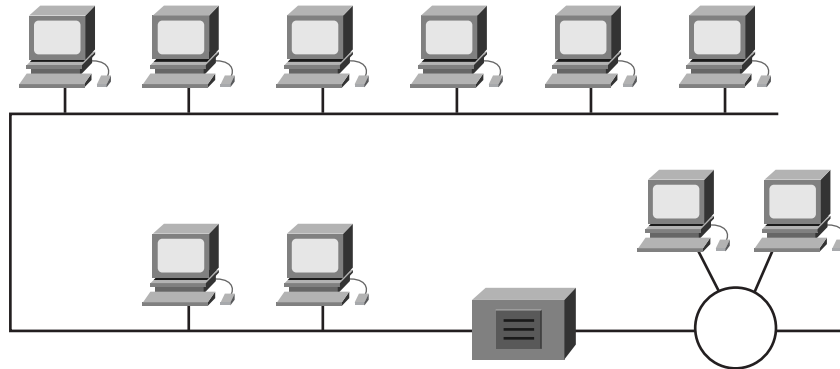
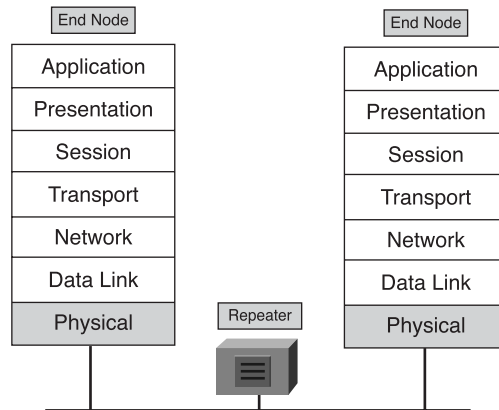


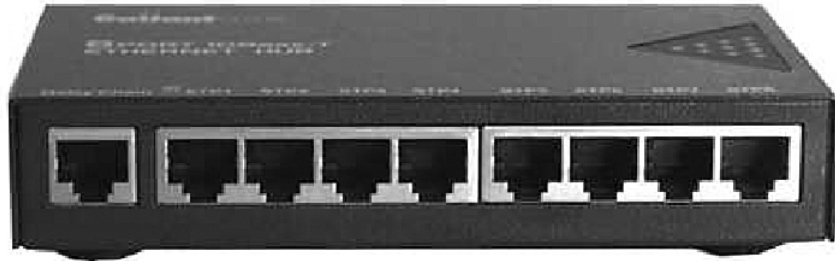
Figure 4-30 Repeaters Connect Two End Nodes



Hubs

Hubs are actually multiport repeaters. In many cases, the difference between the two devices is the number of ports that each provides. While a typical repeater has just 2 ports, a hub generally has from 4 to 24 ports, as shown in Figure 4-31. Additionally, hubs are most commonly used in Ethernet 10BASE-T or 100BASE-T networks, although other network architectures use them as well.



Figure 4-31 Eight-Port Hub

Using a hub changes the network topology from a linear bus, where each device plugs directly into the wire, to a star. With hubs, data arriving over the cables to a hub port is electrically repeated on all the other ports connected to the same network segment, except for the port on which the data was sent.

Hubs come in two basic types:

- **Active**—An *active hub* must be plugged into an electrical outlet because it needs power to amplify the incoming signal before passing it out to the other ports.
- **Intelligent**—An *intelligent hub* are sometimes called *smart hubs*. These devices basically function as active hubs, but also include a microprocessor chip and diagnostic capabilities. They are more expensive than active hubs, but are useful in troubleshooting situations.

All devices that are attached to a hub hear all traffic. Therefore, hubs maintain a single collision domain. A collision is a situation where two end stations send data over the network wire at the same time.

Sometimes, hubs are called concentrators because they serve as a central connection point for an Ethernet LAN.



Lab Activity Hubs Purchase

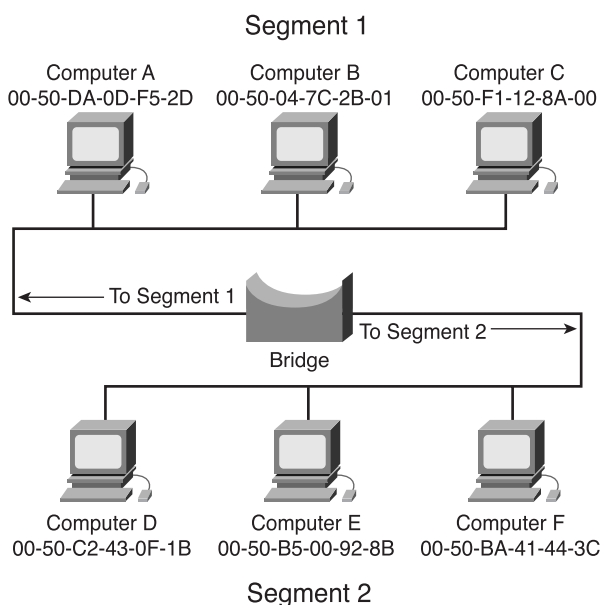
In this lab, you are introduced to the variety and prices of network components out in the market. This lab looks specifically at Ethernet hubs and NICs.

Bridges

At times, you need to break up a large LAN into smaller, more easily managed segments. This strategy decreases the amount of traffic on a single LAN and can extend

the geographical area past what a single LAN can support, as shown in Figure 4-32. The devices that are used to connect network segments together include bridges, switches, routers, and gateways. Switches and bridges operate at the data link layer of the OSI model. The function of the bridge is to make intelligent decisions about whether or not to pass signals on to the next segment of a network. Bridges can also be used to connect dissimilar protocols and media as with wireless bridges interconnecting Ethernet LANs in a metropolitan area.

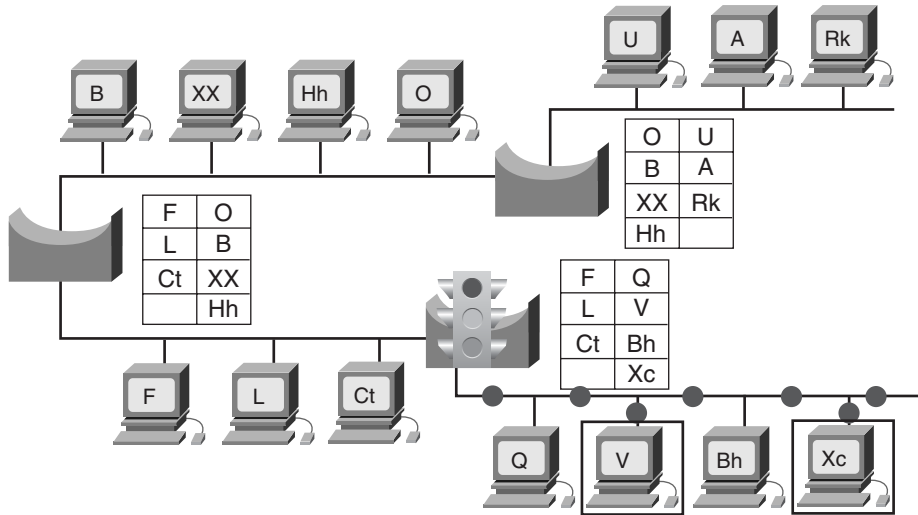
Figure 4-32 Bridges Segmenting a Network



When a bridge receives a frame on the network, the destination MAC address is looked up in the bridge table to determine whether to filter, flood, or copy the frame onto another segment. This decision process occurs as follows:

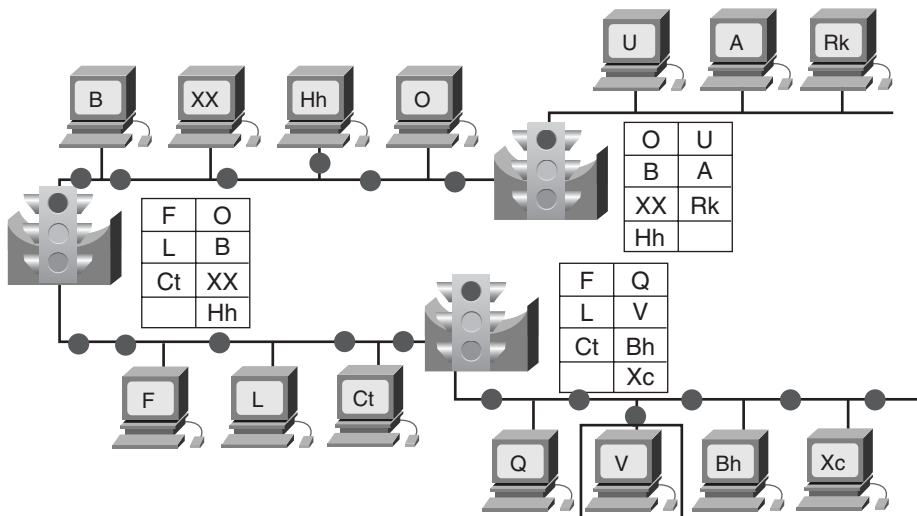
- If the destination device is on the same segment as the frame, the bridge blocks the frame from going on to other segments, as shown in Figure 4-33. This process is known as *filtering*.
- If the destination device is on a different segment, the bridge forwards the frame to the appropriate segment, as shown in Figure 4-34.

Figure 4-33 Bridges Segmenting a Network: Filtering



In this example, a data packet originates from Computer V and its destination is Computer Xc. The packet reaches its final destination and is not broadcast to other segments of the network.

Figure 4-34 Bridges Segmenting a Network: Forwarding



In this example, a data packet originates from Computer V and its destination is Computer Hh. The bridge checks its table to determine whether or not to allow the signal to continue to other segments of the network.

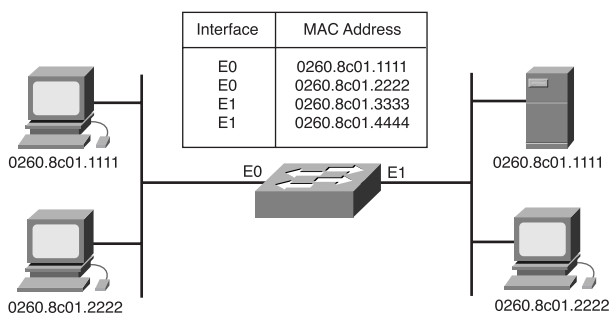
- If the destination address is unknown to the bridge, the bridge forwards the frame to all segments except the one on which it was received. This process is known as *flooding*.

If placed strategically, a bridge greatly improves network performance.

Switches

A *switch* is sometimes described as a multiport bridge. While a typical bridge might have just two ports (linking two network segments), the switch can have multiple ports depending on how many network segments are to be linked. Like bridges, switches learn certain information about the data packets that they receive from various computers on the network. They use this information to build forwarding tables to determine the destination of data being sent by one computer to another computer on the network as demonstrated in Figure 4-35.

Figure 4-35 Switching Table



Although some similarities exist between the two, a switch is a more sophisticated device than a bridge. A bridge determines whether the frame is forwarded to the other network segment based on the destination MAC address. A switch has many ports with many network segments connected to them. A switch chooses the port to which the destination device or workstation is connected. Ethernet switches are becoming popular connectivity solutions because, like bridges, they improve network performance (speed and bandwidth).

Switching is a technology that alleviates congestion in Ethernet LANs by reducing traffic and increasing bandwidth. Switches often replace shared hubs because they work with existing cable infrastructures, which improves performance with a minimum of intrusion into an existing network.

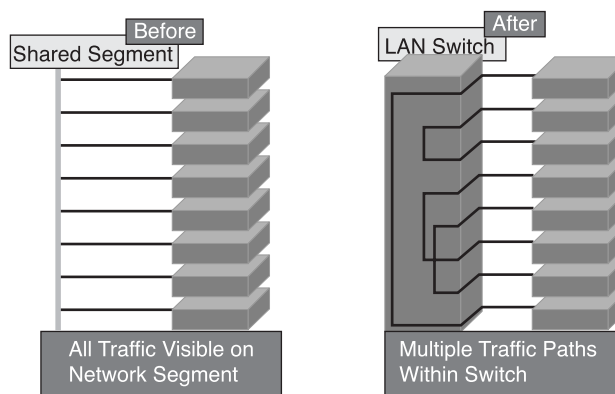
Today, in data communications, all switching equipment performs two basic operations:

- **Switching data frames**—The process by which a frame is received on an input medium and then transmitted to an output medium.
- **Maintenance of switching operations**—Switches build and maintain switching tables and search for loops.

Switches operate at much higher speeds than bridges and can support other functionality, such as virtual LANs.

An Ethernet switch has many benefits, such as allowing many users to communicate in parallel through the use of virtual circuits and dedicated network segments in a virtually collision-free environment, as shown in Figure 4-36. This arrangement maximizes the bandwidth available on the shared medium. Another benefit is that moving to a switched LAN environment is very cost effective because existing hardware and cabling can be reused.

Figure 4-36 Microsegmentation of the Network via Switches



Lab Activity LAN Switches Purchase

In this lab, you are introduced to the variety and prices of network components out in the market. This lab looks specifically at Ethernet switches and NICs.

Wireless Networking Media

A wireless network is an alternative method for connecting a LAN. You don't need to run any cables, and you can easily move computers. Wireless networks use radio frequency (RF), laser, infrared (IR), or satellite/microwaves to carry signals from one

computer to another without a permanent cable connection. Wireless signals are electromagnetic waves that travel through the air. No physical medium is necessary for wireless signals, making them a very versatile way to build a network.

A common application of wireless data communication is for mobile use. Some examples of mobile use include commuters, airplanes, satellites, remote space probes, space shuttles, and space stations.

At the core of wireless communication are devices called transmitters and receivers. The source interacts with the transmitter that converts data to electromagnetic (EM) waves that are then received by the receiver. The receiver then converts these electromagnetic waves back into data for the destination. For two-way communication, each device requires a transmitter and a receiver. Many networking device manufacturers build the transmitter and receiver into a single unit called a transceiver or wireless network card. All devices in wireless LANs (WLANs) must have the appropriate wireless network card installed.

The two most common wireless technologies used for networking are infrared (IR) and radio frequency (RF). IR technology has its weaknesses. Workstations and digital devices must be in the line of sight of the transmitter to operate. An IR-based network suits environments where all the digital devices that require network connectivity are in one room. IR networking technology can be installed quickly, but the data signals can be weakened or obstructed by people walking across the room or by moisture in the air. However, new IR technologies that can work out of sight are being developed.

RF technology allows devices to be in different rooms or even buildings. The limited range of the radio signals still restricts the use of this kind of network. RF technology can be on single or multiple frequencies. A single radio frequency is subject to outside interference and geographic obstructions. Furthermore, a single frequency is easily monitored by others, which makes the transmissions of data insecure. Spread spectrum avoids the problem of insecure data transmission by using multiple frequencies to increase the immunity to noise and to make it difficult for outsiders to intercept data transmissions.

Security in the Wireless Environment

The exponential growth of networking, including wireless technologies, has led to increased security risks. Increasing the security means increasing the time spent managing the system.

The first level of security in a wireless LAN consists of protecting the radio frequency waveform itself. Wireless access points radiate radio waves over a large area that is not contained in a physical building, which makes the radio waves accessible to eavesdroppers and thus increases vulnerability. The radio waves of wireless bridges are

concentrated in a beam. An eavesdropper must get into the beam path to intercept the communication. Therefore, wireless access points usually require better security than wireless bridges.

If you think someone might eavesdrop on your LAN radio links, encryption is the key.

The following sections discuss two wireless security approaches: *wired equivalent privacy (WEP)* and IEEE 802.1X or Extensible Authentication Protocol (EAP).

WEP

WEP is the first step in addressing customer security concerns. WEP is a security mechanism, defined within the 802.11 standard, that is designed to protect the over-the-air transmission between wireless LAN access points and NICs. The IEEE 802.11b requires 40-bit encryption keys. However, many vendors, such as Cisco, support the optional 128-bit standard.

The main goals of WEP are

- Deny access to the network by unauthorized users who do not possess the appropriate WEP key
- Prevent the decoding of captured WLAN traffic that is WEP-encrypted without the possession of the WEP key

WEP uses the RC4 stream cipher that was invented by Ron Rivest of RSA Data Security, Inc., (RSADSI) for encryption. The RC4 encryption algorithm is a symmetric-stream cipher that supports a variable-length key. A symmetric cipher uses the same key for both encryption and decryption. The key is the one piece of information that must be shared by both the encrypting and decrypting endpoints.

Recently, encryption analysts have reported weaknesses in the authentication and WEP encryption schemes in the IEEE 802.11 WLAN standard. Improvements on WEP have been developed to address the weaknesses found by encryption analysts. However, it is not recommended to use WEP as a sole security mechanism for a WLAN. WEP should be supplemented with additional higher-level security mechanisms such as Virtual Private Networks (VPNs) or firewalls.

802.1X/EAP

IEEE 802.1X/Extensible Authentication Protocol (EAP) is an alternative WLAN security approach to WEP, as specified by IEEE 802.11. IEEE 802.1X/EAP focuses on developing a framework for providing centralized authentication and dynamic key distribution. IEEE 802.1X is a standard for port-based network access control. EAP allows wireless client adapters that can support different authentication types to communicate with different back-end servers, such as Remote Authentication Dial-In User Service (RADIUS).

Cisco Systems has developed a derivation of EAP based on mutual authentication, called Lightweight EAP (LEAP). Mutual authentication means that both the user and the access point to which the user is attempting to connect must be authenticated before access onto the corporate network is allowed. Mutual authentication protects enterprises from unauthorized access points serving as a potential entrance into the network.

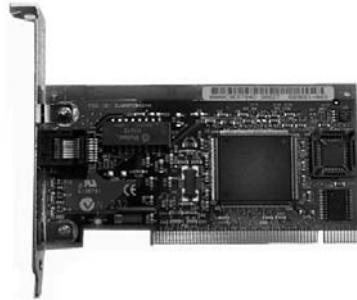
The Cisco LEAP authentication provides the following benefits:

- Centralized authentication and key distribution
- Large-scale enterprise WLAN deployment because of its broad operating system support and dynamic key derivation

Host LAN Connectivity: NICs and Interfaces

In terms of appearance, a NIC, shown in Figure 4-37 and 4-38, is a printed circuit board that fits into the expansion slot of a bus on a computer's motherboard or peripheral device. It is also called a network adapter. On laptop/notebook computers, NICs are usually the size of a credit card. Its function is to connect the host device to the network medium.

Figure 4-37 Network Interface Card (Circuit Board)



NICs operate at both Layer 1 and Layer 2 of the OSI model. NICs are considered Layer 2 devices because each individual NIC throughout the world carries a unique code, called a *Media Access Control (MAC)* address. This address controls data communication for the host on the network. Layer 2 devices, such as a bridge or switch, use each individual NIC's MAC address. This MAC address controls data communication for the host on the network. You learn more about the MAC address in later chapters. As its name implies, the NIC controls the host's access to the medium. For this reason, a NIC also works at Layer 1 because it looks only at bits and not at any address information or higher-level protocols. NICs typically have the transceiver built-in.

Figure 4-38 Network Interface Card (Media Connection)

In some cases, the type of connector on the NIC does not match the type of media that needs to be connected to it. A good example is a Cisco 2500 router. On the router, the Ethernet interface is an AUI connector and that connector needs to connect to a UTP CAT 5 Ethernet cable. To do this, a transceiver (transmitter/receiver) is used. The Ethernet transceiver provides the transmit/receive function (because none is built into the Ethernet interface) and at the same time converts one type of signal or connector to another (for example, to connect a 15-pin AUI interface to an RJ-45 jack).

In diagrams, NICs have no standardized symbol. It is implied that, when networking devices are attached to network media, a NIC or NIC-like device is present. Wherever a dot is seen on a topology map, it represents either a NIC or an interface (port), which acts like a NIC.

Workstation and Server Relationships

By using LAN and WAN technologies, many computers are interconnected to provide services to their users. To accomplish this, networked computers take on different roles or functions in relation to each other. Some types of applications require computers to function as equal partners. Other types of applications distribute their work so that one computer functions to serve a number of others in an unequal relationship. In either case, two computers typically communicate with each other by using request/response protocols. One computer issues a request for a service, and a second computer receives and responds to that request. The requestor takes on the role of a client, and the responder takes on the role of a server.

Peer-to-Peer Networks

In a *peer-to-peer network*, the networked computers act as equal partners, or peers, to each other. Peer-to-peer networks are also referred to as *workgroups*. As peers, each computer can take on the client function or the server function. At one time, for example, computer A might make a request for a file from computer B, which responds by serving the file to computer A. Computer A functions as client, while B functions as the server. At a later time, computers A and B can reverse roles. B, as client, makes a print request of A, which has a shared printer attached, and A, as server, responds to the request from B. A and B stand in a reciprocal or peer relationship to each other.

In a peer-to-peer network, individual users control their own resources. They can decide to share certain files with other users, as shown in Figure 4-39 and Figure 4-40. They might also require passwords before they allow others to access their resources. Because individual users make these decisions, no central point of control or administration exists in the network. In addition, individual users must back up their own systems to be able to recover from data loss in case of failures. When a computer acts as a server, the user of that machine might experience reduced performance as the machine serves the requests made by other systems.

Figure 4-39 Sharing Files

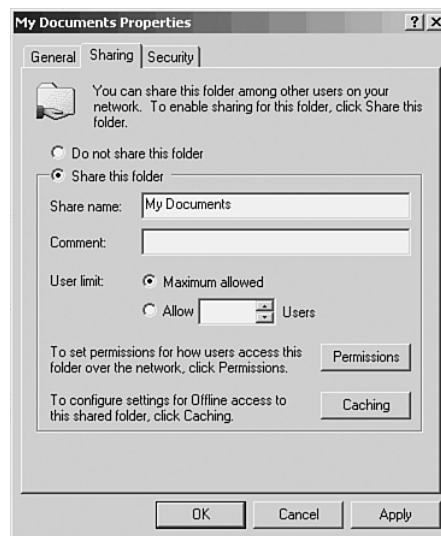
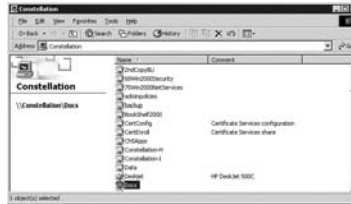


Figure 4-40 Shared File



Peer-to-peer networks are relatively easy to install and operate. No additional equipment is necessary beyond a suitable operating system installed on each computer. Most modern desktop operating systems provide support for peer-to-peer networking. Because users control their own resources, no dedicated administrators are needed.

A peer-to-peer network works well with a small number of computers, perhaps ten or fewer. As networks grow, peer-to-peer relationships become increasingly difficult to coordinate and manage. Because they do not scale well, their efficiency decreases rapidly as the number of computers on the network increases. Also, individual users control access to the resources on their computers, which means security might be difficult to maintain. The client/server model of network can be used to overcome the limitations of the peer-to-peer network.



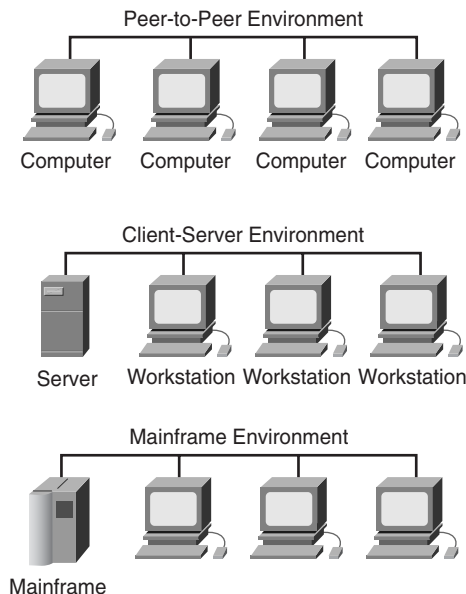
Lab Activity Building a Peer-to-Peer Network

In this lab, you create a simple peer-to-peer network between two PCs. You identify and locate the proper cable, configure workstation IP addresses and test connectivity using the **ping** command. You also share a folder on one PC and access it with the other.

Client/Server Networks

In a client-server arrangement, network services are located on a dedicated computer called a server, which responds to the requests of clients, as shown in Figure 4-41. The server is a central computer that is continuously available to respond to a client's requests for file, print, application, and other services. Most network operating systems (NOSs) adopt the form of client-server relationships. Typically, desktop computers function as clients and one or more computers with additional processing power, memory, and specialized software function as servers.

Figure 4-41 Client-Server Model

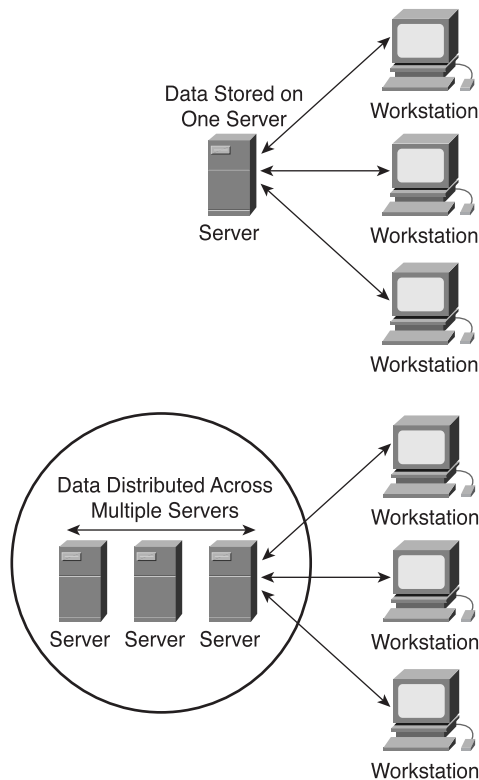


Servers are designed to handle requests from many clients simultaneously, as shown in Figure 4-42. Before a client can access the server resources, the user must be identified and be authorized to use the resource. You handle this authorization by assigning each user an account name and password that is verified by an authentication service acting as a sentry to guard access to the network. By centralizing user accounts, security, and access control, server-based networks simplify the work of network administration.

The concentration of network resources such as files, printers, and applications on servers also makes the data they generate easier to back up and maintain. Rather than having these resources spread around individual machines, they can be located on specialized, dedicated servers for easier access. Most client-server systems also include facilities for enhancing the network by adding new services that extend the usefulness of the network.

The distribution of functions in client-server networks brings substantial advantages, but it also incurs some costs. Although the aggregation of resources on server systems brings greater security, simpler access, and coordinated control, the server introduces a single point of failure into the network. Without an operational server, the network cannot function at all. Servers require a trained, expert staff to administer and maintain. This requirement increases the expense of running the network. Server systems also require additional hardware and specialized software that add to the cost.

Figure 4-42 Server Resources



Tables 4-4 and 4-5 summarize the advantages and disadvantages of peer-to-peer versus client-server.

Table 4-4 Peer-to-Peer/Client-Server Advantages

Advantages of a Peer-to-Peer Network	Advantages of a Client-Server Network
Less expensive to implement.	Provides for better security and scalability.
Does not require NOS server software.	Easier to administer when the network is large because administration is centralized.
Does not require a dedicated network administrator.	All data can be backed up on one central location.

Table 4-5 Peer-to-Peer/Client-Server Disadvantages

Disadvantages of a Peer-to-Peer Network	Disadvantages of a Client-Server Network
Does not scale well to large networks and administration becomes unmanageable.	Requires NOS software such as in Windows NT/2000/XP, Novell NetWare, or UNIX.
Each user must be trained to perform administrative tasks.	Requires expensive, more powerful hardware for the server machine.
Less secure.	Requires a professional administrator.
All machines sharing the resources negatively impact the performance.	Has a single point of failure if there is only one server, and user's data can be unavailable if the server is down.



Lab Activity Building a Hub-Based Network

In this lab, you create a simple network between two PCs using an Ethernet hub. You identify and locate the proper cables, configure workstation IP addresses, and test connectivity using the **ping** command.



Lab Activity Building a Switch-Based Network

In this lab, you create a simple network between two PCs using an Ethernet switch. You identify and locate the proper cables, configure workstation IP addresses, and test connectivity using the **ping** command.

Cabling the WAN

To connect one network to other remote networks, it is sometimes necessary to utilize wide-area network (WAN) services. WAN services provide different connection methods, and the cabling standards differ from those of LANs. Therefore, it is therefore to for you to understand the types of cabling needed to connect to these services.

This section explains the cabling and connectors that are used to interconnect switches and routers in a LAN or WAN. This section also discusses how to cable routers for serial connection, Integrated Services Digital Network Basic Rate Interface (ISDN BRI) connection, digital subscriber line (DSL) connection, and cable connection, as well as how to set up console connection.

WAN Physical Layer

Many physical implementations carry traffic across the WAN. Needs vary, depending on the distance of the equipment from the services, the speed, and the actual service itself. Figure 4-43 lists a subset of data link and physical implementations that support some of the more prominent WAN solutions today. The type of physical layer you choose depends on the distance, speed, and the type of interface you need to connect.

Figure 4-43 WAN Physical Layer Implementations

Cisco High-level Data Link Control (HDLC)	PPP	Frame Relay	ISDN BRI (with PPP)	DSL Modem	Cable Modem
EIA/TIA-232 EIA/TIA-449 X.21 V.24 V.35			RJ -45 <i>Note: ISDN BRI Cable Pinouts Are Different than the Pinouts for Ethernet</i>	RJ -11 <i>Note: Works over Telephone Line</i>	F <i>Note: Works over Cable TV Line</i>

Serial connections are used to support WAN services such as dedicated leased lines that run the Point-to-Point Protocol (PPP) or Frame Relay. The speed of these connections ranges from 2400 bps to T1 (1.544 Mbps).

Other WAN services, such as the ISDN, offer dial-on-demand connections or dial-backup services. An ISDN BRI is composed of two 64-kbps bearer channels (B channels) for data, and one delta channel (D channel) at 16 kbps used for signaling and other link-management tasks. PPP typically is used to carry data over the B channels.

The increasing demand for residential broadband (high-speed) services has increased the popularity for DSL and cable modem connections. DSL service can achieve T1/E1 speeds over the existing telephone line. Cable services, which work over the existing coaxial cable TV line, also offer high-speed connectivity matching or surpassing that of DSL.

WAN Serial Connections

Serial transmission is a method of data transmission in which bits of data are transmitted sequentially over a single channel. This one-at-a-time transmission contrasts with parallel data transmission, which transmits several bits at a time. For long-distance communication, WANs use serial transmission. To carry the energy represented in bits, serial channels use a specific electromagnetic or optical frequency range.



Frequencies, described in terms of their cycles per second (hertz), function as a band or spectrum for communication. For example, the signals transmitted over voice-grade telephone lines use up to 3 kHz (kilohertz, or thousand hertz). The size of this frequency range is called the *bandwidth*.

Another way to express bandwidth is to specify the amount of data in bits per second that the serial channel can carry.

Table 4-6 compares physical standards for EIA/TIA-232 and EIA/TIA-449, v.35, X.21, and EIA-530 WAN serial connection options.

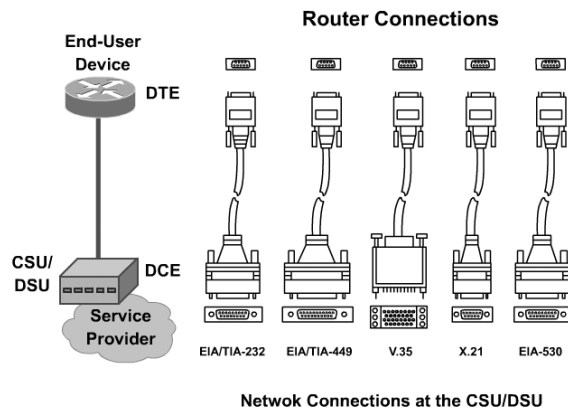
Table 4-6 Comparison of Physical Standards

Data (bps)	Distance (Meters) EIA/TIA-232	Distance (Meters) EIA/TIA-449, V.35, X.21, EIA-530
2400	60	1250
4800	30	625
9600	15	312
19,200	15	156
38,400	15	78
115,200	3.7	—
T1 (1.544 Mbps)	—	15

Several types of physical connections enable you to connect to serial WAN services. You must select the correct serial cable type to use with the router, depending on the physical implementation that you choose or the physical implementation that your service provider imposes. Figure 4-44 shows all the different serial connector options available. Serial connectors are used to connect end-user devices and service providers. Note that serial ports on Cisco routers use a proprietary 60-pin connector or smaller “smart serial” connector, which enables two serial connections on a WAN interface card. The type of connector on the other end of the cable is dependent on the service provider or end-device requirements, but V.35 is quite common.



Figure 4-44 WAN Serial Connection Options



Routers and Serial Connections

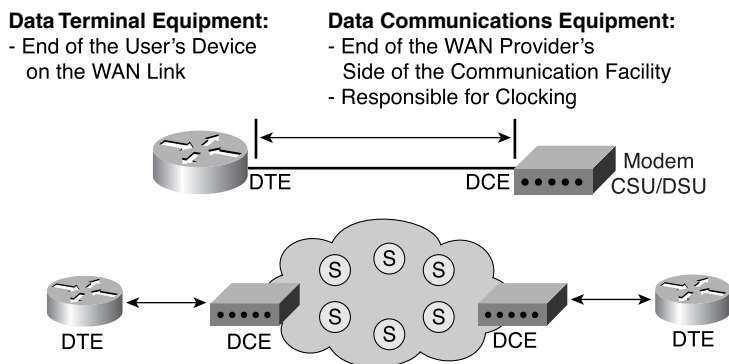
In addition to determining the cable type, you need to determine whether you need data terminal equipment (DTE) or data communications equipment (DCE) connectors for your equipment. The DTE is the endpoint of the user's device on the WAN link. The DCE is the device used to convert the user data from the DTE into a form acceptable to the facility providing WAN services.

NOTE

Clocking is a method used to synchronize data transmission between devices. In a WAN serial connection, the CSU/DSU controls the clocking of the transmitted data.

As shown in Figure 4-45, if connecting directly to a service provider or to a device that performs signal clocking (such as a channel service unit/data service unit [CSU/DSU]), the router is a DTE and needs a DTE serial cable. This situation is typically the case for routers.

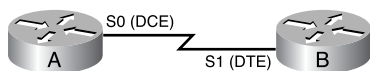
Figure 4-45 Serial Implementation of DTE and DCE





However, in some cases the router must be the DCE, as shown in Figure 4-46. For example, if performing a back-to-back router scenario (meaning that routers are used at both ends of the connection) in a test environment, one of the routers is a DTE, and the other is a DCE to provide the clock.

Figure 4-46 Back-to-Back Serial Connection



When you are cabling routers for serial connectivity, the routers have either fixed or modular ports. The type of port being used affects the syntax that you use later to configure each interface.

Figure 4-47 shows an example of a router with fixed serial ports (interfaces). Each port is given a label of port type and port number—for example, serial 0. To configure a fixed interface, you specify the interface using the port type and port number convention—for example, Serial 0.

Figure 4-47 Fixed Interfaces

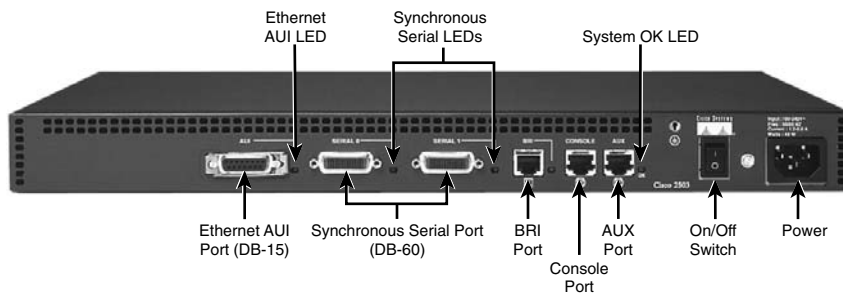
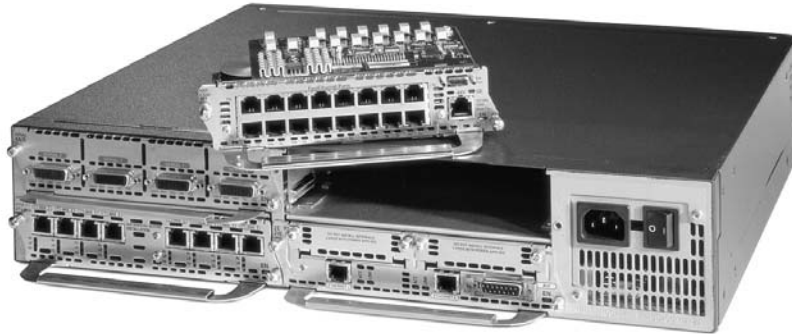


Figure 4-48 shows examples of routers with modular serial ports. Usually, each port is given a label of port type, slot (the location of the module), and port number. To configure a port on a modular card, you are asked to specify the interface using the convention “port type slot number/port number”—for example, serial 1/0, in which the type of interface is a serial interface, the slot number where the serial interface module is installed is slot 1, and the specific port that you are referencing on that serial interface module is port 0.



Figure 4-48 Modular Serial Port Interfaces**Lab Activity** Connecting Router LAN Interfaces

In this lab, you identify the Ethernet or Fast Ethernet interfaces on the router. Then identify and locate the proper cables to connect the routers to hubs or switches. Finally, use the cables to connect the router and computers to the hub or switch.

**Lab Activity** Building a Basic Routed WAN

In this lab, you connect two simple LANs, each consisting of a workstation and a switch (or hub), to form a basic router-to-router WAN.

Routers and ISDN BRI Connections

With ISDN BRI, you can use two types of interfaces: BRI S/T and BRI U. In ISDN BRI service, a user (U) interface is the electrical interface for the twisted-pair wire connection from a user to a Network Termination 1 (NT1) device. A terminal (T) interface is the electrical interface between an NT1 device and an NT 2 device, which is usually a private branch exchange (PBX). A system (S) interface is the electrical interface between an NT1 and ISDN devices such as a computer or a telephone. In BRI, the T interface is electrically identical to the S interface. Thus, the two interfaces are typically combined in a single interface, referenced as an S/T interface.

To determine which interface type you need, you must find out whether you or the service provider provides an NT1 device. An NT1 device is an intermediate device between

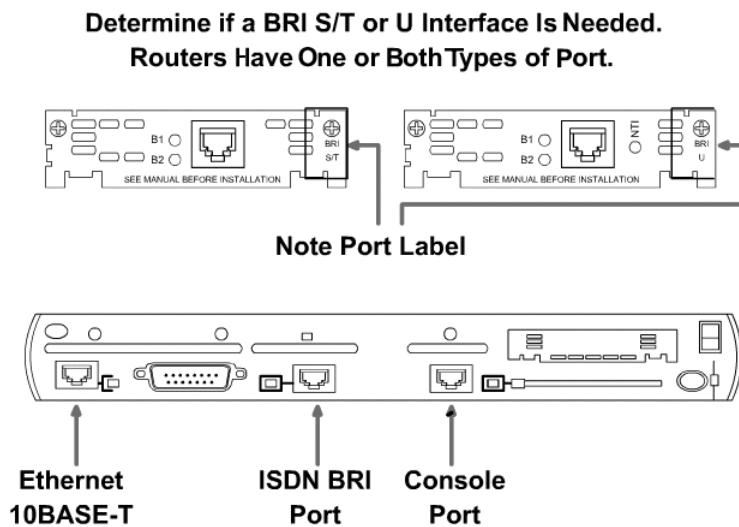
the router and the service-provider ISDN switch (cloud) that is used to connect four-wire subscriber wiring to the conventional two-wire local loop. In North America, the customer typically provides the NT1; in the rest of the world, the service provider provides the NT1 device.

If the NT1 device needs to be provided by the customer, an ISDN BRI with a U interface can be used. A U interface has an NT1 built in. If an external NT1 device is used or if the service provider uses an NT1 device, the router needs an ISDN BRI S/T interface. Because routers can have multiple ISDN interface types, the interface needed must be determined when the router is purchased. Some routers have both a U and an S/T interface. The type of ISDN connector that the router has can be determined by looking at the port label. Figure 4-49 shows the different port types for the ISDN interface.

CAUTION

It is important to insert a cable running from an ISDN BRI port only to an ISDN jack or an ISDN switch. ISDN BRI uses voltages that can seriously damage non-ISDN devices.

Figure 4-49 Cabling Routers for ISDN Connections



To interconnect the ISDN BRI port on the router to the service-provider device, use a UTP CAT 5 straight-through cable with RJ-45 connectors. Note that the ISDN BRI cable pinouts are different than the pinouts for Ethernet. Table 4-7 shows the ISDN BRI S/T interface connector pinouts.

Table 4-7 ISDN BRI S/T Interface Connector Pinouts

Pin	Signal
1	Unused
2	Unused
3	Transmit (Tx+)
4	Receive (Rx+)
5	Receive (Rx-)
6	Transmit (Tx-)
7	Unused
8	Unused

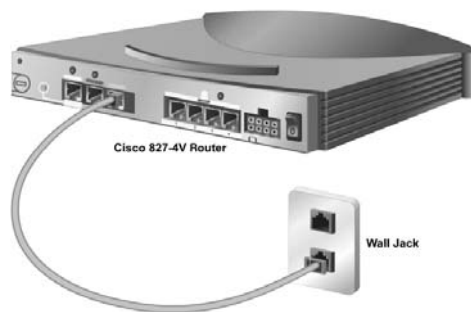
Routers and DSL Connections

DSL technology is a modem technology that enables inexpensive, high-speed digital transmission over existing twisted-pair telephone lines. For most small offices or home offices today, DSL technology is a good choice for many business applications, such as file transfer and access to a corporate intranet. Asymmetric digital subscriber line (ADSL) is the most common and is part of a larger family of technologies generically referred to as *xDSL*.

The Cisco 800 series of fixed-configuration DSL routers provides enhanced security, low cost of ownership, proven reliability, and safe investment through the power of Cisco IOS Software tailored for small offices and telecommuters.

The Cisco 827-4V ADSL router has one ADSL interface, as shown in Figure 4-50, that can connect users to the Internet or to a corporate LAN via DSL.

Figure 4-50 Cisco 827-4V Router



To connect an ADSL line to the ADSL port on a router, perform the following simple steps:

- Step 1** Connect the phone cable to the ADSL port on the router.
- Step 2** Connect the other end of the phone cable to the external wall phone jack.

To connect a router for DSL service, you need a phone cable with RJ-11 connectors. DSL works over standard telephone lines. It uses only two pins on the RJ-11 connector, as shown in Table 4-8.

Table 4-8 Telephone Connector Pinouts (RJ-11)

Pin	Signal
1	Unused
2	Unused
3	Transmit (Tx)
4	Receive (Rx)
5	Unused
6	Unused

NOTE

If you are connecting non-DSL devices to a phone line with DSL service, you need to install a filter to prevent interference between data and voice services.

Routers and Cable Connections

Cable modems enable two-way, high-speed data transmissions using the same coaxial lines that transmit cable television. Some cable service providers are promising data speeds up to six and a half times that of T1 leased lines. With the demand for broadband services, cable modem connection is becoming more popular.

The Cisco uBR905 cable access router provides high-speed network access on the cable television system to residential and Small Office, Home Office (SOHO) subscribers. The uBR905 router has a coaxial cable (F-connector) interface that can be connected to a cable system. Coaxial cable and an F connector are used to connect the router and cable system. The coaxial cable can be either radio grade 59 (RG-59) or RG-6, although RG-6 is recommended.

To connect the Cisco uBR905 cable access router to the cable system, follow these steps:

- Step 1** Verify that the router is not connected to power.
- Step 2** Locate the RF coaxial cable coming from the coaxial cable CATV wall outlet.

NOTE

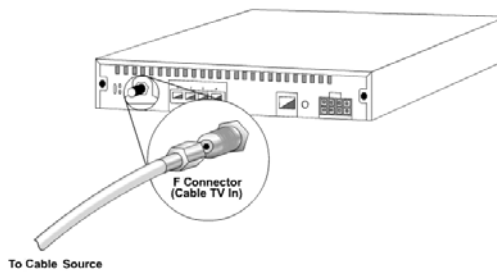
RF coaxial cable connects radio frequencies to antennas. The majority of cable TV systems use coaxial cable as their wiring system. The main trunk lines that run from the cable provider to a neighborhood distribution boxes might be fiber-optic, but coaxial cables are likely to be used in runs between the distribution boxes and the end user.

CAUTION

Do not overtighten the connector; doing so can break off the connector. Use of a torque wrench is not recommended because of the danger of tightening the connector more than the recommended 1/6 turn after it is finger-tight.

- Step 3** Install a cable splitter/directional coupler, if needed, to separate signals for TV and computer use. If necessary, also install a high-pass filter to prevent interference between the TV and computer signals.
- Step 4** Connect the coaxial cable to the F connector of the router, as shown in Figure 4-51. Hand-tighten the connector, making sure that it is finger-tight, and then give it a 1/6 turn with a wrench.

Figure 4-51 F Connector



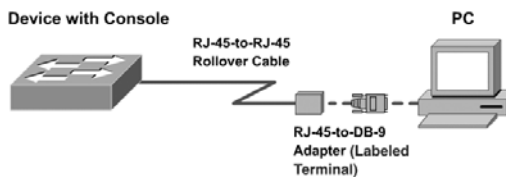
- Step 5** Make sure that all other coaxial cable connectors—all intermediate splitters, couplers, or ground blocks—are securely tightened from the distribution tap to the Cisco uBR905 router, following the instructions in Step 4.

Setting Up Console Connections

To initially configure your Cisco device, you need to provide a management connection directly to the device. For Cisco equipment, this management attachment is called a *console port*. The console port enables you to monitor and configure a Cisco hub, switch, or router.

The cable used between a terminal and a console port is a *rollover cable* with RJ-45 connectors, as illustrated in Figure 4-52.

Figure 4-52 Setting Up a Console Connection



The rollover cable, also known as a console cable, has a different pinout than the straight-through or crossover RJ-45 cables used with Ethernet or the ISDN BRI. The pinout for a rollover is as follows:

- 1 to 8
- 2 to 7
- 3 to 6
- 4 to 5
- 5 to 4
- 6 to 3
- 7 to 2
- 8 to 1

To set up a connection between your terminal and the Cisco console port, you must perform the following steps:

Step 1 Cable the devices using a rollover cable. You likely need an RJ-45-to-DB-9 or an RJ-45-to-DB-25 adapter for your PC or terminal.

Step 2 Configure your terminal emulation application with the following common equipment (COM) port settings:

- 9600 bps
- 8 data bits
- No parity
- 1 stop bit
- No flow control



Lab Activity Establishing a Console Connection to a Router or Switch

In this lab, you connect a PC to a router or a switch to establish a console session and observe the user interface.



Lab Activity Troubleshooting Interconnected Devices

In this lab, you create a simplerouted WAN with two PCs, two switches (or hubs), and two routers. You configure workstation IP addresses. You then identify and correct networking problems related to cabling issues and workstation IP addressing issues.

NOTE

The auxiliary (AUX) port on the router is used to provide remote management through a modem. The AUX port must be configured using the console port before it can be used. The AUX port also uses the settings of 9600 bps, 8 data bits, no parity, 1 stop bit, and no flow control. The speed can be set up to 38,400 bps.

Summary

In this chapter, you learned the following key points:

- Waves are energy traveling from one place to another and are created by disturbances. All waves have similar attributes such as amplitude, period, and frequency.
- Sine waves are periodic, continuously varying functions. Analog signals look like sine waves.
- Square waves are periodic functions whose values remain constant for a period of time and then change abruptly. Digital signals look like square waves.
- Exponents are used to represent very large numbers. The base of a number raised to a particular exponent is equal to the base multiplied by itself exponent times (e.g., $10^3 = 10 * 10 * 10 = 1000$).
- Logarithms are similar to exponents. A logarithm to the base of 10 of a number equals the exponent to which 10 has to be raised to equal the number (e.g., $\log_{10} 1000 = 3$ because $10^3 = 1000$).
- Decibels are measurements of a gain or loss in the power of a signal. Negative values represent losses and positive values represent gains.
- Time-domain analysis is the graphing of voltage or current with respect to time using an oscilloscope. Frequency-domain analysis is the graphing of voltage or power with respect to frequency using a spectrum analyzer.
- Noise is undesirable signals in communications. Noise originates from other cables, RFI, and EMI. White noise affects all frequencies, while narrowband interference affects only a certain subset of frequencies.
- Analog bandwidth is the frequency range that is associated with certain analog transmission, such as television or FM radio.
- Digital bandwidth measures how much information can flow from one place to another in a given amount of time. Its units are in various multiples of bits per second.
- It is important to have a basic understanding of these topics in order to understand the cable testing concepts presented in the next lesson.
- The OSI layer at which most of the problems on a LAN occur is the physical layer. The only way to prevent or troubleshoot most of these problems is through the use of cable testers. Knowledge regarding sources of noise on LAN media is important for the proper installation of cable connectors and cabling runs.
- A NIC provides network communication capabilities to and from a PC.
- The three common LAN protocols are Ethernet, Token Ring, and FDDI.

- The term *Ethernet* is often used to refer to all CSMA/CD LANs that generally conform to the Ethernet specifications.
- The Ethernet family of LAN implementations includes four main categories: Ethernet and IEEE 802.3, Fast Ethernet, Gigabit Ethernet, and 10G or 10000-Mbps Ethernet.
- Use a crossover cable to connect between similar devices (like switch to switch, router to router, PC to PC, and hub to hub).
- Use a straight-through cable to connect between dissimilar devices (like switch to router, switch to PC, hub to router, and hub to PC).
- Two major types of LANs exists, peer-to-peer and client-server.
- WANs use serial data transmission.
- A router is usually the DTE and needs a DTE serial cable to connect to a DCE device such as a CSU/DSU.
- The ISDN BRI has two types of interfaces: S/T and U. To interconnect the ISDN BRI port to the service-provider device, a UTP CAT 5 straight-through cable is used.
- A phone cable and an RJ-11 connector are used to connect a router for DSL service.
- Coaxial cable and an F connector are used to connect a router for cable service.
- Rollover cable is used to connect a terminal and the console port of a router.

To supplement all that you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab Activities on the CD-ROM accompanying this book.

Key Terms

active hub Must be plugged into an electrical outlet because it needs power to amplify the incoming signal before passing it out to the other ports.

alien crosstalk When crosstalk is caused by a signal from outside the cable.

amplitude The amplitude of an electrical signal represents its height, but it is measured in volts instead of meters.

analog bandwidth Typically refers to the frequency range of an analog electronic system. Analog bandwidth can be used to describe the range of frequencies transmitted by a radio station or an electronic amplifier.

attenuation The decrease in signal amplitude over the length of a link.

AUI (attachment unit interface) The 15-pin physical connector interface between a computer's NIC and Ethernet cable.

crossover cable A cable that crosses the critical pair to properly align, transmit, and receive signals on the device with line connections.

crosstalk The transmission of signals from one wire pair to nearby pairs. Adjacent wire pairs in the cable act like antennas generating a weaker but similar electrical signal onto the nearby wire pairs. This crosstalk causes interference with data that might be present on the adjacent wires.

decibel An important way of describing networking signals as a unit that measures the loss or gain of the power of a wave. Decibels are usually negative numbers representing a loss in power as the wave travels, but can also be positive values representing a gain in power if the signal is amplified.

delay skew The propagation delays of different wire pairs in a single cable can differ slightly because of differences in the number of twists and electrical properties of each wire pair. Delay skew is the delay difference between pairs.

digital bandwidth Measures how much information can flow from one place to another in a given amount of time.

ELFEXT (equal-level far-end crosstalk) A test that measures FEXT.

EMI (electromagnetic interference) Noise from nearby sources such as motors and lights.

FEXT (far-end crosstalk) Crosstalk that occurs when signals on one twisted pair are coupled to another pair as they arrive at the far end of a multipair cable system.

frequency The amount of time between each wave.

GBIC (Gigabit Interface Converter) A hot-swappable input/output device that plugs into a Gigabit Ethernet port.

hertz The unit of measure for the frequency of an electrical signal in the number of complete cycles per second.

IEEE 802.1X/Extensible Authentication Protocol (EAP) An alternative WLAN security approach to WEP as specified by IEEE 802.11. IEEE 802.1X/EAP focuses on developing a framework for providing centralized authentication and dynamic key distribution.

impedance A measurement of the resistance of the cable to AC and is measured in ohms.

insertion loss The combination of the effects of signal attenuation and impedance discontinuities on a communications link.

intelligent hub Sometimes called “smart hubs.” These devices basically function as active hubs, but also include a microprocessor chip and diagnostic capabilities. They are more expensive than active hubs, but are useful in troubleshooting situations.

logarithms Equals the exponent that a given number has to be raised to in order to generate a certain value.

narrowband interference Noise that only affects small ranges of frequencies.

NEXT (near-end crosstalk) Computed as the ratio in voltage amplitude between the test signal and the crosstalk signal when measured from the same end of the link.

noise As related to communications, noise refers to undesirable signals. Noise can originate from natural and technological sources and is added to the data signals in communications systems.

oscilloscope An important electronic device used to view electrical signals such as voltage waves and pulses.

peer-to-peer network Networked computers act as equal partners, or peers, to each other. As peers, each computer can take on the client function or the server function.

propagation delay A simple measurement of how long it takes for a signal to travel along the cable being tested.

PSELFEXT (power sum equal-level far-end crosstalk (PSELFEXT)) The combined effect of ELFEXT from all wire pairs.

PSNEXT (power sum near-end crosstalk) Measures the cumulative effect of NEXT from all wire pairs in the cable.

pulse Determines the value of the data being transmitted. If a disturbance is deliberately caused and involves a fixed, predictable duration, it is called a pulse.

repeater A device that regenerates and retimes network signals at the bit level to allow them to travel a longer distance on the media.

RFI (radio frequency interference) Noise from other signals being transmitted nearby.

RJ-45 A connector commonly used for finishing a twisted-pair cable

sine waves Graphs of mathematical functions of many natural occurrences that change regularly over time, such as the distance from the earth to the sun, the distance from the ground while riding a Ferris wheel, and the time of day that the sun rises.

spectrum analyzer An electronic device that creates graphs for frequency-domain analysis. Engineers also use frequency-domain analysis to study signals.

square waves Graphs that do not continuously vary with time. The values remain the same for some time, then suddenly change, then remain the same, and then suddenly return to the initial value.

straight-through cable A cable that maintains the pin connection all the way through the cable. Thus, the wire connected to pin 1 is the same on both ends of the cable.

switch Sometimes described as a multiport bridge. While a typical bridge might have just two ports (linking two network segments), the switch can have multiple ports, depending on how many network segments are to be linked.

TIA/EIA-568-B standard Specifies ten tests that a copper cable must pass if it is used for modern, high-speed Ethernet LANs.

wave Energy traveling from one place to another.

WEP (wired equivalent privacy) A security mechanism, defined within the 802.11 standard, that is designed to protect the over-the-air transmission between wireless LAN access points and NICs.

white noise Noise that affects all transmission frequencies equally.

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. Which of the following is an 802.3u specification?
 - A. 10BASE-F
 - B. 10BASE-T
 - C. 100BASE-TX
 - D. 1000BASE-CX
2. Which of the following is the most appropriate choice for Ethernet connectivity?
 - A. Use 10-Mbps Ethernet as a connection between server and LAN.
 - B. Use Gigabit Ethernet as the link at the user level to provide good performance.
 - C. Use Fast Ethernet as a link between the user level and network devices to support the aggregate traffic from each Ethernet segment on the access link.
 - D. None of the above.
3. Which standards body created the cables and connector specification used to support Ethernet implementation?
 - A. ISO
 - B. ANSI
 - C. TIA/EIA
 - D. IETF
4. Which of the following statements does *not* correctly describe a media connector?
 - A. An RJ-45 connector is an 8-pin connector used mainly for terminating coaxial cable.
 - B. An AUI is a 15-pin connector used between a NIC and an Ethernet cable.
 - C. The GBIC is a transceiver that converts serial electric currents to optical signals, and vice versa.
 - D. None of the above.

5. For which of the following would you *not* need to provide a crossover cable?
 - A. Connecting uplinks between switches
 - B. Connecting routers to switches
 - C. Connecting hubs to switches
 - D. None of the above
6. Which technology is *not* a type of wireless communication?
 - A. Cellular
 - B. Wideband
 - C. Infrared
 - D. Spread spectrum
7. Which of the following is *not* a feature of wired equivalent privacy (WEP)?
 - A. WEP uses the RC4 stream cipher for encryption.
 - B. WEP is a security mechanism defined within in the 802.3 standards.
 - C. One of the goals of WEP is to deny access to the network by unauthorized users who do not possess the appropriate WEP key.
 - D. None of the above.
8. Which of the following is not a WAN implementation?
 - A. DSL
 - B. ISDN
 - C. Frame Relay
 - D. Ethernet
9. What type of data-transmission method is used by a WAN?
 - A. Parallel
 - B. Serial
 - C. Single
 - D. None of above
10. What best describes a DCE?
 - A. User device at the end of a network
 - B. Equipment that serves as the data source or destination
 - C. Physical devices such as protocol translators and multiplexers
 - D. Devices that make up the network end of the user-to-network interface

11. Which of the following media is used to interconnect the ISDN BRI port to the service-provider device?
 - A. CAT 5 UTP straight-through
 - B. CAT 5 UTP crossover
 - C. Coaxial
 - D. Fiber optic
12. What type of connector is used for DSL connection?
 - A. RJ-45
 - B. RJ-11
 - C. F
 - D. DB-9
13. What type of connector is used to connect a router and a cable system?
 - A. RJ-45
 - B. RJ-11
 - C. F
 - D. AUI
14. What type of cable is used to connect a terminal and a console port?
 - A. Straight-through
 - B. Rollover
 - C. Crossover
 - D. Coaxial



Objectives

Upon completion of this chapter, you will be able to

- Describe briefly the history of Ethernet
- Identify the IEEE standards
- Understand MAC addressing
- Identify the common fields of the data link layer frames
- Describe Media Access Control (MAC)
- Describe CSMA/CD
- Understand the operation of Ethernet
- Identify different types of collisions
- Explain collisions, collision domains, and broadcast domains
- Identify the Layer 1, 2, and 3 devices used to create collision domains and broadcast domains
- Discuss data flow and the problem with broadcasts
- Understand collisions and collision domains
- Understand broadcasts and broadcast domains
- Understand segmentation of a network and the devices used to create the segments

Chapter 5

Ethernet Fundamentals

Ethernet, in its various forms, is the most widely used local-area network (LAN) technology. Ethernet was designed to fill the middle ground between long-distance, low-speed networks and specialized, computer-room networks carrying data at high speeds for very limited distance.

Ethernet is well suited to applications in which a local communication medium must carry sporadic, occasionally heavy traffic at high-packet data rates. It was designed to enable sharing resources on a local workgroup level. Design goals include simplicity, low cost, compatibility, fairness, low delay, and high speed.

In this chapter, you learn about the history of Ethernet and IEEE Ethernet standards. This chapter discusses the operation of Ethernet, Ethernet framing, and error handling, as well as the different types of the collisions on Ethernet networks. In addition, this chapter introduces collision domains and broadcast domains. Finally, this chapter describes segmentation and the devices used to create network segments.

Please be sure to look at this chapter's associated e-Lab Activities, Videos, and Photo-Zooms that you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

History and Evolution of Ethernet

LANs are high-speed, low-error data networks that cover a relatively small geographic area (up to a few thousand meters). LANs connect workstations, peripherals, terminals, and other devices in a single building or other geographically limited area.

Ethernet is the dominant LAN technology in the world. Most of the traffic on the Internet originates and ends with an Ethernet connection. From its beginning in the 1970s, Ethernet has evolved to meet the increasing demand for high-speed LANs. When a new medium, fiber optics, was produced, Ethernet adapted to take advantage of fiber's great bandwidth and low error rate. Now the same basic protocol that transported data at 3 megabits per second (Mbps) in 1973 is carrying data at 10 gigabits per second (Gbps).

Ethernet's success is a result of its simplicity and ease of maintenance, its capability to incorporate new technologies, its reliability, and its low cost of installation and upgrade. With the introduction of Gigabit Ethernet, what started as a LAN technology has now had its reach extended to distances that make Ethernet a metropolitan-area and even a wide-area networking standard. This section provides an overview of the Ethernet, including the history of Ethernet, Ethernet naming convention, and Ethernet frame formats.

Introduction to Ethernet

The original idea for Ethernet grew out of the problem of allowing two or more users to use the same medium without each user's signals interfering with each other. This problem of multiple user access to a shared medium was studied in the early 1970s at the University of Hawaii. A system called Alohanet was developed to allow various stations on the Hawaiian Islands to each have structured access to the shared radio frequency band in the atmosphere. The original technology that today's Ethernet is based on was wireless. This work later formed the basis for the famous Ethernet MAC method known as *carrier sense multiple access collision detect (CSMA/CD)*. CSMA/CD is discussed in more detail later in this chapter.

The original version of Ethernet was the world's first LAN. It was designed more than 30 years ago by Robert Metcalfe and his coworkers at Xerox. The first Ethernet standard was published by a consortium of Digital Equipment Company, Intel, and Xerox (DIX) in 1980. Metcalfe wanted Ethernet to be a shared standard from which everyone could benefit. Therefore, DIX made the new standard an open standard, meaning that it was available to any company. This was not often done in the computer industry. The first products developed using the Ethernet standard were sold during the early 1980s. Ethernet products transmitted at 10 Mbps over thick (about the diameter of your smallest finger) coaxial cable up to a distance of 2 km. Ethernet was an instant success.

The *Institute of Electrical and Electronic Engineers (IEEE)* is a professional organization that defines network standards. In 1985, the IEEE standards committee for local and metropolitan networks published its standards for LANs. The IEEE LAN standards are the predominant and best-known LAN standards in the world today. These standards start with the number 802. The standard that was based on Ethernet is standard

802.3. The IEEE wanted to make sure that its standards were compatible with and fit into the ISO's OSI reference model. The IEEE divides the OSI data link layer into two separate sublayers: Media Access Control (MAC) and Logical Link Control (LLC).

As a result, some small modifications to the original Ethernet standard were made in the 802.3 standard. Some differences exist between the DIX Ethernet and the 802.3 specifications. However, the differences between the two standards are so minor that any Ethernet network interface card (NIC) can transmit and receive Ethernet and 802.3 packets and frames. Essentially, Ethernet and IEEE 802.3 are the same standards. Just remember that 802.3 is now the official IEEE Ethernet standard.

During the mid-1980s, Ethernet's 10-Mbps bandwidth was more than enough for the PCs of that era. By the early 1990s, PCs had become much faster and people were beginning to complain about the bottleneck caused by the small bandwidth of Ethernet LANs. In 1995, the IEEE announced a standard for a 100-Mbps Ethernet. This was followed by standards for Gigabit (1 billion bits per second) Ethernet in 1998 and 1999. IEEE approved the standards for 10-Gb Ethernet in June 2002. These more modern standards are still Ethernet (802.3).

All the new Ethernet standards are essentially compatible with the original Ethernet standard. An Ethernet packet (a frame) could leave an older 10-Mbps NIC in a PC, eventually be placed by a router onto a 10-Gbps Ethernet fiber link, and then end up at a 100-Mbps Ethernet card. As long as the packet stayed on Ethernet networks, it would not be changed. This illustrates one of the main reasons for Ethernet's great success—it is very scalable. That means that the bandwidth of the network could be increased again and again without changing the underlying Ethernet technology.

The original Ethernet (IEEE 802.3) has been supplemented a number of times to incorporate new transmission media and to enable higher transmission rates. However, it is important to understand that the essential qualities of the original Ethernet have been retained. The Ethernet 802.3 standards all belong to the same family. Differences exist between the standards, but their similarities are greater than their differences. What has been retained from the original in each new standard means that the 802.3 family of protocols are all compatible.

IEEE Ethernet Naming Rules

The term *Ethernet* refers to a family of networking technologies that include original Ethernet, *Fast Ethernet*, *Gigabit Ethernet* (or Gig-E), and *10-Gb Ethernet* (or 10-G). These various types of Ethernet are discussed in detail in Chapter 6, "Ethernet Technologies and Ethernet Switching."

Ethernet interfaces can range from US\$10 to \$100,000. Ethernet speeds can be 10, 100, 1000, or 10,000 Mbps. This section explores more details of original Ethernet (10BASE-T), Fast Ethernet (100BASE-TX and 100BASE-FX), Gigabit Ethernet (1000BASE-T and 1000BASE-X), and 10-Gb Ethernet. Two features of Ethernet remain consistent across all forms of Ethernet: the basic frame format and the IEEE sublayers of OSI Layer 2.

When Ethernet needs to be expanded to add a new medium or capability, the IEEE issues a new supplement to the 802.3 standard. The new supplements are given a one- or two-letter designation—for example, 802.3u is Fast Ethernet. An abbreviated description (called an identifier) also is assigned to the supplement. The following are examples of some of the supplements:

- 10BASE2 (IEEE 802.3a)
- 10BASE5 (IEEE 802.3)
- 100BASE-T (IEEE 802.3i)
- 1000BASE-TX (IEEE 802.3X)

As you can see, the abbreviated description consists of these parts:

- A number indicating the number of megabits per second transmitted
- The word BASE, indicating that baseband signaling is used
- Numbers (the 2 and 5) that refer to the coaxial cable segment length (the 185m length has been rounded up to 2, for 200)
- One or more letters of the alphabet indicating the type of medium used (F = fiber optical cable, T = copper unshielded twisted pair)

Baseband signaling is the simplest method of signaling. In baseband signaling, the whole bandwidth of the transmission medium is used for the signal. The data signal (a voltage on UTP or a flash of light on fiber) is transmitted directly over the transmission medium. No other special signal (known as a carrier signal) is required. Ethernet uses baseband signaling.

A second method of signaling, broadband signaling, is not used in Ethernet. In broadband signaling, the data signal is never placed directly on the transmission medium. Instead, an analog signal called the carrier signal is modulated by the data signal. Then this modulated carrier signal is transmitted. Radio broadcasts and cable TV use broadband signaling.

Like the International Organization for Standardization (ISO), the IEEE is a standards-making organization. The manufacturers of networking equipment are not required to fully comply with all the specifications of any standard. The goals of IEEE are as follows:

- To supply the engineering information necessary to build devices that comply with an Ethernet standard
- To not stifle innovation by manufacturers

If you are setting up or maintaining a small LAN, you can buy all your equipment from one reputable manufacturer. Then you can be assured of the compatibility of all the devices. However, if you are responsible for a large network made up of many smaller Ethernet LANs with equipment from a mix of vendors, your situation is very different. The capability to use equipment from a variety of vendors to interoperate reliably is a very important issue. It is unfortunate that no industry or governmental agency exists to test and certify that a device fully meets an IEEE standard. However, that is a very good reason for you to educate yourself about the standards and the industry. The fact is, you have only your own knowledge and that of your coworkers on which to base your design and purchasing decisions.

IEEE 802.3/Ethernet and the OSI Model

LAN standards define the physical media and the connectors used to connect devices to media at the physical layer of the OSI reference model. LAN standards also define the way devices communicate at the data link layer. In addition, LAN standards define how to encapsulate protocol-specific traffic in such a way that traffic going to different upper-layer protocols can use the same channel that passes through those layers of the OSI model. To provide these functions, the IEEE Ethernet data link layer has two sublayers:

- **Media Access Control (MAC) (802.3)**—As the name implies, the MAC sublayer defines how to transmit frames on the physical wire. It handles physical addressing associated with each device, network topology definition, and line discipline.
- **Logical Link Control (LLC) (802.2)**—As the name implies, the LLC sublayer is responsible for logically identifying different protocol types and then encapsulating them. A type code or a service access point (SAP) identifier performs the logical identification. The type of LLC frame used by an end station depends on what identifier the upper-layer protocol (such as IP) expects. Although *IEEE 802.2* represents one standard type of frame *encapsulation*, there are others, such as Ethernet II (used primarily with TCP/IP-based Ethernet LANs). These are discussed later in the chapter.

As shown in Figure 5-1, the *IEEE 802.3* standard defines the physical layer (Layer 1) and the MAC portion of the data link layer (Layer 2).

Figure 5-1 802.3 Ethernet and the OSI Model

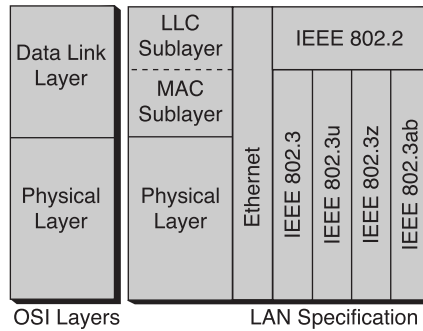
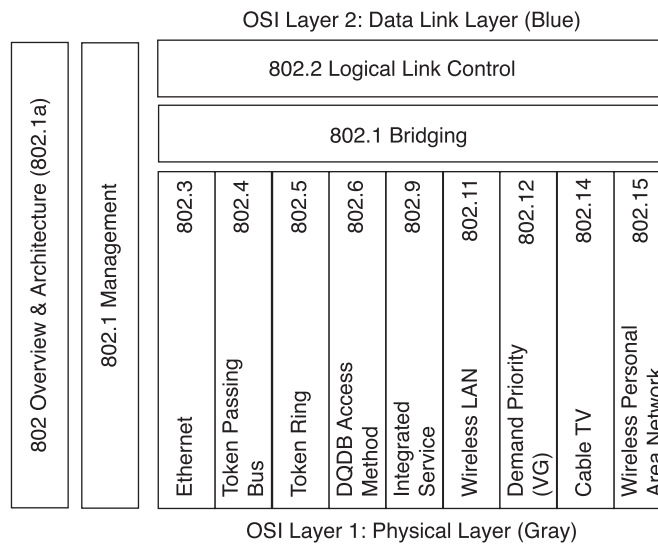


Figure 5-2 maps a variety of technologies to OSI Layer 1 and the lower half of Layer 2. In this book, we focus primarily on Ethernet LAN technology. Layer 1, the physical layer, involves interfacing with media, signals, bit streams that travel on media, components that put signals on media, and various topologies. The physical layer performs a key role in the communication that takes place between computers, but its efforts alone are not enough. Each of its functions has its limitations. Layer 2 addresses these limitations.

Figure 5-2 LAN Specifications and OSI Model



For each limitation in Layer 1, Layer 2 has a solution, as documented in Table 5-1.

Table 5-1 Layer 1 Limitations Versus Layer 2 Solutions

Layer 1 Limitation	Layer 2 Solution
Layer 1 cannot communicate with the upper-level layers.	Layer 2 communicates with upper-level layers via the LLC sublayer.
Layer 1 cannot identify computers.	Layer 2 identifies computers using the MAC addressing scheme.
Layer 1 can only describe streams of bits.	Layer 2 uses framing to organize or group the bits. (This process ultimately provides a way for the bits to convey meaning.)
Layer 1 cannot decide which computer will transmit binary data from a group that is all trying to transmit at the same time.	Layer 2 uses the MAC sublayer to accomplish this.

The Layer 2 sublayers, LLC and MAC, are active, vital agreements that make technology compatible and computer communication possible. The MAC sublayer is concerned with the physical components that will be used to communicate the information. Like the other layers, the LLC remains relatively independent of the physical equipment that will be used for the communicative process. The LLC allows multiple Layer 3 protocols, such as IP and IPX, to be simultaneously supported along with multiple frame types.

Figure 5-3 maps a variety of Ethernet technologies to the lower half of OSI Layer 2, and all of Layer 1. Although there are other varieties of Ethernet, the ones depicted are the most widely used and are the focus of this course.

Figure 5-3 Ethernet Technologies and OSI Model

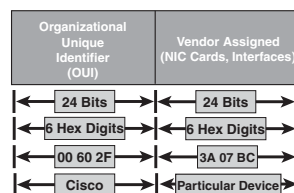
Logical Link Control Sublayer 802.3 Media Access Control	
Physical Signaling Layer	Physical Medium
10BASE5 (500 m) 50 Ohm Coax N-Style	10BASE5 (500 m) 50 Ohm Coax N-Style
10BASE2 (185 m) 50 Ohm Coax BNC	10BASE2 (185 m) 50 Ohm Coax BNC
10BASE-T (100 m) 100 Ohm UTP RJ45	10BASE-T (100 m) 100 Ohm UTP RJ45
10BASE-TX (100 m) 100 Ohm UTP RJ45	10BASE-TX (100 m) 100 Ohm UTP RJ45
100BASE-FX (228_412 m) MM Fiber SC	100BASE-FX (228_412 m) MM Fiber SC
1000BASE-T (100 m) 100 Ohm UTP RJ45	1000BASE-T (100 m) 100 Ohm UTP RJ45
1000BASE-SX (220-550 m) MM Fiber SC	1000BASE-SX (220-550 m) MM Fiber SC
1000BASE-LX (550-5000 m) MM Fiber Sc	1000BASE-LX (550-5000 m) MM Fiber Sc
10BASE-(Various) MM or Sm Fiber SC	10BASE-(Various) MM or Sm Fiber SC

MAC Addressing

To allow for local delivery of frames on the Ethernet, there must be an addressing system, a way of naming the computers and interfaces. Every computer has a unique way of identifying itself. Each computer on a network has a physical address. No two physical addresses on a network should ever be alike. Referred to as the *Media Access Control (MAC) address*, the physical address is located on the NIC. Other terms for the MAC address include the hardware address, the NIC address, the Layer 2 address, and the Ethernet address.

Ethernet uses MAC addresses to uniquely identify individual devices. Every device (PC, router, switch) with an Ethernet interface to the LAN must have a MAC address; otherwise, other devices cannot communicate with it. A MAC address is 48 bits in length and is expressed as 12 hexadecimal digits. The first six hexadecimal digits, which are administered by the IEEE, identify the manufacturer or vendor and thus comprise the *organizationally unique identifier (OUI)*. The remaining six hexadecimal digits comprise the interface serial number, or another value administered by the specific vendor. MAC addresses sometimes are referred to as burned-in addresses (BIAs) because they are burned into read-only memory (ROM) and are copied into random-access memory (RAM) when the NIC initializes. Figure 5-4 illustrates the MAC address format.

Figure 5-4 MAC Address Format



Without MAC addresses, the LAN would be a group of computers without identifiers, and it would be impossible to deliver an Ethernet frame. Therefore, at the data link layer, a *header* and a *trailer* are added to upper-layer data. The header and trailer contain control information intended for the data link layer entity in the destination system. Data from upper-layer entities is encapsulated in the data link layer header and trailer.

Ethernet and 802.3 LANs are broadcast networks. All stations see all frames. Each station must examine every frame to determine whether that station is the desired destination.

On an Ethernet network, when one device wants to send data to another device, it can open a communication pathway to the other device by using its MAC address. When a

source device sends data out on a network, the data carries the MAC address of its intended destination. As this data propagates along the network medium, the NIC in each device on the network checks to see if its MAC address matches the physical destination address carried by the data frame. If there is no match, the NIC discards the data frame.

If there is a match, the NIC verifies the destination address in the frame header to determine whether the packet is properly addressed. When the data passes its destination station, the NIC for that station makes a copy, takes the data out of the envelope, and gives the data to the computer to be processed by upper-layer protocols such as IP and TCP.

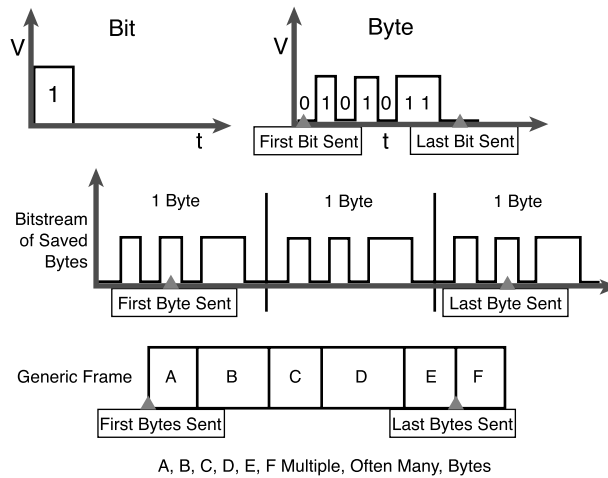
Framing in General

Encoded bit streams on physical media represent a tremendous technological accomplishment, but they alone are not enough to make communication happen. Framing helps obtain essential information that could not otherwise be obtained with coded bit streams alone. Examples of such information are listed here:

- Which computers are communicating with one another
- When communication between individual computers begins and when it terminates
- Recognition of errors that occur during the communication
- Whose turn it is to “talk” in a computer “conversation”
- Where the data is located within the frame

When you have a way to identify computers, you can move on to framing. Framing is the Layer 2 encapsulation process. A frame is the Layer 2 protocol data unit. Figure 5-5 illustrates the ideas of bits and frames.

When you work with bits, the most accurate diagram you can use to visualize them is a graph showing voltage versus time. However, because you usually deal with larger units of data and addressing and control information, this type of graph could become ridiculously large and confusing. Another type of diagram you could use is the frame format diagram, which is based on voltage versus time graphs. You read them from left to right, just like an oscilloscope graph. The frame format diagram shows different groupings of bits (fields); certain functions are associated with the different fields.

Figure 5-5 From Bits to Frame

Many different types of frames are described by various standards. A single generic frame has sections called *fields*, and each field is composed of bytes (see Figure 5-6). The names of the *fields* commonly found in a data link layer frame are as follows:

- Frame Start field
- Address field
- Length/Type/Control field
- Data field
- Frame Check Sequence (FCS) field

Figure 5-6 A Generic Frame Format

Field Names				
A	B	C	D	E
Start Frame Field	Address Field	Length/Type/Control Field	Data Field	FCS Field

The sections that follow describe the different frame fields in more detail.

Frame Start Field

When computers are connected to a physical medium, there must be a way for them to grab the attention of other computers to broadcast the message, as in, “Here comes a frame!” Various technologies have different ways of doing this process, but, regardless of technology, all frames have a beginning signaling sequence of bytes.

Address Field

All frames contain identification information, such as the address of the source computer (MAC address) and the address of the destination computer (MAC address).

Length and Type Fields

Most frames have some specialized fields. In some technologies, a Length field specifies the exact length of a frame. Some have a Type field, which specifies the Layer 3 protocol making the sending request. There is also a set of technologies in which no such fields are used.

Data Field

The reason for sending frames is to get higher-layer data, ultimately the user application data, from the source computer to the destination computer. The data package that you want to deliver includes the message that you want to send (the data). Padding bytes are added sometimes so that the frames have a minimum length. Logical Link Control (LLC) bytes also are included with the data field in the IEEE standard frames. Remember that the LLC sublayer adds control information to the network protocol data, a Layer 3 packet, to help deliver that packet to its destination. Layer 2 communicates with upper layers through LLC.

Frame Check Sequence Field

All frames (and the bits, bytes, and fields contained within them) are susceptible to errors from a variety of sources. The Frame Check Sequence (FCS) field contains a number based on the data in the frame; this number is calculated by the source computer. When the destination computer receives the frame, it recalculates the FCS number and compares it with the FCS number included in the frame. If the two numbers are different, an error is assumed and the frame is discarded.

The Frame Check Sequence number normally is calculated through the use of a cyclic redundancy check (CRC), which performs polynomial calculations on the data.

Ethernet Frame Structure

At the MAC sublayer, the frame structure is nearly identical for all speeds of Ethernet (10/100/1,000/10,000 Mbps). Half-duplex Gigabit Ethernet 1000BASE-T and the “W” versions of 10-Gb Ethernet have certain timing issues that require minor differences in how the interframe spacing is handled by the MAC sublayer, but these are otherwise the same as the other speeds. However, at the physical layer, almost all versions of Ethernet are substantially different from one another, and each speed has its own set of architecture design rules.

IEEE 802.3 Ethernet Frame

In addition to the 802.2 frame type discussed previously, there is a simpler IEEE 802.3 frame type, which was the first developed by the IEEE. As with 802.2, however, it is not used widely in today’s Ethernet LANs. Figure 5-7 shows the basic IEEE 802.3 Ethernet frame format.

Figure 5-7 IEEE 802.3 Ethernet Frame Structure

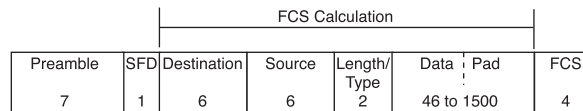


Table 5-2 lists the octet number and name for each 802.3 Ethernet frame field.

Table 5-2 IEEE 802.3 Ethernet Frame Fields

Octets in Each Frame Field	Frame Field
7	Preamble
1	Start Frame Delimiter (SFD)
6	Destination MAC Address
6	Source MAC Address
2	Length/Type Field (Length if less than 0600 in hexadecimal—otherwise, protocol Type)
46 to 1500	Data and Pad
4	Frame Check Sequence (CRC Checksum)

Ethernet II Frame

In the DIX version of Ethernet that was developed before the adoption of the IEEE 802.3 version of Ethernet, the Preamble and Start Frame Delimiter (SFD) fields were combined into a single field, although the binary pattern was identical. The field labeled Length/Type was listed only as Length in the early IEEE versions and only as Type in the DIX version. These two uses of the field officially were combined in a later IEEE version because both uses of the field were common throughout the industry. The early DIX Ethernet frame format, also known as Ethernet Version 2 or Ethernet II, is the most commonly used frame type with TCP/IP-based Ethernet LANs. Figure 5-8 illustrates the Ethernet II frame format.

Figure 5-8 Ethernet II Frame Format

Preamble	Destination	Source	Type	Data	Pad	FCS
8	6	6	2	46 to 1500		4

Table 5-3 lists the octet number and name for each Ethernet II frame field.

Table 5-3 Ethernet II Frame Fields

Octets in Each Frame Field	Frame Field
8	Preamble (ending in pattern 10101011, the 802.3 SFD)
6	Destination MAC Address
6	Source MAC Address
2	Type Field (46 to 1500 data—if less than 46 octets, a pad must be added to the end)
46 to 1500	Data and Pad
4	Frame Check Sequence (CRC Checksum)

As indicated in Table 5-3, use of the Ethernet II Type field is incorporated into the current 802.3 frame definition. Upon receipt, a station must determine which higher-layer protocol is present in an incoming frame. This first is attempted by examining the Length/Type field. If the two-octet value is equal to or greater than 600 hex, the frame is interpreted according to the Ethernet II type code indicated. If it is less than 600 hex, the frame is interpreted as an 802.3 frame and the length of the frame is indicated. Further investigation is required to determine how to proceed. To proceed from here, the first four octets of the 802.3 Data field are examined. The value found in those first

four octets usually is checked for two unique values; if they are not present, the frame is assumed to be an 802.2 Logical Link Control (LLC) sublayer encapsulation and is decoded according to the 802.2 LLC encapsulation indicated. One of the two values tested for is AAAA in hexadecimal, which indicates an 802.2/802 (Subnetwork Access Protocol [SNAP]) encapsulation. The other value tested for is FFFF in hexadecimal, which might indicate an old Novell Internetwork Packet Exchange (IPX) “raw” encapsulation.

Ethernet Frame Fields

The following list shows most of the fields permitted or required in an 802.3 Ethernet Frame. Refer back to Figure 5-8 for an illustration of the 802.3 Ethernet frame:

- **Preamble**—This field contains an alternating pattern of 1s and 0s that was used for timing synchronization in the asynchronous 10-Mbps and slower implementations of Ethernet. Faster versions of Ethernet are synchronous, so this timing information is redundant but is retained for compatibility. The preamble is seven octets in length and is represented by the following binary pattern:

```
10101010 10101010 10101010 10101010 10101010 10101010 10101010
```

- **Start Frame Delimiter (SFD)**—This a one-octet field that marks the end of the timing information. It is represented by the binary pattern 10101011. In the early DIX form of Ethernet, this octet was the last in the eight-octet preamble. Although the old DIX Ethernet described the first eight octets differently than the IEEE Ethernet, the pattern and usage is identical. Also, the timing information represented by the preamble and SFD is discarded and is not counted toward the minimum and maximum frame sizes.
- **Destination Address**—This field contains the six-octet MAC destination address. The destination address can be a unicast (single node), multicast (group of nodes), or broadcast address (all nodes).
- **Source Address**—This field contains the six-octet MAC source address. The source address is supposed to be only the unicast address of the transmitting Ethernet station. However, there are an increasing number of virtual protocols in use, which use and sometimes share a specific source MAC address to identify the virtual entity.

In the early Ethernet specifications, MAC addresses were optionally two or six octets, as long as the size was constant throughout the *broadcast domain*. Two-octet addressing first was excluded explicitly in paragraph 3.2.3 in the 1998 version of 802.3 and no longer is supported in 802.3 Ethernet.

- **Length/Type**—If the value is less than 1536 decimal (0600 hexadecimal), value indicates Length. The Length interpretation is used where the LLC layer provides the protocol identification.
 - **Type (Ethernet)**—The Type specifies the upper-layer protocol to receive the data after Ethernet processing is complete.
 - **Length (IEEE 802.3)**—The Length indicates the number of bytes of data that follows this field. If the value is equal to or greater than 1536 decimal (0600 hexadecimal), the value indicates Type, and the contents of the Data field are decoded per the protocol indicated. A list of common Ethertype protocols is found in RFC 1700, beginning around page 168.

- **Data and Pad**—This field can be of any length that does not cause the frame to exceed the maximum frame size. The *maximum transmission unit (MTU)* for Ethernet is 1500 octets, so the data should not exceed that size. The content of this field is unspecified. An unspecified pad is inserted immediately after the user data when there is not enough user data for the frame to meet the minimum frame length.

The frame structure figures depict the Data field as being between 46 and 1500 octets. In fact, Ethernet does not specify this. The frame is required to be not less than 64 octets or more than 1518 octets, without actually specifying the size of the data field. This left the user to calculate the size of the data field by subtracting all the other fields from the frame size. If the currently required six octet MAC addresses are used, the data field size will be between 46 (padded, if necessary) and 1500 octets.

- **Data (IEEE 802.3)**—After physical layer and data link layer processing is complete, the data is sent to an upper-layer protocol, which must be defined within the data portion of the frame. If data in the frame is insufficient to fill the frame to its minimum 64-byte size, padding bytes are inserted to ensure at least a 64-byte frame.
- **Frame Check Sequence (FCS)**—This sequence contains a 4-byte CRC value that is created by the sending device and is recalculated by the receiving device to check for damaged frames. The mathematical result of a cyclic redundancy check (CRC) algorithm is placed in this four-octet field. The sending station calculates the checksum for the transmitted frame, and the resulting four-octet value is appended following the Data/Pad. Receiving station(s) perform the same calculation and compare the new checksum against the checksum found at the end of the transmitted frame. If the two match, the frame is good. The fields used in the calculation include everything from the beginning of the destination address to the end of the Data/Pad as shown in Figure 5-7. The preamble, shown in Figure 5-8,

illustrates that SFD and Extension fields are not included in the calculation. The FCS is the only Ethernet field transmitted in noncanonical order (MSB first).

Because the corruption of a single bit anywhere from the beginning of the destination address through the end of the FCS field causes the checksum to be different, the coverage of the FCS includes itself. It is not possible to distinguish between corruption of the FCS itself and corruption of any preceding field used in the calculation.

Ethernet Operation

When multiple stations (nodes) must access physical media and other networking devices, various media access control strategies are used. This section briefly reviews the access-control strategies and focuses on Ethernet access control method—CSMA/CD.

It should be noted that although CSMA/CD has immense historical importance and practical importance in original Ethernet, it is diminishing somewhat in implementation for two reasons:

- When four-pair UTP is used, separate wire pairs for transmission (Tx) and reception (Rx) exist making, copper UTP potentially free from collisions and capable of full-duplex operation, depending on whether it is deployed in a shared (hub) or switched environment.
- Similar logic applies to optical fiber links, where separate optical paths—a transmission fiber and an reception fiber—are used.

One new form of Ethernet—1000BASE-TX, Gigabit Ethernet over copper—uses all four wire pairs simultaneously in both directions, resulting in a permanent collision. In older forms of Ethernet, such a permanent collision, preclude the system from working. Yet in 1000BASE-TX, sophisticated circuitry can accommodate this permanent collision, resulting from an attempt to get as much data as possible over UTP.

Media Access Control

Media Access Control (MAC) refers to protocols that determine which computer on a shared-medium environment (collision domain) is allowed to transmit the data. MAC, with LLC, comprises the IEEE version of Layer 2. MAC and LLC are both sublayers of Layer 2. Two broad categories of MAC exist:

- Deterministic (taking turns)
- Nondeterministic (first come, first served)

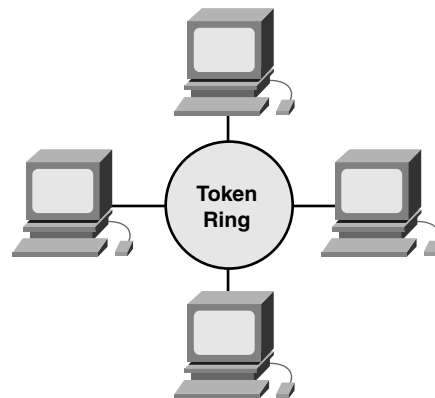
Token Ring and FDDI are deterministic, and Ethernet/802.3 is nondeterministic (also called probabilistic).

Deterministic MAC Protocols

Deterministic MAC protocols use a form of taking turns. Token passing is example of the deterministic MAC protocol. Some Native American tribes used the custom of passing a “talking stick” during gatherings. Whoever held the talking stick was allowed to speak. When that person finished, he or she passed it to another person.

In this analogy, the shared medium is the air, the data is the words of the speaker, and the protocol is possession of the talking stick. The stick might even be called a token. This situation is similar to a data link protocol called a Token Ring. In a Token Ring network, individual hosts are arranged in a ring, as shown in Figure 5-9. A special data token circulates around the ring. When a host wants to transmit, it seizes the token, transmits the data for a limited time, and then places the token back in the ring, where it can be passed along, or seized, by another host.

Figure 5-9 A Token Ring Network



Nondeterministic MAC Protocols

Nondeterministic MAC protocols use a first-come, first-served (FCFS) approach. CSMA/CD is an example of a nondeterministic MAC protocol.

To use this shared-medium technology, Ethernet allows the networking devices to arbitrate for the right to transmit. Stations on a CSMA/CD network listen for quiet, at which time it's okay to transmit. However, if two stations transmit at the same time, a *collision* occurs and neither station's transmission succeeds. All other stations on the network also hear the collision and wait for silence. The transmitting stations, in turn, each wait a random period of time (a backoff period) before retransmitting, thus minimizing the probability of a second collision.

Three Specific Topological Implementations and Their MACs

Three well-known Layer 2 technologies are Token Ring, FDDI, and Ethernet. Of these, Ethernet is by far the most common; however, they all serve to illustrate a different approach to LAN requirements. All three specify Layer 2 elements (for example, LLC, naming, framing, and MAC), as well as Layer 1 signaling components and media issues. The specific technologies for each are as follows:

- **Ethernet**—Logical bus topology (information flow on a linear bus) and physical star or extended star (wired as a star)
- **Token Ring**—Logical ring topology (in other words, information flow controlled in a ring) and a physical star topology (in other words, wired as a star)
- **FDDI**—Logical ring topology (information flow controlled in a ring) and physical dual-ring topology (wired as a dual-ring)

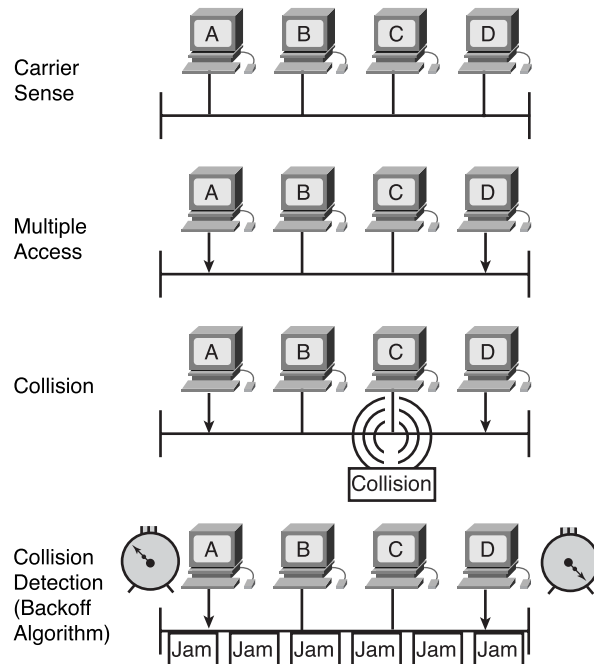
Ethernet MAC

Ethernet is a shared-media broadcast technology. The access method CSMA/CD used in Ethernet performs three functions:

- Transmitting and receiving data packets
- Decoding data packets and checking them for valid addresses before passing them to the upper layers of the OSI model
- Detecting errors within data packets or on the network

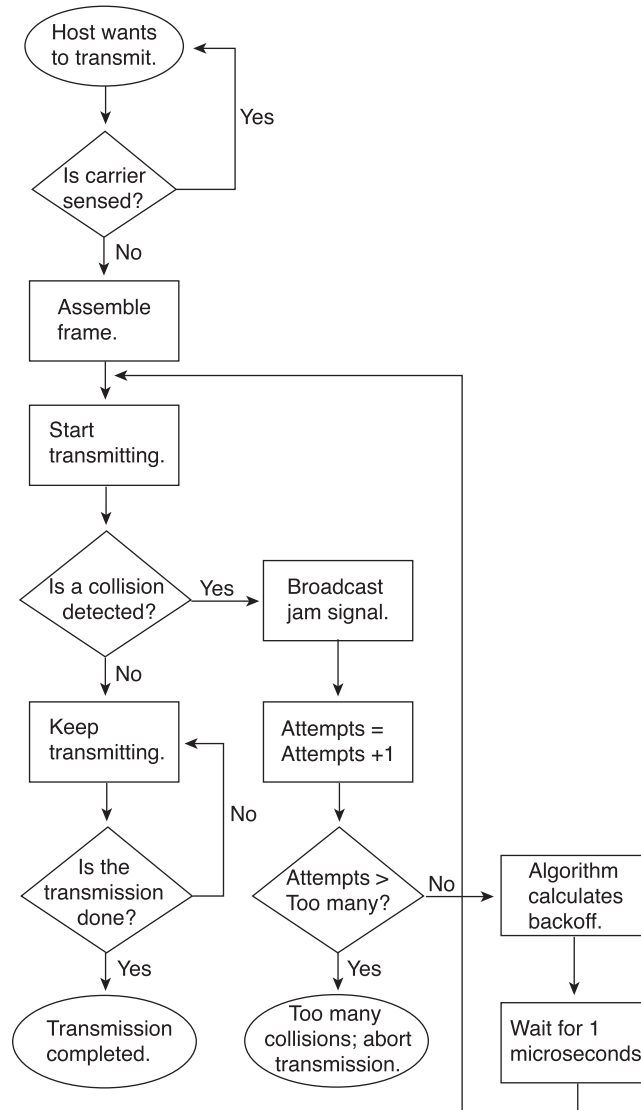
In the CSMA/CD access method, networking devices with data to transmit over the networking media work in a listen-before-transmit mode (CS = carrier sense). With shared Ethernet, this means that when a device wants to send data, it first must check to see whether the networking medium is busy. The device must check whether there are any signals on the networking media. After the device determines that the networking media is not busy, the device begins to transmit its data. While transmitting its data in the form of signals, the device also listens, to ensure that no other stations are transmitting data to the networking medium at the same time. If two stations send data at the same time, a collision occurs, as shown in the upper half of Figure 5-10. When it completes transmitting its data, the device returns to listening mode. With traditional shared Ethernet, only one device can transmit at a time. This is not true with switched Ethernet, which is covered in Chapter 6.

Figure 5-10 CSMA/CD



Networking devices are capable of detecting when a collision has occurred because the amplitude of the signal on the networking media increases (CD = collision detect). When a collision occurs, each device that is transmitting continues to transmit data for a short time, to ensure that all devices see the collision. When all devices on the network have seen that a collision has occurred, each transmitting device invokes an algorithm, known as a *backoff* algorithm. When all transmitting devices on the network have backed off for a certain period of time (random and, therefore, different for each device), any device can attempt to gain access to the networking media once again. When data transmission resumes on the network, the devices that were involved in the collision do not have priority to transmit data. Figure 5-11 summarizes the CSMA/CD process.

Figure 5-11 CSMA/CD Process



Ethernet is a *broadcast* transmission technology. This means that all devices on a network can see all frames that pass along the networking medium. However, not all the devices on the network will process the data. Only the device whose MAC address matches the destination MAC address carried by the frame copies the frame into its buffer. Ethernet is not concerned with Layer 3 network addresses such as IP or IPX. If the MAC addresses match, the frame is copied and passed up to Layer 3 to check the destination IP or IPX address for a match.

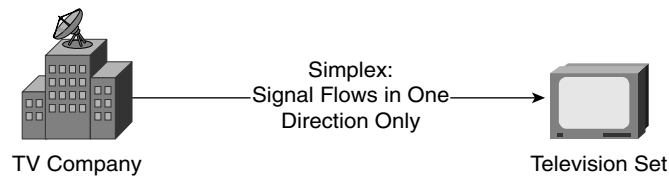
After a device has verified the destination MAC and IP addresses carried by the data, it checks the data packet for errors. If the device detects errors, the data packet is discarded. The destination device does not notify the source device, regardless of whether the packet arrived successfully. Ethernet is a *connectionless* network architecture and is referred to as a *best-effort delivery system*.

Simplex, Half-Duplex, and Full-Duplex Operation

The data channels over which a signal is sent can operate in one of three ways: simplex, half duplex, or full duplex. The distinction among these is in the way the signal can travel.

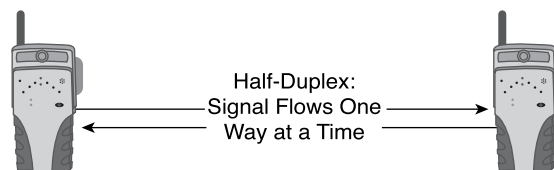
Simplex transmission, as its name implies, is simple. It is also called unidirectional because the signal travels in only one direction, just like traffic flows on a one-way street. Television or radio transmission is an example of simplex communication, as illustrated in Figure 5-12.

Figure 5-12 Simplex Transmission



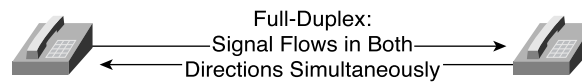
Half-duplex transmission is an improvement over simplex transmission; the traffic can travel in both directions. Half-duplex transmission enables signals to travel in either direction, but not in both directions simultaneously, as illustrated in Figure 5-13. Half-duplex Ethernet, defined in the original 802.3 Ethernet, uses only one wire, with a digital signal running in both directions on the wire. It allows data transmission in only one direction at a time between a sending station and a receiving station. It also uses the CSMA/CD protocol to help prevent collisions and retransmit if a collision does occur.

Figure 5-13 Half-Duplex Transmission



Full-duplex transmission, as illustrated in Figure 5-14, operates like a two-way, two-lane street. Traffic can travel in both directions at the same time. Ethernet full-duplex operation is made possible using switch technology, which is covered in greater depth in Chapter 6. Full-duplex switched networking technology increases performance because data can be sent and received at the same time. Full-duplex Ethernet uses two pairs of wires, which allow simultaneous data transmission between a sending station and a receiving station. Virtually no collisions occur in full-duplex Ethernet because switching technology creates a two-station point-to-point virtual circuit, or “microsegments,” when two devices need to communicate. Full-duplex Ethernet is supposed to offer 100 percent efficiency in both directions. This means that you can get 20 Mbps with a 10-Mbps Ethernet running in full-duplex operation. A 100-Mbps switch potentially can offer 200 Mbps to a station in full-duplex mode.

Figure 5-14 Full-Duplex Transmission



Ethernet Timing

Ethernet was designed to operate on a bus structure, which is a technical way to say that every station always hears all messages at almost the exact same time. The official designation is CSMA/CD. CSMA/CD can be interpreted simplistically to mean that when two stations realize that they are talking at the same time, they are supposed to stop and wait a polite amount of time before trying again.

The basic rules and specifications for proper operation of Ethernet are not particularly complicated, although some of the faster physical layer implementations are becoming so. Despite the basic simplicity, when a problem occurs in Ethernet, it is often quite difficult to isolate the source of the problem. Because of the common bus architecture of Ethernet (which can be described as a distributed single point of failure), the scope of the problem is usually all stations within the collision domain that are attached to the segment. When repeaters are used, this can include stations up to four segments away.

According to the rules, any station on an Ethernet network that wants to transmit a message first listens to ensure that no other station currently is transmitting. If the cable is quiet, the station begins transmitting immediately. But because the electrical signal takes a small amount of time to travel down the cable (called *propagation delay*), and each subsequent repeater encountered introduces a small amount of latency in forwarding the frame from one port to the next, it is possible for more than one station to begin transmitting at or near the same time. A collision then results.

If the attached station is operating in full duplex, the station can send and receive simultaneously, and collisions should not be present. Full-duplex operation also changes the timing considerations and eliminates the concept of slot time. Full-duplex operation allows for larger network architecture designs because the timing restriction for collision detection is removed.

In half-duplex operation, assuming that a collision does not occur, the sending station transmits 64 bits of timing synchronization information that often is known collectively as the preamble. The contents are as follows:

- Destination and source MAC addressing information
- Certain other header information
- The actual data payload
- A checksum (FCS) used to ensure that the message was not corrupted along the way

Stations receiving the frame recalculate the FCS to determine whether the incoming message is valid, and hand good messages to the next higher layer in the protocol stack.

For 10-Mbps Ethernet and slower versions, which are asynchronous, each receiving station uses the eight octets of timing information to synchronize its receive circuit to the incoming data but then discard it. The 100 Mbps higher-speed implementations of Ethernet are synchronous, so the timing information is not actually required at all. However, for compatibility reasons, the preamble and SFD are present. All information following the SFD at the end of the timing information is passed to the next higher layer. A new checksum is calculated and compared with the checksum found at the end of the received frame. If the frame is intact, it then must be interpreted according to the rules for whichever protocol is indicated by the Length/Type field or the LLC-layer protocol indicated by the first few octets of the data.

A notable number of changes to the basic structure of Ethernet were included in the 1998 and 2000 versions of the standard. One significant change was that two-octet addresses explicitly were excluded, although they were included in all previous versions. When used for Length, the maximum value for the 802.3 Length/Type field clearly was specified as 1536 (600 hex), where it previously was assumed to match the maximum MTU data size of 1500 (5DC hex).

For all speeds of Ethernet transmission at or below 1000 Mbps, the standard describes how a transmission can be no smaller than *slot time*. Slot time for 10 and 100 Mbps Ethernet is 512 bit-times (64 octets). Slot time for 1000 Mbps Ethernet is 4096 bit-times (512 octets, including the extension). Slot time is not defined for 10 Gbps Ethernet because it does not permit half-duplex operation. Slot time is just longer than the longest

possible round-trip delay time when maximum cable lengths are used on the largest legal network architecture and all hardware propagation delay times are at the legal maximum; the 32-bit jam signal is used when collisions are detected. In other words, slot time is just longer than the time it theoretically can take to go from one extreme end of the largest legal Ethernet collision domain to the other extreme end, collide with another transmission at the last possible instant, and then have the collision fragments return to the sending station and be detected. For the system to work, the first station must learn about the collision before it finishes sending the smallest legal frame size. To allow 1000 Mbps Ethernet to operate in half duplex, the Extension field was added when sending small frames, purely to keep the transmitter busy long enough for a collision fragment to make it back. This field is present only on 1000 Mbps half-duplex links, and it allows minimum-size 64-octet frames to be stretched long enough to meet slot-time requirements. Extension bits are discarded by the receiving station.

To examine the issue briefly, consider the following: On a 10 Mbps Ethernet, 1 bit at the MAC sublayer requires 100 nanoseconds (ns) to transmit. At 100 Mbps, that same bit requires 10 ns to transmit, and at 1000 Mbps, it takes only 1 ns. Table 5-4 summarizes the bit-time of different types of Ethernet.

Table 5-4 Bit-Time

Ethernet Speed	Bit-Time
10 Mbps	100 nanosecond
100 Mbps	10 nanosecond
1000 Mbps = 1 Gbps	1 nanosecond
10,000 Mbps = 10 Gbps	.1 nanosecond

As a rough estimate, 8 inches (20.3 cm) per nanosecond often is used for calculating propagation delay down a UTP cable. For 100m of UTP, this means that it takes just under 5 bit-times for a 10BASE-T signal to travel the length of a 100m cable (about 4.92 bit-times). Simply moving the decimal point over results in 49.2 bit-times at 100 Mbps, and 492 bit-times at 1000 Mbps.

For CSMA/CD Ethernet to operate, the sending station must become aware of a collision before it has completed transmission of a minimum-size frame. At 100 Mbps, the system timing is barely capable of accommodating 100m cables. At 1000 Mbps, special (very inefficient) adjustments were required because nearly an entire minimum-size frame has been transmitted before the first bit reaches the end of the first 100 meters of UTP cable. It is easy to see why half duplex was not permitted in 10-Gb Ethernet.

Interframe Spacing and Backoff

Table 5-5 shows the minimum spacing between two noncolliding packets, also called the interframe spacing, from the last bit of the FCS field of the first frame to the first bit of the preamble of the second frame.

Table 5-5 Interframe Spacing

Speed	Interframe Spacing	Time Required
10 Mbps	96 bit-times	9.6 μ sec
100 Mbps	96 bit-times	0.96 μ sec
1 Gbps	96 bit-times	0.096 μ sec
10 Gbps	96 bit-times	0.0096 μ sec

After a frame has been sent, all stations on a 10-Mbps Ethernet are required to wait a minimum of 96 bit-times (9.6 microseconds) before any station legally can transmit the next frame. On faster versions of Ethernet, the spacing remains the same: 96 bit-times. However, the time required for that interval grows correspondingly shorter, as shown in Table 5-6. This interval alternately is referred to as the interframe spacing, the interframe gap, and the interpacket gap, and it is intended to allow slow stations time to process the previous frame and prepare for the next frame.

Table 5-6 Slot Time Parameter

Speed	Slot Time*	Time Interval
10 Mbps	512 bit-times	51.2 μ sec
100 Mbps	512 bit-times	5.12 μ sec
1 Gbps	4096 bit-times	4.096 μ sec
10 Gbps	Not applicable	—

*Slot time applies only to half-duplex Ethernet links

However, a repeater is expected to regenerate the full 64 bits of timing information (preamble and SFD) at the start of any frame, despite the potential loss of some of the beginning preamble bits to slow synchronization. Thus, because of this forced reintroduction of timing bits, some minor reduction of the interframe gap is not only possible, but expected. Some Ethernet chip sets are sensitive to a shortening of the interframe

spacing and begin failing to see frames as the gap is reduced. With the increase in processing power at the desktop, it would be very easy for a personal computer to saturate an Ethernet segment with traffic and to begin transmitting again before the interframe spacing delay time is satisfied. Over the years, some vendors deliberately have violated the interframe gap a little to improve throughput testing results in competitive product comparisons. For the most part, this cheating on the interframe spacing has not caused problems, but it has the potential to do so.

After a collision occurs and all stations allow the cable to become idle (each waits the full interframe spacing), the stations that collided must wait an additional—and potentially progressively longer—period of time before attempting to retransmit the collided frame. The waiting period intentionally is designed to be semi-random so that two stations do not delay for the same amount of time before retransmitting; otherwise, the result would be more collisions. This is accomplished in part by expanding the interval from which the random retransmission time is selected on each retransmission attempt. The waiting period is measured in increments of the parameter slot time.

Retransmission is controlled by this formula:

$$0 = r < 2k$$

Here, r is some random number of slot times and k is the number of backoff attempts (up to a maximum of 10 for the backoff value). Backoff time is defined as follows:

$$r * \text{slot time}$$

The total maximum number of retransmission attempts is 16, although the backoff value remains at 10 for the last few attempts. The formula specifies the minimum waiting period for a retransmission attempt. It is quite acceptable, though not necessarily desirable, for a station to introduce extra delays that will degrade its own throughput.

As an example, after the fifth consecutive collision without being able to transmit the current 10BASE-T frame, the waiting time would be a random delay interval between 0 and 32 slot times ($0 = r < 25$). Restated, the delay would be a random number of 51.2 microsecond time units, ranging from an immediate retry attempt up to 1638.4 microseconds later.

If the MAC sublayer still cannot send the frame after 16 attempts, it gives up and generates an error to the next layer up. Such an occurrence is fairly rare and happens only under extremely heavy network loads or when a physical problem exists on the network.

In a special situation, the MAC sublayer experiences much more frequent failures to send a frame despite the 16 attempts, usually found on switched links. This is called

the capture effect or the packet starvation effect. When two devices (switches, stations, or both) connect in half-duplex operation and each is attempting to send a large block of traffic, a collision will certainly occur. Whichever station “wins” the first retransmission has a progressively greater chance to transmit with each subsequent collision. Assume that a second collision has taken place. The first station, which was capable of transmitting its first frame, again selects its random delay between 0 and 1 time intervals, while the second station now selects from 0, 1, 2, and 3 time intervals. It is highly likely that the first station will again select a shorter delay time and be capable of transmitting. The first station will probably win the retransmission for 16 consecutive attempts by the second station. The second station then will give up and discard that frame. It also will record an excessive collisions error. This type of error usually is revealed using the *Simple Network Management Protocol (SNMP)* to query a switch port, and it often is found even where only a single device is attached to the affected port. Because Ethernet is inherently bursty, this might be reported on ports with relatively low average utilization.

Error Handling

The most common (and usually benign) error condition on an Ethernet is the collision. Collisions are the mechanism for resolving contention for network access. A few collisions provide a smooth, simple, low-overhead way for network nodes to arbitrate contention for the network resource. When the network cannot operate properly because of various problems, collisions can become a significant impediment to useful network operation. Collisions are possible only on half-duplex segments.

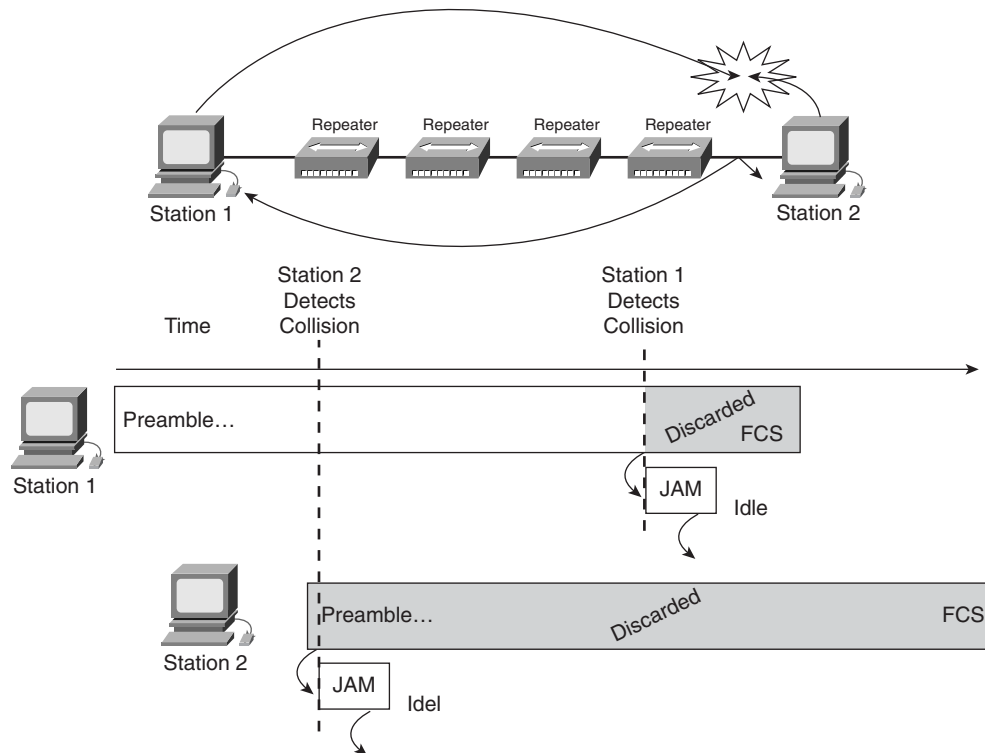
Collisions waste time in two ways: First, network bandwidth loss is equal to the initial transmission and the collision jam signal. This is called consumption delay, and it affects all network nodes. Consumption delay significantly can reduce network throughput. Following each successful or failed transmission attempt is an enforced idle time (backoff period) for all stations, called the interframe spacing (or interframe gap), that further impacts throughput. The second type of delay is a result of this collision backoff algorithm. Backoff delays are not usually significant.

The considerable majority of collisions occur very early in the frame, often before the SFD. Collisions occurring before the SFD usually are not reported to the higher layers, as if the collision did not occur. As soon as a collision is detected, the sending station(s) transmit a 32-bit jam signal that will enforce the collision. This is done so that any data being transmitted thoroughly is corrupted and all stations have a chance to detect the collision.

In Figure 5-15, two stations are listening to ensure that the cable is idle and then transmit. The 802.3 standard provides worst-case limits on how long each component in the system can delay a signal. The maximum allowed round-trip delay for a 10-Mbps

collision domain is 512 bit-times, a value that determines the minimum frame size. Station 1 is the first station transmitting, so that station sends the most data before a collision is detected. Station 2 is capable of sending only a few bits before the collision is detected.

Figure 5-15 Routine Error Handling in a 10-Mbps Collision Domain



Examine Figure 5-15 closely. Station 1 can transmit a significant percentage of the frame before the signal even reaches the last cable segment. Station 2 does not receive the first bit of the transmission before beginning its own transmission. Station 2 can send only several bits before the NIC senses the collision. Station 2 immediately truncates the current transmission and substitutes the 32-bit jam signal in its place. Then Station 2 ceases all transmissions. During the collision and jam event that Station 2 is experiencing, the collision fragments work their way back through the repeated collision domain toward Station 1. Station 2 completes transmission of the 32-bit jam signal and becomes silent before the collision can propagate back to Station 1. Station 1, still unaware of the collision, continues to transmit. When the collision fragments finally

reach Station 1, it also truncates the current transmission and substitutes a 32-bit jam signal in place of the remainder of the frame being transmitted. Upon sending the 32-bit jam signal, Station 1 ceases all transmissions.

A jam signal can be composed of any binary data, as long as it does not form a proper checksum for the portion of the frame already transmitted. The most commonly observed data pattern for a jam signal is simply a repeating 1, 0, 1, 0 pattern, the same as the preamble. When viewed by a protocol analyzer, this pattern appears as a repeating hexadecimal 5 or A sequence. The corrupted, partially transmitted messages often are referred to as collision fragments and sometimes by the slang term *runts*. Compared to late collisions, normal collisions are less than 64 octets in length and, therefore, fail both the minimum length test and the FCS checksum test.

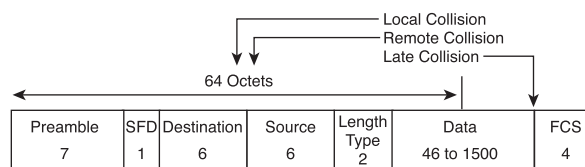
Types of Collisions

Collisions typically take place when two or more Ethernet stations transmit simultaneously within a collision domain. Collisions are reported by event counts by most diagnostic tools, but they might be reported separately as single collisions or multiple collisions when a switch or other station is queried with SNMP. A single collision refers to a collision that was detected while trying to transmit a frame, but, on the next attempt, the frame was transmitted successfully. Multiple collisions indicate that the same frame collided repeatedly before being successfully transmitted. This is different from frames with deferred transmissions because the deferred transmission frame did not collide. The medium was busy when the station or switch sought to transmit, and it was required to wait its turn to transmit. Because of repeated collisions of the same frame, the frame might not be transmitted at all, which would be reported as being aborted as the result of excessive collisions.

The results of collisions—partial and corrupted frames that are less than 64 octets and that have an invalid FCS—often are called collision fragments. Some protocol analyzers and network monitors call these fragments *runts*, but the term is imprecise.

The main Ethernet frame error types that can be captured through a protocol-analysis session are local collision, remote collision, and late collision. Figure 5-16 illustrates those collision types. The sections that follow briefly describe each frame error type.

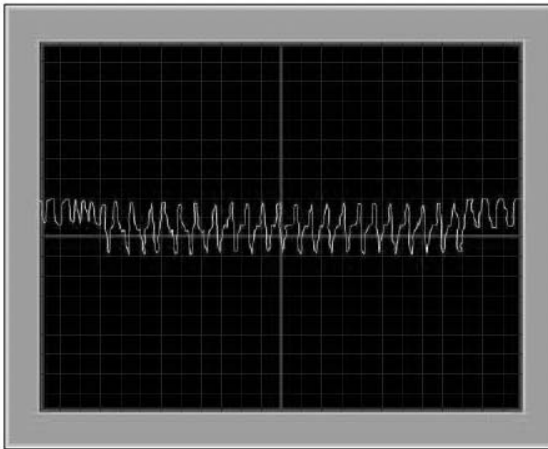
Figure 5-16 Summary of Collision Types: Local, Remote, and Late



Local Collision

To create a local collision on coax cable (10BASE2 and 10BASE5), the signal travels down the single cable until it encounters a signal from the other station. The waveforms then overlap, canceling out some parts of the signal and reinforcing (doubling) other parts. The doubling of the signal pushes the voltage level of the signal beyond the allowed maximum. This overvoltage condition is sensed by all of the stations on the local cable segment as a collision. A special circuit in the NIC monitors for this overvoltage condition. The overvoltage threshold is around -1.5 volts, as measured on the coax cable. Figure 5-17 shows a midframe in 10BASE2/10BASE5 collision captured by a digital storage oscilloscope.

Figure 5-17 10BASE2/10BASE5 Local Collision



In Figure 5-17, the beginning of the waveform represents normal Manchester-encoded data. A few cycles into the sample, the amplitude of the wave doubles. That is the beginning of the collision, where the two waveforms overlap. Just before the end of the sample, the amplitude returns to normal when the first station to detect the collision quit transmitting, and a jam from the second colliding station still is observed.

On UTP cable (such as 10BASE-T, 100BASE-TX, and 1000BASE-T), a collision is detected on the local segment only when a station detects a signal on the RX (receive) pair at the same time it is sending on the TX (transmit) pair. Because the two signals are on different pairs, there is no characteristic change in the signal, as shown in Figure 5-17. Collisions are recognized on UTP only when the station is operating in half duplex. The only functional difference between half- and full-duplex operation in this regard is whether both transmit and receive pairs are permitted to be used simultaneously. If the station is not engaged in transmitting, it cannot detect a local collision.

Conversely, a cable fault, such as excessive crosstalk, can cause a station to perceive its own transmission as a local collision.

Remote Collision

The characteristics of a remote collision are a frame that is less than the minimum length has an invalid FCS checksum, but does not exhibit the local collision symptom of overvoltage or simultaneous RX/TX activity. This sort of collision usually results from collisions that occur on the far side of a repeated connection. A repeater will not forward an overvoltage state and cannot cause a station to have both the TX and RX pairs active at the same time. The station would have to be transmitting to have both pairs active, and that would constitute a local collision. On UTP networks, this is the most common sort of collision observed. Nearly all monitoring tools that report collisions, such as software protocol analyzers and Remote Monitoring (RMON) probes, will detect only remote collisions because they are passive listening devices.

Late Collision

No possibility exists for a normal or legal collision after the first 64 octets of data have been transmitted by the sending station(s). The theoretical maximums for legal network propagation times are exceeded before then. Collisions that occur after the first 64 octets are called late collisions. The most significant difference between late collisions and collisions that occur before the first 64 octets is that the Ethernet NIC retransmits a normally collided frame automatically but does not automatically retransmit a frame that collided late. As far as the NIC is concerned, everything went out fine, and the upper layers of the protocol stack must deduce that the frame was lost. Other than retransmission, a station that detects a late collision handles it in exactly the same way as a normal collision.

In all but one case, the 802.3 standard permits a station to attempt to retransmit a frame that collided late, but it does not require this. Gigabit Ethernet explicitly denies late-collided frames from being retransmitted.

A late remote collision takes place after slot time has elapsed *and* on the far side of a repeater. However, because the repeater would prevent observation of the local collision symptoms of an overvoltage state or simultaneous receive/transmit event, monitoring hardware would have to be present on the distant segment to detect a late collision and report that information to the monitoring station. You also can infer that a late remote collision took place somewhere on the other side of a repeater by analyzing the last few octets of a bad frame for the presence of the pattern normally associated with a jam signal. Typically, this type of collision would be detected on the local segment simply as an FCS error.

Ethernet Errors

Why learn about Ethernet errors? Because Ethernet is a dominant LAN technology, an intimate knowledge of typical errors is invaluable for understanding both the operation and troubleshooting of Ethernets.

Whereas local and remote collisions are considered to be a normal part of Ethernet operation, the late collision is considered to be an error. The presence of errors on Ethernet always suggests that further investigation is warranted. The severity of the problem indicates the troubleshooting urgency related to the detected error(s). A handful of errors detected over many minutes or over hours would be a low priority. Thousands detected over a few minutes suggest that urgent attention is warranted. Situations that are considered Ethernet errors are as follows:

- Simultaneous transmission occurring before the slot time has elapsed (collision or runt)
- Simultaneous transmission occurring after the slot time has elapsed (late collision)
- Excessively or illegally long transmission (jabber, long frame, and range errors)
- Illegally short transmission (short frame, collision fragment, or runt)
- Corrupted transmission (FCS error)
- Insufficient or excessive number of bits transmitted (alignment error)
- Mismatch of actual and reported number of octets in frame (range error)
- Unusually long preamble or jam event (ghost or jabber)

Each situation is defined separately. Frames associated with error conditions are frequently, but not always, discarded. Normal collisions are included simply to provide a more complete list but are not actually considered errors. The sections that follow briefly describe some of the Ethernet errors.

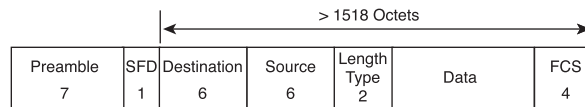
Jabber

Jabber is defined several places in the 802.3 standard as being a transmission of at least 20,000 to 50,000 bit-times in duration. However, most diagnostic tools report jabber whenever a detected transmission exceeds the maximum legal frame size—which is considerably smaller than 20,000 to 50,000 bit-times. This presents a rather fuzzy definition because the reporting device *might* or *might not* consider a 1518-octet frame with VLAN tagging added to be larger than the legal limit. Also, no indication exists as to whether jabber has a good or bad FCS. Most references to jabber more properly are called long frames.

Long Frame

A *long frame* is one that is longer than the maximum legal size and that takes into consideration whether the frame was tagged. It does not consider whether the frame had a valid FCS checksum. This error usually is meant when someone says that jabber was detected on the network. Figure 5-18 illustrates that a long frame is longer than 1518 octets.

Figure 5-18 Long Frame



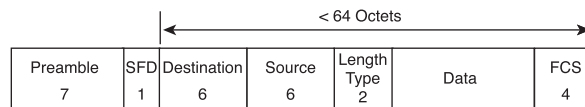
Jabber and long frames are both in excess of the maximum frame size. Jabber is significantly larger, however. If the frame is 802.1q tagged, that usually is not counted toward being illegally large. The IEEE 802.1Q standard defines the operation of virtual LAN (VLAN) bridges that permit the definition, operation, and administration of VLAN topologies within a bridged LAN infrastructure. The IEEE's 802.1Q standard was developed to address the problem of how to break large networks into smaller parts so that broadcast and multicast traffic would not grab more bandwidth than necessary.

Short Frame

A short frame is a frame smaller than the minimum legal size of 64 octets, with a good frame check sequence. Some protocol analyzers and network monitors call these frames runs, but the term is imprecise. In general, you should not see short frames, although their presence is no guarantee that the network is failing.

Short frames are formed properly in all but one aspect and have valid FCS checksums; they are less than the minimum frame size (64 octets), however. Figure 5-19 illustrates that a short frame is shorter than 64 octets.

Figure 5-19 Short Frame



Runt

The term *runt* is generally an imprecise slang term that means something less than a legal frame size. It can refer to short frames with a valid FCS checksums. It usually

refers to collision fragments. The Ethernet standard describes an SNMP management attribute called a runt that is approximately greater than 74 bit-times but less than the minimum frame size (64 octets at 10-/100-Mbps speeds, or the minimum half-duplex transmission event of 517 octets at 1000 Mbps); is *not* a local collision.

FCS Errors

A received frame with a bad frame check sequence (also referred to as a checksum or CRC error) is different by at least 1 bit from what was transmitted. In a frame with an FCS error, the header information is probably correct (the addressing and such), but the checksum calculated by the receiving station does not match the checksum appended to the end of the frame by the sending station. Trusting the accuracy of the addressing in a single frame is probably a bad idea, but if many frames have the same source address, there is a pretty good chance that the source address is correct.

A high number of FCS errors from a single station usually indicates a faulty NIC or faulty or corrupted software drivers, or a bad cable connecting that station to the network. If FCS errors are associated with many stations, it generally is traceable to bad cabling, a faulty version of a NIC driver, a faulty hub port, or induced noise in the cable system.

FCS errors are reported when at least 1 bit in the transmission is different. When a new checksum is calculated by the receiving station and compared to the checksum in the FCS field, the two do not match. The frame then is discarded.

Alignment Error

A message that does not end on an octet boundary is known as an *alignment error*. That is, instead of the correct number of binary bits to form complete octet groupings, some additional bits (less than 8) are left over. Such a frame is truncated to the nearest octet boundary; if the FCS checksum fails, an alignment error is reported. This often is caused by bad software drivers or a collision, and frequently is accompanied by a failure of the FCS checksum. Other causes are characterized by a read and write operation error, which is caused by software bugs. If an alignment error is not corrected, this can cause a crash. Usually, the software corrects itself, but this causes a sudden spike in CPU resources for the router.

Range Error

A frame that has a legal-size value in the Length field but that does not match the actual number of octets counted in the Data field of the received frame is known as a *range error*. This error also appears when the Length field value is less than the

minimum legal unpadding size of the Data field. A similar error, Out of Range, is reported when the value in the Length field indicates a data size that is too large to be legal.

Ghost

Fluke Networks has coined the term *ghost* to mean energy (noise) detected on the cable that appears to be a frame but that lacks a valid SFD. To qualify as a ghost, this “frame” must be at least 72 octets long (including the preamble); otherwise, it is classified as a remote collision. Because of the peculiar nature of ghosts, it is important to note that test results largely are dependent upon where on the segment the measurement is made.

Some types of noise fool nodes on a network segment into thinking they are receiving a frame. However, the sensed frame never comes, so no data is passed up into the NIC to be processed. After a while, the sensed transmission ceases and the NIC resumes sending its own messages. Different network interfaces react differently, and no standards define how or when an NIC should react to a noisy segment. Repeaters usually propagate these noise signals into other segments of the collision domain.

The visible symptom of ghosting is a network that is slow for no apparent reason. The file servers are nearly idle, and network-monitoring equipment shows very low network utilization, yet users complain that the network is excessively slow or completely down. The symptom might be geographically limited, with one end of a large/long segment seeming to operate and the other being slow or completely down.

Ground loops and other wiring problems are usually the cause of ghosting. Ghosts cause some repeaters to respond as though a frame is being received. Because the repeater reacts only to an AC voltage riding on the cable, there is no valid frame to pass on to the other ports. The repeater, however, transmits this energy on to its other port(s). The retransmitted ghost might appear as a jam pattern or a very long preamble.

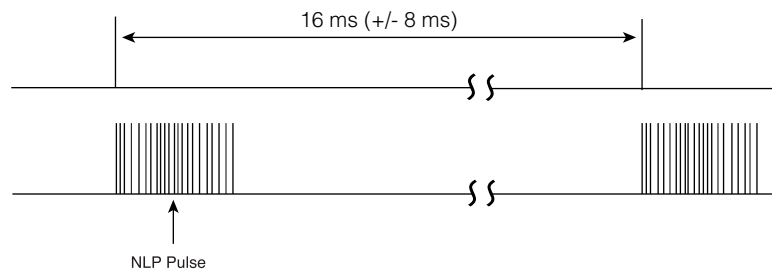
Most network-monitoring tools do not recognize the existence of ghosts, for the same reason that they do not recognize preamble collisions—they rely entirely on what the chip set tells them. Software-only protocol analyzers, many hardware-based protocol analyzers and hand-held diagnostic tools, and as most RMON probes do not report these events.

Ethernet Autonegotiation

As Ethernet grew from 10 to 100 and 1000 Mbps, one goal was to make each technology interoperable, even to the point that 10, 100, and 1000 interfaces could be directly connected. A process called autonegotiation (of speeds and half duplex or full duplex) was developed. Specifically, at the time that Fast Ethernet was introduced, the standard

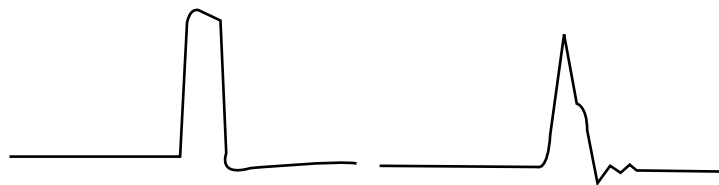
included a method of automatically configuring a given interface to match the speed and capabilities of the link partner. This process defines how two link partners automatically can negotiate a configuration that offers the best common performance level. It has the additional advantage of involving only the lowest part of the physical layer. 10BASE-T required each station to transmit a link pulse about every 16 milliseconds whenever the station was not engaged in transmitting a message. Autonegotiation adopted this signal and renamed it a Normal Link Pulse (NLP). When a series of NLPs are sent in a group for the purpose of autonegotiation, the group is called a Fast Link Pulse (FLP) burst. Each FLP burst is sent at the same timing interval as an NLP and is intended to allow older 10BASE-T devices to operate normally if they receive an FLP burst. Figure 5-20 illustrates the NLP and FLP timing.

Figure 5-20 NLP Versus FLP Timing



10BASE-T transmits using signaling between +1 and -1 volts, for a 2-volt peak-to-peak differential signal. NLP signaling uses only the range from 0 to +1 volts. The duration of a single NLP pulse is 100 ns. Figure 5-21 illustrates two sample NLP pulses. The left pulse is very sharp and clean, and is from an interface capable of 1000-Mbps operation. The right pulse is from an older device capable of only 10/100-Mbps operation, which does not require as precise of a signal.

Figure 5-21 NLP Pulses



Autonegotiation is accomplished by transmitting a burst of 10BASE-T link pulses from each of the two link partners. The burst communicates the capabilities of the transmitting station to its link partner. After both stations have interpreted what the other

partner is offering, both switch to the highest-performance common configuration and establish link at that speed. If anything interrupts communications and the link is lost, the two link partners first attempt to link again at the last negotiated speed. If that fails, or if it has been too long since the link was lost, the autonegotiation process starts over. The link can be lost because of external influences, such as a cable fault, or because one of the partners issues a reset.

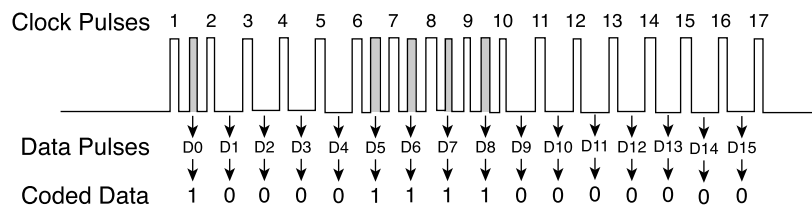
Figure 5-22 shows the actual FLP autonegotiation burst. The FLP burst is made up of multiple NLP link pulses.

Figure 5-22 FLP Autonegotiation Burst



An FLP burst consists of 33 pulse positions, which represent a 16-bit link code word that is framed by 17 clocking pulses. Pulses within a burst are separated by 62.5 ms (± 7 ms). Data pulse positions are found between each clocking pulse. If a data pulse is present, it is interpreted as a binary 1. The absence of a data pulse in the window between two clocking pulses is interpreted as a binary 0. As shown in Figure 5-23, the 17 clocking pulses are always present. The 16 data pulses are present only if they represent binary 1; they are absent if they represent binary 0 in the encoded 16-bit data word. The pulses interpreted as binary 1s for data are highlighted in gray.

Figure 5-23 Interpretation of Autonegotiation Pulse



When autonegotiation is implemented, additional information can be added using the concept of pages. Pages are additional bits representing more sophisticated negotiation and link parameters.

After a device has decoded the link code word offered by its link partner, it acknowledges receipt of the current word by sending at least three FLP bursts with the Acknowledge bit set. After both link partners acknowledge the current FLP link code word exchange in that manner, the link partners either move on to the next page or enable the agreed

configuration and attempt to link accordingly. Link partners can send any number of next pages following the initial configuration base page and any necessary next pages that are associated with the base page.

Link Establishment and Full/Half Duplex

Link partners are allowed to skip offering configurations that they are capable of offering, but are not allowed to include configurations that they are not capable of offering. This enables the network administrator to force ports to a selected speed and duplex setting, without disabling autonegotiation.

Autonegotiation is optional for most Ethernet implementations. Gigabit Ethernet requires its implementation, although the user can disable it. Autonegotiation originally was defined for UTP implementations of Ethernet. It has been extended to work with other fiber-optic implementations through the use of /C/ ordered sets in the place of the FLP bursts.

When an autonegotiating station first attempts to link, it is supposed to enable 10BASE-T parts of the front-end chip set to attempt to immediately establish a link. If 10BASE-T signaling is present and the station supports 10BASE-T, it attempts to establish a link without negotiating. If either signaling produces a link, or if FLP bursts are received, the station proceeds with that technology. If a link partner does not offer an FLP burst, but instead offers NLPs, that device automatically is assumed to be a 10BASE-T station. During this initial interval of testing for other technologies, the transmit path sends FLP bursts. The standard does not permit parallel detection of any other technologies.

If a link is established through parallel detection, it is required to be half duplex. Only two methods of achieving a full-duplex link exist:

- Through a completed cycle of autonegotiation
- By administratively forcing both link partners to full duplex

If one link partner is forced to full duplex but the other partner parallel-detects while attempting to autonegotiate, there is certain to be a duplex mismatch, resulting in collisions and errors on that link. If you force one end, you *must* force the other. The exception to this is that 10 Gigabit Ethernet does not support half duplex.

Many vendors implement their hardware in such a way that it cycles through the various possible states. It transmits FLP bursts to autonegotiate for a while, then it configures itself for Fast Ethernet and attempts to link for a while, and finally it simply listens for a while. Some vendors do not offer any transmitted attempt to link until the interface

first hears an FLP burst or some other signaling scheme. In the silent listening state, a portable computer is capable of conserving enough battery power to be quite worthwhile, although this mode is not supported by the standard.

Ethernet Duplex Operation

Two duplex modes exist: half and full. For shared media, the half-duplex mode is mandatory. All of the coaxial implementations are inherently half duplex in nature and cannot operate in full duplex. UTP and fiber implementations can be operated in half duplex, but that mode is an administrative imposition. All 10-Gbps implementations are specified for full duplex only.

In half duplex, only one station can transmit at a time. For the coaxial implementations, a second station transmitting causes the signals to overlap and collide, becoming corrupted. Because UTP and fiber generally transmit on separate pairs, the signals have no opportunity to overlap and become corrupted. Ethernet has established arbitration rules for resolving conflicts that arise when more than one station attempts to transmit at the same time. Both stations in a point-to-point full-duplex link are permitted to transmit at any time, regardless of whether the other station is transmitting at the same time.

Autonegotiation avoids most situations in which one station in a point-to-point link is transmitting under half-duplex rules and the other is operating under full-duplex rules. Only two methods exist of achieving a full-duplex connection at speeds below 10 Gigabit Ethernet:

- By using autonegotiation
- By administratively forcing the interface mode

If one station in a point-to-point link is autonegotiating and the other is not, the autonegotiating station is required to select half duplex. Thus, if one end of a link is forced, it is incumbent upon the network support staff to force the other end as well. Failure to force both ends results in an artificially elevated error level and poor performance on the link. Duplex mismatches are perhaps the most common problem found on switched networks.

Priority Resolution

In the anticipated event that link partners share more than one common technology capability, the following list is used to determine which technology should be chosen from the offered configurations. In other words, it is desirable for 10-/100-/1000-Mbps

versions of copper-based Ethernet to agree automatically on the best way for two interfaces to link. The list is ranked by priority, with the most desirable link configuration at the top:

- Full duplex
- Half duplex
- Full duplex
- Half duplex
- Full duplex
- Half duplex

Fiber-optic Ethernet implementations are not included in this priority resolution list because the interface electronics and optics do not permit easy reconfiguration between implementations. It is assumed that the interface configuration is fixed. If the two interfaces are capable of autonegotiating, they are already using the same Ethernet implementation, although there remain a number of configuration choices, such as the duplex setting or which station will act as the master for clocking purposes.

Collision Domains and Broadcast Domains

This section presents topics that relate to collision and broadcast domains. Excessive broadcasts and collisions can affect the network performance. This section discusses how to reduce the impact of broadcasts and collisions on the performance of the network. The term *segment* is defined, and different types of segmentation are discussed.

Directly Connected Networks

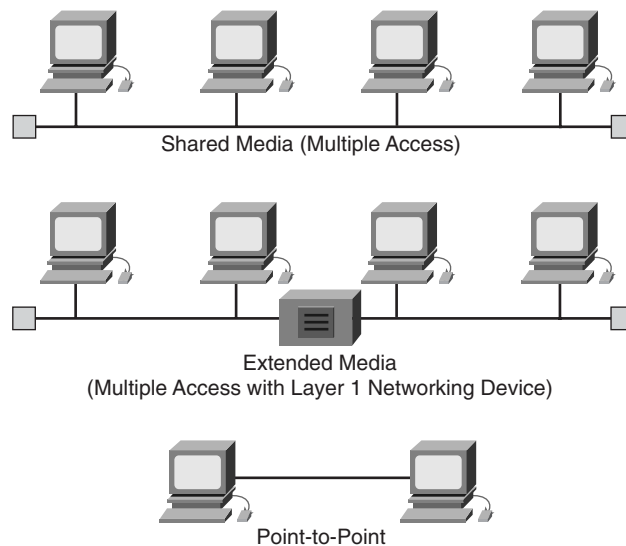
To understand collision domains, it is first necessary to examine the issues of what a collision is and how it is caused. To help explain collisions, it is useful to review Layer 1 media and topologies.

As illustrated in Figure 5-24, some of the various types of directly connected networks include the following:

- **Shared-media environment**—A shared-media environment occurs when multiple hosts have access to the same medium. For example, if several PCs are attached to the same physical wire or optical fiber, or share the same airspace, they all share the same media environment. In this case, they are said to share the same collision domain. Traditional bus-based (coaxial cable) Ethernet and hub-based Ethernet (UTP cable) are shared-media environments.

- **Extended shared-media environment**—This is a special type of shared-media environment in which networking devices can extend the environment so that it can accommodate multiple access or longer cable distances. Using Ethernet repeaters or multiple hubs can create an extended shared-media environment. This creates an extended collision domain.
- **Point-to-point network environment**—This is widely used in dialup network connections and is the most familiar to the home user. It is a shared networking environment in which one device is connected to only one other device, such as connecting a computer to an Internet service provider by modem and a phone line. Because this is a point-to-point dedicated connection, there is no potential for collisions. No other devices share the link.

Figure 5-24 Directly Connected Networks



Indirectly Connected Networks

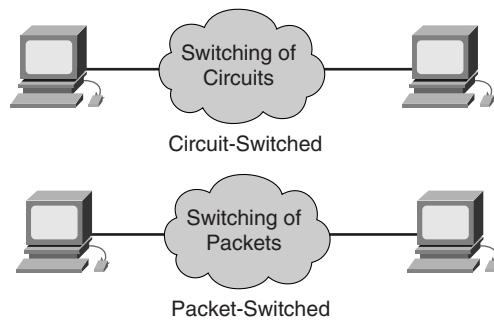
Some networks are indirectly connected, meaning that some higher-layer networking devices or some geographical distance is between the two communicating hosts. Figure 5-25 also shows the two types of indirectly connected networks, which are described as follows:

- **Circuit-switched**—An indirectly connected network in which actual electrical circuits are maintained for the duration of the communication. Circuit switching sets up a physical, end-to-end connection between the endpoints. The bandwidth

is dedicated to this point-to-point connection. The current telephone system is still, in part, circuit-switched, although the telephone systems in many countries now are concentrating less on circuit-switched technologies. Because this is not a shared environment, there are no collisions.

- **Packet-switched**—Instead of dedicating a link as an exclusive circuit connection between two communicating hosts, the source sends messages in packets. Each packet contains enough information for it to be routed to the proper destination host. Packet-switched networks frequently share physical media, but because logical point-to-point connections are created, there are no collisions.

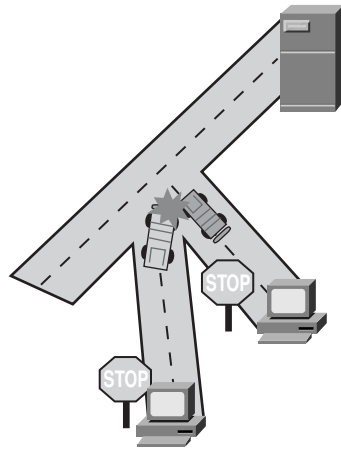
Figure 5-25 Indirectly Connected Networks



Collisions and Collision Domains

It is important to identify the medium as a shared environment because this shared environment causes collisions. A similar situation can occur with an automobile on a highway. If there is only one car, there is nothing to collide with. However, if more than one automobile is trying to use the same section of road at the same time, as shown in Figure 5-26, a collision occurs. The same is true for networks: If more than one computer tries to transmit data on the same network segment at the same time, a collision occurs.

A *collision* is a situation that can occur when 2 bits propagate at the same time on the same network. A small, slow network could work out a system that allows only two computers to send messages, with both agreeing to take turns. The problem is that many computers are connected to large networks, with each one wanting to communicate millions of bits every section.

Figure 5-26 Collision

Collision domains are the connected physical network segments where collisions can occur. Collisions cause the network to be inefficient. Every time there is a collision on a network, all transmission stops for a period of time. This time is variable, as determined by a backoff algorithm for each network device, which is necessary to allow broadcast transmission to resume.

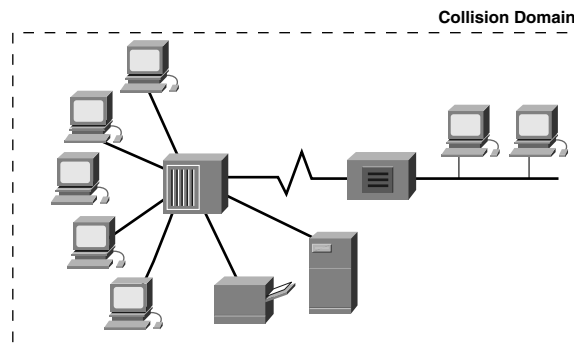
Except for a single isolated Ethernet LAN environment, the types of devices that interconnect the media segments define collision domains. These devices have been classified as OSI Layers 1, 2, or 3 devices. Layer 1 devices do not break up collision domains; Layers 2 and 3 devices do break up collision domains, as described in Figure 5-27. Breaking up or increasing the number of collision domains with Layer 2 and 3 devices is known as *segmentation*.

Figure 5-27 Collision Domain Segmentation

Application	
Presentation	
Session	
Transport	
Network	Breaks Up Collision Domain
Data Link	Breaks Up Collision Domain
Physical	One Collision Domain

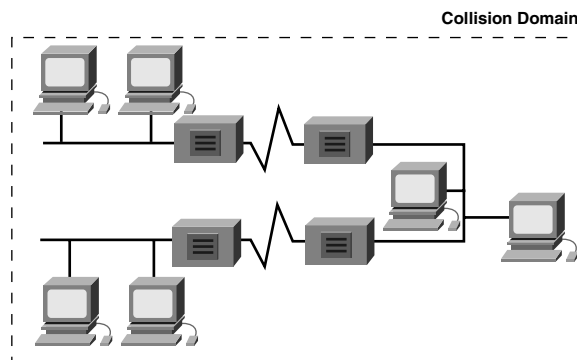
Layer 1 devices, such as repeaters and hubs, serve the primary function of extending the Ethernet cable segments. By extending the network, more hosts can be added. However, every host that is added increases the amount of potential traffic on the network. Because Layer 1 devices pass on everything that is sent on the medium, the more traffic that is transmitted within a collision domain, the greater the chances of collisions are. The final result is diminished network performance, which is even more pronounced if all the computers on that network demand large amounts of bandwidth. Simply put, Layer 1 devices extend collision domains, as shown in Figure 5-28, but the length of a LAN also can be overextended and can cause other collision issues.

Figure 5-28 A Repeater Increases the Collision Domain



The four-repeater rule in Ethernet states that no more than four repeaters or repeating hubs can be between any two computers on the network, as shown in Figure 5-29. To ensure that a repeated 10BASET network will function properly, the round-trip delay calculation must be within certain limits; otherwise, all the workstations will not be capable of hearing all the collisions on the network.

Figure 5-29 A Repeater Increases the Collision Domain



Repeater latency, propagation delay, and NIC latency all contribute to the four-repeater rule. Exceeding the four-repeater rule can lead to violating the maximum delay limit. When this delay limit is exceeded, the numbers of late collisions dramatically increase. A late collision occurs when a collision happens after the first 64 bytes of the frame are transmitted. The chip sets in NICs are not required to retransmit automatically when a late collision occurs. These late-collision frames add delay that is referred to as consumption delay. As consumption delay and latency increase, network performance decreases. This Ethernet rule of thumb also is known as the 5-4-3-2-1 rule. This means that the following guidelines should not be exceeded:

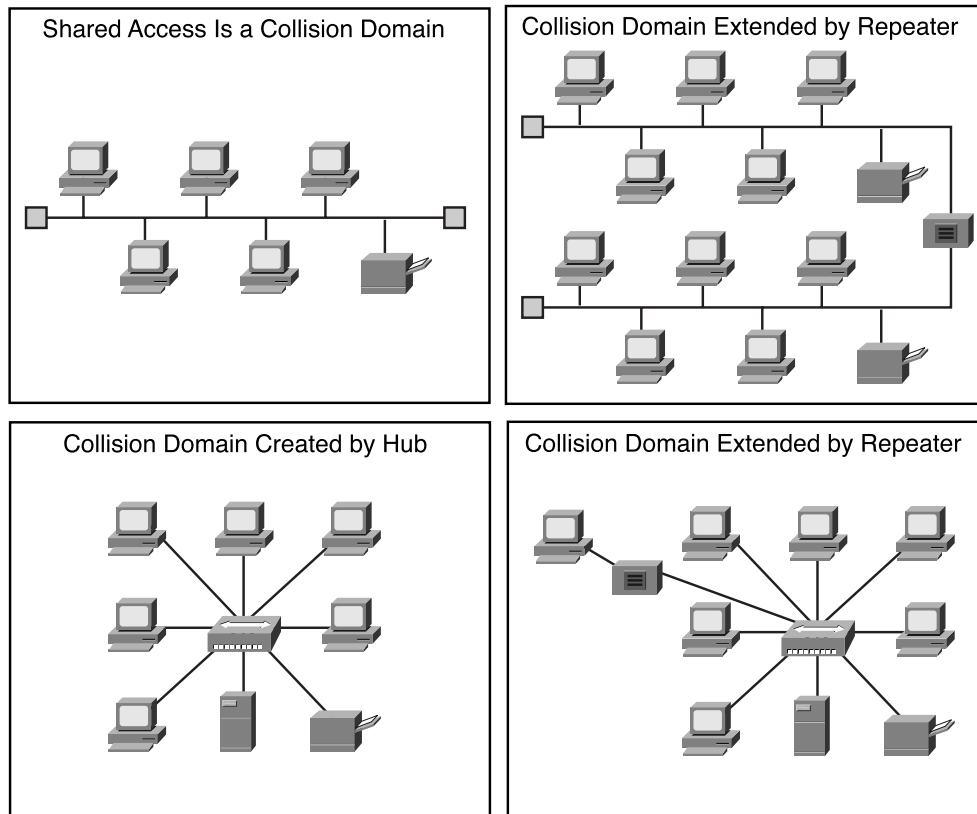
- Host sections consist of
 - 5 sections of network media
 - 4 repeaters or hubs
 - 3 sections of the network
- 2 sections are link sections (no hosts)
- 1 large collision domain

Segmentation

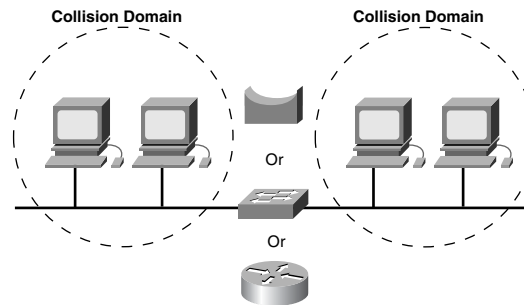
For a networking professional, one important skill is the ability to recognize collision domains. Connecting several computers to a single shared-access medium that has no other networking devices attached creates a collision domain. This situation limits the number of computers that can use the medium, also called a *segment*. As illustrated in Figure 5-30, Layer 1 devices extend but do not control collision domains.

Layer 2 devices segment or divide collision domains. Controlling frame propagation using the MAC address assigned to every Ethernet device performs this function. Layer 2 devices, bridges and switches, keep track of the MAC addresses and which segment they are on. By doing this, these devices can control the flow of traffic at the Layer 2 level. This function makes networks more efficient by allowing data to be transmitted on different segments of the LAN at the same time, without the frames colliding. By using bridges and switches, the collision domain effectively is broken up into smaller parts, each being its own collision domain.

These smaller collision domains will have fewer hosts and less traffic than the original domain, and thereby increase the amount of bandwidth available to each host in that domain. The lower the amount of traffic is in a collision domain, the greater the chance there is that when a host wants to transmit data, the media will be available. This works well as long as the traffic between segments is not too heavy. Otherwise, the Layer 2 device actually can slow communication and become a bottleneck itself.

Figure 5-30 Layer 1 Devices Extend the Collision Domains

Layer 3 devices, like Layer 2 devices, do not forward collisions. Because of this, the use of Layer 3 devices in a network has the effect of breaking up collision domains into smaller domains. Layer 3 devices perform more functions than just breaking up a collision domain. These devices and their functions are covered in more depth in the section, “Broadcast Domains.” Figure 5-31 illustrates that Layer 2 and Layer 3 devices can break up the collision domain.

Figure 5-31 Limiting the Collision Domain

Layer 2 Broadcasts

To communicate with all collision domains, protocols use broadcast and multicast frames at Layer 2 of the OSI model. When a node needs to communicate with all hosts on the network, it sends a frame with a destination MAC address `0xFFFFFFFF` (a broadcast). This is an address to which the NIC of every host must recognize.

Layer 2 devices must flood all broadcast and multicast traffic. The accumulation of broadcast and multicast traffic from each device in the network is referred to as broadcast radiation. Figure 5-32 illustrates a bridge forwarding the broadcast to all hosts on the network.

Because the NIC must interrupt the CPU to process each broadcast or multicast group that it belongs to, broadcast radiation affects the performance of hosts in the network. Most often, the host does not benefit from processing the broadcast because it is not the destination being sought. Either the host does not care about the service that is being advertised or it already knows about the service. High levels of broadcast radiation noticeably can degrade host performance, as shown in Figure 5-33. The three sources of broadcasts and multicasts in IP networks are workstations, routers, and multicast applications.

Workstations broadcast an Address Resolution Protocol (ARP) request every time they need to locate a MAC address that is not in the ARP table. For example, the command `telnet mumble.com` translates into an IP address through a Domain Name System (DNS) search, and then an ARP request is broadcast to find the actual station. Generally, IP workstations cache 10 to 100 addresses about 2 hours. The ARP rate for a typical workstation might be about 50 addresses every 2 hours, or 0.007 ARPs per second. Thus, 2000 IP end stations produce about 14 ARPs per second.

Figure 5-32 Layer 2 Broadcast

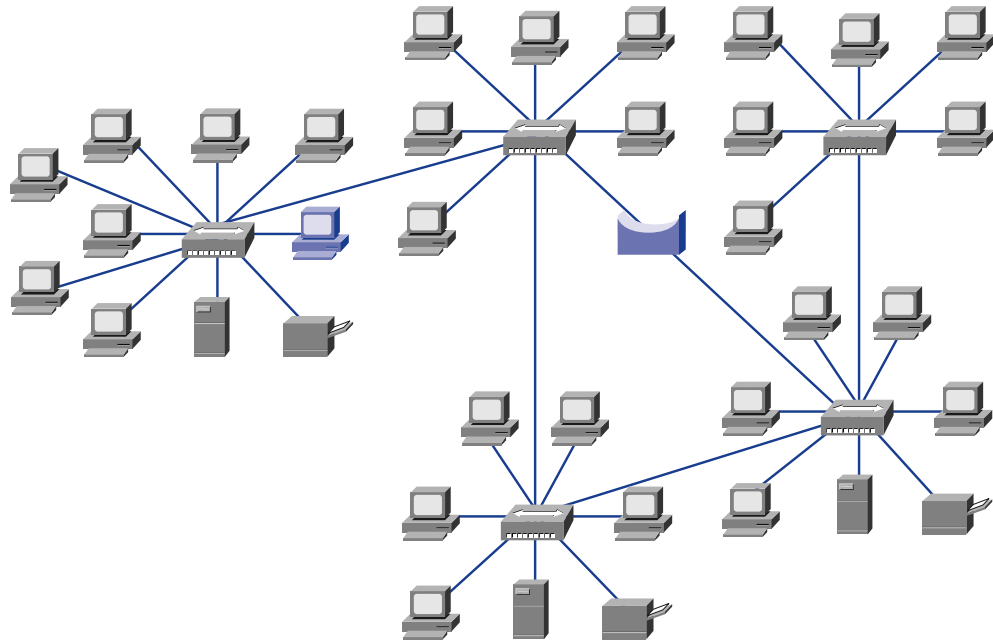


Figure 5-33 Effect of Broadcast Radiation on Hosts in IP Network

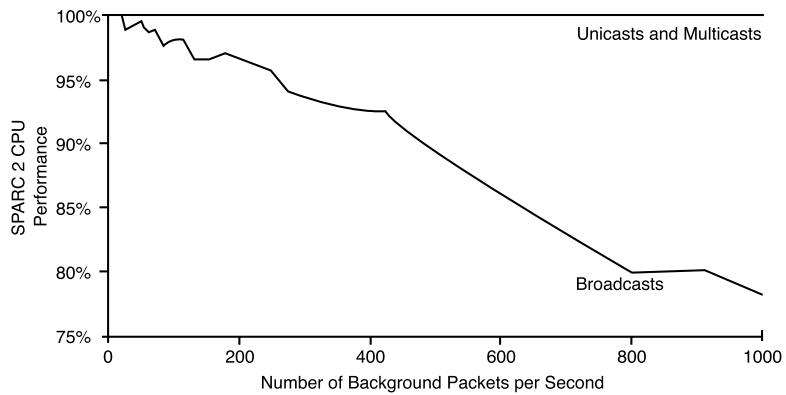


Table 5-7 lists the average number of broadcast and multicasts for IP networks.

Table 5-7 Average Number of Broadcast and Multicasts for IP Networks

Number of Hosts	Average Percentage of CPU Loss Per Host
100	0.14
1000	0.96
10,000	9.15

Although the numbers in Table 5-7 might appear low, they represent an average, well-designed IP network that is not running the Routing Information Protocol (RIP). When broadcast and multicast traffic peak because of storm behavior, peak CPU loss can be orders of magnitude greater than average. Broadcast storms can be caused by a device requesting information from a network that has grown too large. So many responses are sent to the original request that the device cannot process them, or the first request triggers similar requests from other devices that effectively block normal traffic flow on the network.

An IP router is a router or workstation that runs any distance vector routing protocol. Some administrators configure all workstations to run RIP (a routing protocol) as a redundancy and reachability policy. Every 30 seconds, RIP uses broadcasts to retransmit the entire RIP routing table to other RIP routers. If a large number of routers were configured to run RIP and, on average, 50 packets were required to transmit the routing table, the routers would generate 3333 broadcasts per second. Most network administrators configure only a small number of routers—usually five to ten—to run RIP. For a routing table that has a size of 50 packets, 10 RIP routers would generate about 16 broadcasts per second. (Routing protocols and routing table are discussed in Chapter 8, “Routing Fundamentals and Subnets.”)

IP multicast applications adversely can affect the performance of large, scaled, switched networks. Although multicasting is an efficient way to send a stream of multimedia data to many users on a shared-media hub, it affects every user on a flat-switched network. A flat-switched network is a network of interconnected switches that does not utilize Layer 3 routing or something similar. A particular packet video application can generate a 7-megabyte (MB) stream of multicast data that, in a switched network, would be sent to every segment, resulting in severe congestion.

Broadcast Domains

A *broadcast domain* is a grouping of collision domains that are connected by Layer 2 devices. Breaking up a LAN into multiple collision domains improves network efficiency by allowing multiple transmissions of data simultaneously on separate collision domains. But broadcasts travel across the Layer 2 devices and, if excessive, can reduce the efficiency of the overall LAN. Broadcasts must be controlled at Layer 3 because Layer 1 and 2 devices have no way of controlling them. The total size of a broadcast domain can be identified by looking at all of the collision domains that the same broadcast frame is processed by. In other words, all the nodes are a part of that network segment bounded by a Layer 3 device. Broadcast domains are controlled at Layer 3 because routers do not forward broadcasts. In Figure 5-34, the router will not forward the broadcast from the blue-highlighted workstation in the left side to the hosts on the right.

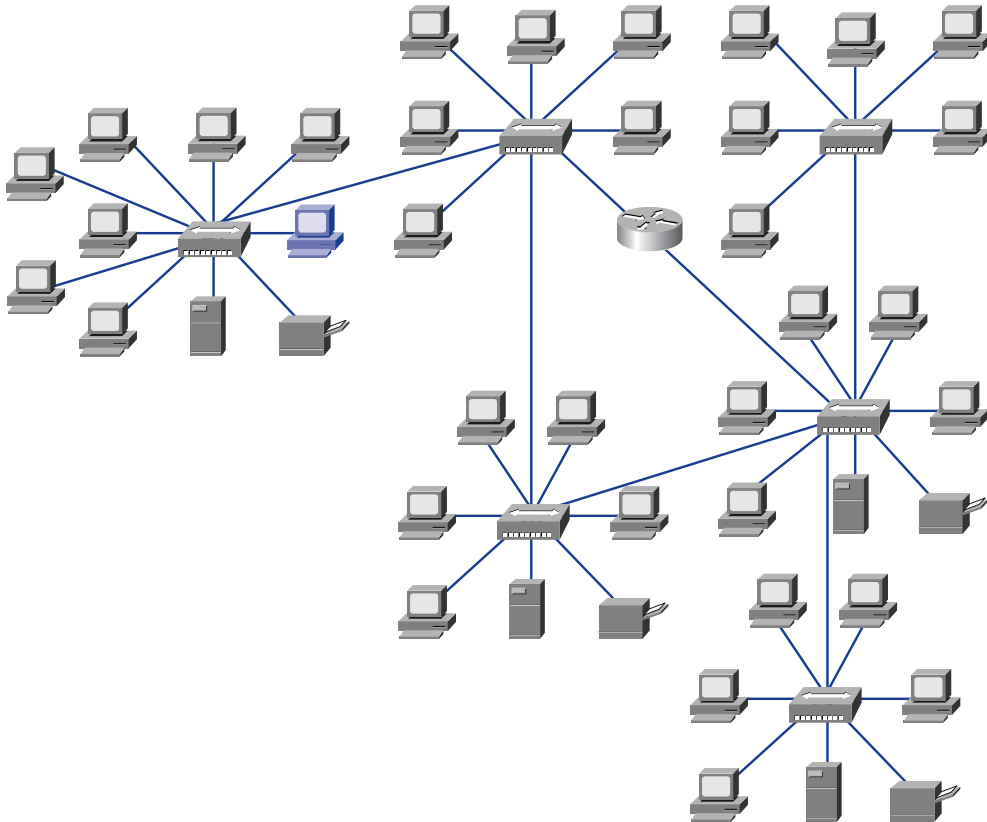
Routers actually work at Layers 1, 2, and 3. Like all Layer 1 devices, they have a physical connection to and transmit data onto the medium. They have a Layer 2 encapsulation on all interfaces and perform just like any other Layer 2 device. Layer 3 allows the router to segment broadcast domains.

For a packet to be forwarded through a router, it must have been processed already by Layer 2, and the frame information must have been stripped off. Layer 3 forwarding is based on the destination IP address, not the MAC address. For a packet to be forwarded, it must contain an IP address that is outside the range of addresses assigned to the LAN segment, and the router must have a destination to send the specific packet to in its routing table.

Introduction to Data Flow

Data flow in the context of collision and broadcast domains focuses on how data frames propagate through a network. It refers to the movement of data through Layer 1, 2, and 3 devices, as well as how data must be encapsulated to effectively make that journey. Remember that data is encapsulated at the network layer with an IP source and destination address, and at the data link layer with a MAC source and destination address.

The basic rule to follow here is that a Layer 1 device always forwards the frame, a Layer 2 device wants to forward the frame (in other words, it forwards unless something prevents it), and a Layer 3 device does not forward unless it has to. Using this rule helps identify how data flows through a network.

Figure 5-34 Broadcast Domain Segmentation

Layer 1 devices (repeaters and hubs) do no filtering, so everything that is received is passed on to the next segment. The frame simply is regenerated and retimed, and thus returned to its original transmission quality. Any segments connected by Layer 1 devices are part of the same domain, both collision and broadcast.

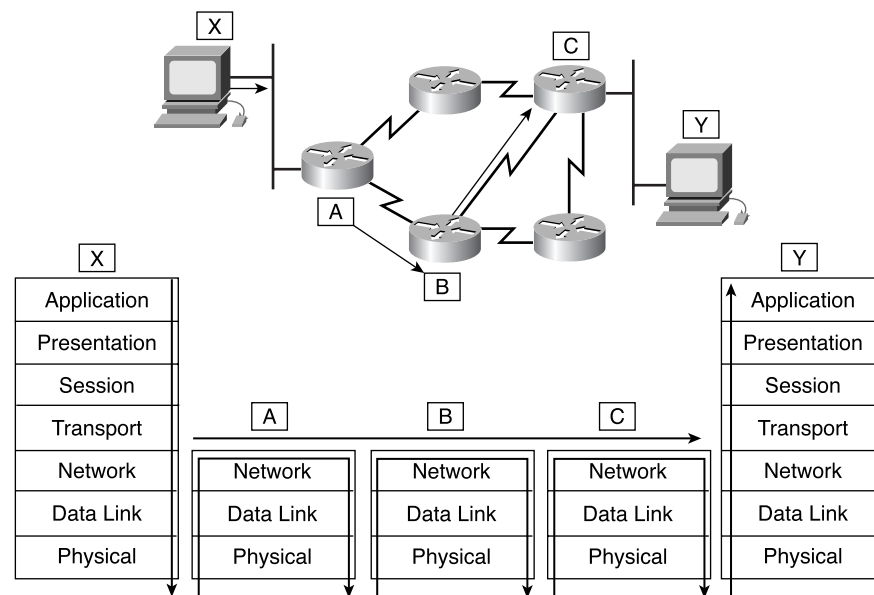
Layer 2 devices (bridges and switches) filter data frames based on the destination MAC address. A frame is forwarded if it is going to an unknown destination (outside the collision domain). The frame also is forwarded if it is a broadcast, multicast, or unicast going outside the local collision domain. The only time that a frame is not forwarded is when the Layer 2 device finds that the sending host and the receiving host are in the same collision domain. A bridging device (Layer 2) creates multiple collision domains but maintains only one broadcast domain.

Layer 3 devices (routers and some high-end switches) filter data packets based on IP destination address. The only way that a packet is forwarded is if its destination IP

address is outside the broadcast domain and the router has an identified location to send the packet. A Layer 3 device creates multiple collision and broadcast domains.

Data flow through a routed IP-based network involves data moving across traffic-management devices at Layers 1, 2, and 3 of the OSI model. Layer 1 is used for transmission across the physical medium, Layer 2 is used for collision domain management, and Layer 3 is used for broadcast domain management. Figure 5-35 shows data flowing from Workstation X through Routers A, B, and C to Workstation Y.

Figure 5-35 Data Flow Through a Network



Network Segment

As with many terms and acronyms, *segment* has multiple meanings. The dictionary definition of the term is as follows:

- A separate piece of something
- One of the parts into which an entity or quantity is divided or marked off by, or as if by natural boundaries

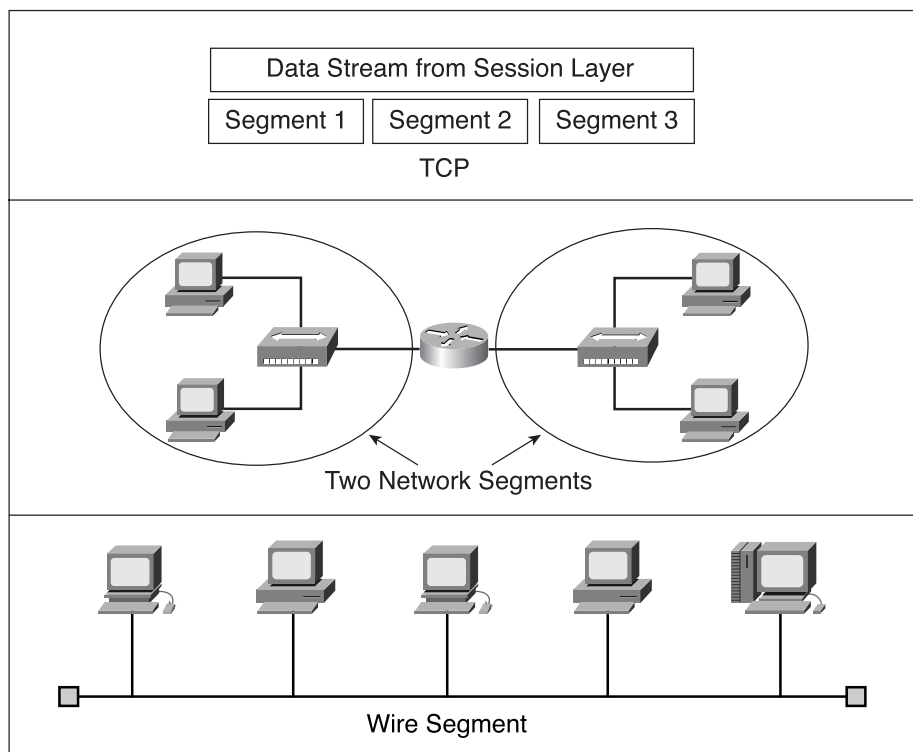
In the context of data communication, the following definitions are used:

- Section of a network that is bounded by bridges, routers, or switches.
- In a LAN using a bus topology, a continuous electrical circuit that is often connected to other such segments with repeaters.

- Term used in the TCP specification to describe a single transport layer unit of information. The terms datagram, frame, message, and packet also are used to describe logical information groupings at various layers of the OSI reference model and in various technology circles.

Figure 5-36 illustrates the three definitions of the term *segment* within the content of the data communication.

Figure 5-36 Segments



To define the term *segment* properly, the context of the usage must be presented with the word. If *segment* is used in the context of TCP, it is defined as a separate piece of the data. If segment is being used in the context of physical networking media in a routed network, it is seen as one of the parts or sections of the total network.

Summary

The following key points were presented in this section:

- The Institute of Electrical and Electronic Engineers (IEEE) is a professional organization that defines network standards. IEEE LAN standards are the best-known IEEE communication standards and are the predominant LAN standards in the world today.
- The IEEE divides the OSI data link layer into two separate sublayers: Media Access Control (MAC) and Logical Link Control (LLC).
- Ethernet uses the MAC address, which is the physical address located on a NIC.
- Framing helps obtain essential information that could not otherwise be obtained with coded bit streams alone.
- Two broad categories of Media Access Control exist: deterministic (taking turns) and nondeterministic (first come, first served).
- Ethernet uses carrier sense multiple access collision detect (CSMA/CD).
- Half-duplex transmission enables signals to travel in either direction, but not in both directions simultaneously. Full-duplex transmission enables data to be sent and received at the same time.
- Using a shared-media environment can cause traffic congestion that leads to network inefficiency.
- The most common (and usually benign) error condition on an Ethernet is the collision.
- The main Ethernet frame error types that can be captured through a protocol-analysis session are local collision, remote collision, and late collision.
- Situations that are considered Ethernet errors are jabber, long frame, short frame, runts, FCS errors, alignment error, and range error.
- The fundamental grouping of devices in a shared-media environment is a collision domain.
- Collision domains can be segmented to reduce congestion and improve network efficiency.
- Collision domains are segmented by both Layer 2 and Layer 3 devices.
- Broadcasts are designed to travel throughout collision domains and can cause network inefficiency.
- Broadcast domains can be segmented by using Layer 3 devices.

- Data flow is controlled by data encapsulation in conjunction with Layer 2 and Layer 3 devices.
- Definitions of networking terms and acronyms must be defined in context, not as isolated terms.

To supplement all that you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab Activities on the CD-ROM accompanying this book.

Key Terms

10-Gb Ethernet Built on the Ethernet technology used in most of today's LANs, 10-Gb Ethernet is described as a technology that offers a more efficient and less expensive approach to moving data on backbone connections between networks, while also providing a consistent technology end to end. Ethernet now can step up to offering data speeds at 10 Gbps.

alignment error A message that does not end on an octet boundary.

backoff The retransmission delay enforced when a collision occurs.

broadcast A data packet that is sent to all nodes on a network. Broadcasts are identified by a broadcast address.

broadcast domain A set of all devices that will receive broadcast frames originating from any device within the set. Broadcast domains typically are bounded by routers (or, in a switched network, by VLANs) because routers do not forward broadcast frames.

collision In Ethernet, the result of two nodes transmitting simultaneously. The frames from each device impact and are damaged when they meet on the physical media. See also *collision domain*.

collision domain In Ethernet, the network area within which frames that have collided are propagated. Repeaters and hubs propagate collisions; LAN switches, bridges, and routers do not.

connectionless Data transfer without the existence of a virtual circuit.

CSMA/CD (*carrier sense multiple access collision detect*) A media-access mechanism wherein devices ready to transmit data first check the channel for a carrier. If no carrier is sensed for a specific period of time, a device can transmit. If two devices transmit at once, a collision occurs and is detected by all colliding devices. This collision subsequently delays retransmissions from those devices for some random length of time. CSMA/CD access is used by Ethernet and IEEE 802.3.

encapsulation Wrapping of data in a particular protocol header. For example, upper-layer data is wrapped in a specific Ethernet header before network transit. Also, when bridging dissimilar networks, the entire frame from one network simply can be placed behind the header used by the data link layer protocol of the other network.

