CHAPTER

20

Fiber System Standards

About This Chapter

For two people to communicate, they must speak the same language. Communication systems likewise work only if transmitters and receivers attached to them speak the same language. Communication engineers have devised standards to assure that equipment from different companies will be able to interface properly.

This chapter will introduce you to the system-level standards most important for fiber-optic systems. Some are specific to fiber optics; others also cover other communications technologies. The topic of standards is complex and continuously evolving, so I will not go into much depth, especially for standards with little direct impact on fiber-optic systems. However, you should at least learn to recognize the most important standards and their functions.

Why Standards Are Needed

As you learned earlier, signals can be transmitted in a variety of ways, with different types of digital or analog coding. However, those differences only scratch the surface of the immense potential for variations. You can think of those physical differences as being similar to the distinctions among the media you use to communicate with other people—speech, the written word, sign language, pictures, and so on.

There are many other levels of variations in signal formats, just as people speak many different languages or computer programs store data in different formats. Unlike human languages, signal formats are designed by engineers to transmit signals efficiently and economically. Their choices depend on the types of signals being carried, the distances and types of terminals involved, and the hardware and software they have available. The results can vary widely with factors such as time and network scale.

These differences become a problem when you want networks to connect to each other or when you want to combine two or more generations of equipment, such as existing telephones with new digital switches and transmission lines. Then you need common languages and ways of translating signals between formats. That's when you need standards.

Standards have evolved considerably over the years, changing with both the marketplace and the technology. In the 1970s, AT&T was effectively America's telephone monopoly, so it set the standards for telecommunication systems. Since the 1984 breakup of AT&T, industry groups have come to set the standards. Many standards have become international, so you can make phone calls to Brazil, send faxes to India, and dispatch e-mail to Indonesia.

Changing standards have accommodated changes in industry practice. In the 1960s, telephone lines carried only analog voice telephone conversations. By the 1970s, the telephone network started to convert to digital voice transmission between switching centers. In the 1980s, the telephone network started to handle more computer data and video transmission, plus fax signals. Today, the high-speed lines operated by long-distance carriers are digital data highways that transmit a wide variety of signals, all digitized into a common form that can be reconverted to other formats at the receiving end. Standards make this multipurpose system possible.

Standards serve diverse functions.

Standards serve a variety of functions. They establish common physical features as well as common languages, so devices can fit together as well as understand each other. They may also assure that equipment meets the requirements of specific customers such as telephone companies or the military.

This chapter covers standards that apply to fiber-optic systems. Some important examples include:

- Physical standards for connectors, to make sure they mate optically and mechanically.
- Optical, electronic, and mechanical interface standards for packaged devices, so they connect properly to each other.
- Standard formats for data transmission.
- Telephone industry standards for data transmission and device performance.

Other standards also affect fiber-optic equipment. Fire-safety standards affect the choice of materials for cables. Component standards assure that connectors, transmitters, and laser modules are interchangeable. We won't talk about these standards here because they affect system design only indirectly.

Standards may be industry-wide, proprietary, or some combination of the two. For example, industry committees set standard data formats for Ethernet transmission, but software usually stores data it generates in a proprietary format. In some cases proprietary formats become de facto standards, like Microsoft Word format for word processing files. Usually proprietary standards are optimized for a particular company's equipment, while industry-wide standards are a compromise that works reasonably well on everyone's equipment.

Companies often battle over standards as they try to gain a competitive edge. Sometimes two or more groups create competing standards. However, agreed-upon standards are crucial to the function of an open, deregulated market involving many vendors and equipment that must interconnect.

Standards are crucial in an open, deregulated market.

You need to be sure you can plug any phone you buy today into the telephone jack in your wall and use it with any local or long-distance carrier. Most standards take into account the existence of old equipment and can accommodate much of it. You can use your digital PCS cell phone to call your grandmother on the heavy black dial phone she has used since 1952. Neither you nor your grandmother should notice the automatic electronic conversion between the two formats. You should remember, however, that some new standards do not accommodate old equipment, such as standards for digital television transmission, which make no effort to talk with the "old" analog set you bought brand new in 2004.

Families of Standards

Families of standards have been developed to meet specific transmission requirements. Typically this means sending voice, video, or data signals in different environments. For example, there are standards for how to digitize voice telephone calls and how to interleave the data streams from individual conversations to give higher and higher data rates. Other standards specify formats for data transmission over certain types of computer networks.

Families of standards exist for voice, data, and video systems.

Standards for voice, video, and data signals evolved separately and remain somewhat distinct. Many standards are administered by different organizations, or by different subgroups within large organizations such as the International Telecommunications Union. Table 17.2 lists many of the organizations involved in fiber-optic system standards.

Telecommunications standards evolved to meet specific industry requirements. In general, they specify interfaces rather than internal operations. In other words, what matters is not what goes on inside the box, but what goes into and comes out of the box. For example, it doesn't matter if your home telephone looks like a beer can, Mickey Mouse, or an antique pay phone as long as it sends and receives standard voice signals. This provides industry the flexibility to improve the technology as long as it stays within performance standards.

Most standards specify interfaces rather than internal operations.

Traditional circuit-switched telephone transmission has well-established standards that range from requirements for wire-line telephones to high-speed data-transmission rates. The telephone industry designed this family of standards to work together, and many of these standards are used in long-distance transmission.

Standards for transmitting computer data now center on the packet-switching formats used on the Internet. These standards include Ethernet and the Internet Protocol, and can handle data flow at uneven rates. Packet-switching standards continue to evolve to handle other services. An example is *Voice over Internet Protocol (VoIP)*, which converts voice signals into packets for Internet transmission.

Video transmission standards are largely industry-specific, developed by television broadcasters and cable companies. Broadcast signal formats require approval by government agencies that regulate broadcasting, such as the Federal Communications Commission in the United States. Video transmission is evolving slowly from old analog formats to new digital formats, producing completely new standards that are incompatible with old equipment.

We will explore specific standards later, but first you should learn how modern standards are structured.

Layers of Standards

Modern standards are structured in layers that serve distinct functions.

Modern standards are developed as a series of *layers*, each of which serves a distinct function. Essentially, each layer provides a set of interfaces for users of that layer, which effectively covers over deeper layers that the users don't need to worry about. The layered structure comes from the *Open System Interconnection (OSI)* model developed by the International Organization for Standardization. Many older standards, like those for digital telephone transmission, have been modified to fit the OSI layered model. Analog services appear only as inputs to the top layer of the stack.

