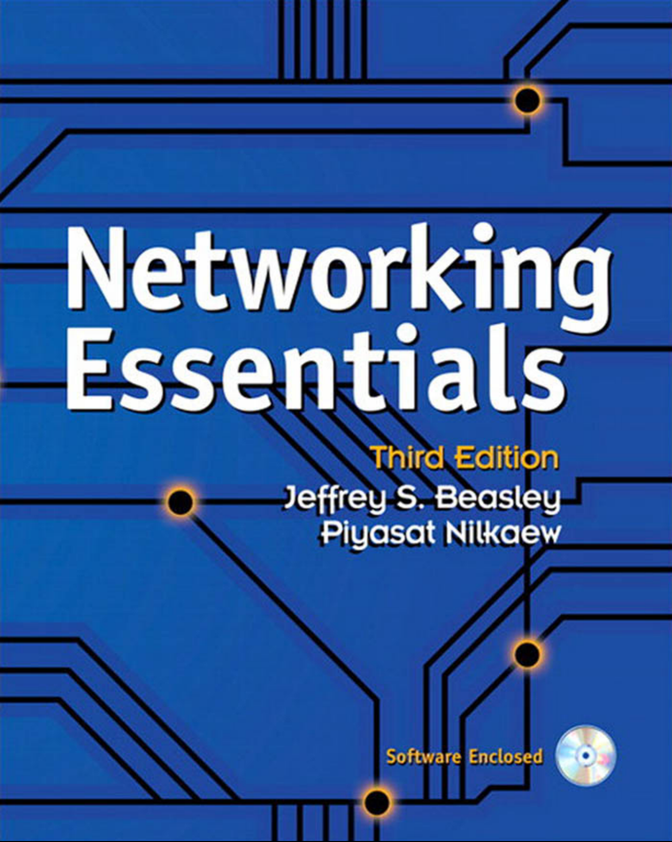
Networking Essentials
Third Edition
Jeffrey S. Beasley
Piyasat Nilkaew
Software Enclosed

Networking Essentials

Third Edition

Jeffrey S. Beasley and
Piyasat Nilkaew

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Dedications

This book is dedicated to my family, Kim, Damon, and Dana.
–Jeff Beasley

This book is dedicated to my parents, Boonsong and Pariya Nilkaew. Thank you for your unwavering love and support that guide me through various stages of my life. Thank you for all the wisdom and values you have instilled in me to build my life's foundation. You are my best teachers and I am eternally grateful.
–Piyasat Nilkaew

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Special thanks to our families for their continued support and patience.

—Jeffrey S. Beasley and Piyasat Nilkaew

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Introduction

This book provides a look at computer networking from the point of view of the network administrator. It guides readers from an entry-level knowledge in computer networks to advanced concepts in Ethernet networks, router configuration, TCP/IP networks, routing protocols, local, campus, and wide area network configuration, network security, wireless networking, optical networks, Voice over IP, the network server, Linux networking, and industrial networks. After covering the entire text, readers will have gained a solid knowledge base in computer networks.

In my years of teaching, I have observed that technology students prefer to learn "how to swim" after they have gotten wet and taken in a little water. Then they are ready for more challenges. Show the students the technology, how it is used, and why, and they will take the applications of the technology to the next level. Allowing them to experiment with the technology helps them to develop a greater understanding. This book does just that.

Organization of the Text

Thoroughly updated to reflect the latest version of CompTIA's Network+ exam, **Networking Essentials, 3rd Edition,** is a practical, up-to-date, and hands-on guide to the basics of networking. Written from the viewpoint of a working network administrator, it requires absolutely no experience with either network concepts or day-to-day network management. This new edition splits the previous edition into two volumes. This first volume has been revised and reorganized around the needs of introductory networking students, and assumes no previous knowledge. Throughout the text, the students will gain an appreciation of how basic computer networks and related hardware are interconnected to form a network. This involves understanding the concepts of twisted pair cable, fiber optics, interconnecting LANs, configuring TCP/IP, subnet masking, basic router configuration, switch configuration and management, wireless networking, and network security.

Key Pedagogical Features

- *Chapter Outline, Network+ Objectives, Key Terms,* and *Introduction* at the beginning of each chapter clearly outline specific goals for the reader. An example of these features is shown in Figure P-1.

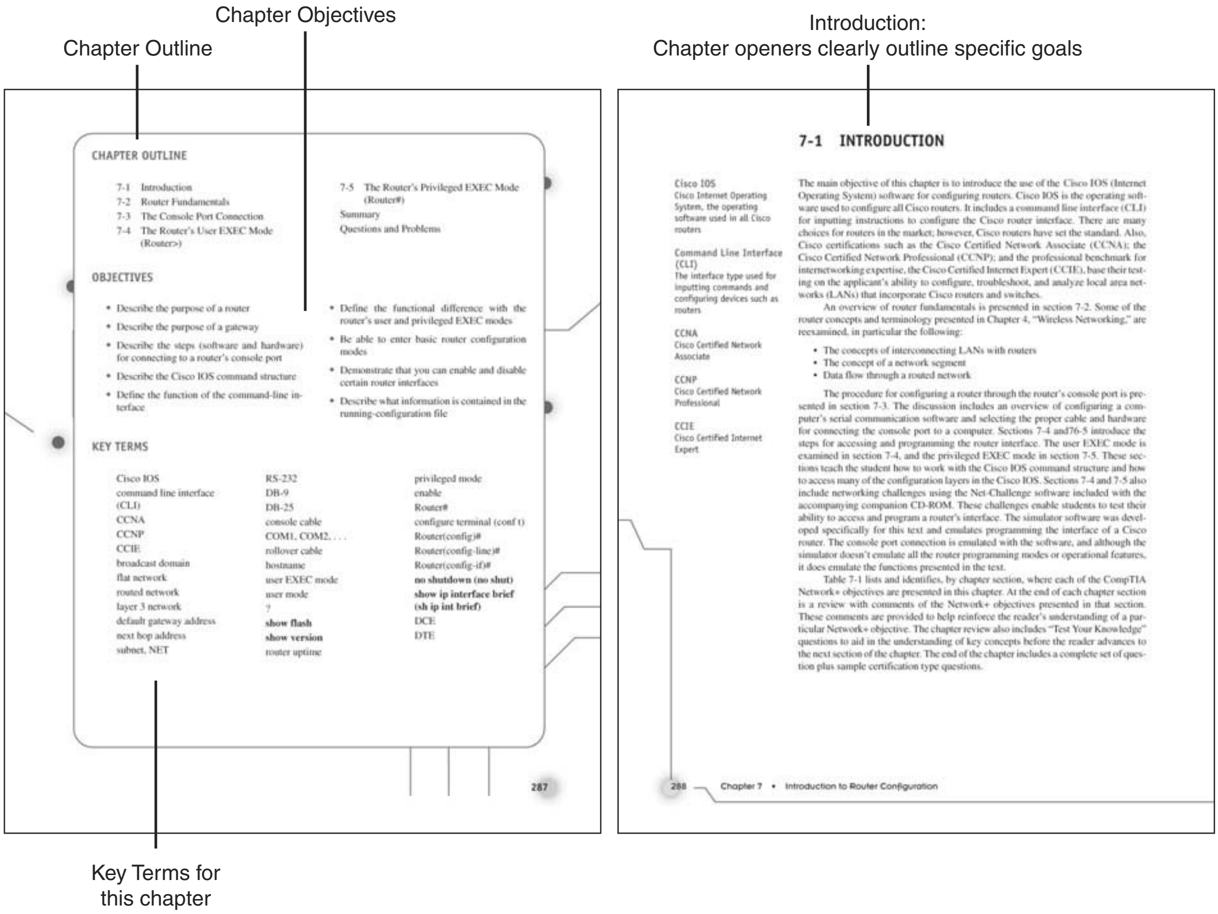


FIGURE P-1

- *Net-Challenge Software* provides a simulated, hands-on experience in configuring routers and switches. Exercises provided in the text (see Figure P-2) and on the CD challenge readers to undertake certain router/network configuration tasks. The challenges check the students' ability to enter basic networking commands and to set up router function, such as configuring the interface (Ethernet and Serial) and routing protocols (that is, RIP, and static). The software has the look and feel of actually being connected to the router's console port.

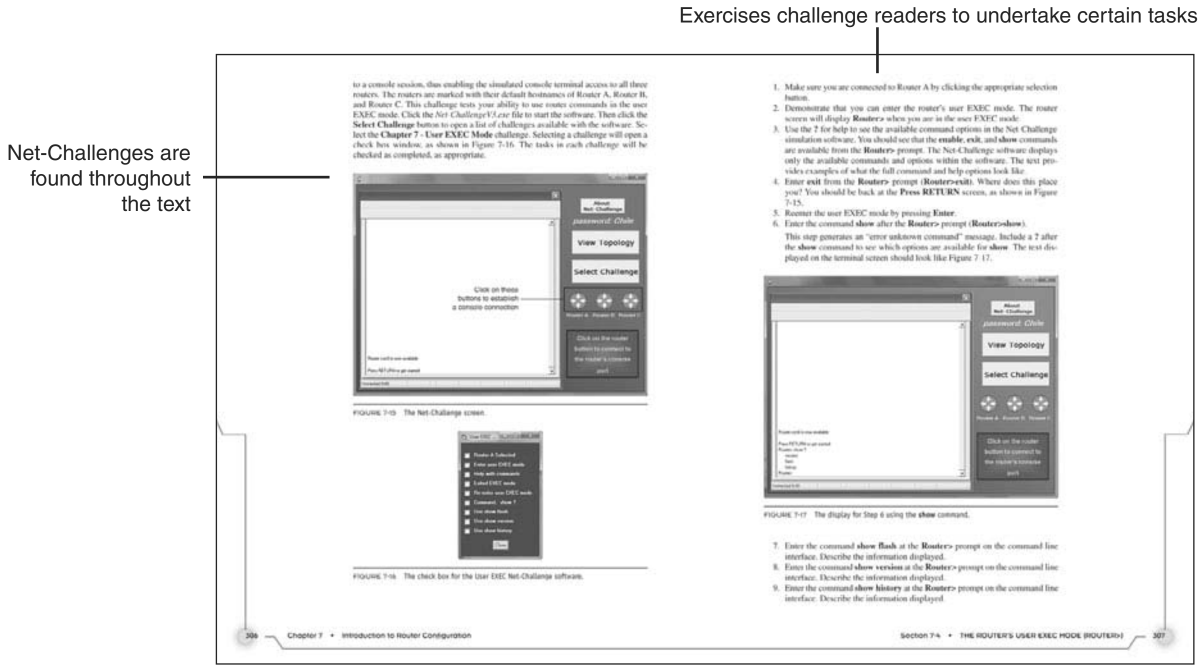


FIGURE P-2

- The textbook features and introduces how to use the *Wireshark Network Protocol Analyzer*. Examples of using the software to analyze data traffic are included throughout the text. *Numerous worked-out examples* are included in every chapter to reinforce key concepts and aid in subject mastery, as shown in Figure P-3.

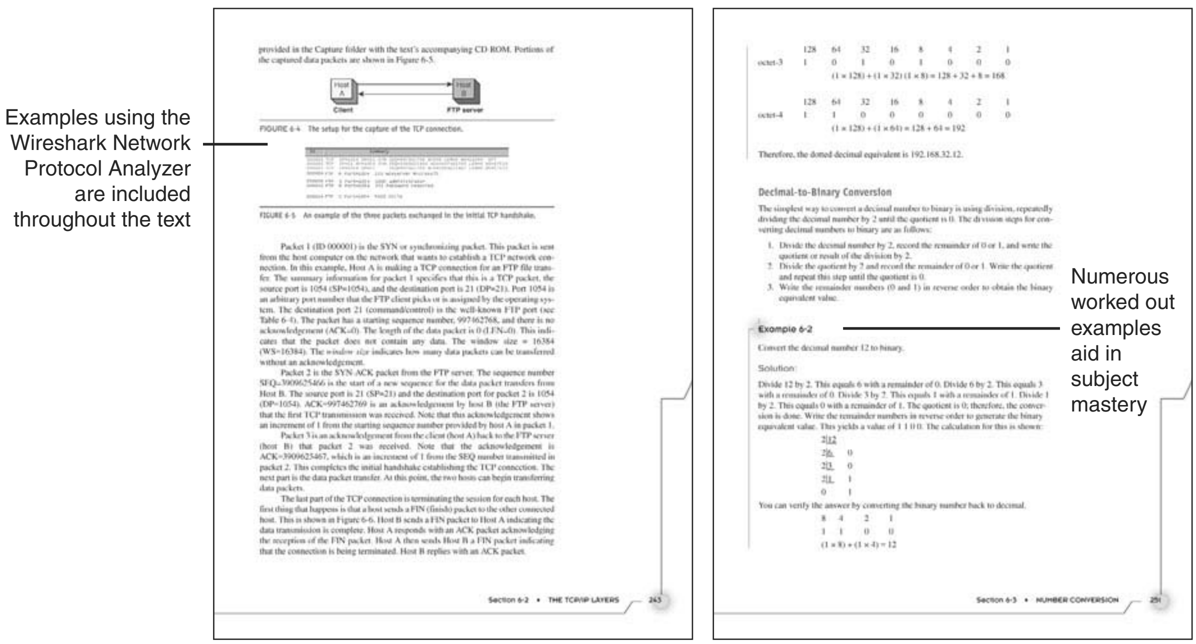
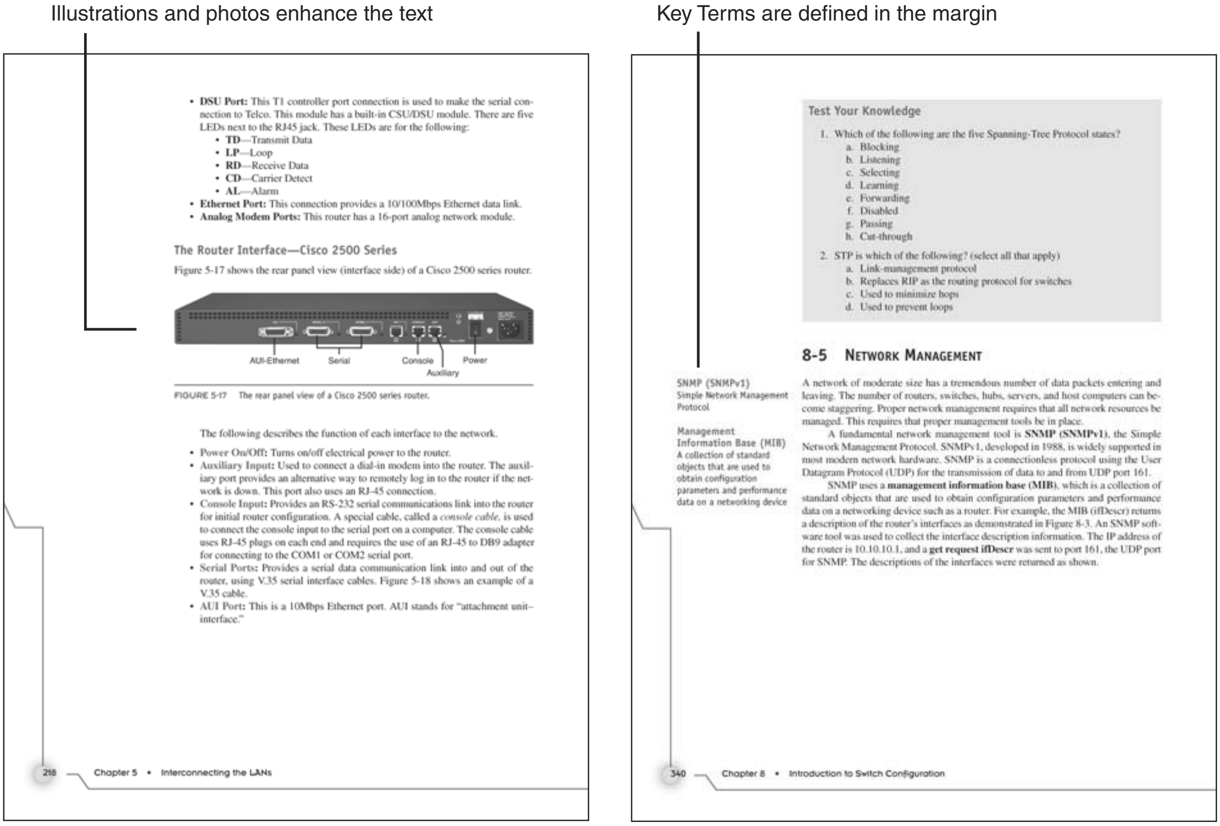


