CHAPTER

26

Internet Access and Local-Area Networks

About This Chapter

Computer data transmission differs in fundamental ways from standard telephone voice transmission. One is that computer data flows in bursts, whereas voice traffic travels at a steady rate. This means that voice and data signals are handled differently. Although voice and data share major parts of the global telecommunications network, networks optimized for data are designed differently. This chapter covers data networks and the transmission technologies they use, then describes the networking standards that specify fiber-optic transmission.

Data and Voice Transmission

The first data networks appeared in the 1960s, when universities and other large organizations installed data terminals connecting directly to large mainframe computers. Thus users didn't need to bring tapes or decks of punched cards to the computer center. Interactive computing grew quickly, leading to proposals for systems that would allow people without their own computer to access remote computers over phone lines. At the same time, the Defense Advanced Research Projects Agency (DARPA) began interconnecting computers at major research universities and government laboratories so they could share resources.

Early data networks linked dumb terminals to mainframe computers.

Early data networks linked simple teletype machines to mainframe computers. Teletypes basically were little more than electronic keyboards that printed data sent to and from the mainframe on a roll of paper. Such terminals later were called "dumb" terminals because they lacked any computer power of their own. The emergence of the personal computer changed the picture because it could process information without a mainframe. Users of personal computers developed software and hardware to send data and messages to each other over voice telephone lines. When companies began buying personal computers, and installed local-area networks so users could share data and access information on mainframe computers.

The first networks were private or proprietary, with the DARPA-sponsored "internetwork" available only to university and government computer labs. Computer users wanted to be able to communicate with everyone who had a computer, so they pressed for more connectivity between networks. As a result, the government-university "internetwork" evolved into the Internet, and development of the World Wide Web made the Internet a vital resource that we take almost for granted today.

Like the voice telephone network, the Internet has become global.

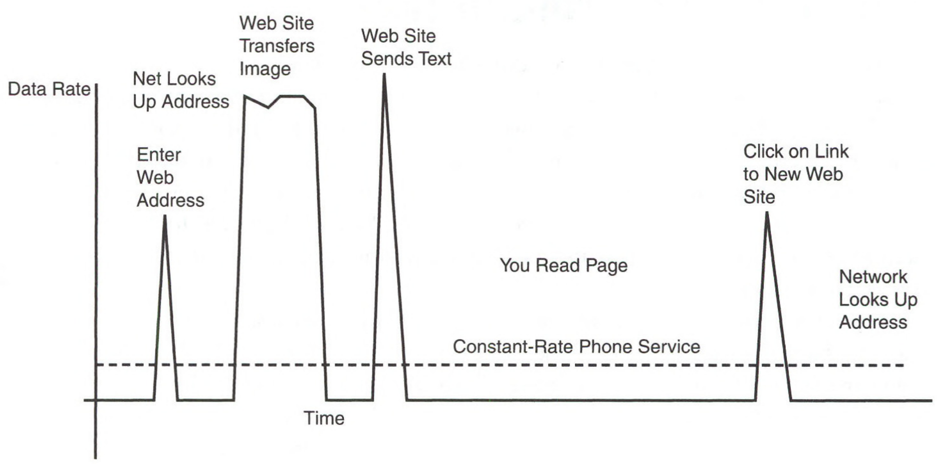
Nature of Data Transmission

Data transmission is bursty.

Most data transmission comes in short bursts, as you can see if you watch your own activities on your computer. When you browse the Web, you first enter a web address, which your computer transmits. Then you wait for a remote server to look up the Web page and request the site to send you information. The site may send you data in two or more blocks, as in Figure 26.1 where it transmits a large image file and a block of text. Then you read the downloaded Web page—with no traffic to and from the Internet—until you click on a link to a new Web site. You see the same pattern when you read e-mail or download files; brief periods of data transmission separated by long periods of inactivity. This type of data transmission is called *bursty* data.

All bursts are not the same size. Entering a one-line Web address may trigger the transfer of a one-megabyte graphic image on the Web site's home page. One e-mail may be a single sentence inviting you to lunch, and the next a two-megabyte report. Smoothing this uneven traffic flow requires a data link that has a very high bandwidth at any given instant, but not all the time. In contrast, standard voice telephones provide a fixed transmission capacity for the entire duration of a call, whether or not anyone is talking. This ensures that

FIGURE 26.1
Bursty computer data on a web link.



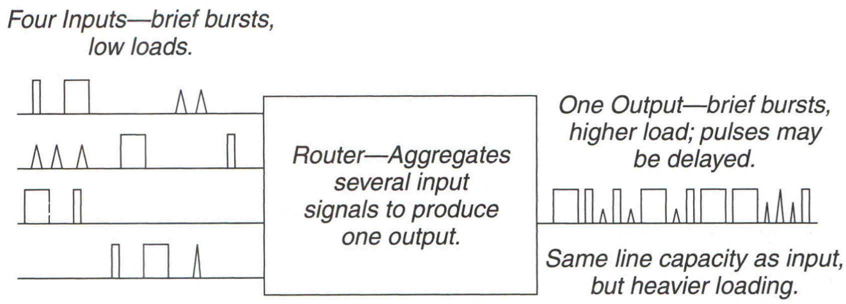


FIGURE 26.2
Aggregation of signals in a data network.

the capacity is available for speakers to use immediately. (Voice over Internet Protocol works differently, as you learned in Chapter 25.)

To accommodate bursty data transmission, data are transmitted and switched in packets, as you learned in Chapter 19. Each data packet includes a header, which carries the destination address and other routing information. Individual data network connections can transmit signals at high peak speeds, but the network design assumes that the average connection transmits data only a small fraction of the time, so its overall load is low. Figure 26.2 shows how this packet switching principle packs data from several high-capacity, low-usage lines into a single high-capacity, high-usage line.

Packet switching works well with bursts of data.

The transmission of data packets is irregular, so one packet can arrive while another is being transmitted, or two packets can arrive at the same time. Most older data-transmission protocols simply queue the input packets and transmit them in the same order as they arrived. This works fine with most communications software, which can tolerate delays in data packet transmission. However, some services, notably voice, are sensitive to time delays as we notice when voice and pictures in a video or movie slip out of synchronization. To cope with delays, some newer protocols assign different *priorities* to packets depending on the service they carry. Thus packets carrying voice signals can have the highest priority and go straight through the system, just as if they had a reserved channel.

Data Network Protocols and Layers

Like telephone networks, data networks have their own standards and *protocols*, which determine how signals are transmitted. The protocols determine things like data formats and packet sizes. Some allow data packets to vary in length; others require a standard length for all packets. Likewise, the protocols specify the information that headers carry, so the network can interpret data in a consistent manner.

As you learned in Chapter 20, data-transmission standards are arranged as a stack of layers. Figure 26.3 shows the layers for computer networks and their associated protocols.

Data network protocols are arranged as a stack of layers.

Your computer is at the top of the stack. When you send e-mail, an application on your computer (layer 7) prepares the messages and monitors how they flow from and to your computer. Protocols, such as SMTP (simple mail transfer protocol), that the server uses to handle your e-mail are in layers 5 and 6. Farther down in layer 4 are the transmission

FIGURE 26.3
Layering and computer network protocols.

Layer Designation	Protocols
7 Application	Electronic mail, file transfer, etc.
6 Presentation	Various protocols, SMTP (simple mail transfer protocol), FTP (file transfer protocol), etc., span both layers.
5 Session	
4 Transport	TCP (transmission control protocol)
3 Network	Internet protocol (and others)
2 Data Link	Network-specified protocols (Ethernet, etc.)
1 Physical Layer	Stream of bits (SONET, etc.)
WDM and optical layer are down here.	

control protocol (TCP) settings that determine how your computer and the server transmit signals to each other, and Internet Protocol (IP) settings (layer 3) that affect transmission on the rest of the network. All the layers typically are handled in software. The physical format for data transmission over your local network is set by the Data Link standard in layer 2; Ethernet is a typical example. The physical format of the data in the global telecommunications network is set on layer 1, the physical layer. As you learned earlier, the data packets from each layer are packaged into packets for the next lower layer at the transmitter end; at the receiver end the data packets travel up the stack to your computer.

