CHAPTER

25

Local Telephone or "Access" Networks

About This Chapter

The most visible part of the telephone system is the local network, connecting individual phones to the local switching office. Technological and industrial changes are reshaping the local phone network, as well as the rest of the telephone system. This chapter introduces you to the local phone system, sometimes called the access network, and shows how it serves home, business, and other users. It will explain the changes gradually spreading through the system, and the increasing role of fiber optics in delivering services to business and home customers.

Structure of the Local Phone Network

The local telephone network distributes signals to and from individual users. Traditionally, it was called the *subscriber loop*, industry jargon for the wires that form a circuit or loop from the local switching office to your home phone. At the switching office, local lines connected to a switch that could route signals to other local lines, the regional phone network, or the long-distance network.

That picture has become far more complicated as the network has grown and added new capabilities. The modern version is sometimes called the *access network* because it gives subscribers access to the global telecommunications network, and no longer carries only standard wire-line telephone calls. Facsimile and data traffic also goes through standard telephone lines. Cellular or mobile phone networks also carry voice traffic, although the signals don't go through wires. Voice also may be digitized and converted into Internet format at the phone itself, a new type of telephone traffic. The local telephone network also may carry additional digital signals from computer networks and broadband terminals.

Some of the new signals are additions to the public switched telephone network and are routed through standard switching offices or their equivalents. Fax traffic goes through standard telephone lines; cell phones are directed through cellular switches. Much data traffic is routed through cables originally laid for telephone traffic because the lines are convenient. In this modern topology, the access network runs between individual subscribers and the *network edge*, the point where signals enter the regional or global telecommunications network.

The major difference between the traditional subscriber loop and the new access network is that the access network includes services and options that have been added to the traditional local phone network. Many details of access networks and traditional subscriber loops differ. However, the access network has its roots in the traditional telephone network, and the two retain a common functional structure. To understand that structure, let's look at it step by step, moving toward the individual subscriber.

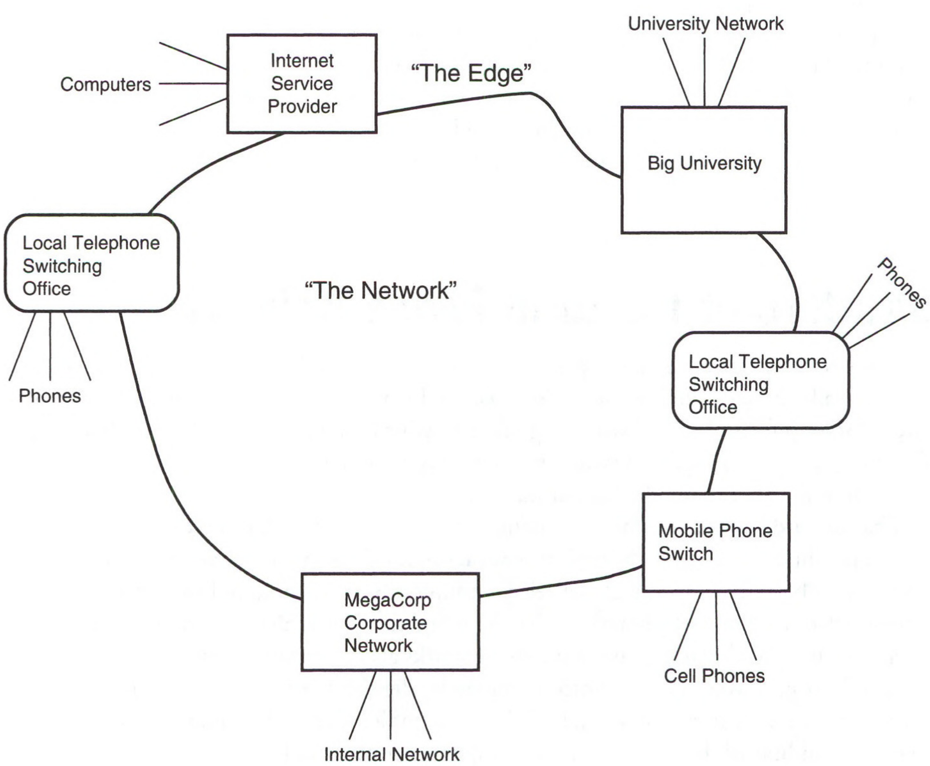
The subscriber loop distributes telephone signals to individual users.

(Over the past two decades, the local telephone network has converged in many ways with the cable-television networks described in Chapter 27 and the data networks described in Chapter 26. You'll learn about this convergence later.)

The Network Edge

The "edge" of the network is the point where signals enter the regional or global telecommunications network. As Figure 25.1 shows, the edge includes traditional local telephone

FIGURE 25.1
The network edge.



switching offices as well as mobile telephone switches, Internet Service Providers, and large organizations that make heavy use of telecommunication services. The figure greatly oversimplifies, by hiding the core of the network and covering the edge in only one region. The point is that equipment on the edge serves as a link between individual users and the telecommunications network as a whole, whether the user has a new mobile phone, an old wire-line phone, or some other connection.

The network edge is the interface where signals are directed into the global network.

The edge is an interface from which signals are directed. Switches in a central office direct individual telephone calls elsewhere in the telecommunications network. Switches operated by mobile phone carriers and competitive phone companies serve the same function. Likewise, an Internet Service Provider directs data packets, typically to routers somewhere inside the network. Corporate and university networks have come to serve similar functions internally rather than directing signals through a telephone switching office or Internet Service Provider.

The Telephone Switching Office

A *switching office* or *central office* is the facility where a wire-line telephone company makes connections to and from individual telephone customers. It is a central point in the community from which telephone services radiate outward over cables to individual users. Figure 25.2 shows the concept, which dates back to the early days of the telephone industry. The dark lines show where fiber has replaced copper.

A switching office makes connections to individual customers.