FIGURE P-3

- *Key Terms* and their definitions are highlighted in the margins to foster inquisitiveness and ensure retention. Illustrations and photos are used throughout to aid in understanding the concepts discussed.This is illustrated in Figure P-4.



- **DSU Port:** This T1 controller port connection is used to make the serial connection to Telco. This module has a built-in CSU/DSU module. There are five LEDs next to the RJ45 jack. These LEDs are for the following:
  - **TD**—Transmit Data
  - **LP**—Loop
  - **RD**—Receive Data
  - **CD**—Carrier Detect
  - **AL**—Alarm
- **Ethernet Port:** This connection provides a 10/100Mbps Ethernet data link.
- **Analog Modem Ports:** This router has a 16-port analog network module.

The Router Interface—Cisco 2500 Series

Figure 5-17 shows the rear panel view (interface side) of a Cisco 2500 series router.

FIGURE 5-17 The rear panel view of a Cisco 2500 series router.

The following describes the function of each interface to the network.

- Power On/Off: Turns on/off electrical power to the router.
- Auxiliary Input: Used to connect a dial-in modem into the router. The auxiliary port provides an alternative way to remotely log in to the router if the network is down. This port also uses an RJ-45 connection.
- Console Input: Provides an RS-232 serial communications link into the router for initial router configuration. A special cable, called a *console cable*, is used to connect the console input to the serial port on a computer. The console cable uses RJ-45 plugs on each end and requires the use of an RJ-45 to DB9 adapter for connecting to the COM1 or COM2 serial port.
- Serial Ports: Provides a serial data communication link into and out of the router, using V.35 serial interface cables. Figure 5-18 shows an example of a V.35 cable.
- AUI Port: This is a 10Mbps Ethernet port. AUI stands for "attachment unit–interface."

218 Chapter 5 • Interconnecting the LANs

Test Your Knowledge

1. Which of the following are the five Spanning-Tree Protocol states?
   a. Blocking
   b. Listening
   c. Selecting
   d. Learning
   e. Forwarding
   f. Disabled
   g. Passing
   h. Cut-through
2. STP is which of the following? (select all that apply)
   a. Link-management protocol
   b. Replaces RIP as the routing protocol for switches
   c. Used to minimize hops
   d. Used to prevent loops

8-5 Network Management

SNMP (SNMPv1)
Simple Network Management Protocol

Management Information Base (MIB)
A collection of standard objects that are used to obtain configuration parameters and performance data on a networking device

A network of moderate size has a tremendous number of data packets entering and leaving. The number of routers, switches, hubs, servers, and host computers can become staggering. Proper network management requires that all network resources be managed. This requires that proper management tools be in place.

A fundamental network management tool is **SNMP (SNMPv1)**, the Simple Network Management Protocol. SNMPv1, developed in 1988, is widely supported in most modern network hardware. SNMP is a connectionless protocol using the User Datagram Protocol (UDP) for the transmission of data to and from UDP port 161.

SNMP uses a **management information base (MIB)**, which is a collection of standard objects that are used to obtain configuration parameters and performance data on a networking device such as a router. For example, the MIB (ifDescr) returns a description of the router's interfaces as demonstrated in Figure 8-3. An SNMP software tool was used to collect the interface description information. The IP address of the router is 10.10.10.1, and a **get request ifDescr** was sent to port 161, the UDP port for SNMP. The descriptions of the interfaces were returned as shown.

340 Chapter 8 • Introduction to Switch Configuration

FIGURE P-4

- *Extensive Summaries*, *Questions and Problems*, *Critical Thinking*, as well as *Network+-specific Certification Questions are found* at the end of each chapter, as shown in Figure P-5

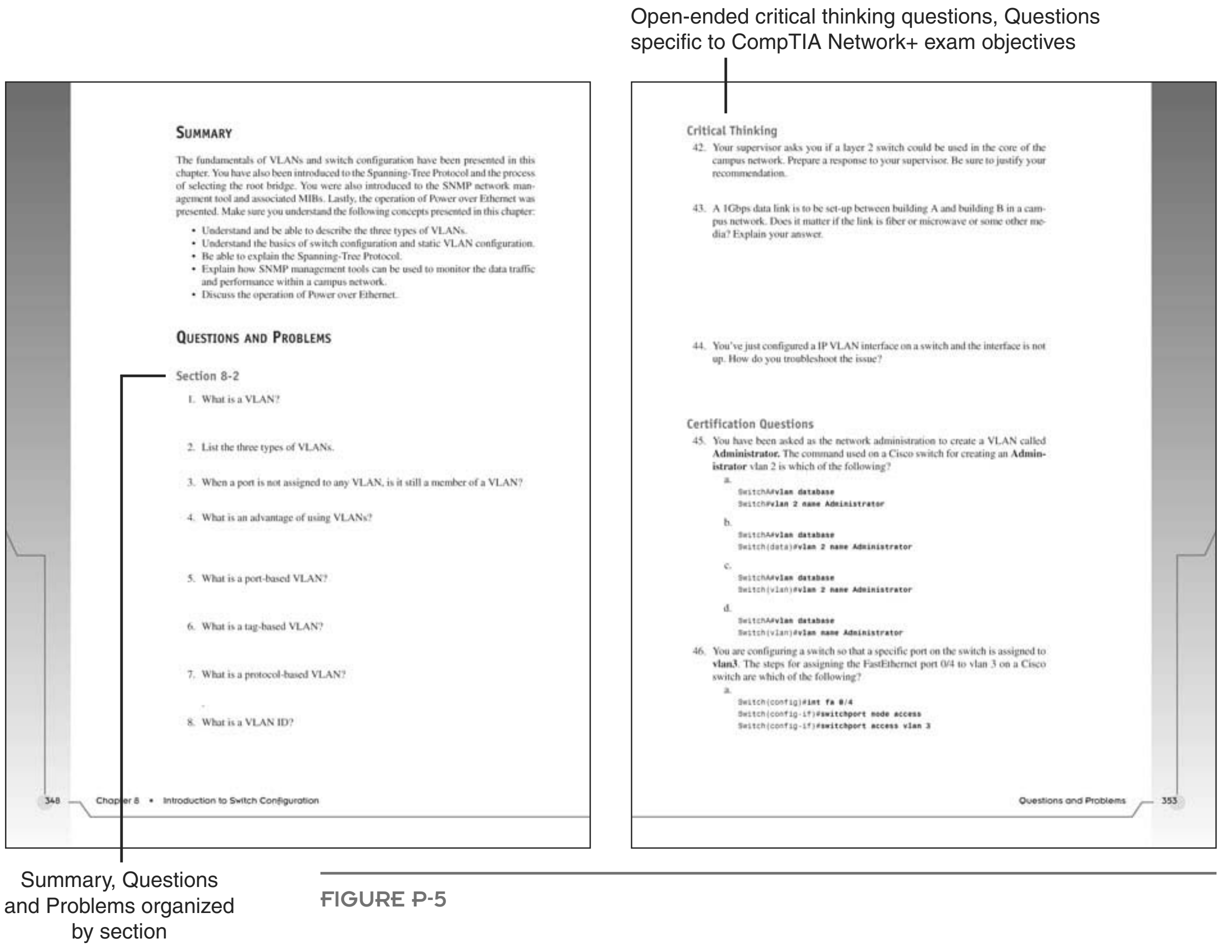
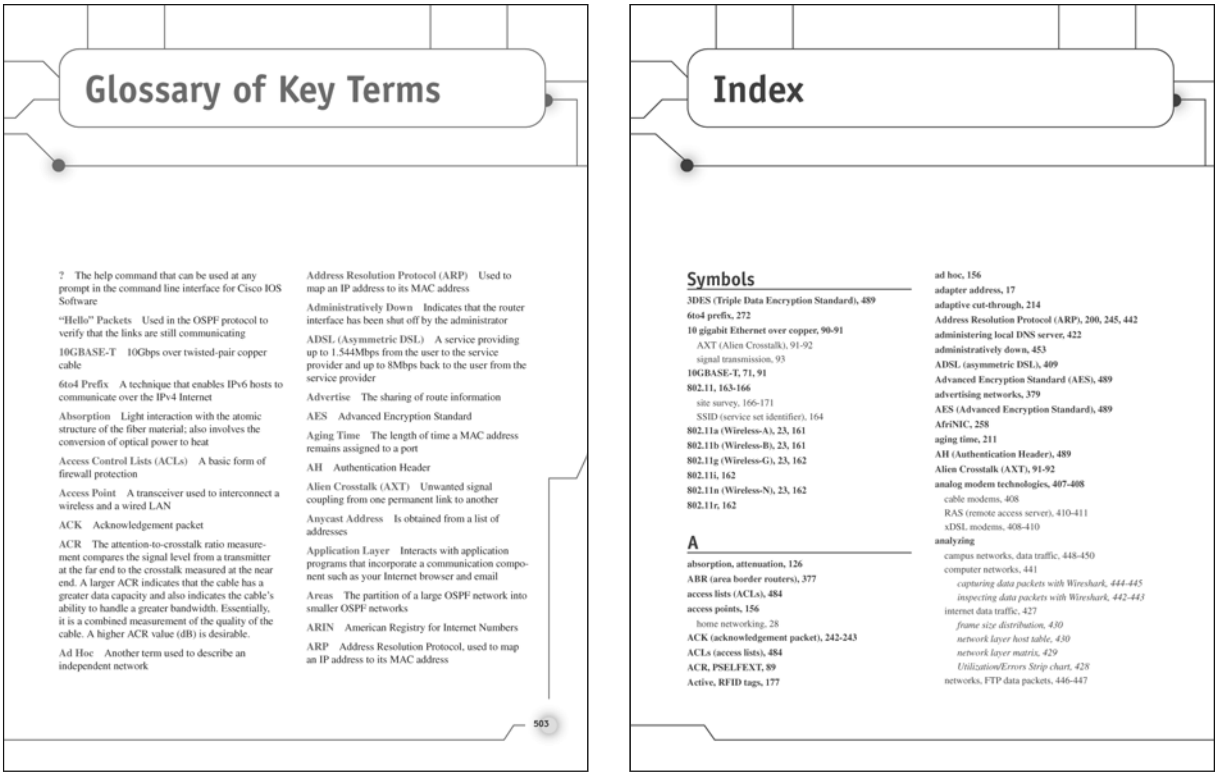


FIGURE P-5

- An extensive Glossary is found at the end of the book and offers quick, accessible definitions to key terms and acronyms, as well as an exhaustive Index (Figure P-6).



Glossary of Key Terms

? The help command that can be used at any prompt in the command line interface for Cisco IOS Software

"Hello" Packets Used in the OSPF protocol to verify that the links are still communicating

10GBASE-T 10Gbps over twisted-pair copper cable

6to4 Prefix A technique that enables IPv6 hosts to communicate over the IPv4 Internet

Absorption Light interaction with the atomic structure of the fiber material; also involves the conversion of optical power to heat

Access Control Lists (ACLs) A basic form of firewall protection

Access Point A transceiver used to interconnect a wireless and a wired LAN

ACK Acknowledgement packet

ACR The attention-to-crosstalk ratio measurement compares the signal level from a transmitter at the far end to the crosstalk measured at the near end. A larger ACR indicates that the cable has a greater data capacity and also indicates the cable's ability to handle a greater bandwidth. Essentially, it is a combined measurement of the quality of the cable. A higher ACR value (dB) is desirable.