Ethernet A baseband LAN specification invented by Xerox Corporation and developed jointly by Xerox, Intel, and Digital Equipment Corporation. Ethernet networks use CSMA/CD and run over a variety of cable types at 10, 100, and 1000 Mbps. Ethernet is similar to the IEEE 802.3 series of standards.

Fast Ethernet Any of a number of 100-Mbps Ethernet specifications. Fast Ethernet offers a speed increase 10 times that of the 10BASE-T Ethernet specification, while preserving such qualities as frame format, MAC mechanisms, and MTU. Such similarities allow the use of existing 10BASE-T applications and network-management tools on Fast Ethernet networks. Fast Ethernet is based on an extension to the IEEE 802.3 specification.

FDDI (Fiber Distributed Data Interface) A LAN standard, defined by American National Standards Institute (ANSI) 3T9.5, specifying a 100-Mbps token-passing network using fiber-optic cable, with transmission distances of up to 2 km. FDDI uses a dual-ring architecture to provide redundancy.

full duplex The capability for simultaneous data transmission between a sending station and a receiving station.

ghost Fluke Networks coined this new term to mean energy (noise) detected on the cable that appears to be a frame but that lacks a valid SFD. To qualify as a ghost, this “frame” must be at least 72 octets long (including preamble); otherwise, it is classified as a remote collision.

Gigabit Ethernet Standard for a high-speed Ethernet, approved by the IEEE 802.3z standards committee in 1996.

half duplex A capability for data transmission in only one direction at a time between a sending station and a receiving station.

header Control information placed before data when encapsulating that data for network transmission.

IEEE 802.2 An IEEE LAN protocol that specifies an implementation of the LLC sublayer of the data link layer. IEEE 802.2 handles errors, framing, flow control, and the network layer (Layer 3) service interface.

IEEE (Institute of Electrical and Electronic Engineers) A professional organization whose activities include the development of communications and network standards. IEEE LAN standards are the predominant LAN standards today.

IEEE 802.3 An IEEE LAN protocol that specifies an implementation of the physical layer and the MAC sublayer of the data link layer. IEEE 802.3 uses CSMA/CD access at a variety of speeds over a variety of physical media. Extensions to the IEEE 802.3 standard specify implementations for Fast Ethernet. Physical variations of the original IEEE 802.3 specification include 10BASE2, 10BASE5, 10BASE-F, 10BASE-T, and 10BROAD36. Physical variations for Fast Ethernet include 100BASE-TX and 100BASE-FX.

jabber Defined several places in the 802.3 standard as being a transmission of at least 20,000 to 50,000 bit-times in duration. However, most diagnostic tools report jabber whenever a detected transmission exceeds the maximum legal frame size—which is considerably smaller than 20,000 to 50,000 bit-times.

LLC (Logical Link Control) The higher of the two data link layer sublayers defined by the IEEE. The LLC sublayer handles error control, flow control, framing, and MAC-sublayer addressing. The most prevalent LLC protocol is IEEE 802.2, which includes both connectionless and connection-oriented variants.

long frame A frame that is longer than the maximum legal size and that takes into consideration whether the frame was tagged.

MAC (Media Access Control) The lower of the two sublayers of the data link layer defined by the IEEE. The MAC sublayer handles access to shared media, such as whether token passing or contention will be used. See also *LLC*.

MAC address A standardized data link layer address that is required for every device that connects to a LAN. Other devices in the network use these addresses to locate specific devices in the network and to create and update routing tables and data structures. MAC addresses are 6 bytes long and are controlled by the IEEE. Also known as a hardware address, a MAC-layer address, or a physical address.

MTU (Maximum Transmission Unit) The maximum packet size, in bytes, that a particular interface can handle.

OUI (organizationally unique identifier) Three octets assigned by the IEEE in a block of 48-bit LAN addresses.

propagation delay The time required for data to travel over a network from its source to its ultimate destination.

range error A frame that had a legal-size value in the Length field but that did not match the actual number of octets counted in the Data field of the received frame.

segment A section of a network that is bounded by bridges, routers, or switches.

simplex The capability for transmission in only one direction between a sending station and a receiving station. Broadcast television is an example of a simplex technology.

SNMP (Simple Network Management Protocol) A network-management protocol used almost exclusively in TCP/IP networks. SNMP provides a means of monitoring and controlling network devices and managing configurations, statistics collection, performance, and security.

Token Ring A token-passing LAN developed and supported by IBM. Token Ring runs at 4 or 16 Mbps over a ring topology.

trailer Controls information appended to data when encapsulating the data for network transmission.

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. Which of the following is *not* one of the recognized IEEE sublayers?
 - A. Media Access Control
 - B. Data Link Control
 - C. Logical Link Control
 - D. None of the above
2. The recognized IEEE sublayers are concerned with what layers of the OSI reference model?
 - A. 2 and 3
 - B. 1 and 2
 - C. 3 and 4
 - D. 1 and 3
3. The LLC, as a sublayer, participates in the _____ process.
 - A. Encryption
 - B. Encapsulation
 - C. Framing
 - D. All of the above
4. The first six hexadecimal numbers in a MAC address represent an _____?
 - A. Interface serial number
 - B. Organizationally unique identifier
 - C. Interface unique identifier
 - D. None of the above

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5. MAC addresses are _____ bits in length.
- A. 12
 - B. 24
 - C. 48
 - D. 64
6. What is the name of the access method used in Ethernet that explains how Ethernet works?
- A. TCP/IP
 - B. CSMA/CD
 - C. CMDA/CS
 - D. CSMA/CA
7. Where does the MAC address reside?
- A. Transceiver
 - B. Computer BIOS
 - C. NIC
 - D. CMOS
8. Which of the following statements best describes communication between two devices on a LAN?
- A. The source device encapsulates data in a frame with the MAC address of the destination device and then transmits it. Everyone on the LAN sees it, but the devices with nonmatching addresses otherwise ignore the frame.
 - B. The source encapsulates the data and places a destination MAC address in the frame. It puts the frame on the LAN, where only the device with the matching address can check the address field.
 - C. The destination device encapsulates data in a frame with the MAC address of the source device and puts it on the LAN. The device with the matching address removes the frame.
 - D. Each device on the LAN receives the frame and passes it up to the computer, where software decides whether to keep or to discard the frame.

9. Which functions are associated with framing?
- A. Identifies which computers are communicating with one another
 - B. Signals when communication between individual computers begins and when it ends
 - C. Flags corrupted frames
 - D. All of the above
10. How does a computer on a LAN detect an error in a frame?
- A. It sends a copy of the frame back to the sender for verification.
 - B. It checks the destination address to verify that the frame really was intended for it.
 - C. It compares an FCS in the frame to one that the computer calculates from the contents of the frame.
 - D. It calculates a checksum from the data in the frame and then sends it back to the source for verification.
11. Media Access Control refers to what?
- A. The state in which a NIC has captured the networking medium and is ready to transmit.
 - B. Rules that govern media capture and release.
 - C. Protocols that determine which computer on a shared-medium environment is allowed to transmit the data.
 - D. A formal byte sequence has been transmitted.
12. Which best describes a CSMA/CD network?
- A. One node's transmission traverses the entire network and is received and examined by every node.
 - B. Signals are sent directly to the destination if the source knows both the MAC and IP addresses.
 - C. One node's transmission goes to the nearest router, which sends it directly to the destination.
 - D. Signals always are sent in broadcast mode.

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- 13.** In an Ethernet or IEEE 802.3 LAN, when do collisions occur?
 - A.** When one node places a packet on a network without informing the other nodes
 - B.** When two stations listen for a traffic, hear none, and transmit simultaneously
 - C.** When two network nodes send packets to a node that no longer is broadcasting
 - D.** When jitter is detected and traffic is disrupted during normal transmission
- 14.** Which is an important Layer 2 data link layer function?
 - A.** Logical link control
 - B.** Addressing
 - C.** Media access control
 - D.** All of the above
- 15.** Which of the following is an Ethernet frame error type?
 - A.** Local collision
 - B.** Remote collision
 - C.** Late collision
 - D.** All of the above
- 16.** Which protocol is a nondeterministic protocol?
 - A.** Token Ring
 - B.** CSMA/CD
 - C.** IPX
 - D.** RIP
- 17.** Which is true of a deterministic MAC protocol?
 - A.** It defines collisions and specifies what to do about them.
 - B.** It allows the hub to determine the number of users active at any one time.
 - C.** It allows hosts to “take turns” sending data.
 - D.** It allows the use of a “talking stick” by network administrators to control the media access of any users considered “troublemakers.”

18. The network area within which data packets originated and collide is called a _____?
- A. Collision domain
 - B. Network domain
 - C. Broadcast domain
 - D. Network segment
19. Which best describes broadcasting?
- A. Sending a single frame to many stations at the same time
 - B. Sending a single frame to all routers to simultaneously update their routing tables
 - C. Sending a single frame to all routers at the same time
 - D. Sending a single frame to all hubs and bridges at the same time
20. Using repeaters _____ the collision domain.
- A. Reduces
 - B. Has no effect on
 - C. Extends
 - D. None of the above
21. The process of using the complex networking devices, such as bridges, switches, and routers, to break up the collision domains is known as
- A. Sectioning
 - B. Segmentation
 - C. Collision domain reduction
 - D. None of the above



Objectives

Upon completion of this chapter, you will be able to

- Understand the evolution of Ethernet technology
- Understand the MAC method, frame format, and transmission process of Ethernet technologies
- Understand the specific media and encoding used in each Ethernet technology
- Understand the pinouts and wiring typical of each Ethernet technology
- Understand the basic architectural considerations of each Ethernet technology
- Define microsegmentation
- Describe Layer 2 bridging
- Describe how a LAN switch operates
- Describe full-duplex transmission
- Identify the common switching methods: cut-through switching, store-and-forward switching, and fragment-free switching
- Describe the functions and features of the Spanning Tree Protocol (STP)
- Describe how STP works
- Describe the different STP port states

Chapter 6

Ethernet Technologies and Ethernet Switching

Ethernet, along with its associated IEEE 802.3 protocols, is one of the world's most important networking standards. Because of the great success of the original Ethernet and the soundness of its design, it has evolved over time. This evolution was in response to the developing needs of modern LANs. Ethernet most likely will continue to evolve in response to future demands for network capability.

The previous chapter introduced both the history of Ethernet and the standards associated with Ethernet. You also learned that the term *Ethernet* refers a family of the Ethernet technologies. This chapter discusses the Ethernet technologies in more detail.

In addition, this chapter introduces Layer 2 bridging and switching techniques. Switching and bridging are techniques that decrease congestion in LANs by reducing traffic and increasing bandwidth.

Finally, this chapter introduces the Spanning Tree Protocol (STP), tells how STP works, and covers the STP switch port states.

Please be sure to look at this chapter's associated e-Lab Activities, Videos, and PhotoZooms that you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

10-Mbps and 100-Mbps Ethernet

This section introduces the specifics of the most important varieties of Ethernet. The goal is not to memorize all the facts about each type of Ethernet, but rather to develop a sense of what is common to all forms of Ethernet and what are the specific strengths and weaknesses of the commercially important forms of Ethernet.

Ethernet's popularity began with the thick coaxial 10BASE5. However, Thicknet cable had undesirable installation properties. 10BASE2 used *Thinnet*—thinner coaxial cable that was easier to install and terminate; the distance decreased from 500 to 185 meters (m). This trend toward easy installation and lower cost took a great step forward with the introduction of UTP-based 10BASE-T. However, the length that an unrepeatd signal could travel decreased to 100m, necessitating the introduction of repeaters and then multiport repeaters (hubs). The repeater concept allowed 10BASE-T networks of up to 500m. As workgroups grew in size and applications increased in complexity, the shared bandwidth of the hub became a limiting factor. The introduction of Ethernet 10BASE-T switches addressed both the length and bandwidth limitations—station-to-switch links were now point-to-point.

The power, versatility, and cost-effectiveness of 10BASE-T coincided with an explosion in the number of LAN users, the number of Internet users (which also increased LAN traffic), and the complexity of applications. Demand for higher bandwidth grew, and Fast Ethernet was introduced. The copper cable version of Fast Ethernet that became commercially successful was 100BASE-TX, and many clever features were developed for interoperability with 10BASE-T systems (the emergence of 10/100 interfaces, for example). To compete with the backbone/LAN technology of FDDI, fiber-based 100BASE-FX was introduced. Throughout all of these Ethernet technologies, the MAC addressing concept, the frame format, and the CSMA/CD MAC method were maintained.

10-Mbps Versions of Ethernet

Figure 6-1 shows a subset of physical layer implementations that you can deploy to support Ethernet. The *10BASE5*, *10BASE2*, and *10BASE-T* implementations of Ethernet are considered legacy implementations and are referred to as such in the sections that follow.

Figure 6-1 Types of Ethernet

Logical Link Control Sublayer	
802.3 Media Access Control	
Physical Signaling Sublayer	Physical Medium
10BASE5 (500 m) 50 Ohm Coax N-Style	10BASE2 (185 m) 50 Ohm Coax BNC
10BASE-T (100 m) 100 Ohm UTP RJ45	10BASE-TX (100 m) 100 Ohm UTP RJ45
100BASE-FX (228_412 m) MM Fiber SC	100BASE-T (100 m) 100 Ohm UTP RJ45
100BASE-SX (220-550 m) MM Fiber SC	100BASE-LX (550-5000 m) MM Fiber Sc
10BASE-(Various) MM or Sm Fiber SC	

Four things are common among legacy Ethernet:

- Timing parameters
- Frame format
- Transmission process
- A basic design rule

After you learn about what these three historically important versions have in common, you will examine each in more detail.

10BASE5, 10BASE2, and 10BASE-T all share the same timing parameters, as shown in Table 6-1. Note that 1 bit-time at 10 Mbps = 100 nanosecond = 0.1 μ second = 1 ten-millionth of a second.

Table 6-1 Parameters for 10-Mbps Ethernet Operation

Parameter	Value
Bit-time	100 nsec
Slot time	512 bit-times
Interframe spacing	96 bits*
Collision attempt limit	16
Collision backoff limit	10
Collision jam size	32 bits
Maximum untagged frame size	1518 octets
Minimum frame size	512 bits (64 octets)

*The value listed is the official interframe spacing.

The frame format is common to 10BASE5, 10BASE2, and 10BASE-T. Figure 6-2 shows an Ethernet frame as observed at the MAC sublayer.

Figure 6-2 Ethernet Frame

Preamble	SFD	Destination	Source	Length/ Type	Data	Pad	FCS
7	1	6	6	2	46 to 1500		4

The Legacy Ethernet transmission process is identical until the lower part of the OSI physical layer. As the frame passes from the MAC sublayer to the physical layer, further processes occur before the bits are placed on the medium from the physical layer. One process that is particularly important at this level is the signal quality error (SQE) signal. This signal is typical of what you will see in many networking technologies. At the physical layer, the network is “alive” with communications other than the user data to ensure a properly functioning network. SQE always is used in half duplex; it is not required but is permitted in full-duplex operation. SQE is active in the following instances:

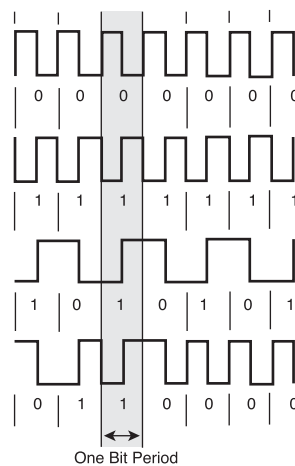
- Within 4 to 8 microseconds following a normal transmission, to indicate that the outbound frame successfully was transmitted.
- Whenever there is a collision on the medium.
- Whenever there is an *improper* signal on the medium. Improper signals might include detected jabber, or the reflections that result from a cable fault, such as a short. (There are separate conditions depending on which medium is attached.)
- Whenever a transmission has been interrupted as jabber—that is, it has transmitted longer than allowed.

NOTE

In NRZ encoding, signals are maintained at constant voltage levels, with no signal transitions (no return to a 0V level) during a bit interval.

All 10-Mbps forms of Ethernet take octets received from the MAC sublayer and perform a process called *line encoding*. Line encoding describes how the bits actually are signaled on the wire. The simplest *encodings* (such as *nonreturn to zero*, or NRZ, in which a 1 bit is 5 volts [V] and the 0 bits are 0V) typically have undesirable timing and electrical characteristics. Therefore, line codes have been engineered to have desirable transmission properties and tailored to each medium. The form of line encoding used in 10-Mbps systems is called *Manchester encoding*. Figure 6-3 shows a Manchester encoding example. The y-axis is voltage; the x-axis is time.

Figure 6-3 Manchester Encoding Examples



Manchester encoding relies on the direction of the edge transition in the middle of the timing window to determine the binary value for that bit period. In the encoding example shown in Figure 6-3, one timing window is highlighted vertically through all four waveform examples. The top waveform has a falling edge in the center of the timing window, so it is interpreted as a binary 0.

The result is that in the center of the timing window for the second waveform, there is a rising edge, which is interpreted as a binary 1.

Instead of a repeating sequence of the same binary value in the third waveform example, there is an alternating binary sequence. In the first two examples, the signal must transition back between each bit period so that it can make the same-direction transition each time in the center of the timing window. With alternating binary data, there is no need to return to the previous voltage level in preparation for the next edge in the center of the timing window. Thus, any time there is a long separation between one edge and the next, you can be certain that both edges represent the middle of a timing window. The fourth waveform example is random data that enables you verify that whenever there is a wide separation between two transitions, both edges are in the center of a timing window and represent the binary value for that timing window.

Legacy (10-Mbps) Ethernet has some common architectural features. All of these legacy versions are referred to as *shared Ethernet* because they share a common collision domain. It is not only allowed, but it is expected that an Ethernet network could contain multiple types of media (for example, 10BASE5, 10BASE2, 10BASE-T, and so on). The standard goes out of its way to ensure that interoperability is maintained. However, when implementing a mixed-media network, it is important to pay particular attention to the overall architecture design. It becomes easier to violate maximum delay limits as the network grows and becomes more complex. The timing limits are based on parameters such as these:

- Cable length and its propagation delay
- Delay of repeaters
- Delay of transceivers (including NICs, hubs, and switches)
- Interframe gap shrinkage
- Delays within the station



Lab Activity Waveform Decoding

The purpose of this lab is to integrate knowledge of networking media; OSI Layers 1, 2, and 3; and Ethernet, by decoding a digital waveform of an Ethernet frame.

5-4-3 Rule

10-Mbps Ethernet operates within the timing limits offered by a series of no more than five segments separated by no more than four repeaters. That is, no more than four repeaters can be connected in series between any two distant stations. The coaxial implementations have a further requirement that there can be no more than three populated segments between any two distant stations. The other two allowed coaxial segments are used to extend the diameter of the collision domain and are called link segments. The primary characteristic of a link segment is that it has exactly two devices attached. All twisted-pair links, such as 10BASE-T, meet the definition of a link segment.

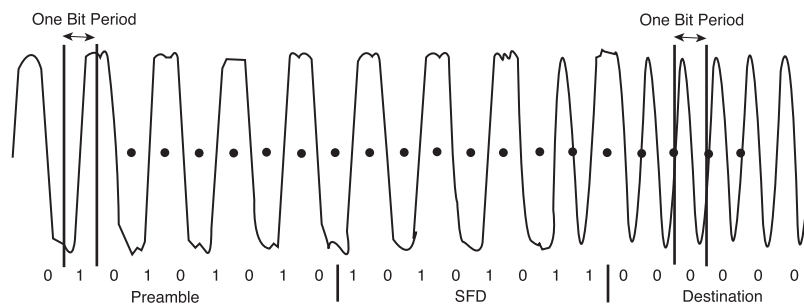
10BASE5

The original (1980) Ethernet product (10BASE5) transmitted 10 Mbps over a single thick coaxial cable bus, thus the name *Thicknet*. 10BASE5 is important for historical reasons: It was the first medium used for Ethernet. 10BASE5 was part of the original 802.3 standard. It can be found today as part of legacy installations. It is not a preferred choice for new networks because its primary benefit, length, can be accomplished in other ways. Although 10BASE5 systems are inexpensive and require no configuration (there is no need for hubs to extend the length of the system), basic components such as NICs are very difficult to find, and the technology is very sensitive to signal reflections on the cable. In addition, 10BASE5 systems are very cable-dependent across the whole collision domain and thus represent a large single point of failure.

The timing, frame format, and transmission process were described previously in Chapter 5, “Ethernet Fundamentals,” and are common to all 10-Mbps legacy Ethernet.

10BASE5 uses Manchester-encoded signals on thick coaxial cable. Figure 6-4 is an example of a 10BASE5 signal. It is transmitted from approximately 0V to -1V. 10BASE5 potentially could be idle (0V) for days if no station wanted to transmit. 10BASE5 is asynchronous.

Figure 6-4 10BASE5 Signal Decoded



In Figure 6-4, timing marks have been added to aid you in recognizing the timing windows from which the binary data was decoded. The y-axis is voltage; the x-axis is time. Voltage has been measured between the central conductor and the outer sheathing of the coaxial cable.

A 10BASE5 *thick* coax cable, as shown in Figure 6-5, has a solid central conductor, a minimum nominal velocity of propagation (NVP) of 0.77c, and 50 ohms of impedance/termination resistance; it uses N-style screw-on connections. Each of the maximum five segments of thick coax can be up to 500m (1640 ft.) long, and each station is connected to a transceiver on the coax via an Attachment Unit Interface (AUI) cable that can be up to 50m (164 ft.) long. The cable is large, heavy, and difficult to install, but the distance limitations were favorable; this prolonged its use in certain applications.

Figure 6-5 10BASE5 Thicknet Cable



Other specifications or limitations of 10BASE5 cable include the following:

- Only one station can transmit at a time (or a collision will occur).
- 10BASE5 can run *only* in half-duplex mode, subject to the CSMA/CD rules.
- Up to 100 stations, including repeaters, can exist on any individual 10BASE5 segment.

10BASE2

10BASE2 (originally 802.3a-1985) was introduced in 1985 because its coaxial cable of a smaller size, lighter weight, and greater flexibility made installation easier than 10BASE5. Because of its use of thinner cable, 10BASE2 often is referred to as *Thinnet*. 10BASE2 still exists in legacy networks. Although there is little reason to install a 10BASE2 network today, its low cost and lack of need for hubs are attractive. Essentially, 10BASE2 requires no configuration, although obtaining NICs is increasingly difficult. Just like 10BASE5 systems, 10BASE2 systems are very cable-dependent across the whole collision domain and represent a large single point of failure.

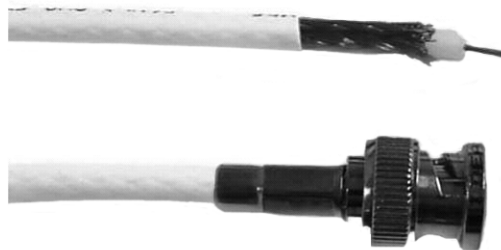
The timing, frame format, and transmission were described previously in Chapter 5 and are common to all 10-Mbps Legacy Ethernet.

10BASE2 uses Manchester-encoded signals on thin coaxial cable. A 10BASE2 signal is transmitted from approximately 0V to -1V. (The y-axis is voltage; the x-axis is time. Voltage is measured between the center conductor and the outer sheathing conductor.) 10BASE2 potentially could be idle (0V) for days if no station wanted to transmit. 10BASE2 is asynchronous.

The computers on the LAN were linked together like the beads of a necklace by an unbroken series of coaxial cable lengths. These lengths of coaxial cable were attached by British Naval Connectors (BNCs) to a T-shape connector on the NIC, as shown in Figure 6-6. This single coaxial cable was the shared bus for the network. Workstations easily could be moved and reattached, or new workstations could be added to the LAN. Otherwise, 10BASE2 used the same original Ethernet half-duplex protocol.

A 10BASE2 *thin* coax cable, as shown in Figure 6-8, has a stranded central conductor. (Be sure that stranded coax is specified when new cable is ordered. Some installers find it hard to work with and use solid-core coax when possible.) It has a minimum nominal velocity of propagation (NVP) of 0.65c, has 50 ohms of impedance/termination resistance, and uses BNC T-style connections. Each of the maximum five segments of thin coax can be up to 185m long (600 ft.), and each station is connected directly to the BNC T connector on the coax.

Figure 6-6 Thinnet and BNC Connector



10BASE-T

10BASE-T (originally 802.3i-1990) substituted the cheaper and easier-to-install UTP copper cable for coaxial cable. This cable plugged into a central connection device, a hub or a switch, that contained the shared bus. The type of cable used in 10BASE-T, the distances that the cable could extend from the hub, and the way in which the UTP was installed, interconnected, and tested were standardized in a “structured cabling

system,” which increasingly specified a star or extended star topology. 10BASE-T was originally a half-duplex protocol, but full-duplex features were added later. The explosion in Ethernet’s popularity in the 1990s—when Ethernet came to dominate LAN technology—was 10BASE-T running on Category (Cat) 5 UTP. To reacquaint yourself with network topologies and networking media, refer back to Chapter 2, “Networking Fundamentals,” and Chapter 3, “Networking Media.”

The timing, frame format, and transmission were described previously and are common to all 10-Mbps legacy Ethernet.

10BASE-T uses Manchester line-encoded signals over Category 3 (now 5, 5e, or better) UTP.

10-Mbps Ethernet is asynchronous, and the cable often is completely idle (0V) for long periods of time between transmissions. 10BASE-T links have a *link pulse* present about every 125 milliseconds (eight times per second), but can otherwise be idle. 10BASE-T networks are “alive” with link pulses.

A 10BASE-T unshielded twisted-pair (UTP) cable has a solid conductor for each wire in the maximum 90m horizontal cable, which should be 0.4 mm to 0.6 mm (26 to 22 American Wire Gauge [AWG]) in diameter. The 10m of allowed patch cables use similar-dimension stranded cable for durability because it is expected to experience repeated flexing. Suitable UTP cable has a minimum NVP of 0.585c, has 100 ohms of impedance, and uses eight-pin RJ-45 modular connectors as specified in ISO/IEC 8877. Cables between a station and a hub generally are described as between 0m and 100m long (0 ft. to 328 ft.), although the precise maximum length is determined by propagation delay through the link segment (any length that does not exceed 1000 ns of delay is acceptable). Usually, 0.5 mm (24 AWG) diameter UTP wire in a multipair cable will meet the requirements at 100m.

Although Category 3 cable is adequate for use on 10BASE-T networks, it is strongly recommended that any new cable installations be made with Category 5e or better materials and wiring practices. Use all four pairs, and use either the T568A or T568B cable pinout arrangement. With this type of cable installation, it should be possible to operate many different media access protocols (including 1000BASE-T) over the same cable plant, without rewiring.

Table 6-2 shows the pinout for a 10BASE-T connection. Notice that two separate transmit/receive paths exist (whereas coaxial cable has only one).

Table 6-2 10BASE-T Cable Pinouts

Pin Number	Signal
1	TD+ (Transmit Data, positive-going differential signal)
2	TD- (Transmit Data, negative-going differential signal)
3	RD+ (Receive Data, positive-going differential signal)
4	Unused
5	Unused
6	RD- (Receive Data, negative-going differential signal)
7	Unused
8	Unused

Figure 6-7 shows conceptual and physical connections between two stations. A cross-over cable is required, so Tx on device A sends signals to Rx on device B. Note that two point-to-point connections exist (TxA to RxB, and TxB to RxA).

Figure 6-7 10BASE-T Station to Station

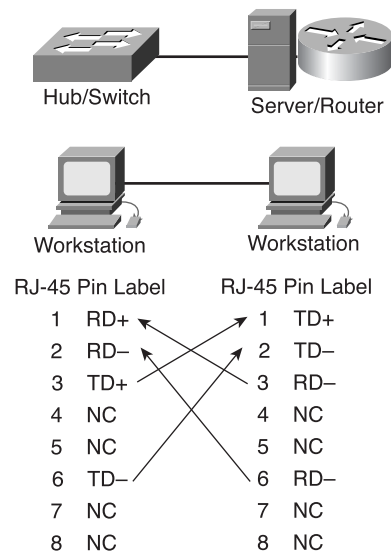
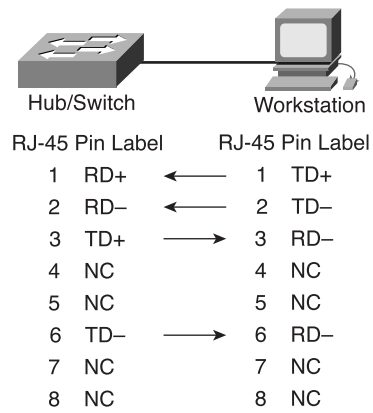


Figure 6-8 shows the connection between stations and repeaters, multiport repeaters (hubs), or switches. The same connection would be used between a router and a hub or a switch. A straight-through cable is used. Note that inside the hub is a bus topology, which is a collision domain. When a workstation is connected to a switch using a straight-through cable, all individual links are point-to-point. The switch fabric circuitry allows full bandwidth simultaneously between pairs of ports without collisions.

Figure 6-8 10BASE-T Straight-Through Cable



Because station-to-station, switch-to-switch, and station-to-switch connections all are point-to-point links, they have two physically separate communication pathways/channels on two separate UTP wire pairs. In this case, collisions are not physical events, but rather the result of the decision to not allow simultaneous Tx and Rx. Thus, either half duplex (subject to the administrative imposition of CSMA/CD) or full duplex (no physical collisions occur) is a configuration choice. Most of the time, you run these connections in full duplex, which not only eliminates collisions, but also doubles the throughput of the connection. When first introduced, the relevant IEEE standard was entitled 802.3x-1997 Full-Duplex. However, station-to-hub connections involve the bus topology within the hub, an actual physical collision domain. Hence, this connection can run *only* half duplex and is subject to CSMA/CD because of the physical nature of the structure.

10BASE-T carries 10 Mbps of traffic in half-duplex mode; however, 10BASE-T in full-duplex mode actually can exchange 20 Mbps of traffic (although, again, some of this is overhead, not user data). This concept will become increasingly important with the desire to increase the speed of Ethernet links.

10BASE-T Architecture

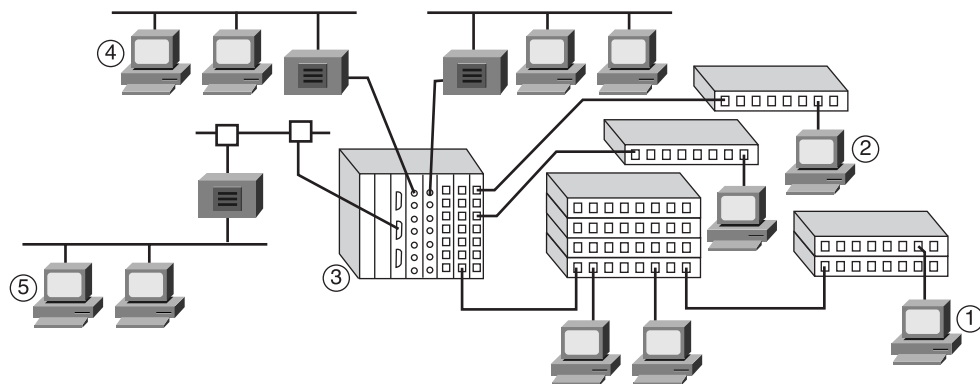
10BASE-T links generally consist of a connection between the station and a hub or switch. Hubs should be thought of as multiport repeaters and count toward the limit on repeaters between distant stations. Switches can be thought of as multiport bridges and are subject to 100m length limitations but no limit on switches between distant stations.

Although hubs can be linked in series (sometimes called daisy-chaining, or cascading), it is best to avoid this arrangement when possible, to keep from violating the limit for maximum delay between distant stations. The physical size of a 10BASE-T network is subject to the same rules as 10BASE5 and 10BASE2 concerning the number of repeaters. When multiple hubs are required, it is best to arrange them in hierarchical order, to create a tree structure instead of a chain. Also, performance will be improved if fewer repeaters separate stations. “Stackable” hubs, or concentrators with common backplanes that will support several multiport adapter cards, permit large numbers of stations to be connected to a device that counts as a single hub (repeater). Daisy-chaining switches is fine and is not subject to restrictions.

All distances between stations are acceptable, although in one direction, the architecture is at its limit. The most important aspect to consider is how to keep the delay between distant stations to a minimum—regardless of the architecture and media types involved. A shorter maximum delay provides better overall performance. Consider the following architectures:

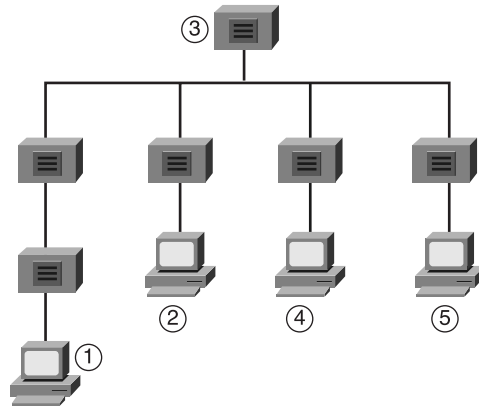
- In Figure 6-9, there are five segments and four repeaters from Station 1 to any other station in these paths. For 10BASE-T connections, the maximum of three segments with stations does not apply because no other stations are on the same cable. Each connection is described as a link segment.

Figure 6-9 Example 10-Mbps Mixed Architecture 1



- In Figure 6-10, from any station (except Station 1) to any other station, the path is only three repeaters. Because these alternate paths include 10BASE5 and 10BASE2 links, the other requirements still apply there (such as only three segments with stations).

Figure 6-10 Example 10-Mbps Mixed Architecture 2



10BASE-T links can have unrepeated distances up to 100m. This might seem like a long distance, but it typically is used up quickly when wiring an actual building. Hubs can solve this distance issue, although a maximum of four repeaters could be chained together because of timing considerations. The widespread introduction of switches has made this distance limitation less important. As long as workstations are located within 100m of a switch, the 100m distance starts over at the switch, which could be connected via another 100m to another switch, and so on. Because most modern 10BASE-T Ethernet is switched, these are the practical limits between devices. Ring, star, and extended star topologies all are allowed. The issue then becomes one of logical topology and data flow, not timing or distance limitations.

Table 6-3 shows a chart of the 10BASE-T link characteristics.

Table 6-3 10BASE-T Link Characteristics Chart

Connection	Maximum Segment
Station to station, station to switch, switch to switch	100m, with no limitations on daisy chaining
Station to hub	100m, but subject to four-repeater rule

100-Mbps Versions of Ethernet

100-Mbps Ethernet, also known as Fast Ethernet (in comparison to the original 10-Mbps Ethernet), was a series of technologies. The two technologies that became commercially important are **100BASE-TX** (copper UTP-based) and **100BASE-FX** (multimode optical fiber-based). This section examines the commonalities between these two technologies and then examines their differences individually.

Three things are common to 100BASE-TX and 100BASE-FX:

- The timing parameters
- The frame format
- Parts of the transmission process

Table 6-4 shows the parameters for 100-Mbps Ethernet operation.

Table 6-4 Parameters for 100-Mbps Ethernet Operation

Parameter	Value
Bit-time	10 nsec
Slot time	512 bit-times
Interframe spacing	96 bits
Collision attempt limit	16
Collision backoff limit	10
Collision jam size	32 bits
Maximum untagged frame size	1518 octets
Minimum frame size	512 bits (64 octets)

100BASE-TX and 100BASE-FX both share timing parameters. Note that 1 bit-time in 1000-Mbps Ethernet is 10 nsec = .01 microseconds = 1 100-millionth of a second.

The 100-Mbps frame format is the same as the 10-Mbps frame. Unlike 10-Mbps Ethernet, in which the process was the same for all technologies until the signal was applied to the medium.

Fast Ethernet represents a tenfold increase in speed. With this increase in speed comes extra requirements. The bits being sent get shorter in duration and occur more frequently. They require more careful timing, and their transmission requires frequencies closer to

medium-bandwidth limitations and become more susceptible to noise. In response to these issues of synchronization, bandwidth, and *signal-to-noise ratio (SNR)*, two separate encoding steps are used by 100-Mbps Ethernet. The basic idea is to use codes—which can be engineered to have desirable properties—to represent the user data in a way that is efficient to transmit, including synchronization, efficient usage of bandwidth, and improved SNR characteristics. The first part of the encoding uses a technique called 4-bit/5-bit (4B/5B); the second part of the encoding is the actual line encoding specific to copper or fiber.

The two forms of 100-Mbps Ethernet of consideration in this course, 100BASE-TX and 100BASE-FX, encode nibbles (4-bit groupings) from the upper parts of the MAC sublayer. The 4-bit patterns are converted into 5-bit symbols; symbols sometimes control information (such as start frame, end frame, or medium-is-idle conditions). The entire frame to be transmitted is comprised of control symbols and data symbols (data code groups). Again, all of this extra complexity is necessary to achieve the tenfold increase in network speed.

After the 4B/5B encoding, the bits (in the form of code groups) still need to be placed on the medium (that is, they must be line-encoded). The conversion from 4 bits to 5 bits also means that there are now 125 Mbps to be transmitted instead of 100 Mbps during the same time interval. This puts more strict requirements on the medium, transmitters, and receivers used. For example, the cable must be tested at higher frequencies to ensure proper transmission characteristics. Any time that there is no data to be sent, “idle code” groups still are sent to fill the empty periods and maintain synchronization. At this point, the data path diverges depending on whether you are using copper (100BASE-TX) or fiber (100BASE-FX) media.

100BASE-TX

The need for faster networks led to the announcement of the 100BASE-T Fast Ethernet and autonegotiation standard in 1995 (originally 802.3u-1995). 100BASE-T increased Ethernet’s bit rate to 100 Mbps. 100BASE-TX was the Category 5 UTP version of 100BASE-T that became commercially successful. Soon 10/100 hubs and switches enabled Ethernet transmissions at the original rate of 10 Mbps to share the network with frames sent at 100 Mbps.

The original coaxial Ethernet used half-duplex transmission; therefore, only one device could transmit at a time. In 1997, Ethernet was expanded to include a full-duplex capability (originally 802.3x) that allowed more than one PC on a network to transmit at the same time. Devices called Ethernet switches were developed that enabled this full-duplex communication and handled network traffic more efficiently than hubs.

These switches increasingly replaced hubs in high-speed networks because of their full-duplex capability and rapid handling of Ethernet frames.

The timing, frame format, and transmission were described previously in Chapter 5 and are common to both versions of 100-Mbps Fast Ethernet considered in this chapter.

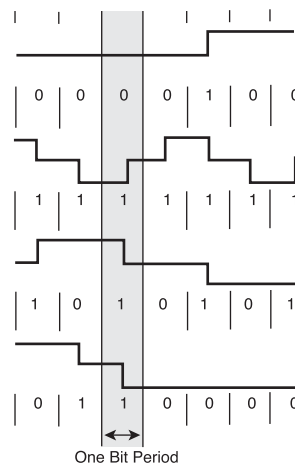
NOTE

In NRZI encoding, signals maintain constant voltage levels with no signal transitions (no return to a 0V level) but interpret the presence of data at the beginning of a bit interval as a signal transition. Likewise, they interpret the absence of data as no transition.

100BASE-TX uses 4B/5B encoded data, which then is scrambled and converted to multilevel transmit—three levels, or MLT-3, line encoding on Category 5 UTP (or better). The MLT-3 encoding converts the binary data stream to an electrical waveform using a continuous signaling system. MLT-3 is different from *nonreturn to zero inverted (NRZI)*, in that the signal level alternates between above and below the zero level instead of using only two levels.

Figure 6-11 shows some MLT-3 encoding examples. The basic rule of MLT-3 is that binary 1s cause the voltage level to cycle to the next level down and then back up again. Binary 0s do not cause a level transition.

Figure 6-11 MLT-3 Encoding Examples

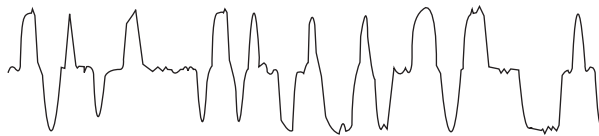


In the encoding example in Figure 6-11, one timing window is highlighted vertically through all four waveform examples. The top waveform has no transition in the center of the timing window. No transition indicates that a binary 0 is present. If the example waveform was all 0s on that line, the signal level represented would be either a constant high, 0, or low across the waveform. A single 1 was introduced to move the remaining 0s to a different voltage level and show that 0s can appear at more than one voltage level. The level depends upon what the previous (high or low) voltage level was and moves in the opposite direction. In this first waveform, it is thus evident that the previous voltage level (not shown) was a low level.

The second waveform in Figure 6-11 has a transition in the center of the timing window. A binary 1 is represented by a transition. It does not matter whether the transition is rising or falling, or whether the new level reached is high, 0, or low. Instead of a repeating sequence of the same binary value in the third waveform example, there is an alternating binary sequence. Again, this pattern helps demonstrate that the absence of a transition indicates a binary 0, and the presence of a transition indicates a binary 1. Rising or falling edges indicate 1s. The very steep signal changes from one extreme to the other, with a slight decrease in gradient at 0, indicate consecutive 1s. Any noticeable horizontal line in the signal indicates a 0, or consecutive 0s.

Figure 6-12 is an example of 100BASE-TX signal taken from an oscilloscope. (In Figure 6-12, the y-axis is voltage; the x-axis is time. Voltage is measured as a differential signal between 2.)

Figure 6-12 100BASE-TX Signal Sample



During the initial process of establishing synchronization with the link partner to establish a link, the receiver circuit expects to see only 4B/5B idle code groups.

The cable pinout for a 100BASE-TX connection is identical to the one for 10BASE-T. Two separate transmit/receive paths exist. For the connection between two stations or two switches, a crossover cable is required. As for the connection between stations and repeaters/multiport repeaters (hubs), a straight-through cable is used. Note that inside an exclusively 100-Mbps hub is a bus topology, which is a collision domain. However, if the hub is a 10/100 autosensing hub, which is vastly more common, the internal topology is more complex, to account for the speed differential between 10BASE-T and 100BASE-TX. It should be noted that, even though a 100-Mbps Ethernet hub is significantly faster than a 10-Mbps hub, collisions are still a problem because both are based on a shared bus architecture. Only through the use of switches and full duplex are collisions avoided.

For the connection between a station and a switch, a straight-through cable is used. The switch fabric circuitry allows full bandwidth simultaneously on multiple ports without collisions.

Station-to-station, switch-to-switch, and station-to-switch connections in Fast Ethernet all are point-to-point links: They have two physically separate communication pathways/channels. In this case, collisions are not physical events, but rather the result of an administrative decision to not allow simultaneous Tx and Rx. Therefore, either half duplex (subject to the administrative imposition of CSMA/CD) or full duplex (no physical collisions occur) is a configuration choice. Most of the time, you run these connections in full duplex.

However, station-to-hub connections must account for the bus topology within the hub, a collision domain. Hence, this connection can *only* run half duplex and is subject to CSMA/CD because of the physical nature of the structure.

Can a 100-Mbps technology allow 200 Mbps of traffic? 100BASE-TX carries 100 Mbps of traffic in half-duplex mode (although some of this is overhead, not user data). But 100BASE-TX in full-duplex mode can exchange 200 Mbps of traffic (although, again, some of this is overhead, not user data). The concept of full duplex will become increasingly important with the desire to increase the speed of Ethernet links. You will learn about the 100BASE-TX architecture rules later in this chapter.

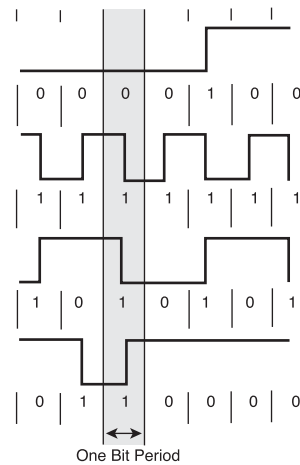
100BASE-FX

Why use 100BASE-FX (introduced as part of the 802.3u-1995 standard)? At the time copper-based Fast Ethernet was introduced, a fiber version was desired for backbone applications, connections between floors and buildings where copper is less desirable, and high-noise environments. 100BASE-FX also was positioned as an alternative to the then-popular FDDI (100-Mbps dual fiber-optic Token Ring). However, the vast majority of Fast Ethernet installations today are 100BASE-TX. One reason for the relative lack of adoption of 100BASE-FX was the rapidity of the introduction of Gigabit Ethernet copper and fiber standards, which are now the dominant technology for backbone installations, high-speed cross-connects, and general infrastructure needs.

The timing, frame format, and transmission were described previously in Chapter 5 and are common to both versions of 100-Mbps Fast Ethernet considered in this chapter.

100BASE-FX uses 4B/5B encoded data with NRZI line encoding. Signals are LED pulses on multimode optical fiber. NRZI encoding relies on the presence or absence of a transition in the middle of the timing window to determine the binary value for that bit period. 100BASE-FX is synchronous.

Figure 6-13 illustrates the NRZI encoding examples. (The y-axis is optical power; the x-axis is time.)

Figure 6-13 NRZI Encoding Examples

In the encoding examples in Figure 6-13, one timing window is highlighted vertically through all four waveform examples. The top waveform has no transition in the center of the timing window, so it is interpreted as a binary 0. No transition indicates that a binary 0 is present. If the example waveform was all 0s on that line, the signal level represented would be either low or high across the waveform. A single 1 was introduced to indicate that 0s could be either level.

The second waveform has a transition in the center of the timing window. A binary 1 is represented by a transition. It does not matter whether the transition is rising or falling. Instead of a repeating sequence of the same binary value in the third waveform, there is an alternating binary sequence. In this example, it is more obvious that no transition indicates a binary 0, and the presence of a transition indicates a binary 1.

The NRZI-encoded, serialized bit stream is ready for transmission using pulsed light. Because of cycle time problems related to turning the transmitter completely on and off each time, the light is pulsed using low and high power. A logic 0 is represented by low power, and a logic 1 is represented by high power.

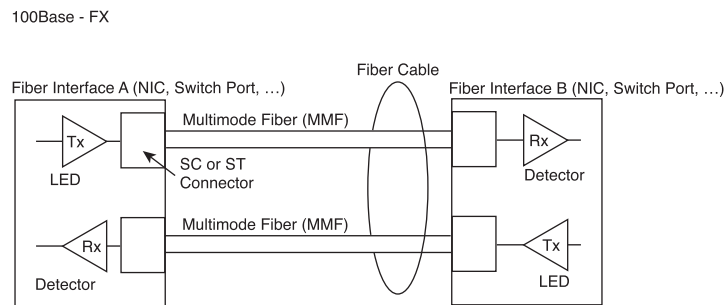
Table 6-5 summarizes a 100BASE-FX link and the pinouts. A fiber pair with either (ST) or (SC) connectors most commonly is used.

Table 6-5 100BASE-FX Pinout

Fiber	Signal
1	Tx (LED and laser transmitters)
2	Rx (high-speed photodiode detectors)

Figure 6-14 shows an interface-to-interface fiber link. The two separate strands of multimode fiber are often in the same cable structure, with dual connectors on each end.

Figure 6-14 Fiber Interface-to-Interface Connection



The MAC method treats the link as point-to-point, and fiber is intrinsically full duplex because of separate Tx and Rx fibers. 100BASE-TX could run in half duplex, but this would have length implications (the timing is actually a codeterminant, along with attenuation/dispersion/fiber properties of length limitations and restrictions on numbers of segments). Again, physical collisions between voltages are not an issue—these are serial streams of light pulses on an optical fiber—but administratively can impose CSMA/CD based on not allowing simultaneous Tx and Rx.

Can 100-Mbps fiber technology allow 200 Mbps of traffic? Somewhat analogous to the separate transmit and receive paths in UTP, there are two such paths in 100BASE-FX optical fiber, and 200 Mbps is possible.

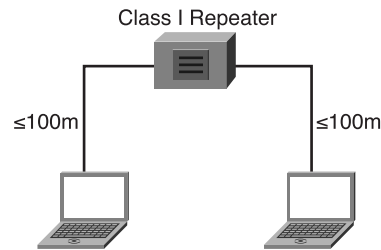
Fast Ethernet Architecture

Fast Ethernet links generally consist of a connection between the station and a hub or switch. Hubs should be thought of as multiport repeaters and count toward the limit on repeaters between distant stations. Switches can be thought of as multiport bridges. They are subject to the 100m UTP media distance limitation, but they have no limitation on daisy-chaining.

Repeaters must be labeled with the word *Class* followed by a Roman numeral I or II inside a circle, indicating Class I or Class II. A Class I repeater can introduce up to 140 bit-times of latency (delay). Any repeater that changes between one Ethernet implementation and another (for example, 100BASE-TX and 100BASE-FX) is a Class I repeater. Also assume that any unlabeled repeater is a Class I device. Figure 6-15 illustrates

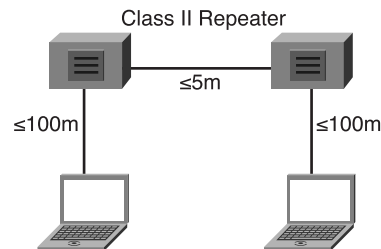
the maximum collision domain diameter for a Class I repeater for 100BASE-TX. Using switches removes these restrictions, and the limiting factor becomes the media-determined maximum length between interfaces.

Figure 6-15 Maximum Collision Domain Diameter for a Class I Repeater



A Class II repeater can introduce only a maximum of 92 bit-times of latency. Because of the reduced latency, it is possible to have two Class II repeaters in a series, but only if the cable between them is very short. Figure 6-16 illustrates the maximum collision domain diameter for a Class II repeater for 100BASE-TX. Using switches removes these restrictions, and the limiting factor becomes the media-determined maximum length between interfaces.

Figure 6-16 Collision Domain Diameter for a Class II Repeater



As with 10-Mbps versions, it is possible to modify some of the architecture rules for 100-Mbps versions; however, there is virtually no allowance for additional delay. If your network is implemented using new high-performance hardware, it is possible that some of these limits can be exceeded. For example, if a longer cable is used between repeaters, shorter cables would have to be used to each station. Modification of the architecture rules *strongly* is discouraged for 100BASE-TX. Refer to the technical timing descriptions detailed in Clause 29 of the current 802.3 standard and the technical information about your hardware performance before attempting it. Any device that

adapts between different Ethernet speeds, such as between 10 Mbps and 100 Mbps, is an OSI Layer 2 bridge. It is not possible to adapt between speeds and still be a repeater. However, the same device can repeat between ports linked at the same speed.

A 100BASE-TX UTP cable is about the same as a 10BASE-T cable, except that link performance must meet the higher-quality Category 5 or ISO Class D requirements. The 100BASE-TX cable between Class II repeaters cannot exceed 5m.

Links operating in full duplex can be substantially longer than what is shown in Table 6-6 because they are limited only by the capability of the medium to deliver a robust enough signal for proper decoding, not the round-trip delay. It is not uncommon to find Fast Ethernet operating in half duplex. However, half duplex is undesirable because the signaling scheme is inherently full duplex, and forcing half-duplex communications rules onto a full-duplex signaling system is not a wise use of resources.

It is recommended that all links between a station and a hub or switch be configured for autonegotiation, to permit the highest common performance configuration to be established with risking misconfiguration of the link. Disable autonegotiation and force connection configurations only if autonegotiation fails or on certain selected connections. The average station connection should be established by autonegotiation.

Table 6-6 summarizes the architectural rules for Fast Ethernet.

Table 6-6 Architecture Configuration Cable Distances

Architecture	100BASE-TX	100BASE-FX	100BASE-FX and 100BASE-TX
Station to station, station to switch, switch to switch (half or full duplex)	100m	412m	—
One Class I repeater (half duplex)	200m	272m	100m TX 160.8m FX
One Class II repeater (half duplex)	200m	320m	100m TX 208m FX
Two Class II repeaters (half duplex)	205m	228m	105m TX 211.2m FX

100BASE-TX links can have unrepeated distances up to 100m. This might seem like a long distance, but it typically is used up quickly when wiring an actual building. Hubs can solve this distance issue, subject to the restrictions in Table 6-6 because of timing considerations. The widespread introduction of switches has made this distance limitation less important. As long as workstations are located within 100m of a switch, the 100m distance starts over at the switch, which could be connected via another 100m to another switch, and so on. Because most Fast Ethernet is switched, these are the practical limits between devices. Ring, star, and extended star topologies all are allowed. The issue then becomes one of logical topology and data flow, not timing or distance limitations.

Gigabit, 10-Gb, and Future Ethernet

Fast Ethernet (100 Mbps) represented a major improvement over legacy Ethernet (10 Mbps). Yet the even more rapid progression from Fast Ethernet to Gigabit Ethernet is testimony to the power of IEEE standards, engineering advances, and market forces. Gigabit Ethernet, 1000 Mbps, is a hundredfold increase in network speed over the wildly popular 10BASE-T. Although MAC addressing, CSMA/CD, and, most important, the frame format from earlier versions of Ethernet are preserved, many other aspects of the MAC sublayer, the physical layer, and the medium have been changed.

Copper interfaces capable of 10/100/1000 operation are now common. Gigabit switch and router ports and blades are becoming routine in wiring closets. More multimode and single-mode optical fiber is being installed. One major emphasis of Gigabit Ethernet is optical fiber technology, but the need for a copper version—to use existing cable plants and to use the ruggedness of copper in user environments—led to a very clever scheme to get 1000 Mbps down the same Category 5 UTP used so successfully in 10-Mbps and 100-Mbps Ethernet. All of the Gigabit technologies are intrinsically full duplex. The inexorable forward march of technology continues as standards and technologies for 40 Gbps, 100 Gbps, and 160 Gbps currently are being implemented. Most dramatic is the evolution of Ethernet from LAN applications only to an end-to-end LAN, MAN, and WAN technology.

1000-Mbps Versions of Ethernet (Gigabit)

In 1998, the IEEE 802.3z committee adopted 1000BASE-X standard. This standard raised the data transmission rate to 1 Gbps full duplex over optical fiber, a hundredfold increase in speed over 10BASE-T. The 1000BASE-T standard, specifying 1 Gbps full duplex over Category 5 or higher UTP, was adopted in 1999.

Table 6-7 shows the parameters for 1000-Mbps Ethernet operation.

Table 6-7 Parameters for Gigabit Ethernet Operation

Parameter	Value
Bit-time	1 nsec
Slot time	4096 bit-times
Interframe spacing	96 bits*
Collision attempt limit	16
Collision backoff limit	10
Collision jam size	32 bits
Maximum untagged frame size	1518 octets
Minimum frame size	512 bits (64 octets)
Burst limit	65,536 bits

*The value listed is the official interframe spacing.

1000BASE-T, *1000BASE-SX*, and *1000BASE-LX* all share the same timing parameters. Note that bit-time at 1000 Mbps = 1 nsec = .001 microseconds = 1 billionth of a second. You also need to note that some differences in timing relative to legacy and Fast Ethernet now are appearing because of the special issues that arise with such short bit and slot times.

The 1000-Mbps (Gigabit) Ethernet frame has the same format as is used for 10- and 100-Mbps Ethernet. 1000-Mbps Ethernet has different paths for the process of converting frames to bits on the cable, depending on which implementation is used.

Gigabit Ethernet is a tenfold increase in speed over Fast Ethernet. Just as with Fast Ethernet, with this increase in speed comes extra requirements—the bits being sent get shorter in duration (1 nanosecond), occur more frequently, and require more careful timing. Their transmission also requires frequencies closer to medium bandwidth limitations, and they become more susceptible to noise. In response to these issues of synchronization, bandwidth, and signal-to-noise ratio, Gigabit Ethernet uses two separate encoding steps. The basic idea is to use codes—which can be engineered to have desirable properties—to represent the user data in a way that is efficient to transmit, including synchronization, efficient usage of bandwidth, and improved SNR characteristics.

Bit patterns from the MAC sublayer are converted into symbols, with symbols sometimes controlling information (such as start frame, end frame, and medium idle conditions). The entire frame is broken up into control symbols and data symbols (data code groups). All of this extra complexity is necessary to achieve the tenfold increase in network speed over Fast Ethernet. For 1000BASE-T, the first part of the encoding uses a technique called *8Bit-1Quinary quarter (8B1Q4)*; the second part of the encoding is the actual line encoding specific to copper, called *4-dimensional 5 level pulse amplitude modulation (4D-PAM5)*. The 8B1Q4 encoding followed by the 4D-PAM5 line encoding provide the synchronization, bandwidth, and SNR characteristics needed to make possible the four wire pairs (working in parallel) running full duplex on each wire pair simultaneously. For 1000BASE-X, 8-bit/10-bit (8B/10B) encoding (similar to the 4B/5B concept) is used, followed by the simple NRZ line encoding of light on optical fiber.

1000BASE-T

Goals for 1000BASE-T (introduced as 802.3ab-1999 1000BASE-T Gigabit Ethernet over twisted-pair) included these:

- Capability to function over existing Category 5 copper cable plants
- Assurance that this cable would work by passing a Category 5e test, which most cable can pass after a careful retermination
- Interoperability with 10BASE-T and 100BASE-TX
- Applications such as building backbones, interswitch links, wiring closet applications, server farms, and high-end desktop workstations
- Provision of 10x bandwidth of Fast Ethernet, which became very widely installed by end users, helping to necessitate more speed upstream in the network

To achieve this speed running over Category 5e copper cable, 1000BASE-T needed to use all four pairs of wires. Category 5e cable reliably can carry up to 125 Mbps of traffic. Using sophisticated circuitry, full-duplex transmissions on the same wire pair allow 250 Mbps per pair; multiplied by four wire pairs, this gives a total of 1000 Mbps (1 Gbps). For some purposes, it is helpful to think of these four wire pairs as “lanes” over which the data travels simultaneously (to be reassembled carefully at the receiver).

The timing, frame format, and transmission were described previously in Chapter 5 and are common to all versions of 1000-Mbps Ethernet considered here.

1000BASE-T uses 8B1Q4 encoding with 4D-PAM5 line encoding on Cat 5e or better UTP. Achieving the 1-Gbps rate required use of all four pairs in full-duplex simultaneously. This results in a permanent collision on the wire pairs, which is very different from the first coaxial Ethernet systems. The “permanent” collisions—transmission and receipt of data happens in both directions on the same wire at the same time—results

in very complex voltage patterns. But using sophisticated integrated circuits, which, among other things, use a technique called *echo cancellation*, works well.

Despite the constant collision of the signals, the system is capable of operating through a careful selection of voltage levels and use of Layer 1 forward error correction (FEC).

Figure 6-17 shows the outbound (transmitting [Tx]) 1000BASE-T signal (the y-axis is voltage; the x-axis is the time taken from an oscilloscope—voltage is a “differential signal” measured between two paired wires in one of the four pairs present in UTP cable).

Figure 6-17 Outbound (Tx) 1000BASE-T Signal

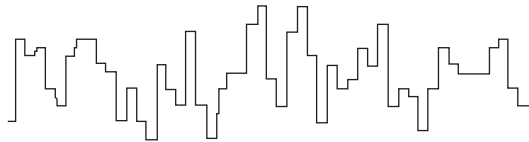


Figure 6-18 shows actually 1000BASE-T signal captured with a digital storage oscilloscope after several meters of cable. (the y-axis is voltage; the x-axis is time—voltage is a “differential signal” measured between two paired wires in one of the four pairs present in UTP cable).

Figure 6-18 Actual 1000BASE-T Signal



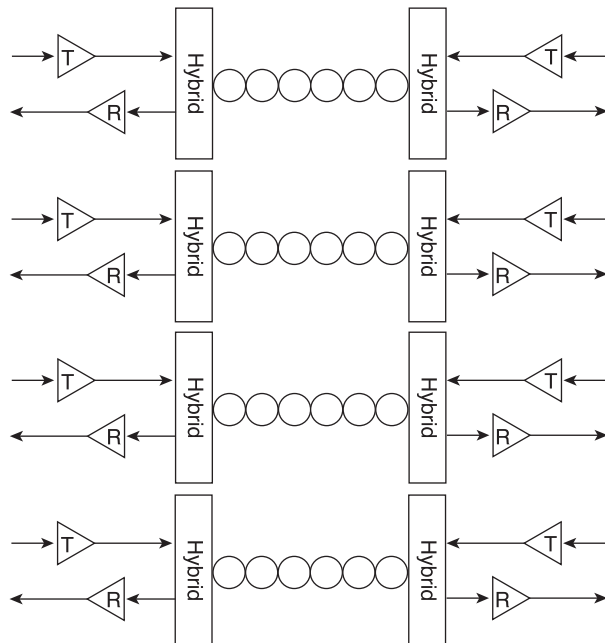
It is quite remarkable that the signal can be recovered at all when it is revealed that during idle periods, there are nine voltage levels found on the cable, and during data transmission periods, there are 17 voltage levels on the cable. Note the complex line encoding to begin with. Then, in Figure 6-18, look at the actual signal on the wire with constant collisions, as well as attenuation effects and noise. The signal looks analog. The key here is that sophisticated circuitry is decoding all of this. However, the system is susceptible to cable problems, termination problems, and noise unless standards are followed. Gigabit Ethernet works very well if the cabling, termination, and noise guidelines are followed.

Table 6-8 summarizes the use of all four pairs in the UTP cable. A, B, C, and D could be considered “lanes” of data. The data from the sending station carefully is divided into four parallel streams, encoded, transmitted and detected in parallel, and then reassembled into one received bit stream.

Table 6-8 1000BASE-T Pinout

Pin Number	Signal
1	BI_DA+ (bidirectional data, positive going)
2	BI_DA- (bidirectional data, negative going)
3	BI_DB+ (bidirectional data, positive going)
4	BI_DC+ (bidirectional data, positive going)
5	BI_DC- (bidirectional data, negative going)
6	BI_DB- (bidirectional data, negative going)
7	BI_DD+ (bidirectional data, positive going)
8	BI_DD- (bidirectional data, negative going)

Figure 6-19 is a schematic representation of simultaneous full-duplex on four wire pairs. Station-to-station, switch-to-switch, and station-to-switch cabling connections are the same as in Fast Ethernet.

Figure 6-19 1000BASE-T Signal Transmission

It is especially important to desktop, office, and wiring closet applications that there be interoperability among Gigabit, Fast, and 10BASE-T Ethernet. This might seem to be a hopeless affair. But upon close inspection, note that if the cabling installed in the walls tests out (as it often does or easily can be made to by retermination) at Category 5e and if all eight wires in the RJ-45 connectors and jacks are connected, the signal paths exist for Gigabit, Fast, and 10BASE-T Ethernet to interoperate. Just as 10/100 devices emerged in Fast Ethernet, 10/100/1000 interfaces have been developed for interoperability. By using the same frame format, compatible wiring paths, and clever interface engineering, it all works well.

For historical reasons, CSMA/CD and half duplex are options on 1000BASE-T. But the overwhelming use of 1000BASE-T is full duplex. This is accomplished with sophisticated hybrid circuits that can act as Tx and Rx at the same time for the same wires.

Before communications can begin, the two link partners must determine which will source the master clock and which will use the data stream to recover the slave clock. The master clock and slave clock are used as time markers for signal transmission. This process usually is determined during autonegotiation, although it can be configured manually. A number of other parameters also are determined in the same manner, including duplex type. Autonegotiation usually determines that a multiport device (a switch or hub) should become the master clock. The overall message here is that with the 1 nanosecond bit-times, 1 billion bps data transfer rate, and four wire pairs simultaneously transmitting and receiving, synchronization is extremely important.

When the topic of 1000BASE-X (1000BASE-SX and 1000BASE-LX) is presented, comparisons with 1000BASE-T architecture are included.

1000BASE-SX and 1000BASE-LX

Gigabit Ethernet over fiber is one of the most recommended backbone technologies. Its benefits are tremendous:

- 1000-Mbps data transfer, which can aggregate groupings of widely deployed Fast Ethernet devices
- Noise immunity
- Lack of any ground potential problems between floors or buildings
- An explosion in 1000BASE-X device options
- Excellent distance characteristics

Gigabit Ethernet over fiber originally was introduced in the IEEE 802.3 supplement entitled “802.3z-1998 1000BASE-X Gigabit Ethernet.” The only application for which 1000BASE-SX and 1000BASE-LX has not caught on as rapidly is the office

desktop—1000BASE-TX is considered more “user-proof” in terms of day-to-day wear, and 10-/100-/1000-Mbps copper interfaces are common.

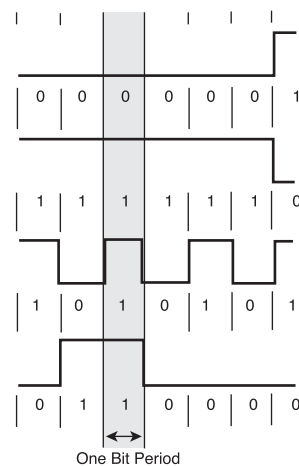
The timing, frame format, and transmission were described previously in Chapter 5 and are common to all versions of 1000-Mbps Ethernet considered here.

1000BASE-X uses 8B/10B encoding converted to NRZ line encoding, with either lower-cost short-wavelength 850 nm laser (or sometimes LED) sources and multimode optical fiber (1000BASE-SX, S for short), or long-wavelength 1310 nm laser sources and single-mode optical fiber (1000BASE-LX, L for long).

NRZ encoding relies on the signal level found in the timing window to determine the binary value for that bit period. Unlike most of the other encoding schemes described, this encoding system is *level-driven* instead of *edge-driven*.

In the encoding example in Figure 6-20, one timing window is highlighted vertically through all four waveform examples. The top waveform is low across the timing window. A low signal level represents a binary 0. A single 1 was introduced at the end of the waveform to show the other signal level.

Figure 6-20 NRZ Encoding Example



The second waveform is high across the timing window. A high signal level represents a binary 1. Again, a single 0 was introduced at the end of the waveform to show the other signal level. Instead of a repeating sequence of the same binary value in the third waveform, there is an alternating binary sequence. In this example, it is more obvious that a low signal level indicates a binary 0 and a high signal indicates a binary 1.

The fourth waveform example is random data. Three of these examples are good examples of why this encoding scheme has the potential to cause dc voltage drift on copper media. The second example is changing levels each bit period and would not suffer from dc voltage drift. It is very easy for a string of the same binary signal to cause a dc voltage bias on the cable, which has the potential of causing clocking errors. On fiber media, this is not an issue.

The NRZ-encoded serialized bit stream is ready for transmission using pulsed light as specified for 1000BASE-SX or 1000BASE-LX. Because of cycle time problems related to turning the transmitter completely on and off each time, the light is pulsed using low and high power. A logical 0 is represented by low power, and a logical 1 is represented by high power.

Table 6-9 shows the amazingly simple interface-to-interface interconnection for Gigabit Ethernet over fiber. SC fiber-optic connectors most commonly are used.

Table 6-9 Interface-to-Interface Interconnection for Gigabit Ethernet

Fiber	Signal
1	Tx (laser transmitters)
2	Rx (high-speed photodiode detectors)

Figure 6-21 shows the interface-to-interface connection for 1000BASE-SX. Short-wavelength laser (or sometimes LED) sources typically are used with multimode optical fiber.

Figure 6-21 1000BASE-SX Fiber Interface-to-Interface Connection

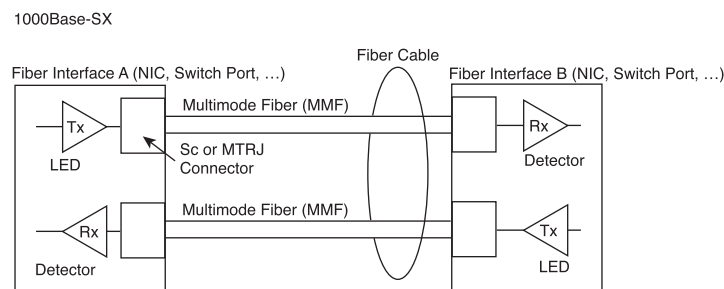
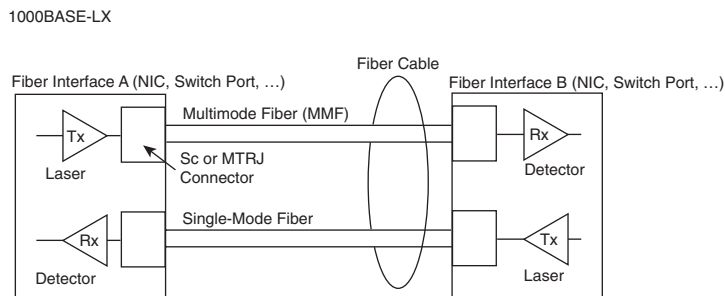


Figure 6-22 shows the interface-to-interface connection for 1000BASE-LX. Laser sources typically are used with single-mode fiber to achieve distances of up to 5000m.

Figure 6-22 1000BASE-LX Interface-to-Interface Connection

The MAC method used treats the link as point-to-point, and fiber is intrinsically full duplex because separate Tx and Rx fibers. Gigabit Ethernet permits a single repeater between two stations.

Gigabit Ethernet Architecture

Any device that adapts between different Ethernet speeds, such as between 100 Mbps and 1000 Mbps, is an OSI Layer 2 bridge. It is not possible to adapt between speeds and still be a repeater.

Full-duplex links can be substantially longer than what is shown in Tables 6-9 and 6-10 because they are limited only by the medium, not by the round-trip delay. Gigabit Ethernet architecture is overwhelmingly station-to-station, station-to-switch, switch-to-switch, and switch-to-router connections running at full duplex. 1000BASE-SX is specified for multimode fiber. 1000BASE-LX is specified for multimode and single-mode fiber.

Tables 6-10 and 6-11 show distance limitations for 1000BASE-SX and 1000BASE-LX. Because most Gigabit Ethernet is switched, these are the practical limits between devices. Daisy-chaining, star, and extended star topologies all are allowed. The issue then becomes one of logical topology and data flow, not timing or distance limitations.

Table 6-10 Maximum 1000BASE-SX Cable Distances

Medium	Modal Bandwidth	Maximum Distance
62.5 μm MMF	160	220m
62.5 μm MMF	200	275m
50 μm MMF	400	500m
50 μm MMF	500	550m

The maximum 1000BASE-SX cable distances at 805 nm (minimum overfilled launch).

Table 6-11 Maximum 1000BASE-LX Cable Distances

Medium	Modal Bandwidth	Maximum Distance
62.5 μm MMF	500	550m
50 μm MMF	400	550m
50 μm MMF	500	550m
10 μm SMF	—	5000m

The maximum 1000BASE-LX cable distances at 805 nm (minimum overfilled launch).

A 1000BASE-T UTP cable is about the same as a 10BASE-T and 100BASE-TX cable, except that link performance must meet the higher-quality Category 5e or ISO Class D (2000) requirements.

As with 10-Mbps and 100-Mbps versions, it is possible to modify some of the architecture rules slightly; however, there is virtually no allowance for additional delay in half duplex. Modification of the architecture rules strongly is discouraged for 1000BASE-T. At 100m, 1000BASE-T is operating close to the edge of the hardware's capability to recover the transmitted signal. Any cabling problems or environmental noise could render an otherwise-compliant cable inoperable even at distances that are within the specification. Refer to the technical timing descriptions in the current 802.3 standard and the technical information about your hardware performance before attempting any adjustments to the architecture rules.

Links operating in full-duplex links might be longer that what is indicated in Table 6-12 because they are limited only by the capability of the medium to deliver a robust enough signal to decode the signaling; they are not limited by the round-trip delay. It is extremely rare to find Gigabit Ethernet operating in half duplex. Half duplex is undesirable because the signaling scheme is inherently full duplex, and forcing half-duplex communications rules onto a full-duplex signaling system is not a wise use of resources. Operating under half-duplex rules requires adherence to slot time round-trip delay limitations that reduce the effective cable lengths, and there is also a substantial increase in overhead introduced by the carrier extension. Furthermore, very few Gigabit repeaters are in service, which means that the link is probably between a station and an OSI Layer 2 bridge, or between two bridges, so the collision domain would end at the bridge anyway.

It is recommended that all links between a station and a switch be configured for auto-negotiation, to permit the highest common performance configuration to be established without risking misconfiguration of the link, and to avoid accidental misconfiguration of the other required parameters for proper Gigabit Ethernet operation.

Table 6-12 shows the speed case for half-duplex operation. But because most Gigabit Ethernet is switched, it is subject to link-by-link rules shown previously in Tables 6-10 and 6-11.

Table 6-12 Architecture Configuration Cable Distances for Half-Duplex Operation

Architecture	1000BASE-T	1000BASE-SX/LX	1000BASE-SX/LX and 1000BASE-T
Station to station	100m	316m	—
One repeater	200m	220m	100m 1000BASE-T (plus) 110m 1000BASE-SX/LX

10-Gbps Versions of Ethernet

Most recently, in 2002, IEEE 802.3ae was adapted. This standard specifies 10-Gbps full-duplex transmission over fiber-optic cable. Taken as a whole, the similarities between 802.3ae and 802.3 (the original Ethernet) and all of the other varieties of Ethernet are remarkable. Metcalfe's original design has evolved, but it is still very apparent in the modern Ethernet. Recently, 10-Gb Ethernet (10GbE) has emerged as the latest example of the extensibility of the Ethernet system. Usable for LANs, storage-area networks (SANs), metropolitan-area networks (MANs), and WANs, 10GbE offers exciting new networking possibilities. What is 10GbE, and why should it be used?

Legacy Ethernet, Fast Ethernet, and Gigabit Ethernet now dominate the LAN market. The next step in the evolution of Ethernet is to move to 10-Gb Ethernet (10GbE, operating at 10,000,000,000 bps). By maintaining the frame format and other Ethernet Layer 2 specifications, increasing bandwidth needs can be accommodated with the low-cost, easily implementable, and easily interoperable 10GbE. 10GbE runs only over optical fiber media. End-to-end Ethernet networks become possible.

Because of massive growth in Internet- and intranet-based traffic, and the rapidly increasing use of Gigabit Ethernet, even higher bandwidth interconnections are needed. Internet service providers (ISPs) and network service providers (NSPs) can use 10GbE to create high-speed, low-cost, easily interoperable connections between colocated carrier switches and routers. Points of presence (POPs), intranet server farms comprised of Gigabit Ethernet servers, digital video studios, SANs, and backbones already are envisaged applications.

Perhaps most significantly, a major conceptual change comes with 10GbE. Ethernet traditionally is thought of as a LAN technology. But 10GbE physical layer standards allow both an extension in distance (to 40 km over single-mode fiber) and compatibility

with Synchronous Optical Network (SONET)/Synchronous Digital Hierarchy (SDH) networks. Operation at a 40 km distance makes 10GbE a viable MAN technology. Compatibility with SONET/SDH networks operating up to OC-192 speeds (9.584640 Gps) makes 10GbE a viable WAN technology. 10GbE also might compete with Asynchronous Transfer Mode (ATM) for certain applications.

The following summarizes how 10GbE compares to other varieties of Ethernet:

- Frame format is the same, allowing interoperability among all varieties of legacy, Fast, Gigabit, and 10-Gb Ethernet, with no reframing or protocol conversions.
- Bit-time now at 0.1 nanoseconds. All other time variables scale accordingly.
- No need for CSMA/CD because only full-duplex fiber connections are used.
- IEEE 802.3 sublayers within OSI Layers 1 and 2 that are mostly preserved, with a few additions to accommodate 40-km fiber links and interoperability with SONET/SDH technologies.
- Possibility of flexible, efficient, reliable, relatively low cost end-to-end Ethernet networks.
- Capability to run TCP/IP over LANs, MANs, and WANs with one Layer 2 transport method

The basic standard governing CSMA/CD is IEEE 802.3. An IEEE 802.3 supplement, entitled 802.3ae, governs the 10GBASE family. As is typical for new technologies, a variety of implementations are being considered, including these:

- **10GBASE-SR**—Intended for short distances over already-installed multimode fiber, supports a range between 26 m and 82 m.
- **10GBASE-LX4**—Uses *wavelength-division multiplexing (WDM)*. Supports 240 m to 300 m over already-installed multimode fiber, and 10 km over single-mode fiber.
- **10GBASE-LR and 10GBASE-ER**—Supports 10 km and 40 km over single-mode fiber.
- **10GBASE-SW, 10GBASE-LW, and 10GBASE-EW**—Intended to work with OC-192/STM SONET/SDH WAN equipment.

The IEEE 802.3ae task force and the 10-Gb Ethernet Alliance (10 GEA) are working to standardize these emerging technologies.

10-Gb Ethernet (IEEE 802.3ae) was standardized in June 2002. It is a full-duplex protocol that uses only fiber-optic fiber as a transmission medium. The maximum transmission distances depend on the type of fiber being used. When using single-mode fiber as the transmission medium, the maximum transmission distance is 40 km (25 miles). Some discussions between IEEE members suggest the possibility of standards for 40-Gbps, 80-Gbps, and even 100-Gbps Ethernet. Given the history of Ethernet, there is no reason

to expect that its evolution will cease. The higher speeds and greater transmission distances that are making Ethernet both a LAN and a MAN protocol are not the only additions to the Ethernet standard that we are likely to see. Because fiber is being used as the transmission medium, the likelihood that an error in the data might occur during the passage of the Ethernet packet across the network is very low, much lower than in the original Ethernet. On a network with a very low error rate, it makes sense to transmit larger packets of data.

The upper limit on the amount of data that can be carried in an Ethernet packet (a frame) is 1500 bytes. Sending more data than that in a frame would make it an invalid Ethernet frame and cause the network to discard it. This has been the standard since Ethernet was created. Given a low likelihood of errors on a network, large files could be moved over the network more efficiently if a larger amount of data could be carried in each frame. The reason for this is that it takes time for computers to generate and to process Ethernet headers and trailers. Each Ethernet frame must have a header and a trailer. For example, if six times as much data could be sent per frame, there would be fewer frames (only one sixth as many) needed to carry all the data in a file. This means that fewer headers and trailers would have to be generated by the transmitter and processed by the receiver. The result is a shorter amount of time needed to move a large file over a network between two computers. WANs that use fiber as their transmission medium routinely transmit large data packets.

For this reason, especially when multigigabit LANs are connected to WANs, it is likely that we will see the use of Jumbo Ethernet frames. A Jumbo frame is any Ethernet frame that is carrying more than 1500 bytes of data. The proposed upper limit for the amount of data carried in a Jumbo frame is about 9,000 bytes. Jumbo frames are not currently a part of the new IEEE 802.3ae standard. However, it is very likely that some vendors of Ethernet networking equipment will allow Jumbo frames to be carried on Ethernet networks built using only their equipment. This might force the IEEE 802.3 committee to make support for larger frame sizes an option in new multigigabit standards.

Table 6-13 shows the parameters for 10-Gb Ethernet operation.

Table 6-13 Parameters for 10-Gbps Ethernet Operation

Parameter	Value
Bit-time	0.1 nsec
Slot time	—*
Interframe spacing	96 bits**

continues

Table 6-13 Parameters for 10-Gbps Ethernet Operation (Continued)

Parameter	Value
Collision attempt limit	—*
Collision backoff limit	—*
Collision jam size	—*
Maximum untagged frame size	1518 octets
Minimum frame size	512 bits (64 octets)
Burst limit	—*
Interframe spacing stretch ratio	104 bits***

* 10-Gbps Ethernet does not permit half-duplex operation, so parameters related to slot timing and collision handling do not apply.

** The value listed is the *official* interframe spacing.

*** The interframe spacing stretch ratio applies exclusively to 10GBASE-W definitions.

Amazingly, 10GbE uses the same frame format (with a few special case exceptions) as 10-, 100-, and 1000-Mbps Ethernet.

10GbE Media, Connections, and Architecture

10-Gb Ethernet is a tenfold increase in speed over Gigabit Ethernet. Just as with Gigabit Ethernet, with this increase in speed comes extra requirements—the bits being sent get shorter in duration (1 ns), occur more frequently, and require more careful timing. In addition, their transmission requires frequencies closer to medium bandwidth limitations and they become more susceptible to noise. In response to these issues of synchronization, bandwidth, and SNR, two separate encoding steps are used by 10-Gb Ethernet. The basic idea is to use codes—which can be engineered to have desirable properties—to represent the user data in a way that is efficient to transmit, including synchronization, efficient usage of bandwidth, and improved SNR characteristics.

Bit patterns from the MAC sublayer are converted into symbols, with symbols sometimes controlling information (such as start frame, end frame, and medium idle conditions). The entire frame is broken up into control symbols and data symbols (data code groups). All of this extra complexity is necessary to achieve the tenfold increase in network speed over Gigabit Ethernet. 8B/10B encoding (similar to the 4B/5B concept) is used, followed by several different types of line encoding on the optical fiber.

Figure 6-23 represents what happens to the 8B-10B before it is line-encoded. 10-Gb Ethernet uses a variety of complex encodings before line encoding, including 8B/10B and 64B/66B. Bits from these codes then are converted to line signals: low power light for binary 0 and higher power light for binary 1. Complex serial bit streams are used for all versions of 10GbE except for 10GBASE-LX4, which uses wide wavelength-division multiplexing (WDM) to multiplex 4-bit simultaneous bit streams as four wavelengths of light launched into the fiber at one time.

Figure 6-23 How 10GbE Converts MAC Frames to Four Lanes of Bits

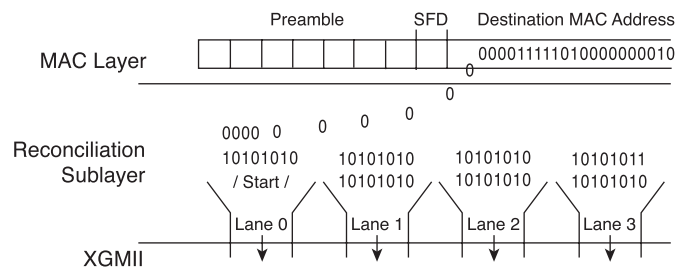
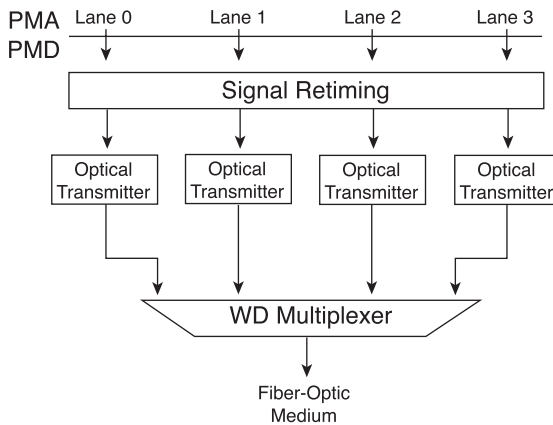


Figure 6-23 shows how 10GbE converts MAC frames to four lanes of bits for parallel transmission on four wire pairs of UTP or as a bit stream that is then serialized for laser transmission on single-mode fiber.

Figure 6-24 represents the particular case of using four slightly different-colored laser sources. Upon receipt from the medium, the optical signal stream is demultiplexed into four separate optical signal streams. The four optical signal streams then are converted back into four electronic bit streams as they travel in approximately the reverse process back up through the sublayers to the MAC sublayer.

Currently, most 10GbE products are in the form of modules (line cards) for addition to high-end switches and routers. As the 10GbE technologies evolve, an increasing diversity of signaling components can be expected. As optical technologies involve, improved transmitters and receivers will be incorporated into these products, further taking advantage of modularity. All 10GbE varieties use optical-fiber media. Fiber types include 10 μ m single-mode fiber, and 50 μ m and 62.5 μ m multimode fibers. A range of fiber attenuation and dispersion characteristics are supported, but they limit operating distances.

Figure 6-24 10GBASE-LX4 Signal Multiplexing

SC fiber optic connectors most commonly are used. Because optical fiber is the medium used by 10GbE, typically a fiber pair connects Tx for device 1 to Rx for device 2, and vice versa. The primary devices connecting currently via 10GbE are high-end modular switches and routers. Table 6-14 lists the pinout options for 10GbE.

Table 6-14 10GbE Pinout

Fiber	Signal
1	Tx (laser transmitters)
2	Rx (high-speed photodiode detectors)

10-Gb Ethernet is available in full-duplex mode only and runs only over optical fiber. Hence, collisions are nonexistent and CSMA/CD is unnecessary.

As 10GbE standards and products evolve, a wide range of architectures and application guidelines is becoming possible. Most important to consider is that the addition of 10GbE, with its LAN, SAN, MAN, and WAN capabilities, enables network engineers to consider very sophisticated end-to-end Ethernet networks. LAN, SAN, MAN, and WAN topologies using Gigabit Ethernet all are being implemented.

10-Gb Ethernet is supported only over fiber-optic media. Support is available for 62.5 μm and 50 μm multimode fiber, as well as 10 μm single-mode fiber. Even though support is limited to fiber-optic media, some of the maximum cable lengths are surprisingly short. No repeater is defined for 10-Gb Ethernet because half duplex explicitly is not supported.

As with 10-Mbps, 100-Mbps and 1000-Mbps versions, it is possible to modify some of the architecture rules slightly. Possible architecture adjustments are related to signal loss and distortion along the medium. Because of dispersion of the signal and other issues, the light pulse becomes undecipherable beyond certain distances. Refer to the technical timing and spectral requirements in the current 802.3 standard, as well as the technical information about your hardware performance, before attempting any adjustments to the architecture rules.

Table 6-15 shows the 10-Gb Ethernet implementations. Both R and W specifications are covered by each appropriate entry (for example, 10GBASE-E covers both 10GBASE-ER and 10GBASE-EW).

Table 6-15 10-Gb Ethernet Implementations

Implementation	Wavelength	Medium	Minimum Modal Bandwidth	Operating Distance
10GBASE-LX4	1310 nm	62.5 μ m MMF	500 MHz/km	2m to 300m
10GBASE-LX4	1310 nm	50 μ m MMF	400 MHz/km	2m to 240m
10GBASE-LX4	1310 nm	50 μ m MMF	500 MHz/km	2m to 300m
10GBASE-LX4	1310 nm	10 μ m SMF	—	2 km to 10 km
10GBASE-S	850 nm	62.5 μ m MMF	160 MHz/km	2m to 26m
10GBASE-S	850 nm	62.5 μ m MMF	200 MHz/km	2m to 33m
10GBASE-S	850 nm	50 μ m MMF	400 MHz/km	2m to 66m
10GBASE-S	850 nm	50 μ m MMF	500 MHz/km	2m to 82 m
10GBASE-S	850 nm	50 μ m MMF	2000 MHz/km	2m to 300 m
10GBASE-L	1310 nm	10 μ m SMF	—	2 km to 10 km
10GBASE-E	1550 nm	10 μ m SMF	—	2 km to 30 km*

*The standard permits 40-km lengths if link attenuation is low enough.

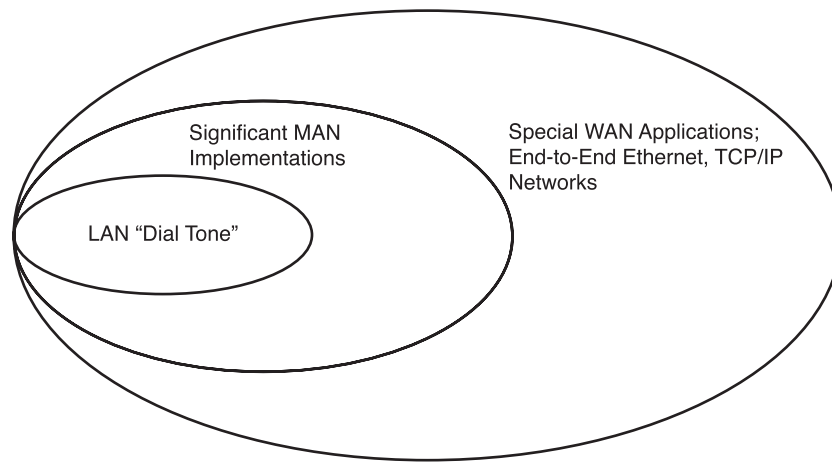
Note the versatility of 10GbE. A diverse set of fiber types and laser sources can be used to achieve not only LAN, but also MAN and WAN distances.

The Future of Ethernet

As the last several sections have documented, Ethernet has gone through an evolution from legacy to Fast to Gigabit to multigigabit technologies. Although other LAN technologies are still in place (legacy installations), Ethernet dominates new LAN installations—so much so that some have referred to Ethernet as the LAN “dial tone.” Ethernet is now the standard for horizontal, vertical, and interbuilding connections. In fact, recently developing versions of Ethernet are blurring the distinction between LANs, MANs, and WANs in terms of geographic distance covered as part of one network.

Figure 6-25 illustrates the expanding scope of Ethernet.

Figure 6-25 Ethernet’s Expanding Scope



Although Gigabit Ethernet is now widely available and 10-Gb products becoming more available, the IEEE and the 10-Gb Ethernet Alliance currently have released 40-Gbps, 100-Gbps, and even 160-Gbps standards. Which technologies actually are adopted will depend on a number of factors, including the rate of maturation of the technologies and standards, the rate of adoption in the market, and cost.

Proposals for Ethernet arbitration schemes other than CSMA/CD have been made. But the problem of collisions, so fundamental to physical bus topologies of 10BASE5, 10BASE2, 10BASE-T, and 100BASE-TX hubs, are no longer so common. Use of UTP and optical fiber, both of which have separate Tx and Rx paths, and the decreasing costs of switched instead of hubbed connections, make single shared-media, half-duplex media connections much less important.

The future of networking media is threefold:

- Copper (up to 1000 Mbps, perhaps more)
- Wireless (approaching 100 Mbps, perhaps more)
- Optical fiber (currently at 10,000 Mbps and soon to be more)

Unlike copper and wireless media, in which certain physical and practical limitations on the highest-frequency signals that can be transmitted are being approached, the bandwidth limitation on optical fiber is extremely large and is not a limiting factor for the foreseeable future. In fiber systems, the electronics technology (such as emitters and detectors) and the fiber-manufacturing processes most limit the speed. Therefore, upcoming developments in Ethernet likely will be heavily weighted toward laser light sources and single-mode optical fiber.

When Ethernet was slower, half duplex (subject to collisions and a “democratic” process for prioritization) was not considered to have the quality of service (QoS) capabilities required to handle certain types of traffic. This included such things as IP telephony and video multicast.

However, the full-duplex, high-speed Ethernet technologies that now dominate the market are proving to be sufficient at supporting even QoS-intensive applications. This makes the potential applications of Ethernet even wider. Ironically, end-to-end QoS capability helped drive a push for ATM to the desktop and to the WAN in the mid-1990s, but now Ethernet, not ATM, is approaching this goal.

At 30 years old, Ethernet technologies continue to grow and have a very bright future.

Ethernet Switching

As more nodes are added to an Ethernet physical segment, the contention for the medium increases. The addition of more nodes increases the demands on the available bandwidth and places additional loads on the medium. With the additional traffic, the probability of collisions increases, resulting in more retransmissions. A solution to the problem is to break the large segment into parts and separate it using Catalyst switches. This isolates these newly segmented sections into isolated collision domains. This reduces the number of collisions and increases the reliability of the network.

Bridging and switching are technologies that decrease congestion in LANs by reducing traffic and increasing bandwidth. LAN switches and bridges, operating at Layer 2 of the OSI reference model, forward frames based on the MAC addresses to perform the switching function. If the Layer 2 MAC address is unknown, the device floods the frame in an attempt to reach the desired destination. LAN switches and bridges also

forward all broadcast frames. The result could be storms of traffic being looped endlessly through the network. The *Spanning Tree Protocol (STP)* is a loop-prevention protocol; it is a technology that enables switches to communicate with each other to discover physical loops in the network.

The sections that follow introduce Layer 2 bridging, Layer 2 switching, switching modes, and the Spanning Tree Protocol (STP).

Layer 2 Bridging

A *bridge* is a Layer 2 device designed to create two or more LAN segments, each of which is a separate collision domain. In other words, bridges were designed to create more usable bandwidth. The purpose of a bridge is to filter traffic on a LAN to keep local traffic local, yet allow connectivity to other parts (segments) of the LAN for traffic that is directed there. To filter or selectively deliver network traffic, bridges build tables of all MAC addresses located on a network segment and other networks, and map them to associated ports. The process is as follows:

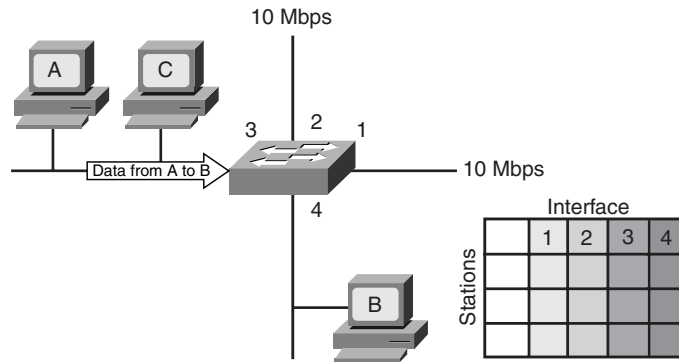
- If data comes along the network medium, a bridge compares the destination MAC address carried by the data to MAC addresses contained in its tables.
- If the bridge determines that the destination MAC address of the data is from the same network segment as the source, it does not forward the data to other segments of the network. This process is known as *filtering*. By performing this process, bridges significantly can reduce the amount of traffic between network segments by eliminating unnecessary traffic.
- If the bridge determines that the destination MAC address of the data is not from the same network segment as the source, it forwards the data to the appropriate segment.
- If the destination MAC address is unknown to the bridge, the bridge broadcasts the data to all devices on a network except the one on which it was received. The process is known as *flooding*.

Generally, a bridge has only two ports and divides a collision domain into two parts. All decisions made by a bridge are based on MAC addresses or Layer 2 addressing, and do not affect the logical or Layer 3 addressing. Thus, a bridge divides a collision domain but not a logical or broadcast domain. No matter how many bridges are in a network, unless a device such as a router works on Layer 3 addressing, all of the network will share the same logical (broadcast) address space. A bridge will create more (and smaller) collision domains but will not add broadcast domains. Because every device on the network must pay attention to broadcasts, bridges always forward them. Therefore, all segments in a bridged environment are considered to be in the same broadcast domain.

Layer 2 Switching

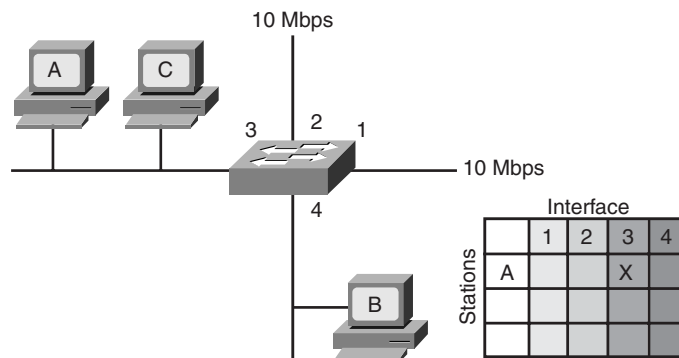
LAN switches are essentially multiport bridges that use *microsegmentation* to reduce the number of collisions in a LAN and increase the bandwidth. LAN switches also support features such as full-duplex communication and multiple simultaneous conversations. Figure 6-30 shows a LAN with three workstations, a LAN switch, and the LAN switch's address table. The LAN switch has four *interfaces* (or network connections). Stations A and C are connected to the switch's Interface 3, and Station B is on Interface 4. As indicated in Figure 6-26, Station A needs to transmit data to Station B.

Figure 6-26 LAN Switch Operation



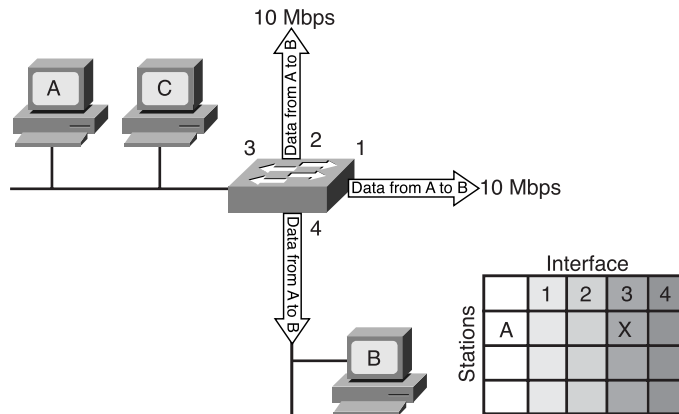
Remember that as this traffic goes through the network, the switch operates at Layer 2, meaning that the switch can look at the MAC layer address. When Station A transmits and the switch receives the frames, the switch assesses the traffic as it goes through to discover the source MAC address and store it in the address table, as shown in Figure 6-27.

Figure 6-27 Building an Address Table



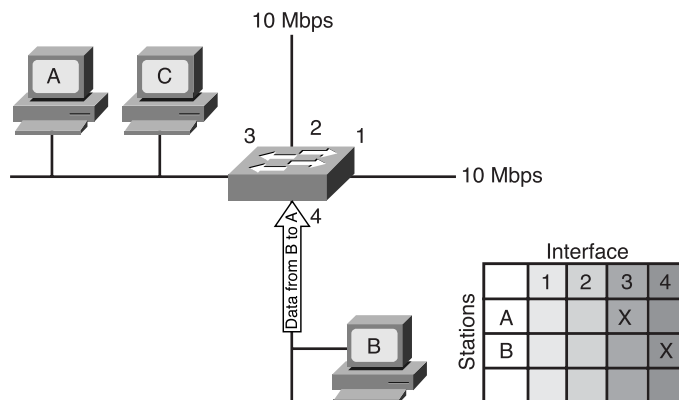
As the traffic goes through the switch, an entry is made in the address table identifying the source station and the interface that it is connected to on the switch. The switch now knows where Station A is connected. When that frame of data is in the switch, it floods to all ports because the destination station is unknown, as shown in Figure 6-28.

Figure 6-28 Flooding Data to All Switch Ports

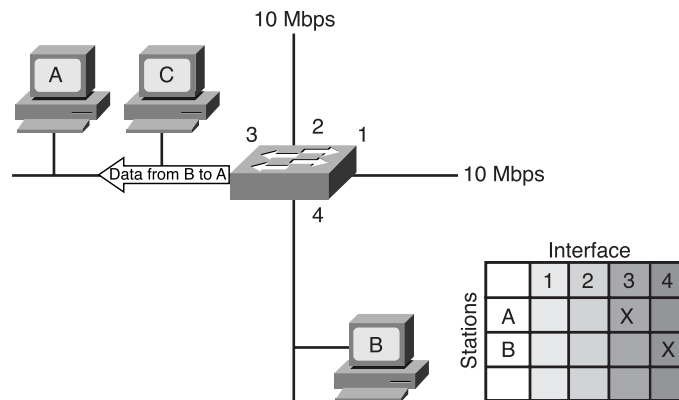


After the address entry is made in the table, however, a response comes back from Station B to Station A. The switch now knows that Station B is connected to Interface 4, as shown in Figure 6-29.

Figure 6-29 Responding to the Flooding Message



The data is transmitted into the switch, but notice that the switch does not flood the traffic this time. The switch sends the data out of only Interface 3 because it knows where Station A is on the network, as shown in Figure 6-30.

Figure 6-30 Transmitting Data to a Known Station

The original transmission indicated where that MAC address came from, enabling the switch to deliver traffic in the network more efficiently.

Microsegmentation

As technology improved, it became possible to build bridges with more capability. Naturally, the ultimate goal is to have only one node on each port of a bridge. This would reduce the collision domains so that collisions would be nearly nonexistent. A switch does exactly that and is simply a bridge with many ports. These small physical segments are called *microsegments*.

Microsegmentation facilitates the creation of a dedicated segment and provides dedicated bandwidth to each user on the network. Each user receives instant access to the full bandwidth and does not have to contend for available bandwidth with other users. This means that pairs of devices on the same switch can communicate in parallel with a minimum number of collisions. Microsegmentation reduces collisions in a network and effectively increases the capacity for each station connected to the network.

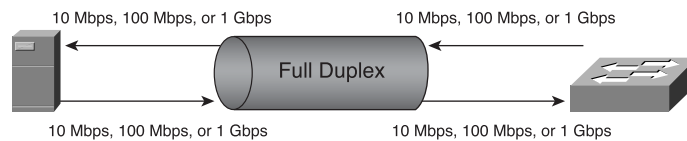
In addition to faster microprocessors and memory, two other technological advances made switches possible. Content Addressable Memory (CAM) is memory that essentially works backward compared to conventional memory. Entering data into the memory returns the associated address. Using CAM allows a switch to directly find the port that is associated with a MAC address without using search algorithms. An application-specific integrated circuit (ASIC) is a device consisting of undedicated logic gates that can be programmed to perform functions at logic speeds. Operations that might have been done in software now can be done in hardware using an ASIC. The use of these technologies greatly reduced the delays caused by software processing and enabled a switch to keep pace with the data demands of many microsegments and high bit rates.

Full-Duplex Transmission

Another function of LAN switching that dramatically improves bandwidth is full-duplex transmission, which effectively doubles the amount of bandwidth between nodes. Full-duplex transmission between stations is achieved by using point-to-point Ethernet connections. This feature can be important, for example, between high-bandwidth consumers, such as a connection between a switch and a server. Full-duplex transmission provides a collision-free transmission environment. Because both nodes can transmit and receive at the same time, there are no negotiations for bandwidth.

In 10-Mbps connections, for example, full-duplex transmission provides 10 Mb of transmit capacity and 10 Mb of receive capacity, for effectively 20 Mb of capacity on a single connection. Likewise, a 100-Mbps connection offers effectively 200 Mbps of throughput, as illustrated in Figure 6-31. Full-duplex communication also supports two data transmission paths, with speeds up to 1 Gbps.

Figure 6-31 Switching Technology: Full Duplex



Latency

Latency, sometimes called *propagation delay*, is the time that a frame, or packet, of data takes to travel from the source station or node to its final destination on the network. A wide variety of conditions can cause delays as a frame travels from source to destination:

- Media delays caused by the finite speed that signals can travel through the physical media.
- Circuit delays caused by the electronics that process the signal along the path.
- Software delays caused by the decisions that software must make to implement switching and protocols.
- Delays caused by the content of the frame and where in the frame switching decisions can be made. For example, a device cannot route a frame to a destination until the destination MAC address has been read.

Latency is the time delay between when a frame first starts to leave the source device and when the first part of the frame reaches its destination.

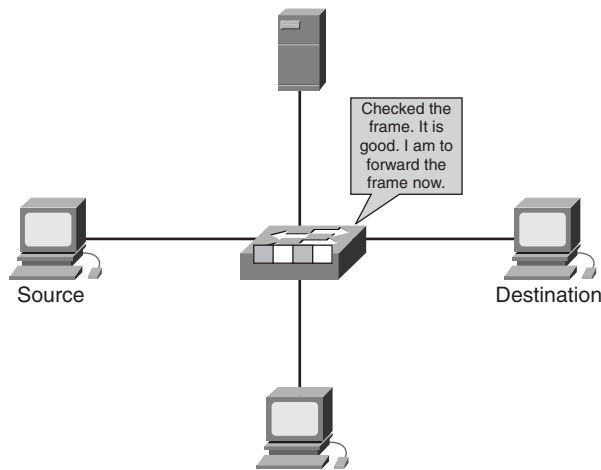
Switch Modes

How the content of a frame is switched to the destination port is a trade-off of latency and reliability. The three modes of switching—store-and-forward, cut-through, and fragment-free switching—offer different performance and latency.

Store-and-Forward Switching

In *store-and-forward switching*, the switch reads the entire frame of data, checks the frame for errors, decides where it needs to go, and then sends it on its way. Figure 6-32 illustrates the operation of store-and-forward switching. The obvious trade-off here is that it takes the switch longer to read the entire frame. As it reads the entire frame, however, it detects any errors on that frame. If the frame is in error, the frame is not forwarded and is discarded. Although cut-through switching is faster, it offers no error detection. The latency introduced by store-and-forward switching is usually not a significant issue.

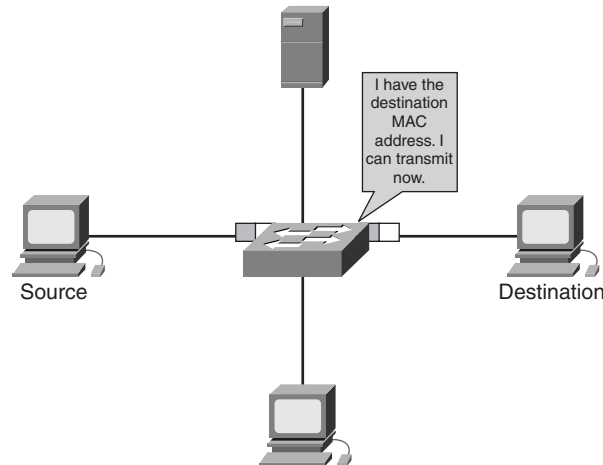
Figure 6-32 Store-and-Forward Switching



Cut-Through Switching

In *cut-through switching*, the switch reads the beginning of the frame up to the destination MAC address as the traffic flows through the switch and “cuts through” to its destination without continuing to read the rest of the frame, as illustrated in Figure 6-33.

Cut-through switching decreases the latency of the transmission. However, cut-through switching has no error detection.

Figure 6-33 Cut-Through Switching

Fragment-Free Switching

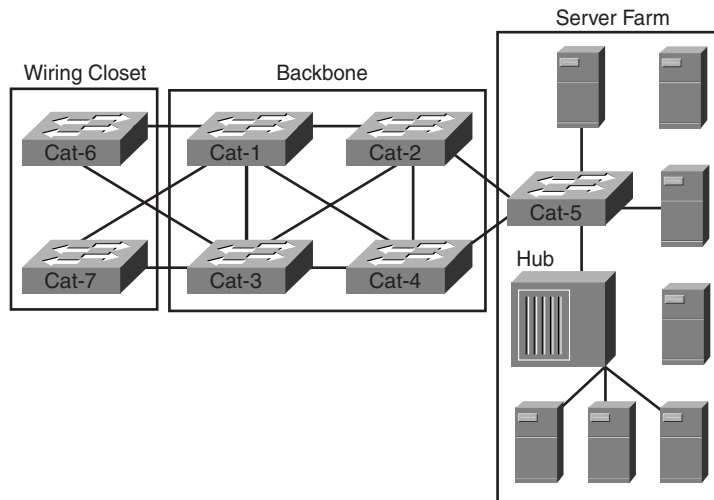
Fragment-free switching is a modified form of cut-through switching. Fragment-free switching filters out collision fragments, which are the majority of packet errors, before forwarding begins. Fragment-free switching waits until the received packet has been determined not to be a collision fragment before forwarding the packet.

When to Use Each Switching Mode

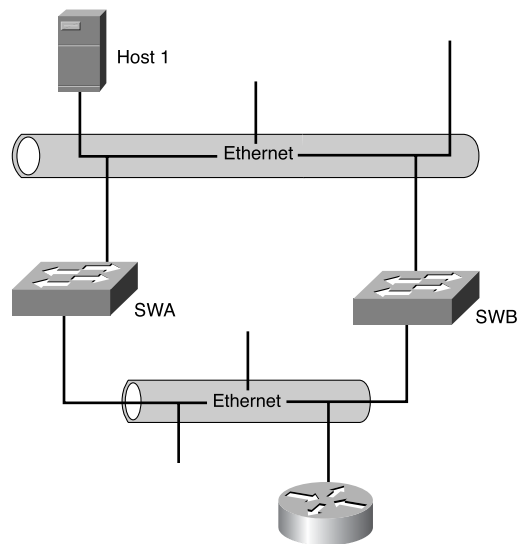
When using cut-through and fragment-free modes, both the source port and the destination port must be operating at the same bit rate to keep the frame intact. This is called *synchronous switching*. If the bit rates are not the same, the frame must be stored at one bit rate before it is sent out at the other bit rate. This is known as *asynchronous switching*. Store-and-forward mode must be used for asynchronous switching. Asymmetric switching provides switched connections between ports of unlike bandwidths, such as a combination of 100 Mbps and 1000 Mbps. Asymmetric switching is optimized for client/server traffic flows in which multiple clients simultaneously communicate with a server, requiring more bandwidth dedicated to the server port to prevent a bottleneck at that port.

Introduction to the Spanning Tree Protocol

When multiple switches are connected, there is a possibility of creating a loop where there is no clear path from source to destination. If switches are arranged in a simple hierarchical tree, no loops will occur, as shown in Figure 6-34.

Figure 6-34 STP Reducing Routing Loops

However, when extra switches and bridges are added to provide redundant paths for reliability and fault tolerance, loops can occur, as shown in Figure 6-35.

Figure 6-35 Broadcast Storms

In Figure 6-35, the following steps are occurring:

1. Host 1 broadcasts.
2. SWA and SWB receive the frame.
3. SWA forwards to SWB.
4. SWB forwards to SWA.
5. Each switch now begins to see multiple frames of the same broadcast, thus resulting in routing loops.

To counteract the possibility of loops, switches are provided with a protocol for them to talk with each other to resolve the condition. A switch sends special messages called *bridge protocol data units (BPDUs)* out all its ports to let other switches know of its existence, as shown in Figures 6-36 and 6-37. The switches use a spanning tree algorithm (STA) to resolve and shut down the redundant paths. The process of shutting down a port is called *blocking*. The result of resolving and eliminating the loops is a logical hierarchical tree created with no loops. However, the alternate paths are still available, in case they are needed. The protocol used to resolve and eliminate loops is known as the Spanning Tree Protocol (STP). This creates another switch and bridge operation mode known as loop-avoidance mode.

Figure 6-36 BPDUs Communication

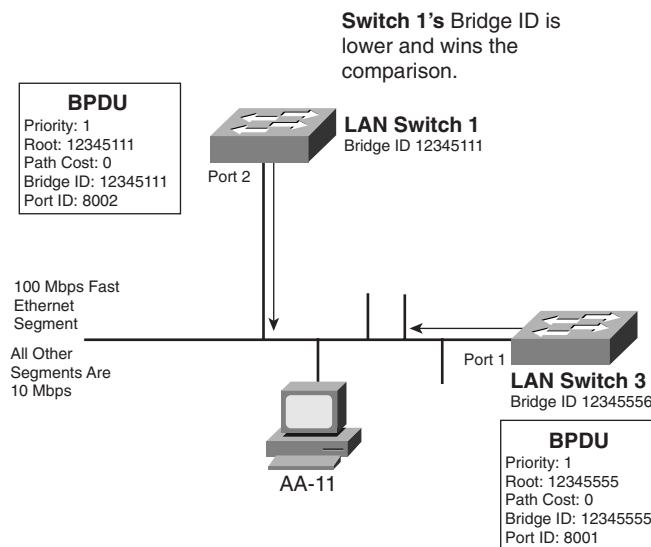
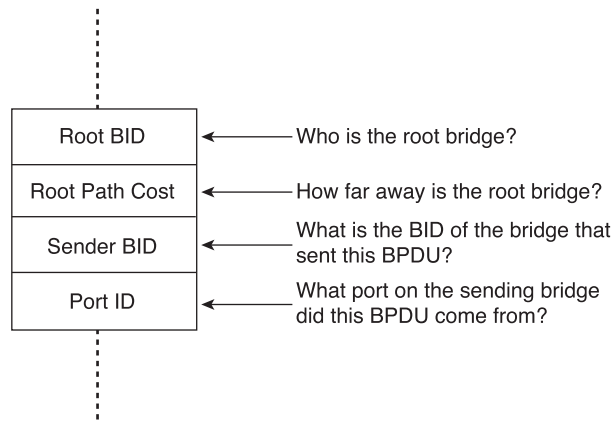


Figure 6-37 BPDU Protocol Layout

Consequently, switches have five operating modes:

- **Blocking**—A port in blocking state sends and listens to BPDUs but does not forward frames. By default, all ports are in blocking state when the switch is turned on.
- **Listening**—In listening state, a port listens to the BPDUs to make sure there are no loops on the network. No frames are forwarded in this state.
- **Learning**—In this state, a port learns MAC addresses and builds a address table, but it does not forward frames.
- **Forwarding**—A port in the forwarding state forwards frames. BPDUs are sent and listened to.
- **Disabled**—A port in the disabled state does not participate in the operation of STP. Therefore, it does not listen to BPDUs or forward frames.

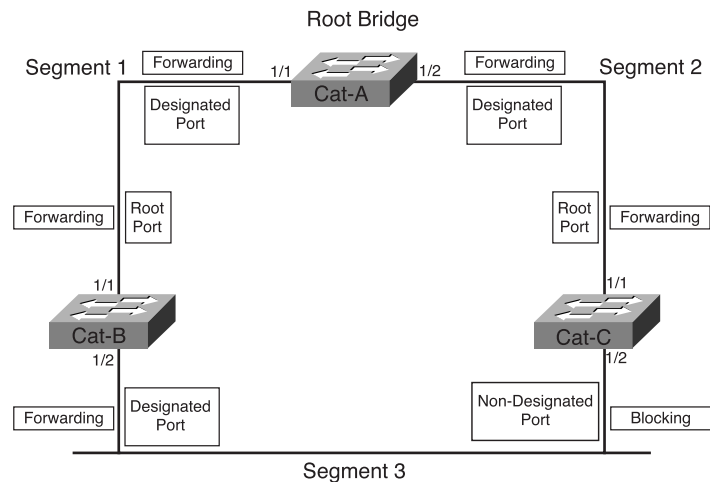
Figure 6-38 illustrates some of the port states and operating modes in a switched network using STP.



Lab Activity Introduction to Fluke Network Inspector

This lab is a tutorial demonstrating how to use the Fluke Networks Network Inspector (NI) to discover and analyze network devices within a broadcast domain. This lab demonstrates the key features of the tool that can be incorporated into various troubleshooting efforts in the remaining labs.

Figure 6-38 Port States



Lab Activity Introduction to Fluke Protocol Inspector

This lab is a tutorial demonstrating how to use the Fluke Networks Protocol Inspector to analyze network traffic and data frames. This lab demonstrates key features of the tool that can be incorporated into various troubleshooting efforts in the remaining labs.

Summary

In this chapter, you learned the following key points:

- Several types of Ethernet exist: Ethernet, Fast Ethernet, Gigabit Ethernet, and 10-Gb Ethernet. Each type is associated with a different transfer rate.
- Ethernet uses carrier sense multiple access collision detect (CSMA/CD).
- 10-Mbps Ethernet operates within the timing limits offered by a series of no more than five segments separated by no more than four repeaters.
- Switches can provide dedicated access to improve shared LAN technologies.
- A switch segments a LAN into microsegments. Microsegmentation reduces the number of collisions to a minimum and increases the effective bandwidth.
- Switches achieve high-speed transfer by reading the destination Layer 2 MAC address of the frame packet.

- Full-duplex communication allows two devices to communicate with each other simultaneously and effectively doubles the throughput that the LAN switch can translate.
- Switches can support multiple simultaneous conversations in a network.
- Three switching modes can be used to forward frames through a switch: store-and-forward, cut-through, and fragment-free switching.
- The main task of the Spanning Tree Protocol (STP) is to prevent the occurrence of network loops on a Layer 2 network.
- The ports on a bridge or switch using STP exist in one of the following five states: blocking, listening, learning, forwarding, or disabled.

To supplement all that you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab Activities on the CD-ROM accompanying this book.

Key Terms

10BASE2 10-Mbps baseband Ethernet specification using 50-ohm thin coaxial cable. 10BASE2, which is part of the IEEE 802.3 specification, has a distance limit of 185m (606 ft.) per segment.

10BASE5 10-Mbps baseband Ethernet specification using standard (thick) 50-ohm baseband coaxial cable. 10BASE5, which is part of the IEEE 802.3 baseband physical layer specification, has a distance limit of 500m (1640 ft.) per segment.

10BASE-T 10-Mbps baseband Ethernet specification using two pairs of twisted-pair cabling (Category 3, 4, or 5): one pair for transmitting data and the other for receiving data. 10BASE-T, which is part of the IEEE 802.3 specification, has a distance limit of approximately 100m (328 ft.) per segment.

100BASE-FX 100-Mbps baseband Fast Ethernet specification using two strands of multimode fiber-optic cable per link. To guarantee proper signal timing, a 100BASE-FX link cannot exceed 400m (1312 ft.) in length. It is based on the IEEE 802.3 standard.

100BASE-TX 100-Mbps baseband Fast Ethernet specification using two pairs of either UTP or STP wiring. The first pair of wires is used to receive data; the second is used to transmit. To guarantee proper signal timing, a 100BASE-TX segment cannot exceed 100m (328 ft.) in length. It is based on the IEEE 802.3 standard.

1000BASE-T 1000-Mbps baseband Gigabit Ethernet specification using four pairs of Category 5 UTP cable for a maximum length of 100m (328 ft.).

1000BASE-SX 1000-Mbps baseband Gigabit Ethernet specification using a short laser wavelength on multimode fiber-optic cable for a maximum length of 550m (1804.5 ft.).

1000BASE-LX 1000-Mbps baseband Gigabit Ethernet specification using a long wavelength for a long-haul fiber-optic cable for a maximum length of 10,000 (32808.4 ft.).

4D-PAM5 The symbol-encoding method used in 1000BASE-T. The four-dimensional quinary symbols (4D) received from the 8B1Q4 data encoding are transmitted using five voltage levels (PAM5). Four symbols are transmitted in parallel each symbol period.

8B1Q4 For IEEE802.3, the data-encoding technique used by 1000BASE-T when converting GMII data (8B-8 bits) to four quinary symbols (Q4) that are transmitted during one clock (1Q4).

BPDU (*bridge protocol data unit*) Spanning Tree Protocol hello packet that is sent out at configurable intervals to exchange information among bridges in the network.

cut-through switching A packet-switching approach that streams data through a switch so that the leading edge of a packet exits the switch at the output port before the packet finishes entering the input port. A device using cut-through packet switching reads, processes, and forwards packets as soon as the destination address is looked up and the outgoing port is determined. *See also* store-and-forward switching.

encoding Process by which bits are represented by voltages.

fragment-free switching Switching that filters out collision fragments, which are the majority of packet errors, before forwarding begins.

latency Delay between the time when a device receives a frame and the time when that frame is forwarded out the destination port.

Manchester encoding Digital encoding scheme, used by IEEE 802.3 and Ethernet, in which a mid-bit-time transition is used for clocking; a 1 is denoted by a high level during the first half of the bit time.

microsegmentation The division of a network into smaller segments, usually with the intention of increasing aggregate bandwidth to network devices.

NRZ (nonreturn to zero) Signals that maintain constant voltage levels with no signal transitions (no return to a 0V level) during a bit interval.

NRZI (nonreturn to zero inverted) Signal that maintains constant voltage levels with no signal transitions (no return to a 0V level). It interprets the presence of data at the beginning of a bit interval as a signal transition and interprets the absence of data as no transition.

SNR (signal-to-noise ratio) The ratio of useable signal being transmitted to the undesired signal (noise). It is a measure of transmission quality. The ratio of good data (signal) to bad (noise) on a line, expressed in decibels (dB).

store-and-forward switching A packet-switching technique in which frames are processed completely before being forwarded out the appropriate port. This processing includes calculating the CRC and checking the destination address. In addition, frames must be stored temporarily until network resources (such as an unused link) are available to forward the message.

STP (Spanning Tree Protocol) Bridge protocol that uses the spanning tree algorithm, enabling a learning bridge dynamically to work around loops in a network topology by creating a spanning tree. Bridge exchange BPDU messages with other bridges to detect loops and then remove the loops by shutting down selected bridge interfaces.

Thinnet Term used to define a thinner, less expensive version of the cable specified in the IEEE 802.3 10BASE2 standard.

WDM (*wavelength-division multiplexing*) Multiple optical wavelength can share the same transmission fiber. The spectrum occupied by each channel must be separated adequately from the other.

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. What is the name of the method used in Ethernet that explains how Ethernet works?
 - A. TCP/IP
 - B. CSMA/CD
 - C. CMDA/CS
 - D. CSMA/CA
2. What is the maximum distance for thick Ethernet without using a repeater?
 - A. 185m (606.95 ft.)
 - B. 250m (820.2 ft.)
 - C. 500m (1640.4 ft.)
 - D. 800m (2624.64 ft.)
3. 10-Mbps Ethernet operates within the timing limits offered by a series of no more than _____ segments separated by no more than _____ repeaters.
 - A. Three, two
 - B. Four, three
 - C. Five, four
 - D. Six, five
4. Fast Ethernet supports up to what transfer rate?
 - A. 5 Mbps
 - B. 10 Mbps
 - C. 100 Mbps
 - D. 1000 Mbps

5. Identify two Gigabit Ethernet cable specifications.
 - A. 1000BASE-TX
 - B. 1000BASE-FX
 - C. 1000BASE-SX
 - D. 1000BASE-LX
 - E. 1000BASE-X
6. What is the transmission medium for 1000BASE-SX?
 - A. Long-wave laser over single-mode and multimode fiber
 - B. Category 5 UTP copper wiring
 - C. Balanced, shielded, 150-ohm, two-pair STP copper cable
 - D. Short-wave laser over multimode fiber
7. 4D-PAM5 encoding method is used in which of the following Gigabit Ethernet?
 - A. 1000BASE-LX
 - B. 1000BASE-SX
 - C. 1000BASE-T
 - D. 1000BASE-CX
8. What is the IEEE standard for 10-Gb Ethernet?
 - A. 802.3z
 - B. 802.3u
 - C. 802.3ae
 - D. 803.3
9. Which of the following is *not* a feature of microsegmentation?
 - A. It enables dedicated access.
 - B. It supports multiple conversations at any given time.
 - C. It increases the capacity for each workstation connected to the network.
 - D. It increases collisions.

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10. Which of the following is used by LAN switches for making the forwarding decision?
 - A. IP address
 - B. MAC address
 - C. Network address
 - D. Host address
11. Which of the following is a feature of full-duplex transmission?
 - A. It offers two 10- to 1-Gbps data-transmission paths.
 - B. It doubles bandwidth between nodes.
 - C. It provides collision-free transmission.
 - D. All of the above.
12. The three common types of switching methods are _____, _____, and _____.
13. The Spanning-Tree Protocol allows which of the following?
 - A. Bridges to communicate Layer 3 information
 - B. A redundant network path without suffering the effects of loops in the network
 - C. Static network paths for loop prevention
 - D. None of the above
14. Which of the following is *not* one of the STP port states?
 - A. Blocking
 - B. Learning
 - C. Listening
 - D. Transmitting
15. Which of the following is true concerning a bridge and its forwarding decisions?
 - A. Bridges operate at OSI Layer 2 and use IP addresses to make decisions.
 - B. Bridges operate at OSI Layer 3 and use IP addresses to make decisions.
 - C. Bridges operate at OSI Layer 2 and use MAC addresses to make decisions.
 - D. Bridges operate at OSI Layer 3 and use MAC addresses to make decisions.

16. Which of the following is *not* a feature of bridges?
- A. They operate at Layer 2 of the OSI model.
 - B. They are more intelligent than hubs.
 - C. They do not make any forwarding decisions.
 - D. They build and maintain address tables.
17. Which of the following statements is true of microsegmentation?
- A. Each workstation gets its own dedicated segment through the network.
 - B. All the workstations are grouped as one segment.
 - C. Microsegmentation increases the number of collisions on a network.
 - D. None of the above.
18. Which of the following is true for LAN switches?
- A. They repair network fragments known as microsegments.
 - B. They are very high-speed multiport bridges.
 - C. Lower bandwidth makes up for higher latency.
 - D. They require new network interface cards on attached hosts.



Objectives

Upon completion of this chapter, you will be able to

- Identify the TCP/IP model components
- Describe the future IP version
- Discuss the relationship of TCP/IP to the OSI model
- Identify applications and protocols from each layer of the TCP/IP model
- Identify the order and relationship of the four TCP/IP layers
- Explain the format and significance of each of these components of an IP network: IP address, IP address classes, reserved IP address space, private IP address space, and IP subnetting
- Calculate valid IP subnetwork addresses and mask values such that user/network requirements are met when given an IP address scheme
- Explain the evolution of IP addressing, including the need for an increase in the size of the IP address space

Chapter 7

TCP/IP Protocol Suite and IP Addressing

This chapter presents an overview of the *Transmission Control Protocol/Internet Protocol (TCP/IP)* protocol suite. It starts with the history and future of TCP/IP. Then it compares the TCP/IP protocol model to the OSI model, identifying and describing each layer of the TCP/IP protocol suite and how it relates to the Internet architecture. TCP/IP is covered in more detail in Chapter 9, “TCP/IP Transport and Application Layer.”

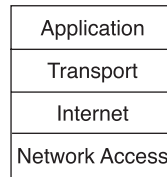
This chapter also discusses IP addressing in depth. This includes how to convert decimal and binary addresses and how to identify the different classes of IP addresses—Class A, B, C, D, and E. IPv4, which has been the standard by which IP addresses have been assigned for years, is being replaced by a much more advanced IP addressing scheme called IPv6. This chapter describes and compares IPv4 and IPv6.

Be sure to look at this chapter’s associated e-Lab Activities, Videos, and PhotoZooms, which you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

Introduction to TCP/IP

The U.S. Department of Defense (DoD) created the TCP/IP reference model, shown in Figure 7-1, because it wanted a network that could survive any conditions. To illustrate further, imagine a world criss-crossed by different kinds of connections—wires, micro-waves, optical fibers, and satellite links. Then imagine a need for data to be transmitted, regardless of the condition of any particular node or network on the internetwork. The DoD wants its packets to get through every time, under any conditions, from any one point to any other point. It was this very difficult design problem that brought about the creation of the TCP/IP model, which has since become the standard on which the Internet has grown.

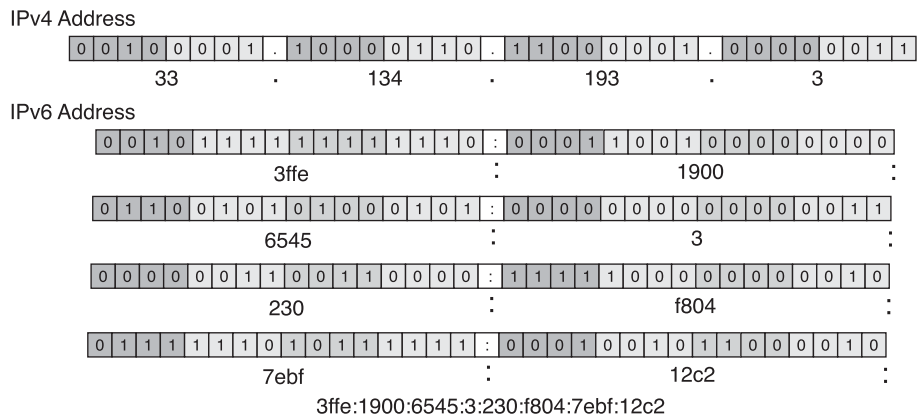
Figure 7-1 TCP/IP Protocol Suite Layers



In reading about the TCP/IP model layers, keep in mind the original intent of the Internet; it will help explain why certain things are as they are. The TCP/IP model has four layers: the application layer, the transport layer, the Internet layer, and the network access layer. It is important to note that some of the layers in the TCP/IP model have the same names as layers in the OSI model. Do not confuse the layer functions of the two models. The layer numbers are different, so the functions Layer 2 performs in the OSI model might not be the same as Layer 2 in the TCP/IP model. For example, in the OSI model, Layer 3 is IP, just as Layer 2 in the TCP/IP model is IP. Another case is the TCP/UDP functions at Layer 4 (the transport layer) in the OSI model and Layer 3 (the transport layer) in the TCP/IP model.

The present version of TCP/IP is old. Internet Protocol Version 4 (IPv4) was standardized in September 1981. In 1992 the standardization of a new generation of Internet Protocol (IP), often called IPng, was supported by the Internet Engineering Task Force (IETF). IPng is now called *Internet Protocol Version 6 (IPv6)*. IPv6, shown in Figure 7-2, has not yet gained wide implementation, but it has already been released by most vendors of networking equipment and will become the dominant standard in the future.

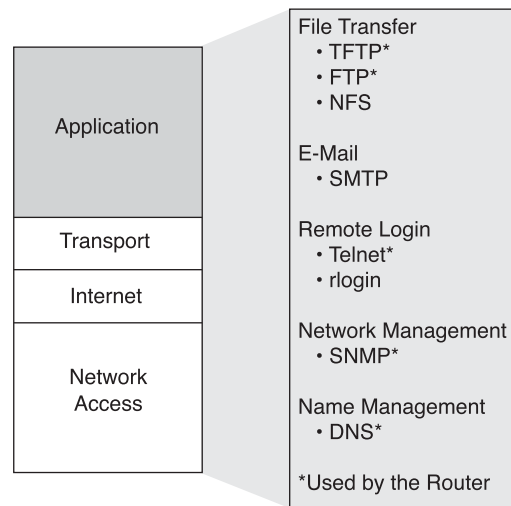
Figure 7-2 IPv4 Versus IPv6



Application Layer

TCP/IP was designed with a high-level protocol layer that includes OSI session, presentation, and application layer details. The *application layer*, shown in Figure 7-3, handles high-level protocols and issues of representation, encoding, and dialog control.

Figure 7-3 TCP/IP Application Layer Protocols



The TCP/IP protocol suite combines all application-related issues into one layer and ensures that this data is properly packaged for the next layer. TCP/IP includes not only Internet and transport layer specifications (such as IP and TCP) but also specifications for common applications. TCP/IP has protocols to support file transfer, e-mail, and remote login, including the following applications:

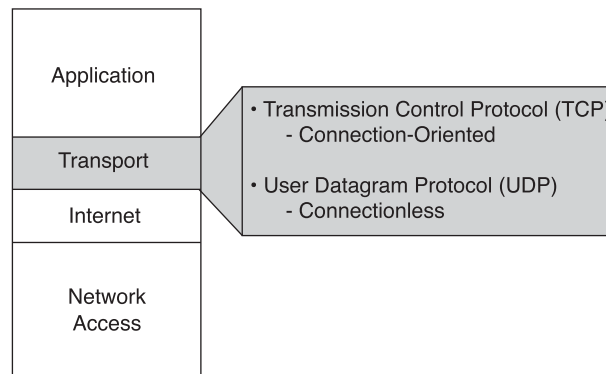
- **Hypertext Transfer Protocol (HTTP)**—The underlying protocol used by the World Wide Web. HTTP defines how messages are formatted and transmitted and what actions web servers and browsers should take in response to various commands.
- **Trivial File Transfer Protocol (TFTP)**—A connectionless service that uses User Datagram Protocol (UDP). TFTP is used on the router to transfer configuration files and Cisco IOS images and to transfer files between systems that support TFTP. It is useful in some LANs because it operates faster than FTP in a stable environment.

- **File Transfer Protocol (FTP)**—A reliable, connection-oriented service that uses TCP to transfer files between systems that support FTP. It supports bidirectional binary file and ASCII file transfers.
- **Network File System (NFS)**—A distributed file system protocol suite developed by Sun Microsystems that allows remote file access across a network.
- **Simple Mail Transfer Protocol (SMTP)**—Governs the transmission of e-mail over computer networks. It does not provide support for transmission of data other than plain text.
- **Terminal emulation (Telnet)**—Provides the capability to remotely access another computer. It lets a user log into an Internet host and execute commands. A Telnet client is called a local host; a Telnet server is called a remote host.
- **Simple Network Management Protocol (SNMP)**—A protocol that provides a means to monitor and control network devices and to manage configurations, statistics collection, performance, and security.
- **Domain Name System (DNS)**—A system used on the Internet to translate names of domains and their publicly advertised network nodes into IP addresses.

Transport Layer

The *transport layer* provides transport services from the source host to the destination host. It constitutes a logical connection between the network's endpoints: the sending host and the receiving host. Transport protocols, shown in Figure 7-4, segment and reassemble data that upper-layer applications send, into the same data stream between endpoints. The transport layer data stream provides end-to-end transport services, sometimes called end-to-end services.

Figure 7-4 TCP/IP Transport Layer Protocols



The transport layer data stream is a logical connection between a network's endpoints. Using UDP, the transport layer's primary duty is to transport data from source to destination. End-to-end control, provided by sliding windows and reliability in sequencing numbers and acknowledgments, is the primary duty of the transport layer when using TCP. The transport layer defines end-to-end connectivity between host applications. Transport services using TCP include all of the following services, whereas using UDP provides only the first two:

- Segmenting upper-layer application data
- Sending segments from one end device to another end device
- Establishing end-to-end operations
- Flow control provided by sliding windows
- Reliability provided by sequence numbers and acknowledgments

The transport layer assumes that it can use the network as a "cloud" to send data packets from the sender source to the receiver destination, as shown in Figure 7-5. The cloud deals with issues such as which of several paths is best for a given route, as shown in Figure 7-6.

Figure 7-5 Internet Cloud

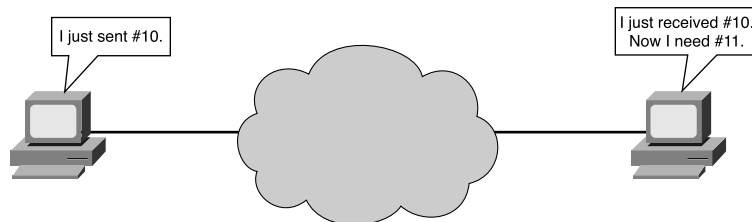
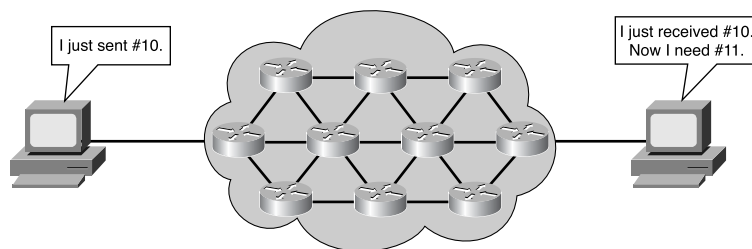


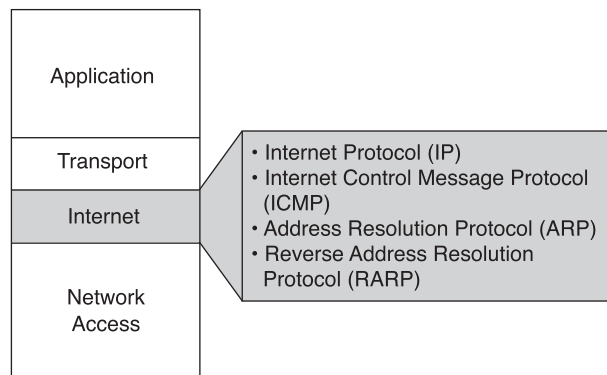
Figure 7-6 Internet Paths



Internet Layer

In the OSI reference model, the network layer isolates the upper-layer protocols from the details of the underlying network and manages the connections across the network. IP is normally described as the TCP/IP network layer. Because of TCP/IP's internet-working emphasis, this is commonly called the *Internet layer* in the TCP/IP model (see Figure 7-7). All upper- and lower-layer communications travel through IP as they are passed through the TCP/IP protocol stack. The purpose of the Internet layer is to send packets from a device using the correct protocol that functions at this layer. Best path determination and packet switching occur at this layer. Think of it in terms of the postal system. When a letter is mailed, it doesn't matter how it gets there (there are various possible routes), but it is important that it arrives.

Figure 7-7 TCP/IP Internet Layer Protocols



Several protocols operate at the TCP/IP Internet layer:

- **IP**—Provides connectionless, best-effort delivery routing of packets. It is not concerned with the packets' content. Instead, it looks for a way to move the packets to their destination.
- **Internet Control Message Protocol (ICMP)**—Provides control and messaging capabilities.
- **Address Resolution Protocol (ARP)**—Determines the data link layer addresses (Media Access Control [MAC] addresses) for known IP addresses.
- **Reverse Address Resolution Protocol (RARP)**—Determines IP addresses when data link layer addresses (MAC addresses) are known.

IP performs the following operations:

- Defining a packet and an addressing scheme

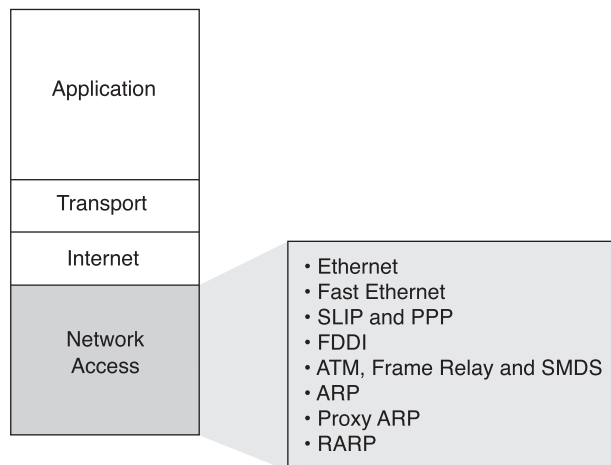
- Transferring data between the Internet layer and the network access layer
- Routing packets to remote hosts

Finally, to clarify terminology, IP is sometimes referred to as an unreliable protocol. This does not mean that IP does not accurately deliver data across a network; it simply means that IP does not perform error checking and correction. That function is handled by upper-layer protocols from the transport or application layer.

Network Access Layer

The *network access layer*, shown in Figure 7-8, is also called the host-to-network layer. It is the layer that is concerned with all the issues that an IP packet requires to make a physical link to the network medium. It includes the LAN and WAN technology details and all the details contained in the OSI physical and data link layers.

Figure 7-8 TCP/IP Network Access Layer Protocols



Software applications and drivers that are designed for individual pieces of hardware, such as Ethernet or Token Ring network interface cards (NICs), ISDN, or modem cards, often handle the network access layer. This causes confusion for users because a wide variety of protocols are defined by other standards that reside at the network access layer. The Internet and transport layer protocols (IP, TCP, and UDP) are much more quickly recognized, as are the application protocols (SMTP, HTTP, and FTP), as being part of TCP/IP.

Network access layer functions include mapping IP addresses to physical hardware addresses and encapsulating IP packets into frames. Based on the hardware type of the

network interface, the network access layer defines the connection with the physical network medium.

A good example of network access layer configuration is setting up a Windows system using a third-party NIC. Depending on the version of Windows, the operating system automatically detects the NIC, and the proper drivers are installed. If an older version of Windows is being used, the user must specify the network card driver. The card manufacturer supplies these drivers on disks or CD-ROMs.

Comparing the OSI Reference Model Layers and the TCP/IP Reference Model Layers

Figure 7-9 compares the OSI model and the TCP/IP model.

Figure 7-9 Comparing the TCP/IP Model to the OSI Model

TCP/IP Model		OSI Model	
Application	Protocols	Application	Application Layers
Transport		Presentation	
Internet	Networks	Session	
Network Access		Transport	Data Flow Layers
	Network		
	Data Link		
	Physical		

Notice that the models have similarities and differences:

- Similarities
 - Both have layers.
 - Both have application layers, although they include very different services.
 - Both have comparable transport and network layers.
 - Packet-switched (not circuit-switched) technology is assumed.
 - Networking professionals need to know both.
- Differences
 - TCP/IP combines the presentation and session layers into its application layer.
 - TCP/IP combines the OSI data link and physical layers into its network access layer.
 - TCP/IP appears simpler because it has fewer layers.

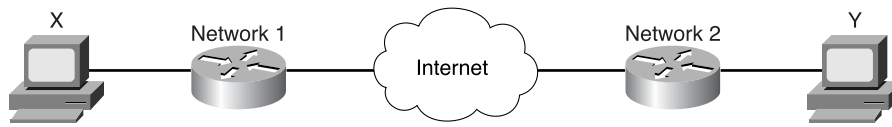
- The TCP/IP transport layer using UDP does not always guarantee reliable delivery of packets, as the transport layer in the OSI model does.

TCP/IP protocols are the standards around which the Internet developed, so the TCP/IP model gains credibility just because of its protocols. In contrast, networks typically aren't built on the OSI protocol; the OSI reference model is used as a guide for understanding the communication process.

Internet Architecture

Although the Internet is complex, some basic ideas underlie its operation. This section investigates the basic architecture of the Internet—a deceptively simple idea that, when repeated on a large scale, enables nearly instantaneous worldwide data communications between anyone, anywhere, at any time. In Figure 7-10, X and Y represent computers that are connected and that can communicate with each other from across the world.

Figure 7-10 Routers Connecting Two Networks



One limitation of LANs is that they do not scale

- Beyond a certain number of stations
- Beyond a certain geographic separation

Astonishing progress is being made in the number of stations that can be efficiently attached to a hierarchical LAN, and there have been advances in technologies such as Metro Optical and Gigabit Ethernet and 10 Gigabit Ethernet. However, ultimately stations must make recourse to a long-distance, WAN-like, packet-switching network.

One assumption of the Internet's architecture is that the details of host computers, and the LANs on which they reside, are separate from the details of getting messages from one network to another.

One approach to the big-picture architecture for the Internet was to focus on the application layer interactions between the source and destination computers and any intermediate computers. Identical instances of an application, put on all the computers in the network, could facilitate delivery of messages across the large network. However, this does not scale well. New software functionality would require new applications to be installed on every computer in the network; new hardware functionality would

require modifying the software. Failure of an intermediate computer or its application would break the chain on which the messages are passed.

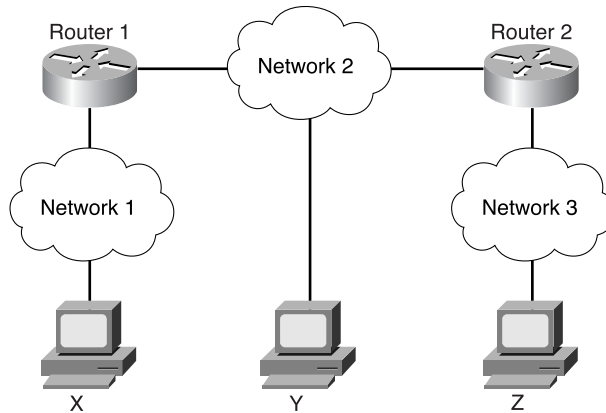
Instead, the Internet uses the principle of network layer interconnection. Using the OSI model as an example, the goal is to build the network's functionality in independent modules. The desire is to allow a diversity of LAN technologies at Layers 1 and 2. You want to allow a diversity of applications functioning at Layers 5, 6, and 7. However, you want a system that hides the details of the lower and upper layers, allowing intermediate networking devices to relay traffic without having to bother with the details of the LAN (best administered locally, and the network envisioned will be global) or the applications generating network traffic.

This leads to the concept of *internetworking*—building networks of networks. A network of networks is called an internet (with a lowercase i). (An uppercase I is used to refer to the networks that grew out of the DoD on which the WWW runs, and to refer to *the* Internet.) Internetworking must have the following characteristics:

- It must be scalable in the number of networks and computers attached.
- It must be able to handle the transport of data across vast distances, including entire-earth and near-earth space.
- It must be flexible to account for constant technological innovations.
- It must adjust to dynamic conditions on the network.
- It must be cost-effective.
- It must be a system that permits anytime, anywhere data communications to anyone.

Figure 7-10 illustrated the connection of one physical network to another through a special-purpose computer called a router. This diagram is not unlike the problem that led to the beginning of Cisco Systems at Stanford University in 1984 and the invention of the router. These networks are described as “directly connected” to the router. The router here is useful for handling any “translations” required for the two networks to communicate. However, because users seek anytime and anywhere connections to anyone, this scheme for connecting just two networks quickly becomes inadequate.

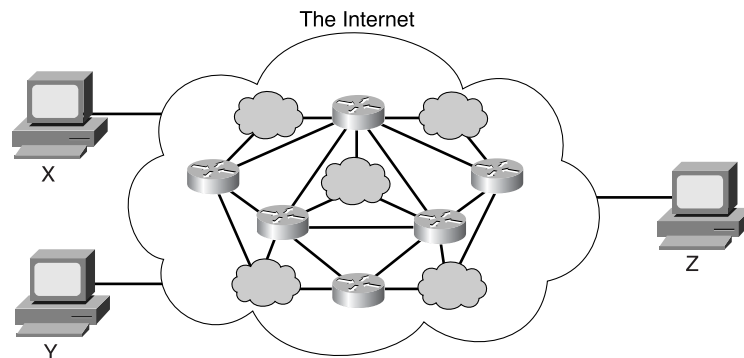
Figure 7-11 shows two routers connecting three physical networks. Now the routers must make more-complex decisions. Because all users on all networks want to communicate with each other, even without being directly connected to one another, the router must have some way of dealing with this.

Figure 7-11 Local and Remote Networks

One way would be for the router to keep a list of all user computers and the paths to them. The router would decide whether and where to forward data packets based on this table of all users, forwarding based on the destination computer. However, this would quickly become problematic as the number of users grows—it is not scalable. What if the router could instead keep a list of all networks, leaving the local delivery details to the local physical networks? This solution is better and more scalable—forwarding based on the destination network. In this case, the routers relay messages. In principle, if the routers can share some information about which networks they are connected to, doing so can scale this idea to many routers.

Figure 7-12 shows the results of this extension, showing the user's desired view: universal interconnections, with a minimum of details required by the end users to get their packets across the "cloud." Yet the physical/logical structure to accomplish this can be extremely complex. Indeed, the Internet cloud has grown exponentially, with devices and protocols constantly being improved to allow more users. The fact that the Internet has grown so large, with more than 90,000 core routes and more than 300,000,000 end users, is testimony to the soundness of the basic Internet architecture.

Thus, two computers, anywhere in the world, following certain hardware, software, and protocol specifications, can communicate reliably ("anyplace/anytime/anyone"). Even when they are not directly connected (or even not close to being directly connected), cooperation and procedures for moving data across this network of networks have made the Internet possible.

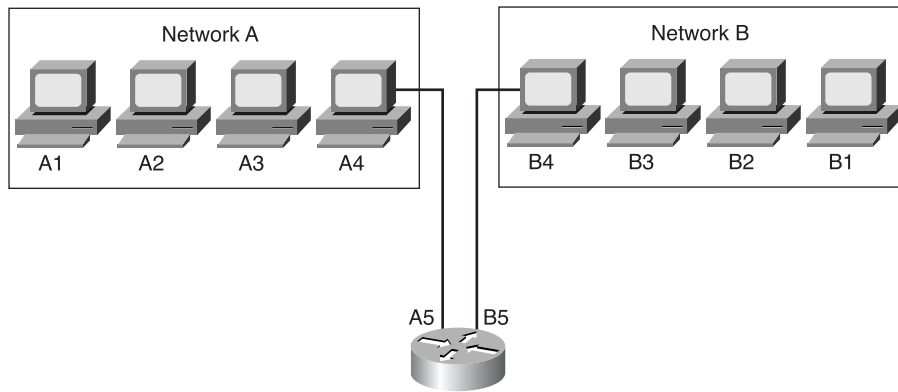
Figure 7-12 Physical Details Hidden from the User

IP Addresses

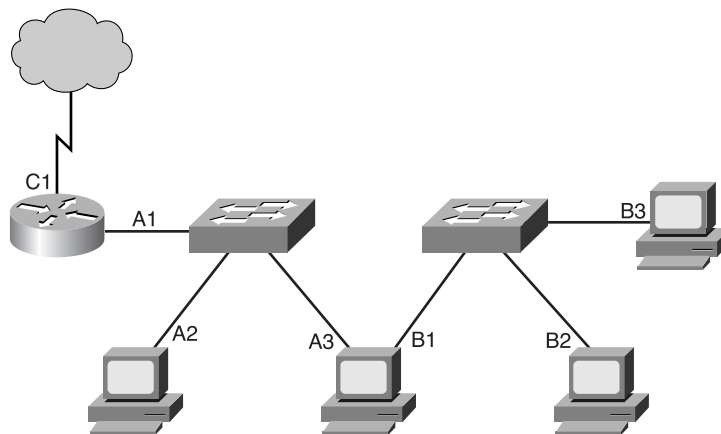
The network layer is responsible for navigating data through a network. The function of the network layer is to find the best path through a network. Devices use the network layer addressing scheme to determine the destination of data as it moves through the network. This section examines IP addressing and the five classes of IP addresses, along with subnetworks and subnet masks and their roles in IP addressing schemes. In addition, this portion of the chapter discusses the differences between public and private addresses, IPv4 and IPv6 addressing, and unicast and broadcast messages.

32-Bit Dotted-Decimal IP Address

For any two systems to communicate, they must be able to identify and locate each other, as shown in Figure 7-13. Although these addresses are not actual network addresses, they represent the concept of address grouping. The A and B identify the network, and the number sequence identifies the individual host. The combination of letter (network address) and number (host address) creates a unique address for each device on the network. In everyday life, names or numbers (such as telephone numbers) are often used as unique identifiers. Similarly, each computer in a TCP/IP network must be given at least one unique identifier, or address. This address allows one computer to locate another on a network.

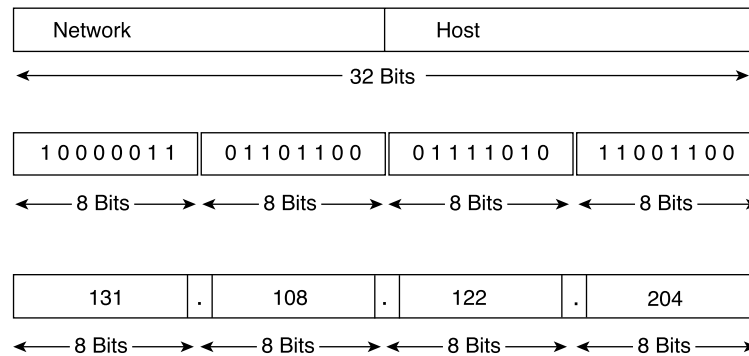
Figure 7-13 Host Addresses

A computer might be connected to more than one network, as shown in Figure 7-14. This is an example of a computer that is connected to two different networks. This is done by having two network interface cards in the computer. This is called a dual-homed device. The important thing to notice here is that the computer's two interfaces are in completely different networks and consequently have different network identifiers in the addresses. One other important note is that this computer doesn't pass data through it unless it is specifically configured to do so; it merely has access to both networks. If this is the case, the system must be given more than one address, each address identifying its connection to a different network. Strictly speaking, a device cannot be said to have an address, but each of its connection points (or interfaces) to a network has an address that allows other computers to locate it on that particular network.

Figure 7-14 Dual-Homed Computers

Inside a computer, an IP address is stored as a 32-bit sequence of 1s and 0s, as shown in Figure 7-15. To make the IP address easier to use, it is usually written as four decimal numbers separated by periods. For instance, an IP address of one computer is 192.168.1.2. Another computer might have the address 128.10.2.1. This way of writing the address is called *dotted-decimal format*. In this notation, each IP address is written as four parts separated by periods, or dots. Each part of the address is called an *octet* because it is made up of 8 binary digits. For example, the IP address 192.168.1.8 is 11000000.10101000.00000001.00001000 in binary notation. It is plain to see that it is easier for humans to understand dotted-decimal notation instead of the binary 1s and 0s. This prevents a large number of transposition errors that would result if only the binary numbers were used.

Figure 7-15 IP Addressing Format



Using dotted decimal also allows number patterns to be much more quickly understood, as shown in Figure 7-15. Both the binary and decimal numbers in the figure represent the same values, but it is much easier to see with the dotted-decimal values. This is one of the common problems with working directly with binary numbers. The long strings of repeated 1s and 0s make these numbers prone to transposition and omission errors. In other words, it is easier to see the relationship between these two numbers:

192.168.1.8

192.168.1.9

than it is to recognize the relationship between their dotted-decimal binary equivalents:

11000000.10101000.00000001.00001000

11000000.10101000.00000001.00001001

Looking at the binaries, it is almost impossible to see that they are consecutive numbers.

Decimal and Binary Conversion

There is usually more than one way to solve a math problem, and decimal-to-binary conversion is no exception. This section explores one method, but feel free to use another method if it is easier.

To convert a decimal number to binary, the idea is to first find the biggest power of 2 that “fits” into the decimal number, as shown in Table 7-1. If this process is designed to work with computers, the most logical place to start is with the largest values that fit into 1 or 2 bytes.

Table 7-1 Calculating Available Host Addresses

2^{15}	2^{14}	2^{13}	2^{12}	2^{11}	2^{10}	2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
32678	16384	8192	4096	2048	1024	512	256	128	64	32	16	8	4	2	1

As mentioned, the most common grouping of bits is 8, which make up one byte. But sometimes the largest value that can be held in 1 byte (255) is not large enough for the values needed. In this situation you must combine bytes, so instead of having two 8-bit numbers you have one 16-bit number, or instead of three 8-bit numbers you have one 24-bit number. The same rules apply as for 8-bit numbers: You multiply the previous position value by 2 to get the present column value. Table 7-1 documents these values (starting with a 2-byte/16-bit number), which are very important when you’re learning the mechanics of subnetting.

Because working with computers often is referenced by bytes, it is easiest to start with byte boundaries and calculate from there, as shown in Table 7-2. To better demonstrate, look at the next couple of calculation examples, the first being 6,783. Because this number is greater than 255, the largest value possible in a single byte, you use 2 bytes. Start calculating from 2^{15} . The result is that 6,783 equals 00011010 01111111.

Table 7-2 Decimal-to-Binary Conversion Chart

Position Power	Decimal Value	Position Value	Binary Count	Remainder
2^{15}	6783	32678	0	6783
2^{14}	6783	16384	0	6783
2^{13}	6783	8192	0	6783
2^{12}	6783	4096	1	2687

continues

Table 7-2 Decimal-to-Binary Conversion Chart (Continued)

Position Power	Decimal Value	Position Value	Binary Count	Remainder
2^{11}	2687	2048	1	639
2^{10}	639	1024	0	639
2^9	639	512	1	127
2^8	127	256	0	127
2^7	127	128	0	127
2^6	127	64	1	63
2^5	63	32	1	31
2^4	31	16	1	15
2^3	15	8	1	7
2^2	7	4	1	3
2^1	3	2	1	1
2^0	1	1	1	0

The second example is 104. Because this number is less than 255, the conversion can be done in 1 byte, as shown in Table 7-3.

Table 7-3 Converting an 8-Bit Number

Position Power	Decimal Value	Position Value	Binary Count	Remainder
2^7	104	128	0	104
2^6	104	64	1	40
2^5	40	32	1	8
2^4	8	16	0	8
2^3	8	8	1	0
2^2	0	4	0	0
2^1	0	2	0	0
2^0	0	1	0	0

So 104 is 01101000.

This method works for any decimal number. Consider the decimal number 1,000,000. Because 1,000,000 is greater than the largest value that can be held in 2 bytes (65535), you need at least 3 bytes. By multiplying by 2 until you reach 24 bits (3 bytes), you get the value 8,388,608, meaning that the largest value that 24 bits can hold is 16,777,215. So starting at the 24 bit, follow the process until you get to 0. Continuing with the procedure, you'll determine that the decimal number 1,000,000 equals the binary number 00001111 01000010 01000000.

Binary-to-decimal conversion is just the opposite. Simply place the binary number in the table. If there is a 1 in a column position, add that value to the total. Table 7-4 demonstrates an example of this. It shows converting 00000100 00011101 to decimal, resulting in 1053.

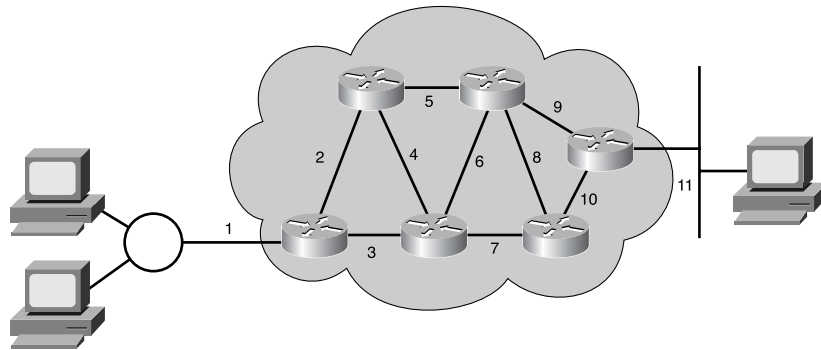
Table 7-4 Decimal-to-Binary Conversion of a 16-Bit Number

Position Power	Decimal Value	Position Value	Binary Count	Remainder
2^{15}	0	32678	0	0
2^{14}	0	16384	0	0
2^{13}	0	8192	0	0
2^{12}	0	4096	0	0
2^{11}	0	2048	0	0
2^{10}	0	1024	1	1024
2^9	1024	512	0	1024
2^8	1024	256	0	1024
2^7	1024	128	0	1024
2^6	1024	64	0	1024
2^5	1024	32	0	1024
2^4	1024	16	1	1040
2^3	1040	8	1	1048
2^2	1048	4	1	1052
2^1	1052	2	0	1052
2^0	1052	1	1	1053

IPv4 Addressing

IP forwards packets from the network on which they originate to the destination network, as shown in Figure 7-16. This addressing scheme, therefore, must include an identifier for both the source and destination networks. By using the destination network identifier, IP can deliver a packet to the destination network. When the packet arrives at a router connected to the destination network, IP must then locate the particular computer connected to that network. This works in much the same way as the postal system. When the mail is routed, it must first be delivered to the post office at the destination city using the zip code, and then that post office must locate the final destination in that city using the street address. This is a two-step process.

Figure 7-16 Communication Path



Accordingly, every IP address has two parts, as shown in Figure 7-17. One part identifies the network to which the system is connected, and a second part identifies that particular system on the network. This kind of address is called a hierarchical address, because it contains different levels, as shown in Figure 7-18. As Figure 7-18 illustrates, each octet ranges from 0 to 255. Each octet breaks down into 256 subgroups, and they break down into another 256 subgroups with 256 addresses in each. By referring to the group address directly above a group in the hierarchy, all the groups that branch from that address can be referenced as a single unit. An IP address combines these two identifiers into one number. This number must be unique, because duplicate addresses are not allowed. The first part identifies the system's network address. The second part, the host part, tells which particular machine it is on that network.

Figure 7-17 Network and Host Portions of the IP Address

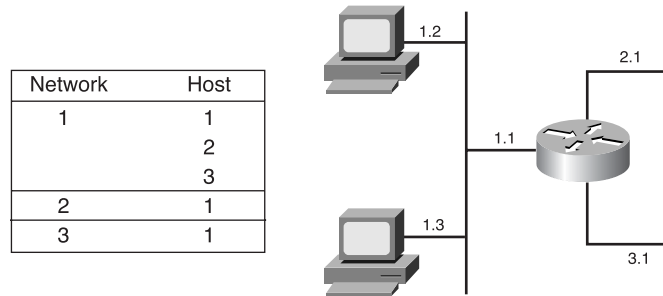
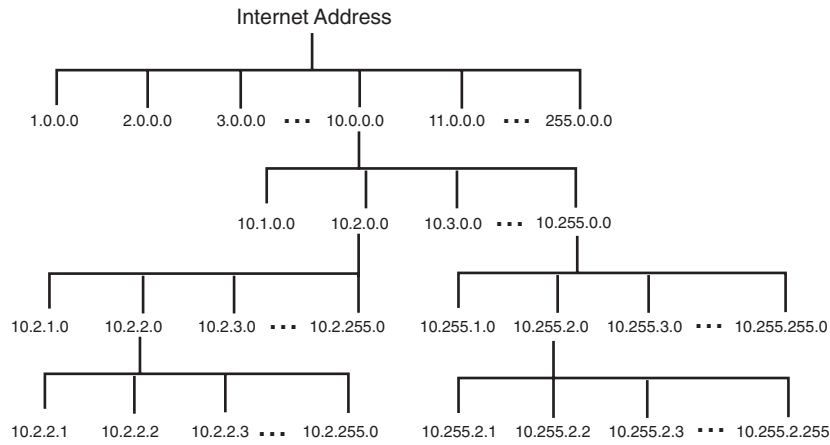


Figure 7-18 Hierarchical IP Addresses



How does a user determine which portion of the address identifies the network and which portion identifies the host? The answer begins with the designers of the Internet, who thought networks would be built in different sizes, depending on the number of computers (hosts) they contained, as shown in Table 7-5.

Table 7-5 IP Address Classes

Address Class	Number of Networks	Number of Hosts Per Network
A	126*	16,777,216
B	16,384	65,535
C	2,097,152	254
D (multicast)	—	—

* The 127.x.x.x address range is reserved as a loopback address, used for testing and diagnostic purposes.

The assumption was that there would be a relatively small number of large networks, possibly with millions of computers. The designers envisioned a larger number of medium-sized networks, with perhaps thousands of computers each. Finally, they saw a great number of networks having several hundred or fewer machines. Thus, the designers divided the available IP addresses into classes to define the large (Class A), medium (Class B), and small (Class C) networks, as shown in Table 7-6. Knowing the class of an IP address is the first step in determining which part of the address identifies the network and which part identifies the host.

Table 7-6 Identifying Address Classes

Address Class	High-Order Bits	First Octet Address Range	Number of Bits in the Network Address
A	0	0 to 127 [*]	8
B	10	128 to 191	16
C	110	192 to 223	24
D (Multicast)	1110	224 to 239	28

^{*} 127 (01111111) is a Class A address reserved for loopback testing and cannot be assigned to a network.

IP Address Classes

To accommodate different-sized networks and to aid in classifying them, IP addresses are divided into groupings called classes, as shown in Figure 7-19. This is called classful addressing. Each complete 32-bit IP address is broken into a network part and a host part. A bit or bit sequence at the start of each address determines the class of the address, as shown in Figure 7-20. There are five *IP address classes*.

Figure 7-19 Network and Host Division

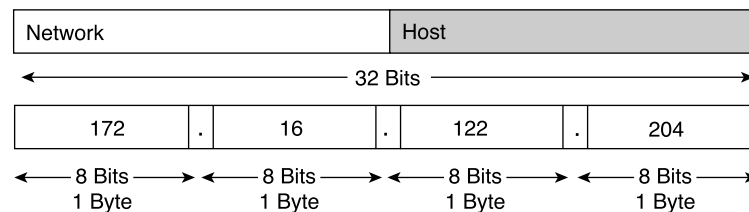


Figure 7-20 Address Class Prefixes

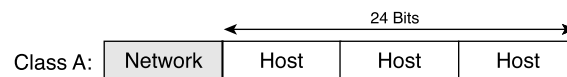
No. of Prefix Bits	1	7	24
Class A: Prefix Value	0	Network Bits	Host Bits
No. of Prefix Bits	2	14	16
Class B: Prefix Value	10	Network Bits	Host Bits
No. of Prefix Bits	3	21	8
Class C: Prefix Value	110	Network Bits	Host Bits
No. of Prefix Bits	4	28	
Class D: Prefix Value	1110	Address	
No. of Prefix Bits	4	28	
Class E: Prefix Value	1111	Address	

Class D addresses are used for multicast groups. There is no need to allocate octets or bits to separate network and host addresses.

Class E addresses are reserved for research use only.

Class A Addresses

The *Class A address*, shown in Figure 7-21, was designed to support extremely large networks. A Class A IP address uses only the first octet to indicate the network address. The remaining three octets enumerate host addresses.

Figure 7-21 Class A Addresses

The first bit of a Class A address is always 0. With that first bit a 0, the lowest number that can be represented is 00000000 (decimal 0), and the highest number that can be represented is 01111111 (decimal 127). However, these two numbers, 0 and 127, are reserved and cannot be used as a network address. Any address that has a value between 1 and 126 in the first octet is a Class A address.

Class B Addresses

The *Class B address*, shown in Figure 7-22, was designed to support the needs of moderate- to large-sized networks. A Class B IP address uses two of the four octets to indicate the network address. The other two octets specify host addresses.

NOTE

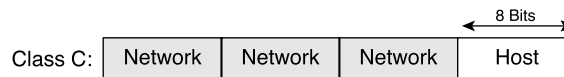
The 127.0.0.0 network is reserved for loopback testing (routers or local machines can use this address to send packets to themselves). Therefore, it cannot be assigned to a network.

Figure 7-22 Class B Addresses

The first 2 bits of the first octet of a Class B address are always 10. The remaining 6 bits may be populated with either 1s or 0s. Therefore, the lowest number that can be represented with a Class B address is 10000000 (decimal 128), and the highest number that can be represented is 10111111 (decimal 191). Any address that starts with a value in the range of 128 to 191 in the first octet is a Class B address.

Class C Addresses

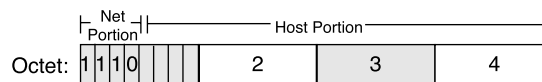
The *Class C address*, shown in Figure 7-23, is the most commonly used of the original address classes. This address space was intended to support a lot of small networks.

Figure 7-23 Class C Addresses

A Class C address begins with binary 110. Therefore, the lowest number that can be represented is 11000000 (decimal 192), and the highest number that can be represented is 11011111 (decimal 223). If an address contains a number in the range of 192 to 223 in the first octet, it is a Class C address.

Class D Addresses

The *Class D address*, shown in Figure 7-24, was created to enable multicasting in an IP address. A *multicast address* is a unique network address that directs packets that have that destination address to predefined groups of IP addresses. Therefore, a single station can simultaneously transmit a single stream of data to multiple recipients.

Figure 7-24 Class D Addresses

The Class D address space, much like the other address spaces, is mathematically constrained. The first 4 bits of a Class D address must be 1110. Therefore, the first octet range for Class D addresses is 11100000 to 11101111, or 224 to 239. An IP address that starts with a value in the range of 224 to 239 in the first octet is a Class D address.

Class E Addresses

A *Class E address*, shown in Figure 7-25, has been defined. However, the Internet Engineering Task Force (IETF) reserves these addresses for its own research. Therefore, no Class E addresses have been released for use in the Internet. The first 4 bits of a Class E address are always set to 1. Therefore, the first octet range for Class E addresses is 11110000 to 11111111, or 240 to 255.

Figure 7-25 Class E Addresses

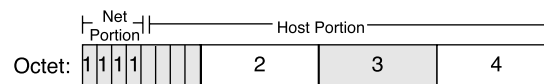


Table 7-7 shows the IP address range of the first octet (in decimal and binary) for each IP address class.

Table 7-7 IP Address Classes: Range of the First Octet

IP Address Class	IP Address Range (First Octet Decimal Value)
Class A	1 to 126 (00000001 to 01111110)*
Class B	128 to 191 (10000000 to 10111111)
Class C	192 to 223 (11000000 to 11011111)
Class D	224 to 239 (11100000 to 11101111)
Class E	240 to 255 (11110000 to 11111111)

Determine the class based on the decimal value of the first octet.

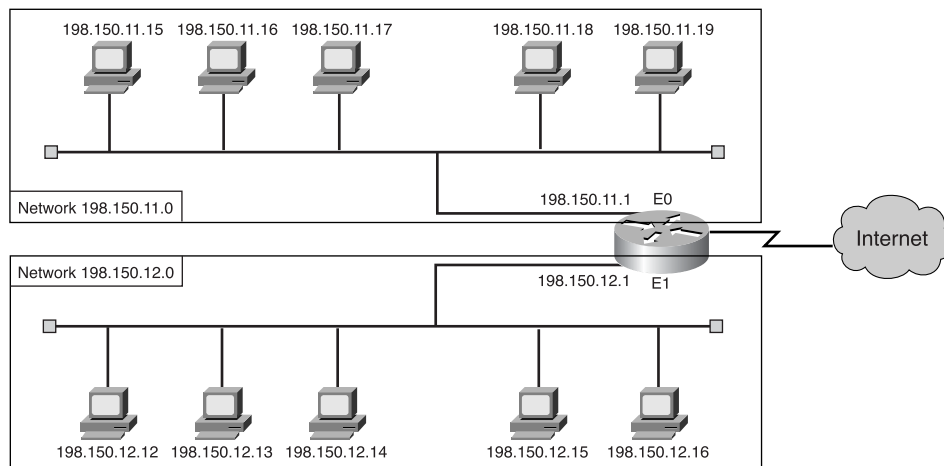
* 127 (01111111) is a Class A address reserved for loopback testing and cannot be assigned to a network.

Reserved IP Addresses

Certain addresses are reserved and cannot be assigned to devices on a network. These reserved host addresses include the following:

- Network addresses are used to identify the network itself (see Figure 7-26). The upper box represents the 198.150.11.0 network. Data that is sent to any host on that network (198.150.11.1 to 198.150.11.254) is seen outside the LAN as 198.159.11.0. The only time the host numbers matter is when the data is on the LAN. The LAN in the lower box is treated the same as the upper LAN, except that its network number is 198.150.12.0.
- The *broadcast address* is used to broadcast packets to all the devices on a network (see Figure 7-27). The upper box represents the 198.150.11.255 broadcast address. Data that is sent to the broadcast address is read by any host on that network (198.150.11.1 to 198.150.11.254). The LAN in the lower box is treated the same as the upper LAN, except that its broadcast address is 198.150.12.255.

Figure 7-26 Network Address



An IP address that has binary 0s in all host bit positions is reserved for the *network address*, as shown in Figure 7-28. This Class B address has all its host bits set to 0. That is why it is identified as the network address. Therefore, as a Class A network example, 113.0.0.0 is the IP address of the network containing the host 113.1.2.3. A router uses the network IP address when it forwards data on the Internet. As a Class B network example, the IP address 176.10.0.0 is a network address, as shown in Figure 7-28.