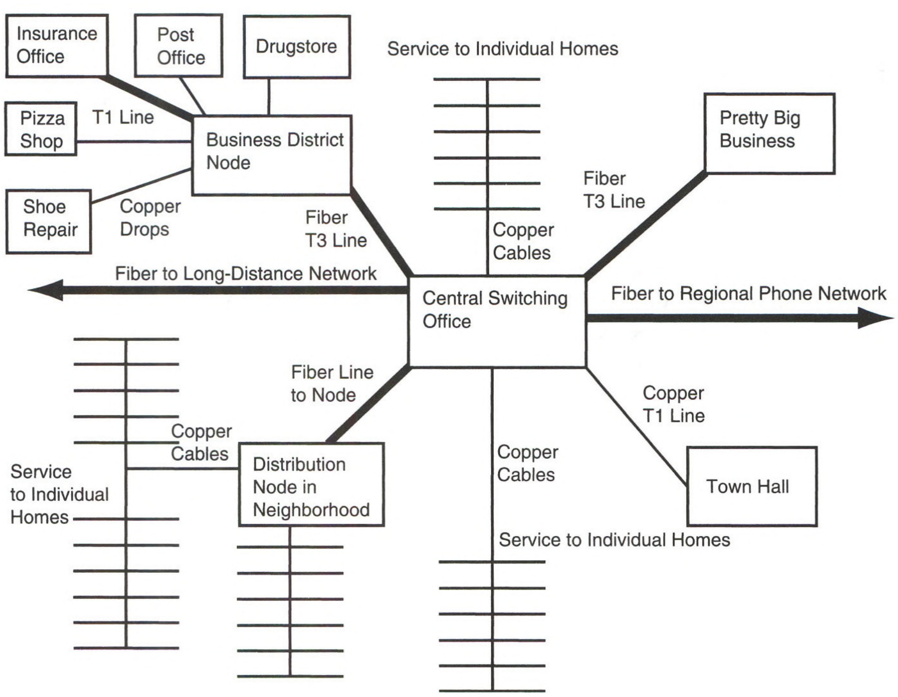


FIGURE 25.2
A telephone switching office has a central role in distributing signals.

Cables from homes run directly to the switching office or to an intermediate node. At nodes, individual phone lines may be multiplexed together to generate a single digital signal for transmission from the node to the switching office over fiber or over copper. Typically homes near the switching office are served directly from there, but homes farther away—particularly clustered in new developments—may be served from a local node or concentrator that distributes signals from a remote point.

The small businesses in the business district receive their service through a local distribution node. The insurance office needs the capacity of a T1 line but most other businesses, like the shoe-repair shop, need only one or two ordinary phone lines. The Town Hall has its own T1 line direct from the central office. The biggest business in our little town has its own T3 fiber-optic connection to the switching office.

All these services are processed through the central office. If the town manager calls the shoe repair shop to see if her shoes are finished, the call goes through the central office, where a switch connects one of the town phone lines to another phone line going to the shoe shop. If someone wants to call overseas, the switching office directs the call to the long-distance network, which makes the overseas connection. Incoming calls from the regional phone network go through the switching office, which makes the connections needed to direct them to the proper destination.

Telephone switching offices do not have one outgoing line for every customer because normally all phone lines are not in use simultaneously. Telephone companies decide how many output lines to allocate to a switch, based on statistical averages of usage.

"Access" Customers

All local traffic does not have to pass through a traditional switching office.

Changes in the telecommunications network mean that local traffic need not pass through a traditional telephone switching office. Figure 25.1 showed a number of other organizations on the edge of the network, such as large corporations and universities. These organizations could have their own internal switches and be hooked directly to a metro network, as seen in Figure 24.3. Their telephone traffic could go directly to long-distance carriers, to regional carriers, or over lines that they leased from regional carriers for corporate use. For example, a state university might have leased lines from administration offices in the state capitol to campuses around the state.

Internet Service Providers are also on the edge of the network. Instead of sending circuit-switched signals to telephone switches, they generate packet-switched signals, which are routed over the Internet Protocol network. As you learned in Chapter 23, some Internet traffic winds up on leased phone lines.

Large organizations typically generate both Internet and telephone traffic, which they may transmit over metro networks to their Internet and telephone connections.

Other Carriers

Cell phone and competitive phone companies have their own switching offices.

Back in the days of telephone monopolies, every community had one central office, operated by *the* telephone company. In urban and suburban parts of the United States, that was generally AT&T, but in small towns it was often a small local company that served just that community and maintained links to AT&T's regional network.

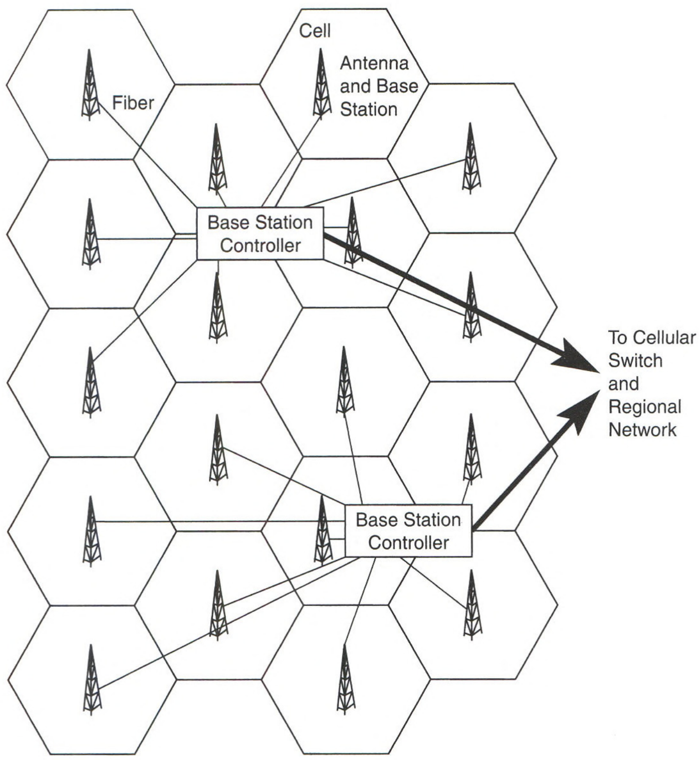


FIGURE 25.3
Cell-phone network.

Two trends have changed that pattern: the spread of mobile or cellular telephones, and the introduction of competition into the local fixed telephone network.

Cellular or mobile phones connect to the telephone network using radio waves. The service area is divided into cells, as shown in Figure 25.3, each with an antenna and a base station that serve phones located within the cell's area. As a user moves across the service area, the call is handed off from cell to cell. The antennas and base stations function like distribution nodes in a wire-line phone system, receiving signals from the switch and relaying them to individual phones. Cables carry the signals from the base transceiver back to a base station controller, which links to the switching office that serves the cellular phone network.

Because this book is about fiber optics, we won't look closely at the cellular network. However, the cellular network isn't always divided up into the neat hexagons shown in Figure 25.3. Terrain, buildings, vegetation, and changes in weather can affect transmission.

CLECs compete with incumbent wire-line phone companies.

Telecommunications regulations encouraged development of *competitive local exchange carriers* (CLECs), which provide local telephone service over cables. Many CLECs folded when the telecommunications bubble collapsed, but four basic types remain:

- Companies that lease space on the dominant phone company's network of cables, paying a rate set by regulators. The cables they lease connect to the competitive carrier's telephone switches, which make the required connections in the area and around the world.