Ad Hoc Another term used to describe an independent network

Address Resolution Protocol (ARP) Used to map an IP address to its MAC address

Administratively Down Indicates that the router interface has been shut off by the administrator

ADSL (Asymmetric DSL) A service providing up to 1.544Mbps from the user to the service provider and up to 8Mbps back to the user from the service provider

Advertise The sharing of route information

AES Advanced Encryption Standard

Aging Time The length of time a MAC address remains assigned to a port

AH Authentication Header

Alien Crosstalk (AXT) Unwanted signal coupling from one permanent link to another

Anycast Address Is obtained from a list of addresses

Application Layer Interacts with application programs that incorporate a communication component such as your Internet browser and email

Areas The partition of a large OSPF network into smaller OSPF networks

ARIN American Registry for Internet Numbers

ARP Address Resolution Protocol, used to map an IP address to its MAC address

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FIGURE P-6

Accompanying CD-ROM

The CD-ROM packaged with the text includes the captured data packets used in the text. It also includes the Net-Challenge Software, which was developed specifically for this text.

CHAPTER 3

Physical Layer Cabling: Fiber Optics

CHAPTER OUTLINE

OBJECTIVES

- Describe the advantages of glass fiber over copper conductors
- Describe the differences in how light travels in single- and multimode fiber
- Define *attenuation* and *dispersion* in fiber–optic cabling
- Describe the components of a fiber-optic system
- Describe the issues of optical networking, including fiber-to-the-business and fiber to-the-home
- Describe the new networking developments associated with optical Ethernet
- Understand the safety issues when working with fiber optics

KEY TERMS

refractive index
infrared light
optical spectrum
cladding
numerical aperture
multimode fiber
pulse dispersion
graded-index fiber
single-mode fiber
step-index fiber
long haul
mode field diameter
scattering
absorption
macrobending
microbending
dispersion
modal dispersion
chromatic dispersion
polarization mode–dispersion
zero-dispersion–wavelength
dispersion compensating fiber
fiber Bragg grating
DL
LED
distributed feedback (DFB) laser
dense wavelength division multiplex (DWDM)
vertical cavity surface emitting lasers (VCSELs)
tunable laser
fiber, light pipe, glass
isolator
received signal level (RSL)
fusion splicing
mechanical splices
index-matching gel
SC, ST, FC, LC, MT-RJ
SONET/SDH
STS
FTTC
FTTH
FTTB
FTTD
optical Ethernet
fiber cross-connect
GBIC
SFP
XENPAK
XPAK
X2
XFP

continues

KEY TERMS continued

SFP+	logical fiber map	sm
IDC	physical fiber map	backbone
IC	mm	

3-1 INTRODUCTION

Recent advances in the development and manufacture of fiber-optic systems have made them the latest frontier in the field of optical networking. They are being used extensively for both private and commercial data links and have replaced a lot of copper wire. The latest networking technologies to benefit from the development in optical networking are gigabit Ethernet and 10 gigabit Ethernet.

A fiber-optic network is surprisingly simple, as shown in Figure 3-1. It is comprised of the following elements:

1. A fiber-optic transmission strand can carry the signal (in the form of a modulated light beam) a few feet or even hundreds or thousands of miles. A cable may contain three or four hair-like fibers or a bundle of hundreds of such fibers.
2. A source of invisible infrared radiation—usually a light-emitting diode (LED) or a solid-state laser—that can be modulated to impress digital data or an analog signal on the light beam.
3. A photosensitive detector to convert the optical signal back into an electrical signal at the receiver.
4. Efficient optical connectors at the light source-to-cable interface and at the cable-to-photo detector interface. These connectors are also critical when splicing the optical cable due to excessive loss that can occur at connections.

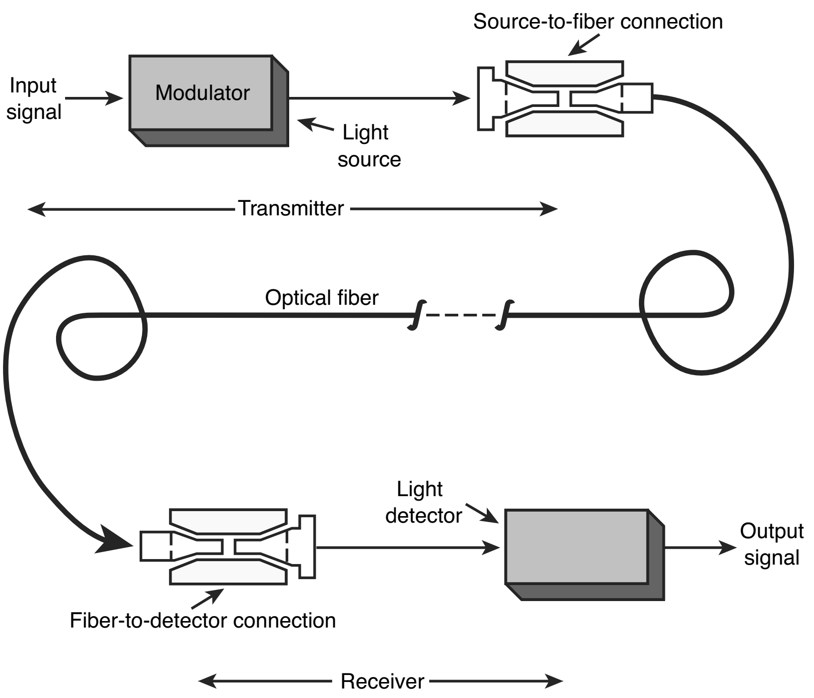

FIGURE 3-1 Fiber-optic communication system. (From *Modern Electronic Communication 9/e,* by J.S. Beasley & G. M. Miller, 2008, p. 781. Copyright ©2002 Pearson Education, Inc. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.)

The advantages of optical communication links compared to copper conductors are enormous and include the following:

1. **Extremely wide system bandwidth:** The intelligence is impressed on the light by varying the light's amplitude. Because the best LEDs have a 5 ns response time, they provide a maximum bandwidth of about 100MHz. With laser light sources, however, data rates over 10Gbps are possible with a single-mode fiber. The amount of information multiplexed on such a system, in the hundreds of Gbps, is indeed staggering.
2. **Immunity to electrostatic interference:** External electrical noise and lightning do not affect energy in a fiber-optic strand. However, this is true only for the optical strands, not the metallic cable components or connecting electronics.
3. **Elimination of crosstalk:** The light in one glass fiber does not interfere with, nor is it susceptible to, the light in an adjacent fiber. Recall that crosstalk results from the electromagnetic coupling between two adjacent copper wires.
4. **Lower signal attenuation than other propagation systems:** Typical attenuation of a 1GHz bandwidth signal for optical fibers is 0.03 dB per 100 ft., compared to 4.0 dB for RG-58U coaxial.
5. **Lower costs:** Optical fiber costs are continuing to decline. The costs of many systems are declining with the use of fiber, and that trend is accelerating.
6. **Safety:** In many wired systems, the potential hazard of short circuits requires precautionary designs. Additionally, the dielectric nature of optic fibers eliminates the spark hazard.
7. **Corrosion:** Given that glass is basically inert, the corrosive effects of certain environments are not a problem.
8. **Security:** Due to its immunity to and from electromagnetic coupling and radiation, optical fiber can be used in most secure environments. Although it can be intercepted or tapped, it is very difficult to do so.

This chapter examines the issues of optical networking. Section 3-2 presents an overview of optical fiber fundamentals including a discussion on wavelengths and type of optical fibers. Section 3-3 examines the two distance-limiting parameters in fiber-optic transmission, attenuation, and dispersion. Optical components are presented in section 3-4. This includes the various types of connectors currently used on fiber. Optical networking is presented in section 3-5. An overview of SONET and FDDI are presented, followed by optical Ethernet. This section includes a discussion on setting up the building and campus distribution for fiber. Safety is extremely important when working with fiber. A brief overview of safety is presented in section 3-6.

Table 3-1 lists and identifies, by chapter section, where each of the CompTIA Network+ objectives are presented in this chapter. At the end of each chapter section is a review with comments of the Network+ objectives presented in that section. These comments are provided to help reinforce the reader's understanding of a particular Network+ objective. The chapter review also includes "Test Your Knowledge" questions to aid in the understanding of key concepts before the reader advances to the next section of the chapter. The end of the chapter includes a complete set of question plus sample certification type questions.

TABLE 3-1 Chapter 3 - CompTIA Network+ Objectives

Domain/ Objective Number	Domain/ Objective Description	Section Where Objective Is Covered
3.0	***Network Media and Topologies***	
3.1	Categorize standard media types and associated properties	3-2, 3-3, 3-6
3.2	Categorize standard connector types based on network media	3-4
3.7	Compare and contrast different LAN technologies	3-5
3.8	Identify components of wiring distribution	3-5
4.0	***Network Management***	
4.5	Describe the purpose of configuration management documentation	3-5

3-2 THE NATURE OF LIGHT

Before you can understand the propagation of light in a glass fiber, it is necessary to review some basics of light refraction and reflection. The speed of light in free space is 3×10^8 m/s but is reduced in other media, including fiber-optic cables. The reduction as light passes into denser material results in refraction of the light. Refraction causes the light wave to be bent, as shown in Figure 3-2. The speed reduction and subsequent refraction is different for each wavelength, as shown in Figure 3-2(b). The visible light striking the prism causes refraction at both air/glass interfaces and separates the light into its various frequencies (colors) as shown. This same effect produces a rainbow, with water droplets acting as prisms to split the sunlight into the visible spectrum of colors (the various frequencies).

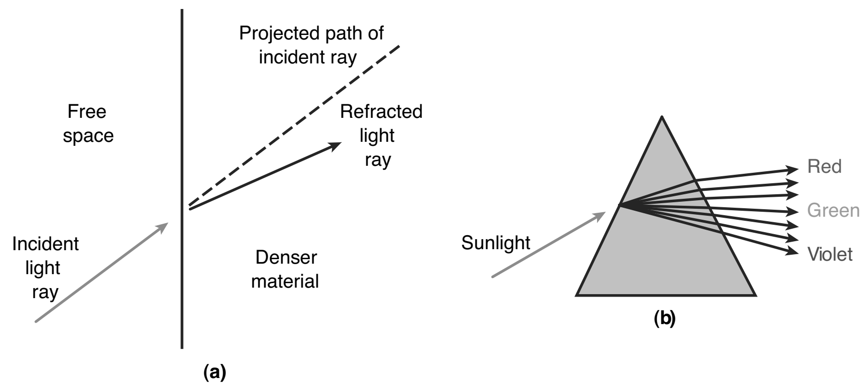

FIGURE 3-2 Refraction of light. (From *Modern Electronic Communication 9/e,* by J.S. Beasley & G. M. Miller, 2008, p. 782. Copyright ©2002 Pearson Education, Inc. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.)

Refractive Index
Ratio of the speed of light in free space to its speed in a given material

Infrared Light
Light extending from 680 nm up to the wavelengths of the microwaves

Optical Spectrum
Light frequencies from the infrared on up

The amount of bend provided by refraction depends on the **refractive index** of the two materials involved. The refractive index, *n,* is the ratio of the speed of light in free space to the speed in a given material. It is slightly variable for different frequencies of light, but for most purposes a single value is accurate enough.

In the fiber-optics industry, spectrum notation is stated in nanometers (nm) rather than in frequency (Hz) simply because it is easier to use, particularly in spectral-width calculations. A convenient point of commonality is that 3×10^{14} Hz, or 300THz, is equivalent to 1 μm, or 1000 nm. This relationship is shown in Figure 3-3. The one exception to this naming convention is when discussing dense wavelength division multiplexing (DWDM), which is the transmission of several optical channels, or wavelengths, in the 1550-nm range, all on the same fiber. For DWDM systems, notations, and particularly channel separations, are stated in terahertz (THz). Wavelength division multiplexing (WDM) systems are discussed in section 3-5. An electromagnetic wavelength spectrum chart is provided in Figure 3-3. The electromagnetic light waves just below the frequencies in the visible spectrum extending from 680 nm up are called **infrared light** waves. Whereas visible light has a wavelength from approximately 430 nm up to 680 nm, infrared light extends from 680 nm up to the microwaves. The frequencies from the infrared on up are termed the **optical spectrum**.

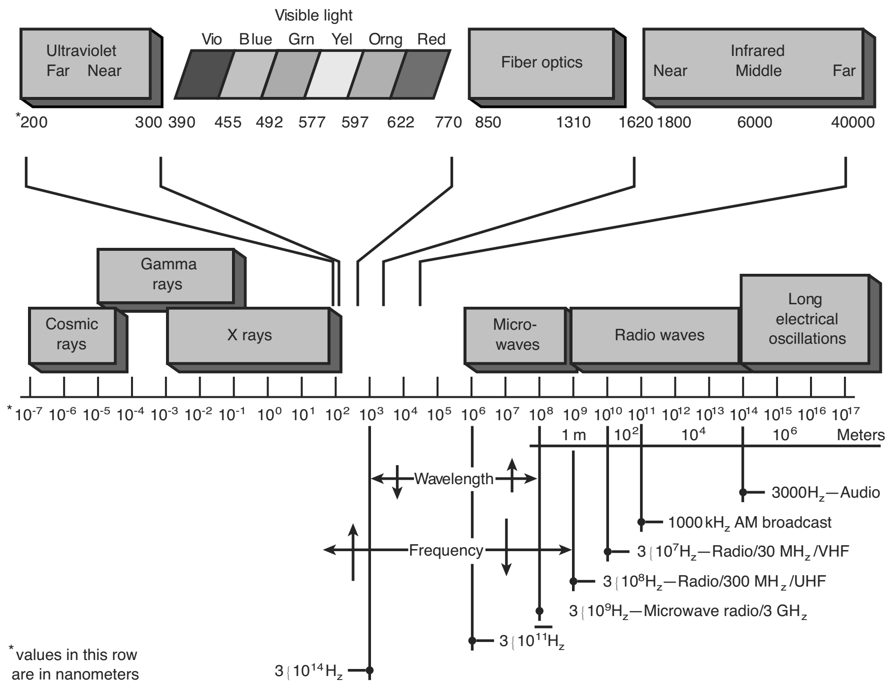

FIGURE 3-3 The electromagnetic wavelength spectrum. (From *Modern Electronic Communication 9/e,* by J.S. Beasley & G. M. Miller, 2008, p. 784. Copyright ©2008 Pearson Education, Inc. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.)