Figure 7-27 Broadcast Address

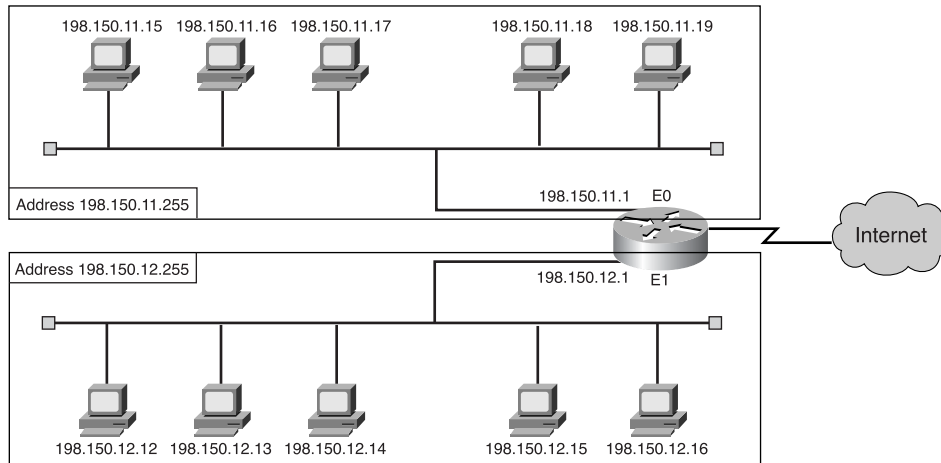
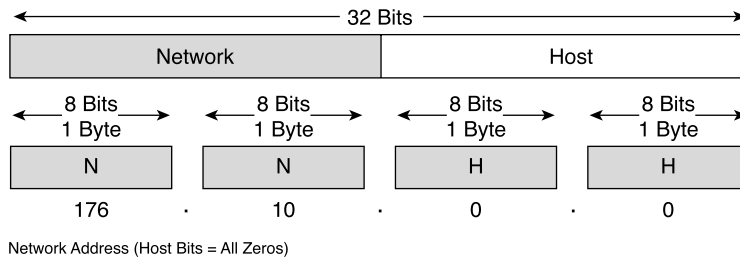


Figure 7-28 Network Address

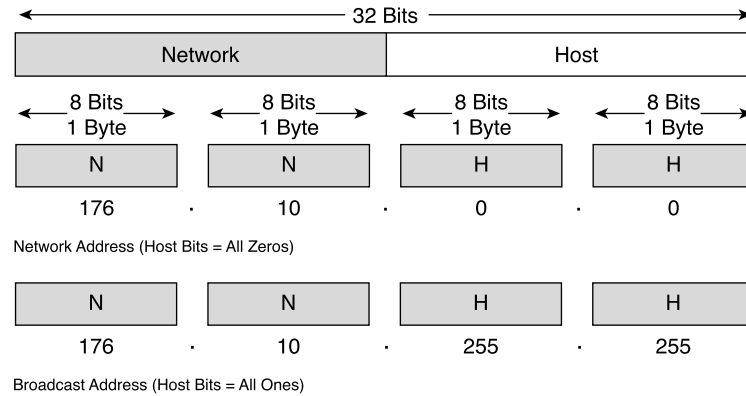


In a Class B network address, the first two octets, written as dotted-decimal numbers, are assigned by default. The last two octets contain 0s because those 16 bits are for host numbers and identify devices that are attached to the network. This is called a unicast address (*uni* means *one*). A unicast address points to just one host on the network. The IP address in the example (176.10.0.0) is reserved for the network address and is never used as an address for any device that is attached to it. An example of an IP address for a device on the 176.10.0.0 network is 176.10.16.1. In this example, 176.10 is the network address portion, and 16.1 is the host address portion.

To send data to all the devices on a network, a broadcast address is needed. A broadcast occurs when a source sends data to all devices on a network, as shown in Figure 7-29. This Class B address is the broadcast address for this network. When packets are received with this destination address, the data is processed by every computer. To ensure that

all the other devices on the network process the broadcast, the sender must use a destination IP address that they can recognize and process. Broadcast IP addresses end with binary 1s in the entire host part of the address (the Host field).

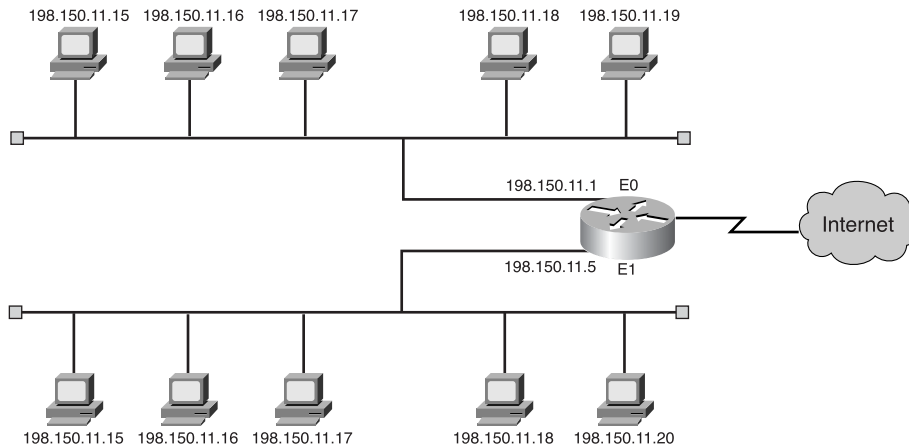
Figure 7-29 Broadcast Address



For the network 176.10.0.0, where the last 16 bits make up the Host field (or the host part of the address), the broadcast that is sent to all devices on that network includes a destination address of 176.10.255.255 (because 255 is the decimal value of an octet containing 11111111).

Public and Private Addresses

Internet stability depends directly on the uniqueness of publicly used network addresses. As shown in Figure 7-30, there is an issue with the networking addressing scheme. Both networks have a network address of 198.150.11.0. When data transmissions reach the router, which network would it forward to? A scheme such as this one would greatly increase the amount of network traffic and would defeat a router's basic function. Therefore, some mechanism was needed to ensure that addresses were, in fact, unique. This responsibility originally rested with the InterNIC (Internet Network Information Center). This organization is now defunct and has been succeeded by the Internet Assigned Numbers Authority (IANA). IANA carefully manages the remaining supply of IP addresses to ensure that duplication of publicly used addresses does not occur. Such duplication would cause instability in the Internet and compromise its capability to deliver datagrams to networks using the duplicated addresses.

Figure 7-30 Required Unique Addresses

Public IP addresses are unique. No two machines that connect to a public network can have the same IP address, because public IP addresses are global and standardized. All machines connected to the Internet agree to adhere to the system. Public IP addresses must be obtained from an Internet service provider (ISP) or a registry at some expense.

With the rapid growth of the Internet, public IP addresses were beginning to run out, so new addressing schemes such as classless interdomain routing (CIDR) and IPv6 were developed to help solve the problem. CIDR and IPv6 are discussed later.

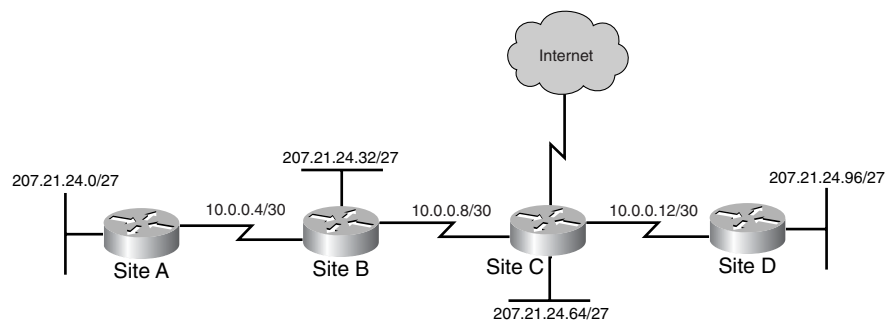
Another solution that was developed is the use of private IP addresses, as shown in Table 7-8. As stated previously, Internet hosts require a globally unique IP address. However, private networks that are not connected to the Internet can use any valid address, as long as it is unique within the private network. Many private networks exist alongside public networks. Grabbing “just any address” is strongly discouraged because that network might eventually be connected to the Internet.

RFC 1918 sets aside three blocks of IP addresses (a single Class A address, a range of Class B addresses, and a range of Class C addresses) for private, internal use. Addresses in this range are not routed on the Internet backbone; Internet routers immediately discard private addresses.

Table 7-8 Private IP Addresses

IP Address Class	RFC 1918 Internal Address Range
Class A	10.0.0.0 to 10.255.255.255
Class B	172.16.0.0 to 172.31.255.255
Class C	192.168.0.0 to 192.168.255.255

If you are addressing a nonpublic intranet, a test lab, or a home network, these private addresses can be used instead of globally unique addresses. Private IP addresses can be intermixed with public IP addresses, as shown in Figure 7-31, to conserve the number of addresses used for internal connections.

Figure 7-31 Using Private IP Addresses Within the WAN

Connecting a network to the Internet using private addresses requires translating the private addresses to public addresses. This translation process is called Network Address Translation (NAT). A router usually is the device that performs NAT.

Introduction to Subnetting

Another way to conserve IP addresses, like CIDR, IPv6, and private addresses, is the use of *subnetting*. This method of dividing full network address classes into smaller pieces has helped prevent complete IP address exhaustion. Figure 7-32 shows a Class B network (131.108.0.0) divided into three subnetworks. It is impossible to cover TCP/IP without mentioning subnetting. As a system administrator, you must understand subnetting as a means of dividing and identifying separate networks throughout the LAN. It is not always necessary to subnet a small network, but for large or extremely large networks, subnetting is required. Simply stated, subnetting a network means using the subnet mask to divide the network and break a large network into smaller, more efficient, more manageable segments, or subnets, as shown in Figure 7-33. This is like the

American telephone system, which breaks the system into area codes, and then exchange codes, and finally local numbers. These elements of the phone system are comparable to network numbers, subnets, and individual host addresses, respectively, in an IP internetwork.

Figure 7-32 Addressing with Subnets

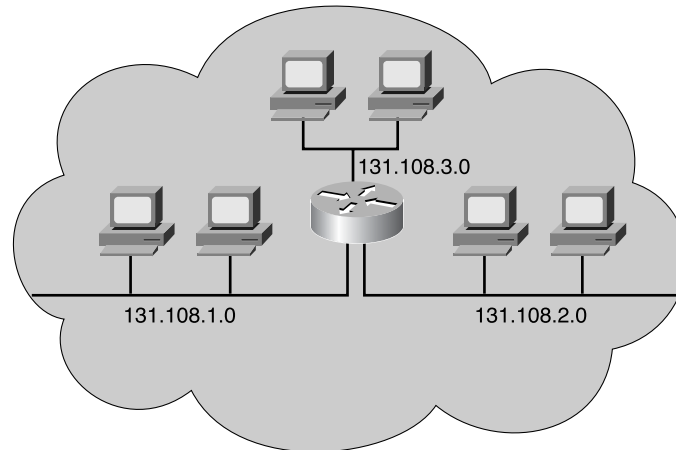
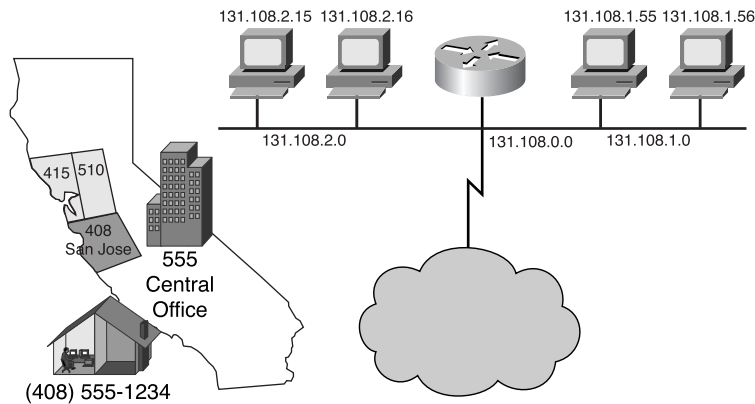


Figure 7-33 Subnet Addresses



The system administrator must resolve these issues when adding and expanding the network. It is important to know how many subnet/networks are needed and how many hosts are allowed to be on each network. With subnetting, the network is not limited to the standard Class A, B, or C network masks and there is more flexibility in the network design.

Subnet addresses include the Class A, Class B, or Class C network portion, plus a Subnet field and a Host field. These fields are created from the original host portion for the entire network. The ability to decide how to divide the original host portion into the new Subnet and Host fields provides addressing flexibility for the network administrator.

To create a subnet address, a network administrator borrows bits from the Host field and designates them as the Subnet field, as shown in Table 7-9. The minimum number of bits that can be borrowed is 2. If you were to borrow only 1 bit, to create a subnet, you would have only a network number (the .0 network) and a broadcast number (the .255 network). The maximum number of bits that can be borrowed can be any number that leaves at least 2 bits for the host number. In Table 7-9's example of a Class C IP address, bits from the Host field have been borrowed for the Subnet field.

Table 7-9 Subnet Addresses

Decimal Notation for First Host Octet	Number of Subnets	Number of Class A Hosts Per Subnet	Number of Class B Hosts Per Subnet	Number of Class C Hosts Per Subnet
.192	2	4,194,302	16,382	62
.224	6	2,097,150	8,190	30
.240	14	1,048,574	4,094	14
.248	30	524,286	2,046	6
.252	62	262,142	1,022	2
.254	126	131,070	510	—
.255	254	65,534	254	—



Lab Activity IP Addressing Basics

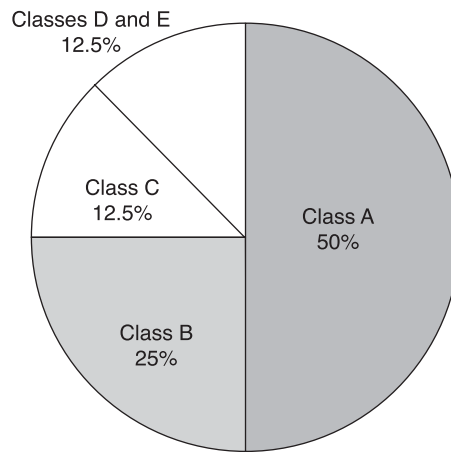
This exercise helps you develop an understanding of IP addresses and how TCP/IP networks operate.

IPv4 Versus IPv6

When TCP/IPa was adopted in the 1980s, it relied on a two-level addressing scheme, which at the time offered adequate scalability. Unfortunately, the architects of TCP/IP could not have predicted that their protocol would eventually sustain a global network of information, commerce, and entertainment. More than 20 years ago, IPv4 offered an addressing strategy that, although scalable for a time, resulted in an inefficient allocation of addresses.

Class A and B addresses make up 75 percent of the IPv4 address space, as shown in Figure 7-34, but a relative handful of organizations (fewer than 17,000) can be assigned a Class A or B network number. Class C network addresses are far more numerous than Class A and Class B addresses, but they account for only 12.5 percent of the possible 4 billion IP addresses.

Figure 7-34 IPv4 Address Allocation



Unfortunately, Class C addresses are limited to 254 hosts, not meeting the needs of larger organizations that cannot acquire a Class A or B address. Even if there were more Class A, B, and C addresses, too many network addresses would cause Internet routers to grind to a halt under the weight of the enormous routing tables required to store the routes to reach the networks.

As early as 1992, the IETF identified two specific concerns:

- **Exhaustion of the remaining, unassigned IPv4 network addresses**—At the time, the Class B space was on the verge of depletion.
- **The rapid and substantial increase in the size of Internet routing tables because of the Internet's growth**—As more Class C networks came online, the resulting flood of new network information threatened the capability of Internet routers to cope effectively.

Over the past two decades, numerous extensions to IPv4 have been developed that are specifically designed to improve the efficiency with which the 32-bit address space can be used. Two of the more important are subnet masks and CIDR.

Meanwhile, an even more extensible and scalable version of IP, IPv6, has been defined and developed. IPv6 uses 128 bits rather than the 32 bits currently used in IPv4, as

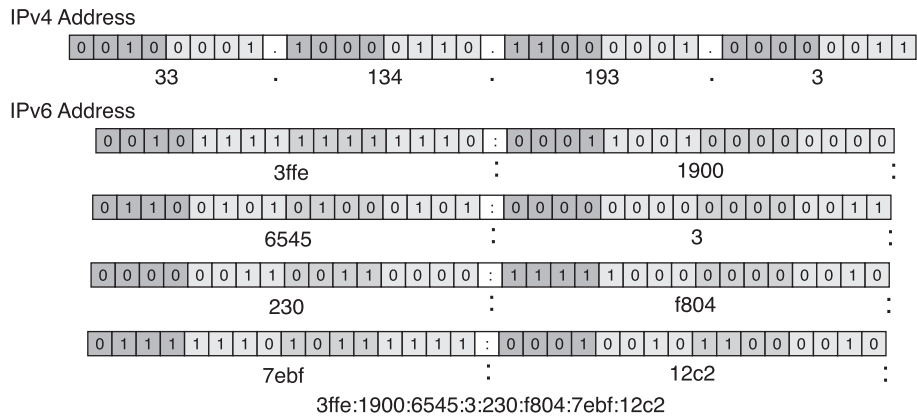
shown in Figure 7-35. IPv6 uses hexadecimal numbers to represent the 128 bits. It provides 16 billion IP addresses (3.4×10^{38} addresses). This version of IP should provide sufficient addresses for future communication needs.

Figure 7-35 IPv4 and IPv6

Internet Protocol Version 4 (IPv4)	4 Octets
11010001.11011100.11001001.01110001	
209.156.201.113	
4,294,467,295 IP Addresses	
Internet Protocol Version 6 (IPv6)	16 Octets
11010001.11011100.11001001.01110001.11010001.11011100. 110011001.01110001.11010001.11011100.11001001. 01110001.11010001.11011100.11001001.01110001	
A524:72D3:2C80:DD02:0029:EC7A:002B:EA73	
3.4×10^{38} IP Addresses	

The IPv6 shorthand representation of the 128 bits uses eight 16-bit numbers, shown as four hexadecimal digits, as shown in Figure 7-36. The groups of four hex digits are separated by colons. If there are leading 0s in the hex digits, they may be omitted.

Figure 7-36 IPv4 and IPv6



After years of planning and development, IPv6 is slowly being implemented in select networks. Eventually, IPv6 might replace IPv4 as the dominant Internet protocol.

IP Address Assignment, Acquisition, and Hierarchy

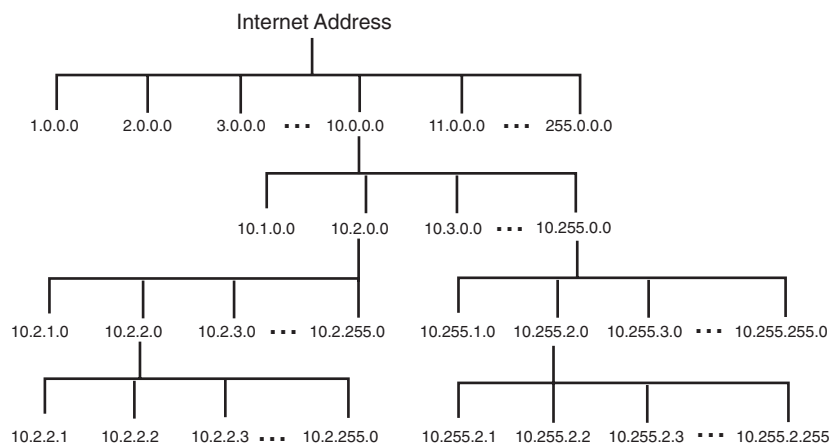
This section discusses how network devices obtain IP addresses. For a network to keep functioning, the IP addresses must be assigned according to a specific hierarchy. How and why this is done are discussed in the following section. IP addresses can be assigned either statically or dynamically. Both methods are covered here.

Obtaining an Internet Address

For a host on a network to function on the Internet, it needs to obtain a globally unique address. A host's physical or MAC address is only locally significant. Being locally significant means that the address can only identify the host in its own LAN. It has no meaning to any device that is not in that LAN.

IP is the most widely used global addressing scheme. It is a hierarchical addressing scheme that allows individual addresses to be associated and treated as groups, as shown in Figure 7-37. These groups of addresses allow efficient transfer of data across the Internet.

Figure 7-37 Internet Address Hierarchy



There are essentially two methods for assigning IP addresses—*static addressing* and *dynamic addressing*. The next few sections cover static and dynamic addressing. Regardless of which addressing scheme is chosen, no two interfaces can have the same IP address. This would cause a conflict that might cause both the hosts involved not to operate properly.

Static Assignment of an IP Address

When IP addresses are assigned statically, each device must be configured with an IP address. Each operating system has its own way of configuring TCP/IP. This method requires records of the address assignments to be kept, because problems can occur in a network if duplicate IP addresses are used. Some operating systems, such as Windows 95 and Windows NT, send an ARP request to check for a duplicate IP address when they attempt to initialize TCP/IP. If a duplicate is discovered, the operating system does not initialize TCP/IP and generates an error message. Not all operating systems identify duplicate IP addresses. This again emphasizes the need for good record-keeping.

The main reason that a device would be assigned a static IP address is if the device needs to be referenced by other devices. A good example is a web server. If a web server got a new IP address each time it started up, it would be difficult to find the web server. As an example of this address changing, if a city were to constantly change street names and building addresses, maps would no longer help you locate a particular building. If an address changes, it is no longer easy to return to the location. If a building is difficult to get to, people will stop trying to locate it.

Certain types of devices need to maintain a static IP address. Web servers, network printers, application servers, and routers are good examples of devices that require permanent IP addresses.

Address Resolution Protocol

For devices to communicate, the sending device needs the destination device's IP address and MAC address. When a device tries to communicate with a device whose IP address it knows, it must determine the MAC address. The TCP/IP suite has a protocol called Address Resolution Protocol (ARP) that can automatically obtain the MAC address. ARP lets a computer find the MAC address of the computer that is associated with an IP address, as shown in Figure 7-38.

Some devices keep ARP tables, which contain the MAC addresses and IP addresses of other devices that are connected to the same LAN. ARP tables map IP addresses to the corresponding MAC addresses. ARP tables are sections of RAM memory that are maintained automatically on each device, as shown in Tables 7-10 and 7-11. It is rare that you must manually make an ARP table entry. Each computer on a network maintains its own ARP table.

Figure 7-38 ARP Obtains the IP Address Via the MAC Address

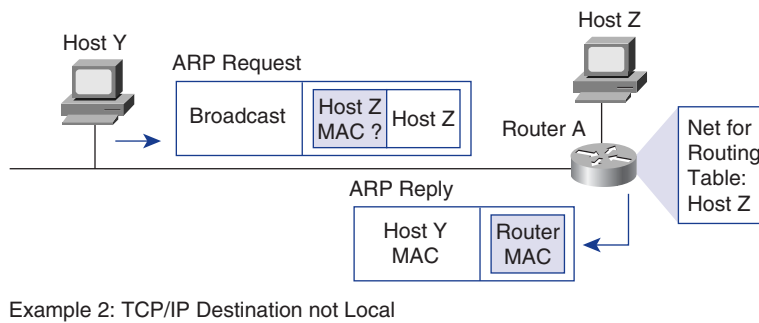
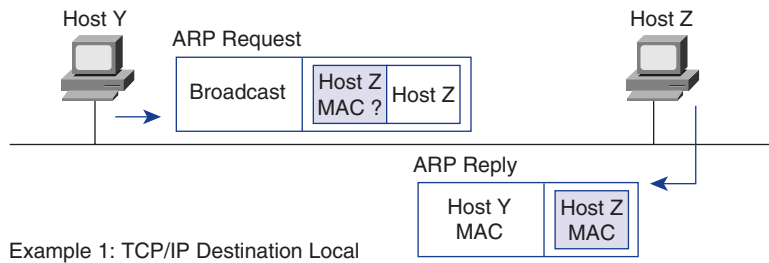


Table 7-10 ARP Table Entry

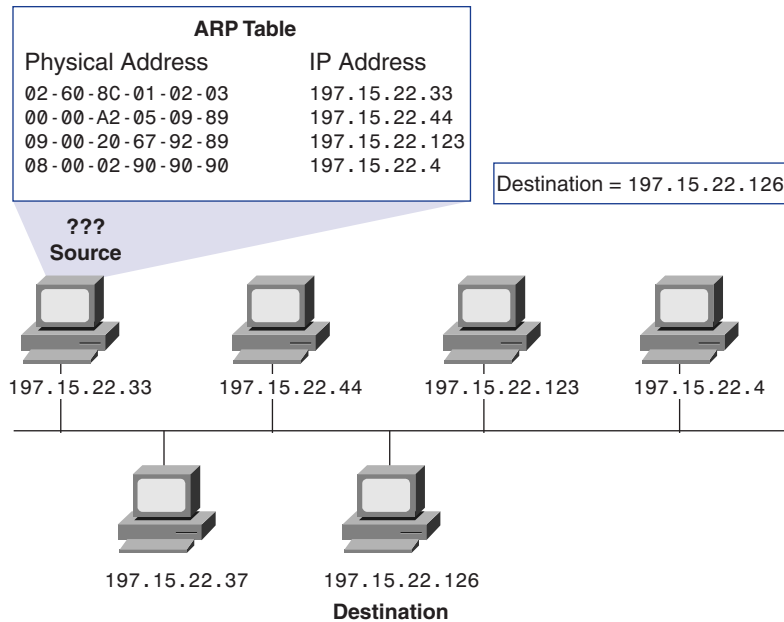
Internet Address	Physical Address	Type
68.2.168.1	00-50-57-00-76-84	Dynamic

Table 7-11 ARP Table for 198.150.11.36

MAC Address	IP Address
FE:ED:F9:44:45:66	198.150.11.34
DD:EC:BC:AB:04:AC	198.150.11.33
DD:EC:BC:00:94:D4	198.150.11.35
FE:ED:F9:23:44:EF	198.150.11.36

Whenever a network device wants to send data across a network, it uses information provided by its ARP table. In Figure 7-39, a source device wants to send data to another device.

Figure 7-39 ARP Tables



ARP Operation Within a Subnet

If a host wants to send data to another host, it must know the destination IP and MAC addresses. If it cannot locate a MAC address for the destination IP address in its ARP table, the host initiates a process called an ARP request, as shown in Figure 7-39.

An ARP request lets a host discover the destination MAC address. A host builds an ARP request packet and sends it to all devices on the network. This ARP request packet is divided into two parts:

- The frame header
- The ARP message

To ensure that all devices see the ARP request, the source uses a broadcast MAC address. The broadcast address in a MAC addressing scheme has all places set to hexadecimal F. Thus, a MAC broadcast address has the form FF-FF-FF-FF-FF-FF. Because ARP request packets travel in a broadcast mode, all devices on the local network receive the packets and pass them up to the network layer for further examination. If a device's IP address matches the destination IP address in the ARP request, that device responds by sending the source its MAC address. This is called the ARP reply.

When the originating device receives the ARP reply, it extracts the MAC address from the sender hardware address field and updates its ARP table. The originating device can

then properly address its data with both a destination MAC address and a destination IP address. It uses this new information to perform Layer 2 and Layer 3 encapsulations of the data before it sends them out over the network. When the data arrives at the destination, the data link layer makes a match, strips the MAC header, and transfers the data up to the network layer. The network layer examines the data and finds that its IP address matches the destination IP address carried in the IP header. The network layer strips the IP header and transfers the encapsulated data to the next-highest layer in the OSI model, the transport layer (Layer 4). This process is repeated until the rest of the packet's partially de-encapsulated data reaches the application, where the user data can be read.



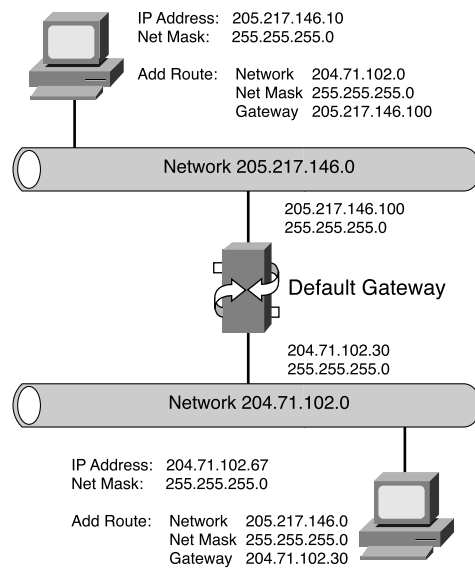
Lab Activity Address Resolution Protocol (ARP)

In this lab you use the workstation ARP table and the `arp -a` command to confirm that a computer is successfully resolving network (Layer 3) addresses to MAC (Layer 2) addresses.

Default Gateway

A default gateway is the IP address of the interface on the router that connects to the network segment on which the source host is located. The default gateway's IP address must be in the same network segment as the source host, as shown in Figure 7-40.

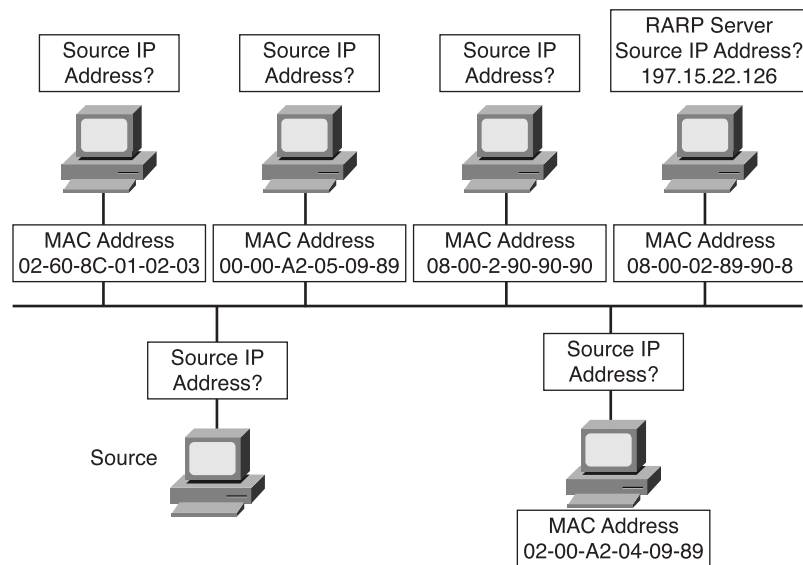
Figure 7-40 Default Gateway



RARP IP Address Assignment

Reverse Address Resolution Protocol (RARP) binds MAC addresses to IP addresses. This binding allows some network devices to encapsulate data before sending it out on the network. A network device or workstation might know its MAC address but not its IP address. Devices using RARP require that a RARP server be present on the network to answer RARP requests, as shown in Figure 7-41.

Figure 7-41 RARP IP Address Assignment



Consider an example in which a source device wants to send data to another device. The source knows the destination's MAC address but is unable to locate its IP address in the ARP table. For the destination device to retrieve the data, pass it to higher layers of the OSI model, and respond to the originating device, the source must include both its MAC address and IP address. Therefore, the source initiates a process called a RARP request, which helps it detect its own IP address. The device builds a RARP request packet, as shown in Figure 7-42, and sends it out on the network. To ensure that all devices see the RARP request on the network, the device uses a broadcast MAC address.

Figure 7-42 ARP/RARP Message Structure

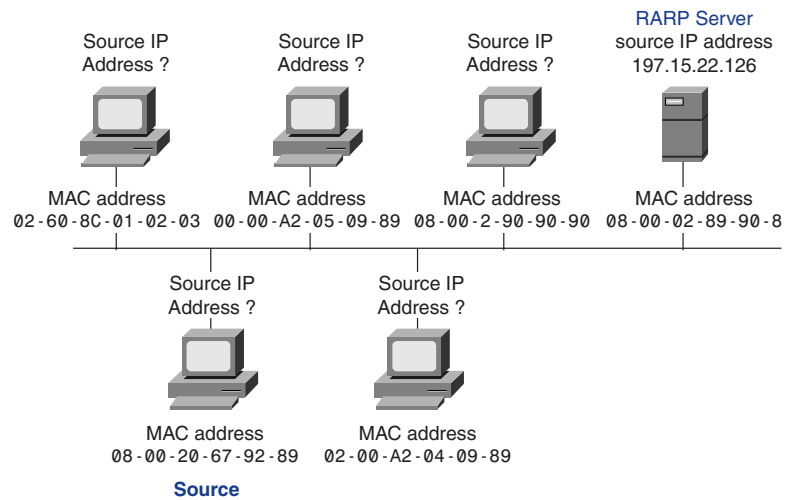
0-15 Bits		16-31 Bits
Hardware Type		Protocol Type
HLen (1 Byte)	PLen (1 Byte)	Operation
Sender HA (Bytes 1-4)		
Sender HA (Bytes 5-6)		Sender PA (Byte 1-2)
Sender PA (Byte 3-4)		Target HA (Byte 1-2)
Target HA (Bytes 3-6)		
Target PA (Bytes 1-4)		
<i>RARP Header Structure</i>		

The various parts of the RARP header structure are as follows:

- **Hardware type**—Specifies a hardware interface type for which the sender requires a response.
- **Protocol type**—Specifies the type of high-level protocol address the sender has supplied.
- **HLen**—Hardware address length
- **PLen**—Protocol address length
- **Operation**—Values are as follows:
 - 1: ARP request
 - 2: ARP response
 - 3: RARP request
 - 4: RARP request
 - 5: Dynamic RARP request
 - 6: Dynamic RARP reply
 - 7: Dynamic RARP error
 - 8: InARP request
 - 9: InARP reply
- **Sender (HA) hardware address**—HLen bytes in length
- **Sender (PA) protocol address**—PLen bytes in length
- **Target (HA) hardware address**—HLen bytes in length
- **Target (PA) protocol address**—PLen bytes in length

RARP uses the same packet format as ARP. But in a RARP request, the MAC headers and operation code are different from an ARP request. The RARP packet format contains places for MAC addresses of both destination and source. The source IP address field is empty. The broadcast goes to all devices on the network; therefore, the destination MAC address is set to all binary 1s. Workstations running RARP have codes in ROM that direct them to start the RARP process. Figure 7-43 shows the RARP process.

Figure 7-43 RARP Process



Bootstrap Protocol (BOOTP) IP Address Assignment

Like RARP, BOOTP operates in a client/server environment and requires only a single packet exchange to obtain IP information. However, unlike RARP, which sends back only a four-octet IP address, BOOTP packets can include the IP address as well as the address of a router (default gateway), the address of a server, and vendor-specific information, as shown in Figure 7-44.

One of the problems with BOOTP is that it was not designed to provide dynamic address assignment. With BOOTP, a network administrator creates a configuration file that specifies the parameters for each device. The administrator must add hosts and maintain the BOOTP database. Also, even though the addresses are dynamically assigned, there is still a one-to-one relationship between the number of IP addresses and the number of hosts. This means that for every host on the network, there must be a BOOTP profile with an IP address assignment. No two profiles can have the same IP address, because those profiles might be used at the same time, and that would mean that two hosts have the same IP address.

Figure 7-44 BOOTP Message Structure

0-7 Bits	8-15 Bits	16-24 Bits	25-31 Bits
Op (1)	Htype (1)	Hlen (1)	Hops (1)
Xid (4 Bytes)			
Seconds (2 Bytes)		Unused	
Ciaddr (4 Bytes)			
Yiaddr (4 Bytes)			
Siaddr (4 Bytes)			
Giaddr (4 Bytes)			
Chaddr (16 Bytes)			
Server Host Name (32 Bytes)			
Boot File Name (64 Bytes)			
Vendor Specific Area (32 Bytes)			
<i>BOOTP Message Structure</i>			

A device uses BOOTP when it starts up to obtain an IP address. BOOTP uses UDP to carry messages; the UDP message is encapsulated in an IP packet. A computer uses BOOTP to send a broadcast IP packet (using a destination IP address of all 1s—255.255.255.255—in dotted-decimal notation). A BOOTP server receives the broadcast and then sends back a broadcast. The client receives a frame and checks the MAC address. If it finds its own MAC address in the destination address field and a broadcast in the IP destination field, it takes and stores the IP address and other information supplied in the BOOTP reply message.

Dynamic Host Configuration Protocol (DHCP) IP Address Assignment

Dynamic Host Configuration Protocol (DHCP) is the successor to BOOTP. Unlike BOOTP, DHCP allows a host to obtain an IP address dynamically without the network administrator's having to set up an individual profile for that machine. All that is required for using DHCP is a defined range of IP addresses on a DHCP server. As hosts come online, they contact the DHCP server and request an address. The DHCP server chooses an address and leases it to that host. With DHCP, the entire computer's TCP/IP configuration can be obtained in one message. This includes all the data supplied by the BOOTP message, plus a leased IP address and subnet mask.

The major advance that DHCP makes over BOOTP is that it allows users to be mobile. This allows them to freely change network connections from location to location. There is no longer a requirement for a fixed profile for every device attached to the network as there is with the BOOTP system. The key to this DHCP advancement is its capability to lease an IP address to a device and then reclaim that IP address for another user after the first user releases it. This means that there is now a one-to-many ratio of IP addresses and that an address is available to anyone who connects to the network.

DHCP uses the same message format as BOOTP, as shown in Figure 7-45, with the following exceptions. The unused field in the BOOTP format now represents a Flags field. The most-significant bit is the only flag defined currently. It represents a broadcast message. DHCP and BOOTP also define the vendor-specific area, as follows:

- 1-byte Option field
- 1-byte Length field
- Variable-length (specified by the Length field) Option Data field

Figure 7-45 DHCP Message Structure

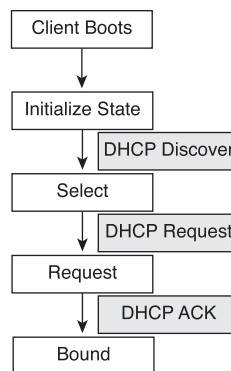
0-7 Bits	8-15 Bits	16-24 Bits	25-31 Bits
Op (1)	Htype (1)	Hlen (1)	Hops (1)
Xid (4 Bytes)			
Seconds (2 Bytes)		Flags (2 Bytes)	
Ciaddr (4 Bytes)			
Yiaddr (4 Bytes)			
Siaddr (4 Bytes)			
Giaddr (4 Bytes)			
Chaddr (16 Bytes)			
Server Host Name (32 Bytes)			
Boot File Name (64 Bytes)			
Vendor Specific Area (32 Bytes)			
<i>DHCP Message Structure</i>			

For DHCP message types, the values for the fields are as follows:

- 53 for the Option field, indicating a DHCP message
- 1 for the Length field, indicating that the Data field is 1 byte long

When a DHCP client boots, it enters an initialize state. It sends DHCPDISCOVER broadcast messages, which are UDP packets with the port number set to the BOOTP port. After sending the DHCPDISCOVER packets, the client moves into the select state and collects DHCP OFFER responses from DHCP servers. The client then selects the first response it receives and negotiates the lease time (how long it can keep the address without renewing it) with the DHCP server by sending a DHCPREQUEST packet. Next, the DHCP server acknowledges a client request with a DHCPACK packet. The client can now enter the bound state and begin using the address. Figure 7-46 summarizes the DHCP state.

Figure 7-46 DHCP Startup States



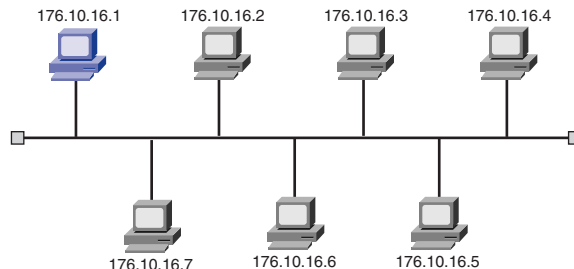
Lab Activity DHCP Client Setup

In this lab, you set up a networked computer as a DHCP client to use DHCP services.

Problems in Address Resolution

One of the major problems in networking is how to communicate with other network devices. In TCP/IP communications, a datagram on a LAN must contain both a destination MAC address and a destination IP address. In Figure 7-47, computer 176.10.16.1 wants to send data to 176.10.16.4. It has its IP address, but data transmission requires both the IP and MAC address of 176.10.16.4. How does it get that MAC address to perform the data transmission?

Figure 7-47 Address Resolution Issues



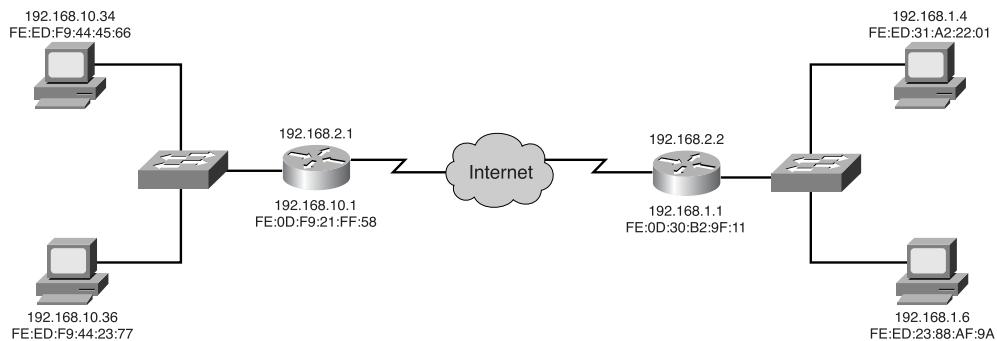
These addresses must be correct and match the destination host's MAC and IP addresses, or the destination host discards them. So on LANs there must be a way to automatically resolve (or translate) IP addresses to MAC addresses. Doing the resolution manually would be much too rigid and time-consuming for the user. This solution covers only LAN issues; a different set of issues are raised when data is sent outside the LAN.

There are two parts to the problem in communicating with devices that are not on the same physical network segment:

- Obtaining the MAC address of the intermediate devices
- Transferring the data packets from one network segment to another to get to the destination host

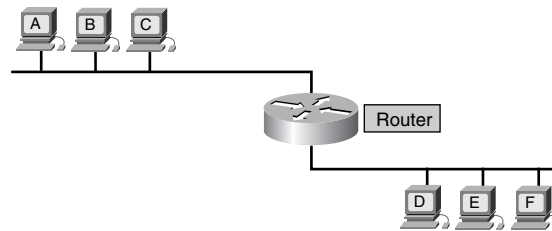
Figure 7-48 illustrates this problem with an example. Computer 192.168.10.34 needs to communicate with computer 192.168.1.1. How does it get the MAC address for 192.168.1.1, and would it do any good if it *could* get the MAC address? Remember that MAC addresses are useful only in LANs. They won't be any help outside the 192.168.10.0 network. So you need the router's MAC address to get the data out of the LAN and on to the WAN system.

Figure 7-48 Remote Address Resolution Issues



Routers running proxy ARP capture ARP packets. They respond with their MAC addresses for those requests in which the IP address is not in the range of addresses of the local subnet. For example, in Figure 7-49, if Machine A sends an ARP request to Machine F, the router processes the request and replies to A with its own MAC address to be mapped to the IP address of Machine F. In the previous description of how data is sent to a host on a different subnet, the default gateway is configured. If the source host does not have a default gateway configured, it sends an ARP request. All hosts on the segment, including the router, receive the ARP request. The router compares the IP destination address with the IP subnet address to determine whether the destination IP address is on the same subnet as the source host. If the subnet address is the same, the router discards the packet. The packet is discarded because the destination IP address is on the same segment as the source's IP address. This means that the destination device on the segment should respond to the ARP request. The exception to this is that the destination IP address is not currently assigned, which generates an error response on the source host.

Figure 7-49 Proxy ARP Network Example



Summary

In this chapter, you learned the following key points:

- To provide extra flexibility for the network administrator, networks—particularly large ones—are often divided into smaller networks called subnetworks or subnets. Subnetting allows a network administrator to get around IPv4's limitations by dividing a single network address into many subnets visible only within that single network.
- The function of a subnet mask is to tell devices which part of an address is the network number, including the subnet, and which part is the host.
- Internetworking functions of the network layer include network addressing and best-path selection for data traffic.

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- How to explain IP addressing, IP address classes, reserved IP address space, private IP address space, and IP subnetting
- How to explain the evolution of IP addressing, including the need for an increase in the size of the IP address space
- A computer needs an IP address (hierarchical address) to communicate on the Internet.
- There are two ways to configure IP addresses: statically and dynamically.
- There are multiple ways to assign an IP address dynamically.
- When a device does not know its own IP address, it uses RARP, BOOTP, or DHCP.
- When the device that originated a RARP request receives a RARP reply, it copies its IP address into its memory cache, where it resides for as long as the session lasts.
- BOOTP supplies more information to a client than just an IP address.
- DHCP allows computers to be mobile, connecting to many different networks as needed.

To supplement all you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab Activities on the CD-ROM accompanying this book.

Key Terms

application layer Handles high-level protocols and issues of representation, encoding, and dialog control. The TCP/IP protocol suite combines all application-related issues into one layer and ensures that this data is properly packaged for the next layer.

broadcast address Used to broadcast packets to all the devices on a network.

Class A address Designed to support extremely large networks. A Class A IP address uses only the first octet to indicate the network address. The remaining three octets enumerate host addresses.

Class B address Designed to support the needs of moderate- to large-sized networks. A Class B IP address uses two of the four octets to indicate the network address. The other two octets specify host addresses.

Class C address The most commonly used of the original address classes. This address space was intended to support a lot of small networks.

Class D address Created to enable multicasting in an IP address.

Class E address The IETF reserves these addresses for its own research. Therefore, no Class E addresses have been released for use in the Internet.

dotted-decimal format In this notation, each IP address is written as four parts separated by periods, or dots.

IP address class A 32-bit IP address is broken into a network part and a host part. A bit or bit sequence at the start of each address determines the address's class.

IP Version 6 (IPv6) The replacement for the current version of IP (Version 4). IPv6 includes support for flow ID in the packet header, which can be used to identify flows. Formerly called IPng (IP next generation).

multicast address A unique network address that directs packets that have that destination address to predefined groups of IP addresses.

network access layer The layer that is concerned with all the issues that an IP packet requires to make a physical link to the network medium.

subnetting The method of dividing full network address classes into smaller pieces. This has prevented complete IP address exhaustion.

Transmission Control Protocol/Internet Protocol (TCP/IP) The common name for the suite of protocols developed by the U.S. DoD in the 1970s to support the construction of worldwide internetworks. TCP and IP are the two best-known protocols in the suite.

transport layer Provides transport services from the source host to the destination host. It constitutes a logical connection between the network's endpoints: the sending host and the receiving host.

Review Questions

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, "Check Your Understanding Answer Key."

1. What transport layer protocol does TFTP use?
 - A. TCP
 - B. IP
 - C. UDP
 - D. CFTP
2. Which of the following is a basic service of the transport layer?
 - A. Provides reliability by using sequence numbers and acknowledgments
 - B. Segments upper-layer application data
 - C. Establishes end-to-end operations
 - D. All of the above
3. Which of the following protocols operate at the TCP/IP Internet layer?
 - A. IP
 - B. ICMP
 - C. ARP
 - D. All of the above
4. What is the first thing that happens when a DHCP client boots?
 - A. DHCPREQUEST
 - B. DHCPBOOT
 - C. DHCPDISCOVER
 - D. None of the above

5. How does the network layer forward packets from the source to the destination?
 - A. By using a routing table
 - B. By using ARP responses
 - C. By referring to a name server
 - D. By referring to the bridge
6. If a device doesn't know the MAC address of a device on an adjacent network, it sends an ARP request to what?
 - A. The default gateway
 - B. The closest router
 - C. The router interface
 - D. All of the above
7. What is in a RARP request?
 - A. A MAC header and the RARP request message
 - B. A MAC header, a RARP header, and a data packet
 - C. A RARP header and MAC and IP addresses
 - D. A RARP header and an ARP trailer
8. What are the two parts of an IP address?
 - A. Network address and host address
 - B. Network address and MAC address
 - C. Host address and MAC address
 - D. MAC address and subnet mask
9. What Internet protocol is used to map a known IP address to an unknown MAC address?
 - A. UDP
 - B. ICMP
 - C. ARP
 - D. RARP
10. Which of the following initiates an ARP request?
 - A. A device that can locate the destination IP address in its ARP table
 - B. The RARP server in response to a malfunctioning device
 - C. A diskless workstation with an empty cache
 - D. A device that cannot locate the destination MAC address in its ARP table

11. Which of the following best describes an ARP table?
 - A. A way to reduce network traffic by providing lists of shortcuts and routes to common destinations
 - B. A way to route data within networks that are divided into subnetworks
 - C. A protocol that performs an application layer conversion of information from one stack to another
 - D. A section of RAM on each device that maps IP addresses to MAC addresses
12. Which of the following best describes the ARP reply?
 - A. A device sends its MAC address to a source in response to an ARP request
 - B. The shortest path between the source and the destination
 - C. The updating of ARP tables through intercepting and reading messages traveling on the network
 - D. The method of finding IP addresses based on the MAC address, used primarily by RARP servers
13. Why are current, updated ARP tables important?
 - A. For testing links in the network
 - B. For limiting the number of broadcasts
 - C. For reducing network administrator maintenance time
 - D. For resolving addressing conflicts
14. Why is a RARP request made?
 - A. A source knows its MAC address but not its IP address.
 - B. The data packet needs to find the shortest route between the destination and the source.
 - C. The administrator needs to manually configure the system.
 - D. A link in the network faults, and a redundant system must be activated.
15. Which of the following best describes TCP/IP?
 - A. It is a suite of protocols that can be used to communicate across any set of interconnected networks.
 - B. It is a suite of protocols that allows LANs to connect to WANs.
 - C. It is a suite of protocols that allows for data transmission across a multitude of networks.
 - D. It is a suite of protocols that allows different devices to be shared by interconnected networks.

16. Which of the following does not describe the TCP/IP protocol stack?
- A. It maps closely to the OSI reference model's upper layers.
 - B. It supports all standard physical and data link protocols.
 - C. It transfers information in a sequence of datagrams.
 - D. It reassembles datagrams into complete messages at the receiving location.
17. The TCP/IP protocol suite has specifications for which layers of the OSI model?
- A. 1 through 3
 - B. 1 through 4 and 7
 - C. 3, 4, and 5 through 7
 - D. 1, 3, and 4
18. Which of the following is not a function of the network layer?
- A. RARP determines network addresses when data link layer addresses are known.
 - B. ICMP provides control and messaging capabilities.
 - C. ARP determines the data link layer address for known IP addresses.
 - D. UDP provides connectionless exchange of datagrams without acknowledgments.
19. Which of the following is one of the protocols found at the transport layer?
- A. UCP
 - B. UDP
 - C. TDP
 - D. TDC



Objectives

Upon completion of this chapter, you will be able to

- Describe the purpose of routable/routed protocols such as IP
- Understand the function of IP as a connectionless versus connection-oriented networking service
- Explain how routers operate at the network layer
- Describe how routed protocols define the format and use of the fields in a packet
- Compare OSI Layer 2 LAN switching to Layer 3 routing
- Explain how routing protocols are used between routers to determine paths and maintain routing tables
- Explain how routers accomplish path selection and switching functions to transport packets through an internetwork
- Describe the differences between static and dynamic routing
- Describe the differences between distance-vector and link-state routing protocols, including convergence
- Describe the differences between interior and exterior routing protocols, and cite examples of each
- Understand the purpose and benefits of subnetting
- Create subnets using the subnet mask based on requirements
- Calculate the resident network through the ANDing process

Chapter 8

Routing Fundamentals and Subnets

This chapter covers topics related to the Internet Protocol (IP). IP is the fundamental protocol used in the Internet. Topics discussed include how IP is delivered, how the header is modified at Layer 3 devices, and the actual layout of the IP packet. This chapter also covers the relationship between connectionless and connection-oriented networking services. You will learn the difference between routing and routed protocols and how routers track distance between locations. This chapter introduces the distance-vector, link-state, and hybrid routing approaches and how each resolves common routing problems.

Be sure to look at this chapter's associated e-Lab Activities, Videos, and PhotoZooms, which you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

Routed, Routable, and Routing Protocols

A protocol is a standards-based set of rules that determines how computers communicate with each other across networks. A protocol also serves as the common denominator or medium by which different applications, hosts, or systems communicate. When computers communicate with one another, they exchange data messages. To accept and act on these messages, computers must have definitions of how a message is defined and what it means. Examples of messages include establishing a connection to a remote machine, sending or receiving e-mail, and transferring files and data.

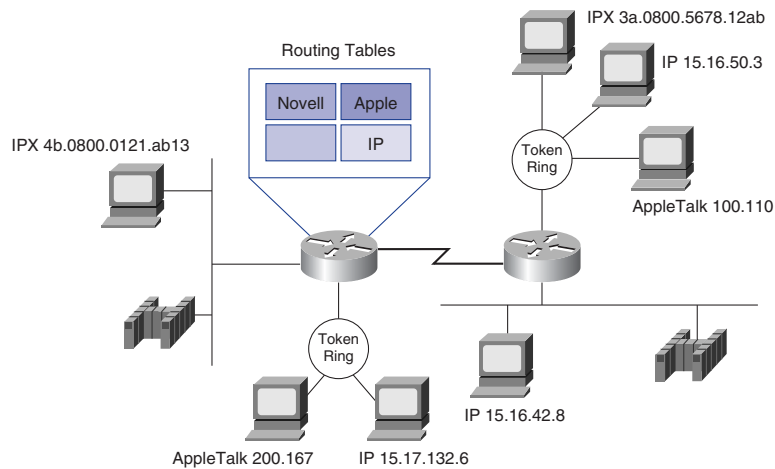
A protocol describes

- The format that a message must take
- The way in which computers must exchange a message within the context of a particular activity, such as sending messages across networks

Because of the similarity of a routed/routable protocol versus a routing protocol, confusion over these terms often exists. The following provides some clarification:

- **Routed protocol**—Any network protocol that provides enough information in its network layer address to allow a packet to be forwarded from one host to another host based on the addressing scheme. Routed protocols define the field formats within a *packet*. Packets are generally conveyed from end system to end system. A routed protocol uses the routing table to forward packets. Examples of routed or routable protocols are shown in the routing table in Figure 8-1. They include the following:
 - Internet Protocol (IP)
 - Internetwork Packet Exchange (IPX)
 - AppleTalk

Figure 8-1 Routed/Routable Protocols



- **Routing protocol**—Supports a routed protocol by providing mechanisms for sharing routing information. Routing protocol messages move between the routers. A routing protocol allows the routers to communicate with other routers to update and maintain tables. Here are some TCP/IP examples of routing protocols:
 - Routing Information Protocol (RIP)
 - Interior Gateway Routing Protocol (IGRP)
 - Enhanced Interior Gateway Routing Protocol (EIGRP)
 - Open Shortest Path First (OSPF)

For a protocol to be routable, it must provide the capability to assign a network number, as well as a host number, to each individual device. Some protocols, such as Internet Network Packet Exchange (IPX), only require that an administrator assign a network number, because they use a host's Media Access Control (MAC) address for the physical number. Other protocols, such as IP, require that a complete address be provided, as well as a network mask.

Both the **IP address** and network mask are required to have a routed network. A network mask separates the network and host portions of a 32-bit IP address. IPX uses the MAC address concatenated with an administrator-assigned network address to create the complete address and does not use a network mask. With IP addresses, the network address is obtained by comparing the address with the network mask.

A network mask allows groups of sequential IP addresses to be treated as a single unit. If this grouping were not allowed, each host would have to be mapped individually for routing. That would not be possible with the millions of hosts on the Internet. As shown in Figure 8-2, all 254 addresses in the sequence of 192.168.10.1 to 192.168.10.254 can be represented by the network address 192.168.10.0. This allows data to be sent to any one of these hosts just by locating the network address. This means that routing tables need to contain only one entry of 192.168.10.0 instead of all 254 individual entries. This is according to the Internet Software Consortium (www.isc.org). For routing to function, this process of grouping must be used.

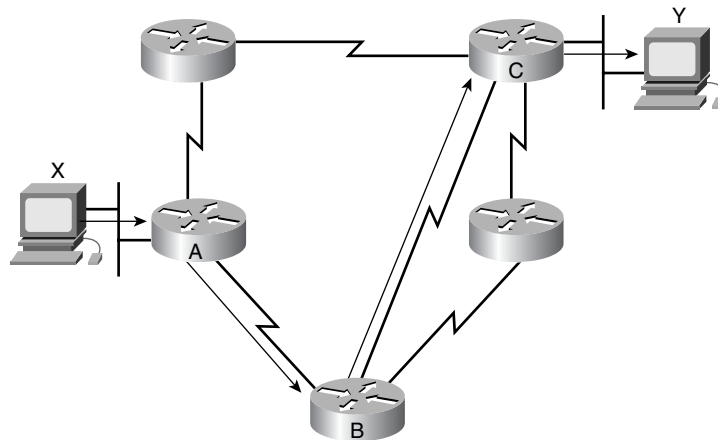
The following sections describe the router's use and operations in performing the key internetworking function of the Open System Interconnection (OSI) reference model's network layer, Layer 3. In addition, you'll learn about the difference between routing and routed protocols and how routers track distance between locations. Finally, you'll learn more about distance-vector, link-state, and hybrid routing approaches and how each resolves common routing problems.

Figure 8-2 Network and Host Addresses

Host Addresses	Network Address
192.168.10.1	192.168.10.0
192.168.10.2	
192.168.10.3	
192.168.10.4	
192.168.10.5	
192.168.10.6	
192.168.10.7	
•	
•	
192.168.10.250	
192.168.10.251	
192.168.10.252	
192.168.10.253	
192.168.10.254	

Routing Overview

Routing is an OSI Layer 3 function. It functions as a hierarchical organizational scheme that allows individual addresses to be grouped and treated as a single unit until the individual address is needed for final delivery of the data. Routing is the process of finding the most efficient path from one device to another, as shown in Figure 8-3. The main device that performs this process is the *router*.

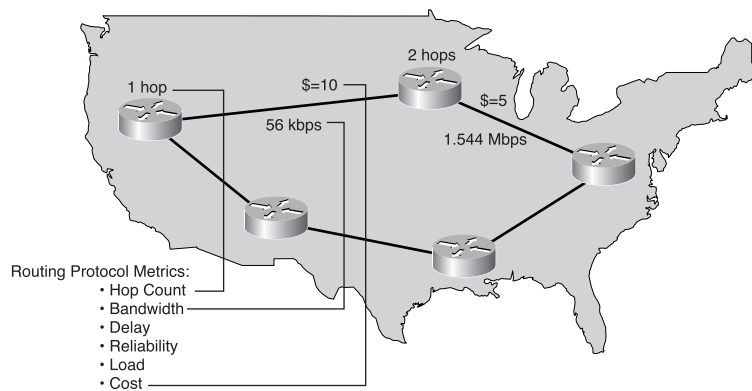
Figure 8-3 Network Layer Protocol Operation

A router has two key functions:

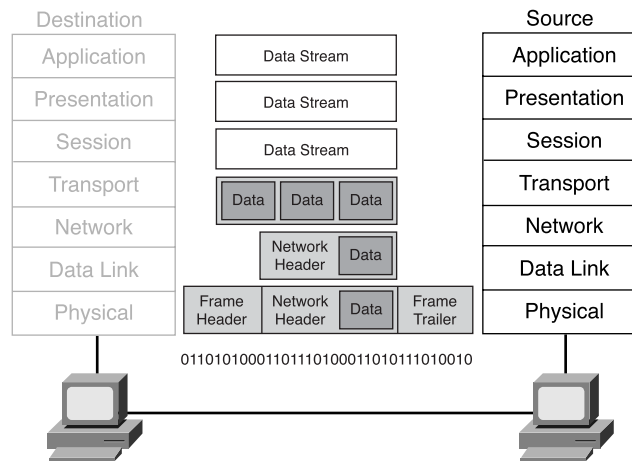
- To maintain routing tables and make sure other routers know of changes in the network topology. This function is performed using a routing protocol to communicate network information to other routers.
- When packets arrive at an interface, the router must use the routing table to determine where to send the packets. It switches them to the appropriate interface, adds the necessary framing for the interface, and then transmits the frame.

A router is a network layer device that uses one or more *routing metrics* to determine the optimal path along which network traffic should be forwarded. The routing metric is a value used to determine the route's desirability. Routing protocols use various combinations of criteria for determining the routing metric, as shown in Figure 8-4.

Figure 8-4 Routing Protocol Metrics



The metrics of hop count, bandwidth, delay, reliability, load, and cost are calculated in various combinations to determine the best path through an internetwork. Routers interconnect network segments or entire networks. They pass data frames between networks based on Layer 3 information. Routers make logical decisions regarding the best path for the delivery of data on an internetwork and then direct packets to the appropriate output port to be encapsulated for transmission. The encapsulation/de-encapsulation process occurs each time a packet passes through a router and data is sent from one device to another, as shown in Figure 8-5. Encapsulation breaks the data stream into segments, adds the appropriate headers and trailers, and transmits the data. The de-encapsulation process is the opposite, removing the headers and trailers and then recombining the data into a seamless stream. Routers take frames from LAN devices (for example, workstations) and, based on Layer 3 information, forward them through the network.

Figure 8-5 Data Encapsulation

This chapter and the rest of the book focus on the most commonly used routable (or routed) protocol—IP. Even though the focus is on IP, it is important to know that there are other routable protocols, such as IPX/SPX and AppleTalk.

Protocols such as IP, IPX/SPX, and AppleTalk provide Layer 3 support and therefore are routable. Protocols that do not support Layer 3 are called nonroutable protocols. The most common of these is *NetBIOS Extended User Interface (NetBEUI)*—a small, fast, efficient protocol that is limited to running on one segment.

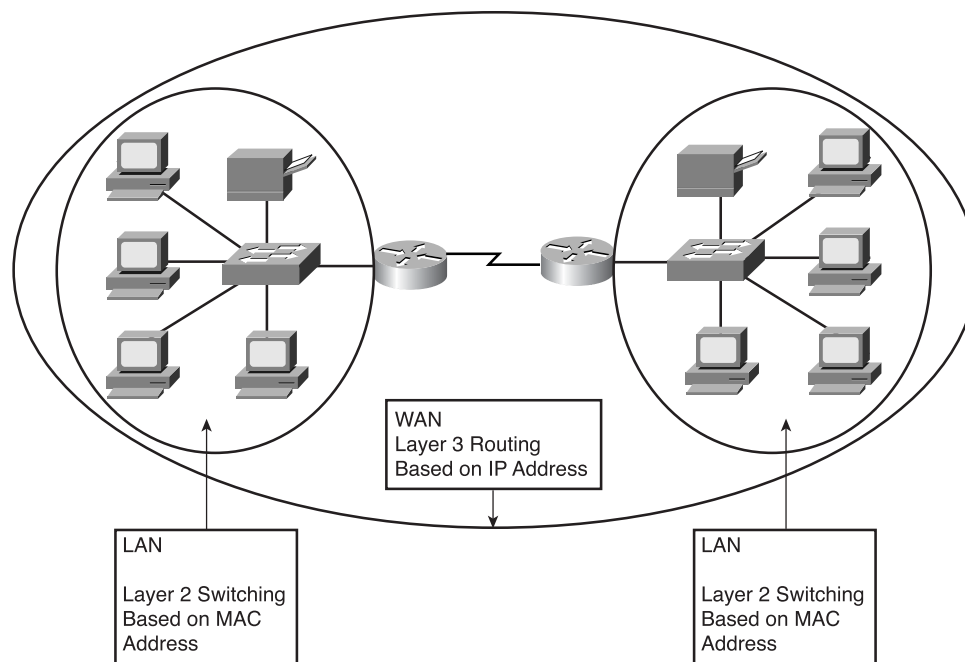
Routing Versus Switching

Routing is often contrasted with Layer 2 switching, which might seem to perform the same function to the casual observer. The primary difference between the two is that switching occurs at Layer 2 (the data link layer) of the OSI model, and routing occurs at Layer 3. This distinction means that routing and switching use different information in the process of moving data from source to destination.

The relationship between switching and routing parallels that of local and long distance telephone calls. When a telephone call is made to another local number (a number with the same area code), a local switch handles the call. However, the local switch cannot keep track of all the telephone numbers in the world—only its own local numbers. When the switch receives a request for a call outside its area, it switches the call to a higher-level switch that recognizes area codes. The higher-level switch switches the call so that it eventually gets to the local switch for the area code dialed.

The router performs a function similar to that of the higher-level switch in the telephone network, as shown in Figure 8-6. Layer 2 switching takes place within the LAN, also called a *broadcast domain*. Layer 3 routing moves traffic between broadcast domains. This requires the hierarchical addressing scheme that a Layer 3 addressing scheme like IP provides. The Layer 2 switch cannot recognize the Layer 3 IP address—only local MAC addresses. When a host has data for a nonlocal IP address, it sends the frame to its default gateway, the router, by using the router's MAC address.

Figure 8-6 Layer 2 Switching and Layer 3 Routing

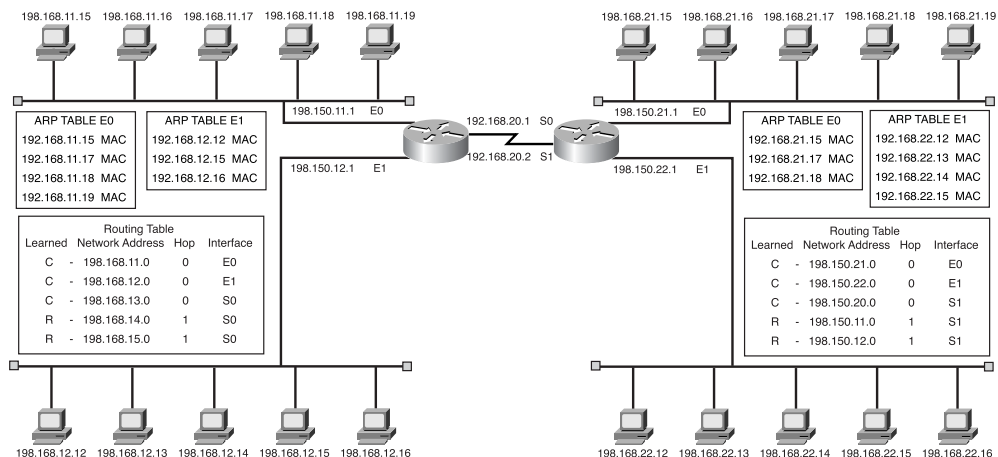


A Layer 2 switch interconnects segments belonging to the same logical network or *subnetwork*. If Host X needs to send a frame to another host on a different network or subnetwork, Host X sends the frame to the router that is also connected to the switch. Host X knows the router IP address because the Host IP configuration includes the IP address of the default gateway, but it does not know its MAC address. Host X learns the router's MAC address by using an Address Resolution Protocol (ARP) request, which translates IP addresses to MAC addresses. The switch forwards the frame to the router based on the router's destination MAC address. The router examines the packet's Layer 3 destination address to make the forwarding decision. The default gateway is the router that is on the same network or subnetwork as Host X.

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Much like the way a Layer 2 switch keeps a table of known MAC addresses, the router keeps a table of IP network addresses called a *routing table*, as shown in Figure 8-7. Each computer and router Ethernet interface maintains an ARP table for Layer 2 communication. The ARP table is effective only for the broadcast domain that it is connected to. The router also maintains a routing table that allows it to route data outside the broadcast domains. Each ARP table contains the IP-MAC address pair. (The MAC address in Figure 8-7 is represented by the acronym MAC because the actual addresses are too long to fit in the figure.) The routing tables show how the route was learned—in this case, directly connected (C) and RIP (R)—the network IP address for reachable networks, the hop count to get those networks, and the interface the data must be sent out to get to the destination network. The difference between these two types of addresses is that the MAC address is not organized in any particular way. This is OK, though, because any individual network segment does not have a large number of hosts, so it is manageable. If the IP network addresses were treated the same way, the Internet simply would not work. There would be no way to organize all the addresses and the directions on how to get to them (hierarchically or otherwise). Organizing IP addresses hierarchically lets you group addresses to be treated as a single unit until you need to locate an individual host. A way to understand this is to think of a library that contains only millions of individual pages in a large pile. This material is useless, because it is impossible to locate an individual document. If the pages were organized into books, and each page were individually identified, and if the books were listed in an index, it would be much easier to find and use the data.

Figure 8-7 Router ARP Tables



Another difference between switched and routed networks is that Layer 2 switched networks do not block Layer 3 broadcasts. As a result, they can be swamped by broadcast storms. Routers normally block broadcasts so that a broadcast storm affects only the broadcast domain it originated on. Routers also provide higher security and bandwidth control than Layer 2 switches because they block broadcasts.

Table 8-1 compares routers and switches.

Table 8-1 Router and Switch Feature Comparison

Feature	Router	Switch
Speed	Slower	Faster
OSI layer	Layer 3	Layer 2
Addressing used	IP	MAC
Broadcasts	Blocks	Forwards
Security	Higher	Lower
Segment networks	Segment broadcast domains	Segment collision domains

Routed Versus Routing

There are two categories of protocols at the network layer—routed and routing (see Figure 8-8). Routed protocols transport data across a network, and routing protocols allow routers to properly direct the data from one location to another.

Protocols that transfer data from one host to another across a router are routed or routable protocols.

A routed protocol operates as shown in Figure 8-9:

- It includes any network protocol suite that provides enough information in its network layer address to allow a router to forward it to the next device and ultimately to its destination.
- It defines the format and use of the fields within a packet. Packets generally are conveyed from end system to end system.

IP and IPX are examples of routed protocols. Other examples include DECnet, AppleTalk, Banyan VINES, and Xerox Network Systems (XNS).

Routers use routing protocols to exchange routing tables and share routing information. In other words, *routing* protocols let routers route *routed* protocols after a path has been determined.

Figure 8-8 Routed and Routing Protocols

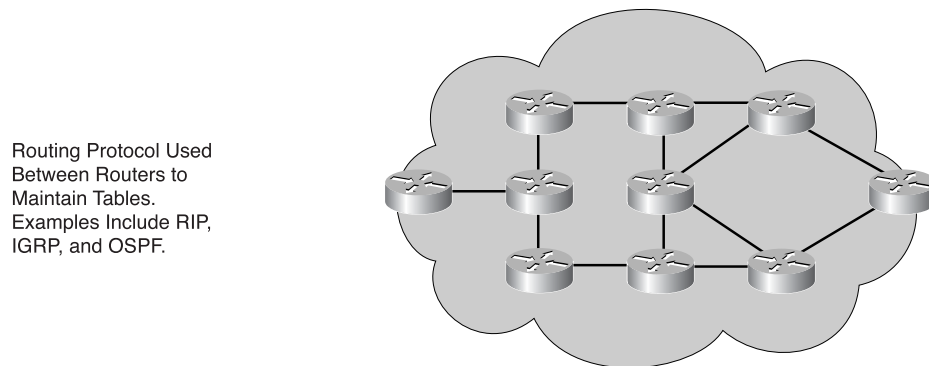
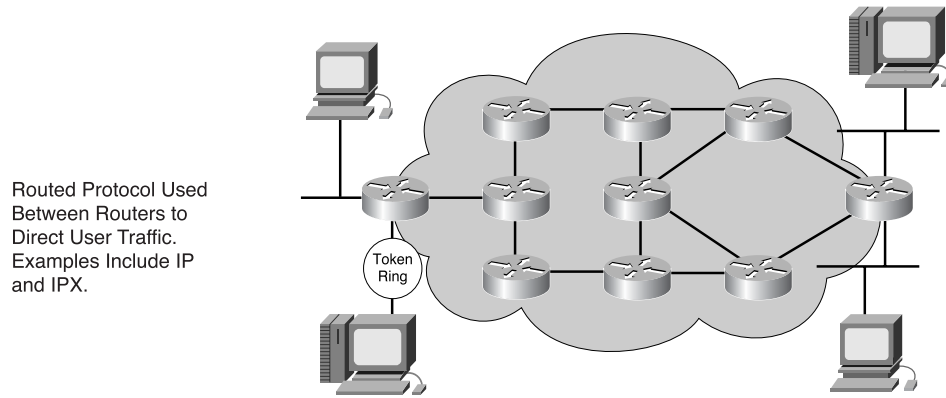
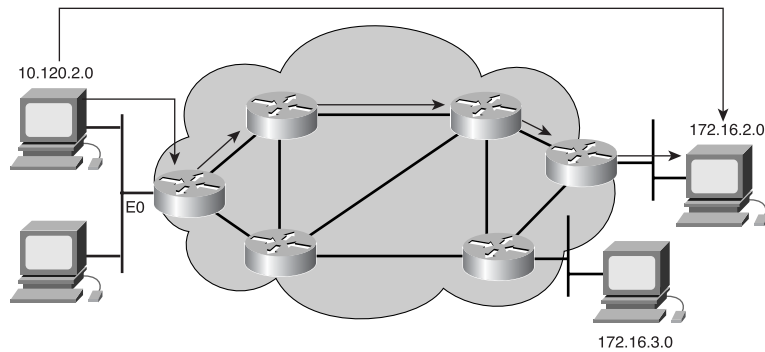


Figure 8-9 Routed Protocol

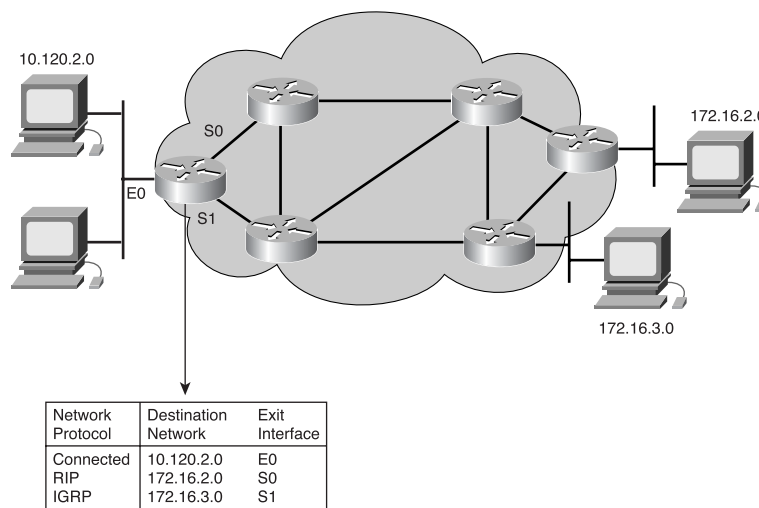


A routing protocol operates as shown in Figure 8-10:

- It provides processes for sharing routing information.
- It allows routers to communicate with other routers to update and maintain the routing tables.

Examples of routing protocols that support IP routed protocols include RIP, IGRP, OSPF, Border Gateway Protocol (BGP), and EIGRP.

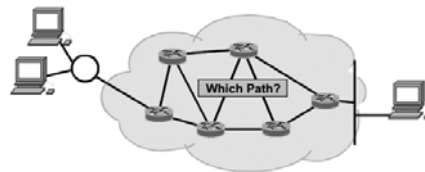
Figure 8-10 Routing Protocol



Path Determination

Path determination occurs at Layer 3 (the network layer). It lets a router evaluate the available paths to a destination and establish the preferred handling of a packet. Routing services use network topology information when evaluating network paths, as shown in Figure 8-11. Path determination is the process that a router uses to choose the next hop in a path toward a packet's ultimate destination. This process is also called *routing* the packet.

Figure 8-11 Choosing a Path



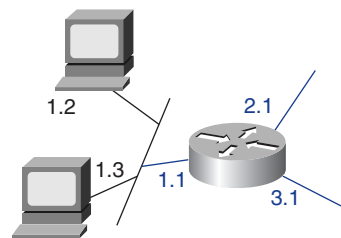
Path determination for a packet can be compared to a person driving a car from one side of a city to another. The driver has a map that shows the streets to take to get to the destination. The drive from one intersection to another is a *hop*. Similarly, a router uses a map that shows the available paths to a destination. Routers can also make their decisions based on the traffic density and the link's speed (bandwidth), just as a driver might choose a faster path (a highway) or use less-crowded back streets. In this section, you'll see how a router determines the best path for packets traveling from one network to another.

Network Layer Addressing

A network address helps the router identify a path within the network cloud and also provides hierarchical or subnet information. The router uses the network address to identify the destination network of a packet within an internetwork. In addition to the network address, network protocols use some form of host, or node, address. For some network layer protocols, a network administrator assigns host addresses according to some predetermined network addressing plan. For other network layer protocols, assigning host addresses is partially or completely dynamic or automatic. Figure 8-12 shows three devices in Network 1 (two workstations and a router), each with its own unique host address. (The figure also shows that the router is connected to two other networks—networks 2 and 3.)

Figure 8-12 Network Addresses

Network	Host
1	1 2 3
2	1
3	1



Logical addressing occurs at the network layer. Recall the analogy that compares network addresses to telephone numbers. The first portions of a phone number are the area code and the first three digits. The last four digits of a phone number tell the phone company equipment which specific phone to ring. This is similar to the function of the host portion of an address. The host portion tells the router the specific device to which it should deliver a packet.

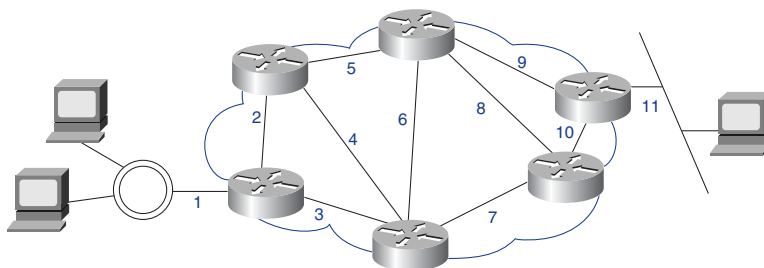
Without network layer addressing, routing cannot take place. Routers require network addresses to ensure proper delivery of packets. Without some hierarchical addressing structure, packets could not travel across an internetwork. Similarly, without some hierarchical structure to telephone numbers, postal addresses, or transportation systems, there would be no smooth delivery of goods and services.

A *MAC address* can be compared to your name, and a network layer address can be compared to your mailing address (network and host address). For example, if you were to move to another town, your name would remain unchanged, but your mailing address would indicate your new location. Network devices (routers as well as individual computers) have both a MAC address and a protocol (network layer) address. When you move a computer to a different network, the computer maintains the same MAC address, but you must assign it a new network layer address.

The Communication Path

The function of the network layer is to find the best path through the network. To be truly practical, a network must consistently represent the paths available between routers. As Figure 8-13 shows, each line between the routers has a number that the routers use as a network address. These addresses must convey information that can be used by a routing process. This means that an address must have information about the path of media connections that the routing process uses to pass packets from a source toward a destination.

Figure 8-13 Network Media Connections

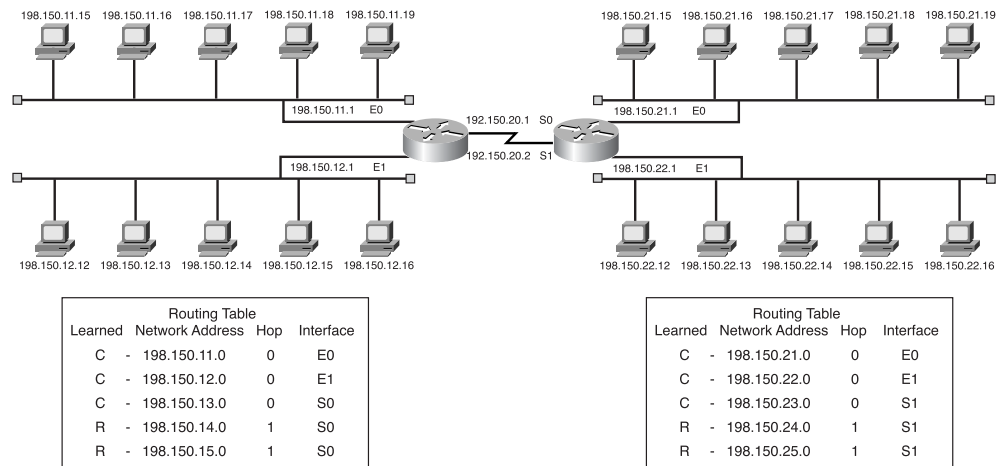


Using these addresses, the network layer can provide a relay connection that interconnects independent networks. The consistency of Layer 3 addresses across the entire internetwork also improves the use of bandwidth by preventing unnecessary broadcasts. *Broadcasts* invoke unnecessary process overhead and waste capacity on any devices or links that do not need to receive the broadcast. By using consistent end-to-end addressing to represent the path of media connections, the network layer can find a path to the destination without unnecessarily burdening the devices or links on the internetwork with broadcasts.

Routing Tables

To aid in the process of path determination, routing protocols build and maintain routing tables, which contain route information, as shown in Figure 8-14. Route information varies, depending on the routing protocol used. Routing protocols fill routing tables with a variety of information.

Figure 8-14 Routing Tables



Routers keep track of important information in their routing tables:

- **Protocol type**—The type of routing protocol that created the routing table entry.
- **Destination/next-hop associations**—Tell a router that a particular destination is either directly connected to the router or that it can be reached via another router called the *next hop* on the way to the final destination. When a router receives an incoming packet, it checks the destination address and attempts to match it with a routing table entry.

- **Routing metrics**—Different routing protocols use different routing metrics. Routing metrics are used to determine a route's desirability. For example, RIP uses *hop count* as its routing metric. IGRP uses bandwidth, load, delay, and reliability to create a composite metric value. This is covered in more depth in CCNA2.
- **Outbound interface**—The interface that the data must be sent out to reach the final destination.

Routers communicate with one another to maintain their routing tables through the transmission of routing update messages. Depending on the particular routing protocol, routing update messages can be sent periodically or only when there is a change in the network topology. The routing protocol also determines whether just the changed routes or the entire routing table is sent in the routing update. By analyzing the routing updates from the neighboring routers, a router can build and maintain its routing table.

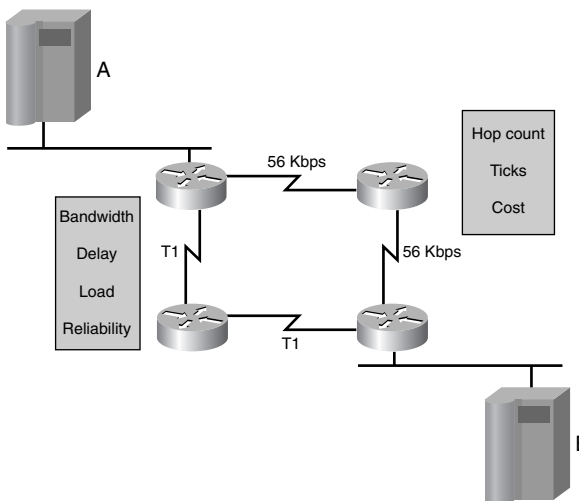
Routing Algorithms and Metrics

Routing protocols often have one or more of the following design goals:

- **Optimization**—Optimization describes the capability of the routing protocol/algorithm to select the best route, depending on metrics and metric weightings used in the calculation. For example, one algorithm might use hop count and delay for its metric but might weigh delay more heavily in the calculation.
- **Simplicity and low overhead**—Ideally efficient routing algorithm functionality is achieved if the routers have minimum CPU and memory overhead. This is important so that the network can scale to large proportions, such as the Internet.
- **Robustness and stability**—A routing algorithm should perform correctly in the face of unusual or unforeseen circumstances, such as hardware failures, high load conditions, and implementation errors.
- **Rapid convergence**—Convergence is the process of all routers agreeing on routes. When a network event causes changes in router availability, recalculations are needed to reestablish network connectivity. Routing algorithms that converge slowly can cause data to not be delivered.
- **Flexibility**—A routing algorithm should quickly adapt to a variety of network changes. These changes include router availability, changes in bandwidth, queue size, and network delay.
- **Scalability**—Some routing protocols are better designed for scalability than others. It is important to keep in mind that if the network is intended to grow (or even if this option is to be left open), a routing protocol such as EIGRP rather than RIP should be used.

When a routing *algorithm* updates a routing table, its primary objective is to determine the best information to include in the table. Routing algorithms use different metrics to determine the best route. Each routing algorithm interprets what is best in its own way. The routing algorithm generates a number, called the metric value, for each path through the network. Sophisticated routing algorithms can base route selection on multiple metrics, combining them in a single composite metric, as shown in Figure 8-15. Typically, the smaller the metric, the better the path.

Figure 8-15 Routing Metrics



Metrics can be based on a single characteristic of a path or can be calculated based on several characteristics. The metrics that are most commonly used by routing protocols are as follows:

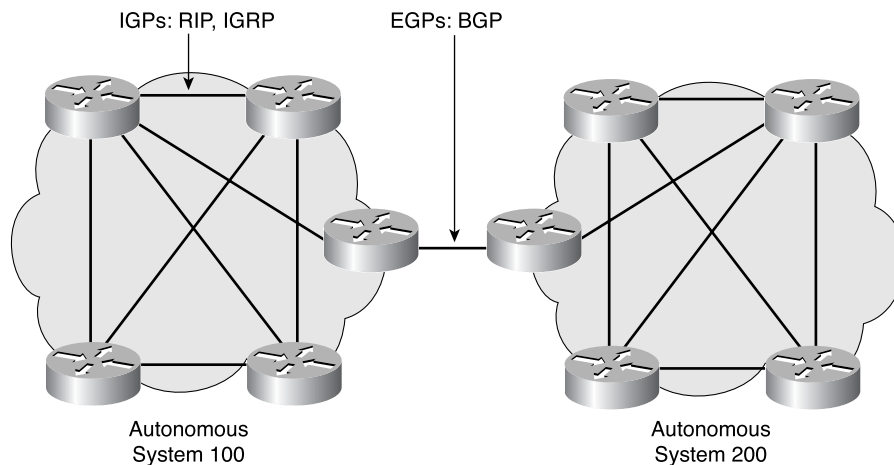
- **Bandwidth**—A link's data capacity. (Normally, a 10-Mbps Ethernet link is preferable to a 64-kbps leased line.)
- **Delay**—The length of time required to move a packet along each link from source to destination. Delay depends on the bandwidth of intermediate links, port queues at each router, network congestion, and physical distance.
- **Load**—The amount of activity on a network resource such as a router or link.
- **Reliability**—Usually refers to the error rate of each network link.
- **Hop count**—The number of routers that a packet must travel through before reaching its destination. Whenever data goes through a router, this is one hop. A path that has a hop count of 4 indicates that data traveling along that path passes through four routers before reaching its final destination. If there are multiple paths to a destination, the router chooses the path with the fewest hops.

- **Cost**—An arbitrary value, usually based on bandwidth, monetary expense, or another measurement, that is assigned by a network administrator.

Interior and Exterior Routing Protocols

Routers use routing protocols to exchange routing information. In other words, routing protocols determine how routed protocols are routed. Two families of routing protocols are the *Interior Gateway Protocols (IGPs)* and the *Exterior Gateway Protocols (EGPs)*, as shown in Figure 8-16. These families are classified based on how they operate with regard to autonomous systems.

Figure 8-16 IGPs and EGPs



An *autonomous system* is a network or set of networks that are under the administrative control of a single entity, such as the cisco.com domain. An autonomous system consists of routers that present a consistent view of routing to the external world. The Internet Assigned Numbers Authority (IANA) allocates autonomous system numbers to the regional registries. These registries are ARIN (hostmaster@arin.net) for the Americas, the Caribbean, and Africa; RIPE-NCC (ncc@ripe.net) for Europe; and AP-NIC (admin@apnic.net) for the Asia Pacific region. This autonomous system is a 16-bit number. A routing protocol such as BGP requires that you specify this unique, assigned autonomous system number in your configuration.

IGPs route data within an autonomous system. Here are some examples of IGPs:

- RIP and RIP V2
- IGRP
- EIGRP

- OSPF
- Intermediate System-to-Intermediate System (IS-IS) protocol

EGPs route data between autonomous systems. BGP is the most pervasive example of an EGP.

Routing Protocols

Routing protocols can be classified in many different ways, such as IGPs or EGPs. Another classification that describes routing protocols is distance-vector or link-state. Whereas IGP and EGP describe the physical relationships of routers, the distance-vector and link-state categories describe how routers interact with each other in terms of routing updates.

Distance-Vector Protocols

The *distance-vector routing* approach determines the direction (vector) and distance (hop count) to any link in the internetwork. Distance-vector algorithms periodically (such as every 30 seconds) send all or some portion of their routing table to their adjacent neighbors. Routers running a distance-vector routing protocol send periodic updates even if there are no changes in the network. By receiving a neighbor's routing table, a router can verify all the known routes and make changes to the local routing table based on updated information received from the neighboring router. This process is called "routing by rumor" because the understanding that a router has of the network is based on the neighbor's perspective of the network topology. Distance-vector protocols use the Bellman-Ford Algorithm to calculate the best paths.

Examples of distance-vector protocols include the following:

- *Routing Information Protocol (RIP)*—The most common IGP in the Internet, RIP uses hop count as its routing metric.
- *Interior Gateway Routing Protocol (IGRP)*—Cisco developed this IGP to address the issues associated with routing in large, heterogeneous networks.

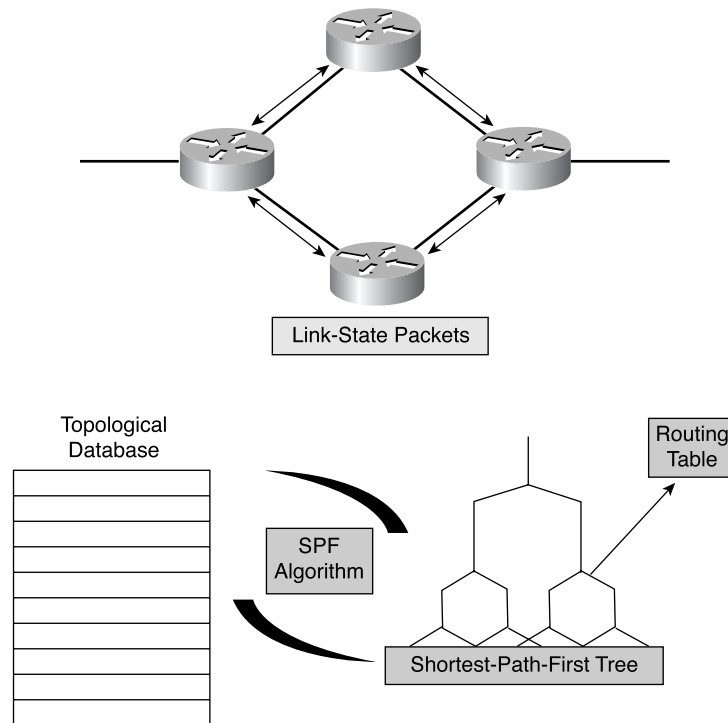
Link-State Protocols

Link-state routing protocols were designed to overcome the limitations of distance-vector routing protocols. Link-state routing protocols respond quickly to network changes, send trigger updates only when a network change has occurred, and send periodic updates (called link-state refreshes) at long time intervals, such as every 30 minutes.

When a link changes state, the device that detected the change creates a link-state advertisement (LSA) concerning that link (route), and that LSA is propagated to all neighboring devices. Each routing device takes a copy of the LSA, updates its link-state (topological) database, and forwards the LSA to all neighboring devices. This

flooding of the LSA is required to ensure that all routing devices update their databases before creating an updated routing table that reflects the new topology, as shown in Figure 8-17.

Figure 8-17 Link-State Routing Protocols



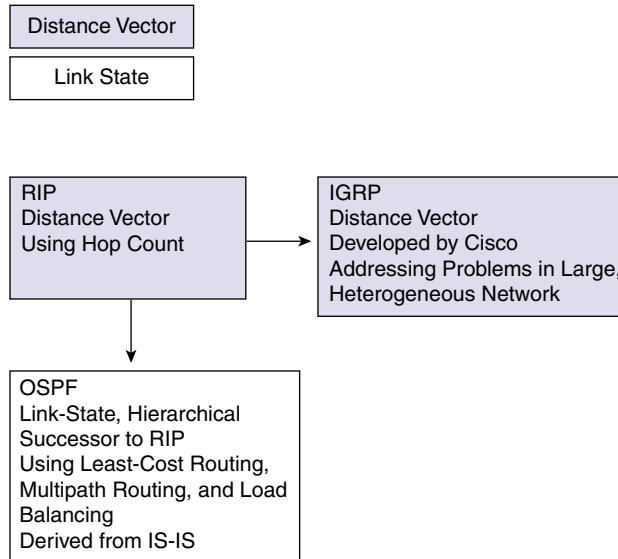
The link-state database is used to calculate the best paths through the network. Link-state routers find the best paths to destinations by applying the Dijkstra Shortest Path First (SPF) algorithm against the link-state database to build the SPF tree. The best (shortest) paths are then selected from the shortest-path-first tree and are placed in the routing table.

Examples of link-state protocols are OSPF and IS-IS, as shown in Figure 8-18.

Routing Protocol Characteristics

The following sections describe the metrics, network usability, and other significant characteristics of the most commonly used routing protocols.

Figure 8-18 Link-State Routing Protocols: OSPF and IS-IS



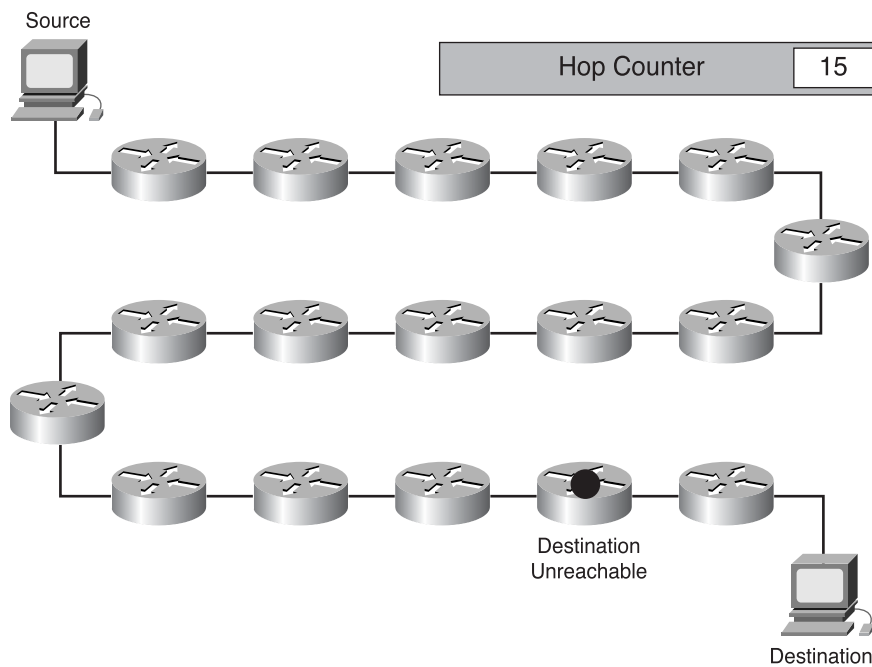
RIP

RIP uses hop count to determine the direction and distance to any link in the internet-network, as shown in Figure 8-19. If there are multiple paths to a destination, RIP selects the path with the fewest hops. However, because hop count is the only routing metric RIP uses, it does not necessarily select the fastest path to a destination. RIP-1 uses only classful routing. This means that all devices in the network must use the same subnet mask, because RIP-1 does not include the subnet information with the routing update.

RIP-2 provides what is called *prefix routing* and sends subnet mask information with the route updates. This supports the use of classless routing. With classless routing protocols, different subnets within the same network can have different subnet masks. The use of different subnet masks within the same network is called variable-length subnet masking (VLSM).

IGRP

IGRP is a distance-vector routing protocol developed by Cisco specifically to address problems associated with routing in large networks that are beyond the scope of protocols such as RIP. IGRP can select the fastest path based on the delay, bandwidth, load, and reliability. By default, IGRP uses bandwidth and delay metrics only and uses a 24-bit metric. IGRP also has a much higher maximum hop-count limit than RIP to allow the network to scale. IGRP uses only classful routing.

Figure 8-19 RIP Uses Hop Count as Its Metric

EIGRP

Like IGRP, EIGRP is a proprietary Cisco protocol. EIGRP is an advanced version of IGRP and uses a 32-bit metric. Specifically, EIGRP provides superior operating efficiency such as faster convergence and lower overhead bandwidth. It is an advanced distance-vector protocol. EIGRP also uses some of the link-state protocol functions. Hence, the term *hybrid* is also used to describe EIGRP.

OSPF

OSPF is a link-state routing protocol. The Internet Engineering Task Force (IETF) developed OSPF in 1988. The most recent version, OSPF Version 2, is described in RFC 2328. OSPF is an IGP, which means that it distributes routing information between routers belonging to the same autonomous system. OSPF was written to address the needs of large, scalable internetworks that RIP could not.

IS-IS

Intermediate System-to-Intermediate System (IS-IS) is the dynamic link-state routing protocol for the OSI *protocol stack*. As such, it distributes routing information for routing Connectionless Network Protocol (CLNP) data for the ISO Connectionless

NOTE

CLNP refers to the OSI network layer protocol that does not require a circuit to be established before data is transmitted.

Network Service (CLNS) environment. Integrated IS-IS is an implementation of the IS-IS protocol for routing multiple network protocols. Integrated IS-IS tags CLNP routes with information about IP networks and subnets. It provides an alternative to OSPF in the IP world, mixing ISO CLNS and IP routing in one protocol. It can be used purely for IP routing, purely for ISO routing, or for a combination of the two.

BGP

Border Gateway Protocol (BGP) is an example of an EGP. BGP exchanges routing information between autonomous systems while guaranteeing loop-free path selection. It is the principal route advertising protocol used by major companies and ISPs on the Internet. BGP-4 is the first version of BGP that supports *classless interdomain routing (CIDR)* and route aggregation. Unlike common IGPs such as RIP, OSPF, and EIGRP, BGP does not use metrics such as hop count or bandwidth or delay. Instead, BGP makes routing decisions based on network policies or rules using various BGP path attributes.

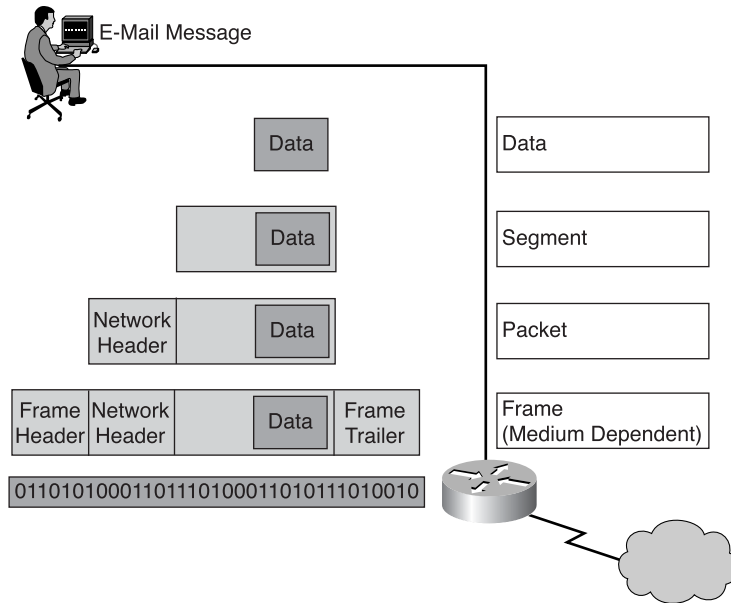
**Lab Activity** Small Router Purchase (Cable/DSL Router)

The purpose of this lab is to introduce the variety and prices of network components in the market. This lab looks specifically at small routers used by telecommuters when working from home.

IP as a Routed Protocol

IP is the most widely used implementation of a hierarchical network addressing scheme. IP is a connectionless, unreliable, best-effort delivery system protocol used on the Internet. The term *connectionless* means that no dedicated circuit connection is required, as there would be for a telephone call. There is no call setup before data is transferred between hosts. The IP protocol takes whichever route is the most efficient based on the routing protocol decision. Unreliable and best-effort do not mean that the system is unreliable and doesn't work well, but that the IP protocol does not make any effort to see if the packet was delivered. This function is handled by the upper-layer protocols.

As information flows down the layers of the OSI model, the data is processed at each layer. At the network layer, the data is encapsulated within packets called *datagrams*, as shown in Figure 8-20.

Figure 8-20 Encapsulation

IP determines the form of the IP packet header (which includes addressing and other control information) but does not concern itself with the actual data. It accepts whatever is passed down from the higher layers, as shown in Figure 8-21.

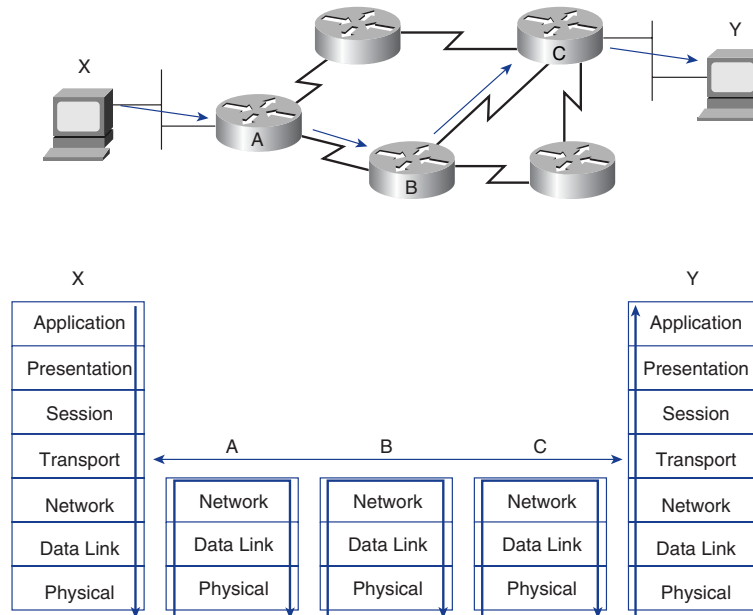
Figure 8-21 IP Header

Packet Propagation and Switching Within a Router

As a packet travels through an internetwork to get to its final destination, the frame's headers and trailers are stripped and replaced at every router (Layer 3) device, as shown in Figure 8-22. The reason for this is that Layer 2 units (frames) are for local addressing and Layer 3 units (packets) are for end-to-end addressing.

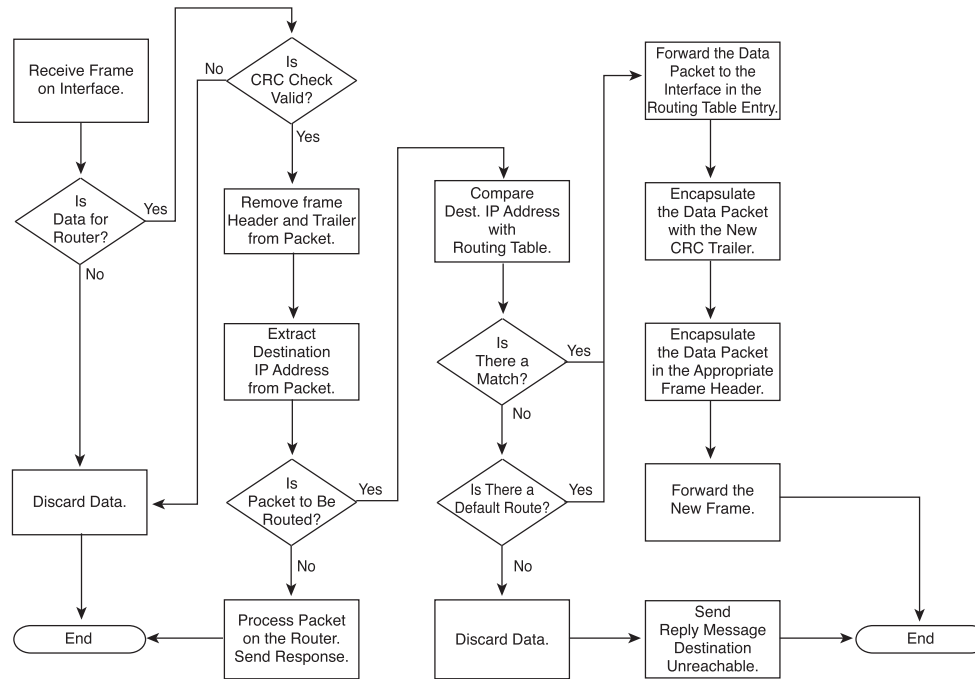
Layer 2 Ethernet frames are meant to work within a broadcast domain and to work with the MAC addresses that are assigned to the physical devices. Other Layer 2 frame types include point-to-point serial links and Frame Relay WAN connections that use their own Layer 2 addressing scheme. The main point is that no matter what type of Layer 2 addressing is used, it is designed to stay within a Layer 2 broadcast domain. As the data crosses a Layer 3 device, the Layer 2 information changes.

Figure 8-22 Network Layer Device Data Flow



The exact process that is performed at a Layer 3 device is detailed in Figure 8-23 and the following paragraph.

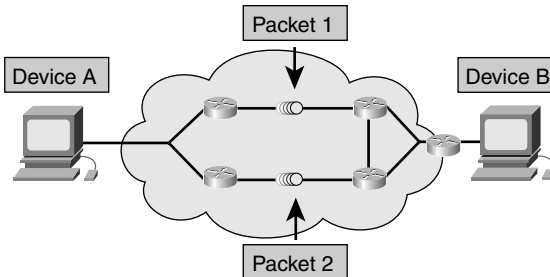
As a frame is accepted at a router interface, the destination MAC address is extracted and checked, as is done by all devices in a *collision domain*, to see if the frame is directly addressed to the interface or is a broadcast. In either of these cases, the packet is accepted; otherwise, it is discarded, because it was destined for another device on the collision domain. The accepted frame has the cyclic redundancy check (CRC) extracted from the frame trailer and is calculated to verify that the frame arrived without error at the interface. If the check fails, the frame is discarded. If the check is valid, the frame header and trailer are stripped, and the packet is passed up to Layer 3. The packet is then checked to see if it is destined for the router or is to be routed to another device in the internetwork. The types of packets that are destined for the router have an IP address of one of the router interfaces as the destination IP address. This packet has the Layer 3 header stripped and passed up to Layer 4. If the packet is to be routed, the destination IP address is compared to the routing table. If a match is found or there is a default route, the packet is sent to the interface specified in the matching routing table statement.

Figure 8-23 Encapsulation Changes in a Router

When the packet is switched to the outgoing interface, a new CRC value is added as a frame trailer, and, depending on the type of interface (Ethernet, serial, or Frame Relay), the proper frame header is added to the packet. The frame is then transmitted to the next broadcast domain for the next part of the trip to the final destination.

Connectionless Versus Connection-Oriented Network Services

Most OSI model network services use a connectionless delivery system (TCP), as shown in Figure 8-24. They treat each packet separately and send it on its way through the network. The packets might take different paths to get through the network, but they are reassembled when they arrive at the destination. In a connectionless system, the destination is not contacted before a packet is sent. A good analogy for a connectionless system is the postal system. The recipient is not contacted before a letter is sent from one destination to another. The letter is sent on its way, and the recipient learns of the letter when it arrives.

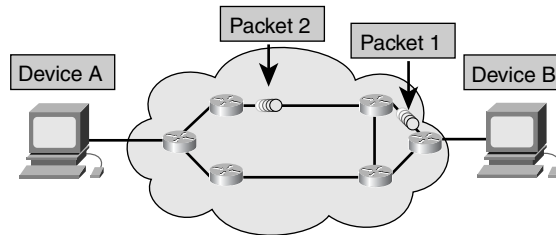
Figure 8-24 Connectionless Delivery System for Network Services

Connectionless network processes are often referred to as being *packet-switched*. In these processes, as the packets pass from source to destination, they can switch to different paths, as well as (possibly) arrive out of order. Devices make the path determination for each packet based on a variety of criteria. Some of the criteria (such as available bandwidth) might differ from packet to packet.

The Internet is a huge connectionless internetwork in which all packet deliveries are handled by IP. TCP (Layer 4) adds connection-oriented and reliable services on top of IP (Layer 3). TCP segments are encapsulated into IP packets for transport across the Internet.

IP is a connectionless system; it treats each packet independently. For example, if you use an FTP program to download a file, IP does not send the file in one long stream of data; it treats each packet independently. Each packet can travel different paths; some can even get lost. IP relies on the transport layer protocol to determine whether packets have been lost and to request retransmission. The transport layer is also responsible for reordering the packets.

In *connection-oriented* systems, a connection is established between the sender and the recipient before any data is transferred, as shown in Figure 8-25. An example of a connection-oriented network is the telephone system. You place a call, a connection is established, and then communication occurs. Connection-oriented network processes first establish a connection with the recipient and then begin the data transfer. All packets travel sequentially across the same physical circuit—or, more commonly, across the same virtual circuit.

Figure 8-25 Connection-Oriented Delivery System for Network Services

Anatomy of an IP Packet

The Layer 3 packet/datagram becomes Layer 2 data, which is then encapsulated into frames as previously discussed.

Similarly, the IP packet, shown in Figure 8-26, consists of the data from upper layers plus an IP header:

- **Version**—A 4-bit field that indicates the version of IP currently used. All devices must be running the same version of IP, or the device that is different rejects the packets.
- **IP Header Length (HLEN)**—A 4-bit field that indicates the datagram header length in 32-bit words. This is the total length of all header information, accounting for the two variable-length header fields.
- **Type of Service (TOS)**—An 8-bit field that specifies the level of importance that has been assigned by a particular upper-layer protocol.
- **Total Length**—A 16-bit field that specifies the length of the entire packet in bytes, including data and header. To get the length of the data payload, subtract the HLEN from the total length.
- **Identification**—A 16-bit field that contains an integer that identifies the current datagram. This is the sequence number.
- **Flags**—A 3-bit field in which the 2 low-order bits control fragmentation. The first bit specifies whether the packet can be fragmented, and the second bit specifies whether the packet is the last fragment in a series of fragmented packets.
- **Fragment Offset**—A 13-bit field that helps piece together datagram fragments. This field allows the Flags field to end at a 16-bit boundary.
- **Time-to-Live (TTL)**—An 8-bit field that maintains a counter that gradually decreases, in increments, to 0. At this point, the datagram is discarded, keeping the packets from looping endlessly. An example is hop count.

- **Protocol**—An 8-bit field that indicates which upper-layer protocol receives incoming packets after IP processing has been completed. Examples are TCP and UDP.
- **Header Checksum**—A 16-bit field that helps ensure IP header integrity.
- **Source IP Address**—A 32-bit field that specifies the sending node IP address.
- **Destination IP Address**—A 32-bit field that specifies the receiving node IP address.
- **Options**—A variable-length field that allows IP to support various options, such as security.
- **Padding**—Extra 0s are added to this field to ensure that the IP header is always a multiple of 32 bits.
- **Data**—A variable-length (maximum 64 Kb) field that contains upper-layer information.

Figure 8-26 IP Packet Contents

0		4		8		16		19		24		31	
VERS		HLEN		Service Type		Total Length							
Identification						Flags		Fragment Offset					
Time-To-Live				Protocol		Header Checksum							
Source IP Address													
Destination IP Address													
IP Options (If Any)								Padding					
Data													
...													

The IP packet consists of upper-layer data and the header information just described. Although the focus of this book so far has been the IP source and destination addresses, the other header fields are what make IP so flexible and resilient. The header fields are the information that is provided to the upper-layer protocols that defines the data in the packet. Several earlier chapters discussed the idea of layer independence; the header information in the preceding list is what allows that independence to happen.

The Mechanics of Subnetting

The Internet's original two-level hierarchy assumed that each site would have only a single network. Therefore, each site would need only a single connection to the Internet. Initially, these were safe assumptions. Over time, however, network computing matured and expanded. By 1985, it was no longer safe to assume that an organization would have only a single network or that it would be satisfied with a single connection to the Internet.

As sites began to develop multiple networks, it became obvious to the IETF that a mechanism was needed to differentiate among the multiple logical networks that were emerging as subsets of the Internet's second tier. Otherwise, there could be no efficient way to route data to specific end systems in sites with multiple networks.

Introduction to and Reasons for Subnetting

To create the subnetwork structure, host bits must be reassigned as network bits by dividing the host *octet(s)*. This is often called *borrowing* bits, but a more accurate term would be *lending* bits. The starting point for this process is always the leftmost host bit, dependent on the IP class.

In addition to the need for manageability, subnetting lets the network administrator provide broadcast containment and low-level security on the LAN. Security, through subnetting on the LAN, is provided because access to other subnets is provided by a router. The router, as you will learn in Chapter 20, "Access Control Lists," can be configured to permit or deny access to a subnet based on varied criteria, thereby providing security. Some owners of Class A and Class B networks have also discovered that subnetting creates a revenue source for the organization through the leasing or sale of previously unused IP addresses.

In such multiple-network environments, each subnetwork is connected to the Internet via a common point—a router, as shown in Figure 8-27. The details of the internal network environment are inconsequential to the Internet. They comprise a private network that is (or should be) capable of delivering its own datagrams. Therefore, the Internet must concern itself only with how to reach that network's gateway router to the Internet. Inside the private network, the host portion of the IP address can be subdivided to create subnetworks.

Because the *subnet address* is taken from the host number portion of Class A, Class B, and Class C addresses, it is assigned locally, usually by the network administrator. Also, like the other portions of IP addresses, each subnet address must be unique within its scope, as shown in Figure 8-28.

Figure 8-27 Subnetworks

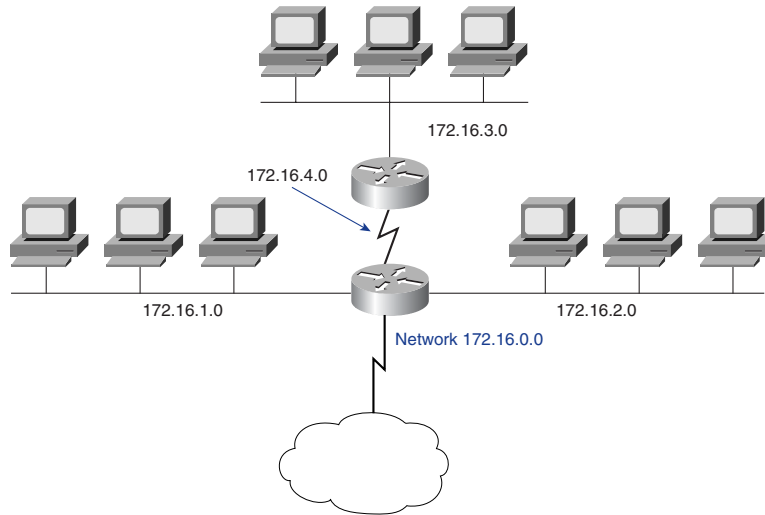
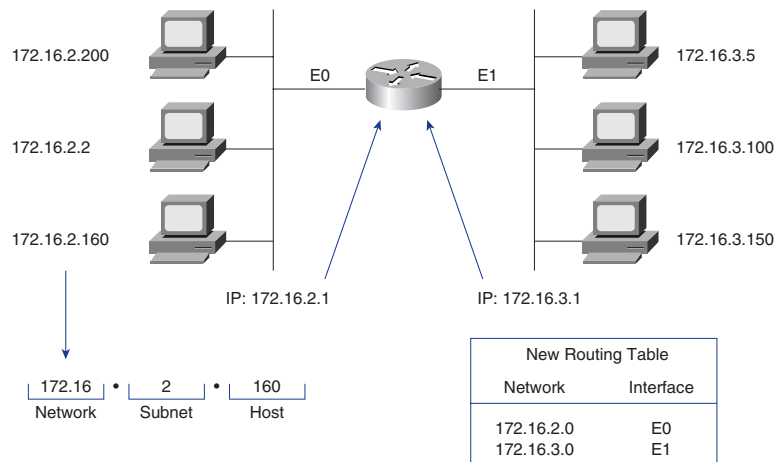


Figure 8-28 Subnet Address



Subnetting is frequently necessary when LANs are to be interconnected to form a WAN. For example, if you want to connect two LANs in geographically separate locations, you can assign a unique subnet to each of the LANs and to the WAN link between them. Two routers can then be used (one on each LAN) to route packets between the LANs (subnets).

Another primary reason for using subnets is to reduce the size of a broadcast domain. Broadcasts are sent to all hosts on a network or subnetwork. When broadcast traffic begins to consume too much of the available bandwidth, network administrators might choose to reduce the size of the broadcast domain.

The outside world sees a LAN as a single network with no knowledge of the internal network structure. This view of the network keeps the routing tables small and efficient. Given a local node address of 192.168.10.14, the world outside the LAN sees only the advertised major network number of 192.168.10.0. The reason for this is that the local address of 192.168.10.14 is valid only within the LAN 192.168.10.0. It cannot function anywhere else.

Subnet addresses include the Class A, Class B, and Class C network portion, plus a subnet field and a host field. These fields are created from the original host portion of the major IP address by assigning bits from the host portion to the original network portion of the address. The ability to divide the original host portion of the address into the new subnet and host fields provides addressing flexibility for the network administrator, as shown in Figures 8-29, 8-30, and 8-31. This simply means that the administrator has more options available when it comes to assigning an IP addressing scheme both initially and when it is time to expand the network.

Figure 8-29 Subdividing the Host Octet of a Class C Address

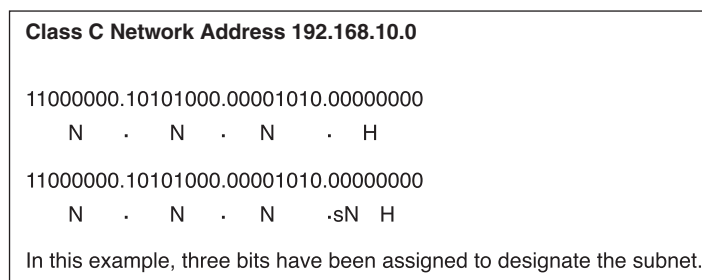


Figure 8-30 Subdividing the Host Octets of a Class B Address

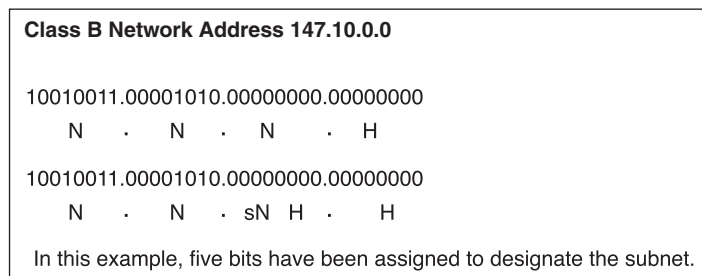


Figure 8-31 Subdividing the Host Octets of a Class A Address

Class A Network Address 28.0.0.0			
00011100.00000000.00000000.00000000			
N	.	H	. H . H
00011100.00000000.00000000.00000000			
N	.	sN	. sN H . H

In this example, 12 bits have been assigned to designate the subnet.

Establishing the Subnet Mask Address

Selecting the number of bits to use in the subnet process depends on the required maximum number of hosts per subnet. To calculate the result of using host bits to create subnetworks, you must understand some basic binary math and the position value of the bits in each octet, as shown in Table 8-2.

Table 8-2 Subnetting Chart: Bit Position and Value

Bit	1	2	3	4	5	6	7	8
Value	128	64	32	16	8	4	2	1

Regardless of the IP address class, the last 2 bits in the last octet can never be assigned to the subnetwork. These are called the *last two significant bits*. Using all the available bits except these two results in subnets with only two usable hosts. This is a practical address conservation method for addressing serial router links. However, for a working LAN, this would result in prohibitive equipment costs.

To create the *subnet mask* that gives the router the information required to compute which subnet a particular host resides on, select the column with the number of bits and refer to the mask number above it, as shown later in Figure 8-35. This number is calculated by adding the position value of the bits used. If 3 bits were used, the mask for a Class C address would be 255.255.255.224, as shown in Table 8-3. This mask can also be illustrated in the slash format as /27. The number following the slash is the total number of bits in the network portion and subnet mask.

Table 8-3 Subnetting Chart: Subnet Mask Identifier (Two Formats)

Slash Format	/25	/26	/27	/28	/29	/30	—	—
Mask	128	192	224	240	248	252	254	255
Bit	1	2	3	4	5	6	7	8
Value	128	64	32	16	8	4	2	1

To determine the number of bits to be used, the network designer needs to calculate how many hosts the largest subnetwork requires and the number of subnetworks. For example, assume that this requirement is 30 hosts and five subnetworks. To calculate how many bits to reassign, consult the Usable Hosts row in Table 8-4. For example, for 30 usable hosts, 3 bits are required. This also creates six usable subnetworks, which satisfies the requirements of this scheme. Again, the difference between usable and total hosts is a result of using the first available address as the ID and the last available address as the broadcast for each subnetwork. Classful routing does not provide the capability to use these subnetworks, whereas classless routing recovers many of these “lost” addresses, as shown in Table 8-4. This table illustrates the loss of subnets and hosts when you don’t use a classless routing protocol.

Table 8-4 Subnetting Chart: Subnets and Hosts

Slash Format	/25	/26	/27	/28	/29	/30	—	—
Mask	128	192	224	240	248	252	254	255
Bit	1	2	3	4	5	6	7	8
Value	128	64	32	16	8	4	2	1
Total Subnets		4	8	16	32	64		
Usable Subnets		2	6	14	30	62		
Total Hosts		64	32	16	8	4		
Usable Hosts		62	30	14	6	2		

An alternative way to compute the subnet mask and the number of networks is to use the following formulae:

The number of usable subnets equals 2 to the power of the assigned subnet bits minus 2:

$$(2^{\text{power of bits assigned}}) - 2 = \text{usable subnets}$$

For example, $2^3 - 2 = 6$

The number of usable hosts equals 2 to the power of the bits remaining minus 2:

$$(2^{\text{power of bits remaining}}) - 2 = \text{usable hosts}$$

For example, $2^5 - 2 = 30$

Creating a Subnet

To create subnets, you must extend the routing portion of the address. The Internet “knows” your network as a whole, identified by the Class A, B, or C address, which defines 8, 16, or 24 routing bits (the network number). The subnet field represents additional routing bits so that the routers within your organization can recognize different locations, or subnets, within the whole network.

Subnet masks use the same format as IP addresses. In other words, each subnet mask is 32 bits long and is divided into four octets. Subnet masks have all 1s in the network and subnetwork portion and all 0s in the host portion. By default, if no bits are borrowed, the subnet mask for a Class B network is 255.255.0.0. However, if 8 bits were borrowed, the subnet mask for the same Class B network would be 255.255.255.0, as shown in Figures 8-32 and 8-33. However, because there are two octets in the host field of a Class B network, up to 14 bits can be borrowed to create subnetworks. A Class C network has only one octet in the host field. Therefore, only up to 6 bits can be borrowed in Class C networks to create subnetworks.

The subnet field always immediately follows the network number. That is, the borrowed bits must be the first n bits of the default host field, where n is the desired size of the new subnet field, as shown in Figure 8-34. The subnet mask is the tool used by the router to determine which bits are routing bits and which bits are host bits.

Determining Subnet Mask Size

Again, subnet masks contain all 1s in the network bit positions (determined by the address class) as well as the subnet bit positions, and they contain all 0s in the remaining bit positions, designating them as the host portion of an address.

Figure 8-32 Network and Host Addresses

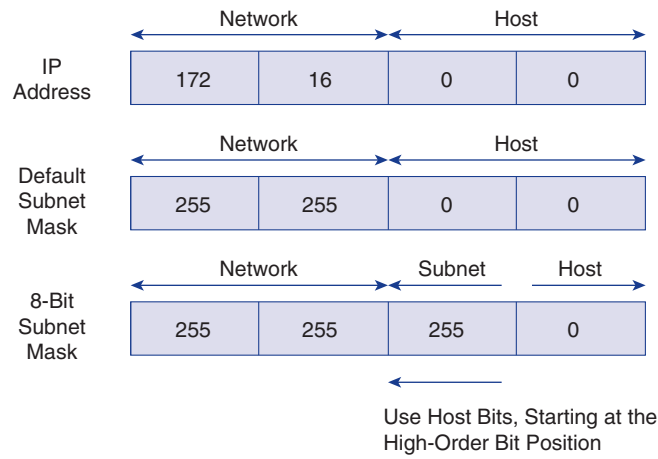
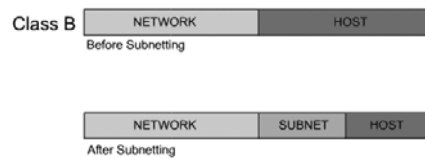


Figure 8-33 Binary Conversion Chart

128	64	32	16	8	4	2	1		
1	0	0	0	0	0	0	0	=	128
1	1	0	0	0	0	0	0	=	192
1	1	1	0	0	0	0	0	=	224
1	1	1	1	0	0	0	0	=	240
1	1	1	1	1	0	0	0	=	248
1	1	1	1	1	1	0	0	=	252
1	1	1	1	1	1	1	0	=	254
1	1	1	1	1	1	1	1	=	255

Figure 8-34 Subnetting a Class B Address



By default, if you borrow no bits, the subnet mask for a Class B network would be 255.255.0.0, which is the dotted-decimal equivalent of 1s in the 16 bits corresponding to the Class B network number and 0s in the other 16 bits.

If 8 bits were borrowed for the subnet field, the subnet mask would include 8 additional 1 bits and would become 255.255.255.0. For example, if the subnet mask 255.255.255.0 were associated with the Class B address 130.5.2.144 (8 bits borrowed for subnetting), the router would know to route this packet to subnet 130.5.2.0 rather than just to network 130.5.0.0, as shown in Figure 8-35.

Figure 8-35 Subnet Masking: Class B Address

	Network	Subnet	Host
130.5.0.0	10000010	00000101	00000000
255.255.255.0	11111111	11111111	11111111
Extended Network Prefix (Subnet Mask)			

Another example is the Class C address 197.15.22.131 with a subnet mask of 255.255.255.224. With a value of 224 in the final octet (11100000 in binary), the 24-bit Class C network portion has been extended by 3 bits to make the total 27 bits. The 131 in the last octet presents the third usable host address in the subnet 197.15.22.128, as shown in Figure 8-36. The routers in the Internet (that don't know the subnet mask) only worry about routing to the Class C network 197.15.22.0. The routers inside that network, knowing the subnet mask, look at 27 bits to make a routing decision.

Figure 8-36 Subnet Masking: Class C Address

11000101	00001111	00010110	10000011
Network Field		Subnetwork Field	Host Field

Computing the Subnet Mask and IP Address

Whenever you borrow bits from the host field, it is important to note the number of additional subnets that are being created each time you borrow one more bit. You have already learned that you cannot borrow only 1 bit; the fewest you can borrow is 2. Borrowing 2 bits creates four possible subnets (2×2) (but you must remember that there are two reserved/unusable subnets). Each time you borrow another bit from the

host field, the number of subnets created increases by a power of 2. Eight possible subnets are created by borrowing 3 bits ($2 \times 2 \times 2$). Sixteen possible subnets are created by borrowing 4 bits ($2 \times 2 \times 2 \times 2$). From these examples and from the binary conversion chart that was shown in Figure 8-33, it is easy to see that each time you borrow another bit from the host field, the number of possible subnets doubles.

Computing Hosts Per Subnetwork

Each time you borrow 1 bit from a host field, there is 1 less bit remaining that can be used for host numbers. Specifically, each time you borrow another bit from the host field, the number of host addresses that you can assign decreases by a power of 2 (gets cut in half).

To understand how this works, consider a Class C network address. If there is no subnet mask, all 8 bits in the last octet are used for the host field. Therefore, 256 (2^8) possible addresses are available to assign to hosts (254 usable addresses after you subtract the two you know you can't use). Now, imagine that this Class C network is divided into subnets. If you borrow 2 bits from the default 8-bit host field, the host field decreases in size to 6 bits. If you wrote out all the possible combinations of 0s and 1s that could occur in the remaining 6 bits, you would discover that the total number of possible hosts that could be assigned in each subnet would be reduced to 64 (2^6). The number of usable host numbers would be reduced to 62.

In the same Class C network, if you borrow 3 bits, the size of the host field decreases to 5 bits, and the total number of hosts you can assign to each subnet is reduced to 32 (2^5). The number of usable host numbers decreases to 30.

The number of possible host addresses that can be assigned to a subnet is related to the number of subnets that have been created. In a Class C network, for example, if a subnet mask of 255.255.255.224 has been applied, 3 bits (224 in decimal equals 11100000 in binary) are borrowed from the host field. Six usable subnets are created ($8 - 2$), each having 30 ($32 - 2$) usable host addresses.

Calculating the Resident Subnetwork Through ANDing

As mentioned earlier, the network or subnet address has all 0s in the host portion. To route a data packet, the router must first determine the destination network/subnet address. To accomplish this, the router performs a logical AND using the destination host's IP address and the subnet mask for that network.

Imagine that you have a Class B network with the network number 172.16.0.0. After assessing your network's needs, you decide to borrow 8 bits to create subnets. As you learned earlier, when you borrow 8 bits with a Class B network, the subnet mask is 255.255.255.0, as shown in Figure 8-37.

Figure 8-37 8 Bits of Subnetting

	Network	Subnet	Host
IP Host Address 172.16.2.120	10101100 00010000	00000010	01111000
Subnet Mask 255.255.255.0 or /24	11111111 11111111	11111111	00000000
Subnet	10101100 00010000 172 16	00000010 2	00000000 0

Someone outside the network sends data to the IP address 172.16.2.120. To determine where to deliver the data, the router ANDs this address with the subnet mask.

When the two numbers are ANDed, the host portion of the result is always 0. What is left is the network number, including the subnet. Thus, the data is sent to subnet 172.16.2.0, and only the final router notices that the packet should be delivered to host 120 in that subnet.

Now, imagine that you have the same network, 172.16.0.0. This time, however, you decide to borrow only 7 bits for the subnet field. The binary subnet mask for this is 11111111.11111111.11111110.00000000. What is this in dotted-decimal notation?

Again, someone outside the network sends data to host 172.16.2.120. To determine where to send the data, the router again ANDs this address with the subnet mask. As before, when the two numbers are ANDed, the host portion of the result is 0. So what is different in this second example? Everything looks the same—at least, in decimal. The difference is in the number of subnets available and the number of hosts available per subnet. You can see this only by comparing the two different subnet masks, as shown in Figure 8-38.

Figure 8-38 Network Number Extended by 7 Bits

	Network	Subnet	Host
IP Host Address 172.16.2.120	10101100 00010000	00000010	01111000
Subnet Mask 255.255.254.0 or /23	11111111 11111111	11111110	00000000
Subnet	10101100 00010000 172 16	00000010 2	00000000 0

With 7 bits in the subnet field, there can be only 126 subnets. How many hosts can there be in each subnet? How long is the host field? With 9 bits for host numbers, there can be 510 hosts in each of those 126 subnets.

**Lab Activity** Basic Subnetting

This exercise provides a basic overview of the subnetting and the ANDing processes. Given a network address and requirements, you determine the subnet mask, the number of subnets and hosts per subnet, and the number of usable subnets and hosts. You also use the ANDing process to determine if a destination IP address is local or remote. Finally, you identify valid and invalid IP host addresses based on a given a network number and subnet mask.

**Lab Activity** Subnetting a Class A Network

In this exercise, you analyze a Class A network address with the number of network bits specified to determine the subnet mask, number of subnets, hosts per subnet, and information about specific subnets.

**Lab Activity** Subnetting a Class B Network

In this exercise, you analyze a Class B network address with the number of network bits specified to determine the subnet mask, number of subnets, hosts per subnet, and information about specific subnets.

**Lab Activity** Subnetting a Class C Network

In this exercise, you analyze a Class C network address with the number of network bits specified to determine the subnet mask, number of subnets, hosts per subnet, and information about specific subnets.

Summary

In this chapter, you learned the following key points:

- The differences between, mechanics of, and characteristics of routing and routed protocols.

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- To provide extra flexibility for the network administrator, networks—particularly large ones—are often divided into smaller networks called subnetworks or subnets. Subnetting allows a network administrator to get around the limitations of availability of IP addresses by dividing a single network address into many subnets visible only within that single network.
- The function of a subnet mask is to tell devices which part of an address is the network number, including the subnet, and which part is the host.
- Internetworking functions of the network layer include network addressing and best-path selection for data traffic.
- How to explain IP addressing, IP address classes, reserved IP address space, private IP address space, and IP subnetting.

To supplement all that you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab Activities on the CD-ROM accompanying this book.

Key Terms

algorithm A well-defined rule or process for arriving at a solution to a problem. In networking, algorithms are commonly used to determine the best route for traffic from a particular source to a particular destination.

autonomous system A network or set of networks that are under the administrative control of a single entity, such as the Cisco.com domain.

broadcast A data packet that is sent to all nodes on a network. Broadcasts are identified by a broadcast address.

broadcast domain A set of all devices that receive broadcast frames originating from any device within the set. Broadcast domains are typically bounded by routers (or, in a switched network, by VLANs) because routers do not forward broadcast frames.

classless interdomain routing (CIDR) A technique supported by BGP and based on route aggregation. CIDR allows routers to group routes to cut down on the quantity of routing information carried by the core routers. With CIDR, several IP networks appear to networks outside the group as a single, larger entity.

collision domain In Ethernet, the network area within which frames that have collided are propagated. Repeaters and hubs propagate collisions; LAN switches, bridges, and routers do not.

connectionless Data transfer without the existence of a virtual circuit.

connection-oriented Data transfer that requires the establishment of a virtual circuit.

datagram A logical grouping of information sent as a network layer unit over a transmission medium without prior establishment of a virtual circuit. IP datagrams are the primary information units in the Internet. The terms *cell*, *frame*, *message*, *packet*, and *segment* also describe logical information groupings at various layers of the OSI reference model and in various technology circles.

distance-vector routing A class of routing algorithms that iterate on the number of hops in a route to find a shortest-path spanning tree. Distance-vector routing algorithms call for each router to send its entire routing table in each update, but only to its neighbors. Distance-vector routing algorithms can be prone to routing loops but are computationally simpler than link-state routing algorithms. Also called the Bellman-Ford routing algorithm.

Exterior Gateway Protocol (EGP) An Internet protocol used to exchange routing information between autonomous systems. Border Gateway Protocol (BGP) is the most common EGP.

hop The passage of a data packet from one network node, typically a router, to another.

hop count A routing metric used to measure the distance between a source and a destination. RIP uses hop count as its sole metric.

Interior Gateway Protocol (IGP) An Internet protocol used to exchange routing information within an autonomous system. Examples of common Internet IGPs are IGRP, OSPF, and RIP.

Interior Gateway Routing Protocol (IGRP) An IGP developed by Cisco to address the problems associated with routing in large, heterogeneous networks.

IP address A 32-bit address assigned to hosts using TCP/IP. An IP address belongs to one of five classes (A, B, C, D, or E) and is written as four octets separated by periods (that is, dotted-decimal format). Each address consists of a network number, an optional subnetwork number, and a host number. The network and subnetwork numbers together are used for routing, and the host number is used to address an individual host within the network or subnetwork. A subnet mask is used to extract network and subnetwork information from the IP address. CIDR provides a new way to represent IP addresses and subnet masks. Also called an *Internet address*.

MAC address A standardized data link layer address that is required for every device that connects to a LAN. Other devices in the network use these addresses to locate specific devices in the network and to create and update routing tables and data structures. MAC addresses are 6 bytes long and are controlled by the IEEE. Also called a *hardware address*, *MAC-layer address*, or *physical address*.

NetBIOS Extended User Interface (NetBEUI) An enhanced version of the NetBIOS protocol used by network operating systems such as LAN Manager, LAN Server, Windows for Workgroups, and Windows NT. NetBEUI formalizes the transport frame and adds functions. NetBEUI implements the OSI LLC2 protocol.

octet 8 bits. In networking, the term *octet* is often used (rather than *byte*) because some machine architectures employ bytes that are not 8 bits long.

packet A logical grouping of information that includes a header containing control information and (usually) user data. Packets most often refer to network-layer units of data. The terms *datagram*, *frame*, *message*, and *segment* also describe logical information groupings at various layers of the OSI reference model and in various technology circles.

protocol stack A set of related communications protocols that operate together and, as a group, address communication at some or all of the seven layers of the OSI reference model. Not every protocol stack covers each layer of the model, and often a single protocol in the stack addresses a number of layers at once. TCP/IP is a typical protocol stack.

routed protocol Any network protocol that provides enough information in its network layer address to allow a packet to be forwarded from one host to another host based on the addressing scheme.

router A network-layer device that uses one or more metrics to determine the optimal path along which network traffic should be forwarded. Routers forward packets from one network to another based on network-layer information contained in routing updates. Occasionally called a *gateway* (although this definition of *gateway* is becoming increasingly outdated).

Routing Information Protocol (RIP) An IGP supplied with UNIX BSD systems. The most common IGP in the Internet. RIP uses hop count as a routing metric.

routing metric A method by which a routing algorithm determines that one route is better than another. This information is stored in routing tables and is sent in routing updates. Metrics include bandwidth, communication cost, delay, hop count, load, MTU, path cost, and reliability. Sometimes simply called a *metric*.

routing protocol A protocol that accomplishes routing through the implementation of a specific routing algorithm. Examples of routing protocols are IGRP, OSPF, and RIP.

routing table A table stored in a router or some other internetworking device that keeps track of routes to particular network destinations and, in some cases, metrics associated with those routes.

subnet address A portion of an IP address that is specified as the subnetwork by the subnet mask.

subnet mask A 32-bit address mask used in IP to indicate the bits of an IP address that are used for the subnet address. Sometimes simply called a *mask*.

subnetwork 1. In IP networks, a network sharing a particular subnet address. Subnetworks are networks arbitrarily segmented by a network administrator to provide a multilevel, hierarchical routing structure while shielding the subnetwork from the addressing complexity of attached networks. Sometimes called a *subnet*. 2. In OSI networks, a collection of ESs and ISs under the control of a single administrative domain and using a single network access protocol.

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. How many bits are in an IP address?
 - A. 16
 - B. 32
 - C. 64
 - D. None of the above
2. What is the maximum value of each octet in an IP address?
 - A. 28
 - B. 255
 - C. 256
 - D. None of the above
3. The network number plays what part in an IP address?
 - A. It specifies the network to which the host belongs.
 - B. It specifies the identity of the computer on the network.
 - C. It specifies which node on the subnetwork is being addressed.
 - D. It specifies which networks the device can communicate with.
4. The host number plays what part in an IP address?
 - A. It designates the identity of the computer on the network.
 - B. It designates which node on the subnetwork is being addressed.
 - C. It designates the network to which the host belongs.
 - D. It designates which hosts the device can communicate with.
5. What is the decimal equivalent of the binary number 101101?
 - A. 32
 - B. 35
 - C. 45
 - D. 44

6. Convert the decimal number 192.5.34.11 to its binary form.
 - A. 11000000.00000101.00100010.00001011
 - B. 11000101.01010111.00011000.10111000
 - C. 01001011.10010011.00111001.00110111
 - D. 11000000.00001010.01000010.00001011
7. Convert the binary IP address 11000000.00000101.00100010.00001011 to its decimal form.
 - A. 190.4.34.11
 - B. 192.4.34.10
 - C. 192.4.32.11
 - D. None of the above
8. What portion of the Class B address 154.19.2.7 is the network address?
 - A. 154
 - B. 154.19
 - C. 154.19.2
 - D. 154.19.2.7
9. What portion of the IP address 129.219.51.18 represents the network?
 - A. 129.219
 - B. 129
 - C. 14.1
 - D. 1
10. Which of the following addresses is an example of a broadcast address on the network 123.10.0.0 with a subnet mask of 255.255.0.0?
 - A. 123.255.255.255
 - B. 123.10.255.255
 - C. 123.13.0.0
 - D. 123.1.1.1

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11. How many host addresses can be used in a Class C network?
 - A. 253
 - B. 254
 - C. 255
 - D. 256
12. How many subnets can a Class B network have?
 - A. 16
 - B. 256
 - C. 128
 - D. None of the above
13. What is the minimum number of bits that can be borrowed to form a subnet?
 - A. 1
 - B. 2
 - C. 4
 - D. None of the above
14. What is the primary reason for using subnets?
 - A. To reduce the size of the collision domain
 - B. To increase the number of host addresses
 - C. To reduce the size of the broadcast domain
 - D. None of the above
15. How many bits are in a subnet mask?
 - A. 16
 - B. 32
 - C. 64
 - D. None of the above
16. Performing the Boolean function as a router would on the IP addresses 131.8.2.5 and 255.0.0.0, what is the network/subnetwork address?
 - A. 131.8.1.0
 - B. 131.8.0.0
 - C. 131.8.2.0
 - D. None of the above

17. How many bits can be borrowed to create a subnet for a Class C network?
- A. 2
 - B. 4
 - C. 6
 - D. None of the above
18. With a Class C address of 197.15.22.31 and a subnet mask of 255.255.255.224, how many bits have been borrowed to create a subnet?
- A. 1
 - B. 2
 - C. 3
 - D. None of the above
19. Performing the Boolean function as a router would on the IP addresses 172.16.2.120 *and* 255.255.255.0, what is the subnet address?
- A. 172.0.0.0
 - B. 172.16.0.0
 - C. 172.16.2.0
 - D. None of the above
20. Which of the following best describes one function of Layer 3, the network layer, in the OSI model?
- A. It is responsible for reliable network communication between nodes.
 - B. It is concerned with physical addressing and network topology.
 - C. It determines which is the best path for traffic to take through the network.
 - D. It manages data exchange between presentation layer entities.
21. What function allows routers to evaluate available routes to a destination and to establish the preferred handling of a packet?
- A. Data linkage
 - B. Path determination
 - C. SDLC interface protocol
 - D. Frame Relay

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- 22.** How does the network layer forward packets from the source to the destination?
- A.** By using an IP routing table
 - B.** By using ARP responses
 - C.** By referring to a name server
 - D.** By referring to the bridge
- 23.** What are the two parts of a network layer address that routers use to forward traffic through a network?
- A.** Network address and host address
 - B.** Network address and MAC address
 - C.** Host address and MAC address
 - D.** MAC address and subnet mask



Objectives

Upon completion of this chapter, you will be able to

- Describe the functions of the TCP/IP transport layer
- Describe flow control
- Describe the processes of establishing a connection between peer systems
- Describe windowing
- Describe acknowledgment
- Identify and describe transport layer protocols
- Describe the Transmission Control Protocol (TCP) header format and port numbers
- Describe the User Datagram Protocol (UDP) header format and port numbers

Chapter 9

TCP/IP Transport and Application Layer

The transport layer uses the services provided by the network layer, such as best-path selection and logical addressing, to provide end-to-end communication between source and destination. This chapter describes how the transport layer regulates the flow of information from source to destination reliably and accurately. The primary characteristics of the transport layer are discussed, including the following:

- The transport layer data stream is a logical connection between the endpoints of a network.
- End-to-end control and reliability are provided by sliding windows, sequencing numbers, and acknowledgments.
- Layer 4 protocols TCP and UDP use *port* numbers to keep track of different conversations that cross the network at the same time, and to pass information to the upper layers.

The primary characteristics of the TCP/IP application layer include the following:

- End-user applications reside at this layer.
- Commonly used applications include NFS, DNS, ARP, rlogin, talk, FTP, NTP, and traceroute.

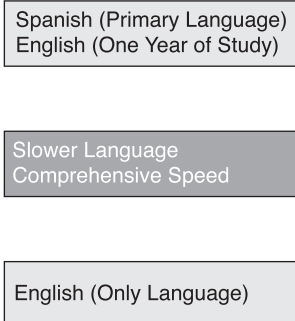
Please be sure to look at this chapter's associated e-Lab Activities, Videos, and Photo-Zooms that you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

Understanding the TCP/IP Transport Layer

The phrase “quality of service” often is used to describe the purpose of Layer 4, the transport layer. UDP, which is covered later, also operates at Layer 4 and provides connectionless transport services. However, the primary protocol operating at this layer is connection-oriented TCP. Its main function is to transport and regulate the flow of information from source to destination reliably and accurately. The primary duties of the transport layer are to provide end-to-end control, to provide flow control via sliding windows, and to ensure reliability via sequencing numbers and acknowledgments.

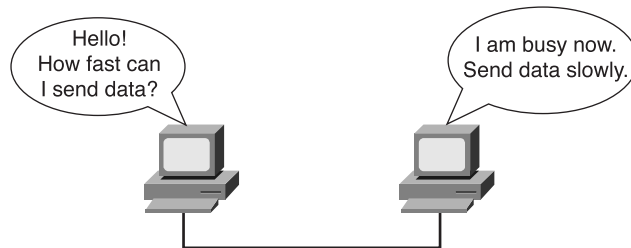
To understand reliability and flow control, think of a person who speaks really fast. In conversation, the listener might need to ask this person to repeat some words if they are not understood (for reliability) and to speak slowly, so the listener can catch the words (flow control), as shown in Figure 9-1.

Figure 9-1 Transport Layer Analogies



The transport layer provides transport services from the source host to the destination host. It constitutes a logical connection between the endpoints of the network. Transport services segment and reassemble data that is sent by several upper-layer *applications* onto the same transport layer data stream. This transport layer data stream provides end-to-end transport services.

The transport layer data stream is a logical connection between the endpoints of a network. The transport layer defines end-to-end connectivity between host applications. Figure 9-2 illustrates the transport layer.

Figure 9-2 Transport Layer Role in Communication Between Network Devices

The transport layer provides the following basic services:

- Segmenting upper-layer application data
- Establishing end-to-end operations
- Sending segments from one end host to another end host
- Ensuring flow control provided by sliding windows
- Ensuring reliability provided by sequence numbers and acknowledgments

The transport layer assumes that it can use the network as a “cloud,” to send data packets from source to destination. The cloud deals with issues of which of several paths is best for a given route. This starts to illustrate the role that routers perform in this process.

TCP/IP is a combination of two individual protocols, TCP and IP. IP is a Layer 3 protocol, a connectionless service that provides best-effort delivery across a network. TCP is a Layer 4 protocol, a connection-oriented service that provides flow control as well as reliability. Pairing the protocols enables them to provide a wider range of services. The TCP/IP protocol suite is made up of many protocols, but TCP and IP are the key ones. TCP/IP is the protocol suite on which the Internet is based.

Flow Control

As the TCP transport layer protocol sends data segments, it can ensure the integrity of the data. One method of doing this is called *flow control*. Flow control avoids the problem of a transmitting host overflowing the buffers in the receiving host. Overflows can present serious problems because they can result in the loss of data.

Transport layer services enable reliable data transport between hosts and destinations. To obtain such reliable transport of data, a connection-oriented relationship is used

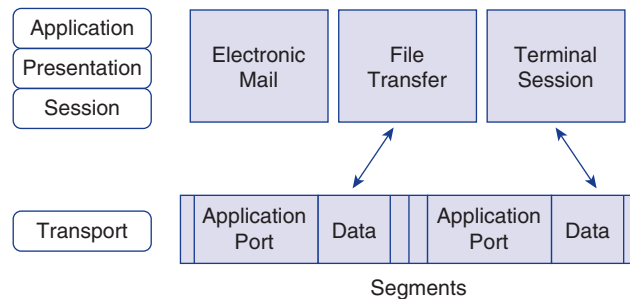
between the communicating end systems. Reliable transport can accomplish the following:

- Ensure that segments delivered will be acknowledged to the sender
- Provide for retransmission of any segments that are not acknowledged
- Put segments back into their correct sequence at the destination
- Provide congestion avoidance and control

Session Establishment, Maintenance, and Termination Overview

In the OSI and TCP/IP reference models, multiple applications can share the same transport connection. Transport functionality is accomplished segment by segment. This means that different applications can send data segments on a first-come, first-served basis. Such segments can be intended for the same destination or for different destinations. This setup sometimes is referred to as the multiplexing of upper-layer conversations, as shown in Figure 9-3.

Figure 9-3 Multiple Types of Application Layer Data Share the Transport Layer



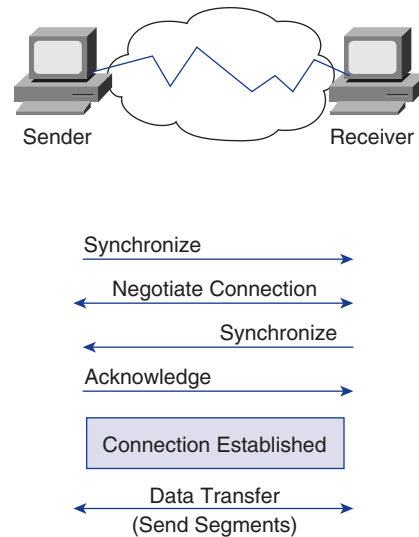
One function of the transport layer is to establish a connection-oriented session with its peer system. For data transfer to begin, both the sending and the receiving applications inform their respective operating systems that a connection will be initiated. One machine initiates a connection that must be accepted by the other. Protocol software modules in the two operating systems communicate by sending messages across the network to verify that the transfer is authorized and that both sides are ready.

After all synchronization has occurred, a connection is said to be established and the transfer of data begins. During transfer, the two machines continue to communicate with their protocol software to verify that data is received correctly.

Figure 9-4 shows a typical connection between sending and receiving systems. The first handshake requests synchronization. The second and third handshakes acknowledge

the initial synchronization request, as well as synchronize connection parameters in the opposite direction. The final handshake segment is an *acknowledgment* used to inform the destination that both sides agree that a connection has been established. After the connection is established, data transfer begins.

Figure 9-4 Establishing a Connection with a Peer System



When data transfer is in progress, congestion can occur for two reasons. First, a high-speed computer might be capable of generating traffic faster than a network can transfer it. Second, if many computers simultaneously need to send datagrams to a single destination, that destination can experience congestion, although no single source caused the problem.

When datagrams arrive too quickly for a host or gateway to process, they temporarily are stored in memory. If the traffic continues, the host or gateway eventually exhausts its memory and must discard additional datagrams that arrive.

Instead of allowing data to be lost, the transport function can issue a “not ready” indicator to the sender. Acting like a stop sign, this indicator signals the sender to stop sending data. When the receiver can handle additional data, the receiver sends a “ready” transport indicator, which is like a go signal. When it receives this indicator, the sender can resume segment transmission.

At the end of data transfer, the sending host sends a signal that indicates the end of the transmission. The receiving host at the end of the data sequence acknowledges the end of transmission, and the connection is terminated.

Three-Way Handshake

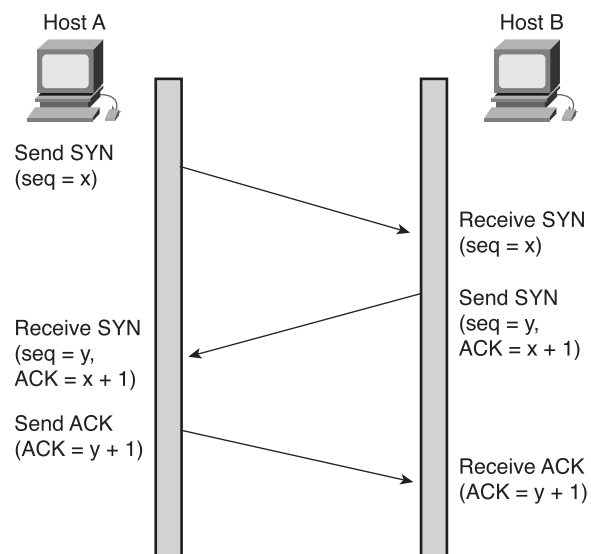
TCP is connection-oriented, so it requires connection establishment before data transfer begins. For a connection to be established or initialized, the two hosts must synchronize on each other's initial sequence numbers (ISNs). Synchronization is done in an exchange of connection-establishing segments that carry a control bit called SYN (for synchronize) and the ISNs. Segments that carry the SYN bit also are called SYNs. Hence, the solution requires a suitable mechanism for picking an initial sequence number and a slightly involved handshake to exchange the ISNs.

The synchronization requires each side to send its own initial sequence number and to receive a confirmation of it in an acknowledgment (ACK) from the other side. Each side also must receive the other side's ISN and send a confirming ACK. The sequence follows:

1. **A→B SYN**—My initial sequence number is X, the ACK number is 0, and the SYN bit is set, but the ACK bit is not set.
2. **B→A ACK**—Your sequence number is X+1, my initial sequence number is Y, and the SYN and ACK bits are set.
3. **A→B ACK**—Your sequence number is Y+1, my sequence number is X+1, and the ACK bit is set, but the SYN bit is not set.

This exchange, shown in Figure 9-5, is called the *three-way handshake*.

Figure 9-5 Three-Way Handshake



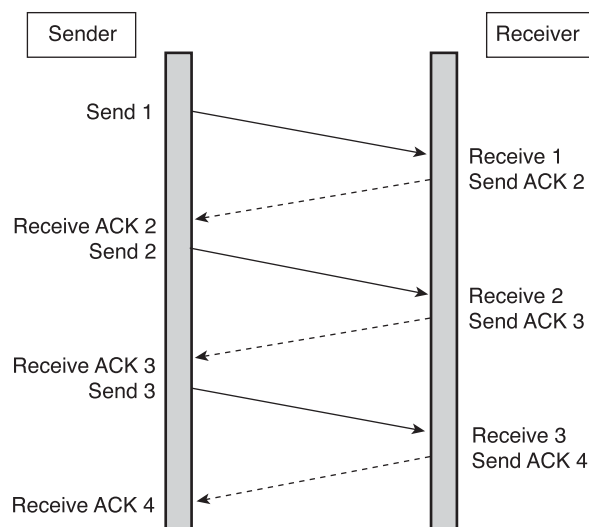
A three-way handshake is an asynchronous connection mechanism, which is necessary because sequence numbers are not tied to a global clock in the network; therefore, TCP protocols can have different mechanisms for picking the ISN. The three-way handshake addresses a lot more issues than just the sequence numbers. Other issues that are addressed include window size, MTU, and any network latency to expect. The receiver of the first SYN has no way of knowing whether the segment was an old delayed one, unless it remembers the last sequence number used on the connection (which is not always possible), so it must ask the sender to verify this SYN.

Windowing

In the most basic form of reliable, connection-oriented data transfer, data packets must be delivered to the recipient in the same order in which they were transmitted. The protocol fails if any data packets are lost, damaged, duplicated, or received in a different order. The basic solution is to have a recipient acknowledge the receipt of each data segment.

If the sender must wait for an acknowledgment after sending each segment, as shown in Figure 9-6, throughput is low. Therefore, most connection-oriented, reliable protocols allow more than one frame or segment to be outstanding at a time. Because time is available after the sender finishes transmitting the data packet and before the sender finishes processing any received acknowledgment, the interval is used for transmitting more data. The number of data packets that the sender is allowed to have outstanding without having received an acknowledgment is known as the window.

Figure 9-6 Window Size of 1



TCP uses expectational acknowledgments, meaning that the acknowledgment number refers to the octet that is expected next. Windowing refers to the fact that the window size is negotiated dynamically during the TCP session. *Windowing* is a flow-control mechanism requiring that the source device receive an acknowledgment from the destination after transmitting a certain amount of data.

To govern the flow of data between devices, TCP uses a flow-control mechanism. The receiving TCP device reports a “window” to the sending TCP device. This window specifies the number of octets, starting with the acknowledgment number, that the receiving TCP device currently is capable of receiving.

For example, with a window size of 3, the source device can send three octets to the destination. It then must wait for an acknowledgment. If the destination receives the three octets, it sends an acknowledgment to the source device, which now can transmit three more octets. If the destination does not receive the three octets—for example, because of overflowing buffers—it does not send an acknowledgment. Because the source does not receive an acknowledgment, it knows that the octets should be retransmitted and that the transmission rate should be slowed.

TCP window sizes are variable during the lifetime of a connection. Each acknowledgment contains a window advertisement that indicates the number of bytes that the receiver can accept. TCP also maintains a congestion-control window, which is normally the same size as the receiver’s window but is cut in half when a segment is lost (for example, there is congestion). This approach permits the window to be expanded or contracted as necessary to manage buffer space and processing. A larger window size controls the permissible number of octets that can be transmitted.

If the sender sends three octets, it is expecting an ACK of 4. If the receiver can handle a window size of only two octets, it drops packet 3, specifies 3 as the next octet, and specifies a new window size of 2. The sender sends the next two octets but still specifies its own window size of 3 (for example, it still can accept three octets from the receiver). The receiver replies by requesting octet 5 and specifying a window size of 2.

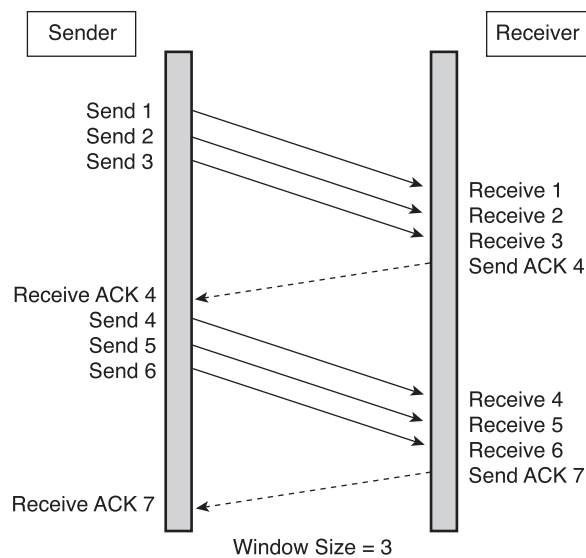
Acknowledgment

Reliable delivery guarantees that a stream of data sent from one machine is delivered through a data link to another machine without duplication or data loss. Positive acknowledgment with retransmission is one technique that guarantees reliable delivery of data. Positive acknowledgment requires a recipient to communicate with the source, sending back an acknowledgment message when it receives data. The sender keeps a record of each data packet (TCP segment) that it sends and expects an acknowledgment.

The sender also starts a timer when it sends a segment, and it retransmits a segment if the timer expires before an acknowledgment arrives.

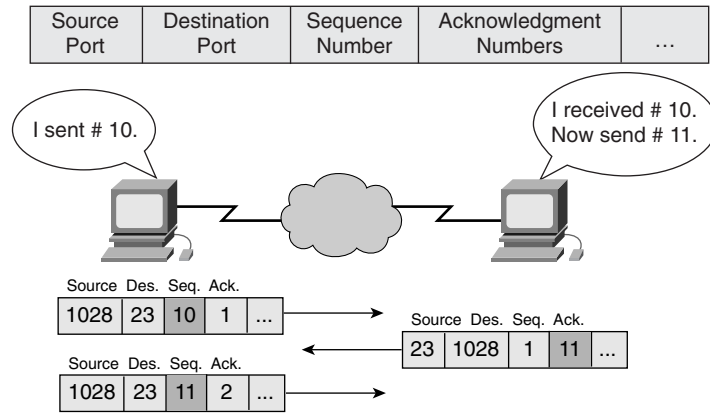
Figure 9-7 shows the sender transmitting data packets 1, 2, and 3. The receiver acknowledges receipt of the packets by requesting packet 4. Upon receiving the acknowledgment, the sender sends packets 4, 5, and 6. If packet 5 does not arrive at the destination, the receiver acknowledges with a request to resend packet 5. The sender resends packet 5 and then receives an acknowledgment to continue with the transmission of packet 7.

Figure 9-7 Window Size of 3



TCP provides sequencing of segments with a forward reference acknowledgment. Each datagram is numbered before transmission, as shown in Figure 9-8. At the receiving station, TCP reassembles the segments into a complete message. TCP must recover from data that is damaged, lost, duplicated, or delivered out of order by the Internet communication system. This is achieved by assigning a sequence number to each octet transmitted and requiring a positive acknowledgment (ACK) from the receiving TCP. If the ACK is not received within a timeout interval, the data is retransmitted. At the receiver, the sequence numbers are used to correctly order segments that might be received out of order and to eliminate duplicates. Damage is handled by adding a checksum to each segment transmitted, checking it at the receiver, and discarding damaged segments.

Figure 9-8 TCP Sequence and Acknowledgment



TCP

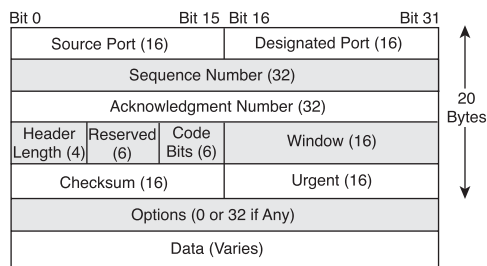
Transmission Control Protocol (TCP) is a connection-oriented transport layer protocol that provides reliable full-duplex data transmission. TCP is part of the TCP/IP protocol stack. In a connection-oriented environment, a connection is established between both ends before transfer of information can begin. TCP is responsible for breaking messages into segments, reassembling them at the destination station, resending anything that is not received, and reassembling messages from the segments. TCP supplies a virtual circuit between end-user applications.

These protocols use TCP:

- File Transfer Protocol (FTP)
- Hypertext Transfer Protocol (HTTP)
- Simple Mail Transfer Protocol (SMTP)
- Domain Name System (DNS)

Figure 9-9 shows the TCP segment format.

Figure 9-9 TCP Segment Format



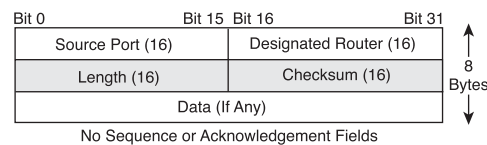
The following list defines the fields in the TCP segment shown in Figure 9-9:

- **Source Port**—Number of the calling port
- **Destination Port**—Number of the called port
- **Sequence Number**—Number used to ensure correct sequencing of the arriving data
- **Acknowledgment Number**—Next expected TCP octet
- **HLEN**—Number of 32-bit words in the header
- **Reserved**—Set to 0
- **Code Bits**—Control functions (such as setup and termination of a session)
- **Window**—Number of octets that the sender is willing to accept
- **Checksum**—Calculated checksum of the header and data fields
- **Urgent Pointer**—Indication of the end of the urgent data
- **Options**—One option currently defined—maximum TCP segment size
- **Data**—Upper-layer protocol data

UDP

User Datagram Protocol (UDP), the segment format for which is shown in Figure 9-10, is the connectionless transport protocol in the TCP/IP protocol stack. UDP is a simple protocol that exchanges datagrams without acknowledgments or guaranteed delivery. This simplicity is evident when comparing the UDP segment format with that of TCP. Error processing and retransmission must be handled by upper-layer protocols. For example, if a TFTP download gets interrupted for some reason, the human operator can just retry until it is successfully done.

Figure 9-10 UDP Segment Format



The following list defines the fields in the UDP segment shown in Figure 9-10:

- **Source Port**—Number of the calling port
- **Destination Port**—Number of the called port
- **Length**—Number of bytes, including header and data
- **Checksum**—Calculated checksum of the header and data fields
- **Data**—Upper-layer protocol data

UDP uses no windowing or acknowledgments; therefore, *application layer* protocols provide reliability. UDP is designed for applications that do not need to put sequences of segments together.

These protocols use UDP:

- Trivial File Transfer Protocol (TFTP)
- Simple Network Management Protocol (SNMP)
- Dynamic Host Configuration Protocol (DHCP)
- Domain Name System (DNS)

TCP and UDP Port Numbers

Both TCP and UDP use port numbers to pass information to the upper layers. The combination of an IP address and a port number is referred to as a socket. Port numbers are used to keep track of different conversations crossing the network at the same time.

Application software developers agree to use well-known port numbers that are controlled by the Internet Assigned Numbers Authority (IANA). For example, any conversation bound for the FTP application uses the standard port numbers 20 (for the data) and 21 (for control), as shown in Figure 9-11. Conversations that do not involve an application with a well-known port number are assigned port numbers randomly from within a specific range above 1023. Some ports are reserved in both TCP and UDP, but applications might not be written to support them, as shown in Table 9-1. Port numbers have the assigned ranges shown in this table.

Figure 9-11 Port Numbers

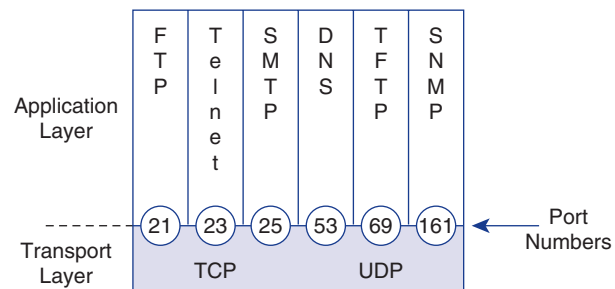


Table 9-1 Reserved TCP and UDP Port Numbers

Decimal Port Number	Keyword	Description
0	—	Reserved
1 to 4	—	Unassigned
5	Rje	Remote job entry
7	Echo	Echo
9	Discard	Discard
11	Users	Active users
13	Daytime	Daytime
15	Netstat	Who is up, or netstat
17	Quote	Quote of the day
19	Chargen	Character generator
20	ftp-data	File Transfer Protocol (data)
21	ftp	File Transfer Protocol
23	telnet	Terminal connection
25	Sntp	Simple Mail Transfer Protocol
37	Time	Time of day
39	Rlp	Resource Location Protocol
42	Nameserver	Host name server
43	nickname	Who is
53	Domain	Domain Name Server
67	Bootps	Bootstrap protocol server
68	Bootpc	Bootstrap protocol client
69	Tftp	Trivial File Transfer Protocol
75	—	Any private dial-out service
77	—	Any private RJE service

continues

Table 9-1 Reserved TCP and UDP Port Numbers (Continued)

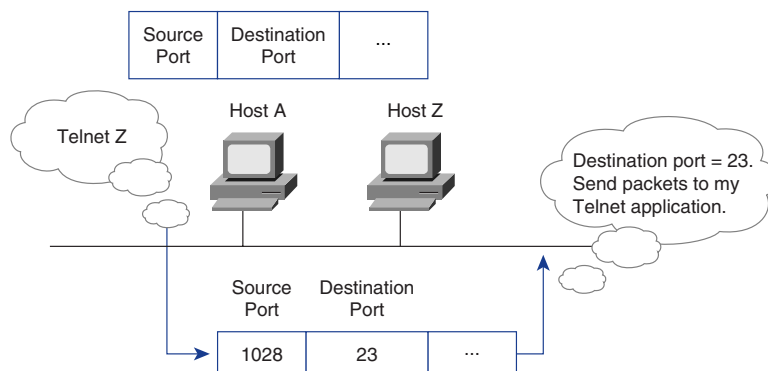
Decimal Port Number	Keyword	Description
79	Finger	Finger
80	HTTP	Hypertext Transfer Protocol
123	Ntp	Network Time Protocol
133 to 159	—	Unassigned
160 to 223	—	Reserved
224 to 241	—	Unassigned
242 to 255	—	Unassigned

Numbers below 1024 are considered well-known port numbers.

Numbers above 1024 are assigned port numbers dynamically.

Registered port numbers are those registered for vendor-specific applications. Most are above 1024.

As shown in Figure 9-12, end systems use port numbers to select the proper application. Originating source port numbers are assigned dynamically by the source host, with some number greater than 1023. As an example, a host attempting to connect to another using FTP sends a packet with a destination TCP port number of 21 (FTP) and a dynamically generated source port number such as 1028. This pair of port numbers (destination and source) defines the unique “conversation” between these hosts. If the same host initiates another FTP session to a second host, the destination port still is 21, but the source port generated is different (for example, 1030), to keep the two sessions separate.

Figure 9-12 Port Numbers Dictate Application Used

TCP/IP Application Layer

The last layer of both the OSI and the TCP/IP model is referred to as the application layer. The application layer is the closest to the end user when interacting with software applications such as sending and receiving e-mail over a network. You see how the application layer deals with data packets from client/server applications, domain name services, and network applications by examining the following elements:

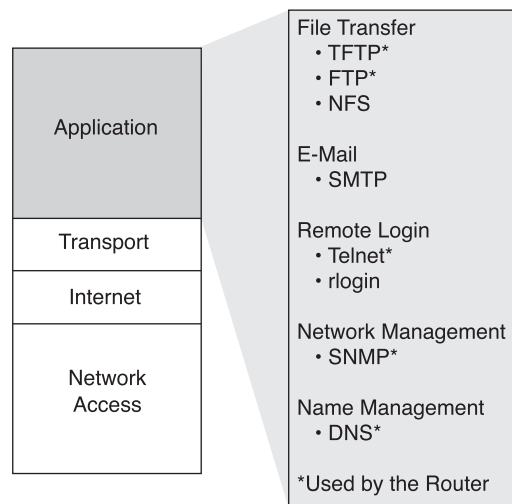
- Client/server
- Redirectors
- Domain Name System
- E-mail
- Telnet
- FTP
- HTTP

Introduction to the Application Layer

In the context of the OSI reference model, the application layer (Layer 7) supports the communicating component of an application, as shown in Figure 9-13. The application layer is responsible for the following:

- Identifying and establishing the availability of intended communication partners
- Synchronizing cooperating applications
- Establishing agreement on procedures for error recovery
- Controlling data integrity

Figure 9-13 Application Layer



The application layer is the layer closest to the end user. This determines whether sufficient resources exist for communication between systems. Without the application layer, there would be no network communication support. The application layer does not provide services to any other layer, but it does provide services to application processes lying outside the scope of the TCP/IP model, such as spreadsheet programs, word processing programs, and banking terminal programs. Additionally, the application layer provides a direct interface to the rest of the model for network applications (such as browser or e-mail program) or an indirect interface for standalone applications (such as word processors, spreadsheets, and presentation managers) with a network redirector.

Direct Network Applications

Most applications that work in a networked environment are classified as client/server applications. These applications, such as FTP clients (not protocols), web browsers, and e-mail programs, all have two components that allow them to function—the client side and the server side. The client side is located on the local computer and is the requestor of the services. The server side is located on a remote computer and provides services in response to the client's requests.

A client/server application works by constantly repeating the following looped routine: client request, server response; client request, server response. For example, a web browser accesses a web page by requesting a uniform resource locator (URL), which is resolved to an IP address on a remote web server. After it locates the URL, the web server that is identified by that URL responds to the request. Then, based on the information received from the web server, the client can request more information from the same web server or can access another web page from a different web server.

Netscape Navigator and Internet Explorer are probably the most commonly used network applications. An easy way to understand a web browser is to compare it to a television remote control. A remote control gives you the capability to directly control a TV's functions: volume, channels, brightness, and so on. For the remote control to function properly, you do not need to understand how the remote control functions electronically. The same is true of a web browser; the browser gives you the capability to navigate through the web by clicking hyperlinks. For the web browser to function properly, it is not necessary for you to understand how the lower-layer OSI protocols work and interact.

Indirect Network Support

Within a LAN environment, indirect-application network support is also a client/server function. If a client wants to save a file from a word processor to a network server, the

redirector enables the word-processing application to do so transparently. Remember that this transparency is supplied by the session layer Remote Procedure Call (RPC) functionality.

A redirector is an OSI model session layer function that works with computer operating systems and network clients instead of specific application programs.

Examples of protocols that use redirectors are as follows:

- AppleTalk Filing Protocol
- NetBIOS Extended User Interface (NetBEUI)
- Novell IPX/SPX protocols
- Network File System (NFS) of the TCP/IP protocol suite

A redirector enables a network administrator to assign remote resources to logical names on the local client. When you select one of these logical names to perform an operation such as saving a file or printing a file, the network redirector sends the selected file to the proper remote resource on the network for processing. If the resource is on a local computer, the redirector ignores the request and allows the local operating system to process the request.

The advantage of using a network redirector on a local client is that the applications on the client never have to recognize the network. In addition, the application that requests service is located on the local computer, and the redirector reroutes the request to the proper network resource, while the application treats it as a local request.

Redirectors expand the capabilities of non-network software. They also enable users to share documents, templates, databases, printers, and many other resource types without having to use special application software.

Networking has had a great influence on the development of programs such as word processors, spreadsheets, presentation managers, database programs, graphics, and productivity software. Many of these software packages are now network-integrated or network-aware; they have the capabilities of launching integrated web browsers or Internet tools and publishing their output to the *Hypertext Markup Language (HTML)* for easy web integration.

Making and Breaking a Connection

It is important to note that in each of the examples mentioned in the preceding sections, the connection to the server was maintained only long enough to complete a single task. In the web example, the connection was maintained just long enough to download the current web page. In the printer example, the connection was maintained just long

enough to send the document to the print server. After the processing was completed, the connection was broken and had to be re-established for the next processing request to take place. This is one of the two ways that communication sessions take place.