You can see how a layered standard operates by considering the voice layer of the modern telephone network, shown in Figure 20.1. When you make a telephone call, you dial a phone number and hear the phone ring and a person answer, just as if the call were traveling over standard telephone wires, whether you're calling across town or across the country. You shouldn't notice that your voice is chopped into bits that are interleaved with bits from other telephone calls. All these operations are in the "cloud" of the telecommunications system (shown at the bottom of the figure). The system acts like you're calling one of your neighbors over dedicated local phone lines (shown at the top of the figure). The network reaches both cell phones and regular phones, and you can tell them apart only by their sounds. Faxes also travel over voice telephone lines, and they respond the same way whether you call a fax machine or a computer with fax software.

A layer in a layered standard can be viewed as providing interfaces to black boxes that represent other layers. The engineer who designs a phone, for example, works only on the voice layer of the telephone network, with no need to know about the other layers. The engineer is concerned only with the standard interfaces the phone has with the user and the network, which are other layers in the OSI model.

Layers in the Network

The services most users see are the top of a stack of layers.

Figure 20.2 shows the overall layered standard structure in a somewhat simplified form that neglects data-transmission details normally handled by software. It shows the layers used in the telephone network and the Internet. There has been serious discussion about simplifying this layered structure to reduce equipment costs, but change has been slow. Note the layers were numbered before the emergence of wavelength-division multiplexing.

Each service shown in the top layer has its own standard format. Some of these services actually perform multiple functions for the user. Standard analog voice telephone lines can transmit signals from faxes and dial-up modems as well as voice. The faxes and modems send digital data as audio tones that the phone network processes like ordinary voice phone

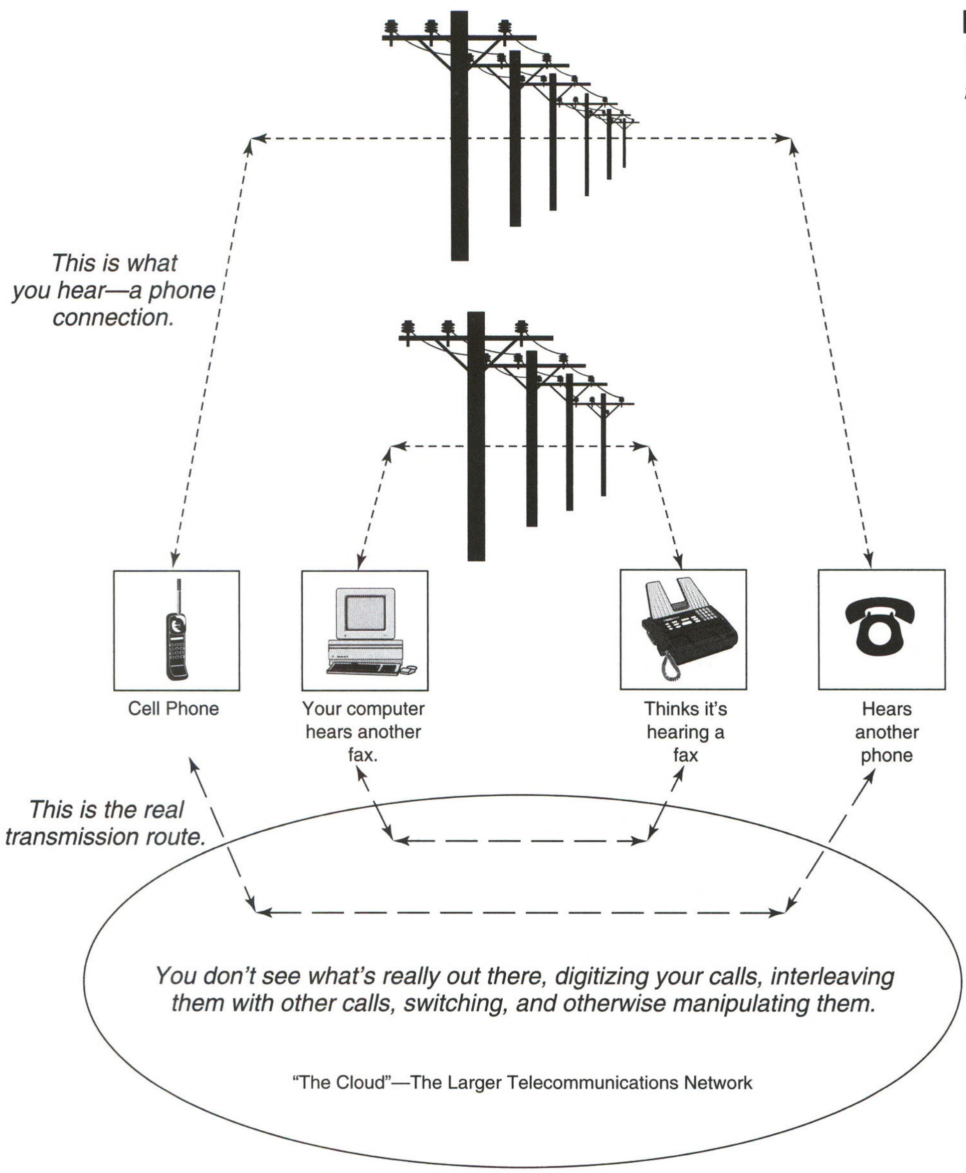

FIGURE 20.1
Voice layer of the telephone system.

calls. Broadband Internet connections provide service directly in digital form. This top layer is called the *services layer* or *layer 5*.

The next layer down, layer 4, is the *adaptation layer*, which converts signals into the formats needed for data interchange. This includes converting analog signals into digital format, and converting digital signals from special service formats into those used for data interchange.

The interchange layer uses IP and ATM formats.

The *network* or *interchange layer*, known as layer 3, covers the interchange of data packaged in standard formats. The two most important standards are the *Internet Protocol (IP)*,