The commonly used wavelengths in today's fiber-optic systems are

- **Multimode fiber**: (850 and 1310) nm
- **Single mode fiber**: (1310 and 1550) nm
- **Fiber to the home/business**: 1600–1625 nm

Figure 3-4 shows the typical construction of an optical fiber. The *core* is the portion of the fiber strand that carries the transmitted light. The **cladding** is the material surrounding the core. It is almost always glass, although plastic cladding of a glass fiber is available but rarely used. In any event, the refraction index for the core and the cladding are different. The cladding must have a lower index of refraction to keep the light in the core. A plastic coating surrounds the cladding to provide protection. Figure 3-5 shows examples of fiber strands from a fiber bundle.

Cladding
Material surrounding the core, which must have a lower index of refraction to keep the light in the core

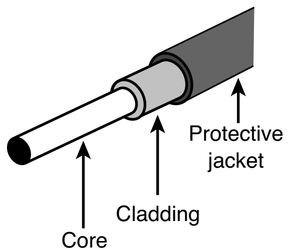

FIGURE 3-4 Single-fiber construction. (From *Modern Electronic Communication 9/e,* by J.S. Beasley & G. M. Miller, 2008, p. 785. Copyright ©2008 Pearson Education, Inc. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.)

FIGURE 3-5 Fiber strands (courtesy of Anixter, Inc.).

Numerical Aperture
A measure of a fiber's ability to accept light

Another measure of a fiber's light acceptance is **numerical aperture**. The numerical aperture is a basic specification provided by the manufacturer that indicates the fiber's ability to accept light and shows how much light can be off-axis and still propagate.

Several types of optical fibers are available, with significant differences in their characteristics. The first communication-grade fibers (early 1970s) had light-carrying core diameters about equal to the wavelength of light. They could carry light in just a single waveguide mode.

Multimode Fiber
A fiber that supports many optical waveguide modes

The difficulty of coupling significant light into such a small fiber led to development of fibers with cores of about 20 to 100 μm. These fibers support many waveguide modes and are called **multimode fibers**. The first commercial fiber-optic systems used multimode fibers with light at 800–900 nm wavelengths. A variation of the multimode fiber was subsequently developed, termed graded-index fiber. This afforded greater bandwidth capability.

As the technology became more mature, the single-mode fibers were found to provide lower losses and even higher bandwidth. This has led to their use at 1300 nm, 1550 nm, up to 1625 nm in many telecommunication and fiber-to-the home applications. The new developments have not made old types of fiber obsolete. The application now determines the type used. The following major criteria affect the choice of fiber type:

1. Signal losses
2. Ease of light coupling and interconnection
3. Bandwidth

Figure 3-6 presents a graphic of a fiber showing three modes (that is, multimode) of propagation:

- The lowest-order mode is seen traveling along the axis of the fiber.
- The middle-order mode is reflected twice at the interface.
- The highest-order mode is reflected many times and makes many trips across the fiber.

Pulse Dispersion
Stretching of received pulse width because of multiple paths taken by the light

As a result of these variable path lengths, the light entering the fiber takes a variable length of time to reach the detector. This results in a pulse-broadening or dispersion characteristic, as shown in Figure 3-6. This effect is termed **pulse dispersion** and limits the maximum distance and rate at which data (pulses of light) can be practically transmitted. You will also note that the output pulse has reduced amplitude as well as increased width. The greater the fiber length, the worse this effect will be. As a result, manufacturers rate their fiber in bandwidth per length, such as 400MHz/km. This means the fiber can successfully transmit pulses at the rate of 400MHz for 1 km, 200MHz for 2 km, and so on. In fact, current networking standards limit multimode fiber distances to 2 km. Of course, longer transmission paths are attained by locating regenerators at appropriate locations. Step-index multimode fibers are rarely used in networking due to their very high amounts of pulse dispersion and minimal bandwidth capability.

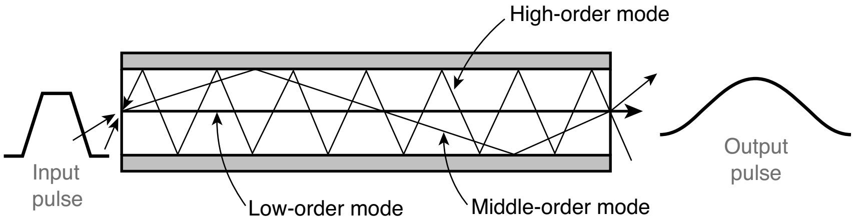

FIGURE 3-6 Modes of propagation for step-index fiber. (From *Modern Electronic Communication 9/e,* by J.S. Beasley & G. M. Miller, 2008, p. 787. Copyright ©2008 Pearson Education, Inc. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.)

Graded-Index Fiber

Graded-index Fiber
The index of refraction is gradually varied with a parabolic profile

In an effort to overcome the pulse-dispersion problem, the **graded-index fiber** was developed. In the manufacturing process for this fiber, the index of refraction is tailored to follow the parabolic profile shown in Figure 3-7. This results in low-order modes traveling through the constant-density material in the center. High-order modes see a lower index of refraction material farther from the core, and thus the velocity of propagation increases away from the center. Therefore, all modes, even though they take various paths and travel different distances, tend to traverse the fiber length in about the same amount of time. These fibers can therefore handle higher bandwidths and/or provide longer lengths of transmission before pulse dispersion effects destroy intelligibility and introduce bit errors.

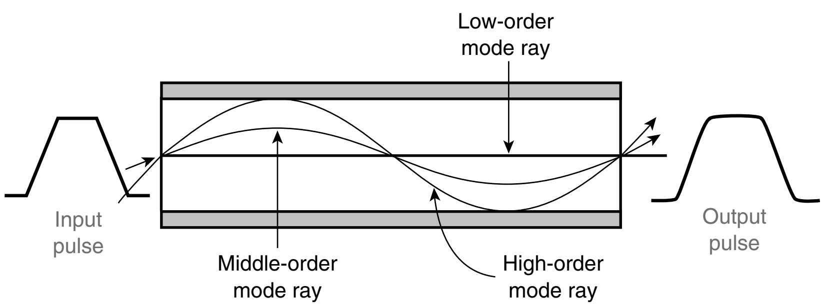

FIGURE 3-7 Modes of propagation for graded-index fiber. (From *Modern Electronic Communication 9/e,* by J.S. Beasley & G. M. Miller, 2008, p. 788. Copyright ©2008 Pearson Education, Inc. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.)

Graded-index multimode fibers with 50 μm-diameter cores and 125 μm cladding are used in many telecommunication systems at up to 300 megabits per second (Mbps) over 50-km ranges without repeaters. Graded-index fiber with up to a 100 μm core is used in short-distance applications that require easy coupling from the source and high data rates, such as for video and high-speed local area networks (LANs). The larger core affords better light coupling than the 50 μm core and does not significantly degrade the bandwidth capabilities. In the telecommunications industry, there are two commonly used core sizes for graded-index fiber, these being 50 μm and 62.5 μm. Both have 125 μm cladding. The large core diameter and the high NA (numerical aperture) of these fibers simplify input cabling and allow the use of relatively inexpensive connectors. Fibers are specified by the diameters of their core and cladding. For example, the fibers just described would be called 50/125 fiber and 62.5/125 fiber.

Single-Mode Fibers

Single-mode Fiber
Fiber cables with core diameters of about 7–10 μm; light follows a single path

A technique used to minimize pulse dispersion effects is to make the core extremely small—on the order of a few micrometers. This type accepts only a low-order mode, thereby allowing operation in high-data-rate, long-distance systems. This fiber is typically used with high-power, highly directional modulated light sources such as a laser. Fibers of this variety are called **single-mode** (or monomode) **fibers**. Core diameters of only 7–10 μm are typical.

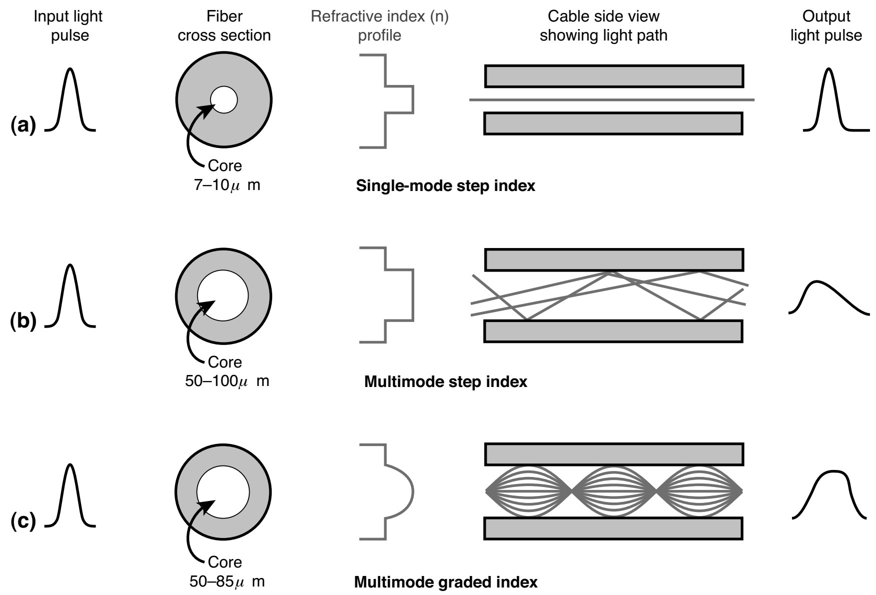

FIGURE 3-8 Types of optical fiber. (From *Modern Electronic Communication 9/e,* by J.S. Beasley & G. M. Miller, 2008, p. 789. Copyright ©2008 Pearson Education, Inc. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.)

Long Haul
The transmission of data over hundreds or thousands of miles

Single-mode fibers are widely used in **long-haul** and wide area network (WAN) applications. They permit transmission of about 10Gbps and a repeater spacing of up to 80km. These bandwidth and repeater spacing capabilities are constantly being upgraded by new developments.

When describing the core size of single-mode fibers, the term **mode field diameter** is the term more commonly used. Mode field diameter is the actual guided optical power distribution diameter. In a typical single-mode fiber, the mode field diameter is 1 μm or so larger than the core diameter. The actual value depends on the wavelength being transmitted. In fiber specification sheets, the core diameter is stated for multimode fibers, but the mode field diameter is typically stated for single-mode fibers.

Figure 3-8 provides a graphical summary of the three types of fiber discussed, including typical dimensions, refractive index profiles, and pulse-dispersion effects.

Mode Field Diameter
The actual guided optical power distribution, which is typically a micron or so larger than the core diameter; single-mode fiber specifications typically list the mode field diameter

Section 3-2 Review

This section has covered the following **Network+** Exam objectives.

3.1 Categorize standard media types and associated properties

This section has introduced the reader to the nature of light and fiber-optics; in particular, single-mode and multimode fiber. Figure 3-4 provides a good graphical view of the composition of a fiber-optic cable. The concept of how light travels in an optical waveguide such as fiber was also presented.

Test Your Knowledge

1. What are the light waves just below the frequencies in the visible spectrum extending up called?
   a. Sub-light waves
   b. Infrared light waves
   c. Refractive waves
   d. Multimode waves
   e. Polar waves
2. What is the material surrounding the core of an optical waveguide called?
   a. Cladding
   b. Aperture
   c. Mode field
   d. Step-index
   e. Graded-index
3. Single-mode fiber cables have a core diameter of about 7–10 micrometers. True or False?

3-3 FIBER ATTENUATION AND DISPERSION

There are two key distance-limiting parameters in fiber-optic transmissions: attenuation and dispersion.

Attenuation

Attenuation is the loss of power introduced by the fiber. This loss accumulates as the light is propagated through the fiber strand. The loss is expressed in dB/km (decibels per kilometer) of length. The loss, or attenuation, of the signal is due to the combination of four factors: scattering, absorption, macrobending, and microbending. Two other terms for attenuation are intrinsic and extrinsic.

Scattering
Caused by refractive index fluctuations; accounts for 96 percent of attenuation loss

Absorption
Light interaction with the atomic structure of the fiber material; also involves the conversion of optical power to heat

Macrobending
Loss due to light breaking up and escaping into the cladding

Microbending
Loss caused by very small mechanical deflections and stress on the fiber

Scattering is the primary loss factor over the three wavelength ranges. Scattering in telecommunication systems accounts for 96 percent of the loss and is the basis of the attenuation curves and values, such as that shown in Figure 3-9, and industry data sheets. The scattering is known as *Rayleigh scattering* and is caused by refractive index fluctuations. Rayleigh scattering decreases as wavelength increases, as shown in Figure 3-9.

Absorption is the second loss factor, a composite of light interaction with the atomic structure of the glass. It involves the conversion of optical power to heat. One portion of the absorption loss is due to the presence of OH hydroxol ions dissolved in the glass during manufacture. These cause the water attenuation or OH peaks shown in Figure 3-9 and other attenuation curves.

Macrobending is the loss caused by the light mode breaking up and escaping into the cladding when the fiber bend becomes too tight. As the wavelength increases, the loss in a bend increases. Although losses are in fractions of dB, the bend radius in small splicing trays and patching enclosures should be minimal.

Microbending is a type of loss caused by mechanical stress placed on the fiber strand, usually in terms of deformation resulting from too much pressure being applied to the cable. For example, excessively tight tie wraps or clamps will contribute to this loss. This loss is noted in fractions of a dB.