- Facilities-based competitive carriers, which build networks of cables that overlay an area served by the dominant telephone carrier. Few of these companies exist today.
- Cable television companies that offer telephone service over their coaxial cable networks (see Chapter 27).
- Voice over Internet Protocol (VoIP) systems, which digitize voice signals at homes or offices and transmit the resulting data signals over the Internet or over digital lines using Internet Protocol. Many cable television systems use this technology.

The rest of this chapter concentrates on standard local wire-line telephone networks. You will learn more about VoIP systems later. Chapter 27 covers voice service on cable networks.

Distribution, Concentrators, and the Subscriber Loop

Cables distribute signals from the central office to subscribers.

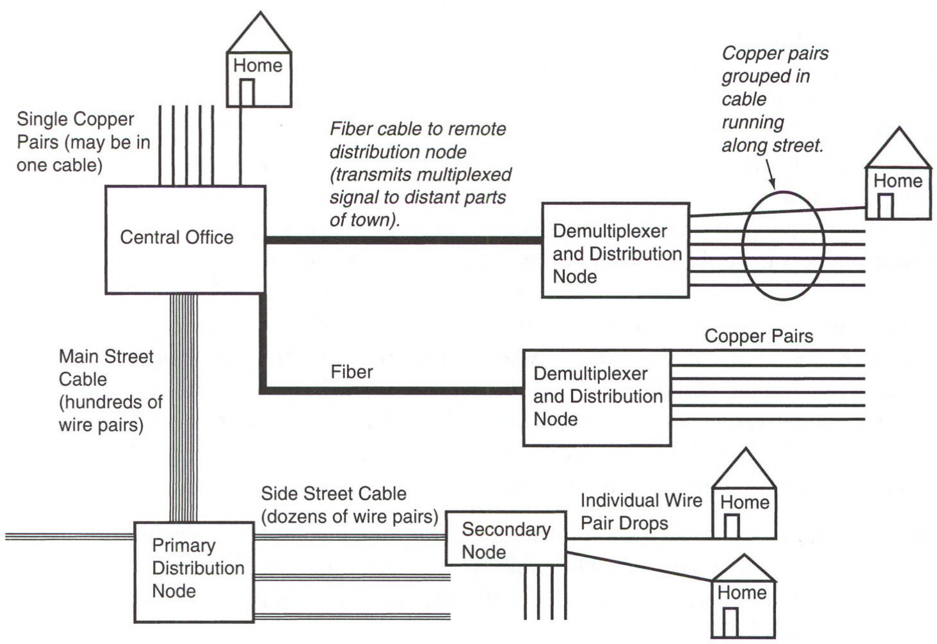
Twisted pairs of copper wires connect to telephones.

A network of cables distributes signals from the central office to subscribers. The structure of this network varies from place to place.

Figure 25.4 shows a typical network structure. Homes near the switching office are served by copper wire pairs running directly to the switch, as shown at top. Thick cables with hundreds of wire pairs run along main streets to service boxes or manholes, where the cables are split into smaller cables with dozens of wire pairs, as shown at bottom left. The smaller cables run down side streets and distribute service to individual homes. The wires running from these cables to homes are called *drops.*

The copper wiring used in these cables, called *twisted pairs,* traditionally is a pair of wires twisted together to reduce the noise they pick up from other sources. Flat ribbon cables

FIGURE 25.4
Subscriber loop distribution.



with two or four lines are used over short distances, such as in household telephone wiring, but long runs of untwisted wiring can act as antennas and pick up noise like radio signals. Each wire pair carries traffic for a single telephone circuit or phone line.

Distant homes are served by multiplexing signals at the central office and sending the multiplexed signals through fiber-optic cables to remote distribution nodes, as shown at the right in Figure 25.4. Although the scale of the figure doesn't show it, typically these fiber cables run a few miles. Copper cables run from the remote distribution node to homes, with fat cables subdividing into smaller cables with lower wire counts on side streets, as shown near the central office in the figure.

Copper wires can carry voice telephone signals several miles without serious degradation. However, the maximum transmission distance is shorter for other services, particularly Digital Subscriber Line (DSL), which I will cover later in this chapter. That has led to some refinements in design of subscriber loops.

Copper wires can carry voice, but not DSL, for several miles.

In the 1980s and early 1990s, telephone companies installed systems called *digital loop carriers* that multiplexed together many voice channels and distributed them at remote locations, as shown at the right of Figure 25.4. This seemed like a good idea at the time, because a single fiber transmitting at the modest 6.3 Mbit/s T2 rate could carry 96 telephone circuits. The fiber cables were much smaller, cheaper, and sturdier than copper cables with equivalent capacity. A single 12-fiber cable could easily carry 500 phone lines at 6.3 Mbit/s per fiber, so these systems were installed to new developments or during upgrading of existing phone systems.

However, old digital loop carriers posed a problem when telephone companies started thinking about DSL. Digital loop carriers transmit only the voice frequencies carried by phone lines, but DSL relies on transmitting higher frequencies that are lost in multiplexing. Thus the old digital loop carriers can't deliver DSL to phone lines they serve. It's hardly the only case where yesterday's bright idea becomes tomorrow's bottleneck.

To get around this bottleneck, telephone carriers must install modern fiber systems that transmit signals differently. Data to be delivered over DSL can be separated from digitized voice signals at the central office, then multiplexed in separate data streams. At the remote demultiplexing node, the two signals can be combined into an analog voice/DSL line, as they would be at the central office if the DSL subscriber were closer. The important difference is that the modern systems can move more functions of the switching office to the remote node; the older systems can only multiplex voice signals.

Business subscribers are served the same way as home telephone subscribers. The larger the business, the bigger the information pipelines needed to serve them. You can see this if you look back to Figure 25.2. The smaller businesses like the shoe-repair shop need just a phone line or two. Businesses that need more phone lines or high-speed Internet access may lease blocks of lines from the phone company. The insurance office and town hall both have T1 lines. The "pretty big business" has a 45-Mbit/s T3 line. The higher-capacity services may be delivered partly or entirely over fiber. A T3 fiber-optic cable runs from the switching office to the node serving the business district, and a short copper cable delivers T1 service from that node to the insurance company.

The structure of the local phone network is changing as technology develops, companies offer new services, and subscribers respond to the new technology and services. We will return to these evolving trends later, after describing conventional and emerging services.

Subscriber and Access Services

Traditional phone lines were designed to carry only analog voice signals.

The traditional subscriber loop was designed to carry voice telephone signals, called *Plain Old Telephone Service* or *POTS* in the industry. The local telephone network now provides many other services. When facsimile machines came into use, it was much easier to add them to the existing telephone network than to build a separate fax network. All you did was install a new phone line, plug in the fax machine, and tell people to send faxes to the new phone number. Likewise, dial-up modems take advantage of existing phone networks between your home or office and your Internet Service Provider instead of requiring a complete new network. Digital Subscriber Line technology expands on this trend by enhancing the transmission capacity of voice phone lines.