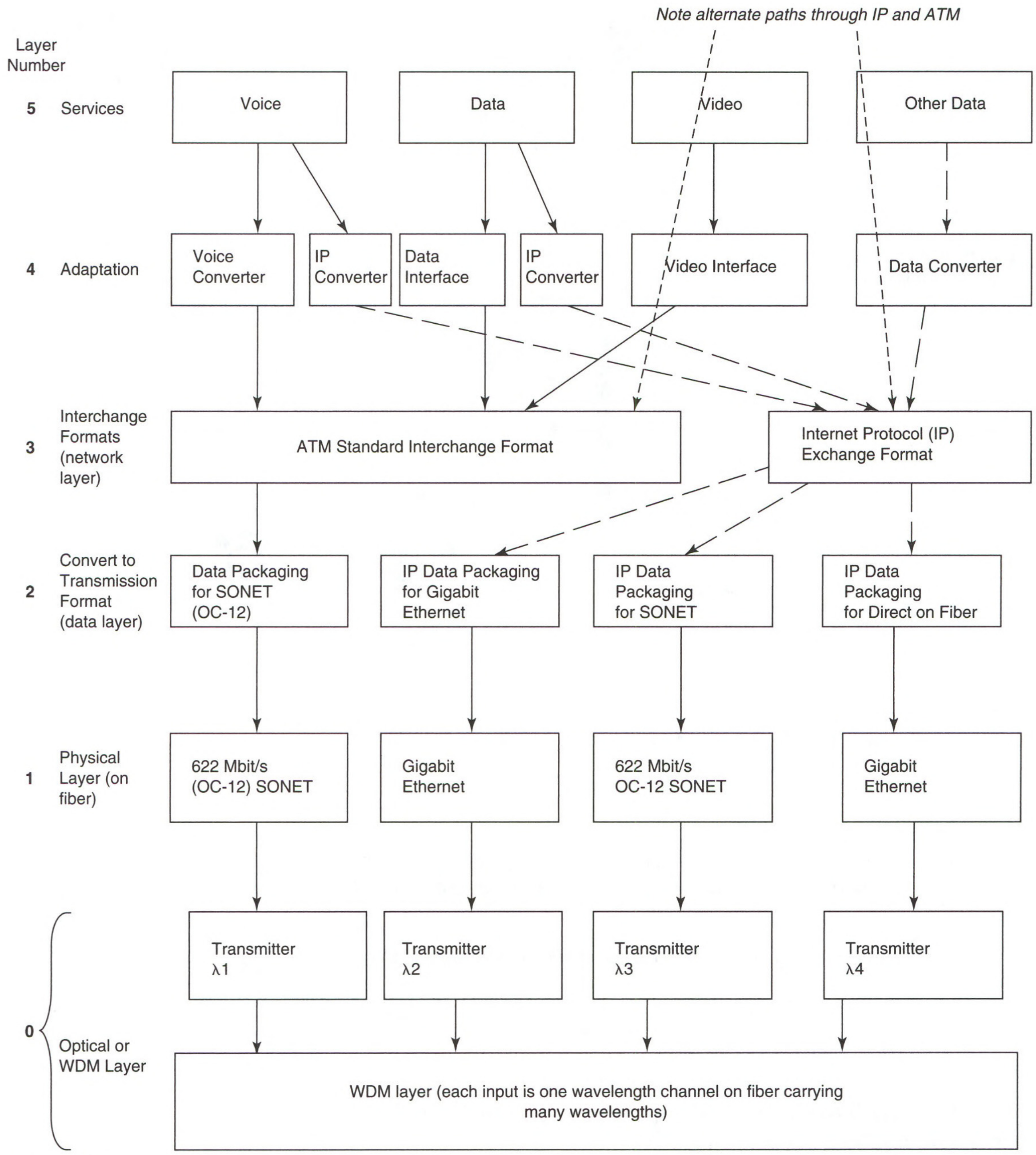

FIGURE 20.2

Standard layers for communications services, data interchange and transmission.

developed for Internet data exchange, and *Asynchronous Transfer Mode (ATM)*, developed for data and voice transmission on telephone networks. Interchange standards specify how bits are arranged, but not what medium transmits the bits. Many different signals intermingle in the interchange layer, where they are merely packages of data bits accompanied by label bits that identify them and describe their purpose. (ATM and IP formats do not serve identical purposes, and sometimes IP signals are repackaged into ATM format for transmission on telephone lines, although this is not shown in Figure 20.2.)

The *data conversion layer* is below the network layer. Called *layer 2*, it repackages data from the interchange layer into standard forms suitable for transmission on various media.

The *physical layer* or *layer 1* is the medium that carries signals, such as the optical fiber. The network transmits bits through this medium in specific formats. Figure 20.2 shows three of these standard formats:

- *Synchronized Optical Network (SONET)*, a set of standard time-division multiplexed data rates developed by the telephone industry, one of which is 622 Mbit/s.
- *Gigabit Ethernet*, an Ethernet format carrying 1 Gbit/s.
- Raw IP format data at 1 Gbit/s.

Each data stream in the physical layer corresponds to a series of light pulses passing through an optical fiber. The physical layer is usually called *layer 1*, and was originally the bottom layer for data transmission. Once in this format, signals were sent through an optical fiber to their destination.

WDM adds another layer beneath the physical layer.

The development of WDM created another possibility. Data streams generated in the physical layer can modulate signals at separate wavelengths transmitted through a single fiber; that is, as shown in Figure 20.2, each channel in the physical layer can correspond to one wavelength in an optical fiber carrying a WDM signal. In this case the *optical* or *WDM layer* is the bottom layer (sometimes called *layer 0*) of a telecommunications network.

Implementation of Layered Networks

As shown in Figure 20.2, signals may follow different paths through a layered network. Standard wire-line telephone calls may follow the path shown by the solid line at left. They first are converted into ATM format for interchange, then into SONET format for transmission on the physical layer. Internet data may follow the path shown by the dashed line at right, first put into IP format for interchange, then transmitted on the physical layer in Gigabit Ethernet format.

Other paths are possible if you follow other series of arrows through the stack of layers. For example, voice may be converted first to IP format, then transmitted over the Internet as Voice over Internet Protocol. Conversely, Internet data may remain in IP format on the interchange layer, then be packaged for SONET transmission in the physical layer.

Actual network implementation may differ from the nominal layered standard model. The layered structure is designed for modularization, so engineers can plug in modules from other layers knowing only interface specifications, not design details. Modularization can be a good thing if different organizations are building or operating different parts of the network, because it encourages competition among many vendors of services and equipment. However, implementing each layer requires costly equipment, and some layers add extra bits to manage the transmitted signal, building up overhead. If signals travel only within a single network that uses the same standards throughout, it's often cheaper and easier to avoid conversion to interchange formats and go directly to the format used on the physical layer. Signals require interchange formats only when passing through two or more networks that use different formats. Signals may even remain on the services layer if they do not travel beyond the service network, such as a local-area network for computer data or a local telephone exchange for voice.

The details of layered standards are beyond the scope of this book. Much of what happens in the service and adaptation layers is more in the realm of software than fiber-optic hardware. The standards that are important for fiber optics deal with the interchange, physical, and optical layers. These layers differ in important ways, particularly in how they direct or switch signals.

Circuit and Packet Switching

Routers operate in the interchange layer.

In Chapter 19, you learned the fundamental difference between circuit and packet switching. The two types of switching also are used on different layers, as shown in Figure 20.3. Routers provide packet switching for the interface layer and circuit switches direct transmission on the physical layer. This reflects the different functions of the two layers.