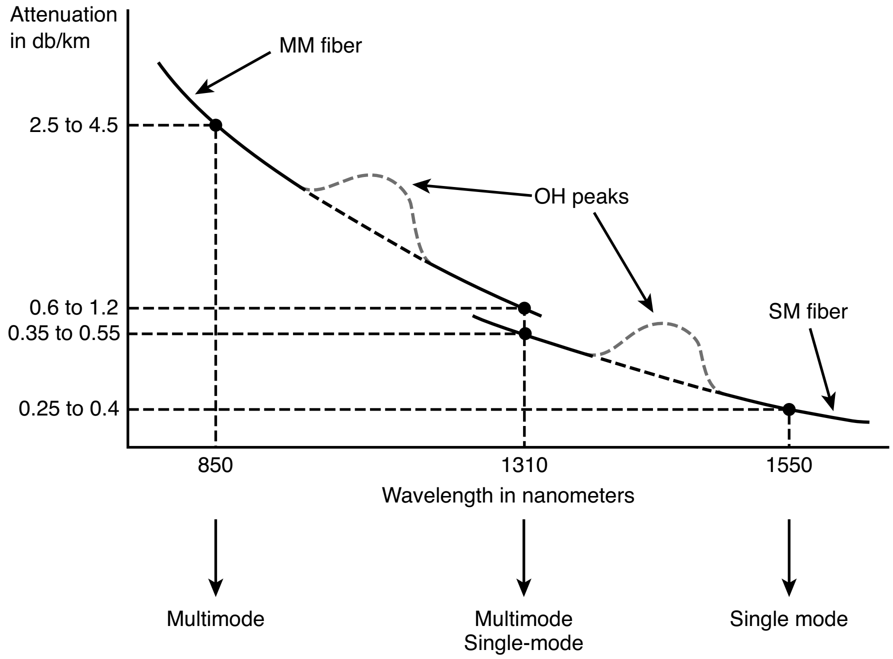

FIGURE 3-9 Typical attenuation of cabled fiber strands. (From *Modern Electronic Communication 9/e,* by J.S. Beasley & G. M. Miller, 2008, p. 792. Copyright ©2008 Pearson Education, Inc. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.)

Dispersion

Dispersion, or pulse broadening, is the second of the two key distance-limiting parameters in a fiber-optic transmission system. It is a phenomenon in which the light pulse spreads out in time as it propagates along the fiber strand. This results in a broadening of the pulse. If the pulse broadens excessively, it can blend into the adjacent digital time slots and cause bit errors. Figure 3-10 illustrates the effects of dispersion on a light pulse.

Dispersion
Broadening of a light pulse as it propagates through a fiber strand

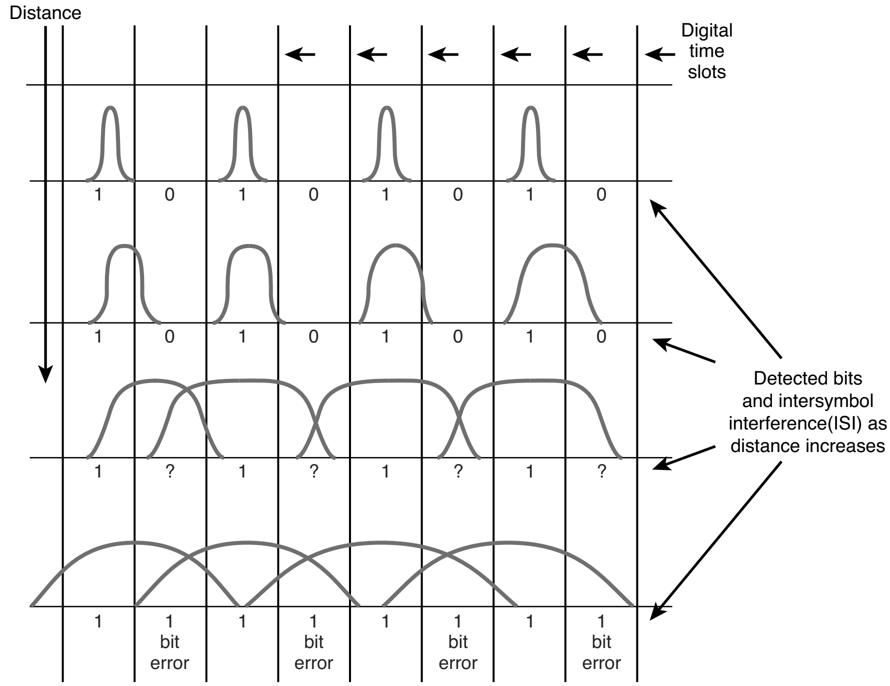

FIGURE 3-10 Pulse broadening or dispersion in optical fibers. (Adapted from *Modern Electronic Communication 9/e,* by J.S. Beasley & G. M. Miller, 2008, p. 793. Copyright ©2008 Pearson Education, Inc. Adapted by permission of Pearson Education, Inc., Upper Saddle River, NJ.)

There are three types of dispersion:

- **Modal dispersion:** The broadening of a pulse due to different path lengths taken through the fiber by different modes.
- **Chromatic dispersion:** The broadening of a pulse due to different propagation velocities of the spectral components of the light pulse.
- **Polarization mode dispersion:** The broadening of a pulse due to the different propagation velocities of the *X* and *Y* polarization components of the light pulse.

Modal dispersion occurs predominantly in multimode fiber. From a light source, the light rays can take many paths as they propagate along the fiber. Some light rays do travel in a straight line, but most take variable-length routes. As a result, the rays arrive at the detector at different times, and the result is pulse broadening. This was shown in Figures 3-6 and 3-7. The use of graded-index fiber greatly reduces the effects of modal dispersion and therefore increases the bandwidth to about 1GHz/km. On the other hand, single-mode fiber does not exhibit modal dispersion, given that only a single mode is transmitted.

A second equally important type of dispersion is chromatic. Chromatic dispersion is present in both single-mode and multimode fibers. Basically, the light source, both lasers and LEDs, produce several different wavelength light rays when generating the light pulse. Each light ray travels at a different velocity, and as a result, these rays arrive at the receiver detector at different times, causing the broadening of the pulse.

There is a point where dispersion is actually at zero, this being determined by the refractive index profile. This happens near 1310 nm and is called the **zero dispersion wavelength**. By altering the refractive index profile, this zero dispersion wavelength can be shifted to the 1550-nm region. Such fibers are called *dispersion-shifted.* This is significant because the 1550-nm region exhibits a lower attenuation than at 1310 nm. This becomes an operational advantage, particularly to long-haul carriers because with minimum attenuation and minimum dispersion in the same wavelength region, repeater and regenerator spacing can be maximized.

Zero-dispersion Wavelength
Point where the dispersion is actually zero

Polarization mode is the type of dispersion found in single-mode systems and becomes of particular concern in long-haul and WAN high-data-rate digital and high-bandwidth analog video systems. In a single-mode fiber, the single propagating mode has two polarizations, horizontal and vertical, or *X* axis and *Y* axis. The index of refraction can be different for the two components; this affects their relative velocity as shown in Figure 3-11.

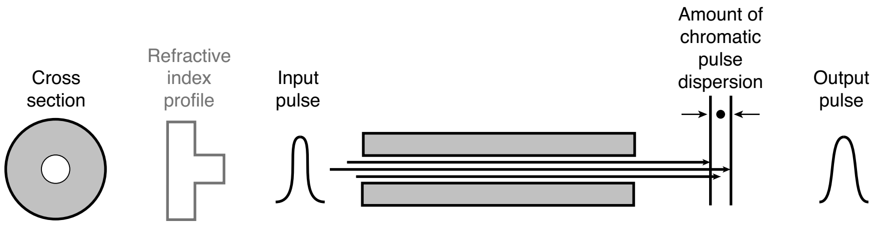

FIGURE 3-11 Polarization mode dispersion in single-mode fiber. (From *Modern Electronic Communication 9/e,* by J.S. Beasley & G. M. Miller, 2008, p. 794. Copyright ©2008 Pearson Education, Inc. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.)

Dispersion Compensation

A considerable amount of fiber in use today was installed in the 1980s and early 1990s. This cable was called the class IVa variety. These cables were optimized to operate in the 1310-nm region, which means their zero-dispersion point was in the 1310-nm wavelength. Due to continuous network expansion needs in recent years, it is often desired to add transmission capacity to the older fiber cables by using the 1550-nm region, particularly because the attenuation at 1550 nm is less than at 1310 nm. One major problem arises at this point. The dispersion value is higher at 1550 nm, which severely limits its distance capability.

To overcome this problem, a fiber called **dispersion compensating fiber** was developed. This fiber acts like an equalizer, negative dispersion canceling positive dispersion. The fiber consists of a small coil normally placed in the equipment rack just prior to the optical receiver input. This does introduce some insertion loss (3–10 dB) and may require the addition of an optical-line amplifier.

Dispersion Compensating Fiber
Acts like an equalizer, canceling dispersion effects and yielding close to zero dispersion in the 1550-nm region

A new device is a **fiber Bragg grating**. This technology involves etching irregularities onto a short strand of fiber, which changes the index of refraction and, in turn, reflects slower wavelengths to the output before the faster ones. This results in a compressed, or narrower, light pulse, minimizing intersymbol interference (ISI).

Fiber Bragg Grating
A short strand of modified fiber that changes the index of refraction and minimizes intersymbol interference

Section 3-3 Review

This section has covered the following **Network+** Exam objectives.

3.1 Categorize standard media types and associated properties

There are two key distance-limiting parameters in a fiber-optic transmission system. These are attenuation and dispersion, and these concepts were presented. Knowledge of the properties of fiber-optics is critical for planning a network installation or upgrade.

Test Your Knowledge

1. Which of the following terms refers to broadening of a light pulse as it propagates through a fiber strand?
   a. Pulse shaping
   b. Diffusion
   c. Absorption
   d. Dispersion
2. Which of the following terms is caused by refractive index fluctuations and accounts for 96% of attenuation loss?
   a. Scattering
   b. Absorption
   c. Dispersion
   d. Diffusion
3. Which of the following terms refers to loss due to light breaking up and escaping into the cladding?
   a. Microbending
   b. Scattering
   c. Macrobending
   d. Absorption

3-4 OPTICAL COMPONENTS

DL
Diode laser

LED
Light-emitting diode

Two kinds of light sources are used in fiber-optic communication systems: the diode laser (**DL**) and the high-radiance light-emitting diode (**LED**). In designing the optimum system, the special qualities of each light source should be considered. Diode lasers and LEDs bring to systems different characteristics:

1. Power levels
2. Temperature sensitivities
3. Response times
4. Lifetimes
5. Characteristics of failure

The diode laser is a preferred source for moderate-band to wideband systems. It offers a fast response time (typically less than 1 ns) and can couple high levels of useful optical power (usually several mW) into an optical fiber with a small core and a small numerical aperture. The DL is usually used as the source for single-mode fiber because LEDs have a low input coupling efficiency.

Some systems operate at a slower bit rate and require more modest levels of fiber-coupled optical power (50–250 μW). These applications allow the use of high-radiance LEDs. The LED is cheaper, requires less complex driving circuitry than a DL, and needs no thermal or optical stabilizations.

The light output wavelength spread, or spectrum, of the DL is much narrower than that of LEDs: about 1 nm compared with about 40 nm for an LED. Narrow spectra are advantageous in systems with high bit rates since the dispersion effects of the fiber on pulse width are reduced, and thus pulse degradation over long distances is minimized.

Another laser device, called a **distributed feedback (DFB) laser**, uses techniques that provide optical feedback in the laser cavity. This enhances output stability, which produces a narrow and more stable spectral width. Widths are in the range of 0.01–0.1 nm. This allows the use of more channels in **dense wavelength division multiplex (DWDM)** systems. Another even more recent development is an entirely new class of laser semiconductors called **vertical cavity surface emitting lasers (VCSELs)**. These lasers can support a much faster signal rate than LEDs, including gigabit networks. They do not have some of the operational and stability problems of conventional lasers, however.

VCSELs have the simplicity of LEDs with the performance of lasers. Their primary wavelength of operation is in the 750–850-nm region, although development work is underway in the 1310-nm region. Reliabilities approaching 10^7 hours are projected.

Most lasers emit a fixed wavelength, but there is a class called **tunable lasers** in which the fundamental wavelength can be shifted a few nanometers, but not from a modulation point of view as in frequency modulation. Figure 3-12 shows an example of a tunable laser diode module. The primary market for these devices is in a network operations environment where DWDM is involved. Traffic routing is often made by wavelength, and, as such, wavelengths or transmitters must be assigned and reassigned to accommodate dynamic routing or networking, bandwidth on demand, seamless restoration (serviceability), optical packet switching, and so on. Tunable lasers are used along with either passive or tunable WDM filters.

Distributed Feedback (DFB) Laser
A more stable laser suitable for use in DWDM systems

Dense Wavelength Division Multiplex (DWDM)
Incorporates the propagation of several wavelengths in the 1550-nm range for a single fiber

Vertical Cavity Surface Emitting Lasers (VCSELs)
Lasers with the simplicity of LEDs and the performance of lasers

Tunable Laser
Laser in which the fundamental wavelength can be shifted a few nanometers, ideal for traffic routing in DWDM systems

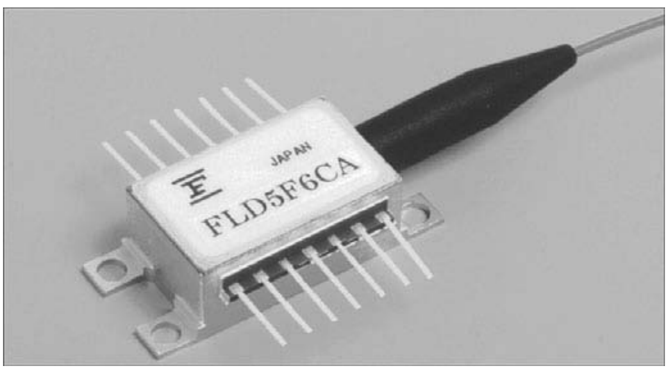

FIGURE 3-12 A tunable laser diode module (courtesy of Fujitsu Compound Semiconductor, Inc.).