A broader range of services is offered to business and access customers, whose demand has steadily grown from multiple voice phone lines to large numbers of phone lines and high-speed data links. We'll look briefly at the most important services.

Leased Lines

Businesses lease phone lines for high-volume service.

Telecommunication users who need a large volume of service often *lease lines,* renting transmission capacity in bulk from a carrier. When dealing with telephone companies, they generally lease bulk capacity in a standard telephone-industry format, such as a T1 or T3 line, or an OC-3 carrier. The lines may run between user facilities, such as between buildings used by a large company or between a city's data-processing center and city hall. They also may run from the user's facility to another point, such as between a university and a regional Internet node or a long-distance carrier.

Although the service is called a *leased line,* the signals may not be carried over a physically separate wire, fiber, or cable along the entire route. If a company leases a T3 line between a downtown office building and a suburban factory, it is buying a guaranteed capacity of 45 Mbit/s on that route. The telephone company may time-division multiplex that 45-Mbit/s signal into a 2.5-Gbit/s OC-48 signal that a fiber transmits from downtown to the suburban central office, then run a separate fiber pair to the plant. The user sees no difference between that service and a separate pair of fibers—but the phone company can lease the capacity more cheaply.

Access lines generally serve the same purpose, but may be arranged differently. For example, the company may rent one optical channel on a fiber in a metro network that runs from downtown to near its suburban plant. The carrier may transport the signal in OC-1 or OC-3 form through the fiber, using its own equipment. Alternatively, the company could supply its own transmission equipment and send the signal in whatever form it wanted. If the line is intended to link the local-area networks in the factory and company headquarters, the signal might be in Gigabit Ethernet form.

Access lines also can go beyond the region. If a large magazine publisher has offices in Boston and Chicago, it might lease an OC-12 circuit between the two cities so it can transmit signals at up to 622 Mbit/s. The publisher might also lease OC-3 lines between both magazine offices and its printer in Mississippi. The company's signals can be combined with other signals and multiplexed to higher speeds for part of the route, but the user would not see any difference. Alternatively, users could lease wavelengths or dark fibers and have all the capacity they could use for themselves between two points.

Telephone Lines

Traditional phone lines carry analog signals at 300 to 3000 Hz for voice telephony. This isn't high fidelity, but it's adequate for intelligible speech. The bandwidth is limited by the attenuation of copper wire pairs, which increases with frequency and distance. Over short distances, copper wires can have surprisingly high bandwidths, so suitable copper cables can carry 1 Gbit/s on the desktop, but telephone companies long ignored these capabilities.

Fax machines and dial-up modems encode digital data as audio tones.

Fax machines and dial-up modems encode digital data as audio tones in the 300 to 3000 Hz audio range transmitted by analog phone lines. These signals must be clear and strong enough to survive conversion to digital format for regional and long-distance transmission. Standard level 3 fax signals can transmit up to 14,400 bits per second, and dial-up modems have nominal data rates to 56,000 bits per second, although in practice they are limited to about 53,000 bits/s.

The traditional telephone system converts these analog signals to digital form at the switching office or an intermediate node between the subscriber and the switch. Newer services transmit signals in digital format direct from the subscriber.

The original digital telephone service was *Integrated Services Digital Network (ISDN)*, transmitting 144 kbit/s over twisted wire pairs. As envisioned in the 1980s, that capacity would be divided between two 64-kbit/s digitized voice lines and one 16-kbit/s data line. More recent versions dedicate all the transmission capacity to digital data. However, ISDN required expensive special telephone equipment, phone companies were very slow to offer it, and few customers wanted it, especially in the United States. The service is still available in some locations, but is often called IDSL so that it sounds similar to DSL, although the two use different technologies.

DIGITAL SUBSCRIBER LINE (DSL)

DSL transmits data on phone lines at frequencies above the normal voice range.

Digital Subscriber Line (DSL) transmits digital data over copper wires at frequencies higher than those used for analog voice transmission. Ideally, DSL signals can be transmitted over the same twisted-pair lines used for voice conversations, with a standard phone responding only to the voice signals and the DSL modem responding only to the data. In practice, it often isn't that simple, and may require a device, called a *splitter*, that separates the low analog voice frequencies from the higher frequencies carrying the digital data.

There are several versions of DSL. The data rates they can transmit depend on the quality of the phone lines and the length of wire separating the subscriber from the switching office, as well as on the design. Load coils used to improve the quality of analog voice transmission also attenuate the high frequencies that carry DSL signals, so they can't be used with DSL. Some phone lines can't carry high frequencies well enough. Even in the best phone lines, attenuation increases with frequency, so the data rate possible decreases with transmission distance, as shown in Figure 25.5 for two types of DSL.

Table 25.1 lists several DSL-related technologies and their nominal data rates and maximum transmission distances. The actual data rate achieved at the maximum distance typically is well below the maximum rate, unless noted. The limiting distance is measured along the cable route, which is not a straight line, so many homes fall outside the limit even

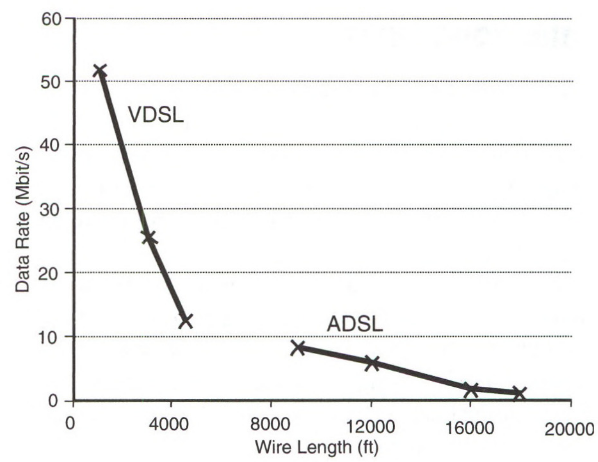


FIGURE 25.5
DSL data rates vs. wire length.

in cities or inner suburbs. Because data rate decreases with distance, it generally is impossible to achieve the maximum speed over the maximum possible distance. For example, the *Asymmetric Digital Subscriber Line* (ADSL) format is rated to send 8.448 Mbit/s to a terminal 9000 ft (2.7 km) away, but only 1.5 Mbit/s to a terminal at 18,000 ft (5.5 km).

As Table 25.1 shows, higher-speed DSL formats, notably VDSL, can't carry signals far. That's an intentional design choice; VDSL is intended for use in areas where a short length of copper runs between a home and a fiber-optic node. That trade-off is inevitable because of the bandwidth limitations of copper.

DSL rates depend on length and quality of lines and marketing decisions.