The Internet and Its Structure

Like the global and national telecommunications networks you saw in Chapter 23, the Internet has a complex structure. Small networks feed into larger ones, which in turn feed into a high-capacity *backbone system*. We won't go into detail, but you should understand this basic structure.

The Internet Backbone

The Internet backbone is a network of high-speed transmission lines between major nodes called *Points of Presence* or *POPs*. Figure 23.12 showed one backbone system; Figure 26.4 shows another.

The Internet backbone links POPs.

Routers at POPs direct packets from the input port to a POP that is nearer to the packets' ultimate destination. The routers work on IP packets at the network layer, reading headers and transferring the packets to the physical layer. There the packets are converted to a stream of data bits and transmitted through fiber to the next POP. At the final POP, the bit stream is converted back into IP packets for delivery to their ultimate destination. This process is repeated for every packet. It may sound inefficient, but it actually uses transmission lines more efficiently.

POPs are analogs of major urban switching nodes.

Comparing the Internet backbone map of Figure 23.12 with the same carrier's telecommunications backbone map in Figure 23.11 shows that Internet POPs are analogous to major urban switching centers, which are nodes on long-haul networks. POPs are the points where Internet traffic enters and leaves the Internet backbone system. Long-haul switching centers serve the same purpose in the telephone network. A variety of carriers operate regional Internet networks. These connect to local points of presence, which link to individual users.

Internet Connectivity

Homes and offices connect to the Internet in a variety of ways, including:

- Dial-up modem connections over voice telephone lines
- Digital Subscriber Line (DSL) over twisted-wire phone lines
- Cable modem (described in Chapter 27)
- Organizational metropolitan-area and local-area networks, which link many computers in a building or within an organization
- Wireless local-area networks and hot spots
- Terrestrial microwave links
- Satellite data links
- Fiber-to-the-home systems
- Wireless connection through cell phones
- Optical links through the air (called *free-space optics*)

Dial-up connections steadily increased in capacity from 300 bits per second in the early 1980s to a nominal 56 kilobits per second in the mid 1990s, when they reached the limits of standard telephone lines. These services were offered by companies called *Internet Service Providers* (ISPs) who used banks of modems to receive calls from customer modems making connections to the Internet. The earliest ISPs specialized in such connections and didn't operate other telecommunication services. This situation has changed over the years.

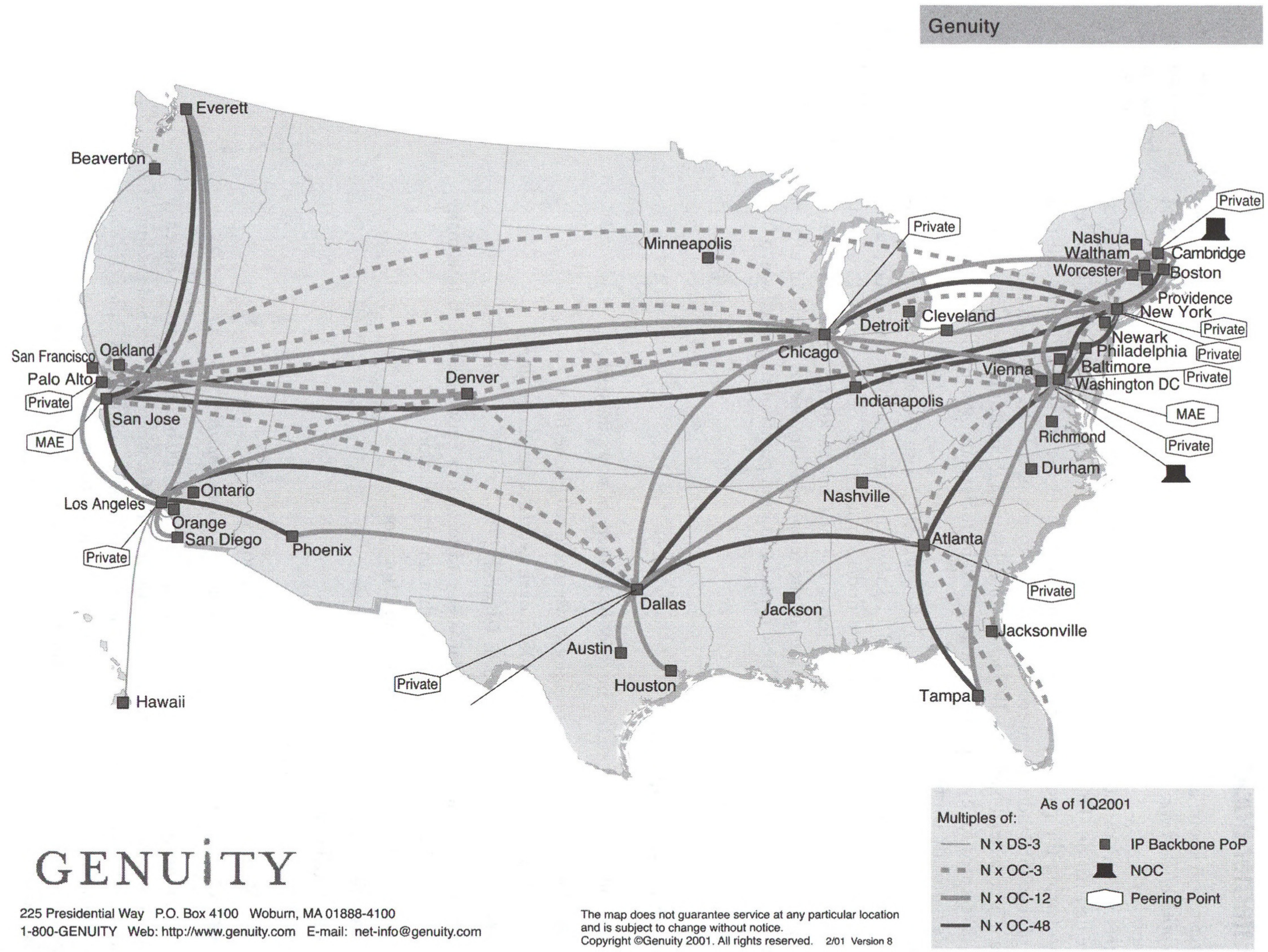


FIGURE 26.4

UUNet's Internet backbone in the United States. (Courtesy of UUNet)

The next step up is *broadband* service, which includes DSL, cable modems, fiber to the home, and some wireless connections. About half of all U.S. households with Internet access have broadband links. Broadband typically has downstream transmission of at least a few hundred kilobits per second. Fiber to the home has the greatest potential bandwidth. Broadband services were introduced by regional phone companies, cable television operators, and some competitive carriers. Local phone and cable networks provide most broadband services, although other companies may lease capacity to do so, depending on regulations.

Broadband includes DSL, cable modem, and fiber to the home.

Wireless Wi-Fi networks provide temporary connectivity at sites like Internet cafes, allowing roving users to connect to the Internet. Hotels, airports, and convention centers also offer Wi-Fi services, either for profit or as an enticement to attract customers for other services.

Individual users within organizations normally connect to the Internet through an organization-wide network. To understand how that works, let's look at the various levels of networking, starting from the user connection.

Local-Area Networks

Individual users connect to a *local-area network* or *LAN*, which links individual computers and other devices in an area. The definition of "local" can vary significantly. A household may operate its own local-area network when it connects a few computers and a printer to a router linked to a cable modem, as shown in Figure 26.5. Ethernet cables link the three computers and the printer to a home router, which allows the computers to share files and the printer. The router directs all signals to the proper place, connecting to the outside world through the cable. Wireless links could replace the cables from the router.

LANs link computers and other devices in a small area.