Intermediate Components

Fiber, Light Pipe, Glass
Terms used to describe a fiber-optic strand

The typical fiber-optic telecommunication link (as shown previously in Figure 3-1) is a light source or transmitter and light detector or receiver interconnected by a strand of optical **fiber**, **light pipe**, or **glass**. An increasing number of specialized networks and system applications have various intermediate components along the span between the transmitter and the receiver. A brief review of these devices and their uses is provided in the list that follows.

Isolator
An inline passive device that allows optical power to flow only in one direction

Received Signal Level (RSL)
The input signal level to an optical receiver

- **Isolators**: An **isolator** is an inline passive device that allows optical power to flow in one direction only.
- **Attenuators**: Attenuators are used to reduce the **received signal level (RSL)**. They are available in fixed and variable configurations.
- **Branching devices**: Branching devices are used in simplex systems where a single optical signal is divided and sent to several receivers, such as point-to-multipoint data or a CATV distribution system.
- **Splitters**: Splitters are used to split, or divide, the optical signal for distribution to any number of places.
- **Wavelength division multiplexers**: Wavelength division multiplexers combine or divide two or more optical signals, each having a different wavelength. They are sometimes called optical beam splitters.
- **Optical-line amplifiers**: Optical-line amplifiers are analog amplifiers. Placement can be at the optical transmitter output, midspan, or near the optical receiver.

Detectors

The devices used to convert the transmitted light back into an electrical signal are a vital link in a fiber-optic system. This important link is often overlooked in favor of the light source and fibers. However, simply changing from one photodetector to another can increase the capacity of a system by an order of magnitude.

The important characteristics of light detectors are as follows:

- **Responsivity:** This is a measure of output current for a given light power launched into the diode.
- **Response speed:** This determines the maximum data rate capability of the detector.
- **Spectral response:** This determines the responsivity that is achieved relative to the wavelength at which responsivity is specified.

Optical fibers are joined either in a permanent fusion splice or with a mechanical splice (for example, connectors and camsplices). The connector allows repeated matings and unmatings. Above all, these connections must lose as little light as possible. Low loss depends on correct alignment of the core of one fiber to another, or to a source or detector. Losses for properly terminated fusion and mechanical splices is typically 0.2 dB or less. Signal loss in fibers occurs when two fibers are not perfectly aligned within a connector. Axial misalignment typically causes the greatest loss—about 0.5 dB for a 10 percent displacement. Figure 3-13 illustrates this condition as well as other loss sources.

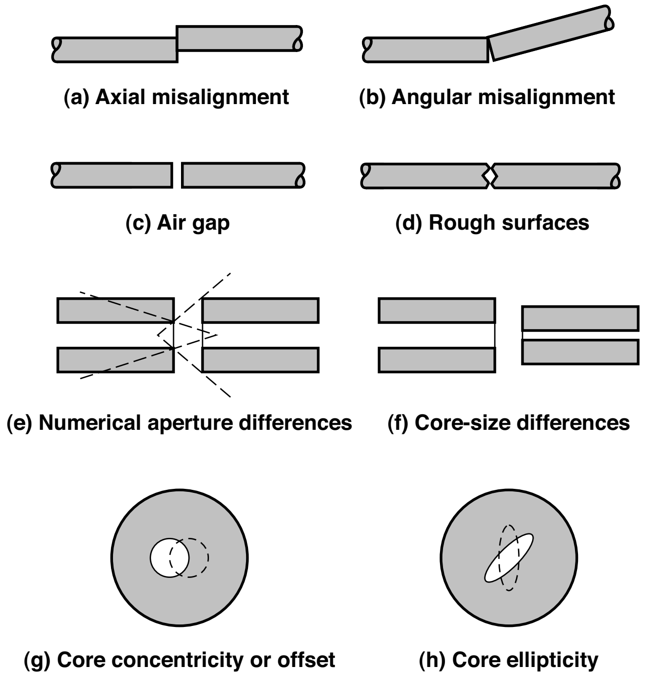

FIGURE 3-13 Sources of connection loss. (From *Modern Electronic Communication 9/e,* by J.S. Beasley & G. M. Miller, 2008, p. 806. Copyright ©2008 Pearson Education, Inc. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.)

Angular misalignment [Figure 3-13(b)] can usually be well controlled in a connector. Most connectors leave an air gap, as shown in Figure 3-13(c). The amount of gap affects loss since light leaving the transmitting fiber spreads conically.

The losses due to rough end surfaces shown in Figure 3-13(d) are often caused by a poor cut, or "cleave," but can be minimized by polishing or using pre-polished connectors. Polishing typically takes place after a fiber has been placed in a connector. The source of connection losses shown in Figure 3-13(d) can, for the most part, be controlled by a skillful cable splicer. There are four other situations that can cause additional connector or splice loss, although in smaller values. These are shown in Figure 3-13(e), (f), (g), and (h). These are related to the nature of the fiber strand at the point of connection and are beyond the control of the cable splicer. The effect of these losses can be minimized somewhat by the use of a rotary mechanical splice, which by the joint rotation will get a better core alignment.

With regard to connectorization and splicing, there are two techniques to consider for splicing. **Fusion splicing** is a long-term method, in which two fibers are fused or welded together. The two ends are stripped of their coating, cut or cleaved, and inserted into the splicer. The ends of the fiber are aligned, and an electric arc is fired across the ends, melting the glass and fusing the two ends together. There are both manual and automatic fusion splicers; the choice usually depends on the number of splices to be done on a given job, technician skill levels available, and of course the budget. Typical insertion losses of less than 0.1 dB—frequently in the 0.05 dB range—can be consistently achieved.

Fusion Splicing
A long-term method where two fibers are fused or welded together

Mechanical Splices
Two fibers joined together with an air gap, thereby requiring an index-matching gel to provide a good splice

Index-matching Gel
A jellylike substance that has an index of refraction much closer to glass than to air

Mechanical splices can be permanent and an economical choice for certain fiber-splicing applications. Mechanical splices also join two fibers together, but they differ from fusion splices in that an air gap exists between the two fibers. This results in a glass-air-glass interface, causing a severe double change in the index of refraction. This change results in an increase in insertion loss and reflected power. The condition can be minimized by applying an **index-matching gel** to the joint. The gel is a jellylike substance that has an index of refraction much closer to the glass than air. Therefore, the index change is much less severe. Mechanical splices have been universally popular for repair and for temporary or laboratory work. They are quick, cheap, easy, and appropriate for small jobs. The best method for splicing depends on the application, including the expected future bandwidth (that is, gigabit), traffic, the job size, and economics. The loss in a mechanical splice can be minimized by using an OTDR to properly align the fiber when you are making the splice.

Fiber Connectorization

SC, ST, FC, LC, MT-RJ
Typical fiber connectors on the market

For fiber connectorization, there are several choices on the market such as **SC, ST, FC, LC, MT-RJ,** and others. The choice of the connector is typically dictated by the hardware being used and the fiber application. Figure 3-14(a–e) provides some examples of SC, ST, FC, LC, and MTRJ connectors

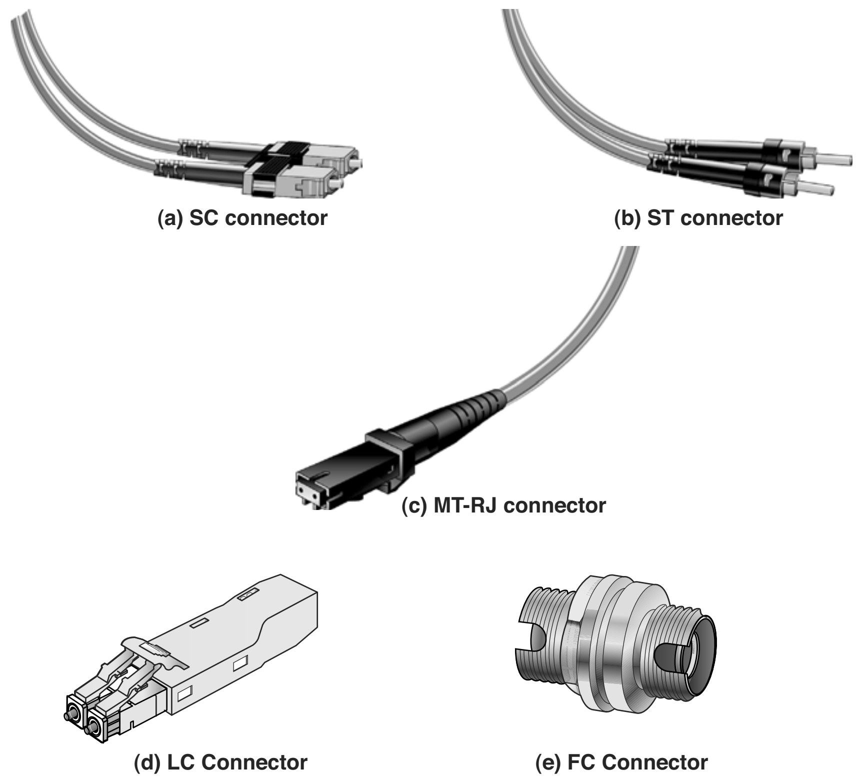

FIGURE 3-14 Typical fiber connections. [(a), (b), and (c) From *Modern Electronic Communication 9/e,* by J.S. Beasley & G. M. Miller, 2008, p. 808. Copyright ©2008 Pearson Education, Inc. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ. (d) and (e) from Black Box Corporation.]

Some general requirements for fiber connectors are as follows:

- Easy and quick to install
- Low insertion loss—a properly installed connector will have as little as 0.25 dB insertion loss
- High return loss greater than 50 dB—this is increasingly important in gigabit networks, DWDM systems, high-bandwidth video, and so on
- Repeatability
- Economical

In preparing the fiber for splicing or connectorization, only the coating is removed from the fiber strand. The core and the cladding are not separable. The 125m cladding diameter is the portion that fits into the splice or connector, and therefore most devices can handle both single and multimode fiber.

Sometimes the issue arises as to the advisability of splicing together fibers of different core sizes. The one absolute rule is do *not* splice single- and multimode fiber together! Similarly, good professional work does not allow different sizes of multimode fiber to be spliced together. However, in an emergency, different sizes can be spliced together if the following is considered:

When transmitting from a small- to large-core diameter, there will be minimal, if any, increase in insertion loss. However, when the transmission is from a larger to a smaller core size, there will be added insertion loss and a considerable increase in reflected power should be expected.

Industrial practice has confirmed the acceptability of different core size interchangeability for emergency repairs in the field, mainly as the result of tests with 50 m and 62.5 m multimode fiber for a local area network.

Section 3-4 Review

This section has covered the following **Network+** Exam objectives.

3.2 Categorize standard connector types based on network media

This section presented a look at optical components. Issues with connection loss are shown in Figure 3-13 and the different types of connectors are shown in Figure 3-14.

Test Your Knowledge

1. Fusion-splicing is characterized by which of the following?
   a. A temporary method for splicing fiber
   b. An inexpensive alternative to mechanical splices
   c. Requires index-matching gel
   d. A long-term method where two fibers are fused or welded together
2. The function of an attenuator is to reduce the receive signal level. True or False?

3-5 OPTICAL NETWORKING

The need for increased bandwidth is pushing the fiber-optic community into optical networking solutions that are almost beyond the imagination of even the most advanced networking person. Optical solutions for long-haul, wide area, metropolitan, campus, and local area networks are available. Cable companies are already using the high-bandwidth capability of fiber to distribute cable programming as well as data throughout their service areas.

The capital cost differences between a fiber system and a copper-based system are diminishing, and the choice of networking technology for new networks is no longer just budgetary. Fiber has the capacity to carry more bandwidth, and because the fiber infrastructure cost decreases, fiber will be chosen to carry the data. Of course, the copper infrastructure is already in place, and new developments are providing increases in data speed over copper (for example, CAT6 and CAT7). However, optical fiber is smaller and easier to install in already crowded ducts and conduits. Additionally, security is enhanced because it is difficult to tap optical fiber without detection. Will fiber replace copper in computer networks? For many years, a hybrid solution of fiber and copper is expected.

Defining Optical Networking

Optical networks are becoming a major part of data delivery in homes, in businesses, and for long-haul carriers. The telecommunications industry has been using fiber to carry long-haul traffic for many years. Some major carriers are merging with cable companies so that they are poised to provide high-bandwidth capabilities to the home. Developments in optical technologies are reshaping the way we will use fiber in future optical networks.

But there is a new slant with optical networks. Dense wave division multiplexing and tunable lasers have changed the way optical networks can be implemented. It is now possible to transport many wavelengths over a single fiber. Lab tests at AT&T have successfully demonstrated the transmission of 1,022 wavelengths over a single fiber. Such transport of multiple wavelengths opens up the possibilities to routing or switching many different data protocols over the same fiber but on different wavelengths. The development of cross-connects that allow data to arrive on one wavelength and leave on another opens other possibilities.

SONET/SDH
Synchronous optical network; protocol standard for optical transmission in long-haul communication/synchronous digital hierarchy

Synchronous optical network (**SONET**) and **SDH** were the North American and international standards for the long-haul optical transport of telecommunication for many years. SONET/SDH defined a standard for the following:

- Increase in network reliability
- Network management
- Defining methods for the synchronous multiplexing of digital signals such as DS-1 (1.544Mbps) and DS-3 (44.736Mbps)
- Defining a set of generic operating/equipment standards
- Flexible architecture

SONET/SDH specifies the various optical carrier (OC) levels and the equivalent electrical synchronous transport signals (**STS**) used for transporting data in a fiber-optic transmission system. Optical network data rates are typically specified in terms of the SONET hierarchy. Table 3-2 lists the more common data rates.