Later in this chapter, you learn about the second method in which communication sessions take place. This is illustrated by the Telnet and FTP examples, in which a connection to the server is established and maintained until all processing has been performed. The client computer terminates the connection when the user determines that he or she has finished. All communication activity falls into one of these two categories. In the next section, you learn about the *Domain Name System (DNS)*, which is supported by the application layer processes.

DNS

The Internet is built on a hierarchical addressing scheme. This allows for routing that is based on classes of addresses, as opposed to individual addresses. The problem that this creates for the user is associating the correct address with the Internet site. The only difference between the addresses 198.151.11.12 and 198.151.11.21 is one transposed digit. It is very easy to forget an address to a particular site because there is nothing to associate the contents of the site with its address.

To associate the contents of the site with its address, a domain-naming system was developed. DNS is a system used on the Internet for translating names of domains and their publicly advertised network nodes into IP addresses. A domain is a group of computers that are associated by their geographical location or their business type. A domain name is a string of characters and/or numbers, usually a name or abbreviation that represents the numeric address of an Internet site. More than 200 top-level domains exist on the Internet; examples include the following:

- **.us**—United States
- **.uk**—United Kingdom

There are also generic names, examples of which include the following:

- **.edu**—Educational sites
- **.com**—Commercial sites
- **.gov**—Government sites
- **.org**—Nonprofit sites
- **.net**—Network service
- **.mil**—U.S. military sites
- **.int**—International database/treaty organization sites

NOTE

For more information on domain names, visit the IANA website (www.iana.org/domain-names.htm) for domain names.

The Domain Name Server

The Domain Name System (DNS) server is a device on a network that responds to requests from clients to translate a domain name into the associated IP address. The DNS system is set up in a hierarchy that creates different levels of DNS servers.

If a local DNS server is capable of translating a domain name into its associated IP address, it does so and returns the result to the client. If it cannot translate the address, it passes the request up to the next higher-level DNS server on the system, which then tries to translate the address. If the DNS server at this level is capable of translating the domain name into an associated IP address, it does so and returns the result to the client. If not, it sends the request to the next higher level. This process repeats itself until the domain name has been translated or until the top-level DNS server has been reached. If the domain name cannot be found on the top-level DNS server, it is considered to be an error and the corresponding error message is returned. Any type of application that uses domain names to represent IP addresses uses the DNS server to translate that name into its corresponding IP address.

FTP and TFTP

The *File Transfer Protocol (FTP)* is designed to download files (received or gotten from the Internet) and upload files (sent or put to the Internet). The capability to upload and download files is one of the most valuable features of the Internet. This is especially helpful for people who rely on computers for many purposes and who might need software drivers and upgrades immediately. Network administrators rarely can wait even a few days to get the necessary drivers that enable their network servers to function again. The Internet can provide these files immediately by using FTP. Like e-mail and Telnet, FTP is a client/server application. It requires server software running on a host that can be accessed by client software.

An FTP session is established the same way in which a Telnet session is established. Just like Telnet, the FTP session is maintained until the client terminates it or until there is some sort of communication error. When you establish a connection to an FTP process or daemon, you must supply a login ID and a password. Normally, you use Anonymous as the login ID and your e-mail address as the password. This type of connection is known as *anonymous FTP*. After your identity is established, a command link opens between your client machine and the FTP server. This is similar to a Telnet session, in which commands are sent and executed on the server and the results are returned to the client. This feature enables you to create and change folders, erase and rename files, and execute many other functions associated with file management.

The main purpose of FTP is to transfer files from one computer to another by copying and moving files from servers to clients and from clients to servers. When you copy files from a server, FTP establishes a second connection, a data link between the computers, across which the data is transferred. Data transfer can occur in American Standard Code for Information Interchange (ASCII) mode or binary mode. These two modes determine how the data file is to be transferred between the stations. ASCII format returns a human-readable representation of the number in seven ASCII characters. The first character is a space or a negation sign, followed by three digits, a decimal point, and two more digits. If a number has less than three digits to the left of the decimal point, then the optional sign and digits are right-justified in the seven character field, and spaces are filled in on the left. Because binary-mode numbers take only 4 bytes each, compared to the 7 of an ASCII representation, the binary representation takes less time to send over the serial link to the computer. However, there are marked advantages to using the ASCII representation. After the file transfer has ended, the data connection terminates automatically. After you complete the entire session of copying and moving files, you might log off, thus closing the command link and ending the session.

The *Trivial File Transport Protocol (TFTP)* is a connectionless service that uses UDP. TFTP is used on routers and switches to transfer configuration files and Cisco IOS Software images, and to transfer files between systems that support TFTP. It is designed to be small and easy to implement. Therefore, it lacks most of the features of regular FTP. The only thing it can do is read and write files (or mail) from or to a remote server. It cannot list directories, and currently it has no provisions for user authentication. It is useful in some LANs because it operates faster than FTP in a stable environment.

Another protocol that has the capability to download files is Hypertext Transfer Protocol (HTTP), as discussed in the next section. One limitation of HTTP is that you can use it only to download files, not upload them.

HTTP

The *Hypertext Transfer Protocol (HTTP)* works with the World Wide Web, which is the fastest-growing and most used part of the Internet. One of the main reasons for the extraordinary growth of the web is the ease in which it allows access to information. A web browser is a client/server application, which means that it requires both a client and a server component to function. A web browser presents data in multimedia formats on web pages that use text, graphics, sound, and video. The web pages are created with a format language called the Hypertext Markup Language (HTML). HTML directs a web browser on a particular web page to produce the appearance of the page in a specific manner. In addition, HTML specifies locations for the placement of text, files, and objects that are to be transferred from the web server to the web browser.

Hyperlinks make the World Wide Web easy to navigate. A hyperlink is an object (word, phrase, or picture) on a web page that, when clicked, transfers you to a new web page. The web page contains (often hidden within its HTML description) an address location known as a uniform resource locator (URL).

Table 9-2 shows the components of a standard URL address (<http://www.cisco.com/edu/> in this case).

Table 9-2 URL Components

http://	www.	Cisco.com	/cgi/
Identifies to the browser what protocol should be used.	Identifies what type of site is being contacted by the browser.	Represents the domain entry of the web site.	Identifies the folder where the web page is located on the server. Also, because no name is specified, the browser loads the default page identified by the server.

When you open a web browser, the first thing you usually see is a starting (or “home”) page. The URL of the home page already has been stored in the configuration area of your web browser and can be changed at any time. From the starting page, you can click one of the web page hyperlinks or type a URL in the browser’s address bar. The web browser then examines the protocol to determine whether it needs to open another program, and it determines the IP address of the web server. After that, the transport layer, network layer, data link layer, and physical layer initiate a session with the web server. The data that is transferred to the HTTP server contains the folder name of the web page location (the data also can contain a specific filename for an HTML page). If no name is given, the server uses a default name (as specified in the server’s configuration).

The server responds to the request by sending all of the text, audio, video, and graphic files, as specified in the HTML instructions, to the web client. The client browser reassembles all the files to create a view of the web page and then terminates the session. If you click another page that is located on the same server or a different server, the whole process begins again.

SMTP

E-mail servers communicate with each other using the Simple Mail Transfer Protocol (SMTP) to send and receive mail. The SMTP protocol transports e-mail messages in ASCII format using TCP. You can connect to an SMTP server by performing a ping test to the SMTP port (25). This is a good way to test if a mail server is reachable.

When a mail server receives a message destined for a local client, it stores that message and waits for the client to collect the mail. Mail clients can collect their mail in several ways: They can use programs that access the mail server files directly or can use one of many network protocols. The most popular mail client protocols are Post Office Protocol Version 3 (POP3) and Internet Messaging Access Protocol Version 4 (IMAP4), which both use TCP to transport data. Even though mail clients use these special protocols to collect mail, they almost always use SMTP to send mail. Because two different protocols, and possibly two different servers, are used to send and receive mail, it is possible that mail clients can perform one task and not the other. Therefore, you should troubleshoot the sending of mail and the receiving of mail separately.

When verifying the configuration of a mail client, both the mail relay server (SMTP) and mail servers (POP or IMAP) should be verified. SMTP does not offer much in the way of security and does not require any authentication. To prevent unauthorized users from bouncing mail messages off their servers, administrators often don't allow hosts that are not part of their network to use their SMTP server to send (or relay) mail.

SNMP

The *Simple Network Management Protocol (SNMP)* is an application layer protocol that facilitates the exchange of management information between network devices. SNMP enables network administrators to manage network performance, find and solve network problems, and plan for network growth.

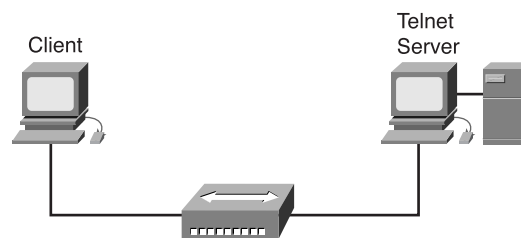
An SNMP-managed network consists of the following three key components:

- **Managed device**—A network node that contains an SNMP agent and that resides on a managed network. Managed devices collect and store management information and make this information available to NMSs using SNMP. Managed devices, sometimes called network elements, can be routers and access servers, switches and bridges, hubs, computer hosts, or printers.
- **Agent**—A network-management software module that resides in a managed device. An agent has local knowledge of management information and translates that information into a form compatible with SNMP.
- **Network-management system (NMS)**—Executes applications that monitor and control managed devices. NMSs provide the bulk of the processing and memory resources required for network management. One or more NMSs must exist on any managed network.

Telnet

Terminal emulation (*Telnet*) software provides the capability to remotely access another computer. It enables you to log in to an Internet host and execute commands. Telnet commonly is used for remote administration of servers and network equipment such as routers and switches. A Telnet client is referred to as a *local host*, and a Telnet server, which uses special software called a daemon, is referred to as a *remote host*, as shown in Figure 9-14.

Figure 9-14 Telnet



To make a connection from a Telnet client, you must select a connection option. The host name and terminal type will need to be entered on the command-line prompt. The host name is the IP address (DNS) of the remote computer to which you connect. The terminal type describes the type of terminal emulation that you want the computer to perform. The Telnet operation uses none of the transmitting computer's processing power. Instead, it transmits the keystrokes to the remote host and sends the resulting screen output back to the local monitor. All processing and storage takes place on the remote computer.

When a DNS name for a Telnet location is entered, the name must be translated into its associated IP address before a connection can be established. The Telnet application works mainly at the top three layers of the OSI model—the application layer (commands), the presentation layer (formats, usually ASCII), and the session layer (transmits). The data then passes to the transport layer, where it is segmented, and the port address and error checking are added. The data then passes to the network layer, where the IP header (containing the source and destination IP addresses) is added. Next, the packet travels to the data link layer, which encapsulates the packet in a data frame, adds the source and destination MAC address, and adds a frame trailer. If the source computer doesn't have the MAC address of the destination computer, it performs an ARP request. When the MAC address has been determined, the frame travels across the physical medium (in binary form) to the next device. Telnet is a good network troubleshooting tool because it tests all seven layers of the OSI model and allows remote diagnostics to be performed.

When the data reaches the remote host computer, the data link layer, the network layer, and the transport layer reassemble the original data commands. The remote host computer executes the commands and transmits the results back to the local client computer by using the same process of encapsulation that delivered the original commands. This whole process repeats itself, sending commands and receiving results until the local client has completed the work that needs to be done. When the work is done, the client terminates the session.

Summary

In this chapter, you learned about the functions of the TCP/IP application layer and transport layer. You also learned about the different processes that occur as data packets travel through this layer. More specifically, you learned that the application layer is responsible for these actions:

- Identifies and establishes the availability of intended communication partners
- Synchronizes cooperating applications
- Establishes agreement on procedures for error recovery
- Controls data integrity

In addition, you learned that the application layer supports the following:

- Direct and indirect network applications
- The Domain Name System
- Telnet, FTP, and HTTP
- TCP, UDP, SMTP, and SNMP

To supplement all that you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab Activities on the CD-ROM accompanying this book.

Key Terms

acknowledgment Notification sent from one network device to another to acknowledge that some event (for example, receipt of a message) occurred. Sometimes abbreviated ACK.

application A program that performs a function directly for a user. FTP and Telnet clients are examples of network applications.

application layer Layer 7 of the OSI reference model. This layer provides services to application processes (such as e-mail, file transfer, and terminal emulation) that are outside the OSI reference model. The application layer identifies and establishes the availability of intended communication partners (and the resources required to connect with them), synchronizes cooperating applications, and establishes agreement on procedures for error recovery and control of data integrity.

ASCII (American Standard Code for Information Interchange) An 8-bit code (7 bits plus parity) for character representation.

DNS (Domain Name System) The system used in the Internet for translating names of network nodes into addresses.

flow control A technique for ensuring that a transmitting entity does not overwhelm a receiving entity with data. When the buffers on the receiving device are full, a message is sent to the sending device to suspend the transmission until the data in the buffers has been processed. In IBM networks, this technique is called pacing.

FTP (File Transfer Protocol) An application protocol, part of the TCP/IP protocol stack, used for transferring files between network nodes. FTP is defined in RFC 959.

HTML (Hypertext Markup Language) A simple hypertext document formatting language that uses tags to indicate how a given part of a document should be interpreted by a viewing application, such as a web browser.

HTTP (Hypertext Transfer Protocol) The protocol used by web browsers and web servers to transfer files, such as text and graphics files.

port In IP terminology, an upper-layer process that receives information from lower layers. Ports are numbered, and many are associated with a specific process. For example, SMTP is associated with port 25. A port number of this type is called a well-known port or address.

TCP (Transmission Control Protocol) A connection-oriented transport-layer protocol that provides reliable full-duplex data transmission. TCP is part of the TCP/IP protocol stack.

Telnet A standard terminal emulation protocol in the TCP/IP protocol stack. Telnet is used for remote terminal connection, enabling users to log in to remote systems and use resources as if they were connected to a local system. Telnet is defined in RFC 854.

TFTP (Trivial File Transfer Protocol) A simplified version of FTP that allows files to be transferred from one computer to another over a network.

three-way handshake A sequence of messages exchanged between two or more network devices to ensure transmission synchronization before sending user data.

UDP (User Datagram Protocol) A connectionless transport layer protocol in the TCP/IP protocol stack. UDP is a simple protocol that exchanges datagrams without acknowledgments or guaranteed delivery, requiring that error processing and retransmission be handled by other protocols. UDP is defined in RFC 768.

windowing A flow-control mechanism requiring that the source device receive an acknowledgment from the destination after transmitting a certain amount of data.

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. When conversing with an individual whose primary language is different than yours, you might need to repeat your words and speak more slowly. Repeating your words can be compared to _____, and the need to speak slowly can be compared to the _____ functions of the transport layer.
 - A. Reliability; flow control
 - B. Flow control; reliability
 - C. Transport; acknowledgment
 - D. Flow control; transport
2. The following characteristics describe what TCP/IP protocol: connection-oriented; resends anything not received; divides outgoing messages into segments.
 - A. IPX
 - B. TCP
 - C. UDP
 - D. SPS

3. What does the window field in a TCP segment indicate?
 - A. Number of 32-bit words in the header
 - B. Number of the called port
 - C. Number used to ensure correct sequencing of the arriving data
 - D. Number of octets that the device is willing to accept
4. What transport protocol exchanges datagrams without acknowledgments or guaranteed delivery?
 - A. UDP
 - B. TCP
 - C. IRQ
 - D. LLC
5. What do TCP and UDP use to keep track of different conversations crossing a network at the same time?
 - A. Port numbers
 - B. IP addresses
 - C. MAC addresses
 - D. Route numbers
6. How does TCP synchronize a connection between the source and the destination before data transmission?
 - A. Two-way handshake
 - B. Three-way handshake
 - C. Four-way handshake
 - D. Holton functions
7. Which range of port numbers is unregulated?
 - A. Below 255
 - B. Between 256 and 512
 - C. Between 256 and 1023
 - D. Above 1023

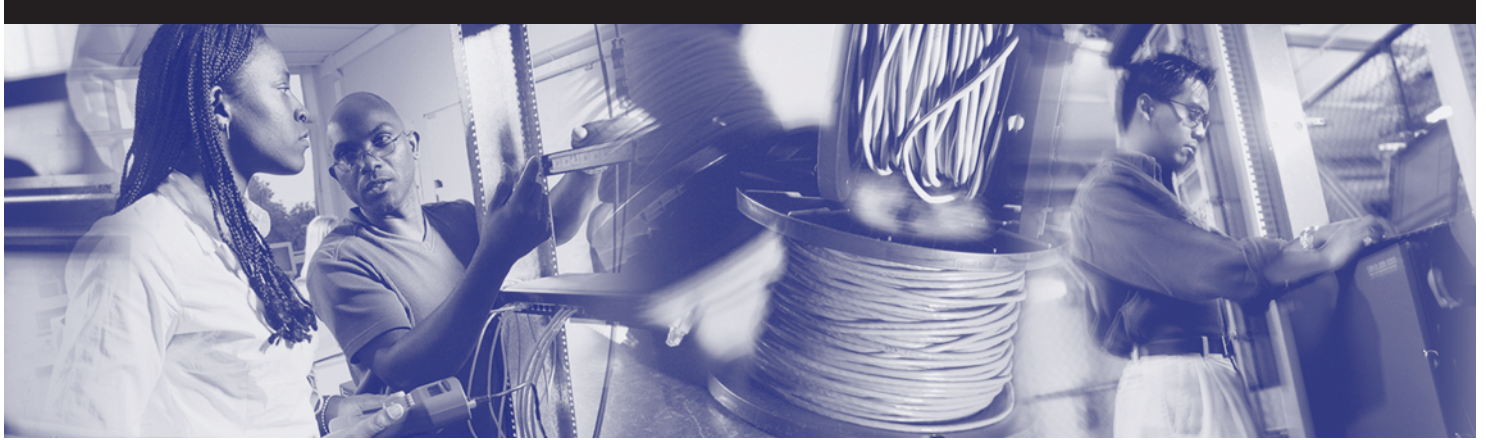
504 Chapter 9: TCP/IP Transport and Application Layer

8. With TCP transmission, what occurs if a segment is not acknowledged in a certain time period?
 - A. UDP takes over the transmission.
 - B. The virtual circuit is terminated.
 - C. Nothing happens.
 - D. Retransmission occurs.
9. Which best describes flow control?
 - A. A method of managing limited bandwidth
 - B. A method of connecting two hosts synchronously
 - C. A method of preventing buffer overrun
 - D. A method of checking data for viruses before transmission
10. Which of the following best describes the purpose of the TCP/IP protocol stack?
 - A. Maps closely to the OSI reference model's upper layers
 - B. Supports all standard physical and data link protocols
 - C. Transfers information from one host to another in a sequence of datagrams
 - D. Reassembles datagrams into complete messages at the receiving location
11. Which of the following is one of the protocols found in the transport layer?
 - A. UCP
 - B. UDP
 - C. TDP
 - D. TDC
12. What is the purpose of port numbers?
 - A. They keep track of different upper-layer conversations crossing the network at the same time.
 - B. Source systems use them to keep a session organized.
 - C. End systems use them to assign end users dynamically to a particular session, depending on their application use.
 - D. Source systems generate them to predict destination addresses.

13. Why are TCP three-way handshake/open connections used? Select all that apply.
- A. To ensure that lost data can be recovered if problems occur later
 - B. To determine how much data the receiving station can accept at one time
 - C. To provide efficient use of bandwidth by users
 - D. To change binary ping responses into information in the upper layers
14. What does a dynamic TCP window field do?
- A. It makes the window larger so that more data can come through at once, which results in more efficient use of bandwidth.
 - B. The window size slides to each section of the datagram to receive data, which results in more efficient use of bandwidth.
 - C. It allows the window size to be negotiated dynamically during the TCP session, which results in more efficient use of bandwidth.
 - D. It limits the incoming data so that each segment must be sent one by one, which is an inefficient use of bandwidth.
15. UDP segments use what protocols to provide reliability?
- A. Network layer protocols
 - B. Application layer protocols
 - C. Internet protocols
 - D. Transmission control protocols
16. A network redirector enables data to travel _____.
- A. Only to a network print server
 - B. Only to a network file server
 - C. In a single direction
 - D. None of the above
17. An example of a client/server application is _____.
- A. E-mail
 - B. A spreadsheet
 - C. A NIC
 - D. Hard-drive utilities

18. The client side of the client/server relationship is _____.
- A. Located on the remote computer
 - B. The requestor of services
 - C. The most important
 - D. Always located on the server
19. Which of the following best describes a domain name?
- A. It represents the numeric address of an Internet site.
 - B. It is the same as the name you give your primary server.
 - C. It represents the specific location where your LAN is located.
 - D. It is an IP address used to represent a print server.
20. .com is the domain typically assigned to _____.
- A. Client machines
 - B. Customers
 - C. Network provider companies
 - D. Corporations
21. During a Telnet connection, the remote computer is responsible for _____.
- A. Nothing
 - B. Processing
 - C. Client-side Telnet application
 - D. Client-side printing
22. At which three layers of the OSI model does Telnet primarily work?
- A. Application layer, session layer, transport layer
 - B. Presentation layer, session layer, transport layer
 - C. Data link layer, transport layer, presentation layer
 - D. Application layer, presentation layer, session layer

23. Typical anonymous FTP sessions use _____ as the login ID and _____ as the password.
- A. Anonymous; the user e-mail address
 - B. The user e-mail address; FTP
 - C. FTP; FTP
 - D. Guest; anonymous
24. Instead of working with specific application programs, redirectors work with _____.
- A. Computer operating systems
 - B. Spreadsheets
 - C. E-mail
 - D. Web browsers



Objectives

Upon completion of this chapter, you will be able to

- Identify different types of WAN connections, encapsulations, and protocols
- Know the difference between a WAN and LAN and which type of addresses each uses



Chapter 10

WANs and Routers

In this chapter, you learn about WAN devices, technologies, and standards. In addition, you learn about the function of a router in a WAN.

Please be sure to look at this chapter's e-Labs, Videos, and PhotoZooms that you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

WAN Characteristics

A *wide-area network (WAN)* is a data communications network that extends across a large geographic area. WANs often use transmission facilities provided by common carriers, for example, telephone companies.

A WAN differs from a local-area network (LAN) in several ways. For example, unlike a LAN, which connects workstations, peripherals, terminals, and other devices in a single building or other small geographic area, a WAN makes data connections across a broad geographic area. Companies use a WAN to connect various company sites so that information can be exchanged between distant offices.

A WAN operates at the physical layer (Layer 1) and the data link layer (Layer 2) of the OSI reference model. It interconnects LANs that are usually separated by large geographic areas. WANs provide for the exchange of data packets/frames between *routers/switches* and the LANs they support.

Table 10-1 lists some CPU information indicative of specific examples of data networks.



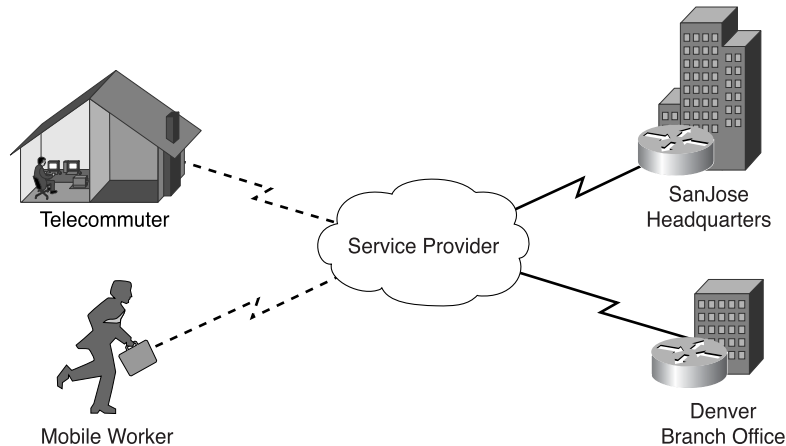
Table 10-1 Data Networks

Name	Location of Hosts	Distances Between Devices
LAN Classroom	Room	10 m
LAN School	Building	100 m
LAN University	Campus	1000 m = 1 km
WAN Cisco Systems, Inc.	Country	100,000 m = 100 km
WAN Africa	Continent	1,000,000 m = 1000 km
WAN Internet	Planet	10,000,000 m = 10,000 km
WAN Earth and Artificial Satellites	Earth-Moon Systems	100,000,000 m = 100,000 km

As shown in Figure 10-1, the major characteristics of WANs are as follows:

- They connect devices that are separated by wide geographical areas.
- They use the services of carriers such as the regional Bell operating companies (RBOCs), Sprint, and MCI.
- They use serial connections of various types to access bandwidth over large geographic areas.
- They connect devices that are separated by wide geographical areas.

Figure 10-1 WAN Connection



More Information: WAN Performance Criteria

Component Uptime

Each physical component of the WAN can be monitored and measured for its availability using uptime. **Uptime** is the opposite of downtime: It is the amount of time that the device is functional and in service relative to the users' requirements for its availability. It is common for uptime to be statistically overstated by measuring it on a 7-day-24-hour basis, even though the users' requirements might be for only 5 days-a-week 12 hours a day. Remember to tailor this metric and every other metric as closely as possible to your users' stated requirements for network performance.

Although electronic devices are highly reliable, they eventually fail. Most manufacturers provide a *mean time between failure (MTBF)* rating for their equipment as a reassurance of how reliable their products really are. Typically, MTBF ratings are in the tens of thousands of hours. These hours could conceivably translate into years of trouble-free service. Unfortunately, these ratings are statistically derived. The actual time between failures of any given device depends greatly on a number of factors, including the following:

- Ambient temperature ranges of the operating environment
- Cleanliness of the commercial electric power
- Quality of the handling of the devices before and during operation

Monitoring and tracking uptime of individual components enables you to demonstrate to your user community how well you are satisfying their requirements for the network's availability. Component uptime data can also be charted over time to identify potentially problematic components in your network infrastructure. Such trends can provide information about the general reliability of a given type or brand of hardware, which then can be used to identify individual components that might be at risk of failure.

continues

More Information: WAN Performance Criteria (Continued)

Note that the term *availability* is sometimes used to generically describe aggregate network uptime. Unfortunately, it is not a good metric. In theory, network availability provides a quantified synopsis of the network's readiness. In practice, availability is so nebulous that it is virtually meaningless.

To illustrate this point, if a router at a premise location fails, the entire network is unavailable to the users at that location. The network, however, is available to users at every other location. They will not be able to access hosts at the affected location, but they will also not be impeded from accessing every other host in the network. The extent to which the network is available varies greatly by location and by usage requirements. Therefore, quantifying network availability can be more onerous than it is valuable.

Traffic Volumes

One of the more important metrics for any WAN is the volume of traffic that it is expected to support. Volume is almost always volatile; it varies with time, business cycles, seasons, and so on. In other words, you can count on traffic volumes being anything but constant. Given this volatility, it is important to measure volumes in two different ways, maximum volumes and average volumes:

- The maximum volume that you expect the network to support is known as the *peak volume*. As its name implies, this peak volume is the greatest amount of traffic that you expect the network to have to support.
- *Average volumes* are the traffic loads that you can reasonably expect during the course of a business day from any given work location.

Establishing these two traffic volumes is critical to sizing the WAN's transmission facilities, as well as the facilities of its routers. If you expect any given location to generate a traffic load of 100 kbps during the course of a business day, for example, a 56-kbps transmission facility is clearly inadequate.

Delay

Delay is one of the more common metrics that can be used to measure network performance. *Delay* is the time that elapses between two events. In data communications, these two events are typically the transmission and reception of data. Therefore, delay is the total amount of time that is required by the network to transport a packet from its point of origin to its destination. Given this definition, delay is an aggregate phenomenon with many potential causes.

Three of the more common types of delay are the following:

- **Propagation delay**—Propagation delay is the cumulative amount of time required to transmit, or propagate, the data across an end-to-end transmission path. The network infrastructure within each transmission facility in the network path directly contributes to the aggregate forwarding delay of any given transmission. An additional factor in propagation delay is traffic volume. The more traffic that is flowing across a given facility, the less bandwidth that is available for new transmissions. Propagation delay is inherent in terrestrial circuits, regardless of whether they traverse glass or copper media or are transmitted through the air using microwave radio frequencies.

More Information: WAN Performance Criteria (Continued)

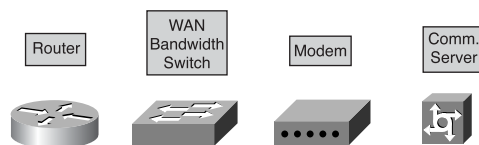
- **Satellite uplink/downlink delays**—Some transmission facilities are satellite-based, requiring the signal to be transmitted up to the satellite and then transmitted back down from the satellite. Because of the great distances between the terrestrial transmission facilities and the satellite, these delays can be quite noticeable.
- **Forwarding delay**—Forwarding delay in a network is the amount of time that a physical device needs to receive, buffer, process, and forward data. The actual forwarding delay of any given device can vary over time. Individual devices operating at or near capacity will likely experience a greater forwarding delay than comparable devices that are less utilized. Additionally, forwarding delay can be exacerbated by heavy traffic or error conditions in the network. Forwarding delay can be described as latency within individual components.

WAN Devices

The following devices are used in WANs, as represented in Figure 10-2:

- **Routers**—Offer many services, including internetworking and WAN interface ports.
- **Switches**—Connect to WAN bandwidth for voice, data, and video communication.
- **Modems**—Include interfaces to voice-grade services (analog dialup modems); channel service units/digital service units (CSU/DSUs) that interface T1/E1 services; and terminal adapters/Network Termination 1s (TAs/NT1s) that interface Integrated Services Digital Network (ISDN) services.
- **Communication servers**—Concentrate dial-in and dial-out user communication.

Figure 10-2 Common WAN Devices

**WAN Standards**

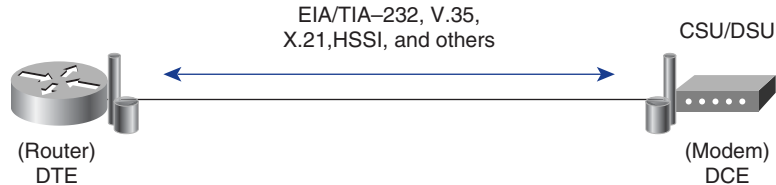
WAN data-link protocols describe how frames are carried between systems on a single data link. They include protocols designed to operate over dedicated point-to-point, multipoint, and multiaccess switched services, such as Frame Relay. WAN standards are defined and managed by a number of recognized authorities, including the following agencies:

- **International Telecommunication Union-Telecommunication Standardization Sector (ITU-T)**, formerly the Consultative Committee for International Telegraph and Telephone (CCITT)

- International Organization for Standardization (ISO)
- Internet Engineering Task Force (IETF)
- Electronic Industries Association (EIA)
- Institute of Electrical and Electronics Engineers (IEEE)

The WAN physical layer describes the interface between the *data terminal equipment (DTE)* and the *data circuit-terminating equipment (DCE)*. Typically, a DCE device is service provider equipment that provides clocking and switching services within a network, and a DTE device is an attached customer device. In this model, the services offered to the DTE are made available through a modem or a CSU/DSU (see Figure 10-3).

Figure 10-3 WAN Services



To ensure that the correct protocol is used, you must configure the appropriate Layer 2 encapsulation on the router. The choice of the protocol depends on the WAN technology and communicating equipment being utilized.

WAN physical layer protocols describe how to provide electrical, mechanical, operational, and functional connections for WAN services. These services are usually obtained from WAN service providers, such as RBOCs; alternate carriers; and Post, Telephone, and Telegraph (PTT) agencies.

The following physical layer standards are specified:

- **EIA/TIA-232**—Common physical layer interface standard that supports unbalanced circuits at signal speeds of up to 64 kbps. Closely resembles the V.24 specification.
- **EIA/TIA-449**—A faster (up to 2 Mbps) version of EIA/TIA-232 capable of longer cable runs.
- **V.24**—Physical layer interface between DTE and DCE. V.24 is essentially the same as the EIA/TIA-232.
- **V.35**—A synchronous, physical layer protocol for communications between a network access device and a packet network. V.35 is most commonly used in the United States and in Europe and is recommended for speeds up to 48 kbps.

- **X.21**—Protocol for serial communications over synchronous digital lines. The X.21 protocol is used primarily in Europe and Japan.
- **G.703**—ITU-T electrical and mechanical specifications for connections between telephone company equipment and DTE using BNC connectors and operating at E1 data rates.
- **EIA-530**—Refers to two electrical implementations of EIA/TIA-449: RS-422 (for balanced transmission) and RS-423 (for unbalanced transmission).

Synchronous serial lines have several data link encapsulations associated with them, the characteristics for which are listed in Table 10-2.

Table 10-2 Synchronous Serial Line Data Link Encapsulations

Encapsulation	Characteristics
High-Level Data Link Control (HDLC)	<p>An IEEE standard.</p> <p>Is the default encapsulation on point-to-point dedicated links, and circuit-switch connections.</p> <p>Cisco HDLC is a proprietary version, bit-oriented, synchronous data link layer protocol typically used when communicating between two Cisco devices.</p> <p>Cisco HDLC might be incompatible with other vendors' versions due to the method of implementation those vendors have chosen.</p> <p>Supports both point-to-point and multipoint configurations with minimal overhead.</p>
Frame Relay	<p>Uses high-quality digital facilities.</p> <p>Uses simplified framing with no error correction mechanisms, which means it can send Layer 2 information much more rapidly than other WAN protocols.</p> <p>Industry-standard switched data link layer protocol that handles multiple virtual circuits.</p> <p>Next generation to X.25, Frame Relay is streamlined to eliminate some of the time-consuming processes that were employed in X.25, such as error correction and flow control.</p>

continues

Table 10-2 Synchronous Serial Line Data Link Encapsulations (Continued)

Encapsulation	Characteristics
Point-to-Point Protocol (PPP)	<p>Described by RFC 1661.</p> <p>Two standards developed by the IETF.</p> <p>Contains a Protocol field to identify the network layer protocol.</p> <p>Provides router-to-router and host-to-network connections over synchronous and asynchronous circuits.</p> <p>Designed to work with several network layer protocols, such as Internet Protocol (IP) and Internetwork Packet Exchange (IPX).</p> <p>Built-in security mechanisms, such as Password Authentication Protocol (PAP) and Challenge Handshake Authentication Protocol (CHAP).</p>
Synchronous Data Link Control (SDLC) Protocol	<p>IBM-designed WAN data link protocol for System Network Architecture (SNA) environments.</p> <p>Largely being replaced by the more versatile HDLC.</p>
Serial Line Internet Protocol (SLIP)	<p>Extremely popular WAN data link protocol for carrying IP packets.</p> <p>Replaced in many applications by the more versatile PPP.</p> <p>Standard protocol for point-to-point serial connections using Transmission Control Protocol/Internet Protocol (TCP/IP).</p>
Link Access Procedure Balanced (LAPB)	<p>Used by X.25.</p> <p>Has extensive error-checking capabilities.</p>
Link Access Procedure on the D channel (LAPD)	<p>Protocol used for signaling and call setup on an Integrated Services Digital Network (ISDN) D channel.</p>
Link Access Procedure Frame (LAPF)	<p>Used for Frame-Mode Bearer Services.</p> <p>Similar to LAPD, used with Frame Relay technologies.</p>
X.25/Link Access Procedure Balanced (LAPB)	<p>An ITU-T standard that defines how connections between DTE and DCE are maintained for remote terminal access and computer communications in public data networks.</p> <p>Specifies LAPB, a data link layer protocol.</p> <p>Predecessor to Frame Relay.</p>

Figure 10-4 illustrates some of the common data link encapsulations associated with synchronous serial lines.

Figure 10-4 Data Link Encapsulations

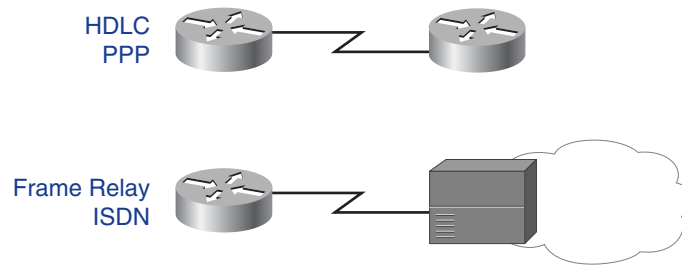
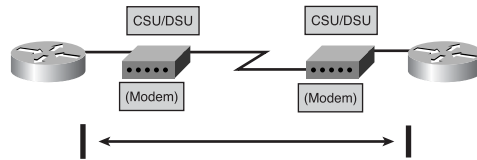


Figure 10-5 illustrates the synchronous serial communications model where services offered to the router are made available through a modem or a CSU/DSU.

Figure 10-5 CSU/DSU



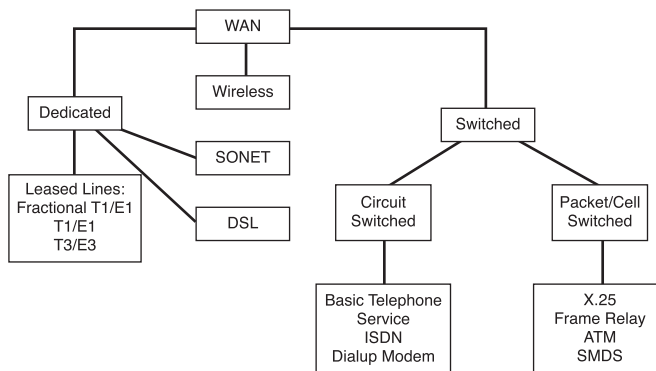
WAN Connection Options

You can use different WAN connection options to interconnect LANs. The following subsections give a brief description of the most common WAN connection services:

- Circuit-switched services
- Packet-switched services
- Cell-switched services
- Dedicated digital services
- Dialup, cable, and wireless services

Figure 10-6 depicts the different WAN connection services.

Figure 10-6 WAN Connection Services



Circuit-Switched Services

Circuit switching is a WAN switching method in which a dedicated physical circuit through a carrier network is established, maintained, and terminated for each communication session. ISDN is an example of a circuit-switched WAN technology. Figure 10-7 illustrates a network topology that supports circuit switching.

Figure 10-7 Circuit Switching

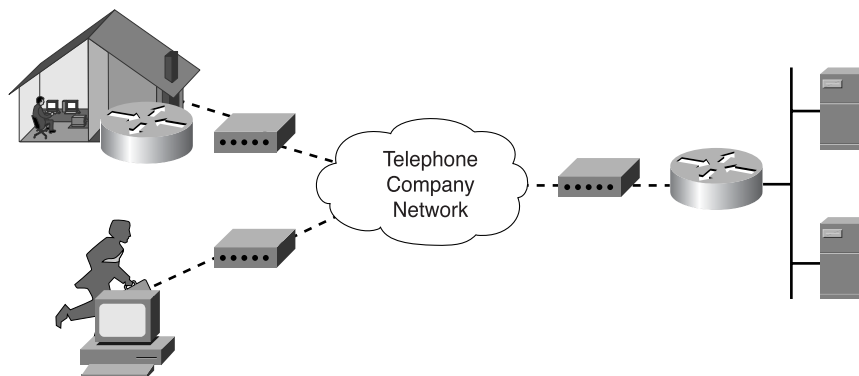


Table 10-3 describes the characteristics of two most common circuit-switched services—plain old telephone service (POTS) and narrowband Integrated Services Digital Network (ISDN).

Table 10-3 Circuit-Switched Services

Circuit-Switched Service	Characteristics
POTS	Not a computer data service, but included because many of its technologies are part of the growing data infrastructure, and it is an incredibly reliable, easy-to-use, wide-area communications network. Typical medium is twisted-pair copper wire.
Narrowband ISDN	A versatile, widespread, historically important technology. Was the first all-digital dialup service. Cost is moderate. Maximum bandwidth is 128 kbps for the lower cost Basic Rate Interface (BRI) and about 3 Mbps for the Primary Rate Interface (PRI). Usage is fairly widespread, though it varies considerably from country to country. Typical medium is twisted-pair copper wire.

POTS and ISDN are dialup services, which means that when the call is made, an end-to-end physical path is set up and the bandwidth is reserved end to end. Both POTS and ISDN use straight time-division multiplexing (TDM), which is sometimes referred to as synchronous transfer mode (STM).

Packet-Switched Services

Packet-switched services route small units of data called *packets* through a network based on the destination address contained within each packet. Figure 10-8 shows an example network topology that supports packet-switched services.

Figure 10-8 Packet Switching

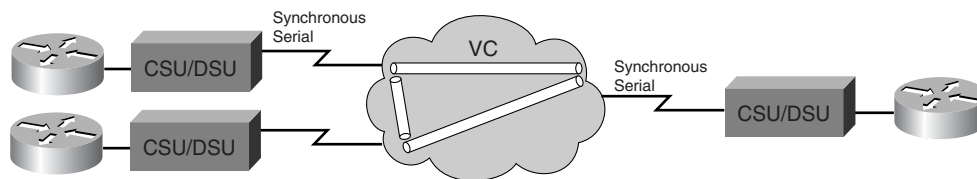


Table 10-4 describes the characteristics of two most common packet-switched services—X.25 and Frame Relay.

Table 10-4 Packet-Switched Services

Packet-Switched Service	Characteristics
X.25	<p>An older technology, but still widely used.</p> <p>Has extensive error-checking capabilities from the days when WAN links were more prone to errors. This makes it reliable but limits its bandwidth.</p> <p>Bandwidth can be as high as 2 Mbps.</p> <p>Usage is fairly extensive.</p> <p>Cost is moderate.</p> <p>Typical medium is twisted-pair copper wire.</p>
Frame Relay	<p>A packet-switched version of narrowband ISDN.</p> <p>Has become an extremely popular WAN technology in its own right.</p> <p>More efficient than X.25, but with similar services.</p> <p>Maximum bandwidth is 44.736 Mbps.</p> <p>56 kbps and 384 kbps are extremely popular in the U.S.</p> <p>Usage is widespread.</p> <p>Cost is moderate to low.</p> <p>Typical media include twisted-pair copper wire and optical fiber.</p>

X.25 is both connection-oriented and reliable at both Layers 2 and 3, which is a big part of why it is so much slower than Frame Relay.

Frame Relay is typically regarded as a much faster, sleeker version of X.25; it has no defined Layer 3 protocol, nor is it reliable. However, it is connection-oriented.

Circuit-switched services use time-division multiplexing (TDM) and are said to be synchronous (they use STM), whereas packet-switched services use statistical TDM and are sometimes said to be asynchronous (similar to ATM).

Cell-Switched Services

Cell-switched services provide a dedicated-connection switching technology that organizes digital data into cell units and transmits them over a physical medium using digital signal technology.

Table 10-5 describes the characteristics of two most common cell-switched services—Asynchronous Transfer Mode (ATM) and Switched Multimegabit Data Service (SMDS).

Table 10-5 Cell-Switched Services

Cell-Switched Service	Characteristics
ATM	<p>Closely related to broadband ISDN.</p> <p>Is becoming an increasingly important WAN technology.</p> <p>Uses small, fixed 53-byte length cells to carry data.</p> <p>Maximum bandwidth is currently 622 Mbps, though higher speeds are being developed.</p> <p>Typical media are twisted-pair copper wire and optical fiber.</p> <p>Usage is widespread and increasing.</p> <p>Cost is high.</p>
SMDS	<p>Closely related to ATM, and typically used in metropolitan-area networks (MANs).</p> <p>Maximum bandwidth is 44.736 Mbps.</p> <p>Typical media are twisted-pair copper wire and optical fiber.</p> <p>Usage is not very widespread.</p> <p>Cost is relatively high.</p>

Dedicated Digital Services

Dedicated digital services also provide circuit-switched services but the connection is “always-up.”

Table 10-6 describes the characteristics of the most common dedicated digital services—T1, T3, E1, E3; digital subscriber line (xDSL); and Synchronous Optical Network (SONET).

Table 10-6 Dedicated Digital Services

Dedicated Digital Service	Characteristics
T1, T3, E1, E3	<p>The T series of services in the U.S. and the E series of services in Europe are extremely important WAN technologies.</p> <p>They use TDM to slice up and assign time slots for data transmission.</p> <p>Bandwidths for the T and E series lines are 1.544 Mbps for T1, 44.736 Mbps for T3, 2.048 Mbps for E1, and 34.368 Mbps for E3. Other bandwidths are also available.</p> <p>The media used are typically twisted-pair copper wire and optical fiber.</p> <p>Usage is extremely widespread.</p> <p>Cost is moderate.</p>
xDSL	<p>A new and developing family of WAN technologies intended primarily for home use.</p> <p>xDSL indicates the entire family of DSL technologies, including high-bit-rate DSL (HDSL), single-line DSL (SDSL), asymmetric DSL (ADSL), and very-high-data-rate DSL (VDSL).</p> <p>Bandwidth decreases with increasing distance from the phone company's equipment.</p> <p>Top speeds of 51.84 Mbps are possible near a phone company office; however, most bandwidths are much lower from hundreds of kbps to several Mbps.</p> <p>Cost is moderate and decreasing.</p>
SONET	<p>A family of very high-speed physical layer technologies.</p> <p>Designed for optical fiber, but can also run on copper cables.</p> <p>Has a series of data rates available with special designations.</p> <p>Implemented at different Optical Carrier (OC) levels, ranging from 51.84 Mbps (OC-1) to 9,952 Mbps (OC-192).</p> <p>Can achieve high data rates by using wavelength division multiplexing (WDM). WDM is when lasers are tuned to slightly different colors, or wavelengths, to send huge amounts of data optically.</p> <p>Usage is widespread among Internet backbone entities.</p> <p>The cost is expensive. This is not a technology that connects to homes.</p>

Dialup, Cable, and Wireless Services

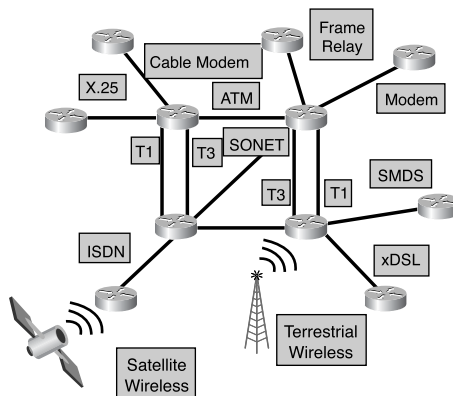
Table 10-7 describes the characteristics of other WAN services that do not fall into any of the previously covered categories of WAN technologies. Among these miscellaneous technologies are dialup modems, cable modems, and terrestrial and satellite wireless.

Table 10-7 Dialup, Cable, and Wireless Services

WAN Service	Characteristics
Dialup modem (switched analog)	Limited in speed, but quite versatile. Works with existing phone network. Maximum bandwidth approximately 56 kbps. Cost is low. Usage is still very widespread. Typical medium is the twisted-pair phone line.
Cable modem (shared analog)	Puts data signals on the same cable as television signals. Increasing in popularity in regions that have large amounts of existing cable TV coaxial cable. Ninety percent of homes in United States have existing cable TV coaxial cable. Maximum bandwidth can be 10 Mbps, though this decreases as more users attach to a given network segment. Behaves like an unswitched (shared) LAN. Cost is relatively low. The medium is coaxial cable.
Wireless	Wireless requires no medium since the signals are electromagnetic waves that are transmitted through the air. A variety of wireless WAN links exist, including the following: Terrestrial has bandwidths typically in the 11 Mbps range (for example, microwave). Cost is relatively low, line of sight (LOS) is usually required, and usage is moderate. Satellite can serve mobile users such as those in a cellular telephone network and remote users that are too far from any wires or cables. Usage is widespread, and the cost is high.

Figure 10-9 illustrates different WAN technologies connected by routers.

Figure 10-9 WAN Technologies Connected by Routers



Comparison of WAN Technologies

Table 10-8 shows an overview of the previously discussed WAN technologies.

Table 10-8 WAN Technologies

WAN Acronym	WAN Name	Maximum Bandwidth	Comments
POTS	plain old telephone service	4 kHz analog	Standard for reliability
ISDN	Integrated Services Digital Network	128 kbps	Data and voice together
X.25	X.25	2 Mbps	Old reliable workhorse
Frame Relay	Frame Relay	Up to 44.736 Mbps	New workhorse
ATM	Asynchronous Transfer Mode	622 Mbps	High-powered networks
SMDS	Switched Multi-megabit Data Service	1.544 Mbps and 44.736 Mbps	MAN variant of ATM
T1, T3	T1, T3	1.544 Mbps and 44.736 Mbps	Widely used telecommunications

Table 10-8 WAN Technologies (Continued)

WAN Acronym	WAN Name	Maximum Bandwidth	Comments
xDSL	digital subscriber line	384 kbps	Technology over phone lines
SONET	Synchronous Optical Network	9,992 Mbps	Fast optical fiber transmission
Dialup modem	modem	56 kbps	Mature technology using phone lines
Cable modem	cable modem	10 Mbps	Technology using cable TV
Terrestrial wireless	wireless	11 Mbps	Microwave and laser links
Satellite wireless	wireless	2 Mbps	Microwave and laser links

More Information: Costs of the WAN
<p>Tempering the various performance criteria of the WAN is cost. The costs of owning and operating a WAN include the initial startup costs, as well as the monthly recurring expenses. Not surprisingly, the larger and more powerful network components are much more expensive than smaller, less-robust components. Therefore, designing a WAN becomes an economic exercise in which a careful balance of performance and cost is achieved.</p> <p>Achieving this balance can be painful. No one wants to design a WAN that disappoints the users with its performance, but no one wants to design a WAN that blows the budget, either! Fortunately, the following suggestions can help guide the design of a WAN that satisfies existing requirements, provides flexibility for future growth, and doesn't exceed the budget:</p> <ul style="list-style-type: none"> ■ The capital investments in routers and other network hardware become a fixed part of the network. After the hardware components are placed in operation, the logistics of replacing hardware become quite complicated. And, depending on your depreciation schedule for capital equipment, you might find yourself obligated to use the hardware for five or more years! It might behoove you to purchase a larger router that is relatively low in port density. You can add hardware (memory, CPUs, and interfaces) in the future as the need for them arises. This method allows future expansion at modest incremental costs and little (if any) operational downtime. ■ The transmission facilities are relatively easy to replace with other transmission facilities. They are an expense item, not a capital investment, so there is no depreciation expense to retire. These can be replaced with other facilities as often as your lease agreement with the carrier permits. Therefore, you might want to explore your options for meeting performance requirements with the various available transmission facilities and technologies.

More Information: Resource Utilization Rates

The degree to which the various physical resources of the WAN are being utilized is also a good indicator of how well, or how poorly, the WAN is performing relative to the performance requirements. Two main categories of resource utilization rates should be monitored carefully:

- Router CPU and memory utilization rates
- Transmission facility utilization rates

Router Physical Resource Rates

Routers are one of the most vital components of any WAN. And, unlike the transmission facilities, they are outside the view of the telecommunications carrier. Therefore, they are distinctly the responsibility of the customer. Fortunately, routers are intelligent devices that contain their own CPU and memory. These physical resources are indispensable in the calculation of WAN routes and the forwarding of packets. They can also be used to monitor the performance of the router.

If either CPU or memory utilization rates approach 100 percent, performance suffers. Numerous conditions can result in either utilization rate temporarily spiking upward with subsequent performance degradation. One example is a sudden increase in transmissions from the LAN to the WAN. LANs can operate at speeds of up to 1 Gbps, but they usually operate only at 10, 16, or 100 Mbps. Any of these speeds is a gross mismatch against the typical WAN transmission facility, which offers a paltry 1.544 Mbps of bandwidth. This mismatch in bandwidth must be buffered by the router's memory. It won't take long for a router to become resource constricted given a sustained period of heavy LAN transmissions.

If such situations are rarely experienced, they should be considered aberrations. Aberrations should be monitored, but they shouldn't drive physical upgrades. If these resource constrictions recur or constitute a trend, however, something needs to be done. Usually this requires an upgrade, either to the next larger router or via an expansion of memory. If a router is chronically at or near 100 percent of capacity with its memory, it is time to purchase additional memory.

However, responding to chronically high CPU utilization rates might not be as simple as a memory upgrade. Really, only three options exist for improving high CPU utilization rates:

- If possible, add another CPU to the router.
- Upgrade to a more powerful router.
- Investigate the WAN's traffic patterns to see if the load on the problematic router can be reduced.

Manipulating traffic patterns is really only a viable option in larger WANs with complex topologies that can afford route redundancy.

Transmission Facility Rates

Transmission facilities can also be monitored for utilization. Typically, this utilization rate is expressed in terms of the percentage of consumed bandwidth. If you are using a T1, for example, a given sample might indicate that 30 percent of its 1.544 Mbps of available bandwidth is currently being utilized.

More Information: Resource Utilization Rates (Continued)

These rates can be tricky to analyze and might even be misleading. It is not uncommon, for example, for network-management software packages to capture utilization data in time intervals. These intervals can be 1 hour, 5 minutes, or just about any other interval. If set too coarsely, the sampling frequency can miss short-duration fluctuations in bandwidth consumption. If the sampling is too frequent, you can find yourself mired in a meaningless morass of data points. The trick is finding the right frequency that provides meaningful data about how the network is performing relative to the users' expectations.

Beyond merely selecting the sampling rate is the issue of sampling window. The sampling window should be determined by the users' requirements for WAN availability. If the utilization samples are spread over a 24-hour day and a 7-day week, whereas the users work only 10 hours per day, 5 days per week, the statistical data is not indicative of how well the users' requirements are being met.

Utilization rates are a wonderful statistical tool for monitoring and measuring the status of transmission facilities. However, they are not the only metric for assessing a network's performance. The network is successful only if it satisfies the users' requirements. Therefore, a combination of performance metrics that provides a multifaceted, composite perspective is likely to provide a better assessment of the network's success than any single metric can offer.

WAN Routers

Just as computers need operating systems to run software applications, routers need Cisco IOS Software to run configuration files. These configuration files contain the instructions and parameters that control the flow of traffic in and out of the routers. Specifically, by using routing protocols to direct routed protocols and routing tables, routers make decisions regarding the best path for packets. The configuration file specifies all the information the router needs to make these decisions.

Router Internal Components

Table 10-9 outlines the main internal configuration components of the router.

Table 10-9 Main Internal Configuration Components of a Router

Internal Component	Characteristics
Random-access memory (RAM/ DRAM)	<p>Stores routing tables.</p> <p>Address Resolution Protocol (ARP) cache.</p> <p>Fast-switching cache.</p> <p>Packet buffering (shared RAM).</p> <p>Packet-hold queues.</p> <p>Provides temporary and running memory for the configuration file of the router while the router is powered on.</p> <p>RAM content is lost when powered down or restarted.</p>
Nonvolatile random-access memory (NVRAM)	<p>Stores the backup/startup configuration file for the router.</p> <p>Retains content when the router is powered down or restarted.</p>
Flash memory	<p>Erasable, programmable read-only memory (EPROM).</p> <p>Holds the operating system image and microcode.</p> <p>Allows software to be updated without removing and replacing chips on the processor.</p> <p>Content remains when powered down or restarted.</p> <p>Multiple versions of Cisco IOS Software can be stored in Flash memory.</p>
Read-only memory (ROM)	<p>Maintains instructions for power-on self test (POST) diagnostics.</p> <p>Stores a bootstrap program, and basic operating system software.</p> <p>Software upgrades in ROM require replacing pluggable chips on the CPU.</p>
Interface	<p>Network connection through which packets enter and exit a router.</p> <p>Located on the motherboard or on a separate interface module.</p>

More Information: A Closer Look at Routers

Routers are designed to interconnect multiple networks. This interconnection enables machines on different networks to communicate with each other. Interconnected networks can be co-located or geographically dispersed. Networks that are geographically dispersed are usually interconnected via a WAN. WANs are constructed of numerous different technologies, including routers, transmission facilities, and line drivers. It is the router's capability to interconnect networks in a WAN that has made it indispensable.

A router is an intelligent network device that operates predominantly at the first three layers of the OSI reference model. Routers, like any host, are actually capable of operating at all seven layers of the OSI reference model. Depending on your particular configuration, you might or might not use all seven layers of functionality. However, the need for the first three layers is virtually universal. Communication across the first two layers allows routers to communicate directly with LANs (data link layer constructs). More importantly, routers can identify routes through networks based on Layer 3 addresses. This enables routers to internetwork multiple networks by using network layer addressing, regardless of how near or far they might be relative to each other.

Understanding routers and routing requires examining a router from two different perspectives: physical and logical. From a physical perspective, routers contain myriad parts, each of which has a specific function. From a logical perspective, routers perform many functions, including finding other routers in the network, learning about potential destination networks and hosts, discovering and tracking potential routes, and forwarding datagrams toward their specified destination. Together, these physical components and logical functions enable you to build and use internetworks, including WANs.

Physical Components of a Router

A router is a remarkably complex device. Its complexity lies in its routing engine logic that enables the physical device to perform the various routing functions. The complexity of routing logic is hidden by the relative simplicity of the router's physical form. The most common type of router is actually a highly specialized type of computer; it contains the same basic components as any other computer. These components include the following:

- A central processing unit (CPU)
- Random-access memory (RAM)
- A basic input/output system (BIOS)
- An operating system (OS)
- A motherboard
- Physical input/output (I/O) ports
- A power supply, chassis, and sheet-metal skin

continues

More Information: A Closer Look at Routers (Continued)

The vast majority of a router's components will remain forever shielded from the eyes of network administrators by the chassis' sheet-metal skin. These components are extremely reliable and, under normal operating conditions, shouldn't see the light of day. The obvious exceptions to this general statement are born of expansion. Any time you need to add more resources to the router, you might have to take off its cover. Such resources usually include either memory or I/O ports.

The components that a network administrator will encounter most often are the OS and the I/O ports. A router's OS (in Cisco Systems' case, the Internetwork Operating System or IOS) is the software that controls the various hardware components and makes them usable. Network administrators mostly use a command-line interface to develop a logical configuration. The configuration is a profile of the system: the numbers, the locations, the types of each I/O port, and details such as addressing and bandwidth information. A router's configuration can also include security information such as which users are permitted access to specific I/O ports and configuration modes.

The I/O ports are the one physical router component that network administrators see on a routine basis. These ports bear out the router's unique capability to interconnect seemingly endless combinations of LAN and WAN transmission technologies. Each one of these ports, whether LAN or WAN, must have its own I/O port on the router. These ports function like a network interface card (NIC) in a LAN-attached computer; they are related to the medium and framing mechanisms expected and provide the appropriate physical interfaces. Many of these physical interfaces appear quite similar to each other. This physical similarity belies the differences between the higher-layer functions of those technologies. Therefore, you will find it more useful to examine transmission technologies than to examine specific physical interfaces.

Functions of a Router

The logical functions that a router performs are just as important as providing physical interconnectivity for multiple networks. These functions make the physical interconnections usable. For example, internetworked communications require that at least one physical path interconnect the source and destination machines. However, having and using a physical path are two very different things. Specifically, the source and destination machines must speak a common language (a *routed protocol*). It also helps if the routers that lie between them also speak a common language (a *routing protocol*) and agree on which specific physical path is the best one to use.

Therefore, some of the more salient functions that a router provides are

- Physical interconnectivity
- Logical interconnectivity
- Route calculation and maintenance
- Security

More Information: A Closer Look at Routers (Continued)

Physical Interconnectivity

A router has a minimum of two (and frequently many more) physical I/O ports. I/O ports, or *interfaces* as they are better known, are used to physically connect network transmission facilities to a router. Each port is connected to a circuit board that is attached to the router's motherboard. Thus, the motherboard actually provides the interconnectivity among multiple networks.

The network administrator must configure each interface via the router's console. Configuration includes defining the interface's port number in the router, the specific transmission technology and bandwidth available on the network connected to that interface, and the types of protocols that will be used through that interface. The actual parameters that must be defined vary based on the type of network interface.

Note that on the higher-end platforms (7500 and 12000) the interfaces (VIP2 or line card) can forward packets without interrupting the main CPU.

Logical Interconnectivity

As soon as a router interface is configured, it can be activated. The interface's configuration identifies the type of transmission facility that it connects to, the interface's IP address, and the address of the network that it connects to. Upon activation of a port, the router immediately begins monitoring all the packets that are being transmitted on the network attached to the newly activated port. This monitoring allows it to "learn" about network and host IP addresses that reside on the networks that can be reached via that port. These addresses are stored in tables called *routing tables*. Routing tables correlate the port number of each interface in the router with the network layer addresses that can be reached (either directly or indirectly) via that port.

A router can also be configured with a *default route*. A default route associates a specific router interface with all unknown destination addresses. This association allows a router to forward a datagram to destinations that it has not yet learned of. Default routes can be useful in other ways, too. Default routes can be used to minimize the growth of routing tables, for example, or can be used to reduce the amount of traffic generated between routers as they exchange routing information.

However, consider your default route carefully because it could potentially cause problems if not thoroughly thought out as for traffic flow.

Route Calculation and Maintenance

Routers communicate with each other using a predetermined protocol, a routing protocol. Routing protocols enable routers to do the following:

- Identify potential routes to specific destination networks
- Perform a mathematical calculation, based on the routing protocol's algorithm, to determine the best path to each destination
- Continuously monitor the network to detect any topology changes that might render known routes invalid

continues

More Information: A Closer Look at Routers (Continued)

Many different types of routing protocols exist. Some, such as the Routing Information Protocol (RIP), are quite simple. Others, such as Open Shortest Path First (OSPF), are remarkably powerful and feature-rich but complicated. In general, routing protocols can use two approaches to make routing decisions: distance vectors and link states. A distance-vector routing protocol makes its decisions based on some measurement of the distance between source and destination machines. A link-state protocol bases its decisions on various states of the links, or transmission facilities, that interconnect the source and destination machines. Neither one is right or wrong; they are just different ways of making the same decisions. However, they result in different levels of performance, including convergence times.

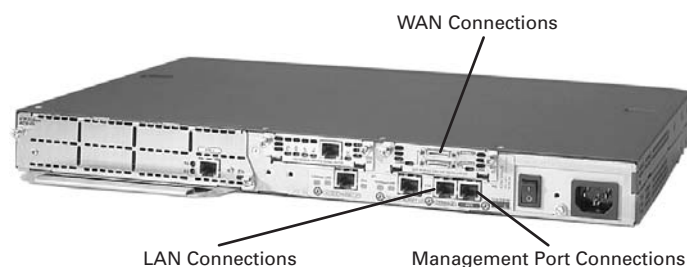
You can evaluate routing protocols using numerous, more-specific criteria than just which approaches they use. Some of the more meaningful criteria include the following:

- **Optimality**—Optimality describes a routing protocol's capability to select the best available route. Unfortunately, the word *best* is ambiguous. Many different ways exist to evaluate different routes to any given destination. Each way could result in the selection of a different "best" route depending on the criteria used. The criteria used by routing protocols to calculate and evaluate routes are known as *routing metrics*. A wide variety of metrics are used, and they vary widely by routing protocol. One simple metric is *hop count*, the number of hops, or routers, that lie between the source and destination machines.
- **Efficiency**—Another criterion to consider when evaluating routing protocols is their operational efficiency. Operational efficiency can be measured by examining the physical resources, including router RAM and CPU time, and network bandwidth required by a given routing protocol. You might need to consult your router manufacturer or vendor to determine the relative efficiencies of any protocols you are considering.
- **Robustness**—A routing protocol should perform reliably at all times, not just when the network is stable. Error conditions, including hardware or transmission-facility failures, router configuration errors, and even heavy traffic loads, adversely affect a network. Therefore, that a routing protocol functions properly during periods of network failure or instability is critical.
- **Convergence**—Because they are intelligent devices, routers can automatically detect changes in the internetwork. When a change is detected, all the routers involved must converge on a new agreement of the network's topology and recalculate the routes to known destinations accordingly. This process of reaching mutual agreement is called *convergence*. Each routing protocol uses different mechanisms for detecting and communicating network changes. Therefore, each one converges at a different rate. In general, the slower a routing protocol converges, the greater the potential for disrupting service across the internetwork.
- **Scalability**—A network's scalability is its capability to grow. Although growth isn't a requirement in every organization, the routing protocol that you select should be capable of scaling upward to meet your network's projected growth.

Router External Connections

The three basic types of connections on a router are LAN interfaces, WAN interfaces, and management ports, as illustrated by Figure 10-10. LAN interfaces allow the router to connect to the LAN media, which is usually some form of Ethernet. However, it could be some other LAN technology such as Token Ring or ATM.

Figure 10-10 Router External Connections



WAN connections provide connections through a service provider to a distant site or to the Internet. These connections can be serial connections or any number of other WAN interfaces. With some types of WAN interfaces, an external device such as a CSU is required to connect the router to the service provider's local connection. With other types of WAN connections, the router might be directly connected to the service provider.

The function of management ports is different from that of the other connections. The LAN and WAN connections provide network connections through which frame packets are passed. The management port provides a text-based connection for the configuration and troubleshooting of the router. The common management interfaces are the console and auxiliary ports. These are EIA-232 asynchronous serial ports. They are connected to a communications port on a computer. The computer will run a terminal emulation program to provide a text-based session with the router. Through this session the network administrator can manage the device.

Management Port Connections

The console port and the auxiliary (AUX) port are management ports. These asynchronous serial ports are not designed as networking ports. One of these two ports is required for the initial configuration of the router. The console port is recommended for this initial configuration. Not all routers have an auxiliary port.

When the router is first put into service, no networking parameters are configured. Therefore, the router cannot communicate with any network. To prepare for initial start-up and configuration, attach an RS-232 ASCII terminal, or a computer emulating an ASCII terminal, to the system console port. Then you can enter configuration commands to set up the router.

Once you enter this initial configuration into the router through the console or auxiliary port, you can then connect the router to the network for troubleshooting or monitoring.

You can also configure the router from a remote location by dialing to a modem connected to the console or auxiliary port on a router.

The console port is also preferred over the auxiliary port for troubleshooting. This preference for the console port is because it displays router startup, debugging, and error messages by default. You can use the console port when the networking services have not been started or have failed. Therefore, you can use the console port for disaster and password recovery procedures.

The Function of a Router in a WAN

While you can use routers to segment LANs, the major use for a router is as a WAN device. Routers have both LAN and WAN interfaces. In fact, WAN technologies are frequently used to connect routers. These routers communicate with each other through WAN connections. Routers are the backbone devices of large intranets and of the Internet. They operate at Layer 3 of the OSI model, making decisions based on network addresses (on the Internet, by using IP).

The two main functions of a router are as follows:

- The selection of best paths for incoming data packets
- The switching of packets to the proper outgoing interface

Routers accomplish these functions by building routing tables and exchanging the network information contained within them with other routers.

An administrator can maintain routing tables by configuring static routes. However, routing tables are generally maintained dynamically through the use of a routing protocol that exchanges network topology, or path, information with other routers.

An example is when computer x needs to communicate with computer y and computer z. Both computer y and computer z are located in distant parts of the world. For computer x to communicate with the other computers, a routing feature for information



flow is required, as well as redundant paths for reliability. Many network design decisions and technologies can be traced back to the need for computers x, y, and z to communicate, or internetwork.

Note, however, that an internetwork must also include the following:

- Consistent end-to-end addressing
- Addresses that represent network topologies
- Best path selection
- Dynamic routing and/or static routing
- Switching



Lab Activity Connecting Console Interface

In this activity, you identify the console interfaces on the router. You then identify and locate the proper cable to connect a PC to the router to serve as its management console.



Lab Activity Connecting LAN Interfaces

In this activity, you identify the Fast Ethernet interfaces on the router. You then identify and locate the proper cables to connect the routers. Finally, you use the cables to connect the routers and computer to the hubs.



Connecting WAN Interfaces

In this activity, you identify the serial interfaces on the router. You then identify and locate the proper cables to interconnect the routers. Finally, you use the cables to connect the routers.

More Information: Roles of the Router in WANs

More often than not, internetworks are extensive in terms of the number of routers, transmission facilities, and attached end systems. In an extensive internetwork, such as the Internet or even large private networks, it is virtually impossible for any given machine to know about every other machine. Therefore, some semblance of hierarchy is needed. Hierarchical organization of internetworked machines creates the need for specialized routing functions.

continues



More Information: Roles of the Router in WANs (Continued)

Routers can specialize in learning about and distributing routing information within their domain. These routers are called *interior gateways*. Alternatively, routers can specialize in collecting routing information about networks that lie beyond their domain. These routers are known as *exterior gateways*.

Networking is often used as a generic or universal term. However, networked machines communicate in tremendously different ways. Routers can function in different capacities in an internetwork, for example, as interior, exterior, or border routers.

As you might have noticed in the previous paragraphs, finding interior routers, exterior routers, and border routers described as *interior gateways*, *exterior gateways*, and *border gateways*, respectively, is not uncommon. The term *gateway* is as old as routing itself. Over time, this term has lost some of its descriptive value. Consequently, both sets of terms are technically correct, except in the presence of technological purists. Then you have to determine which terminology they consider correct!

These functional specializations are more than merely academic. Understanding the differences among them requires examining them in the context of a WAN. Therefore, a logical starting point is an examination of the context. The terms *WAN*, *network*, *internetwork*, and *autonomous system* are all used interchangeably, yet each has a slightly different meaning:

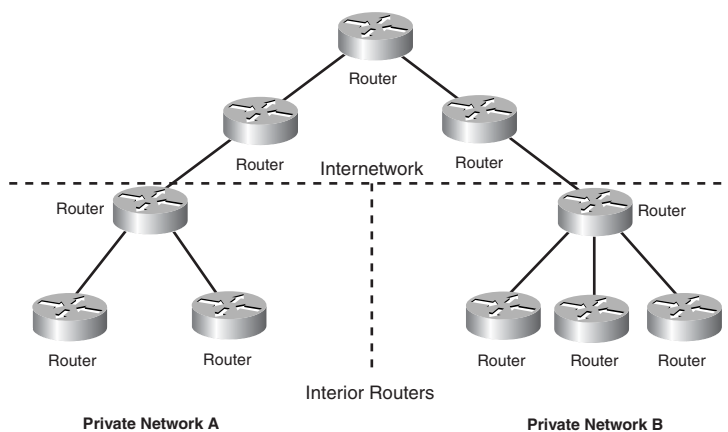
- **WAN**—A *WAN* is a collection of related LANs linked via routers and serial transmission facilities, such as leased lines or Frame Relay circuits. Implicit in this definition is that the LANs in the WAN might be geographically dispersed, but they still fall under the auspices of a single organization such as a company or school.
- **Network**—*Network* is a more nebulous term that defies specificity. Everything from LANs to WANs can be classified as a network. Consequently, for the purposes of this book, a network identifies a generic collection of related networking mechanisms. Therefore, a network can be a LAN or a WAN, but it must belong to a single organization and feature a consistent addressing architecture. This term is sometimes used to indicate an internetwork or even the Internet.
- **Internetwork**—*Internetwork* is only slightly more concrete than network. An internetwork is a collection of loosely related networks that are interconnected. The interconnected networks can belong to different organizations. For example, two companies can use the Internet to interconnect their private WANs. The resulting internetwork consists of one public network and two private networks linked together. The most common definition of internetwork is a set of networks linked by routers. This internetwork is not necessarily a loosely related set of networks, although the term is applied to both a single domain or autonomous system (AS) internetwork or an internetwork comprised of separate autonomous systems.

More Information: Roles of the Router in WANs (Continued)

- Autonomous system**—An autonomous system (AS) is a network or internetwork (either LAN or WAN) that is relatively self-contained. It is administered by a single person (or organization), features a single routed protocol, has an address architecture, and usually involves just one routing protocol. An autonomous system can support connections to other autonomous systems owned and operated by the same organization. Alternatively, an AS might have connections to other networks, such as the Internet, yet it retains autonomy of operation. This term is usually used in conjunction with specific routing protocols, such as Open Shortest Path First (OSPF) or Border Gateway Protocol (BGP), that enable a network to be carved into numbered subsections.

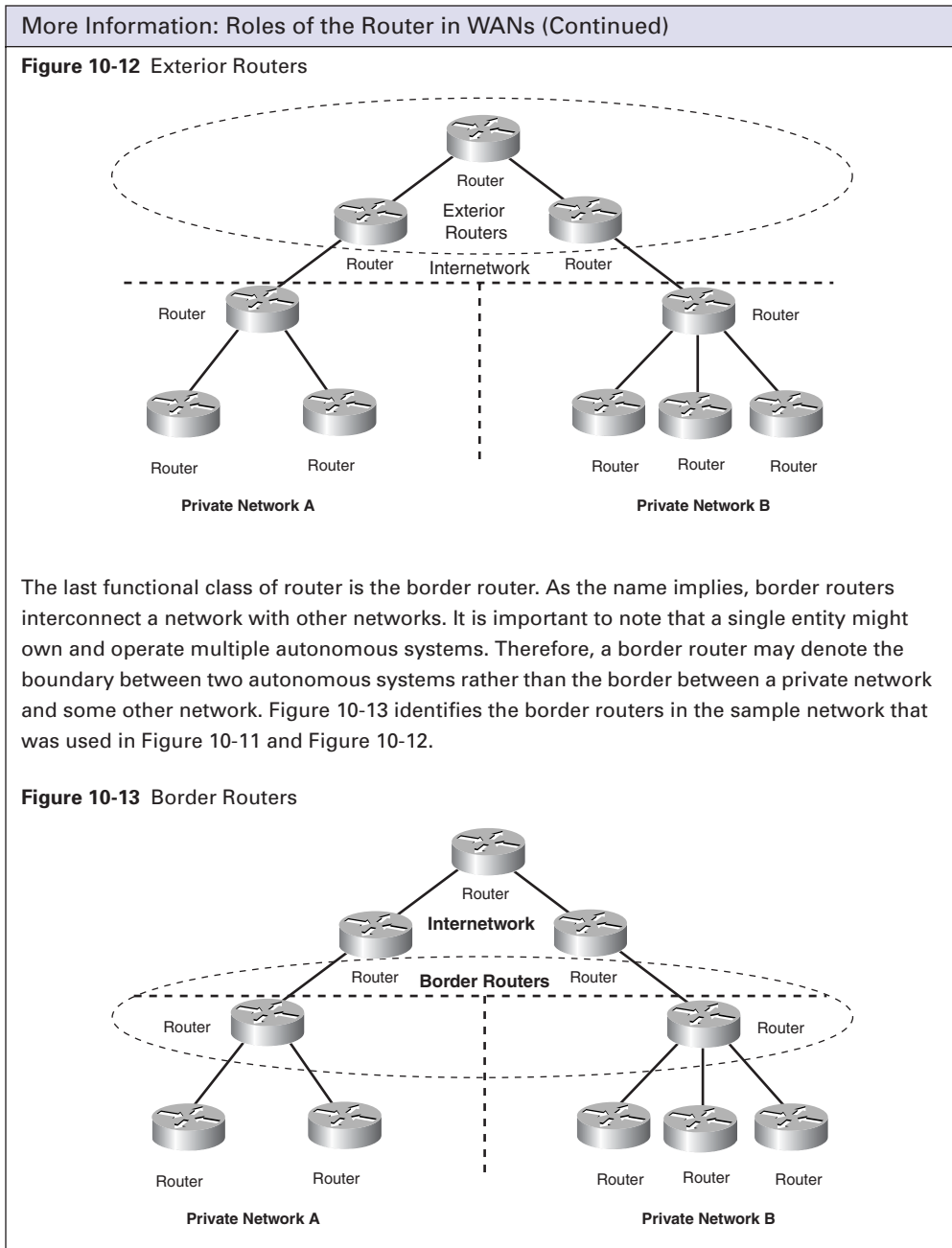
Given these definitions, it is possible to better define the functional classes of routers. An interior router is one that can be used by end systems in a network to access other end systems within the same network. The interior router supports no connections to any other network. Figure 10-11 illustrates a small network and identifies those devices that function as interior routers.

Figure 10-11 Interior Routers in a Network



An exterior router is one that lies beyond the boundaries of any given network. Figure 10-12, although not pretending to depict the Internet's actual topology, presents a highly simplified Internet topology that is solely intended to demonstrate what an exterior router is.

continues



Lab WAN Simulation

A viable WAN connection can connect routers from around the world. In an academy lab, all the networks are connected with a serial or Ethernet cable, and the students can see and physically touch the equipment. In a real-world situation, one router could be in New York, while another router could be in Sydney, Australia. An administrator located in Sydney would have to connect to the router in New York through the WAN cloud to troubleshoot the New York router.

In the academy lab, the whole dedicated circuit cloud has been made extremely small and put in the “crack” between the back-to-back DTE-DCE cables. The connection from one router’s interface s0/0 to another’s router interface s0/1 simulates the entire circuit cloud.

Note that clocking must be configured, or this will not work properly for the use of CSU/DSU.

More Information: Internetworking Scenarios

Having examined the concepts underlying routing and internetworking, as well as some of the terminology inherent with these topics, you can see how they are used by examining three internetworking scenarios. Each scenario demonstrates some of the issues that need to be addressed in any network or internetwork:

- Routing within a network
- Routing between adjacent networks
- Routing between nonadjacent networks

These three generic aspects encompass virtually every form of internetworking that you are likely to encounter. Each one holds different implications for the network administrator, including such routing aspects as route calculation and distribution, convergence, and security. The following sections provide an overview of each internetworking scenario and highlight the areas of concern for a network administrator. The various potential resolutions to these routing concerns are presented throughout this book.

Routing Within a Network

The simplest form of routing is routing within the confines of a single network. Such a network contains just interior routers. In theory, this form of network uses just one routed protocol, one address architecture, and a minimum number of destinations. This structure greatly reduces the workload of each router and maximizes potential network performance. Therefore, the routing issues in intranetwork routing are more closely related to the network’s size and topology than to its address architectures and routing protocols. The topology must be carefully selected to match the requirements of the user community.

continues

More Information: Internetworking Scenarios (Continued)

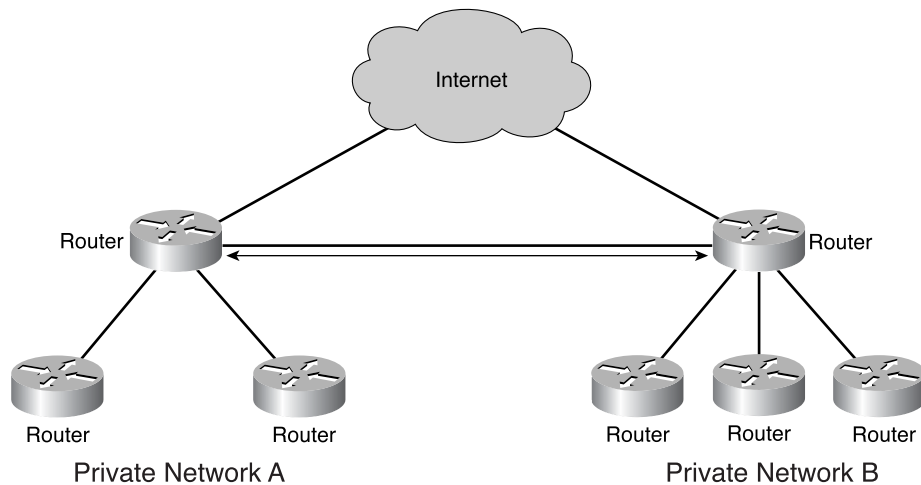
If the network is small enough, it might be feasible for the administrator to preprogram all the possible routes statically rather than introduce the complexity of a dynamic routing protocol. Statically programmed routes, however, can become an onerous burden in a growing or constantly changing network. You have to go to each router and manually update each time a change occurs in the network rather than having routers automatically update.

Routing Between Adjacent Networks

A small step up in complexity from intranetwork routing is internetwork routing between adjacent networks. Physical adjacency means that the two networks are directly connected to each other. Such an adjacency might have been designed to promote rapid convergence, improve security, or satisfy any number of other performance criteria.

The logical separation of the multiple networks implies that the border routers must summarize and redistribute routing information between them. In this fashion, the end systems of one network can directly address the end systems in another network. Figure 10-14 illustrates this type of routing.

Figure 10-14 Routing Between Adjacent Networks



The routing issues you need to address in this type of internetwork arise from the differences between the two networks. Some of the potential differences that must be identified include the following:

- Do the networks belong to the same organization? If not, the border routers need to secure the network's perimeter.
- Do the networks use the same routing protocol? If not, you need to find some mutually acceptable metric.
- Do the networks use the same routed protocol? If not, you might have to support a second routed protocol in your network to facilitate internetworking.

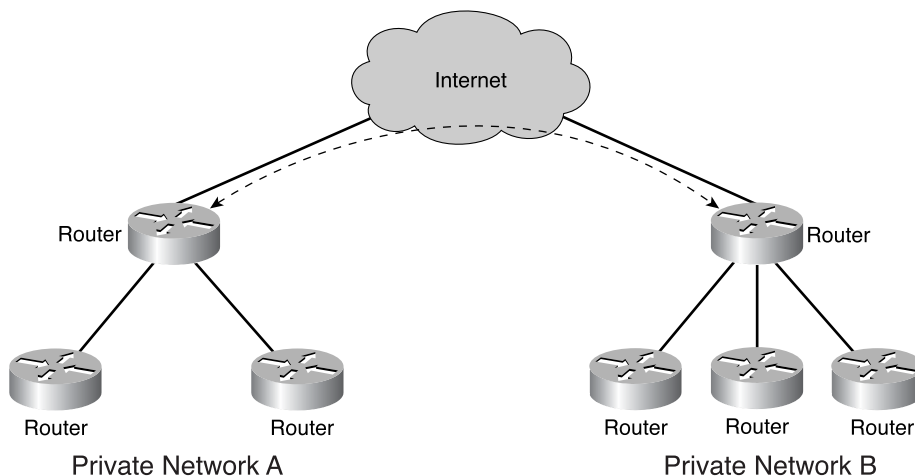
More Information: Internetworking Scenarios (Continued)

Additionally, topology can affect routing between adjacent networks. Using a single point of interconnection between the two networks, for example, makes it easy to control the calculation and redistribution of routing information between the networks. This convenience introduces a single point of failure, however, and it might not be acceptable to your users. Introducing a second (or more) interconnection point solves the single point of failure problem but can create the opportunity for infinite routing loops to occur. Resolving such a dilemma requires an understanding of your users' tolerance for downtime and risk. Armed with this understanding, you can evaluate specific routing protocols for their capabilities to converge quickly and compensate for potential routing problems.

Routing Between Nonadjacent Networks

Routing between nonadjacent networks is simultaneously the most complicated and useful type of routing. Two networks can use a third network as an intermediary. It is highly likely that the three different networks will use different routing protocols, routed protocols, and address architectures. Therefore, the boundary router's job is to overcome these obstacles to communication while also guarding the border of its network. Figure 10-15 illustrates routing between nonadjacent small networks.

Figure 10-15 Routing Between Nonadjacent Networks



The border router of each private network in this illustration needs to protect the border of its network from unwanted intrusion. Because the two networks that need to communicate aren't adjacent and the intermediary network is beyond their control, the risks of unwanted intrusion are much higher than if the networks were directly internetworked. Therefore, the network administrators must develop a set of criteria for allowing specific external users into their network, while disallowing access to everyone else. The border router implements these criteria in an access control list.

continues

More Information: Internetworking Scenarios (Continued)

Another responsibility of the border router is to summarize the internal routes and redistribute this information to the networks beyond. This process enables users outside the bounds of the private network to access its end systems. If this routing information isn't distributed, no one outside that private network is able to access its end systems.

Finally, it is highly likely that the border routers will have to be configured to use multiple routing protocols. An interior gateway protocol will likely be selected for intranetwork routing purposes. Calculating routes across the internetwork, however, might require a different protocol—one that features stronger support for route summarization. Route summarization can reduce routing table size by aggregating routes to multiple networks into one or two routing entries.

Summary

In this chapter, you learned the following the key points:

- The Internet is the interconnection of thousands of large and small networks all over the world.
- A WAN is used to interconnect LANs that are separated by a large geographic distance.
- Dedicated line, circuit-switching, packet-switching, and cell-switching are some of the common WAN connection types.
- Many types of WAN services are available to the WAN subscriber, who must know how to interface to the WAN provider's service.
- WAN devices include routers, WAN switches, modems, CSUs/DSUs, and access servers.
- WAN physical layer protocols describe how to provide electrical, mechanical, operational, and functional connection for WAN services.
- WAN data link layer protocols describe how frames are carried between systems on a single data link.

To supplement all that you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab activities on the CD-ROM accompanying this book.

Key Terms

cell-switched services Provide a dedicated-connection switching technology that organizes digital data into cell units and transmits them over a physical medium using digital signal technology.

circuit switching A WAN switching method in which a dedicated physical circuit through a carrier network is established, maintained, and terminated for each communication session. ISDN is an example of a circuit-switched WAN technology.

DCE (data circuit-terminating equipment) (ITU-T expansion) Devices and connections of a communications network that comprise the network end of the user-to-network interface. The DCE provides a physical connection to the network, forwards traffic, and provides a clocking signal used to synchronize data transmission between DCE and DTE devices. Modems and interface cards are examples of DCE.

DTE (data terminal equipment) Device at the user end of a user-network interface that serves as a data source, destination, or both. DTE connects to a data network through a DCE device (for example, a modem) and typically uses clocking signals generated by the DCE. DTE includes such devices as computers, protocol translators, and multiplexers.

modem Device that converts digital and analog signals. At the source, a modem converts digital signals to a form suitable for transmission over analog communication facilities. At the destination, the analog signals are returned to their digital form. Modems allow data to be transmitted over voice-grade telephone lines. The term *modem* is also used to describe various digital devices such as CSU/DSUs and ISDN terminal adapters.

packet-switched services Routes small units of data called packets through a network based on the destination address contained within each packet.

propagation delay Time required for data to travel over a network from its source to its ultimate destination.

router Network layer device that uses one or more metrics to determine the optimal path along which network traffic should be forwarded. Routers forward packets from one network to another based on network layer information.

switch Network device that filters, forwards, and floods frames based on the destination address of each frame. The switch operates at the data link layer of the OSI model.

uptime The amount of time that the device is functional and in service relative to the users' requirements for its availability.

WAN (wide-area network) A data communications network spanning a large geographic area, such as a state, province or country. WANs often use transmission facilities provided by common carriers, for example, telephone companies.

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. Which of the following best describes a WAN?
 - A. Connects LANs that are separated by a large geographic area
 - B. Connects workstations, terminals, and other devices in a metropolitan area
 - C. Connects LANs within a large building
 - D. Connects workstations, terminals, and other devices within a building
2. How do WANs differ from LANs?
 - A. WANs emphasize access over serial interfaces operating at lower speeds.
 - B. WANs provide high-speed multiple access services.
 - C. WANs typically exist in small geographic areas.
 - D. WANs use tokens to regulate network traffic.
3. Which of the following are examples of WAN technologies?
 - A. Token Ring, ARCNet
 - B. Frame Relay, ISDN
 - C. Star, Banyan VINES
 - D. CSU/DSU, ARCView
4. Which layers of the OSI model do WAN standards describe?
 - A. Data link and network
 - B. Data link and presentation
 - C. Physical and application
 - D. Physical and data link

5. Which best describes data circuit-terminating equipment (DCE)?
 - A. Consists of the user device at the end of a network
 - B. Serves as the data source or destination
 - C. Consists of physical devices such as protocol translators and multiplexers
 - D. Consists of physical devices at the end of a WAN connection
6. Which of the following components provides interface voice-grade services, channel service units/digital service units (CSUs/DSUs) that interface T1/E1 services, and terminal adapters/Network Termination 1 (TAs/NT1s) that interface Integrated Services Digital Network (ISDN) services?
 - A. Switches
 - B. Routers
 - C. Modems
 - D. Communication servers
7. Which of the following concentrates the dial-in and dial-out user connections?
 - A. Switches
 - B. Routers
 - C. Modems
 - D. Communication servers
8. Some WAN physical and data link layer standards are:
 - A. EIA/TIA-232
 - B. PPP
 - C. Frame Relay
 - D. All of the above
9. Match the functions with the components.
 - 1) RAM/DRAM
 - 2) NVRAM
 - 3) ROM
 - 4) Flash memory
 - 5) Interface

Options:

- a. RAM that retains its contents when a unit is powered off
- b. Volatile memory that can be read and written by the microprocessor
- c. Volatile memory that can be read but not written by a microprocessor
- d. Nonvolatile storage that can be electrically erased and reprogrammed so that software images can be stored, booted, and rewritten as necessary
- e. Connection between two systems or devices

Select your answer:

- A.** 1-b, 2-a, 3-c, 4-e, 5-d
- B.** 1-a, 2-b, 3-c, 4-e, 5-d
- C.** 1-b, 2-a, 3-e, 4-c, 5-d
- D.** 1-b, 2-a, 3-c, 4-d, 5-e

- 10.** Any internetwork will probably include the following:
- A.** Consistent end-to-end addressing and priority-level bandwidth allocation capabilities
 - B.** Addresses that represent network topologies and assurance of quality of service
 - C.** Best path selection and dynamic routing
 - D.** All of the above
- 11.** Which of the following are data link encapsulations for WAN?
- A.** High-Level Data Link Control (HDLC)
 - B.** Frame Relay
 - C.** Point-to-Point Protocol (PPP)
 - D.** All of the above
- 12.** What are the main functions of routers?
- A.** The determination of best paths for incoming data packets and the switching of packets to the proper outgoing interface
 - B.** Replying to ARP requests when two nodes are on different LANs
 - C.** Building routing tables and exchanging the network information contained within them with other routers
 - D.** Both A and B

13. Which is an IBM-designed WAN data link for Systems Network Architecture (SNA) environments, largely being replaced by the more versatile HDLC?
 - A. Serial Line Interface Protocol
 - B. Point-to-Point Protocol
 - C. Synchronous Data Link Control Protocol
 - D. Simple Data Level Control Protocol
14. Which WAN data link protocol is used for signaling and call setup on an ISDN D channel?
 - A. LAPD
 - B. LAPF
 - C. LAPB
 - D. LAPR
15. Identify the WAN circuit-switched service(s):
 - A. Plain old telephone services (POTS)
 - B. Narrowband ISDN with a maximum bandwidth of 1.544 Mbps
 - C. Narrowband ISDN with a maximum bandwidth of 128 kbps
 - D. Both A and C
16. Which service has become an extremely popular WAN technology in its own right, is more efficient than X.25 but with similar services, has a maximum bandwidth of 44.736 Mbps, and offers extremely popular 56-Kbps and 384-Kbps implementations in the United States?
 - A. Frame Relay
 - B. X.25
 - C. POTS
 - D. ATM
17. Identify the cell-switched technology/technologies:
 - A. ATM
 - B. Switched Multimegabit Data Service
 - C. T1
 - D. Both A and B

18. Identify the common type(s) of DSL technology/technologies:
 - A. High-bit-rate DSL (HDSL)
 - B. Single-line DSL (SDSL)
 - C. Asymmetric DSL (ADSL)
 - D. All of the above
19. Which is a family of very high-speed physical layer technologies with a series of data rates available with special designations, implemented at different Optical Carrier (OC) levels ranging from 51.84 Mbps (OC-1) to 9952 Mbps (OC-192), that can achieve these amazing data rates by using wavelength division multiplexing (WDM)?
 - A. SONET
 - B. HDSL
 - C. ATM
 - D. SMDS
20. Which are the kind of routers that form the primary paths for traffic that is sourced from and destined to other networks?
 - A. Internal routers
 - B. Area Border Routers
 - C. Backbone routers
 - D. Autonomous System (AS) Boundary Routers

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Objectives

Upon completion of this chapter, you will be able to

- Establish a HyperTerminal session
- Log into a router
- Use the help feature in the command-line interface
- Troubleshoot command errors
- Understand basic operation of Cisco IOS Software and its features
- Troubleshoot Cisco IOS Software
- Use the **show version** command
- Understand router user interface and modes

Chapter 11

Router Fundamentals

In this chapter, you learn how to start a router for the first time by using the correct commands and startup sequence to do an initial configuration of the router. This chapter also explains the startup sequence of a router and the setup dialog that the router uses to create an initial configuration file using current versions of Cisco Internetwork Operating System (IOS) Software.

Please be sure to look at this chapter's associated e-Lab Activities, Videos, and PhotoZooms that you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

Router Boot Sequence and Setup Mode

A router initializes by loading the *bootstrap*, the operating system, and a configuration file. If the router cannot find a configuration file, it enters setup mode. The router stores a backup copy of the new configuration created from setup mode in *nonvolatile random-access memory (NVRAM)*.

When a Cisco router powers up, it performs a *power-on self-test (POST)*. During this self-test, the router performs diagnostics from ROM on all hardware modules. These diagnostics verify the basic operation of the CPU, memory, and network interface ports. After verifying the hardware functions, the router proceeds with software initialization, characterized by the following two processes:

- System startup routines initiate router software.
- Fallback routines provide startup alternatives as needed.

The goal of the startup routines for Cisco IOS Software is to start the router operations. The router must deliver reliable performance in its job of connecting the user networks that it was configured to serve. To do this, the startup routines must do the following:

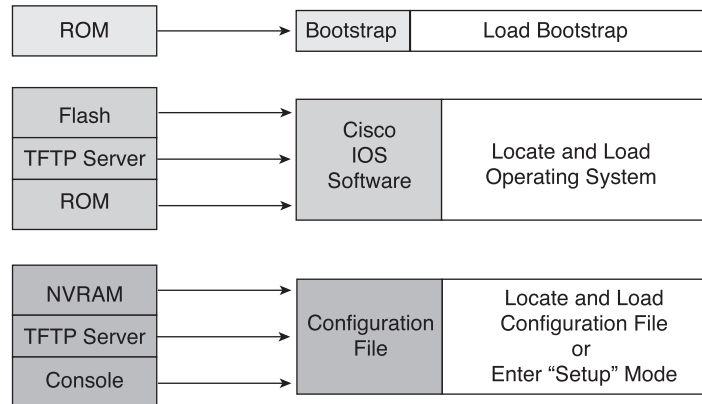
1. Make sure that the router hardware is tested and functional.
2. Find and load the Cisco IOS software that the router uses for its operating system.
3. Find and apply the startup configuration file or enter the setup mode.

Router Startup Sequence

After the POST, the following events occur as the router initializes:

1. The generic bootstrap loader in ROM is carried out. A bootstrap is a simple, pre-set operation that loads instructions. These instructions then cause other instructions to be loaded into memory or cause entry into other configuration modes.
2. The Cisco IOS Software image can be found in several places. The boot field of the configuration register determines the location to be used in loading Cisco IOS Software images. If the boot field indicates a *Flash* memory or network load, **boot system** commands in the configuration file indicate the exact name and location of the image.
3. The Cisco IOS Software image is loaded. Then, when Cisco IOS Software is loaded and operational, the operating system locates the hardware and software components and lists the results on the console terminal.
4. The configuration file saved in NVRAM is loaded into main memory and executed one line at a time. The configuration commands start routing processes, supply addresses for interfaces, set media characteristics, and so on.
5. If no valid configuration file exists in NVRAM, or if NVRAM is erased, the operating system executes a question-driven initial configuration routine referred to as the system configuration dialog, also called the setup dialog when the router is rebooted.

Figure 11-1 shows the startup sequence.

Figure 11-1 Startup Sequence

System Configuration Dialog

Setup is not intended as the mode for entering complex protocol features in the router. The main purpose of setup mode is to quickly install a minimal configuration for any router that cannot find its configuration from another source.

For many of the prompts in the system configuration dialog of the setup command facility, default answers appear in square brackets ([]) following the question. Press the Enter key to use these defaults.

If the system has been previously configured, the defaults that appear will be the currently configured values. To get a fresh start, the command **erase startup-config** can be used to remove the current configuration file from NVRAM. The **reload** command reboots the router and initiates setup again. If the system is being configured for the first time, the factory defaults are provided. If there is no factory default, as in the case of passwords, nothing is displayed after the question mark (?). During the setup process, you can press Ctrl-C at any time to terminate the process and start over. When setup is terminated, all interfaces will administratively be shut down. Example 11-1 shows the setup command.

Example 11-1 setup Command

```
# setup

-- System Configuration Dialog --

At any point you may enter a question mark '?' for help.
```

continues

Example 11-1 *setup Command (Continued)*

```

Use ctrl-c to abort configuration dialog at any prompt.
Default settings are in square brackets '['].

Basic management setup configures only enough connectivity
for management of the system, extended setup will ask you
to configure each interface on the system

Would you like to enter basic management setup? [yes/no]: no

First, would you like to see the current interface summary? [yes]: yes

Interface      IP-Address      OK? Method Status          Protocol
Ethernet0      198.133.219.1  YES NVRAM  up              down
Serial0        unassigned      YES NVRAM  administratively down  down
Serial1        unassigned      YES NVRAM  administratively down  down

```

When the configuration process is completed in setup mode, the screen displays the configuration that was created. When you are asked whether to use this configuration, enter **yes**; the configuration executes and is saved to NVRAM. If you enter **no**, the configuration is not saved and the process begins again. If a **--More--** prompt appears, press the spacebar to continue to another screen of information.

Setting Up Global Parameters

After you view the current interface summary, a prompt appears on your monitor, as shown in Example 11-2, indicating that you must enter the global parameters for your router. These parameters are the configuration values that you select.

The first statement indicates that you are configuring the global parameters in the router. The first global parameter enables you to set the router host name. This host name will be part of the Cisco IOS Software prompts for all EXEC modes. At initial configuration, the router name default is displayed between square brackets as [Router]. After you set the router name default, you need to set the various passwords used on the router.

Example 11-2 *Global Parameters*

```
Configuring global parameters:

Enter host name [Router]: Cisco

The enable secret is a password used to protect access to
privileged EXEC and configuration modes. This password, after
entered, becomes encrypted in the configuration.
Enter enable secret: cougars

The enable password is used when you do not specify an
enable secret password, with some older software versions, and
some boot images.
Enter enable password: lumberjacks

The virtual terminal password is used to protect
access to the router over a network interface.
Enter virtual terminal password: matadors
Configure SNMP Network Management? [yes]: no
```

You must enter an enable password. When you enter a string of password characters for the prompt Enter enable secret, the characters are processed by Cisco-proprietary encryption. This enhances the security of the password string. Whenever anyone lists the contents of the router configuration file, this enable password appears as a meaningless string of characters.

Setup recommends, but does not require, that the *enable password* be different than the *enable secret word*. The enable secret word is a one-way cryptographic secret word that is used instead of the enable password, when it exists. The enable password is used when no enable secret word exists. Because of this one-way encryption, the enable secret password cannot be recovered if forgotten, whereas the enable password is clear text and can be read from the config file.

The enable password also is used with other versions of Cisco IOS Software. All passwords are case sensitive and can be alphanumeric.

It is possible to secure the router by using passwords to restrict access to individual lines as well. Example 11-3 uses the **line-console 0** command followed by the **login** and **password** subcommands to establish a login password for the console terminal. The purpose here is to establish the need for a user to log into the console before gaining

access to the router. **console 0** designates the router's console connection, and **login** prompts the user for a password before allowing console connectivity.

Example 11-3 *Configuring the Router's Console Password*

```
Router(config)# line console 0
Router(config-line)# login
Router(config-line)# password cisco
```

As demonstrated in Example 11-4, the **line vty 0 4** command followed by the **password** subcommand establishes a login password on incoming Telnet sessions.

Example 11-4 *Configuring the Router's Virtual Terminal Password*

```
Router(config)# line vty 0 4
Router(config-line)# password sanjose
```

After you enter the passwords for the various ports, the router asks you to enter the routing protocols that are to be used, as shown in Example 11-5. When you are prompted for parameters for each protocol, use the configuration values that you have selected for your router. Whenever you answer yes to a prompt, additional questions might appear regarding the protocol.

Example 11-5 *Prompts for Global Parameters at the Console*

```
Configure IP? [yes]:
    Configure IGRP routing? [yes]: 200
% Please answer 'yes' or 'no'.
    Configure IGRP routing? [yes]: yes
        Your IGRP autonomous system number [1]: 200
Configuring interface parameters:

Do you want to configure Ethernet0 interface? [yes]: yes
    Configure IP on this interface? [yes]: yes
        IP address for this interface: 10.10.10.1
        Subnet mask for this interface [255.0.0.0] :
            Class A network is 10.0.0.0, 8 subnet bits; mask is /8

Do you want to configure Serial0 interface? [yes]: n
```

Example 11-5 Prompts for Global Parameters at the Console (Continued)

```
Do you want to configure Serial1 interface? [yes]: n

The following configuration command script was created:

hostname Cisco
enable secret 5 $1$37Kq$va6UckC1KEBz0IWGIF54U/
enable password lumberjacks
line vty 0 4
password wildcats
no snmp-server
!
no bridge 1
ip routing
!
interface Ethernet0
ip address 10.10.10.1 255.0.0.0
!
--- output omitted ---
```

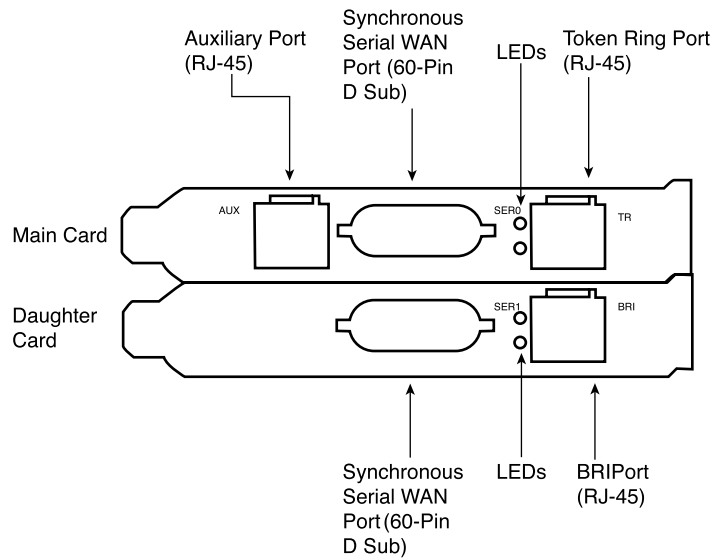
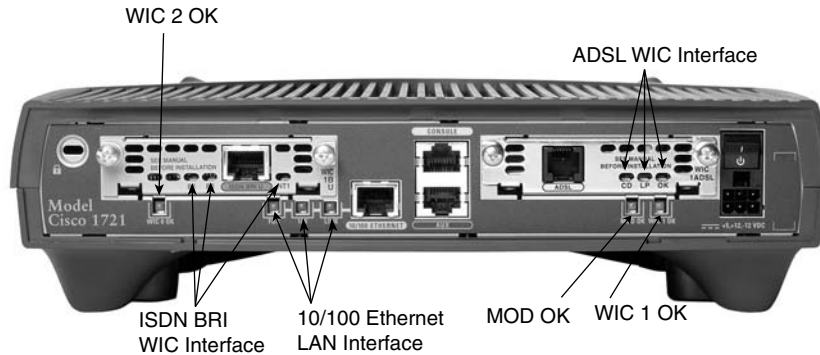
**Lab Activity** Router Configuration Using Setup

In this lab, you use the System Configuration Dialogue (setup) to establish some of the basic router configuration parameters.

Router LED Indicators

Cisco routers use *light-emitting diode (LED)* indicators to provide status information. Depending on the Cisco router model, the LED indicators vary.

The upper LED on the daughter card indicates the activity on serial 1 port on the daughter card. The lower LED on the daughter card indicates the activity of the WAN, or BRI port. Figures 11-2 and 11-3 illustrate the router LED indicators.

Figure 11-2 2500 Series Router LED Indicators**Figure 11-3** 1721 Series Router LED Indicators

The LEDs on the interface indicate the activity of the corresponding interface. If the LED is not on when the interface is active, *and* the interface is correctly connected, this might indicate a problem. If an interface is extremely busy, its LED is always on. The green OK LED on the bottom of both WAN interface cards comes on after the system initializes correctly.

Initial Router Boot-Up Output

Each time a router is powered on, it goes through the following boot sequence:

1. The router goes through POST diagnostics to verify basic operation of the CPU, memory, and interfaces.

2. To verify that the system bootstrap software is loaded correctly, the boot image executes and searches for a valid Cisco IOS Software image (router operating system software). The source of the Cisco IOS Software image, whether a Flash memory or a Trivial File Transfer Protocol (TFTP) server, is determined by the configuration register setting. The factory-default setting for the configuration register is 0x2102. This indicates that the router should attempt to load a Cisco IOS Software image from Flash memory.
3. If after five attempts a valid Cisco IOS Software image is not found in Flash memory, the router reverts to boot ROM mode. This mode is used to install or upgrade a Cisco IOS Software image.
4. If a valid Cisco IOS Software image is found, the router searches for a valid configuration file.
5. If a valid configuration file is not found in NVRAM, the router searches for a TFTP server over all interfaces. If a configuration file is not found, the router runs the system configuration dialog so a configuration can be manually configured.

In Examples 11-6 and 11-7, the messages displayed vary, depending on the interfaces in the router and the Cisco IOS release. The screen displays in this graphic are for reference only and might not exactly reflect the screen displays on the console.

Example 11-6 *NVRAM Invalid*

```
System Bootstrap, Version X.X(XXXX) [XXXXX XX], RELEASE SOFTWARE
Copyright (c) 1986-199X by Cisco Systems
1721 processor with 4096 Kbytes of main memory

Notice: NVRAM invalid, possibly due to write erase.

--- output omitted ---
```

Example 11-7 *Bootstrap and Cisco IOS Software Version*

```
--- output omitted ---
IOS (tm) 1721 Software (XXX-X-X), Version [XXXXX XXX]
Copyright (c) 1986-199X by Cisco Systems, Inc.
```

Notice in Example 11-6 that the NVRAM is invalid; this is possibly because of write erase. This tells the user that the router has not been configured for the first time or that the NVRAM has been erased. A router cannot be used until it is configured.

In Example 11-7, the user can determine the bootstrap version and the Cisco IOS Software version that the router is using. The user also can determine the router model, the processor, and the amount of memory that the router contains. Other information listed in this output includes the following information and is shown in Example 11-8:

- How many interfaces the router has
- What types of interfaces the router has
- The amount of NVRAM
- The amount of Flash memory

Example 11-8 *Bootstrap and Cisco IOS Software Version*

```
Processor board ID 10226279
R4700 CPU at 100Mhz, Implementation 33, Rev 1.0
MICA-6DM Firmware: CP ver 2730 - 5/23/2001, SP ver 2730 - 5/23/2001.
Bridging software.
X.25 software, Version 3.0.0.
SuperLAT software (copyright 1990 by Meridian Technology Corp).
TN3270 Emulation software.
Primary Rate ISDN software, Version 1.1.
2 Ethernet/IEEE 802.3 interface(s)
24 Serial network interface(s)
4 Low-speed serial(sync/async) network interface(s)
6 terminal line(s)
1 Channelized T1/PRI port(s)
DRAM configuration is 64 bits wide with parity disabled.
125K bytes of non-volatile configuration memory.
32768K bytes of processor board System flash (Read/Write)

Configuration register is 0x2102
```

Establishing a HyperTerminal Session

All Cisco routers include an EIA/TIA-232 asynchronous serial console port (RJ-45). Cables and adapters are needed to connect a console terminal (an ASCII terminal or PC running terminal emulation software) to the console port. To connect a PC running terminal emulation software to the console port, use the RJ-45-to-RJ-45 rollover cable with a female RJ-45-to-DB-9 or RJ-45-to-DB-25 adapter.

The default parameters for the console port are 9600 baud, 8 data bits, no parity, 1 stop bit, and no flow control. The console port does not support hardware flow control.

Take the following steps to connect a terminal to the console port on the router:

- Step 1** Connect the terminal or PC using the RJ-45-to-RJ-45 rollover cable and an RJ-45-to-DB-9 or RJ-45-to-DB-25 adapter.
- Step 2** Configure the terminal or PC terminal emulation software for 9600 baud, 8 data bits, no parity, 1 stop bit, and no flow control.

Figure 11-4 shows an example of the console connection to a PC, to establish a HyperTerminal connection with a PC.

Table 11-1 shows a list of operating systems and the terminal emulation software that can be used with each operating system.

Table 11-1 Available Terminal Emulation Software

PC Operating System	Software
Windows 9x, NT, 2000, and XP	HyperTerminal (included with Windows software), ProComm Plus
Windows 3.1	Terminal (included with Windows software)
Macintosh	ProComm, VersaTerm, ZTerm (supplied separately)



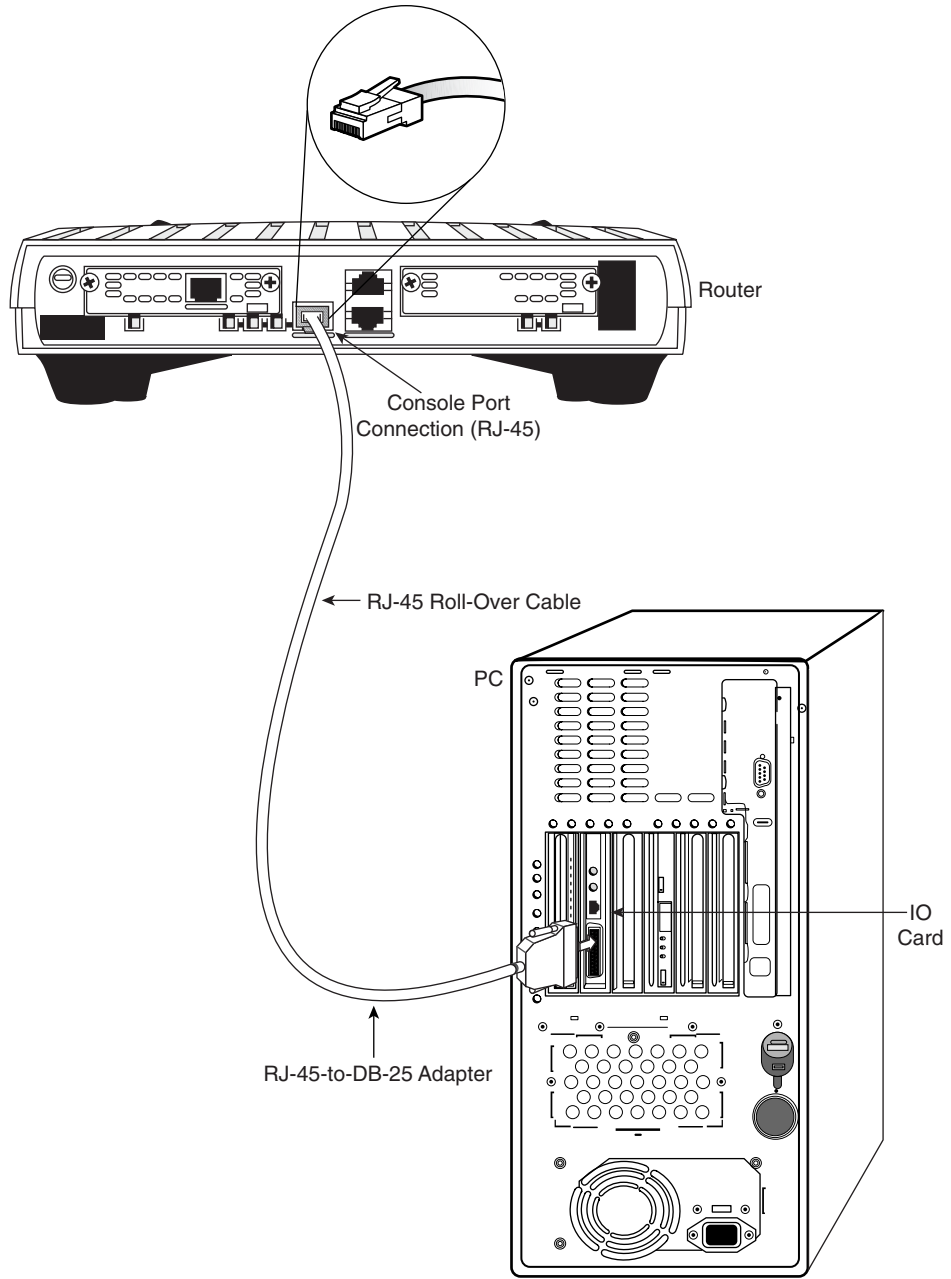
Lab Activity Establishing a Console Connection with HyperTerminal

In this lab, a workstation will be connected to the router using a console cable and HyperTerminal will be configured to establish a console session with router.

NOTE

If you are using a crossover cable at this end, the other end must be straight-through or something similar.

Figure 11-4 Terminal Console Cable



Logging into the Router

To configure Cisco routers, the user interface must be accessed on the router with a terminal or by remote access. When accessing a router, a user must log into the router before any other commands are entered.

For security purposes, the router has two levels of access to commands, as demonstrated by Example 11-9:

- **User EXEC mode**—Typical tasks include those that check the router status. In this mode, router configuration changes are not allowed.
- **Privileged EXEC mode**—Typical tasks include those that change the router configuration.

The user EXEC mode prompt is displayed upon login to a router. Commands available at this user level are a subset of the commands available at the privileged EXEC level. For the most part, these commands enable a user to display information without changing router configuration settings.

Example 11-9 Router Modes

```
Router> ----- User Mode
Router>enable
Password:
Router# ----- Privileged-Mode
Router>disable
Router>
```

To access the full set of commands, privileged EXEC mode must be entered. At the > prompt, type **enable**. At the password prompt, enter the password that has been set with the **enable secret** command. When the login steps have been completed, the prompt changes to a #, to indicate that you are now in privileged EXEC mode. From privileged EXEC mode, global configuration mode and other specific modes, including the following, can be accessed:

- Interface (central_2(config-if)#)
- Subinterface (central_2(config-subif)#)
- Line (central_2(config-line)#)
- Router (central_2(config-router)#)
- Route-map (central_2(config-map-class)#)

To return to user EXEC mode, type **disable**. To log out of the router, type **exit**. Screen output varies with the specific Cisco IOS Software level and router configuration.

More Information: Basic Operation of Cisco IOS Software

The Cisco Internetwork Operating System (IOS) Software platform is implemented on the various hardware used in this course. It is the embedded software architecture in all the Cisco routers.

Cisco IOS Software enables the following network services in these products:

- Features to carry the chosen network protocols and functions
- Connectivity for high-speed traffic between devices
- Security to control access and discourage unauthorized network use
- Scalability to add interfaces and capability as needed for network growth
- Reliability to ensure dependable access to networked resources

The Cisco IOS Software command-line interface (CLI) can be accessed through a console connection, a modem connection, or a Telnet session. Regardless of which connection method is used, access to the IOS command-line interface generally is referred to as an EXEC session.

Keyboard Help

Typing a question mark (?) at the user EXEC mode prompt or the privileged EXEC mode prompt displays a list of available commands, as demonstrated in Example 11-7.

Notice the --More-- at the bottom of the sample display. The screen displays 22 lines at one time. The --More-- prompt at the bottom of the display indicates that multiple screens are available as output. Whenever a --More-- prompt appears, you can view the next available screen by pressing the spacebar. To display just the next line, press the Enter key. Press any other key to return to the prompt.

NOTE

At this point, the list of commands displayed is context sensitive. You see a different list when you are in user mode versus enable mode, and when in global configuration versus configure interface modes.

Example 11-10 Keyboard Help

```
?
Exec commands:
access-enable      Create a temporary Access-List entry
access-profile     Apply user-profile to interface
access-template    Create a temporary Access-List entry
archive            manage archive files
bfe                For manual emergency modes setting
cd                 Change current directory
clear              Reset functions
clock              Manage the system clock
configure          Enter configuration mode
connect            Open a terminal connection
```

Example 11-10 *Keyboard Help (Continued)*

```
copy          Copy from one file to another
debug        Debugging functions (see also 'undebug')
delete       Delete a file
dir          List files on a filesystem
disable      Turn off privileged commands
disconnect   Disconnect an existing network connection
elog        Event-logging control commands
enable       Turn on privileged commands
erase        Erase a filesystem
exit         Exit from the EXEC
help         Description of the interactive help system

--More--

isdn         Make/disconnect an isdn data call on a BRI interface
lock        Lock the terminal
login       Log in as a particular user
logout      Exit from the EXEC
more        Display the contents of a file
mrinfo      Request neighbor and version information from a multicast router
mrm         IP Multicast Routing Monitor Test
mstat       Show statistics after multiple multicast traceroutes
mtrace      Trace reverse multicast path from destination to source
name-connection Name an existing network connection
no          Disable debugging functions
pad         Open a X.29 PAD connection
ping        Send echo messages
ppp         Start IETF Point-to-Point Protocol (PPP)
pwd         Display current working directory
reload      Halt and perform a cold restart
resume      Resume an active network connection
rlogin      Open an rlogin connection
rsh         Execute a remote command
send        Send a message to other tty lines
setup       Run the SETUP command facility
show        Show running system information
```

continues

Example 11-10 *Keyboard Help (Continued)*

```
--More--
slip          Start Serial-line IP (SLIP)
start-chat    Start a chat-script on a line
systat        Display information about terminal lines
telnet        Open a telnet connection
terminal      Set terminal line parameters
test          Test subsystems, memory, and interfaces
traceroute    Trace route to destination
tunnel        Open a tunnel connection
udptn         Open an udptn connection
undebug       Disable debugging functions (see also 'debug')
verify        Verify a file
where         List active connections
write         Write running configuration to memory, network, or terminal
x28           Become an X.28 PAD
x3            Set X.3 parameters on PAD
```

To access privileged EXEC mode, type **enable** or the abbreviation **ena**. Typing **enable** causes the router to prompt the user for a password. Typing a question mark at the privileged EXEC mode prompt (see Example 11-11) displays a longer list of commands than would be displayed at the user EXEC mode prompt.

Example 11-11 *Privileged EXEC Mode Commands*

```
Cisco# ?
Exec commands:
  access-enable  Create a temporary Access-List entry
  access-profile Apply user-profile to interface
  access-template Create a temporary Access-List entry
  archive        manage archive files
  bfe            For manual emergency modes setting
  cd             Change current directory
  clear          Reset functions
  clock          Manage the system clock
  configure      Enter configuration mode
  connect        Open a terminal connection
  copy           Copy from one file to another
```


Example 11-11 *Privileged EXEC Mode Commands (Continued)*

```
debug          Debugging functions (see also 'undebug')
delete         Delete a file
dir            List files on a filesystem
disable        Turn off privileged commands
disconnect     Disconnect an existing network connection
elog          Event-logging control commands
enable         Turn on privileged commands
erase          Erase a filesystem
exit           Exit from the EXEC
help           Description of the interactive help system
--More--
```

Screen output varies, depending on Cisco IOS Software level and router configuration.

Router Help Functions

Suppose that a user wants to set the router clock. If the necessary command is not known, that user can use the help function to check the syntax for setting the clock. The following exercise illustrates one of the many uses of the help function. The task is to set the router clock. Assuming that the command is not known, proceed using the following steps:

- Step 1** Use ? to find the command for setting the clock. The help output shows that the **clock** command is required.
- Step 2** Check the syntax for changing the time.
- Step 3** Enter the current time by using hours, minutes, and seconds, as shown. The system indicates that additional information needs to be provided to complete the command. The help output in Example 11-12 shows that the **set** keyword is required.

Example 11-12 *Clock set Keyword*

```
Cisco# clok
Translating "clok"...domain server (255.255.255.255)

% Unknown command or computer name, or unable to find computer address
```

continues

Example 11-12 *Clock set Keyword (Continued)*

```
Cisco# c1?
clear clock

Cisco# clock
% Incomplete command.

Cisco# clock ?
set Set the time and date

Cisco# clock set
% Incomplete command.

Cisco# clock set ?
hh:mm:ss Current Time
```

- Step 4** Check the syntax for entering the time, and enter the current time using hours, minutes, and seconds. As shown in Example 11-13, the system again indicates that additional information is required to complete the command.

Example 11-13 *Clock Time and Date Set Format*

```
Cisco# clock set 19:50:00
% Incomplete command.

Cisco# clock set 19:50:00 ?
<1-31> Day of the month
MONTH Month of the year

Cisco# clock set 19:50:00 14 7
^
% Invalid input detected at '^' marker.

Cisco# clock set 19:50:00 14 July
% Incomplete command.

Cisco# clock set 19:50:00 14 July ?
<1993-2035> Year
```

Example 11-13 *Clock Time and Date Set Format (Continued)*

```
Cisco# clock set 19:50:00 14 July 2003
```

```
Cisco#
```

- Step 5** Press **Ctrl + P** or the up arrow to repeat the previous command entry automatically. Then add a space and a question mark (?) to reveal the additional arguments. Now the command entry can be completed.
- Step 6** The caret symbol (^) and help response indicate that there is an error. The placement of the caret symbol shows where the possible problem is located. To input the correct syntax, re-enter the command up to the point where the caret symbol is located, and then enter a question mark (?).
- Step 7** Enter the year, using the correct syntax, and press Enter to execute the command.

The user interface provides syntax checking by placing a ^ where the error occurred. The ^ appears at the point in the command string where an incorrect command, keyword, or argument was entered. The error location indicator and interactive help system enable syntax errors to be found and easily corrected.

Cisco IOS Software Editing Commands

The user interface includes an enhanced editing mode that provides a set of editing key functions with which the user can edit a command line as it is being typed. Use the key sequences indicated in Table 11-2 to move the cursor at the command line for corrections or changes. Although enhanced editing mode automatically is enabled with the current software release, it can be disabled if written scripts do not interact well while enhanced editing is enabled. To disable enhanced editing mode, type **terminal no editing** at the privileged EXEC mode prompt.

Table 11-2 Editing Commands

Command	Description
Ctrl + a	Moves to the beginning of the command line
Ctrl + e	Moves to the end of the command line

continues

Table 11-2 Editing Commands (Continued)

Command	Description
Esc + b	Moves back one word
Ctrl + f	Moves forward one character
Ctrl + b	Moves back one character
Esc+ f	Moves forward one word

The editing command set provides a horizontal scrolling feature for commands that extend beyond a single line on the screen. When the cursor reaches the right margin, the command line shifts ten spaces to the left. The first ten characters of the line cannot be seen, but a user can scroll back and check the syntax at the beginning of the command. To scroll back, press Ctrl+ b or the left arrow key repeatedly until the beginning of the command entry is reached. Ctrl + a returns a user directly to the beginning of the line.

In Example 11-14, the command entry extends beyond one line. When the cursor first reaches the end of the line, the line is shifted ten spaces to the left and is redisplayed. The dollar sign (\$) indicates that the line has been scrolled to the left. Each time the cursor reaches the end of the line, the line again is shifted ten spaces to the left.

Example 11-14 *Extension of Command Entry*

```
Cisco>$ value for our customers, employees, investors, and partners
```

Screen output varies, depending on the Cisco IOS Software level and router configuration.

The Ctrl + z command backs out of configuration mode. This command returns the user to the privileged EXEC mode prompt.

Router Command History

The user interface provides a history, or record, of commands that have been entered. This feature is particularly useful for recalling long or complex commands or entries. With the command history feature, the following tasks can be completed:

- Set the command history buffer size
- Recall commands
- Disable the command history feature

By default, the command history is enabled and the system records ten command lines in its history buffer. To change the number of command lines that the system records during a terminal session, use the **terminal history size** or the **history size** commands. The maximum number of commands is 256. Table 11-3 shows command history commands.

Table 11-3 Router Command History

Command	Description
Ctrl + p	This key sequence or the up arrow key recalls the last (previous) command
Ctrl + n	This key sequence or the down arrow key recalls the most recent command
show history	Displays the command buffer
terminal history [size <i>numberof-lines</i>]	Sets the command buffer size
terminal no editing	Disables advanced editing features
Router> terminal editing	Re-enables advanced editing features
Tab	Completes the entry

To recall commands in the history buffer, beginning with the most recent command, press Ctrl + p. Continue to press Ctrl + p or the up arrow key to recall successively older commands. To return to more recent commands in the history buffer, after using the Ctrl + p or the up arrow, press Ctrl + n or the down arrow key repeatedly to recall successively more recent commands.

When typing commands, as a shortcut, you can enter the unique characters for a command. Press the Tab key, and the interface finishes the entry. When the typed letters uniquely identify the command, the Tab key simply acknowledges visually that the router has understood the specific command that was intended.

On most computers, additional select and copy functions are available. A previous command string can be copied and then pasted or inserted as the current command entry.

**Lab Activity** Command Line Fundamentals

In this lab, you log into a router in both user and privilege modes. You use several basic router commands to determine how the router is configured. You also become familiar with the router help facility and use the command history and editing features.

Cisco IOS Software Fundamentals

Like any computer, a router or switch cannot function without an operating system. Cisco calls its operating system the Cisco Internetwork Operating System, or Cisco IOS Software. It is the embedded software architecture in almost all of the Cisco routers and Catalyst switches. Some Catalyst switches use a Cisco command-line interface (CLI). A router does not become functional until it loads Cisco IOS Software. Without an operating system, the hardware has no capability. Cisco IOS Software provides the following network services:

- Basic routing and switching functions
- Reliable and secure access to networked resources
- Network scalability

Operation of Cisco IOS Software

Cisco IOS Software devices have three distinct operating environments or modes:

- ROM monitor
- Boot ROM
- Cisco IOS

The startup process of the router normally loads into RAM and performs in one of these operating environments. The configuration register setting can be used by system administrators to control which of these modes is used by the router to load.

The ROM monitor performs the bootstrap process and provides low-level functionality and diagnostics. The ROM monitor is used to recover from system failures and to recover a lost password. The ROM monitor cannot be accessed through any of the network interfaces, but only through a console port session.

When the router is running in boot ROM mode, only a limited subset of the Cisco IOS Software feature set is available. Boot ROM allows write operations to Flash memory and is used primarily to replace the Cisco IOS Software image that is stored in Flash

memory. The Cisco IOS Software image can be modified in boot ROM mode by using the **copy tftp flash** command, which copies an IOS image stored on a TFTP server into the Flash memory of the router.

The normal operation of a router requires the full Cisco IOS Software image from Flash memory. In some devices, the IOS is performed directly from Flash. However, most Cisco routers require a copy of the Cisco IOS Software image to be loaded into RAM and also executed from RAM. Some Cisco IOS Software images are stored in Flash in a compressed format and must be expanded when copied to RAM.

To see the Cisco IOS Software image and version that is running, use the **show version** command, which also indicates the configuration register setting. The **show flash** command in Example 11-15 verifies that the system has sufficient memory to load a new Cisco IOS Software image.

Example 11-15 *Verifying the Cisco IOS Software Image*

```
Cisco> show flash

System flash directory:
File Length Name/status
  1 8022152 /c2500-i-1.121-16.bin
[8022216 bytes used, 366392 available, 8388608 total]
8192K bytes of processor board System flash (Read ONLY)
```

Cisco IOS Software Features

Cisco provides Cisco IOS Software images for devices spanning a wide range of network product platforms. To optimize the Cisco IOS Software required by various product platforms, Cisco is working to develop many different Cisco IOS Software images. Each image represents a different feature set that serves the various device platforms, available memory resources, and customers' needs.

Numerous Cisco IOS Software images exist for different Cisco device models and feature sets. However, the basic configuration command structure is the same. The configuration and troubleshooting skills acquired on any one device apply across a wide range of products.

The naming convention for the different Cisco IOS Software releases contains three parts:

- The platform on which the image runs
- The special capabilities supported in the image
- Where the image runs and whether it has been zipped or compressed

This material is covered in more detail in Chapter 14, “Managing Cisco IOS Software.” The Cisco IOS Software naming conventions, image content, and other details are subject to change.

After choosing the options that meet the network requirements, select a Cisco IOS Software release that is supported by the hardware. The software requirements of each device are listed in the “Cisco Product Documentation” section of the Documentation CD. The Cisco Software Advisor is an interactive tool that provides the most current information.

One of the main considerations when selecting a new IOS image is that it is compatible with the router flash and RAM memory. In general, the newer the release is and the more features it provides, the more memory it requires. Use the **show version** command, as shown in Example 11-13, from the Cisco device to check the current image and available Flash memory. The Cisco support site has tools available to help determine the amount of Flash memory and RAM required for each image.

Before installing a new Cisco IOS Software image on the router, check to see if the router meets the memory requirements for that image. To see the amount of RAM, issue the **show version** command and look for the following output in Example 11-16.

Example 11-16 show version *Command Output*

```
Cisco> show version
Cisco Internetwork Operating System Software
--- output omitted ---
image file is "flash:/c2500-i-1.121-16.bin"
cisco 2600 (68030) processor (revision N) with 6144K/2048K bytes of memory.
```

The highlighted line shows how much main and shared memory is installed in the router. Some platforms use a fraction of dynamic RAM (DRAM) as shared memory. The memory requirements take this into account, so both numbers must be added to determine the amount of DRAM installed on the router.

To determine the amount of free Flash memory, issue the **show flash** command, as shown in Example 11-17.

Example 11-17 show flash *Command Output*

```
Cisco> show flash

System flash directory:
File Length Name/status
  1 8022152 /c2500-i-1.121-16.bin
[8022216 bytes used, 366392 available, 8388608 total]
8192K bytes of processor board System flash (Read ONLY)
```

The show version Command

The **show version** command displays information about the Cisco IOS Software version that currently is running on the router. This includes the configuration register and the boot field setting.

- Cisco IOS Software version and descriptive information
- Bootstrap ROM version
- Boot ROM version
- Router up time
- Last restart method
- System image file and location
- Router platform
- Configuration register setting

Router User Interface

Recall that the Cisco IOS Software uses a *command-line interface (CLI)* as its traditional console environment. Cisco IOS Software is a core technology that extends across most of the Cisco product line. Its operation details vary, depending upon the internetworking device using it.

This CLI environment is accessible through several methods:

- Through a console session. A console uses a low-speed serial connection directly from a computer or terminal to the console connection on the router. This method does not require the configuration of network services on the router.
- Through a dialup connection by using a modem or a null modem connected to the router AUX port. This method does not require the configuration of network services on the router, either.

- Through a Telnet connection to the router as a virtual terminal. To establish a Telnet session to the router, at least one interface must be configured for IP. Virtual terminal sessions also must be configured for login and passwords.

Router User Interface and Modes

The Cisco CLI uses a hierarchical structure. This structure requires entry into different modes to accomplish particular tasks. For example, interface configuration mode must be entered to configure a router interface. From interface configuration mode, all configurations entered apply only to that particular interface. Each command mode is indicated with a distinctive prompt and allows only commands that are appropriate for that mode.

Cisco IOS Software provides a command interpreter service known as the command executive (EXEC). After each command is entered, the EXEC validates and executes the command.

As a security feature, Cisco IOS Software separates the EXEC sessions into two access levels. These levels are user EXEC mode and privileged EXEC mode, which is also known as enable mode.

User EXEC mode allows only a limited number of basic monitoring commands. This often is referred to as a view-only mode. The user EXEC level does not allow any commands that could change the configuration of the router. The user EXEC mode can be identified by the > prompt.

Privileged EXEC mode provides access to all router commands. Privileged EXEC mode can be protected by requiring a user ID and a password. This mode allows only authorized users to access the router. Configuration and management commands require that the network administrator be at the privileged EXEC level. Global configuration mode and all other more specific configuration modes can be reached only from privileged EXEC mode. Privileged EXEC mode can be identified on the CLI session by the # prompt.

To access the privileged EXEC level from the user EXEC level, enter the **enable** command at the > prompt. If a password is configured, the router asks for a password at this point. For security reasons, a Cisco network device will not show the password that is entered. When the correct password is entered, the router prompt changes to #, indicating that the user is now at the privileged EXEC level. Entering a question mark (?) at the privileged EXEC level reveals many more command options than those available at the user EXEC level.

Troubleshooting Cisco IOS Software

Several things could prevent the router from booting properly:

- Configuration file with a missing or incorrect **boot system** statement
- Incorrect configuration register value
- Corrupted Flash image
- Hardware failure

When the router boots, it looks in the configuration file for a **boot system** statement. This statement can force the router to boot from another image instead of the Cisco IOS Software image in Flash. To identify the boot image source, type the **show version** command and look for the line that identifies the image boot source, as shown in Example 11-18.

Example 11-18 Image Boot Source

```
Cisco> show version
--- output omitted ---

ROM: System Bootstrap, Version 11.0(10c), SOFTWARE
BOOTLDR: 3000 Bootstrap Software (IGS-BOOT-R), Version 11.0(10c), RELEASE
SOFTWARE (fc1)
```

An incorrect configuration register setting prevents the Cisco IOS Software from loading from Flash memory. The value in the configuration register tells the router where to get the Cisco IOS Software image. This can be confirmed by using the **show version** command and looking at the last line for the configuration register, as shown in Example 11-19.

Example 11-19 Configuration Register

```
Cisco> show version
---- output omitted ----

Configuration register is 0x2102
```

The correct value varies in different hardware platforms. The Cisco IOS Software documentation should include a printed copy of the **show version** output. If that documentation is not available, there are resources on the Cisco Documentation CD or at Cisco.com to identify the correct configuration register value. Correct this by changing the configuration register in the configuration and saving this as the startup configuration.

If there is still a problem, the router might have a corrupted Flash image file. If this is the case, an error message should be displayed during boot. The error message might display as follows:

```
open: read error...requested 0x4 bytes, got 0x0
trouble reading device magic number
boot: cannot open "flash:"
boot: cannot determine first file name on device "flash:"ú
```

If the Flash image is corrupt, a new Cisco IOS Software image should be uploaded into the router. If the problem has not been identified in this section, the router could have a hardware failure. If this is the case, you should contact the Cisco Technical Assistance Center (TAC). Although hardware failures are rare, they do occur.

Table 11-4 lists and describes other helpful router status commands. You can obtain a list of all **show** commands by entering the **show** command followed by a space and a question mark.

Table 11-4 Router Status Commands

Command	Description
show version	Displays the configuration of the system hardware, the software version, the names and sources of configuration files, and the boot images, and displays the reason for the last system reboot.
show processes	Displays information about the active processes.
show protocols	Displays the configured protocols. This command shows the status of any configured Layer 3 (network layer) protocol.
show memory	Shows statistics about the router's memory, including memory-free pool statistics.
show stacks	Monitors the stack use of processes and interrupt routines.
show buffers	Provides statistics for the buffer pools on the router.
show flash	Shows information about the Flash memory device.

Table 11-4 Router Status Commands (Continued)

Command	Description
show running-config (write term on Cisco IOS Software Release 10.3 or earlier)	Displays the active configuration file.
show startup-config (show config on Cisco IOS Software Release 10.3 or earlier)	Displays the backup configuration file.
show interface	Displays statistics for all interfaces configured.

Summary

The keys points discussed in this chapter were the following:

- Establishing a HyperTerminal session
- Logging into the router
- Using the help feature in the command-line interface
- Using enhanced editing commands
- Using command history
- Troubleshooting command errors
- The router can boot into either ROM monitor, boot ROM, or Cisco IOS mode.
- The **show version** and **show flash** commands provide information on Cisco IOS Software and configuration register settings currently on the router.
- Router commands are entered at the command-line interface (CLI) in either user EXEC, privileged EXEC, global configuration, or specific configuration mode.

To supplement all that you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab Activities on the CD-ROM accompanying this book.

Key Terms

Cisco Internetwork Operating System (IOS) Software Software stored as an image file in Flash memory on the router that, when loaded into RAM, provides the operating system that runs the router.

command-line interface (CLI) An interface that enables the user to interact with the operating system by entering commands and optional arguments.

daughter card Similar to an expansion board, but it accesses the motherboard components (memory and CPU) directly instead of sending data through the slower expansion bus.

Flash memory A special type of EEPROM that can be erased and reprogrammed in blocks instead of 1 byte at a time. Many modern PCs have their BIOS stored on a Flash memory chip so that it can be updated easily, if necessary. Flash memory is also popular in modems because it enables the modem manufacturer to support new protocols as they become standardized.

light-emitting diode (LED) Semiconductor device that emits light produced by converting electrical energy. Status lights on hardware devices are typically LEDs.

nonvolatile RAM (NVRAM) RAM that retains its contents when a unit is powered off.

power-on self-test (POST) Set of hardware diagnostics that runs on a hardware device when that device is powered up.

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. A router initializes by doing which of the following?
 - A. Loading the NVRAM, the setup procedure, and the operating system
 - B. Loading the bootstrap, the operating system, and a configuration file
 - C. Loading the bootstrap, the setup procedure, and the operating system
2. During the setup process in a router, what keys can be used to escape the sequence?
 - A. Ctrl-A
 - B. Ctrl-E
 - C. Ctrl-C

3. Match the configuration setting on the right with the items on the left that are needed to establish a HyperTerminal session:
- A. BAUDNone
 - B. DATA BITS1
 - C. PARITY8
 - D. STOP BITSNone
 - E. FLOW CONTROL9600
4. Which of the following is true at initial boot-up output?
- A. The Cisco IOS Software version that the router uses can be seen.
 - B. The Cisco IOS Software version that the router uses cannot be seen.
5. Which of the following is true at initial boot-up output?
- A. The amount of Flash memory can be seen.
 - B. The amount of Flash memory cannot be seen.
6. Match the commands on the left with the correct descriptions on the right.
- | | |
|----------|--|
| Ctrl + a | Moves out of configuration mode |
| Ctrl + b | Moves to the end of the command line |
| Ctrl + e | Moves back one word |
| Ctrl + f | Moves to the beginning of the command line |
| Esc + b | Moves forward one character |
| Esc + f | Moves forward one word |
| Ctrl + a | Moves back one character |
7. Match the commands on the left with the correct descriptions on the right.
- | | |
|-------------------------|------------------------------------|
| Tab | Enables advanced editing |
| Ctrl + p | Sets the command buffer size |
| Ctrl + n | Recalls the most recent command |
| show history | Shows the command buffer |
| terminal history size # | Recalls the last command |
| terminal editing | Completes the entry |
| no Terminal editing | Disables advanced editing features |

8. What are the major elements of a typical router configuration?
 - A. Passwords, interfaces, routing protocols, DNS
 - B. Boot sequence, interfaces, TFTP server, NVRAM
 - C. NVRAM, ROM, DRAM, interfaces
 - D. Interfaces, routing protocols, configuration register, Flash memory
9. Which of the following correctly describes a method for specifying how a router loads the Cisco IOS Software?
 - A. Designate fallback sources for the router to use in sequence from NVRAM.
 - B. Configure the Cisco IOS software image for the location where it will bootstrap.
 - C. Manually boot a default system image at a virtual terminal.
 - D. Manually boot a default system image at the network server.
10. Which of the following is not a boot option that can be set with the configuration register boot field?
 - A. Cisco IOS Software boots in ROM monitor mode.
 - B. Cisco IOS Software automatically boots from ROM.
 - C. Cisco IOS Software automatically boots from a TFTP server.
 - D. NVRAM is examined for boot system commands.
11. Which of the following is information displayed by the Cisco IOS Software `show version` command?
 - A. Detailed statistics about each page of the router's memory
 - B. The name of the system image
 - C. The names and sizes of all files in Flash memory
 - D. The status of configured network protocols
12. Which of the following has a limited version of router Cisco IOS Software?
 - A. ROM
 - B. Flash memory
 - C. TFTP server
 - D. Bootstrap

13. If you want to completely back out of configuration mode, which of the following must you enter?
 - A. Exit
 - B. **no config-mode**
 - C. Ctrl + e
 - D. Ctrl + z
14. If you are planning to configure an interface, what prompt should be on the router?
 - A. router(config)#
 - B. router(config-in)#
 - C. router(config-intf)#
 - D. router(config-if)#
15. What is the acronym used to describe a Cisco router's text-based user interface?
 - A. CLI
 - B. TCP/IP
 - C. OSPF
 - D. OSI
16. What two modes of access to router commands exist for Cisco routers?
 - A. User and privileged
 - B. User and guest
 - C. Privileged and guest
 - D. Guest and anonymous
17. Which mode do you use to make router configuration changes on Cisco routers?
 - A. User
 - B. Privileged
 - C. Administrator
 - D. Root



Objectives

Upon completion of this chapter, you will be able to

- Name a router
- Set passwords
- Examine **show** commands
- Configure a serial interface
- Configure an Ethernet interface
- Execute changes to a router
- Save changes to a router
- Configure an interface description
- Configure a message-of-the-day banner
- Configure host tables
- Describe backup documentation
- Recover passwords

Chapter 12

Router Configuration

This chapter covers the router modes and configuration methods to update a router's configuration file. It is important to have a firm understanding of Cisco IOS Software and know the procedures for starting a router. In addition, this chapter describes the tasks necessary for password recovery.

Please be sure to look at this chapter's e-Labs, Videos, and PhotoZooms that you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

Command-Line Interface Command Modes

To gain access to a router, a login is required. After login, there is a choice of modes. The modes interpret the commands that are typed and carry out the operations. Two EXEC modes exist:

- User mode
- Privilege mode (or enable mode)

The following sections define the two command modes and their associated commands.

User Command List

A user is automatically in user EXEC mode upon first login to the router. *User mode* is a limited examination of the router. Table 12-1 provides the user mode commands and their descriptions.

NOTE

At this point, the list of commands displayed is context sensitive. You see a different list when you are in user mode versus enable mode, and when in *global configuration mode* versus configure *interface* modes.

Table 12-1 User ModeCommands

Command	Description
access-enable	Creates a temporary access list entry
atmsig	Executes ATM signaling commands
cd	Changes current device
clear	Resets functions
connect	Opens a terminal connection
dir	Lists files on a given device
disable	Turns off privileged commands
disconnect	Disconnects an existing network
enable	Turns on privileged commands
exit	Exits EXEC
help	Gets a description of the interactive help system
lat	Opens a LAT connection
lock	Locks the terminal
login	Logs in as a particular user
logout	Exits EXEC mode
mrinfo	Requests neighbor and version information from a multicast router
mstat	Shows statistics after multiple multicast traceroutes
mtrace	Traces the reverse multicast path from destination to source
name-connection	Names an existing network connection
pad	Opens an X.29 PAD connection
ping	Sends echo messages
ppp	Starts IETF Point-to-Point Protocol (PPP)
pwd	Displays current device
resume	Resumes an active network connection
rlogin	Opens an rlogin connection

Table 12-1 User Mode Commands (Continued)

Command	Description
show	Shows running system information
slip	Starts Serial Line IP (SLIP)
systat	Displays information about terminal lines
telnet	Opens a Telnet connection
terminal	Sets terminal line parameters
tn3270	Opens a TN3270 connection
traceroute	Sets a traceroute to the destination
tunnel	Opens a tunnel connection
where	Lists active connections
x3	Sets X.3 parameters on PAD
xremote	Enters Xremote mode

Privileged Mode Command List

Privileged EXEC mode provides a detailed examination of the router and allows configuration changes to be made to the router. A specific mode is entered depending upon the configuration change that is required. From privileged EXEC mode, other modes can be entered; privileged EXEC mode must be entered before entering these other modes (see the next section, “Router Configuration Modes”).

To access *privileged mode* from user EXEC mode, type **enable** (or the abbreviation **en**):

```
Router>enable  
Password:
```

```
Router>en  
Password:
```

You are prompted for a password. If you type a question mark (?) at the privileged mode prompt Router#?, the screen displays a longer list of commands than it would at the user mode prompt. Table 12-2 provides a complete list with descriptions of privileged mode commands.

Note that the list of commands varies depending on the type of router platform being configured.

Table 12-2 Privileged Mode Commands

Command	Description
access-enable	Creates a temporary access list entry
access-template	Creates a temporary access list entry
appn	Sends a command to the APPN subsystem
atmsig	Executes ATM signaling commands
bfe	Sets manual emergency modes
calendar	Manages the hardware calendar
cd	Changes the current device
clear	Resets functions
clock	Manages the system clock
cmt	Starts or stops FDDI connection-management functions
configure	Enters configuration mode
connect	Opens a terminal connection
copy	Copies configuration or image data
debug	Uses debugging functions (see also undebug)
delete	Deletes a file
dir	Lists files on a given device
disable	Turns off privileged commands
disconnect	Disconnects an existing network connection
enable	Turn on privileged commands
erase	Erases Flash or configuration memory
exit	Exits EXEC mode
format	Formats a device
help	Gets a description of the interactive help system
lat	Opens a LAT connection

Table 12-2 Privileged Mode Commands (Continued)

Command	Description
lock	Locks the terminal
login	Logs in as a particular user
logout	Exits EXEC mode
mbranch	Traces the multicast route down the tree branch
mrbranch	Traces the reverse multicast up the tree branch
mrinfo	Requests neighbor and version information from a multicast router
mstat	Shows statistics after multiple multicast traceroutes
mtrace	Traces reverse multicast path from destination source
name-connection	Names an existing network connection
ncia	Starts or stops an NCIA server
pad	Opens an X.29 PAD connection
ping	Sends echo messages
ppp	Starts the IETF Point-to-Point Protocol (PPP)
pwd	Displays current device
reload	Halts and performs a cold return
resume	Resumes an active network connection
rlogin	Opens an rlogin connection
rsh	Executes a remote command
sdhc	Sends SDLC test frames
send	Sends a message over tty lines
setup	Runs the setup command facility
show	Shows running system information
slip	Starts Serial Line IP (SLIP)
squeeze	Squeezes a device

continues

Table 12-2 Privileged Mode Commands (Continued)

Command	Description
start-chat	Starts a chat script on a line
Systat	Displays information about terminal lines
tarp	Targets ID Resolution Process (TARP) commands
telnet	Opens a Telnet connection
terminal	Sets terminal-line parameters
test	Tests subsystems, memory, and interfaces
tn3270	Opens a TN3270 connection
traceroute	Sets a traceroute to the destination
tunnel	Opens a tunnel connection
undebug	Disables debugging functions (see also debug)
undelete	Undeletes a file
verify	Verifies the checksum of a Flash file
where	Lists active connections
which-route	Does an OSI route table lookup and displays results
write	Writes running configuration to memory, network, or terminal
x3	Sets X.3 parameters on PAD
xremote	Enters Xremote mode

Router Configuration Modes

Global configuration commands are used in a router to apply configuration statements that affect the system as a whole. Use the privileged EXEC command **configure** to enter global configuration mode. After this command is entered, a prompt asking for the source of the configuration commands appears, at which you can specify terminal, nvram, or network. The default selection is to type in commands from the terminal console. Pressing the Enter key begins this configuration method.

The first configuration mode is referred to as global configuration mode, or global config, for short. Table 12-3 describes some of the configuration modes that you access from global configuration mode.

Table 12-3 Router Configuration Modes

Configuration Mode	Prompt
Interface	Router(config-if)#
Subinterface	Router(config-subif)#
Controller	Router(config-controller)#
Map-list	Router(config-map-list)#
Map-class	Router(config-map-class)#
Line	Router(config-line)#
Router	Router(config-router)#
IPX-router	Router(config-ipx-router)#
Route-map	Router(config-route-map)#

Typing **exit** at one of these specific configuration modes returns the router to global configuration mode. Pressing Ctrl-Z leaves the configuration modes completely and returns the router to privileged EXEC mode.

Example 12-1 demonstrates this sequence of transitioning between configuration modes.

Example 12-1 Navigating Privileged EXEC, Global Config, and Specific Configuration Modes

```
Router# configure terminal
Router(config)#(commands)
Router(config)# exit
Router#

Router#configure terminal
Router(config)# router protocol
Router(config-router)#(commands)
Router(config-router)# exit
Router(config)#interface type port
Router(config-if)#(commands)
Router(config-if)# exit
Router(config)# exit
Router#
```

Router Startup Modes

Whether it is accessed from the console or by a Telnet session through a vty port, a router can be placed in several modes. Each mode provides different functions:

- **ROM monitor** mode is generally a recovery mode. It allows certain configuration tasks, such as recovering a lost password or downloading software (IOS). The router boots into ROM monitor mode if the router does not find a valid system image or if the boot sequence is interrupted during startup. In many routers, Rommon> is the default prompt for ROM monitor mode.
- **Setup** mode is a prompted dialog that helps users create a first-time basic configuration. Setup mode consists of a series of questions with default answers in brackets. Setup mode does not have a defining default prompt. The router prompts the user to enter setup mode if a valid startup configuration file is not found. Setup can also be entered by typing **setup** from privileged mode. Note that setup mode also can be invoked manually if the user erased the NVRAM and rebooted the router.
- **RXBoot** mode is a special mode that the router can enter by changing the settings of the configuration register and rebooting the router. RXBoot mode provides the router with a subset of Cisco IOS Software and enters a streamlined setup mode. The streamlined setup mode differs from the standard setup mode because streamlined setup does not configure global router parameters. There are prompts only to configure interface parameters, which permit the router to boot. This allows the router to boot when it cannot find a valid Cisco IOS Software image in Flash memory. The default prompt is the host name followed by <boot>.

Table 12-4 briefly describes some of the commonly used configuration commands.

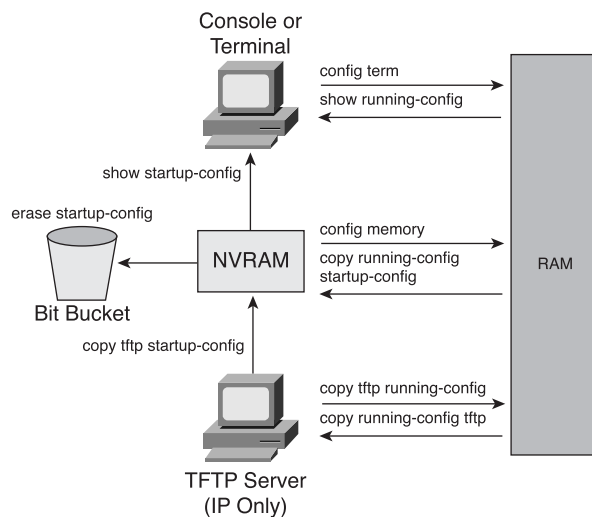
Table 12-4 Selection of Router Configuration Commands

Command	Description
configure terminal	Configures manually from the console terminal
configure memory	Loads configuration information from NVRAM
copy tftp running-config	Loads configuration information from a network TFTP server into RAM
show running-config	Displays the current configuration in RAM

Table 12-4 Selection of Router Configuration Commands (Continued)

Command	Description
<code>copy running-config startup-config</code>	Stores the current configuration from RAM into NVRAM
<code>copy running-config tftp</code>	Stores the current configuration from RAM on a network TFTP server
<code>show startup-config</code>	Displays the saved configuration, which is the contents of NVRAM
<code>erase startup-config</code>	Erases the contents of NVRAM

Use the commands shown in Figure 12-1 for routers running Cisco IOS Software Release 11.0 or later.

Figure 12-1 Configuration File Commands

Configuring a Router Name

One of the first basic configuration tasks is to name the router, as shown in Example 12-2. Naming a router helps to better manage the network by uniquely identifying each router within the network. The router is named in global configuration mode. The name of the router is called the host name and is displayed as the system prompt. If a router is not named, the system default is Router.

Example 12-2 *Naming a Router*

```
Router(config)#hostname Cougars
Cougars(config)#
```

**Lab Activity** CLI Modes and Router Identification

In this lab, you identify the basic router modes of user and privilege. You also use several commands that will enter specific modes to become familiar with the router prompt for each mode. In addition, you name the router.

Configuring and Protecting Router Passwords

A router can be secured to restrict access by using passwords. Passwords can be established for virtual terminal lines and the console line. Privileged mode EXEC also can have a password.

From global configuration mode, use the **enable password** command to restrict access to privileged mode. This password, however, will be visible from the router's configuration files. To enter an encrypted password in privileged mode, use the command **enable secret**. If an enable secret password is configured, it is used instead of the enable password. From the configuration files, a person can view only the encryption, not the actual password.

Enable secret passwords cannot be read; another user might be able to break into the configuration, but the only thing that can be done is to overwrite the password because it is one-way encrypted and cannot be converted back to clear text.

Passwords can be further protected from display through the use of the **service password-encryption** command. This command is entered from global configuration mode.

The line console 0 configuration mode can be used to establish a login password on the console terminal. This is useful on a network on which multiple people have access to the router. This prevents anyone not authorized from accessing the router.

Telnet requires a password check. Different hardware platforms have different numbers of vty lines defined. The range 0 through 4 is used to specify five vty lines. These five incoming Telnet sessions can be simultaneous. The same password can be used for

all lines, or one line can be set uniquely. This often is used in large networks with many network administrators. If a catastrophic problem occurs on a network and all common vty lines are used, the one unique line can be reserved for recovery.

Use the command **line vty 0 4** to establish a login password on incoming Telnet sessions. Example 12-3 demonstrates the different ways to configure and protect passwords.

Example 12-3 *Configuring/Protecting Passwords*

```
! Console Password
Router(config)# line console 0
Router(config-line)# login
Router(config-line)# password cisco
! Virtual Terminal Password
Router(config)# line vty 0 4
Router(config-line)# login
Router(config-line)# password cisco
! Enable Password
Router(config)# enable password san-fran
!Perform Password Encryption
Router(config)# service password encryption set password here
Router(config)# no service password encryption
```



Lab Activity Configuring Router Passwords

In this lab, you configure passwords for the console, virtual terminals, and a secret password.

Examining the show Commands

Many **show** commands exist, which help examine the contents of files in the router and are useful in troubleshooting. From each mode in the router, the **show ?** command can be used to see all the available options. Table 12-5 lists some of the **show** command options.

Table 12-5 show Commands

Command	Description
show interfaces	Displays all the statistics for all the interfaces on the router. If a user wants to view the statistics for a specific interface, he can enter the show interfaces command followed by the specific interface and port number. For example: Router# show interfaces serial 1
show controllers serial	Displays information specific to the interface hardware.
show clock	Displays the time set in the router.
show hosts	Displays a cached list of host names and addresses.
show users	Displays all users who are connected to the router.
show history	Displays a history of commands that have been entered.
show flash	Displays information about Flash memory and what Cisco IOS Software files are stored there.
show version	Displays information about the Cisco IOS Software image that is running in RAM.
show arp	Displays the router's address resolution (ARP) table.
show protocol	Displays the global and interface-specific status of any configured Layer 3 protocols.
show startup-configuration	Displays the saved configuration located in NVRAM.
show running-configuration	Displays the configuration currently running in RAM.

Examples 12-4, 12-5, and 12-6 display sample output from the **show protocols**, **show version**, and **show interfaces** commands, respectively.

Example 12-4 show protocols *Command Output*

```
Router# show protocols
Global values:
Internet Protocol routing is enabled
DECnet routing is enabled
```

Example 12-4 show protocols *Command Output (Continued)*

```
XNS routing is enabled
Vines routing is enabled
AppleTalk routing is enabled
Novell routing is enabled
--More--
Ethernet0 is up, line protocol is up
Internet address is 183.8.126.2, subnet mask is 255.255.255.128
DECnet cost is 5
XNS address is 3010.aa00.0400.0284
CLNS enabled
Vines metric is 32
AppleTalk address is 3012.93, zone ld-e0
Novell address is 3010.aa00.0400.0284
--More--
```

Example 12-5 show version *Command Output*

```
Router# show version
Cisco Internetwork Operating System Software
IOS (tm) 4500 Software (C4500-J-M). Version 12.1.5
Copyright (c) 1986-1996 by Cisco Systems, Inc.
Compiled Fri 28-Jun-96 16:32 by rbeach
Image text-base: 0x600088A0, data-base: 0x6076E000
ROM: System Bootstrap, Version 5.1(1) RELEASE SOFTWARE (fc1)
ROM: 4500-XBOOT Bootstrap Software, Version 10.1(1) RELEASE SOFTWARE (fc1)
router uptime is 1 week, 3 days, 32 minutes
System restarted by reload
System image file is c4500-j-mz, booted via tftp from 171.69.1.129
--More--
```

Example 12-6 show interfaces *Command Output*

```
Router# show interfaces
Serial0 is up, line protocol is up
Hardware is MK5025
Internet address is 183.8.64.129, subnet mask is 255.255.255.128
```

continues

Example 12-6 show interfaces *Command Output (Continued)*

```
MTU 1500 bytes, BW 56 kbit, DLY 20000 usec, rely 255/255. load 9/255
Encapsulation HDLC, loopback not set, keepalive set (10 sec)
Last input 0:00:00, output 0:00:01, output hang never
Last clearing of show interfaces counters never
Output queue 0/40, 0 drops, input queue 0/75, 0 drops
Five minute input rate 1000 bits/sec, 0 packets/sec
331885 packets input, 62400237 bytes, no buffer
Received 230457 broadcasts, 0 runts, 0 giants
3 input errors, 3 CRC, 0 frame, 0 overrun, 0 ignored, 0 abort
403591 packets output, 66717279 bytes, 0 underruns
0 output errors, 0 collisions, 8 interface resets, 0 restarts
45 carrier transitions
```

**Lab Activity** Using the **show** Commands

This lab helps you become familiar with the router **show** commands. The **show** commands are the most important information-gathering commands available for the router.

Configuring a Serial Interface

A serial interface can be configured from the console or through a virtual terminal line. Serial interfaces require a clock signal to control the timing of the communications. In most environments, a data communications equipment (DCE) device such as a channel service unit/data service unit (CSU/DSU) provides the clock. By default, Cisco routers are data terminal equipment (DTE) devices, but they can be configured as DCE devices.

On serial links that are directly interconnected, one side must be considered as a DCE and provide a clocking signal. The clock is enabled and its speed is specified with the **clockrate** command. The available clock rates in bits per second are 1200, 2400, 9600, 19,200, 38,400, 56,000, 64,000, 72,000, 125,000, 148,000, 500,000, 800,000, 1,000,000, 1,300,000, 2,000,000, and 4,000,000. However, some bit rates might not be available on certain serial interfaces depending on their capacity.

To configure a serial interface, perform the following steps and see Example 12-7:

- Step 1** Enter global configuration mode.
- Step 2** Enter interface mode.
- Step 3** Specify the bandwidth.

Step 4 Set the DCE clock rate (skip this step on DTE).

Step 5 Turn on the interface.

Example 12-7 *Configuring a Serial Interface*

```
Router(config)# interface serial 1/0
Router(config-if)# bandwidth 56
Router(config-if)# clockrate 56000
Router(config-if)# no shutdown
```

By default, interfaces are turned off. To turn on an interface, you must enter the command **no shutdown**. The interface might need to be administratively turned off to perform hardware maintenance, change the interface configuration, perform troubleshooting, or perform other maintenance. The command **shutdown** turns off an interface.

The following command administratively turns off the interface:

```
Router(config-if)# shutdown
```

The following command turns on an interface that has been shut down:

```
Router(config-if)# no shutdown
```

The following command quits the current interface configuration mode:

```
Router(config-if)# exit
```



Lab Activity Configuring a Serial Interface

In this lab, you configure a serial interface on two routers so that they can communicate with each other.

Configuring an Ethernet Interface

An Ethernet interface can be configured from the console or a virtual terminal line. Each Ethernet interface must have an IP address and subnet mask.

To configure an Ethernet interface, perform the following steps and see Example 12-8:

Step 1 Enter global configuration mode.

Step 2 Enter interface configuration mode.

Step 3 Specify the interface address and subnet mask.

Step 4 Turn on the interface.

Example 12-8 *Configuring an Ethernet Interface*

```
Router(config)# interface e0
Router(config-if)# 183.8.126.2 255.255.255.128
Router(config-if)# no shutdown
```

By default, interfaces are turned off. To turn on an interface, enter the command **no shutdown**. The interface might need to be administratively turned off to perform hardware maintenance, change the interface configuration, perform troubleshooting, or perform other maintenance. The command **shutdown** turns off an interface.

**Lab Activity** Configuring an Ethernet Interface

In this lab, you configure an Ethernet or FastEthernet interface on the router for a LAN.

Executing Changes to the Router

If a change is needed to a configuration, enter the appropriate mode and make the change. For example, if an interface was not turned on, enter global configuration mode and then enter interface mode, and issue the command **no shutdown**.

To verify changes, use the **show running-config** command. This command displays the current configuration. If the variables displayed are not what was intended, the environment can be corrected by doing the following:

- Issuing the **no** form of a configuration command
- Restarting the system and reloading the original configuration file from NVRAM
- Removing the startup configuration file with the **erase startup-configuration** command, restarting the router, and entering setup mode

To save the configuration variables to the startup configuration file in NVRAM, enter the following command at the privileged EXEC prompt:

```
Router# copy running-configuration startup-configuration
```

Table 12-6 shows commands used to manage the contents of NVRAM in Cisco IOS Software Release 11.x and later.

Table 12-6 Commands Used to Manage the Contents of NVRAM in Cisco IOS Software Release 11.x and Later

Command	Description
<code>configure memory</code>	Loads configuration information from NVRAM
<code>erase startup-config</code>	Erases the contents of NVRAM
<code>copy running-config startup-config</code>	Stores the current configuration in RAM (that is, the running configuration) into NVRAM (as the startup configuration)
<code>show startup-config</code>	Displays the saved configuration, which is the contents of NVRAM

**Lab Activity** Making Changes to a Configuration

In this lab, you prepare to make changes to the existing configuration in a router. You bring an interface down and then back up and view its status.

Finishing the Configuration

The following lists recommended tasks for finishing the configuration. (Some organizations do not have some of the recommended configuration tasks, such as a message-of-the-day.)

- Establishing configuration standards
- Providing and configuring interface descriptions
- Configuring login banners
- Configuring a message-of-the-day (MOTD) banner
- Performing host name resolution
- Performing configuration backup and documentation

Importance of Configuration Standards

It is important to develop standards for configuring files within an organization. This facilitates control of the number of configuration files that must be maintained, how the files are stored, and where the files are stored.

A standard is a set of rules or procedures that are either widely used or officially specified. Without standards in an organization, a network could be in chaos if an interruption in service occurs.

To manage a network, there must be a centralized support standard. Configuration, security, performance, and other issues must be adequately addressed for the network to function smoothly. Creating standards for network consistency helps reduce network complexity, the amount of unplanned downtime, and exposure to events that might have an impact on network performance.

Providing Interface Descriptions

An interface description should be used to identify important information such as a distant router, a circuit number, or a specific network segment. A description of an interface can help a network user remember specific information about the interface, such as what network the interface services. The next section, “Configuring Interface Descriptions,” provides a specific example.

The description is meant solely as a comment about the interface. Although the description appears in the configuration files that exist in router memory, a description does not affect the operation of the router. Descriptions are created by following a standard format that applies to each interface. The description can include the purpose and location of the interface, other devices or locations connected to the interface, and circuit identifiers. Descriptions enable support personnel to better understand the scope of problems related to an interface and allow for faster resolution of problems.

Configuring Interface Descriptions

Enter global configuration mode to configure an interface description. Perform the following steps and see Example 12-9:

- Step 1** Enter global configuration mode by entering the command **configure terminal**.
- Step 2** Enter specific interface mode (for example, interface Ethernet 0) by entering the command **interface ethernet 0**.
- Step 3** Enter the command **description**, followed by the information that is to be displayed (for example, XYZ Network, Building 10).
- Step 4** Exit interface mode back to privileged EXEC mode by pressing Ctrl-z.
- Step 5** Save the configuration changes to NVRAM by using the command **copy running-config startup-config**.

Example 12-9 *Configuring an Interface Description*

```
Router(config)# interface ethernet 0
Router(config-if)# description SkyDome LAN Communication Building
Router(config-if)# exit
! Results of issuing the show running-config command
interface Ethernet0
  description SkyDome LAN Communication Building
  ip address 198.133.215.1 255.255.255.0
```

**Lab Activity** Configuring Interface Descriptions

In this lab, you choose a description for an interface and use interface configuration mode to enter that description.

Login Banners

A login banner is a message that is displayed at login. The login banner is useful for conveying messages that affect all network users, such as notices of impending system shutdowns.

Anyone can see login banners. Therefore, careful attention should be used in the wording of a banner message. “Welcome” is an invitation for anyone to enter a router and is probably not an appropriate message.

A login banner should be a warning not to attempt login unless authorized. A message such as, “This is a secure system, authorized access only!” instructs unwanted visitors that any further intrusion or attempt is unwanted and illegal. Example 12-10 shows an example of a login banner.

Example 12-10 *Login Banner*

```
Tokyo con0 is now available
Press RETURN to get started.

This is a secure system.  Authorized Access ONLY!!!
User Access Verification
```

continues

Example 12-10 *Login Banner (Continued)*

```
Password:
Tokyo>enable
Password:
Tokyo#
```

Configuring a Message of the Day

A message-of-the-day (MOTD) or login banner can be displayed on all connected terminals.

Enter global configuration mode to configure a MOTD banner. Use the **banner motd** command, followed by a space and a delimiting character, such as the pound sign (#). Add a message of the day followed by a space and the delimiting character again.

Perform the following steps to create and display a message of the day. See Example 12-11:

- Step 1** Enter global configuration mode by using the command **configure terminal**.
- Step 2** Enter the command **banner motd # The message of the day goes here #**.
- Step 3** Save changes by issuing the command **copy running-configuration startup-configuration**, or **copy run start** for a shortcut.

Example 12-11 *MOTD Display*

```
Tokyo(config)# banner motd #
You have entered a secure system, authorized access ONLY!#
```

**Lab Activity** Configuring Message-of-the-Day

In this lab, you use global configuration mode to enter a message-of-the-day into the router. This procedure enables all users to view the message upon entering the router.

Host Name Resolution

Host name resolution is the process that a computer system uses to associate a host name with a network address.

Protocols such as Telnet use host names to identify network devices. To use host names to communicate with other IP devices, network devices, such as routers, must be capable of associating the host names with IP addresses. A list of host names and their associated IP addresses is called a *host table*. Table 12-7 shows a sample host table.

Table 12-7 Host Table

Router Name	Router Type	E0	E1	S0
Tokyo	2601	205.7.5.1	192.5.5.1	201.100.11.1
Paris	2621	205.7.5.2		204.204.7.2

A host table might include all devices in a network organization. Each unique IP address can have a host name associated with it. Cisco IOS Software maintains a cache of host name-to-address mappings for use by EXEC commands. This cache speeds up the process of converting names to addresses.

Host names, unlike Domain Name System (DNS) names, are significant only on the router on which they are configured. Example 12-12 shows the configuration of a host table on a router.

Example 12-12 Host Table Configuration

```
Router(config)# ip host Auckland 172.16.32.1
Router(config)# ip host Beirut 192.168.53.1
Router(config)# ip host Capetown 192.168.89.1
Router(config)# ip host Denver 10.202.8.1
```

This host table enables the network administrator to type either the host name or the IP address to Telnet to a remote host. An example to use as the host name would be Auckland or 172.16.32.1 for the IP address. To display a list of hosts and their associated IP addresses that are defined for a particular router, use the command **show hosts**.



Lab Activity Configuring Host Tables

In this lab, you use global configuration mode to create IP host tables to allow a router to translate router names with all the attached interfaces on that router.

Configuration Backup and Documentation

The configuration of network devices determines the way the network behaves or acts. Management of device configuration includes the following tasks:

- Listing and comparing configuration files on running devices
- Storing configuration files on network servers
- Performing software installations and upgrades

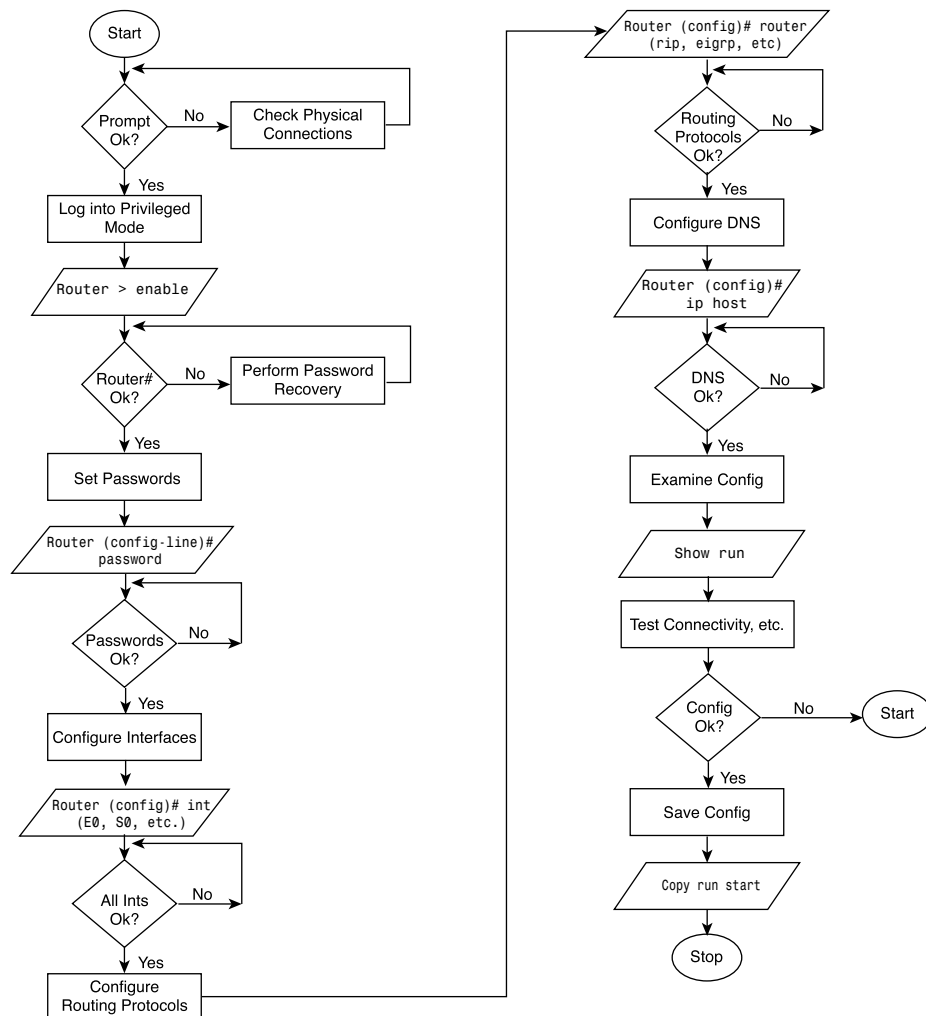
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Configuration files should be stored as backup files in case a problem arises. Configuration files can be stored on a network server, on a TFTP server, or on a disk stored in a safe place. Documentation should be included with this offline information.

The configuration on the router also can be saved to a disk by capturing text in the router and saving it to the disk or hard drive. If the file needs to be copied back to the router, it can be pasted into the router. These methods of saving and restoring the router configuration are covered in greater detail in Chapter 14, “Managing Cisco IOS Software.”

Figure 12-2 shows an overview of the router configuration process.

Figure 12-2 Router Configuration Process Flowchart



Password Recovery

This section explains several password-recovery techniques for Cisco routers and Catalyst switches. You can perform password recovery on most of the platforms without changing hardware jumpers, but all platforms require that the router be rebooted. Password recovery can be done only from the console port (physically attached to the router).