Different sources may quote different maximum data rates for DSL services, and some subscribers may not be able to receive DSL service at all. This reflects wide differences in the quality and length of phone lines, evolution of the technology, and marketing decisions by companies offering DSL services. Some phone lines are not suitable for DSL. Twisted pair attenuation is higher on the high end of the DSL spectrum, so long lines can't handle DSL signals. The nominal limit used to be 18,000 feet, but has been edging higher. Other phone lines may have incompatible equipment attached, or may not meet quality requirements. The reasons aren't always obvious. For unknown reasons, my phone company says two of its three phone lines into my home are suitable for DSL, but the third is not.

After some early problems, DSL has become popular for broadband Internet connections. DSL lags behind cable modems in the United States, but is more common in most other countries.

Emerging Services and Competing Technologies

In telecommunications some technologies that are "just around the corner" stay that way for a long time before quietly evaporating. One example is the video-telephone, which started as the stuff of pulp science fiction in the 1920s (see Figure 25.6). AT&T introduced the first

Table 25.1 Types of digital subscriber line services

Technology	Standards	Nominal Data Rate	Specified Maximum Distance
ISDN	ANSI/ITU	128 or 144 kbit/s both ways	18,000 ft (5.5 km) (longer distances possible)
G.Lite ("Splitterless" DSL)	ITU	1.5 Mbit/s downstream, 384 kbit/s upstream	18,000 ft (5.5 km)
ADSL (Asymmetric Digital Subscriber Line)	ANSI	8 Mbit/s 640 kbit/s downstream, upstream	9,000 ft (2.7 km) (at 8 Mbit/s)
ADSL	ANSI	1.5 Mbit/s downstream	18,000 ft (5.5 km) (at 1.5 Mbit/s)
SHDSL (Symmetric High-rate DSL)	ITU 6.991	2.3 Mbit/s both ways on one pair 192 kbit/s both ways	10,000 ft (3 km) (at 2.3 Mbit/s) 20,000 ft (6 km) (at 192 kbit/s)
T1	Digital Telephone Hierarchy	1.5 Mbit/s both ways	3,000 ft (900 m)
RADSL (Rate Adaptive DSL)	—	Adaptive— to 9 Mbit/s downstream, 1 Mbit/s upstream	12,000 ft (3.6 km)
VDSL (Very high DSL)	ANSI	13 to 52 Mbit/s down, 1.5 to 2.3 Mbit/s upstream	4,500 ft (1.4 km) at 13 Mbit/s; 1000 ft (300 m) at 52 Mbit/s

commercial video-telephone service, called *Picturephone*, in 1970, but it quietly faded away. Today webcams are cheap additions to personal computers, and their pictures appear on thousands of Web sites, but few people bother using them for videoconferencing.

Nonetheless, telecommunications is changing rapidly, so now we'll look at future trends both in the network and in the services it offers.

FIGURE 25.6
Videophones were part of the background that Hugo Gernsback, publisher of the first science-fiction magazines in the 1920s, used for his first science fiction novel. However, the cover artist's vision in this paperback still included a dial. (Courtesy of Fantasy Books)

Voice over Internet Protocol (VoIP)

Digitized voice can be sent as packets over the Internet.

Voice over Internet Protocol (VoIP) has become a favorite technology of market pundits and is offered by a number of companies. VoIP digitizes voice signals at the receiver and transmits them over the Internet as packets. One advantage is that sending Internet packets is much cheaper than using voice circuits. Another advantage is the potential of harnessing computers to process phone calls. These two features are pushing VoIP in opposite directions. One extreme is making cheap phone calls around the world from a computer, an approach that appeals to people with friends and family dispersed around the world. The other is feature-laden phones that turn voice messages into digital files that can be processed electronically. It remains to be seen how well the technology will live up to the considerable expectations of the pundits.

Packet delays can degrade voice transmission.

Quality of service is a serious issue in VoIP. Voice conversations are sensitive to delay, and packets transmitted over separate routes are subject to delay. The public Internet has only begun to adapt IPv6, which can assign special priorities to packets carrying voice signals; most nodes use the older IPv4, which treats voice packets like any other packets. The resulting transmission can be unintelligible. This problem can be avoided if telecommunications companies build their own IP networks using IPv6, and some companies have begun to do that. In this case, the IP lines simply replace SONET lines or other circuit-switched connections, and users should not hear much difference in their calls.

Another issue is compatibility with existing phones. Some VoIP systems require expensive special terminal equipment to use their advanced features. Others provide adapters that convert VoIP signals to the format required by standard analog phones. Extra features may be offered through computers, such as e-mailing digital voice-mail accounts.

Still other potential issues include the loss of features peculiar to the analog voice phone system. Because the phone network has its own power source, you can phone the power company to report an outage on an analog wire-line phone, but not on a cordless phone or a VoIP phone. Emergency 911 services require special equipment present on standard subscriber loops but not on VoIP networks.

Telephone service provided over cable-television networks faces many of the same issues as VoIP, and many cable networks use VoIP technology for their voice service.

Like any new technology, VoIP will have to convince customers that it's better than existing phone service. It may succeed in some niches but not others. Stay tuned.

Cellular versus Wire-Line Phones

Recently people have started to drop wire-line phones and use their cell phones as their main line. Typical examples are young, highly mobile people who are rarely at home to receive phone calls. It's not clear how far this trend will go. The convenience of cell phones is offset by their poorer sound quality and problems in finding a "sweet spot" to make a good connection to the cellular network. Cutting the cord to go all-cellular may not seem like such a good idea if your elderly rich uncle can't understand a word you say on your cell phone. On the other hand, cell phones are good backups for emergency calls or during power failures.

Video and "Triple-Play" Services

Convergence in telecommunications has led telephone and cable-television companies to talk about "triple-play" packages—combinations of voice, video, and broadband Internet connections. Cable companies have exploited this trend successfully to offer voice and data services, but phone companies have had trouble offering video service because their wires have limited bandwidth. Phone companies now offer video services in three ways:

"Triple-play" services offer voice, data, and video.

- Partnerships with satellite television companies, which compete with cable companies and can't offer voice service efficiently.
- *Video-on-demand* services offered over VDSL, which can switch video channels to individual subscribers. Video-on-demand could be packaged with satellite broadcasts so subscribers can request individualized programming as well as broadcast channels.
- *Fiber-to-the-home* (or premises) systems, which have dedicated bandwidth to carry video signals. Fiber can carry the full bandwidth of a cable network, putting phone companies on equal footing with cable companies, which have long had the lead in bandwidth. We'll look at this technology in the final section of this chapter.

Fixed Wireless Broadband Service

Fixed wireless broadband is a potentially competitive service that has been "just around the corner" for several years. This service installs fixed wireless transmitters in each neighborhood to transmit broadband signals—usually video and computer data—to subscribers. The goal is to avoid the high cost of stringing fiber or cable to each home.