Office LANs typically have more equipment than home LANs. Figure 26.6 shows an office LAN serving a small work group. Five office computers and a more powerful workstation share

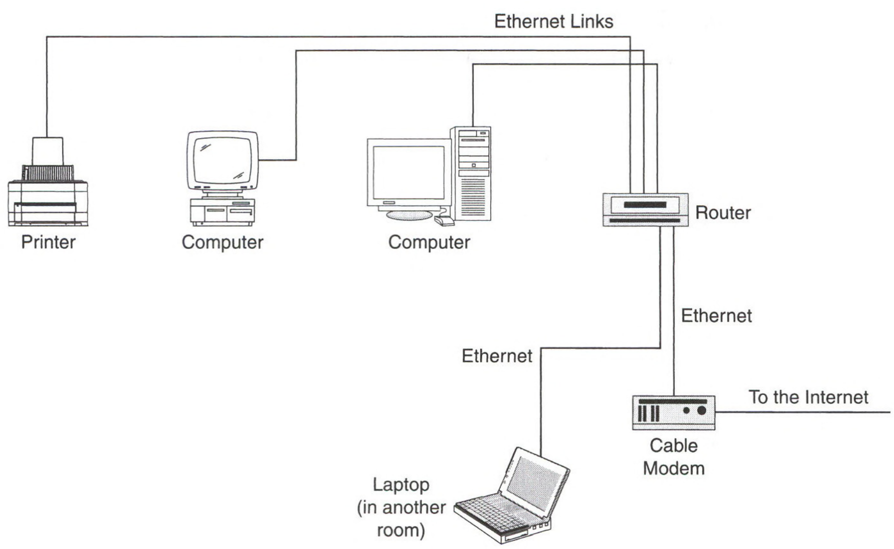


FIGURE 26.5
Home local-area network.

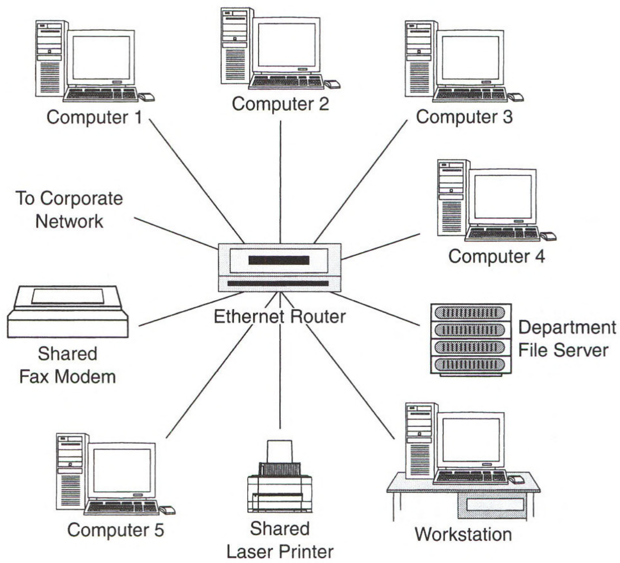


FIGURE 26.6
A LAN interconnects many devices that can send messages to each other and to external devices.

a laser printer and a fax modem. They also connect to a server, which holds master files of the group's projects. Connections are through an Ethernet router, which links to the company-wide network and the Internet.

LANs allow users to share files, data, and software.

Details vary widely, but in general LANs enable all devices to share software, files, and data. Signals can be transmitted through copper or fiber cables, or over wireless links. LANs generally can transmit two or more data streams at once, so the laptop user in the network of Figure 26.5 could surf the Internet while one of the desktop computers printed a file. (Actually, the two processes are not operating simultaneously, but switching back and forth so rapidly that users don't notice.)

LANs may have star, ring, or data-bus geometries.

Local-area networks have three configurations, as shown in Figure 26.7. In a star network, all signals pass through a central node, which may either actively retransmit or passively divide signals. Figures 26.5 and 26.6 show examples of active star Ethernet networks, in which the Ethernet router directs signals to other terminals like a telephone switch. A wireless Wi-Fi network similarly has a central base station, but it broadcasts all signals to all terminals within reach. In a ring network, the transmission medium connects all nodes, and signals can travel in both directions simultaneously (sometimes over two parallel paths for redundancy). In the data-bus topology, a common transmission medium connects all the nodes but does not form a loop, so the signal does not travel through all nodes in series. The ring, data-bus, and wireless star networks actually transmit all signals to all nodes, but the nodes ignore signals not addressed to them.

A local-area network can have many more users than the examples shown. Corporate networks seem to be local networks, but usually consist of a number of smaller department-scale networks linked together. These networks are sometimes called *corporate-area networks* or *campus-area networks.*

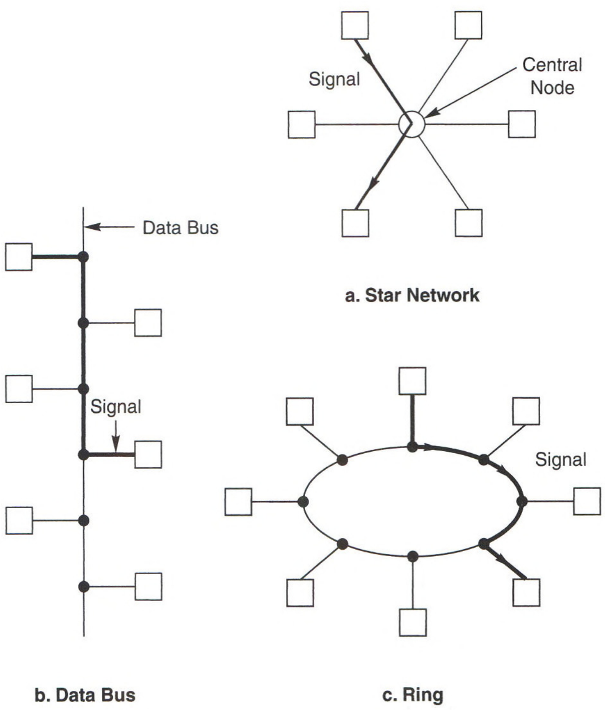


FIGURE 26.7
Star, bus, and ring LAN architectures.

Metro-Area and Wide-Area Networks

Metropolitan-area networks connect separate locations.

Private networks also can connect many separate locations in the same area, such as all the schools and municipal buildings in a city. These networks, called *metropolitan-area* or *wide-area networks*, interconnect other smaller networks, such as local-area networks.

The terms "metropolitan-area" and "wide-area" do not refer consistently to any specific geographic coverage. A metropolitan-area network (MAN) may serve the same area as a metro telephone network, or merely a few buildings on a corporate or college campus. A wide-area network may be a MAN, or it may be similar in scope to a regional or national network. You have to infer the geography from the context.

Desktop Data Transmission

A single personal computer and its peripheral devices may function as a desktop network. Some people attach many peripheral devices to their computers, such as printers, scanners, external backup devices, additional optical drives, external speakers, and fax modems. Generally these devices do not have Internet addresses, so they don't show up on the Internet. (Printers may have Internet addresses if they connect to a local area network through routers, but are visible only to users on the LAN.)

Data Transmission Technologies

So far I have said little about specific data transmission technologies beyond the brief introduction in Chapter 3. Now we'll learn some basic concepts of data networking and transmission. Data networking is a complex technology that can be implemented in different ways, so we'll only talk about common examples.

There are two basic types of data transmission: *data links*, which are point-to-point connections between two devices, and *networks*, which link three or more devices.

The primary emphasis here will be on networks because connectivity is important. However, many networks consist of many individual data links that collectively interconnect many devices. For example, a data link connects your computer to an external display screen, but when you connect the computer to a printer, a scanner, and an Internet server as well, you create a network.

Network Connections

The star, bus, and ring architectures for local-area networks, shown in Figure 26.7, are not the whole story. These three basic approaches can be implemented in different ways using different protocols.

Star networks can have active or passive hubs.

For example, a star network can be a passive system, where the central node is a passive optical star coupler of the type described in Chapter 14. Light from one terminal enters the star coupler, which divides it among all the output ports. However, this passive splitting consumes a lot of power, resulting in an attenuation of 10 dB for a 10-port coupler. In practice, star networks more commonly use active hubs, which can distribute signals by either switching or broadcasting them.

Switching requires a point-to-point connection between the active hub and each connected terminal. The hub receives input signals from terminal devices, then switches them to the destination terminal over the proper point-to-point link, usually a copper or fiber-optic cable. An Ethernet switch or router works like this, as shown in Figures 26.5 and 26.6.

Broadcasting distributes signals to all terminals.