STS
Synchronous transport signals

TABLE 3-2 SONET Hierarchy Data Rates

Signal	Bit Rate	Capacity
OC-1 (STS-1)	51,840Mbps	28DS-Is or 1 DS-3
OC-3 (STS-3)	155.52Mbps	84DS-Is or 3 DS-3s
OC-12 (STS-12)	622.080Mbps	336 DS-1s or 12 DS-3s
OC-48 (STS-48)	2.48832Gbps	1344 DS-1s or 48 DS-3s
OC-192 (STS-192)	9.95328Gbps	5376 DS-Is or 192 DS-3s

OC: Optical carrier—DS-1: 1.544Mbps

STS: Synchronous transport signal—DS-3: 44.736Mbps

The architectures of fiber networks for the home include providing fiber to the curb (**FTTC**) and fiber to the home (**FTTH**). FTTC is being deployed today. It provides high bandwidth to a location with proximity to the home and provides a high-speed data link, via copper (twisted-pair), using VDSL (very high-data digital subscriber line). This is a cost-effective way to provide large-bandwidth capabilities to a home. FTTH will provide unlimited bandwidth to the home; however, the key to its success is the development of a low-cost optical-to-electronic converter in the home and laser transmitters that are tunable to any desired channel.

FTTC
Fiber to the curb

FTTH
Fiber to the home

Another architecture in place is fiber to the business (**FTTB**). A fiber connection to a business provides for the delivery of all current communication technologies including data, voice, video, conferencing, and so on. An additional type is fiber to the desktop (**FTTD**). This setup requires that the computer has a fiber network interface card (NIC). FTTD is useful in applications such as computer animation work that has high-bandwidth requirements.

FTTB
Fiber to the business

FTTD
Fiber to the desktop

Conventional high-speed Ethernet networks are operating over fiber. This is called **optical Ethernet** and uses the numerics listed in Table 3-3 for describing the type of network configuration. Fiber helps to eliminate the 100-m distance limit associated with unshielded twisted-pair (UTP) copper cable. This is possible because fiber has a lower attenuation loss. In a star network, the computer and the switch are directly connected. If the fiber is used in a star network, an internal or external media converter is required. The media converter converts the electronic signal to an optical signal, and vice versa. A media converter is required at both ends, as shown in Figure 3-15. The media converter is typically built in to the network interface card.

Optical Ethernet
Ethernet data running over a fiber link

TABLE 3-3 Optical Ethernet Numerics

Numeric	Description
10BASE-F	10Mbps Ethernet over fiber—generic specification for fiber
10BASE-FB	10Mbps Ethernet over fiber—part of the IEEE 10BaseF specification; segments can be up to 2 km in length
10BASE-FL	10Mbps Ethernet over fiber—segments can be up to 2 km in length; it replaces the FOIRL specification.
10BASE-FP	A passive fiber star network; segments can be up to 500 m in length
100BASE-FX	A 100Mbps fast Ethernet standard that uses two fiber strands
1000BASE-LX	Gigabit Ethernet standard that uses fiber strands using long-wavelength transmitters
1000BASE-SX	Gigabit Ethernet standard using short-wavelength transmitters
10GBASE-R	10 gigabit (10.325Gbps) Ethernet for LANs
10GBASE-W	10 gigabit (9.95328Gbps) Ethernet for WANs using OC-192 and SONET Framing

Multimode fiber—2 km length single mode—10 km length

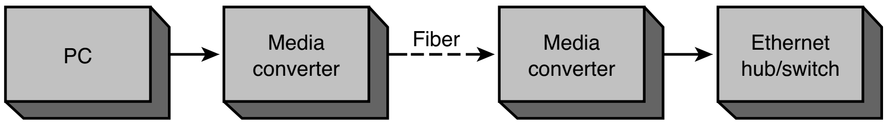

FIGURE 3-15 An example of connecting a PC to an Ethernet hub or switch via fiber. (From *Modern Electronic Communication 9/e,* by J.S. Beasley & G. M. Miller, 2008, p. 820. Copyright ©2008 Pearson Education, Inc. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.)

Two important issues to be considered when designing a fiber network are the guidelines for the following:

Building distribution

Campus distribution

The following subsections discuss techniques for planning the fiber plant, the distribution of the fiber, and the equipment and connections used to interconnect the fiber. The first example is for a building distribution, the second for a campus distribution.

Building Distribution

Figure 3-16 shows an example of a simple fiber network for a building. Fiber lines consist of a minimum of two fibers, one for transmitting and one for receiving. Fiber networks work in the full-duplex mode, meaning that the links must be able to simultaneously transmit and receive; hence, the need for two fibers on each link.

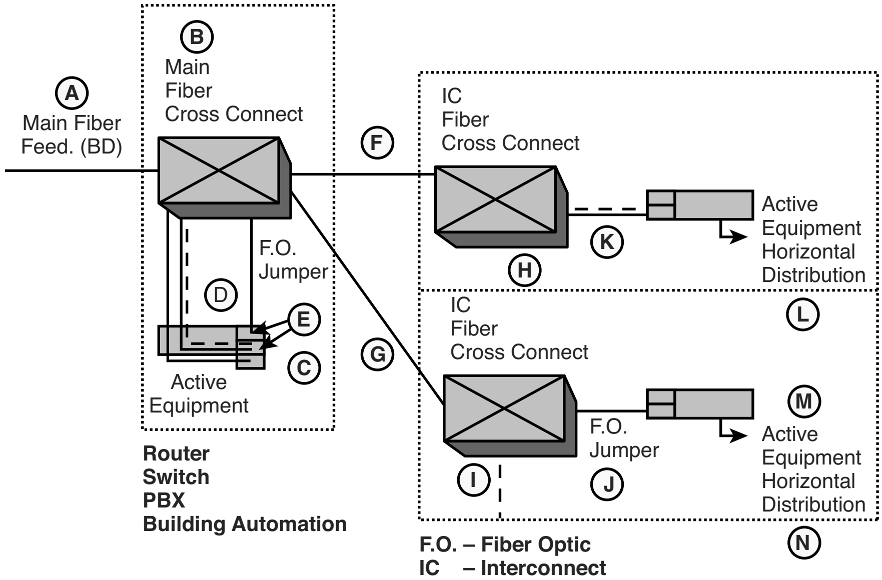

FIGURE 3-16 A simple fiber distribution in a building.

Item A is the main fiber feed for the building. This is called a *building distribution (BD)* fiber. The two fibers for the BD link terminate into a main fiber cross-connect (item B). A **fiber cross-connect** is the optical patch panel used to connect the fiber cables to the next link. The fiber cross-connect typically uses mechanical splices to make the fiber connections.

Fiber Cross-connect
Optical patch panel used to interconnect fiber cables

Items C and E represent the active equipment in the main distribution closet in the building. The active equipment could be a router, switch, or telephone PBX (private branch exchange). Item D shows the jumpers connecting the main fiber cross-connect (item B) to the active equipment (item C).

The active equipment will need some type of optical interface for the optical-electrical signal conversion, such as a **GBIC** (pronounced "gee-bick"). GBIC, or the Gigabit Interface Converter, is a hot-swappable transceiver that is used for transmitting and receiving higher-speed signals over fiber-optic lines. This is shown in Figure 3-17(a).

GBIC
Gigabit interface converter

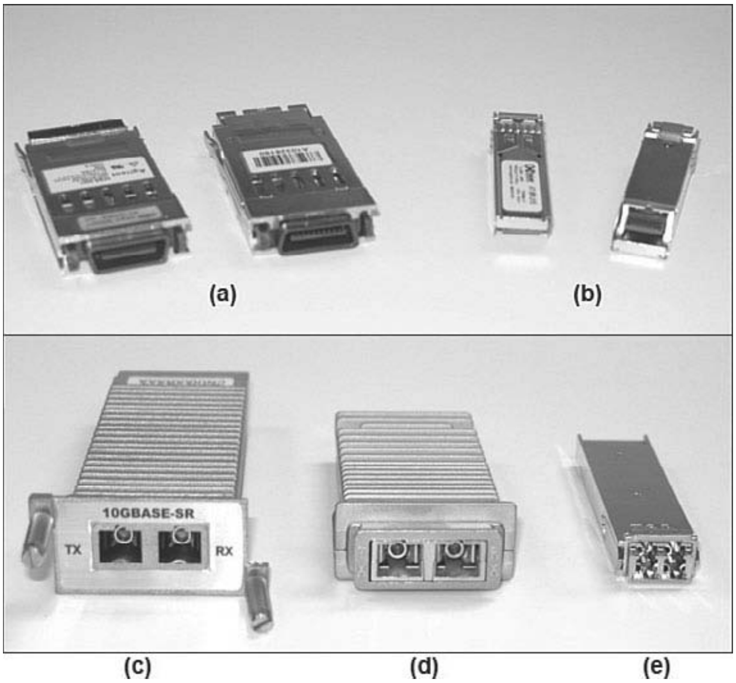

FIGURE 3-17 The Cisco (a) GBIC, (b) SFP, (c) XENPAK, (d) X2, and (e) XFP optical-to-fiber transceivers (courtesy of Cisco).

SFP
Small Form Pluggable

To increase port density on the active network equipment, the industry has been moving toward using a mini-GBIC or **SFP** (Small Form factor Pluggable).This is shown in Figure 3-17(b) The SFP is more than half the size of the GBIC shown in Figure 3-17(a). These modules are used to connect to other fiber-optic systems such as 1000Base-SX, which operates with multimode fiber in a short wavelength, and 1000Base-LX, which operates with the single-mode fiber in a longer wavelength. GBIC and SFP modules are designed to plug into interfaces such as routers and switches.

XENPAK, XPAK, X2, XFP, SFP+
The ten gigabit interface adapter

In the ten gigabits (10G) Ethernet world, several versions of optical-to-fiber transceivers have been developed. It all started with the **XENPAK**, shown in Figure 3-17(c), transceivers which were followed by the **XPAK** and the **X2**, shown in Figure 3-17(d). These later transceiver modules are smaller than the XENPAK. Then, an even smaller size module called XFP was developed. The **XFP**, shown in Figure 3-17(e), has lower power consumption than the XENPAK, XPAK, and X2, but it still can deliver up to 80Km in distance, which is the same as the older modules. With its small size, its lower power consumption, and its reachability, the XFP was thought to be the future of the 10G transceiver. Recently, a new type of 10G transceiver has emerged, and it is a **SFP+**. Its look and size are identical to a 1000Base SFP transceiver. To be able to deliver 10G speed in its small form factor, the working distance that the SFP+ can deliver is reduced to 40Km. So, if the distance is not of the concern, then SFP+ might be the 10G transceiver of choice. These modules support 850, 1310, and 1550 fiber wavelengths. Figure 3-17 collectively shows examples of 1000Base and 10GBase transceivers.

Referring to Figure 3-16, items F and G show the two fiber pairs patched into the main fiber cross-connect connecting to the **IDC**. These fibers (F and G) are called the interconnect (**IC**) fibers. The fibers terminate into the IDC fiber cross-connects (items H and I).

Items J and K in Figure 3-16 are fiber jumpers that connect the fiber cross-connect to the IDC active equipment. Once again, the active equipment must have a GBIC or some other interface for the optical-electrical signal conversion.

A general rule for fiber is that the distribution in a building should be limited to "2 deep." This means that a building should have only the main distribution and the intermediate distribution that feeds the horizontal distribution to the work area.

Figure 3-18(a) and (b) illustrate an example of the "2-deep" rule. Figure 3-18(a) shows an example of a building distribution that meets the "2-deep" rule. The IDC is at the first layer, and the horizontal distribution (HD) is at the second layer. Figure 3-18(b) illustrates an example of a fiber distribution that does not meet the "2-deep" rule. In this example, the HD and work area are 3-deep, or 3 layers from the building's main distribution.

IDC
Intermediate distribution closet

IC
Interconnect fibers branch exchange—item D shows the jumpers connecting the main fiber cross-connect (item B) to the active equipment (item C)

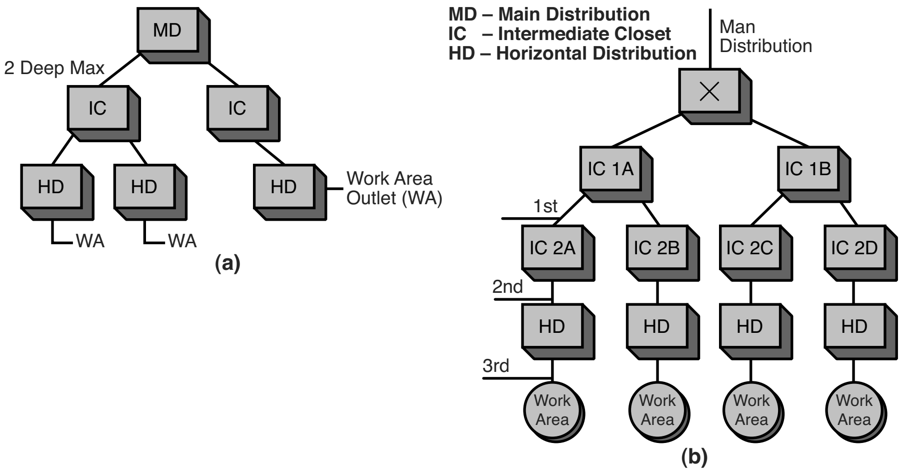

FIGURE 3-18 Examples of the "2-deep" rule: (a) the distribution meeting the requirement; (b) the distribution not meeting the requirement.

Campus Distribution

Figure 3-19 shows a map of the fiber distribution for a campus network. This map shows how the fiber is interconnected and data is distributed throughout the campus and is called a **logical fiber map**. Another style of map often used to show the fiber distribution is a **physical fiber map,** as shown in Figure 3-20. This map shows the routing of the fiber but also shows detail about the terrain, underground conduit, and entries into buildings. Both map styles are important and necessary for documentation and planning of the fiber network. This material focuses on the documentation provided in the logical fiber map.