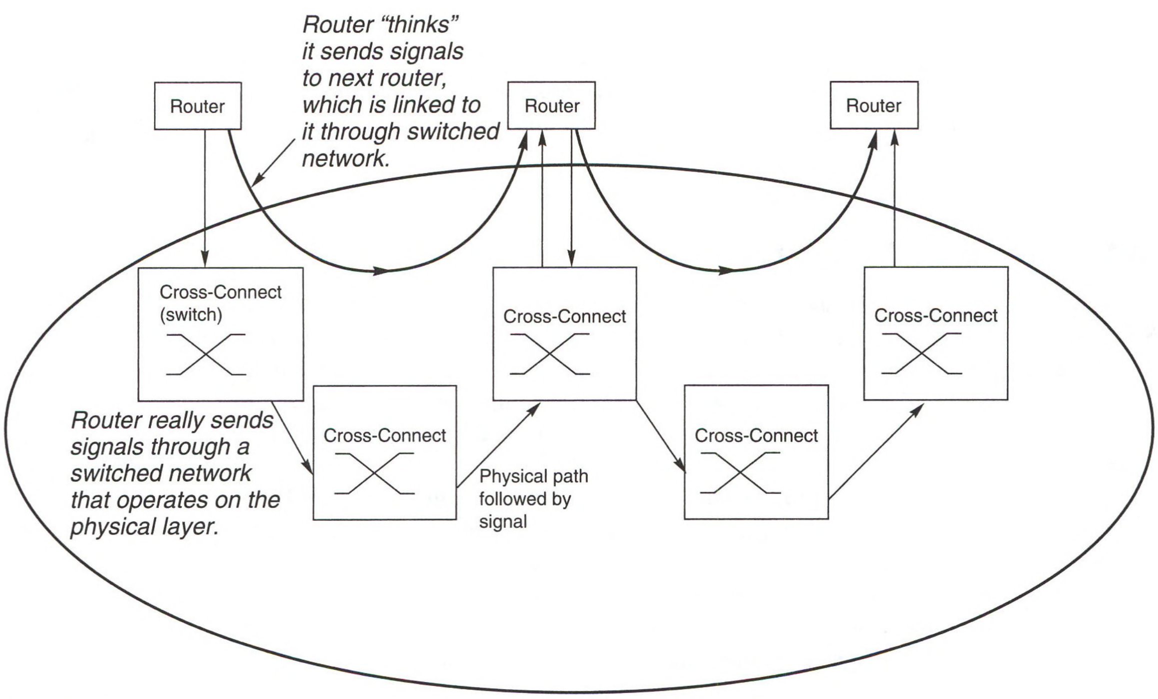

FIGURE 20.3
The interchange layer uses routers; the physical layer uses circuit switches.

The interface or networking layer organizes input signals for efficient transmission over the physical layer. Packet switching is well suited for that purpose. A router reads the packet headers, which specify each packet's destination, and may assign a transmission priority based on the type of signal in the packet. The router uses this information, as well as factors such as network traffic, to manage the data flow in the interface layer, and places the packet in a queue for transmission to the physical layer. From the viewpoint of the interchange layer, the signals appear to be switched from router to router, although they actually follow a more complex path through the physical layer, as shown in Figure 20.3.

The packet-switching standards for the interface layer don't specify a data transmission rate. That's because the actual transmission rate depends on the physical layer. The interchange layer is like a machine that reads labels and stacks parcels in a queue, and the physical layer resembles a conveyor belt that removes parcels at a fixed rate. The two work together, but have different functions. The interchange layer organizes the data packets, but the speed of the physical layer determines the data rate.

Circuit switching is on the physical layer.

The physical layer transmits data through a physical medium—an optical fiber, one wavelength on a WDM fiber, or some other medium. The physical layer does not sort individual packets; it carries a stream of data from point to point at a constant rate. The physical layer uses circuit switches that make connections without examining the packets. The switches thus make a virtual circuit between two points that may go through a series of circuit switches—like the path between the first two routers in Figure 20.3.

This distinction between circuit and packet switching is sharpest for Internet data transmission, where routers "groom" data flow on the interchange layer, and circuit switches are hidden below in the physical layer. Telephone traffic does not have to pass through routers at all, but if it does, the routers must make the service seem circuit-switched.

Interchange Standards

The two primary interchange standards are *asynchronous transfer mode* (ATM) and the *Internet Protocol* (IP). Both package data into packets and append headers containing the data's destination and other important information. They differ in their intended purposes. ATM was developed by the telecommunications industry to handle voice, video, and data, where priority is essential, and it behaves as if it were circuit-switched. IP was developed for data transmission, and initially did not assign priority to data packets; it acts packet-switched.

Asynchronous Transfer Mode (ATM)

ATM creates virtual circuits.

The ATM standard breaks incoming data into 48-byte blocks of user data, to which it prefixes a 5-byte header, producing fixed-length *cells* of exactly 53 bytes, as shown in Figure 20.4. The header contains the destination address, information on the data stream, and a priority code assigned to the data. Two-way voice (telephone) traffic receives the highest priority, because it requires a constant bit rate with no delay to provide adequate service. Video also receives a high priority because it also is vulnerable to delays. Data receives a lower priority, because delays are not considered critical. The short cell length was chosen for maximum throughput for the

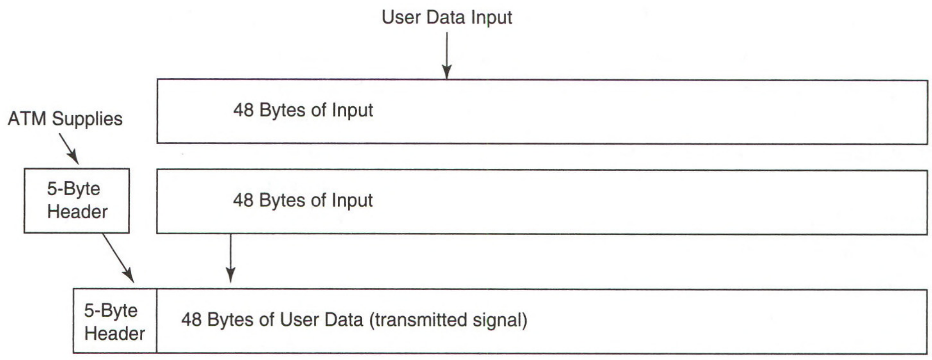

FIGURE 20.4
Asynchronous transfer mode cells.

mixture of voice, video, and data that was expected when the ATM standard was developed many years ago, but is not ideal for modern levels of data transmission because it increases overhead.