The potential savings have attracted many companies from time to time, but the practical drawbacks have stalled deployment of the technology. The microwave frequencies that carry the signals are attenuated by rain and can be blocked by foliage, terrain, or buildings. In short, fixed wireless broadband may work well if you can see the transmitter from where you put your antenna, but you can't count on that.

Fiber to the Home or Premises

Verizon began fiber-to-the-home installations in 2004.

The narrow bandwidth of copper wires reaching individual homes has long limited the telephone network's ability to deliver telecommunications services to homes. DSL is part of a long-term effort to increase that bandwidth so phone companies can offer new services. Plans also include running fiber closer to individual subscribers.

Exactly how close the fiber should come to homes has been controversial. Although it seems logical to bring fiber all the way to the home, many analysts have been skeptical because of the potentially tremendous costs of overhauling the entire local telephone network. However, in the early 2000s rural phone companies and developers of large subdivisions began installing fiber-to-the-home systems. The large regional telephone companies have followed suit. Verizon began constructing its first system in Texas in 2004, with plans to run fiber past a million homes by the end of the year. Two other regional phone companies, SBC and BellSouth, have announced similar plans. Because this is a book on fiber optics, we will devote the rest of this chapter to fiber to the home.

The industry has developed a family of designs grouped as "fiber to the X" (FTTX), with *X* being a particular point in the network. Important variations are:

- *FTTB: Fiber to the Business* (or sometimes, Fiber to the Building)
- *FTTC: Fiber to the Curb* (near homes, but not all the way to them)
- *FTTD: Fiber to the Desk*
- *FTTH: Fiber to the Home*
- *FTTN: Fiber to the Neighborhood* (or Fiber to the Node)
- *FTTP: Fiber to the Premises* (equivalent to Fiber to the Home)

Spreading Fiber into the Local Phone System

There is wide agreement that the local phone system needs more bandwidth if it is to survive. The big questions are how much bandwidth, how best to provide it, and how to develop a future broadband network from today's limited telephone network. The central problem is the expense of replacing the existing network.

Fiber installation will cost $1000 to $1500 per home.

The existing telephone network is both an asset and a problem. It's an asset in that the phone companies have already built it and paid for it—but a problem in that its capacity is limited, and parts of it are aging. It's like an old computer that doesn't support the latest Web browsers and other newer applications. But the real problem is that replacing the existing network is very costly.

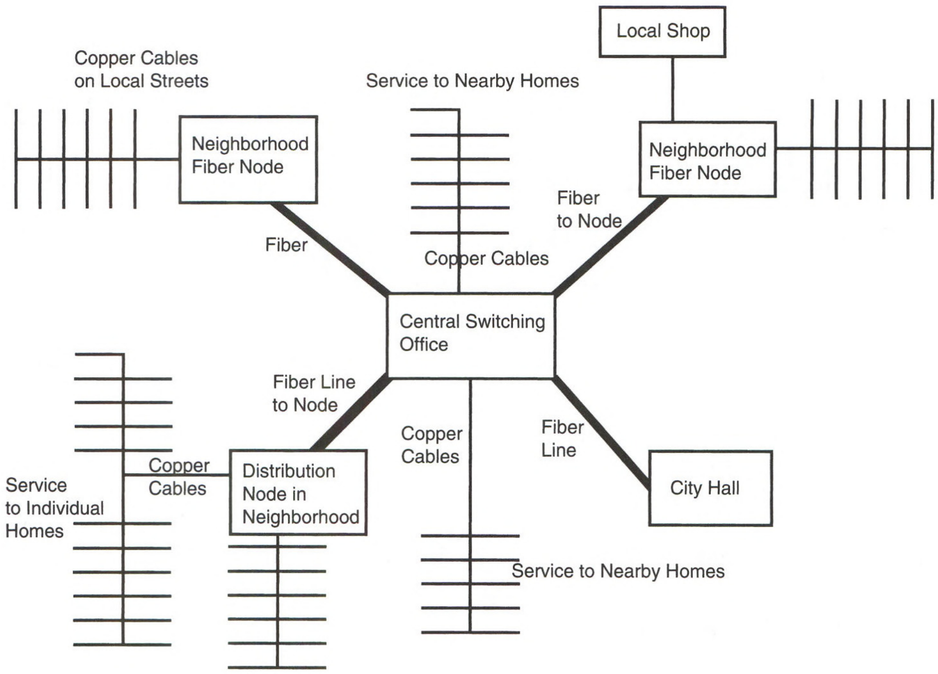


FIGURE 25.7
Fiber to the neighborhood.

Phone companies estimate that replacing existing local phone networks costs $1000 to $1500 per home. Fiber-optic equipment costs slightly more than copper wire, but most of the expense is the labor of installing new cables and equipment. Time is needed to run new cables along overhead poles and drop new lines to each home. Costly equipment and more time are required to replace existing buried utilities with new underground lines to each home. (It's relatively cheap to install fiber along with other utilities in new developments because the holes are already in the ground.)

The sheer scale of the job makes it a budget-buster for phone companies, so they are phasing in fiber. Fiber networks have gradually spread out from switching offices to serve neighborhood nodes. Separately, phone companies plan to replace existing distribution networks gradually with fiber, one neighborhood or community at a time.

Fiber to the Neighborhood

Today's telephone networks use fibers to connect remote neighborhoods to the local distribution system, as shown in Figure 25.4. The next logical step is *fiber to the neighborhood (or node)*, or FTTN, shown in Figure 25.7. High-speed fiber distributes signals to neighborhood nodes, which transfer the signals to copper wires that run along local streets and distribute signals to individual homes. An FTTN node might serve a few hundred telephone subscribers, including small local businesses. Similar fiber nodes service business and government, like the City Hall at the lower right in Figure 25.7. Copper cables run from the switching office to serve its immediate neighborhood.

FTTN nodes serve hundreds of subscribers.

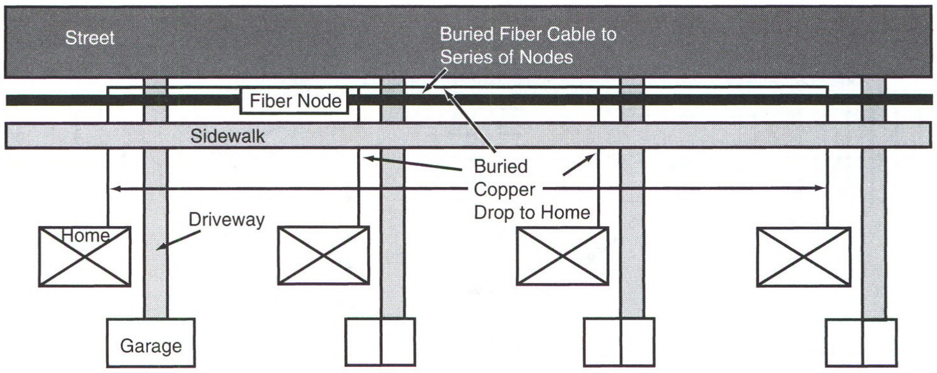


FIGURE 25.8
Fiber to the curb.