Overview of Password Recovery

Three ways exist for restoring access to a router when the password is lost. You can view the password, change the password, or erase the configuration and start over as if the box was new.

Each procedure follows these basic steps:

- Step 1** Configure the router to start up without reading the configuration memory (NVRAM). This is done from what sometimes is called test system mode, ROM mode, or boot mode.
- Step 2** Reboot the system.
- Step 3** Access enable mode (which can be done without a password if you set the configuration register correctly in Step 1).
- Step 4** View or change the password, or erase the configuration.
- Step 5** Reconfigure the router to boot up and read the NVRAM as it normally does.
- Step 6** Reboot the system.

Some password recovery requires a terminal to issue a BREAK signal; you must be familiar with how your terminal or PC terminal emulator issues this signal. In ProComm, for example, the keys Alt-B generate the BREAK signal by default; in Windows HyperTerminal, you press Break or Ctrl-Break. Windows HyperTerminal also enables you to define a function key as BREAK. From the terminal window, select Function Keys and define one as Break by filling in the characters ^\$B (Shift-6, Shift-4, and uppercase B). Several free terminal-emulation packages also are available for download on the Internet, which you might find preferable.

The following sections contain detailed instructions for specific Cisco routers. Locate your product at the beginning of each section to determine which technique to use.

Password Recovery Technique 1

The following are the relevant devices for this technique:

- Cisco 2500 series
- Cisco 3000 series
- Cisco 7000 series running Cisco IOS Software Release 10.0 or later in ROMs

This technique can be used on the Cisco 7000 and Cisco 7010 series only if the router has Cisco IOS Software Release 10.0 ROMs installed on the Route Processor (RP) card. It might be booting Flash Cisco IOS Software Release 10.0, but it needs the actual ROMs on the processor card as well. The following steps outline password recovery technique 1:

- Step 1** Attach a terminal or PC with terminal emulation to the console port of the router. To connect a PC to the console port, attach a null modem adapter (Tandy Null Modem Adapter No. 26-1496 has been tested) to the console port, and then attach a straight-through modem cable to the null modem adapter.
- Step 2** Type **show version** and record the setting of the configuration register. It is usually 0x2102 or 0x102. If you do not get the router prompt to do a **show version**, look on a similar router to obtain the configuration register number, or try using 0x2102.
- Step 3** Power-cycle the router.
- Step 4** Press the Break key on the terminal within 60 seconds of the power-up. You should see the > prompt with no router name. If you don't see this, the terminal is not sending the correct BREAK signal. In that case, check the terminal or terminal emulation setup.
- Step 5** Type **o/r 0x42** at the > prompt to boot from Flash memory, or type **o/r 0x41** to boot from the boot ROMs. (Note that this is the letter *o*, not the numeral zero.) If you have Flash memory and it is intact, 0x42 is the best setting because it is the default. Use 0x41 only if the Flash memory is erased or is not installed. If you use 0x41, you can either view or erase the configuration. You cannot change the password.
- Step 6** Type **i** at the > prompt. The router reboots but ignores its saved configuration.
- Step 7** Answer **no** to all the setup questions, or press Ctrl-C.
- Step 8** Type **enable** at the Router> prompt. You're then in enable mode and can see the Router# prompt.

Step 9 Choose one of the following three options:

- To view the password, type **show start**.
- To change the password (in case it is encrypted, for example), do the following:
 - a. Type **copy start run** to copy the NVRAM into memory.
 - b. Type **show run**.
 - c. If you have the enable secret password set, perform the following:
 - Type **config term** and make the changes.
 - Type **enable secret new_password**.
 - Press Ctrl-Z.
 - d. If you do not have **enable secret xxxx**, type **enable password new_password** and press Ctrl-Z.
 - e. Type **copy run start** to commit the changes.
- To erase the config, type **erase start**.

Step 10 Type **config term** at the prompt.

Step 11 Type **config-register 0x2102**, or whatever value you recorded in Step 2.

Step 12 Press Ctrl-Z to return to privileged EXEC mode.

Step 13 Type **reload** at the prompt. You do not need to write memory.

Password Recovery Technique 2

Use this procedure to recover lost passwords on the following routers:

- Cisco 1003
- Cisco 1600 series
- Cisco 2600 series
- Cisco 3600 series
- Cisco 4500 series
- Cisco 7100 series
- Cisco 7200 series
- Cisco 7500 series
- IDT Orion-based routers
- AS5200 and AS5300 platforms

To recover a password using procedure 2, perform the following steps:

- Step 1** Attach a terminal or PC with terminal-emulation software to the console port of the router.
- Step 2** Enter **show version** and record the setting of the configuration register. It is usually 0x2102 or 0x102.
- The configuration register value is on the last line of the display. Note whether the configuration register is set to enable Break or disable Break.
- The factory-default configuration register value is 0x2102. Notice that the third digit from the left in this value is 1, which disables Break. If the third digit is *not* 1, Break is enabled.
- Step 3** Turn off the router and then turn it on again.
- Step 4** Press the Break key on the terminal within 60 seconds of turning on the router. The rommon> prompt appears. If it does not appear, the terminal is not sending the correct Break signal.
- If the prompt does not appear, check the terminal or terminal emulation setup.
- Step 5** Enter **confreg** at the rommon> prompt.
- The following prompt appears:
- ```
Do you wish to change configuration [y/n]?
```
- Step 6** Enter **yes** and press Return.
- Step 7** Enter **no** to subsequent questions until the following prompt appears:
- ```
ignore system config info [y/n]?
```
- Step 8** Enter **yes**.
- Step 9** Enter **no** to subsequent questions until the following prompt appears:
- ```
change boot characteristics [y/n]?
```
- Step 10** Enter **yes**.
- The following prompt appears:
- ```
enter to boot:
```
- Step 11** At this prompt, either enter **2** and press Enter if booting from Flash memory, or, if Flash memory is erased, enter **1**.
- If Flash memory is erased, the Cisco 4500 must be returned to Cisco for service. If you enter **1**, you can only view or erase the configuration; you cannot change the password.

A configuration summary is displayed and the following prompt appears:

```
Do you wish to change configuration [y/n]?
```

Step 12 Enter **no** and press Return.

The following prompt appears:

```
rommon>
```

Step 13 Enter **reset** at the privileged EXEC prompt or, for Cisco 4500 series and Cisco 7500 series routers, power-cycle the router.

Step 14 As the router boots, enter **no** to all the setup questions until the following prompt appears:

```
Router>
```

Step 15 Enter **enable** to enter enable mode.

The Router# prompt appears.

Step 16 Choose one of the following options:

- To view the password, if it is not encrypted, enter **more nvram:startup-config**.
- To change the password (if it is encrypted, for example), enter the following commands:

```
Router# configure memory  
Router# configure terminal  
Router(config)# enable secret 1234abcd  
Router(config)# ctrl-z  
Router# write memory
```

The **enable secret** command provides increased security by storing the enable secret password using a nonreversible cryptographic function; however, you cannot recover a lost password that has been encrypted.

Step 17 Enter **configure terminal** at the prompt.

Step 18 Type **config-register** and whatever value you recorded in Step 2.

Step 19 Press Ctrl-Z to quit the configuration editor.

Step 20 Enter **reload** at the prompt and enter **write memory** to save the configuration.



Lab Activity Password-Recovery Procedures

In this lab, you gain access to a router when the password is unknown.

Summary

This chapter summarized the key points in configuring a router:

- The router has several modes:
 - User mode
 - Privileged mode
 - Global configuration mode
 - Other configuration modes
- The command-line interface (CLI) is used to change configurations, including doing the following:
 - Setting the host name
 - Setting passwords
 - Configuring interfaces
 - Modifying configurations
 - Showing configurations
- Interface descriptions include important information to help network administrators understand and troubleshoot their networks.
- Login banners and messages of the day provide users with information upon login to the router.
- Host name resolutions translate names to IP addresses to allow the router to quickly convert names to addresses.
- Three ways exist for restoring access to a router when the password is lost:
 - You can view the password.
 - You can change the password.
 - You can erase the configuration and start over as if the box was new.
- Configuration standards are key elements in the success of any organization in maintaining an efficient network. Configuration backup and documentation is extremely important to keep a network operating smoothly.

To supplement all that you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab activities on the CD-ROM accompanying this book.

Key Terms

CLI (command-line interface) An interface that enables the user to interact with the operating system by entering commands and optional arguments.

global configuration mode Used for one-line commands and commands that make global changes to the router configuration.

interface Connection between two systems or devices. In routing terminology, a network connection.

NVRAM (Nonvolatile RAM) RAM that retains its contents when a unit is powered off.

privileged mode Used for copying and managing entire configuration files.

TFTP (Trivial File Transfer Protocol) Simplified version of FTP that allows files to be transferred from one computer to another over a network, usually without the use of client authentication (for example, username and password).

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. What is a standard?
 - A. A formal description of a set of rules and conventions that govern how devices on a network exchange information
 - B. A set of rules or procedures that are either widely used or officially specified
 - C. A way in which network devices access the network medium
2. A description on an interface does what?
 - A. Welcomes users to the router
 - B. Warns users not to enter the router
 - C. Displays a comment about the interface
3. A good example of a login banner is what?
 - A. Welcome everyone
 - B. Everyone please log in
 - C. Authorized access only

4. What is host name resolution?
 - A. The process of associating a name with a network location
 - B. The process of displaying a login message
 - C. The process of displaying a description on a router
5. Configuration backup and documentation is necessary to an organization to maintain an efficient network. True or false?
 - A. True
 - B. False
6. Backup of configuration files is not necessary. True or false?
 - A. True
 - B. False
7. A TFTP server is the only location where backup files can be stored. True or false?
 - A. True
 - B. False
8. If you are planning to configure an interface, what prompt should be on the router?
 - A. router(config)#
 - B. router(config-in)#
 - C. router(config-intf)#
 - D. router(config-if)#
9. Which of the following is the correct order for the process of configuring a router? (Assume that you have already made router changes in configuration mode.)
 - A. Save changes to backup, decide whether the changes are your intended results, examine the results, and examine the backup file.
 - B. Examine the results, decide whether the changes are your intended results, save the changes to backup, and examine the backup file.
 - C. Decide whether the changes are your intended results, examine the backup file, save the changes to backup, and examine the results.
 - D. Examine the results, save the changes to backup, decide whether the changes are your intended results, and examine the backup file.

10. Which of the following is a command that can be used to save router configuration changes to a backup?
 - A. Router# **copy running-config tftp**
 - B. Router# **show running-config**
 - C. Router# **config mem**
 - D. Router# **copy tftp running-config**
11. Which of the following correctly describes password configuration on routers?
 - A. All passwords are established in user EXEC mode.
 - B. All passwords alter the password character string.
 - C. A password can be established on all incoming Telnet sessions.
 - D. The enable password command restricts access to user EXEC mode.
12. Which of the following does not describe password configuration on routers?
 - A. Passwords can be established in every configuration mode.
 - B. A password can be established on any console terminal.
 - C. The enable secret password uses an encryption process to alter the password character string.
 - D. All password establishment begins in global configuration mode.
13. What is used for one-line commands that change the entire router?
 - A. Global configuration mode
 - B. Privileged mode
 - C. User EXEC mode
 - D. Interface mode
14. What does the **exit** command do in a configuration mode with the prompt Router(config-if)#?
 - A. It quits the current configuration interface mode.
 - B. It reaches the privileged EXEC prompt.
 - C. It exits the router.
 - D. It switches to the user EXEC prompt.

15. What are the major elements of a typical router configuration?
- A. Passwords, interfaces, routing protocols, DNS
 - B. Boot sequence, interfaces, TFTP server, NVRAM
 - C. NVRAM, ROM, DRAM, interfaces
 - D. Interfaces, routing protocols, configuration register, Flash memory
16. In a password-recovery procedure, immediately after issuing a Ctrl-Break upon router startup, what should be the config register setting?
- A. 0x2102
 - B. 0x2142
 - C. 0x0000
 - D. 0x10F
17. In a password-recovery procedure, just before saving the running config and after you have enabled a new secret password, what should be the config register setting?
- A. 0x2102
 - B. 0x2142
 - C. 0x0000
 - D. 0x10F



Objectives

Upon completion of this chapter, you will be able to

- Describe how to implement, monitor, and maintain CDP
- Understand how to create a network map of the environment
- Disable and troubleshoot CDP
- Telnet remotely to other routers
- Verify, disconnect, and suspend a Telnet connection
- Perform alternative connectivity tests

Chapter 13

Learning About Neighboring and Remote Devices

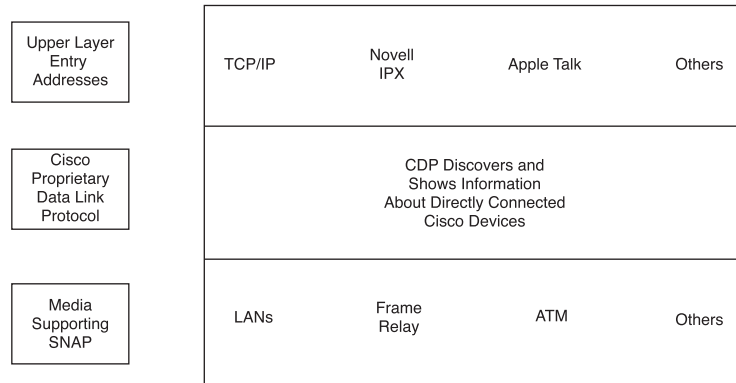
In this chapter, you learn how to implement, monitor, and maintain Cisco Discovery Protocol by using the correct router commands. In addition, this chapter explains the commands most often used to perform address-related troubleshooting.

Please be sure to look at the e-Labs, Videos, and PhotoZooms associated with this chapter that you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

Introduction to CDP

Cisco Discovery Protocol (CDP) is a Layer 2 protocol that connects lower physical media and upper network layer protocols, as shown in Figure 13-1. CDP is used to obtain information about neighboring devices. This information shows the types of devices connected, the router interfaces they are connected to, the interfaces used to make the connections, and the model numbers of the devices. CDP is media and protocol independent, and runs on all Cisco equipment, over the *Subnetwork Access Protocol (SNAP)*. CDP is a proprietary protocol native to Cisco networking devices and will run only on Cisco networking devices.

CDP Version 2 (CDPv2) is the most recent release of the protocol. Cisco IOS Software Release 12.0(3)T version or later supports CDPv2. CDP Version 1 (CDPv1) is enabled globally by default with Cisco IOS Software Release 10.3 or later.

Figure 13-1 Where CDP Fits In

• Media and Protocol Interactions

When a Cisco device boots up, CDP starts up automatically and allows the device to detect neighboring devices that are also running CDP. CDP runs over the data link layer and allows two systems to learn about each other, even if they are using different network layer protocols.

Each device configured for CDP sends periodic messages, known as advertisements, to multiple routers. Each device advertises at least one address at which it can receive *Simple Network Management Protocol (SNMP)* messages. The advertisements also contain Time-To-Live (TTL) or holdtime information. This holdtime information indicates the length of time that receiving devices hold CDP information before discarding it. Additionally, each device listens to periodic CDP messages sent by others to learn about neighboring devices.

Obtaining Information with CDP

The primary use of CDP is to discover all Cisco devices that are directly connected to a local device. A CDP frame can be small, yet can retrieve many useful information about neighboring routers and switches. Use the command `show cdp entry [device name]`, as demonstrated in Example 13-1, to display a single cached CDP entry.

Example 13-1 show cdp entry Command Output

```
routerA# show cdp entry routerB
-----
Device ID: routerB
Entry address(es):
```

Example 13-1 show cdp entry *Command Output (Continued)*

```

IP address: 198.92.68.18
Platform: 2501. Capabilities: Router
Interface: Ethernet), Port ID (outgoing port): Ethernet0
Holdtime: 155 sec

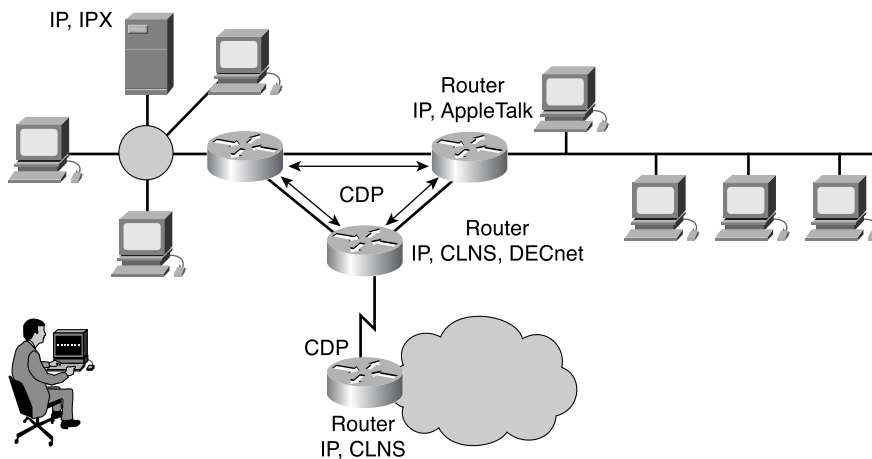
--- output omitted ---

```

Notice that the output from this command includes all the Layer 3 addresses present in the neighbor router, Router B. An administrator can view the IP addresses of the targeted CDP neighbor (Router B) with the single command entry on Router A. The holdtime value indicates the amount of elapsed time since the CDP frame arrived with this information. The `show cdp entry [device name]` command includes abbreviated version information about Router B. Knowing the version of neighboring devices provides you with an idea of the exact physical topology of the network to properly configure the devices.

Showing CDP Neighbors

Figure 13-2 displays an example of how CDP delivers its collection of information to a network administrator. Each router that is running CDP exchanges protocol information with its neighbors. The network administrator displays the results of this CDP information exchange on a console that is connected to a local router.

Figure 13-2 CDP Neighbors

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You use the **show cdp neighbors** command to display information about the networks directly connected to the router. CDP provides information about each CDP neighbor device by transmitting *Type Length Values (TLVs)*. TLVs are blocks of information embedded in CDP advertisements.

Device TLVs displayed by the **show cdp neighbors** command, and as shown in Example 13-2, include the following:

- Device ID
- Local Interface
- Holdtime
- Capability
- Platform
- Port ID
- VTP Management Domain Name (CDPv2 only)
- Native VLAN (CDPv2 only)
- Full/Half-Duplex (CDPv2 only)

Example 13-2 show cdp neighbors Command Output

```
routerA# show cdp neighbors
Capability Codes:
R - Router, T - Trans Bridge,
B - Source Route Bridge,
S - Switch, H - Host, I - IGMP
```

Device ID	Local Interface	Holdtime	Capability	Platform	Port	ID
routerB	Eth 0	151	R	2501	Eth	0
routerB	Ser 0	165	R	2501	Ser	0

To display all the information output generated by **show cdp neighbors**, as well as information like that from **show cdp entry**, you use the optional **show cdp neighbors detail** command, as demonstrated in Example 13-3.

Example 13-3 show cdp neighbors detail Command Output

```
routerA# show cdp neighbors detail
Device ID: routerB
Entry address(es):
```


Example 13-3 show cdp neighbors detail *Command Output (Continued)*

```

IP address: 198.92.68.18
Platform: 2501, Capabilities: Router
Interface: Ethernet0, Port ID (outgoing port): Ethernet0
Holdtime: 143 sec

```

Notice that the lowest router in Figure 13-2 is not directly connected to the administrator's console router. To obtain CDP information about this device, the administrator needs to *Telnet* to a router that is directly connected to this device. As previously stated, you will find this information helps you gain full knowledge about the devices that are on the network, which provides you a better understanding of the physical topology.

Implementing, Monitoring, and Maintaining CDP Information

The commands in Table 13-1 are used to implement, monitor, and maintain CDP information.

Table 13-1 CDP Commands

Command	Mode	Description
<code>cdp run</code>	Global configuration mode	Enables CDP globally on the router.
<code>cdp enable</code>	Interface configuration mode	Enables CDP on an interface.
<code>clear cdp counters</code>	Privileged EXEC mode	Resets the traffic counters to zero.
<code>show cdp</code>	Privileged EXEC mode	Displays the interval between transmissions of CDP advertisements, the number of seconds the CDP advertisement is valid for a given port, and the version of the advertisement.
<code>show cdp entry {entry-name [protocol version]}</code>	Privileged EXEC mode	Displays information about a specific neighbor. Display can be limited to protocol or version information.

continues

Table 13-1 CDP Commands (Continued)

Command	Mode	Description
show cdp interface [<i>type number</i>]	Privileged EXEC mode	Displays information about interfaces on which CDP is enabled.
show cdp neighbors [<i>type number</i>] [detail]	Privileged EXEC mode	Displays the type of device that has been discovered, the name of the device, the number and type of the local interface (port), the number of seconds the CDP advertisement is valid for the port, the device type, the device product number, and the port ID. Issuing the detail keyword displays information on the native VLAN ID, the duplex mode, and the VLAN Trunking Protocol (VTP) domain name associated with neighbor devices.

Use the **cdp run** command to enable CDP globally on the router. By default, CDP is globally enabled. Use the **cdp enable** command to enable CDP on a particular interface. On Cisco IOS Software Release 10.3 and later, CDP could be enabled on each interface of the device by using the **cdp enable** command. Even though CDP is enabled by default on most Cisco devices, you might encounter instances in which you need to manually enable CDP on a per interface basis. Examples of when this manual enabling might need to be done occur on 1900 series switches that do not support using the **cdp run** command. On 1900 series switches, you need to enable or disable CDP on a per interface basis. Other examples include particular interfaces that might not have CDP enabled for security purposes.

Use the **show cdp interface** command to gather information that CDP uses for its advertisement and discovery frame transmission. Example 13-4 demonstrates some sample output from this command. This information helps provide detailed information about such things as the holdtime, the frequency at which CDP packets are sent, the encapsulation time for the interface, and the administrative and protocol conditions of the interface.

Example 13-4 *show cdp interface Command Output*

```
routerA# show cdp interface
Serial 0 is up, line protocol is up, encapsulation is Frame Relay
  Sending CDP packets every 60 seconds
  Holdtime is 180 seconds
Ethernet0 is up, line protocol is up, encapsulation is ARPA
  Sending CDP packets every 60 seconds
  Holdtime is 180 seconds
```

Creating a Network Map of the Environment

CDP was designed and implemented as a simple, low-overhead protocol. Though a CDP frame can be very small, CDP can retrieve a great deal of useful information about connected neighboring routers.

The **show cdp neighbors** command can be used to obtain the following information:

- Device ID
- Address
- Port ID
- Capabilities
- Version
- Platform
- IP Network Prefix
- VTP Management Domain Name (CDPv2 only)
- Native VLAN (CDPv2 only)
- Full/Half-Duplex (CDPv2 only)

This information can be used to create a network map of the connected devices. Devices connected to neighboring devices can be discovered by using Telnet to connect to the neighbors. Use the **show cdp neighbors detail** command to discover what devices are connected to those neighbors.

Disabling and Troubleshooting CDP

As previously mentioned, CDP is globally enabled on the router by default. To disable CDP at the global level, use the **no cdp run** command in global config mode. If CDP is disabled globally, the interface cannot be enabled for CDP. For example, you might disable CDP for security purposes when you do not want information made available about a particular device.

On Cisco IOS Software Release 10.3 and later, CDP is disabled by default on each of interface of the device. You must use the **cdp enable** command before CDP is enabled and CDP messages can be sent and received. To disable CDP on a specific interface after it has been enabled, use the **no cdp enable** command in interface config mode.

Table 13-2 lists and describes troubleshooting commands that you can use to show the version, update information, tables, and traffic.

Table 13-2 CDP Troubleshooting Commands

Command	Description
<code>clear cdp table</code>	Deletes the CDP table of information about neighbors.
<code>clear cdp counters</code>	Resets the traffic counters to zero.
<code>show cdp traffic</code>	Displays CDP counters, including the number of packets sent and received and checksum errors.
<code>show debugging</code>	Displays information about the types of debugging that are enabled for your router.
<code>debug cdp adjacency</code>	Displays information about CDP neighbors.
<code>debug cdp events</code>	Displays information about CDP events.
<code>debug cdp ip</code>	Displays information about CDP IP information.
<code>debug cdp packets</code>	Displays information about CDP packet-related information.
<code>cdp timers</code>	Specifies how often Cisco IOS Software sends CDP updates.
<code>cdp holdtime</code>	Specifies the holdtime the receiving device should hold a CDP packet from your router before discarding.
<code>show cdp</code>	Displays information about CDP update packets.



Lab Activity Creating a Network Map Using CDP

In this activity, you use the CDP commands to get information about neighboring networks and routers.



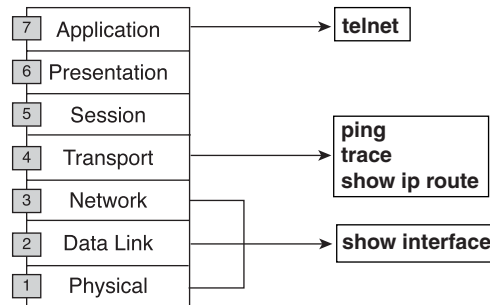
Lab Activity CDP Neighbors

In this activity, you use the CDP commands to get information about neighboring networks and routers. You display information on how CDP is configured for its advertisement and discovery frame transmission.

Getting Information About Remote Devices

This section describes Telnet, *ping*, and *traceroute*, which can be used to obtain information about remote devices, as shown in Figure 13-3.

Figure 13-3 Testing Process Overview



Telnet

Telnet is a virtual terminal protocol that is part of the TCP/IP protocol suite. Telnet enables you to make connections to remote hosts and makes it possible for a network terminal to remotely log in. `telnet` is a Cisco IOS Software EXEC command used to verify the application layer software between source and destination. This command is the most complete test mechanism available.

Telnet performs at the application layer of the OSI model, and it depends on TCP to guarantee the correct and orderly delivery of data between the client and server.

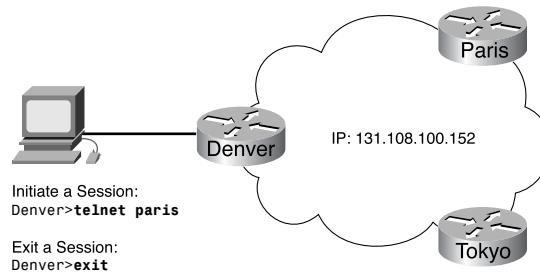
A router can have simultaneous incoming Telnet sessions. The range 0 through 4 specifies five vty or Telnet lines. These five incoming Telnet sessions can take place at one time.

Verifying the application layer connectivity is a byproduct of Telnet. Telnet is mainly used to connect to remote network devices, such as routers, switches, and servers, to gather information or perform maintenance. It is a simple and universal application program.

Establishing and Verifying a Telnet Connection

The `telnet` Cisco IOS Software EXEC command allows a user to Telnet from one Cisco device to another. With the Cisco implementation of TCP/IP, you do not have to enter the command `connect` or `telnet` to establish a Telnet connection. Just enter the host name or the IP address of the remote router. To end a Telnet session, use the EXEC commands `exit` or `logout`. Figure 13-4 demonstrates initiating and exiting a Telnet connection.

Figure 13-4 Telnet Operation



A host name table or access to DNS for Telnet must be present for a name to work in a Telnet session; otherwise, the IP address of the host must be entered. To initiate a Telnet session, use any of the following alternatives:

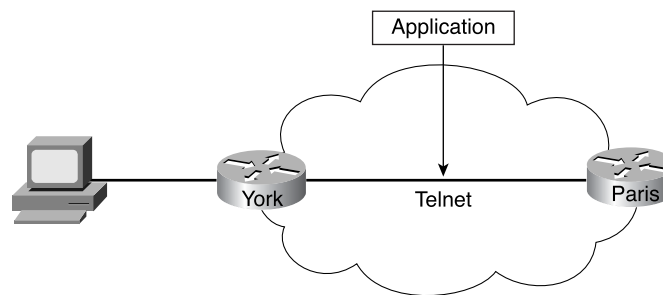
```

Denver>connect paris
Denver>paris
Denver>131.108.100.152
Denver>telnet paris

```

You can use Telnet to perform a test to determine whether access can or cannot be obtained from a remote router. As shown in Figure 13-5, if Telnet is successful in connecting the York router to the Paris router, a basic test of the network connection is successful. This operation can be performed at either the user or privileged EXEC levels.

Figure 13-5 Testing the Application Layer



If remote access can be obtained through another router, at least one TCP/IP application can reach the remote router. A successful Telnet connection indicates that the upper-layer application functions properly.

A successful Telnet can occur to one router, but fail to another router. Specific addressing, naming, or access permission problems are likely culprits for Telnet failure. Further, it is

possible that the problem exists on the source router or on the router that failed as a Telnet target. In this case, the next step is to try **ping**, which is covered later in this chapter. **ping** allows testing of end-to-end connections at the network layer.

Once the Telnet is completed, log off the host. The EXEC terminates any connection after ten minutes of inactivity by default or when you enter the **exit** command at the EXEC prompt.



Lab Activity Establishing and Verifying a Telnet Connection

In this activity, you establish a Telnet connection to a remote router and gather information from it.

Advanced Telnet Operation

You might have several concurrent Telnet sessions open, and you can switch back and forth between these sessions. The number of open sessions that are allowed at one time is defined by the **session limit** command.

To switch between sessions by escaping from one session and resuming a previous opened session, use the following commands:

- **Ctrl + Shift + 6** followed by **hitting the letter x**—Escapes the current connection and returns to the EXEC prompt
- **resume**—Makes the connection

You can make a new connection while at the EXEC prompt. Most routers are limited to five simultaneous sessions.

You can use and suspend multiple Telnet sessions with the **Ctrl + Shift + 6** followed by hitting the letter **x** sequence. The session can be resumed by using the **Enter** key. If the **Enter** key is used, Cisco IOS Software resumes the connection to the most recently suspended Telnet connection. Using the **resume** command requires a connection ID, and you can display the connection IDs for all open sessions by using the **show sessions** command.



Lab Activity Disconnecting and Suspending Telnet Sessions

In this activity, you establish a Telnet session to a remote router. You temporarily suspend and then resume the session.

**Lab Activity** Advanced Telnet Operation

In this activity, you use the **telnet** command to remotely access other routers, verifying that the application layer between source and destination is working properly. You suspend a Telnet session and engage in multiple Telnet sessions. You return to the suspended session and disconnect from the Telnet session.

Alternative Connectivity Tests

The following sections cover many of the commands that can be used to test and examine connectivity between devices. The tools and commands described in this section are as follows:

- ping
- traceroute
- show ip route
- show interfaces serial
- show interfaces/clear counter
- debug

The ping Command

Many network protocols support an echo protocol as an aid to diagnosing basic network connectivity. Echo protocols test whether or not protocol packets are being routed.

The **ping** command sends a packet to the destination host and then waits for a reply packet from that host. Results from this echo protocol can help evaluate the path-to-host reliability, delays over the path, and if the host can be reached or is functioning. This command is a basic testing mechanism, and its operation can be performed in either the user or privileged EXEC modes.

The **ping** user EXEC command can be used to diagnose basic network connectivity. Use the **ping** command as follows:

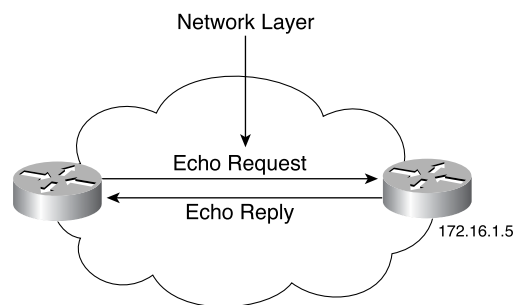
1. **ping** IP address or name of destination.
2. Press the **Enter** key.

Table 13-3 shows the Cisco **ping** return codes. **ping** uses Internet Control Message Protocol (ICMP).

Table 13-3 Cisco ping Return Codes

Code	Meaning	Possible Cause(s)
!	Each exclamation point indicates receipt of an ICMP echo reply.	The ping completed successfully.
.	Each period indicates that the network server timed out while waiting for a reply.	This message can indicate many problems: ping was blocked by an access list or firewall. A router along the path did not have a route to the destination and did not send an ICMP destination unreachable message. A physical connectivity problem occurred somewhere along the path.
U	An ICMP unreachable message was received.	A router along the path did not have a route to the destination address.
C	An ICMP source quench message was received.	A device along the path—possibly the destination—might be receiving too much traffic; check input queues.
&	An ICMP time exceeded message was received.	A routing loop might have occurred.

Figure 13-6 offers a sample diagram to demonstrate how ping works.

Figure 13-6 Testing with the ping Command

The **ping** target 172.16.1.5 in Figure 13-6 responded successfully to all five datagrams sent as indicated by the following:

```
Router>ping 172.16.1.5
Type escape sequence to abort.
Sending 5, 100 byte ICMP Echos to 172.16.1.5,
timeout is 2 seconds:
!!!!
Success rate is 100 percent,
round-trip min/avg/max - 1/3/4 ms
Router>
```

The exclamation points (!) indicate each successful echo. If one or more periods (.) are received instead of exclamations on the display, the application on the router timed out waiting for a given packet echo from the **ping** target.



Lab Activity Alternate Connectivity Tests (**ping**)

In this activity, you use the **ping** command to send ICMP datagrams to a target host and verify that the network layer between source and destination is working properly. You retrieve information to evaluate the path-to-host reliability, determine delays over the path, and determine if the host can be reached or is functioning.

The **tracert** Command

The **tracert** command (abbreviated as **trace**) is the ideal tool for finding where data is being sent in a network. The **tracert** command is similar to the **ping** command, except that instead of testing end-to-end connectivity, **tracert** tests each step along the way. This operation can be performed at either the user or privileged EXEC levels.

Use the **tracert** command as follows:

1. **tracert** IP address or name of destination.
2. Press the **Enter** key.

Table 13-4 shows the Cisco **tracert** return codes.

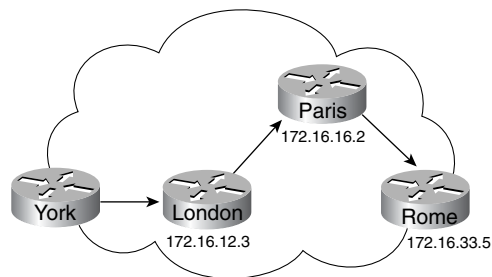
Table 13-4 Cisco **tracert** Return Codes

Code	Meaning	Possible Cause(s)
<i>nn</i> msec	This gives, for each node, the round-trip time (in milliseconds) for the specified number of probes.	This is normal.

Table 13-4 Cisco **traceroute** Return Codes (Continued)

Code	Meaning	Possible Cause(s)
*	The probe timed out.	A device along the path either did not receive the probe or did not reply with an ICMP “packet life exceeded” message.
A	Administratively prohibited.	A device along the path, such as a firewall or router, might be blocking the probe and possibly other or all traffic; check access lists.
Q	Source quench.	A device along the path might be receiving too much traffic; check input queues.
H	An ICMP unreachable message has been received.	A routing loop might have occurred.

To demonstrate how **traceroute** works, look at the sample diagram in Figure 13-7.

Figure 13-7 **traceroute** Command

In this example, the path from York to Rome is being traced with the following results:

```

York# trace Rome
Type escape to abort.
Tracing the route to Rome (172.16.33.5)
 1 LONDON (172.16.12.3) 1000 msec 8 msec 4 msec
 2 PARIS (172.16.16.2) 8 msec 8 msec 8 msec
 3 ROME (172.16.35.5) 8 msec 8 msec 4 msec
  
```

York#

Along the way, the path must go through London and Paris. If one of these routers is unreachable, three asterisks (*) are returned instead of the name of the router. The

traceroute command will continue attempting to reach the next step until the **Ctrl-Shift-6** escape sequence is used.

The **traceroute** command takes advantage of the error messages generated by routers when a packet exceeds its TTL or hop count value. The **traceroute** command sends several **ping** packets with an incrementing TTL value and displays the round-trip time for each. Because the TTL value is incremented each time a **ping** is sent, each successive **ping** gets closer to the destination. The benefit of the **traceroute** command is that it also tells which router in the path was the last one to be reached, which allows for fault isolation.

Testing the Network Layer with the **show ip route** Command

The router offers some powerful tools at this point in the search. You can actually look at the routing table, which contains directions that the router uses to determine how it will direct traffic across the network, and use another basic test that focuses on the network layer. Use the **show ip route** command as demonstrated in Example 13-5 to determine whether a routing table entry exists for the target network. The output in Example 13-5 shows that Rome (131.108.33.0) is reachable by Paris (131.108.16.2) via the Ethernet1 interface.

Example 13-5 **show ip route** Command Output

```
Paris# show ip route
Codes: I - IGRP derived, R - RIP derived, O - OSPF derived
       C - connected, S - static, E - EGP derived, B - BGP derived
       i - IS-IS derived, D - EIGRP derived
       * - candidate default route, IA - OSPF inter area route
       E1 - OSPF external type 1 route, E2 - OSPF external type 2 route
       L1 - IS-IS level-1 route, L2 - IS-IS level-2 route
       EX - EIGRP external route

Gateway of last resort is not set
I    144.253.0.0 [100/1300] via 133.3.32.2 0:00:22 Ethernet1
131.108.0.0 is subnetted (mask is 255.255.255.0), 3 subnets
I    131.108.33.0 [100/180771] via 131.108.16.2, 0:01:29, Ethernet1
C    131.108.12.0 is directly connected, Ethernet1
C    101.108.16.0 is directly connected, Ethernet0
I    219.100.103.0 [100/1200] via 133.3.32.2, 0:00:22, Ethernet1
```

**Lab Activity** Alternate Connectivity Tests (**tracert** and **show ip route**)

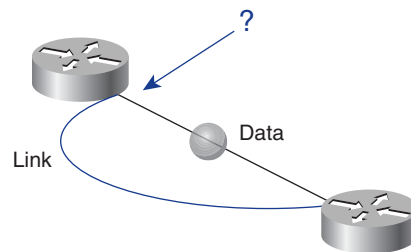
In this activity, you use the **tracert** Cisco IOS Software command to verify that the network layer between source, destination, and each router along the way is working properly. The **tracert** Windows OS command is used from source workstation to destination router. You also use the **show ip route** command to display the router's routing table.

Testing the Physical and Data Link Layers with the `show interfaces serial` Command

Figure 13-8 shows a serial connection between two router interfaces. The interface has two pieces, physical (hardware) and logical (software):

- The hardware (including cables, connectors, and interfaces) must make the actual connection between the devices.
- The software is responsible for the messages, such as keepalive messages, control information, and user information, that are passed between adjacent devices. This data is being passed between the two connected router interfaces.

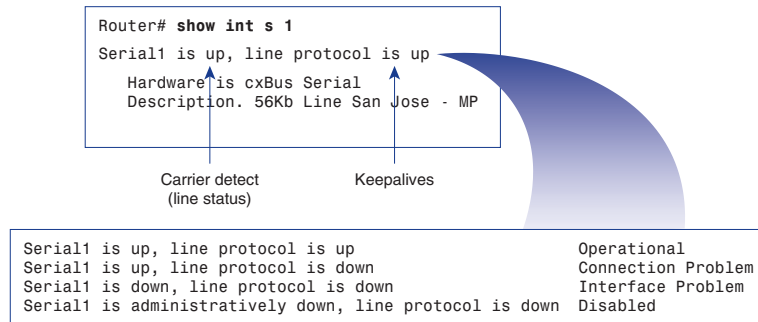
Figure 13-8 Testing the Physical and Data Link Layers



When you test the physical and data link layers, ask these questions:

- Is there a carrier detect signal?
- Is the physical link between devices good?
- Are the keepalive messages being received?
- Can data packets be sent across the physical link?

One of the most important elements of the **show interfaces serial** command output is the display of the line and data link protocol status. Figure 13-9 indicates the key summary line used to check the status of the line and the data link protocol.

Figure 13-9 Identifying Line and Protocol Problems

The line status in this example is triggered by a carrier detect signal and refers to the physical layer status. However, the line protocol, triggered by keepalive frames, refers to data link framing (a Layer 2 function).

Using the **show interfaces** and **clear counters** Commands

The router tracks statistics that provide information about the interfaces. Use the **show interfaces** command to display the statistics, as demonstrated in Example 13-6.

Example 13-6 show interfaces *Command Output*

```

Router# show interfaces serial 1
Serial1 is up, line protocol is up
Hardware is cxBus Serial
Description: 56Kb Line San Jose - MP
Internet address is 150.136.190.203, subnet mask is 255.255.255.0
MTU 1500 bytes, BW 56 Kbit, DLY 20000 usec, rely 255/255, load 1/255
Encapsulation HDLC, loopback not set, keepalive set (10 sec)
Last input 0:00:07, output 0:00:)), output hang never
Last clearing of show interfaces counters 2w4d
Output queue 0/40, 0 drops; input queue 0/75, 0 drops
Five minute input rate 0 bits/sec, 0 packets/sec
Five minute output rate 0 bits/sec, 0 packets/sec
    16263 packets input, 1347238 bytes, no buffer
    Received 13983 broadcasts, 0 runts, 0 giants
    2 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored, 2 abort
    0 input packets with dribble condition detected

```

Example 13-6 show interfaces *Command Output (Continued)*

```

22146 packets output, 2383680 bytes, 0 underruns
0 output errors, 0 collisions, 2 interface resets, 0 restarts
1 carrier transitions

```

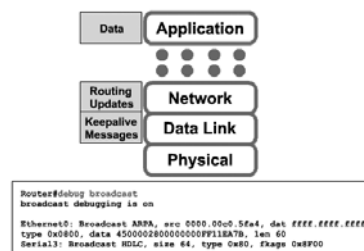
The statistics reflect router operation since the last time the counters were cleared. Use the **clear counters** command to reset the counters to 0. By starting from 0, you get a better picture of the current status of the network. The **show interfaces** command can also be used to check the status of other interface types, such as Ethernet (E0), Fast Ethernet (Fa0), and Integrated Services Digital Network (ISDN) (BRI0).

Checking Real-Time Traffic with the **debug** Command

The router includes hardware and software to aid it in tracking down problems on it or on other hosts in the network. The **debug** privileged EXEC command starts the console display of the network events specified in the command parameter. Use the **terminal monitor** command to forward **debug** output to your Telnet session terminal.

Figure 13-10 displays the data-link broadcasts received by the router using the **debug broadcasts** command. Use the **undebug all** (or **no debug all**) command to turn off debugging when you no longer need it. Debugging is really intended for solving problems.

Figure 13-10 Checking Real-Time Traffic with the **debug** Command



By default, the router sends system error messages and output from the **debug** EXEC command to the console terminal. However, you can redirect messages to a UNIX host or to an internal buffer. The **terminal monitor** command enables you to redirect these messages to a terminal, which can be useful in cases where you use a UNIX or Linux host instead of the console terminal as a means of administering the devices.

CAUTION

Be careful with the **debug** command on a live network. Substantial debugging on a busy network slows the network significantly. Do not leave debugging turned on; use it to diagnose a problem, and then turn it off. Excessive debugging on routers with minimal RAM can cause the router to force a reload.

**Lab Activity** Troubleshooting IP Address Issues

In this activity, you configure IP addresses for workstations and test end-to-end network connectivity.

Summary

In this chapter, you learned the following key points:

- CDP is a media- and protocol-independent, Cisco-proprietary protocol used for neighbor discovery.
- CDP shows information only about directly connected neighbors.
- You use CDP to show Layer 2 and 3 information about neighbors.
- You should test network connectivity layer by layer.
- Dealing with connectivity issues is the most common problem situation that occurs on IP networks. The following three commands are used to perform address-related troubleshooting:
 - **ping** uses the ICMP protocol to verify the hardware connection and the IP address of the network layer. This command is a very basic testing mechanism.
 - **telnet** verifies the application layer software between source and destination. This command is the most complete test mechanism available.
 - **tracert** allows the location of failures in the path from the source to destination. **tracert**, or **trac**, uses TTL values to generate messages from each router along the path.

To supplement all that you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab Activities on the CD-ROM accompanying this book.

Key Terms

CDP (Cisco Discovery Protocol) Used to obtain information about neighboring devices, such as the types of devices connected, the router interfaces they are connected to, the interfaces used to make the connections, and the model numbers of the devices.

debugging To find and remove errors (bugs) from a program or design.

ping Packet internet groper. ICMP echo message and its reply. Often used in IP networks to test the reachability of a network device.

SNAP (Subnetwork Access Protocol) Internet protocol that operates between a network entity in the subnetwork and a network entity in the end system. SNAP specifies a standard method of encapsulating IP datagrams and ARP messages on IEEE networks. The SNAP entity in the end system makes use of the services of the subnetwork and performs three key functions: data transfer, connection management, and QoS selection.

SNMP (Simple Network Management Protocol) Network management protocol used almost exclusively in TCP/IP networks. SNMP provides a means to monitor and control network devices, and to manage configurations, statistics collection, performance, and security.

Telnet Standard terminal emulation protocol in the TCP/IP protocol stack. Telnet is used for remote terminal connection, enabling users to log in to remote systems and use resources as if they were connected to a local system.

TLVs (Type Length Values) Blocks of information embedded in CDP advertisements.

traceroute Program available on many systems that traces the path a packet takes to a destination. It is used mostly to debug routing problems between hosts.

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. What is a definition for **telnet**?
 - A. A command to determine whether a specific IP address is accessible. It works by sending a packet to the specified address and waiting for a reply.
 - B. A command that uses Time-To-Live (TTL) values to generate messages from each router used along the path.

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- C. A command used to verify the application layer software between source and destination stations. This command is the most complete test mechanism available.
2. What information does testing a network by using the **show interfaces serial** command provide?
 - A. It displays line and data link protocol status.
 - B. It displays how the router directs traffic across the network.
 - C. It displays the path that packets follow across the network.
 - D. It displays the names of routers on the network.
 3. What information does the **show cdp neighbors** command provide for each CDP neighbor?
 - A. Device identifiers
 - B. Address list
 - C. Port identifier
 - D. All of the above
 4. The **show cdp interface** command is used to display which of the following?
 - A. The values of the CDP timers and the interface status
 - B. The encapsulation used by CDP for its advertisement and discovery frame transmission
 - C. The interface configuration of the neighboring routers
 - D. Both A and B
 5. Which of these is true for the output of the command **show cdp entry [device name]**?
 - A. It displays all the Layer 3 addresses present in the neighbor router.
 - B. It displays the value of neighbors that the router has.
 - C. It displays the list of the device numbers of all the neighboring routers.
 - D. It displays all the Layer 2 addresses on the interfaces of the neighbor router.
 6. To display the information that is obtained both from the **show cdp neighbors** and **show cdp entry [device name]** commands, which of the following commands is used?
 - A. **show cdp neighbors detail**
 - B. **show cdp interface entry**
 - C. **show cdp neighbors entry**
 - D. **show cdp details**

7. What information is displayed by the **show cdp neighbors** command?
 - A. Neighbor device ID
 - B. Local port type and number
 - C. Decremental holdtime value, in seconds
 - D. All of the above
8. What four important pieces of information do you receive after issuing a **ping** command?
 - A. The size and quantity of ICMP packets; the timeout duration; the success rate; and the minimum, average, and maximum round-trip times
 - B. The size and quantity of ICMP packets; the MAC address; the success rate; and the minimum, average, and maximum round-trip times
 - C. All of the above
 - D. None of the above
9. What information does testing a network by using the **tracert** command provide?
 - A. It determines if the line protocol is operational.
 - B. It determines if a routing table entry exists for the target network.
 - C. It maps every router that a packet goes through to reach its destination.
 - D. It determines if upper-layer applications are functioning properly.
10. In reply to the **ping** command, exclamation points (!) indicate which of these?
 - A. The number of successful echos
 - B. The number of unsuccessful echos
 - C. The number of hops before reaching the destination
 - D. All of the above
11. What is true of the router **debug** commands?
 - A. The **debug** privileged EXEC command starts the console display of the network events specified in the command parameter.
 - B. The **undebug all** command (or **no debug all**) turns off debugging.
 - C. The **buffer debug** command is used to buffer the login.
 - D. Both A and B.



Objectives

Upon completion of this chapter, you will be able to

- Identify the stages of the router boot sequence
- Determine how a Cisco device locates and loads Cisco IOS Software
- Use the **boot system** command
- Identify the configuration register values
- Describe the process used to locate Cisco IOS Software
- Describe the process and commands for creating and loading a software image and configuration file backup
- Describe Cisco IOS Software naming conventions

Chapter 14

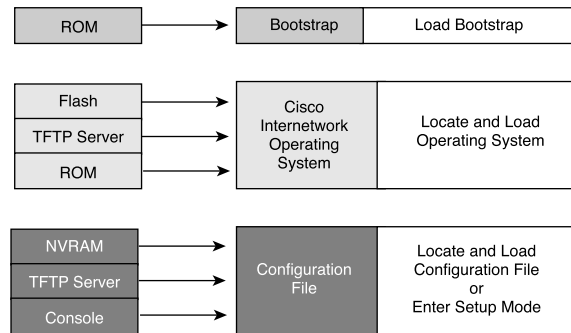
Managing Cisco IOS Software

This chapter examines the stages of the router boot sequence, including how the Cisco router locates and loads Cisco IOS Software. This chapter also introduces the **boot system** command and explains how the **boot system** command tells the router to boot up. Also, you learn how to use a variety of Cisco IOS Software source options and execute commands to load Cisco IOS Software onto the router, maintain backup files, and upgrade Cisco IOS Software. In addition, you learn about the functions of the configuration register and how to determine which version of the Cisco IOS Software image file you have. Finally, this chapter describes how to use a TFTP server as a software source for the Cisco IOS Software image and configuration files.

Please be sure to look at this chapter's associated e-Labs, Videos, and PhotoZooms that you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

Stages of the Router Power-On/Boot Sequence

A router initializes by loading the *bootstrap*, the operating system, and a configuration file. If the router cannot find a configuration file, then it enters setup mode. The router stores a backup copy of the new configuration from setup mode in *nonvolatile random-access memory (NVRAM)*. Figure 14-1 shows the events that occur as the router initializes.

Figure 14-1 Router Startup Sequence

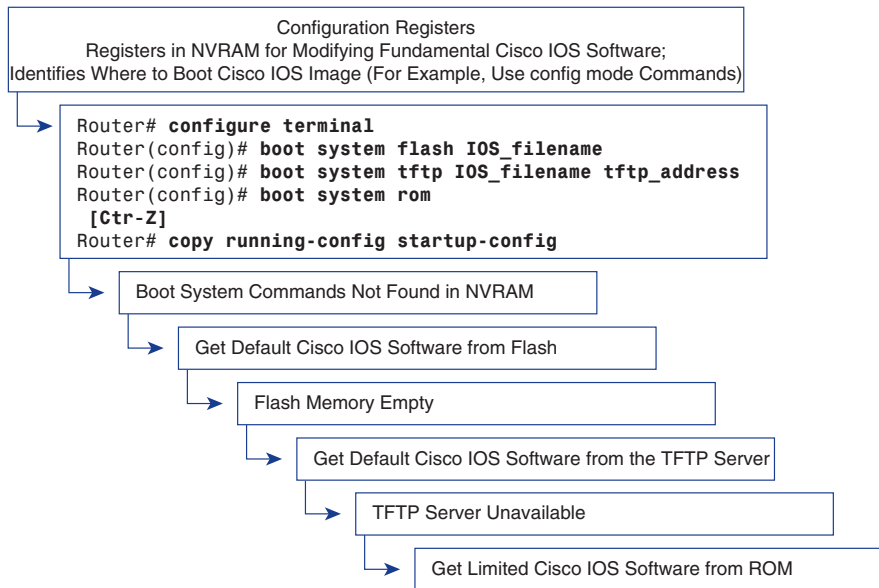
The goal of the startup routines for Cisco IOS Software is to start the router operations. The router must deliver reliable performance in connecting to the user networks it was configured to serve. To do this, the startup routines must do the following:

1. Make sure that the router loads ROM.
2. Find and load the Cisco IOS Software image that the router uses for its operating system.
3. Find and apply configuration statements, including protocol functions and interface addresses.

When a Cisco router powers up, it performs a power-on self test (POST). During this self test, the router executes diagnostics from ROM on all hardware modules. These diagnostics verify the basic operation of the CPU, memory, and network interface ports. After verifying the hardware functions, the router proceeds with software initialization.

Locating and Loading Cisco IOS Software

The default source for Cisco IOS Software startup depends on the hardware platform. However, the router usually looks to the **boot system** commands saved in NVRAM. Cisco IOS Software does, however, allow you to use several alternatives. You can specify that the router look at other sources for software. Also, the router can use its own fallback sequence, as necessary, to load the software. Figure 14-2 illustrates how the Cisco IOS Software image is located.

Figure 14-2 Locating Cisco IOS Software

The settings in the configuration register enable the following alternatives:

- You can specify global configuration mode **boot system** commands to enter fallback sources for the router to use in sequence. When the router restarts, it uses these commands in sequence as needed.
- If NVRAM does not have **boot system** commands that the router can use, the system uses the Cisco IOS Software in *Flash memory* by default.
- If Flash memory is empty, the router next attempts to use *Trivial File Transfer Protocol (TFTP)* to load a Cisco IOS Software image from the network. The router uses the configuration register value to form a filename from which to boot a default system image stored on a network server.
- If a TFTP server is unavailable, the router will load the limited version Cisco IOS Software image stored in ROM.

Using the boot system Command

You can enter multiple **boot system** commands to specify the fallback sequence for booting Cisco IOS Software. Examples 14-1, 14-2, and 14-3 show **boot system** entries that specify that a Cisco IOS Software image will load first from Flash memory, then from a network server, and finally from ROM.

The command **copy running-config startup-config** saves the commands in NVRAM. The router executes the **boot system** commands as needed and in the order in which they were originally entered into configuration mode. To see if any boot system commands have been entered, issue the **show startup-config** command.

Booting from Flash Memory

Booting from Flash memory involves loading a system image from electrically erasable programmable read-only memory (EEPROM). The advantage here is that information stored in Flash memory is not vulnerable to network failures that can occur when loading system images from TFTP servers. Example 14-1 specifies that the **gsnew-image** Cisco IOS Software file be loaded from Flash.

Example 14-1 *Booting from Flash Memory*

```
Router# configure terminal
Router#(config)# boot system flash gsnew-image
[Ctrl-Z]
Router# copy running-config startup-config
```

Booting from a Network Server

In case Flash memory becomes corrupted, a system image can provide a backup by specifying that it should be loaded from a TFTP server. Example 14-2 specifies that the **test.ext** image file be loaded from the TFTP server at IP address 172.16.13.111.

Example 14-2 *Booting from a Network Server*

```
Router# configure terminal
Router#(config)# boot system tftp IOS_image 172.16.13.111
[Ctrl-Z]
Router# copy running-config startup-config
```

Booting from ROM

If Flash memory is corrupted and the network server fails to load the image, booting from ROM is the final bootstrap option in software. However, the system image in ROM will likely be a subset of Cisco IOS Software. This subset lacks the protocols, features, and configurations of full Cisco IOS Software. Also, if the software has been updated since the router was purchased, the router might have an older version of Cisco IOS Software. Example 14-3 demonstrates this last bootstrap option.

Example 14-3 *Booting from ROM*

```
Router# configure terminal
Router(config)# boot system rom
[Ctrl-Z]
Router# copy running-config startup-config
```

**Lab Activity** Using the **boot system** Command

In this activity, you gather information about the Cisco IOS Image and determine its boot source. You also check the config register settings and document a fallback boot sequence.

Configuration Register Values

The order in which the router looks for Cisco IOS Software images to load depends on the boot field setting in the configuration register. You can change the default configuration register setting with the global configuration command **config-register**. Use a hexadecimal number as the argument for this command, as shown in Example 14-4.

Example 14-4 *Changing the Boot Field Setting in the Configuration Register*

```
Router# configure terminal
Router(config)# config-register 0x10F
[Ctrl - Z]
```

The configuration register is set so that the router examines the startup file in NVRAM for boot system options. The configuration register is a 16-bit register in NVRAM. The lowest 4 bits of the configuration register (bits 3, 2, 1, and 0) form the boot field. To change the boot field and leave all other bits set at their original values, follow these guidelines:

- Set the configuration register value to 0x100 if the ROM monitor needs to be entered. This setting is primarily a programmer's environment. Boot the operating system manually from the ROM monitor. Use the **b** command at the ROM monitor prompt to boot the system. This value sets the boot field bits to 0-0-0-0.
- Set the configuration register to 0x101 to configure the system to boot automatically from the limited Cisco IOS Software image in ROM. This value sets the boot field bits to 0-0-0-1.

- Set the configuration register to any value from 0x102 to 0x10F to configure the system to use the boot system commands in NVRAM. This setting is the default. These values set the boot field bits to 0-0-1-0 through 1-1-1-1.

If there are no boot system commands in NVRAM, the system will typically look to Flash memory for the Cisco IOS Software image.

Table 14-1 shows the boot field values in the configuration register.

Table 14-1 Boot Field Values in the Configuration Register

Value	Description
0x100	Use ROM monitor mode (manually boot using the b command).
0x101	Automatically boot from ROM (default if router has no Flash memory).
0x102 to 0x10F	Examine NVRAM for boot system commands (0x102 is the default if the router has Flash memory).

To check the boot field setting and to verify the `config-register` command, use the `show version` command.



Lab Activity Troubleshooting Config Register Boot Problems

In this activity, you check and document the configuration register settings related to boot method and configure the router to boot from Flash.

Displaying the Currently Running Cisco IOS Software Version

The `show version` command, as shown in Example 14-5, displays information about the Cisco IOS Software version that is currently running on the router. This version information includes the configuration register and the boot field setting.

Example 14-5 Configuration Register

```
Router# show version
Cisco Internetwork Operating System Software IOS (tm) 2500 Software (C2500-JS-L),
Version 12.1(5), RELEASE SOFTWARE (fc1) Copyright (c) 1986-2000 by
cisco Systems, Inc. Compiled Wed 25-Oct-00 05:18 by cmong Image text-base:
0x03071DB0, data-base: 0x00001000
```

Example 14-5 *Configuration Register (Continued)*

```
ROM: System Bootstrap, Version 5.2(8a), RELEASE SOFTWARE BOOTFLASH:
 3000 Bootstrap Software (IGS-RXB00T), Version 10.2(8a), RELEASE SOFTWARE (fc1)
Router uptime is 7 minutes System returned to ROM by reload System image file
 is "flash:c2500-js-l_121-5.bin"
cisco 2500 (68030) processor (revision D) with 16384K/2048K bytes of memory.
 Processor board ID 03867477, with hardware revision 00000000 Bridging software.
 X.25 software, Version 3.0.0. SuperLAT software (copyright 1990 by
 Meridian Technology Corp). TN3270 Emulation software. 1 Token Ring/IEEE 802.5
 interface(s) 2 Serial network interface(s) 32K bytes of non-volatile
 configuration memory. 16384K bytes of processor board System flash (Read ONLY)
 Configuration register is 0x2142
```

In the example, the Cisco IOS Software version and descriptive information are highlighted on the second line of output. The screen captured shows Software Release 12.1(5).

The next highlighted portion of the output shows the system image file is c2500-js-l, booted using Flash. Notice the portion of the filename that indicates that this image is for a Cisco 2500 platform.

As the output of the **show version** command continues, information is displayed about the type of platform on which the version of Cisco IOS Software is currently running. The final highlighted output provides the targeted results of the command—**config-register 0x2142**. This information is used to enter configuration register values.

NOTE

There is no evidence of any config-register setting in output from either the **show running-config** or **show startup-config** command.

Managing Cisco IOS Software Images

Routers and switches depend on software for their operation. The two types of software required are operating systems and configuration.

The operating system used in almost all Cisco devices is the Cisco Internetwork Operating System (IOS). Cisco IOS Software allows the hardware to function as a router or switch. The Cisco IOS Software file is several megabytes in size. Cisco IOS Software is the platform that ensures that the network provides the connectivity, reliability, security, quality of service, scalability, and management capabilities required for applications.

The software a router or switch uses is referred to as the *configuration file* or the *config*. The configuration file contains the instructions that define how the device is to route or switch. A network administrator creates a configuration file that defines the desired functions of the Cisco device. Examples of the functions that can be specified by the config are the IP addresses of the interfaces, routing protocols, and networks to be advertised. The configuration file typically is a few hundred to a few thousand bytes in size.

Each of the software components is stored in memory as a separate file. These files are also stored in different types of memory.

The Cisco IOS Software image is stored in a memory area called Flash. Flash memory provides nonvolatile storage of a Cisco IOS Software image that can be used as an operating system at startup. Flash allows you to upgrade Cisco IOS Software or to store multiple Cisco IOS Software files. In many router architectures, the Cisco IOS Software image is copied from Flash and run from *random-access memory (RAM)*.

A copy of the configuration file is stored in NVRAM to be used as a configuration during startup. This NVRAM configuration is referred to as the *startup config*. The startup config is copied into RAM at boot time. This configuration in RAM is the configuration used to operate the router. The RAM configuration is referred to as the *running config*.

A single interface to all the file systems that a router uses is provided in Software Release 12 of Cisco IOS Software. This version is referred to as the Cisco IOS File System (IFS). The IFS provides a single method to perform all the file system management that a router uses. This IFS includes the Flash memory file systems, the network file systems, and reading or writing data. The network file systems include TFTP, *remote copy protocol (RCP)*, and File Transfer Protocol (FTP). The reading or writing data includes NVRAM, the running configuration, and ROM. The IFS uses a common set of prefixes to specify file system devices. Table 14-2 provides an overview of the IFS.

Table 14-2 IOS File System

Prefix	Description
bootflash:	Boot flash memory.
flash:	Flash memory. This prefix is available on all platforms. For platforms that do not have a device named Flash, the prefix flash: is aliased to slot0:. Therefore, the prefix flash: can be used to refer to the main Flash memory storage area on all platforms.

Table 14-2 IOS File System (Continued)

Prefix	Description
flh:	Flash load helper log files.
nvram:	NVRAM.
rcp:	Remote copy protocol (RCP) network server.
Slot0:	First Personal Computer Memory Card Industry Association (PCMCIA) Flash memory card.
Slot1:	Second PCMCIA Flash memory card.
system:	Contains the system memory, including the running configuration.
Tftp:	TFTP network server.

The IFS uses the Universal Resource Locator (URL) convention to specify files on network devices and the network. The URL convention identifies the location of the configuration files following the colon as `[[[//location]/directory]/filename]`. The IFS also supports FTP file transfer. Table 14-3 lists the commands used to manage Cisco IOS Software for Software Release 12.0 and compares them against counterpart commands used in Cisco IOS Software releases prior to 12.0.

Table 14-3 Commands for Managing Cisco IOS Software Release 12.0 and Earlier

Pre Cisco IOS Software Release 12.0 Commands	Cisco IOS Software Release 12.x Commands
<pre>configure network (pre-Cisco IOS Software Release 10.3) copy rcp running-config copy tftp running-config</pre>	<pre>copy ftp: system:running-config copy rcp: system:running-config copy tftp: system:running-config</pre>

continues

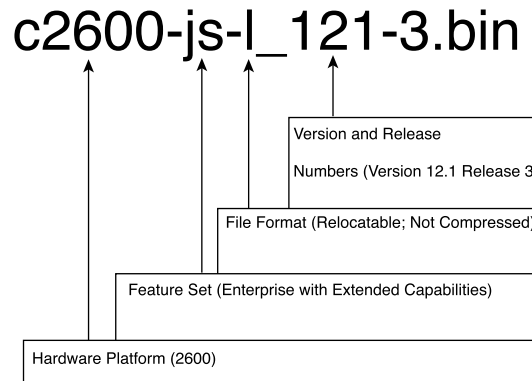
Table 14-3 Commands for Managing Cisco IOS Software Release 12.0 and Earlier (Continued)

Pre Cisco IOS Software Release 12.0 Commands	Cisco IOS Software Release 12.x Commands
configure overwrite-network (pre-Cisco IOS Software Release 10.3) copy rcp startup-config copy tftp startup-config	copy ftp: nvram:startup-config copy rcp: nvram:startup-config copy tftp: nvram:startup-config
show configuration (pre-Cisco IOS Software Release 10.3) show startup-config	more nvram:startup-config
write erase (pre-Cisco IOS Software Release 10.3) erase startup-config	erase nvram:
write memory (pre-Cisco IOS Software Release 10.3) copy running-config startup-config	copy system:running-config nvram:startup-config
write network (pre-Cisco IOS Software Release 10.3) copy running-config rcp copy running-config tftp	copy system:running-config ftp: copy system:running-config rcp: copy system:running-config tftp
write terminal (pre-Cisco IOS Software Release 10.3) show running-config	more system:running-config

Cisco IOS Software Naming Conventions

Cisco develops many different versions of Cisco IOS Software. Cisco IOS Software supports varied hardware platforms and features. Cisco continuously develops and releases new versions of Cisco IOS Software.

Cisco has a naming convention for Cisco IOS Software files to identify the different versions of these Cisco IOS Software files, as illustrated by Figure 14-3.

Figure 14-3 Cisco IOS Software Naming Conventions

As Figure 14-3 shows, this Cisco IOS Software naming convention uses different fields in the name:

- **Hardware Platform**—The first part of the filename identifies the hardware platform. This image is designed for the hardware platform.
- **Feature Set**—The second part of the filename identifies the various features that the Cisco IOS Software file contains. You can choose from many different features, and these features are packaged in “software images.” Each feature set contains a specific subset of Cisco IOS Software features. Examples of the feature set categories are as follows:
 - **Basic**—Basic is a basic feature set for the hardware platform. Examples of Basic are IP and IP/FW.
 - **Plus**—Plus is a basic feature set plus additional features such as IP Plus, IP/FW Plus, and Enterprise Plus.
 - **Encryption**—Encryption has the 56-bit data encryption feature sets added to either a Basic or Plus feature set. Examples include IP/ATM PLUS IPSEC 56 or Enterprise Plus 56. The encryption designators are k8/k9 starting with the Cisco IOS Software Release 12.2. k8 is less than or equal to 64-bit encryption on Release 12.2 and up. k9 is greater than 64-bit encryption on Release 12.2 and up.
- **File Format**—The third part of the IOS filename indicates the file format. The third part specifies if Cisco IOS Software is stored in Flash memory in a compressed format and if the Cisco IOS Software image is relocatable. If the Flash image is compressed, Cisco IOS Software must be expanded during boot as the image is copied to RAM. A relocatable image is copied from Flash memory into RAM to run. A non-relocatable image is run directly from Flash memory.

- **Version and Release**—The fourth part of the IOS filename identifies the version number and release of Cisco IOS Software. As Cisco develops newer versions of Cisco IOS Software, the numerical version number increases.

Managing Configuration File Using TFTP

In a Cisco router or switch, the active configuration is in RAM. The default location for the startup configuration in a Cisco router or switch is NVRAM. In the event the configuration is lost, you should back up this startup configuration. You can store one of these backup copies of the configuration on a TFTP server. You can use the **copy running-config tftp** command to back up the configuration. The steps to perform this backup process are as follows:

- Step 1** Enter **copy tftp running-config**.
- Step 2** Enter the IP address of the TFTP server that is to store the configuration file at the prompt.
- Step 3** Enter the name to assign to the configuration file or accept the default name.
- Step 4** Confirm the choices by typing **yes** each time.

Example 14-6 demonstrates the actual process.

Example 14-6 Backing Up the Startup Configuration on a TFTP Server

```
Cougar# copy running-config tftp
Address or name of remote host [] 192.168.119.20
Destination file name [Cougar-config]?
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
624 bytes copied in 7.05 secs
Cougar#
```

NOTE

If the router config file is missing or if the **erase startup-config** and **reload** commands have been used, the router will not have any interfaces configured. TFTP requires IP to make a connection, so you will need to connect to the router using the console port and configure an IP address for the interface that will provide access to the TFTP server.

You can restore the router configuration by loading the backup configuration file from a TFTP server. The steps you can take to restore the configuration are as follows:

- Step 1** Enter **copy tftp running-config**.
- Step 2** Select a host or network configuration file at the prompt.
- Step 3** At the system prompt, enter the IP address of the TFTP server where the configuration file is located.
- Step 4** At the system prompt, enter the name of the configuration file or accept the default name.
- Step 5** Confirm the configuration filename and the server address that the system supplies.

Example 14-7 demonstrates the process of restoring the configuration from a TFTP server.

Example 14-7 *Restoring the Startup Configuration from a TFTP Server*

```
Cougar# copy tftp running-config
Address or name of remote host [] 192.168.119.20
Source filename []? Cougar-config

Destination filename [running-config]?

Accessing tftp://192.168.119.20/GAD-config...
Loading GAD-config from 192.168.119.20
  (via FastEthernet 0/0): !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
[OK-624 bytes]
624 bytes copied in 9.45 secs Cougar#
```

To copy the configuration file from the TFTP server back to the router, perform the following steps:

- Step 1** Enter configuration mode by entering the `copy tftp running-config` command.
- Step 2** At the system prompt, select a host or network configuration file. The network configuration file contains commands that apply to all routers and terminal servers on the network. The host configuration file contains commands that apply to one router in particular. At the system prompt, enter the optional IP address of the remote host where the configuration file is located. In Example 14-8, the router is configured from the TFTP server at IP address 131.108.2.155.
- Step 3** At the system prompt, enter the name of the configuration file or accept the default name. The filename convention is UNIX-based. The default filename is `hostname -config` for the host file and `network -config` for the network configuration file. In the DOS environment, the server filenames are limited to eight characters plus a three-character extension. An example is `router.cfg`. Confirm the configuration filename and the server address that the system supplies. Notice in Example 14-8 that the router prompt changes to `tokyo` immediately. This change is evidence that the reconfiguration happens as soon as the new file is downloaded.

Example 14-8 demonstrates the process of copying the configuration file from a TFTP server.

Example 14-8 *Copying the Configuration File from a TFTP Server*

```
tokyo# copy tftp running-config
Host or network configuration file [host]?
IP address of remote host [255.255.255.255]? 131.108.2.155
Name of configuration file [Router-config]? tokyo.2
Configure using tokyo.2 from 131.108.2.155? [confirm] y
Booting tokyo.2 from 131.108.2.155:!! [OK-874/16000 bytes]
tokyo#
```



Lab Activity Managing Configuration Files with TFTP

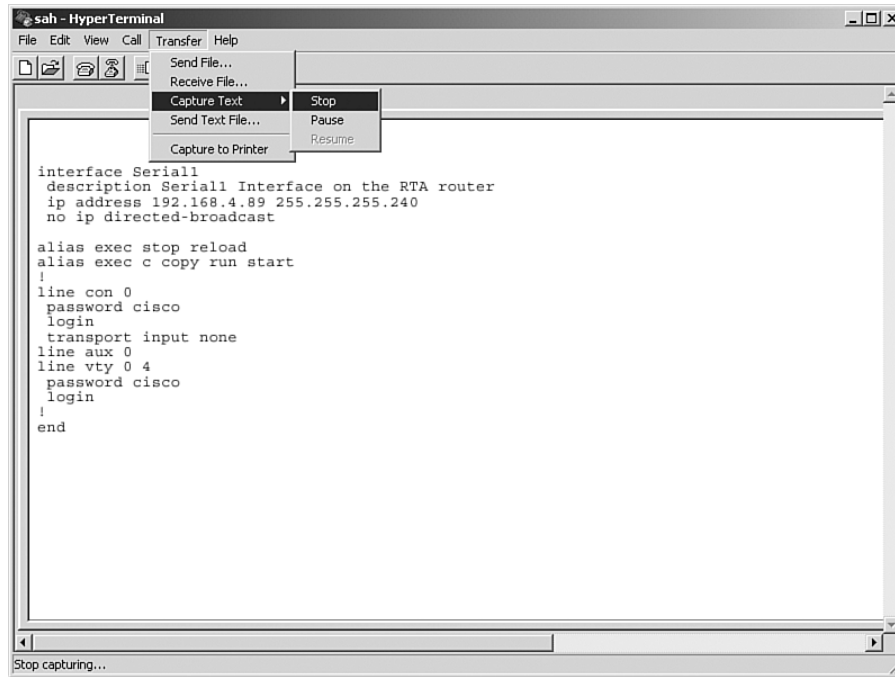
In this activity, you copy a router configuration file to a TFTP server and then configure the router by copying the file back from the TFTP server.

Managing Configuration Files with HyperTerminal

Capturing the output of the `show running-config` command is another way to create a backup copy of the configuration. You can perform this backup from the terminal session by copying the output, pasting to a text file, and saving the text file. However, this file needs some editing done before you can use it to restore configuration to the router. Figure 14-4 shows an example of cutting and pasting configurations.

To capture the configuration in HyperTerminal text that is displayed on the screen to a text file, use the following steps:

- Step 1** Select **Transfer**.
- Step 2** Select **Capture Text**.
- Step 3** Specify the name for the text file to the capture configuration.
- Step 4** Select **Start** to start capturing text.
- Step 5** Display the configuration to the screen by entering `show running-config`.
- Step 6** Press the space bar when each “-More -” prompt appears, which continues with the configuration until the end is reached.
- Step 7** When the complete configuration has been displayed, stop the capture using the following steps:
 - a. Select **Transfer**.
 - b. Select **Capture Text**.
 - c. Select **Stop**.

Figure 14-4 Capturing the Config File

After the capture is complete, you need to edit the configuration file to remove extra text. To create this file in a form to be copied and pasted back into the router, remove any unnecessary information from the captured configuration. You can add comments to the text to explain the various parts of the configuration. Add a comment by beginning a line with an exclamation mark (!).

You can edit the configuration file from a text editor such as Notepad. To edit the file from Notepad, complete the following steps:

- Step 1** Click **File > Open**.
- Step 2** Find the captured file and select it.
- Step 3** Click **Open**.

The lines you need to delete contain the following:

- show running-config
- Building configuration...
- Current configuration:
- - More -
- Any lines that appear after the word *End*

At the end of each of the interface sections, add the **no shutdown** command. Clicking **File > Save** saves the clean version of the configuration.

You can then restore the backup configuration from a HyperTerminal session. However, before you restore the configuration, remove any remaining configuration from the router, which you can do by entering the command **erase startup-config** at the enable router prompt and then restarting the router by entering **reload**.

After you remove any remaining configuration, you can use HyperTerminal to restore a configuration. You can copy the clean backup of the configuration into the router as follows:

- Step 1** Go into the router global configuration mode.
- Step 2** From the HyperTerminal, choose **Transfer > Send > Text File**.
- Step 3** Select the name of the file for the saved backup configuration.
- Step 4** The lines of the file are entered into the router as if the lines are being typed.
- Step 5** Look for any errors.
- Step 6** After the configuration is entered, press **Ctrl + z** to exit the global configuration mode.
- Step 7** Restore the startup configuration with **copy running-config startup-config**.



Lab Activity Copying, Editing, and Pasting Configurations

In this activity, you capture the running configuration of a router to an ASCII text file with HyperTerminal. You clean up the configuration by editing or modifying the captured text file with a text editor such as Notepad. Then, you upload the clean text file to configure another router using HyperTerminal.

Managing Cisco IOS Software Images with TFTP

Occasionally, the router will need to have the Cisco IOS Software image upgraded or restored. The first time a router is used, the Cisco IOS Software should be backed up to a TFTP server using the **copy flash tftp** command. This Cisco IOS Software image can be stored in a central server with other Cisco IOS Software images to restore or upgrade the Cisco IOS Software image on routers and switches in the internetwork.

This server should have a TFTP service running. You can initiate the Cisco IOS Software upgrade from the privilege EXEC mode with the **copy tftp flash** command as shown in Example 14-9.

Example 14-9 *Backing Up Cisco IOS Software to a TFTP Server*

```
Cougar# copy tftp flash
Address or name of remote host []? 192.168.119.20
Destination filename [C2600-js-l_121-3.bin]?
Accessing tftp://192.168.119.20/C2600-js-l_121-3.bin
Erase flash: before copying? [confirm]
Erasing the flash file system will remove all files
Continue? [confirm]
Erasing device  eeeeeee...eeeeeeeeeeeeee...erased
Loading C2600-js-l_121-3.bin from 192.168.119.20 (via FastEthernet 0/0):
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
Verifying Check sum.....OK
[OK-8906589 bytes]
8906589 bytes copied in 277.45 secs
Cougar#
```

The router prompts you to enter the IP address of the TFTP server. When you are prompted for the filename of the Cisco IOS Software image on the server, the router might then prompt you to erase Flash. This prompt to erase Flash often happens if there is not sufficient Flash memory available for the new image. As the image is erased from Flash, a series of letter “e”’s appear to show the erase process.

As each datagram of the Cisco IOS Software image file is downloaded, an “!” will be displayed. This Cisco IOS Software image is several megabytes in size and might take some time to download.

The new Flash image is verified after it is downloaded. The router is now ready to be reloaded to use the new Cisco IOS Software image.

Example 14-10 uses a different router and TFTP server and provides additional information on the steps used to copy the Cisco IOS Software image from the TFTP server back to the router.

After you enter the **copy tftp flash** command, as shown in Example 14-10, the system prompts you for the IP address (or name) of the TFTP server. This address or name can be another router serving ROM or Flash software images. The system then prompts you for the filename of the software image. Example 14-10 shows sample output from copying a system image, named C4500-I, into Flash memory.

NOTE

The symbol “!” means that the Flash file is loading successfully. The symbol “.” means that the Flash file cannot be found. If the symbol “.” appears, make sure you typed the correct command syntax.

The first step in this process is to identify why the Cisco IOS Software image did not load from Flash. This problem could be due to a corrupt or missing image or damaged Flash memory. Examine the Flash memory with the **dir flash:** command.

If you locate an image that appears to be valid, attempt to boot from that image. You perform this boot attempt by using the **boot flash:** command. For example, if the image name is c2600-is-mz.121-5, the command is as follows:

```
rommon > boot flash:c2600-is-mz.121-5
```

You need to check a couple of items if the router boots properly because you need to be determine why the router booted to the ROMmon instead of using Cisco IOS Software from Flash. First, use the **show version** command to check the configuration register to ensure that it is configured for the default boot sequence. If the configuration register value is correct, use the **show startup config** command. This command shows if there is a boot system command instructing the router to use the Cisco IOS Software for ROMmon.

If the router will not properly boot from the image or there is no Cisco IOS Software image, you need to download a new Cisco IOS Software image. You can recover the Cisco IOS Software file either through using Xmodem to restore the image through the console or by downloading the image using TFTP from the ROMmon mode.

Downloading Cisco IOS Software Using Xmodem from ROMmon

To restore the Cisco IOS Software image through the console, the local PC needs to have a copy of the Cisco IOS Software file to restore and a terminal emulation program such as HyperTerminal. You can restore the Cisco IOS Software image using the default console speed of 9600 bps. You can change the baud rate to 115200 bps to speed up the download. You can change the console speed from ROMmon mode using the **confreg** command. After you enter the **confreg** command, the router will prompt for the various parameters that can be changed, as shown in Example 14-11.

Example 14-11 Changing the Console Speed

```
rommon 1 >confreg
Configuration Summary
...<output omitted>...
  console baud: 9600
boot: the ROM Monitor
do you wish to change the configuration? y/n [n]: y
enable "diagnostic mode"? y/n [n]:
```

continues

Example 14-11 *Changing the Console Speed (Continued)*

```

...<output omitted>...
enable "ignore system config info"? y/n [n]:
change console baud rate? y/n [n]: y
enter rate: 0 = 9600, 1 = 4800, 2 = 1200, 3 = 2400
4 = 19200, 5 = 38400, 6 = 57600, 7 = 115200 [0]: 7
change the boot characteristics? y/n [n]:

Configuration Summary
enabled are:
break/abort has effect
console baud: 115200
boot: the ROM Monitor

do you wish to change the configuration? y/n [n]:

```

You must reset or power cycle for the new config to take effect.

When prompted: “change console baud rate? y/n [n]:” selecting y provides you with a prompt to select the new speed. After changing the console speed, restart the router into the ROMmon mode. The terminal session at 9600 bps is terminated, and a new session is started at 115200 bps to match the console speed.

You can use the **xmodem** command from the ROMmon mode to restore a Cisco IOS Software image from the PC. The format for the **xmodem** command is as follows:

```
xmodem -c image_file_name
```

For example, to restore a Cisco IOS Software image file with the name c2600-is-mz.122-10a.bin, type the command as shown in Example 14-12.

Example 14-12 *Restoring a Cisco IOS Software Image File with the xmodem Command*

```

rommon 1 >
rommon 1 >xmodem -?
xmodem: illegal option - - ?
usage: xmodem [-cyrx] <destination filename>
-c CRC-16
-y ymodem-batch protocol
-r copy image to dram for launch
-x do not launch on download completion

```


Example 14-12 Restoring a Cisco IOS Software Image File with the `xmodem` Command (Continued)

```
rommon 2 > xmodem -c c2600-is-mz.122-10a.bin

Do not start the sending program yet...

Warning: All existing data in bootflash will be lost!

Invoke this application only for disaster recovery.
Do you wish to continue? y/n [n]: y
Ready to receive file c2600-is-mz.122-10a.bin ...
```

The `-c` in the command format instructs the Xmodem process to use cyclic redundancy check (CRC) for error checking during the download.

You will receive a prompt from the router to not begin the transfer and a warning message will be shown. The warning message indicates that the bootflash will be erased, and the router asks to confirm whether or not to continue with the process. When you continue the process, the router then prompts to start the transfer.

You now need to start the Xmodem transfer from the terminal emulator. In HyperTerminal, select **Transfer > Send**. Then, in the Send File popup, specify the image name/location, select Xmodem as the protocol, and start the transfer. During the transfer, the Sending File popup displays the status of the transfer.

After the transfer is complete, a message appears indicating that flash is being erased. This message is followed by the “Download Complete!” message. Before restarting the router, you need to set the console speed back to 9600 bps and the configuration register back to `0x2102`. Use the `confreg 0x2102` command at the privileged EXEC prompt to set back the configuration register.

While the router is rebooting, you need to end the 115200 bps terminal session and begin a 9600 bps session.

Using Environmental Variables for Restoring Cisco IOS Software Images

You can also restore the Cisco IOS Software from a TFTP session. Downloading the image using TFTP from ROMmon is the fastest way to restore a Cisco IOS Software image to the router. You perform this process by setting the environmental variables and then using the `tftpdnld` command.

NOTE

All environmental variable names are case sensitive.

Because ROMmon has limited functions, no configuration file is loaded during boot. The router, therefore, has no IP or interface configuration. The environmental variables provide a minimal configuration to allow for the TFTP of the Cisco IOS Software image. The ROMmon TFTP transfer works only on the first LAN port, so a simple set of IP parameters are set for this interface. To set a ROMmon environment variable, you type the variable name, then the equal sign (=), and the value for the variable (*VARIABLE_NAME=value*). For example, to set the IP address to 10.0.0.1, type **IP_ADDRESS=10.0.0.1** at the ROMmon prompt.

The minimum variables required to use **tftpdnld** are as follows:

- **IP_ADDRESS**—The IP address on the LAN interface
- **IP_SUBNET_MASK**—The subnet mask for the LAN interface
- **DEFAULT_GATEWAY**—The default gateway for the LAN interface
- **TFTP_SERVER**—The IP address of the TFTP server
- **TFTP_FILE**—The Cisco IOS Software filename on the server

To check the ROMmon environment variables, you can use the **set** command, as shown in Example 14-13.

Example 14-13 *Checking ROMmon Environmental Variables*

```
rommon 10> set
IP_ADDRESS=10.0.0.1
IP_SUBNET_MASK=255.255.255.0
DEFAULT_GATEWAY=10.0.0.254
TFTP_SERVER=192.168.1.1
TFTP_FILE=GAD/original_2003_Jan_22/c2600-i-mz.121-5
```

Once you set the variables for the Cisco IOS Software download, you enter the **tftpdnld** command, as shown in Example 14-14, with no arguments. The ROMmon echoes the variables, and then a confirmation prompt appears with a warning that this process will erase the Flash memory.

Example 14-14 *tftpdnld*

```
rommon 12 > tftpdnld
IP_ADDRESS: 10.0.0.1
IP_SUBNET_MASK: 255.255.255.0
DEFAULT_GATEWAY: 10.0.0.254
TFTP_SERVER: 192.168.1.1
```

Example 14-14 *ftpdnld (Continued)*

```
TFTP_FILE: GAD/original_2003_Jan_22/c2600-i-mz.121-5
Invoke this command for disaster recovery only.
WARNING: all existing data in all partitions on flash will be lost!
Do you wish to continue? y/n: [n]: y
Receiving GAD/original_2003_Jan_22/c2600-i-mz.121-5 from
192.168.1.1!!!!.!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
File reception completed.
Copying file GAD/original_2003_Jan_22/c2600-i-mz.121-5 to flash.
Erasing flash at 0x607c0000
program flash location 0x60440000
rommon 13>
```

As each datagram of the Cisco IOS Software file is received, a “!” is displayed. When the complete Cisco IOS Software file has been received, the Flash is erased and the new IOS image file is written. Appropriate messages are displayed as the process is completed. When the new image is written into Flash and the ROMmon prompt is displayed, you can restart the router by typing **i**. The router now boots from the new Cisco IOS Software image in Flash memory.

**Lab Activity** Managing IOS Images with ROMmon and Xmodem

In this activity, you recover a Cisco 1700 series router from ROM monitor mode due to missing or corrupt IOS / boot flash image.

Verifying the File System

You can use several commands to verify the router file system. One of those commands is the **show version** command, which you can use to check the current image and the total amount of Flash memory. This command also verifies two other items concerning loading the Cisco IOS Software image. The **show version** command identifies the source of the Cisco IOS Software image that the router used to boot and displays the configuration register. You can examine the boot field setting of the configuration register to determine where the router is to load the Cisco IOS Software image. If the current image and the boot field setting of the configuration register do not agree, there might be a corrupt or missing Cisco IOS Software image in Flash or there might be **boot system** commands in the startup config.

Example 14-15 demonstrates use of the **show version** command.

Example 14-15 *Verifying the Router File System*

```
HMH# show version
Cisco Internetwork Operating System Software
IOS (tm) 1700 Software (C1700-BNSY-L), Version 12.2(11)P, RELEASE SOFTWARE (fc1)
... <output omitted>...
System image file is "flash:c1700-bnsy-l.122-11.p", booted via flash
cisco 171 (68360) processor (revision C) with 3584K/512K bytes of memory.
Processor board ID 12014633, with hardware revision 00000000
Bridging software.
X.25 software, Version 2.0, NET2, BFE and GOSIP compliant.
1 Ethernet/IEEE 802.3 interface(s)
2 serial(sync/async) network interface(s)
System/IO memory with parity disabled
2048K bytes of DRAM onboard 2048K bytes of DRAM on SIMM
System running from FLASH
8K bytes of non-volatile configuration memory.
6144K bytes of processor board PCMCIA flash (Read ONLY)
Configuration register is 0x2102
HMH#
```

You can also use the **show flash** command to verify the file system and to identify the Cisco IOS Software image or images in Flash and the amount of Flash memory that is available. The **show flash** command is often used to confirm that there is enough space to store a new Cisco IOS Software image. Example 14-16 demonstrates sample output from the **show flash** command.

Example 14-16 *show flash Command Output*

```
Router# show flash
4096 bytes of flash memory on embedded flash (in XX).
file offset length name
0 0x40 1204637 xk09140z
[903848/2097152 bytes free]
```

As mentioned, the configuration file might contain **boot system** commands. You can use these commands to identify the source of the desired Cisco IOS Software boot image. You can use multiple boot system commands to create a fallback sequence to discover and load a Cisco IOS Software image. These **boot system** commands are processed in the order of their appearance in the configuration file.

Summary

In this chapter, you learned the following key points:

- The default source for Cisco IOS Software depends on the hardware platform, but, most commonly, the router looks to the configuration commands saved in NVRAM.
- You can use the **show version** command to display information about the Cisco IOS Software version that is currently running on the router.
- You can enter multiple boot system commands to specify the fallback sequence for booting Cisco IOS Software. Routers can boot Cisco IOS Software from Flash memory, from a TFTP server, and from ROM.
- You use the **show flash** command to verify that you have sufficient memory on your system for the Cisco IOS Software that you want to load.
- With Cisco IOS Software Release 11.2 and later, the naming convention for Cisco IOS contains the following three parts:
 - The platform on which the image runs
 - The special capabilities of the image
 - Where the image runs and whether it has been zipped or compressed
- You can copy a system image back to a network server. This copy of the system image can serve as a backup copy and can be used to verify that the copy in Flash memory is the same as the original file.
- If you need to load the backup Cisco IOS Software version, you can use a variation of the copy command, **copy tftp flash**, to download the image that you previously uploaded to the TFTP server.

To supplement all that you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab Activities on the CD-ROM accompanying this book.

Key Terms

bootstrap The protocol used by a network node to determine the IP address of its Ethernet interfaces to affect network booting.

Flash memory A special type of EEPROM that can be erased and reprogrammed in blocks instead of one byte at a time. Many modern PCs have their BIOS stored on a Flash memory chip so that it can be updated easily if necessary. Such a BIOS is sometimes called a Flash BIOS. Flash memory is also popular in modems because it enables the modem manufacturer to support new protocols as they become standardized.

NVRAM (nonvolatile random-access memory) RAM that retains its contents when a unit is powered off.

RAM (random-access memory) Volatile memory that can be read and written by a microprocessor.

RCP (remote copy protocol) Protocol that allows users to copy files to and from a file system residing on a remote host or server on the network.

TFTP (Trivial File Transfer Protocol) Simplified version of FTP that allows files to be transferred from one computer to another over a network, usually without the use of client authentication (for example, username and password).

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. Which of the following correctly describes a method for specifying how a router loads the Cisco IOS software?
 - A. Designate fallback sources for the router to use in sequence from NVRAM.
 - B. Configure the Cisco IOS Software image for the location where it will bootstrap.
 - C. Manually boot a default system image at a virtual terminal.
 - D. Manually boot a default system image at the network server.

2. Which of the following is not a boot option that can be set with the configuration register boot field?
 - A. Cisco IOS Software boots in ROM monitor mode.
 - B. Cisco IOS Software automatically boots from ROM.
 - C. Cisco IOS Software automatically boots from a TFTP server.
 - D. NVRAM is examined for **boot system** commands.
3. Which of the following is information displayed by the **show version** command?
 - A. Detailed statistics about each page of the router's memory
 - B. The name of the system image
 - C. The names and sizes of all files in Flash memory
 - D. The status of configured network protocols
4. Which command is used to discover the configuration register setting?
 - A. show register
 - B. show running-config
 - C. show version
 - D. show startup-config
5. What information is not provided in the Cisco image filename system?
 - A. The capabilities of the image
 - B. The platform on which the image runs
 - C. Where the image runs
 - D. The size of the image
6. Which of the following is not part of the recommended procedure for loading a new Cisco IOS Software image to Flash memory from a TFTP server? (The procedures are listed in correct order.)
 - A. Back up a copy of the current software image to the TFTP server.
 - B. Enter the **copy flash tftp** command to start downloading the new image from the server.
 - C. The procedure asks if you are willing to erase Flash memory.
 - D. A series of Vs on the display indicates successful checksum verification.

7. What is the initial boot attempt if the router configuration register is set to 0x101?
 - A. Setup mode
 - B. TFTP server
 - C. ROM
 - D. Flash memory
8. Which of the following has a limited version of router Cisco IOS Software?
 - A. ROM
 - B. Flash memory
 - C. TFTP server
 - D. Bootstrap
9. What is the initial boot attempt if the router configuration register is set to 0x102?
 - A. Flash memory
 - B. TFTP server
 - C. ROM
 - D. Check for **boot system** commands
10. Which of the following is the sequence used by the router for automatic fallback to locate the Cisco IOS Software?
 - A. Flash memory, (2) NVRAM, (3) TFTP server
 - B. NVRAM, (2) TFTP server, (3) Flash memory
 - C. NVRAM, (2) Flash memory, (3) TFTP server
 - D. TFTP server, (2) Flash memory, (3) NVRAM
11. Which of the following is not displayed by the Cisco IOS **show version** command?
 - A. Statistics for configured interfaces
 - B. The type of platform running the Cisco IOS Software
 - C. The configuration register setting
 - D. The Cisco IOS Software version

12. Which of the following correctly describes preparing to use a TFTP server to copy software to Flash memory?
- A. The TFTP server must be a connected router or a host system, such as a UNIX workstation or a laptop computer.
 - B. The TFTP server must be a system connected to an Ethernet network.
 - C. The name of the router containing the Flash memory must be identified.
 - D. The Flash memory must be enabled.
13. Why do you create a Cisco IOS Software image backup?
- A. To verify that the copy in Flash memory is the same as the copy in ROM
 - B. To provide a fallback copy of the current image before copying the image to a new router
 - C. To create a fallback copy of the current image as part of the procedures during recovery from system failure
 - D. To create a fallback copy of the current image before updating with a new version
14. What is the command you need to issue if you want to upgrade an old version of the Cisco IOS Software by downloading a new image from the TFTP server?
- A. `boot system tftp 131.21.11.3`
 - B. `copy tftp flash`
 - C. `show flash`
 - D. `tftp ios.exe`



Objectives

Upon completion of this chapter, you will be able to

- Understand routing basics
- Describe routed and routing protocols
- Describe interior and exterior protocols
- Describe static versus dynamic routes
- Configure static routes
- Configure default routes
- Troubleshoot static route configurations
- Describe why dynamic routing protocols are necessary
- Describe distance vector routing
- Describe link-state routing
- Understand how to use different routing protocols in context

Chapter 15

Routing and Routing Protocols

In this chapter, you learn more about the router's use and operations in performing the key internetworking function of the Open System Interconnection (OSI) reference model's network layer, Layer 3. In addition, you review the difference between routing and routed protocols and how routers track distance between locations. Finally, you learn more about distance vector, link-state, and hybrid routing approaches and how each resolves common routing problems.

Please be sure to look at the e-Labs, Videos, and PhotoZooms associated with this chapter that you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

Routing Basics

Path determination for traffic going through a network cloud occurs at the network layer (Layer 3). The path-determination function enables a router to evaluate the available paths to a destination and to establish the preferred handling of a packet. Routing services use network topology information when evaluating network paths. This information can be configured by the network administrator or can be collected through dynamic processes running in the network.

The network layer provides best-effort end-to-end packet delivery across interconnected networks. The network layer uses the IP routing table to send packets from the source network to the destination network. After the router determines which path to use, it proceeds with forwarding the packet. The router forwards the packet that it accepted on one interface to another interface or port that reflects the best path to the packet's destination.

Routing is the process that a router uses to forward packets toward the destination network. A router makes decisions based upon the destination IP address of a packet. All devices along the way use the destination IP address to point the packet in the correct

direction. The destination IP address enables the packet to eventually arrive at its destination. To make the correct decisions, routers must learn the direction to remote networks. When routers use dynamic routing, the direction to remote networks is learned from other routers. When static routing is used, a network administrator configures information about remote networks manually.

Because static routes must be configured manually, any network topology changes require the network administrator to add and delete static routes to account for the changes. In a large network, this manual maintenance of routing tables could require a tremendous amount of administrative time. On small networks with very few possible changes, static routes require very little maintenance. Static routing does not have the scalability of dynamic routing because of the extra administrative requirements. However, even in large networks, static routes that are intended to accomplish a very specific purpose often are configured in combination with a dynamic routing protocol. Although dynamic routing protocols can determine automatically routes, they still must be activated initially and configured by a network administrator to accomplish this.

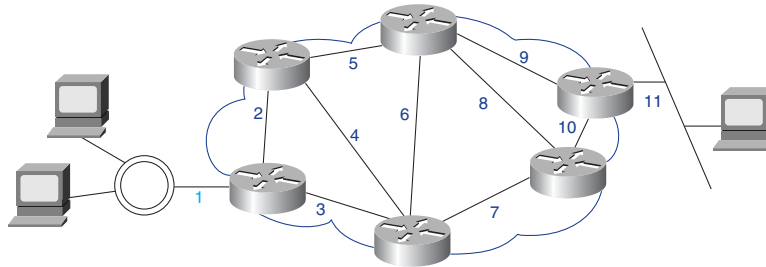
The sections that follow cover various routing concepts:

- The process of routing packets from source to destination
- Addressing
- Path selection and packet switching
- Routed and routing protocols

How Routers Route Packets from Source to Destination

To be truly practical, a network must consistently represent the paths available between routers. As Figure 15-1 shows, each line between the routers has a number that the routers use as a network address. These addresses must convey information that can be used by a routing process to pass packets from a source toward a destination. Using these addresses, the network layer can provide a relay connection that interconnects independent networks.

The consistency of Layer 3 addresses across the entire internetwork also improves the use of bandwidth by preventing unnecessary broadcasts. Broadcasts invoke unnecessary process overhead and waste capacity on any devices or links that do not need to receive the broadcasts. By using consistent end-to-end addressing to represent the path of media connections, the network layer can find a path to the destination without unnecessarily burdening the devices or links on the internetwork with broadcasts.

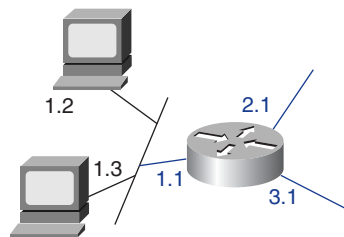
Figure 15-1 Network Addresses

Network and Host Addressing

The router uses the network address to identify the destination network of a packet within an internetwork. Figure 15-2 shows three network numbers identifying segments connected to the router.

Figure 15-2 Network Addresses with Host Portions

Network	Host
1	1 2 3
2	1
3	1



Most network protocol-addressing schemes use some form of host or node address. For some network layer protocols, a network administrator assigns network host addresses according to a predetermined internetwork addressing plan. For other network layer protocols, assignment of host addresses is partially or completely dynamic. In Figure 15-2, three hosts share the network number 1.

Path Selection and Packet Switching

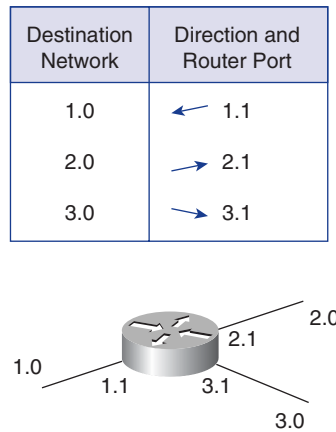
A router generally relays a packet from one data link to another using two basic functions:

- A path-determination function
- A switching function

Figure 15-3 illustrates how routers use addressing for these routing and switching functions. The router uses the network portion of the address to make path selections to pass the packet to the next router along the path.

The switching function allows a router to accept a packet on one interface and forward it through a second interface. The path-determination function enables the router to select the most appropriate interface for forwarding a packet. The node portion of the address is used by the final router (the router connected to the destination network) to deliver the packet to the correct host.

Figure 15-3 How Routers Use Addressing for Routing and Switching Functions



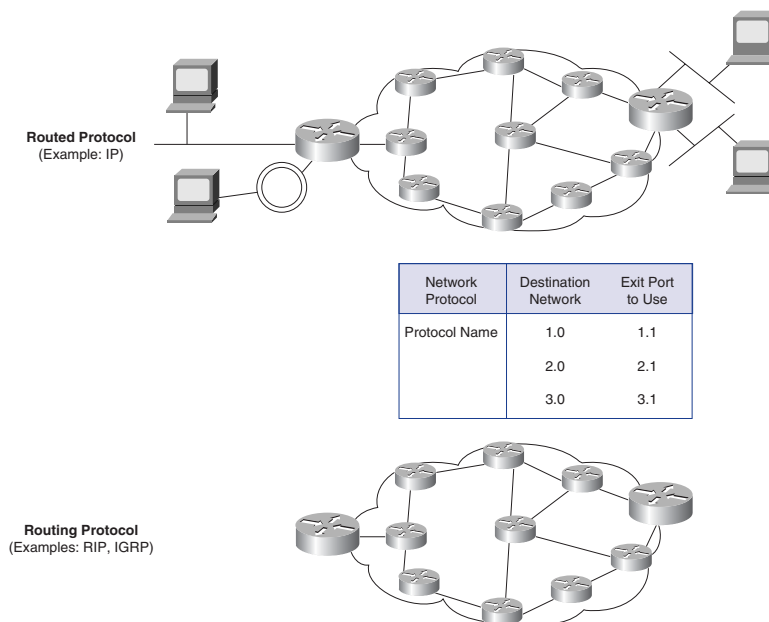
Routed Protocols Versus Routing Protocols

Because of the similarity of the two terms, confusion often exists regarding the routed protocol and the routing protocol (see Figure 15-4). The following provides some clarification:

- **Routed protocol**—Any network protocol that provides enough information in its network layer address to allow a packet to be forwarded from one host to another host based on the addressing scheme. Routed protocols define the field formats within a packet. Packets generally are conveyed from end system to end system. A routed protocol uses the routing table to forward packets. The Internet Protocol (IP) is an example of a routed protocol.

- **Routing protocol**—Protocol that supports a routed protocol by providing mechanisms for sharing routing information. Routing protocol messages move between the routers. A routing protocol allows the routers to communicate with other routers to update and maintain tables. TCP/IP examples of routing protocols are listed here:
 - Routing Information Protocol (RIP)
 - Interior Gateway Routing Protocol (IGRP)
 - Enhanced Interior Gateway Routing Protocol (EIGRP)
 - Open Shortest Path First (OSPF)

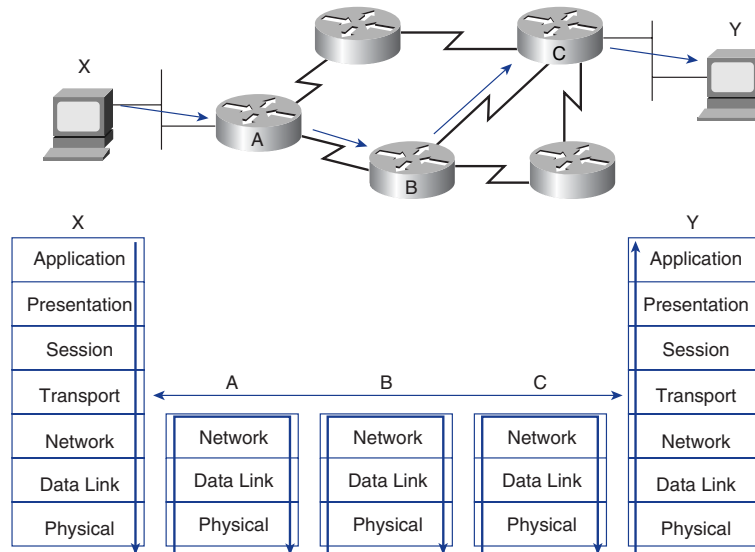
Figure 15-4 Router and Routing Protocols



Network Layer Protocol Operations

Suppose that a host application needs to send a packet to a destination on a different network. The host addresses the data link frame to the router, using the address of one of the router's interfaces. The router's network layer process examines the incoming packet's Layer 3 header to determine the destination network and then references the routing table, which associates networks to outgoing interfaces (see Figure 15-5). The packet is encapsulated again in the data link frame that is appropriate for the selected interface and is queued for delivery to the next hop in the path.

Figure 15-5 Router Services

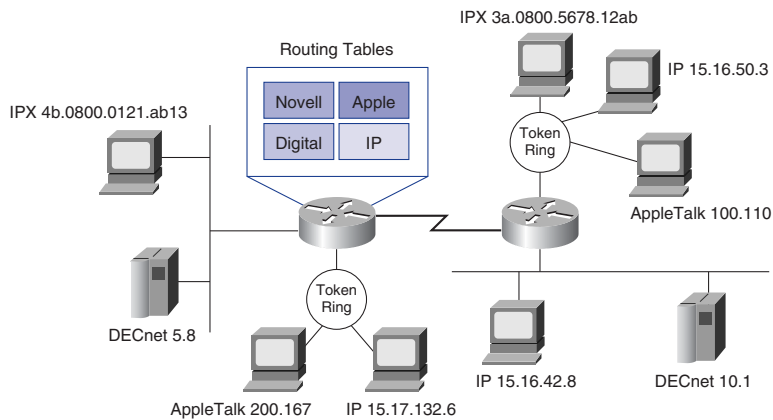


This process occurs each time that the packet is forwarded through another router. When the packet reaches the router that is connected to the destination host's network, it is encapsulated in the destination LAN's data link frame type and is delivered to the destination host.

Multiprotocol Routing

Routers are capable of supporting multiple independent routing protocols and maintaining routing tables for several routed protocols. This capability allows a router to deliver packets from several routed protocols over the same data links (see Figure 15-6).

Figure 15-6 Router Traffic



Static Routing

Routing is nothing more than directions for getting from one network to another. These directions, also known as routes, can be given to the router dynamically by another router. An administrator also can statically assign these directions to the router. This section concentrates on routes that are assigned by an administrator.

Static Versus Dynamic Routes

Static route knowledge is administered manually by a network administrator who enters it into a router's configuration. The administrator must update this static route entry manually whenever an internetwork topology change requires an update.

Dynamic route knowledge works differently. After a network administrator enters configuration commands to start dynamic routing, the route knowledge automatically is updated by a routing process whenever new information is received from the internetwork. Changes in dynamic knowledge are exchanged between routers as part of the update process.

The Purpose of a Static Route

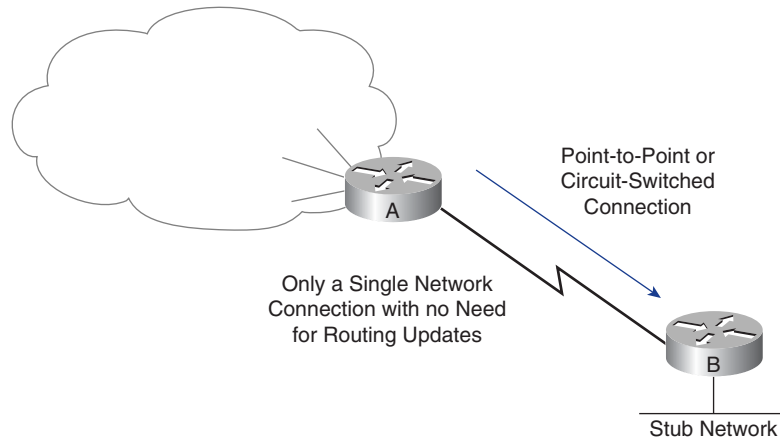
Static routing has several useful applications. Dynamic routing tends to reveal everything known about an internetwork; for security reasons, however, you might want to hide parts of an internetwork. *Static routing* enables you to specify the information that you want to reveal about restricted networks.

When a network is accessible by only one path, a static route to the network can be sufficient. This type of network is called a *stub network*. A stub network is an OSPF area that carries a default route, intra-area routes, and interarea routes, but that does not carry external routes. Configuring static routing to a stub network avoids the overhead of dynamic routing, as shown in Figure 15-7.

Static Route Operation

Static route operations can be summarized into a three-part sequence:

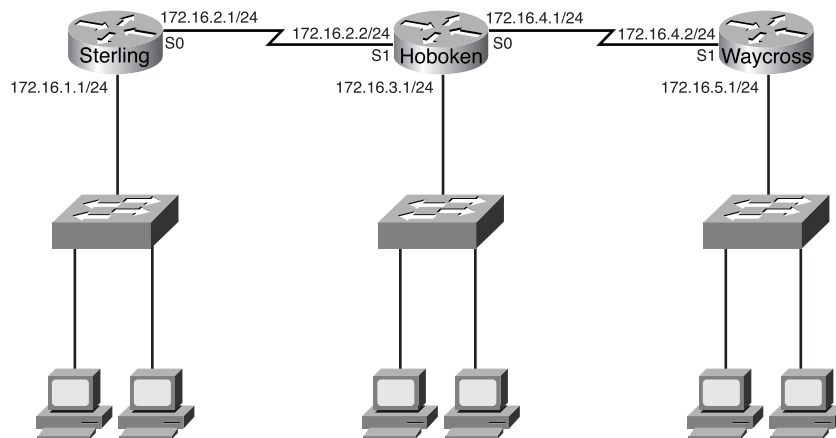
1. The network administrator configures the route.
2. The router installs the route in the routing table.
3. Packets are routed using the static route.

Figure 15-7 Static Route Operation

Because a static route is configured manually, the administrator must configure the static route on the router using the `ip route` command. The correct syntax for the `ip route` command is as follows:

```
Router(config)# ip route prefix mask {address | interface}[distance]
```

In Figure 15-8, the network administrator of the Hoboken router needs to configure a static route pointing to the 172.16.1.0/24 and 172.16.5.0/24 networks on the other routers.

Figure 15-8 Static Routes

The administrator could enter one of two commands to accomplish this objective. The method in Example 15-1 specifies the outgoing interface (Serial 0). The method in Example 15-2 specifies the next-hop IP address of the adjacent router (172.16.2.2). Either of the commands installs a static route in the routing table of Hoboken. The only difference between the two commands is in the *administrative distance* that the router assigns to the route as it is placed in the routing table.

Example 15-1 *IP Route Using Interface*

```
Sterling(config)# ip route 172.16.3.0 255.255.255.0 s0
```

Example 15-2 *IP Route Using Next-Hop Router IP*

```
Sterling(config)# ip route 172.16.3.0 255.255.255.0 172.16.2.2
```

The administrative distance is an optional parameter that provides a measure of the reliability of the route. A lower value for the administrative distance indicates a more reliable route. This means that a route with a lower administrative distance will be installed before an identical route with a higher administrative distance. The default administrative distance when using next-hop address is 1. The default administrative distance when using the outgoing interface is 0. Table 15-1 show Cisco's administrative distance values for each supported protocol. Routes with lower administrative distances are trusted over identical routes with higher administrative distances. If an administrative distance other than the default is desired, a value between 0 and 255 is entered after the next-hop or outgoing interface, as follows:

```
ip route 172.16.3.0 255.255.255.0 192.168.2.1 255
```

Table 15-1 Cisco Administrative Distances

Route Source	Default Distance Values
Connected interface	0
Static route	1
Enhanced Interior Gateway Routing Protocol (EIGRP) summary route	5
External Border Gateway Protocol (BGP)	20
Internal EIGRP	90
IGRP	100

continues

Table 15-1 Cisco Administrative Distances (Continued)

Route Source	Default Distance Values
OSPF	110
Intermediate System-to-Intermediate System (IS-IS)	115
Routing Information Protocol (RIP)	120
Exterior Gateway Protocol (EGP)	140
External EIGRP	170
Internal BGP	200
Unknown	255

If the router cannot reach the outgoing interface that is being used in the route, the route will not be installed in the routing table. This means that if the interface is down, the route will not be placed in the routing table.

Sometimes static routes are used for backup purposes. A static route can be configured on a router that will be used only when the dynamically learned route has failed. To use a static route in this manner, set the administrative distance higher than that of the dynamic routing protocol being used.

Configuring Static Routes

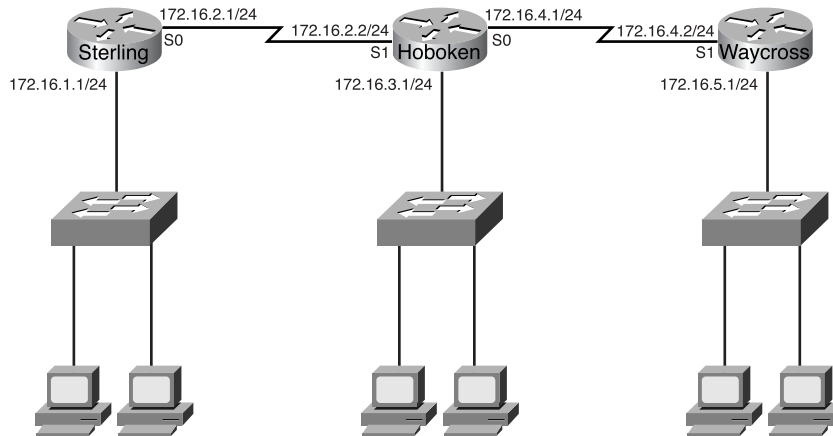
This section lists the steps for configuring static routes and gives an example of a simple network for which static routes might be configured.

Use the following steps to configure static routes:

- Step 1** Determine all desired destination networks, their subnet masks, and their gateways. A gateway can be either a local interface or a next-hop address that leads to the desired destination.
- Step 2** Enter global configuration mode.
- Step 3** Type the **ip route** command with a destination network address and subnet mask followed by their corresponding gateway from Step 1. Including an administrative distance is optional.
- Step 4** Repeat Step 3 for as many destination networks as were defined in Step 1.
- Step 5** Exit global configuration mode.
- Step 6** Save the active configuration to NVRAM by using the **copy running-config startup-config** or **write memory** commands.

The example network in Figure 15-9 is a simple three-router configuration. Hoboken must be configured so that it can reach the 172.16.1.0 network and the 172.16.5.0 network. Both of these networks have a subnet mask of 255.255.255.0.

Figure 15-9 Static Route Operation

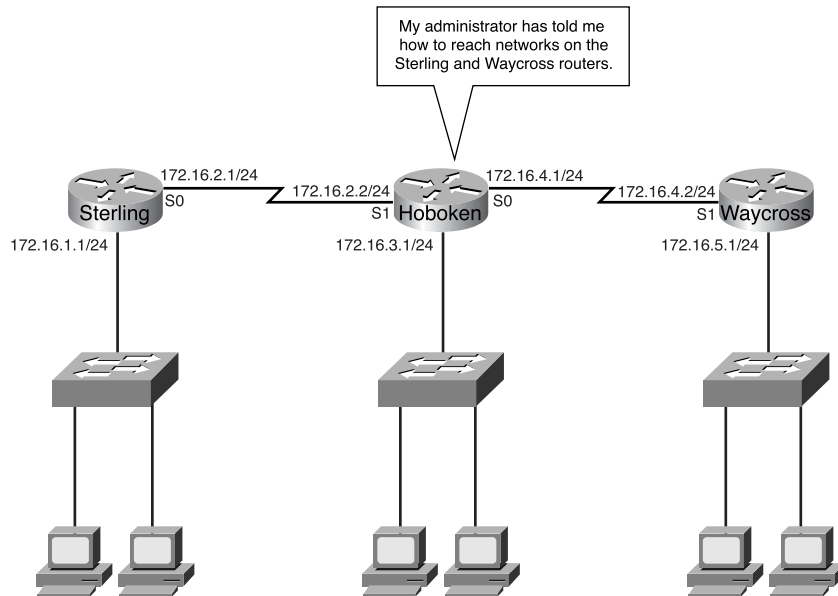


Packets that have a destination network of 172.16.1.0 need to be routed to Sterling. Packets that have a destination address of 172.16.5.0 need to be routed to Waycross. Static routes can be configured to accomplish this using the outgoing router interfaces (S0 and S1), as shown in Example 15-3.

Example 15-3 *IP Route with Outgoing Interfaces*

```
Hoboken(config)#ip route 172.16.1.0 255.255.255.0 s1
Hoboken(config)#ip route 172.16.5.0 255.255.255.0 s0
```

Both static routes first are configured to use a local interface as the gateway to the destination networks, as in Figure 15-10. Because the administrative distance was not specified, it defaults to 0 when the route is installed in the routing table. Remember that an administrative distance of 0 is the same as a directly connected network.

Figure 15-10 Static Routes Configured by Administrator

The same two static routes also can be configured using a next-hop address as their gateway. The first route to the 172.16.1.0 network has a gateway of 172.16.2.1. The second route to the 172.16.5.0 network has a gateway of 172.16.4.2. Example 15-4 shows configuring static routes using the next-hop interface address and includes comments (preceded by !) that will show up in the configuration file. Because the administrative distance was not specified, it defaults to 1.

Example 15-4 *IP Route with Next Hop and Comment*

```
Hoboken(config)# ip route 172.16.1.0 255.255.255.0 172.16.2.1
!This command points to Sterling's LAN

Hoboken(config)# ip route 172.16.5.0 255.255.255.0 172.16.4.2
!This command points to Waycross LAN
```

**Lab Activity** Using Static Routes

In this lab, you configure static routes between routers to allow data transfers between them without the use of dynamic routing protocols.

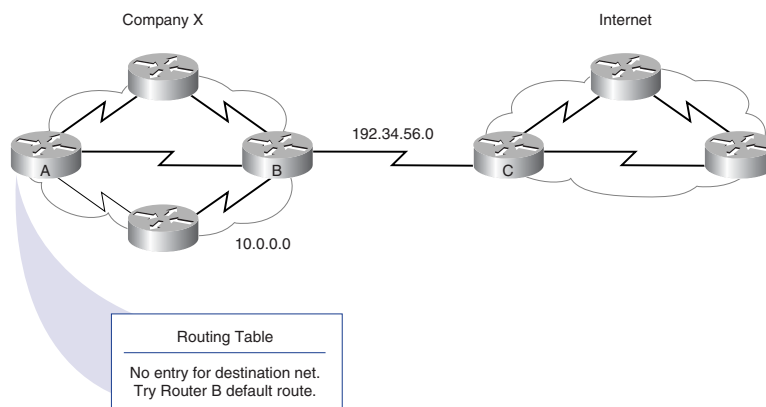
How a Default Route Is Used

Figure 15-11 shows a use for a default route, a routing table entry that directs packets to the next hop when that hop is not explicitly listed in the routing table. You can set default routes as part of the static configuration.

In this example, the Company X routers possess specific knowledge of the topology of the Company X network, but not of other networks. Maintaining knowledge of every other network accessible by way of the Internet cloud is unnecessary and unreasonable, if not impossible.

Instead of maintaining specific network knowledge, each router in Company X is informed of the default route that it can use to reach any unknown destination by directing the packet to the Internet.

Figure 15-11 Static Default Route Using Next Hop



Configuring Default Route Forwarding

Default routes route packets with destinations that do not match any of the other routes in the routing table. Routers typically are configured with a default route for Internet-bound traffic because it is often impractical and unnecessary to maintain routes to all networks in the Internet. A default route is actually a special static route that uses the following format:

```
ip route 0.0.0.0 0.0.0.0 [next-hop-address | outgoing interface]
```

Use the following steps to configure default routes:

Step 1 Enter global configuration mode.

NOTE

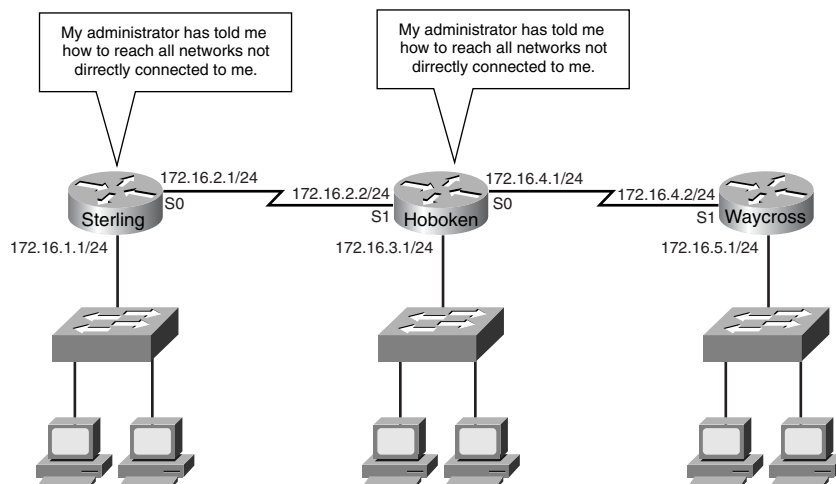
The 0.0.0.0 mask, when logically ANDed to the destination IP address of the packet to be routed, always yields the network 0.0.0.0. If the packet does not match a more specific route in the routing table, it is routed to the 0.0.0.0 network.

- Step 2** Type the `ip route` command with 0.0.0.0 for the destination network address and 0.0.0.0 for the subnet mask. The gateway for the default route can be either the local router interface that connects to the outside networks or the IP address of the next-hop router. In most cases, it is preferred that the IP address of the next hop router is specified.
- Step 3** Exit global configuration mode.
- Step 4** Save the active configuration to NVRAM by using the `copy running-config startup-config` command.

Earlier in this chapter, in Figure 15-8, static route configuration was demonstrated on router Hoboken to make networks 172.16.1.0 on Sterling and 172.16.5.0 on Waycross accessible. It should now be possible to route packets to both of these networks from Hoboken. However, as configured, neither Sterling nor Waycross will know how to return packets to any network that is not directly connected. A static route could be configured on Sterling and Waycross for each of the destination networks that are not directly connected, but on a larger network this would not be a scalable solution.

Sterling connects to all non-directly connected networks via interface s0. Waycross has only one connection to all non-directly connected networks. This is through interface Serial 1. A default route on both Sterling and Waycross provides routing for all packets that are destined for networks that are not directly connected, as demonstrated in Figure 15-12. Examples 15-5 and 15-6 show the commands necessary to define a default static route on Waycross and Sterling, respectively.

Figure 15-12 Static Route for Waycross



Example 15-5 *Default Route for Waycross*

```
Waycross(config)# ip route 0.0.0.0 0.0.0.0 s1
```

Example 15-6 *Default Route for Sterling*

```
Sterling(config)# ip route 0.0.0.0 0.0.0.0 s0
```

Verifying Static Route Configuration

It is important to verify that the static routes are present in the routing table and that routing is working as expected after the static routes are configured. The command **show running-config** is used to view the active configuration in NVRAM to verify that the static route was entered correctly. The **show ip route** command is used to make sure that the static route is present in the routing table.

Use the following steps to verify static route configuration:

- Step 1** In privileged mode, enter the command **show running-config** to view the active configuration.
- Step 2** Verify that the static route has been entered correctly. If the route is not correct, it will be necessary to go back into global configuration mode to remove the incorrect static route and enter the correct one.
- Step 3** Enter the command **show ip route**.
- Step 4** Verify that the route that was configured is in the routing table.

Troubleshooting Static Route Configuration

Having knowledge of troubleshooting tools and procedures is just as important in static routing as in any other aspect of networking. You can use the **show interfaces** command to check the state and configuration of the interface that is to be used for the route gateway. Using the **ping** command helps you to determine whether end-to-end connectivity exists. If an echo reply is not received after a **ping**, you can use the **traceroute** command to determine which router in the route path is dropping the packets. The routing process must happen on each router the packet travels through, or the packet will be dropped. In many cases, packets actually reach their destination, but the remote network router has no knowledge of a route to reply to the sender.

Use the following steps to troubleshoot a static route configuration:

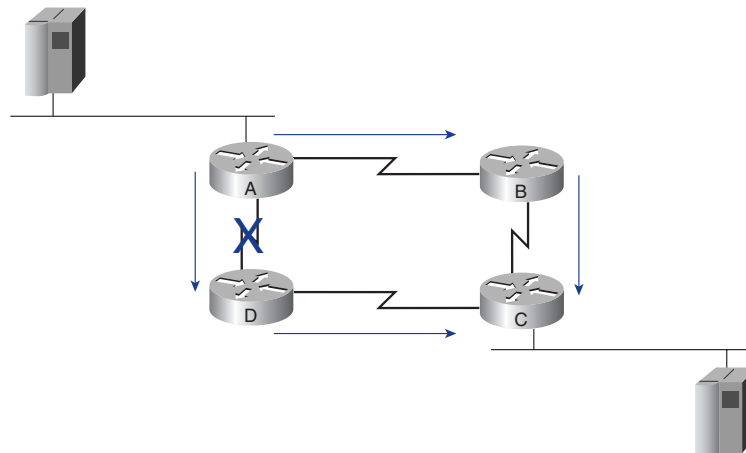
- Step 1** Make sure that the link that is to be used as the gateway by the route is available.
- Step 2** Enter the command **show interfaces**, and verify that the interface is up and that the line protocol is up.

- Step 3** Verify that the IP address being used on the interface is correct.
- Step 4** **ping** the IP address on the remote router interface that is connected directly to the route gateway. If the **ping** is not successful, the problem is not related to routing. The interfaces of one or both of the directly connected routers might be configured incorrectly, or a physical problem might exist with the link. Return to Step 1 to troubleshoot.
- Step 5** If the **ping** of the far-end router fails, use the **tracert** command to determine which router in the route path is dropping the packet.
- Step 6** Log into the router with the failed **tracert**. Return to Step 1 and start again.
- Step 7** If the **ping** is successful, attempt to **ping** the far-end router. If this **ping** is successful, complete end-to-end connectivity has been achieved. The test of the static route is complete.

Dynamic Routing Overview

Dynamic routing is necessary to allow networks to update and adapt quickly to changes. The network shown in Figure 15-13 adapts differently to topology changes depending on whether it uses statically or dynamically configured routing information.

Figure 15-13 Dynamic Route



Static routing allows routers to properly route a packet from network to network based on manually configured information. In the example, Router A always sends traffic destined for Router C to Router D. The router refers to its routing table and follows

the static knowledge residing there to relay the packet to Router D. Router D does the same and relays the packet to Router C. Router C delivers the packet to the destination host.

If the path between Router A and Router D fails, Router A is not capable of relaying the packet to Router D using that static route. Until Router A manually is reconfigured to relay packets by way of Router B, communication with the destination network is impossible. Dynamic routing offers more flexibility. According to the routing table generated by Router A, a packet can reach its destination over the preferred route through Router D.

However, a second path to the destination is available by way of Router B. When Router A recognizes that the link to Router D is down, it adjusts its routing table, making the path through Router B the preferred path to the destination. The routers continue sending packets over this link.

When the path between Routers A and D is restored to service, Router A again can change its routing table to indicate a preference for the counterclockwise path through Routers D and C to the destination network. Dynamic routing protocols also can direct traffic from the same session over different paths in a network for better performance. This is known as *load sharing*.

Routing Protocol Examples

This section provides a brief overview of some of the most common routing protocols and their key characteristics.

RIP originally was specified in RFC 1058. Its key characteristics include the following:

- It is a distance vector routing protocol.
- It uses hop count as the metric for path selection. If the hop count is greater than 15, the packet is discarded.
- By default, routing updates are broadcast every 30 seconds.

IGRP is a distance vector routing protocol developed by Cisco. IGRP sends routing updates at 90-second intervals, advertising networks for a particular autonomous system. IGRP offers the following design characteristics and features:

- Versatility for automatically handling indefinite or complex topologies
- Flexibility for handling segments with different bandwidth and delay characteristics
- Scalability for functioning in large networks

By default, IGRP uses two metrics, bandwidth and delay. IGRP can be configured to use a combination of variables to determine a composite metric. Possible configurations include the following variables:

- Bandwidth
- Delay
- Load
- Reliability

OSPF is a link-state routing protocol used for IP. Link-state protocols keep a detailed topology, which allows the protocol to use calculations that prevent loops. With OSPF, the subnet mask also is transmitted, enabling features such as variable-length subnet masking (VLSM) and route summarization.

EIGRP is a balanced hybrid routing protocol developed by Cisco. EIGRP has characteristics in common with both distance vector protocols and link-state protocols. EIGRP calculates the best route to each network or subnet and provides alternative routes that can be used if the current route fails. EIGRP also transmits the subnet mask for each routing entry. Therefore, features such as VLSM and route summarization easily are supported.

BGP is an exterior routing protocol. BGP is designed to operate between autonomous systems. BGPs can be used between two ISPs or between a company and an ISP.

Purpose of a Routing Protocol and Autonomous Systems

The goal of a routing protocol is to build and maintain the routing table. This table contains the learned networks and associated ports for those networks. Routers use routing protocols to manage information received from other routers and information generated from the configuration of its own interfaces.

The routing protocol identifies all available routes, places the best routes into the routing table, and removes routes when they are no longer valid. The router uses the information in the routing table to forward routed protocol packets.

The routing algorithm is fundamental to dynamic routing. Whenever the topology of a network changes because of growth, reconfiguration, or failure, the network knowledge base also must change. The network knowledge needs to reflect an accurate and consistent view of the new topology.

When all routers in an internetwork are operating with the same knowledge, the internetwork is said to have converged. Fast convergence is desirable because it reduces the time period of incorrect routing decisions.

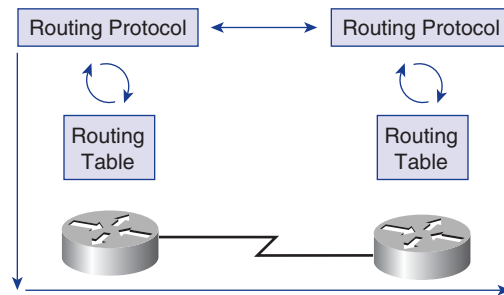
Autonomous systems divide the global internetwork into smaller and more manageable networks. Each AS has its own set of rules and policies and an AS number that distinguishes it from all other autonomous systems in the world.

Dynamic Routing Operations

The success of dynamic routing depends on two basic router functions:

- Maintenance of a routing table
- Timely distribution of knowledge, in the form of routing updates, to other routers (see Figure 15-14)

Figure 15-14 Routing Protocols Maintain Routing Information

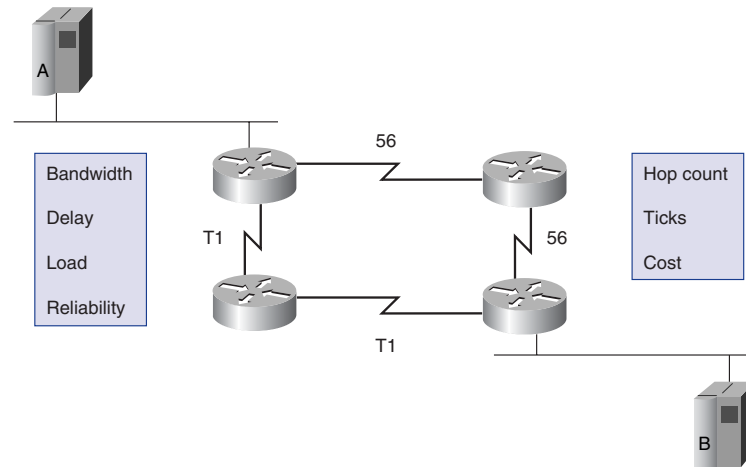


Dynamic routing relies on a routing protocol to share knowledge among routers. A routing protocol defines the set of rules used by a router when it communicates with neighboring routers. For example, a routing protocol describes the following:

- How to send updates
- What knowledge is contained in these updates
- When to send this knowledge
- How to locate recipients of the updates

How Distances on Network Paths Are Determined by Various Metrics

When a routing algorithm updates a routing table, its primary objective is to determine the best information to include in the table. Each routing algorithm interprets what is best in its own way. The algorithm generates a number called the *metric* value for each path through the network. Typically, the smaller the metric number is, the better the path is, as shown in Figure 15-15.

Figure 15-15 Metrics Used to Define Best Path

You can calculate simple metrics based on a single characteristic such as path, or you can calculate more complex metrics by combining several characteristics. The metric characteristics that most commonly are used by routers are as follows:

- **Bandwidth**—The data capacity of a link. (Normally, a 10-Mbps Ethernet link is preferable to a 64-kbps leased line.)
- **Delay**—The length of time required to move a packet along each link from source to destination.
- **Load**—The amount of activity on a network resource such as a router or a link.
- **Reliability**—Usually a reference to the error rate of each network link.
- **Hop count**—The number of routers that a packet must travel through before reaching its destination.
- **Ticks**—The delay on a data link using IBM PC clock ticks (approximately 55 milliseconds, or 1/18 second).
- **Cost**—An arbitrary value, usually based on bandwidth, monetary expense, or other measurement, that is assigned by a network administrator.

Identifying the Classes of Routing Protocols

Most routing algorithms can be classified under one of the following three categories:

- Distance vector
- Link-state
- Balanced hybrid

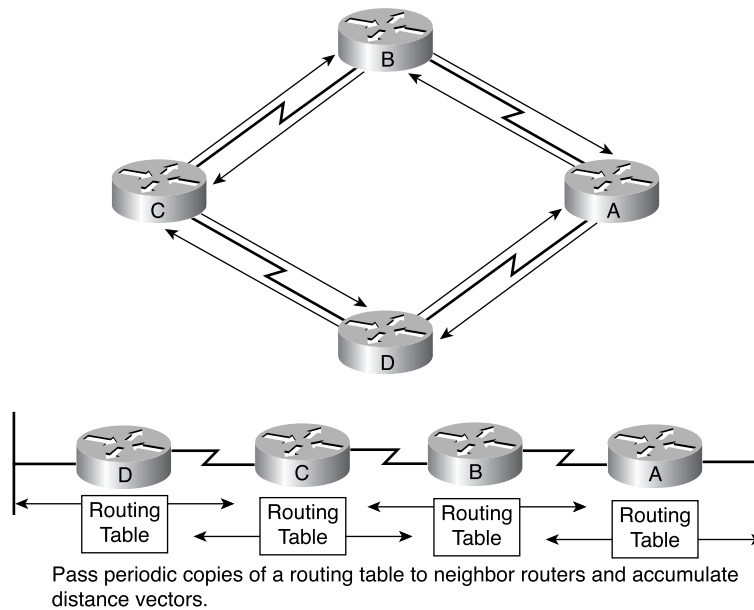
The *distance vector routing protocol* approach determines the direction, or the vector, and the distance to any link in the internetwork. The *link-state routing protocol* approach, also called shortest path first (SPF), recreates the exact topology of the entire internetwork. The *balanced hybrid routing protocol* approach combines aspects of the link-state and distance vector algorithms.

Distance Vector Routing Protocol Features

Distance vector routing algorithms pass periodic copies of a routing table from router to router. These regular updates between routers communicate topology changes. Distance vector–based routing algorithms also are known as Bellman-Ford algorithms.

In Figure 15-16, each router receives a routing table from its neighboring routers. Router B receives information from Router A. Router B adds a distance vector number, such as a number of hops, which increases the distance vector. Then Router B passes this new routing table to its other neighbor, Router C. This step-by-step process occurs in all directions between all neighbor routers.

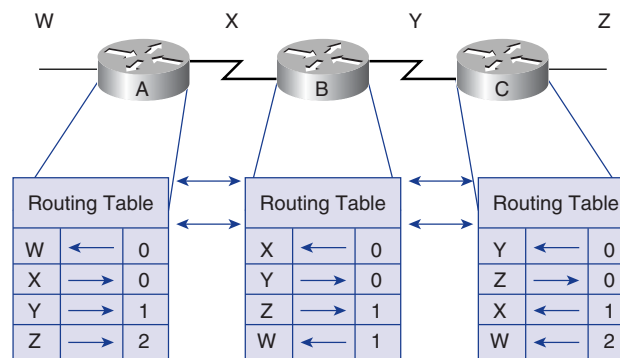
Figure 15-16 Distance Vector Concepts



The algorithm accumulates network distances so that it can maintain a database of network topology information. However, distance vector algorithms do not provide routers with the exact topology of an internetwork because each router is aware of only its neighbor routers.

Each router that uses distance vector routing begins by identifying its neighbors. Figure 15-17 shows distance vector discovery. The interface that leads to each directly connected network is shown as having a distance of 0. As the distance vector network discovery process proceeds, routers discover the best path to destination networks based on the information they receive from each neighbor. For example, Router A learns about other networks based on the information that it receives from Router B. Each of the other network entries in the routing table has an accumulated distance vector to show how far away that network is in a given direction.

Figure 15-17 Distance Vector Network Discovery



Routing table updates occur when the topology changes. As with the network discovery process, topology change updates proceed step by step from router to router, as shown in Figure 15-18. Distance vector algorithms call for each router to send its entire routing table to each of its adjacent neighbors. The routing tables include information about the total path cost as defined by its metric and the logical address of the first router on the path to each network contained in the table. The metric is made up of several components, as shown in Figure 15-19.

Figure 15-18 Distance Vector Topology Changes

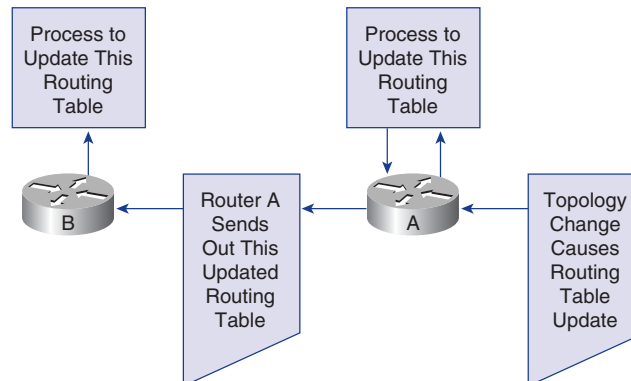
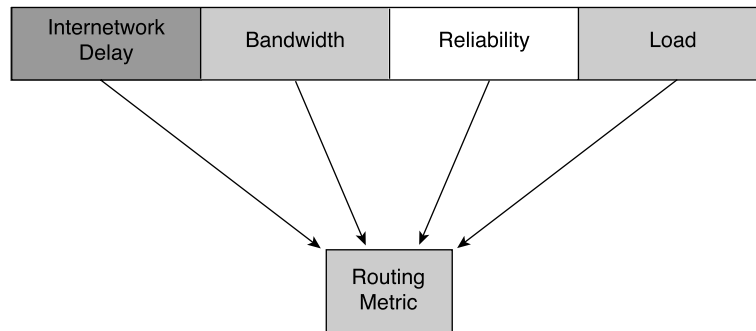


Figure 15-19 Distance Vector Routing Metric Components

Routing Updates Explained

Each router receives a routing table from its directly connected neighboring routers. For example, in Figure 15-18, Router B receives information from Router A. Router B adds a distance vector number (such as a number of hops), which increases the distance vector and passes this new routing table to its another neighbor router. This same step-by-step process occurs in all directions between direct-neighbor routers.

A distance vector is comparable to the signs along a highway. Highway signs direct drivers toward a destination and indicate the distance to that destination. Farther down the highway, additional signs point toward the same destination, but now the distance is shorter. As long as the distance continues to become shorter, the traffic is on the right path.

Link-State Routing Basics

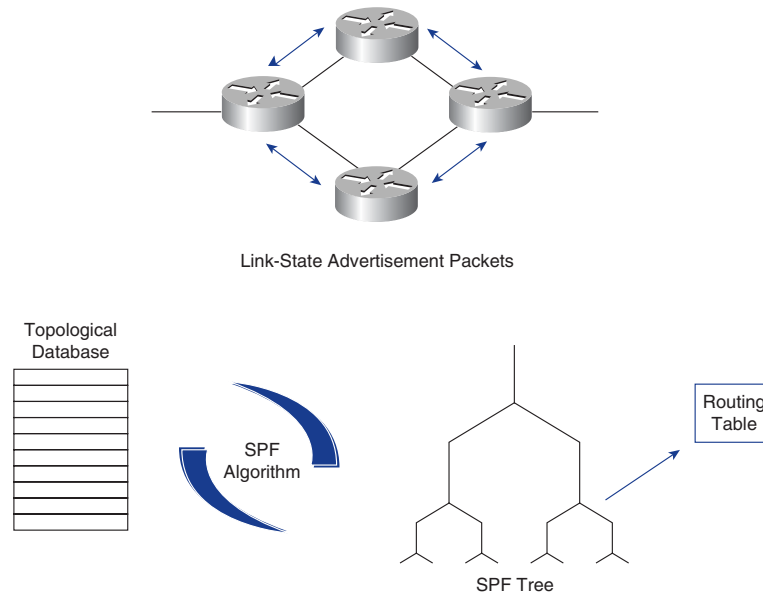
The second basic algorithm used for routing is the link-state algorithm. Link-state algorithms are also known as Dijkstras algorithm or as shortest path first (SPF) algorithms. They maintain a complex database of topology information. Whereas the distance vector algorithm has nonspecific information about distant networks and no knowledge of distant routers, a link-state routing algorithm maintains full knowledge of distant routers and how they interconnect. Link-state routing uses the following:

- **Link-state advertisements (LSAs)**—Small packets of routing information that are sent between routers
- **Topological database**—A collection of information gathered from LSAs
- **Shortest path first (SPF) algorithm**—A calculation performed on the database resulting in the SPF tree
- **Routing table**—A list of the known paths and interfaces

Engineers have implemented this link-state concept in Open Shortest Path First (OSPF) routing. RFC 1583 contains a description of OSPF link-state concepts and operations.

Figure 15-20 illustrates these link-state concepts.

Figure 15-20 Link-State Concepts



Network Discovery Processes for Link-State Routing

LSAs are exchanged between routers, starting with directly connected networks. Each router, in parallel with others, constructs a topological database consisting of all the exchanged LSAs.

The SPF algorithm computes network accessibility. The router constructs this logical topology as a tree, with itself as the root, consisting of all possible paths to each network in the link-state protocol internetwork. It then sorts these paths using SPF. The router lists the best paths and the interfaces to these destination networks in the routing table. The router also maintains other databases of topology elements and status details.

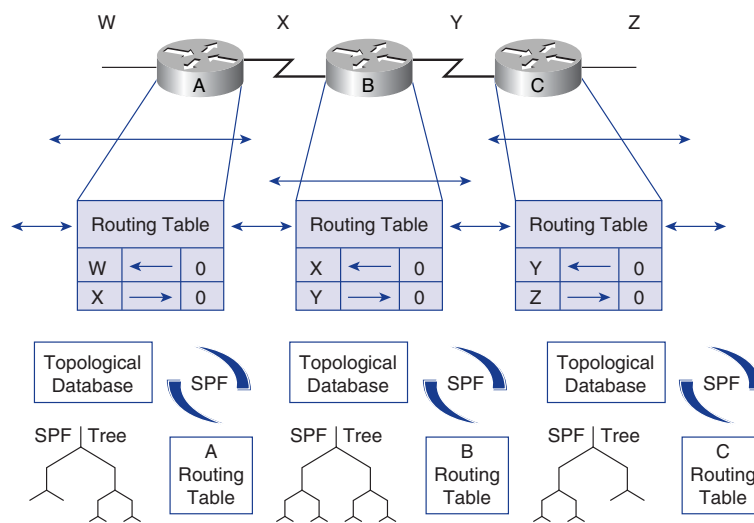
How Link-State Protocols Exchange Routing Information

Link-state network-discovery mechanisms are used to create a common picture of the entire network. All link-state routers share this view of the network. This is similar to having several identical maps of a town. In Figure 15-21, four networks (W, X, Y, and

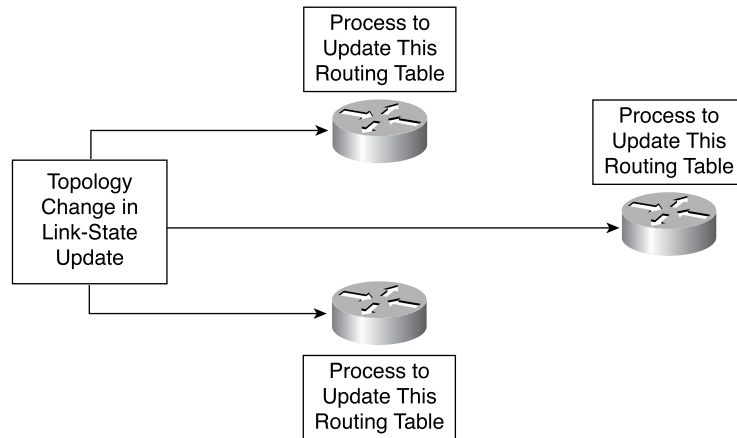
Z) are connected by three link-state routers. Network discovery for link-state routing uses the following processes:

1. Routers exchange LSAs with each other. Each router begins with directly connected networks for which it has direct, firsthand information.
2. Each router, in parallel with the others, constructs a topological database consisting of all the LSAs from the internetwork.
3. The SPF algorithm computes network reachability. The router constructs this logical topology as a tree, with itself as root, consisting of all possible paths to each network in the link-state protocol internetwork. It then sorts these paths by shortest path first (SPF).
4. The router lists its best paths and the ports to these destination networks in the routing table. It also maintains other databases of topology elements and status details.

Figure 15-21 Link-State Algorithm Shortest Path Calculations



When a router becomes aware of a link-state topology change, it forwards the information so that all other routers can use it for updates. This involves sending common routing information to all routers in the internetwork. To achieve convergence, each router keeps track of its neighbor routers, the router name, interface status, and the cost of the link to the neighbor. The router constructs an LSA packet that lists this information along with new neighbors, changes in link costs, and links that are no longer valid. The LSA packet then is sent out so that all other routers receive it. Figure 15-22 shows an example of link-state topology changes.

Figure 15-22 Link-State Topology Changes

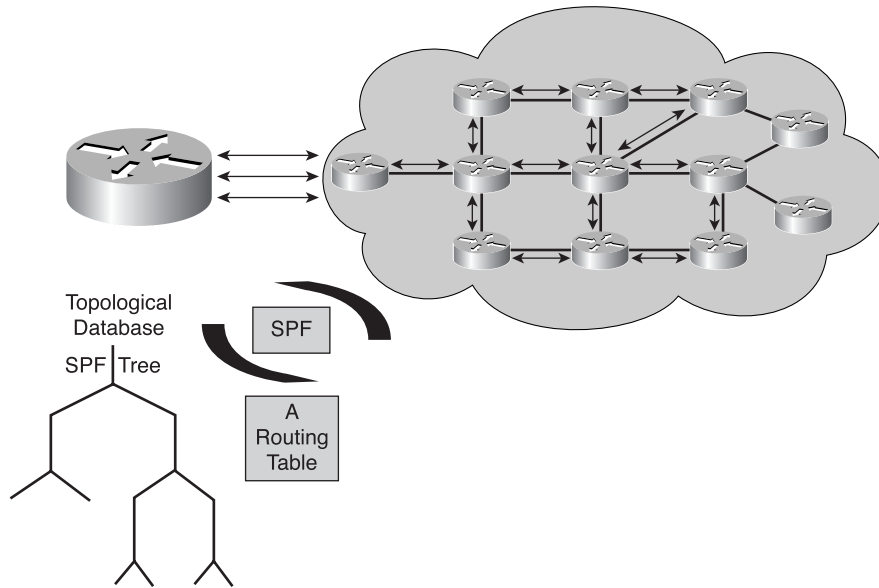
When the router receives an LSA packet, the database is updated with the most recent information. The accumulated data is used to compute a map of the internetwork, and the SPF algorithm calculates the shortest path to other networks. Each time an LSA packet changes the link-state database, SPF recalculates the best paths and updates the routing table. Every router takes the topology change into account to determine the shortest path to use for packet routing.

Three Link-State Concerns

Running link-state protocols brings up three primary concerns:

- Processor overhead
- Memory requirements
- Bandwidth consumption

Routers running link-state protocols require more memory and perform more processing than distance vector routing protocols. Routers must have enough memory to hold all the information from the various databases, the topology tree, and the routing table, as shown in Figure 15-23. Initial link-state packet flooding consumes bandwidth. During the initial discovery process, all routers using link-state routing protocols send LSA packets to all other routers. This action floods the internetwork and temporarily reduces the bandwidth available for routed traffic carrying user data. After this initial flooding, link-state routing protocols generally require only minimal bandwidth to send infrequent or event-triggered LSA packets reflecting topology changes.

Figure 15-23 Link State Concerns

Hybrid Routing Protocol Features

A third type of routing protocol, balanced hybrid routing, combines aspects of both distance vector and link-state routing protocols. Balanced hybrid routing protocols use distance vectors with more accurate metrics to determine the best paths to destination networks. However, they differ from most distance vector protocols by using topology changes to trigger routing database updates instead of periodic updates.

Like link-state protocols, the balanced hybrid routing protocol converges rapidly. However, it differs from distance vector and link-state protocols by using less bandwidth, memory, and processor overhead. Examples of hybrid protocols are Intermediate System-to-Intermediate System (IS-IS) and Enhanced Interior Gateway Routing Protocol (EIGRP).

Configuring a Router to Use Routing Protocols

To enable an IP routing protocol on a router, both global and interface parameters must be set. Global tasks include selecting a routing protocol, such as RIP, IGRP, EIGRP, or OSPF. The major task in the routing configuration mode is to indicate IP

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network numbers. Dynamic routing uses broadcasts and multicasts to communicate with other routers. The routing metric helps routers find the best path to each network or subnet.

The **router** command starts a routing process. The syntax for the router command is as follows:

```
Router(config)#router protocol {options}
```

where

- *protocol* is either RIP, IGRP, or EIGRP.
- *options* refers to autonomous system number such as those used by IGRP and EIGRP.

The **network** command is necessary because it enables the routing process to identify the interfaces that participate in the sending and receiving of routing updates. The syntax for the **network** command is as follows:

```
Router(config-router)#network network number
```

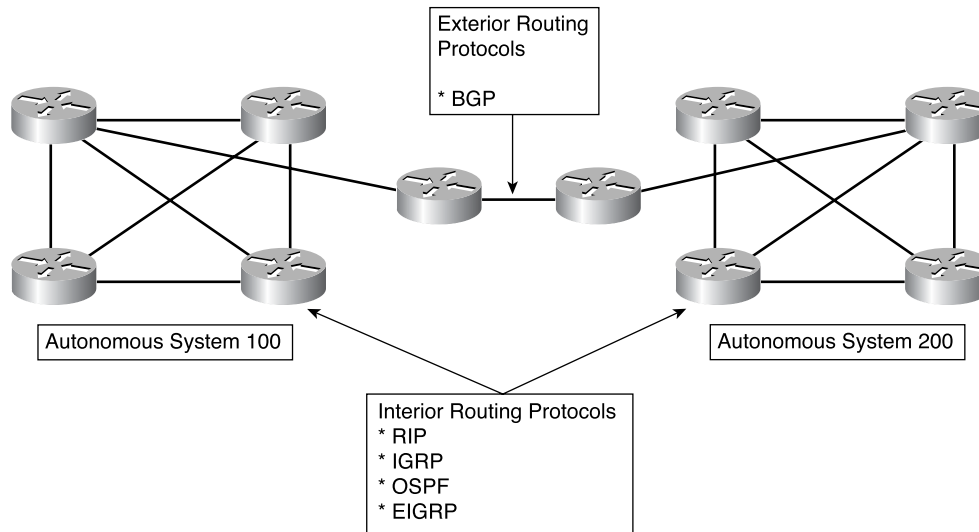
where *network number* is the IP network number of a directly connected network.

For RIP and IGRP, the network numbers must be based on the network class addresses, not subnet addresses or individual host addresses. Major network addresses are limited to Class A, B, and C network numbers.

At the Internet layer of the TCP/IP suite of protocols, a router can use an IP routing protocol to accomplish routing through the implementation of a specific routing algorithm. Examples of IP routing protocols include the following, as shown in Figure 15-24:

- **Routing Information Protocol (RIP)**—A distance vector interior routing protocol
- **Interior Gateway Routing Protocol (IGRP)**—A distance vector interior routing protocol developed by Cisco
- **Open Shortest Path First (OSPF)**—A link-state interior routing protocol
- **Enhanced Interior Gateway Routing Protocol (EIGRP)**—A balanced hybrid interior routing protocol developed by Cisco
- **Border Gateway Protocol (BGP)**—An exterior routing protocol

Figure 15-24 Routing Protocols



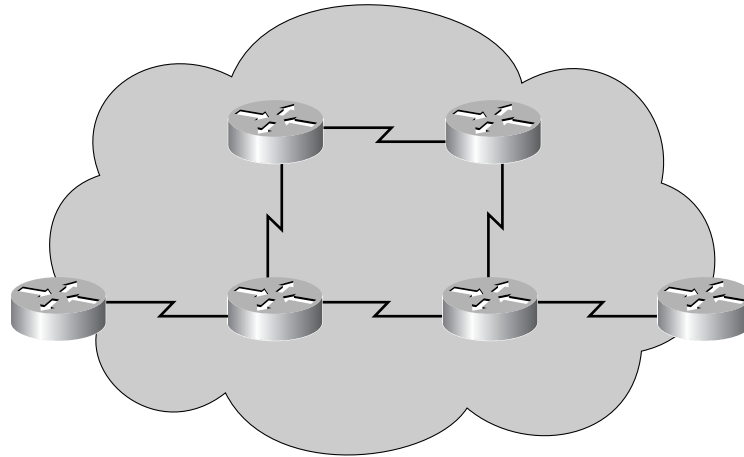
Autonomous Systems and IGP vs. EGP

An *interior gateway protocol (IGP)* is designed for use in a network controlled or administered by a single organization. An IGP is designed to find the best path through the network. In other words, the metric and how that metric is used is the most important element in an IGP.

An *exterior gateway protocol (EGP)* is designed for use between networks that are controlled by two different organizations. EGPs typically ARE used between Internet service providers (ISPs) or between a company and an ISP. For example, a company would run BGP, an EGP, between one of its routers and a router inside an ISP. IP EGPs require the following three sets of information before routing can begin:

- A list of neighbor routers to exchange routing information with
- A list of networks to advertise as directly reachable
- The autonomous system number of the local router

An EGP must isolate autonomous systems. Because autonomous systems are managed by different administrations, networks must have a protocol to communicate between different systems. Figure 15-25 shows an autonomous system.

Figure 15-25 Autonomous System

Every autonomous system is assigned a 16-bit identifying number by the American Registry of Internet Numbers (ARIN) or an ARIN provider. Routing protocols such as Cisco IGRP and EIGRP require that a unique, autonomous system number be assigned.

Summary

In this chapter, you learned the following points:

- A router will not forward a packet without a route to a destination network.
- Network administrators manually configure static routes.
- Default routes are special static routes that provide routers with gateways of last resort.
- Static and default routes are configured using the **ip route** command.
- Static and default route configuration can be verified using the **show ip route**, **ping**, and **tracert** commands.
- Three types of routing protocols exist:
 - Distance vector
 - Link-state
 - Balanced hybrid
- An autonomous system (AS) is a collection of networks under a common administration and sharing a common routing strategy.

To supplement all that you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab Activities on the CD-ROM accompanying this book.

Key Terms

administrative distance A rating that shows trustworthiness of a routing information source. This value is shown as a numeric value between 0 and 255. The higher the value is, the lower the trustworthiness rating is.

autonomous system A collection of networks under a single administrative domain.

balanced hybrid routing protocol Routing protocols that utilize elements of distance vector and link-state routing protocols.

distance vector routing protocol A class of routing algorithms that iterate on the number of hops in a route to find a shortest-path spanning tree. Distance vector routing algorithms call for each router to send its entire routing table in each update, but only to its neighbors. Distance vector routing algorithms can be prone to routing loops but are computationally simpler than link-state routing algorithms. Also called a Bellman-Ford routing algorithm.

dynamic routing Routing that adjusts automatically to network topology or traffic changes. Also called adaptive routing. Requires that a routing protocol be run between routers.

exterior gateway protocol (EGP) A routing protocol designed for use between networks that are controlled by two different organizations.

interior gateway protocol (IGP) A routing protocol that is designed for use in a network controlled or administered by a single organization.

link-state advertisements (LSAs) Small packets of routing information that are sent between routers.

link-state routing protocol A routing algorithm in which each router broadcasts or multicasts information regarding the cost of reaching each of its neighbors to all nodes in the internetwork. Link-state algorithms create a consistent view of the network and are therefore not prone to routing loops. However, they achieve this at the cost of relatively greater computational difficulty and more widespread traffic than do distance vector routing algorithms.

load sharing When dynamic routing protocols direct traffic from the same session over different paths in a network for better performance.

metric An algorithm that generates a number for each path through the network. Typically, the smaller the metric number is, the better the path is.

routed protocol A protocol that can be routed by a router. A router must be capable of interpreting the logical internetwork as specified by that routed protocol. Examples of routed protocols are AppleTalk, IPX, and IP.

routing protocol A protocol that accomplishes routing through the implementation of a specific routing algorithm. Examples of routing protocols are IGRP, OSPF, and RIP.

routing table A list of the known paths and interfaces.

routing The process of finding a path to a destination host. Routing is very complex in large networks because of the many potential intermediate destinations that a packet might traverse before reaching its destination host.

shortest path first (SPF) algorithm A calculation performed on the database resulting in the SPF tree.

static routing The process of manually defining and configuring the routes.

topological database A collection of information gathered from LSAs.

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. Which of the following best describes one function of Layer 3, the network layer, in the OSI model?
 - A. It is responsible for reliable network communication between nodes.
 - B. It is concerned with physical addressing and network topology.
 - C. It determines which is the best path for traffic to take through the network.
 - D. It manages data exchange between presentation layer entities.
2. What function allows routers to evaluate available routes to a destination and to establish the preferred handling of a packet?
 - A. Data linkage
 - B. Path determination
 - C. SDLC interface protocol
 - D. Frame Relay

3. How does the network layer forward packets from the source to the destination?
 - A. By using an IP routing table
 - B. By using ARP responses
 - C. By referring to a name server
 - D. By referring to the bridge
4. What two parts of a network layer address do routers use to forward traffic through a network?
 - A. Network address and host address
 - B. Network address and MAC address
 - C. Host address and MAC address
 - D. MAC address and subnet mask
5. Which of the following best describes a routed protocol?
 - A. Its address provides enough information to allow a packet to be forwarded from host to host.
 - B. It provides information necessary to pass data packets up to the next-highest network layer.
 - C. It allows routers to communicate with other routers to maintain and update address tables.
 - D. It allows routers to bind MAC and IP addresses together.
6. Which of the following best describes a routing protocol?
 - A. A protocol that accomplishes routing through the implementation of an algorithm
 - B. A protocol that specifies how and when MAC and IP addresses are bound together
 - C. A protocol that defines the format and use of fields within a data packet
 - D. A protocol that allows a packet to be forwarded from host to host
7. What is one advantage of distance vector algorithms?
 - A. They are not likely to count to infinity.
 - B. You can implement them easily on very large networks.
 - C. They are not prone to routing loops.
 - D. They are computationally simple.

8. Which of the following best describes a link-state algorithm?
 - A. It recreates the exact topology of the entire internetwork.
 - B. It requires numerous computations.
 - C. It determines distance and direction to any link on the internetwork.
 - D. It uses little network overhead and reduces overall traffic.
9. Why do routing loops occur?
 - A. Slow convergence occurs after a modification to the internetwork.
 - B. Split horizons artificially are created.
 - C. Network segments fail catastrophically and take down other network segments in a cascade effect.
 - D. Default routes never were established and initiated by the network administrator.
10. Which of the following best describes balanced hybrid routing?
 - A. It determines best paths, but topology changes trigger routing table updates.
 - B. It uses distance-vector routing to determine best paths between topology during high-traffic periods.
 - C. It uses topology to determine best paths but does frequent routing table updates.
 - D. It uses topology to determine best paths but uses distance vectors to circumvent inactive network links.
11. What is a network with only one path to a router called?
 - A. Static network
 - B. Dynamic network
 - C. Entity network
 - D. Stub network
12. Which best describes a default route?
 - A. Urgent-data route manually entered by a network administrator
 - B. Route used when part of the network fails
 - C. Route used when the destination network is not listed explicitly in the routing table
 - D. Preset shortest path



Objectives

Upon completion of this chapter, you will be able to

- Describe initial router configuration
- Describe RIP characteristics
- Configure RIP routing
- Describe IGRP characteristics
- Configure IGRP routing
- Describe and test load balancing over multiple paths

Chapter 16

Distance Vector Routing Protocols

Now that you have learned about routing protocols, you are ready to configure IP routing protocols. As you know, routers can be configured to use one or more IP routing protocols. In this chapter, you learn the initial configuration of the router to enable the Routing Information Protocol (RIP) and the Interior Gateway Routing Protocol (IGRP). In addition, you learn how to monitor IP routing protocols.

Please be sure to look at this chapter's associated e-Labs, Videos, and PhotoZooms that you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

Initial Router Configuration

After testing the hardware and loading the Cisco IOS Software image, the router finds and applies the configuration statements. These entries provide the router with details about router-specific attributes, protocol functions, and interface addresses. Remember that if the router cannot locate a valid startup-config file, it enters an initial router configuration mode called setup mode or system configuration dialog.

With the setup mode command facility, you can answer questions in the system configuration dialog. This facility prompts you for basic configuration information. The answers that you enter enable the router to build a sufficient but minimal router configuration. The setup facility provides the following:

- An inventory of interfaces
- An opportunity to enter global parameters
- An opportunity to enter interface parameters
- A setup script review
- An opportunity to indicate whether or not you want the router to use this configuration

After you confirm setup mode entries, the router uses the entries as a running configuration. The router also stores the configuration in nonvolatile random-access memory (NVRAM) as a new startup-config, and you can start using the router. For additional protocol and interface changes, you can then use the enable mode and enter the command **configure**.

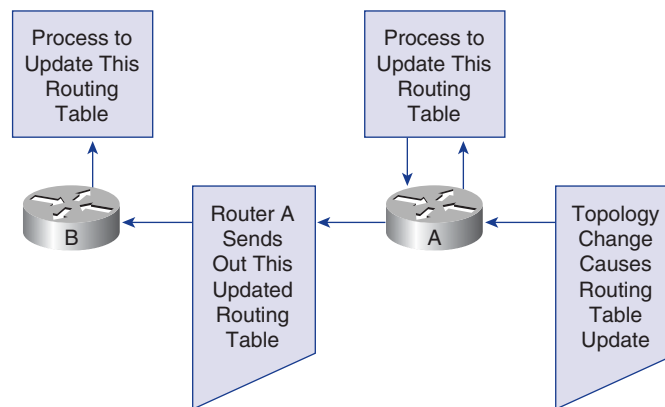
Distance Vector Routing

This section discusses distance vector routing protocols and their shortcomings, as well as identifies solutions to the problems presented by distance vector routing. Distance vector–based routing algorithms pass periodic copies of a routing table from router to router. These regular updates between routers communicate topology changes.

Maintaining Routing Information Through Distance Vector Protocols

Routing table updates occur periodically when the topology in a distance vector protocol network changes. It is important for a routing protocol to be efficient in updating the routing tables. As with the network discovery process, topology change updates proceed systematically from router to router. Figure 16-1 illustrates how distance vector protocols handle topology changes.

Figure 16-1 Distance Vector Topology Changes



Distance vector algorithms instruct each router to send its entire routing table to each of its *adjacent neighbors*. The routing tables include information about the total path cost, as defined by the metrics, and the logical address of the advertising router on the path to each network.

Load Balancing Across Multiple Paths

Load balancing describes the capability of a router to transmit packets to a destination IP address over multiple paths. Load balancing is a concept that allows a router to take advantage of multiple paths to a given destination. The paths are derived either statically or with dynamic protocols, such as RIP, Enhanced IGRP (EIGRP), Open Shortest Path First (OSPF), and IGRP. Figure 16-2 shows an example of load balancing.

When a router learns of multiple routes to a specific network through multiple routing processes or routing protocols, it installs the route with the lowest administrative distance into the routing table. Sometimes, the router must choose from many routes provided by the same routing process with the same administrative distance. In this case, the router chooses the path with the lowest cost or metric to the destination. Each routing process calculates its cost differently, and the costs might need to be manually configured to achieve load balancing.

If the router receives and installs multiple paths with the same administrative distance and cost to a destination, load balancing can occur. Cisco IOS Software imposes a six equal-cost routes limit on the routing table, but some Interior Gateway Protocols (IGPs) set their own limitations. For example, EIGRP allows up to four equal-cost routes.

By default, most IP routing protocols install a maximum of four parallel routes in a routing table. Static routes always install six routes. The exception is the exterior routing protocol Border Gateway Protocol (BGP), which by default allows only one path to a destination.

The number of maximum paths ranges from one to six paths. To change the maximum number of parallel paths allowed in a routing table, use the following command while in router configuration mode:

```
maximum-paths maximum
```

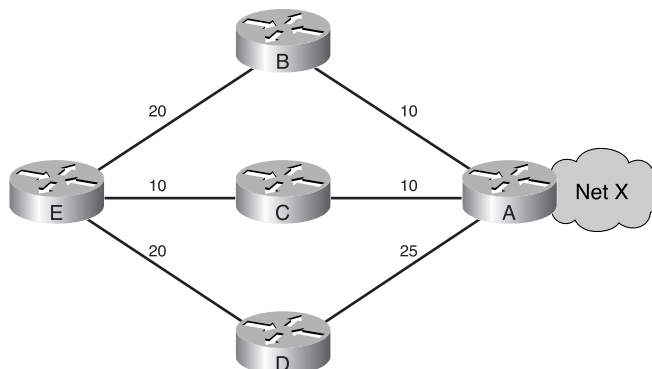
IGRP can load balance up to six unequal links. RIP networks must have the same hop count to load balance, whereas IGRP uses bandwidth to determine how to load balance.

In Figure 16-2, there are three ways to access Network X:

- E to B to A with a metric of 30
- E to C to A with a metric of 20
- E to D to A with a metric of 45

Router E chooses the second path, E to C to A with a metric of 20, which is a lower cost than 30 and 45. If two or more of the paths had the same metric, load balancing could occur.

Figure 16-2 Load Balancing



When routing IP, Cisco IOS Software offers two methods of load balancing:

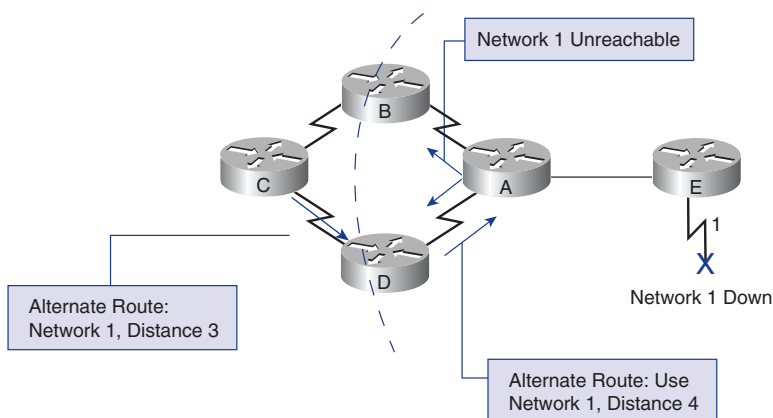
- Per-packet load balancing
- Per-destination load balancing

If process switching is enabled, the router alternates paths on a per-packet basis. If fast switching is enabled, only one of the alternate routes is cached for the destination address, so all packets in the packet stream bound for a specific host take the same path. Packets bound for a different host on the same network might use an alternate route, in which case traffic is load balanced on a per-destination basis.

How Routing Loops Occur in Distance Vector

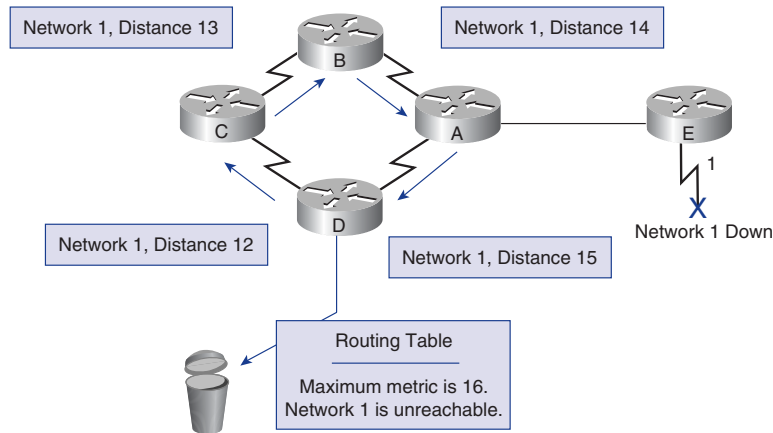
Routing loops can occur if a network experiences slow *convergence* as the result changes in the network or routing topology causing inconsistent routing entries. Figure 16-3 demonstrates routing loops.

Figure 16-3 Routing Loops



Distance vector routing algorithms are self-correcting, but a routing loop problem can require a count to infinity to resolve. To avoid this prolonged problem, distance vector protocols define infinity as a specific maximum number. This number refers to a routing metric, which might simply be the hop count. Figure 16-5 demonstrates this concept.

Figure 16-5 Defining a Maximum Metric



By assigning a maximum number to infinity, the routing protocol permits the routing loop to continue until the metric exceeds its maximum allowed value. Figure 16-5 shows the metric value as 16 hops, which exceeds the distance vector default maximum of 15 hops, and the router discards the packet. In any case, when the metric value exceeds the maximum value, Network 1 is considered unreachable.

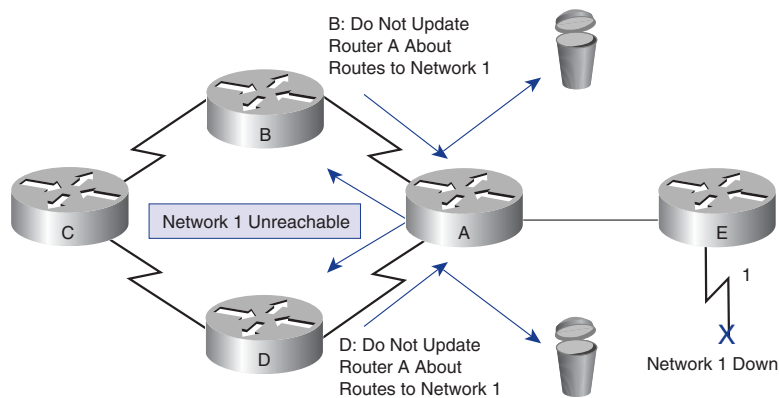
Eliminating Routing Loops Through Split Horizon

Another possible source for a routing loop occurs when incorrect information that has been sent back to a router contradicts the correct information that the router originally distributed. The following process, as shown in Figure 16-6, explains how this problem occurs:

1. Router A passes an update to Router B and Router D indicating that Network 1 is down. However, Router C transmits an update to Router B indicating that Network 1 is available at a distance of four by way of Router D. This action does not violate split-horizon rules.
2. Router B concludes, incorrectly, that Router C still has a valid path to Network 1, although at a much less favorable metric. Router B sends an update to Router A, advising Router A of the new route to Network 1.

3. Router A now determines that it can send information to Network 1 by way of Router B. Router B determines that it can send information to Network 1 by way of Router C, and Router C determines that it can send information to Network 1 by way of Router D. Any packet introduced into this environment loops between the routers.
4. Split horizon attempts to avoid this situation. If a routing update for Network 1 arrives from Router A, then Router B and Router D cannot send information about Network 1 back to Router A, as in Figure 16-6. *Split horizon* thus reduces incorrect routing information and reduces routing overhead.

Figure 16-6 Split Horizon



Route Poisoning

Route poisoning is used by various distance vector protocols to overcome large routing loops and offer explicit information when a subnet or network is not accessible. Route poisoning is usually accomplished by setting the hop count to one more than the maximum.