ATM designers wanted to combine the cost advantages of packet switching with the "quality of service" needed for voice traffic. Voice and video both require a guaranteed minimum capacity. The capacity of the transmission line limits the total number of virtual voice and video circuits, but ATM guarantees each virtual voice and video circuit the capacity it needs. Data receives a lower priority, and essentially fits into the spaces between the voice and video signals. That isn't as bad as it sounds, because voice conversations are not continuous, but data may have to wait for quiet intervals or other events that make transmission slots available.

Strictly speaking, ATM is packet-switched, but the telephone user shouldn't notice its presence. ATM is a resource-allocation scheme that helps data signals share phone lines without degrading the voice signals.

Internet Protocol (IP)

IP uses variable-length packets.

The Internet Protocol (IP) is another packet-switched standard that breaks incoming data into packets of variable length instead of into fixed-length cells. The header contains information on the packet's length as well as its destination.

The IP standard has evolved over the years to interconnect networks transmitting digital data. It was originally designed for "internetworking"—the interchange of data between networks at different institutions, some with different architectures and data formats. This purpose firmly entrenched it in layer 3, the interchange or networking layer of the standard system.

IP packets are stored in a buffer until transmission.

The flow of computer data fluctuates much more widely and quickly than the volume of voice telephone calls. Computers can tolerate transmission delays as long as the data packets can be reassembled in the proper order, so data networks average the flow over time to fill available transmission capacity more evenly. They do this by putting packets in a buffer storage until outgoing lines are available to transmit them. Figure 20.5 shows how this works in a simple system that can transmit 1000 bits per microsecond. If the packets that arrive during the first microsecond total only 100 bits, blank bits are transmitted along with the 100 data bits. If the packets arriving during the next microsecond contain 1500 bits, 1000 bits are transmitted and the other 500 bits sit in a buffer, to be transmitted during the next microsecond. If 600 bits

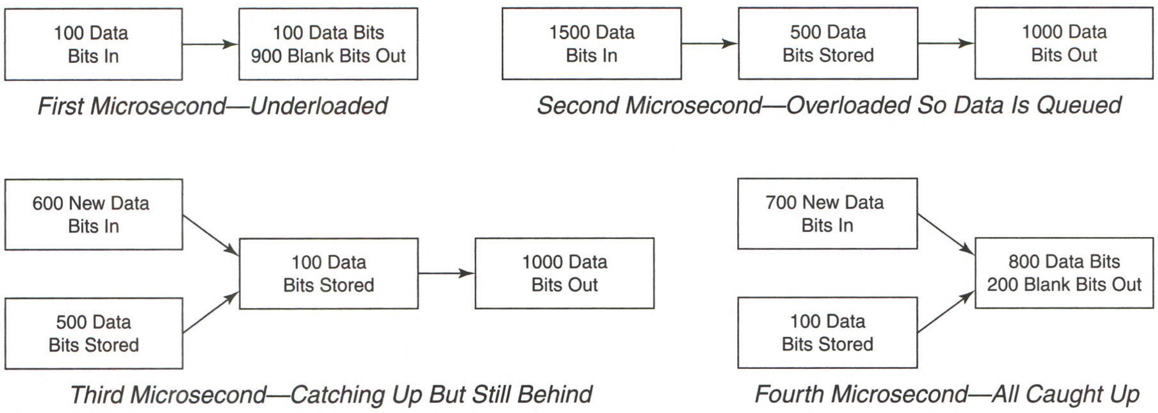

FIGURE 20.5
Packet switch stores extra bits until it can catch up on transmission.

arrive in the following microsecond, the 500 bits in the buffer and the first 500 new bits are transmitted, with 100 bits left over in the queue. If 700 bits come in the next microsecond, the 100 leftover bits are transmitted, then the 700 new bits, emptying the buffer.

Designers originally assumed that the Internet would handle only computer data, so IP headers did not assign priority levels to each packet, unlike ATM. This is still the case with the most widely used version of Internet Protocol, IPv4. With no priority codes, each IP node attempts to transmit each packet in the order in which it arrived on a "best effort" basis, so packets are transmitted in the order they were processed. The headers include counters that record how long the packet has been waiting for transmission. Packets that are stuck for a long time eventually time out and are discarded. That means your browser sometimes waits for a packet that will never come. A newer version of Internet Protocol, IPv6 (there is no version 5), assigns priority codes to packets, but is not yet widely implemented.

IPv4 lacks priority codes for data packets.

The lack of priority codes limits how well the Internet can transmit high-priority signals such as voice. Telephone calls can be made over the Internet using a protocol called Voice over IP (VoIP), but the quality of the service depends on Internet traffic. If traffic is low to moderate, packets experience few delays and the quality is good. If traffic is high, packets can be delayed and signal quality suffers. Implementation of IPv6 is expected to improve voice quality by reducing delays.

An important feature of IP is that the total capacity of input lines to a router can be greater than the total capacity of the output lines. This is possible because the average load on the input ports normally is well below the peak capacity. For example, the average load on 100-Mbit/s lines might be only 5 Mbit/s, so 20 input lines could be connected to a router linked to a single Gigabit Ethernet output without causing serious data traffic jams.

Fiber Transmission Standards

Physical layer standards cover transmission on fibers.

Fiber-optic transmission standards function as physical layer standards, although some of them don't fit into the simplified picture of Figure 20.3, which shows the physical layer as the core of the network between routers. The physical layer also exists outside the network core, delivering signals to remote equipment or servers. Physical-layer transmission differs in fundamental ways from the interchange or network layer.

The physical layer is essentially a set of transmission lines that deliver data between pairs of points. In the network core, these points may be individual devices or circuit switches, which direct streams of data along dedicated transmission lines or virtual circuits. In this sense the physical layer works like traditional telephone lines in the core of the network, although it may include routers on the periphery.

Physical layer standards cover long- and short-distance links.

Physical layer standards structure digital transmission for specific media, specifying data transmission rates and formats. Some of these standards, such as SONET, SDH, and the digital telephone hierarchy, are designed for long-distance transmission in the network core. Others such as *Fibre Channel* and *Ethernet* are designed for specific types of networks on the periphery. All of these standards provide particular functions needed by the applications they cover. SONET was developed by the telephone industry to guarantee integrity of long-distance transmission lines, so it monitors network operation. Fibre Channel was designed specifically for storage-area networks, which connect data banks to computers and provide backup data storage. Other formats, including raw IP data streams, are also used in the physical layer, although those formats may lack important monitoring functions.

We won't go into the details of these standards and their relationship with the layered model. You don't need to worry about them while you're learning about fiber optics. But you should know how these standards work, so we'll look briefly at the most important ones.

Digital Telephone Hierarchy

Digital telephone lines are based on a hierarchy of TDM rates.