Broadcast transmission sends signals to all terminals in the receiving area. This technique is used for wireless LANs, as shown in Figure 26.8. The base station receives wireless input signals, then broadcasts them to the local terminals. Only the target terminal for which a signal is intended can receive and decode the signal. A wireless LAN usually also has a connection to the Internet. The popular Wi-Fi system is an example.

A ring or data-bus network physically passes all data through the transmission medium, dropping parts of the signal at each terminal. The actual implementation varies. Signals can be dropped by using a passive coupler to split them, although the signal loses power at each node. The terminal then extracts the signals directed to it. Alternatively, each node can use an active coupler to decode the input signal, then retransmit it both to the attached terminal and to the next node.

Cable Transmission

Three main classes of cables are used in data connections: twisted copper wires, copper coaxial cable, and fiber.

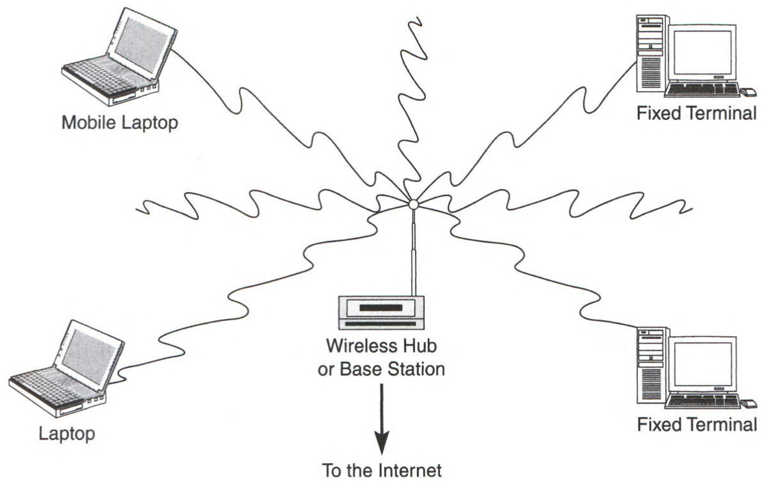


FIGURE 26.8
A wireless local-area network has an active central hub, which transmits signals to all terminals.

Twisted-wire pairs, which provide telephone and DSL service, have limited bandwidth. Special versions developed for data communications offer enhanced bandwidth. Figure 26.9 plots the loss per 100 m (*not* per km) versus signal frequency for four types of copper data-transmission cable. Categories 3 and 5 are unshielded twisted pairs meeting EIA/TIA standards. Shielded twisted pair is similar except the wire pairs are shielded by a metal foil

Category 5 cables use high-bandwidth twisted-wire pairs.

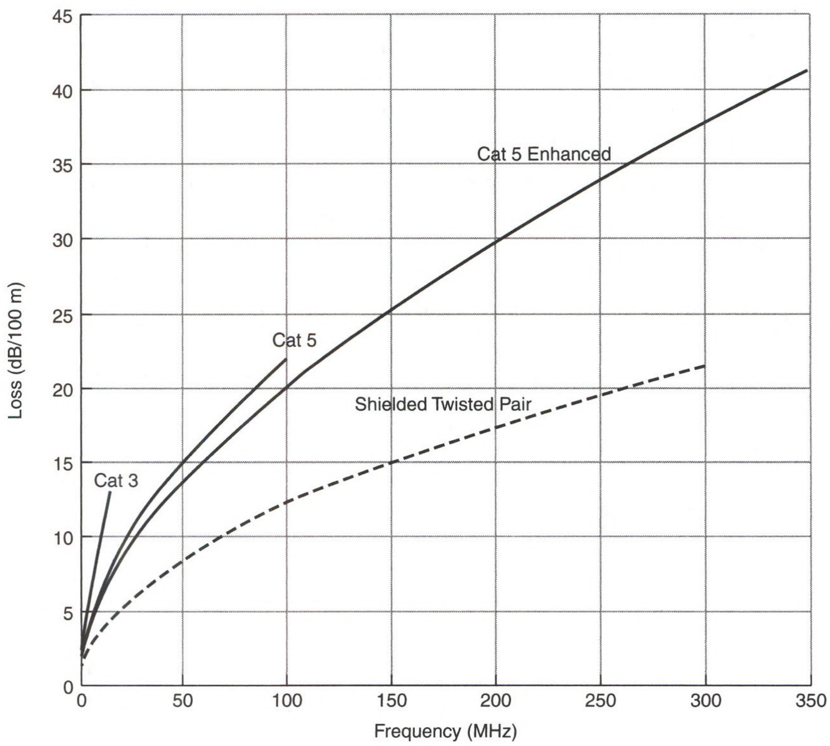


FIGURE 26.9
Typical loss of twisted-pair wiring designed for high-frequency use.

layer. Category 5 cable was developed for 100-Mbit/s fast Ethernet, and can carry signals up to 1 Gbit/s over the short distances of desktop connections. But as transmission distance and signal frequency increase, proper installation becomes critical.

Coaxial cable was used in many early data links and LANs, but few applications use it now because it is difficult to install. Coaxial cable is used for cable television systems that provide data service through cable modems.

Fiber offers much higher bandwidth and lower attenuation than either twisted-pair wiring or coaxial cable, and is used for fiber-to-the-home or fiber-to-the-premises systems. However, signals are generated in electronic form, so extra equipment is needed to convert electronic signals into optical form for transmission, then convert them back into electronic form for use at the receiving end. The extra cost is worthwhile if the signals are at high speed or must go long distances. But the cost is prohibitive for a link from your desktop computer to a cable modem—unless you have special requirements.

Fiber data links avoid electromagnetic interference, eavesdropping, and ground loops.

Because fibers carry signals as light rather than as electrical current, they avoid three types of problems that can occur when using copper: electromagnetic interference (EMI), vulnerability to eavesdropping, and undesired cable conductivity.

- *Electromagnetic interference* or *EMI* arises because long copper wires make good antennas, picking up signals radiating through the air. For example, the radio waves from a nearby strong AM radio station can induce electric current in telephone wiring, producing signals audible on the phone. Noise can also be induced in data communications by power lines running near equipment in locations such as elevator shafts or power substations.
- Just as radio signals can induce current variations in long copper wires, the variations in current flow as a signal is being transmitted cause the wires to emit radio waves. The emitted radio signals are faint, but can be detected with sensitive equipment. Eavesdropping is not a significant source of worry for most users, but it is for security agencies and financial organizations.
- Electronic designers assume that voltages vary relative to a common potential called the ground level. That's a reasonable assumption if the ground is a single metal chassis. But if a cable connects equipment in different buildings, that's a potential problem because semiconductor electronics are sensitive to variations of only a few volts. Differences in ground potential at the ends of a cable can generate current paths called *ground loops*, which produce noise. This problem is very common in electrical facilities. Voltage differentials also can generate sparks, which could cause explosions in oil refineries or chemical plants.

Because of these problems, fiber data links are used in special cases, even when copper cables could deliver the required bandwidth.

Wireless Transmission

There are several distinct types of wireless data transmission, ranging from wireless networks inside buildings to satellite data links. They both compete with fiber-optic systems and are part of the overall data network.

Wi-Fi is a wireless LAN for mobile computers.

Wi-Fi (for Wireless Fidelity) is the best-known example of wireless data transmission because it is widely used for personal computers. Wi-Fi is based on the IEEE (Institute of Electrical and Electronics Engineers) 802.11 family of standards and operates over short distances in the unlicensed radio bands at 900 MHz, 2.4 GHz, and 5 GHz. Wi-Fi networks have active hubs at their center, which can link to computers within 15 to 50 meters indoors, or somewhat longer distances outdoors. Another standard, called *Bluetooth*, allows lower-speed transmission over shorter distances with less expensive electronics. Both standards can connect with mobile devices.

Worldwide Interoperability for Microwave Access, or WiMAX, is a wireless metropolitan-area network design based on IEEE 802.16 standards. At this point, WiMAX covers a broad range of possible networks rather than a single specific network. The protocols allow operation at frequencies of 2 to 11 GHz or 10 to 66 GHz, and at the low end of that range high-power transmitters could reach 50 kilometers. However, most WiMAX networks probably will span no more than a few kilometers. Initially the active base station will transmit only to fixed terminals, but mobile terminals may be added later. WiMAX is intended to link Wi-Fi base stations to Internet servers and to distribute other data services.