Logical Fiber Map
Shows how the fiber is interconnected and data is distributed throughout a campus

Physical Fiber Map
Shows the routing of the fiber but also shows detail about the terrain, underground conduit, and entries into buildings

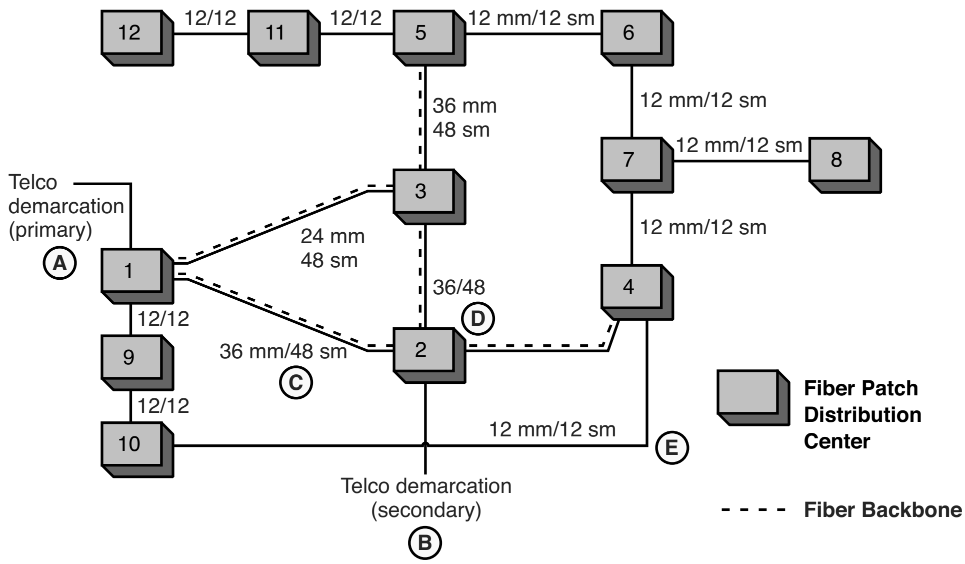

FIGURE 3-19 A logical fiber map.

mm
Multimode

sm
Single mode

Backbone
Main fiber distribution

Referring to the logical fiber map in Figure 3-19, this campus network has two connections to the Telco: the primary Telco demarcation (item A) in building 1 and the secondary Telco demarcation (item B) in building 2. These two Telco connections provide for redundant Internet and wide area network data services. If something happens in building 1 that shuts down the external data services, Internet and WAN data traffic can be switched to building 2. Also data traffic can be distributed over both connections to prevent bottlenecking. Buildings 1 and 2 are interconnected with 36 multimode (**mm**) and 48 single-mode (**sm**) fibers. This is documented on the line interconnecting buildings 1 and 2 (item C) and written as 36/48 (item D). The dotted line between buildings 1 and 2 indicates the **backbone** or main fiber distribution for the campus network. The bulk of the campus network data traffic travels over these fibers. The campus backbone (green dotted line) also extends from building 2 to building 4 and from building 3 to building 5.

This setup enables the data to be distributed over the campus. For example, data traffic from the primary Telco demarcation (item A) reaches building 12 by traveling via fiber through buildings 1-3-5-11-12. If the building 3 connection is down, then data traffic from the primary Telco demarcation can be routed through buildings 1-2-4-7-6-5-11-12. What happens to the data traffic for building 12 if building 5 is out of operation? In this case, data traffic to/from buildings 11 and 12 is lost.

Item E shows a fiber connection to/from buildings 4 and 10. This fiber bundle provides an alternative data path from the primary Telco demarcation to the other side of the campus network.

FIGURE 3-20 An example of a physical fiber map (courtesy of Palo Alto Utilities).

The cabling between buildings is a mix of multimode and single-mode fiber. The older fiber runs a 12/12 cable (12 multimode/12 single-mode). Fiber cables are bundled in groups of 12 fibers. For example, a 12/12 fiber will have two bundles: one bundle of multimode and one bundle of single-mode fiber. A 36/48 cable will have 3 bundles of multimode and 4 bundles of single-mode fiber. Each bundle of fibers is color-coded as listed in Table 3-4. For example, in a 36/48 fiber cable, the 3 bundles of multimode are in loose tubes that are color-coded blue/orange/green. The four bundles of single mode are in loose tubes that are color-coded brown/slate/white/red.

TABLE 3-4 The Fiber Color-code for the Twelve Fibers in a Bundle

Pair	Color
1/2	Blue/Orange
3/4	Green/Brown
5/6	Slate/White
7/8	Red/Black
9/10	Yellow/Violet
11/12	Rose/Aqua Marine

In this example, the newer fiber cabling installations were run with a 36/48 and 24/48 mix. Why the difference? The main reason is economics. The cost per foot (meter) of the new fiber is cheaper, so more fiber can be placed in a cable for the same cost per foot.

The fiber connecting the buildings is typically run either in PVC conduit, which makes it easy to add or remove fiber cables, or in trenches or tunnels. Running fiber in trenches is very expensive and significantly increases the installation cost. (*Note:* Network administrators need to be aware of any trenches being dug on campus.) Even if the budget doesn't allow for buying fiber at the time, at least have a conduit and pull line installed.

Fiber provides substantially increased bandwidth for building and campus networks and can easily handle the combined traffic of PCs, switches, routers, video, and voice services. Fiber has greater capacity, which enables faster transfer of data, minimizes congestion problems, and provides tremendous growth potential for each of the fiber runs.

Another important application of optical Ethernet is extending the reach of the Ethernet network from the local and campus network out to the metropolitan and wide area networks. Essentially, optical networking is introducing Ethernet as a viable WAN technology. Extending Ethernet into a WAN is a seamless integration of the technologies. The Ethernet extension into the WAN simply requires optical adapters such as a GBIC (gigabit interface converter) and two fiber strands, one for transmitting and one for receiving. Conventional high-speed Ethernet LANs operating over fiber use the numerics listed in Table 3-4 for describing the network configuration.

Section 3-5 Review

This section has covered the following **Network+** Exam objectives.

3.7 Compare and contrast different LAN technologies

The issues with configuring an optical network have been introduced in this chapter. The concept of optical networking is defined as well as FTTH (Fiber to the Home) and FTTB(Fiber to the Business).

3.8 Identify components of wiring distribution

A block diagram for fiber distribution in a building is provided in Figure 3-18. A logical fiber map that shows how the fiber is interconnected in a network is provided in Figure 3-19. An example of a physical fiber map showing detail such as terrain and entries into a building is provided in Figure 3-20.

4.5 Describe the purpose of configuration management documentation

Documenting a fiber-optic network becomes extremely important when trying to keep track of how the data is routed and which fibers are being used. Equally important are which fibers are available for future expansion.

Test Your Knowledge

1. What does the logical fiber map show? (select all that apply)
   a. How data is distributed throughout a campus
   b. The routing of the fiber
   c. Terrain and underground conduits
   d. How the fiber is interconnected
2. What does the physical fiber map show? (select all that apply)
   a. The routing of the fiber
   b. The LAN connections
   c. Terrain issues
   d. Router placement
3. What is the name of the optical-to-fiber interface used at 10 gigabits?
   a. GBIC
   b. 10GBIC
   c. XENPAK
   d. ZENPAK

3-6 SAFETY

Any discussion of fiber-optics or optical networking is not complete unless it addresses safety issues, even if only briefly. As the light propagates through a fiber, two factors will further attenuate the light if there is an open circuit:

1. A light beam will disperse or fan out from an open connector.
2. If a damaged fiber is exposed on a broken cable, the end will likely be shattered, which will considerably disperse the light. In addition, there would be a small amount of attenuation from the strand within the cable, plus any connections or splices along the way.

However, there are two factors that can increase the optical power at an exposed fiber end.

1. There could be a lens in a pigtail that could focus more optical rays down the cable.
2. In the newer DWDM systems, there will be several optical signals in the same fiber; although separate, they will be relatively close together in wavelength. The optical power incident on the eye will then be multiplied.

There are two factors to be aware of:

1. The eye can't see fiber-optic communication wavelength, so there is no pain or awareness of exposure. However, the retina can still be exposed and damaged. (Refer to Figure 3-3, the electromagnetic spectrum.)

2. Eye damage is a function of the optical power, wavelengths, source or spot diameter, and duration of exposure.

So for those working on fiber-optic equipment:

1. *DO NOT EVER* look into the output connector of energized test equipment. Such equipment can have higher powers than the communication equipment itself, particularly OTDRs.
2. If you need to view the end of a fiber, *ALWAYS turn off the transmitter,* particularly if you don't know whether the transmitter is a laser or LED, given that lasers are higher-power sources. If you are using a microscope to inspect a fiber, the optical power will be multiplied.

From a mechanical point of view:

1. Good work practices are detailed in safety, training, and installation manuals. READ AND HEED.
2. Be careful with machinery, cutters, chemical solvents, and epoxies.
3. Fiber ends are brittle and will break off easily, including the ends cut off from splicing and connectorization. These ends are extremely difficult to see and can become "lost" and/or easily embedded in your finger. You won't know until your finger becomes infected. Always account for all scraps.
4. Use safety glasses specifically designed to protect the eye when working with fiber-optic systems.
5. Obtain and *USE* an optical safety kit.
6. Keep a *CLEAN* and orderly work area.

In all cases, be sure the craft personnel have the proper training for the job!

Section 3-6 Review

This section has covered the following **Network+** Exam objectives.

3.1 Categorize standard media types and associated properties

Anytime you are working with fiber, you need to be careful. This section presents an overview of safety.

Test Your Knowledge

1. The eye cannot see fiber-optic communication wavelengths, so never look into the end of a fiber. True or False?

2. It is important to be very careful working with fiber ends. These ends are extremely difficult to see and can become "lost" and/or easily embedded in your finger. True or False?

SUMMARY

Chapter 3 introduced the field of fiber-optics and optical networking. The chapter has provided examples using fiber to interconnect LANs in both a building and a campus network. The major topics that the student should understand include the following:

- The advantages offered by optical networking
- The properties of light waves
- The physical and optical characteristics of optical fibers
- Attenuation and dispersion effects in fiber
- The description of the common techniques used to connect fiber
- The usage of fiber-optics in LANs, campus networks, and WANs
- System design of optical networks
- Safety considerations when working with fiber
- Analysis of OTDR waveforms

QUESTIONS AND PROBLEMS

Section 3-1

1. List the basic elements of a fiber-optic communication system.

2. List five advantages of an optical communications link.

Section 3-2

3. Define refractive index.

4. What are the commonly used wavelengths in fiber-optic systems?

5. Which part of an optical fiber carries the light?

6. What is a measure of a fiber's light acceptance?

7. Define pulse dispersion.

8. What are the typical core/cladding sizes (in microns) for multimode fiber?

9. What is the typical core size for single-mode fiber?

10. Define *mode field diameter*.

Section 3-3

11. What are the two key distance-limiting parameters in fiber-optic transmissions?

12. What are the four factors that contribute to attenuation?

13. Define *dispersion*.

14. What are three types of dispersion?

15. What is meant by the *zero-dispersion wavelength*?

16. What is a dispersion compensating fiber?

Section 3-4

17. What are the two kinds of light sources used in fiber-optic communication systems?

18. Why is a narrower spectra advantageous in optical systems?

19. Why is a tunable laser of importance in optical networking?

20. What is the purpose of an optical attenuator?

21. List two purposes of optical detectors.

22. What is the advantage of fusion splicing over mechanical splicing?

Section 3-5

23. Define: (a) FTTC; (b) FTTH; (c) FTTB; (d) FTTD.

24. What is the purpose of a GBIC?

25. What is the "2-deep" rule?

26. What is the purpose of a logical fiber map?

27. What are the typical maximum lengths for (a) multimode and (b) single-mode fiber?

28. What is FDDI?

Section 3-6

29. Why is safety an important issue in optical networking?

30. A campus network is planning to install fiber-optic cables to replace outdated coaxial cables. They have the choice of installing single-mode, multimode, or a combination of single–multimode fibers in the ground. Which fiber type should they select? Why?

31. The networking cables for a new building are being installed. You are asked to prepare a study about which cable type(s) should be used. Discuss the issues related to the cable selection.

Certification Questions

32. Which of the following are advantages of optical communication links? (select three)
    a. Extremely wide bandwidth
    b. Elimination of crosstalk
    c. Elimination of attenuation
    d. Security
33. The stretching of a received pulse is due to what? (select two)
    a. Multiple paths taken by the light waves
    b. Misaligned connectors
    c. Pulse-dispersion
    d. OTDR testing
34. The broadening of a pulse due to the different path lengths taken through the fiber by different modes is called what?
    a. Chromatic dispersion
    b. Polarization mode dispersion
    c. Modal dispersion
    d. Diffusion
35. The broadening of a pulse due to different propagation of the spectral components of the light pulse is called what?
    a. Chromatic dispersion
    b. Modal dispersion
    c. Polarization mode dispersion
    d. Diffusion
36. The broadening of a light pulse due to the different propagation velocities of the X and Y polarization components of the light pulse is called what?
    a. Modal dispersion
    b. Chromatic dispersion
    c. Diffusion
    d. Polarization mode dispersion
37. What is the data rate for OC-192?
    a. 1.522Mbps
    b. 155.52Mbps
    c. 9.95Gbps
    d. 2.488Gbps

38. What is the name of the optical-to-fiber interface used at 1 gigabit?
    a. XENPAK
    b. GBIC
    c. 10GBIC
    d. ZENPAK

39. What is the "two deep" rule relative to optical networking?
    a. This means the horizontal distribution to the work floor can only have two 8P8C connections.
    b. This means the horizontal distribution to the work floor can only have two ST connections to the fiber patch panel.
    c. This is no longer an issue with high-speed, single-mode fiber and wave division multiplexing equipment.
    d. This means that a building should have only the main distribution and the intermediate distribution that feeds the horizontal distribution to the work area.

40. Which type of fiber is preferred for use in modern computer networks?
    a. Multimode
    b. Polarized mode
    c. Single-mode
    d. All of these answers are correct

41. What is the material surrounding the core of an optical waveguide called?
    a. Aperture
    b. Mode field
    c. Step-index
    d. Cladding
    e. Graded-index

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