Back when AT&T monopolized telephone service in most of the United States, it devised standards for digital telephone transmission. This digital telephone hierarchy remains in use at data rates to 45 Mbit/s. This standard is called the *plesiochronous digital hierarchy* or PDH, because many independent clocks provide timing for a hierarchy of data rates. The International Telecommunications Union devised a similar—but not identical—standard used in much of the rest of the world. (You'll learn more about these standards in Chapter 23, which explains the global telecommunications network; Appendix C lists the data rates.)

The digital telephone hierarchy is a sequence of these time-division multiplexed data rates. It starts with the electronics that convert a standard analog voice telephone signal into digital format at 64,000 bit/s. The bit streams from 24 digitized phone lines are interleaved to give a single stream of 1.5 Mbit/s (called the *DS1 rate*), which is transmitted through T1 lines that may be fiber but often are copper. T1 lines, in turn, feed multiplexers that generate 6-Mbit/s T2 and 45-Mbit/s T3 lines. The top of the original hierarchy, the T4 rate of 274 Mbit/s, is no longer used. This hierarchy provides virtual circuits in the form of reserved slots in the data stream. The data streams were picked to match the needs of voice transmission, and they are not broken into packets.

The digital telephone hierarchy has some drawbacks. One is that the only way to extract a lower-speed signal from one at higher speed is to break the entire signal into its component parts. Another drawback is that the data stream lacks the control signals needed in a modern network.

SONET/SDH

The *Synchronous Optical Network* (SONET) standard calls for long-distance transmission over fibers at a hierarchy of digital rates higher than those of the old digital telephone hierarchy. SONET is the North American standard; its international counterpart (set by ITU) is the *Synchronous Digital Hierarchy* (SDH). SONET and SDH differ only slightly, to accommodate differences in lower-speed telephone standards. Both standards interface with the ATM interchange format and provide features not available in the old digital telephone hierarchy.

SONET/SDH is a hierarchy of digital rates for fiber links.

SONET organizes data into 810-byte blocks called *frames*. Each frame includes 27-byte headers containing information on signal routing and destination in addition to the signal data. The system generates and inserts headers as it packages input signals into SONET frames. The frames can be switched individually without breaking the signal up into its component parts.

Developed to carry mixed traffic over fiber, SONET/SDH explicitly defines a series of time-division multiplexed transmission rates (designated *OC-x*). The SONET base rate (OC-1) is 51.84 Mbit/s, which with overhead accommodates the widely used T3 rate of the North American digital telephone hierarchy. Next is the 155.52 Mbit/s OC-3 rate, nominally produced by interleaving frames from three OC-1 signals; this rate is the base level of SDH (SDH-1). Above OC-3 are OC-12 at 622 Mbit/s, OC-48 at 2.5 Gbit/s, OC-192 at 10 Gbit/s, and OC-768 at 40 Gbit/s. Appendix C lists these transmission rates.

The frame structure in SONET allocates a fixed number of slots per second for input signals. Although the frames may look like packets, SONET uses them to provide circuit-switched TDM services, which guarantee transmission capacity. SONET frames also can handle packet-switched data, but they do so by creating a virtual circuit to transmit the signal on the physical layer.

SONET frames guarantee transmission capacity.

The SONET/SDH standards do more than specify data rates and frame sizes. They also specify that the network be arranged in the ring topology shown in Figure 20.6, rather than in the older hub-and-spoke or branching system. A SONET ring includes a complete set of redundant fibers, which enables the SONET hardware to reroute signals if a cable is broken. Thus the system continues operating when a cable fails.

Ethernet Standards

The *Ethernet* family of standards transmit data to and from personal computers on local-area networks and are the most familiar physical layer transmission standards used in fiber optics. Ethernet operates on the physical layer, formatting data to be transmitted through networking cables, but it also works as a packet-based standard on the data layer (layer 2) and is switched by routers.

Ethernet is a family of physical layer standards.

On the physical layer, Ethernet transmits two error-correcting bits with each eight-bit byte, a total of 10 bits per byte. The original standard, just called *Ethernet*, supported 10 Mbit/s data transmission. Later versions are *Fast Ethernet* at 100 Mbit/s, *Gigabit Ethernet* at 1 Gbit/s, and *10 Gigabit Ethernet* at 10 Gbit/s. In practice, fiber is common for Gigabit Ethernet and standard for 10 Gigabit Ethernet (although copper may be used over short distances). Standard Ethernet and Fast Ethernet usually are transmitted on copper.

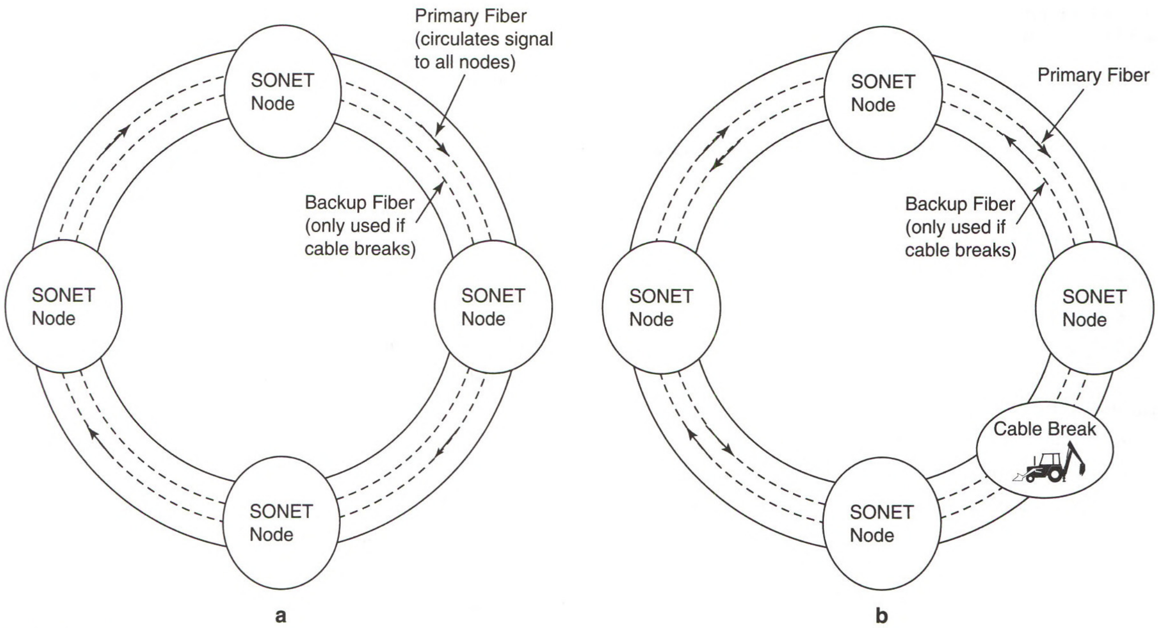

FIGURE 20.6
Intact SONET ring links all nodes through one fiber. Broken SONET ring still links all nodes through primary and backup fibers.