WiMAX is a wireless metropolitan-area network.

Two other types of fixed wireless systems also can distribute data: *LMDS* (local multipoint distribution systems) and *MMDS* (multichannel multipoint distribution systems). LMDS base stations transmit up to 8 km in a line of sight in multiple bands between 28 and 31 GHz in the United States. LMDS is not widely used for its original application of distributing voice, video, and data services to homes, but it does provide wireless data links for businesses with a clear line of sight to the base station. MMDS operates at frequencies of 2.5 to 2.7 GHz, where a clear line of sight is not essential. However, its overall bandwidth is limited to 200 MHz, the equivalent of 33 6-MHz video channels, so it also is not widely used for home voice, video, and data service. MMDS is used for business data links, and has adequate range for rural signal distribution.

Satellites also can transmit data at high speeds, but their broad coverage areas make them more suitable for broadcasting than for point-to-point data transmission. Satellite data links to single users typically are limited to tens of kilobits per second—comparable to dial-up modems—and are expensive. Satellites are used mainly for connectivity in remote areas where other services are not available.

Satellites are better suited for broadcasting than for point-to-point links.

Microwaves also can be used for point-to-point data links. Systems direct microwaves in a narrow range of angles by using a dish antenna that is large relative to the wavelength. These systems can be used where cables are impractical or expensive to install, but generally require licenses from the FCC.

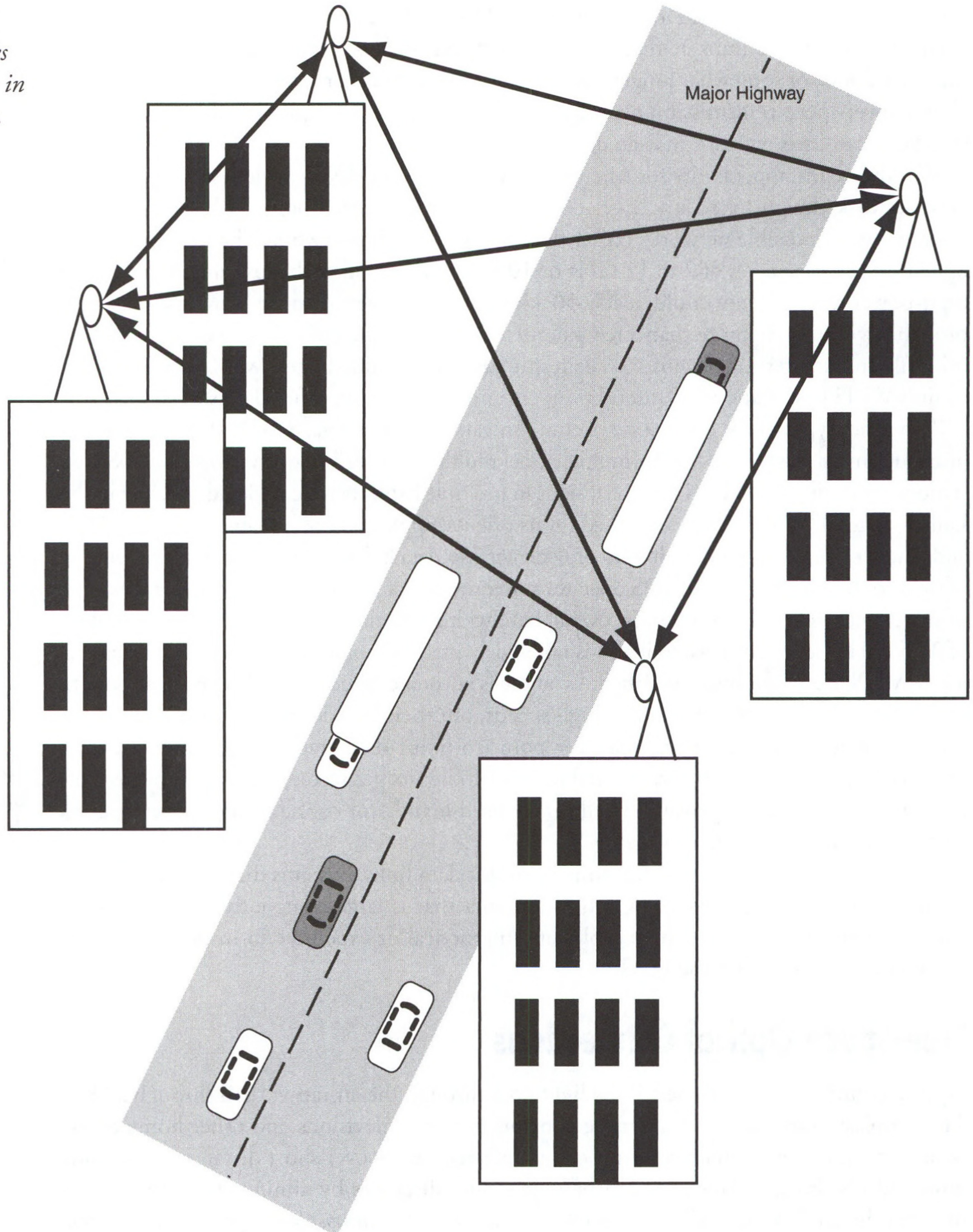
Free-space Optical Connections

Optical connections are wireless if the light goes through the air rather than through a fiber. The simplest examples are the remote controls used on televisions and other home entertainment equipment, which transmit coded infrared pulses over short distances using low-power LEDs. Higher data rates can be sent longer distances by aiming laser transmitters through the air. This technique is called *free-space optics* or *atmospheric optical transmission.*

Laser beams are normally tightly focused, so their output is concentrated in a small spot. But most laser links through open air spread the beam out to cover a larger area. This both avoids the potential eye hazard from a tightly focused laser beam and makes the light easier to pick up with an optical receiver. Even with this defocusing, laser beams remain highly directional, so they concentrate their output into a much narrower range of angles than a radio antenna. This makes free-space optics attractive for point-to-point communications.

Free-space optics transmit light between buildings.

FIGURE 26.10
Laser mesh links through the air in downtown area.



Air is not a reliable transmission medium because clouds, fog, or precipitation can block light, and haze scatters light over long distances. The attraction of free-space optics is that it avoids the cost of laying fiber. Point-to-point laser links can be combined to create a mesh among downtown buildings, as shown in Figure 26.10. The mesh architecture enables the links to continue transmitting signals even if one beam is temporarily blocked by a dense patch of fog or a passing pigeon. Typically individual links are only a few hundred meters.

Fiber Data-Link Design

The design examples in Chapter 21 and 22 were largely aimed at telecommunications applications. Data links and computer networks are generally much shorter, so coupling losses are more important than fiber attenuation.

Data links and local-area networks use graded-index *multimode* fibers, which now play little role in telecommunications. Although graded-index fibers are more expensive than step-index single-mode fibers, they can reduce the costs of transmitters, receivers, and connectors enough to justify their expense. Data links and LANs may even use step-index multimode fiber in certain cases. Dispersion does become an issue at high data rates, so most network standards have options for single-mode fibers, which rarely cause dispersion problems for data communications.

Multimode fibers are widely used in LANs and data links.

Data transmitters and transceivers often operate over specified span lengths of fiber, and are matched with receivers. Thus ratings are given in distance spanned rather than power level. Many data links also specify span losses of less than 10 dB, so they don't require bright transmitters.

Very-low-cost networks confined to single structures may use plastic fibers. Three configurations are possible:

Plastic fibers are used in short, low-speed data links.

- Step-index plastic fiber transmitting at 650 nm
- Graded-index plastic fiber transmitting in the visible light range
- Coarse-WDM over plastic fibers in the visible light range

Graded-index glass fibers are common in data networks, and many standards are built around them, as you will see in the next section. Graded-index fibers typically are used with laser or LED transmitters operating in the 850- and 1300-nm windows. Some standards include coarse-WDM in the 1300-nm window, but WDM is rarely used near 850 nm.