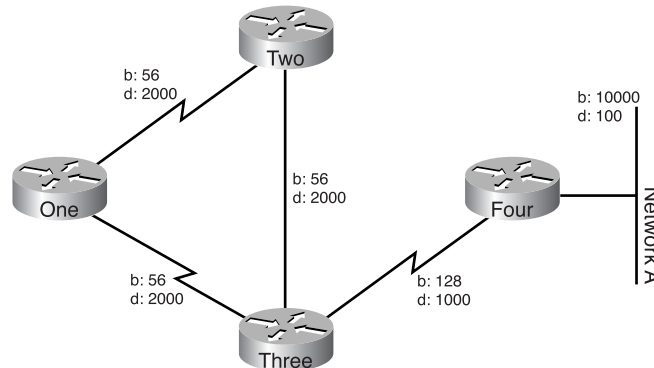
Poison reverse is another way of avoiding routing loops. Its rule states:

Once you learn of a route through an interface, advertise it as unreachable back through that same interface.

Assume that the routers in Figure 16-7 have poison reverse enabled. When Router One learns about Network A from Router Two, it advertises Network A as unreachable

through its link to Routers Two and Three. Router Three, if it shows any path to Network A through Router One, removes that path because of the unreachable advertisement. EIGRP combines these two rules to help prevent routing loops.

Figure 16-7 Route Poisoning



EIGRP uses split horizon or advertises a route as unreachable when

- Two routers are in startup mode (exchanging topology tables for the first time)
- Advertising a topology table change
- Sending a query

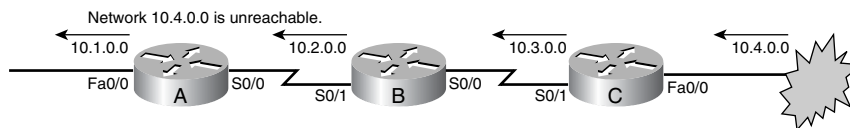
When route poisoning is used with triggered updates, it will speed up convergence time because neighboring routers do not have to wait 30 seconds before advertising the poisoned route. Route poisoning causes a routing protocol to advertise infinite-metric routes for a failed route. Route poisoning does not break split-horizon rules. Split horizon with poison reverse is essentially route poisoning, but specifically placed on links that split horizon would not normally allow routing information to flow across. In either case, the result is that failed routes are advertised with infinite metrics.

Avoiding Routing Loops with Triggered Updates

New routing tables are usually sent to neighboring routers on a regular basis. RIP updates occur every 30 seconds. However, a *triggered update* is sent immediately in response to some change in the routing table. The router that detects a topology change immediately sends an update message to adjacent routers. Those routers then generate triggered updates, notifying their adjacent neighbors of the change. When a route fails, an update is sent, rather than waiting on the update timer to expire. The use of triggered updates, in conjunction with route poisoning, ensures that all routers know of failed routes before any hold-down timers can expire.

A triggered update is an update that is sent without waiting for the update timer to expire. The router immediately sends another routing update on its other interfaces, rather than waiting for the routing update timer to expire. This action causes the updated information about the status of the route to be forwarded and starts the hold-down timers more rapidly on the neighboring routers. This wave of updates is transmitted throughout the network. Figure 16-8 demonstrates this principle.

Figure 16-8 Triggered Updates



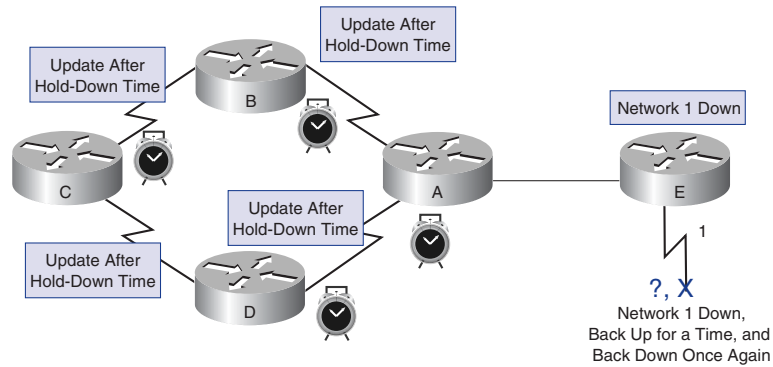
Router C issues a triggered update, announcing that network 10.4.0.0 is unreachable. Upon receipt of this information, Router B announces that network 10.4.0.0 is down through interface S0/1. In turn, Router A sends out an update through interface Fa0/0.

Preventing Routing Loops with Hold-Down Timers

A count to infinity problem can be avoided by using hold-down timers. The correct sequence for this procedure is as follows:

1. When a router receives an update from a neighbor indicating that a previously accessible network is now inaccessible, the router marks the route as inaccessible and starts a hold-down timer. If an update is received from the same neighbor before the hold-down timer expires indicating that the network is again accessible, the router marks the network as accessible and removes the hold-down timer.
2. If an update arrives from a different neighboring router with a better metric than that originally recorded for the network, the router marks the network as accessible and removes the hold-down timer.
3. If at any time before the hold-down timer expires, an update is received from a different neighboring router with a poorer metric, the update is ignored. Ignoring updates under these conditions allows more time for the knowledge of a disruptive change to travel through the entire network, as Figure 16-9 shows.

Figure 16-9 Hold-Down Timers



Preventing Routing Updates Through an Interface

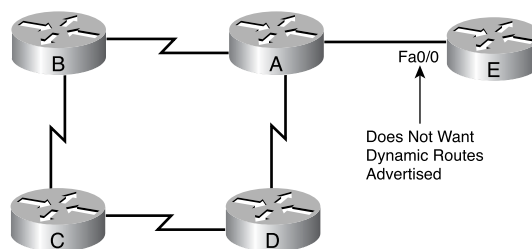
Route filtering works by regulating the routes that are entered into or advertised out of a route table. The effects are different on link-state routing protocols than they are on distance vector protocols. A router running a distance vector protocol advertises routes based on the information in its route table. As a result, a route filter influences which routes the router advertises to its neighbors.

Conversely, routers running link-state protocols determine routes based on information in the link-state database, rather than the route entries advertised by neighboring routers. Route filters have no effect on link-state advertisements or the link-state database. For this reason, the information presented here applies only to distance vector IP routing protocols such as RIP and IGRP.

Using the **passive-interface** command can prevent routers from sending routing updates through a router interface. Keeping routing update messages from being sent through a router interface prevents other systems on that network from learning about routes dynamically. As illustrated in Figure 16-10, Router E uses the **passive-interface** command to keep routing updates from being sent:

```
RouterE(config-router)# passive-interface Fa0/0
```

Figure 16-10 Defining a Passive Interface



For RIP and IGRP, the **passive-interface** command stops the router from sending updates to a particular neighbor, but the router continues to accept and utilize routing updates from that neighbor. Keeping routing update messages from being sent through a router interface prevents other systems on the interface from learning about routes dynamically.

Examining the Routing Table

A router might learn about routes to destination networks using a dynamic routing protocol. It might learn about routes when a network administrator configures static routes. The router very likely uses a combination of dynamic and static routing to discover routing information. Whatever the method used for route discovery, when a router determines that a route is the best path to a destination, it installs the route in its routing table. This section describes methods for examining and interpreting the contents of the routing table and covers the following topics:

- The **show ip route** command
- Determining the gateway of last resort
- Determining the route source and destination address
- Determining route administrative distance
- Determining route metric
- Determining route next hop
- Determining last route updates
- Observing multiple paths to destination

The show ip route Command

One of a router's primary functions is to determine the best path to a given destination. A router learns paths, also called routes, from an administrator's configuration or from other routers via routing protocols. They store this routing information in "routing tables" using onboard random-access memory (RAM). A routing table contains a list of the best available routes that routers use to make packet forwarding decisions.

The **show ip route** command displays the contents of the IP routing table. This table contains entries for all known networks and subnetworks, as well as a code that indicates how that information was learned. The additional keywords that can be used with the **show ip route** command are as follows:

- **connected**—Used to show the IP routing table on the router
- **network**—Gives detailed routing information about the specified network
- **rip**—Used to show the IP routing table information related to RIP on the router

- **igrp**—Used to show the IP routing table information related to IGRP on the router
- **static**—Used to show the static IP routing table information on the router

A routing table maps network prefixes to an outbound interface. When RTA receives a packet destined for 192.168.4.46, it looks for the prefix 192.168.4.0/24 in its table. RTA then forwards the packet out an interface (Ethernet0) based on the routing table entry. If RTA receives a packet destined for 10.3.21.5, it sends that packet out Serial 0/0.

Additionally, RTA drops any packet destined for a network that is not listed in the routing table. To forward to other destinations the routing table for RTA has to include more routes. These new routes can be added via one of two methods:

- **Static routing**—An administrator manually defines routes to one or more destination networks.
- **Dynamic routing**—Routers follow rules defined by a routing protocol to exchange routing information and independently select the best path.

Administratively defined routes are said to be *static* because they do not change until a network administrator manually programs the changes. Routes learned from other routers are *dynamic* because they can change automatically as neighboring routers update each other with new information. Each method has fundamental advantages and disadvantages.

Determining the Gateway of Last Resort

It is not feasible, or even desirable, for a router to maintain routes to every possible destination. Instead, routers keep a default route, or a gateway of last resort. Default routes are used when the router is unable to match a destination network with a more specific entry in the routing table. The router uses the default route to hand off to another router, the gateway of last resort, in an effort to forward the packet.

A key scalability feature is that default routes keep routing tables as small as possible. They make it possible for routers to forward packets destined to any Internet host without having to maintain a table entry for every Internet network. The default route, in many cases, points to the ISP's network. Default routes can be statically entered by an administrator or dynamically learned via a routing protocol.

Default routing begins with the administrator. Before routers can dynamically exchange information, an administrator must configure at least one router with a default route. An administrator can use two very different commands to statically configure default routes:

```
ip route 0.0.0.0 0.0.0.0
ip default-network.
```

The **ip default-network** command establishes a default route in networks using dynamic routing protocols.

The global command **ip default-network 195.16.11.0** defines the Class C network 195.16.11.0 as the destination path for packets that have no routing table entries. For every network configured with **ip default-network**, if a router has a route to the network, that route is flagged as a candidate for the default route.

Creating an **ip route** to 0.0.0.0/0 is another way to configure a default route:

```
Router(config)# ip route 0.0.0.0 0.0.0.0 [next-hop-ip-address | exit-interface]
```

After configuring a default route or default network, the command **show ip route** shows the following:

```
Gateway of last resort is 172.16.1.2 to network 0.0.0.0
```

If router RTY does not have the network in the routing table, it sends the packet to 172.16.1.2.

Determining Route Source to Route Destination

For traffic going through a network cloud, path determination occurs at the network layer. The path determination function enables a router to evaluate the available paths to a destination and to establish the preferred handling of a packet. Routing services use network topology information when evaluating network paths. This information can be configured by the network administrator or collected through dynamic processes running in the network.

The network layer provides best-effort, end-to-end packet delivery across interconnected networks. The network layer uses the IP routing table to send packets from the source network to the destination network. After the router determines which path to use, it takes the packet from one interface and forwards it to another interface or port that reflects the best path to the packet's destination.

Determining Layer 2 and Layer 3 Addresses from the Source to the Destination

While network layer (Layer 3) addresses, also known as MAC addresses, are used to get packets from source to destination, it is important to understand that a different type of address is used to get packets from one router to the next. For a packet to get from the source to the destination, both Layer 2 and Layer 3 addresses are used.

The Layer 3 address is used to route the packet from the source network to the destination network. The source and destination IP addresses remain the same. The MAC address (Layer 2) changes at each hop or router. A data link layer address is necessary

because the source host must have a way of addressing the next-hop router to which the packets are being forwarded. Also, when the packet is delivered to the intended host on a LAN, the router sends it directly to the host's MAC address.

Determining Route Administrative Distance

One of the intriguing aspects of Cisco routers, especially for those new to routing, is how the router chooses which route is the best among those presented by routing protocols, manual configuration, and various other means.

As each routing process receives updates and other information, it chooses the best path to any given destination and attempts to add this path to the routing table.

The router decides whether or not to add the routes presented by the routing processes based on the administrative distance of the route in question. If a path has the lowest administrative distance to a particular destination, it is added in the routing table; if not, then the route is rejected. Table 16-1 lists the default values for protocols supported by Cisco IOS Software.

Table 16-1 Default Administrative Distances

Route Type	Administrative Distance
Connected	0
Static	1
EIGRP summary route	5
external Border Gateway Protocol (eBGP)	20
EIGRP (internal)	90
IGRP	100
OSPF	110
IS-IS	115
RIP	120
EIGRP (external)	170
internal Border Gateway Protocol iBGP	200

Determining Route Metric

Routing protocols use *metrics* to determine the best route to a destination. The metric is a value that measures the desirability of a route. Some routing protocols use only one factor to calculate a metric; for example, RIP-1 uses hop count as the only factor to determine the metric of a route. Other protocols base their metric on hop count, bandwidth, delay, load, reliability, ticks delay, maximum transmission unit (MTU), and cost. Table 16-2 lists and describes each metric.

Table 16-2 Route Metrics

Metric	Description
Hop count	The number of routers that must be traversed to reach a destination. The path with the lowest hop count is preferred.
Bandwidth	The link speed. The path with the greatest bandwidth is preferred.
Delay	The amount of time it takes for a packet to travel a link. The path with the least delay is preferred.
Load	The amount of activity on a link. On Cisco routers, the value can typically range anywhere between 1 and 255, where 1 represents a link with the less load and 255 a link with the most load. Paths with the smallest load are preferred.
Reliability	The error rate on a link. On Cisco routers, the value can typically range anywhere between 1 and 255, with 255 representing a link with the highest reliability. Paths with the greatest reliability are preferred.
Ticks delay	Used by IPX RIP and represents the number of 1/18-second intervals required to forward a packet across a link. Paths with the lowest ticks delay are preferred.
Maximum transmission unit (MTU)	The largest packet size (in bytes) allowed on a link. Paths with the highest commonly shared MTU are preferred.
Cost	An administratively defined metric. Least-cost paths are preferred.

Each routing algorithm interprets what is best in its own way. The algorithm generates a number, called the metric value, for each path through the network. Typically, the smaller the metric number, the better the path.

Factors such as bandwidth and delay are static, in that they remain the same for each interface until the router is reconfigured or the network is redesigned. Factors such as load and reliability are dynamic, meaning that they are calculated for each interface in real time by the router.

The more factors that make up a metric, the greater the flexibility to tailor network operations to meet specific needs. By default IGRP uses two static factors to calculate a metric value: bandwidth and delay. These two factors can be configured manually, allowing precise control over what routes a router chooses. IGRP can also be configured to include load and reliability, two dynamic factors in the metric calculation. By using dynamic factors, IGRP routers can make decisions based on current conditions. Thus, if a link becomes heavily loaded or unreliable, IGRP increases the metric of routes using that link. Alternate routes might present a lower metric than the downgraded route and are used instead.

IGRP calculates the metric by adding the weighted values of different characteristics of the link to the network in question. These values (bandwidth, bandwidth divided by load, and delay) are weighted with the constants K1, K2, and K3.

$$\text{Metric} = K1 \times \text{Bandwidth} + (K2 \times \text{Bandwidth}) / 256 - \text{load} + K3 \times \text{Delay}$$

The default constant values are $K1 = K3 = 1$ and $K2 = K4 = K5 = 0$, so

$$\text{Metric} = \text{Bandwidth} + \text{Delay}$$

Determining Route Next Hop

Routing algorithms fill routing tables with a variety of information. Destination/next hop associations tell a router that a particular destination can be reached optimally by sending the packet to a particular router representing the “next hop” on the way to the final destination.

When a router receives an incoming packet, it checks the destination address and attempts to associate this address with a next hop.

Determining Last Route Updates

A network administrator can use the following commands to find the last route update:

- **show ip route**—Used to display the IP routing table on the router.

- **show ip route *network***—Provides detailed routing information about the specified network.
- **show ip protocols**—Used to display IP routing protocol information.
- **show ip rip database**—Displays the contents of the RIP private database when triggered extensions to RIP are enabled.

The default update time for RIP is 30 seconds and for IGRP is 90 seconds.

Example 16-1 shows the output for the command **show ip route**.

Example 16-1 show ip route *Command Output*

```

rt1# show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

R    200.200.200.0/24 [120/1] via 192.168.10.2, 00:00:14, Serial0/0
C    192.168.10.0/24 is directly connected, Serial0/0
C    192.168.0.0/24 is directly connected, Loopback0

```

Rt1 has received a RIP update for the network 200.200.200.0 from 192.168.10.2. RIP updates every 30 seconds, and the shaded area is the amount of time since the last update.

Example 16-2 shows the output for the command **show ip route 200.200.200.0**.

Example 16-2 show ip route 200.200.200.0 *Command Output*

```

rt1# show ip route 200.200.200.0
Routing entry for 200.200.200.0/24
  Known via "rip", distance 120, metric 1
  Redistributing via rip
  Last update from 192.168.10.2 on Serial0/0, 00:00:11 ago

```

continues

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Example 16-2 show ip route 200.200.200.0 Command Output (Continued)

```

Routing Descriptor Blocks:
  * 192.168.10.2, from 192.168.10.2, 00:00:11 ago, via Serial0/0
    Route metric is 1, traffic share count is 1
Rt1 has received a RIP update for the network 200.200.200.0 from 192.168.10.2.
RIP updates every 30 seconds and the last update was 11 seconds ago.

```

Example 16-3 shows the output for the command **show ip protocols**.

Example 16-3 show ip protocols Command Output

```

rt1# show ip protocols
Routing Protocol is "rip"
  Sending updates every 30 seconds, next due in 9 seconds
  Invalid after 180 seconds, hold down 180, flushed after 240
  Outgoing update filter list for all interfaces is
  Incoming update filter list for all interfaces is
  Redistributing: rip
  Default version control: send version 1, receive any version
    Interface      Send Recv Triggered RIP Key-chain
    Serial0/0      1    1 2
    Loopback0      1    1 2
  Routing for Networks:
    192.168.0.0
    192.168.10.0
  Routing Information Sources:
    Gateway         Distance      Last Update
    192.168.10.2    120          00:00:03
  Distance: (default is 120)

```

Example 16-4 shows the output for the command **show ip rip database**.

Example 16-4 show ip rip database Command Output

```

rt1# show ip rip database
192.168.0.0/24    auto-summary
192.168.0.0/24    directly connected, Loopback0
192.168.10.0/24   auto-summary
192.168.10.0/24   directly connected, Serial0/0

```


Example 16-4 show ip rip database *Command Output (Continued)*

```

200.200.200.0/24    auto-summary
200.200.200.0/24
[1] via 192.168.10.2, 00:00:20, Serial10/0
    
```

This command outputs shows the last update was received 20 seconds ago.

Observing Multiple Paths to Destination

Some routing protocols support multiple paths to the same destination. Unlike single path algorithms, these multipath algorithms permit traffic over multiple lines, provide better throughput, and are more reliable.

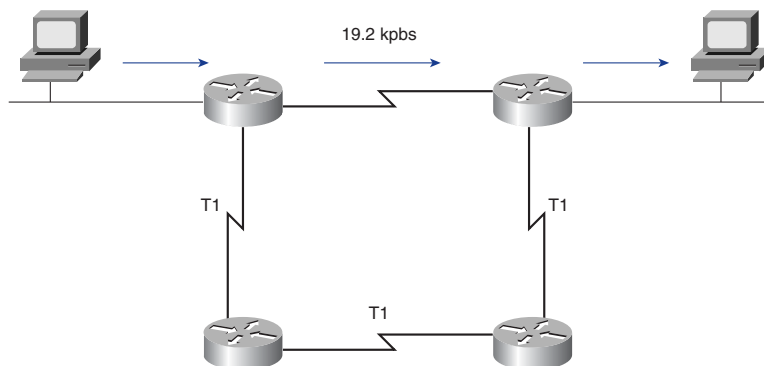
RIP Features

Routing Information Protocol (RIP) was originally specified in RFC 1058 in 1988. Its key characteristics include the following:

- It is a distance vector routing protocol.
- Hop count is used as the metric for path selection (see Figure 16-11).
- If the hop count is greater than 15, the packet is discarded.
- By default, *routing updates* are broadcast every 30 seconds.

Note in Figure 16-11 that the 19.2-kbps path between the two hosts using the top routers is 2 hops. The lower alternate path using the three T-1 links is 4 hops. Because RIP path selection is based solely on the number of hops, in this case, RIP path selection chooses the 19.2-kbps link instead of the much faster T1 links.

Figure 16-11 RIP Uses Hop Count as Its Metric



RIP has evolved over the years from a classful routing protocol, RIP Version 1 (RIP-1), to a classless routing Protocol, RIP Version 2 (RIP-2). RIP-2 enhancements include the following:

- Capability to carry additional packet routing information
- Authentication mechanism to secure table updates
- Capability to support subnet masks

RIP prevents routing loops from continuing indefinitely by implementing a limit on the number of hops allowed in a path from the source to a destination. The maximum number of hops allowed in a path is 15. When a router receives a routing update that contains a new or changed entry, the metric value is increased by one. If this causes the metric to be incremented beyond 15, it is considered to be infinity, and the network destination is considered unreachable. RIP includes a number of features that are common in other routing protocols. For example, RIP implements split horizon and hold-down mechanisms to prevent incorrect routing information from being propagated.

Enabling RIP on an IP Network

The **router rip** command enables RIP as the routing protocol. The **network** command is then used to tell RIP which networks are directly connected for the router to advertise. The routing process then associates these interfaces with the network addresses and begins using RIP on interfaces.

RIP sends routing-update messages at regular intervals and triggered updates when the network topology changes. When a router receives a routing update that includes changes to an entry, it updates its routing table to reflect the new route. The metric value for the path is increased by one, and the source interface of the update is indicated as the next hop in the route. RIP routers maintain only the best route to a destination; however, RIP routers can maintain multiple routes to the same destination if those routes have the same metric.

After updating its routing table due to a configuration change, the router immediately begins transmitting routing updates to inform other network routers of the change. These updates are sent independently of the regularly scheduled updates that RIP routers forward. RIP advertises classful networks or major class networks only.

To enable RIP, use the commands in Table 16-3, beginning in global configuration mode.

Table 16-3 Commands to Enable RIP

Command	Purpose
Router(config)# router rip	Enables a RIP routing process, which then switches to the router configuration mode
Router(config-router)# network <i>network-number</i>	Associates a network with a RIP routing process

The following commands show the process of enabling RIP and specifying directly connected networks.

```
BHM(config)#router rip
! selects RIP as the routing protocol
BHM(config-router)#network 1.0.0.0
! specifies a directly connected network)
BHM(config-router)#network 2.0.0.0
! specifies a directly connected network
```

The Cisco router interfaces that are connected to networks 1.0.0.0 and 2.0.0.0 send and receive RIP updates. These routing updates enable the router to learn the network topology from a neighboring router that is running RIP.

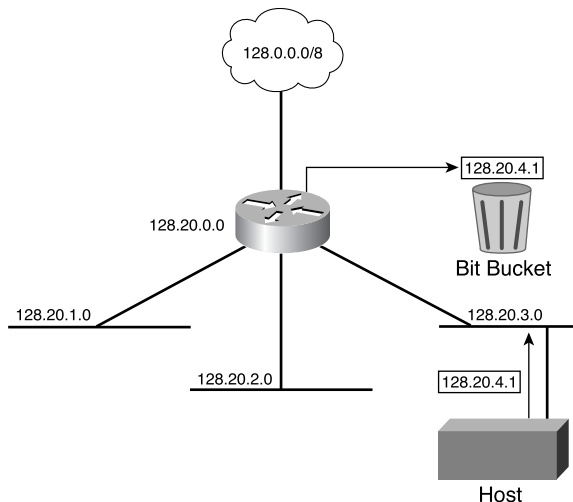
Using the **ip classless** Command

Sometimes, a router receives packets destined for an unknown subnet of a network that has directly connected subnets. To forward these packets to the best supernet route possible, use the **ip classless** global configuration command. The **ip classless** command is enabled by default in Cisco IOS Software Release 11.3 and later. To disable this feature, use the **no** form of this command.

When this feature is disabled and a packet is being sent to a subnet of a network that has no network default route, the router discards the packet. Figure 16-12 illustrates this principle. If the host sends a packet to 128.20.4.1 and no network default route exists, the router discards the packet.

IP classless affects only the operation of the forwarding processes in IOS. IP classless does not affect the way the routing table is built. This degree of impact is the essence of classful routing. If part of a major network is known and the destination subnet toward which the packet is destined is unknown, the packet is dropped.

Figure 16-12 No IP Classless Routing



The most confusing aspect of this rule is that the router uses the default route only if the major network destination does not exist in the routing table. By default, a router assumes that all subnets of a directly connected network are present in the routing table. If a packet is received with an unknown destination address within an unknown subnet of an attached network, the router assumes that the subnet does not exist. Therefore, the router drops the packet, even if a default route exists. Configuring **ip classless** on the router resolves this problem by instructing the router to ignore the classful boundaries of the networks in its routing table and simply route to the default route, as Figure 16-13 demonstrates.

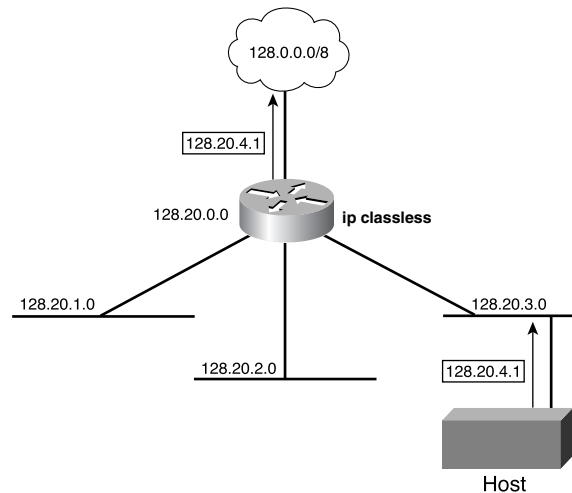
Common RIP Configuration Issues

RIP routers must rely on neighboring routers for network information. RIP uses a distance vector routing algorithm. All distance vector routing protocols have problems that result in slow convergence.

Some of these issues include routing loops and counting to infinity. These problems both result in inconsistencies due to routing update messages with outdated routes being propagated around the internetwork.

To reduce routing loops and counting to infinity, RIP uses the following methods:

- Split horizon
- Poison reverse
- Hold-down timer
- Triggered updates

Figure 16-13 IP Classless

Some of these methods might require some configuration, while others do not require or rarely require configuration.

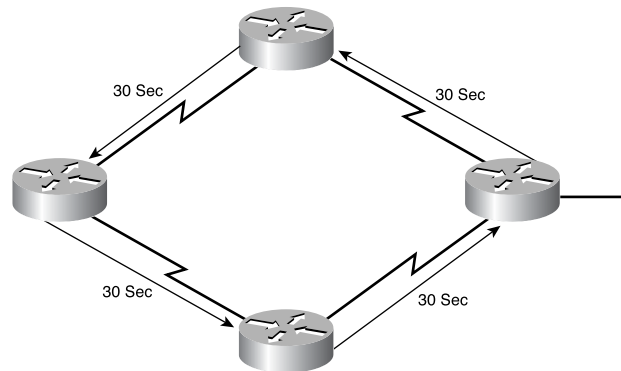
RIP permits a maximum hop count of 15. Any destination greater than 15 hops away is tagged as unreachable. The maximum hop count for RIP greatly restricts its use in large internetworks, but prevents a problem called count to infinity from causing endless network routing loops.

The split-horizon rule is based on the fact that it is usually not useful to send information about a route back in the direction from which the route came. In some network configurations, it might be necessary to disable split horizon. It is disabled on a per-interface basis.

To disable **split horizon**, use the following command:

```
Router(config-if)# no ip split-horizon
```

The hold-down timer is another mechanism that might need some changes. Hold-down timers help prevent counting to infinity but also increase convergence time. The default holddown for RIP is 180 seconds. This holddown prevents any inferior route from being updated, but might also prevent a valid alternative route from being installed. The hold-down timer can be decreased to speed up convergence, but take such action with caution. The ideal solution is to set the timer just longer than the longest possible update time for the internetwork. In Figure 16-14, the loop consists of four routers. With each router having an update time of 30 seconds, the longest loop possible is 120 seconds. Therefore, the hold-down timer should be set to slightly more than 120 seconds.

Figure 16-14 Hold-Down Timers

To change the hold-down timer, use the following command:

```
GAD(config-router)# holddown-timer seconds
```

One additional item that affects convergence and can be configured is the update interval. By default, Cisco IOS Software runs IP RIP updates every 30 seconds. This time can be reconfigured for longer intervals to conserve bandwidth or for a shorter interval to decrease convergence time.

To change the update interval, use the following command:

```
GAD(config-router)#update-timer seconds
```

As discussed earlier in this chapter, another issue with routing protocols is the unwanted advertisement of routing updates out a particular interface. When a **network** command is issued, RIP sends advertisements out all interfaces within that network address range. To control the set of interfaces that exchanges routing updates, the network administrator can disable the sending of routing updates on specified interfaces by configuring the **passive-interface** command.

Because RIP is a broadcast protocol, the network administrator might have to configure RIP to exchange routing information in a nonbroadcast network such as Frame Relay. In this type of network, RIP needs to be informed of other neighboring RIP routers. To define a neighboring router with which to exchange routing information, use the following command:

```
GAD(config-router)neighbor ip address
```

By default, the software receives RIP-1 and RIP-2 packets, but sends only RIP-1 packets. The network administrator can configure the router to receive and send only RIP-1 packets or to send only RIP-2 packets. To configure the router to send and receive packets from only one version, use the commands in the router configuration mode as specified in Table 16-4.

Table 16-4 Specifying the RIP Version

Command	Purpose
(config-router)#version {1 2 }	Configures the software to receive and send only RIP-1 or only RIP-2 packets.
(config-if)#ip rip send version 1	Configures an interface to send only RIP-1 packets.
(config-if)#ip rip send version 2	Configures an interface to send only RIP-2 packets.
(config-if)#ip rip send version 1 2	Configures an interface to send only RIP-1 or RIP-2 packets.

To control how packets received from an interface are processed, use the following commands described in Table 16-5.

Table 16-5 Controlling Packets

Command	Purpose
(config-if)#ip rip receive version 1	Configures an interface to receive only RIP-1 packets.
(config-if)#ip rip receive version 2	Configures an interface to receive only RIP-2 packets.
(config-if)#ip rip receive version 1 2	Configures an interface to receive only RIP-1 or RIP-2 packets.



Lab Activity Configuring RIP

In this lab, you set up an IP addressing scheme using Class C networks and configure RIP on all routers.

Verifying RIP Configuration

Several commands can be used to verify that RIP is properly configured. Two of the most commonly used commands are **show ip route** and **show ip protocols**.

The **show ip protocols** command outputs information about all the IP routing protocols configured on the router, as demonstrated in Example 16-5. This output can be

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used to verify most, if not all, of the RIP configuration. Some of the most common configuration items to verify are the following:

- That RIP is configured
- That the correct interfaces are sending and receiving RIP updates
- That the correct RIP version is being sent and received
- That the router is advertising the correct networks

Example 16-5 show ip protocols *Command Output*

```
GAD# show ip protocols
Routing Protocol is "rip"
! Line above verifies that RIP is configured
  Sending updates every 30 seconds, next due in 5 seconds
  Invalid after 180 seconds, hold down 180, flushed after 240
  Outgoing update filter list for all interfaces is
  Incoming update filter list for all interfaces is
  Redistributing: rip
  Default version control: send version 1, receive any version
! Line above verifies the RIP version
  Interface          Send  Recv  Triggered RIP  Key-chain
! Line above verifies RIP interfaces
  FastEthernet0/0    1     1 2
  Serial0/0          1     1 2
Routing for Networks:
  192.168.1.0
  192.168.2.0
! Lines above verify networks being advertised
Routing Information Sources:
  Gateway           Distance    Last Update
  192.168.2.2        120         00:00:11
Distance: (default is 120)
```

The **show ip route** command can be used to verify that the routes received by RIP are being installed in the routing table, as Example 16-6 shows. Examine the output of the command and look for RIP routes, signified by “R.” Remember that the network takes some time to converge so the routes might not appear immediately.

Example 16-6 show ip route *Command Output*

```
GAD# show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

C    192.168.1.0/24 is directly connected, FastEthernet0/0
C    192.168.2.0/24 is directly connected, Serial0/0
R    192.168.3.0/24 [120/1] via 192.168.2.2, 00:00:07, Serial0/0
! line above verifies RIP routes received
```

The last entry, beginning with the letter **R**, indicates that network 192.168.3.0 was learned from RIP and it can be reached via adjacent router (next hop) interface 192.168.2.2, which is remotely attached to this router's Serial 0/0 interface.

Additional commands you can use to check RIP configuration are as follows:

- **show interface** *interface*
- **show ip interface** *interface*
- **show running-config**

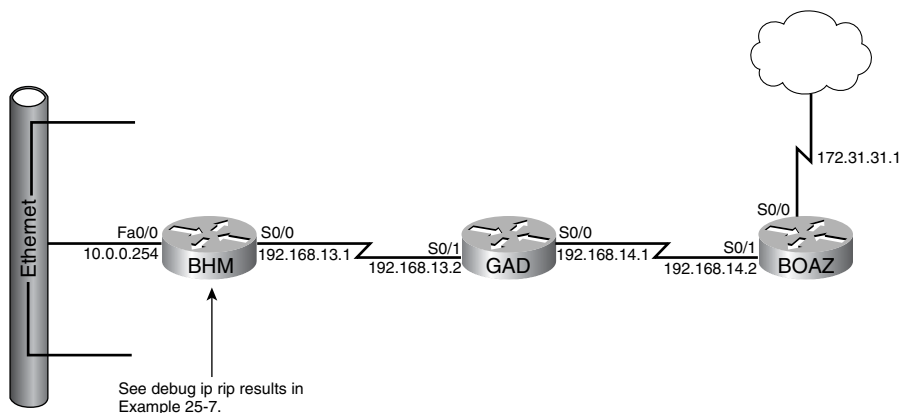
These commands are useful when it is necessary to find out information about a particular interface. Using the **show interface** command displays all information about an interface, including whether it is up or down and what type of protocol, IP address, or encapsulation type might be configured on the interface. Basically, these commands provide an administrator with all the configuration information that is available about a particular interface. The **show running-config** command, however, is used to show the current configuration on the router and all its interfaces. Recall that a Cisco router runs each protocol separately from other protocols. For this reason including the **ip** in the **show ip interface** command is necessary to list specifically just IP information regarding the specific interface.

Troubleshooting RIP

Most of the RIP configuration errors involve an incorrect **network** statement, discontinuous subnets, or split horizon. The primary tool for finding RIP update issues is the **debug ip rip** command.

The **debug ip rip** command displays RIP routing updates as they are sent and received. Figure 16-15 and Example 16-7 demonstrate a router using **debug ip rip** and receiving an update.

Figure 16-15 RIP Network for Debugging



Example 16-7 debug ip rip Output

```

BHM# debug ip rip
RIP event debugging is on
BHM#
00:45:36 RIP:received v1 update from 192.168.13.2 on Serial0/0
00:45:36   192.168.14.0 in 1 hop
00:45:36   172.31.0.0 in 2 hops
00:45:36   172.29.0.0 in 15 hops
00:45:36 RIP sending v1 update to 255.255.255.255 via Serial0/0 (192.168.13.1)
00:45:36   network 10.0.0.0, metric 1
00:45:36 RIP sending v1 update to 255.255.255.255 via FastEthernet0/0 (10.0.0.254)
00:45:36   network 192.168.13.0 metric 1
00:45:33   network 192.168.14.0 metric 2
00:45:33   network 172.31.0.0 metric 3
00:45:36   network 172.29.0.0 metric 16
    
```

The router sends update information out the two RIP interfaces. The output shows the router is using RIP-1 and broadcasts the update (address 255.255.255.255). The number in parentheses represents the source address encapsulated into the IP header of the RIP update.

You can look for several problems in the **debug ip rip** output. A couple of the problems that you can diagnose are discontinuous subnetworks or duplicate networks. A symptom of these problems is a routing protocol's advertising a network route with a metric that is less than the metric received for that network.

Example 16-8 shows the output of the **debug ip rip** command.

Example 16-8 debug ip rip *Command Output*

```
BMH# debug ip rip
RIP event debugging is on
BMH#
7w2d: RIP: received v1 update from 192.168.13.2 on serial0/0
7w2d:      192.168.14.0 1 hop
7w2d:      172.31.0.0 in 2 hops
7w2d: RIP: sending v1 update to 255.255.255.255 via Serial0/0 (192.168.13.1)
7w2d:      network 172.31.0.0 metric 1
7w2d: RIP: sending v1 update to 255.255.255.255 via FastEthernet0/0
(10.0.0.254)
7w2d:      192.168.13.0 metric 1
7w2d:      192.168.14.0 metric 2
```

Additionally, you can use the following commands to troubleshoot RIP:

- **show ip rip database**—Used to display the contents of the private database when triggered extensions to RIP are enabled.
- **show ip protocols {summary}**—Used to display IP routing protocol information.
- **show ip route**—Used to show the IP routing table on the router.
- **debug ip rip {events}**—Used to display the RIP information the router is processing across the prompt for an administrator to see.
- **show ip interface brief**—Lists a summary of an interface's IP information and status in privileged EXEC mode. The **brief** parameter is an option that displays a brief summary of IP status and configuration.

All of these commands provide information that can be helpful when troubleshooting a router.



Lab Activity Troubleshooting RIP

In this lab, you set up an IP addressing scheme using Class B networks and configure RIP on the routers. You observe routing activity using the `debug ip rip` command and examine routes using the `show ip route` command.

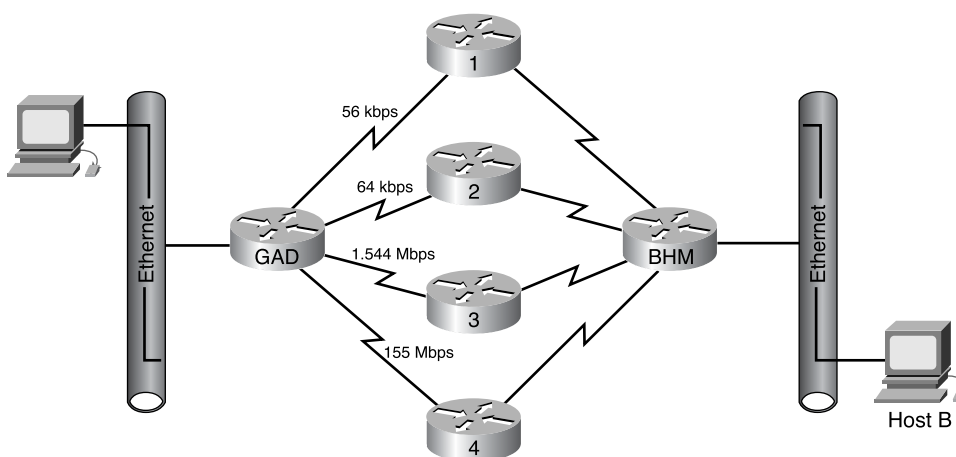
Load Balancing with RIP

Load balancing is a concept that allows a router to take advantage of multiple best paths to a given destination. These paths are derived either statically or with a dynamic protocol such as RIP.

RIP is capable of load balancing over as many as six equal-cost paths. Load balancing over four paths is the default. RIP performs what is referred to as *round robin* load balancing, which means that RIP takes turns forwarding packets over the parallel paths.

Figure 16-16 shows an example of RIP routes with four equal-cost paths. The router starts with an interface pointer to the interface connected to router 1. Then the interface pointer cycles through the interfaces and routes in a deterministic fashion such as 1-2-3-4-1-2-3-4-1 and so on. Because the metric for RIP is hop count, no regard is given to the speed of the links. Therefore, the 56-kbps path handles as much traffic between the two networks as the 155-Mbps path.

Figure 16-16 Load Balancing RIP



Equal-cost routes can usually be found by using the **show ip route** command. Example 16-9 is a display of the output for **show ip route** to a particular subnet with multiple routes.

Example 16-9 *Verifying Equal Cost Routes via show ip route Command Output*

```
RouterC# show ip route 192.168.2.0
Routing entry for 192.168.2.0/24
  Known via "rip", distance 120, metric 1
  Redistributing via rip
  Last update from 192.168.4.2 on FastEthernet0/0, 00:00:18 ago
  Routing Descriptor Blocks:
    192.168.4.1, from 192.168.4.1, 00:02:45 ago, via FastEthernet0/0
      Route metric is 1, traffic share count is 1
    * 192.168.4.2, from 192.168.4.2, 00:00:18 ago, via FastEthernet0/0
      Route metric is 1, traffic share count is 1
```

Notice there are two routing descriptor blocks. Each block is one route. Also, an asterisk (*) is next to one of the block entries. This asterisk corresponds to the active route that is used for new traffic.



Lab Activity Preventing Routing Updates Through an Interface

In this lab, you prevent routing updates through an interface to regulate advertised routes and observe the results. You use the *Passive-interface* command and add a *default route*.



Lab Activity Load Balancing Across Multiple Paths

In this lab, you configure load balancing across multiple paths with RIP and then observe the load balancing process.

Integrating Static Routes with RIP

Static routes are user-defined routes that force packets to take a specified path to their destination. Static routes become very important if Cisco IOS Software cannot build a route to a particular destination. They are also useful for specifying a “gateway of last resort,” which all packets without a more specific route are sent through.

A router running RIP can receive a default network address through an update from another router running RIP. Another option is for the router to generate the default network itself.

The static routes can be removed using the `no ip route` global configuration command. The administrator can override a dynamic route with static routing information using administrative distance values. Each dynamic routing protocol has a default administrative distance, which allows the static route to act as a backup for the dynamic route in the event that it fails.

Static routes that point to an interface are advertised via RIP, because static routes that point to an interface are considered to be connected in the routing table and thus lose their static nature. If a static route is assigned to an interface that is not one of the networks defined in a `network` command, no dynamic routing protocols advertise the route unless a `redistribute static` command is specified for these protocols.

When an interface goes down, all static routes through that interface are removed from the IP routing table. Additionally, when the software can no longer find a valid next hop for the address specified as the forwarding address for a router in a static route, the static route is removed from the IP routing table.

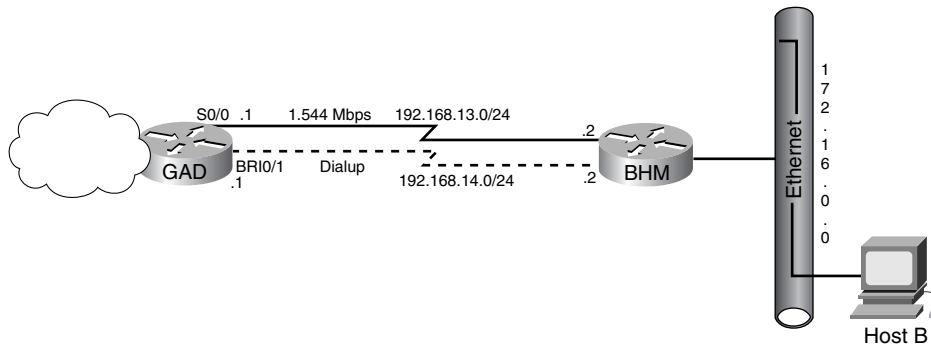
A static route is one that is specifically entered by an administrator so that the router specifically knows the route to a destination. A dynamic route is one that is learned by the router using the various routing protocol standards. In this case, it is not guaranteed that the router knows the route to the intended destination.

To configure a static route, use the following command in global configuration mode:

```
ip route prefix mask {address | interface} [distance] [tag tag] [permanent]
```

In Figure 16-17, a static route is configured in the GAD router to take the place of the RIP route in the event that the RIP route fails. Example 16-10 shows the static route being added with an administrative distance of 130, which is referred to as a floating static route. The floating static route is configured by declaring an administrative distance (130), which is greater than the administrative distance of RIP (120). The BHM router needs to be configured with a default route.

Figure 16-17 RIP with Floating Static Routes



Example 16-10 shows the configuration for the static route in Figure 16-17.

Example 16-10 *Floating Static Route*

```
GAD# configure terminal
GAD(config)# ip route 172.16.0.0 255.255.0.0 192.168.14.2 130
GAD(config)# ^z
GAD# show ip route

Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

C    192.168.113.0/24 is directly connected, Serial0/0
C    192.168.14.0/24 is directly connected, BRI0/1
R    172.16.0.0/16 [120/1] via 192.168.13.2, 00:00:24, Serial0/0
```

Note that the static route is treated like a dynamic route because the next-hop interface is specified. It starts with an *R* instead of an *S*.

IGRP

Like RIP, *Interior Gateway Routing Protocol (IGRP)* is a distance vector routing protocol. Unlike RIP, IGRP is a Cisco-proprietary protocol rather than a standards-based protocol. While remaining very simple to implement, IGRP is a more complex routing protocol than RIP, and it is able to use a number of factors to determine the best route to a destination network. This section introduces IGRP configuration and troubleshooting as well as the following IGRP topics:

- IGRP features
- IGRP metrics
- IGRP routes
- IGRP stability features
- Configuring IGRP
- Migrating RIP to IGRP
- Verifying IGRP configuration
- Troubleshooting IGRP

IGRP Features

IGRP is a distance vector IGP. Distance vector routing protocols mathematically compare routes by measuring distances. This measurement is known as the *distance vector*. Routers using distance vector protocols must send all or a portion of their routing table in a routing update message at regular intervals to each of their neighboring routers. As routing information proliferates through the network, routers can perform the following functions, among others:

- Identify new destinations
- Learn of failures

IGRP is a distance vector routing protocol developed by Cisco. IGRP sends routing updates at 90-second intervals, advertising networks for a particular autonomous system. Key design characteristics of IGRP are as follows:

- The versatility to automatically handle indefinite, complex topologies
- The flexibility needed to segment with different bandwidth and delay characteristics
- Scalability for functioning in very large networks

By default, the IGRP routing protocol uses bandwidth and delay as metrics. Additionally, IGRP can be configured to use a combination of variables to determine a composite metric. Those variables include

- Bandwidth
- Delay
- Load
- Reliability

IGRP Metrics

The `show ip protocols` command displays parameters, filters, and network information concerning the routing protocols in use on the router. You need this information to define the value of the K1–K5 metrics and provide information concerning the maximum hop count to calculate the composite metric for IGRP, which is figured as follows:

$$\text{Metric} = [\text{K1} \times \text{Bandwidth} + (\text{K2} \times \text{Bandwidth}) / (256 - \text{Load}) + \text{K3} \times \text{Delay}] \times [\text{K5} / (\text{Reliability} + \text{K4})]$$

The metric K1 represents bandwidth, and the metric K3 represents delay. By default the values of the metrics K1 and K3 are set to 1, while K2, K4, and K5 are set to 0.

The default constant values are K1 = K3 = 1 and K2 = K4 = K5 = 0. If K5 = 0, the $[\text{K5} / (\text{reliability} + \text{K4})]$ term is not used. So, given the default values for K1 through K5, the composite metric calculation used by IGRP reduces to

$$\text{Metric} = \text{Bandwidth} + \text{Delay}.$$

The K values in these formulas are constants that can be defined using the following router configuration command:

```
metric weights tos k1 k2 k3 k4 k5
```

To find the bandwidth, find the smallest of all the bandwidths from outgoing interfaces and divide 10,000,000 by that number. (The bandwidth is scaled by 10,000,000 in kilobits per second.) To find the delay, add all the delays from the outgoing interfaces and divide this number by 10. (The delay is in tens of microseconds.) Remember, the path with the smallest metric is the best path.

This composite metric is more accurate than RIP's hop-count metric when choosing a path to a destination. The path that has the smallest metric value is the best route.

IGRP's metric includes the following components:

- **Bandwidth**—The lowest bandwidth value in the path

- **Delay**—The cumulative interface delay along the path
- **Reliability**—The reliability on the link toward the destination as determined by the exchange of keepalives
- **Load**—The load on a link toward the destination based on bits per second
- **MTU**—The maximum transmission unit value of the path

IGRP uses a composite metric, which is calculated as a function of bandwidth, delay, load, and reliability. By default, only the bandwidth and delay characteristics are considered; the other parameters are considered only if enabled via configuration. Delay and bandwidth are not measured values, but are set via the **delay** and **bandwidth interface** commands. The `show ip route` command in Example 16-11 shows the IGRP metric values in brackets. The first number represents the administrative distance, and the second number is the calculated metric value. A link with a higher bandwidth has a lower metric, and a route with a lower cumulative delay has a lower metric.

Example 16-11 `show ip route` Command Output Reveals IGRP Metric Values

```
RouterA# show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

C    192.168.1.0/24 is directly connected, FastEthernet0/0
C    192.168.2.0/24 is directly connected, Serial0/0
I    192.168.3.0/24 [100/80135] via 192.168.2.2, 00:00:30, Serial0/0
```

Interior, System, and Exterior IGRP Routes

IGRP advertises three types of routes:

- **Interior routes** are routes between subnets of a network attached to a router interface. If the network attached to a router is not subnetted, IGRP does not advertise interior routes.

- **System routes** are routes to networks within an autonomous system. Cisco IOS Software derives system routes from directly connected network interfaces and system route information provided by other IGRP-speaking routers or access servers. System routes do not include subnet information.
- **Exterior routes** are routes to networks outside the autonomous system that are considered when identifying a gateway of last resort. Cisco IOS Software chooses a gateway of last resort from the list of exterior routes that IGRP provides. The software uses the gateway (router) of last resort if a better route is not found and the destination is not a connected network. If the autonomous system has more than one connection to an external network, different routers can choose different exterior routers as the gateway of last resort.

IGRP Stability Features

IGRP has a number of features that are designed to enhance its stability, such as

- **Holddowns**
- **Split horizon**
- **Poison reverse updates**

Holddowns are used to prevent regular update messages from inappropriately reinstating a route that might not be up. When a router goes down, neighboring routers detect this status via the lack of regularly scheduled update messages.

Split horizon is derived from the premise that it is usually not useful to send information about a route back in the direction from which it came. The split-horizon rule helps prevent routing loops.

Split horizon prevents routing loops between adjacent routers, but poison reverse updates are necessary to defeat larger routing loops. Generally speaking, increases in routing metrics indicate routing loops. Poison reverse updates then are sent to remove the route and place it in holddown. With IGRP, poison reverse updates are sent only if a route metric has increased by a factor of 1.1.

IGRP also maintains a number of timers and variables containing time intervals that include the following:

- **Update timer**—Specifies how frequently routing update messages are sent. The IGRP default for this variable is 90 seconds.
- **Invalid timer**—Specifies how long a router waits in the absence of routing-update messages about a specific route before declaring that route invalid. The IGRP default for this variable is three times the update period.

NOTE

Today, IGRP is showing its age; it lacks support for variable-length subnet masks (VLSMs). Rather than develop an IGRP version 2 to correct this problem, Cisco has built upon IGRP's legacy of success with Enhanced IGRP (EIGRP).

- **Hold-time timer**—Specifies the amount of time for which information about poorer routes is ignored. The IGRP default for this variable is three times the update timer period plus 10 seconds.
- **Flush timer**—Indicates how much time passes before a route is flushed from the routing table. The IGRP default is seven times the routing update timer.

Example 16-12 shows the output from the `show ip protocols` command. Notice the line that indicates the IGRP is running and its metric values.

Example 16-12 IGRP Routing Statistics

```
RouterB# show ip protocols
Routing Protocol is "igrp 101"
  Sending updates every 90 seconds, next due in 51 seconds
  Invalid after 270 seconds, hold down 280, flushed after 630
  Outgoing update filter list for all interfaces is
  Incoming update filter list for all interfaces is
  Default networks flagged in outgoing updates
  Default networks accepted from incoming updates
  IGRP metric weight K1=1, K2=0, K3=1, K4=0, K5=0
  IGRP maximum hopcount 100
  IGRP maximum metric variance 1
  Redistributing: igrp 101

  Routing for Networks:
    192.168.2.0
    192.168.3.0

  Routing Information Sources:
    Gateway         Distance      Last Update
    192.168.2.1     100          00:00:54

  Distance: (default is 100)
```

Configuring IGRP

To configure the IGRP routing process, use the `router igrp` global configuration command:

```
RouterA(config)# router igrp as-number
```

To shut down an IGRP routing process, use the **no form of this command**.

```
RouterA(config)# no router igrp as-number
```

The autonomous system number is one that identifies the IGRP process. It is also used to tag the routing information.

To specify a list of networks for IGRP routing processes, use the **network** router configuration command:

```
RouterA(config)# router igrp 101  
RouterA(config-router)# network 192.168.1.0
```

To remove an entry, use the **no** form of the command:

```
RouterA(config)# no router igrp 101  
RouterA(config-router)# no network 192.168.1.0
```

Example 16-13 demonstrates how to configure IGRP using AS 101 on RouterA and RouterB.

Example 16-13 *Configuring IGRP*

```
RouterA(config)# router igrp 101  
RouterA(config-router)# network 192.168.1.0  
RouterA(config-router)# network 192.168.2.0  


---

  
RouterB(config)# router igrp 101  
RouterB(config-router)# network 192.168.2.0  
RouterB(config-router)# network 192.168.3.0
```



Lab Activity Configuring IGRP

In this lab, you set up an IP addressing scheme using Class C networks and configure IGRP on all routers.

Verifying the IGRP Configuration

To verify that IGRP has been configured properly, enter the **show ip route** command and look for IGRP routes signified by an I.

Additional commands for checking IGRP configuration are as follows:

- **show interface *interface***—Verifies that the Ethernet interface is properly configured.
- **show running-config**—Verifies that IGRP is enabled on the router.
- **show running-config interface *interface***—Verifies that the proper IP address has been used.
- **show running-config | begin interface *interface***—Verifies that IGRP is running on the router's interfaces starting at a specific interface.

- **show running-config | begin igrp**—Verifies that IGRP is enabled on the router.
- **show ip protocols**—Verifies that IGRP is enabled on the router.

To verify that the Ethernet interface is properly configured, enter the **show interface fa0/0** command. Example 16-14 illustrates the output.

Example 16-14 show interface *Command Output*

```
RouterA# show interface fa0/0
FastEthernet0/0 is up, line protocol is up
  Hardware is AmdFE, address is 0009.7c89.5620 (bia 0009.7c89.5620)
  Internet address is 192.168.1.1/24
  --- Output Omitted ---
```

To see if IGRP is enabled on the router, use the commands demonstrated in Example 16-15.

Example 16-15 show ip protocols and show running-config *Command Output*

```
RouterA# show ip protocols
Routing Protocol is "igrp 101"
  ---Output Omitted ---

RouterA# show running-config | begin igrp
router igrp 101
 network 192.168.1.0
 network 192.168.2.0
!
  --- Output Omitted ---
```

To check for proper IP addresses use the command demonstrated in Example 16-16.

Example 16-16 show running-config interface *Command Output*

```
RouterA# show running-config interface fa0/0
Building configuration...

Current configuration:
!
interface FastEthernet0/0
```

Example 16-16 show running-config interface *Command Output (Continued)*

```
ip address 192.168.1.1 255.255.255.0
no ip directed-broadcast
end
```

Example 16-17 illustrates the output from the **show ip route** command and displays the routes available via this router's interfaces.

Example 16-17 show ip route *Command Output*

```
RouterA# show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

C    192.168.1.0/24 is directly connected, Loopback0
C    192.168.2.0/24 is directly connected, Serial0/0
I    192.168.3.0/24 [100/80135] via 192.168.2.2, 00:01:00, Serial0/0
```

Troubleshooting IGRP

Most IGRP configuration errors involve a mistyped network statement, discontiguous subnets, or an incorrect autonomous system number.

The following commands are useful when troubleshooting IGRP:

- **show ip protocols**—Used to display IP routing protocol information in summary form.
- **show ip route**—Used to show the IP routing table on the router.
- **debug ip igrp events**—Displays information about summary IGRP routing that is running on the network.
- **debug ip igrp transactions**—Shows message requests from neighbor routers asking for an update and the broadcasts sent from the originating router towards that neighbor router.

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- **ping**—A utility used to determine whether a specific IP address is accessible.
- **tracert**—A utility that traces a packet from your computer to an Internet host, showing how many hops the packet requires to reach the host and how long each hop takes.

Example 16-18 illustrates output from `debug ip igrp events` command.

Example 16-18 `debug ip igrp events` *Command Output*

```
RouterA# debug ip igrp events
IGRP event debugging is on

00:21:38: IGRP: sending update to 255.255.255.255 via FastEthernet0/0 (192.168.1
.1)
00:21:38: IGRP: Update contains 0 interior, 2 system, and 0 exterior routes.
00:21:38: IGRP: Total routes in update: 2
00:21:38: IGRP: sending update to 255.255.255.255 via Serial0/0 (192.168.2.1)
00:21:38: IGRP: Update contains 0 interior, 1 system, and 0 exterior routes.
00:21:38: IGRP: Total routes in update: 1
```

Example 16-19 illustrates output from `debug ip igrp transactions` command.

Example 16-19 `debug ip igrp transactions` *Command Output*

```
RouterA# debug ip igrp transactions
IGRP protocol debugging is on

00:22:17: IGRP: received update from 192.168.2.2 on Serial0/0
00:22:17:      network 192.168.3.0, metric 80135 (neighbor 110)
00:23:07: IGRP: sending update to 255.255.255.255 via FastEthernet0/0 (192.168.1
.1)
00:23:07:      network 192.168.2.0, metric=80125
00:23:07:      network 192.168.3.0, metric=80135
00:23:07: IGRP: sending update to 255.255.255.255 via Serial0/0 (192.168.2.1)
00:23:07:      network 192.168.1.0, metric=110
```


If it is discovered that the wrong AS number is being used, correcting it as in Example 16-20 results in the corrected output.

Example 16-20 debug ip igrp transactions

```
RouterA(config)# no router igrp 102
RouterA(config)# router igrp 101
RouterA(config-router)# network 192.168.1.0
RouterA(config-router)# network 192.168.2.0

00:27:50: IGRP: broadcasting request on FastEthernet0/0
00:27:50: IGRP: sending update to 255.255.255.255 via FastEthernet0/0
(192.168.1.1)
00:27:51: IGRP: Update contains 0 interior, 0 system, and 0 exterior routes.
00:27:51: IGRP: Total routes in update: 0 - suppressing null
00:28:01: IGRP: sending update to 255.255.255.255 via FastEthernet0/0
(192.168.1.1)
00:28:01:      network 192.168.2.0, metric=80125
00:28:01:      network 192.168.3.0, metric=80135
00:28:01: IGRP: Update contains 0 interior, 2 system, and 0 exterior routes.
00:28:01: IGRP: Total routes in update: 2
00:28:01: IGRP: sending update to 255.255.255.255 via Serial0/0 (192.168.2.1)
00:28:01:      network 192.168.1.0, metric=110
00:28:01: IGRP: Update contains 0 interior, 1 system, and 0 exterior routes.
00:28:01: IGRP: Total routes in update: 1
```



Lab Activity Default Routing with RIP and IGRP

In this lab, you configure a default route and use RIP to propagate this default information to other routers. When you have this configuration working, you must migrate the network from RIP to IGRP and configure default routing to work with that protocol as well.



Lab Activity Unequal Cost Load Balancing with IGRP

In this lab, you configure and tune IGRP for unequal-cost load balancing and observe load balancing using debug commands.

Summary

In this chapter, you learned the following:

- Routing information is maintained through updates as the topology changes in a network.
- Routing loops occur in a network from alternate routes, slow convergence, and inconsistent routing updates.
- Defining a maximum can be achieved to prevent count to infinity.
- Three methods of preventing routing loops: split horizon, triggered updated, and hold-down timers.
- Route poisoning is used by various distance vector protocols to overcome large routing loops and offer information about when a subnet or network is not accessible.
- To configure routing protocols: RIP and IGRP.
- To use the ip classless command.
- To troubleshoot routing protocols: RIP and IGRP.
- To verify routing protocols: RIP and IGRP.
- To configure default routes.

To supplement all that you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab Activities on the CD-ROM accompanying this book.

Key Terms

adjacent neighbor Two directly connected routers that participate in the exchange of routing information are said to be *adjacent*.

convergence The speed and capability of a group of internetworking devices running a specific routing protocol to agree on the topology of an internetwork after a change in that topology.

count to infinity A problem that can occur in routing algorithms that are slow to converge in which routers continuously increment the hop count to particular networks. Typically, some arbitrary hop-count limit is imposed to prevent this problem.

exterior routes Routes to networks outside the autonomous system that are considered when identifying a gateway of last resort.

flush timer Indicates how much time passes before a route is flushed from the routing table. The IGRP default is seven times the routing update timer.

holddowns Prevent regular update messages from inappropriately reinstating a route that might not be up.

hold-time timer Specifies the amount of time for which information about better routes is ignored. The IGRP default for this variable is 3 times the update timer period plus 10 seconds.

IGRP (Interior Gateway Routing Protocol) An IGP developed by Cisco to address the problems associated with routing in large, heterogeneous networks. *Compare with* EIGRP. *See also* IGP, OSPF, and RIP.

interior routes Routes between subnets of a network attached to a router interface. If the network attached to a router is not subnetted, IGRP does not advertise interior routes.

invalid timer Specifies how long a router waits in the absence of routing-update messages about a specific route before declaring that route invalid. The IGRP default for this variable is three times the update period.

poison reverse updates Updates that are necessary to defeat larger routing loops. Generally speaking, increases in routing metrics indicate routing loops. Poison reverse updates are then sent to remove the route and place it in holddown.

RIP (Routing Information Protocol) An IGP supplied with UNIX BSD systems. The most common IGP in the Internet. RIP uses hop count as a routing metric.

routing metric A method by which a routing algorithm determines that one route is better than another. This information is stored in routing tables and sent in routing updates. Metrics include bandwidth, communication cost, delay, hop count, load, MTU, path cost, and reliability. Sometimes referred to simply as a metric.

routing protocol A protocol that accomplishes routing through the implementation of a specific routing algorithm. Examples of routing protocols are IGRP, OSPF, and RIP.

routing table A table stored in a router or some other internetworking device that keeps track of routes to particular network destinations and, in some cases, metrics associated with those routes.

routing update A message sent from a router to indicate network reachability and associated cost information. Routing updates are typically sent at regular intervals and after a change in network topology. Compare with flash update.

split horizon A routing technique in which information about routes is prevented from exiting the router interface through which that information was received. Split-horizon updates are useful in preventing routing loops.

system routes Routes to networks within an autonomous system. Cisco IOS Software derives system routes from directly connected network interfaces and system route information provided by other IGRP-speaking routers or access servers. System routes do not include subnet information.

triggered update A triggered update is an update that is sent without waiting for the update timer to expire.

update timer Specifies how frequently routing update messages are sent. The IGRP default for this variable is 90 seconds.

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. What kind of entries does a router initially refer to?
 - A. Entries about networks or subnets that are directly connected
 - B. Entries that it has learned about from the Cisco IOS Software
 - C. Entries whose IP address and mask information are known
 - D. Entries that it has learned about from other routers

2. Which of the following best describes a static route?
 - A. A routing table entry that is used to direct frames for which a next hop is not explicitly listed in the routing table
 - B. A route that is explicitly configured and entered into the routing table and that takes precedence over routes chosen by dynamic routing protocols
 - C. A route that adjusts automatically to network topology or traffic changes
 - D. A route that adjusts involuntarily to direct frames within a network topology
3. Which of the following best describes a default route?
 - A. A routing table entry that is used to direct frames for which a next hop is not explicitly listed in the routing table
 - B. A route that is explicitly configured and entered into the routing table
 - C. A route that adjusts automatically to network topology or traffic changes
 - D. A route that adjusts involuntarily to direct frames within a network topology
4. What are exterior routing protocols used for?
 - A. To transmit between nodes on a network
 - B. To deliver information within a single autonomous system
 - C. To communicate between autonomous systems
 - D. To set up a compatibility infrastructure between networks
5. What are interior routing protocols used for?
 - A. They are used to set up a compatibility infrastructure between networks.
 - B. They are used to communicate between autonomous systems.
 - C. They are used to transmit between nodes on a network.
 - D. They are used within a single autonomous system.
6. Which of the following is a global task?
 - A. Addressing IP network numbers by specifying subnet values
 - B. Enabling a routing protocol such as RIP or IGRP
 - C. Assigning network/subnet addresses and the appropriate subnet mask
 - D. Setting up a routing metric to find the best path to each network

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7. What metric does RIP use to determine the best path for a message to travel on?
 - A. Bandwidth
 - B. Hop count
 - C. Varies with each message
 - D. Administrative distance
8. You suspect that one of the routers connected to your network is sending bad routing information. What command can you use to check?
 - A. `router(config)# show ip route`
 - B. `router# show ip route`
 - C. `router> show ip protocol`
 - D. `router(config-router)# show ip protocol`
9. Why would you display the IP routing table?
 - A. To set the router update schedule
 - B. To identify destination network addresses and next-hop pairs
 - C. To trace where datagrams are coming from
 - D. To set the parameters and filters for the router
10. If you want to learn which routing protocol a router was configured with, what command structure should you use?
 - A. `router> show router protocol`
 - B. `router(config)> show ip protocol`
 - C. `router(config)# show router protocol`
 - D. `router> show ip protocol`
11. In the following command, what does the last number stand for?
Router (config)# `ip route 2.0.0.0 255.0.0.0 1.0.0.2 5`
 - A. The number of hops
 - B. The number of routes to the destination
 - C. The administrative distance
 - D. The destination's reference number in the routing table

12. An administrative distance of 15 indicates which of the following?
- A. The IP address is static.
 - B. The IP address is dynamic.
 - C. The routing information source is relatively trustworthy.
 - D. The routing information source is relatively untrustworthy.
13. If you just added a new LAN to your internetwork and you want to manually add the network to your routing table, what command structure would you use?
- A. `router (config)> ip route 2.0.0.0 255.0.0.0 via 1.0.0.2`
 - B. `router (config)# ip route 2.0.0.0 255.0.0.0 1.0.0.2`
 - C. `router (config)# ip route 2.0.0.0 via 1.0.0.2`
 - D. `router (config)# ip route 2.0.0.0 1.0.0.2 using 255.0.0.0`



Objectives

Upon completion of this chapter, you will be able to

- Describe ICMP
- Describe the ICMP message format
- Identify ICMP error message types
- Identify potential causes of specific ICMP error messages
- Identify a variety of ICMP control messages used in networks today
- Determine the causes for ICMP control messages

Chapter 17

TCP/IP Error and Control Messages

Now that you have learned about the router configuration process, it is time to learn about Transmission Control Protocol/Internet Protocol (TCP/IP) suite error and control messages. In this chapter, you learn how the Internet Control Message Protocol (ICMP) provides control and message functions. In addition, you learn about potential causes of ICMP error messages and how to identify them.

Please be sure to look at this chapter's associated e-Labs, Videos, and PhotoZooms that you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

Functionality and Role of IP in Error Control

The function of IP is to facilitate network communication between hosts. The design of IP allows for the addressing of hosts and networks. This distinguishes IP from nonroutable protocols that can address individual hosts but that are not designed to make distinctions between networks. IP acceptance is so widespread that, in addition to being the protocol used for data delivery over the Internet, it has become the default internal protocol for small LANs that do not necessarily require routing capabilities.

The limitation of IP is that it is a best-effort delivery system. IP has no mechanism to ensure that the data is delivered regardless of any problems encountered on the network. Data might fail to reach its destination for a variety of reasons, such as hardware failure, improper configuration, or incorrect routing information. If an intermediary device such as a router fails, or if a destination device is disconnected from the network, data cannot be delivered. This is why applications that use IP are typically faster: They don't have the

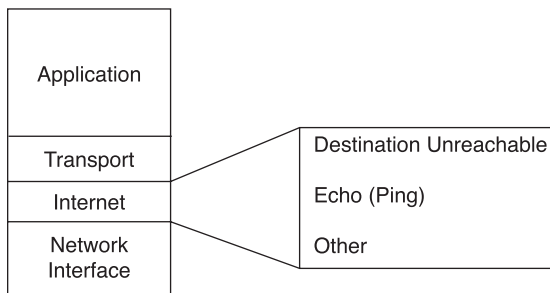
error control or reliable mechanism that TCP has. To help identify these failures, IP uses the *Internet Control Message Protocol (ICMP)*. ICMP notifies the sender of the data that an error occurred in the delivery process.

The following sections review the different types of ICMP error messages and the forms they take. Knowledge of ICMP error messages and an understanding of the potential causes of these messages are essential parts of network troubleshooting.

ICMP

ICMP is the component of the *TCP/IP* protocol stack that addresses IP's failure to ensure data delivery. ICMP does not overcome the unreliability limitation that exists in IP. ICMP simply sends error messages to the sender of the data, indicating that problems occurred with data delivery. Figure 17-1 shows where ICMP resides within the TCP/IP model.

Figure 17-1 ICMP and the TCP/IP Model



This section covers the various facets of ICMP, including ICMP message delivery, error reporting and correction, and ways of detecting and handling reachability issues.

ICMP Message Delivery

ICMP messages are delivered using the IP protocol. ICMP messages are encapsulated into datagrams in the same way that any other data is delivered using IP. Table 17-1 displays the encapsulation of an ICMP packet within the IP packet datagram data area. The frame header can be from a LAN protocol, such as Ethernet, or a WAN protocol, such as HDLC.

Table 17-1 ICMP Encapsulation

Frame header	IP datagram header	ICMP header	ICMP data
Frame header	IP datagram header	IP datagram data area	
Frame header	Frame data area		

Data is encapsulated within a datagram when it reaches the network layer. From there, the datagram and its encapsulated data are encapsulated further into a frame at the data link layer. ICMP messages have their own header information. However, this information, along with the ICMP data, is encapsulated just as any other data is within the datagram. ICMP messages are transmitted in the same way as any other data. Therefore, ICMP messages are subject to the same delivery failures. This creates a scenario in which error reports could generate more error reports, causing increased congestion on an already ailing network. For this reason, errors created by ICMP messages do not generate their own ICMP messages. Therefore, it is possible for a datagram delivery error to occur but never be reported back to the sender of the data.

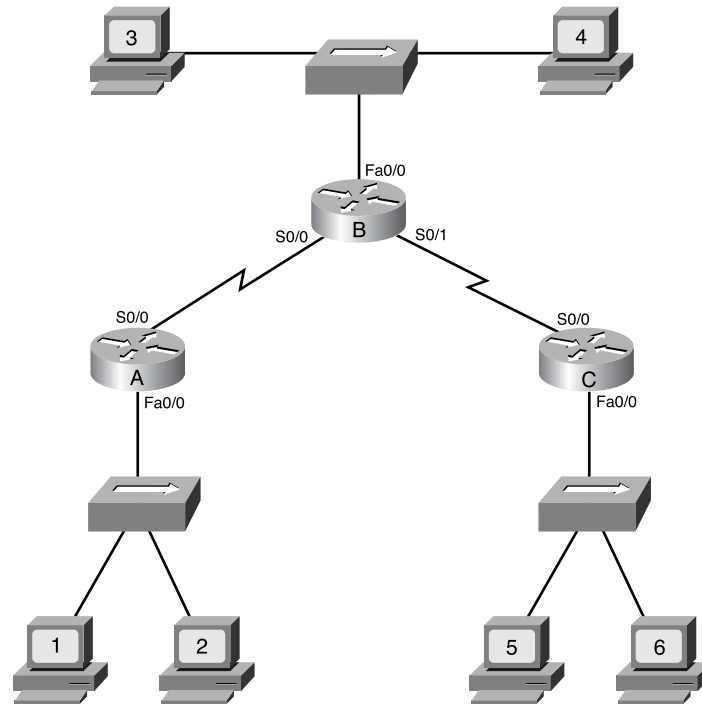
Error Reporting and Error Correction

ICMP is an error-reporting protocol for IP. When datagram delivery errors occur, ICMP reports these errors to the sender of the datagram. For example, Workstation 1 in Figure 17-2 is sending a datagram to Workstation 6. When the corresponding interface on Router C goes down, Router C uses ICMP to send a message back to Workstation 1 indicating that the datagram could not be delivered. ICMP does not correct the encountered network problem.

In the example from Figure 17-2, ICMP does not attempt to correct the problem with the interface on Router C that is preventing datagram delivery. The only capability of ICMP is to report the errors back to Workstation 1.

Router C will not notify the intermediary devices of the delivery failure. Therefore, Router C will not send ICMP messages to Router A and Router B or to the originating device. Router C also does not know what path the *datagram* has taken to arrive there. Datagrams contain only source and destination IP addresses; they do not contain information about all the intermediary devices. The reporting device has only the sender's IP address with which to communicate. Although Routers A and B are not notified directly, they might become aware of the down interface on Router C. However, disseminating this information to neighbor routers is not the function of ICMP. Instead, ICMP reports on the status of the delivered packet to the sender; its function is not to propagate information about network changes.

Figure 17-2 Error Reporting Being Updated



Unreachable Networks

Network communication depends on certain basic conditions:

- The TCP/IP protocol stack must be properly configured in the sending and receiving devices. This includes the installation of TCP/IP and proper configuration of the IP address and the subnet mask. A default gateway also must be configured if datagrams are to travel outside the local network.
- Intermediary devices must be in place to route the datagram from the source device and its network to the destination network. Routers serve this function.
- A router must have the TCP/IP protocol properly configured on its interfaces, and it must use an appropriate routing protocol or static routes.

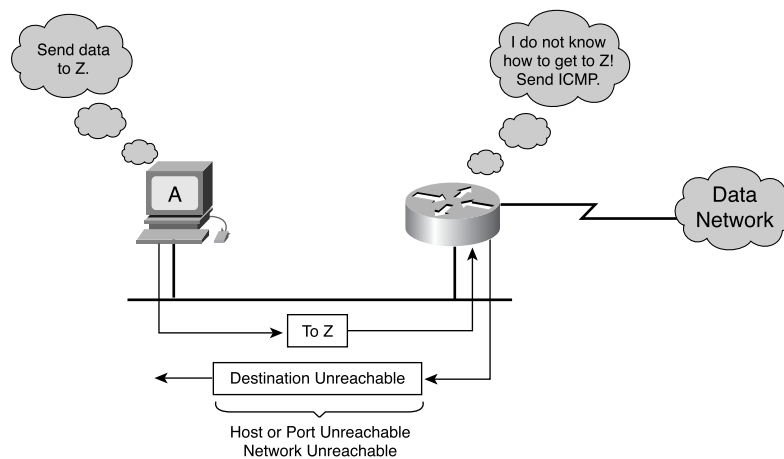
If these conditions are not met, network communication cannot take place. For example, the sending device might address the datagram to a nonexistent IP address or to a destination device that is disconnected from its network. Routers also can be points of failure if a connecting interface is down or if the router does not have the information necessary to find the destination network. If a destination network is not accessible, it is said to be an *unreachable network*.

Destination unreachable messages include the following:

- **Network unreachable**—This message usually implies routing or addressing failures.
- **Host unreachable**—This message usually implies delivery failures, such as a wrong subnet mask.
- **Protocol unreachable**—This message usually implies that the destination does not support the upper-layer protocol specified in the packet.
- **Port unreachable**—This message usually implies that the TCP port (socket) is not available.

Figure 17-3 shows a router receiving a packet that it cannot deliver to its ultimate destination. The packet might be undeliverable because there is no known route to the destination. Because there is no known route, the router sends an ICMP host unreachable message to the source.

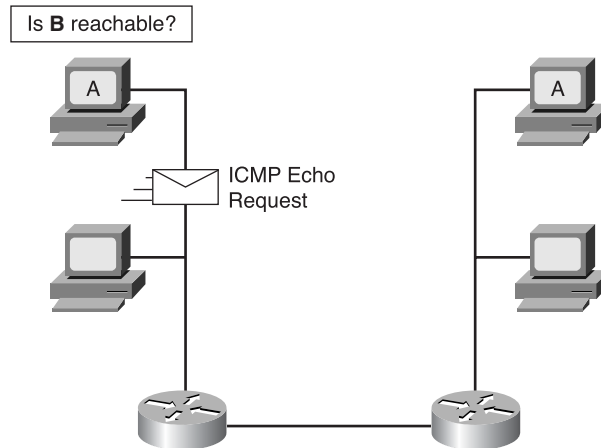
Figure 17-3 ICMP Host Unreachable



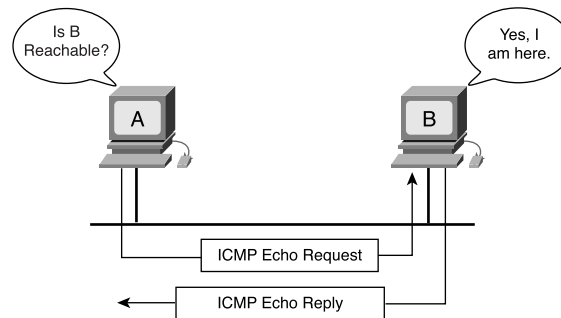
Using ping to Test Destination Reachability

The ICMP protocol can be used to test the availability of a particular destination.

Figure 17-4 shows ICMP being used to issue an echo request message to the destination device. When the destination device receives the ICMP echo request, it formulates an echo reply message to send back to the source of the echo request. If the sender receives the echo reply, this confirms that the destination device can be reached using the IP protocol.

Figure 17-4 Echo Request

The echo request message typically is initiated using the *ping* command, as demonstrated in Example 17-1. In this example, the command is used with the IP address of the destination device. Example 17-1 and Figure 17-5 show a successful ping or echo request/reply.

Figure 17-5 ICMP ping**Example 17-1** Echo Request Initiated by ping

```
C:\> ping 198.133.219.25
```

```
Pinging 198.133.219.25 with 32 bytes of data:
```

```
Reply from 198.133.219.25: bytes=32 time=30ms TTL=247
```

```
Reply from 198.133.219.25: bytes=32 time=20ms TTL=247
```

Example 17-1 *Echo Request Initiated by ping (Continued)*

```
Reply from 198.133.219.25: bytes=32 time=20ms TTL=247
Reply from 198.133.219.25: bytes=32 time=20ms TTL=247

Ping statistics for 198.133.219.25:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 20ms, Maximum = 30ms, Average = 22ms

C:\>
```

The **ping** command also can be used as demonstrated in Example 17-2 using the DNS name of the destination device (assuming that DNS is available).

Example 17-2 *Using ping with Destination Device DNS Name*

```
C:\> ping www.cisco.com

Pinging www.cisco.com [198.133.219.25] with 32 bytes of data:

Reply from 198.133.219.25: bytes=32 time=30ms TTL=247
Reply from 198.133.219.25: bytes=32 time=20ms TTL=247
Reply from 198.133.219.25: bytes=32 time=20ms TTL=247
Reply from 198.133.219.25: bytes=32 time=20ms TTL=247

Ping statistics for 198.133.219.25:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 20ms, Maximum = 30ms, Average = 22ms

C:\>
```

In these workstation examples, the **ping** command issues four echo requests and receives four echo replies confirming IP connectivity between the two devices. The output generated by the router **ping** command is somewhat different than the workstation **ping** command. Example 17-3 shows a successful and unsuccessful ping from RouterA to RouterB (IP address 192.168.100.100). The exclamation marks (!) indicate a successful ping, and the periods (.) indicate failure. Table 17-2 shows Cisco ping return codes generated when pinging between Cisco devices.

Example 17-3 Router ping Examples: Success and Failure

```

RouterA# ping 192.168.100.100

Type escape sequence to abort.

Sending 5, 100byte ICMP Echoes to 192.168.100.100, timeout is 2 seconds:
!!!!

Success rate is 100 percent (5/5), round-trip min/avg/max = 36/36/36 ms

RouterA# ping 192.168.100.100

Type escape sequence to abort.
Sending 5, 100byte ICMP Echoes to 192.168.100.100, timeout is 2 seconds:
. . . . .

Success rate is 0 percent (0/5)

```

Table 17-2 Cisco ping Return Codes

Code	Meaning	Possible Cause(s)
!	Each exclamation point indicates receipt of an ICMP echo reply.	The ping completed successfully.
.	Each period indicates that the network server timed out while waiting for a reply.	This message can indicate many problems: <ul style="list-style-type: none"> ■ The ping was blocked by an access list or firewall. ■ A router along the path did not have a route to the destination and did not send an ICMP destination unreachable message. ■ A physical connectivity problem occurred somewhere along the path.
U	An ICMP unreachable message was received.	A router along the path did not have a route to the destination address.

Table 17-2 Cisco ping Return Codes (Continued)

Code	Meaning	Possible Cause(s)
C	An ICMP source quench message was received.	A device along the path—possibly the destination—might be receiving too much traffic; check input queues.
&	An ICMP time exceeded message was received.	A routing loop might have occurred.

Detecting Excessively Long Routes

Several problem situations can occur in network communication. In one situation, a datagram travels in a circle, never reaching its destination. In another situation, no path exists between the source and the destination that conforms to the limitations of the routing protocol. An example of the first situation arises when two routers continually route a datagram back and forth. In this scenario, each router operates with the understanding that the other router should be the next hop to the destination. One potential cause of this problem is faulty routing information. Routing protocols can also have limits on the distance that a packet is allowed to travel. For example, RIP has a hop limit of 15, which simply means that the packet is allowed to pass through only 15 routers.

In each of these cases, an excessively long route exists. Whether the actual path includes too many hops or a circular routing path exists, the packet eventually will reach the end of its life. When a packet reaches the end of its life, it has reached its Time-To-Live (TTL). The TTL value typically matches the maximum hop count defined by the routing protocol. In each datagram, a TTL value is defined. As each router processes the datagram, it decreases the TTL value by one. When the TTL value of the datagram reaches 0, the packet is discarded. ICMP uses a time exceeded message to notify the source device that the TTL has been exceeded.

ICMP Message Format: Echo Messages

As with any type of packet, ICMP messages have special formats. Each ICMP message type shown in Table 17-3 has its own unique characteristics. However, all ICMP message formats start with the following three fields:

- Type
- Code
- Checksum

The Type field indicates the type of ICMP message being sent. The Code field includes further information that is specific to the message type. The Checksum field, as in other types of packets, verifies the integrity of the data.

Table 17-3 ICMP Message Types

ICMP	Message Types
0	Echo reply
3	Destination unreachable
4	Source quench
5	Redirect/change request
8	Echo request
9	Router advertisement
10	Router selection
11	Time exceeded
12	Parameter problem
13	Timestamp request
14	Timestamp reply
15	Information request
16	Information reply
17	Address mask request
18	Address mask reply

Figure 17-6 shows the message format for the ICMP echo request and echo reply messages. The relevant type and code numbers are shown for each message type. The Identifier and Sequence Number fields are unique to the echo request and echo reply messages. The Identifier and Sequence fields are used to match the echo replies to the corresponding echo request. The Data field contains additional information that might be a part of the echo reply or echo request message.

Figure 17-6 Message Format for Echo Request and Echo Reply

0	8	16	31
Type (0 or 8)	Code (0)	Checksum	
Identifier		Sequence Number	
Optional Data			
...			

ICMP Message Format: Destination Unreachable Message

Datagrams cannot always be forwarded to their destinations, as shown in Figure 17-7. Hardware failures, improper protocol configuration, down interfaces, and incorrect routing information are some of the reasons why successful delivery might not be possible. In these cases, ICMP delivers back to the sender a destination unreachable message indicating that the datagram could not be properly forwarded.

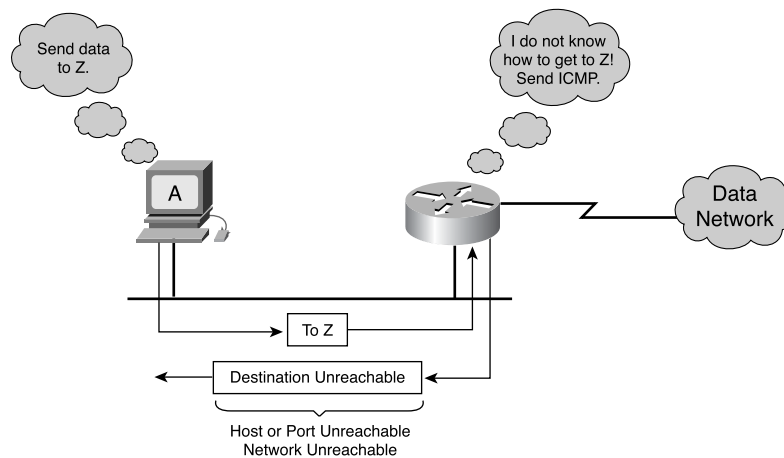
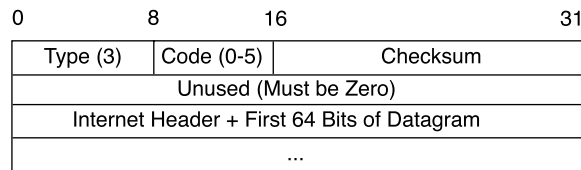
Figure 17-7 Destination Unreachable Message

Figure 17-8 shows an ICMP destination unreachable message header. The value of 3 in the Type field indicates that it is a destination unreachable message. The Code value indicates the reason why the packet could not be delivered. The Code value is 0, indicating that the network was unreachable. Table 17-4 displays Code values and description.

Figure 17-8 Destination Unreachable Message Format**Table 17-4** Code Value and Description

Code Value	Description
0	Network unreachable
1	Host unreachable
2	Protocol unreachable
3	Port unreachable
4	Fragmentation needed and DF set
5	Source route failed
6	Destination network unknown
7	Destination host unknown
8	Source host isolated
9	Communication with data network administratively prohibited
10	Communication with data host administratively prohibited
11	Network unreachable for type of service
12	Host unreachable for type of service

A destination unreachable message also might be sent when packet fragmentation is required to forward a packet. Fragmentation is usually necessary when a datagram is forwarded from a Token Ring network to an Ethernet network. If the datagram does not allow fragmentation, the packet cannot be forwarded. Therefore, a destination unreachable message is sent. Destination unreachable messages also can be generated if IP-related services such as FTP or web services are unavailable. To effectively troubleshoot an IP network, it is necessary to understand the various causes of ICMP destination unreachable messages.

Miscellaneous Error Reporting

Devices that process datagrams might not be capable of forwarding a datagram because of some type of error in the header. This error does not relate to the state of the destination host or network, but it still prevents the datagram from being processed and delivered. In this case, an ICMP Type 12 parameter problem message is sent to the source of the datagram. Figure 17-9 shows the parameter problem message header.

The parameter problem message includes the Pointer field in the header. When the Code value is 0, the Pointer field indicates the octet of the datagram that produced the error.

Figure 17-9 Parameter Problem Message Format

0	8	16	31
Type (12)	Code (0-2)	Checksum	
Pointer	Unused (Must be Zero)		
Internet Header + First 64 Bits of Datagram			
...			

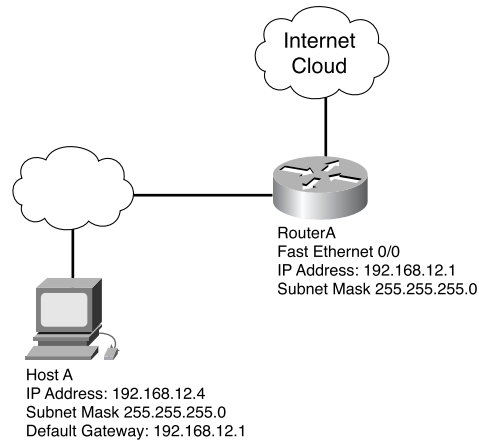
TCP/IP Suite Control Messages

Unlike error messages, control messages are not the result of lost packets or error conditions that occur during packet transmission. Instead, control messages inform hosts of conditions such as network congestion or the existence of a better gateway to a remote network. Like all ICMP messages, ICMP control messages are encapsulated within an IP datagram. ICMP uses IP datagrams to traverse multiple networks.

ICMP uses multiple types of control messages; Table 17-3 listed some of the most common. Many of these control messages are discussed in the following sections.

ICMP Redirect/Change Requests

A common ICMP control message is the ICMP redirect/change request. This type of message can be initiated only by a gateway. All hosts that communicate with multiple IP networks must be configured with a default gateway. This default gateway is the address of a router port connected to the same network as the host. Figure 17-10 displays a host connected to a router that has access to the Internet.

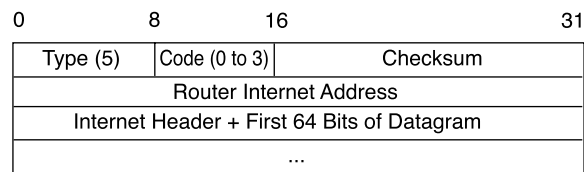
Figure 17-10 Redirect Request

After it is configured with the IP address of Fa 0/0 as its default gateway, Host B uses that IP address to reach any network not directly connected to it. Normally, Host B connects to only a single gateway. However, in some circumstances, a host connects to a segment that has two or more directly connected routers. In this case, the host's default gateway might need to use a redirect/change request to inform the host of the best path to a certain network.

Default gateways send ICMP redirects/change requests only if the following conditions are met:

- The interface on which the packet comes into the router is the same interface on which the packet gets routed out.
- The subnet/network of the source IP address is the same subnet/network of the next-hop IP address of the routed packet.
- The datagram is not source-routed (that is, it is not routed from the place from which the data is taken).
- The route for the redirect is not another ICMP redirect or a default route.
- The router is configured to send redirects. By default, Cisco routers send ICMP redirects. The interface subcommand **no ip redirects** disables ICMP redirects.

The ICMP redirect/change request uses the format shown in Figure 17-11. The request has an ICMP type code of 5. In addition, the request has a code value of 0, 1, 2, or 3. The meanings of these code values with their required actions are shown in Table 17-5.

Figure 17-11 Redirect Request Message Format**Table 17-5** Code Value with Required Action

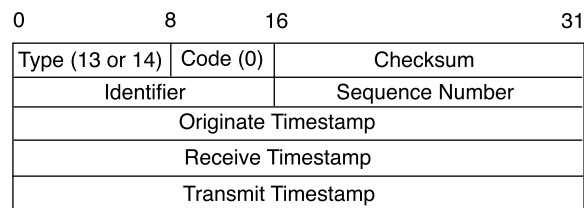
Code Value	Required Action
0	Redirect datagrams for the network
1	Redirect datagrams for the host
2	Redirect datagrams for the type of service and the network
3	Redirect datagrams for the type of service and the host

The receiver of the redirect should use the gateway Internet address in the ICMP redirect as the router IP address when forwarding packets for a particular network. In the example shown in Figure 17-10, the ICMP redirect sent from Router A to Host B would have a gateway Internet address of 192.168.12.2, which is the IP address of Router B.

Clock Synchronization and Transit Time Estimation

The TCP/IP protocol suite allows systems to connect to one another over vast distances through multiple networks. Each individual network provides clock synchronization in its own way. This can result in problems when hosts on different networks try to communicate using software that requires time synchronization. The ICMP timestamp message type is designed to help reduce this problem.

The ICMP timestamp request message allows a host to ask for a remote host's current time. The remote host uses an ICMP timestamp reply message to respond to the request. Figure 17-12 shows the format for an ICMP timestamp request or reply.

Figure 17-12 Timestamp Request

The Type field on an ICMP timestamp message can be either 13 for a timestamp request or 14 for a timestamp reply. The Code field value is always set to 0 because no additional parameters are available. The ICMP timestamp request contains an originate timestamp, which specifies the time on the requesting host just before the timestamp request was sent. The receive timestamp is the time that the destination host received the ICMP timestamp request. The transmit timestamp is filled in just before the ICMP timestamp reply is returned. Originate, receive, and transmit timestamps are computed in milliseconds elapsed since midnight Universal Time (UT).

All ICMP timestamp reply messages contain the originate, receive, and transit timestamps. Using these three timestamps, the host that originated the ICMP timestamp request can estimate transit time across the network. By subtracting the originate time from the transit time, the host can try to guess its transit time. However, this is only a guess because the true transit time can vary widely, depending on traffic and congestion on the network. Also, using these three timestamps, the host that originated the ICMP timestamp request can estimate the local time of the remote computer.

ICMP timestamp messages provide a simple way of estimating time on a remote host and the total network transit time. However, this is not the best way to obtain this information. Instead, protocols such as the Network Time Protocol (NTP), at the higher layers of the TCP/IP protocol stack, perform clock synchronization in a more reliable manner.

Information Requests and Reply Message Formats

The ICMP information requests and reply messages originally were intended to enable a host to determine the number of the network that it occupied. Figure 17-13 shows the format for an ICMP information request and reply message.

Figure 17-13 Information Request and Reply Message Format

0	8	16	31
Type (15 or 16)	Code (0)	Checksum	
Identifier		Sequence Number	

Two type codes are available in this message. Type 15 code signifies an information request message. Type 16 code identifies an information reply message. This particular ICMP message type is considered obsolete. Other protocols, such as BOOTP and

Dynamic Host Configuration Protocol (DHCP), now are used to allow hosts to obtain their network numbers to which they are attached.

Address Mask Requests

When a network administrator uses the process of subnetting to divide a major IP address into multiple subnets, a new subnet mask is created. This new subnet mask is crucial in identifying network, subnet, and host bits in an IP address. If a host does not know the subnet mask, it might send an address mask request to the local router. If the address of the router is known, this request can be sent as *unicast*. If the address is not known, this request is sent using *broadcast*. When the router receives the request, it responds with an address mask reply. This address mask reply identifies the correct subnet mask. For example, assume that a host is located within a Class B network and has an IP address of 172.16.5.3. This host does not know the subnet mask, so it broadcasts an address mask request:

```
Source address      172.16.5.3
Destination address 255.255.255.255
Protocol           ICMP = 1
Type              Address Mask Request = AM1
Code              0
Mask              0
```

This broadcast is received by 168.5.5.1, the local router. That router responds with the address mask reply:

```
Source address      172.16.5.1
Destination address 172.16.5.3
Protocol           ICMP = 1
Type              Address Mask Reply = AM2
Code              0
Mask              255.255.255.0
```

Figure 17-14 shows the frame format for the address mask request. Table 17-6 lists the ICMP address mask request messages. Notice that the same frame format is used for both the address mask request and the reply. However, an ICMP type number of 17 is assigned to the request, and 18 is assigned to the reply.

Figure 17-14 Address Mask Requests

0	8	16	31
Type (17...18)	Code (0)	Checksum	
Identifier		Sequence Number	
Address Mask			
...			

Table 17-6 ICMP Address Mask Request Messages

ICMP Field	Description
Type 17	Address mask request message.
Type 18	Address mask reply message.
Code 0	Address mask request message.
Code 0	Address mask reply message.
Checksum	The 16-bit 1s complement of the 1s complement sum of the ICMP message starting with the ICMP type. For computing the checksum, the checksum field should be 0. The checksum might be replaced in the future.
Identifier	An identifier to aid in matching requests and replies. It can be 0.
Sequence Number	A sequence number to aid in matching requests and replies. It can be zero.
Address Mask	A 32-bit mask. A gateway receiving an address mask request should return it with the Address Mask field set to the 32-bit mask of the bits identifying the subnet and the network for the subnet on which the request was received. If the requesting host does not know its own IP address, it can leave the source field 0; the reply then should be broadcast. However, this approach should be avoided if at all possible because it increases the superfluous broadcast load on the network. Even when the replies are broadcast, there is no need to match requests with replies because there is only one possible address mask for a subnet. The Identifier and Sequence Number fields can be ignored. Type AM1 can be received from a gateway or host. Type AM2 can be received from a gateway, or a host acting in lieu of a gateway.

Router-Discovery Message

The host can learn the available routers through the process of router discovery when the host has not been manually configured with a default gateway. This process begins with the host sending a *multicast* router-solicitation message to all routers, using the address 224.0.0.2. Figure 17-15 shows the ICMP router-solicitation message. This router solicitation also can be sent using broadcast to include routers that might not be configured for multicasting. RFC 1812 indicates that routers should be capable of supporting the router-discovery process for all the networks that are directly connected.

However, this support is not always the case. If a router-solicitation message is sent to a router that does not support the discovery process, the solicitation will go unanswered.

Figure 17-15 Router-Discovery Message

0	8	16	31
Type (9)	Code (0)	Checksum	
Number of Addresses	Address Entry Size	Lifetime	
Router Address 1			
Preference Level 1			
Router Address 2			
Preference Level 2			

When a router that supports the discovery process receives the router-solicitation message, a router advertisement is sent in return. Table 17-7 provides an explanation for each field of the frame format.

Table 17-7 Router Frame Format

ICMP Field	Description
Type	9.
Type	0.
Checksum	The 16-bit 1s complement of the 1s complement sum of the ICMP message starting with the ICMP type. For computing the checksum, the checksum field should be 0.
Number of Addresses	The number of router addresses advertised in this message.
Address Entry Size	The number of 32-bit words of information per each router address (2 in the version of protocol described here).
Lifetime	The maximum number of seconds that the router addresses are considered valid.
Router Addresses	The sending router IP address(es). The number of the address interface from which this message is sent.
Preference Level	The preference of each router address. The number address as a default router address, relative to other router addresses on the same subnet. A signed twos-complement value; higher values mean more preferable.

Router-Solicitation Message

A host generates an ICMP router-solicitation message in response to a missing default gateway. This message is sent using multicast. This message is the first step in the router-discovery process. A local router responds with a router advertisement identifying the default gateway for the local host.

Figure 17-16 identifies the frame format, and Table 17-8 gives an explanation of each field.

Figure 17-16 Router-Solicitation Message Frame Format

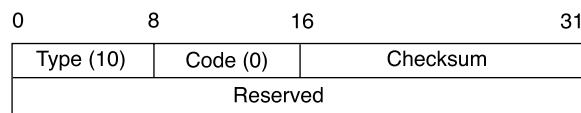


Table 17-8 Router-Solicitation Message Frame Field Descriptions

ICMP Field	Description
Type	10.
Code	0.
Checksum	The 16-bit 1s complement of the 1s complement sum of the ICMP message starting with the ICMP type. For computing the checksum, the checksum field should be 0.
Reserved	Sent as 0; ignored on reception.

Congestion and Flow-Control Messages

If multiple computers try to access the same receiver, the receiver can be overcome with traffic. Congestion also can occur when traffic from a high-speed LAN reaches a slower WAN connection. Congestion on the network or the receiver causes dropped packets, which results in a loss of data. To reduce the amount of data lost, ICMP messages must be sent to the source of the congestion. This type of ICMP message is called a *source quench message*. The source quench message notifies the sender of the congestion and asks the sender to reduce the rate at which it is transmitting packets. In most cases, congestion subsides after a short period of time. The source slowly increases the transmission rate as long as no other source quench messages are received. Most Cisco routers do not send source quench messages by default. This is because the source quench message might, in itself, add to the network congestion.

ICMP source quench message might be used effectively in a small office, home office (SOHO). One such SOHO could consist of four computers networked together using Category 5 cable and Internet connection sharing (ICS) over a 56-kbps modem. It is easy to see that the 10-Mbps bandwidth of the SOHO LAN easily could overwhelm the available 56-kbps bandwidth of the WAN link. This could result in data loss and retransmissions. With ICMP messaging, the host acting as the gateway in the ICS can request that the other hosts reduce their transmission rates to a manageable level. Reducing the transmission rates prevents continued data loss.

Summary

These key points were discussed in this chapter:

- IP is a best-effort delivery method that uses ICMP messages to alert the sender that the data did not reach its destination.
- ICMP echo request and echo reply messages enable the network administrator to test IP connectivity to aid in the troubleshooting process.
- ICMP messages are transmitted using the IP protocol, so their delivery is unreliable.
- ICMP packets have their own special header information, starting with a Type field and a Code field.
- Functions of ICMP control messages.
- ICMP redirect/change request messages.
- ICMP clock synchronization and transit time estimation messages.
- ICMP information request and reply messages.
- ICMP address mask request and reply messages.
- ICMP router-discovery message.
- ICMP router-solicitation message.
- ICMP congestion and flow-control messages.

To supplement all that you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab Activities on the CD-ROM accompanying this book.

Key Terms

broadcast Data packet that are sent to all nodes on a network.

datagram In IP networks, packets often are called datagrams.

ICMP (Internet Control Message Protocol) Network layer Internet Protocol that reports errors and provides other information relevant to IP packet processing. It is documented in RFC 792.

multicast Single packets copied by the network and sent to a specific subset of network addresses.

ping (Packet Internet Groper) ICMP echo message and its reply. Often used in IP networks to test the reachability of a network device.

TCP/IP (Transmission Control Protocol/Internet Protocol) Common name for the suite of protocols developed by the U.S. Department of Defense in the 1970s to support the construction of worldwide internetworks. TCP and IP are the two best-known protocols in the suite.

unicast Message sent to a single network destination

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. ICMP is an error-reporting protocol for IP. True or false?
 - A. True
 - B. False
2. ICMP stands for what?
 - A. Internal Control Message Protocol
 - B. Internet Control Message Portal
 - C. Internal Control Message Protocol
 - D. Internet Control Message Protocol
3. ICMP messages are encapsulated as data in datagrams in the same way that any other data is delivered using IP. True or false?
 - A. True
 - B. False

4. A default gateway must be configured if datagrams are to travel outside the local network. True or false?
 - A. True
 - B. False
5. TTL stands for what?
 - A. Time-To-List
 - B. Time-To-Live
 - C. Terminal-To-Live
 - D. Terminal-To-List
6. All ICMP message formats start with which of these fields?
 - A. Type
 - B. Code
 - C. Checksum
 - D. All of the above
7. Default gateways send ICMP redirects/change requests only when which of the following conditions are met?
 - A. The interface on which the packet comes into the router is the same interface on which the packet gets routed out.
 - B. The subnet/network of the source IP address is the same subnet/network of the next-hop IP address of the routed packet.
 - C. The datagram is not source-routed.
 - D. The route for the redirect is not another ICMP redirect or a default route.
 - E. All of the above.
8. The Type field on an ICMP timestamp message can be either a 13 (timestamp request) or what?
 - A. 14 timestamp reply
 - B. 14 time
 - C. 14 reply
 - D. 26 timestamp reply
 - E. All of the above

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9. All ICMP timestamp reply messages do not contain the originate, receive, and transit timestamps. True or false?
 - A. True
 - B. False
10. What is ICMP type number for a router-solicitation message?
 - A. 9
 - B. 10
 - C. 17
 - D. 18



Objectives

Upon completion of this chapter, you will be able to

- Perform basic network testing
- Use the **ping** command to perform basic network connectivity tests
- Use the **telnet** command to verify the application layer software between source and destination hosts
- Troubleshoot by testing OSI layers
- Use the **show interfaces** command to confirm Layer 1 and Layer 2 problems
- Use the **show ip route** and **show ip protocol** command to identify routing issues
- Use the **show cdp** command to verify Layer 2 connectivity
- Use the **traceroute** command to identify the path that a packet takes between networks
- Use the **show controller serial** command to ensure that the proper cable is attached
- Use basic **debug** commands to show router activity

Chapter 18

Basic Router Troubleshooting

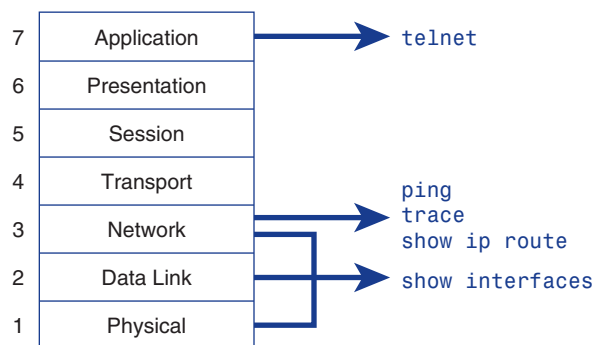
This chapter provides an overview of network testing and emphasizes the necessity of using a structured approach to troubleshooting. This chapter also describes the fundamentals of troubleshooting routers.

Please be sure to look at this chapter's associated e-Labs, movies, and PhotoZooms that you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

Introduction to Network Testing

Basic testing of a network should proceed in sequence from one OSI reference model layer to the next, as shown in Figure 18-1.

Figure 18-1 Testing Utilities and the OSI Reference Model



It is best to begin with Layer 1 and work to Layer 7, if necessary. Beginning with Layer 1, look for simple problems such as power cords unplugged at the wall.

Layer 2 issues can include improperly configured serial or Ethernet interfaces, improper clock rate settings on serial interfaces, or network interface card (NIC) problems.

The most common problems that occur on IP networks result from errors in the addressing scheme, which are Layer 3 issues.

The various problems that can occur at all the layers of the OSI model are covered in detail later in this chapter. It is important to test the address configuration before continuing with further configuration steps.

Each test presented in this section focuses on network operations at a specific layer of the OSI model.

Structured Approach to Troubleshooting

Troubleshooting is a process that helps a user to find problems on a network. An orderly process to troubleshooting should be used, based on the networking standards set in place by an administration. Documentation is a very important part of the troubleshooting process. The flowchart in Figure 18-2 shows a recommended logical sequence for troubleshooting network problems.

Figure 18-2 Troubleshooting Methodology

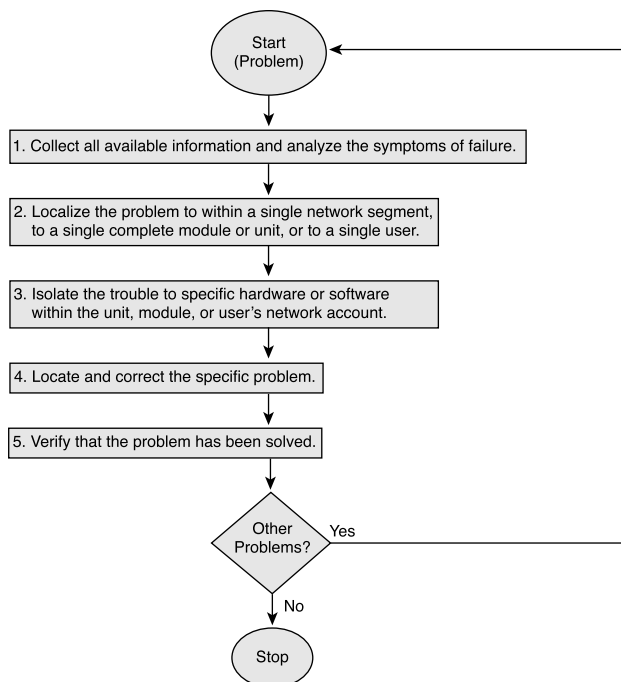
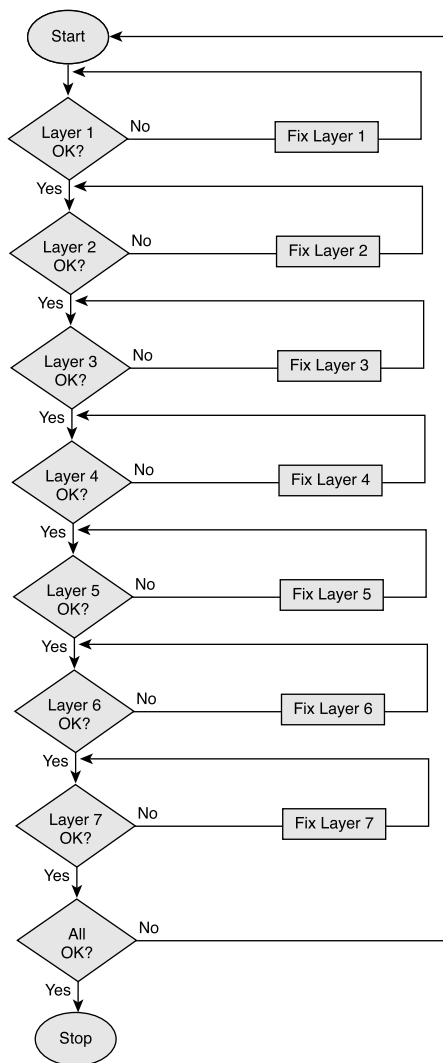


Figure 18-3 shows one approach to troubleshooting network problems.

Figure 18-3 OSI Layer Troubleshooting



With a structured approach, members of the network know what each member has completed to solve a problem. If a variety of ideas are used without any organization, the problem solving becomes chaotic. Without a structured approach, very few problems are solved.

The flowcharts in Figure 18-2 and Figure 18-3 are not the only methods of troubleshooting; however, the orderly process is very important to ensure that a network runs smoothly and efficiently.

Testing by OSI Layers

Testing should begin with Layer 1 of the OSI model and work to Layer 7, if necessary.

Layer 1 (physical layer) errors can include the following:

- Broken cables
- Disconnected cables
- Cables connected to the wrong ports
- Intermittent cable connection
- Wrong cables used for the task at hand (must use rollovers, crossover cables, and straight-through cables correctly)
- Transceiver problems
- Data communications equipment (DCE) cable problems
- Data terminal equipment (DTE) cable problems
- Devices turned off

After exhausting all Layer 1 problems as possibilities for a network problem, the next step is to investigate Layer 2 problem possibilities.

Layer 2 errors can include the following:

- Improperly configured serial interfaces
- Improperly configured Ethernet interfaces
- Improper encapsulation set (High-Level Data Link Control [HDLC] is default for serial interfaces)
- Improper clock rate settings on serial interfaces
- *Network interface card (NIC)* problems

After exhausting all Layer 2 problems as possibilities for a network problem, the next step is to investigate Layer 3 problem possibilities.

Layer 3 errors can include the following:

- Routing protocol not enabled
- Wrong routing protocol enabled
- Routing protocol incorrectly configured
- Incorrect IP addresses

- Incorrect subnet masks
- Incorrect default gateway

If errors or problems related to connectivity appear on the network, testing through the layers using connectivity tools, such as **ping** or **telnet**, should be the first step in determining the point in the network where the packet gets dropped. The **ping** command can be used at Layer 3 to test connectivity. At Layer 7, the **telnet** command can be used to verify the application layer software between source and destination stations. Both of these commands are discussed in detail later in the chapter.

Troubleshooting Layer 1 Using Indicators

Indicators are useful tools for troubleshooting. Most interfaces or NICs have indicator lights that show whether there is a valid connection. This light usually is referred to as the *link light*. The interface also might have lights to indicate whether traffic is being sent (TX) or received (RX). If the interface has indicator lights that do not show a valid connection, power off the device and reset the interface card. The NIC functions at both Layers 1 and 2.

Many indicators are considered Layer 1 problems in a network, including the following:

- Broken cables
- Disconnected cables
- Cables connected to the wrong ports
- Intermittent cable connection
- Wrong cables used for the task at hand
- Transceiver problems
- Devices turned off

A faulty or incorrect cable could result in a link light indicating a bad connection or no link.

Check to make sure that all cables are connected to the appropriate ports. Make sure that all cross-connects are patched properly to the correct location using the appropriate cable and method. Verify that all switch or hub ports are set in the correct VLAN or collision domain, and have appropriate options set for Spanning Tree and other considerations.

Verify that the proper cable is being used. If a direct connection exists between two end systems—for example, between a PC and a router or between two switches—a special crossover cable might be required. Verify that the cable from the source interface

is connected properly and is in good condition. If it does not seem to be a good connection, reset the cable and ensure that the connection is secure. Try replacing the cable with a known working cable. If the cable connects to a wall jack, use a cable tester to ensure that the jack is wired properly.

Also check any transceiver in use to ensure that it is the correct type and is properly connected and configured. If replacing the cable does not resolve the problem, try replacing the transceiver, if one is being used.

Before you run diagnostics or attempt complex troubleshooting, always check to make sure that the device is powered on. Some problems result from the simplest of errors.

Troubleshooting Layer 2 Using the `show interface` Command

The `show interface` command is perhaps the single most important tool to discover Layer 1 and Layer 2 problems with the router. The first output parameter, or line, refers to the physical layer. The second parameter, or protocol, indicates whether Cisco IOS Software processes that control the line protocol consider the interface usable. This is determined by whether keepalives successfully are received. If the interface misses three consecutive keepalives, the line protocol is marked as down.

If the line is down, the protocol also must be down. This is because there would be no usable media for the protocol. This occurs when the interface is down because of a hardware issue or if it is “administratively down” because of a configuration issue.

If the interface is up and the line protocol is down, a Layer 2 problem exists. The following list contains some possible causes:

- No keepalives
- No clock rate
- Mismatch in encapsulation type

These problems can be determined when the `show interface` command has been entered and a line appears stating, “interface is up and the line protocol is down.” Using the `clockrate` command or the `encapsulation` command, verify that there is no mismatch between interfaces.

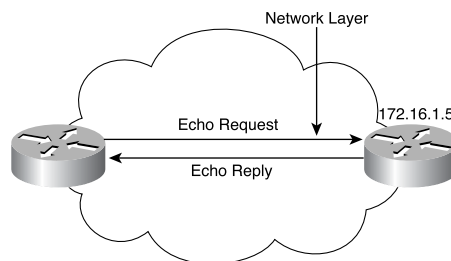
The `show interfaces serial` command should be used after configuring a serial interface, to verify the changes and ensure that the interface is operational.

Troubleshooting Layer 3 Using ping

The *ping* utility is used to test network connectivity. To aid in diagnosing basic network connectivity, many network protocols support an echo protocol, which is used to test whether protocol packets are being routed. The **ping** command sends a packet to the destination host and then waits for a reply packet from that host. Results from this echo protocol can help evaluate the path-to-host reliability, delays over the path, and whether the host can be reached or is functioning. The ping output displays the minimum, average, and maximum times that it takes for a ping packet to find a specified system and return. ping uses the Internet Control Message Protocol (ICMP) to verify the hardware connection and the logical address of the network layer. This is a basic testing mechanism.

For the network in Figure 18-4, the ping target 172.16.1.5 responded successfully to all five datagrams sent, as shown in Example 18-1.

Figure 18-4 Network for Testing with ping



Example 18-1 ping Results for Target 172.16.1.5

```
Router> ping 172.16.1.5
Type escape sequence to abort
Sending 5, 100 byte ICMP Echos to 172.16.1.5,
timeout is 2 seconds:
!!!!
Success rate is 100 percent,
round-trip min/avg/max - 1/3/4 ms
Router>
```

The exclamation points (!) indicate each successful echo. If any periods (.) instead of exclamations are received on a display, the application on the router timed out waiting for a given packet echo from the ping target. The **ping** command can be used to diagnose basic network connectivity.

ping tests network connections by sending ICMP echo requests to a target host and waiting for replies. When testing a connection, ping tracks the number of packets sent, the number of replies received, the percentage of packets lost, and the amount of time required for the packets to reach the destination and for replies to be received. This information enables users to verify whether their workstations can communicate with other hosts, and they can determine whether any information was lost.

The **ping** command can be initiated from both user EXEC mode and privileged EXEC mode. The **ping** command can be used to confirm basic network connectivity on AppleTalk, ISO Connectionless Network Service (CLNS), IP, Novell, Apollo, VINES, DECnet, or XNS networks.

ICMP uses messages to accomplish various tasks. Table 18-1 shows a list of ICMP message types.

Table 18-1 CMP Message Types

Message	Purpose
Destination unreachable	This tells the source host that there is a problem delivering a packet.
Time exceeded	The time that it takes a packet to be delivered has been too long, and the packet has been discarded.
Source quench	The source is sending data faster than it can be forwarded. This message requests that the sender slow down.
Redirect	The router sending this message has received some packet for which another router would have had a better route. The message tells the sender to use the better route.
Echo	This is used by the ping command to verify connectivity.
Parameter problem	This is used to identify a parameter that is incorrect.
Timestamp	This is used to measure round-trip time to particular hosts.

Table 18-1 CMP Message Types (Continued)

Message	Purpose
Address mask request/reply	This is used to inquire about and learn the correct subnet mask to be used.
Router advertisement and selection	This is used to allow hosts to dynamically learn the IP addresses of the routers attached to the subnet.

The extended command mode of the **ping** command permits users to specify the supported IP header options. This allows the router to perform a more extensive range of test options. To enter ping extended command mode, type the **ping** command with no options in privileged mode and press Enter. You are prompted for some basic options as well as the Extended Commands option. Enter yes at the Extended commands prompt to specify various extended ping options. An extended ping works the same way as a regular ping, but it supports the manipulation of some different parameters, such as packet size and frequency.

It is a good idea to use the **ping** command when the network is functioning properly, to see how the command works under normal conditions and so that you have something to compare against when troubleshooting.

Troubleshooting Layer 3 Issues Using traceroute

The *traceroute* command is used to discover the routes that packets take when traveling to their destinations. *traceroute* also can be used to test the network layer, or Layer 3, on a hop-by-hop basis and to provide performance benchmarks.

The output of the **traceroute** command generates a list of hops that successfully were reached, as shown in Example 18-2. If the data successfully reaches the intended destination, then the output indicates every router that the datagram passes through. This output can be captured and used for future troubleshooting of the internetwork.

Example 18-2 *traceroute* Command Output

```
Cougars> traceroute 168.71.8.2
traceroute to pc-b.cisco.com (168.71.8.2), 30 hops max, 40 byte packets
 1  routerb (168.71.6.3)  3 ms  3 ms  3 ms
 2  * * *
```

continues

Example 18-2 *traceroute Command Output (Continued)*

```
3 * * *
4 * * *
5 * * *
Cougars>
```

traceroute output also indicates the specific hop at which the failure is occurring. For each router in the path, a line of output is generated on the terminal indicating the IP address of the interface that the data entered. If an asterisk (*) appears, the packet failed. You can isolate the problem area by obtaining the last good hop from the traceroute output and comparing it to a diagram of the internetwork.

traceroute also provides information indicating the relative performance of links. The round-trip time (RTT) is the time required to send an echo packet and get a response, as shown in Example 18-2. In this example, each of the three packets sent has an RTT of 3 milliseconds (ms). This is useful for an approximate idea of the delay on the link. These figures are not precise enough to be used for an accurate performance evaluation; however, this output can be captured and used for future performance troubleshooting of the internetwork.

The device receiving the traceroute also must know how to send the reply back to the source of the traceroute. For the traceroute or ping data to successfully make the round trips between routers, there must be known routes in both directions. A failed response is not always an indication of a problem because ICMP messages could be rate-limited or filtered at the host site. This is especially true across the Internet.

traceroute sends out a sequence of User Datagram Protocol (UDP) datagrams from the router to an invalid port address on the remote host. For the first sequence of three datagrams sent, a Time-To-Live (TTL) field value is set to 1. The TTL value of 1 causes the datagram to time out at the first router in the path. This router then responds with an ICMP time exceeded message (TEM) indicating that the datagram has expired.

Three more UDP messages now are sent, each with the TTL value set to 2. This causes the second router to return ICMP TEMs. This process continues until the packets reach the other destination.

Because these datagrams are trying to access an invalid port at the destination host, ICMP port unreachable messages are returned instead of ICMP TEMs. This indicates an unreachable port and signals the traceroute program, terminating the process.

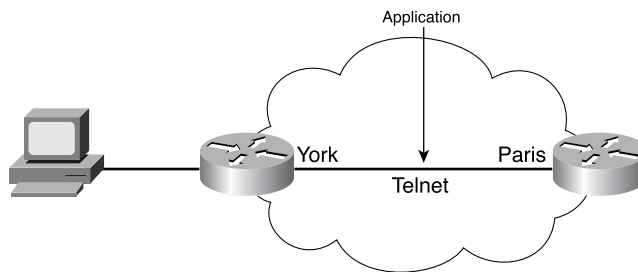
Troubleshooting Layer 7 Using Telnet

Telnet is a virtual terminal protocol that is part of the TCP/IP protocol suite. Telnet allows the verification of the application layer software between source and destination stations. This is the most complete test mechanism available. Telnet allows connections to be made to remote devices, to gather information and run commands and applications.

Telnet is the most complete testing tool because it uses IP at the network layer and TCP at the transport layer to create a session with a remote host. If Telnet is successful, IP connectivity must be good.

The `telnet` command provides a virtual terminal so that administrators can use Telnet operations to connect with other network devices (such as routers and switches) running TCP/IP. If a router can be remotely accessed using Telnet, at least one TCP/IP application can reach the remote router. A successful Telnet connection indicates that the upper-layer application and the services of lower layers are functioning properly. Figure 18-5 illustrates a Telnet connection.

Figure 18-5 Using Telnet



If an administrator can Telnet to one router but not to another router, the Telnet failure likely is caused by specific addressing, naming, or access permission problems. These problems can exist on the administrator's router or on the router that failed as a Telnet target.

If the Telnet to a particular server fails from one host, try connecting from a router and several other devices. Also try using ping as a more basic test. If you can ping the host, but cannot achieve a login prompt when trying to Telnet, check the following:

- Can a reverse DNS lookup on the client's address be found? Many Telnet servers do not allow connections from IP addresses that have no DNS entry. This is a common problem for DHCP-assigned addresses in which the administrator has not added DNS entries for the DHCP pools.

- A Telnet application might not be capable of negotiating the appropriate options and, therefore, will not connect. On a Cisco router, this negotiation process can be viewed using **debug telnet**. Look for error messages or invalid IP or DNS address, which would indicate this problem.
- It is possible that Telnet is disabled or has been moved to a port other than 23 on the destination server. Recall that port 23 is the default port for Telnet.

**Lab Activity** Troubleshooting Using **ping** and **telnet**

In this lab, you use knowledge of OSI Layers 1, 2, and 3 to diagnose network configuration errors while using the **ping** and **telnet** utilities.

Troubleshooting Router Issues Using the **show interface** and **show interfaces** Commands

Cisco IOS Software contains numerous commands for troubleshooting. Among the more widely used are the **show** commands. Every aspect of the router can be viewed with one or more of the **show** commands. The **show interface** command is used to check the status and statistics of the interfaces. Variations of this command can be used to check the status of the different types of interfaces. To view the status of the FastEthernet interfaces, use **show interfaces fastethernet**. This command also can be used to view the status of one particular interface. To view the status of the Serial 0/0 interface, use **show interface serial0/0**. To view the status of FastEthernet 0/0, use **show interface fa0/0**.

The **show interfaces** command displays the status of two important portions of the interfaces. These can be related to the Layer 1 and the Layer 2 functions:

- **Physical (hardware) portion**—The hardware includes cables, connectors, and interfaces showing the condition of the physical connection between the devices.
- **Logical (software) portion**—The software status shows the state of messages such as *keepalives*, control information, and user information that are passed between adjacent devices. This relates to the condition of a data link layer protocol passed between two connected neighboring router interfaces.

These important elements of the **show interface serial** command output are displayed as the line and data-link protocol status shown in Example 18-3.

Example 18-3 show interface serial Command

```
Cougars# show interface serial 0
Serial0 is up, line protocol is up
  Hardware is HD64570
  MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,
    reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation HDLC, loopback not set
  Keepalive set (10 sec)
  Last input never, output never, output hang never
  Last clearing of "show interface" counters 00:02:57
  Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
  Queueing strategy: weighted fair
  Output queue: 0/1000/64/0 (size/max total/threshold/drops)
    Conversations 0/0/256 (active/max active/max total)
    Reserved Conversations 0/0 (allocated/max allocated)
    Available Bandwidth 1158 kilobits/sec
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
    0 packets input, 0 bytes, 0 no buffer
    Received 0 broadcasts, 0 runts, 0 giants, 0 throttles
    0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored, 0 abort
    0 packets output, 0 bytes, 0 underruns
    0 output errors, 0 collisions, 8 interface resets
    0 output buffer failures, 0 output buffers swapped out
    0 carrier transitions
  DCD=up DSR=up DTR=up RTS=up CTS=up
```

The first parameter (Serial0 is up) refers to the hardware layer and essentially reflects whether the interface is receiving the carrier detect signal from the other end (DCE). If the line is down, a problem with the cabling might exist in a back-to-back connection, with one end being “administratively down.” If the interface is administratively down, it has been disabled manually in the configuration.

The **show interfaces serial** command also provides information to help diagnose other Layer 1 issues that are not as easy to determine.

The following problems can be caused by an increasing number of carrier transitions counts on a serial link:

- Line interruptions from the service provider network
- Faulty switch, DSU, or router hardware

If an increasing number of input errors appear in the **show interfaces serial** output, several possible sources of those errors exist. Some common problems related to Layer 1 are as follows:

- Faulty telephone company equipment
- Noisy serial line
- Incorrect cable or cable length
- Damaged cable or connection
- Defective CSU or DSU
- Defective router hardware

Another area to examine is the number of interface resets. Interface resets are the result of too many missed keepalives. Layer 1 problems also could be caused by the following:

- Bad phone line causing CD transitions
- Possible hardware problem at the CSU, DSU, or switch

The number of errors should be interpreted relative to the amount of traffic that the router has processed and the length of time that the statistics have been captured. The router tracks statistics that provide information about the interface. The statistics reflect router operation since it was started or since the last time the counters were cleared, as shown in Example 18-4.

Example 18-4 *Statistics Accumulation*

```
Cougars# show interface serial 0
Serial0 is up, line protocol is up
  Hardware is HD64570
  MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,
    reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation HDLC, loopback not set
  Keepalive set (10 sec)
  Last input never, output never, output hang never
  Last clearing of "show interface" counters 00:02:57
```


If the **show interfaces** output shows the last clearing of the counters as never, use the **show version** command to determine how long the router has been functional, as shown in Example 18-5.

Example 18-5 Router Uptime

```
Cougars# show version
Cisco Internetwork Operating System Software
IOS (tm) 2600 Software (C2600-BNSY-L), Version 12.2(6h), RELEASE SOFTWARE (fc1)
Copyright (c) 1986-2002 by cisco Systems, Inc.
Compiled Mon 26-Aug-02 23:23 by kellythw
Image text-base: 0x0303ED8C, data-base: 0x00001000

ROM: System Bootstrap, Version 11.0(10c), SOFTWARE
BOOTLDR: 3000 Bootstrap Software (IGS-BOOT-R), Version 11.0(10c), RELEASE SOFTWA
RE (fc1)

Cougars uptime is 14 minutes
```

Use the **clear counters** command, as shown in Example 18-6, to reset the counters to 0. These counters always should be cleared after an interface problem has been corrected. Starting from 0 gives a better picture of the current status of the network and helps verify that the issue has been corrected.

Example 18-6 clear counters Command

```
Cougars# clear counters
Clear "show interface" counters on all interfaces [confirm]yes
Cougars#
00:17:24: %CLEAR-5-COUNTERS: Clear counter on all interfaces by console
Cougars#
```

Troubleshooting Routing Issues Using the show cdp neighbors Command

Cisco Discovery Protocol (CDP) advertises device information to its direct neighbors, including MAC and IP addresses and outgoing interfaces.

The output from the **show cdp neighbors** command displays information about directly connected neighbors, as demonstrated in Example 18-7.

Example 18-7 show cdp neighbors *Command Output*

```

routerA# show cdp neighbors
Capability Codes:
R - Router, T - Trans Bridge,
B - Source Route Bridge,
S - Switch, H - Host, I - IGMP

Device ID      Local Interface  Holdtime  Capability  Platform Port  ID
routerB        Eth 0            151       R           2501   Eth    0
routerB        Ser 0            165       R           2501   Ser    0

```

This information is useful for debugging connectivity issues. If a cabling problem is suspected, enable the interfaces with the **no shutdown** command and then execute the **show cdp neighbor detail** command, as shown in Example 18-8, before any other configuration. The command displays specific device detail such as the active interfaces, the port ID, and the device.

Example 18-8 show cdp neighbors detail *Command*

```

routerA# show cdp neighbors detail
Device ID: routerB
Entry address(es):
  IP address: 198.92.68.18
Platform: 2501, Capabilities: Router
Interface: Ethernet0, Port ID (outgoing port): Ethernet0
Holdtime: 143 sec

```

If the physical layer is functioning properly, all other directly connected Cisco devices should be displayed. If a known device does not show up, there is probably a Layer 1 issue.

One area of concern with CDP is security. The amount of information that CDP provides is so extensive that it can be a potential security risk. For security reasons, CDP should be configured only on links between Cisco devices and should be disabled on user ports or links that are not managed locally.

Troubleshooting Routing Issues Using show ip route and show ip protocol

The **show ip protocol** and **show ip route** commands display information about routing protocols and the routing table. The output from these commands can be used to verify the routing protocol configuration.

The **show ip route** command is perhaps the single most important command for troubleshooting routing issues. This command displays the contents of the IP routing table. The output in Example 18-9 shows the entries for all known networks and subnetworks and how the information was obtained.

Example 18-9 show ip route Command Output

```
Cougars> show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
i - IS-IS, L1 - IS-IS level 1, L2 - IS-IS level 2
* - candidate default

Gateway of last resort is not set

    144.253.0.0 is subnetted (mask is 255.255.255.0), 1 subnets
C   144.253.100.0 is directly connected, Ethernet1
R   153.50.0.0 [120/1] via 183.8.128.12, 00:00:09, Ethernet0
    183.8.0.0 is subnetted (mask is 255.255.255.128), 4 subnets
R     183.8.0.128 [120/1] via 183.8.128.130.00, 00:00:17, Serial0
        [120/1] via 183.8.64.130, 00:00:17, Serial1
C   183.8.128.0 is directly connected, Ethernet0
C   183.8.64.128 is directly connected, Serial1
C   183.8.128.128 is directly connected, Ethernet0
```

If there is a problem reaching a host in a particular network, the output of the **show ip route** command can be used to verify that the router has a route to that network.

If the output of the **show ip route** command does not show the expected learned routes or shows no learned routes, the problem is possibly that routing information is not being exchanged. In this case, use **show ip protocols** commands, as shown in Example 18-10, on the router to check for a routing protocol configuration error.

Example 18-10 show ip protocols *Command Output*

```

Router> show ip protocol
Routing Protocol is rip
Sending updates every 30 seconds, next due in 13 seconds
Invalid after 180 seconds, hold down 180, flushed after 240
Outgoing update filter list for all interface is not set
Incoming update filter list for all interface is not set
Redistributing: rip
Routing for Networks:
183.8.0.0
144.253.0.0
Routing Information Sources:
Gateway          Distance      Last Update
183.8.128.12     120          0:00:14
183.8.64.130     120          0:00:19
183.8.128.130    120          0:00:03
Distance: (default is 120)

```

The **show ip protocols** command displays values about IP routing protocol information on the entire router. This command can be used to confirm which protocols are configured, which networks are being advertised, which interfaces are sending updates, and the sources of routing updates. The **show ip protocols** output also displays the routing parameters about timers, filters, and other information related to the routing protocol. When multiple routing protocols are configured, the information about each protocol is listed in a separate section.

The **show ip protocols** command output can be used to diagnose many routing issues, such as identifying a router that is suspected of delivering bad router information. The command output also can be used to confirm that the expected protocols, advertised networks, and routing neighbors are present. As with any troubleshooting process, identifying the problem is difficult, if not impossible, if there is no documentation indicating the expected results.

**Lab Activity** Using **show ip route** to Examine Routing Tables

In this lab, you configure RIP and IGRP on routers and then examine the impact on the routing table of multiple routing protocols using the **show ip route** command.

**Lab Activity** Troubleshooting Routing Issues with **show ip route** and **show ip protocol**

In this lab, you use the show ip route and show ip protocol commands to diagnose a routing configuration problem.

**Lab Activity** Gateway of Last Resort (Default Gateway)

In this lab, you configure RIP routing and add default routes (gateways) to the routers. You remove RIP and the default routes, then configure IGRP routing and add default routes (gateways) to the routers again.

**Lab Activity** Last Route Update

In this lab, you gather information about routing updates and routing protocols to determine the most recent routing table updates.

Troubleshooting Router Connections Using the show controllers serial Command

Router configuration and troubleshooting frequently are done remotely. Therefore, it is not possible to physically inspect the router connections. The **show controllers serial** command, shown in Example 18-11, is used to determine the type of cable connected without inspecting the cables.

Example 18-11 show controllers serial *Command Output*

```
Cougars# show controllers serial 0/0
QUICC Serial unit 0
idb at 0x20A31A8, driver data structure at 0x20A4C60
SCC Registers:
General [GSMR]=0x2:0x00000030, Protocol-specific [PSMR]=0x0
Events [SCCE]=0x0000, Mask [SCCM]=0x001F, Status [SCCS]=0x0006
Transmit on Demand [TODR]=0x0, Data Sync [DSR]=0x7E7E
Interrupt Registers:
... output omitted ...
DTE V.35 serial cable attached.
... output omitted ...
```

Being able to determine the type of cable that the controller detects is useful for finding a serial interface with no cable, the wrong type of cable, or a defective cable.

The **show controllers serial** command queries the integrated circuit, or chip, that controls the serial interfaces and displays information about the physical interface. This output varies among controller chips. Even within a router type, different controller chips can be used.

Regardless of the controller type, the **show controllers serial** command produces a tremendous amount of output. Other than the cable type, most of this output is internal technical detail regarding the controller chip status. Without specific knowledge of the integrated circuit, this information is not useful.

Introduction to debug

The **debug** commands assist in the isolation of protocol and configuration problems. The **debug** command is used to display dynamic data and events. Because the **show** commands display only static information, they provide a historical picture of the router operation. The **debug** command output provides more insight into the current events of the router. These events include traffic on an interface, error messages generated by nodes on the network, protocol-specific diagnostic packets, and other useful troubleshooting data. Example 18-12 shows sample output from the **debug ip rip** command.

Example 18-12 debug ip rip *Command*

```

Router# debug ip rip
RIP Protocol debugging is on
Router#
RIP:    received update from 183.8.128.130 on Serial0
183.8.0.128 in 1 hops
183.8.64.128 in 1 hops
0.0.0.0 in 16 hops (inaccessible)
RIP:    received update from 183.8.64.140 on Serial1
183.8.0.128 in 1 hops
183.9.128.128 in 1 hops
0.0.0.0 in 16 hops (inaccessible)
RIP:    received update from 183.8.128.130 on Serial0
183.8.0.128 in 1 hops
183.8.64.128 in 1 hops
    
```

Example 18-12 `debug ip rip` Command (Continued)

```
0.0.0.0 in 16 hops (inaccessible)
RIP:    sending update to 255.255.255.255 via Ethernet0 (183.8.128.2)
subnet 183.8.0.128, metric 2
subnet 183.8.64.128, metric 1
subnet 183.8.128.128, metric 1
default 0.0.0.0, metric 16
network 144.253.0.0, metric 1
RIP:    sending update to 255.255.255.255 via Ethernet1 (144.253.100.202)
default 0.0.0.0, metric 16
network 153.50.0.0, metric 2
network 183.8.0.0, metric 1
```

The highlighted material in Example 18-12 shows that RIP debugging has been turned on and shows which routes, networks, and interfaces are accessible and inaccessible.

The dynamic output of the **debug** command comes at a performance cost, which produces high processor overhead that can disrupt normal router operation. For this reason, you should use it conservatively. Use **debug** commands to examine specific types of traffic or concerns after problems have been narrowed to a few possible causes. In other words, **debug** commands should be used to isolate specific problems, not to monitor normal network operation.

By default, the router sends the debug output and system messages to the console. If a Telnet session is being used to examine the router, the debug output and system messages can be redirected to the remote terminal. This is done through the Telnet session by issuing the **terminal monitor** command. Use extra caution when selecting the **debug** commands from a Telnet session. No command should be selected that will cause the debug output to create additional traffic. If this occurs, the Telnet session rapidly saturates the link with traffic, or the router exhausts one or more resources. A good rule to follow to prevent this production of traffic is to never debug any activity on the port where the session is established.

The output of the different **debug** commands varies. Some frequently generate many lines, while others output a line or two every few minutes. Example 18-13 shows the **debug ip packet detail** command.

NOTE

The **debug all** command, in particular, should be used sparingly because it can disrupt router operations.

Example 18-13 debug ip packet detail *Command Output*

```
Router# debug ip packet detail
10w6d:      TCP src=1075, dst=80, seq=785595392, ack=3448593899, win=64240 ACK
10w6d: IP: s=192.168.120.145 (Ethernet0/0), d=192.168.119.9 (Ethernet0 /0),
      g=192.168.119.9, len 60, forward
10w6d:      TCP src=1075, dst=80, seq=785595392, ack=3448599739, win=64240 ACK
10w6d: IP: s=192.168.120.145 (Ethernet0 /0), d=192.168.119.9 (Ethernet0 /0),
      g=192.168.119.9, len 60, forward
10w6d:      TCP src=80, dst=1075, seq=3448603559, ack=785595392, win=8446 ACK PSH
10w6d: IP: s=192.168.120.145 (Ethernet0), d=192.168.119.9 (Ethernet0 /0),
      g=192.168.119.9, len 60, forward
10w6d:      TCP src=1075, dst=80, seq=785595392, ack=3448604710, win=64240 ACK
10w6d: IP: s=10.1.1.81 (Serial0 /0), d=224.0.0.10, len 64, rcvd 2, proto=88
10w6d: IP: s=210.107.197.105 (Serial0 /0), d=192.168.119.255, len 1028,
      access denied
10w6d:      ICMP type=8, code=0
10w6d: IP: s=10.1.1.82 (local), d=224.0.0.10 (Serial0 /0), len 22,
      sending broad/multicast, proto=88
10w6d: IP: s=0.0.0.0 (Ethernet0 /0), d=255.255.255.255, len 590, rcvd 2
10w6d:      UDP src=68, dst=67
10w6d: IP: s=192.168.120.50 (Ethernet0 /0), d=192.168.120.255 (Ethernet0 /0),
      len 243, rcvd 3

Router# undebug all
All possible debugging has been turned off
GAD#
```

The highlighted material in the previous example indicates what networks are involved and shows access being denied from packets into or out of 210.107.197.105.

Another Cisco IOS Software service that enhances the usefulness of the debug output is the **timestamps** command. This command puts a timestamp on a debug message. This information provides the time when the debug event occurred and the duration of time between events. The **service timestamps debug uptime** command can provide the hour:minute:second of the output, determine the amount of time since the router was last powered up, or identify when a **reload** command was executed.

The **no debug all** command and **undebug all** command turn off all diagnostic output. To disable a particular **debug** command, use the no form of the command. For example, if debug for monitoring RIP was enabled with the command **debug ip rip**, it can be disabled with **no debug ip rip**. To view what is currently being examined by a **debug** command, use **show debugging**.



Lab Activity Troubleshooting Routing Issues with **debug**

In this lab, you use a systematic OSI troubleshooting process and various **show** commands to gather information to diagnose routing problems. You then use various **debug** commands to assist in troubleshooting.

Summary

In this chapter, you learned the following:

- Network testing should be utilized to keep a network running smoothly and efficiently. It should be tested layer by layer.
- You should use a structured approach to troubleshooting.
- **ping** and **telnet** are two commands that are helpful in troubleshooting network problems.
- The **tracert** command can be used to determine the status of links between routers
- The different **show** commands help to confirm Layer 1 and Layer 2 problems.
- The **show ip route** and **show ip protocol** commands help to identify routing issues.
- Basic **debug** commands help to discover information about router activity.

To supplement all that you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab Activities on the CD-ROM accompanying this book.

Key Terms

keepalive Message sent by one network device to inform another network device that the virtual circuit between the two is still active.

network interface card (NIC) Board that provides network communication capabilities to and from a computer system.

ping Packet Internet groper. ICMP echo message and its reply. Used in IP networks to test the reachability of a network device.

Telnet Standard terminal-emulation protocol in the TCP/IP protocol suite. Telnet is used for remote terminal connection, enabling users to log in to remote systems and use resources as if they were connected to a local system.

traceroute Program available on many systems that traces the path that a packet takes to a destination. It is used mostly to debug routing problems between hosts.

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. When a technician performs basic testing of a network, which of the following is true?
 - A. The technician should proceed in sequence from one OSI reference model layer to the next.
 - B. The technician should proceed with any desired OSI layer.
 - C. The technician should proceed with the management level.
 - D. The technician should test for OSI reference model layer issues in a random fashion.
2. What approach should a technician start with when he/she troubleshoots a network?
 - A. The technician should start with a structured approach.
 - B. The technician should start with an approach of his choice.
 - C. The technician should start with any approach.
 - D. The technician should start with a hit-and-miss approach.

3. When a technician troubleshoots a problem on a network?
 - A. Begin with Layer 1
 - B. Begin with Layer 2
 - C. Begin with Layer 3
 - D. Begin with Layer 4
4. If a technician wants to test network connectivity, which basic command should be used?
 - A. telnet
 - B. ping
 - C. debug
 - D. traceroute
5. When a network administrator wants to verify the application layer software between source and destination stations, which of the following commands should be used?
 - A. ping
 - B. telnet
 - C. debug
 - D. traceroute
6. You suspect that one of the routers connected to your network is sending bad routing information. What command can you use to check?
 - A. router(config)# show ip route
 - B. router# show ip route
 - C. router> show ip protocol
 - D. router(config-router)# show ip protocol
7. Why would you display the IP routing table?
 - A. To set the router update schedule
 - B. To identify destination network addresses and next-hop pairs
 - C. To trace where datagrams are coming from
 - D. To set the parameters and filters for the router

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8. If you wanted to see RIP routing updates as they are sent and received, what command structure would you use?
 - A. router# **show ip rip**
 - B. router# **debug ip protocols**
 - C. router# **debug ip rip**
 - D. router# **show ip rip update**
9. The dynamic output of the **debug** command comes at a performance cost, which produces _____ processor overhead?
 - A. High
 - B. Low
 - C. Medium
 - D. Maximum
10. By default, the router sends the **debug** output and system messages to what?
 - A. The console
 - B. The switch
 - C. The PC
 - D. The user
11. The **telnet** command provides what type of terminal?
 - A. Register
 - B. Virtual
 - C. Cisco IOS Software
 - D. Command
12. ICMP stands for what?
 - A. Internet Control Message Parameter
 - B. Internal Control Message Protocol
 - C. Internet Control Message Protocol
 - D. Internet Control Message Performance

13. Most interfaces or NICs have what type of lights that show whether there is a valid connection?
- A. Indicator
 - B. Catalyst
 - C. Responsive
 - D. Inactive
14. Telnet is used at what layer of the OSI reference model?
- A. Layer 1
 - B. Layer 5
 - C. Layer 6
 - D. Layer 7
15. If the routing protocol is not enabled or the IP address cannot be determined, at which layer of the OSI model should an administrator begin to look?
- A. Layer 1
 - B. Layer 2
 - C. Layer 3
 - D. Layer 4



Objectives

Upon completion of this chapter, you will be able to

- Describe TCP and its functions
- Describe TCP synchronization and flow control
- Describe User Datagram Protocol (UDP) operation and processes
- Identify common port numbers
- Describe multiple conversations between hosts
- Identify ports used for services and clients
- Describe port numbering and well-known ports
- Compare MAC addresses, IP addresses, and port numbers

Chapter 19

Intermediate TCP

In this chapter, you learn about TCP/IP operation to ensure communication across any set of interconnected networks. In addition, you learn about the TCP/IP protocol stack components, such as protocols to support file transfer, e-mail, remote login, and other applications. You learn about reliable and unreliable transport layer protocols and about connectionless datagram (packet) delivery at the network layer. Finally, you learn how ARP and RARP work.

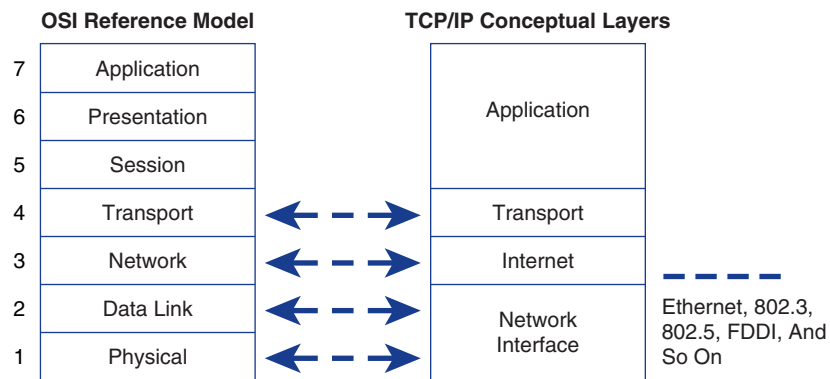
Please be sure to look at the e-Labs, Videos, and PhotoZooms associated with this chapter that you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

The TCP/IP Protocol Suite

The TCP/IP suite of protocols was developed as part of the research done by the Defense Advanced Research Projects Agency (DARPA). It was originally developed to provide communication within DARPA. Later, TCP/IP was included with the Berkeley Software Distribution of UNIX. Now, TCP/IP is the de facto standard for internetwork communications and serves as the transport protocol stack for the Internet, enabling millions of computers to communicate globally. This chapter focuses on TCP/IP for several reasons:

- TCP/IP is a universally available protocol that you likely use at work.
- TCP/IP is a useful reference for understanding other protocols because it includes elements that are representative of other protocols.
- TCP/IP is important because the router uses it as a configuration tool.

The function of the TCP/IP protocol stack is to transfer information from one network device to another. In doing so, it closely maps the OSI reference model in the lower layers and supports all standard physical and data link protocols (see Figure 19-1).

Figure 19-1 Four Layer Model of TCP/IP

The OSI layers most closely related to TCP/IP are Layer 7 (application layer), Layer 4 (transport layer), and Layer 3 (network layer). Included in these layers are various types of protocols with a variety of purposes/functions, all of which are related to the transfer of information. The TCP/IP layers map quite well to the OSI model: TCP (at the transport or host-to-host layer) maps to the OSI transport layer, and the Internet layer maps to the OSI network layer.

TCP/IP enables communication among any set of interconnected networks and is equally well suited for both LAN and WAN communication. TCP/IP includes not only Layer 3 and 4 specifications (such as IP and TCP), but also specifications to support such common applications as e-mail, remote login, terminal emulation, and file transfer.

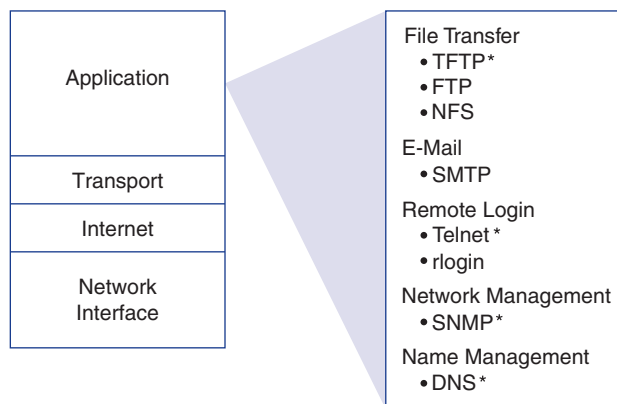
TCP/IP Protocol Stack and the Application Layer

The application layer of the TCP/IP or Internet protocols combines the functionality found in the OSI session, presentation, and application layers. TCP/IP has protocols to support file transfer, e-mail, and remote login, including the following (see Figure 19-2):

- **Domain Name System (DNS)** is a system used on the Internet for translating names of domains and their publicly advertised network nodes into IP addresses. This translation is considered to be transport layer functionality because it provides services to the layer above (application layer) and receives services from the layer below (Internetwork layer).
- **Windows Internet Naming Service (WINS)** is a Microsoft-developed standard for Microsoft Windows NT that automatically associates NT workstations with Internet domain names.

- **HOSTS** is a file created by network administrators and maintained on servers. The file is used to provide static mappings between IP addresses and computer names.
- **Post Office Protocol (POP3)** is an Internet standard for storing e-mail on a mail server until you can access it and download it to your computer. It enables users to receive mail from their inboxes using various levels of security.
- **Simple Mail Transfer Protocol (SMTP)** governs the transmission of e-mail over computer networks. It does not provide support for transmission of data other than plain text.
- **Simple Network Management Protocol (SNMP)** is a protocol that provides a means to monitor and control network devices and to manage configurations, statistics collection, performance, and security.
- **File Transfer Protocol (FTP)** is a reliable, connection-oriented service that uses TCP to transfer files between systems that support FTP. It supports bidirectional binary file and ASCII file transfers.
- **Trivial File Transfer Protocol (TFTP)** is a connectionless service that uses UDP. TFTP is used on the router to transfer configuration files and IOS images, and to transfer files between systems that support TFTP. It is useful in some LANs because it operates faster than FTP in a stable environment.
- **Hypertext Transfer Protocol (HTTP)** is the Internet standard that supports the exchange of information on the World Wide Web as well as on internal networks. It supports many different file types, including text, graphics, sound, and video. It defines the process by which web browsers originate requests for information to send to web servers.

Figure 19-2 Application Layer Protocols



* Used by the Router

The following list provides an overview of some troubleshooting protocols:

- **Telnet** is a standard terminal emulation protocol used by clients to make remote terminal connections to Telnet server services. It enables users to remotely connect to routers to enter configuration commands.
- **Packet Internet Groper (ping)** determines whether a computer is reachable. ping uses the Internet Control Message Protocol (ICMP) echo request and reply messages.
- The **tracert** program is available on many systems and is similar to ping, except that tracert provides more information than ping. tracert traces the path that a packet takes to a destination and is used to debug routing problems.

You also need to be familiar with a few Windows-based utilities:

- **NBSTAT**—A utility used to troubleshoot NetBIOS name resolution and used to view and remove entries from the name cache.
- **NETSTAT**—A utility that provides information about TCP/IP statistics; it can be used to provide information about the status of TCP/IP connections and summaries of ICMP, TCP, and UDP.
- **ipconfig/winipcfg**—Utilities used to view current network settings for all network interface cards (NICs) on a device; they can be used to view the MAC address, IP address, subnet mask, and gateway, as well as DNS and Dynamic Host Configuration Protocol (DHCP) information.

TCP/IP Protocol Stack and the Transport Layer

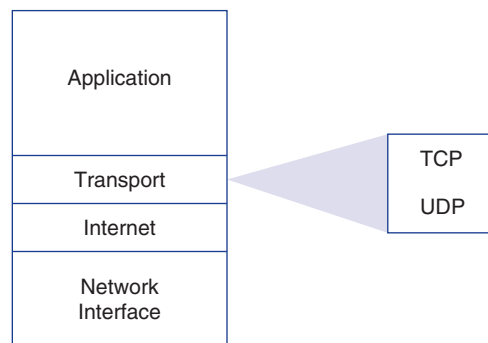
This section introduces the *Transmission Control Protocol (TCP)*, a Layer 4 protocol in the TCP/IP suite. TCP is a reliable, connection-oriented protocol that helps ensure reliable data delivery through the use of synchronization, windowing and window size, sequencing numbers, and acknowledgements (ACK).

The transport layer enables a user's device to segment data from several upper-layer applications for placement on the same Layer 4 data stream and enables a receiving device to reassemble the upper-layer application segments. The Layer 4 data stream is a logical connection between the endpoints of a network; it provides transport services from a source host to a destination host. This service is sometimes referred to as an *end-to-end service*. The transport layer also provides two protocols (see Figure 19-3):

- **TCP**—A connection-oriented, reliable protocol that provides flow control by providing sliding windows and offers reliability by providing sequence numbers and acknowledgments. TCP resends anything that is not acknowledged and supplies a virtual circuit between end-user applications. The advantage of TCP is that it provides guaranteed delivery of segments.

- **User Datagram Protocol (UDP)**—A connectionless and unreliable protocol that is responsible for transmitting messages but provides no software checking for segment delivery. The advantage that UDP provides is speed. Because UDP provides no acknowledgments, less control traffic is sent across the network, making the transfer faster.

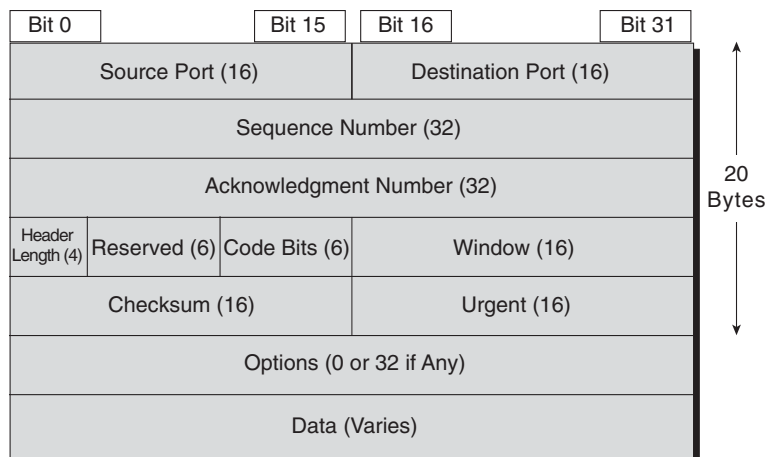
Figure 19-3 Transport Layer Protocols



TCP and UDP Segment Format

TCP is known as a connection-oriented protocol. Connection-oriented means that the end stations are aware of each other and are constantly communicating about the connection. A classic example of a non-technical connection-oriented communication is a telephone conversation between two people. A good example of a connectionless conversation is the U.S. postal service where once you place the letter in the mail you hope that the mailing process gets the package delivered. Figure 19-4 illustrates the TCP segment header format, the field definitions of which are described in the following list.

Figure 19-4 TCP Segment Format



- **Source port**—The number of the source (port) for this segment.
- **Destination port**—The number of the destination (port) for this segment.
- **Sequence number**—The number used to ensure correct sequencing of the arriving data. It is the number assigned to the first octet in the user data field.
- **Acknowledgment number**—The next expected TCP octet.
- **Header length**—The number of 32-bit words in the header.
- **Reserved**—Set to 0.
- **Code bits**—The control functions (for example, setup and termination of a session).
- **Window**—The number of octets that the sender is willing to accept.
- **Checksum**—The calculated checksum of the header and data fields.
- **Urgent**—Indicator of the end of the urgent data.
- **Options**—One currently defined: maximum TCP segment size.
- **Data**—Upper layer protocol data.

When using UDP, application layer protocols must provide for reliability if it is necessary. UDP uses no windowing or acknowledgments. It is designed for applications that do not need to put sequences of segments together. Figure 19-5 shows the UDP header.

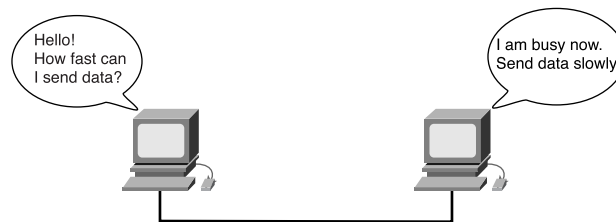
Figure 19-5 UDP Header Format

Source Port (16)	Destination Port (16)	Length (16)	Checksum (16)	Data (Variable)
------------------	-----------------------	-------------	---------------	-----------------

TCP Operation

IP addresses allow for the routing of packets between networks. However, IP makes no guarantees about delivery. The transport layer is responsible for the reliable transport and regulation of data flow from source to destination. This reliability is accomplished by using sliding windows, sequencing numbers, and a synchronization process that ensures each host is ready and willing to communicate, as shown in Figure 19-6.

Figure 19-6 TCP Operation



To understand reliability and flow control, think of two people engaged in a conversation. First, they meet and maybe shake hands to acknowledge to each other that a conversation is about to take place and information is about to be sent. While they are talking and exchanging information, if a word or phrase is inaudible or unreachable to the other person, one person might simply ask the person to repeat their words (for reliability) so he or she can catch the words (flow control). The transport layer, Layer 4 of the OSI model, provides these services to Layer 3 via TCP.

Three-Way Handshake

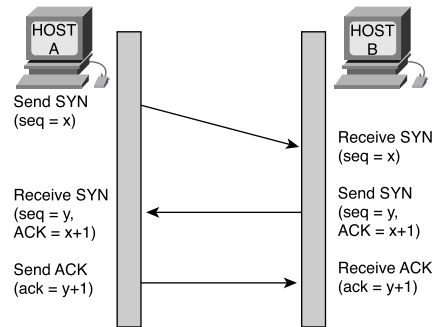
TCP is a connection-oriented protocol. Prior to data transmission the two communicating hosts go through a synchronization process to establish a virtual connection. This synchronization process ensures that both sides are ready for data transmission and enables the devices to determine the initial sequence numbers (ISNs). This process is known as a *three-way handshake*.

Synchronization is accomplished by exchanging packets carrying the ISNs and a control bit called SYN, which stands for *synchronize*. (Packets carrying the SYN bit are also called SYNs.) Successful connection requires a suitable mechanism for choosing an initial sequence and a slightly involved handshake to exchange the ISNs. Synchronization requires that each side send its own ISN and receive a confirmation and ISN from the other side of the connection.

Each side must receive the other side's ISN and send a confirming acknowledgment (ACK) in a specific order. A three-way handshake uses the following three-step process to establish a virtual connection between the two devices:

1. One host initiates a connection by sending a SYN packet indicating its initial sequence number of x with a certain bit in the header set to indicate a connection request. This bit is set in the code field of the TCP header.
2. The other host receives the packet, records the sequence number of x , replies with an acknowledgment of $x + 1$, and includes its own initial sequence number of y . The acknowledgment number of $x + 1$ means the host has received all octets up to and including x and is expecting $x + 1$ next.
3. The initiating host responds with a simple acknowledgement (ACK) of $y + 1$ (the sequence number of the second host + 1), indicating it received the previous ACK, which finalizes the connection process.

Because the second and third steps are combined in a single message, the exchange is called a three-way handshake/open connection. As illustrated in Figure 19-7, both ends of a connection are synchronized with a three-way handshake/open connection sequence.

Figure 19-7 Three-Way Handshake

It is important to understand that sequence numbers are a part of initiating communication between the two devices. Sequence numbers act as reference starting numbers between the two devices. The sequence numbers give each host a way to ACK the SYN, so that the receiver knows the sender is responding to the proper connection request.

A three-way handshake is necessary because TCPs might use different mechanisms for picking the ISN. The receiver of the first SYN has no way of knowing if the segment was an old delayed one unless it remembers the last sequence number used on the connection, which is not always possible. So, it must ask the sender to verify this SYN. At this point, either side can begin communicating, and either side can break the communication because TCP is a peer-to-peer (balanced) communication method.

Denial-of-Service Attacks During Synchronization

Denial-of-service (DoS) attacks are designed to deny services to legitimate hosts attempting to establish connections. DoS attacks are a common method that hackers utilize to halt system response. One type of DoS is known as SYN flooding, which occurs during the three-way handshake synchronization process utilized by TCP.

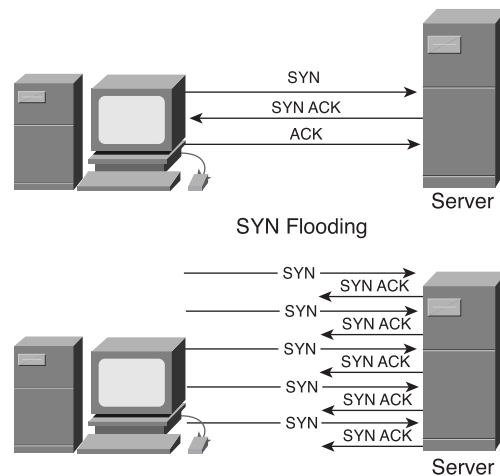
During the three-way handshake, the initiating host sends a SYN packet. The SYN packet includes the source IP address and the destination IP address, just like any other packet. The recipient uses this source and destination address information to send the SYN/ACK packet back to the initiating device.

In a DoS attack, the hacker initiates a synchronization but falsifies the source IP address. The receiving device replies to a non-existent, unreachable IP address and then is placed on hold while waiting to receive the final ACK from the initiator. The waiting request is placed in a connection queue or a holding area in memory. This waiting state requires the attacked device to commit system resources, such as memory,

to the waiting process until the connection timer times out. Hackers flood the attacked host with these false SYN requests, utilizing all of its connection resources to respond and wait for bogus connections, preventing it from responding to legitimate connection requests.

To defend against these attacks, administrators can decrease the connection timeout period and increase the connection queue size. Also, software is available that can detect these types of attacks and initiate defensive measures. Figure 19-8 shows a DoS attack during synchronization.

Figure 19-8 DoS Attack



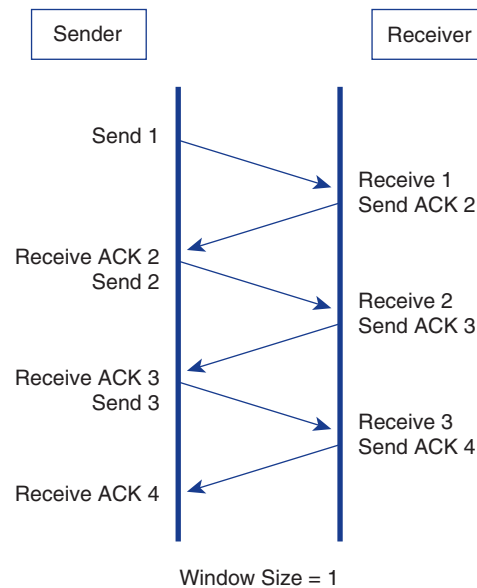
Windowing and Window Size

In many instances, the amount of data that needs to be transmitted is too large to be sent in a single data segment. When this occurs, the data must be broken into smaller pieces to allow for proper data transmission. TCP is responsible for breaking data into segments. This process is similar to feeding a child. Because most small children cannot eat extremely large bites, the person feeding them often cuts their food into smaller pieces that their mouths can accommodate. Additionally, receiving machines might not be able to receive data as quickly as the source can send data. Sometimes discrepancy exists because the receiving device is busy with other tasks; other times the sender is simply a stronger device.

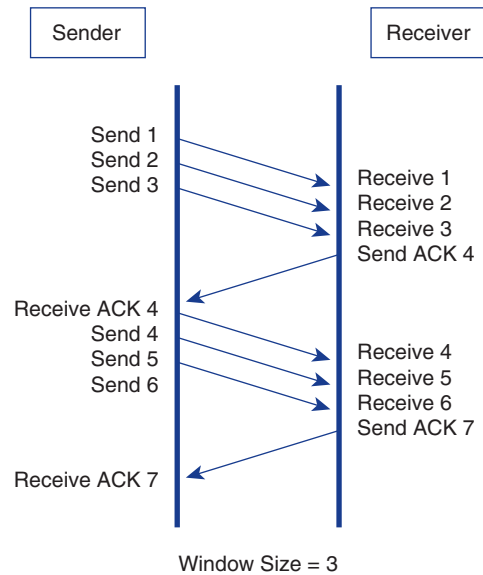
After the data is segmented, it must be transmitted to the destination device. One of the services provided by TCP is *flow control*, which regulates how much data is sent during a given transmission period. The process of flow control is known as *windowing*.

Window size determines the amount of data that can be transmitted at one time before receiving an acknowledgment from the destination. After a host transmits the window-sized number of bytes, the host must receive an acknowledgment that the data has been received before it can send any more messages. For example, with a window size of one, each individual segment must be acknowledged before the next segment can be sent as shown in Figure 19-9.

Figure 19-9 Window Size of 1



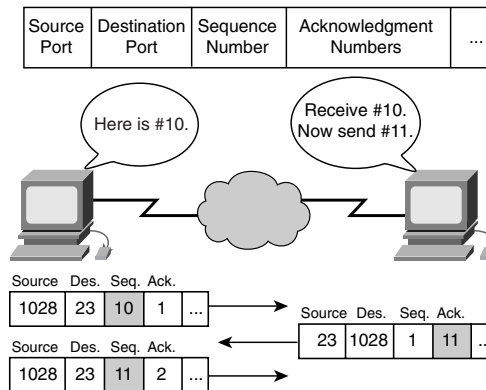
TCP utilizes a sliding window when determining transmission size. A sliding window enables devices to negotiate a window size to allow for more than one byte to be sent during a single transmission, as shown in Figure 19-10. This sliding window also enables the destination device to communicate with the source. The destination device, if it is incapable of dealing with that much data, can indicate a need to decrease the amount of data being sent. Conversely, the destination device can instruct the source to increase the amount of data being sent if it can process more data than is currently being sent.

Figure 19-10 Larger Window Size

Sequencing Numbers

TCP breaks data into segments. The data segments are then transported from sender to receiver. Data transportation follows the synchronization process and the negotiation of a window size that dictates the number of bytes that can be transmitted at once. The data segments being transmitted must be reassembled once all of the data is received. No guarantee exists that the data will arrive in the order that it was transmitted, so TCP addresses this problem by using sequence numbers. TCP applies sequence numbers to the data segments it is transmitting so that the receiver will be able to properly reassemble the bytes in their original order. Sequencing numbers indicate to the destination device the correct order in which to put the bytes when they are received.

These sequencing numbers also act as reference numbers so that the receiver knows if it has received all of the data and can identify the missing data pieces to the sender so it can retransmit the missing data as shown in Figure 19-11. This feature offers increased efficiency because the sender is required to retransmit only the missing segments instead of retransmitting the entire set of data.

Figure 19-11 Sequence Acknowledgment Numbers

Each TCP segment is numbered before transmission. Figure 19-4 from earlier in the chapter showed the TCP segment format. Notice that the Sequence number portion follows the Destination port in the segment format. At the receiving station, TCP uses the sequence numbers to reassemble the segments into a complete message. If a sequence number is missing in the series, that segment is retransmitted.

Positive ACK

Acknowledgement is a common step in the synchronization process, sliding windows, and the sequencing of data. In a TCP segment, the Sequence number field is followed by the Acknowledgement field, also referred to as the Code field. This field is where ACKs and SYNs are indicated.

One problem with the unreliable IP protocol is that no verification method exists in it for determining that data segments actually reached their destination. Therefore, data segments might be forwarded with no knowledge as to whether or not they were actually received. TCP utilizes positive acknowledgement and retransmission to control data flow and confirm data delivery.

Positive acknowledgement and retransmission (PAR) is a common technique many protocols use to provide reliability. With PAR, the source sends a packet, starts a timer, and waits for an acknowledgment before sending the next packet. If the timer expires before the source receives an acknowledgment, the source retransmits the packet and restarts the timer. TCP uses expectant acknowledgments in which the acknowledgment number refers to the next octet that is expected.

Windowing is a flow control mechanism. During windowing, the source device is required to receive an acknowledgment from the destination after transmitting a certain amount of data. With a window size of three, the source device can send three

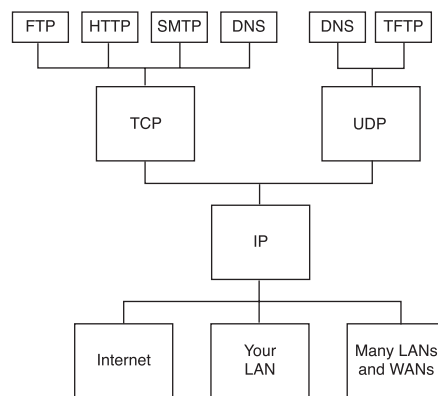
octets to the destination. It must then wait for an acknowledgment. If the destination receives the three octets, it sends an acknowledgment to the source device, which can now transmit three more octets. If the destination does not receive the three octets, due to overflowing buffers or some other reason, it does not send an acknowledgment. If the source does not receive an acknowledgment, it knows that the octets must be retransmitted and that the transmission rate should be slowed.

UDP Operation

The TCP/IP protocol stack contains many different protocols, and each protocol is designed to perform a specific task. IP provides Layer 3 connectionless transport through an internetwork. TCP enables connection-oriented, reliable transmission of packets at Layer 4 of the OSI model. UDP provides connectionless, non-guaranteed transmission of packets at Layer 4 of the OSI model.

Both TCP and UDP use IP as their underlying Layer 3 protocol. In addition, TCP and UDP are used by various application layer protocols. TCP provides services for applications such as FTP, HTTP, SMTP, and DNS. UDP is the transport layer protocol used by DNS, TFTP, SNMP, and DHCP. Figure 19-12 illustrates the relationship between TCP/IP application, transport, and network layer protocols.

Figure 19-12 TCP/IP Application, Transport, and Network Layer Protocols



TCP must be used when applications need to guarantee that a packet arrives intact, in sequence, and unduplicated. However, the overhead associated with ensuring delivery of the packet is sometimes a problem when using TCP. Not all applications need to guarantee delivery of the data packet, and therefore, some use the faster, connectionless delivery mechanism offered by UDP. The UDP standard, described in RFC 768, is a simple protocol that exchanges segments without acknowledgments or guaranteed

delivery. As an example, TFTP can be used to transfer a configuration file or a Cisco IOS Software image from a TFTP server to a router on an Ethernet network. TFTP uses the efficient UDP transport protocol because the quality of physical connections is usually very good and the acknowledgement and retransmission capabilities of TCP are not necessary.

UDP does not use windowing or acknowledgments. Therefore, application layer protocols provide error detection. UDP is designed for applications that do not need to put sequences of segments together.

Figure 19-5 earlier in this chapter displayed the UDP segment format. The Source Port field is an optional field, used only if information needs to return to the sending host. The Destination Port field specifies the application to which UDP must pass the protocol. A DNS request from a host to a DNS server has a Destination Port field of 53, the UDP port number for DNS. The Length field identifies the number of octets in the UDP segment. The UDP checksum is optional, but should be used to ensure that the data has not been damaged during transmission. For transport across the network, UDP is encapsulated within the IP packet.

After a UDP segment arrives at the destination IP address, a mechanism must exist that allows the receiving host to determine the destination application of the segment. Ports are used for this purpose. If a host is running both TFTP and DNS services, it must be able to determine what service the arriving UDP segments need. The Destination Port field in the UDP header determines the application to which a UDP segment is delivered.

Overview of Transport Layer Ports

Transport layer ports are 16-bit numbers used to identify the connection end points on either side of the connecting devices. A particular network connection is then identified by a four-part (source address, source port, destination address, destination port) sequence. In principle, this scheme allows for unique UDP connections between any two hosts. UDP is still connectionless and unreliable. To support connection-oriented applications that require reliable, in-sequence data streams, TCP is used. Like UDP, TCP also uses ports to identify connection endpoints.

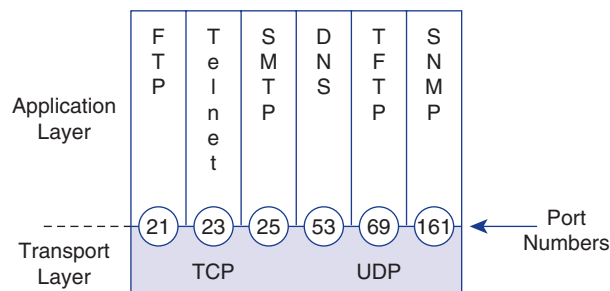
Multiple Conversations Between Hosts

At any given moment, thousands of packets providing hundreds of different services are traveling through a modern network. In many cases, servers provide several different services simultaneously, which causes unique problems for the addressing of packets. For example, if a server is running both SMTP and World Wide Web services, a client cannot construct a packet destined for the IP address of the server just using TCP

because both SMTP and the World Wide Web services use TCP as their transport layer protocol. A port number must be associated with the conversation between hosts to ensure that the packet reaches the appropriate service on the server. Without a way to distinguish between different conversations, the client is unable to send an e-mail and browse a web page at the same time using one server. A method to separate transport layer conversations must be used.