Fiber to the business (or building in the sense of apartment building) fits into a fiber-to-the-node system, with some of the nodes located at office and apartment buildings rather than in residential neighborhoods.

FTTN can be adapted to transmit and distribute DSL digital signals separately from phone calls to the node, which rearranges the signals to add DSL to phone lines.

Fiber to the Curb (FTTC)

Fiber to the curb is used with high-speed VDSL.

Fiber to the curb runs fiber down every street, ending at a curbside distribution node in front of the homes. Copper drop cables run from the curbside node to every home, as shown in Figure 25.8. In this example, an add-drop multiplexer connects a buried fiber cable to a curbside service node, typically a weatherproof box slightly larger than a standard television that sits on the ground near the street, like a fire hydrant. Buried copper cables run from the box to homes on the block. If the neighborhood has aerial cables, the distribution node may hang on a utility pole.

Typically the FTTC node is less than a thousand feet (300 meters) from homes, close enough for short twisted-pair copper drops to carry high-speed VDSL signals between the fiber and the home. This allows the telephone network to deliver up to 52 Mbit/s to homes, enough to carry a few video-on-demand channels, but not enough to deliver the whole spectrum of cable-television signals to homes.

FTTC curb networks have been built in some areas, but their future is unclear. They may be a stopgap on the way to fiber to the home.

Fiber to the Home (FTTH)

Demand for Internet bandwidth pushed home fiber development.

Telecommunications visionaries have been thinking about fiber to the home (FTTH) since 1972, when John Fulenwider first suggested the idea for a wired-city project being studied by General Telephone and Electronics. The first experimental system, called Hi-OVIS, began operation in 1978 in Higashi-Ikoma, Japan. Canada, France, and a few U. S. telephone companies tested fiber to the home in the years that followed. In most cases, the technology worked, but the economics didn't. No one found a combination of services that could generate enough income to justify the high cost of installing fiber to every home.

Today several trends have combined to shift the balance toward fiber to the home. Over the past 20 years, personal computer users have gone from 1200 bits/s dial-up modems to broadband DSL or cable-modem connections at speeds exceeding 1 Mbit/s. This tremendous increase in raw speed has been offset by bloated computer files and the increasing richness of features like streaming video and audio on the World Wide Web, which drive the demand for more bandwidth. Like the household clutter that fills closets, information needs continue to expand indefinitely.

The prices of optical equipment have dropped, and the technology for fiber installation has improved. For example, companies specializing in fiber-to-the-home systems have developed factory-terminated drop cables, so technicians can plug cable into sockets on a home terminal without cutting it and installing connectors or splices. These improvements have reduced the cost of installing new fiber networks to only about 5% to 10% more than that for copper networks. This trend makes fiber extremely attractive for new installations.

Fiber cables are more reliable in harsh outdoor environments. Fibers are not as vulnerable to moisture as copper. Passive optical networks also eliminate the need to install active components outdoors, which are a major cause of failure of copper cables.

Regional wire-line phone companies are under intense competitive pressure. Their total number of voice lines has decreased as subscribers turn entirely to cell phones, or shift their second line from a wired phone to a cell phone. They need more bandwidth so they can offer video and compete head-to-head against cable companies.

Many early home fiber installations were in rural areas.

The current wave of fiber-to-the-home installations began with publicly owned rural utilities and suburban developers. Large phone and cable companies lagged badly in bringing broadband Internet access to rural areas, some of which had little or no cable service and poor dial-up connections. Public utilities and telephone cooperatives decided to fill the gap. Run by local governments or cooperatives, they didn't have to answer to stockholders. Residents who paid for the services would get the benefits themselves. Some believed they needed better telecommunications to promote development in their areas. Government loan programs encouraged their investment.

Developers building higher-end housing also saw benefits in fiber to the home. Laying fiber wasn't excessively expensive because they had to provide telephone service for many newly built homes or apartments. They quickly discovered that advanced telecommunication services could help them sell their houses at higher prices—and satisfy the needs of the buyers.

FTTH lets phone companies offer voice, data, and video.

The big phone companies were latecomers to FTTH. They had talked about fiber-to-the-home systems before, but had stopped short of investing serious money in new equipment. But that changed as competitive pressures increased and the cost differential between fiber and copper dropped. New versions of home fiber networks are based on industry standards—an important feature for phone companies that want a choice of equipment vendors. These new designs can transmit cable-television services as well as voice and data, so phone companies can offer "triple-play" services. Government regulations have changed, and the phone companies have realized that DSL is only a stopgap unlikely to meet long-term needs.

Verizon's starting point for "fiber to the premises" systems was Keller, Texas, a town of 16,000 homes and 33,000 people just west of Dallas. Verizon promised to lay fiber past one million homes by the end of 2004, and twice that many in 2005. Other large phone companies have yet to start installing home fiber systems, although Bell South and SBC have said they will. But don't expect fiber to come to your house tomorrow. With more than 100 million households in the United States, changing five million homes a year to fiber would take 20 years.

Verizon plans to pass a million homes by the end of 2004, but doesn't specify how many homes will be connected to fiber then. Making the connections takes more time and costs

Old copper phone lines will remain in service.

more money, because phone companies first want to test how the fiber systems work and how customers respond. Verizon is starting in Keller because the town has strong competition and overhead cables, which are easier to replace than buried lines. The installation schedule will depend on competitive pressures and the condition of existing phone lines. The high-speed broadband service possible over fiber will come at a premium price.

The new fiber systems will overlay the old copper phone networks, which will remain in place with customers connected to them. The shift to fiber will be gradual, spreading company investment over time. As customers upgrade to broadband Internet or video services, Verizon plans to shift them to the fiber connection, which has the bandwidth needed for those services. Only at that point will the phone company run the fiber-optic drop line and hook up the home optical interfaces. Customers also may be shifted to the fiber system if the copper lines go down. Telephone engineers expect the fiber systems to work better than conventional phone lines because they should be less vulnerable to failures of outdoor electronics and moisture damage.

A major performance concern with home fiber connections is powering the phone service. Copper phone lines carry a 48-volt bias voltage that standard phones need to operate. (Cordless phones and many electronic phones require power from local electric lines.) Most designs for home fiber links rely on local electric power with a battery backup, which requires users to monitor batteries and limits phone operating time in the event of a power failure. How customers will regard this issue remains to be seen.