Single-mode fiber may be used at higher speeds or over longer distances. Single-mode fibers transmitting at 1300 or 1550 nm are fairly common in metropolitan-area networks and single links spanning more than a hundred meters. WDM is uncommon because it's often cheaper to lay another fiber than to set up the multiplexing and demultiplexing optics.

The acceptance of data link designs depends heavily on their use in industry standards.

Fiber in Standard Data Networks

Local-area networks such as the highly successful Ethernet family are based on industry-standard designs and interfaces. So are links between computers and peripherals. As transmission rates have increased, many of these standards have added options for fiber-optic transmission, although fibers are not widely used below data rates of 1 Gbit/s.

Fibers are not widely used in data networks below 1 Gbit/s.

The growth in data rates has been steady. The first generation of local-area networks, such as the original Ethernet (10 BaseT) and the IBM Token Ring network, transmitted at about 10 Mbit/s. Higher-speed systems, originally developed to interconnect local-area networks within an organization, have been adopted for LANs as well. Fast Ethernet at 100 Mbit/s (100 BaseT) followed the original Ethernet. Gigabit Ethernet (1000 BaseX) followed in 1998, and later 10-Gigabit Ethernet. Fibers are important in the higher-speed Ethernet standards, and in the Fibre Channel and Fiber Distributed Data Interface (FDDI) standards.

Now that standards have been developed, the economics of mass production have made standardized components attractive for other applications. Personal computers have had standard 10-Mbit/s Ethernet ports for several years, and 100-Mbit/s Fast Ethernet ports have become common. Gigabit Ethernet is used in fiber-to-the-home systems, as well as to transport signals in metro networks. Let's look at the most important standards and how they cover data-transmission fibers.

10-Mbit/s Ethernet

The first LAN to gain much acceptance was the original Ethernet codified as IEEE standard 802.3. Its original form covered distribution of variable-length digital data packets to transceivers along a coaxial cable data bus, as shown in Figure 26.11. Separate cables up to 50 meters long, containing four twisted-wire pairs, run from transceivers to individual devices such as personal computers or printers. The system can include up to four kilometers of cable and 1024 terminals.

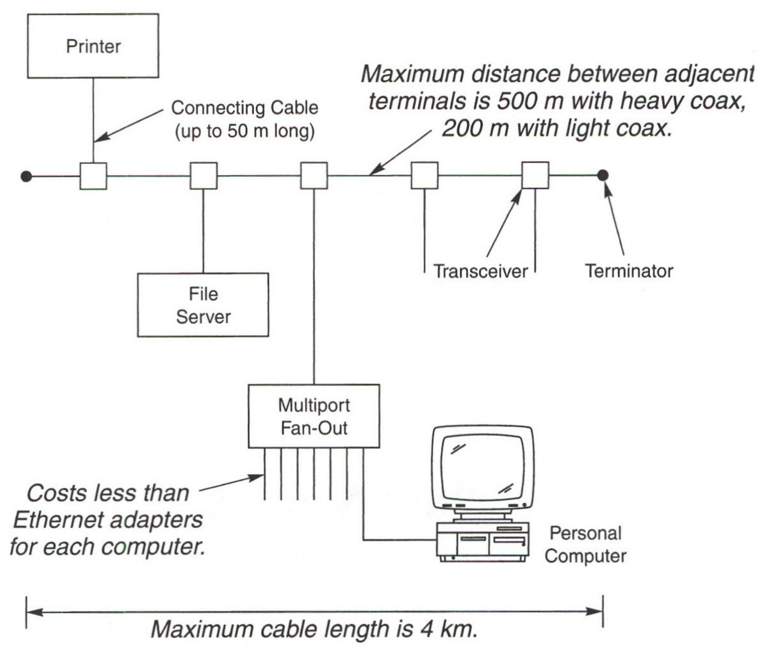


FIGURE 26.11
Original elements of 10-Mbit/s Ethernet.

Ethernet networks have no overall controller; transceivers share control functions. If a terminal is ready to transmit a signal, its transceiver checks to see if the data bus is transmitting another signal, and waits if it detects one. If the data bus is free, the terminal starts transmitting and continues until it either finishes or detects data transmitted simultaneously by another terminal (an event called a *data collision*). Data collisions occur because signals take time to travel through the data bus. If signal velocity is 1 meter every 6 nanoseconds, a collision can occur if two terminals 300 m apart start transmitting within 1.8 μs of each other. If a terminal detects a collision, it waits a random interval before trying again.

Ethernet has changed over the years. Lighter coaxial cables or twisted wire pairs can replace the original heavy coax data bus, although this reduces the cable's maximum span. Routers or switches that serve as active hubs in a star-geometry network, like the ones shown in Figures 26.5 and 26.6, can replace simple transceivers.

Fiber can extend the range of 10-Mbit/s Ethernet.

Optical fibers can stretch transmission beyond the limit imposed by the attenuation of coaxial cable to the one imposed by signal transmission time through the network. For example, a fiber cable might extend to a remote terminal in a separate building, beyond the limit of copper cables. The limit depends on whether the network operates in *full-duplex mode*, in which terminals transmit and receive simultaneously, or *half-duplex mode*, in which terminals can do only one thing at a time. In half-duplex mode, either single-mode or multimode fiber can transmit up to 2 km; in full-duplex mode, multimode fiber can transmit up to 2.5 km between terminals, and single-mode can span up to 15 km.

Fast Ethernet (100 Mbit/s)

Fiber can extend Fast Ethernet spans beyond 100 m.

Fast Ethernet (100 BaseT) is a faster version of the original Ethernet. It retains the frame format and transmission protocols of the original 10-Mbit/s Ethernet, but uses interface cards that operate at 100 Mbit/s. Fast Ethernet uses the same cables, but the faster speed limits the maximum runs on coax or Category 5 cable to 100 m.

The fiber-optic version, called 100Base-FX, allows half-duplex transmission to 412 meters, and full-duplex transmission to 2 km for multimode fiber and 10 km for single-mode fiber. Loss is limited to 11 dB per fiber span, including connector loss.

In practice, copper is used for most Ethernet and Fast Ethernet links.

Gigabit Ethernet (1 Gbit/s)

Gigabit Ethernet needs fiber to transmit beyond 100 m.

The next step is Gigabit Ethernet, which as you might expect operates at 1 Gbit/s. This standard uses the same protocols and frame format as slower Ethernets, but with only full-duplex transmission. Because of the high speed, Gigabit Ethernet node spacing is shorter. A special cable called *twinax*—a coaxlike cable with a shielded twisted pair at the center instead of a single metal wire—is used for jumper cables to 25 m (1000BaseCX). Splitting the 1 Gbit/s among the four twisted-wire pairs in a Category 5 cable allows it to span distances to 100 m (1000BaseT).

Fiber allows longer transmission distances, and is considered the backbone for Gigabit Ethernet. The standard terminology distinguishes only between 850-nm short-wavelength transmission (1000BaseSX) and 1300-nm long-wavelength systems (1000BaseLX), but

Table 26.1 Fiber transmission formats for Gigabit Ethernet

Transceiver	Fiber Types	Bandwidth (MHz-km)	Maximum Range (m)
850-nm laser	62.5/125	160	220
850-nm laser	62.5/125	200	275
850-nm laser	50/125	400	500
850-nm laser	50/125	500	550
1300-nm laser	62.5/125	500	550
1300-nm laser	50/125	400	550
1300-nm laser	50/125	500	550
1300-nm laser (1000Base-LX)	9/125 (single-mode)	—	5000
1300-nm long-haul laser (1000Base-LH)	9/125	—	50,000 (50 km)
1550-nm long-haul laser (1000Base-LH)	9/125	—	100,000 (100 km)

more fiber and wavelength combinations are possible, as listed in Table 26.2. Note that the bandwidth specifications show two grades of both 50/125 and 62.5/125 graded-index fiber.

Gigabit Ethernet includes several types of fiber links.

Two factors limit transmission distances: fiber dispersion and transmitter power. Fiber dispersion dominates for multimode graded-index fibers. Attenuation limits transmission distance for single-mode fibers. Transceivers using high-power lasers at 1310 or 1550 nm (1000BaseLH) can span much greater distances than the nominal 5 km of 1000BaseLX, but not all such transceivers can reach the distance limits shown in Table 26.1. These long-haul transceivers are used mainly in metro networks, and the receiver end must not be overloaded with excess laser power.