Although data rates increase by a factor of 10 in each step to higher speed, Ethernet is not a time-division multiplexed system that interleaves data bits or frames. It's a packet-switched system that merges streams of packets, so the potential input data rate does not have to match the specified output rate; for example, you can have more than 10 Fast Ethernet inputs to a Gigabit Ethernet link. You will learn more about Ethernet transmission in Chapters 25 and 26.

Fibre Channel

Fibre Channel was developed for storage-area networks.

The *Fibre Channel* standard was developed to relay data from computer networks to data banks on site or in remote locations. This application is called a *storage-area network*, and generally does not require spanning long distances. The British spelling, *fibre*, was chosen to indicate that this standard applies to metal cables in addition to single-mode and multimode fibers. Fibre Channel transmits at data rates of 1, 2, 4, and 10 Gbit/s, and like Ethernet adds two error-correction bits to each eight-bit data byte.

Fibre Channel groups data into frames, encodes and decodes the frames, and physically transports them through various media. These functions correspond to the interchange, data, and physical layers shown in Figure 20.2. Fibre Channel can handle point-to-point transmission between a computer and storage devices, transmission around a loop, or transmission through a switched network.

Current Standards Issues

So far we've discussed mature standards that have been codified and approved. Because fiber-optic technology changes fast, some standards-related issues remain in a state of flux. The telecommunications bubble raised unrealistic expectations about the rate of traffic growth, and venture-funded companies charged ahead with over-optimistic visions of the future. Many new ideas have not been formally codified and approved as standards, leaving important technical and commercial issues.

Optical Layer Standards

The optical layer exists "under" the physical layer.

The OSI model for telecommunications was developed before wavelength-division multiplexing became practical. The emergence of practical WDM technology led to the possibility of an optical layer as an extension of the physical layer, with individual wavelengths serving as physical channels that are merged into a single optical signal. Signals could be processed in the optical domain using wavelength conversion and all-optical switching.

From a standards viewpoint, the optical layer is below the physical layer, as shown in Figure 20.7. Standards specify important features needed for wavelength-division multiplexing, such as channel wavelengths and spacing. It also is possible to split the optical layer into sublayers for optical channels (which carry physical-layer signals), optical multiplexing, and the actual optical transmission.

Currently, many issues need to be resolved before the optical layer can become a reality. Should an "optical wrapper" of overhead data be added in the optical layer, just as headers are added to data packets in the interchange layer? Should the optical layer be a "transparent" network, where switching and transmission are all-optical? Or can optical signals be converted into electronic form for some operations, creating an "opaque" network (because no single photon can pass through the entire network)? How much signal processing needs to be done optically?

Video Standards and Copy Protection

Video standards are in a state of flux as the industry moves from analog to digital format. Existing analog equipment doesn't work with the digital technology used in other types of

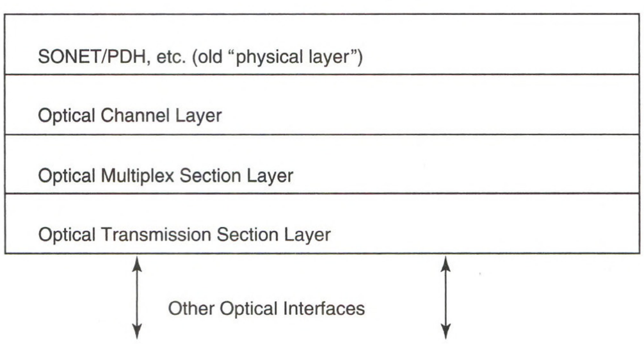

FIGURE 20.7
Optical networking layers.

THINGS TO THINK ABOUT

Market Pressures and Standards

Standards are compromises that companies reach in order to serve market needs. Sometimes market needs conflict so sharply that these compromises are very difficult to reach. Such is the case with *digital rights management*, technology that restricts the copying of digital media.

Entertainment and consumer electronics companies make money in different ways. Entertainment companies want to sell as many programs as possible to as many people as possible, so they don't want free copies circulating. They're glad to sell you copies of their programs, but they don't want you giving copies of them away to other people. In fact, they'd really like to charge you each time you watch or listen to them. They'd like to ban all copying, as was evident two decades ago, when they tried unsuccessfully to outlaw analog video recorders.

On the other hand, consumer electronics companies want to sell video recorders and home networking equipment used to record and distribute programs. They make money when you buy hardware, but not when you buy programs, so they defend *limited* copying. (Nobody openly advocates mass-producing unauthorized copies of programs.) A big problem today is striking a balance between the rights of customers who own legitimate copies and the interests of entertainment companies.

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communications, so analog signals have long been transmitted separately. Yet efforts to integrate video with other communications services have run into serious commercial problems.

Controversy surrounds efforts by the entertainment industry to ban the sale and use of hardware and software that allows digital copying and distribution of audio and video programs. This is a serious loss to consumers who make copies strictly for personal use, like recording television programs for later viewing or mixing their own audio recordings. Limits on distribution of digital programs could hurt development of home entertainment networks that could record programs from the family-room set and send them to a bedroom set. The electronics industry worries that restrictions on program use will hurt its sales, and telecommunications carriers don't want to monitor their customers' activities. This conflict has stalled development of video standards on multiple fronts.

Proprietary Technologies and Market Pressures

Proprietary equipment doesn't follow standards.

Standards are agreements made by companies to manufacture equipment that provides specified functions and uses specified formats. The goal of standards is to create an open market for vendors who agree to follow them. However, some companies decide not to follow standards and offer proprietary equipment that is unavailable from other companies.

Depending on your viewpoint, proprietary technologies are either the best systems companies can offer to their customers, or an effort to trap customers into buying more equipment in the future. In practice, all systems are somewhat proprietary on the inside, as modern standards cover interfaces, not inner workings. For example, some carriers may not convert IP signals into SONET for transmission on their networks if their physical fiber-optic connection takes IP signals directly to the next router. These carriers wouldn't need physical layer interfaces inside their own networks, so they could just transmit raw IP format signals at a data rate the link can handle.

Market pressures ultimately determine what standards are accepted and widely used by industry.

What Have You Learned?