Hosts running TCP/IP associate ports at the transport layer with certain applications. Port numbers are used to keep track of different conversations that cross the network at the same time. Port numbers are necessary when a host is communicating with a server running multiple services. Both TCP and UDP use port, or socket, numbers to pass information to the upper layers. Figure 19-13 shows an example of TCP and UDP port numbers.

Figure 19-13 TCP and UDP Port Numbers



Application software developers have agreed to use the well-known port numbers that are defined in RFC 1700. For example, any conversation bound for the FTP application uses the standard port number 21. Conversations that do not involve applications with well-known port numbers are assigned port numbers that have been randomly selected from within a specific range. These port numbers are used as source and destination addresses in the TCP segment. Table 19-1 lists the reserved TCP and UDP port numbers.

Table 19-1 Reserved TCP and UDP Port Numbers

Decimal	Keyword	Description
0	-	Reserved
1-4	-	Unassigned
5	rje	Remote job entry (RJE)

continues

Table 19-1 Reserved TCP and UDP Port Numbers (Continued)

Decimal	Keyword	Description
7	echo	Echo
9	discard	Discard
11	users	Active users
13	daytime	Daytime
15	netstat	Who is up or netstat
17	quote	Quote of the day
19	chargen	Character generator
20	ftp-data	FTP (data)
21	ftp	FTP
23	telnet	Terminal connection
25	smtp	SMTP
37	time	Time of day
39	rlp	Resource Location Protocol
42	nameserver	Host name server
43	nickname	Who is
53	domain	DNS
67	bootps	Bootstrap protocol server
68	bootpc	Bootstrap protocol client
69	tftp	TFTP
75	-	Any private dial-out service
77	-	Any private RJE Service
79	finger	Finger
80	HTTP	Hypertext Transfer Protocol
123	ntp	Network Time Protocol (NTP)
133–159	-	Unassigned
160–223	-	Reserved

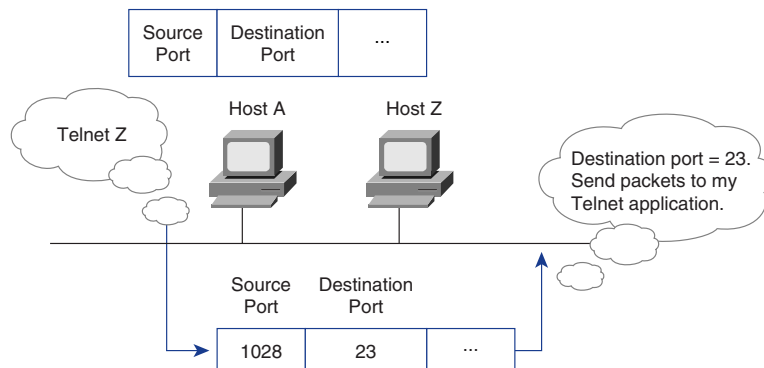
Table 19-1 Reserved TCP and UDP Port Numbers (Continued)

Decimal	Keyword	Description
224–241	-	Unassigned
242–255	-	Unassigned

Port numbers have the following assigned ranges:

- Numbers below 255 are for public applications.
- Numbers from 255 to 1023 are assigned to companies for marketable applications.
- Numbers above 1023 are unregulated.

End systems use port numbers to select proper applications. As shown in Figure 19-14, the originating source port number (1028) is dynamically assigned by the source host. Usually, this port number is larger than 1023. The Internet Assigned Numbers Authority (IANA) controls Port numbers in the range of zero to 1023.

Figure 19-14 Source and Destination Ports

Ports for Services

Services running on hosts must have a port number assigned to them for communication to occur. A remote host attempting to connect to a service expects that service to run on certain transport layer protocols at particular ports. Some ports, defined in RFC 1700, are known as the *well-known ports*. These ports are reserved in both TCP and UDP.

These well-known ports can identify applications that run above the transport layer protocols. For example, a server running the FTP service forwards TCP connections using ports 20 and 21 from clients to its FTP application. This way, the server can

determine exactly what service a client is requesting. TCP and UDP use port numbers to determine the correct service to forward service requests to.

Ports for Clients

Whenever a client connects to a service on a server, a source and destination port must be specified. TCP and UDP segments contain fields for source and destination ports. Destination ports, or ports for services, are normally defined using the well-known ports. Source ports, those set by the client, are determined dynamically.

In general, a client determines the source port by randomly assigning a number above 1023. For instance, a client attempting to communicate with a web server uses TCP and assigns the destination port as 80 and the source port as 1045. When the packet arrives at the server, it passes up to the transport layer and eventually to the World Wide Web service, which operates at port 80. The World Wide Web server responds to the client's request with a segment that uses port 80 as the source and port 1045 as the destination. In this way, clients and servers use ports to distinguish what process the segment is associated with. If a client has two browser sessions open to two different web servers, the destination port is 80 for both sessions. However, the source port is a different number for each session (for example, 1045 and 1048). This difference allows the client to keep track of the two different conversations.

Port Numbering and Well-Known Ports

Port numbers are represented by 2 bytes in the header of a TCP or UDP segment. This 16-bit value can result in port numbers ranging from 0 to 65,535. These port numbers are divided into three different categories:

- Well-known ports
- Registered ports
- Dynamic or private ports

The first 1023 ports are well-known ports. As previously discussed, these ports are used for well-known network services such as FTP, Telnet, DNS, or HTTP. Registered ports range from 1024 to 49151 and identify services such as Cisco-Net-Mgmt and Calendar Access Protocol. Finally, ports between 49152 and 65535 are defined as dynamic or private ports.

Example of Multiple Sessions Between Hosts

Port numbers are used to track multiple sessions that can occur between hosts. A port number and a network address combine to form a socket. A pair of sockets, one on each

host, forms a unique connection. For example, a host can have a Telnet connection through port 23, while simultaneously surfing the net through port 80. The IP address and the MAC address are the same because the packets are coming from the same host. However, the port numbers are different because they are different protocols and, thus, different sockets.

**Lab Activity—Multiple Active Host Sessions**

In this activity, you enable HTTP services on a router and observe multiple HTTP and Telnet sessions on a single host using the `netstat` command.

**Lab Activity—Well-Known Port Numbers and Multiple Sessions**

In this activity, you observe the well-known port numbers of multiple sessions on a single host using the `netstat` command.

Comparison of MAC Addresses, IP Addresses, and Port Numbers

MAC addresses, IP addresses, and port numbers are often confusing, but this confusion can be avoided if the addresses are explained in reference to the OSI reference model. Port numbers are located at the transport layer and are serviced by the network layer. The network layer assigns the logical address, or IP. It is then serviced by the data link layer, which assigns the physical address, or MAC.

TCP/IP and the Internet Layer

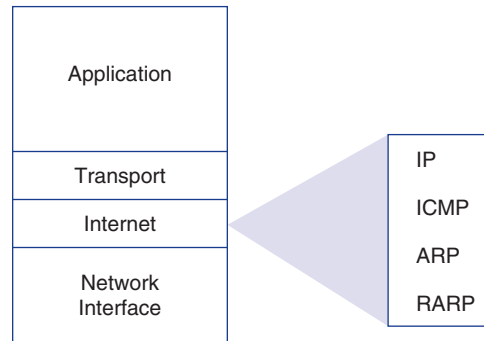
Internet Protocol (IP) is the Layer 3 protocol responsible for the addressing scheme that allows packets to be properly routed over intranets and the Internet to their destinations. Routers use the IP address information in an IP packet header to determine which interface the packet should be switched to in order to reach its destination. IP does not provide any services to ensure that the packet reaches its destination. IP is described as an unreliable, connectionless protocol. Packets might be dropped in route, arrive in the wrong order, or be transmitted faster than the receiver can accept them. IP has no means of overcoming these and other delivery issues.

The Internet layer of the TCP/IP stack corresponds to the network layer of the OSI model. The network layer is responsible for getting packets through a network using software addressing.

As shown in the Figure 19-15, several protocols operate at the TCP/IP Internet layer, corresponding to the OSI network layer:

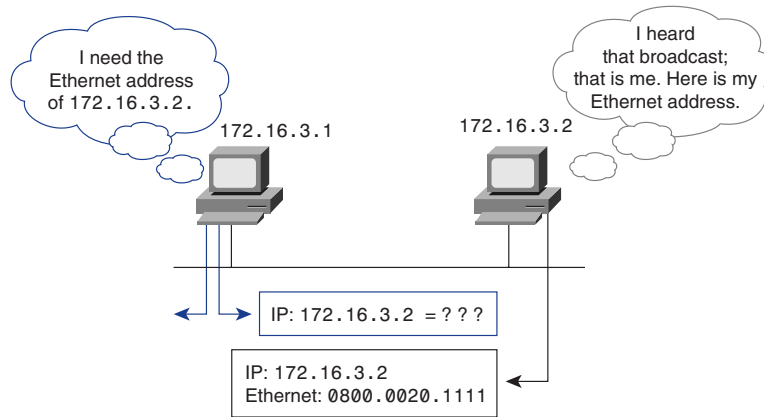
- **IP**—Provides addressing and connectionless, best-effort delivery routing of datagrams, is not concerned with the content of the datagrams, and looks for a way to move the datagrams to their destination
- **ICMP**—Provides control and messaging capabilities
- **Address Resolution Protocol (ARP)**—Determines the data link layer (MAC) addresses for known IP addresses
- **Reverse Address Resolution Protocol (RARP)**—Determines network addresses when data link layer addresses are known

Figure 19-15 OSI Network Layer



How ARP Works

ARP is used to resolve or map a known IP address to a MAC sublayer address. This mapping allows for communication because the data link hardware will not accept a frame unless the MAC address in the frame matches the hardware MAC address (or it is a broadcast MAC address). To determine a destination MAC address for a datagram, a table called the ARP cache is checked. Every host on a TCP/IP network (routers, workstations, servers, and so on) maintains an ARP cache. If the address is not in the table, ARP sends a broadcast that is received by every station on the network, looking for the destination station. The term *local ARP* describes the search for an address when the requesting host and the destination host share the same medium or wire. As shown in Figure 19-16, before issuing the ARP, the subnet mask must be consulted. In this case, the mask determines that the nodes are on the same subnet.

Figure 19-16 OSI Network Layer

RARP is a TCP/IP protocol that permits a physical address, such as an Ethernet address, to be translated into an IP address. Consequently, this protocol is the opposite of ARP. Hosts such as diskless workstations often know only their hardware interface addresses, or MAC address, when booted, but not their IP addresses. They must discover their IP addresses from an external source. Usually, a RARP server using the RARP protocol can resolve this situation.

Summary

In this chapter, you learned the following:

- TCP is a connection-oriented transport layer protocol that provides necessary quality of service processes to the unreliable IP protocol.
- TCP provides reliability, flow control, and virtual connection services.
- TCP utilizes a three-way handshake to establish synchronized communication between hosts.
- Sliding windows allows for dynamic data flow control.
- Sequence numbers ensure proper data reassembly by the receiving host.
- UDP is a connectionless transport layer protocol.
- UDP and TCP use ports to distinguish upper layer applications.

To supplement all that you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab Activities on the CD-ROM accompanying this book.

Key Terms

ARP (Address Resolution Protocol) Internet protocol used to map an IP address to a MAC address.

DoS (denial-of-service) Type of attack on a network that is designed to bring the network to its knees by flooding it with useless traffic.

flow control The process of adjusting the flow of data from one device to another to ensure that the receiving device can handle all of the incoming data.

RARP (Reverse Address Resolution Protocol) Protocol in the TCP/IP stack that provides a method for finding IP addresses based on MAC addresses.

TCP (Transmission Control Protocol) Connection-oriented transport layer protocol that provides reliable full-duplex data transmission. TCP is part of the TCP/IP protocol stack.

UDP (User Datagram Protocol) Connectionless transport layer protocol in the TCP/IP protocol stack. UDP is a simple protocol that exchanges datagrams without acknowledgments or guaranteed delivery, requiring that error processing and retransmission be handled by other protocols.

well-known ports These ports are defined in RFC 1700 and are reserved in both TCP and UDP. These well-known ports can identify applications that run above the transport layer protocols.

windowing Manages the flow. The recipient reports to the sender what size window in terms of octets it's able to accept at this time. The sender then sends that many octets to the receiving host.

Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. Which of the following best describes TCP/IP?
 - A. It is a suite of protocols that can be used to communicate across any set of interconnected networks.
 - B. It is a suite of protocols that allows LANs to connect into WANs.

- C. It is a suite of protocols that allows for data transmission across a multitude of networks.
 - D. It is a suite of protocols that allows different devices to be shared by interconnected networks.
2. Which of the following is one of the protocols found at the transport layer?
- A. UCP
 - B. UDP
 - C. TDP
 - D. TDC
3. What is the purpose of port numbers?
- A. They keep track of different conversations crossing the network at the same time.
 - B. Source systems use them to keep a session organized and to select the proper application.
 - C. End systems use them to dynamically assign end users to a particular session, depending on their application use.
 - D. Source systems generate them to predict destination addresses.
4. Which of the following best describes UDP?
- A. A protocol that acknowledges flawed or intact datagrams
 - B. A protocol that detects errors and requests retransmissions from the source
 - C. A protocol that processes datagrams and requests retransmissions when necessary
 - D. A protocol that exchanges datagrams without acknowledgments or guaranteed delivery
5. Which of the following TCP/IP layers includes file transfer, e-mail, remote login, and network management?
- A. Transport
 - B. Application
 - C. Internet
 - D. Network

6. Why are TCP three-way handshake/open connections used?
 - A. To ensure that lost data can be recovered if problems occur later
 - B. To determine how much data the receiving station can accept at one time
 - C. To provide efficient use of bandwidth by users
 - D. To change binary ping responses into information in the upper layers
7. What does a TCP sliding window do?
 - A. It makes the window larger so that more data can come through at once, which results in more efficient use of bandwidth.
 - B. The window size slides to each section of the datagram to receive data, which results in more efficient use of bandwidth.
 - C. It allows the window size to be negotiated dynamically during the TCP session, which results in more efficient use of bandwidth.
 - D. It limits the incoming data so that each segment must be sent one by one, which is an inefficient use of bandwidth.
8. UDP segments use what protocols to provide reliability?
 - A. Network layer protocols
 - B. Application layer protocols
 - C. Internet protocols
 - D. Transmission Control Protocols
9. Which of the following best describes window size?
 - A. The maximum size of the window that software can have and still process data rapidly
 - B. The number of messages or bytes that can be transmitted while awaiting an acknowledgment
 - C. The size of the window, in picas, that must be set ahead of time so that data can be sent
 - D. The size of the window opening on a monitor, which is not always equal to the monitor size
10. What is the function of ARP?
 - A. It completes research for a Layer 3 destination address.
 - B. It is used to develop a cached Layer 4 address resource table.
 - C. It is used to map an IP address to a MAC address.
 - D. It sends a broadcast message looking for the router IP address.



Objectives

Upon completion of this chapter, you will be able to

- Understand the purpose of ACLs
- Describe how ACLs work
- Determine which wildcard mask should be used
- Describe and use standard ACLs, extended ACLs, and named ACLs
- Describe a simple firewall architecture

Chapter 20

Access Control Lists

In this chapter, you learn about using standard and extended access control lists (ACLs) as a means to control network traffic and how ACLs are used as part of a security solution.

In addition, this chapter includes tips, considerations, recommendations, and general guidelines on how to use ACLs, and includes the commands and configurations needed to create ACLs. Finally, this chapter provides examples of standard and extended ACLs and shows how to apply ACLs to router interfaces.

Please be sure to look at this chapter's associated e-Labs, Videos, and PhotoZooms that you will find on the CD-ROM accompanying this book. These CD elements are designed to supplement the material and reinforce the concepts introduced in this chapter.

ACL Overview

Network administrators must be capable of denying unwanted access to the network while allowing appropriate access. Although security tools such as passwords, callback equipment, and physical security devices are helpful, they often lack the flexibility of basic traffic filtering and the specific controls that most administrators prefer. For example, a network administrator might want to allow users access to the Internet but might not want external users Telnetting into the LAN.

Routers provide basic traffic-filtering capabilities, such as blocking Internet traffic, with *access control lists (ACLs)*. An ACL is a sequential collection of permit or deny statements that apply to addresses or upper-layer protocols.

It is important to configure ACLs correctly and to know where to place ACLs on the network. ACLs serve multiple purposes in a network. Common ACL functions include the following:

- Filtering packets internally
- Protecting the internal network from illegal Internet access
- Restricting access to virtual terminal ports

NOTE

ACLs consume CPU resources in the router because every packet has to be punted to the CPU.

ACLs are lists of instructions that you apply to a router's interface. These lists tell the router what kinds of packets to accept and what kinds of packets to deny. Acceptance and denial can be based on certain specifications, such as source address, destination address, and TCP/UDP port number.

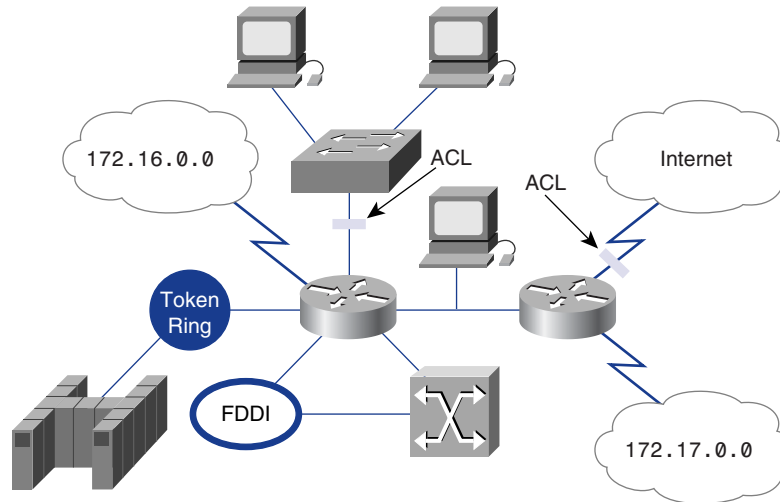
ACLs enable you to manage traffic and scan specific packets by applying the ACL to a router interface. Any traffic going through the interface is tested against certain conditions that are part of the ACL.

ACLs can be created for all routed network protocols, such as Internet Protocol (IP) and Internetwork Packet Exchange (IPX), to filter packets as the packets pass through a router. ACLs can be configured at the router to control access to a network or subnet.

ACLs filter network traffic by controlling whether routed packets are forwarded or blocked at the router's interfaces. The router examines each packet to determine whether to forward or drop it, based on the conditions specified in the ACL. ACL conditions could be the source address of the traffic, the destination address of the traffic, the upper-layer protocol, the port, or applications.

ACLs must be defined on a per-protocol basis. In other words, you must define an ACL for every protocol enabled on an interface if you want to control traffic flow for *that* protocol on *that* interface. (Note that some protocols refer to ACLs as *filters*.) For example, if your router interface were configured for IP, AppleTalk, and IPX, you would need to define at least three ACLs. As shown in Figure 20-1, ACLs can be used as a tool for network control by adding the flexibility to filter the packets that flow in or out of router interfaces. This is accomplished by establishing a numbering range or scheme for each protocol's ACL. You learn more about the ACL numbers later in this chapter.

Figure 20-1 ACL Example



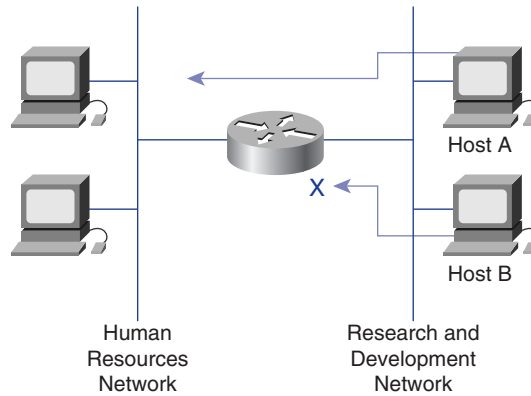
Why Create ACLs?

Many reasons exist for creating ACLs. ACLs can be used to do the following:

- Limit network traffic and increase network performance. For example, ACLs can designate certain packets to be processed by a router before other traffic, on the basis of a protocol. This is referred to as *queuing*. Queuing ensures that routers will not process packets that are not needed. As a result, queuing limits network traffic and reduces network congestion.
- Provide traffic flow control. For example, ACLs can restrict or reduce the contents of routing updates. These restrictions are used to limit information about specific networks from propagating through the network.
- Provide a basic level of security for network access. ACLs can allow one host to access a part of your network and prevent another host from accessing the same area. In Figure 20-2, Host A is allowed to access the Human Resources network, and Host B is prevented from accessing the Human Resources network. If you do not configure ACLs on your router, all packets passing through the router could be allowed onto all parts of the network.
- Decide which type of traffic is forwarded or blocked at the router interface. For example, you can permit e-mail traffic to be routed, but at the same time block all Telnet traffic.

NOTE

The rule of thumb is one ACL per interface per direction.

Figure 20-2 Limiting Network Traffic

Creating an ACL: Why Order Matters

Order matters when creating an ACL. As traffic enters or exits a router's interface, where an ACL is applied, Cisco IOS Software compares the packet against the rules defined in the ACL. Statements are evaluated in the order they were entered into the ACL by the network administrator. The packet is compared, one at a time in sequence, until a match is found. After a match is found, the action specified in the line matching the traffic in question is taken. No more conditions are checked.

NOTE

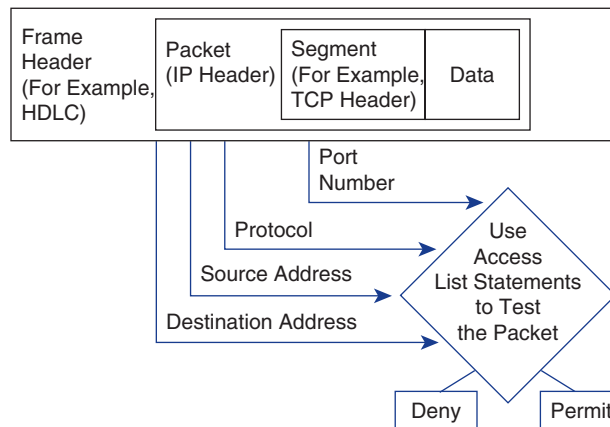
When an ACL is created, new lines are added to the end of the ACL. Individual lines cannot be deleted. Only entire ACLs can be deleted.

For example, if a condition statement permitting all traffic is created, statements added later will never be checked. If additional statements are required or if statements must be changed, you must delete the ACL and re-create it with the new statements. It is a good idea to use a PC text editor to create and modify ACLs and then send them to the router via Trivial File Transfer Protocol (TFTP) or HyperTerminal text file transfer.

Using ACLs

You can create an ACL for each protocol that you want to filter for each router interface. For some protocols, you create one ACL to filter inbound traffic and one ACL to filter outbound traffic.

After an ACL statement checks a packet for a match, the packet can be denied or permitted to use an interface in the access group. Cisco IOS Software ACLs check the packet and upper-layer headers, as shown in Figure 20-3.

Figure 20-3 Checking the Packet and Upper-Layer Headers

How ACLs Work

An ACL is a group of statements that define how packets do the following:

- Enter inbound router interfaces
- Relay through the router
- Exit outbound router interfaces

As shown in Figure 20-4, the beginning of the communication process is the same, whether ACLs are used or not. As a packet enters an interface, the router checks to see whether the packet is routable or bridgeable. Now the router checks whether the inbound interface has an ACL. If one exists, the packet is tested against the conditions in the list. If the packet is allowed, it then is checked against routing table entries to determine the destination interface. ACLs filter not packets that originate in the router itself, but packets from other sources.

Next, the router checks whether the destination interface has an ACL. If it does not, the packet can be sent to the destination interface directly; for example, if it will use E0, which has no ACLs, the packet uses E0 directly.

ACL statements operate in a sequential, logical order. If a condition match is true, the packet is permitted or denied and the rest of the ACL statements are not checked. If all the ACL statements are unmatched, an implicit deny any statement is imposed. Even though you will not see the deny any as the last line of an ACL, it is there by default. In Figure 20-5, if by matching the first test a packet is denied access to the destination, it is discarded and dropped into the *bit bucket*. It is not exposed to any ACL tests that follow. If the packet does not match the conditions of the first test, it drops to the next statement in the ACL.

Figure 20-4 How ACLs Work

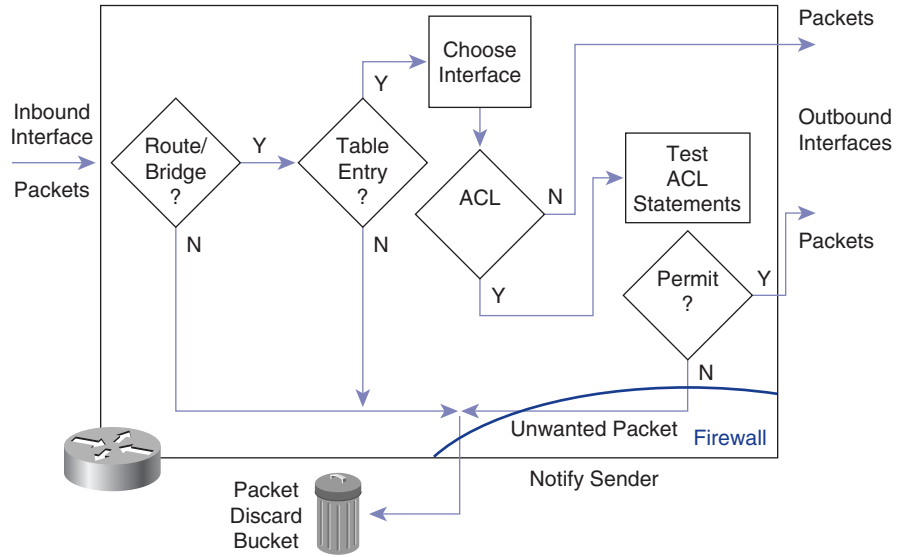
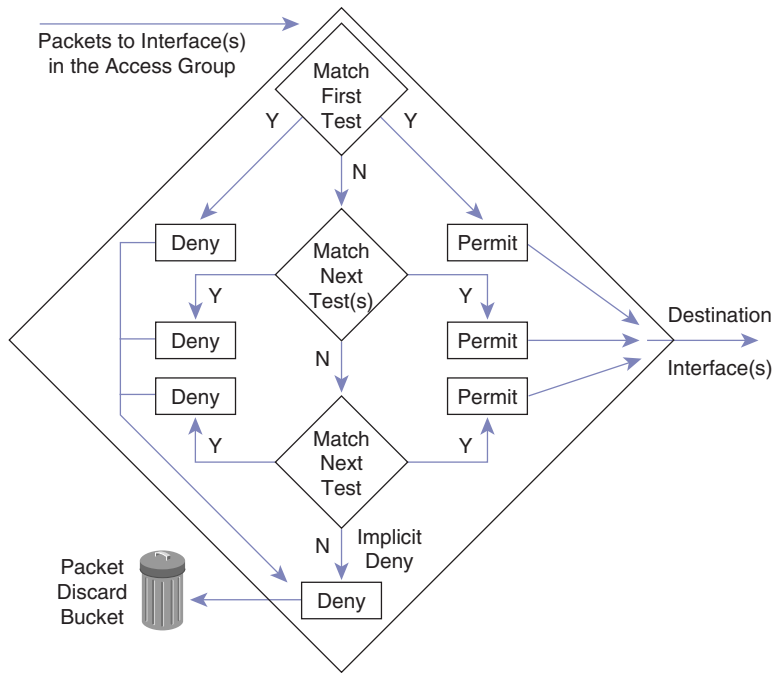


Figure 20-5 ACL Test Matching and Implicit deny any



ACLs enable you to control what clients can access on your network. Conditions in an ACL file can do the following:

- Screen out certain hosts to either allow or deny access to part of your network
- Grant or deny users permission to access only certain types of applications, such as FTP or HTTP

ACL Configuration Tasks

In practice, ACL commands can be lengthy character strings. Key tasks covered in this section for creating ACLs include the following:

- You create ACLs by using global configuration mode.
- Specifying an ACL number from 1 to 99 defines a standard ACL for IP and instructs the router to accept standard ACL statements.
- Specifying an ACL number from 100 to 199 defines an extended ACL for IP and instructs the router to accept extended ACL statements.
- You must carefully select and logically order the ACL. Permitted IP protocols must be specified; all other protocols should be denied unless required.
- You need to select which protocols to check; any other protocols are not checked. Later in the procedure, you can specify an optional destination port for more precision.
- You apply an ACL to an interface.

Although each protocol has its own set of specific tasks and rules that are required to provide traffic filtering, in general most protocols require two basic steps:

Step 1 Create an ACL definition.

Step 2 Apply the ACL to an interface.

ACLs are assigned to one or more interfaces and can filter inbound traffic or outbound traffic, depending on the configuration and how they are applied. Outbound ACLs generally are more efficient than inbound and, therefore, are preferred. A router with an inbound ACL must check every packet to see whether it matches the ACL condition before switching the packet to an outbound interface.

Assigning a Unique Number to Each ACL

When configuring ACLs on a router, you must identify each ACL uniquely by assigning a number to the protocol's ACL. When you use a number to identify an ACL, the

number must be within the specific range of numbers that is valid for the protocol. Example 20-1 defines ACLs 1 and 2 and applies the ACLs to interface Ethernet 0:

Example 20-1 *Assigning ACLs to an Interface*

```
access-list 1 permit 5.6.0.0 0.0.255.255
access-list 1 deny 7.9.0.0 0.0.255.255
!
access-list 2 permit 1.2.3.4
access-list 2 deny 1.2.0.0 0.0.255.255
!
interface ethernet 0
ip address 1.1.1.1 255.0.0.0
!
ip access-group 1 in
ip access-group 2 out
```

Table 20-1 lists valid protocol ACL numbers.

Table 20-1 Protocols, ACLs, and Their Corresponding Numbers

Protocol	Range
IP	1 to 99
Extended IP	100 to 199
AppleTalk	600 to 699
IPX	800 to 899
Extended IPX	900 to 999
IPX Service Advertising Protocol	1000 to 1099

Using Wildcard Mask Bits

A *wildcard mask* is a 32-bit quantity that is divided into four octets, with each octet containing 8 bits. A wildcard mask bit of 0 means “check the corresponding bit value,” and a wildcard mask bit of 1 means “do not check (ignore) that corresponding bit value” (see Figure 20-6).

Figure 20-6 Wildcard Mask Bit Matching

128	64	32	16	8	4	2	1	Octet Bit Position and Address Value for Bit
0	0	0	0	0	0	0	0	=
0	0	1	1	1	1	1	1	=
0	0	0	0	1	1	1	1	=
1	1	1	1	1	1	0	0	=
1	1	1	1	1	1	1	1	=

Examples
Check All Address Bits (Match All)
Ignore Last 6 Address Bits
Ignore Last 4 Address Bits
Check Last 2 Address Bits
Do Not Check Address (Ignore Bits in Octet)

A wildcard mask is paired with an IP address, similar to how a subnet mask is paired with an IP address. Wildcard mask bits use the numbers 1 and 0 to identify how to treat the corresponding IP address bits.

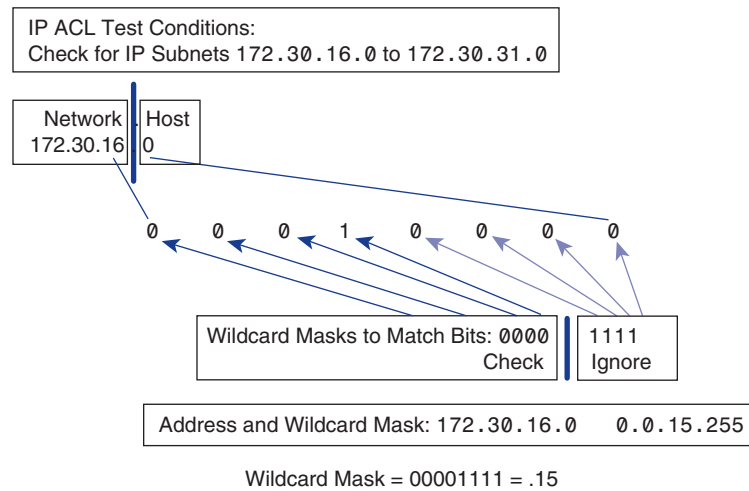
ACLs use wildcard masking to identify a single address or multiple addresses for permit or deny tests. The term *wildcard masking* is a nickname for the ACL mask bit-matching process and comes from of an analogy of a wildcard that matches any other card in a poker game.

Although both are 32-bit quantities, wildcard masks and IP subnet masks operate differently. Recall that the 0s and 1s in a subnet mask determine the network, subnet, and host portions of the corresponding IP address. The 0s and 1s in a wildcard, as just noted, determine whether the corresponding bits in the IP address should be checked or ignored for ACL purposes.

As you have learned, the 0 and 1 bits in an ACL wildcard mask cause the ACL to either check or ignore the corresponding bits in the IP address. Figure 20-7 demonstrates how this wildcard masking process is applied.

Suppose that you want to test an IP address for subnets that will be permitted or denied. Assume that the IP address is a Class B address (that is, the first two octets are the network number) with 8 bits of subnetting (the third octet is for subnets).

You want to use IP wildcard mask bits to permit all packets from any host in the 172.30.16.0 to 172.30.31.0 subnets. Figure 20-7 shows an example of how to use the wildcard mask to do this.

Figure 20-7 Wildcard Mask Example

To begin, the wildcard mask checks the first two octets (172.30), using corresponding 0 bits in the wildcard mask.

Because there is no interest in individual host addresses (a valid host ID does not have .0 at the end of the address), the wildcard mask ignores the final octet, using corresponding 1 bits in the wildcard mask.

In the third octet, the wildcard mask is 15 (00001111), and the IP address is 16 (00010000). The first four 0s in the wildcard mask tell the router to match the first 4 bits of the IP address (0001). Because the last 4 bits are ignored, all numbers in the range of 16 (00010000) to 31 (00011111) will match because they begin in the pattern 0001.

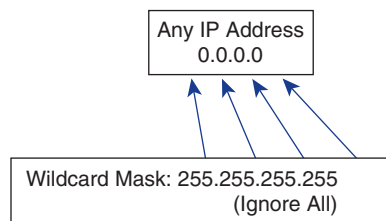
For the final (least-significant) 4 bits in this octet, the wildcard mask ignores the value because in these positions, the address value can be binary 0 or binary 1, and the corresponding wildcard bits are 1s. In this example, the wildcard mask tells the router to match the first 4 bits of the IP address. The remaining 4 bits are ignored altogether. Therefore, the address 172.30.16.0 with the wildcard mask 0.0.15.255 matches subnets 172.30.16.0 to 172.30.31.0. The wildcard mask does not match any other subnets.

Using the Wildcard any

Working with decimal representations of binary wildcard mask bits can be tedious. For the most common uses of wildcard masking, you can use abbreviations. These abbreviations reduce the amount of typing you need to do when configuring address test conditions. One such example is the wildcard any. For example, assume that you

want to specify that any destination address will be permitted in an ACL test. To indicate any IP address, you would enter 0.0.0.0, as shown in Figure 20-8; then, to indicate that the ACL should ignore (that is, allow without checking) any value, the corresponding wildcard mask bits for this address would be all 1s (that is, 255.255.255.255).

Figure 20-8 Wildcard any



You can use the abbreviation of any to communicate this same test condition on Cisco IOS Software. Instead of typing 0.0.0.0 255.255.255.255, you can use the word any by itself as the keyword.

For example, instead of using this:

```
Router(config)#access-list 1 permit 0.0.0.0 255.255.255.255
```

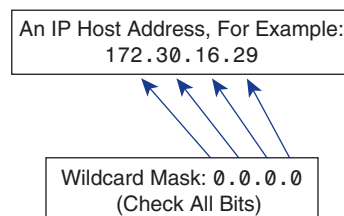
You can use this:

```
Router(config)#access-list 1 permit any
```

Using the Wildcard host

A second common condition in which Cisco IOS Software permits an abbreviation in the ACL wildcard mask arises when you want to match all the bits of an entire IP host address. For example, suppose that you want to specify that a unique host IP address will be permitted in an ACL test. To indicate a host IP address, you would enter the full address (for example, 172.30.16.29, as shown in Figure 20-9). Then, to indicate that the ACL should check all the bits in the address, the corresponding wildcard mask bits for this address would be all 0s (that is, 0.0.0.0).

Figure 20-9 Wildcard host



You can use the abbreviation of host to communicate this same test condition on Cisco IOS Software. In the example, instead of typing `172.30.16.29 0.0.0.0`, you can use the word `host` in front of the address.

For example, instead of using this:

```
Router(config)#access-list 1 permit 172.30.16.29 0.0.0.0
```

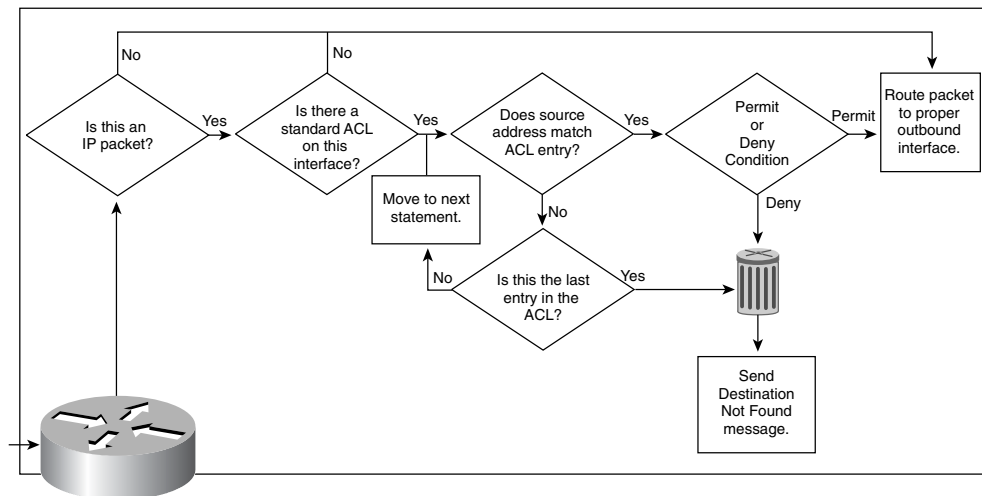
You can use this:

```
Router(config)#access-list 1 permit host 172.30.16.29
```

Standard ACLs

Standard ACLs check the source address of routed IP packets and compare it against the statements defining the ACL, as demonstrated in Figure 20-10.

Figure 20-10 Standard ACL Operations



Standard ACLs either permit or deny access for an entire protocol suite (such as IP), based on the network, subnet, and host addresses. For example, packets coming in interface `E0` or `Fa0/0` are checked for their source addresses and protocols and then are compared against the ACL. When a match is found, that action (permit or deny) is performed. Packets matching permit statements in the ACL then are routed through the router to an output interface. Packets matching deny statements in the ACL are discarded (dropped) at the incoming interface.

The following is the full syntax of the standard ACL command:

```
Router(config)# access-list access-list-number {deny | permit} source
[source-wildcard] [log]
```

The **no** form of this command is used to remove a standard ACL. This following is the syntax for the **no** form of this command:

```
Router(config)# no access-list access-list-number
```

Table 20-2 shows descriptions of the parameters used in this syntax.

Table 20-2 Standard ACL Parameters

Parameter	Description
<i>access-list-number</i>	Number of an access list. This is a decimal number from 1 to 99 or from 1300 to 1999.
deny	Denies access if the conditions are matched.
permit	Permits access if the conditions are matched.
<i>source</i>	Number of the network or host from which the packet is being sent. There are two alternative ways to specify the source: <ul style="list-style-type: none"> ■ Use a 32-bit quantity in four-part dotted-decimal format. ■ Use the any keyword as an abbreviation for a <i>source</i> and <i>source-wildcard</i> of 0.0.0.0 255.255.255.255.
<i>source-wildcard</i>	(Optional) Wildcard bits to be applied to the source. There are two alternative ways to specify the source wildcard: <p>Use a 32-bit quantity in four-part dotted-decimal format. Place 1s in the bit positions you want to ignore.</p> <p>Use the any keyword as an abbreviation for a source and <i>source-wildcard</i> value of 0.0.0.0 255.255.255.255.</p>
log	(Optional) Causes an informational logging message about the packet that matches the entry to be sent to the console. (The level of messages logged to the console is controlled by the logging console command.) <p>The message includes the access list number, whether the packet was permitted or denied, the source address, and the number of packets. The message is generated for the first packet that matches and then at five-minute intervals, including the number of packets permitted or denied in the previous five-minute interval.</p>

continues

Table 20-2 Standard ACL Parameters (Continued)

Parameter	Description
log	<p>Use the ip access-list log-update command to generate the logging messages to appear when the number of matches reaches a configurable threshold (instead of waiting for a five-minute interval). To learn more about the ip access-list log-update command, you can check the following resource at Cisco for more information: www.cisco.com/univercd/cc/td/doc/product/software/ios120/12cgcr/cbkixol.htm.</p> <p>The logging facility might drop some logging message packets if there are too many to be handled or if there is more than one logging message to be handled in one second. This behavior prevents the router from crashing because of too many logging packets. Therefore, the logging facility should not be used as a billing tool or an accurate source of the number of matches to an access list.</p>

The standard version of the **access-list** global configuration command defines a standard ACL with a number ranging from 1 to 99. Example 20-2 shows four ACL statements, all of which belong to access list 2, although this combination is not likely it illustrates how several different statement can work. Also remember that if a packet does not match any of these tests, there is an implicit (unseen) deny any at end of the ACL.

Example 20-2 Standard ACL Statements

```
access-list 2 deny 172.16.1.1
access-list 2 permit 172.16.1.0 0.0.0.255
access-list 2 deny 172.16.1.1 0.0.255.255
access-list 2 permit 172.16.1.1 0.255.255.255
```

In the first ACL statement, notice that there is no wildcard mask. In situations like this, when no wildcard mask is shown, the default mask is used, which is 0.0.0.0. This statement denies the IP address 172.16.1.1.

The second statement permits the specific host 172.16.1.0 or any host from the 172.16.1.0 subnet.

The third statement denies any host from the 172.16.0.0 network, and the fourth statement permits any host from any network starting with 172.

The **ip access-group** command links an existing ACL to an interface. It is necessary to enter interface configuration mode first to access the desired interface (for example, s0/0). The format of the command is as follows:

```
Router(config-if)# ip access-group access-list number {in | out}
```



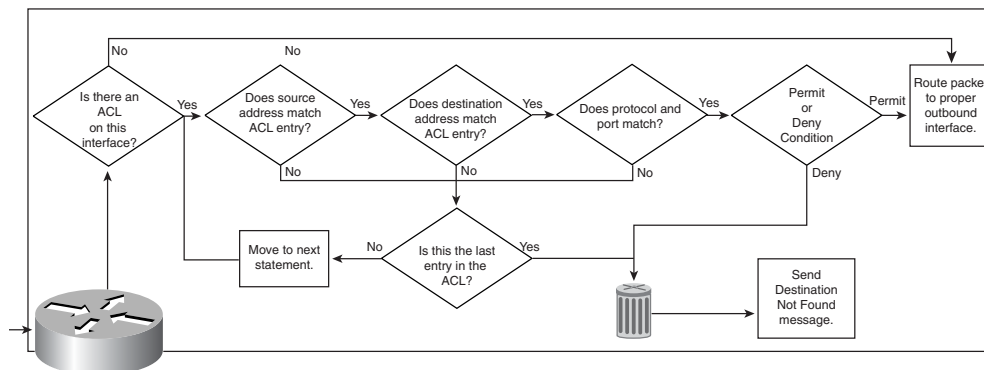
Lab Activity Standard ACLs

In this lab, you plan, configure, and apply a Standard ACL to permit or deny specific traffic and test the ACL to determine whether the desired results were achieved.

Extended ACLs

Extended ACLs are used more often than standard ACLs because they provide a greater range of flexibility and control. Extended ACLs check the source and destination IP addresses and also can check for protocols and TCP or UDP port numbers. Figure 20-11 illustrates the decision process that a router uses to evaluate packets against extended ACLs.

Figure 20-11 Extended ACL Operations



Access can be permitted or denied based on where a packet originated, its destination, the protocol type, the port addresses, and application. An extended ACL can allow e-mail traffic from Fa0/0 to specific S0/0 destinations while denying file transfers and web browsing. When packets are discarded, some protocols send an echo packet to the sender, which states that the destination was unreachable.

Extended ACLs have more granularity in terms of control and packet manipulation than standard ACLs. Whereas standard ACLs can prevent or deny only an entire protocol suite, extended ACL gives you the capability to “nitpick” which protocol in the suite you want to deny or allow. For example, allow HTTP but not FTP.

The following is the full syntax of the extended ACL command:

```
Router(config)# access-list access-list-number [dynamic dynamic-name [timeout
minutes]] {deny | permit} protocol source source-wildcard destination destination-
wildcard [precedence precedence] [tos tos] [log | log-input] [time-range time-
range-name] [fragments]
```

The **no** form of this command is used to remove a standard ACL. The following is the syntax for the **no** form of this command:

```
Router(config)# no access-list access-list-number
```

The syntax for extended ACL statements can get very long and often wraps in the terminal window. Many additional options are available in extended ACLs as documented in Table 20-3.

Table 20-3 Extended ACL Parameters

Parameter	Description
<i>access-list-number</i>	Number of an access list. This is a decimal number from 100 to 199 or from 2000 to 2699.
dynamic <i>dynamic-name</i>	(Optional) Identifies this ACL as a dynamic ACL. Refer to lock-and-key access documented in the “Configuring Lock-and-Key Security (Dynamic Access Lists)” chapter in the <i>Cisco IOS Security Configuration Guide</i> .
timeout <i>minutes</i>	(Optional) Specifies the absolute length of time, in minutes, that a temporary access list entry can remain in a dynamic access list. The default is an infinite length of time and allows an entry to remain permanently. Refer to lock-and-key access documented in the “Configuring Lock-and-Key Security (Dynamic Access Lists)” chapter in the <i>Cisco IOS Security Configuration Guide</i> .
deny	Denies access if the conditions are matched.
permit	Permits access if the conditions are matched.

Table 20-3 Extended ACL Parameters (Continued)

Parameter	Description
<i>protocol</i>	Name or number of an Internet protocol. It can be one of the keywords eigrp , gre , icmp , igmp , igrp , ip , ipinip , nos , ospf , pim , tcp , or udp , or an integer in the range from 0 to 255 representing an Internet protocol number. To match any Internet protocol (including ICMP, TCP, and UDP), use the ip keyword. Some protocols allow further qualifiers.
<i>source</i>	Number of the network or host from which the packet is being sent. There are three alternative ways to specify the source: Use a 32-bit quantity in four-part dotted-decimal format. Use the any keyword as an abbreviation for a <i>source</i> and <i>source-wildcard</i> of 0.0.0.0 255.255.255.255. Use host source as an abbreviation for a source and <i>source-wildcard</i> of <i>source</i> 0.0.0.0.
<i>source-wildcard</i>	Wildcard bits to be applied to the source. Each wildcard bit 0 indicates the corresponding bit position in the source. Each wildcard bit set to 1 indicates that both a 0 bit and a 1 bit in the corresponding position of the IP address of the packet will be considered a match to this access list entry. There are three alternative ways to specify the source wildcard: Use a 32-bit quantity in four-part dotted-decimal format. Place 1s in the bit positions that you want to ignore. Use the any keyword as an abbreviation for a <i>source</i> and <i>source-wildcard</i> of 0.0.0.0 255.255.255.255. Use host source as an abbreviation for a <i>source</i> and <i>source-wildcard</i> of <i>source</i> 0.0.0.0. Wildcard bits set to 1 need not be contiguous in the <i>source</i> wildcard. For example, a <i>source</i> wildcard of 0.255.0.64 would be valid.

continues

Table 20-3 Extended ACL Parameters (Continued)

Parameter	Description
<i>destination</i>	<p>Number of the network or host to which the packet is being sent. There are three alternative ways to specify the destination:</p> <p>Use a 32-bit quantity in four-part dotted-decimal format.</p> <p>Use the any keyword as an abbreviation for the <i>destination</i> and <i>destination-wildcard</i> of 0.0.0.0 255.255.255.255.</p> <p>Use host destination as an abbreviation for a <i>destination</i> and <i>destination-wildcard</i> of destination 0.0.0.0.</p>
<i>destination-wildcard</i>	<p>Wildcard bits to be applied to the destination. There are three alternative ways to specify the destination wildcard:</p> <p>Use a 32-bit quantity in four-part dotted-decimal format. Place 1s in the bit positions that you want to ignore.</p> <p>Use the any keyword as an abbreviation for a <i>destination</i> and <i>destination-wildcard</i> of 0.0.0.0 255.255.255.255.</p> <p>Use host destination as an abbreviation for a <i>destination</i> and <i>destination-wildcard</i> of destination 0.0.0.0.</p>
precedence <i>precedence</i>	(Optional) Packets can be filtered by precedence level, as specified by a number from 0 to 7. This is used by the quality of service (QoS) mechanism.
tos <i>tos</i>	(Optional) Packets can be filtered by type of service level, as specified by a number from 0 to 15. This is used by the QoS mechanism.
log	(Optional) Causes an informational logging message about the packet that matches the entry to be sent to the console. (The level of messages logged to the console is controlled by the logging console command.)

Table 20-3 Extended ACL Parameters (Continued)

Parameter	Description
log	<p>The message includes the access list number, whether the packet was permitted or denied; the protocol, whether it was TCP, UDP, ICMP, or a number; and, if appropriate, the source and destination addresses and source and destination port numbers. By default, the message is generated for the first packet that matches and then at five-minute intervals, including the number of packets permitted or denied in the previous five-minute interval.</p> <p>Use the ip access-list log-update command to generate logging messages when the number of matches reaches a configurable threshold (instead of waiting for a 5-minute interval). See the ip access-list log-update command for more information.</p> <p>The logging facility might drop some logging message packets if there are too many to be handled or if there is more than one logging message to be handled in one second. This behavior prevents the router from crashing because of too many logging packets. Therefore, the logging facility should not be used as a billing tool or an accurate source of the number of matches to an access list.</p>
log-input	(Optional) Includes the input interface and source MAC address or VC in the logging output.
<i>time-range time-range-name</i>	(Optional) Name of the time range that applies to this statement. The name of the time range and its restrictions are specified by the time-range command.
<i>icmp-type</i>	(Optional) ICMP packets can be filtered by ICMP message type. The type is a number from 0 to 255.
<i>icmp-code</i>	(Optional) ICMP packets that are filtered by ICMP message type also can be filtered by the ICMP message code. The code is a number from 0 to 255.
<i>icmp-message</i>	(Optional) ICMP packets can be filtered by an ICMP message type name or ICMP message type and code name.

continues

Table 20-3 Extended ACL Parameters (Continued)

Parameter	Description
<i>igmp-type</i>	(Optional) IGMP packets can be filtered by IGMP message type or message name. A message type is a number from 0 to 15.
<i>operator</i>	<p>(Optional) Compares source or destination ports. Possible operands include lt (less than), gt (greater than), eq (equal), neq (not equal), and range (inclusive range).</p> <p>If the operator is positioned after the <i>source</i> and <i>source-wildcard</i>, it must match the source port.</p> <p>If the operator is positioned after the <i>destination</i> and <i>destination-wildcard</i>, it must match the destination port.</p> <p>The range operator requires two port numbers. All other operators require one port number.</p>
<i>port</i>	<p>(Optional) Indicates the decimal number or name of a TCP or UDP port. A port number is a number from 0 to 65,535. TCP port names can be used only when filtering TCP. UDP port names can be used only when filtering UDP.</p> <p>TCP port names can be used only when filtering TCP. UDP port names can be used only when filtering UDP.</p>
established	(Optional) For the TCP protocol only: Indicates an established connection. A match occurs if the TCP datagram has the ACK, FIN, PSH, RST, SYN, or URG control bits set. The nonmatching case is that of the initial TCP datagram to form a connection.
fragments	(Optional) This ACL entry applies to noninitial fragments of packets; the fragment is either permitted or denied accordingly.

For a single ACL, multiple statements can be configured. Each of these statements should contain the same access-list-*number* to relate the statements to the same ACL, as in Example 20-2. There can be as many condition statements as necessary. These condition statements are limited only by the available router memory. The more statements there are, the more difficult it will be to comprehend and manage the ACL. The

three statements in Example 20-3 combine to permit telnet, ftp, and ftp-data from any host on the 172.16.6.0 subnetwork to any other network.

Example 20-3 *Extended ACL Statements*

```
access-list 114 permit tcp 172.16.6.0 0.0.0.255 any eq telnet
access-list 114 permit tcp 172.16.6.0 0.0.0.255 any eq ftp
access-list 114 permit tcp 172.16.6.0 0.0.0.255 any eq ftp-data
```

Extended ACLs are very versatile and, as such, provide different options and arguments based on the protocol used. Therefore, syntax will differ based on which of these protocols are in use. These protocols are listed here:

- Internet Control Message Protocol (ICMP)
- Internet Group Message Protocol (IGMP)
- Transmission Control Protocol (TCP)
- User Datagram Protocol (UDP)

The sections that follow describe the syntax variation of extended ACLs based on the protocol used.

Configuring Extended ACLs for ICMP

ACLs for ICMP use the following syntax:

```
access-list access-list-number [dynamic dynamic-name [timeout minutes]] {deny |
permit} icmp source source-wildcard destination destination-wildcard [icmp-type
[icmp-code] | icmp-message] [precedence precedence] [tos tos] [log | log-input]
[time-range time-range-name] [fragments]
```

Configuring Extended ACLs for IGMP

ACLs for IGMP use the following syntax:

```
access-list access-list-number [dynamic dynamic-name [timeout minutes]] {deny |
permit} igmp source source-wildcard destination-wildcard [igmp-type]
[precedence precedence] [tos tos] [log | log-input] [time-range time-range-name]
[fragments]
```

Configuring Extended ACLs for TCP

ACLs for TCP use the following syntax:

```
access-list access-list-number [dynamic dynamic-name [timeout minutes]] {deny |
permit} tcp source source-wildcard [operator [port]] destination destination-
wildcard [operator [port]] [established] [precedence precedence] [tos tos] [log |
log-input] [time-range time-range-name] [fragments]
```

Configuring Extended ACLs for UDP

ACLs for UDP use the following syntax:

```
access-list access-list-number [dynamic dynamic-name [timeout minutes]] {deny |
permit} udp source source-wildcard [operator [port]] destination destination-
wildcard [operator [port]] [precedence precedence] [tos tos] [log | log-input]
[time-range time-range-name] [fragments]
```

Extended ACL Defaults

An extended ACL defaults to a list that denies everything. An extended ACL is terminated by an implicit deny statement.

At the end of the extended ACL statement, additional precision is gained from a field that specifies the optional TCP or UDP port number. Figure 20-12 illustrates this concept.

Figure 20-12 Transport/Application Port Numbers

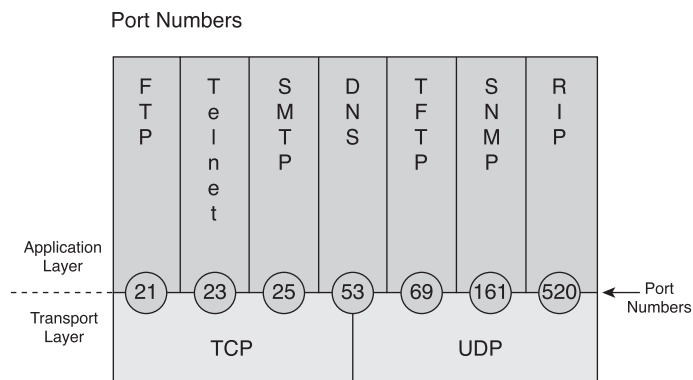


Table 20-4 lists some of the more common reserved UDP and TCP port numbers.

Table 20-4 Some Reserved TCP/UDP Numbers

Decimal	Keyword	Description
0		Reserved
1 to 4		Unassigned
5	RJE	Remote job entry
7	ECHO	Echo
9	DISCARD	Discard
11	USERS	Active users

Table 20-4 Some Reserved TCP/UDP Numbers (Continued)

Decimal	Keyword	Description
13	DAYTIME	Daytime
15	NETSTAT	Who is up, or NETSTAT
17	QUOTE	Quote of the day
19	CHARGEN	Character generator
20	FTP-DATA	File Transfer Protocol (data)
21	FTP	File Transfer Protocol
23	TELNET	Terminal connection
25	SMTP	Simple Mail Transfer Protocol
53	DOMAIN	Domain Name Server (DNS)
69	TFTP	Trivial File Transfer Protocol
80	HTTP	Hypertext Transfer Protocol (WWW)

The `ip access-group` command links an existing extended ACL to an interface. Only one ACL per interface, per direction, per protocol is allowed, as emphasized in Figure 20-13. The format of the command is as follows:

```
Router(config-if)# ip access-group access-list number {in | out}
```

Figure 20-13 ACL Rules

Named ACLs

IP *named ACLs* were introduced in Cisco IOS Software Release 11.2, which allowed standard and extended ACLs to be given names instead of numbers. The advantages that a named access list provides are as follows:

- Intuitively identifies an ACL using an alpha or alphanumeric name
- Eliminates the limit of 99 simple and 100 extended ACLs
- Enables administrators to modify ACLs without having to delete and then reconfigure them

A named ACL is created with the `ip access-list` command. The named ACL syntax is as follows:

```
ip access-list {extended | standard} name
```

This places the user in ACL configuration mode. In this mode, you can specify one or more conditions for permitting or denying access to a packet. The available options are as follows:

```
Router(config-ext-nacl)#permit | deny protocol source source-wildcard [operator
  [port]] destination destination-wildcard [operator [port]] [established]
  [precedence precedence] [tos tos] [log] [time-range time-range-name]
```

The permit or deny operand tells the router what action to take when a packet has met the other criteria specified in the ACL—that is, whether to forward or drop the packet.

Example 20-4 demonstrates applying a named ACL.

Example 20-4 Named ACL Statements

```
! Named ACL created:
Rt(config)# ip access-list extended server-access
Rt(config-ext-nacl)# permit tcp any host 131.108.101.99 eq smtp
Rt(config-ext-nacl)# permit tcp any host 131.108.101.99 eq domain
Rt(config-ext-nacl)# deny ip any any log
Rt(config-ext-nacl)# ^Z
! Named ACL Applied:
Rt(config)# interface fastethernet0/0
Rt(config-if)# ip access-group server-access out
Rt(config-if)# ^Z
```

In Example 20-4, the access list is given the name `server-access`. This access list then is applied to interface Fast Ethernet 0/0. This access list enables users to access the mail and DNS server only; all other requests are denied.

A named ACL allows for the deletion of statements, but statements can be inserted only at the end of a list, as demonstrated in Example 20-5.

Example 20-5 Named ACL Statements

```
router# configure terminal
Enter configuration commands, one per line.
router(config)# ip access-list extended test
router(config-ext-nacl)# permit ip host 2.2.2.2 host 3.3.3.3
router(config-ext-nacl)# permit tcp host 1.1.1.1 host 5.5.5.5 eq www
```


Example 20-5 *Named ACL Statements (Continued)*

```
router(config-ext-nacl)# permit icmp any any
router(config-ext-nacl)# permit udp host 6.6.6.6 10.10.10.0 0.0.0.255 eq domain
router(config-ext-nacl)# ^Z
1d00h: %SYS-5-CONFIG_I: Configured from console by consoles-1
router# show access-list
Extended IP access list test
    permit ip host 2.2.2.2 host 3.3.3.3
    permit tcp host 1.1.1.1 host 5.5.5.5 eq www
    permit icmp any any
    permit udp host 6.6.6.6 10.10.10.0 0.0.0.255 eq domain

router# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
router(config)# ip access-list extended test
!--- The following command deletes a named ACL entry.
router(config-ext-nacl)# no permit icmp any any
!--- The following command adds a named ACL entry.
router(config-ext-nacl)# permit gre host 4.4.4.4 host 8.8.8.8
router(config-ext-nacl)# ^Z
1d00h: %SYS-5-CONFIG_I: Configured from console by consoles-1

router# show access-list
Extended IP access list test
    permit ip host 2.2.2.2 host 3.3.3.3
    permit tcp host 1.1.1.1 host 5.5.5.5 eq www
    permit udp host 6.6.6.6 10.10.10.0 0.0.0.255 eq domain
    permit gre host 4.4.4.4 host 8.8.8.8
```

Consider the following before implementing named ACLs:

- Named ACLs are not compatible with Cisco IOS Software releases prior to Release 11.2.
- The same name cannot be used for multiple ACLs. For example, it is not permissible to specify both a standard and an extended ACL named George.

The series of commands shown in Example 20-6 first create a standard ACL named Internetfilter and an extended ACL named marketing_group. The commands then

access interface e0/5, assign an IP address, and then apply both ACLs to an interface (Ethernet 0/5).

Example 20-6 *Named ACL Creation*

```
. . .
ip access-list standard Internetfilter
permit 1.2.3.4
deny any
ip access-list extended marketing_group
permit tcp any 171.69.0.0 0.255.255.255 eq telnet
deny tcp any any
deny udp any 171.69.0.0 0.255.255.255 lt 1024
deny ip any log
ip interface Ethernet0/5
ip address 2.0.5.1 255.255.255.0
ip access-group Internetfilter out
ip access-group marketing_group in
```



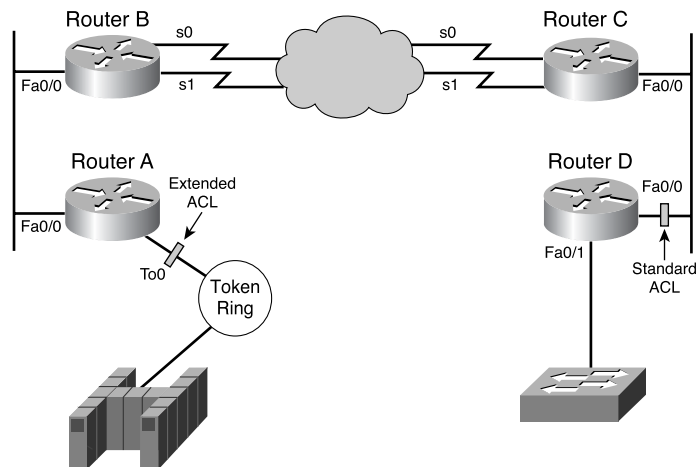
Lab Activity Named ACLs

In this lab, you create a Named ACL to permit or deny specific traffic and test the ACL to determine if the desired results were achieved.

Placing ACLs

ACLs control traffic by filtering packets and eliminating unwanted traffic on a network. An important consideration when implementing ACLs is where the access list is placed. When placed in the proper location, ACLs not only filter traffic, but they also can make the entire network operate more efficiently. For filtering traffic, the ACL should be placed where it has the greatest impact on increasing network efficiency.

Refer to Figure 20-14. Suppose that the enterprise policy wants to deny Telnet or FTP traffic on Router A access to the switched Ethernet LAN on the Fa0/0 port of Router D. At the same time, other traffic must be permitted. This policy can be implemented several ways. The recommended approach uses an extended ACL, specifying both source and destination addresses. If this extended ACL is placed in Router A, packets will not cross the Ethernet of Router A or the serial interfaces of Routers B and C, and will not enter Router D. This will reduce traffic on the network links between Routers A and D. Traffic with different source and destination addresses still will be permitted.

Figure 20-14 Placing ACLs

The general rule is to put the extended ACLs as close to the source of the denied traffic as possible. Standard ACLs do not specify destination addresses, so they should be placed as close to the destination as possible. For example, a standard ACL would be placed on Fa0/0 of Router D to prevent traffic from Router A.

In the advanced configuration, a feature called Turbo ACL compiles the ACL, making the process a lot faster. The Turbo ACL feature allows for a more efficient searching algorithm and also allows the list to be parsed in a more efficient manner.



Lab Activity Extended ACLs

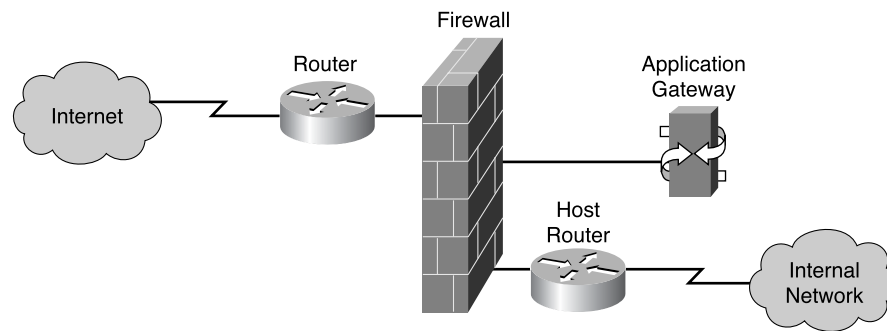
In this lab, you plan, configure, and apply an Extended ACL to permit or deny specific traffic and test the ACL to determine whether the desired results were achieved.

CAUTION

ACL operation can slow the router in performing its routing tasks. The router has to read more of the packet and compare more parameters before it even gets to the routing operations.

Firewalls

A *firewall* is a computer or networking device that exists between the user and the outside world to protect the internal network from intruders. In most circumstances, intruders come from the global Internet and the thousands of remote networks that it interconnects. Typically, a network firewall consists of several different machines that work together to prevent unwanted and illegal access. Figure 20-15 shows a simple firewall architecture.

Figure 20-15 Firewall Architecture

In firewall architecture, the router that is connected to the Internet is referred to as the *exterior router*. It forces all incoming traffic to pass through the application gateway. The router that is connected to the internal network is the *interior router*. The interior router accepts packets only from the application gateway. The gateway controls the delivery of network-based services both to and from the internal network. For example, the firewall might allow only certain users to communicate with the Internet, or permit only certain applications to establish connections between an interior and exterior host. If the only application that is permitted is mail, then only mail packets will be allowed through the router. This protects the application gateway and avoids overwhelming it with unauthorized packets.

Using ACLs with Firewalls

ACLs should be used in firewall routers, which often are positioned between the internal network and an external network, such as the Internet. The firewall router provides a point of isolation so that the rest of the internal network structure is not affected. You also can use ACLs on a router positioned between two parts of the network, to control traffic entering or exiting a specific part of the internal network.

To provide the security benefits of ACLs, you should, at a minimum, configure ACLs on *border routers*, which are routers situated on the boundaries of the network, and are also known as *firewall routers*. This provides basic security from the outside network, or from a less controlled area of the network, into a more private area of the network.

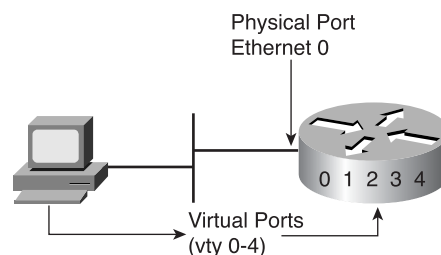
On these border routers, ACLs can be created for each network protocol configured on the router interfaces. You can configure ACLs so that inbound traffic, outbound traffic, or both are filtered on an interface.

Restricting Virtual Terminal Access

Standard and extended ACLs apply to packets traveling through a router. They are not designed to block packets that originate within the router. By default, an outbound Telnet-extended ACL does not prevent router-initiated Telnet sessions.

In addition to physical ports or interfaces on the router, such as Fa0/0 and S0/0, there are virtual ports. These virtual ports are called vty lines. There are five vty lines, which are numbered zero through four, as shown in Figure 20-16. For security purposes, users can be denied or permitted virtual terminal access to the router, but denied access to destinations from that router. For example, an administrator can configure the ACL to allow terminal access to the router for management or troubleshooting purposes, while at the same time restricting access beyond this router.

Figure 20-16 Restricting vty Access with ACLs



Restricting vty access is not commonly used as a traffic control mechanism; instead, it is for increasing network security. vty access is accomplished using the Telnet protocol to make a nonphysical connection to the router. As a result, there is only one type of vty ACL. Identical restrictions should be placed on all vty lines because it is impossible to control which line a user will connect on.

Whereas a vty ACL is created the same way as on an interface, applying the vty ACL to a terminal line requires using the **access-class** command instead of the **access-group** command. Example 20-7 demonstrates creating and applying a virtual terminal access list.

Example 20-7 Restricting vty Access with ACLs

```
! Creating the standard list:  
Rt1(config)# access-list 2 permit 172.16.1.0 0.0.0.255  
Rt1(config)# access-list 2 permit 172.16.2.0 0.0.0.255  
Rt1(config)# access-list 2 deny any
```

continues

Example 20-7 *Restricting vty Access with ACLs (Continued)*

```
! Applying the access list:
Rt1(config)# line vty 0 4
Rt1(config)# login
Rt1(config)# password secret
Rt1(config)# access-class 2 in
```

Keep the following considerations in mind when configuring access lists on vty lines:

- A name or number can be used when controlling access to an interface.
- Only numbered access lists can be applied to virtual lines.
- Identical restrictions should be set on all the virtual terminal lines because a user can attempt to connect to any of them.

Verifying ACLs

The **show ip interface** command displays IP interface information and indicates whether any ACLs are set. Example 20-8 shows the output of the **show ip interface** command. As you can see in rows 9 and 10 in Example 20-8, ACL 10 is set to the outgoing traffic on interface Ethernet 0. There is no ACL set to inbound traffic.

Example 20-8 *show ip interface Command*

```
Router> show ip interface
Ethernet0 is up, line protocol is up
Internet address is 192.54.22.2, subnet mask is 255.255.255.0
Broadcast address is 255.255.255.255
Address determined by nonvolatile memory
MTU is 1500 bytes
Helper address is 192.52.71.4
Secondary address 131.192.115.2, subnet mask 255.255.255.0
Outgoing ACL 10 is set
Inbound ACL is not set
Proxy ARP is enabled
Security level is default
Split horizon is enabled
ICMP redirects are always sent
ICMP unreachable are never sent
ICMP mask replies are never sent
```

Example 20-8 show ip interface *Command (Continued)*

```
IP fast switching is enabled
Gateway Discovery is disabled
IP accounting is disabled
TCP/IP header compression is disabled
Probe proxy name replies are disabled
Router>
```

The **show access-lists** command displays the contents of all ACLs. By entering the ACL name or number as an option for this command, you can see a specific list.

Summary

This chapter presented an overview of the following key points:

- The two main types of ACLs are standard and extended.
- Named ACLs allow access lists to be identified by name instead of number.
- ACLs can be configured for all routed network protocols.
- ACLs typically are used in firewall routers, which often are positioned between the internal network and an external network such as the Internet.
- ACLs also can restrict virtual terminal access to the router.
- ACLs perform several functions within a Cisco router, including implementing security/access procedures.
- ACLs are used to control and manage traffic.
- For some protocols, you can apply up to two ACLs to an interface: one inbound ACL and one outbound ACL.
- With ACLs, after a packet is checked for a match with the ACL statement, it can be denied or permitted the use of an associated interface.
- Wildcard mask bits use the numbers 1 and 0 to determine how to treat the corresponding IP address bits.

To supplement all that you've learned in this chapter, refer to the chapter-specific Videos, PhotoZooms, and e-Lab activities on the CD-ROM accompanying this book.

Key Terms

ACL (access control list)—A means of controlling or limiting network traffic that compares different criteria to a defined rule set.

bit bucket—The destination of discarded bits (dropped packets), as determined by the router.

border router—A router situated at the edges or end of the network boundary, which provides basic security from the outside network or from a less controlled area of the network into a more private area of the network.

extended ACL—Compares source IP address, destination IP address, TCP/UDP port number, and other criteria to the rules defining an extended ACL.

exterior router—In firewall architecture, the router that is connected to the Internet is referred to as the exterior router. It forces all incoming traffic to pass through the application gateway.

firewall—One or more network devices, such as routers or access servers, designated as a buffer between any connected public networks and a private network. A firewall router uses access control lists and other methods to ensure the security of the private network.

interior router—The router that is connected to the internal network. The interior router accepts packets only from the application gateway. The gateway controls the delivery of network-based services both to and from the internal network.

named ACL—ACL that allows standard and extended ACLs to be given names.

queuing—A process by which ACLs can designate certain packets to be processed by a router before other traffic, on the basis of some configurable parameter such as specifying a protocol.

standard ACL—ACL that compares source IP addresses to the rules defining a standard ACL.

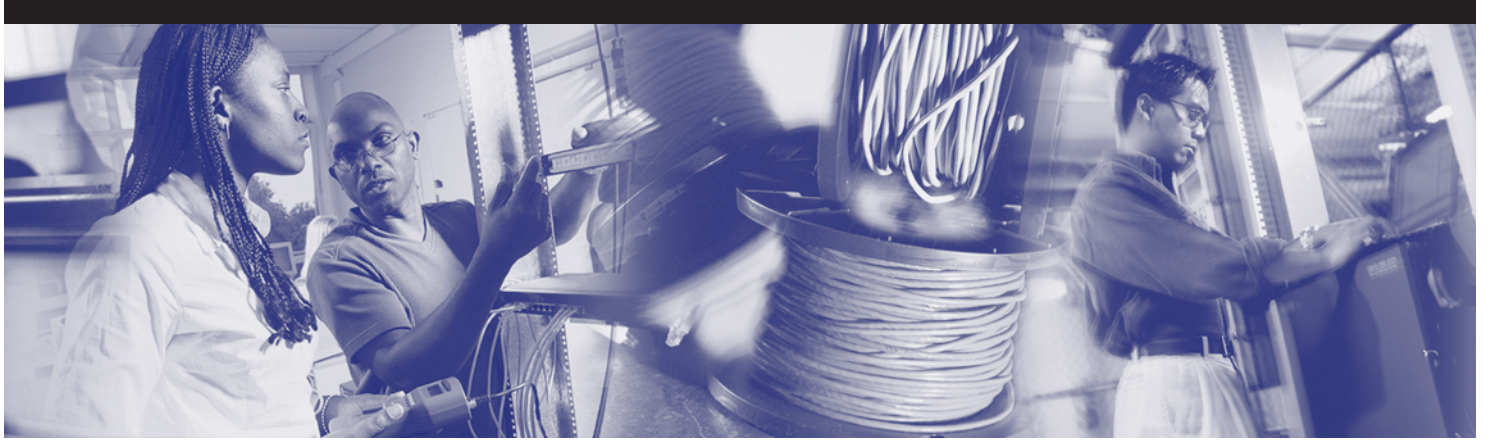
Check Your Understanding

Complete all the review questions to test your understanding of the topics and concepts in this chapter. Answers are listed in Appendix C, “Check Your Understanding Answer Key.”

1. Common ACL functions include filtering packets internally, protecting the internal network from illegal Internet access, and restricting access to virtual terminal ports. True or false?
 - A. True
 - B. False
2. ACL is an acronym for:
 - A. Accessibility control list
 - B. Accountability control list
 - C. Assessment control list
 - D. Access control list
3. A(n) _____ ACL works by comparing the source IP address against the ACL rules.
 - A. Extended
 - B. Named
 - C. Standard
 - D. Router
4. A(n) _____ ACL works by comparing the source IP address, destination IP address, or other parameters against the ACL rules.
 - A. Extended
 - B. Named
 - C. Standard
 - D. Router
5. A(n) _____ ACL uses names instead of numbers to distinguish ACLs.
 - A. Extended
 - B. Named
 - C. Standard
 - D. Router
6. As a general rule, ACLs should be placed where in the network?
 - A. In the Internet
 - B. In the Core
 - C. Closest to the traffic to be controlled
 - D. None of the above

7. In a firewall architecture, which router most likely will be configured with an ACL?
 - A. The most powerful router
 - B. The interior router
 - C. The exterior router
 - D. All of the above
8. Named ACLs were introduced in Cisco IOS 11.2. True or false?
 - A. True
 - B. False
9. What command is used to apply an ACL to a VTY port?
 - A. ip access-list
 - B. ip access-class
 - C. ip access-group
10. Which of the following commands would you use to find out whether any ACLs are set on an interface?
 - A. show running-config
 - B. show ip protocols
 - C. show ip interface
 - D. show ip network
11. What do you call the additional 32 bits of information in the access-list statement?
 - A. Wildcard bits
 - B. Access bits
 - C. 0 bits
 - D. 1 bits
12. If you want to permit traffic based on its addressing or protocol type, you would use which of the following commands?
 - A. Router #**access-list** *access-list number* {**permit** | **deny**} {*test conditions*}
 - B. Router (config)#**access-list** *access-list number* {**permit** | **deny**} {*test conditions*}
 - C. Router (config-if)#**access-list** *access-list number* {**permit** | **deny**} {*test conditions*}
 - D. None of the above

13. Standard IP access lists permit or deny routing of a packet based on the IP address that it originates from and the protocol suite that it is destined for. True or false?
- A. True
 - B. False
14. Access lists impact network security based on which of the following factors?
- A. The data content of the packets
 - B. The destination subnet/host/network for the packets
 - C. The source subnet/host/network of the packets
 - D. The type of the network they are routed through
15. What type of networking device would be needed to implement access lists to increase network security?
- A. Hub
 - B. Router
 - C. Bridge
 - D. Switch
16. What does the following access list allow? `access-list 1 permit 204.211.19.162 0.0.0.0`
- A. "Deny my network only."
 - B. "Permit a specific host."
 - C. "Permit only my network."
 - D. None of the above.





Part III

Appendixes

Appendix A Structured Cabling

Appendix B Glossary of Key Terms

Appendix C Check Your Understanding Answer Key





Objectives

Upon completion of this appendix, you will be able to

- Understand the roots of structured cabling
- Adhere to the rules of structured cabling when designing and performing installations to provide scalability
- Recognize subsystems of structured cabling, including demarcation points, telecommunications and equipment rooms including roles such as, MC, IC, and HC
- Recognize the special requirements of cabling in the work area
- Express familiarity with standards organizations such as Telecommunications Industry Association (TIA), the Electronic Industries Association (EIA) TIA/EIA, and the European Committee for Electrotechnical Standardization (CENELEC), as well as world-level organizations such as the International Organization for Standardization (ISO)
- Perform low-voltage telecommunications work with attention to safety, and be safe around electricity
- Understand basic points of ladder safety and the importance or proper attire for cabling work
- Have a familiarity with the basic specialized hand tools of the installer's craft, as well as with basic telecom test and measurement equipment
- Understand which cabling tasks accompany which phase of a typical project
- Understand the basic business processes that lead to successful cabling organization

Appendix A

Structured Cabling

This appendix covers the following topics:

- Structured cabling systems, standards, and codes
- Safety
- Tools of the trade
- The installation process
- The finish phase
- The cabling business
- Case study

Completing this material and the associated labs in the *Cisco Networking Academy Program CCNA 1 and 2 Lab Companion*, Third Edition, will provide a broad introduction to all facets of structured cabling installation.

Structured Cabling Systems, Standards, and Codes

Structured cabling systems refer to telecommunications wiring built in a standardized, approved manner, starting at the *demarcation point*, working through the various *equipment rooms*, and continuing to the *work area*. The issue of scalability also is addressed.

Items of importance that students should be aware of include these:

- Rules of structured cabling
- Subsystems of structured cabling
- Scalability
- Demarcation point
- Telecommunications and equipment rooms

- Work areas
- MC, IC, and HC
- Telecommunications Industry Association (TIA) and Electronic Industries Association (EIA)
- European Committee for Electrotechnical Standardization (CENELEC)
- International Organization for Standardization (ISO)
- U.S. codes
- Evolution of standards

Rules of Structured Cabling for LANs

Structured cabling is a systematic approach to cabling. It is a method for creating an organized cabling system that can be easily understood by installers, network administrators, and any other technicians that deal with cables.

The following three rules help ensure that the structured cabling design projects are both effective and efficient:

- **Look for a complete connectivity solution**—An optimal solution for network connectivity includes all the systems that are designed to connect, route, manage, and identify structured cabling systems. A standards-based implementation will help to make sure that both current and future technologies can be supported. Following standards makes sure that the project will deliver performance and reliability over the long term.
- **Plan for future growth**—The number of circuits installed should meet these future requirements as well. Category 5e, Category 6, and fiber-optic solutions should be considered where feasible to ensure that future needs will be met. It should be possible to plan a physical layer installation that works for ten or more years.
- **Maintain freedom of choice in vendors**—Even though a closed and proprietary system may be less expensive initially, this could end up being much more costly over the long term. A non-standard system from a single vendor may make it more difficult to make moves, adds, and changes at a later time.

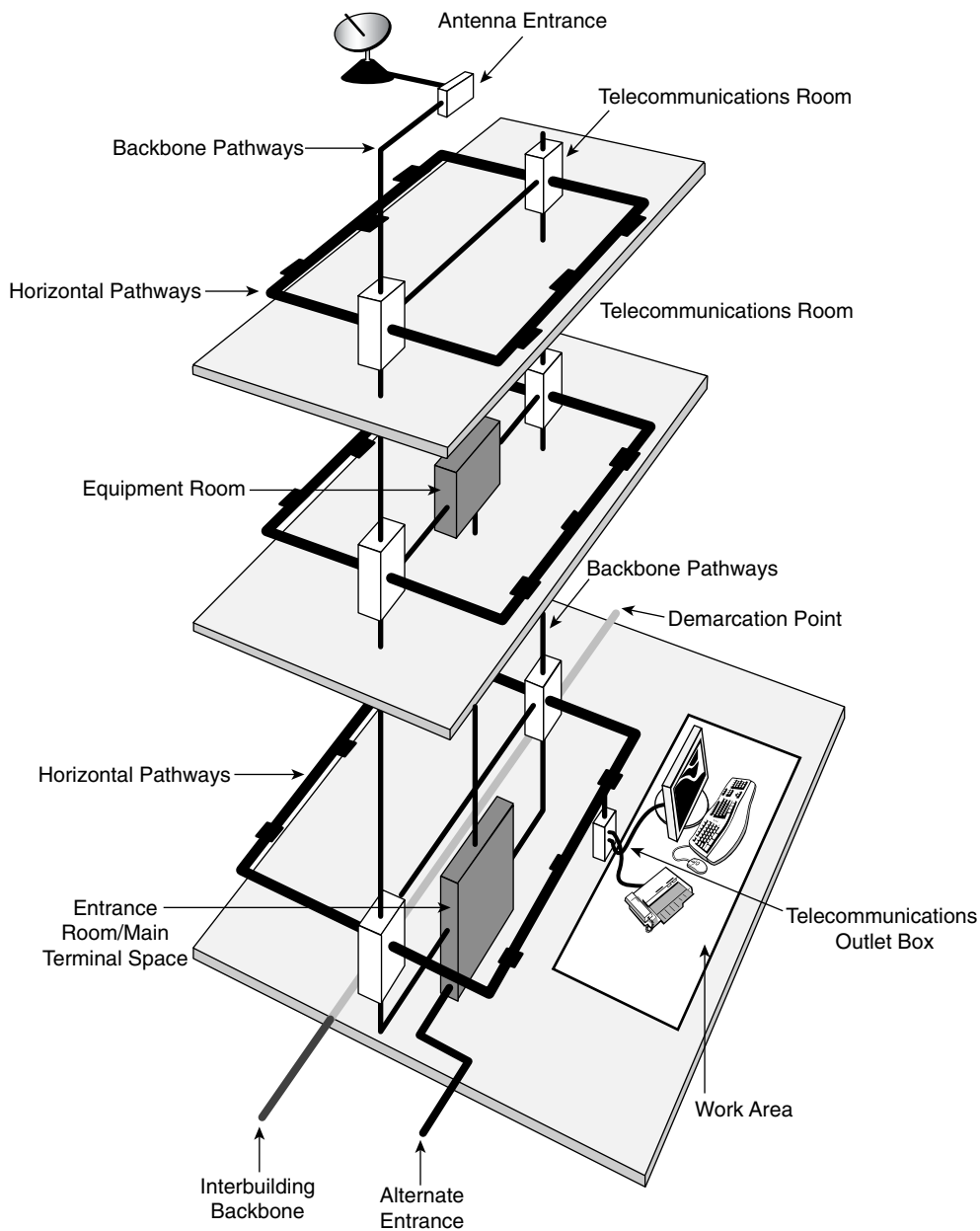
More Information

For more information on the rules of structured cabling, visit
www.panduitnccg.com/NCG_SYSSOL/ncg_syssol_pm/ncg_syssol_pm_markets/Finance/rules.asp.

Subsystems of Structured Cabling

Seven subsystems are associated with the structured cabling system (see Figure A-1). Each subsystem performs certain functions to provide voice and data services throughout the cable plant.

Figure A-1 Subsystems of Structured Cabling



- The demarcation point (demarc) within the entrance facility (EF) in the equipment room
- The *telecommunications room (TR)*
- *Backbone* cabling, also known as vertical cabling
- Distribution cabling, also known as horizontal cabling
- The work area
- Equipment room (ER)
- Administration

The *demarc* is where the outside service provider cables connect to the customer's cables in the facility.

Backbone cabling is the feeder cables that are routed from the demarc to the equipment rooms and then on to the telecommunications rooms throughout the facility. Horizontal cabling distributes cables from the telecommunication rooms to the work areas. The telecommunications rooms are where connections take place to provide a transition between the backbone cabling and horizontal cabling.

These subsystems make structured cabling, by nature, a distributed architecture with management capabilities that are limited to the active equipment (PCs, switches, hubs, etc.). Designing a structured cabling infrastructure that properly routes, protects, identifies and terminates the copper or fiber media is absolutely critical for network performance and future upgrade.

Scalability

A LAN that can accommodate future growth in size is referred to as being scalable. It is important to plan ahead when estimating the number of cable runs and cable drops in a work area. It is always easier to ignore extra installed cables than to not have them when they are required.

In addition to pulling extra cables in the backbone area for future growth, it is also common practice to pull an extra cable to each workstation or desktop for future use. This protects against pairs that might fail during installation and also provides for expansion.

Backbone Scalability

To determine how much extra copper cabling to pull, first determine the number of runs that are needed now and then add some extra, about 20 percent.

One way to obtain this reserve capability is to use fiber-optic cabling and equipment in the building backbone. Updating the termination equipment (by inserting faster lasers and drivers, for example) can accommodate fiber growth.

Work Area Scalability

Although it might be obvious that each work area needs one cable for voice and one for data, other devices might need a connection to either the voice system or the data system. Network printers, fax machines, laptops, or another user in the work area all can require their own network cable drops.

When the cables are in place, use multiport wall plates over the jacks. Many types of configurations are possible for either walls or partition walls. In addition, use jacks that are color-coded to make it easier to identify types of circuits. Administration standards require that every circuit should be clearly labeled to assist in connections and troubleshooting.

A new technology that is becoming popular is *Voice over Internet Protocol (VoIP)*. This technology allows special telephones to use data networks when placing telephone calls. A great advantage to this technology is the capability to avoid costly long-distance charges by using this service over existing network connections. Other devices, such as printers and computers, can be plugged into the IP phone. The IP phone thus becomes a hub or switch for the work area. Even if these types of connections are planned, enough cables should be installed to allow for growth. Especially consider that IP telephony and IP video traffic may share the network cables in the future.

To accommodate the changing needs of users in offices, it is recommended to provide at least one spare cable to the work area outlet. Offices might change from single-user to multiuser spaces. In these cases, a work area can become inefficient if only one set of communication cables were pulled. Assume that every work area could accommodate multiple users in the future (see Figure A-2).

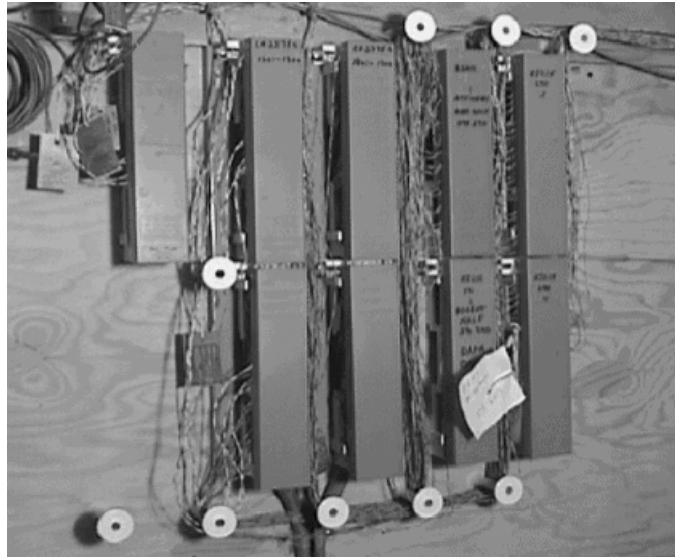
Demarcation Point

The demarcation point (demarc), provides the point at which outdoor cabling interfaces with the intrabuilding backbone cabling (See Figure A-3). It represents the boundary between the service provider's responsibility and that of the customer. In many buildings, this is near the point of presence (POP) for other utilities, such as electricity and water.

Figure A-2 Allow for Growth



Figure A-3 Demarcation Point



The service provider is responsible for everything from the demarc to the service provider's facility. Everything from the demarc into the building is the customer's responsibility.

The local telephone carrier typically is required to terminate cabling within 15m (49.2 ft.) of building penetration and to provide primary voltage protection. This usually is installed and provided by the service provider.

The *Telecommunications Industry Association (TIA)* and Electronic Industries Association (EIA) develop and publish standards for many industries, including the cabling industry. To ensure that the cabling installation is safe, is installed correctly, and retains performance ratings, these standards always should be followed when performing any voice or data cabling installation or maintenance.

TIA/EIA-569-A specifies the standards for the demarc space. The standards for the structure and size of the demarc space are based on the size of the building. In buildings larger than 2000 usable square meters, a locked, dedicated, and enclosed room is recommended.

The following are general guidelines when setting up a demarcation point space:

- Allow 1m² of plywood wall mount for each 20m² (215.3 ft²) area of floor space.
- The surfaces where the distribution hardware is mounted must be covered with fire-rated plywood or plywood that is painted with two coats of fire-retardant paint.
- Either the plywood or the covers for the termination equipment should be colored orange to indicate the point of demarcation.

Telecommunications and Equipment Rooms

After the cable enters the building through the demarc, it travels to the entrance facility (EF), which is usually in the equipment room (ER). The equipment room is the center of the voice and data network. An equipment room is essentially a large telecommunications room that may house the main distribution frame, network servers, routers, switches, the telephone PBX, secondary voltage protection, satellite receivers, modulators, high-speed Internet equipment, and so on. The design aspects of the equipment room are specified in the TIA/EIA-569-A standard.

In larger facilities, the equipment room may feed one or more telecommunications rooms (TR) which are distributed throughout the building (see Figure A-4).

A wiring hub and patch panel in a TR may be mounted to a wall with a hinged wall bracket, a distribution rack (see Figure A-5), or a full equipment cabinet.

Figure A-4 Telecommunications Room

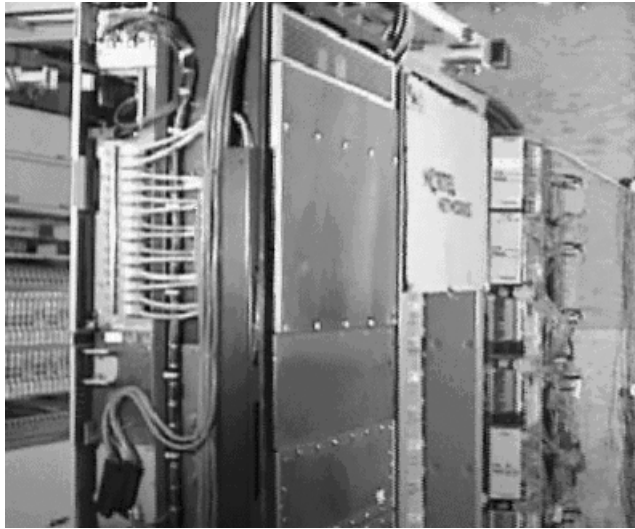


Figure A-5 Panduit Distribution Rack



- If the choice is a hinged wall bracket, the bracket must be attached to the plywood panel that covers the underlying wall surface. The purpose of the hinge is to allow the assembly to swing out so that workers and repairmen easily can access the back side of the wall. Care must be taken, however, to allow 48 cm (18.9 in.) for the panel to swing out from the wall.
- If you are using a distribution rack, it must have a minimum of 1 meter (3 feet) of workspace clearance in the front and rear of the rack. A 55.9-cm (22-in.) floor plate, used to mount the distribution rack, provides stability and determines the minimum distance for its final position.
- If the *patch panel*, hub, and other equipment are mounted in a full equipment cabinet, they require at least 76.2 cm (28.6 in.) of clearance in front, for the door to swing open. Typically, such equipment cabinets are 1.8m high × .74m wide × .66m deep (5.9 ft. × 2.4 ft. × 216.5 ft.).

Equipment must be placed in equipment racks with care. Considerations include whether the equipment uses electricity, cable routing, cable management, and ease of use. For example, a patch panel would not be placed high on a rack if a significant number of changes were to take place after the systems were installed. Convenience of use is a large consideration when planning the equipment layout.

Scalability is also a consideration in an equipment layout because future growth should be accommodated. Space should be left on a rack for future patch panels, or floor space should be left for future rack installations in an initial layout.

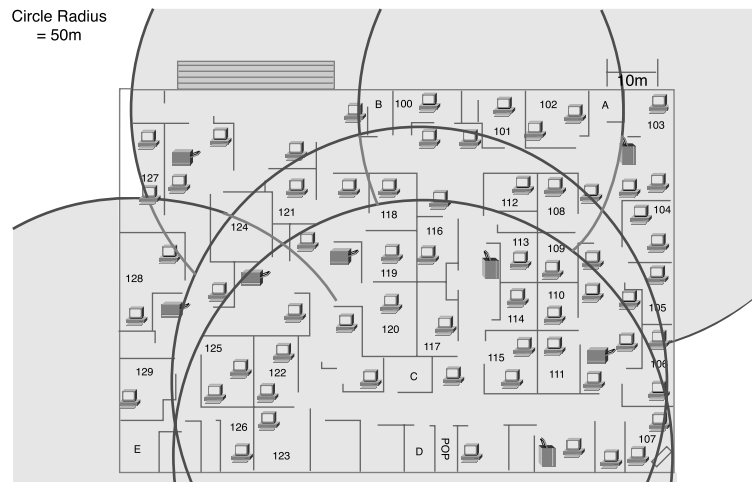
Proper installation of equipment racks and patch panels in the TR allows easy changes and modifications to the cabling installation in the future. This is important when considering the design and layout of the work areas.

Work Areas

The area serviced by an individual telecommunications room is called a work area. In most cases, a work area occupies one floor or part of one floor of a building (see Figure A-6).

The maximum distance for a cable from the termination point in the TR to the termination at the work area outlet must not exceed 90 meters (295 ft). This 90 meter maximum horizontal cabling distance is referred to as the permanent link. Each work area must have at least two cables, one for data and the other for voice. As previously discussed, accommodations for other services and future expansion must also be considered.

Figure A-6 Work Areas



This distance must be reduced because cables usually cannot be strung across the floor; they usually ride in wiring-management devices such as trays, baskets, ladders, and raceways. These devices route the paths of the wires above workspaces, often in the *plenum* areas above suspended ceilings. This means that the height of the ceiling times two (once up to the wiring management device and once back down) must be subtracted from the proposed work area radius.

In addition, ANSI/TIA/EIA-568-B specifies that there can be 5m (16.4 ft.) of patch cord to interconnect equipment patch panels, and 5m of cable from the cable termination point on the wall to the telephone or computer. This additional maximum of 10 meters of patch cords added to the permanent link is referred to as the horizontal channel. The maximum distance for a channel is 100 meters—the 90 meter maximum permanent link plus 10 meters maximum of patch cords.

Finally, the routes that the cables actually take might not be straight to the destination. Wiring-management devices can be costly, and the location of heating, ventilation, and air-conditioning equipment; power transformers; and lighting equipment can dictate paths that add length. This further decreases the radius of the work area. Typically, when everything is taken into account, the actual radius might be closer to 60 to 70m (196.9 to 229.7 ft.) than 100m (328.1 ft.); 50m (164 ft.) commonly is used as a work-area radius for design purposes.

Servicing the Work Area

Patching is done when connectivity changes are needed often or are foreseen. It is much easier to patch cable from the work area outlet to a new position in the TR than it is to remove terminated wires from connected hardware and reterminate them to another circuit. Patch cords also are used to connect networking equipment to the cross-connects in a TR. Patch cords are limited by the TIA/EIA-568-B.1 standard to 5m (16.4 ft.).

A uniform wiring plan must be used throughout a patch panel system. All jacks and patch panels should be wired using the same wiring plan. If the T568A wiring plan is used for the information outlets or jacks, T568A patch panels should be used. The same is true for the T568B wiring plan.

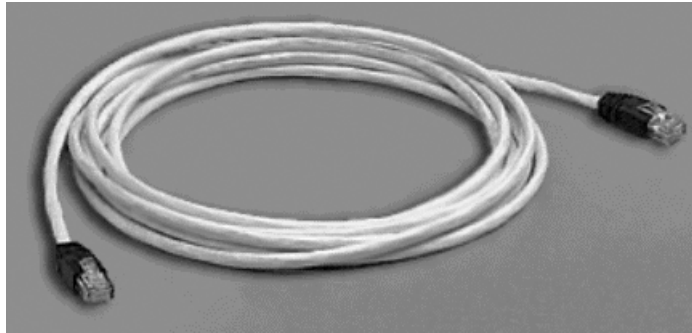
Patch panels can be for unshielded twisted-pair (UTP), shielded twisted-pair (STP), or fiber-optic connections. The most common patch panels are for UTP. These patch panels use RJ-45 jacks; patch cords with RJ-45 plugs connect to these ports.

In most facilities, there is no provision to keep authorized maintenance personnel from installing unauthorized patches or installing an unauthorized hub into a circuit. There is an emerging family of automated patch panels, however, which can provide extensive network monitoring in addition to simplifying the provisioning of moves, adds, and changes. These patch panels normally provide an indicator lamp over any patch cord that need to be removed, and then once the cord is released, provide a second light over the jack to which they should be re-affixed. In this way, the system can automatically guide a relatively unskilled employee through moves, adds, and changes.

The same mechanism that detects when the operator has moved a given jack works also to detect when a jack has been pulled. An unauthorized resetting of a patch can trigger an event in the system log, and if need be, trigger an alarm. For example, if a half-dozen wires to the work area suddenly show up as being open, and it is 2:30 A.M., this is an event worth looking into, because theft may be occurring.

Types of Patch Cables

Patch cables (see Figure A-7) come in a variety of wiring schemes. The most common, the straight-through cable, has the same wiring scheme on both ends of the cable. In other words, pin 1 on one end is connected to pin 1 on the other end. Pin 2 on one end corresponds to pin 2 on the other, and so on. These types of cables connect PCs to a network hub.

Figure A-7 UTP Patch Cable

When connecting a communications device to a network hub, a crossover cable usually is used. Crossover cables use the T568A wiring plan on one end and T568B on the other.

**Lab Activity** Examination of Termination Types

In this lab, you review the T568A, T568B, and RJ-45 USOC wiring standards, and you learn to terminate the ends of a Category 5e cable.

Cable Management

Cable-management devices are used for routing cables and providing a neat and orderly path for the cables and to assure minimum bend radius is maintained. Cable management also eases cable additions and modification to the wiring system. Many options for cable management exist in the TR. Cable baskets can be used when an easy, lightweight installation is needed. Ladder racks often are used when heavy loads of bundled cable need to be supported. Different types of conduits can be used to run cable inside walls, ceilings, and floors, or when they need to be shielded from external conditions. Cable management systems are used vertically and horizontally on telecommunications racks to distribute cable in a neat and orderly fashion (see Figure A-8).

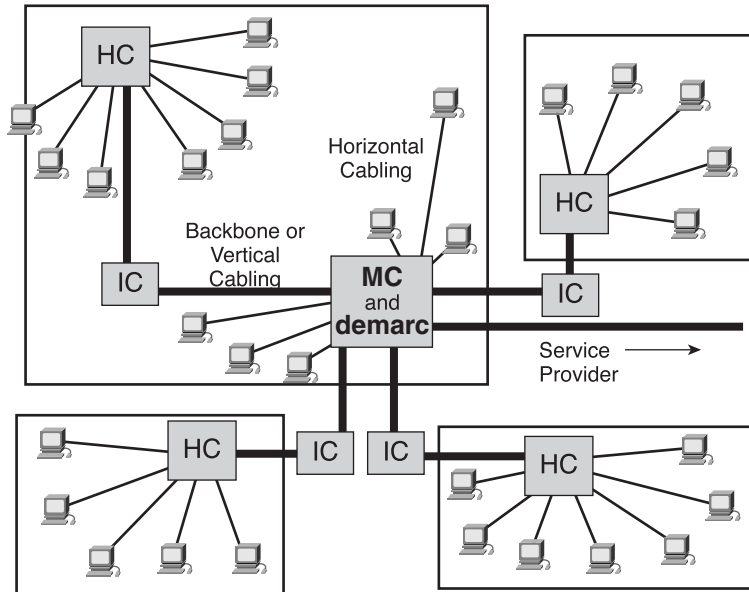
MC, IC, and HC

Most networks have more than one TR for various reasons. First of all, a medium or large network usually is spread over many floors or buildings. A TR is needed for each floor of each building (see Figure A-9). Second, media can carry a signal only so far before the signal starts to degrade or attenuate. Therefore, TRs are located at defined distances throughout the LAN to provide interconnects and cross-connects to hubs and switches to assure desired network performance. These TRs house equipment, such as repeaters, hubs, bridges, or switches, that are needed to regenerate the signals.

Figure A-8 Panduit Rack-Mounted Vertical and Horizontal Cable Management System



Figure A-9 MC, HC, and IC Planning



Not all TRs are equal. The primary TR, called the *main cross-connect (MC)*, is the center of the network. This is where all the wiring originates and where most of the equipment is housed. The *intermediate cross-connect (IC)* is connected to the MC and can house the equipment for a building on a campus. The *horizontal cross-connect (HC)* provides the cross-connect between the backbone and horizontal cables on a single floor of a building.

Main Cross-Connect

The MC is the main concentration point of an entire building or campus. In effect, the MC is the primary TR. It is the room that controls the rest of the TRs (the ICs and HCs) in a building or campus. In some networks, it is the place where the inside cable plant meets the outside world's connectivity (the demarc).

All ICs or HCs are connected to the MC in a star topology. Backbone cabling, or *vertical cabling*, is used to connect those ICs and HCs located on other floors. Where the entire network is confined to a single multistory building, the MC usually is located on one of the middle floors of the building, even though the demarc might be located in an entrance facility on the first floor or in the basement.

For networks that comprise multiple buildings, one building typically houses the MC. Each individual building typically has its own version of the MC, called the intermediate cross-connect (IC), which connects all the HCs within the building. The IC allows the extension of backbone cabling from the MC to each HC because this interconnection point does not degrade the communication signals. Only one MC can exist for the entire structured cabling installation. The MC feeds the ICs, and each IC feeds multiple HCs. There can be only one IC between the MC and any HC.

The backbone cabling (red lines in the figure) runs from the MC to each of the ICs. The ICs are located in each of the campus buildings, and the HCs serve work areas. Horizontal cabling, running from the HCs to the work areas, is represented by the black lines.

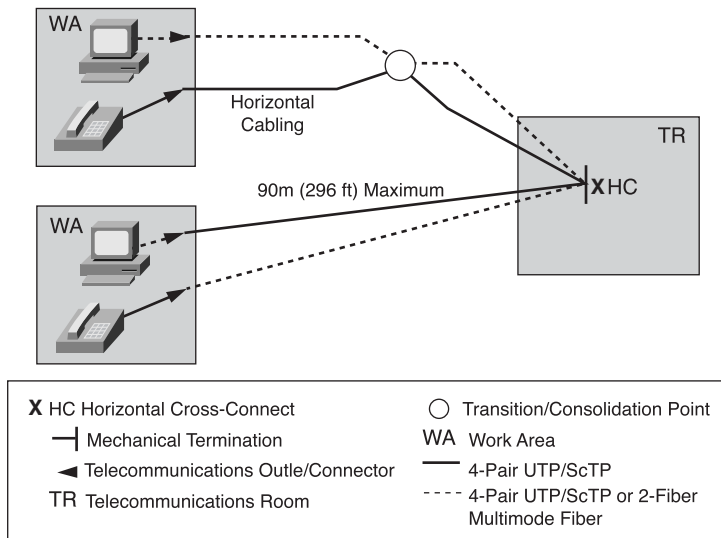
Horizontal Cross-Connect

The horizontal cross-connect (HC) is the TR closest to the work areas. Like all copper cross-connects, the HC is typically a patch panel or punch-down block, and possibly networking devices such as repeaters, hubs, or switches. It can be a rack mounted in a room or in a cabinet. Because a typical horizontal cable system includes multiple cable

runs to each workstation, it can represent the largest concentration of cable in the building infrastructure. A building with a 1000 workstations easily can contain a horizontal cable system consisting of 2000 to 3000 individual cable runs.

Horizontal cabling includes the copper or optical fiber networking media that is used in the area that extends from the wiring closet to a workstation (see Figure A-10). Horizontal cabling includes the networking medium that runs along a horizontal pathway to the telecommunications outlet or connector in the work area, and the patch cords or jumpers in the HC.

Figure A-10 Horizontal Cabling and Symbols



Any cabling installed between the MC and another TR is known as backbone cabling. The difference between horizontal and backbone cabling is defined clearly in the standards.



Lab Activity Terminating a Category 5e Cable on a Category 5e Patch Panel

In this lab, you terminate a Category 5e cable on a Category 5e patch panel and learn the proper use of a 110 punch-down tool as well as a cable stripper.

Backbone Cabling

Any cabling installed between the MC and another TR is known as backbone cabling. The difference between horizontal and backbone cabling is clearly defined in the standards. Backbone cabling is also referred to as vertical cabling. It consists of the backbone cables, intermediate and main cross-connects, mechanical terminations, and patch cords or jumpers used for backbone-to-backbone cross-connection. Backbone cabling includes the following:

- TRs on the same floor (MC to IC, IC to HC)
- Vertical connection (risers) between TRs on different floors (MC to IC)
- Cables between TR and demarcation point
- Cables between buildings (interbuilding) in a multibuilding campus

The maximum distances for cabling runs vary from one type of cable to another. For backbone cabling, the maximum distance for cabling runs also can be affected by how the backbone cabling is to be used. To understand what this means, assume that a decision has been made to use single-mode fiber-optic cable for the backbone cabling. If the networking media were to be used to connect the HC to the MC, then the maximum distance for the backbone cabling run would be 3000m (9842.5 ft).

At times, the maximum distance of 3000m (9842.5 ft) for the backbone-cabling run must be split between two sections, as when the backbone cabling is to be used to connect the HC to an IC and the IC to the MC. When this occurs, the maximum distance for the backbone cabling run between the HC and the IC is 300 m (984 ft). The maximum distance for the backbone cabling run between the IC and the MC is 2700 m (8855 ft).

Fiber-Optic Backbone

Fiber optics are an extremely effective means of moving backbone traffic. This is because optical fibers are impervious to electrical noise and radio frequency interference. Fiber also does not conduct currents that can cause ground loops. Fiber-optic systems also have high bandwidth and can work at high speeds. This means that a fiber-optic backbone with certain characteristics that is installed today can be upgraded in the future to even greater performance when the terminal equipment is available. This can make fiber optic very cost-effective.

Fiber has an additional advantage when used as a backbone medium: It can go much farther than copper. Multimode optical fiber used as a backbone can support lengths of up to 2000m. Single-mode fiber-optic cables can go up to 3000m. Although optical fiber, especially single-mode fiber, can carry signals much farther than this (60 to 70 miles is feasible, depending on terminal equipment), these longer distances are considered to be out of the scope of LAN standards.

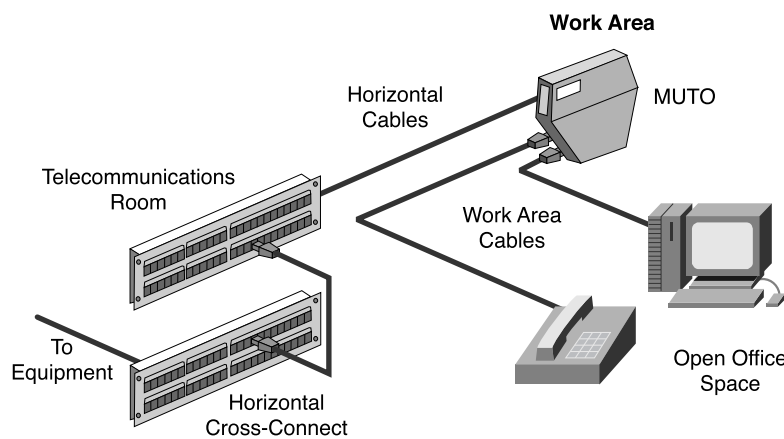
MUTOAs and Consolidation Points

Raised floors and dropped ceilings also can hold patch panels. These typically are used to house consolidation points or *multiuser telecommunications outlet assemblies (MUTOAs)*.

Additional specifications for horizontal cabling in work areas with moveable furniture and partitions have been included in TIA/EIA-568-B.1. Horizontal cabling methodologies are specified for “open-office” environments by means of MUTOAs and consolidation points (see Figure A-11). These methodologies are intended to provide increased flexibility and economy for installations with open-office workspaces that require frequent reconfiguration.

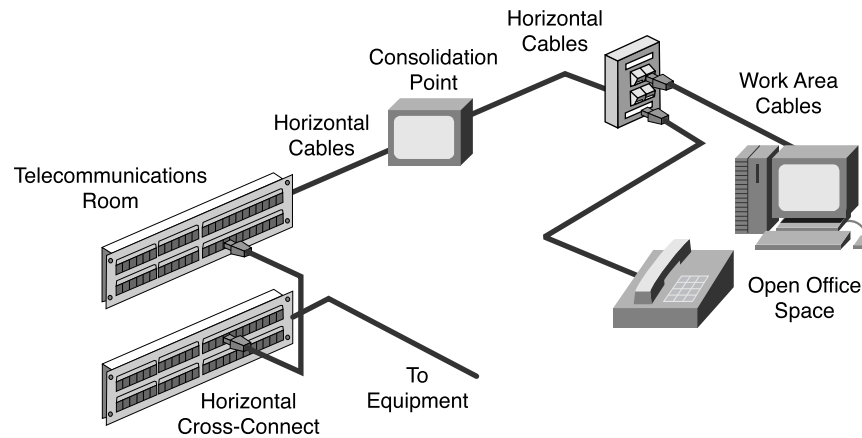
Rather than replacing the entire horizontal cabling system feeding these areas, a CP or MUTOA can be located close to the open office area and eliminate the need to replace the cabling all the way back to the TR whenever the furniture is rearranged. The cabling only needs to be replaced between the new work area outlets and the CP or MUTOA. The longer distance of cabling back to the TR remains permanent.

Figure A-11 Typical MUTOA Installation



A MUTOA is a device that enables users to move and add devices and to make changes in modular furniture settings without rerunning the cable. *Patch cords* can be routed directly from a MUTOA to work-area equipment (see Figure A-12). A MUTOA location must be accessible and permanent, and it cannot be mounted in ceiling spaces or under access flooring. Similarly, it cannot be mounted in furniture unless that furniture is secured permanently to the building structure.

Figure A-12 Typical Consolidation Point Installation



When using MUTOAs, the TIA/EIA-568-B.1 standard specifies the following:

- At least one MUTOA is needed for each furniture cluster.
- A maximum of 12 work areas can be used for each MUTOA.
- Patch cords at work areas shall be labeled on both ends with unique identifiers.
- The maximum patch cord length is 22m (72.2 ft.).

Consolidation points (CP) provide limited area connection access. Typically, a permanent, flush, wall-mounted, ceiling-mounted, or support column-mounted panel serves modular furniture work areas. The panels must be unobstructed and fully accessible without moving fixtures, equipment, or heavy furniture. Consolidation points differ from MUTOAs, in that workstations and other work area equipment do not plug into the CP like they do with the MUTOA. Workstations plug into an outlet that then is connected to the CP.

The TIA/EIA-569 standard specifies the following:

- At least one CP for each furniture cluster
- A maximum of 12 work areas for each CP
- A maximum patch cord length of 5m (16.4 ft.)

For both consolidation points and MUTOAs, TIA/EIA 568-B.1 recommends a separation of at least 15 m (49 ft) equipment between the TR and the CP or MUTOa. This is to avoid problems dealing with crosstalk and return loss.

Structured Cabling Standards and Codes

Standards are sets of rules or procedures that are either widely used or officially specified, and that serve as the gauge or model of excellence. Standards can take many forms. They can be specified by a single vendor or can be industry standards that support multivendor interoperability:

- Standardized media and layout descriptions for both backbone and horizontal cabling
- Standard connection interfaces for the physical connection of equipment
- Consistent and uniform design that follows a system plan and basic design principles

Numerous companies, organizations, and even government bodies regulate and specify the cables in use. In addition to these organizations, local, state, county, and national government agencies issue specifications, requirements, and codes.

The power of standards is this: The network that is built to standards should work well with, or interoperate with, other standard network devices. The long-term performance and investment value of many network cabling systems have been severely diminished by installers who do not know or who follow mandatory and voluntary standards.

It is important to understand that these standards constantly are being reviewed and periodically updated to reflect new technologies and the ever-increasing requirements of voice and data networks. Just as new technologies are added to the standards, others are dropped or phased out. In many cases, a network might include technologies that are no longer a part of the current standard or that are being eliminated. Typically, this does not require an immediate changeover, but these older, slower technologies eventually are replaced in favor of faster ones.

Standards often are developed by or at the direction of international organizations that try to reach some form of universal standard. Organizations such as the IEEE, ISO, and IEC are all examples of international standards bodies. These international standards organizations are composed of members from many nations, each of which has its own standards-making process.

In many countries, the national codes become the model for state/provincial agencies as well as municipalities and other governmental units to incorporate into their laws and ordinances. The enforcement then moves to the most local authority. Always check with local authorities to determine what codes are enforced. For the most part, local codes take precedence over national codes, which take precedence over international codes.

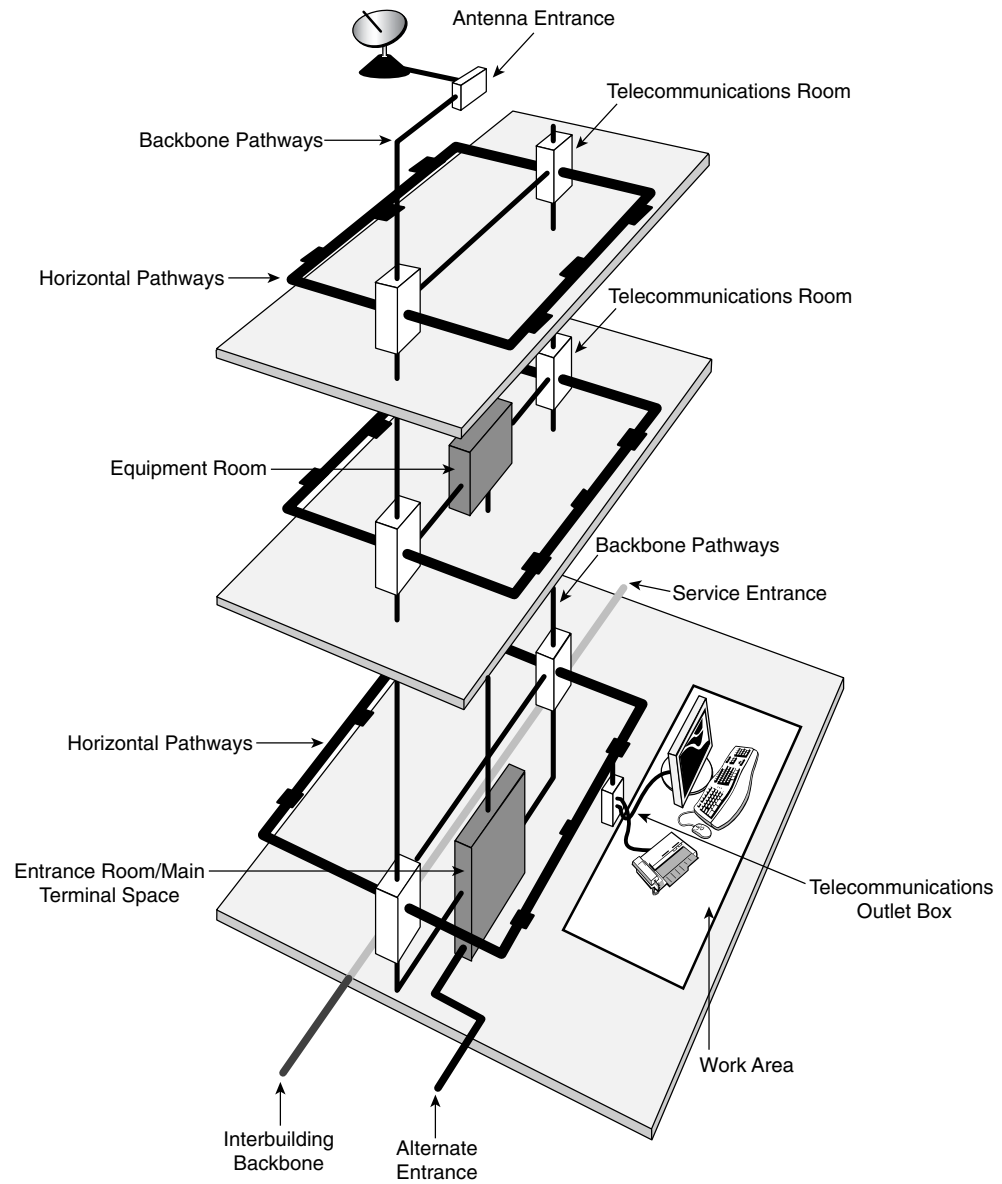
Telecommunications Industry Association and Electronic Industries Alliances

NOTE

For more information on TIA and EIA, visit www.tiaonline.org and www.eia.org.

The Telecommunications Industry Association (TIA) and the Electronic Industries Alliance (EIA) are trade associations that jointly develop and publish a series of standards covering areas of structured voice and data wiring for LANs (see Figure A-13).

Figure A-13 TIA/EIA Standards for Buildings



Both the TIA and the EIA are accredited by the American National Standards Institute (ANSI, section 6.2.7) to develop voluntary industry standards for a wide variety of telecommunications products. This means that many standards often are labeled ANSI/TIA/EIA. The various committees and subcommittees of TIA/EIA develop standards for fiber optics, user premises equipment, network equipment, wireless communications, and satellite communications.

Although there are many standards and supplements, the following are used most frequently by cable installers (see Figure A-14).

Figure A-14 TIA/EIA Structured Cabling Standards

TIA/EIA-568-A	Commercial Building Telecommunications Cabling Standard
TIA/EIA-568-B	Cabling Standards
TIA/EIA-569-A	Commercial Building Standard for Telecommunications Pathways and Spaces
TIA/EIA-570-A	Residential and Light Commercial Telecommunications Wiring Standard
TIA/EIA-606	Administration Standard for the Telecommunications Infrastructure of Commercial Buildings
TIA/EIA-607	Commercial Building Grounding and Bonding Requirements for Telecommunications

- TIA/EIA 568-A is the Commercial Building Standard for Telecommunications Wiring. The standard specifies minimum requirements for telecommunications cabling, recommended topology and distance limits, media and connecting hardware performance specifications, and connector and pin assignments.
- TIA/EIA-568-B is the Cabling Standard. This standard specifies the component and transmission requirements for media. TIA/EIA-568-B.1 specifies a generic telecommunications cabling system for commercial buildings that will support a multiproduct, multivendor environment. TIA/EIA-568-B.1.1 is an addendum that applies to four-pair unshielded twisted-pair (UTP) and four-pair screened twisted-pair (ScTP) patch cables bend radius. TIA/EIA-568-B.2 specifies cabling components, transmission, system models, and the measurement procedures

needed for verification of twisted-pair cabling. TIA/EIA 568-B.2.1 is an addendum that requirements for Category 6 cabling. TIA/EIA-568-B.3 specifies the component and transmission requirements for an optical fiber cabling system.

- TIA/EIA 569-A is the Commercial Building Standard for Telecommunications Pathways and Spaces. The standard specifies design and construction practices within and between buildings that are in support of telecommunications media and equipment.
- TIA/EIA-606-A is the Administration Standard for the Telecommunications Infrastructure of Commercial Buildings, including cable labeling standards. The standard specifies that each hardware termination unit must have some kind of unique identifier. This standard also outlines the requirements for record keeping and maintaining documentation for administering the network.
- TIA/EIA-607-A is the standard for Commercial Building Grounding and Bonding Requirements for Telecommunications. It supports a multivendor, multiproduct environment, as well as the grounding practices for various systems that might be installed on customer premises. The standard specifies the exact interface points between the building grounding systems and the telecommunications equipment grounding configuration, and specifies building grounding configurations needed to support this equipment.

NOTE

For more information on CENELEC, visit www.cenelec.org.

European Committee for Electrotechnical Standardization

CENELEC is known in English as the *European Committee for Electrotechnical Standardization*. It was set up in 1973 as a nonprofit organization under Belgian law. CENELEC develops electrotechnical standards for most of Europe; it works with 35,000 technical experts from 19 European countries to publish standards for the European market. It has been officially recognized as the European standards organization by the European Commission in Directive 83/189/EEC. Many CENELEC cabling standards mirror ISO cabling standards, with minor changes.

Although CENELEC and the International Electrotechnical Commission (IEC) operate at two different levels, their actions have a strong mutual impact because they are the most important standardization bodies in the electrotechnical field in Europe. Cooperation between CENELEC and the IEC is described in what is known as the Dresden Agreement, approved and signed by both partners in that German city in 1996. This agreement was intended to expedite the publication and common adoption of international standards and accelerate the standards preparation process in response to market demands. This agreement also was intended to ensure rational use of available resources. Therefore, full technical consideration of the content of the standard preferably should take place at the international level.

International Organization for Standardization

The International Organization for Standardization (ISO) is an international organization composed of national standards bodies from more than 140 countries. For example, the American National Standards Institute (ANSI) is a member of the ISO. The ISO is a nongovernmental organization established to promote the development of standardization and related activities. The ISO's work results in international agreements, which are published as international standards.

The ISO has defined a number of important computer standards, the most significant of which is perhaps the Open Systems Interconnection (OSI) model, a standardized architecture for designing networks.

U.S. Codes

For some networking projects, a permit is required to ensure that the work is being done properly. Contact local zoning departments for information on permit requirements.

To obtain copies of local or state building codes, contact the building official for the local jurisdiction. All of the basic building codes—CABO, ICBO, BOCA, SBCCI, ICC, and so on—that are adopted throughout the United States can be purchased from the International Conference of Building Officials (ICBO).

It is common for codes requiring local inspection and enforcement to be incorporated into state or provincial governments, and then possibly down to city and county enforcement units. Building codes, fire codes, and electrical codes are examples. Like occupational safety, these were originally local issues, but disparity of standards and often lack of enforcement has led to national standards. When adopted by state or local authorities and enforced to appropriate levels, these standards then are turned over to the lower-level authorities for implementation.

Note that violating these codes often can be expensive in both penalties and delayed project costs.

Some codes are enforced variously by city, county, or state agencies. This means that a project within the city would be handled by the appropriate city agencies, while those outside the city would be covered by county agencies. For instance, fire codes can be enforced by the county building permit department in some communities but by the local fire department in others.

Although local entities inspect and enforce the codes, they often do not write them. Standards-making organizations frequently do that for them. For instance, the National Electrical Code is written to sound like a legal ordinance. This makes it possible for

NOTE

For more information on the ISO, visit www.iso.org/iso/en/ISOOnline.frontpage.

NOTE

The Americans with Disabilities Act (ADA) has led to several important changes in new construction, alterations, and renovations regarding networking and telecommunications. Depending on the use of the facility, these changes might be mandatory, and fines can be assessed for failure to comply.

NOTE

Most countries have similar systems of codes. Knowledge of these local codes is important if you are planning to do a project that crosses national boundaries.

local governments to adopt the code by vote. This might not happen regularly, and the government might fall behind. Always know which version of the NEC is in force for your area.

Evolution of Standards

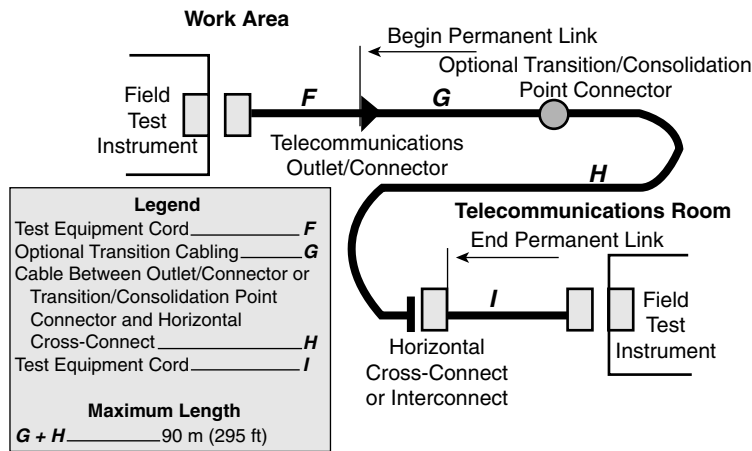
As network bandwidth has increased from 10 Mbps to 1000 Mbps and beyond, it has created new demands on cabling. Older types of cable are often inadequate for use in the faster modern networks. For this reason, the types of cabling used changes over time, and the standards reflect this. The following are the standards for TIA/EIA 568-B.2:

- For twisted-pair cables, only 100-ohm Category 3, 5e, and 6 cables are recognized. Category 5 cable no longer is recommended for new installations and has been moved from the body of the standard into an appendix. Category 5e or greater is now the recommended cable for 100-ohm twisted-pair cable.
- The Category 6 standard specifies performance parameters that ensure that products meeting the standard are component-compliant, backward-compatible, and interoperable between vendors.
- When terminating Category 5e and higher cables, the pairs shall not be untwisted more than 13 mm (0.5 in) from the point of termination. The minimum bend radius for UTP horizontal cabling remains four times the cable diameter. The minimum bend radius for UTP patch cable is now equal to the cable diameter because it contains stranded wires and thus is more flexible than solid-core copper cables used in horizontal cabling.

The acceptable length of patch cords in the telecommunications room has changed from 6m to 5m (19.7 ft. to 16.4 ft.) at maximum. The acceptable length of a jumper cable in the work area has changed from 3m to 5m (9.8 ft. to 16.4 ft.) at maximum. The horizontal segment distance remains at 90m (295.3 ft.). If a MUTOA is used, the work-area jumper can be increased in length if the horizontal length is decreased a corresponding amount to keep the total link segment length not longer than 100m (328.1 ft) (see Figure A-15).

The use of a MUTOA or consolidation point also mandates a separation of at least 15 meters (49 ft) between the TR and the MUTOA or consolidation point in order to limit problems with crosstalk and return loss.

Figure A-15 Changes to Horizontal Cabling Standards



All patch cords and cross-connect jumpers formerly were required to use stranded cable to provide the flexibility needed to survive repeated connection and reconnection. The wording around this topic now has been changed from *shall* to *should* regarding stranded conductors. This allows solid conductor cord designs.

Patch cords are critical elements in the network system. Language regarding the onsite manufacture of patch cords and jumpers still allows these cables to be created, but it now is strongly encouraged that network designers purchase cables that are premade and have been tested.

Category 6 and Category 7 are the newest copper cables available. Because Category 6 cable is used more frequently, it is important for cable installers to understand its benefits.

The significant difference between Category 5e and Category 6 is the means used to maintain the spacing between the pairs inside the cables. Some Category 6 cables use a physical divider down the center of the cable. Others have a unique sheath that locks the pairs into position. Still other Category 6 cables use a foil screen that overwraps the pairs in the cable. The latter type of cable often is called screened twisted-pair cable, or ScTP.

To achieve even greater performance than Category 6, Category 7 cables that are available use a fully shielded construction that limits crosstalk among all pairs. Each pair is enveloped within a foil wrap, and an overall braided sheath surrounds the four foil-wrapped pairs. A drain wire might be provided in future cables to facilitate grounding.

Standards for the structured cabling will continue to evolve. The focus will be on supporting the new technologies that are converging on the data network, such as the following:

- IP telephony and wireless utilizing a power signal in the transmission to provide power to the IP phones or access points.
- Storage area networking utilizing 10 GB Ethernet transmission
- Metro Ethernet “last mile” solutions that require optimizing bandwidth and distance requirements

The standard for Power over Ethernet (PoE) is under development and will be available in the near future. PoE embeds a power signal on cables used for Ethernet transmissions. This power signal is used to free IP phones and wireless access points from the need for connection to AC power outlets, simplifying deployment and reducing costs.

Safety

Safety is an important concept containing information that often is overlooked in coverage of low-voltage telecommunications wiring. Students not accustomed to working in the physical workplace will benefit from labs and training. Other important safety topics include these:

- Safety codes and standards for the United States
- Safety around electricity
- Lab and workplace safety practices
- Personal safety equipment

Safety Codes and Standards for the United States

Most nations have rules designed to protect workers against hazardous conditions. In the United States, the organization charged with worker safety and health is the *Occupational Safety and Health Administration (OSHA)*. Since the agency was created in 1971, workplace fatalities have been cut in half and occupational injury and illness rates have declined 40 percent. At the same time, U.S. employment has nearly doubled from 56 million workers at 3.5 million worksites to 105 million workers at nearly 6.9 million sites.

It is OSHA's responsibility to protect workers by enforcing U.S. labor laws. Technically, OSHA is not an agency related to building code or building permits. However, OSHA inspectors have the power to impose heavy fines and to shut down a job site if they find serious safety violations. Anyone who works on or is responsible for a construction

NOTE

For more information on OSHA, visit www.osha.gov.

site or business facility needs to be familiar with OSHA regulations. The organization offers safety information, statistics, and publications on its website.

MSDS

A *material safety data sheet (MSDS)* is a document that contains information on the use, storage, and handling of a hazardous material. It provides detailed information on the potential health effects of exposure and how to work safely with the material. It tells what the hazards of the material are, how to use it safely, what to expect if the recommendations are not followed, what to do if accidents occur, how to recognize symptoms of overexposure, and what to do if such incidents occur.

Underwriters Laboratories, Inc.

Underwriters Laboratories, Inc. (UL), is an independent, nonprofit product safety testing and certification organization. UL has tested products for public safety for more than a century. The UL focuses on safety standards but has expanded its certification program to evaluate twisted-pair LAN cables for performance according to IBM and TIA/EIA (Telecommunications Industry Association/Electronic Industries Alliance) performance specifications, as well as National Electrical Code (NEC) safety specifications. The UL also established a program to mark shielded and unshielded twisted-pair LAN cables, which should simplify the complex task of making sure that the materials used in the installation are up to specification. Listing by UL denotes initial testing and periodic retesting to ensure continuing conformance to standards.

The UL tests and evaluates samples of cable and then, after granting a UL listing, conducts follow-up tests and inspections. This independent testing and follow-through make the UL markings valuable symbols to buyers.

The UL LAN Certification Program addresses not only safety, but also performance. Companies whose cables earn these UL markings display them on the outer jacket (Level I, LVL I, or LEV I, for example).

National Electrical Code

The purpose of the *National Electrical Code (NEC)* is to safeguard persons and property from hazards arising from the use of electricity. This code is sponsored by the *National Fire Protection Association (NFPA)* under the auspices of the *American National Standards Institute (ANSI)*. The code is revised every three years.

Several organizations, including the UL, have established standards for flame and smoke that apply to network cables laid inside buildings. However, the NEC contains the standards most widely supported by local licensing and inspection officials.

NOTE

For more information on the Underwriters Laboratories, Inc., visit www.ul.com.

NOTE

For more information on the National Fire Protection Association (NFPA), visit www.nfpa.org/Home/index.asp.

NEC Type Codes

NEC type codes are listed in catalogs of cables and supplies. These codes classify specific categories of products for specific uses, as shown in Table A-1.

Table A-1 NEC Cable Type Codes

Type of Cable	Description
OFC (fiber optic)	Contains metal conductors inserted for strength.
OFN (fiber optic)	Contains no metal.
CMP (communication plenum)	Passed tests showing limited spread of flame and low smoke. Plenum cable typically is coated with a special jacket material such as Teflon. The letter <i>P</i> in this code defines a plenum as a channel or ductwork fabricated for handling air.
CMR (communications riser)	The letter <i>R</i> shows that the cable has passed similar but slightly different tests for the spread of flame and production of smoke, compared to CMP cable. For example, riser cable is tested for its burning properties in a vertical position. According to the code, you must use cable rated for riser service when the cable penetrates a floor and a ceiling. Riser cables typically have a polyvinyl chloride (PVC) outer jacket.

Generally, interior network cables are listed in the category of type CM for communications or type MP for multipurpose. Some companies choose to run their cables through the testing process as remote-control or power-limited circuit cables CL2 or CL3 (Class 2 or Class 3) general tests instead of through the CM or CP tests, but the flame and smoke criteria is generally the same for all tests. The differences between these markings concern the amount of electrical power that could run through the cable in the worst case. MP cable is subjected to tests that assume the most power-handling capability, with CM, CL3, and CL2 going through tests with decreasing levels of power handling.

Safety Around Electricity

In addition to learning about the industry's safety organizations, the cable installer should learn about basic safety principles that will be used every day on the job and that are also necessary for the curriculum labs. Because many hazards exist when installing cable, the installer should be prepared for all situations so that accidents or injuries can be prevented.

High Voltage

Cable installers work with wiring designed for low-voltage systems. The voltage applied to a data cable would be hardly noticeable to most people. However, the voltage of network devices that data cables plug into can range from 100V to 240V (in North America). If a circuit failure allowed the voltage to become accessible, it could give the installer a dangerous shock—and it could be fatal. In addition, it is not unheard of for a low-voltage installer inadvertently to skin the insulation off existing high-voltage wiring and contact voltage that way.

Do not become complacent about the hazards of high-voltage wiring nearby just because most of the work deals with low-voltage. If someone suddenly comes in contact with high voltage, that person might find it difficult to control his or her muscles or might not have the ability to pull away.

Lightning and High-Voltage Danger

High voltage is not limited to power lines; lightning is another source of high voltage. Because lightning can be fatal and also can damage network equipment, care must be taken to prevent it from entering the network cabling.

The following precautions should be taken to avoid personal injury and damage to network equipment from lightning and electrical shorts:

- All outside wiring must be equipped with properly grounded and registered signal circuit protectors at the point that they enter the building, known as the entrance point. These protectors must be installed in compliance with local telephone company requirements and applicable codes. Telephone wire pairs should not be used without authorization. If authorization is obtained, do not remove or modify telephone circuit protectors or grounding wires.
- Never run wiring between structures without proper protection. In fact, protection from lightning effects is probably one of the biggest advantages to using fiber-optics between buildings.
- Avoid wiring in or near damp locations.
- Never install or connect copper wiring during electrical storms. Improperly protected copper wiring can carry a fatal lightning surge for many miles.

High-Voltage Safety Test

Voltage is invisible. Its effects are seen in tools that run, equipment that operates, or the unpleasant experience of getting shocked.

When working with anything that plugs into the wall for power, it is a safety best practice to check for voltages on surfaces and devices before coming in contact with them. Using a known reliable voltage-measurement device such as a *multimeter* or voltage detector, take measurements immediately before starting work. Measure again whenever work is resumed the following day or after a break on any job; someone might have made changes. Recheck the measurements again when finished.

Some forms of electricity cannot be predicted. Lightning and static electricity fall into this category. Never install or connect copper wiring during electrical storms; copper wiring can carry a fatal lightning surge for many miles. This is particularly an issue with external wiring that is strung between buildings or underground wiring. Equip all outside wiring with properly grounded and approved signal circuit protectors. These protectors must be installed in compliance with the local codes, which, in most cases, align with national codes.

Grounding

Grounding works by providing a direct path to the earth for any voltages that come in contact with it. Equipment designers purposely isolate the circuits in equipment from the *chassis*—that is, the box where the circuits are mounted. Any voltage that leaks from the equipment to its chassis should not stay in the chassis. Grounding equipment conducts any stray voltage to the earth without hurting that equipment. Without a proper path to the ground, stray voltages use another path to the ground, such as a person's body.

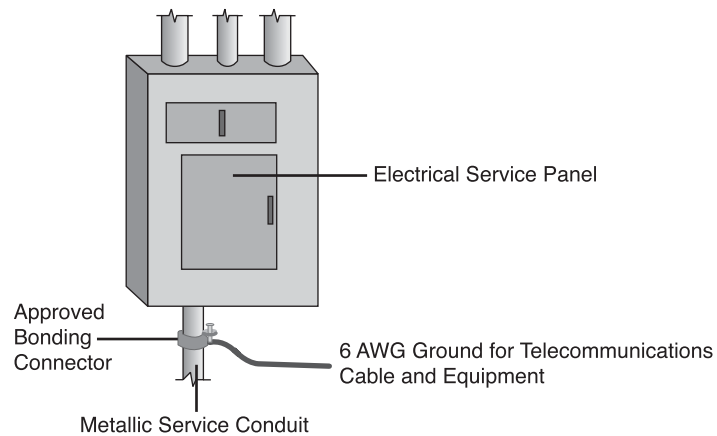
The grounding electrode is the metal rod that is buried in the ground near the entrance point of the building—that is, the place where electricity enters a building. How the ground system connects to the earth is often another matter. For years, cold-water pipes, which enter the building from the underground water mains, were considered good grounds. Large structural members, such as I-beams and girders, were also acceptable. Although these might provide an adequate path to the ground, most local codes now require a dedicated grounding system, such as installed grounding conductors connecting equipment to grounding electrodes.

Be aware of the grounding system in the lab and on each job site. Verify that the grounding system actually works. It is not uncommon to find that grounding was improperly done or never was installed in the first place. A more common situation occurs when an installer takes a few shortcuts and accomplishes a technically adequate ground, but in a nonstandard way. Later, changes to other parts of the network or to the building itself might destroy or eliminate the nonstandard ground system, leaving equipment and people at risk.

Bonding

Bonding involves providing a means for various wiring fixtures to interconnect with the grounding system (see Figure A-16). It can be thought of as an extension of ground wiring. A device such as a switch or a router might have a bonding strap between its case and a ground circuit to ensure a good connection.

Figure A-16 Bonding



Properly installed bonding and grounding will accomplish the following:

- Minimize electrical surge (spike) effects
- Maintain the integrity of the electrical grounding plant
- Provide a safer and more effective path to ground

Telecommunications bonds typically are used in the following ways:

- Entrance facilities
- Equipment rooms
- Telecommunications rooms

Grounding and Bonding Standards

The National Electrical Code contains much information on grounding and bonding. The TIA/EIA standard on grounding and bonding, TIA/EIA-607-A, "Commercial Building Grounding and Bonding Requirements for Telecommunications," extends grounding and bonding into the telecommunications structured cabling system. TIA/EIA-607-A specifies the exact interface points between the grounding system of a building and the telecommunication equipment grounding configuration. It supports a multi vendor,

multi product environment for the grounding practices for various systems that may be installed on customer premises. It also specifies the necessary grounding and bonding configurations needed in the building to support this equipment.

Lab and Workplace Safety Practices

Although cable installation is generally a safe profession, there are plenty of opportunities for being injured. Many injuries are caused when installers come in contact with stray sources of voltage, called foreign voltages, such as lightning, static electricity, or other types of voltages caused by installation faults or induction currents that somehow find themselves onto network cables.

When working in walls, ceilings, or attics, the first thing that should be done is to turn off power to all circuits that might pass through those work areas. If it is not clear which wires pass through the section of the building being worked in, a good rule to follow is to shut off all power. Never touch power cables. Even if all power to the area has been shut off, there is no way to know whether circuits are still “live.”

Most countries have one or more agencies that develop and administer safety standards. Some of these are designed to ensure public safety; others are designed to protect the worker. Those that protect the worker usually cover laboratory safety, general workplace safety, compliance with environmental regulations, and hazardous waste disposal.

Workplace Safety

The following are guidelines for keeping a workplace safe:

- Before beginning work, learn the locations of all fire extinguishers in the area. A small extinguishable fire can get out of control if no one is able to locate an extinguisher quickly.
- Always find out in advance what the local codes are. Some building codes might prohibit drilling or cutting holes in certain areas, such as firewalls or ceilings. The site administrator or facility engineer will be able to help determine which areas are off-limits.
- When installing cable between floors, use a riser-rated cable. Riser cable is covered with a flame-retardant fluorinated ethylene propylene (FEP) jacket and, therefore, will not allow flames from one floor to use the cable to reach another floor.

- Outdoor cables typically have a polyethylene jacket (PVC). Polyethylene burns readily and gives off dangerous gases. NEC codes state that polyethylene building entrance cables cannot be exposed more than 15 m (approximately 49 ft.) into a building. If greater distances are required, the cable must be in metallic conduits.
- Consult the building's maintenance engineer to find out whether there is asbestos, lead, or PCB in the working areas. If so, follow all government regulations in dealing with that material. These materials are called hazardous for a reason. No one's health should be risked by working unprotected in these areas.
- Finally, if cable must be routed through spaces where air is circulated, be sure to use a fire-rated cable (plenum-rated). The most common plenum cables are jacketed with Teflon or Halar. Plenum-grade cable does not give off poisonous gases when it burns, like regular cables, which have a polyvinyl chloride (PVC) jacket.

Ladder Safety

Ladders come in many sizes and shapes to be used for many specific purposes. They can be made of wood, aluminum, or fiberglass, and are designed for either light or industrial use. The two types that are the most common are straight ladders and stepladders. Regardless of the type or construction, be sure that the ladder has a label certifying that it complies with specifications of the American National Standards Institute (ANSI) and that Underwriters Laboratories (UL) lists it as passing its standards.

- Select the right ladder for the job. Be sure that the ladder is long enough to work from comfortably and is sturdy enough to withstand repeated use. Fiberglass ladders most commonly are used in cable installation. Although aluminum ladders are lighter, they are less stable and never should be used around electricity. When working near electricity, only fiberglass ladders should be used.
- Inspect the ladder first. Any ladder can develop a problem that can render it unsafe. Inspect ladders for loose or damaged rungs, steps, rails, or braces. Make certain the spreaders on stepladders can be locked in place and that the ladder has safety feet that will provide more stability and reduce the chances of the ladder slipping while working. Never use a ladder that is defective.
- Stepladders should be fully opened with the hinges locked. Straight ladders should be placed at a 4:1 ratio. This means that the base of the ladder should be 0.25m (10 in.) away from the wall or other vertical surface for every 1m (3 ft.) of height to the point of support. If possible, secure a straight ladder as close to the point of support as possible, to prevent shifting. Ladders always should be placed on a solid, level surface.

- Never climb higher than the second step from the top on a stepladder, or the third from the top on a straight ladder.
- Cordon off the work area with appropriate markers, such as traffic cones or caution tape. Post signs so that people are aware of the ladder. Lock or block any nearby door that might swing toward the ladder if it opens.

Fiber-Optic Safety

Because fiber-optic cable contains glass, it is important to take appropriate precautions. The scrap material is sharp and must be disposed of properly. As with any glass product, when broken it, can cut or can splinter into tiny slivers that can get lodged in the skin.

These rules should be followed to avoid injury when working with fiber optics:

- Always wear safety glasses with side shields.
- Place a mat or piece of adhesive on the table so that all glass shards that fall are more easily identified.
- Do not touch eyes while working with fiber-optic systems until hands have been cleansed thoroughly. Similarly, do not handle contact lenses until hands have been washed thoroughly.
- Put all cut fiber pieces in a safe place and dispose of properly.
- If some of the material gets on clothing, use a piece of adhesive or masking tape to remove it. Use tape to remove shards from fingers and hands.
- No food or beverages in the work area should be allowed.
- Do not look directly into the end of fiber cables. Some laser-driven devices could cause irreversible damage to the eye.

CAUTION

If someone catches on fire, remember the tip, “Stop, Drop, and Roll”:

- Stop, do not run. Fire spreads quickly if a burning person starts running. If a burning person panics and runs down the hall, tackle that person.
- Drop to the floor.

Roll on the floor to extinguish the flames.

Fire Extinguisher Use

Never attempt to fight a fire without knowing how to use a fire extinguisher. Read instructions beforehand and check the valve. In the United States, regulations state that fire extinguishers used in commercial buildings must be checked at regular intervals and replaced if they’re not in good working order.

Fire extinguishers have labels that identify which kinds of fires they are designed to fight. In the United States, these are called ratings. Four different types of fires have been classified in the United States:

- Class A fires involve ordinary materials, such as burning paper, lumber, cardboard, plastics, and so on.
- Class B fires involve flammable or combustible liquids, such as gasoline, kerosene, and common organic solvents used in the laboratory.

- Class C fires involve energized electrical equipment, such as appliances, switches, panel boxes, power tools, hot plates, and most other electronic devices. Water is a particularly dangerous extinguishing medium for Class C fires because of the risk of electrical shock.
- Class D fires involve combustible metals, such as magnesium, titanium, potassium, and sodium. These materials burn at high temperatures and react violently with water, air, and other chemicals.

Personal Safety Equipment

Determine before you enter the workplace that you will work safely that day. Part of having a safe work attitude involves choosing to wear proper work attire. Wearing protective clothing or gear can prevent an injury or make an injury less severe.

When working with power tools, for instance, it is important to protect eyes from flying debris and ears from deafening noises. If goggles and earplugs are not used, eyesight or hearing could be damaged permanently.

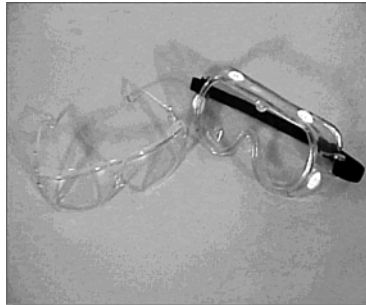
Work Clothes

Long trousers and sleeves help protect the arms and legs from cuts, scratches, and other hazards. Avoid wearing excessively loose or baggy clothing because it might catch on a protruding object or get caught in power tools.

Wear shoes that are appropriate for the job. Sturdy, fully enclosed shoes should be worn. They should be able to protect the soles of the feet from sharp objects on the floor. Thick-soled shoes are best when working around nails, scrap metal, and other materials that could puncture the soles of regular athletic shoes. Steel-toed shoes can protect toes when a heavy object is dropped on the shoes. Also make sure that the soles have traction, to prevent slipping.

Eye Protection

Eyes are much easier to protect than to repair, so safety glasses should be worn when cutting, drilling, sawing, or working in a crawl space (see Figure A-17). With some cable-termination processes, as materials are cut, prepped, and discarded, there are opportunities for small particles to become airborne. While working with fiber optics, the glass fibers, adhesives, and solvents can come in contact with the eyes. Also, small particles or chemicals might get on the hands and accidentally be rubbed into the eyes. Therefore, glasses also protect the eyes from contaminated hands. It is a good idea to wear safety glasses any time when working in a crawl space or above a dropped ceiling. If something falls from above, the eyes will be protected. Many job sites require safety glasses at all times.

Figure A-17 Eye Protection

Eye protection should be worn in all labs. Before starting any lab exercise, review the safety instructions and safety equipment needed.

Hard Hat Use

As with all safety equipment, a hard hat protects the user from injury. Hard hats might be required at job sites, especially those involving construction. Many employers supply hard hats; others require installers to buy their own. The furnished hard hats might be of a company color or might be equipped with company logos to identify the wearer as belonging to a certain organization. Even if you are purchasing a hard hat for personal use, do not adorn it without obtaining permission from the employer. In addition, OSHA does not allow stickers on hard hats because they could hide cracks.

Periodically check the hard hat for cracks. A cracked hat might fail to protect a head. For hard hats to provide effective protection, they must be adjusted properly. Take the time to adjust the internal straps to make sure that they function and ensure that the hat fits snugly and is comfortable. Hard hats are required when working on top of a ladder and often are required when working in new-construction environments.

Tools of the Trade

As with any craft, tools of the trade are often what makes the difference between a hard job with mediocre results and a simple job with outstanding results. Students should get hands-on experience with several of the tools used by low-voltage cabling installers to have professional results.

Students should become versed in the following technologies:

- Stripping and cutting tools
- Termination tools

- Diagnostic tools
- Installation support tools

Stripping and Cutting Tools

Stripping tools are used to cut the cable jacket and insulation of the wires. The Panduit UTP cable-stripping tool (see Figure A-18) is used to remove the outer jacket from four-pair cables. It also can be used for most coaxial cable. The tool features an adjustable cutting blade to accommodate cables with different jacket thicknesses. The cable is inserted into the tool, and then the tool is twisted around the cable. The blade cuts through the outer jacket only, allowing the installer to simply pull the jacket off the cable to expose the twisted pairs.

Figure A-18 Panduit UTP Cable-Stripping Tool



The electrician's scissors and cable knife set (see Figure A-19) also can be used for removing cable jackets. The knife is used for removing the jacket from large cables, such as those that enter the building from the telco or ISP. This knife is sharp, so care should be taken when using this tool. It is recommended that gloves be worn when working with it, preferably gloves that will resist injuring the hand if the knife slips.

The scissors can be used to cut individual wires, remove the outer jacket of smaller cables, and remove the insulation on individual wires. Not visible in the figure, the scissors features two different-size notches on the back of the blade that will strip insulation on wire sizes from 22- to 26-gauge.

Figure A-19 Electrician's Scissors and Cable Knife

Termination Tools

Termination tools are designed to cut and terminate specific types of cable. The multipair termination tool (see Figure A-20) is designed to terminate and cut UTP cable and seat connecting blocks. This tool features an ergonomically designed handle that helps reduce fatigue when trimming wire or seating connecting blocks to the wiring base.

Additionally, it has the following features:

- Terminates five pairs at a time
- Terminates wires on both the cable side and the cross-connect side of connecting blocks
- Has replacement cutting blades available
- Can be used in the cut or noncut position
- Clearly displays CUT designation for proper orientation during termination
- Includes a reliable impact mechanism
- Has an ergonomically designed rubber handle with a ribbed edge that provides a no-slip grip

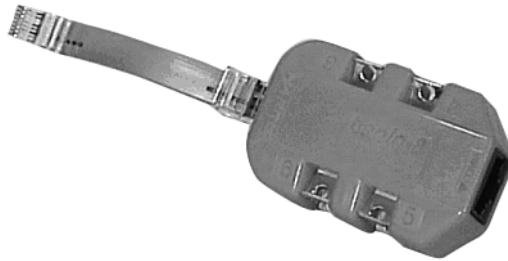
The impact punchdown tool (see Figure A-21) has interchangeable blades so that it can terminate wires on 66 and 110 hardware. Unlike the multipair termination tool, this tool terminates only one wire at a time. The reversible blades have a punch-and-cut function on one side and a punch-only function on the other.

Figure A-20 Panduit Multipair Impact Tool**Figure A-21** Panduit Impact Tool**Lab Activity** Tool Usage and Safety

In this lab, you learn to identify, examine, and use the tools that are used in cable installations.

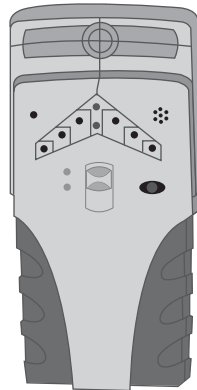
Diagnostic Tools

It is sometimes necessary to access individual wires inside a telecommunications outlet or jack. The modular adapter, or banjo, is used to provide access to these wires (see Figure A-22). A common line cord is plugged into the adapters and then into the jack. The technician can use an ohmmeter or other test devices without having to disassemble the jack. Banjos come in three-pair and four-pair configurations.

Figure A-22 Modular Adapter (Banjo)

To locate metal pipes, wood studs or joists, or other hidden infrastructure behind a wall or under a floor, use wood and metal sensors. This should be done before drilling for any cabling project. A deep-scanning metal sensor can find metal studs, conduit, copper piping, electrical lines, rebar, telephone lines, cable lines, nails, and other metal objects. This tool usually can scan through up to 15 cm (about 6 in.) of a nonmetallic surface, such as concrete, stucco, wood, or vinyl siding. It identifies both the location and the depth of piping or rebar with an accuracy of about 30 cm (about 12 in.).

Another type of sensor is a stud sensor (see Figure A-23). This sensor locates wooden studs and joists behind walls. This tool helps the installer make informed decisions on the best location to drill or saw when installing outlets or raceways. The stud and rebar sensor also detects metal and even can find rebar embedded in up to 100 cm of concrete. All the modes detect AC wires to alert the installer, to prevent drilling or nailing into a live electrical wire.

Figure A-23 Stud Sensor

Installation Support Tools

A cable installer also will find other tools useful. A measuring wheel is used to estimate the length of a cable run (see Figure A-24). The wheel has a counter mounted on the side. An installer simply rolls the wheel down the intended path of the cable. When the end is reached, the counter indicates the distance.

Figure A-24 Measuring Wheel



Cable installers also need tools and materials for cleaning up the job site. Brooms, dust pans, and vacuums make the cleanup process go quickly. Cleanup is one of the final but important steps in completing a cabling project. A shop vacuum is designed for industrial or heavy-use jobs.

Fish Tape

One device specifically designed to make the retrieval of wires inside a wall a quick and easy process is fish tape (see Figure A-25). Fish tape can be run through walls or conduits. After running the fish tape to its intended destination of some convenient partway point, secure the cable to be pulled to the end of the fish tape. Retrieve by pulling and winding. The desired cable will come with it.

For cabling work, a fiberglass fish tape is safer than a steel one. Also, most seasoned cable installers pull a string along with their cables. This provides a convenient way to pull extra cables later.

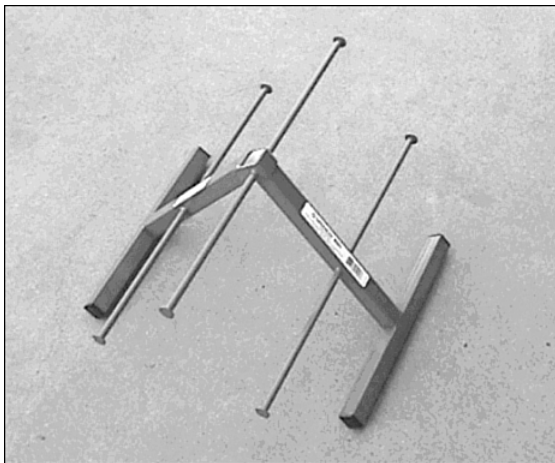
Figure A-25 Fish Tape



Cable Tree

During the rough-in phase, *cable trees*, jacks, and rollers are used to support cable reels to make laying the cable faster and easier, and to prevent injuries. A cable tree supports a number of small reels of cable (see Figure A-26). This enables the cable installer to pull multiple runs of cable simultaneously. Because all cables terminate at the telecommunications room, a cable tree would be set up in the staging area. After cable is pulled to a jack location, the other end is cut from the reel and pulled into the telecommunications room.

Figure A-26 Cable Tree



Cable jacks and reel rollers are designed for large reels that hold backbone cabling. Because large reels are often too large and heavy to lift by hand, cable jacks provide the leverage that enable two people to raise them. After they are raised, the jacks allow the reel to rotate freely and safely during the pulling process.

Reel rollers also are used to support large cable reels. Rollers come in sets of two, each used to support one side of the reel. Rollers mounted on bearings allow the reel to be turned easily. When pulling from a reel roller, one installer generally is stationed at the reel, to assist in the turning of it.

Bullwheels

Bullwheels, in particular, normally are used to make the first or last turn in the path, but they can be used to make an offset or turn in the center of the run.

A bullwheel is a large-diameter pulley that is used in a mechanical cable pulling process. Bullwheels seldom are used when pulling cable by hand. The bullwheel itself generally is made of aluminum, is at least 0.3 m (about 1 ft.) in diameter, and is supported on some type of bearing on its frame. The bullwheel differs from a pulley, in that it often has two shackles for attachment to fixed points. It also can be removed from its frame so that it can be put into a cable run from the middle of the cable.

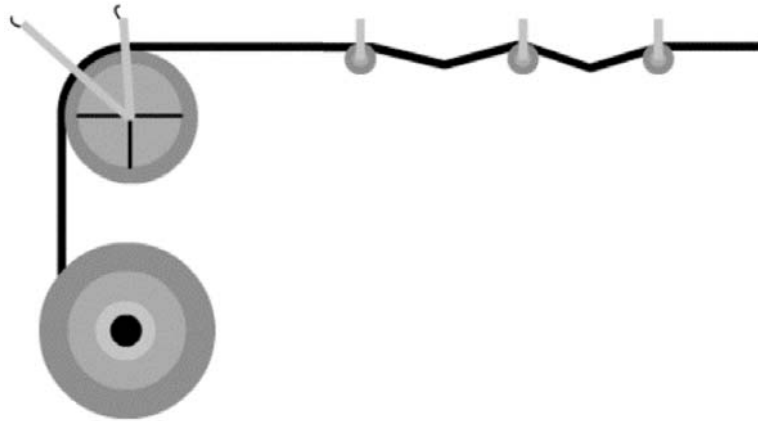
Pulleys

Pulleys are used on long, open cable runs to support cables and prevent them from dragging on surfaces that could damage the cable sheath. They also are used on surfaces that could be damaged by pulling cable across them. Pulleys are used in straight cable runs to support the weight of the cable and reduce pulling friction. Pulleys also can assist with minor offsets in the cable run (see Figure A-27).

Pulleys are used when pulling by hand or when using a cable puller or winch. When turns in the run exceed 45°, use bullwheels instead.

Pulleys are used for both multiple network cable runs and heavy backbone cable runs. Although lightweight pulleys can be used for network cable runs, heavy-duty pulleys should be used for backbone cables. Backbone cable pulleys have a larger frame, and the pulley wheel is a larger diameter.

Figure A-27 Cable Pull Using a Bullwheel and Pulleys

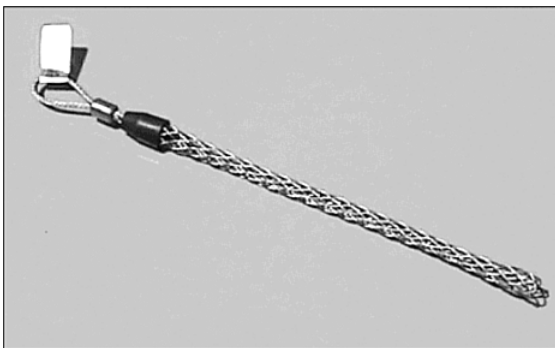


Wire Mesh or Kellem Grips

Wire mesh or Kellem grips are attached to the end of the cable so that a pulling rope can be tied to the end of the cable (see Figure A-28). The grip is slid over the end of the cable, and the last 15 cm (about 6 in.) are taped tightly with good-quality vinyl electrical tape. As tension is placed on the cable, the grip draws tighter around the sheath of the cable. These grips are designed for single-cable use only; they generally are not to be used with a bundle of network distribution cables. These grips come in various sizes to accommodate different cable sizes.

Kellem grips are also available in a split version, for where the end of the cable might not be accessible. These versions are used to pull additional slack in the middle of a cable run. Split grips also are used to support large backbone cables in a riser installation—that is, when cables are pulled between floors. To attach these split Kellem grips, the grip is opened and placed around the cable. A special rod then is threaded through the wire mesh.

Figure A-28 Wire Mesh or Kellem Grip



Installation Process

The installation process contains the many elements of an installation, starting from the rough-in phase, in which the cables first are pulled into place. Riser cables are treated, as are the fire stops used where a wire passes through a fire-rated wall. Copper terminations are covered, as are wall adapters and other fixtures.

Topics that will be treated here include these:

- Rough-in phase
- Vertical cable installation
- Fire-stops
- Termination of copper media
- The trimout phase

Four phases cover all aspects of a cabling project: rough-in, trimout, finish, and customer support. The characteristics of each are as follows:

- **Rough-in phase**—In the rough-in phase, all of the cables are installed in the ceilings, walls, floor ducts, and risers.
- **Trimout phase**—The principal tasks during this phase are cable management and termination of the wires.
- **Finish phase**—The principle tasks during the finish phase are performing cable testing, troubleshooting, and certification.
- **Customer support phase**—The final phase of the project focuses on satisfying the customer. In this phase, a walkthrough of the network is done with the customer, and the customer is presented with formal test results and other documentation, such as as-built drawings. The customer then can sign off on the project if satisfied. Afterward, the cable installation company provides ongoing support to the customer if there are problems with the cabling.

Rough-In Phase

The rough-in phase involves pulling the cable from a work area called the staging area to individual rooms or work areas. The staging area is generally an area just outside the telecommunications room. Each cable is labeled on both ends so that it can be identified. In the work area, enough cable is pulled so that there is plenty to work with when terminating. If the cable is to be run behind a wall, it is pulled out at the termination end so that it is ready for termination in the next phase.

In most cases, a new construction environment is less challenging than a remodeling project because there are fewer obstructions. Special planning usually is not required

in this environment because structures that will support cables and terminals generally are built as needed. However, coordination with other trades on the job site is essential. Other workers must be aware of data cable locations so that they can avoid damage to the newly installed cables.

The staging area is where the cable installation operation is based. This area generally is situated near the telecommunications room, where one end of every cable is terminated. Proper setup of equipment saves time during the cable-pulling process. Different types of cable runs require a different setup. Network distribution cabling normally requires a setup of multiple small cable reels. Backbone cabling, on the other hand, generally requires setting up a single large reel of cable.

**Lab Activity** Identification of Cables

In this lab, you learn to identify the different types of cables used in CCNA 1 and CCNA 2.

Horizontal Cable Installation

Horizontal cable is cable that travels between the HC and the work-area outlet. The cable can travel either horizontally or vertically. When installing horizontal cable, it is important to follow these guidelines:

- Cables always should run parallel to walls.
- Cables never should be placed diagonally across a ceiling.
- When selecting the path for cabling, select the most direct path with the fewest number of turns.
- Do not have cables lying directly on top of ceiling tiles.

After the backbone cabling has been installed, the horizontal network-distribution cable must be installed. Network-distribution cable provides users and devices with network connectivity from the backbone cabling. Generally, this type of distribution cable is from workstations back to the TRs, where it is interconnected to the backbone cabling.

Horizontal Cable Installation in Conduits

Installing horizontal cables in conduits requires similar setups and procedures as installing cables in an open ceiling. Pulleys are not needed for temporary support because the cables are supported within the conduits. Although the initial staging is the same, some special techniques and concerns must be considered when pulling cable in conduits.

The conduit must be large enough to handle all the cables that are being pulled. Conduits never should be filled to more than 40 percent of their capacity. Charts are available that give the maximum cable fill or size for specific conduits. Next, the length of the run and the number of 90° bends in the conduit must be considered. Generally accepted practices are that conduit runs will be no longer than 30m (98 ft.) without a pull box, and a run of conduit shall have no more than two 90° bends. Large cable pulls require long radius conduits for the bends. The standard radius for a 10-cm (4-in.) conduit is 60 cm (24 in.). This is not adequate for large communications distribution cables, such as those with at least 400 pairs. A minimum 90-cm (35-in.) radius conduit should be used in these larger pulls.

A specialized vacuum cleaner attachment can help with this (see Figure A-29). A special foam-rubber missile, sometimes called a mouse, can be inserted into the conduit, with a light pull string tied to the missile. When the missile is lubricated slightly with common household liquid detergent, a high-powered vacuum cleaner, like those for commercial use, can draw the missile (with string attached) through an entire conduit run. Special attachments for the vacuum also can allow the missile to be blown through the conduit. For particularly difficult runs, one vacuum can be set up to blow on one end and another can be set up to draw on the other. When the string has reached the other end of the conduit, it is used to pull a pull rope through the conduit. This, in turn, pulls the cable or cables.

Figure A-29 Conduit Blowing System



Raceways

A *raceway* is a generic term for channels that contain cables in an installation. Raceways include common electrical conduit, specialized cable trays or ladder racks, in-floor duct systems, and plastic or metal surface-mounted raceways.

Surface-mounted raceways are used when there is no hidden path for the cable (see Figure A-30). Plastic surface-mounted raceways come in various sizes, to accommodate any number of cables. These are much easier to install than metallic conduits and are considered much more attractive.

Figure A-30 Raceways



Pulling Cable to the Jacks

At the work-area end of the cables, the cable must be pulled to the jack or outlet location. If conduits are used to run behind the walls from the ceiling to the outlet boxes, a fish tape can be inserted into the outlet box at the end of the conduit and pushed up the conduit until it comes out into the open ceiling. The cable can be attached directly to the fish tape and then pulled down from the ceiling and out through the outlet box.

Some walls, such as concrete and brick walls, obviously do not have the cables run behind them. Surface-mounted raceways are used for these types of walls instead. Before cables are installed, the surface-mounted raceways should be secured to the wall following the manufacturer's recommendations. After cable has been pulled through to the outlets, the cable installers return to the telecommunications room to finish pulling the cable at that end.

Fastening Cable

The final step in the rough-in process is fastening the cables permanently. Many types of fasteners are available, such as J-hooks and hook and loop ties. Network cables never should be tied to electrical cables. Although this might appear to be the most practical approach, especially for individual cables or small bundles, it is a violation of the electrical code. Cables also should never be tied to water or sprinkler pipes.

Because high-performance network cables have a minimum bend radius that cannot exceed four times the diameter of the cable, fasteners should be selected that support the minimum bend radius (see Figure A-31). Fastener spacing might be defined in the job specifications. If no spacing is specified, fasteners should be placed at intervals no greater than every 1.5m (4.9 ft.).

Figure A-31 Panduit Hook and Loop Ties



If a cable tray or basket is installed in the ceiling, permanent fasteners are not needed.

Horizontal Cabling Precautions

Pulling cables can cause damage to the cable sheaths if care is not taken. Too much tension or making corners so tight they exceed the bend radius can decrease the ability of a cable to carry data. Installers stationed along the route of the pull should watch for snags and possible trouble spots before sheath damage can occur.

The following are several of the precautions that should be taken when pulling horizontal cabling:

- As the cable enters the conduit, it can become caught or get scuffed on the end of the conduit. Use a plastic conduit guard or shoe to avoid this type of sheath damage.
- Extremely hard pulls around a 90° turn can cause cables to flatten, even when using bullwheels and pulleys. If pulling tension is too great, shorten the length of the pull and do it in stages. Do not exceed 25 ft./lbs. of pull tension for twisted-pair cable, or 50 ft./lbs. for fiber.

- When pulling with a cable puller or winch, it is important to perform the pull in a single smooth action. When the pull has begun, if at all possible, continue the pull until complete. Stopping and starting can cause additional stress on the cable.

Mounting Jacks in Drywall

Safety Rules

WARNING

Never, ever touch power cables. Even if you cut all power to the area you are working in, there is no way to know whether they are “live.”

Whenever working in walls, ceilings, or attics, the first thing to do is turn off power to all circuits that might pass through those work areas. If it is not clear whether wires pass through the section of the building you are working in, a good rule to follow is to shut off all power.

Before beginning work, learn the locations of all the fire extinguishers in the area.

Wear appropriate clothing. Long pants and sleeves help protect arms and legs. Do not wear excessively loose or baggy clothing because it could catch on something.

If working in a dropped-ceiling area, survey the area. Lift a few of the ceiling tiles and look around. This process will help you locate electrical conduit, air ducts, mechanical equipment, and anything that might cause problems later.

Protect your eyes with safety glasses when cutting or sawing. It is also a good idea to wear safety glasses when working in a crawl space or above a dropped ceiling. If something falls from above, or in the dark, your eyes will be protected.

Consult the maintenance engineer of the building to find out whether there is asbestos, lead, or PCBs where the work is being done. If so, follow all government regulations in dealing with that material.

Keep the work area orderly and neat. Do not leave tools lying in places where someone might trip over them. Use caution with tools that have long extension cords. They are easy to trip over.

NOTE

When working in walls, ceilings, or attics, it is extremely important to turn off the power to all circuits that go to, or pass through, the work area. If it is unclear whether wires pass through the section of the building, a good rule to follow is to shut off all power.

To mount an RJ-45 jack in drywall, follow these steps:

1. Select a position for the jack that will be 30-45 cm (10–15 in) above the floor. Drill a small hole in the selected location. Check for any obstructions behind the hole by bending a piece of wire, inserting it into the hole, and rotating it in a circle. If the wire hits an obstruction, you must select a new location farther away from the first hole. Then, perform the procedure again until you find an unobstructed location.
2. Determine the size of the opening you need for the box that will hold the jack. Trace an outline of the template that was included with the box or bracket.

3. Before cutting into the wall, use a carpenter's level to make sure the opening will be straight. Use a utility knife to cut the opening. Push the knife through the drywall, inside the template outline, until you have an opening large enough to accommodate the blade of either a keyhole saw or a drywall saw.
4. Insert the saw into the hole, and cut along the edge of the penciled outline. Continue cutting carefully along the line until you can pull out the piece of drywall. Make sure the box or bracket will fit the opening.

If you are using a box to flush-mount the jack, do not secure the box until you bring the cable to the opening.

Mounting Jacks in Plaster

It is more difficult to cut into a plaster wall than it is to cut into drywall. To achieve the best results, follow these steps:

1. Determine the appropriate location for the jack.
2. Use a hammer and chisel to remove the plaster from the wall so that the lath behind the plaster is exposed.
3. Use a utility knife to carefully trim plaster away from the lath.
4. Place the template against the lathwork so that it overlaps three strips of lath, equally, at the top and bottom of the opening. Trace an outline around the template. Use an electric saw to cut away the full lath strip that is exposed in the center of the opening.
5. Make several small cuts on the full strip, first on one side and then on the other. Continue to make these small cuts until you completely cut through the center lath.

Finish preparing the opening by removing the required portions of the lath strips at the top and bottom. Cut vertically along the sides of the hole, making several small cuts first on one side and then on the other as before. Continue until the laths are notched evenly with the top and bottom of the hole. Now, cut a curve in the bottom piece of lath from the top-right corner to the bottom-left corner. Bottom out the curve so that it is flat just before it gets to the corner. Remove the lath that should fall free when the cut reaches the corner. Turn the saw around and cut flush along the bottom of the hole until you reach the opposite corner. The remaining lath should fall free. Repeat the process for the top piece of lath.

CAUTION

Be careful when doing this step. If you attempt to cut all the way through one side before cutting into the other side, the saw will cause the lath to vibrate when you make the second cut. This vibration can cause the plaster around the opening to crack and separate from the lath.

Mounting Jacks in Wood

To prepare wood for flush-mounting a jack, follow these steps:

1. Select the position where you want to place the box. Remember, if you place the RJ-45 jack on a wooden baseboard, avoid cutting the box opening into the bottom 5 cm (1.5 in) of the baseboard.
2. Use the box as a template, and trace around the outside. Drill a starter hole in each corner of the outline. Insert a keyhole saw, or jigsaw, into one of the holes and saw along the outline until you reach the next hole. Turn the saw and continue cutting until you can remove the piece of wood.