The Gigabit Ethernet standard is derived from the Fibre Channel specification for 1-Gbit/s transmission, so the two standards share many features.

10-Gigabit Ethernet

10-Gbit/s Ethernet is mainly for MANs and WANs.

The next logical step was to 10-Gigabit Ethernet. This standard was approved by IEEE in 2003 and was designed largely for metropolitan-area networks to provide backbone links between other networks. It also will provide relatively short connections between high-speed equipment in the same building. The transmission format is compatible with the 10-Gbit/s OC-192 SONET rate, so a 10-Gigabit Ethernet output could drive one optical channel in a DWDM system at 10 Gbit/s for long-haul transmission.

Copper can carry 10-Gbit/s signals only over very short distances, so the 10-Gigabit Ethernet standard concentrates on fiber. Table 26.2 shows recommended fiber

Table 26.2 Fiber transmission distances for 10-Gigabit Ethernet

Type	Transmitter and Channels	Fiber Types	Fiber Bandwidth	Distance Limit
10Gbase-S	850 nm, 1	62.5/125 graded-index	160 MHz-km	26 m
10Gbase-S	850 nm, 1	62.5/125 graded-index	200 MHz-km	33 m
10Gbase-S	850 nm, 1	50/125 graded-index	400 MHz-km	66 m
10Gbase-S	850 nm, 1	50/125 graded-index	500 MHz-km	82 m
10Gbase-S	850 nm, 1	50/125 graded-index	2000 MHz-km	300 m
10Gbase-LX4	1300 nm, 4 CWDM	62.5/125 graded-index	500 MHz-km	300 m
10Gbase-LX4	1300 nm, 4 CWDM	50/125 graded-index	400 MHz-km	240 m
10Gbase-LX4	1300 nm, 4 CWDM	50/125 graded-index	500 MHz-km	300 m
10Gbase-LX4	1300 nm, 4 CWDM	9/125 single-mode	—	10 km
10Gbase-L	1300 nm, 1	9/125 single-mode	—	10 km
10Gbase-E	1550 nm, 1	9/125 single-mode	—	40 km

transmission formats, including short links over multimode fiber, coarse-WDM with four 2.5-Gbit/s channels, and single-channel transmission at 10 Gbit/s.

As with Gigabit Ethernet, the high chromatic dispersion of graded-index fiber imposes transmission distance limits on 10-Gigabit Ethernet, particularly at 850 nm. The nominal link power budgets are only 7.3 dB, so the transmitters use low-power VCSELs. Power budgets are only slightly higher in the four-channel CWDM transmitters operating at 1310 nm in graded-index fiber. Much longer transmission distances are possible using single-mode fibers, where the limit comes from laser power, not dispersion.

Chromatic dispersion limits span length for graded-index fiber.

Fibre Channel

The *Fibre Channel* standard was developed for use in computer systems and networks, particularly in *storage-area networks,* which link computers and peripherals used for data storage. Such networks transmit data at high speeds over various distances (whether across a room or across the state). Large financial institutions and corporations usually keep copies of their financial records off-site, backing up their main data banks to remote server farms in case of a catastrophe at headquarters. Figure 26.12 shows the organization of such systems, with back-office servers providing the interface between the storage-area network and the local-area network that serves individual computers in a large company.

Fibre Channel links computers with data storage equipment.

Fibre Channel also can be used for backbone networks and switched transmission. Hubs connect nodes to form loops; switches connect to make a fabric that directs signals between

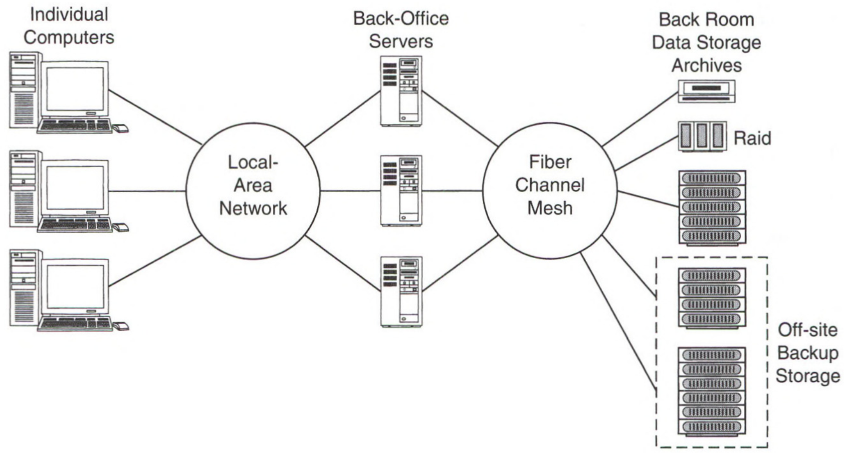


FIGURE 26.12 *A storage-area network includes local and remote data storage.*

devices somewhat like the phone system. It is designed to operate on scales from the backplane of a computer (less than a meter) to a metropolitan-area network larger than five kilometers.

Table 26.3 lists Fibre Channel data rates for current and planned standards. The data rates reflect computer-industry practices, which count data in eight-bit bytes rather than in bits. The bit rate column lists the equivalent data rate in bits per second, not counting error-checking and correction bits.

As mentioned earlier, some of the physical standards for Gigabit Ethernet data transmission were based on Fibre Channel standards, and higher-speed Ethernet standards also draw on ideas from Fibre Channel. Like Gigabit Ethernet, Fibre Channel includes provisions to transmit on copper as well as on fiber, and uses different fiber transmission windows. The Fibre Channel protocol also defines the number of terminals in a loop and the arrangement of hubs and switches. We won't cover the details because they are beyond the scope of this book.

Fiber Distributed Data Interface (FDDI)

FDDI is a 100-Mbit/s token-ring network.

The *Fiber Distributed Data Interface* (FDDI) network is a ring network. As shown in Figure 26.13, two rings transmit signals in opposite directions to a series of nodes at 100 Mbit/s. The standard also specifies concentrator-type terminals that allow stars or branching trees

Table 26.3 Fibre Channel speeds

Designation	Data Rate	Bit Rate (no overhead)
1GFC	200 megabytes/sec	1.6 Gbit/s
2GFC	400 megabytes/sec	3.2 Gbit/s
4GFC	800 megabytes/sec	6.4 Gbit/s
8GFC	1600 megabytes/sec	12.8 Gbit/s
10GFC	2400 megabytes/sec	19.2 Gbit/s

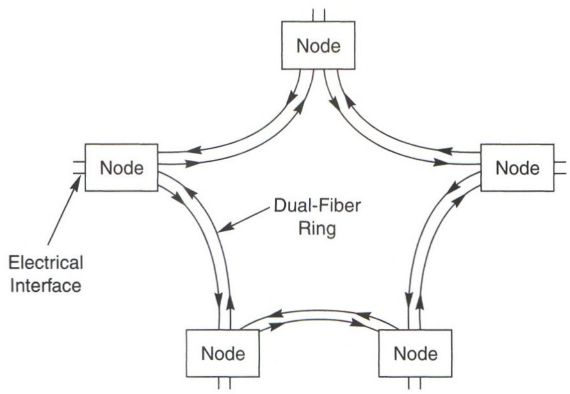


FIGURE 26.13
FDDI dual-fiber ring.

to be added to the main FDDI backbone ring. Normally one ring carries signals while the other is a backup in case of component or cable failure. The maximum distance between nodes is 2 km over multimode fiber at 1300 nm.

FDDI transmission uses the "token passing" scheme used in slower token-ring networks covered by the IEEE 802.5 standard. Terminals do not contend for slots to send signals, as in Ethernet, but instead pass an authorization code called a *token* around the ring, which travels through each node in sequence. When the token reaches a node that is ready to send a message, the node holds the token and sends the message, which is cancelled after it loops around the ring. Then the terminal that sent the message passes the token around the ring again. This is a more orderly protocol than Ethernet, but it has limitations.