1. Standards specify coding techniques so different systems can understand each other. The importance of standards increases with the scale of the system.
2. Families of standards exist for different types of telecommunications, and for different telecommunication functions. They typically specify interfaces and formats that equipment can use to connect and transfer signals.
3. Data transmission standards rely largely on packet switching. Packet headers contain information needed to route packets. Circuit switching is used in many telephone standards.
4. Modern standards consist of a series of layers, each serving its own function. Signals pass through the layers, but users don't see the lower layers. Major layers (from top down) are the service, adaptation, interchange (or network), data conversion, and physical layers.
5. Internet Protocol (IP) and Asynchronous Transfer Mode (ATM) standards apply to the interchange layer. Both standards group data into packets. Routers operate on the interchange layer.
6. SONET (Synchronized Optical Network), the digital telephone hierarchy, and Ethernet apply to the physical layer. The physical layer includes the core of the network, as well as links between devices such as computers and external backup storage. Circuit switches are found in the physical layer.
7. The digital telephone hierarchy is a series of time-division multiplexed digital data rates to 45 Mbit/s. It was originally developed in the 1960s but is still in use.
8. Asynchronous Transfer Mode creates virtual circuits although it is a packet-based protocol. It has priority codes.
9. Internet Protocol was designed for internetworking. It has variable-length packets and is packet-switched. IPv4 does not assign priority codes to packets, but IPv6 does.
10. Wavelength-division multiplexing adds an optical layer below the physical layer. The final shape of the optical layer is still in development.
11. Queued packets are transmitted in the order they were received, as fast as the output port can take them. If they stay in the queue too long, they time out.
12. SONET/SDH specifies digital data transmission in frames at an ordered series of rates starting at 51.84 Mbit/s through optical fibers. It specifies a ring topology to guarantee that service continues if a cable is broken.

13. Fibre Channel is a standard for storage-area networks.
14. The Ethernet family includes standard Ethernet at 10 Mbit/s, Fast Ethernet at 100 Mbit/s, Gigabit Ethernet at 1 Gbit/s, and 10-Gigabit Ethernet at 10 Gbit/s.
15. Analog video standards are treated separately from digital standards. Digital video standards are still in development; a key issue is digital rights management.

What's Next?

In Chapter 21, you will learn the basic elements of designing optical systems that transmit at a single wavelength. Chapter 22 will cover optical networking design.

Further Reading

Vivek Alwayn, *Optical Network Design & Implementation* (Cisco Press, Indianapolis, 2004)

John C. Bellamy, *Digital Telephony*, 3rd ed., (Wiley InterScience, New York, 2000)

Roger L. Freeman, *Fundamentals of Telecommunications* (Wiley InterScience, New York, 1999)

Gil Held, *Voice & Data Internetworking* (McGraw-Hill, New York, 2000)

Jean Walrand and Pravin Varaiya, *High Performance Communication Networks* (Morgan Kaufmann, San Francisco, 2000)

Web Resources

ATM: *http://www.atmforum.com/*

Fibre Channel: *http://www.fibrechannel.com*

Gigabit Ethernet: *http://www.gigabit-ethernet.org/*

Questions to Think About

1. Follow the voice signals in Figure 20.2 through the layers in the diagram. What function does Internet Protocol serve?
2. Some makers of telecommunications equipment propose to transmit IP signals directly on fiber, without going through ATM or SONET coding. What advantages might this have?
3. What difference between ATM and IPv4 formats is most important for voice transmission?
4. Packet switching has a major advantage in that it combines signals that arrive at uneven rates to use transmission capacity efficiently. Suppose you have four packet-switched input signals, which can arrive at peak rates of 1 Gbit/s. However, on average the packets account for only about 20% of the peak capacity. If all goes well, can you squeeze those four input channels through a 1-Gbit/s output?

5. You can pack 24 voice channels on one T1 carrier, four T1 carriers into a T2 channel, and seven T2 carriers into a T3 signal. How many voice channels can a T3 signal carry?
6. How many voice channels can an OC-192 signal carry, assuming an OC-1 carrier transmits the equivalent of one T3 carrier?

Chapter Quiz

1. Which of the following are *not* defined by telecommunications industry standards?
   a. data transmission formats on optical fiber
   b. transmission speeds in digital telecommunications
   c. interchange formats for signals sent to other countries
   d. data transmission in local-area networks
   e. monthly telephone service charges
2. What kind of standard is Asynchronous Transfer Mode (ATM)?
   a. data-interchange format
   b. fiber transmission
   c. analog television
   d. time-division multiplexing
   e. financial transfer for banking
3. Which of the following is a SONET data rate?
   a. T3, 45 Mbit/s
   b. 100 Mbit/s
   c. OC-3, 155 Mbit/s
   d. 1 Gbit/s
   e. none of the above
4. How does packet switching combine signals from different sources?
   a. It assigns each one a different wavelength.
   b. It packages them into a series of packets, with headers indicating destinations.
   c. It assigns each one a different series of time slots in a sequence of bits.
   d. It transmits them simultaneously at different frequencies.
   e. None of the above
5. On what layer(s) of the telecommunication network are routers used?
   a. services layer
   b. interchange layer
   c. physical layer
   d. optical layer
   e. all layers

6. Which of the following statements is true?

a. Circuit switching has become obsolete and is no longer used.

b. Circuit switching is used for most data traffic; packet switching is used in telephone systems.

c. Packet switches can create a virtual circuit in the physical layer between two routers.

d. Circuit switches can create a virtual circuit in the physical layer between two routers.

e. Circuit switches and packet switches cannot be used in the same stack of layers.

7. How many ATM cells can be stacked into the payload of a SONET frame, neglecting reserved fields other than the header?

a. 14

b. 15

c. 16

d. 17

e. 20

8. How many IP packets can be stacked into the payload of a SONET frame, neglecting reserved fields other than the header?

a. 1

b. 4

c. 14

d. 16

e. impossible to tell

9. How does an IPv4 router process data packets?

a. It transmits them as fast as they come in because the input must equal the output.

b. It deletes packets that do not have a priority code above a specified level.

c. It queues packets, then transmits them in the order in which they arrived.

d. It gives first priority to time-sensitive packets and delays other packets.

e. It rejects packets containing time-sensitive data.

10. How does a SONET circuit switch process SONET frames?

a. It transmits them as fast as they come in because the input must equal the output.

b. It deletes packets that do not have a priority code above a specified level.

c. It queues packets, then transmits them in the order in which they arrived.

d. It gives first priority to time-sensitive packets and delays other packets.

e. It rejects packets containing time-sensitive data.

11. Time-division multiplexing at rates to 45 Mbit/s is used in which of the following?

a. SONET
b. Internet Protocol
c. ATM
d. Plesiochronous telephone hierarchy
e. Fibre Channel

12. The cable that carries data from your computer to a backup storage device is part of the

a. services layer.
b. interchange layer.
c. physical layer.
d. optical layer.
e. no layer.