Flush-Mounting a Jack in a Wall

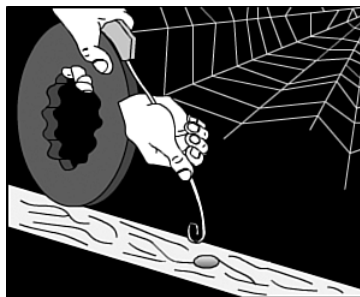
After preparing an opening in which to position the jack, place it in the wall. If using a box to mount the jack, hold the cable and feed it through one of the slots into the box. Then, push the box into the wall opening. Use the screws to secure the box to the wall's surface. As you tighten the screws, you will pull the box tighter to the wall.

If you are mounting the jack in a flat, low-voltage mounting bracket, sometimes called a "wallboard adapter" or "old work box," position it now. Place the bracket against the wall opening, the smooth side facing outward. Push the top and bottom flanges toward the back so that the bracket grips the wall. Then, push one side up and the other down to securely mount the bracket.

Pulling Cable to the Jacks

At the work-area end of the cables, you must pull the cable to the jack or outlet location. If conduits run behind the walls from the ceiling to the outlet boxes, you can insert a fish tape into the outlet box at the end of the conduit and push it up the conduit until it comes out into the open ceiling. You can attach the cable directly to the fish tape and then pull it down from the ceiling and out through the outlet box. (See Figure A-32.)

Figure A-32 Pulling Cable to the Jacks with a Fish Tape



If no conduits are in the walls, you can pull the cable behind the wall. First, cut a hole into the drywall at the location of the jack. You must take care to avoid making the hole too large. Drill another hole into the top plate of the wall. This hole should be 1-2 cm (.39-.79 in) in diameter. Push a fish tape down through the top hole and find it at the lower hole. Some installers use a weight and a string instead, which they drop down from the top hole and tie off so that it cannot accidentally drop down through the hole. At the bottom (outlet) hole, the installer can use a hook or a coat hanger to find the string.

Once you capture the end of the fish tape at the outlet location, tie a pull string to it. Then, pull the fish tape back up to the original location where the cables are tied to the pull string. Finally, pull the pull string down to the outlet location with the cables attached.

Some walls, like concrete or brick walls, will obviously not have the cables run behind them. These types of walls have surface-mounted raceways instead. Before you install cables, you should secure the surface-mounted raceways to the wall following the manufacturer's recommendations. After you pull the cable through to the outlets, you return to the telecommunications room to finish pulling the cable at that end.

Fishing Cable from Below a Wall

When running horizontal cabling in a building that has a basement, fish cable from there to the work areas on the first floor. Do this by following these steps:

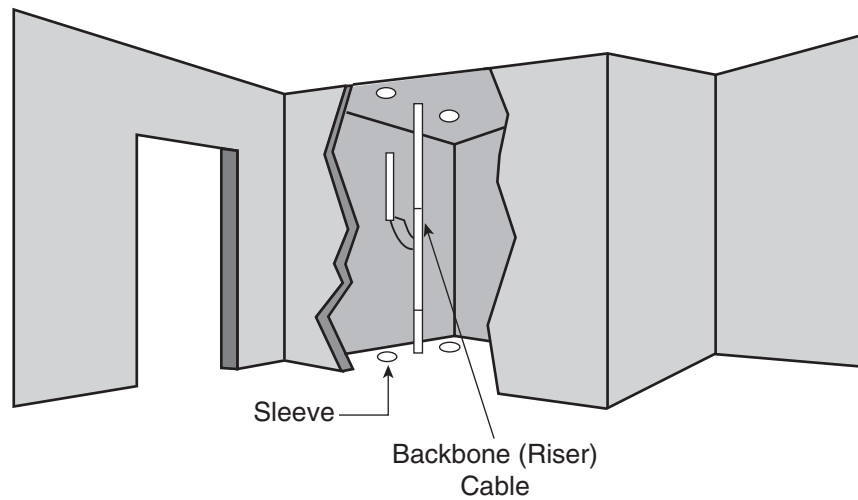
1. Drill a 3.2 mm (1/8 in) hole, at an angle, through the floor next to a baseboard.
2. Push a coat hanger or stiff piece of wire into the hole to indicate the spot in the basement.
3. Go to the basement and locate the wire.
4. Use a tape measure to mark a spot under the area of the wall. This mark should be 57 mm from the hole.
5. Drill a new hole in this spot. This hole should be 19 mm in diameter. Unlike the first hole that you drilled at an angle, drill this hole straight up through the subfloor and wall plate.
6. Push the cable up through this second hole to the wall opening where you want to locate the work-area outlet.
7. Be sure to allow enough excess cable so that it can reach the floor and extend another 60-90 cm (2-3 feet).

Vertical Cable Installation

Pulling cables vertically is quite different from pulling cables horizontally. Vertical cable installation can include network-distribution cables and backbone cables. Although backbone cables can be pulled horizontally, they are considered part of the vertical distribution system. Network-distribution cables, on the other hand, are part of the horizontal distribution system.

Vertical installations generally are done in conduits, in conduit sleeves through the floors, or in slots cut through the floor. A rectangular opening in the floor is called a slot or a pipe chase. Risers are a series of holes in the floor, typically 10 cm (3.9 in.) in diameter, possibly with conduit sleeves installed (see Figure A-33). The conduit sleeves can protrude up to 10 cm (3.9 in.) above and below the floor. Not all risers are stacked perfectly above one another; sometimes they are offset, so riser alignment should be checked before the rough-in phase.

Figure A-33 Typical Riser



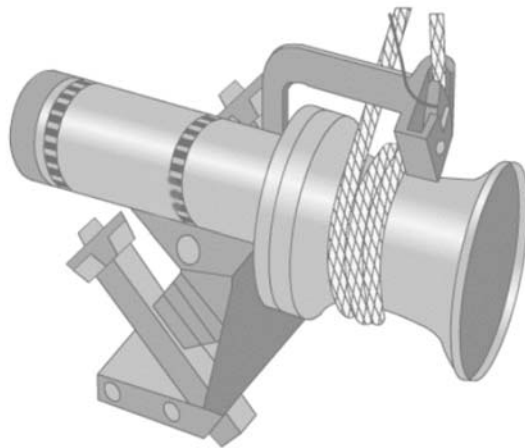
Vertical cable installation takes place either from an upper floor to a lower floor or from a lower floor to an upper floor. In most cases, pulling cables from an upper floor to a lower floor is easier because gravity assists in the effort, and mechanical aids such as winches or cable pullers generally are not needed. Because it is not always possible to bring large reels of cable to upper floors in a building, in some instances vertical cables must be pulled from a lower floor. When pulling upwards, mechanical aids such as winches or cable pullers are generally not needed, but reel brakes are required to prevent a cable free fall.

Cable Winches

Vertical pulls require care when lowering cable so that the cable does not start paying off the reel too fast and falling out of control. A reel brake can help provide added tension.

For lifting cables, a cable winch often is employed (see Figure A-34). Because the equipment used for pulling cable can pose a danger for both cable installers and onlookers, only members of the cable installation crew should be in the area. Pulling large cables with a cable winch creates a great deal of tension on the pulling rope. If this rope were to snap, someone in the area could be injured. Experienced cable installers know that they should avoid being too close to the pull rope under tension.

Figure A-34 Capstan Winch

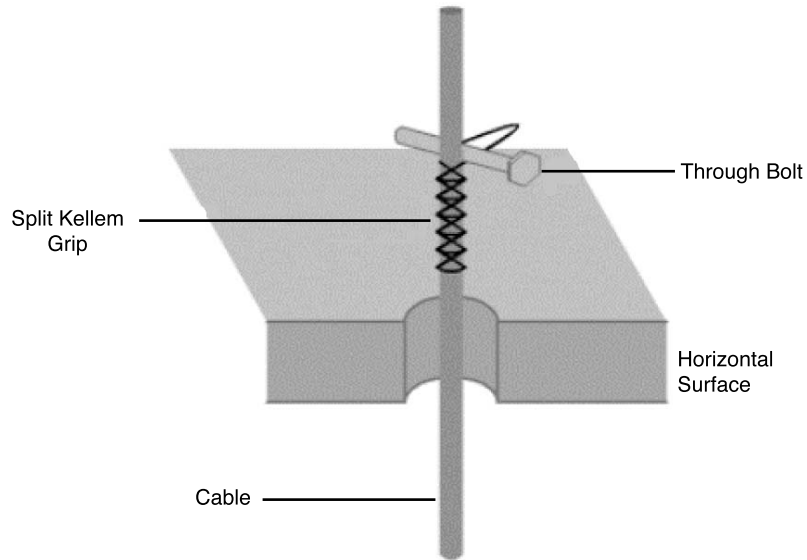


Cables can be ordered from the factory with a pulling eye installed, which is particularly useful for large, heavy pulls. If this is not possible, a Kelllem grip can be used. Again, when the pull begins, it should be a slow steady pull. The pull should not be interrupted unless absolutely necessary. When the cable is pulled into place, the pull rope and winch hold it in place until it is fastened permanently between floors using strut systems, friction clamps, or Kelllem grips secured with bolts (see Figure A-35).

Fastening Vertical Cables

One method for fastening vertical cables is to use a split wire-mesh grip, like a Kelllem grip, and a large bolt that is 25 cm to 30 cm (9.8 in. to 11.8 in.) long. It is important that the grip size be appropriate for the bundle of cables. While the winch or the reel brake supports the cable, a split wire-mesh grip is installed at each floor, and the bolt is installed through the loops in the grip. The cable then is lowered gently until it is supported by the grips. This is a permanent installation.

Figure A-35 Split Kelleem Grip Secured with a Through Bolt



Cable Installation Tips

The following are tips for pulling cable:

- Whenever possible, the staging area should be close to the first 90° bend. It is much easier to pull cable around a bend when it first comes out of the box or off the reel than it is to pull it around a bend near the end of the pull. This is because the installer will be pulling the weight of all the cable pulled up to that point.
- Pulling lubricant should be used for long, difficult pulls to prevent damage to cables.
- Adjust the reel so that cable comes off the top of the reel instead of from beneath it.
- If a fish tape appears to be stuck in a conduit bend, rotate the fish tape a few turns while pushing.
- Pull an additional piece of pull string with the cable. This can be used as a pull string if additional cables are needed later, eliminating the need to use a fish tape through this space again.
- If cable must be coiled on the floor for a secondary pull, coil the cable in a figure-8 configuration to eliminate tangles when uncoiling. Use two safety cones or even buckets as guides for coiling the cable.

- Supporting cables vertically through multiple floors can be a challenge. Run a steel strand or messenger between the floors, and anchor it at both ends. Vertical cable runs can be tie-wrapped to this steel strand for vertical support.

Fire-Stops

The choice of cabling materials and how they are installed can greatly affect how a fire moves through a building, the type of smoke and gasses emitted, and the speed at which the smoke and flames spread. Using plenum-rated cables where required, minimizing penetrations through fire walls, and using proper fire-stopping when penetration is unavoidable can reduce and slow the spread of smoke and flames. It is usually smoke that kills, not flame.

Firewall

A *firewall* is constructed out of special materials and techniques that resist the movement of smoke and gasses from one area to another. Fire-rated walls also limit the spread of flames from the area where a fire originates into areas that are not affected directly. If an area does catch fire, a fire-rated wall slows the spread of flames to new areas. These measures can protect building occupants and firefighters from being exposed to toxic smoke, as well as give them extra time to evacuate the building.

Firewall Penetrations

Sometimes cables must pass through a firewall. This requires making a special opening called a penetration (see Figure A-36).

Figure A-36 Typical Firewall Penetration



Several construction materials are used to construct firewalls. The most common used is likely drywall or sheetrock. When applied floor to ceiling, each layer of this material can resist the spread of flame for roughly a half hour. Two overlapping layers provide protection for twice as long. Other common firewall materials include concrete blocks and poured concrete.

When cable is to be pulled through a firewall, a hole must be drilled through the firewall. This is called a penetration. Penetrations can go all the way through the firewall or can go through one side only. In this case, the penetration is called a membrane penetration.

After the hole is drilled, the penetration usually is sleeved. To do this, a small section of conduit is inserted in the hole. The conduit must be large enough to hold the cables, with extra room for additional cables in the future. This conduit also must protrude 0.3m (11.3 in.) on both sides of the wall. Cables then are pulled through the conduit. After the cables have been pulled through the conduit, the conduit must be sealed with an approved fire-stop material. This prevents fire from spreading from one section of a building to another through the hole in the firewall.

When cables are installed in an existing firewall penetration, the fire-stop material must be removed to clear space for the new cables. After the new cables have been pulled, the hole and conduits should be sealed with new fire-stop material.

Terminating Copper Media

Communications cables are color-coded to identify individual pairs. The color-coding is the same for all telecommunications cables in North America. The use of color codes ensures uniformity in identifying individual cable pairs. Each colored cable pair is associated with a specific number.

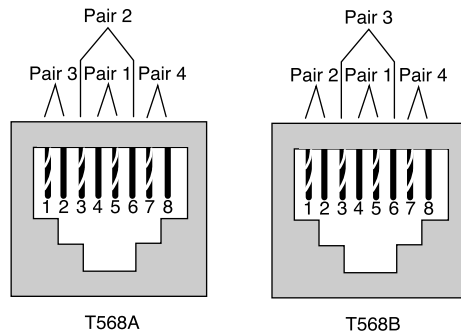
Four-pair Color Code

For most voice and data cabling, UTP cables are used. These cables have four pairs of twisted wires in each cable. The four pair color code is as follows:

- Pair 1—White/blue
- Pair 2—White/orange
- Pair 3—White/green
- Pair 4—White/brown

Pair 1 always appears on positions, or pins, 4 and 5 on an eight-pin jack or plug. Pair 4 always appears on positions, or pins, 7 and 8 on an eight-pin jack or plug. The other pairs have different appearances depending upon the standard (either T568A or T568B) used for the wiring plan (see Figure A-37).

Figure A-37 TIA/EIA T568A and T568B Wiring Schemes



T568A or T568B always should be used for this wiring scheme. A new wiring scheme never should be created because each wire has a specific purpose. If the wiring is not correct, the devices on either end will not be capable of communicating or will experience severely degraded performance.

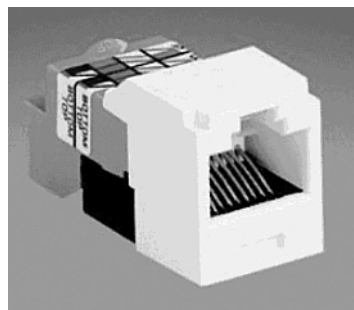
If the installation is in a new building, whether to use either T568A or T568B is likely to be dictated by contract. If the choice is left to the installers, use whatever scheme is most popular in the area. If there is existing wiring in the building that is either T568A or T568B, follow the existing scheme. Remember that every installer on the team must use the same wiring scheme.

Occasionally there is some confusion over pair numbers and pin numbers. A pin is a specific location on a plug or a jack. The colored pairs are always the same. For example, pair 2 is always the white/orange pair. On an RJ-45 jack, however, pair 2 may connect to pins 3 and 6, or to pins 1 and 2, depending on whether T568A or T568B is used.

RJ-45 Plugs and Jacks

RJ-45 jacks are eight conductor jacks that are designed to accept either RJ-45 plugs or RJ-11 plugs (see Figure A-38). Jacks should be wired to the T568A or T568B standards.

Figure A-38 8P8C (RJ-45) Jack



RJ-45 plugs have eight pins that will accommodate up to four pairs of wires. As with RJ-11 plugs and jacks, pair 1 always is terminated on the center pins—in this case, pins 4 and 5. Pair 4 (white/brown) always is terminated on pins 7 and 8. Pairs 2 and 3 might differ depending on the wiring plan. Using T568B, pair 2 (white/orange) terminates on pins 1 and 2. Pair 3 (white/green) terminates on pins 3 and 6. T568A reverses pairs 2 and 3 so that pair 2 terminates on pins 3 and 6, while pair 3 terminates on pins 1 and 2.

A RJ-45 jack terminates one end of the horizontal cable. The other end of the cable typically is terminated on a patch panel with a 110-style connector or a 110-style connecting block.



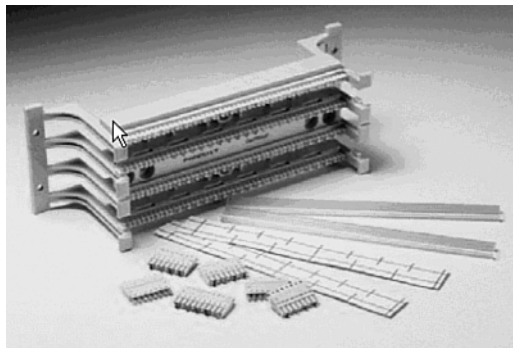
Lab Activity Category 5e Jack Termination

In this lab, you learn the proper safety procedures when using cabling tools, as well as how to use the T568B standard when terminating Category 5e cable on a modular jack at the modular patch panel.

110-Block

110-blocks are high-density termination blocks suitable for either voice or data applications (see Figure A-39). The insulation displacement connection provides a low-resistance gas-tight connection. 110-blocks come in many configurations. Blocks are designed to be stacked in different combinations to accommodate different size requirements. The 110 system includes wire-management troughs that also act as spacers between the blocks. 110-blocks can use a special multipunch tool that can punch down up to five pairs of wire at a time. Care must be taken to avoid using such a tool on patch panels that contain printed circuit boards, however, because the impact could damage the internal wiring.

Figure A-39 110-Block



**Lab Activity** Terminating Category 5e to a 110-Block

In this lab, you learn how to terminate Category 5e cable to a 110-type termination block, as well as how to properly use a 110 punchdown tool and a 110 multipunch tool.

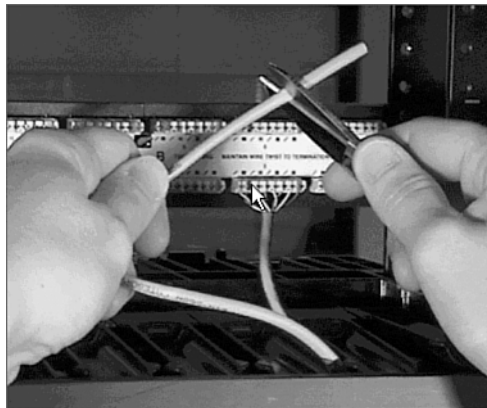
The Trimout Phase

In the rough-in phase of cable installation, excess cable was left at both ends of the cable run. These coils of cable, which are used to take up slack and facilitate later changes, are known as service loops. Service loops are discouraged by EIA/TIA standards. It is not uncommon to have 1m (3 ft.) of ends hanging out of a wall jack at the finish of the rough-in stage. In the telecommunications room (TR), where hundreds of cables are terminated, it is not uncommon to have 2m to 3m (6 ft. to 10 ft.) of ends.

Although this practice appears to be wasteful, experienced installers know that an excess of cable provides more flexibility in cable routing and provides greater access to cables when toning (testing) individual cables. A common mistake of new installers is to cut the cable short. Remember, excess can always be cut off, but a short cable cannot be extended. If a cable is too short, the only alternative is to pull another cable, and this is a costly alternative in terms of labor and time.

If there is 1m (3 ft.) of cable coming out of the wall at the jack location, it is best to cut this back to about 25 cm (9.8 in.). A new label should be applied to the cable about 15 cm (5.9 in.) from the end. The jacket then should be stripped back about 5 cm to 7 cm (2 in. to 2.8 in.), exposing the individual twisted pairs. The completed jack termination should have no more than 1.5 cm (.6 in.) of unjacketed conductor exposed and no more than 1.5 cm (.6 in.) of untwist in the cable pairs. Excess conductor length should be cut off at the final termination (see Figure A-40).

Figure A-40 Cutting Cable to Length



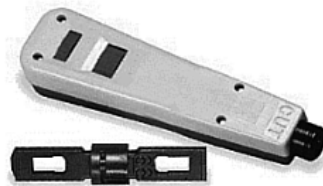
The jack is terminated with approximately 15 cm to 20 cm (6 in. to 8 in.) of cable still protruding from the wall. This excess cable is coiled carefully into the wall or wall box when the jack is installed. This excess cable can be used to reterminate the jack at a later date or enable the removal of the faceplate and the addition of another jack to the outlet. At workstation terminations, it is common for the wires in the jack to lose contact with the pins because the patch cord to the work area often is pulled, kicked, or stretched by the workstation users.

Terminate or Punchdown

The termination of communications cables at a TR is referred to as punching down. Cables also are punched down on termination panels mounted on wall fields and at the rear of cross-connect panels.

Wires are inserted into the appropriate locations on termination panels, and then the punchdown tool is placed over the wires. Depending on the type of termination hardware used, replaceable blades in the termination tool can be changed out to accommodate the termination type (see Figure A-41).

Figure A-41 Removable Termination Blade



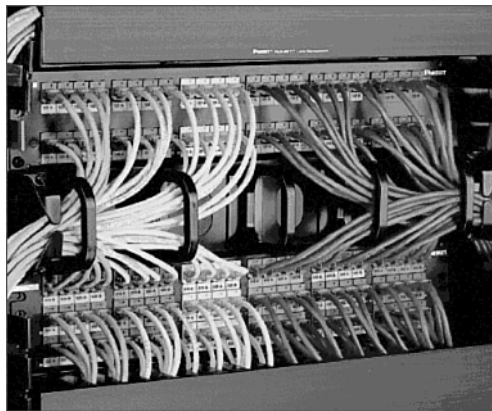
As pressure is exerted on the tool, spring tension increases to a point at which a firing-pin type mechanism releases the energy stored in the spring. The wire instantly is forced between two insulation-displacement connections, and excess wire is cut off in the same operation. The connection is referred to as insulation displacement because the insulation is pushed out of the way by the contacting points on the terminal.

Insulation-displacement connections provide a secure, gas-tight connection, which means that the actual connection is not exposed to the atmosphere because the displaced insulation presses tightly against the block. This is necessary to provide long-term corrosion-free connections. Patch panels typically are used for data networks, as are 110-blocks, which also are used for voice applications.

Wire Management

Some termination systems come with a wire-management scheme built in. 110-blocks use plastic troughs and spacers between blocks. Troughs can be used both horizontally and vertically. Rack-mount installations incorporate a variety of wire-management features (see Figure A-42). Some use a combination of D-rings and troughs.

Figure A-42 Panduit Wire Management



When purchasing cable-management systems, consider the following:

- The system should protect the cable from pinching and should maintain the maximum bend radius.
- The system is scalable, so when more cables are needed, it can handle them.
- The system is flexible, so cables can come into it from all directions.
- The system offers a smooth transition to horizontal pathways so that cable is not damaged or exceeds maximum bend radius.
- The system is durable, so it will last as long as the cables and equipment mounted on it.

Careful Labeling

Labeling is another important part of a structured cabling system. If cables are not labeled clearly on both ends, there can be confusion. TIA/EIA-606 specifies that each hardware termination unit must have some kind of unique identifier. This identifier must be marked on each termination hardware unit or on its label. When identifiers are used at the work area, station terminations must have a label on the faceplate, the housing, or the connector itself. Most Requests For Proposals and specifications require that labels be computer generated so that they are permanent, legible, and more professional in appearance.

Use labels that will remain understandable to someone who might work on the system many years in the future. Many network administrators incorporate room numbers in the label information. They assign letters to each cable that leads to a room. Some labeling systems, particularly those in very large networks, also incorporate color-coding.

To ensure that the labels do not rub off or get cut off (the end) later, mark the cable several times, approximately 60 cm (23.6 in.) apart, at the free end. After the cable is run, repeat the procedure at the box or spool end. To keep all cables tied securely together, use electrical tape. Bind the cable ends with the end of a pull string. Ensure that the pull string does not come loose by tying some half-hitch knots around the cables with the pull string before taping the ends. Do not skimp on the tape. If the string or cables pull out later, it could cost time and money.

After pulling the cable along the selected route, bring it into the TR. Allow enough cable for the ends to reach all the way to each jack location, plus enough excess or slack to reach the floor and extend another 60 cm to 90 cm (23.6 in. to 35.4 in.).

Go back to the spools of cable at the central point or TR. Use the labels on each spool as a reference, and then mark each cable with the appropriate room number and letter. Do not cut the cables unless they have a label. If each of these steps is followed, the networking media used for the horizontal cabling run should be labeled at both ends.

Finish Phase

The finish phase is the point at which installers test and, in some cases, certify their work. Testing makes certain that all the wires route to their appointed destinations. Certification is a statement of the quality of the wiring and connection.

Important aspects of the finish phase include these:

- Cable testing
- Time domain reflectometer (TDR)
- Cable certification and documentation
- Cutting over

Diagnostic tools are important in determining existing and potential problems or flaws in a network cabling installation.

Cable Testing

Cable testers are used to test cables for opens, shorts, split pairs, and other wiring problems. After the cable installer has terminated a cable, the cable should be plugged into the cable tester to verify that the termination was done correctly. If a wire accidentally

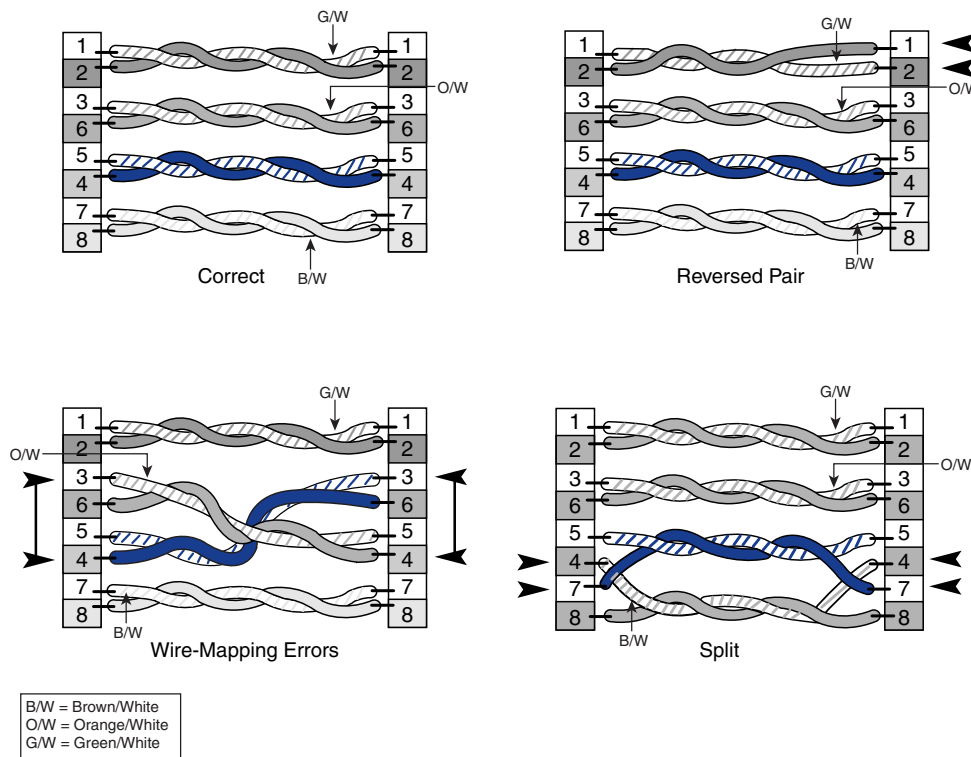
was mapped to the wrong pin, the cable tester will indicate the wiring mistake. Similarly, it can test for problems with the cable, such as shorts or opens. A cable tester should be a part of every cable installer's toolbox. After the cable has been tested for continuity using these cable testers, the cables can be certified by using certification meters.

Testing is the most important step in the finish phase of cable installation. Testing verifies that all wires are working so that the customer does not find that there are problems later. It is better to catch a problem before it becomes a major issue.

Tests relating to cable function are found in TIA/EIA-568-B.1. Common things to test for include the following (see Figure A-43):

- **Opens**—Wires in cables fail to make a continuous path from end to end. This is usually the result of improper termination or breakage. Occasionally it is because of faulty cable.
- **Shorts**—Wires in cables touch each other, shorting the circuit.
- **Split pairs**—Wires are mixed among pairs.
- **Wire-mapping errors**—Wires in a multipair cable do not terminate at the appropriate contacts in the connector at the far end.

Figure A-43 Wiring Faults Caused by Improper Termination

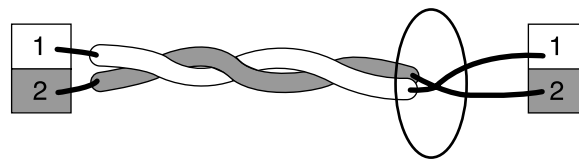


In most cases, simple functional testing for opens, shorts, split pairs, and wire-mapping errors are done from one end of the cable only.

Testing for Shorts

A short is formed when the two wires in a pair touch each other, providing an undesired shortcut in the flow of signal (see Figure A-44). This shortcut is a completion of the circuit before the voltage reaches the intended target.

Figure A-44 Wire Short



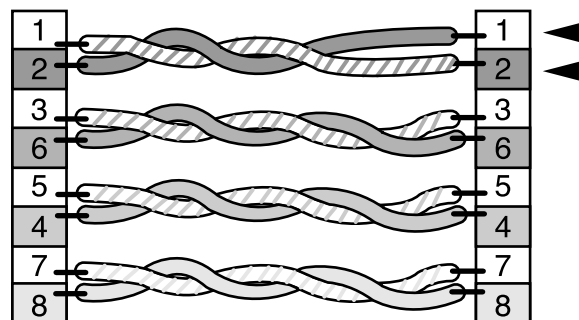
Short = Bare Cables Touch

To determine whether there is a short, measure the continuity or resistance between the wires. No continuity should be measured between them, and there should be an infinite amount of resistance between them. Make these measurements with an ohmmeter using a low-resistance scale. If a higher-resistance scale is used, the installer runs the risk of inadvertently measuring the installer's own body resistance when the wires are held to the probes. Some installers find it useful to create a small test fixture to avoid this problem. Many test probes can be fitted with slip-on alligator clips. They can hold one of the wires that so both leads are not touched at the same time.

Testing for Reversals

A reversal occurs when the tip (or ring) side of a pair is terminated on the ring (or tip) position at the opposite end of the wire (see Figure A-45).

Figure A-45 Reversal

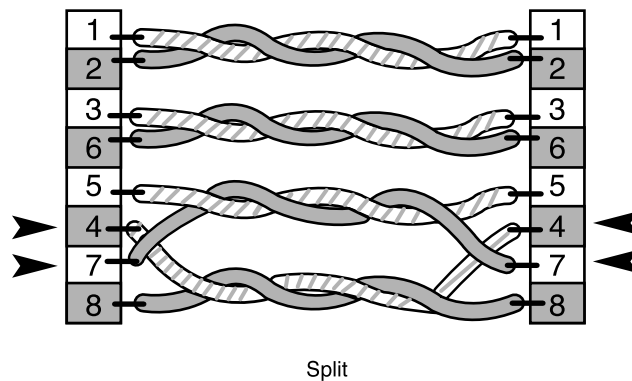


To repair a reversed pair in a cable, the RJ-45 connector must be removed and the cable end with the pair reversal must be terminated again.

Testing for Split Pairs

Split pairs happen when wires are mixed among pairs (see Figure A-46). One way to test for splits is with an ohmmeter. First, test the pairs for shorts. If none is found, place a short across each pair. When it is tested with an ohmmeter, finding a short is the anticipated result. If an open is found, something is wrong. The pair is either split or open. A tone generator then can be used to determine which is the case. Higher-end testers detect split pairs by measuring *crosstalk* between pairs.

Figure A-46 Split Pairs



A simple cable tester can be used to check for split pairs as well. This type of tester uses LEDs that immediately notify the installer if there is a problem with polarity or continuity.

To repair a split, one or both of the connectors must be removed and the cable end must be terminated again.

Time Domain Reflectometer

A *time domain reflectometer (TDR)* works by sending a pulse down the wire and then monitoring the electronic echoes that occur on the cable because of cable problems. TDRs determine whether there is a cable fault and, if so, whether it is an open or short; they also determine the distance from the meter to the fault. The signal is reflected back when it reaches the end of the cable, as well as anytime it encounters a defect in the cable along the way. The speed at which the signal travels is known as the nominal velocity of propagation. This is a known quantity for different cable types. When set,

the tester knows how fast the signal travels and can measure the length of the cable by measuring the amount of time that it takes for the signal to be sent and reflected back. A TDR readout typically is calibrated in feet or meters. This is an extremely efficient means of locating cable problems, although the instrument must be adjusted properly and used with skill.

Cable Certification and Documentation

Testing is not the same as certification. Testing is for functionality—that is, it determines whether the wire can carry the signal from end to end. Certification, or performance testing, is a statement about cable performance. It answers these questions: How well does the signal travel down the cable? Is the signal free from interference? Is the signal of adequate strength at the other end of the cable?

Certification Tester

Certification goes beyond functionality testing. Performance testing also must be done. Structured cabling systems that adhere to installation standards are required to be certified. Certification meters perform all of the required performance tests to adhere to the ANSI/TIA/EIA-568-B standards (see Figure A-47). Meters have an autotest function, so all required tests are performed with the touch of a single button. These tests include near-end crosstalk (NEXT), wire map, impedance, length, DC loop resistance, propagation delay, return loss, delay skew, attenuation, and attenuation-to-crosstalk ratio. These meters hold multiple test results in memory. Test results are downloaded to a computer so that a test report can be generated and presented to the customer. In addition to certification, these meters include diagnostic features that not only identify problems, but also actually show how far these problems are from the end of the cable being tested.

Figure A-47 Fluke Networks 4000 Cable Certification Meter



Performance testing usually takes place at a designated test frequency. The frequency is selected to exercise the cable at a speed that will be part of its intended operation. For example, Category 5e cable is tested at 100 MHz, and Category 6 cable is tested at 250 MHz. Performance testing is described in various addenda to TIA/EIA-568-B. Modern testing hardware and software can provide both text and graphic output. This allows ready comparisons as well as analysis at a glance.

The cable certification process forms a baseline measurement for the cabling system. When the contract is established, the certification standard to which the resulting job must conform usually is included as part of the contract. The installation must meet or exceed the specifications for the wire grade that is being used. Detailed documentation showing that the cabling has reached these standards is submitted to the customer.

The certification procedure is an important step in completing a cabling job. It enables the installer to say unequivocally that at a certain day and time, the cables performed to certain specifications. Any later change in cable performance must be attributable to some cause, and it will be easier to figure out what that cause is if there is hard, fast evidence of the cables' condition at an earlier point. Different grades of cable require different minimum test results to be acceptable. Generally, the higher the cable category is, the tighter the manufacturing tolerances are, the higher the quality is, and the better the performance is.

Certification Tests

To pass certification, cables must meet the minimum test results for their grade. Cables must meet or exceed these specifications. Actual test results that outperform the minimum often are encountered. The difference between the actual test results and the minimum test results is known as headroom. If the results show lots of headroom, less cable maintenance should be needed in the future, and the network should be more tolerant of poor-grade patch cords and equipment cables.

The commonly used specifications include these:

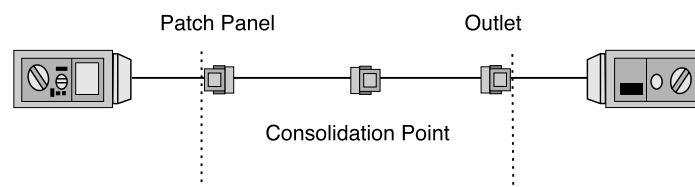
- **Specified frequency range**—Each cable is tested at a frequency range that it is most likely to be used in daily service. The higher the grade is, the higher this range is.
- **Attenuation**—The amount of signal that a cable will absorb is a measure of its attenuation. The lower the attenuation is, the more perfect the conductors are and the higher quality the cable is.
- **Near-end crosstalk (NEXT)**—Near-end crosstalk occurs when signals from one pair interfere with another at the near end of the cable. Crosstalk can affect the capability of the cable to carry data. The amount of NEXT that a cable must be capable of tolerating is specified for each grade.

- **Power Sum NEXT**—In cables in which all the conductors are used (such as Gigabit Ethernet), the signals on one cable interfere with several pairs, not just one. Calculating the effect of these disturbances requires that the interactions of all pairs in the cable be taken into account. The power sum NEXT equation measurement does this.
- **ACR**—The attenuation-to-crosstalk ratio (ACR) is an indication of how much stronger the received signal is when compared to the NEXT or noise on the same cable. Sometimes this measurement is referred to as the signal-to-noise ratio (SNR). Be aware that SNR takes into account external interference as well.
- **Power sum ACR**—When all of the pairs in a cable are used, the interaction between the pairs becomes more complicated. This is because more wires are involved, meaning that there are more mutual interactions. The power sum equations help take this greater mutual disturbance into account.
- **Equal-level far-end crosstalk (ELFEXT)**—Equal-level far-end crosstalk is a calculated measurement of the amount of crosstalk that occurs at the far end of the wire. If this characteristic is high, it means that the cable is not carrying the signals well and that the ACR (signal-to-noise) ratio is not well controlled.
- **Power sum ELFEXT**—As with the other power sum measurements, interaction among multiple pairs in the same cable increase the complexity of equal-level far-end crosstalk characteristics. The power-sum version of the measurements takes this into account.
- **Return loss**—Some of the signal traveling down a wire bounces off imperfections such as impedance mismatches in the wire. It can be reflected back toward the sender and can form a source of interference. This is called return loss.
- **Propagation delay**—The electrical properties of the cable can affect the speed at which signals travel through it. The value of this delay must be known to perform certain measurements, such as time domain reflectometry. Propagation delay for cable usually is specified as a maximum allowable amount of delay, in nanoseconds.
- **Delay skew**—Because each pair in a cable has a different number of twists, signals that enter the cable at the same time are bound to be slightly out-of-sync when they get to the far end. This lagging and leading of signals on adjacent pairs is called delay skew. This problem can be heightened by sloppy termination, in which the cables are asymmetric with respect to the connector pins. Finally, if there is a difference in propagation delay between the wires in a cable pair, it could affect the signal because of delay skew.

Link and Channel Testing

Two methods are used when testing: the channel test and the link test. The channel test goes truly end-to-end from the workstation or telephone to the device in the telecommunications room (TR). The channel test measures all of the cable and patch cords, including the line cord from the jack to the user equipment and the patch cord from the patch panel to the communications equipment. Alternatively, the link test tests only the cable from the wall back to the patch panel. There are two types of link tests, the basic link test and the permanent link test. The basic link test allows no connectors, but the point of measurement starts near the field tester and ends near the field tester remote unit at the other end of the link. The permanent link test excludes the cable portions of the field test units, but includes the mated connection where the cable is connected to the adapter cable at each end (see Figure A-48).

Figure A-48 Permanent Link Test



The permanent link test also allows for a consolidation point, which is desirable for open-office cabling installations and is therefore more practical.

The only accepted test is the permanent link test. The channel test officially has been eliminated by TIA/EIA-568-B.1.

Certification Tips

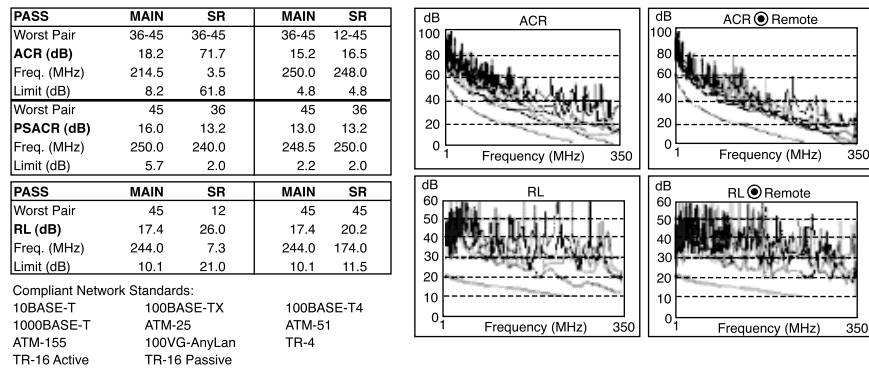
How test results are interpreted is just as important as detecting problems. The best way to learn how to interpret test results is to use test equipment on known good wires and circuits. This will give the installer a knowledge base of how to properly use test equipment and how the test results should appear when the circuits are functioning properly.

To gain experience with troubleshooting and problem identification, create cables with specific problems. Observe how testers react to these problems. Practice identifying these problems based on the results of testers by randomly choosing cables. It will be worth spending the time now to be efficient because the installer will want to be able to quickly determine what is wrong and fix it.

Professional Certification Documentation

Many cable certification tools include the capability to export results in a database format. This can be used in a personal computer to produce high-quality documents (see Figure A-49).

Figure A-49 Cable Certification Documentation



Installation software, generally provided with sophisticated certification testers, enable the contractor to present the test result to the customer in an orderly and presentable manner. The software eliminates the need for entering the results by hand into a spreadsheet. Software packages store test results as either pass or fail. When deficiencies are found and corrected, items are retested and presented to the customer. Customers generally want both an electronic copy of the test results, as well as a paper copy.

Documentation must be accessible to be useful. Electronic delivery ensures that the results are always available to those who might need them. In addition, a paper set of both the as-built documents and the certification results should be provided to the customer, as well as retained in the installer’s permanent records.

When a cabling system undergoes certification testing, the test results should be collected to create the as-built documents. Certification documentation can become important to an installer if there is a question about the quality or accuracy of the wiring job. It shows that on a certain date, the wires existed in a particular order and could carry signals at a particular quality. Changes over time that affect the cable’s capability to move signals can be illustrated by comparing current tests to previous ones.

Because of unexpected obstacles, change orders, and last-minute equipment upgrades, there is a possibility that the network wiring system documentation that was used to construct a facility wiring system is not representative of the system that actually was constructed. Anytime someone is asked to make a modification to the wiring system, it

is imperative to know what really is going on in the system. Otherwise, making changes could have unpredictable effects. As-built documents can help avoid this kind of trouble. Always create change documents before actually making any changes.

Cutting Over

Cutting over is the term used when transferring existing services to a new cable system or when installing new equipment on a newly installed cable system.

Cutover Guidelines

Good cutovers require careful planning, organization, and meticulous attention to detail. When cutting over, follow these guidelines to ensure success:

- Keep detailed records of the installation. Such records will verify that all cables have been installed and that they were installed in the correct location.
- Test every cable that is installed.
- Develop accurate cut sheets, charts of circuits and the cable or circuit on which they operate. The installation supervisor normally develops cut sheets with information received by the customer.
- Schedule the cutover when it inconveniences the customer the least. Because cutovers usually require taking some systems offline, they often are scheduled late at night or on weekends.

Removing Abandoned Cable

When the National Electrical Code, edition 2002, is used, all abandoned cables must be removed when certain criteria defined within the code is met. Currently, this is a decision that is made by the customer and the cable installation contractor regarding whether the cost involved in removing cables is justified. The customer and the contractor must be sure to adhere to local code. Always check with the local authority and discuss the details with the customer before beginning the retrofit.

Before removing any abandoned cable, verify that no live circuits are on the cable. This is accomplished by checking with the customer and then verifying with either a multimeter or a telephone test set. Care must be taken not to damage ceiling tiles or dropped ceiling-support members when removing abandoned cable.

The Cabling Business

The cabling business requires its share of attention, as does the business side of any other enterprise. Before cables can be installed, there must be a bid. Before there can be a bid, there must be a request for a proposal and walkthroughs to determine the precise scope of the work. Documentation both to describe the project and to show how it was actually built might be required. Licenses might be required to perform the work, as well as perhaps union membership. All projects must be performed in a timely manner, with minimal waste of time or materials. This is usually a job for project planning, using program-management applications.

Topics of particular importance in the cabling business listed are these:

- Site survey
- Labor situations
- Contract revision and signing
- Project planning
- Final documentation

As with most jobs, a cable installer's appearance and demeanor can have an affect on how he is perceived by customers, bosses, and fellow employees. The choices that a cable installer makes on the job can affect whether he is promoted or even terminated. As an employee of a company, the cable installer represents that company on a job. His appearance and conduct reflects on the company. Therefore, you should always maintain a professional appearance and demeanor.

When working on a job, follow these guidelines:

- Respect the job site. Be careful not to cause damage or discard trash. Clean up all messes immediately if they affect another person, or clean them up at the end of the day.
- Come to the job site wearing clean, neat work clothes.
- Show up to a job at the agreed upon time. Punctuality is important.
- Be considerate of noise. If working on a retrofit project where business still is being conducted, avoid playing music, whistling, singing, or shouting.
- Treat customers, building occupants, co-workers, and bosses with respect.

Site Survey

The site survey, or project walk-through, is one of the most important events before preparing a cost estimate for the project. It gives the contractor the opportunity to see any issues that might impact the installation. Drawings and specifications supplied by the customer might not indicate problems or complications.

It is advisable to create a sketch of the project while conducting the walk-through. The sketch will be useful for identifying problem areas when it becomes time to actually perform the estimate.

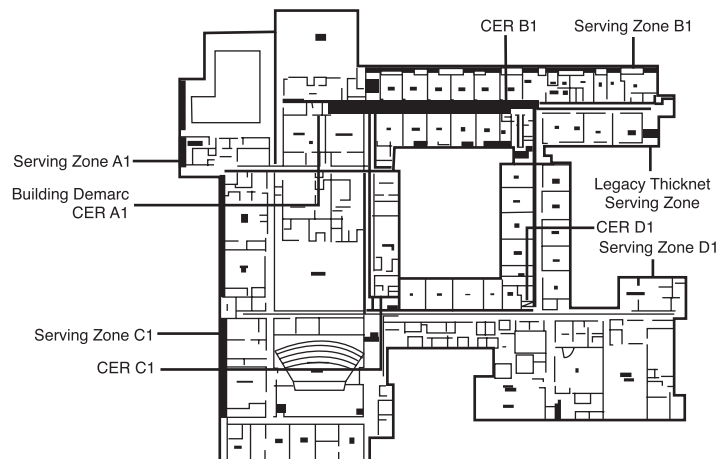
A number of key questions should be asked on a site survey:

- Are there plenum ceiling areas?
- Is there a staging and storage area for materials?
- Are special work hours required?
- Are there special safety requirements? (This is particularly relevant in factory environments.)
- Which walls are firewalls?
- Is there asbestos in the building?
- Will the customer supply spare ceiling tiles in the event of breakage?
- Are there special labor issues to be considered?

Requirements Documents

The *blueprints*, which are scaled drawings, provide distance information required for determining the length of cable runs (see Figure A-50). Blueprints also should show service outlet locations and TRs. They will not always show available paths or routing information. Routing information generally is gathered through the site survey. Most structured wiring systems define a minimum of two four-pair cables per location, while many customers specify more. This information should be duplicated in the specifications for the project.

Figure A-50 Typical Building Blueprints

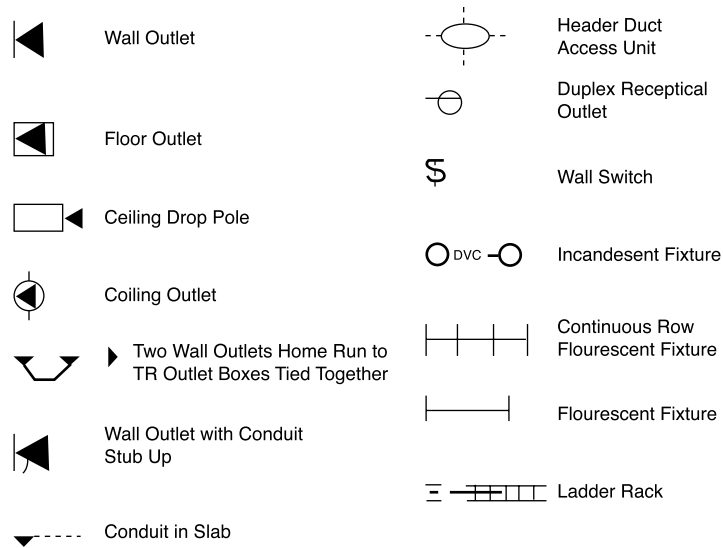


Counting outlet locations and measuring cable distances on a blueprint are referred to as doing take-offs. Doing take-offs requires a great degree of accuracy because this gives the material requirements for the bid. Automated measuring devices are available to help minimize the chance for error.

Installation Icons and Symbols

Standard icons and symbols are used on blueprints and schematics to identify cable runs, different types of raceways, and information about outlets and jacks (see Figure A-51). They provide a uniform method of graphically identifying requirements on a blueprint.

Figure A-51 Cabling Installation Icons



Drawing Types

Construction blueprints follow a standardized format. Drawings are grouped according to category. Drawings are labeled with a prefix that associates the drawings with the category. For example, all drawings that have to do with the electrical system are grouped together and have the prefix *E* for electrical. Architectural sections begin with *A*, plumbing begins with *P*, and so on. Telephone and data usually are grouped together and are represented on the *T* drawings, as follows:

- **T0**—Campus or site plans: exterior pathways and interbuilding backbones
- **T1**—Layout of complete building per floor: serving zone boundaries, backbone, and horizontal pathways

- T2—Serving zone drawings: drop locations and cable labels
- T3—Communication equipment rooms: plan views of racks and elevations of walls
- T4—Typical detail drawings: faceplate labeling, fire-stops, and safety features
- T5—Schedules (cabling and equipment spreadsheets) for cutovers

There may be additional drawings, such as furniture plans. Furniture plans are found in either the A drawings or in a miscellaneous category.

Drawings that the estimator will require include the following:

- A site plan, to get an overview of the project
- Floor plans
- T drawings (telephone)
- E drawings (electrical), for reference
- Furniture plans to help determine outlet placement
- A drawings (architectural), for assistance with available pathways

Design documents provide a narrative describing the project. This might include a description of the functionality of the cabling system to be installed. It might include a statement such as “the system must support 1000BASE-T (Gigabit Ethernet on twisted pair).”

Design documents also usually include trade jargon and acronyms unique to an industry or the system to be installed. The estimator should have a good understanding of all terms in the design document. Glossaries of terms and acronyms are available. The Building Industry Consultants Service International (BICSI) website includes a glossary of such terms and acronyms.

Design documents specify the requirements of the system and the types of materials to be used. Information on the number of cables required per information outlet or jack is supplied in the design document. Design documents also describe testing specifications and labeling specifications and formats.

Schematic Diagrams

Schematic drawings are not to scale. They are used to depict connectivity—that is, the way things are connected. A typical schematic shows the main TR or main cross-connect (MC) and the intermediate cross-connect (IC). It shows the type and size of cables between these points. It generally does not detail the actual terminations at these locations, and it does not show individual cable runs to information outlets or jacks. It shows cable runs to specific pieces of equipment, such as servers or other major components that are used in the project.

Labor Situations

Every cable-installation company must deal with labor issues. Some of these issues can cause problems with unions. The installation company must be aware of the rules and regulations that cover things such as unions and licensing.

Unions

Some projects require the use of union labor. Unions are organizations that represent workers. Although the use of union labor is more common on new-construction projects, it is not limited to new construction. The use of union labor might be part of the contract. If the customer clearly states that union labor must be used, the contractor must use union labor.

Other labor situations dictate the job classification and the work that is allowed. In a union environment, supervisors normally are not allowed to perform installation work of any kind. Likewise, cable installers are not allowed to install raceway. Sometimes, cable installers can install raceway up to a certain size or a certain length; an electrician must install anything beyond that. These rules are defined by a union agreement and often are determined by an agreement between unions of different trades.

Contractor's Licenses

Not all countries or even all states require contractors to be licensed. In the United States, contractor license rules vary from state to state. Some states require the contractor show that he is licensed by displaying the license number on all advertising, business cards, and letterhead. Contractors that operate without a license in a place where a license is required can be fined for doing so. They also can lose certain rights, such as the right to file a lien if the customer does not pay for services rendered.

The requirements for a contractor to become licensed include technical knowledge, business knowledge, and knowledge of the labor laws of the state. It is the contractor's responsibility to know whether he must be licensed in a particular state or country.

Contract Revision and Signing

When all the negotiations are complete, the contract must be revised to reflect the changes that both parties agreed to. Both parties still must review the contract in detail. Contract negotiation is a verbal event in which both parties must ensure that their intentions accurately are represented in the written document. Changes to the contract that occur as the project progresses often are addressed in amendments to the contract. Amendments are agreed to by both parties and signed by both parties.

Responsible and authorized parties from the customer's organization and the contractor's organization must sign the contract before it is a valid agreement. When both parties have signed the contract, the commitment is made. No materials should be ordered and no work should commence before the contract is signed.

Common documents such as change orders can be created in advance as a template and simply filled in with the correct information. These templates can be taken along to the project site and filled out during the initial meeting or at the different walkthroughs.

Any changes to a project after it has been started should be made by written change order only. No changes to the original plan should be started by verbal instructions only; the contractor should have change order forms. The project manager should have these forms on the job site. Change orders that result in extra work should include the cost of the extra labor and materials, whenever possible. If this is not possible, the change order should include a statement that the customer agrees to pay for extra work.

Project Planning

The planning phase of a project actually begins after a project is awarded and before a formal contract is signed. Bidding and estimating information is assembled, special requirements are noted, resource allocations are made, and a final review of the RFP takes place to make sure that all the components will be addressed.

The following are all steps that should be taken in this planning phase:

- Step 1** The first step in planning a cabling project is selecting the project manager or supervisor.
- Step 2** Crews must be selected based on the size of the project, number of hours for completion, skills required, and time allowed for completion.
- Step 3** Subcontractors must be identified and scheduled.
- Step 4** Material delivery schedules must be made.
- Step 5** Provisions for waste disposal must be made.

Suppliers

The estimator normally selects suppliers on the basis of cost, delivery, and service. The estimator uses the following questions to determine the total cost of material:

- Does the supplier's pricing include shipping?
- Does the supplier have a history of delivering goods at the time promised?
- What is the supplier's policy on returned goods?
- Can the supplier provide cut sheets and engineering drawings in a timely manner?
- Can the supplier provide technical advice and support?

Ordering Materials

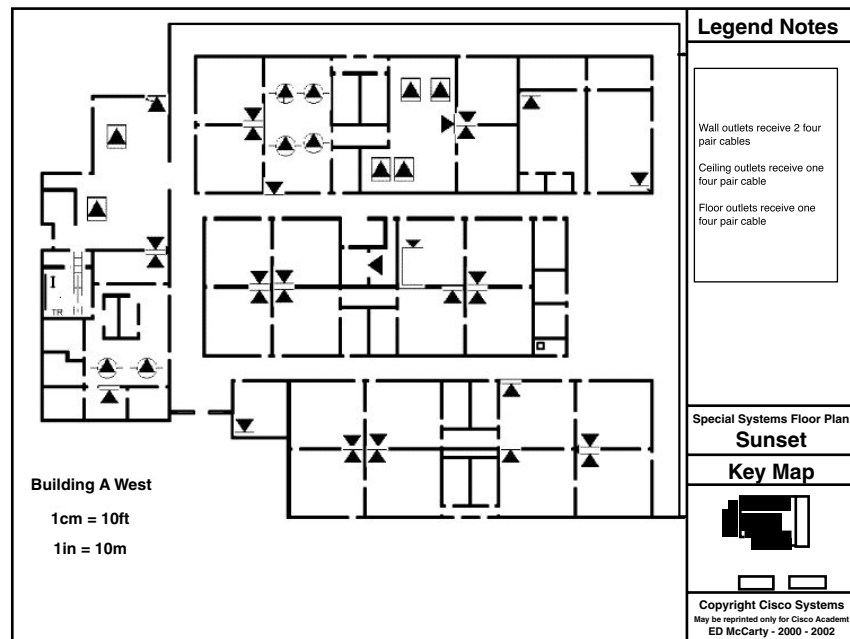
After the contract is signed, written purchase orders should be used to order materials from suppliers. Purchase orders should include the description of the material, the manufacturer's part number, quantity, price, delivery date, and delivery location.

Generally, the lowest-cost supplier that can provide the specified cable and equipment in the quantities that are required is the supplier to select. Shipping costs must be considered when evaluating the lowest cost. Supplier pricing should include a guarantee that the pricing will be firm for a specified period of time. Generally, suppliers guarantee pricing for at least 30 days. The supervisor or lead contractor must take care that no unapproved substitutions are made in an effort to reduce cost.

Final Documentation

Providing as-built drawings to the customer is one of the most important parts of completing a cabling project. The drawings show cable routes, termination points, and cable types as they actually were installed. In most cases, some cables are not installed as originally planned because obstructions or problems were encountered. Typical changes include adding or deleting cable runs or outlets, or routing cables by a different path. The as-built drawings give the customer a diagram of the work that actually was performed (see Figure A-52).

Figure A-52 As-Built Drawings



As-built drawings are not created until all cables are placed, all jacks are installed, and all cables are terminated. Drawing can begin while final testing is taking place, but assurances must be made that no changes or additional work is done that is not reflected accurately in the drawings.

Floor plans, furniture plans, or T drawings usually are used as the basis for as-built drawings. The contractor is not required to redraw the building plans for the as-built drawings. The contractor draws all cable runs, terminations, and outlets, and supplies all labeling information as it was installed.

The punch list is the checklist that the customer provides the contractor with when the contractor considers the project complete (see Figure A-53).

Figure A-53 Typical Punch List

Punch List

A punch list is a record of all items within a project that the contractor must correct or complete to the satisfaction of the homeowner before the job is considered finalized.

Prior to the project closeout and final payments, homeowner and contractor or architect should jointly conduct a project walk-through to observe all items that need correcting or completing.

All parties understand that when the homeowner agrees that the punch list details itemized below have been completed to his or her satisfaction, the project is entirely complete and all outstanding payments are due to the contractor and/or architect.

Punch List Items	Date	Approved

The punch list is a list containing items that were not completed (missing outlets or cable runs, for example), items that were completed unsatisfactorily (cables not fastened to ladder racks or outlets that do not work, for example), or cleanup items (debris left in corridor, for example) that the customer requires corrected before approval for final payment. The punch list can take the form of the customer's final acceptance of the project. When the items on the punch list are completed to the customer's satisfaction, payment is expected.

Case Study: FARB Software Development, Ltd.: Network Design and Implementation

Lab exercises give you the opportunity to practice the manual skills portion of structured cabling installation. The case study is designed to give you a hands-on opportunity to participate in the design of a structured cabling system for a fictitious software-development company that is occupying a new three-story building and requires it to be built out.

Overview

To complete this case study, you should be able to

- Gather information for the preinstallation process and lay plans for the installation process
- Create documentation as would be required for creating a real network
- Comply with TIA, EIA, and electrical standards

Using this supplement, as well as having mastered the CCNA 3 curriculum, will prepare you to complete many tasks related to real-world network creation. These objectives are spelled out within this case study in a letter from Cheryl Farb, president of FARB Software Development, Ltd., who, for this case study, is serving as the client company.

The following are some review items that will help you to focus on the case study.

General Design Process Framework

Network design is best done by following a framework. Determining where the wires go requires knowledge of the structure of the networks. You will need to know where the users are and what their applications are before you can begin to sketch out a viable network. A Layer 1 LAN logical and physical topology must be developed. This development includes the type of cable and the physical (wiring) topology that are selected, as well as the physical placement of infrastructure connection points on the network.

A Layer 2 segmentation plan must be overlaid on the previously created Layer 1 topology. This layer plan includes devices added to the topology to improve its efficiency and functionality. Examples of these devices might be switches and bridges. This layer also includes the use of technologies such as microsegmentation, virtual LANs (VLANs), and the Spanning Tree Protocol (STP), to add efficiency and reliability.

A Layer 3 hierarchical plan then is overlaid on both of the previous two layers. This plan includes adding Layer 3 devices that will provide intranetwork and internetwork functionality to the network, as well as creating a network address plan. Layer 3 is

where routing and firewalls are implemented, imposing a logical structure on the network. They also can be used for segmentation of both collision and broadcast domains.

An extension of the Layer 3 plan might be considered a Layer 4 plan. This plan could be laid over the first three; it moves strictly to software and controls access and availability of the network. It involves access lists and firewall configuration. Although a complete network design keeps moving up the OSI model, it is beyond the focus of this project.

This design focuses on Ethernet, IP, Layer 1, Layer 2, and Layer 3, which is the focus of this curriculum. The design process logically flows up the layers of the OSI model.

That said, it is important to remind ourselves of one of the purposes of structured cabling. The cabling system must be able to withstand change and growth over its life of service. Odds are good that most companies will be in different quarters by the time their structured cabling system is worn out. This means that care must be taken to not follow the current network layout so closely that the cables are not good for any other organization that may follow. An appropriate structured cabling system may be said to fit the network today, but accommodate easily the network of tomorrow.

The most important—and, many times, the most neglected—part of network design and operation is the documentation. The main focus of this project is the documentation of the network design. Documentation for this project should include wiring maps, addressing schemes, any brainstormed ideas, problem-solving matrices, and any other notes made while making these determinations.

Pre-design Process

Before a network can be designed, the data needed to design the network must be gathered. For a network to be effective and serve the needs of its users, this data should be gathered according to a systematic series of preplanned steps. These steps provide a guide to completely discover the data needed to create the network.

The first step in the process is to gather information about the organization. This information should include the following:

- Organization history and current status
- Projected growth
- Operating policies and management procedures
- Building diagrams (blueprints)
- Existing network diagrams and documentation
- Office systems and procedures
- Viewpoints of the people who will be using the LAN

In the information packet that follows this section, you will find communications from the president outlining FARB Software Development, Ltd. This document exists at FARB Software Development LTD.doc.

In this letter, Farb indicates her specific requirements for this project.

The second step is to make a detailed analysis and assessment of the current and projected requirements gathered in the first step. This step identifies and defines issues or problems that need to be addressed (for example, a remote room in the building might not have network access). It also provides information about future network expansion needs, access, and security.

The third step is to identify the resources and constraints of the organization. Organization resources that can affect the implementation of a new LAN system fall into the categories of hardware, software, and human resources. If this were a network expansion or upgrade, existing computer hardware and software would have to be documented. Identification and definition of those projected needs also must be done. The answers to some of these questions also will help determine how much training will be required and how many people will be needed to support the LAN. The questions asked should include the following:

- What are the financial resources of the organization?
- How are these resources currently linked and shared?
- How many people will be using the network?
- What are the computer skill levels of the network users?
- What are the attitudes toward computers and computer applications?

Following these steps, documenting the information in the framework of a formal report will help estimate costs and develop a budget for the implementation of a LAN.

Design Methodology and Deliverables

With the material that has been presented to this point, a strong foundation and understanding should have been developed for the concepts of a layered communications model. Using the OSI model as the framework, an understanding of the functions and devices that support operations at those layers also should have been gained.

To perform this case study, material related to the physical design and installation of a network must be learned. As was presented in previous material, rules and standards govern how a network is designed and built. These rules and standards must be learned before the actual case study can be performed.

Students completing this lesson should be able to

- Develop a Layer 1 and 2 topology
- Gather information for both the preprocess and the process
- Create documentation during the course of the process
- Comply with TIA, EIA, and electrical standards

Note that this aligns with Farb's requests for her company's project.

Standards Organizations

When designing and building networks, it is necessary to ensure compliance with all applicable fire codes, building codes, and safety standards. Perhaps the most important part of the network-design process is designing according to the EIA/TIA and ISO/IEC industry standards. The focus in this curriculum is on the standards for networking media that have been developed and issued by the following groups:

- **ISO**—International Organization for Standardization (not an acronym—see glossary)
- **IEEE**—Institute of Electrical and Electronics Engineers
- **UL**—Underwriters Laboratories
- **EIA**—Electronic Industries Alliance
- **TIA**—Telecommunications Industry Association

The latter two organizations jointly issue a list of standards called the TIA/EIA standards. In addition to these organizations, local, state, county, and national government agencies issue specifications and requirements that can impact the type of cabling that can be used in a local-area network.

It is also important to understand that these standards are being reviewed constantly and are updated periodically to reflect new technologies and the ever-increasing requirements of voice and data networks. Just as new technologies are added to the standards, others are dropped or phased out. In many cases, a network might include technologies that are no longer a part of the current standard or that are being eliminated. Typically, this does not require an immediate changeover, but these older, slower technologies eventually are replaced in favor of faster ones.

Standards Definitions

The primary standards that will affect layer design have been created by the TIA/EIA. The Telecommunications Industry Association (TIA) and the Electronic Industries Alliance (EIA) are trade associations that jointly develop and publish a series of standards

covering structured voice and data wiring for LANs. These industry standards evolved after the U.S. telephone industry deregulation in 1984, which transferred responsibility for on-premises cabling to the building owner. Before that, AT&T used proprietary cables and systems.

Both the TIA and the EIA are accredited by the American National Standards Institute (ANSI, section 6.2.7) to develop voluntary industry standards for a wide variety of telecommunications products. This means that many standards often are labeled ANSI/TIA/EIA. The various committees and subcommittees of TIA/EIA develop standards for fiber optics, user premises equipment, network equipment, wireless communications, and satellite communications.

TIA/EIA 568-A is the Commercial Building Standard for Telecommunications Wiring. The standard specifies minimum requirements for telecommunications cabling, recommended topology and distance limits, media and connecting hardware performance specifications, and connector and pin assignments. Several supplements cover some of the newer, faster copper media. This standard has been replaced by TIA/EIA-568-B.

TIA/EIA-568-B is the Cabling Standard. This standard specifies the component and transmission requirements for media. TIA/EIA-568-B.1 specifies a generic telecommunications cabling system for commercial buildings that will support a multiproduct, multivendor environment. TIA/EIA-568-B.1.1 is an addendum that applies to four-pair unshielded twisted-pair (UTP) and four-pair screened twisted-pair (ScTP) patch cables' bend radius. TIA/EIA-568-B.2 specifies cabling components, transmission, system models, and the measurement procedures needed for verification of twisted-pair cabling. TIA/EIA-568-B.3 specifies the component and transmission requirements for an optical-fiber cabling system.

TIA/EIA 569-A is the Commercial Building Standard for Telecommunications Pathways and Spaces. The standard specifies design and construction practices within and between buildings that are in support of telecommunications media and equipment. Specific standards are given for rooms or areas and pathways into and through which telecommunications equipment and media are installed.

TIA/EIA-606 is the Administration Standard for the Telecommunications Infrastructure of Commercial Buildings, including cable-labeling standards. The standard specifies that each hardware-termination unit must have some kind of unique identifier. This identifier must be marked on each termination hardware unit or on its label. When identifiers are used at the work area, station terminations must have a label on the faceplate, the housing, or the connector itself. All labels must meet legibility, defacement, and adhesion requirements as specified in UL969.

TIA/EIA-607 is the standard for Commercial Building Grounding and Bonding Requirements for Telecommunications. It supports a multivendor, multiproduct environment, as well as the grounding practices for various systems that might be installed on customer premises. The standard specifies the exact interface points between the building grounding systems and the telecommunications equipment grounding configuration, and specifies building grounding configurations needed to support this equipment.

More Information

For more information on the various TIA/EIA standards codes, visit www.rvcomp.com/wiring/EIA/organizations_codes.htm.

Electrical Safety

Generally, electrical current follows the path of least resistance. Because metals such as copper provide little resistance, they frequently are used as conductors for electrical current. Materials such as glass, rubber, and plastic provide more resistance and do not make good electrical conductors. Instead, these materials frequently are used as insulators. They are used to insulate conductors to prevent shock, fires, and short circuits.

Many different shapes of electrical outlets exist throughout the world. Two of the three connection points provide the power circuit. The third connector protects people and equipment from shocks and short circuits. This connector is called the safety ground connection. In electrical equipment where this is used, the safety ground wire is connected to any exposed metal part of the equipment. If there is a wiring fault inside of the device, the ground connection protects people from exposure to hazardous voltages.

An accidental connection between the hot wire and the chassis is an example of a wiring fault that could occur in a network device. If such a fault were to occur, the safety ground wire connected to the device would serve as a low-resistance path to the earth ground. The safety ground connection provides a lower resistance path than the human body, thus reducing the risk of shock or electrocution.

When properly installed, the low-resistance path, provided by the safety ground wire, offers sufficiently low resistance and current carrying capacity to prevent the buildup of hazardously high voltages. The circuit links directly to the hot connection to the earth.

Telecommunications Room Requirements

Layer 1 design is the largest component of the total network design. It involves the implementation of the preliminary designs gathered in the preprocess phase of the network design to create the structured cabling system. This includes, but is not limited to, creating the logical topology, creating the wiring map, selecting wiring closets, and

selecting cable. This design must conform to the appropriate standards organization's rules for design.

Students completing this lesson should be able to:

- List location and design requirements for telecommunications rooms
- Explain cable-management design and specification
- List considerations for selecting and installing equipment racks
- Explain key environmental, safety, and power considerations in telecommunications room location, design, and installation

Work-Area Cabling

Work-area cabling extends from the telecommunications outlet in a room to the user workstation. Work-area cabling is designed to be relatively simple to interconnect so that it can be moved or changed relatively easily. Each work area serves a maximum of 10m² of usable floor space.

Work-area equipment includes the following components:

- Workstation equipment, such as computers, data terminals, telephones, fax machines, and printers
- Cables, such as patch cables, modular cords, PC adapter cables, and fiber jumpers
- Adapters external to the telecommunications outlet

The TIA/EIA-568-B standard requires a minimum of two telecommunication outlets for each individual work area. The first outlet must be a four-pair, 100 Ω unshielded twisted pair (UTP) or screened twisted pair (ScTP) cable and connector. Category 5e is recommended for this outlet. The standard allows three choices for the second outlet:

- Four-pair, 100 Ω UTP or ScTP cable and connector (Category 5e recommended)
- Two-fiber 62.5/125 μm or 50/125 μm optical fiber and connector
- 150 Ω shielded twisted-pair (STP) cable and connector (not recommended for new installations)

Network Applications at FARB

Estimating the amount of traffic that the network will carry requires you to understand the nature of the traffic. Database transfers seem to take a lot of bandwidth, as does videoconferencing. Web applications are often gentle on bandwidth, with the exception of streaming audio and video applications.

The IT staff at FARB has accumulated a list of software applications frequently used by the staff. This is broken out by which group of users uses which application.

You can find the information about FARB and software requirement list in the Case Study Materials section on the CD-ROM that accompanies this book.

Where Does It All Go?

FARB has not progressed in its planning to the point that you have been told which users get what seats, nor even which department gets which area of the building. You have been handed some fairly developed blueprints from which to begin your efforts. They are entirely adequate for locating the telecommunications rooms in the project.

You can find these drawings for desk assignments, plumbing and HVAC, rooms, and electric telephone and lighting, along with the building plan legend, roof cross-section end view and side view, in the Case Study Materials section on the CD-ROM that accompanies this book.

As is often the case, not all the information that you need is on any one drawing. Furthermore, some of the drawings seem to be not useful to your requirements. Nevertheless, they are a good start toward designing a network to meet FARB's requirements.

Note that there is no indication of where the TRs should go, with the exception of the entrance facility, marked Point of Presence, on the ground floor. There is no indication of which areas of the building are to be occupied by which department. Consult the teacher or lab instructor of for this information.

The following section contains hints that should help students work out some of these issues.

Structured Cabling Case Study Hints

This case study will give you experience in practicing your networking and cabling skills. As you work through the study, your goal is to design the network layout for FARB Software Development, Ltd. You will reach this goal by performing several tasks involved in understanding the request for information and in deriving that information from the drawings.

Four layers of documentation are involved:

1. A file that specifies President Cheryl Farb's idea for the network facility in the proposed new FARB building.
2. A requirements document that has been worked up by the internal IP staff, of which you are a part. This lists what must be connected where.
3. Several sets of drawings of each of the four floors of the building.

4. Some detail drawings to give you some idea of the methods of construction to be used. This will help you make decisions about cable routing.

Take your time as you work through this case study. You will find that much of the value will come from trying several different approaches. Discussion with class members and teammates might help solidify your understanding of the important topics that this case study brings forward.

Instructions:

Locate the letter to the internal support team from President Cheryl Farb. This document shows ten items on which your ideas and input are requested. The last part of the letter includes a forecast of the company growth.

Here are the ten items (some of them have several steps):

1. Recommendations of network equipment
2. Recommendations of network cabling
3. Any construction requirements
4. Network equipment locations
5. A wiring plan that includes the following:
 - A horizontal and vertical logical layout
 - A horizontal and vertical physical cabling layout
 - A cabling plan for the server room
 - Layouts of all MDFs and IDFs
 - Work-area cable outlet identification plan
6. Security and fire prevention recommendations for server room, MDF, and IDFs
7. Electrical protection for equipment
8. An IP addressing scheme for all devices on the network
9. A cost projection for the implementation of the network, including the following:
 - Equipment purchase costs
 - Cabling and testing costs
 - Equipment installation costs
 - Training and support costs
10. A timeline for the implementation of the network

Following is a study guide that contains hints to help you complete these tasks.

Hints

You can find the answers to these questions at the conclusion of Appendix C, “Check Your Understanding Answer Key.”

Recommendations for network equipment

Look at page 1 of FloorPlan1-Desk-Assignments-building floor1 (ground floor)

Work through the following questions:

What is the purpose of this floor?

What door will workers move freight through?

What doors will visitors come in?

Where are visitors most likely to go after they sign in?

Where would you consider using wireless technology?

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If your department someday is tasked with wiring IP security cameras, what areas would you want to keep under surveillance?

From where does the telephone company serve this building?

What kind of lock should it have?

Would the POP be a good place for the servers?

If it is determined that the server room must exist separate from the POP, what considerations should guide its location?

Could you install the risers in the POP?

Where might you install the risers?

The horizontal cabling always should go parallel to walls. Getting to Room 1.2 while staying parallel to walls makes a cable run of how many meters? Is this useable?

Floor 2

Floor 2 is dense with offices. It also contains the bottom floor of an auditorium. Not only would the auditorium be a possible candidate for wireless, but it also might affect the routing of wires because it extends several floors in height.

Where might you put the telecommunications room on Floor 2? You might consider using two of them.

Floor 3

Floor 3 has large unplanned spaces in Rooms 3.1 and 3.2. If you place the telecommunications room in Room 3.10, how can you serve these spaces, especially the far side of Room 3.2?

Floor 4

You notice a large deck on Floor 4, as well as a banquet area with a piano. What would you need to provide network connectivity to this area?

Where will you put the TR?

You are now prepared to go to work. Count up the number of desks that would be served by each of these telecommunications rooms. Multiply by two outlets per desk. Divide this number by 16, round up as required, and order that many 16-port switches. That is your first item for the network equipment list.

You will need rack frames to support those switches. Order two frames per room to start.

Order patch panels to cover the number of specified lines. Remember that there is a certain amount of network equipment, such as, switches and routers that must fit in these TRs. To calculate accurate totals, consider entering this information into a spreadsheet.

Network Cabling

You determined how many work-area outlets you needed for each TR in Step 1. Use cabling of a high grade, Category 5e or greater. Using a ruler, map out the routes for these runs and then pick off the dimensions. Add them all up, round up to the nearest 1000, add 1000, and then divide by 1000. This is how much cable (1000-foot boxes) you need.

It is important to pull cable efficiently. Avoid trying to get by with too few boxes or reels or else it may be necessary to duplicate runs. Pulling new cable over existing cables may result in damaging the cable that was pulled earlier.

There is a trick here. Look at drawings called FloorPlan2-Plumbing-and-HVAC-building floor4. This shows the water and air-conditioning duct work. Notice that there is both supply and return air. The ceiling is not a plenum ceiling. You can specify a cable that is not plenum or riser-rated. This will result in considerable savings.

Construction Requirements

You determined that you needed risers between each floor. This requires coring and requires that the bottom floor will pass through the mechanical space. This will require conduit.

You also modified some rooms on the fourth floor by adding the TR.

Next Steps

You now are prepared to work your way through most of the rest of the case study. Have fun. Relax. Remember that the thinking and planning and false starts and discussion with teammates is where the true value of this exercise lies.

Summary

The standards are written in a way that will promote performance. Following standards also tends to unify the methods of construction and installation. For instance, the point at which a telecommunications utility enters the premises almost always is referred to as an entrance facility (EF). The point at which responsibility for the lines and equipment transfers from the network provider to the user is called the point of demarcation, or the demarcation point. The EF and the demarc usually are installed in a room created for that purpose, called a telecommunications room (TR). A TR can have one of several functions. A main cross-connect (MC) distributes the signals to one or more intermediate cross-connects (IC). These, in turn, pass the signal to one or more horizontal cross-connects (HC), which deliver the signal to the area near the end user, called the work area.

Work must be performed in a way that does not injure workers, the public, or the environment. Often this requires marking off the work area with signs or cones to warn passersby. Also, ladder safety is an important practice. Ensure that ladders are in good condition, with no loose or broken portions. When deploying a straight ladder, secure it, if possible, near the point where it contacts a structure. If possible, have someone guard the base of the ladder, and by all means make sure that no one can open a door and knock you off of it. In the case of a stepladder, make sure that the feet firmly contact the ground and that the spreaders are fully extended and latched. Do not use a stepladder as a straight one. Never stand on the very top of any ladder.

Cabling and wiring require tools adapted to the craft, and installers are well advised to use them and not get by with substitutes. Stripping tools take the insulation off pieces of wire, often in multiple levels to accommodate installing connectors. Cutting tools cut off pieces of wire, often in a way that does not compress the inside of the wires. A

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termination tool is used to affix a connector to a prepared cable end. These basic tools should be part of every installer's kit, but perhaps more important are tools for diagnosis. A cable tester gives an indication that every pair is going to the correct place and that each wire is going to the correct terminal.

As the cables are pulled into place, it is important to keep in mind that firewalls must not be penetrated unless the equipment is available to restore them to their original condition. The fire-stopping tools and materials that do this vary but generally consist of materials that are certified to resist the spread of smoke and flame. Following the rough-in phase, cable is routed, terminated, and set into patch panels and cover plates in the trimout and finish phases. The finish phase is also the time during which cables are tested or certified. Certification consists of passing specialized signals through a cable to determine whether the amounts of frequency-specific attenuation and headroom are within tolerance. Certification results usually are presented to the building owner as part of the cabling plant documentation.

There are no cabling jobs to be had if bids are not won, and accurate bidding requires a thorough site survey and careful estimating. Labor regulations and union restrictions might affect the timing of a project and should be taken into account. The external factors of each job can greatly affect the amount of profitability that is expected.

The study presented in this material involves using a company's written requirements and a set of blueprints to develop the necessary plan, estimates, and documentation for a network installation in a four-story office/warehouse complex.

Key Terms

ANSI American National Standards Institute.

backbone A pathway or cable that runs between telecommunications rooms (TRs) and buildings.

blueprint An architectural plan or technical drawing that provides details of a construction project or an existing structure.

bullwheel A large-diameter pulley that is used in a mechanical cable-pulling process.

cable tree A device that supports a number of small reels of cable. This enables the cable installer to pull multiple runs of cable simultaneously.

CENELEC Comité Europe en de Normalisation Electrotechnique, or European Committee for Electrotechnical Standardization

crosstalk The signal from a transmitting pair being coupled to the receiving pair or other pairs in the cable. Crosstalk occurs most frequently near the transmitters in a circuit.

demarc The point at which the service provider's cable interfaces with the building distribution cabling.

demarcation point Usually the point at which the access provider's facilities stop and the customer-owned structured cabling begins.

equipment room Space for equipment. Also can be used as a telecommunications room.

HC (horizontal cross-connect) Area where patch panels or punchdown blocks are used to connect cables from work areas to the MC. The HC can be a telecommunications room, a cabinet, or a floor or ceiling installation.

IC (intermediate cross-connect) The connection point between a backbone cable that extends from the MC to the HC.

MC (main cross-connect) The cross-connect that normally is located in the primary telecommunications room or the equipment room.

MSDS (material safety data sheet) A document that contains information on the use, storage, and handling of a hazardous material. It provides detailed information on the potential health effects of exposure and how to work safely with the material.

multimeter A testing tool used to ensure that no voltage is on the telecommunications line. Most of these devices can measure AC/DC voltage, current, resistance, diode, continuity, and transistor.

MUTOA (*multiuser telecommunications outlet assembly*) A device that holds multiple outlets for use in work areas where modular furniture is used. Computers and telephones are plugged directly into the MUTOA.

NEC National Electrical Code.

NFPA National Fire Protection Association.

OSHA Occupational Safety and Health Administration.

patch cable A cable with a connector on each end, used to transfer signals from one piece of network equipment to another.

patch cord A length of cable used to connect links at the cross-connect.

patch panel A device used to interconnect data networking or voice systems to the physical cable network. The rear of the patch panel has network cables that are punched down. The front of the patch panel has a factory-terminated interface of some type.

plenum An open ceiling that acts as an air-return duct for heating, ventilation, and air-conditioning systems.

raceway Channels that contain cables in an installation. Raceways include common electrical conduit, specialized cable trays or ladder racks, in-floor duct systems, and plastic or metal surface-mounted raceways.

SCS (*structured cabling system*) Integrated cable plans that include the connectors, wiring, distribution centers, and installation techniques developed by specific companies.

structured cabling A uniform cabling system with standards that define the actual cable, cabling distances, type of cable, and type of terminating devices.

TDR (*time domain reflectometer*) A device that can measure the lengths of cables that are installed and locate faults. It does these tasks by sending a signal down a cable and then measuring the amount of time that it takes for that signal to return.

TIA Telecommunications Industry Association.

TR (*telecommunications room*) The area within a building that houses the telecommunications cabling system equipment.

vertical cabling Backbone cables, intermediate and main cross-connects, mechanical terminations, and patch cords or jumpers used for backbone-to-backbone cross-connections.

work area A space where computers, telephones, and other network equipment is used.



Appendix B

Glossary of Key Terms

1000BASE-LX 1000-Mbps baseband Gigabit Ethernet specification using a long wavelength for a long-haul fiber-optic cable for a maximum length of 10,000 (32808.4 ft.).

1000BASE-SX 1000-Mbps baseband Gigabit Ethernet specification using a short laser wavelength on multimode fiber-optic cable for a maximum length of 550m (1804.5 ft.).

1000BASE-T 1000-Mbps baseband Gigabit Ethernet specification using four pairs of Category 5 UTP cable for a maximum length of 100m (328 ft.).

100BASE-FX 100-Mbps baseband Fast Ethernet specification using two strands of multimode fiber-optic cable per link. To guarantee proper signal timing, a 100BASE-FX link cannot exceed 400m (1312 ft.) in length. It is based on the IEEE 802.3 standard.

100BASE-TX 100-Mbps baseband Fast Ethernet specification using two pairs of either UTP or STP wiring. The first pair of wires is used to receive data; the second is used to transmit. To guarantee proper signal timing, a 100BASE-TX segment cannot exceed 100m (328 ft.) in length. It is based on the IEEE 802.3 standard.

10BASE2 10-Mbps baseband Ethernet specification using 50-ohm thin coaxial cable. 10BASE2, which is part of the IEEE 802.3 specification, has a distance limit of 185m (606 ft.) per segment.

10BASE5 10-Mbps baseband Ethernet specification using standard (thick) 50-ohm baseband coaxial cable. 10BASE5, which is part of the IEEE 802.3 baseband physical layer specification, has a distance limit of 500m (1640 ft.) per segment.

10BASE-T 10-Mbps baseband Ethernet specification using two pairs of twisted-pair cabling (Category 3, 4, or 5): one pair for transmitting data and the other for receiving data. 10BASE-T, which is part of the IEEE 802.3 specification, has a distance limit of approximately 100m (328 ft.) per segment.

10-Gb Ethernet Built on the Ethernet technology used in most of today's LANs, 10-Gb Ethernet is described as a technology that offers a more efficient and less expensive approach to moving data on backbone connections between networks, while also providing a consistent technology end to end. Ethernet now can step up to offering data speeds at 10 Gbps.

4D-PAM5 The symbol-encoding method used in 1000BASE-T. The four-dimensional quinary symbols (4D) received from the 8B1Q4 data encoding are transmitted using five voltage levels (PAM5). Four symbols are transmitted in parallel each symbol period.

8B1Q4 For IEEE802.3, the data-encoding technique used by 1000BASE-T when converting GMII data (8B-8 bits) to four quinary symbols (Q4) that are transmitted during one clock (1Q4).

acknowledgment Notification sent from one network device to another to acknowledge that some event (for example, receipt of a message) occurred. Sometimes abbreviated ACK.

ACL (access control list) A means of controlling or limiting network traffic that compares different criteria to a defined rule set.

active hub Must be plugged into an electrical outlet because it needs power to amplify the incoming signal before passing it out to the other ports.

adjacent neighbor Two directly connected routers that participate in the exchange of routing information are said to be *adjacent*.

administrative distance A rating that shows trustworthiness of a routing information source. This value is shown as a numeric value between 0 and 255. The higher the value is, the lower the trustworthiness rating is.

algorithm A well-defined rule or process for arriving at a solution to a problem. In networking, algorithms are commonly used to determine the best route for traffic from a particular source to a particular destination.

alien crosstalk When crosstalk is caused by a signal from outside the cable.

alignment error A message that does not end on an octet boundary.

AM (amplitude modulation) Modulates the height of the carrier wave.

American Standard Code for Information Interchange (ASCII) The most commonly used code for representing alphanumeric data in a computer. Uses binary digits (bits) to represent the symbols typed on the keyboard.

amplitude The amplitude of an electrical signal represents its height, but it is measured in volts instead of meters.

analog bandwidth Typically refers to the frequency range of an analog electronic system. Analog bandwidth can be used to describe the range of frequencies transmitted by a radio station or an electronic amplifier.

angle of incidence Angle of incidence is the angle at which the ray hits the glass surface.

angle of reflection The angle between the reflected ray and the normal.

ANSI American National Standards Institute.

application layer Layer 7 of the OSI reference model. This layer provides services to application processes (such as e-mail, file transfer, and terminal emulation) that are outside the OSI reference model. The application layer identifies and establishes the availability of intended communication partners (and the resources required to connect with them), synchronizes cooperating applications, and establishes agreement on procedures for error recovery and control of data integrity.

application Interprets the data and displays the information in a comprehensible format as the last part of an Internet connection. Applications work with protocols to send and receive data across the Internet.

ARP (Address Resolution Protocol) Internet protocol used to map an IP address to a MAC address.

ASCII (American Standard Code for Information Interchange) An 8-bit code (7 bits plus parity) for character representation.

attenuation The decrease in signal amplitude over the length of a link.

AUI (attachment unit interface) The 15-pin physical connector interface between a computer's NIC and Ethernet cable.

autonomous system A network or set of networks that are under the administrative control of a single entity, such as the cisco.com domain.

backbone A backbone is the part of a network that acts as the primary path for traffic that is most often sourced from, and destined for, other networks.

backoff The retransmission delay enforced when a collision occurs.

backplane A large circuit board that contains sockets for expansion cards.

balanced hybrid routing protocol Routing protocols that utilize elements of distance vector and link-state routing protocols.

bandwidth The amount of information that can flow through a network connection in a given period of time.

binary A number system characterized by 1s and 0s (1 = on, and 0 = off).

bit The smallest unit of data in a computer. A bit equals 1 or 0. It is the binary format in which data is processed, stored, and transmitted by computers. In a computer, bits are represented by on/off switches or the presence or absence of electrical charges, light pulses, or radio waves.

bit bucket The destination of discarded bits (dropped packets), as determined by the router.

blueprint An architectural plan or technical drawing that provides details of a construction project or an existing structure.

Boolean logic In computer operation with binary values, Boolean logic can describe electromagnetically charged memory locations or circuit states that are either charged (1 or true) or not charged (0 or false). The computer can use an AND gate or an OR gate operation to obtain a result that can be used for further processing.

bootstrap The protocol used by a network node to determine the IP address of its Ethernet interfaces to affect network booting.

border router A router situated at the edges or end of the network boundary, which provides basic security from the outside network or from a less controlled area of the network into a more private area of the network.

BPDU (bridge protocol data unit) Spanning Tree Protocol hello packet that is sent out at configurable intervals to exchange information among bridges in the network.

bridge A Layer 2 device designed to create two or more LAN segments, each of which is a separate collision domain.

broadcast A data packet that is sent to all nodes on a network. Broadcasts are identified by a broadcast address.

broadcast address Used to broadcast packets to all the devices on a network.

broadcast domain A set of all devices that receive broadcast frames originating from any device within the set. Broadcast domains are typically bounded by routers (or, in a switched network, by VLANs) because routers do not forward broadcast frames.

bullwheel A large-diameter pulley that is used in a mechanical cable-pulling process.

bus topology Commonly called a linear bus, this topology connects all the devices with a single cable. This cable proceeds from one computer to the next like a bus line going through a city.

bus A collection of circuits through which data is transmitted from one part of a computer to another.

byte A unit of measure that describes the size of a data file, the amount of space on a disk or another storage medium, or the amount of data being sent over a network. 1 byte equals 8 bits of data.

cable tree A device that supports a number of small reels of cable. This enables the cable installer to pull multiple runs of cable simultaneously.

CDP (Cisco Discovery Protocol) Used to obtain information about neighboring devices, such as the types of devices connected, the router interfaces they are connected to, the interfaces used to make the connections, and the model numbers of the devices.

CD-ROM drive An optical drive that can read information from a CD-ROM.

cell-switched services Provide a dedicated-connection switching technology that organizes digital data into cell units and transmits them over a physical medium using digital signal technology.

CENELEC Comité Europe en de Normalisation Electrotechnique, or European Committee for Electrotechnical Standardization.

central processing unit (CPU) The computer's "brain," where most of the calculations take place.

circuit switching A WAN switching method in which a dedicated physical circuit through a carrier network is established, maintained, and terminated for each communication session. ISDN is an example of a circuit-switched WAN technology.

Cisco Internetwork Operating System (IOS) Software Software stored as an image file in Flash memory on the router that, when loaded into RAM, provides the operating system that runs the router.

Class A address Designed to support extremely large networks. A Class A IP address uses only the first octet to indicate the network address. The remaining three octets enumerate host addresses.

Class B address Designed to support the needs of moderate- to large-sized networks. A Class B IP address uses two of the four octets to indicate the network address. The other two octets specify host addresses.

Class C address The most commonly used of the original address classes. This address space was intended to support a lot of small networks.

Class D address Created to enable multicasting in an IP address.

Class E address The IETF reserves these addresses for its own research. Therefore, no Class E addresses have been released for use in the Internet.

classless interdomain routing (CIDR) A technique supported by BGP and based on route aggregation. CIDR allows routers to group routes to cut down on the quantity of routing information carried by the core routers. With CIDR, several IP networks appear to networks outside the group as a single, larger entity.

CLI (command-line interface) An interface that enables the user to interact with the operating system by entering commands and optional arguments.

coaxial cable A coaxial cable is a cable consisting of a hollow outer cylindrical conductor that surrounds a single inner wire conductor.

collision In Ethernet, the result of two nodes transmitting simultaneously. The frames from each device impact and are damaged when they meet on the physical media. *See also collision domain.*

collision domain In Ethernet, the network area within which frames that have collided are propagated. Repeaters and hubs propagate collisions; LAN switches, bridges, and routers do not.

command-line interface (CLI) An interface that enables the user to interact with the operating system by entering commands and optional arguments.

connectionless Data transfer without the existence of a virtual circuit.

connection-oriented Data transfer that requires the establishment of a virtual circuit.

convergence The speed and capability of a group of internetworking devices running a specific routing protocol to agree on the topology of an internetwork after a change in that topology.

count to infinity A problem that can occur in routing algorithms that are slow to converge in which routers continuously increment the hop count to particular networks. Typically, some arbitrary hop-count limit is imposed to prevent this problem.

crossover cable A cable that crosses the critical pair to properly align, transmit, and receive signals on the device with line connections.

crosstalk The transmission of signals from one wire pair to nearby pairs. Adjacent wire pairs in the cable act like antennas generating a weaker but similar electrical signal onto the nearby wire pairs. This crosstalk causes interference with data that might be present on the adjacent wires.

CSMA/CD (*carrier sense multiple access collision detect*) A media-access mechanism wherein devices ready to transmit data first check the channel for a carrier. If no carrier is sensed for a specific period of time, a device can transmit. If two devices transmit at once, a collision occurs and is detected by all colliding devices. This collision subsequently delays retransmissions from those devices for some random length of time. CSMA/CD access is used by Ethernet and IEEE 802.3.

cut-through switching A packet-switching approach that streams data through a switch so that the leading edge of a packet exits the switch at the output port before the packet finishes entering the input port. A device using cut-through packet switching reads, processes, and forwards packets as soon as the destination address is looked up and the outgoing port is determined. *See also* store-and-forward switching.

data center A globally coordinated network of devices designed to accelerate the delivery of information over the Internet infrastructure.

data link layer Layer 2 of the OSI reference model. Provides transit of data across a physical link. The data link layer is concerned with physical addressing, network topology, line discipline, error notification, ordered delivery of frames, and flow control.

datagram A logical grouping of information sent as a network layer unit over a transmission medium without prior establishment of a virtual circuit. IP datagrams are the primary information units in the Internet. The terms *cell*, *frame*, *message*, *packet*, and *segment* also describe logical information groupings at various layers of the OSI reference model and in various technology circles.

daughter card Similar to an expansion board, but it accesses the motherboard components (memory and CPU) directly instead of sending data through the slower expansion bus.

DCE (*data circuit-terminating equipment*) (ITU-T expansion) Devices and connections of a communications network that comprise the network end of the user-to-network interface. The DCE provides a physical connection to the network, forwards traffic, and provides a clocking signal used to synchronize data transmission between DCE and DTE devices. Modems and interface cards are examples of DCE.

debugging To find and remove errors (bugs) from a program or design.

decibel An important way of describing networking signals as a unit that measures the loss or gain of the power of a wave. Decibels are usually negative numbers representing a loss in power as the wave travels, but can also be positive values representing a gain in power if the signal is amplified.

de-encapsulation Unwrapping data in a particular protocol header.

delay skew The propagation delays of different wire pairs in a single cable can differ slightly because of differences in the number of twists and electrical properties of each wire pair. Delay skew is the delay difference between pairs.

demarc The point at which the service provider's cable interfaces with the building distribution cabling.

demarcation point Usually the point at which the access provider's facilities stop and the customer-owned structured cabling begins.

digital bandwidth Measures how much information can flow from one place to another in a given amount of time.

dispersion Dispersion is the broadening of light signals along the length of the fiber.

distance vector routing protocol A class of routing algorithms that iterate on the number of hops in a route to find a shortest-path spanning tree. Distance vector routing algorithms call for each router to send its entire routing table in each update, but only to its neighbors. Distance vector routing algorithms can be prone to routing loops but are computationally simpler than link-state routing algorithms. Also called a Bellman-Ford routing algorithm.

distance-vector routing A class of routing algorithms that iterate on the number of hops in a route to find a shortest-path spanning tree. Distance-vector routing algorithms call for each router to send its entire routing table in each update, but only to its neighbors. Distance-vector routing algorithms can be prone to routing loops but are computationally simpler than link-state routing algorithms. Also called the Bellman-Ford routing algorithm.

DNS (Domain Name System) The system used in the Internet for translating names of network nodes into addresses.

DoS (denial-of-service) Type of attack on a network that is designed to bring the network to its knees by flooding it with useless traffic.

dotted-decimal format In this notation, each IP address is written as four parts separated by periods, or dots.

dotted-decimal notation A syntactic representation for a 32-bit integer that consists of four 8-bit numbers written in base 10 with periods (dots) separating them. Used to represent IP addresses on the Internet, as in 192.67.67.20.

DSSS (direct-sequence spread spectrum) A technology in which transmissions are more reliable because each bit (1 or 0) is represented by a string of 1s and 0s, called a chipping sequence.

DTE (data terminal equipment) Device at the user end of a user-network interface that serves as a data source, destination, or both. DTE connects to a data network through a DCE device (for example, a modem) and typically uses clocking signals generated by the DCE. DTE includes such devices as computers, protocol translators, and multiplexers.

dynamic routing Routing that adjusts automatically to network topology or traffic changes. Also called adaptive routing. Requires that a routing protocol be run between routers.

EIA (Electronic Industries Association) EIA is a group that specifies electrical transmission standards. The EIA and TIA have developed numerous well-known communication standards.

ELFEXT (equal-level far-end crosstalk) A test that measures FEXT.

EMI (electromagnetic interference) EMI is an electromagnetic field that has the potential to disrupt the operation of electronic components, devices, and systems in its vicinity.

encapsulation Wrapping of data in a particular protocol header. For example, upper-layer data is wrapped in a specific Ethernet header before network transit. Also, when bridging dissimilar networks, the entire frame from one network simply can be placed behind the header used by the data link layer protocol of the other network.

encoding Process by which bits are represented by voltages.

equipment room Space for equipment. Also can be used as a telecommunications room.

Ethernet A baseband LAN specification invented by Xerox Corporation and developed jointly by Xerox, Intel, and Digital Equipment Corporation. Ethernet networks use CSMA/CD and run over a variety of cable types at 10, 100, and 1000 Mbps. Ethernet is similar to the IEEE 802.3 series of standards.

expansion slot An opening in a computer, usually on the motherboard, where an expansion card can be inserted to add new capabilities to the computer.

extended ACL Compares source IP address, destination IP address, TCP/UDP port number, and other criteria to the rules defining an extended ACL.

extended-star topology A network in which a star network is expanded to include an additional networking device that is connected to the main networking device.

exterior gateway protocol (EGP) A routing protocol designed for use between networks that are controlled by two different organizations.

Exterior Gateway Protocol (EGP) An Internet protocol used to exchange routing information between autonomous systems. Border Gateway Protocol (BGP) is the most common EGP.

exterior router In firewall architecture, the router that is connected to the Internet is referred to as the exterior router. It forces all incoming traffic to pass through the application gateway.

exterior routes Routes to networks outside the autonomous system that are considered when identifying a gateway of last resort.

extranet Intranet-based applications and services that employ extended, secure access to external users or enterprises.

Fast Ethernet Any of a number of 100-Mbps Ethernet specifications. Fast Ethernet offers a speed increase 10 times that of the 10BASE-T Ethernet specification, while preserving such qualities as frame format, MAC mechanisms, and MTU. Such similarities allow the use of existing 10BASE-T applications and network-management tools on Fast Ethernet networks. Fast Ethernet is based on an extension to the IEEE 802.3 specification.

FDDI (Fiber Distributed Data Interface) A LAN standard, defined by American National Standards Institute (ANSI) 3T9.5, specifying a 100-Mbps token-passing network using fiber-optic cable, with transmission distances of up to 2 km. FDDI uses a dual-ring architecture to provide redundancy.

FEXT (far-end crosstalk) Crosstalk that occurs when signals on one twisted pair are coupled to another pair as they arrive at the far end of a multipair cable system.

FHSS (frequency-hopping spread spectrum) A technology in which transmissions hop from one frequency to another in random patterns. This feature enables the transmissions to hop around narrowband interference, resulting in a clearer signal and higher reliability of the transmission.

fiber-optic cable A fiber-optic cable is a physical medium capable of conducting modulated light transmission. Compared with other transmission media, fiber-optic cable is more expensive but is not susceptible to electromagnetic interference. Sometimes called optical fiber.

File Transfer Protocol An application protocol, part of the TCP/IP protocol suite, used to transfer files between network hosts.

firewall One or more network devices, such as routers or access servers, designated as a buffer between any connected public networks and a private network. A firewall router uses access control lists and other methods to ensure the security of the private network.

Flash memory A special type of EEPROM that can be erased and reprogrammed in blocks instead of one byte at a time. Many modern PCs have their BIOS stored on a Flash memory chip so that it can be updated easily if necessary. Such a BIOS is sometimes called a Flash BIOS. Flash memory is also popular in modems because it enables the modem manufacturer to support new protocols as they become standardized.

flooding A traffic-passing technique used by switches and bridges in which traffic received on an interface is sent out all that device's interfaces except the interface on which the information was received originally.

floppy disk drive Reads and writes to floppy disks.

flow control A technique for ensuring that a transmitting entity does not overwhelm a receiving entity with data. When the buffers on the receiving device are full, a message is sent to the sending device to suspend the transmission until the data in the buffers has been processed. In IBM networks, this technique is called pacing.

flush timer Indicates how much time passes before a route is flushed from the routing table. The IGRP default is seven times the routing update timer.

FM (frequency modulation) Modulates the frequency of the wave.

fragment-free switching Switching that filters out collision fragments, which are the majority of packet errors, before forwarding begins.

frame A logical grouping of information sent as a data link layer unit over a transmission medium.

frequency The amount of time between each wave.

FTP (File Transfer Protocol) An application protocol, part of the TCP/IP protocol stack, used for transferring files between network nodes. FTP is defined in RFC 959.

full duplex The capability for simultaneous data transmission between a sending station and a receiving station.

full-mesh topology Connects all devices (nodes) to each other for redundancy and fault tolerance.

GB (gigabyte) Approximately 1 billion bytes. Sometimes called a "gig." Hard drive capacity on most PCs is typically measured in GB.

GBIC (Gigabit Interface Converter) A hot-swappable input/output device that plugs into a Gigabit Ethernet port.

Gbps (gigabits per second) One billion bits per second. A standard measurement of the amount of data transferred over a network connection. 10G or 10 Gigabit Ethernet operates at 10 Gbps.

ghost Fluke Networks coined this new term to mean energy (noise) detected on the cable that appears to be a frame but that lacks a valid SFD. To qualify as a ghost, this “frame” must be at least 72 octets long (including preamble); otherwise, it is classified as a remote collision.

Gigabit Ethernet Standard for a high-speed Ethernet, approved by the IEEE 802.3z standards committee in 1996.

global configuration mode Used for one-line commands and commands that make global changes to the router configuration.

half duplex A capability for data transmission in only one direction at a time between a sending station and a receiving station.

hard disk drive Reads and writes data on a hard disk. The primary storage device in the computer.

HC (horizontal cross-connect) Area where patch panels or punchdown blocks are used to connect cables from work areas to the MC. The HC can be a telecommunications room, a cabinet, or a floor or ceiling installation.

header Control information placed before data when encapsulating that data for network transmission.

hertz The unit of measure for the frequency of an electrical signal in the number of complete cycles per second.

hierarchical topology Created similar to an extended-star topology. The primary difference is that it does not use a central node. Instead, it uses a trunk node from which it branches to other nodes.

holddowns Prevent regular update messages from inappropriately reinstating a route that might not be up.

hold-time timer Specifies the amount of time for which information about better routes is ignored. The IGRP default for this variable is 3 times the update timer period plus 10 seconds.

hop count A routing metric used to measure the distance between a source and a destination. RIP uses hop count as its sole metric.

hop The passage of a data packet from one network node, typically a router, to another.

HTML (Hypertext Markup Language) A simple hypertext document formatting language that uses tags to indicate how a given part of a document should be interpreted by a viewing application, such as a Web browser.

HTTP (Hypertext Transfer Protocol) The protocol used by Web browsers and Web servers to transfer files, such as text and graphics files.

hub A common connection point for devices in a network. Hubs commonly connect segments of a LAN. A hub contains multiple ports. When a packet arrives at one port, it is copied to the other ports so that all the segments of the LAN can see all the packets.

hyperlink A computer program command that points to other HTML files on a web server or other places on the same documents. Provides shortcuts to other web pages and files.

Hypertext Markup Language (HTML) A simple hypertext document-formatting language that uses tags to indicate how a given part of a document should be interpreted by a viewing application, such as a web browser.

IC (intermediate cross-connect) The connection point between a backbone cable that extends from the MC to the HC.

ICMP (Internet Control Message Protocol) Network layer Internet protocol that reports errors and provides other information relevant to IP packet processing. It is documented in RFC 792.

IEEE (Institute of Electrical and Electronic Engineers) A professional organization whose activities include the development of communications and network standards. IEEE LAN standards are the predominant LAN standards today.

IEEE (Institute of Electrical and Electronic Engineers) IEEE is professional organization whose activities include the development of communications and network standards. IEEE LAN standards are the predominant LAN standards.

IEEE 802.1X/Extensible Authentication Protocol (EAP) An alternative WLAN security approach to WEP as specified by IEEE 802.11. IEEE 802.1X/EAP focuses on developing a framework for providing centralized authentication and dynamic key distribution.

IEEE 802.2 An IEEE LAN protocol that specifies an implementation of the LLC sublayer of the data link layer. IEEE 802.2 handles errors, framing, flow control, and the network layer (Layer 3) service interface.

IEEE 802.3 An IEEE LAN protocol that specifies an implementation of the physical layer and the MAC sublayer of the data link layer. IEEE 802.3 uses CSMA/CD access at a variety of speeds over a variety of physical media. Extensions to the IEEE 802.3 standard specify implementations for Fast Ethernet. Physical variations of the original IEEE 802.3 specification include 10BASE2, 10BASE5, 10BASE-F, 10BASE-T, and 10BROAD36. Physical variations for Fast Ethernet include 100BASE-TX and 100BASE-FX.

IGRP (Interior Gateway Routing Protocol) An IGP developed by Cisco to address the problems associated with routing in large, heterogeneous networks. *Compare with* EIGRP. *See also* IGP, OSPF, and RIP.

impedance A measurement of the resistance of the cable to AC and is measured in ohms.

insertion loss The combination of the effects of signal attenuation and impedance discontinuities on a communications link.

intelligent hub Sometimes called “smart hubs.” These devices basically function as active hubs, but also include a microprocessor chip and diagnostic capabilities. They are more expensive than active hubs, but are useful in troubleshooting situations.

interface Connection between two systems or devices. In routing terminology, a network connection.

Interior Gateway Protocol (IGP) An Internet protocol used to exchange routing information within an autonomous system. Examples of common Internet IGPs are IGRP, OSPF, and RIP.

Interior Gateway Routing Protocol (IGRP) An IGP developed by Cisco to address the problems associated with routing in large, heterogeneous networks.

interior router The router that is connected to the internal network. The interior router accepts packets only from the application gateway. The gateway controls the delivery of network-based services both to and from the internal network.

interior routes Routes between subnets of a network attached to a router interface. If the network attached to a router is not subnetted, IGRP does not advertise interior routes.

Internet Protocol (IP) A network layer protocol in the TCP/IP protocol suite offering a connectionless internetwork service.

Internet The largest global internetwork, connecting tens of thousands of networks worldwide and having a culture that focuses on research and standardization based on real-life use.

intranet A common LAN configuration. Intranets are designed to be accessed by users who have access privileges to an organization’s internal LAN.

invalid timer Specifies how long a router waits in the absence of routing-update messages about a specific route before declaring that route invalid. The IGRP default for this variable is three times the update period.

IP address A 32-bit address assigned to hosts using TCP/IP. An IP address belongs to one of five classes (A, B, C, D, or E) and is written as four octets separated by periods (that is, dotted-decimal format). Each address consists of a network number, an optional subnetwork number, and a host number. The network and subnetwork numbers together are used for routing, and the host number is used to address an individual host within the network or subnetwork. A subnet mask is used to extract network and subnetwork information from the IP address. CIDR provides a new way to represent IP addresses and subnet masks. Also called an *Internet address*.

IP address class A 32-bit IP address is broken into a network part and a host part. A bit or bit sequence at the start of each address determines the address's class.

IP Version 6 (IPv6) The replacement for the current version of IP (Version 4). IPv6 includes support for flow ID in the packet header, which can be used to identify flows. Formerly called IPng (IP next generation).

jabber Defined several places in the 802.3 standard as being a transmission of at least 20,000 to 50,000 bit-times in duration. However, most diagnostic tools report jabber whenever a detected transmission exceeds the maximum legal frame size—which is considerably smaller than 20,000 to 50,000 bit-times.

KB (kilobyte) Approximately 1000 bytes (1024 bytes exactly).

kbps (kilobits per second) One thousand bits per second. A standard measurement of the amount of data transferred over a network connection.

kBps (kilobytes per second) One thousand bytes per second. A standard measurement of the amount of data transferred over a network connection.

keepalive Message sent by one network device to inform another network device that the virtual circuit between the two is still active.

keyboard port Connects a keyboard to a PC.

latency Delay between the time when a device receives a frame and the time when that frame is forwarded out the destination port.

light-emitting diode (LED) Semiconductor device that emits light produced by converting electrical energy. Status lights on hardware devices are typically LEDs.

link-state advertisements (LSAs) Small packets of routing information that are sent between routers.

link-state routing protocol A routing algorithm in which each router broadcasts or multicasts information regarding the cost of reaching each of its neighbors to all nodes in the internetwork. Link-state algorithms create a consistent view of the network and are therefore not prone to routing loops. However, they achieve this at the cost of relatively greater computational difficulty and more widespread traffic than do distance vector routing algorithms.

LLC (Logical Link Control) The higher of the two data link layer sublayers defined by the IEEE. The LLC sublayer handles error control, flow control, framing, and MAC-sublayer addressing. The most prevalent LLC protocol is IEEE 802.2, which includes both connectionless and connection-oriented variants.

load sharing When dynamic routing protocols direct traffic from the same session over different paths in a network for better performance.

local-area network (LAN) A high-speed, low-error data network covering a relatively small geographic area (up to a few thousand meters). LANs connect workstations, peripherals, terminals, and other devices in a single building or another geographically limited area.

logarithms Equals the exponent that a given number has to be raised to in order to generate a certain value.

logical connection Uses standards called protocols.

long frame A frame that is longer than the maximum legal size and that takes into consideration whether the frame was tagged.

MAC (Media Access Control) The lower of the two sublayers of the data link layer defined by the IEEE. The MAC sublayer handles access to shared media, such as whether token passing or contention will be used. *See also LLC.*

MAC address A standardized data link layer address that is required for every device that connects to a LAN. Other devices in the network use these addresses to locate specific devices in the network and to create and update routing tables and data structures. MAC addresses are 6 bytes long and are controlled by the IEEE. Also called a hardware address, MAC-layer address, or physical address.

Manchester encoding Digital encoding scheme, used by IEEE 802.3 and Ethernet, in which a mid[nd]bit-time transition is used for clocking; a 1 is denoted by a high level during the first half of the bit time.

Mb (megabit) Approximately 1 million bits.

MB (megabyte) Approximately 1 million bytes (1,048,576 bytes exactly). A megabyte is sometimes called a “meg.” The amount of RAM in most PCs is typically measured in MB. Large files are typically some number of MB in size.

Mbps (megabits per second) One million bits per second. A standard measurement of the amount of data transferred over a network connection. Basic Ethernet operates at 10 Mbps.

MBps (megabytes per second) One million bytes per second. A standard measurement of the amount of data transferred over a network connection.

MC (main cross-connect) The cross-connect that normally is located in the primary telecommunications room or the equipment room.

Media Access Control (MAC) A hardware address that uniquely identifies each node of a network. This address controls data communication for the host on the network.

Media Access Control (MAC) address A standardized data link layer address that is required for every port of devices that connect to a LAN. Other devices in the network use these addresses to locate specific ports in the network and to create and update routing tables and data structures. MAC addresses are 6 bytes long and are controlled by the IEEE.

media Media is the plural of medium. Media refers to various physical environments through which transmission signals pass. Common network media include twisted-pair, coaxial, fiber-optic cable, and the atmosphere (through which microwave, laser, and infrared transmission occurs).

memory chips RAM chips on memory cards plug into the motherboard.

metric An algorithm that generates a number for each path through the network. Typically, the smaller the metric number is, the better the path is.

metropolitan-area network (MAN) A network that spans a metropolitan area. Generally, a MAN spans a larger geographic area than a LAN but a smaller geographic area than a WAN.

microprocessor A silicon chip that contains a CPU.

microsegmentation Allows the creation of private or dedicated segments—one host per segment. Each host receives instant access to the full bandwidth and does not have to compete for available bandwidth with other hosts.

modal dispersion When multiple modes of light propagating through fiber travel different distances, depending on their entry angles, which causes them to arrive at the destination (receiving end of the cable) at slightly different times.

modem Device that converts digital and analog signals. At the source, a modem converts digital signals to a form suitable for transmission over analog communication facilities. At the destination, the analog signals are returned to their digital form. Modems allow data to be transmitted over voice-grade telephone lines. The term *modem* is also used to describe various digital devices such as CSU/DSUs and ISDN terminal adapters.

motherboard A computer's main circuit board.

mouse port Connects a mouse to a PC.

MSDS (material safety data sheet) A document that contains information on the use, storage, and handling of a hazardous material. It provides detailed information on the potential health effects of exposure and how to work safely with the material.

MTU (Maximum Transmission Unit) The maximum packet size, in bytes, that a particular interface can handle.

multicast Single packets copied by the network and sent to a specific subset of network addresses.

multicast address A unique network address that directs packets that have that destination address to predefined groups of IP addresses.

multimeter A testing tool used to ensure that no voltage is on the telecommunications line. Most of these devices can measure AC/DC voltage, current, resistance, diode, continuity, and transistor.

multimode Multimode is a type of fiber-optic cable that transmits more than one light path.

MUTOA (multiuser telecommunications outlet assembly) A device that holds multiple outlets for use in work areas where modular furniture is used. Computers and telephones are plugged directly into the MUTOA.

named ACL ACL that allows standard and extended ACLs to be given names.

narrowband interference Noise that only affects small ranges of frequencies.

NEC National Electrical Code.

NetBIOS Extended User Interface (NetBEUI) An enhanced version of the NetBIOS protocol used by network operating systems such as LAN Manager, LAN Server, Windows for Workgroups, and Windows NT. NetBEUI formalizes the transport frame and adds functions. NetBEUI implements the OSI LLC2 protocol.

network access layer The layer that is concerned with all the issues that an IP packet requires to make a physical link to the network medium.

network interface card (NIC) A printed circuit board that fits into the expansion slot of a bus on a computer motherboard. Also can be a peripheral device.

network layer Layer 3 of the OSI reference model. This layer provides connectivity and path selection between two end systems. The network layer is the layer at which routing occurs.

NEXT (near-end crosstalk) Computed as the ratio in voltage amplitude between the test signal and the crosstalk signal when measured from the same end of the link.

NFPA National Fire Protection Association.

noise As related to communications, noise refers to undesirable signals. Noise can originate from natural and technological sources and is added to the data signals in communications systems.

nonvolatile RAM (NVRAM) RAM that retains its contents when a unit is powered off.

NRZ (nonreturn to zero) Signals that maintain constant voltage levels with no signal transitions (no return to a 0V level) during a bit interval.

NRZI (nonreturn to zero inverted) Signal that maintains constant voltage levels with no signal transitions (no return to a 0V level). It interprets the presence of data at the beginning of a bit interval as a signal transition and interprets the absence of data as no transition.

NVRAM (nonvolatile random-access memory) RAM that retains its contents when a unit is powered off.

octet 8 bits. In networking, the term octet often is used (rather than byte) because some machine architectures employ bytes that are not 8 bits long.

Open System Interconnection (OSI) reference model A network architectural model developed by the ISO. This model consists of seven layers, each of which specifies particular network functions, such as addressing, flow control, error control, encapsulation, and reliable message transfer. The OSI reference model is used universally as a method for teaching and understanding network functionality.

oscilloscope An important electronic device used to view electrical signals such as voltage waves and pulses.

OSHA Occupational Safety and Health Administration.

OUI (organizationally unique identifier) Three octets assigned by the IEEE in a block of 48-bit LAN addresses.

packet A logical grouping of information that includes a header containing control information and (usually) user data. Packets most often refer to network-layer units of data. The terms *datagram*, *frame*, *message*, and *segment* also describe logical information groupings at various layers of the OSI reference model and in various technology circles.

packet-switched services Routes small units of data called packets through a network based on the destination address contained within each packet.

parallel port An interface that can transfer more than 1 bit simultaneously. It is used to connect external devices, such as printers.

partial-mesh topology At least one device maintains multiple connections to others without being fully meshed. A partial-mesh topology still provides redundancy by having several alternative routes.

patch cable A cable with a connector on each end, used to transfer signals from one piece of network equipment to another.

patch cord A length of cable used to connect links at the cross-connect.

patch panel A device used to interconnect data networking or voice systems to the physical cable network. The rear of the patch panel has network cables that are punched down. The front of the patch panel has a factory-terminated interface of some type.

peer-to-peer communication A form of communication in which each layer of the OSI model at the source must communicate with its peer layer at the destination.

peer-to-peer network Networked computers act as equal partners, or peers, to each other. As peers, each computer can take on the client function or the server function.

Personal Computer Memory Card International Association (PCMCIA) An organization that has developed a standard for small credit card-sized devices called PCMCIA cards (or PC cards). Originally designed to add memory to portable computers, the PCMCIA standard has been expanded several times and is now suitable for many types of devices.

physical connection A connection to a network that is made by connecting a specialized expansion card, such as a modem or NIC, from a PC with a cable to a network.

physical layer Layer 1 of the OSI reference model. The physical layer defines the electrical, mechanical, procedural, and functional specifications for activating, maintaining, and deactivating the physical link between end systems.

ping (Packet Internet Groper) ICMP echo message and its reply. Often used in IP networks to test the reachability of a network device.

plenum An open ceiling that acts as an air-return duct for heating, ventilation, and air-conditioning systems.

plug-in Software or a program that can easily be installed and used as part of a web browser.

PM (phase modulation) Modulates the polarity (phase) of the wave.

poison reverse updates Updates that are necessary to defeat larger routing loops. Generally speaking, increases in routing metrics indicate routing loops. Poison reverse updates are then sent to remove the route and place it in holddown.

port In IP terminology, an upper-layer process that receives information from lower layers. Ports are numbered, and many are associated with a specific process. For example, SMTP is associated with port 25. A port number of this type is called a well-known port or address.

power cord Connects an electrical device to an electrical outlet to provide power to the device.

power supply Supplies power to a computer.

power-on self-test (POST) Set of hardware diagnostics that runs on a hardware device when that device is powered up.

presentation layer Layer 6 of the OSI reference model. This layer ensures that information sent by the application layer of one system can be read by the application layer of another.

printed circuit board (PCB) A thin plate on which chips (integrated circuits) and other electronic components are placed.

privileged mode Used for copying and managing entire configuration files.

propagation delay A simple measurement of how long it takes for a signal to travel along the cable being tested.

protocol stack A set of related communications protocols that operate together and, as a group, address communication at some or all of the seven layers of the OSI reference model. Not every protocol stack covers each layer of the model, and often a single protocol in the stack addresses a number of layers at once. TCP/IP is a typical protocol stack.

protocol suite A set of related communications protocols that operate together and, as a group, address communication at some or all of the seven layers of the OSI reference model. Not every protocol stack covers each layer of the model, and often a single protocol in the suite addresses a number of layers at once. TCP/IP is a typical protocol suite.

protocol A formal description of a set of rules and conventions that govern how devices on a network exchange information.

PSELFEXT (power sum equal-level far-end crosstalk (PSELFEXT)) The combined effect of ELFEXT from all wire pairs.

PSNEXT (power sum near-end crosstalk) Measures the cumulative effect of NEXT from all wire pairs in the cable.

pulse Pulses determine the value of the data being transmitted. If a disturbance is deliberately caused and involves a fixed, predictable duration, it is called a pulse.

queuing A process by which ACLs can designate certain packets to be processed by a router before other traffic, on the basis of some configurable parameter such as specifying a protocol.

raceway Channels that contain cables in an installation. Raceways include common electrical conduit, specialized cable trays or ladder racks, in-floor duct systems, and plastic or metal surface-mounted raceways.

RAM (random-access memory) Volatile memory that can be read and written by a microprocessor.

random-access memory (RAM) Also known as read-write memory. Can have new data written to it as well as stored data read from it.

range error A frame that had a legal-size value in the Length field but that did not match the actual number of octets counted in the Data field of the received frame.

RARP (Reverse Address Resolution Protocol) Protocol in the TCP/IP stack that provides a method for finding IP addresses based on MAC addresses.

RCP (remote copy protocol) Protocol that allows users to copy files to and from a file system residing on a remote host or server on the network.

read-only memory (ROM) A type of computer memory in which data has been prerecorded.

reflection Reflection is the photons of light striking a surface and leaving that surface in an equal but opposite direction.

refraction Refraction is the change in direction of a beam of light when it enters another medium.

repeater A networking device that exists at Layer 1, the physical layer, of the OSI reference model. The purpose of a repeater is to regenerate and retime network signals at the bit level, allowing them to travel a longer distance on the medium.

resistance The property of a material that resists electron movement.

RFI (radio frequency interference) Noise from other signals being transmitted nearby.

ring topology A topology in which hosts are connected in the form of a ring or circle. Unlike the physical bus topology, the ring topology has no beginning or end that needs to be terminated.

RIP (Routing Information Protocol) An IGP supplied with UNIX BSD systems. The most common IGP in the Internet. RIP uses hop count as a routing metric.

RJ-45 A connector commonly used for finishing a twisted-pair cable.

routed protocol A protocol that can be routed by a router. A router must be capable of interpreting the logical internetwork as specified by that routed protocol. Examples of routed protocols are AppleTalk, IPX, and IP.

router A network layer device that uses one or more metrics to determine the optimal path along which network traffic should be forwarded. Routers forward packets from one network to another based on network-layer information contained in routing updates. Occasionally called a *gateway* (although this definition of *gateway* is becoming increasingly outdated).

routing The process of finding a path to a destination host. Routing is very complex in large networks because of the many potential intermediate destinations that a packet might traverse before reaching its destination host.

Routing Information Protocol (RIP) An IGP supplied with UNIX BSD systems. The most common IGP in the Internet. RIP uses hop count as a routing metric.

routing metric A method by which a routing algorithm determines that one route is better than another. This information is stored in routing tables and is sent in routing updates. Metrics include bandwidth, communication cost, delay, hop count, load, MTU, path cost, and reliability. Sometimes simply called a *metric*.

routing protocol A protocol that accomplishes routing through the implementation of a specific routing algorithm. Examples of routing protocols are IGRP, OSPF, and RIP.

routing table A table stored in a router or some other internetworking device that keeps track of routes to particular network destinations and, in some cases, metrics associated with those routes.

routing update A message sent from a router to indicate network reachability and associated cost information. Routing updates are typically sent at regular intervals and after a change in network topology. Compare with flash update.

SCS (*structured cabling system*) Integrated cable plans that include the connectors, wiring, distribution centers, and installation techniques developed by specific companies.

segment A section of a network that is bounded by bridges, routers, or switches.

segment In the TCP specification, a logical information group at transport layers of the OSI reference model.

serial port Can be used for serial communication in which only 1 bit is transmitted at a time.

session layer Layer 5 of the OSI reference model. This layer establishes, manages, and terminates sessions between applications and manages data exchange between presentation layer entities.

shortest path first (SPF) algorithm A calculation performed on the database resulting in the SPF tree.

simplex The capability for transmission in only one direction between a sending station and a receiving station. Broadcast television is an example of a simplex technology.

sine waves Graphs of mathematical functions of many natural occurrences that change regularly over time, such as the distance from the earth to the sun, the distance from the ground while riding a Ferris wheel, and the time of day that the sun rises.

single-mode Single-mode is an optical fiber that has only one mode of light transmission. Contrast with multimode.

SNAP (*Subnetwork Access Protocol*) Internet protocol that operates between a network entity in the subnetwork and a network entity in the end system. SNAP specifies a standard method of encapsulating IP datagrams and ARP messages on IEEE networks. The SNAP entity in the end system makes use of the services of the subnetwork and performs three key functions: data transfer, connection management, and QoS selection.

SNMP (*Simple Network Management Protocol*) A network-management protocol used almost exclusively in TCP/IP networks. SNMP provides a means of monitoring and controlling network devices and managing configurations, statistics collection, performance, and security.

SNR (*signal-to-noise ratio*) The ratio of useable signal being transmitted to the undesired signal (noise). It is a measure of transmission quality. The ratio of good data (signal) to bad (noise) on a line, expressed in decibels (dB).

sound card An expansion board that handles all sound functions.

spectrum analyzer An electronic device that creates graphs for frequency-domain analysis. Engineers also use frequency-domain analysis to study signals.

split horizon A routing technique in which information about routes is prevented from exiting the router interface through which that information was received. Split-horizon updates are useful in preventing routing loops.

square waves Graphs that do not continuously vary with time. The values remain the same for some time, then suddenly change, then remain the same, and then suddenly return to the initial value.

SS (spread spectrum) A modulation technique developed in the 1940s that spreads a transmission signal over a broad band of radio frequencies. The term spread spectrum describes a modulation technique that sacrifices bandwidth to gain signal-to-noise performance.

standard A set of rules or procedures that are either widely used or officially specified.

standard ACL ACL that compares source IP addresses to the rules defining a standard ACL.

star topology The most commonly used physical topology in Ethernet LANs. The star topology is made up of a central connection point that is a device such as a hub, switch, or router, where all the cabling segments meet.

static routing The process of manually defining and configuring the routes.

storage-area network (SAN) A dedicated, high-performance network that moves data between servers and storage resources.

store-and-forward switching A packet-switching technique in which frames are processed completely before being forwarded out the appropriate port. This processing includes calculating the CRC and checking the destination address. In addition, frames must be stored temporarily until network resources (such as an unused link) are available to forward the message.

STP (shielded twisted-pair) STP is a two-pair wiring medium used in a variety of network implementations. STP cabling has a layer of shielded insulation to reduce EMI.

STP (Spanning Tree Protocol) Bridge protocol that uses the spanning tree algorithm, enabling a learning bridge dynamically to work around loops in a network topology by creating a spanning tree. Bridge exchange BPDU messages with other bridges to detect loops and then remove the loops by shutting down selected bridge interfaces.

straight-through cable A cable that maintains the pin connection all the way through the cable. Thus, the wire connected to pin 1 is the same on both ends of the cable.

structured cabling A uniform cabling system with standards that define the actual cable, cabling distances, type of cable, and type of terminating devices.

stub network An OSPF area that carries a default route, intra-area routes, and inter-area routes, but that does not carry external routes.

subnet address A portion of an IP address that is specified as the subnetwork by the subnet mask.

subnet mask A 32-bit address mask used in IP to indicate the bits of an IP address that are used for the subnet address. Sometimes simply called a *mask*.

subnetting The method of dividing full network address classes into smaller pieces. This has prevented complete IP address exhaustion.

subnetwork mask A 32-bit address mask used in IP to indicate the bits of an IP address that are being used for the subnet address.

subnetwork 1. In IP networks, a network sharing a particular subnet address. Subnetworks are networks arbitrarily segmented by a network administrator to provide a multilevel, hierarchical routing structure while shielding the subnetwork from the addressing complexity of attached networks. Sometimes called a *subnet*. 2. In OSI networks, a collection of ESs and ISs under the control of a single administrative domain and using a single network access protocol.

switch A device that connects LAN segments, uses a table of MAC addresses to determine the segment on which a frame needs to be transmitted, and reduces traffic. Switches operate at much higher speeds than bridges.

switch Network device that filters, forwards, and floods frames based on the destination address of each frame. The switch operates at the data link layer of the OSI model.

system routes Routes to networks within an autonomous system. Cisco IOS Software derives system routes from directly connected network interfaces and system route information provided by other IGRP-speaking routers or access servers. System routes do not include subnet information.

system unit The main component of a PC system.

TB (terabyte) Approximately 1 trillion bytes. Hard drive capacity on some high-end computers is measured in TB.

Tbps (terabits per second) One trillion bits per second. A standard measurement of the amount of data transferred over a network connection. Some high-speed core Internet routers and switches operate at more than Tbps.

TCP (*Transmission Control Protocol*) A connection-oriented transport-layer protocol that provides reliable full-duplex data transmission. TCP is part of the TCP/IP protocol stack.

TCP (*Transmission Control Protocol*) Connection-oriented transport layer protocol that provides reliable full-duplex data transmission. TCP is part of the TCP/IP protocol stack.

TCP/IP (*Transmission Control Protocol/Internet Protocol*) Common name for the suite of protocols developed by the U.S. Department of Defense in the 1970s to support the construction of worldwide internetworks. TCP and IP are the two best-known protocols in the suite.

TDR (*time domain reflectometer*) A device that can measure the lengths of cables that are installed and locate faults. It does these tasks by sending a signal down a cable and then measuring the amount of time that it takes for that signal to return.

Telnet A standard terminal emulation protocol in the TCP/IP protocol stack. Telnet is used for remote terminal connection, enabling users to log in to remote systems and use resources as if they were connected to a local system. Telnet is defined in RFC 854.

TFTP (*Trivial File Transfer Protocol*) Simplified version of FTP that allows files to be transferred from one computer to another over a network, usually without the use of client authentication (for example, username and password).

thicknet Thicknet is an early form of coaxial cable using 10BASE5 for networking. Thicknet was once desirable because it could carry signals up to 500 meters.

Thinnet Thinnet is a simple, thin, coaxial network cable for the 10BASE2 system. Thinnet can carry a signal only 185 meters, but was much easier to work with than thicknet.

three-way handshake A sequence of messages exchanged between two or more network devices to ensure transmission synchronization before sending user data.

throughput The rate of information arriving at or passing through a particular point in a network system.

TIA (*Telecommunications Industry Association*) TIA is a standards association that publishes standards for telecommunications.

TIA/EIA-568-B standard Specifies ten tests that a copper cable must pass if it is used for modern, high-speed Ethernet LANs.

TLVs (*Type Length Values*) Blocks of information embedded in CDP advertisements.

token passing An access method by which network devices access the physical medium in an orderly fashion based on possession of a small frame called a token.

Token Ring A token-passing LAN developed and supported by IBM. Token Ring runs at 4 or 16 Mbps over a ring topology.

topological database A collection of information gathered from LSAs.

TR (telecommunications room) The area within a building that houses the telecommunications cabling system equipment.

traceroute Program available on many systems that traces the path a packet takes to a destination. It is used mostly to debug routing problems between hosts.

trailer Control information appended to data when encapsulating the data for network transmission.

Transmission Control Protocol/Internet Protocol (TCP/IP) A common name for the suite of protocols developed by the U.S. DoD in the 1970s to support the construction of worldwide internetworks. TCP and IP are the two best-known protocols in the suite.

transport layer Layer 4 of the OSI reference model. This layer is responsible for reliable network communication between end nodes. The transport layer provides mechanisms to establish, maintain, and terminate virtual circuits, transport fault detection and recovery, and information flow control.

triggered update A triggered update is an update that is sent without waiting for the update timer to expire.

UDP (User Datagram Protocol) A connectionless transport layer protocol in the TCP/IP protocol stack. UDP is a simple protocol that exchanges datagrams without acknowledgments or guaranteed delivery, requiring that error processing and retransmission be handled by other protocols. UDP is defined in RFC 768.

unicast Message sent to a single network destination.

universal serial bus (USB) port Lets peripheral devices such as mice, modems, keyboards, scanners, and printers be plugged in and unplugged without resetting the system.

update timer Specifies how frequently routing update messages are sent. The IGRP default for this variable is 90 seconds.

uptime The amount of time that the device is functional and in service relative to the users' requirements for its availability.

UTP (unshielded twisted-pair) UTP is a four-pair wire medium used in a variety of networks.

vertical cabling Backbone cables, intermediate and main cross-connects, mechanical terminations, and patch cords or jumpers used for backbone-to-backbone cross-connections.

video card A board that plugs into a PC to give it display capabilities.

virtual private network (VPN) A private network constructed within a public network infrastructure such as the global Internet.

WAN (wide-area network) A data communications network spanning a large geographic area, such as a state, province or country. WANs often use transmission facilities provided by common carriers, for example, telephone companies.

wave Energy traveling from one place to another.

wavelength The length of a wave measured from any point on one wave to the corresponding point on the next wave. The wavelength of light is usually measured in nanometers (nm).

WDM (wavelength-division multiplexing) Multiple optical wavelength can share the same transmission fiber. The spectrum occupied by each channel must be separated adequately from the other.

web browser A graphical user interface (GUI)-based hypertext client application, such as Internet Explorer or Netscape Navigator, used to access hypertext documents and other services located on remote servers throughout the WWW and the Internet.

well-known ports These ports are defined in RFC 1700 and are reserved in both TCP and UDP. These well-known ports can identify applications that run above the transport layer protocols.

WEP (wired equivalent privacy) A security mechanism, defined within the 802.11 standard, that is designed to protect the over-the-air transmission between wireless LAN access points and NICs.

white noise Noise that affects all transmission frequencies equally.

wide-area network (WAN) A data communications network that serves users across a broad geographic area and often uses transmission devices provided by common carriers.

windowing A flow-control mechanism requiring that the source device receive an acknowledgment from the destination after transmitting a certain amount of data.

work area A space where computers, telephones, and other network equipment is used.



Appendix C

Check Your Understanding Answer Key

This appendix contains the answers to the Check Your Understanding review questions at the end of each chapter.

Chapter 1

1. The connection to the Internet can be broken down into which of the following?
D. All of the above
2. What is the main circuit board of a computer?
B. Motherboard
3. What are PCMCIA slots?
A. Slots used in laptops
4. What is a NIC?
B. A printed circuit board that provides network communication
5. Which of the following is/are the resource(s) you need before you install a NIC?
D. All of the above
6. Which number system is based on powers of 2?
C. Binary

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7. Match the following terms with their definitions:

1. Bit
 2. Byte
 3. kbps
 4. MHz
- A. The smallest unit of data in a computer
 - B. A standard measurement of the rate at which data is transferred over a network connection
 - C. A unit of frequency; the rate of change in the state or cycle in a sound wave, alternating current, or another cyclical waveform
 - D. A unit of measure that describes the size of a data file, the amount of space on a disk or another storage medium, or the amount of data being transferred over a network

Answers: 1-A, 2-D, 3-B, 4-C

8. What is the largest decimal value that can be stored in 1 byte?
C. 255
9. What is the decimal number 151 in binary?
B. 10010111
10. What is the binary number 11011010 in decimal?
C. 218
11. What is the binary number 0010000100000000 in hexadecimal?
A. 0x2100
12. What is the hexadecimal number 0x2101 in binary?
A. 0010 0001 0000 0001
13. Which of the following statements is true of ping?
D. All of the above

Chapter 2

1. What was the first type of microcomputer network to be implemented?
C. LAN
2. Using modem connections, how many modems would it take to allow connections from ten computers?
C. Ten
3. What is a code that is “burned in” to a network interface card?
B. MAC address
4. Which topology has all its nodes connected directly to one center point and has no other connections between nodes?
C. Star
5. What do TIA and EIA stand for?
B. Telecommunications Industry Association, Electronic Industries Alliance
6. LANs are designed to do which of the following? (Select all that apply.)
A. Operate within a limited geographic area
B. Allow many users to access high-bandwidth media
D. Provide full-time connectivity to local services
7. Which of the following statements best describes a WAN?
A. It connects LANs that are separated by a large geographic area.
8. Which of the following statements correctly describes a MAN?
C. A MAN is a network that spans a metropolitan area such as a city or suburban area.
9. Which of the following is *not* one of the features of a SAN?
D. SANs minimize system and data availability.
10. What service offers secure, reliable connectivity over a shared public network infrastructure?
B. Virtual private network

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11. What links enterprise customer headquarters, remote offices, and branch offices to an internal network over a shared infrastructure?
B. Intranet VPN
12. What is the name of the part of a company's LAN that is made available to select parties such as employees, customers, and partners?
B. The extranet
13. What is the movement of objects through layers?
B. Flow
14. The OSI model has how many layers?
D. Seven
15. What is the OSI model?
D. All of the above
16. Which of the following is the correct order of the network layers?
B.
 - 1: Physical
 - 2: Data link
 - 3: Network
 - 4: Transport
 - 5: Session
 - 6: Presentation
 - 7: Application
17. Which layer of the OSI model handles physical addressing, network topology, network access, and flow control?
B. The data link layer
18. Which of the following best defines encapsulation?
D. Wrapping data in a particular protocol header

19. An e-mail message is sent from Host A to Host B on a LAN. Before this message can be sent, the data must be encapsulated. Which of the following best describes what happens after a packet is constructed?
- B. The packet is put into a frame.**
20. In the TCP/IP model, which layer deals with reliability, flow control, and error correction?
- B. Transport**
21. Repeaters can provide a simple solution for what problem?
- D. Too many nodes or not enough cable**
22. Which of the following is true of a bridge and its forwarding decisions?
- C. Bridges operate at OSI Layer 2 and use MAC addresses to make decisions.**
23. Which of the following is true of a switch's function?
- B. Switches combine the connectivity of a hub with the traffic regulation of a bridge.**
24. What does a router route?
- C. Layer 3 packets**
25. Which of the following statements is true?
- C. A DSLAM serves as the interface point of between a number of subscriber premises and the carrier network.**
26. What is/are the function(s) of an AAA server? (Select all that apply.)
- D. All of the above**
27. What is/are the function(s) of a firewall? (Select all that apply.)
- A. Software-based**
- B. Hardware-based**
- C. Filter traffic**

Chapter 3

1. Match the columns:
 - 1) Neutrons A) Particles that have a negative charge
 - 2) Protons B) Particles that have no charge (neutral)
 - 3) Electrons C) Particles that have a positive charge

C. 1-B, 2-C, 3-A
2. Which of the following regarding electricity is untrue?
D. None of the above.
3. Match the following to their respective units of measurement:
 - 1) Voltage A) Ohm
 - 2) Current B) Ampere
 - 3) Resistance C) Volt

D. 1-C, 2-B, 3-A
4. Electrons flow in _____ loops called _____.
D. Closed, circuits
5. What is the maximum cable length for STP?
C. 100 meters
6. How many pairs of wires make up a UTP cable?
B. 4
7. Which connector does UTP use?
C. RJ-45
8. What is an advantage that coaxial cable has over STP or UTP?
C. It can run for a longer distance unboosted.
9. What does the twisting of the wires do in a twisted-pair cable?
C. It reduces noise problems.
10. What is the importance of the EIA/TIA standards? Select all that apply.
 - B. They provide guidelines for manufacturers to follow to ensure compatibility.**
 - C. They provide the minimum media requirements for multiproduct and multi-vendor environment.**

11. A _____ fiber-optic cable transmits multiple streams of LED-generated light.
A. Multimode
12. What is one advantage of using fiber-optic cable in networks?
D. It is capable of higher data rates than either coaxial or twisted-pair cable.
13. Which fiber-optic cable type is typically used for outside installations?
D. Loose-tube
14. What is the light source typically used in single-mode fiber optics?
B. Laser
15. Which term describes the angle at which a ray hits a glass surface?
C. Angle of incidence
16. Modulation is a process of changing amplitude, frequency, or phase. Which acronym does *not* represent a type of modulation?
D. RM
17. Which range does *not* correctly identify an unlicensed wireless frequency?
C. 9 GHz
18. Which statement does *not* describe a benefit of spread spectrum?
A. Spread-spectrum transmissions are transmitted at high speeds.
19. Which statement does *not* describe the features of direct-sequence spread spectrum (DSSS)?
C. DSSS technology has low throughput of data and short-range access.
20. Which of the following is *not* a feature of wired equivalent privacy (WEP)?
C. WEP is a security mechanism defined within in the 802.3 standards.

Chapter 4

1. Which of the following is an 802.3u specification?
C. 100BASE-TX
2. Which of the following is the most appropriate choice for Ethernet connectivity?
C. Use Fast Ethernet as a link between the user level and network devices to support the aggregate traffic from each Ethernet segment on the access link.

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3. Which standards body created the cables and connector specification used to support Ethernet implementation?
C. TIA/EIA
4. Which of the following statements does *not* correctly describe a media connector?
A. An RJ-45 connector is an 8-pin connector used mainly for terminating coaxial cable.
5. For which of the following would you *not* need to provide a crossover cable?
B. Connecting routers to switches
6. Which technology is *not* a type of wireless communication?
B. Wideband
7. Which of the following is *not* a feature of wired equivalent privacy (WEP)?
B. WEP is a security mechanism defined within in the 802.3 standards.
8. Which of the following is not a WAN implementation?
D. Ethernet
9. What type of data-transmission method is used by a WAN?
B. Serial
10. What best describes a DCE?
D. Devices that make up the network end of the user-to-network interface
11. Which of the following media is used to interconnect the ISDN BRI port to the service-provider device?
A. CAT 5 UTP straight-through
12. What type of connector is used for DSL connection?
B. RJ-11
13. What type of connector is used to connect a router and a cable system?
C. F
14. What type of cable is used to connect a terminal and a console port?
B. Rollover

Chapter 5

1. Which of the following is *not* one of the recognized IEEE sublayers?
B. Data Link Control
2. The recognized IEEE sublayers are concerned with what layers of the OSI reference model?
B. 1 and 2
3. The LLC, as a sublayer, participates in the _____ process.
B. Encapsulation
4. The first six hexadecimal numbers in a MAC address represent an _____?
B. Organizationally unique identifier
5. MAC addresses are _____ bits in length.
C. 48
6. What is the name of the access method used in Ethernet that explains how Ethernet works?
B. CSMA/CD
7. Where does the MAC address reside?
C. NIC
8. Which of the following statements best describes communication between two devices on a LAN?
A. The source device encapsulates data in a frame with the MAC address of the destination device and then transmits it. Everyone on the LAN sees it, but the devices with nonmatching addresses otherwise ignore the frame.
9. Which functions are associated with framing?
D. All of the above
10. How does a computer on a LAN detect an error in a frame?
C. It compares an FCS in the frame to one that the computer calculates from the contents of the frame.
11. Media Access Control refers to what?
C. Protocols that determine which computer on a shared-medium environment is allowed to transmit the data

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12. Which best describes a CSMA/CD network?
 - A. One node's transmission traverses the entire network and is received and examined by every node.
13. In an Ethernet or IEEE 802.3 LAN, when do collisions occur?
 - B. When two stations listen for a traffic, hear none, and transmit simultaneously
14. Which is an important Layer 2 data link layer function?
 - D. All of the above
15. Which of the following is an Ethernet frame error type?
 - D. All of the above
16. Which protocol is a nondeterministic protocol?
 - B. CSMA/CD
17. Which is true of a deterministic MAC protocol?
 - C. It allows hosts to "take turns" sending data.
18. The network area within which data packets originated and collide is called a _____?
 - A. Collision domain
19. Which best describes broadcasting?
 - A. Sending a single frame to many stations at the same time
20. Using repeaters _____ the collision domain.
 - C. Extends
21. The process of using the complex networking devices, such as bridges, switches, and routers, to break up the collision domains is known as:
 - B. Segmentation

Chapter 6

1. What is the name of the method used in Ethernet that explains how Ethernet works?
 - B. CSMA/CD

2. What is the maximum distance for thick Ethernet without using a repeater?
C. 500m (1640.4 ft.)
3. 10-Mbps Ethernet operates within the timing limits offered by a series of no more than _____ segments separated by no more than _____ repeaters.
C. Five, four
4. Fast Ethernet supports up to what transfer rate?
C. 100 Mbps
5. Identify two Gigabit Ethernet cable specifications.
C. 1000BASE-SX
D. 1000BASE-LX
6. What is the transmission medium for 1000BASE-SX?
D. Short-wave laser over multimode fiber
7. 4D-PAM5 encoding method is used in which of the following Gigabit Ethernet?
C. 1000BASE-T
8. What is the IEEE standard for 10-Gb Ethernet?
C. 802.3ae
9. Which of the following is *not* a feature of microsegmentation?
D. It increases collisions.
10. Which of the following is used by LAN switches for making the forwarding decision?
B. MAC address
11. Which of the following is a feature of full-duplex transmission?
D. All of the above.
12. The three common types of switching methods are _____, _____, and _____.
Answer: store-and-forward, cut-through, and fragment-free
13. The Spanning-Tree Protocol allows which of the following?
B. A redundant network path without suffering the effects of loops in the network

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14. Which of the following is *not* one of the STP port states?
D. Transmitting
15. Which of the following is true concerning a bridge and its forwarding decisions?
C. Bridges operate at OSI Layer 2 and use MAC addresses to make decisions.
16. Which of the following is *not* a feature of bridges?
C. They do not make any forwarding decisions.
17. Which of the following statements is true of microsegmentation?
A. Each workstation gets its own dedicated segment through the network.
18. Which of the following is true for LAN switches?
B. They are very high-speed multiport bridges.

Chapter 7

1. What transport layer protocol does TFTP use?
C. UDP
2. Which of the following is a basic service of the transport layer?
D. All of the above
3. Which of the following protocols operate at the TCP/IP Internet layer?
D. All of the above
4. What is the first thing that happens when a DHCP client boots?
C. DHCPDISCOVER
5. How does the network layer forward packets from the source to the destination?
A. By using a routing table
6. If a device doesn't know the MAC address of a device on an adjacent network, it sends an ARP request to what?
D. All of the above
7. What is in a RARP request?
A. A MAC header and the RARP request message

8. What are the two parts of an IP address?
 - A. Network address and host address
9. What Internet protocol is used to map a known IP address to an unknown MAC address?
 - C. ARP
10. Which of the following initiates an ARP request?
 - D. A device that cannot locate the destination MAC address in its ARP table
11. Which of the following best describes an ARP table?
 - D. A section of RAM on each device that maps IP addresses to MAC addresses
12. Which of the following best describes the ARP reply?
 - A. A device sends its MAC address to a source in response to an ARP request
13. Why are current, updated ARP tables important?
 - B. For limiting the number of broadcasts
14. Why is a RARP request made?
 - A. A source knows its MAC address but not its IP address.
15. Which of the following best describes TCP/IP?
 - A. It is a suite of protocols that can be used to communicate across any set of interconnected networks.
16. Which of the following does not describe the TCP/IP protocol stack?
 - A. It maps closely to the OSI reference model's upper layers.
17. The TCP/IP protocol suite has specifications for which layers of the OSI model?
 - C. 3, 4, and 5 through 7
18. Which of the following is not a function of the network layer?
 - D. UDP provides connectionless exchange of datagrams without acknowledgments.
19. Which of the following is one of the protocols found at the transport layer?
 - B. UDP

Chapter 8

- How many bits are in an IP address?
B. 32
- What is the maximum value of each octet in an IP address?
B. 255
- The network number plays what part in an IP address?
A. It specifies the network to which the host belongs.
- The host number plays what part in an IP address?
B. It designates which node on the subnetwork is being addressed.
- What is the decimal equivalent of the binary number 101101?
C. 45
- Convert the decimal number 192.5.34.11 to its binary form.
A. 11000000.00000101.00100010.00001011
- Convert the binary IP address 11000000.00000101.00100010.00001011 to its decimal form.
D. None of the above
- What portion of the Class B address 154.19.2.7 is the network address?
B. 154.19
- What portion of the IP address 129.219.51.18 represents the network?
A. 129.219
- Which of the following addresses is an example of a broadcast address on the network 123.10.0.0 with a subnet mask of 255.255.0.0?
B. 123.10.255.255
- How many host addresses can be used in a Class C network?
B. 254
- How many subnets can a Class B network have?
D. None of the above
- What is the minimum number of bits that can be borrowed to form a subnet?
B. 2

14. What is the primary reason for using subnets?
C. To reduce the size of the broadcast domain
15. How many bits are in a subnet mask?
B. 32
16. Performing the Boolean function as a router would on the IP addresses 131.8.2.5 and 255.0.0.0, what is the network/subnetwork address?
D. None of the above
17. How many bits can be borrowed to create a subnet for a Class C network?
C. 6
18. With a Class C address of 197.15.22.31 and a subnet mask of 255.255.255.224, how many bits have been borrowed to create a subnet?
C. 3
19. Performing the Boolean function as a router would on the IP addresses 172.16.2.120 and 255.255.255.0, what is the subnet address?
C. 172.16.2.0
20. Which of the following best describes one function of Layer 3, the network layer, in the OSI model?
C. It determines which is the best path for traffic to take through the network.
21. What function allows routers to evaluate available routes to a destination and to establish the preferred handling of a packet?
B. Path determination
22. How does the network layer forward packets from the source to the destination?
A. By using an IP routing table
23. What are the two parts of a network layer address that routers use to forward traffic through a network?
A. Network address and host address

Chapter 9

1. When conversing with an individual whose primary language is different than yours, you might need to repeat your words and speak more slowly. Repeating your words can be compared to _____, and the need to speak slowly can be compared to the _____ functions of the transport layer.
A. Reliability; flow control
2. The following characteristics describe what TCP/IP protocol: connection-oriented; resends anything not received; divides outgoing messages into segments.
B. TCP
3. What does the window field in a TCP segment indicate?
D. Number of octets that the device is willing to accept
4. What transport protocol exchanges datagrams without acknowledgments or guaranteed delivery?
A. UDP
5. What do TCP and UDP use to keep track of different conversations crossing a network at the same time?
A. Port numbers
6. How does TCP synchronize a connection between the source and the destination before data transmission?
B. Three-way handshake
7. Which range of port numbers is unregulated?
D. Above 1023
8. With TCP transmission, what occurs if a segment is not acknowledged in a certain time period?
D. Retransmission occurs.
9. Which best describes flow control?
C. A method of preventing buffer overrun
10. Which of the following best describes the purpose of the TCP/IP protocol stack?
C. Transfers information from one host to another in a sequence of datagrams

11. Which of the following is one of the protocols found in the transport layer?
B. UDP
12. What is the purpose of port numbers?
A. They keep track of different upper-layer conversations crossing the network at the same time.
13. Why are TCP three-way handshake/open connections used? Select all that apply.
A. To ensure that lost data can be recovered if problems occur later
B. To determine how much data the receiving station can accept at one time
14. What does a dynamic TCP window field do?
C. It allows the window size to be negotiated dynamically during the TCP session, which results in more efficient use of bandwidth.
15. UDP segments use what protocols to provide reliability?
B. Application layer protocols
16. A network redirector enables data to travel _____.
D. None of the above
17. An example of a client/server application is _____.
A. E-mail
18. The client side of the client/server relationship is _____.
B. The requestor of services
19. Which of the following best describes a domain name?
A. It represents the numeric address of an Internet site.
20. .com is the domain typically assigned to _____.
D. Corporations
21. During a Telnet connection, the remote computer is responsible for _____.
B. Processing
22. At which three layers of the OSI model does Telnet primarily work?
D. Application layer, presentation layer, session layer

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23. Typical anonymous FTP sessions use _____ as the login ID and _____ as the password.
- A. Anonymous; the user e-mail address**
24. Instead of working with specific application programs, redirectors work with _____.
- A. Computer operating systems**

Chapter 10

1. Which of the following best describes a WAN?
- A. Connects LANs that are separated by a large geographic area**
2. How do WANs differ from LANs?
- A. WANs emphasize access over serial interfaces operating at lower speeds.**
3. Which of the following are examples of WAN technologies?
- B. Frame Relay, ISDN**
4. Which layers of the OSI model do WAN standards describe?
- D. Physical and data link**
5. Which best describes data circuit-terminating equipment (DCE)?
- D. Consists of physical devices at the end of a WAN connection**
6. Which of the following components provides interface voice-grade services, channel service units/digital service units (CSUs/DSUs) that interface T1/E1 services, and terminal adapters/Network Termination 1 (TAs/NT1s) that interface Integrated Services Digital Network (ISDN) services?
- C. Modems**
7. Which of the following concentrates the dial-in and dial-out user connections?
- D. Communication servers**
8. Some WAN physical and data link layer standards are:
- D. All of the above**

9. Match the functions with the components.

- A. RAM/DRAM
- B. NVRAM
- C. ROM
- D. Flash memory
- E. Interface

Options:

- A. RAM that retains its contents when a unit is powered off
 - B. Volatile memory that can be read and written by the microprocessor
 - C. Volatile memory that can be read but not written by a microprocessor
 - D. Nonvolatile storage that can be electrically erased and reprogrammed so that software images can be stored, booted, and rewritten as necessary
 - E. Connection between two systems or devices
- D. 1-b, 2-a, 3-c, 4-d, 5-e

10. Any internetwork will probably include the following:

- D. All of the above

11. Which of the following are data link encapsulations for WAN?

- D. All of the above

12. What are the main functions of routers?

- D. Both A and B

13. Which is an IBM-designed WAN data link for Systems Network Architecture (SNA) environments, largely being replaced by the more versatile HDLC?

- C. Synchronous Data Link Control Protocol

14. Which WAN data link protocol is used for signaling and call setup on an ISDN D channel?

- A. LAPD

15. Identify the WAN circuit-switched service(s):

- D. Both A and C

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16. Which service has become an extremely popular WAN technology in its own right, is more efficient than X.25 but with similar services, has a maximum bandwidth of 44.736 Mbps, and offers extremely popular 56-Kbps and 384-Kbps implementations in the United States?
- A. Frame Relay
17. Identify the cell-switched technology/technologies:
- D. Both A and B
18. Identify the common type(s) of DSL technology/technologies:
- D. All of the above
19. Which is a family of very high-speed physical layer technologies with a series of data rates available with special designations, implemented at different Optical Carrier (OC) levels ranging from 51.84 Mbps (OC-1) to 9952 Mbps (OC-192), that can achieve these amazing data rates by using wavelength division multiplexing (WDM)?
- A. SONET
20. Which are the kind of routers that form the primary paths for traffic that is sourced from and destined to other networks?
- C. Backbone routers

Chapter 11

1. A router initializes by doing which of the following?
- C. Loading the bootstrap, the setup procedure, and the operating system
2. During the setup process in a router, what keys can be used to escape the sequence?
- C. Ctrl + c
3. Match the configuration setting on the right with the items on the left that are needed to establish a HyperTerminal session:
- | | |
|-----------------|------|
| A. BAUD | None |
| B. DATA BITS | 1 |
| C. PARITY | 8 |
| D. STOP BITS | None |
| E. FLOW CONTROL | 9600 |

Answers:**BAUD = 9600****DATA BITS = 8****PARITY = None****STOP BITS = 1****FLOW CONTROL = None**

4. Which of the following is true at initial boot-up output?
 - A. The Cisco IOS Software version that the router uses can be seen.
5. Which of the following is true at initial boot-up output?
 - A. The amount of Flash memory can be seen.
6. Match the commands on the left with the correct descriptions on the right.

Ctrl + a	Moves out of configuration mode
Ctrl + b	Moves to the end of the command line
Ctrl + e	Moves back one word
Ctrl + f	Moves to the beginning of the command line
Esc + b	Moves forward one character
Esc + f	Moves forward one word
Ctrl + z	Moves back one character

Answers:**Ctrl + A: Moves to the beginning of the command line****Ctrl + B: Moves back one character****Ctrl + E: Moves to the end of the command line****Ctrl + F: Moves forward one character****Esc + B: Moves back one word****Esc + F: Moves forward one word****Ctrl + Z: Moves out of configuration mode**

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7. Match the commands on the left with the correct descriptions on the right.

Tab	Enables advanced editing
Ctrl + P	Sets the command buffer size
Ctrl + N	Recalls the most recent command
show history	Shows the command buffer
terminal history size #	Recalls the last command
terminal editing	Completes the entry
no Terminal editing	Disables advanced editing features

Answers:

Tab: Completes the entry

Ctrl + P: Recalls the last command

Ctrl + N: Recalls the most recent command

show history: Shows the command buffer

terminal history size #: Sets the command buffer size

terminal editing: Enables advanced editing

No Terminal editing: Disables advanced editing features

8. What are the major elements of a typical router configuration?

A. Passwords, interfaces, routing protocols, DNS

9. Which of the following correctly describes a method for specifying how a router loads the Cisco IOS Software?

A. Designate fallback sources for the router to use in sequence from NVRAM.

10. Which of the following is not a boot option that can be set with the configuration register boot field?

C. Cisco IOS Software automatically boots from a TFTP server.

11. Which of the following is information displayed by the Cisco IOS Software **show version** command?

B. The name of the system image

12. Which of the following has a limited version of router Cisco IOS Software?

A. ROM

13. If you want to completely back out of configuration mode, which of the following must you enter?
A. Exit
14. If you are planning to configure an interface, what prompt should be on the router?
D. router(config-if)#
15. What is the acronym used to describe a Cisco router's text-based user interface?
A. CLI
16. What two modes of access to router commands exist for Cisco routers?
A. User and privileged
17. Which mode do you use to make router configuration changes on Cisco routers?
B. Privileged

Chapter 12

1. What is a standard?
B. A set of rules or procedures that are either widely used or officially specified
2. A description on an interface does what?
C. Displays a comment about the interface
3. A good example of a login banner is what?
C. Authorized access only
4. What is host name resolution?
A. The process of associating a name with a network location
5. Configuration backup and documentation is necessary to an organization to maintain an efficient network. True or false?
A. True
6. Backup of configuration files is not necessary. True or false?
B. False

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7. A TFTP server is the only location where backup files can be stored. True or false?
- B. False**
8. If you are planning to configure an interface, what prompt should be on the router?
- D. router(config-if)#**
9. Which of the following is the correct order for the process of configuring a router? (Assume that you have already made router changes in configuration mode.)
- B. Examine the results, decide whether the changes are your intended results, save the changes to backup, and examine the backup file.**
10. Which of the following is a command that can be used to save router configuration changes to a backup?
- A. Router# copy running-config tftp**
11. Which of the following correctly describes password configuration on routers?
- C. A password can be established on all incoming Telnet sessions.**
12. Which of the following does not describe password configuration on routers?
- A. Passwords can be established in every configuration mode.**
13. What is used for one-line commands that change the entire router?
- A. Global configuration mode**
14. What does the `exit` command do in a configuration mode with the prompt `Router(config-if)#`?
- A. It quits the current configuration interface mode.**
15. What are the major elements of a typical router configuration?
- A. Passwords, interfaces, routing protocols, DNS**
16. In a password-recovery procedure, immediately after issuing a `Ctrl-BREAK` upon router startup, what should be the config register setting?
- B. 0x2142**
17. In a password-recovery procedure, just before saving the running config and after you have enabled a new secret password, what should be the config register setting?
- 0x2102**

Chapter 13

1. What is a definition for **telnet**?
 - C. A command used to verify the application layer software between source and destination stations. This command is the most complete test mechanism available.
2. What information does testing a network by using the **show interfaces serial** command provide?
 - A. It displays line and data link protocol status.
3. What information does the **show cdp neighbors** command provide for each CDP neighbor?
 - D. All of the above
4. The **show cdp interface** command is used to display which of the following?
 - D. Both A and B
5. Which of these is true for the output of the command **show cdp entry [device name]**?
 - A. It displays all the Layer 3 addresses present in the neighbor router.
6. To display the information that is obtained both from the **show cdp neighbors** and **show cdp entry [device name]** commands, which of the following commands is used?
 - A. **show cdp neighbors detail**
7. What information is displayed by the **show cdp neighbors** command?
 - D. All of the above
8. What four important pieces of information do you receive after issuing a **ping** command?
 - A. The size and quantity of ICMP packets; the timeout duration; the success rate; and the minimum, average, and maximum round-trip times
9. What information does testing a network by using the **traceroute** command provide?
 - C. It maps every router that a packet goes through to reach its destination.

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10. In reply to the **ping** command, exclamation points (!) indicate which of these?
- A. The number of successful echos
11. What is true of the router **debug** commands?
- D. Both A and B.

Chapter 14

1. Which of the following correctly describes a method for specifying how a router loads the Cisco IOS software?
 - A. Designate fallback sources for the router to use in sequence from NVRAM.
2. Which of the following is not a boot option that can be set with the configuration register boot field?
 - C. Cisco IOS Software automatically boots from a TFTP server.
3. Which of the following is information displayed by the **show version** command?
 - B. The name of the system image
4. Which command is used to discover the configuration register setting?
 - C. **show version**
5. What information is not provided in the Cisco image filename system?
 - D. The size of the image
6. Which of the following is not part of the recommended procedure for loading a new Cisco IOS Software image to Flash memory from a TFTP server? (The procedures are listed in correct order.)
 - B. Enter the **copy flash tftp** command to start downloading the new image from the server.
7. What is the initial boot attempt if the router configuration register is set to 0x101?
 - C. ROM
8. Which of the following has a limited version of router Cisco IOS Software?
 - A. ROM

9. What is the initial boot attempt if the router configuration register is set to 0x102?
D. Check for boot system commands
10. Which of the following is the sequence used by the router for automatic fallback to locate the Cisco IOS Software?
D. TFTP server, (2) Flash memory, (3) NVRAM
11. Which of the following is not displayed by the Cisco IOS **show version** command?
A. Statistics for configured interfaces
12. Which of the following correctly describes preparing to use a TFTP server to copy software to Flash memory?
A. The TFTP server must be a connected router or a host system, such as a UNIX workstation or a laptop computer.
13. Why do you create a Cisco IOS Software image backup?
D. To create a fallback copy of the current image before updating with a new version
14. What is the command you need to issue if you want to upgrade an old version of the Cisco IOS Software by downloading a new image from the TFTP server?
B. copy tftp flash

Chapter 15

1. Which of the following best describes one function of Layer 3, the network layer, in the OSI model?
C. It determines which is the best path for traffic to take through the network.
2. What function allows routers to evaluate available routes to a destination and to establish the preferred handling of a packet?
B. Path determination
3. How does the network layer forward packets from the source to the destination?
A. By using an IP routing table

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4. What two parts of a network layer address do routers use to forward traffic through a network?
A. Network address and host address
5. Which of the following best describes a routed protocol?
A. Its address provides enough information to allow a packet to be forwarded from host to host.
6. Which of the following best describes a routing protocol?
A. A protocol that accomplishes routing through the implementation of an algorithm
7. What is one advantage of distance vector algorithms?
D. They are computationally simple.
8. Which of the following best describes a link-state algorithm?
A. It recreates the exact topology of the entire internetwork.
9. Why do routing loops occur?
A. Slow convergence occurs after a modification to the internetwork.
10. Which of the following best describes balanced hybrid routing?
A. It determines best paths, but topology changes trigger routing table updates.
11. What is a network with only one path to a router called?
D. Stub network
12. Which best describes a default route?
C. Route used when the destination network is not listed explicitly in the routing table

Chapter 16

1. What kind of entries does a router initially refer to?
A. Entries about networks or subnets that are directly connected
2. Which of the following best describes a static route?
B. A route that is explicitly configured and entered into the routing table and that takes precedence over routes chosen by dynamic routing protocols

3. Which of the following best describes a default route?
 - A. A routing table entry that is used to direct frames for which a next hop is not explicitly listed in the routing table
4. What are exterior routing protocols used for?
 - C. To communicate between autonomous systems
5. What are interior routing protocols used for?
 - D. They are used within a single autonomous system.
6. Which of the following is a global task?
 - B. Enabling a routing protocol such as RIP or IGRP
7. What metric does RIP use to determine the best path for a message to travel on?
 - B. Hop count
8. You suspect that one of the routers connected to your network is sending bad routing information. What command can you use to check?
 - C. `router> show ip protocol`
9. Why would you display the IP routing table?
 - B. To identify destination network addresses and next-hop pairs
10. If you want to learn which routing protocol a router was configured with, what command structure should you use?
 - D. `router> show ip protocol`
11. In the following command, what does the last number stand for? Router
(config)# `ip route 2.0.0.0 255.0.0.0 1.0.0.2 5`
 - C. The administrative distance
12. An administrative distance of 15 indicates which of the following?
 - C. The routing information source is relatively trustworthy.
13. If you just added a new LAN to your internetwork and you want to manually add the network to your routing table, what command structure would you use?
 - B. `router (config)# ip route 2.0.0.0 255.0.0.0 1.0.0.2`

Chapter 17

1. ICMP is an error-reporting protocol for IP. True or false?
A. True
2. ICMP stands for what?
D. Internet Control Message Protocol
3. ICMP messages are encapsulated as data in datagrams in the same way that any other data is delivered using IP. True or false?
A. True
4. A default gateway must be configured if datagrams are to travel outside the local network. True or false?
A. True
5. TTL stands for what?
B. Time-To-Live
6. All ICMP message formats start with which of these fields?
D. All of the above
7. Default gateways send ICMP redirects/change requests only when which of the following conditions are met?
E. All of the above
8. The Type field on an ICMP timestamp message can be either a 13 (timestamp request) or what?
A. 14 timestamp reply
9. All ICMP timestamp reply messages do not contain the originate, receive, and transit timestamps. True or false?
B. False
10. What is ICMP type number for a router-solicitation message?
B. 10

Chapter 18

1. When a technician performs basic testing of a network, which of the following is true?
 - A. The technician should proceed in sequence from one OSI reference model layer to the next.
2. What approach should a technician start with when he/she troubleshoots a network?
 - A. The technician should start with a structured approach.
3. When a technician troubleshoots a problem on a network, which layer of the OSI model should he/she begin with?
 - A. Begin with Layer 1
4. If a technician wants to test network connectivity, which basic command should be used?
 - B. ping
5. When a network administrator wants to verify the application layer software between source and destination stations, which of the following commands should be used?
 - B. telnet
6. You suspect that one of the routers connected to your network is sending bad routing information. What command can you use to check?
 - B. router# show ip route
7. Why would you display the IP routing table?
 - D. To set the parameters and filters for the router
8. If you wanted to see RIP routing updates as they are sent and received, what command structure would you use?
 - C. router# debug ip rip
9. The dynamic output of the **debug** command comes at a performance cost, which produces _____ processor overhead?
 - A. High
10. By default, the router sends the **debug** output and system messages to what?
 - A. The console

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11. The **telnet** command provides what type of terminal?
B. Virtual
12. ICMP stands for what?
C. Internet Control Message Protocol
13. Most interfaces or NICs have what type of lights that show whether there is a valid connection?
A. Indicator
14. Telnet is used at what layer of the OSI reference model?
D. Layer 7
15. If the routing protocol is not enabled or the IP address cannot be determined, at which layer of the OSI model should an administrator begin to look?
C. Layer 3

Chapter 19

1. Which of the following best describes TCP/IP?
A. It is a suite of protocols that can be used to communicate across any set of interconnected networks.
2. Which of the following is one of the protocols found at the transport layer?
B. UDP
3. What is the purpose of port numbers?
A. They keep track of different conversations crossing the network at the same time.
4. Which of the following best describes UDP?
D. A protocol that exchanges datagrams without acknowledgments or guaranteed delivery
5. Which of the following TCP/IP layers includes file transfer, e-mail, remote login, and network management?
B. Application
6. Why are TCP three-way handshake/open connections used?
A. To ensure that lost data can be recovered if problems occur later

7. What does a TCP sliding window do?
 - C. It allows the window size to be negotiated dynamically during the TCP session, which results in more efficient use of bandwidth.
8. UDP segments use what protocols to provide reliability?
 - B. Application layer protocols
9. Which of the following best describes window size?
 - B. The number of messages or bytes that can be transmitted while awaiting an acknowledgment
10. What is the function of ARP?
 - C. It is used to map an IP address to a MAC address.

Chapter 20

1. Common ACL functions include filtering packets internally, protecting the internal network from illegal Internet access, and restricting access to virtual terminal ports. True or false?
 - A. True
2. ACL is an acronym for:
 - D. Access control list
3. A(n) _____ ACL works by comparing the source IP address against the ACL rules.
 - C. Standard
4. A(n) _____ ACL works by comparing the source IP address, destination IP address, or other parameters against the ACL rules.
 - A. Extended
5. A(n) _____ ACL uses names instead of numbers to distinguish ACLs.
 - B. Named
6. As a general rule, ACLs should be placed where in the network?
 - C. Closest to the traffic to be controlled

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7. In a firewall architecture, which router most likely will be configured with an ACL?
C. The exterior router
8. Named ACLs were introduced in Cisco IOS 11.2. True or false?
B. False
9. What command is used to apply an ACL to a VTY port?
A. ip access-list
10. Which of the following commands would you use to find out whether any ACLs are set on an interface?
C. show ip interface
11. What do you call the additional 32 bits of information in the access-list statement?
A. Wildcard bits
12. If you want to permit traffic based on its addressing or protocol type, you would use which of the following commands?
B. Router (config)#access-list access-list number {permit | deny} {test conditions}
13. Standard IP access lists permit or deny routing of a packet based on the IP address that it originates from and the protocol suite that it is destined for. True or false?
A. True
14. Access lists impact network security based on which of the following factors?
C. The source subnet/host/network of the packets
15. What type of networking device would be needed to implement access lists to increase network security?
B. Router
16. What does the following access list allow? `access-list 1 permit 204.211.19.162 0.0.0.0`
B. "Permit a specific host."

Answers to Hints in Appendix A

What is the purpose of this floor?

Answer: Warehouse, reception area

What door will workers move freight through?

Answer: The large garage doors at the rear of the building

What doors will visitors come in?

Answer: Front doors off lobby that has reception station in it.

Where are visitors most likely to go after they sign in?

Answer: The conference room adjacent to the reception area

Where would you consider using wireless technology?

Answer: Guests could log on to the Internet via wireless in the reception and conference areas. Warehouse staff could use wireless for inventory.

If your department someday is tasked with wiring IP security cameras, what areas would you want to keep under surveillance?

Answer: The two secure storage areas, the rear walkthrough door, and the reception area

From where does the telephone company serve this building?

Answer: There is a point of presence [POP] next to the mechanical room.

What kind of lock should it have?

Answer: A good one that can be opened from the inside

Would the POP be a good place for the servers?

Answer: Possibly—it is certainly big enough and is close to the elevators, for easy access.

If it is determined that the server room must exist separate from the POP, what considerations should guide its location?

Answer: The location should be in a TR and should be on a middle floor.

Could you install the risers in the POP?

Answer: No. Check the floor above, and you will see that it has a conference room in that position.

Where might you install the risers?

Answer: There is a small hallway adjacent to each stairway. Check that out.

1044 Appendix C: Check Your Understanding Answer Key

The horizontal cabling always should go parallel to walls. Getting to Room 1.2 while staying parallel to walls makes a cable run of how many meters? Is this useable?

Answer: The distance is about 94 meters. This is barely enough to make the run, go down the walls, and join a work-area connector. The designer must decide whether to cheat a little bit or to take advantage of the wireless system that is installed for the warehouse or conference room. This would present a security hassle but would solve a major problem.

Where might you put the telecommunications room on Floor 2? You might consider using two of them.

Answer: Room 2.31 because it offers ceiling access to Room 3.10 above and to the mechanical room below. You might need to add one at Room 2.7 to accommodate the offices against that wall.

Floor 3 has large unplanned spaces in Rooms 3.1 and 3.2. If you place the telecommunications room in Room 3.10, how can you serve these spaces, especially the far side of Room 3.2?

Answer: Wireless is a good solution for now. Then when the rooms are built out, put a second telecommunications room in either of them.

You notice a large deck on Floor 4, as well as a banquet area with a piano. What would you need to provide network connectivity to this area?

Answer: You would need only one TR and some wireless to serve this area.

Where will you put the TR?

Answer: This is tough. Room 4.5 seems to be an office. However, Room 4.8 is blank. Also, there is a hallway with an exterior door shown next to the staircase by Room 4.10. Because this is the fourth floor, you suspect an error. Furthermore, Room 4.10 is shown with a door facing into a stairwell. Chances are, you could mention these apparent errors and at the same time request that a TR be installed between Rooms 4.4 and 4.5.





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