FDDI was developed for fiber-optic transmission, but a copper version sometimes called CDDI, has been developed for short-distance applications.

Other Data Communications Standards

Other data communications standards also cover fiber-optic data links and networks, and more are in development. Some cover specific applications such as automotive or aerospace systems. Others modify existing standards to include provisions for fiber. New standards are also in development. These include high-speed protocols, such as 40-Gigabit Ethernet, which seemed like a good idea during the telecommunications bubble but are no longer an urgent priority. We won't cover these standards, but you should remember that they do exist.

What Have You Learned?

1. Early local-area networks linked dumb terminals to mainframe computers. The Internet grew from links between local-area networks.
2. Computer data transmission comes in bursts, which are processed using packet switching.

3. Computer networking standards are structured in layers, like other telecommunication standards.
4. The Internet backbone system links Points of Presence (POPs), which are comparable to the major switching nodes on the long-distance telecommunications network.
5. Homes connect to the Internet through dial-up modems or broadband connections. Broadband includes DSL, cable modem, fiber to the home, and some types of wireless systems. Businesses connect through local-area networks and metropolitan-area networks.
6. Local-area networks (LANs) link individual computers and other devices within the same building. Metropolitan-area networks interconnect LANs at separate locations.
7. Computers exchange data over point-to-point links between pairs of devices or through LANs. Common LAN configurations are the star, ring, and bus. Star networks can have active or passive hubs.
8. Copper wires are cheap for data transmission, but they cannot carry signals as far or as fast as fibers. Fibers offer room for potential expansion of services.
9. Category 5 cables are twisted-pair cables with high bandwidth (for copper).
10. Fibers are immune to electromagnetic interference. Fibers do not radiate electromagnetic fields, making data transmission on fiber more secure than on copper.
11. Wireless networks include the Wi-Fi local area network and the WiMAX metropolitan area network.
12. In free-space optics, laser beam links transmit data through the air between pairs of points. Many such links can form a mesh network to connect buildings without the cost of laying cable.
13. Multimode graded-index fibers are widely used for local-area networks and short data links because they allow the use of inexpensive transceivers. Single-mode fiber is needed for distances beyond about 100 meters at 1 Gbit/s. Plastic fiber is used only in very short data links and networks operating at low speeds.
14. Local-area networks, such as the highly successful Ethernet family, are based on industry-standard designs and interfaces.
15. The original Ethernet transmitted 10 Mbit/s. Fast Ethernet transmits at 100 Mbit/s, Gigabit Ethernet at 1 Gbit/s, and 10-Gigabit Ethernet at 10 Gbit/s. The faster standards rely heavily on fiber transmission. Gigabit Ethernet uses components developed for Fibre Channel.
16. Fibre Channel includes point-to-point, loop, and switched transmission for storage-area networks that link computers with data-storage peripherals.

What's Next?

In Chapter 27, I will cover fiber-optic video transmission, with particular emphasis on cable-television networks.

Further Reading

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

Joseph H. Levy and Glenn Hartwig, *Networking Fundamentals*, 2nd ed. (IDG Books, Foster City, CA, 1998)

Peter Rybaczyk, *Novell's Internet Plumbing Handbook* (Novell Press/IDG Books, San Jose, CA, 1998)

Charles Spurgeon, *Ethernet: The Definitive Guide* (O'Reilly and Associates, 2000)

10-Gigabit Ethernet Alliance: *http://www.10gea.org/*

Questions to Think About

1. If the Internet is the computer equivalent of the long-distance backbone system for telephony, what is a good analogy for the regional telecommunications network?
2. Your cable modem shares a loop of cable with other subscribers in your neighborhood. This in effect connects all of you to a local area network run by the cable company. Suppose that the modem delivers 10 Mbit/s to your computer's Ethernet port if nobody else is online. Nine of your neighbors subscribe after you say how great the service is. If the capacity available to you depends only on the number of users, how much of the original capacity is left?
3. A free-space optical network can transmit signals between any two office buildings 95% of the time on foggy days. If you have a single laser link to your building, how much time would you expect to be down during a 24-hour interval of foggy weather? Suppose you could add two more completely independent laser links that would connect you to the same network. How much would your service improve?
4. Your company has just signed a 10-year lease on a renovated building. Your old building had a standard 10-Mbit/s Ethernet, but traffic was doubling every year and the network is now at capacity. You want to stay with Ethernet standards. How long can you use Fast Ethernet before you run out of capacity? How long can you use Gigabit Ethernet?
5. You need to transmit Gigabit Ethernet between a pair of buildings 400 meters apart. What are your options? What are your options if you upgrade to 10-Gigabit Ethernet?
6. Why would you not use DWDM to increase transmission capacity of a local-area network?

Chapter Quiz

1. Points of Presence (POPs) on the Internet are
   a. phone numbers called by dial-up modems.
   b. addresses of Web sites.
   c. major nodes where Internet backbone systems transfer signals.
   d. long-distance data transmission lines.
   e. computers with Internet access.
2. Data flow to and from computers
   a. varies over time in a regular and predictable way.
   b. occurs in irregular bursts.
   c. is at a constant speed determined by your modem.
   d. is at a constant speed determined by your computer.
   e. is at a constant speed from your computer but incoming data rates can vary.
3. Which of the following is a local-area network (LAN)?
   a. a system that interconnects many nodes by sending all signals through a central passive node
   b. a system that connects many nodes by sending all signals through a central active node
   c. a ring network with a transmission medium that passes through all nodes
   d. a common data bus that connects all nodes but does not form a complete ring
   e. all of the above
4. Why are optical fibers immune to EMI?
   a. They transmit signals as light rather than as electric current.
   b. They are too small for magnetic fields to induce currents in them.
   c. Magnetic fields cannot penetrate the glass of the fiber.
   d. They are shielded by the outer conductors in the cable.
5. The main reason optical fibers are not used for short point-to-point links is because
   a. they require switches to direct signals.
   b. they need expensive optical transmitters and receivers to convert electronic signals into optical form.
   c. fiber cannot provide electrical grounding.
   d. fiber does not operate properly at low data rates.
   e. fiber is difficult to upgrade.
6. Broadband connections do *not* include
   a. DSL.
   b. cable modems.

c. dial-up modems.
d. fixed wireless links.

7. What kind of local area network is Wi-Fi?
a. passive star
b. active star
c. data bus
d. ring

8. When would optical fibers be used in standard (10-Mbit/s) Ethernet?
a. Never. The standard requires coaxial cable.
b. to extend transmission distance to reach remote terminals
c. All Ethernet standards require fiber for distances beyond 10 m.
d. when the network includes an active hub
e. when the stockroom is out of coaxial cable

9. When would optical fibers be used in Gigabit Ethernet?
a. Never. The standard requires coaxial cable.
b. Always. The standard is specified only for optical fiber.
c. beyond short distances in most cases
d. only when Gigabit Ethernet must be connected to an FDDI network
e. only when connecting to the Internet

10. What wavelength(s) is/are used in graded-index fiber for Gigabit Ethernet?
a. 650 nm
b. 650 and 850 nm
c. 650, 850, and 1300 nm
d. 850 and 1300 nm
e. 850, 1300, and 1550 nm.

11. Which standard was developed to link servers with data storage systems?
a. Ethernet
b. Fast Ethernet
c. Gigabit Ethernet
d. FDDI
e. Fibre Channel

12. At what distances could graded-index fibers be used in 10-Gigabit Ethernet?
a. only for distances less than 50 m
b. for distances up to 300 m
c. for distances up to 1 km

d. for distances up to 10 km

e. for distances greater than 300 m

13. What type of fiber has the shortest range for 10-Gigabit Ethernet?

a. 9/125 single-mode fiber transmitting one wavelength at 1300 nm

b. 50/125 multimode fiber transmitting four wavelengths at 1300 nm

c. 50/125 multimode fiber transmitting 850 nm

d. 62.5/125 multimode fiber transmitting 850 nm

e. 62.5/125 multimode fiber transmitting four wavelengths at 1300 nm

14. What is the primary limit on the transmission distance in Question 13?

a. chromatic dispersion

b. attenuation in the fiber

c. attenuation in the WDM optics

d. low-power light source

e. all of the above