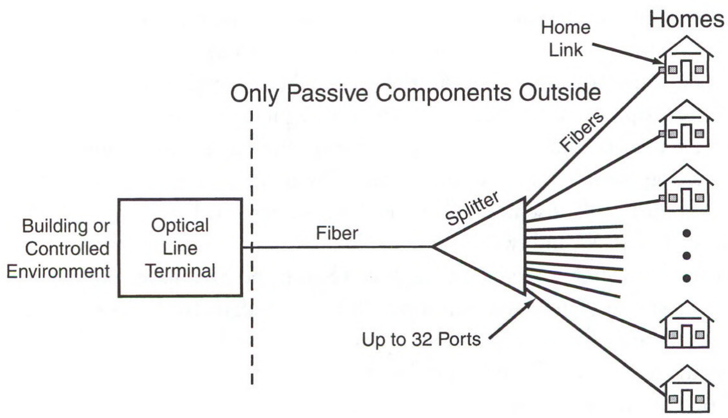
Two fundamentally different approaches are being used for FTTH systems: passive optical networks and Gigabit Ethernet networks. Let's look at the two in detail.

Passive Optical Networks

Passive optical networks have no active components between switch and subscriber.

The *passive optical network* or PON design reduces installation and operating costs by eliminating active components between the transmitting terminal and the subscriber. In its simplest form, shown in Figure 25.9, an *optical line terminal* sends downstream signals through a fiber with a splitter that distributes the signals among as many as 32 output fibers, one for each home served. As in local-area networks, all signals reach all terminals, but each terminal pays attention only to the signals directed to it. Signals may be shared among all terminals or directed to only one. *Optical network terminals* at the home contain transmitters that send signals upstream at a slower data rate. The result is a two-way point-to-multipoint network.

FIGURE 25.9
Simple passive optical network.



Note that only fibers, couplers, and connectors—purely passive components—are used in the outdoor distribution network. Transmitters and receivers are installed only at the end points, typically the switching office and the home. No electrical power runs along the fiber-optic cable, and no active optics or electronics are exposed to hostile outdoor operating conditions. This reduces both maintenance and operating expenses, important issues for phone companies.

Passive splitters divide signals among up to 32 output fibers.

Downstream signals come from a single transmitter, which generates enough power to be shared among up to 32 output ports. In general, the downstream transmitters are relatively expensive, but their cost is shared among many receiving units. Many more upstream transmitters are needed—one per house—so they must be inexpensive. Upstream transmitters typically operate at 1310 nm, where light sources are inexpensive.

Upstream signals return through the passive network to a single receiver at the optical line terminal. The upstream signals are separated from each other by assigning separate time slots to each home transmitter, so only one transmits signals upstream at a time. Upstream and downstream signals are separated by wavelength-division multiplexing, with upstream transmission at 1260 to 1360 nm, and downstream transmission at longer wavelengths from 1480 to 1550 nm. Table 25.2 lists important features of three standards covering PONs.

Video cable service will overlay digital traffic on phone company fiber systems.

Major U.S. telephone companies picked the ITU G.983 *Full Service Access Network (FSAN)* standard for their FTTP systems. G.983 specifies three types of transmission through the network at three different wavelengths.

- Downstream analog (cable-television) video transmission at 1550 nm, where erbium fiber amplifiers can amplify video feeds from external sources
- Downstream data transmission at 622 Mbit/s at 1480–1500 nm using local transmitters, which don't require amplification
- Upstream data transmission at 155 or 622 Mbit/s near 1310 nm

Table 25.2 ITU Standards for PONs

Name	BPON (Broadband PON or Full Service Access Network)	GPON (Gigabit PON)	EPON (Ethernet PON)
Standard	ITU G.983	ITU G.984	IEEE 802.3 ah EFM
Data packets	ATM	ATM or Ethernet	Ethernet
Downstream bandwidth	622 Mbit/s	1.25 or 2.5 Gbit/s	1.25 Gbit/s
Upstream bandwidth	Total 155 or 622 Mbit/s	Total 155 or 622 Mbit/s or 1.2 or 2.5 Gbit/s	1.25 Gbit/s
Downstream wavelengths	Data 1480–1500 nm, video 1550 nm	Data 1480–1500 nm, video 1550 nm	1550 nm
Upstream wavelengths	1260–1360 nm	1260–1360 nm	1310 nm

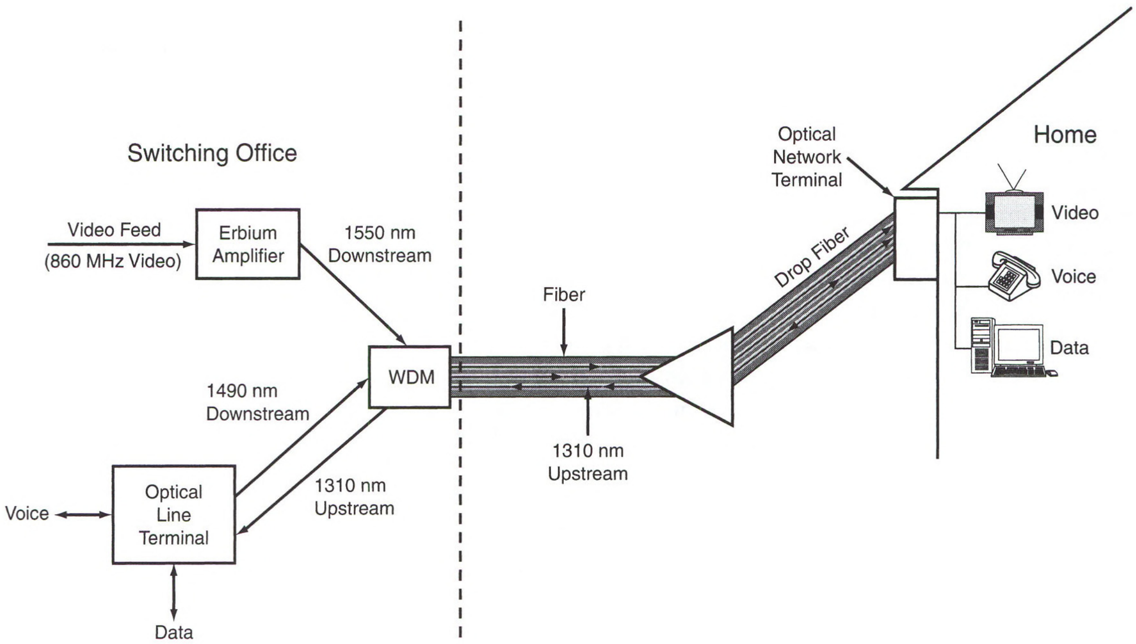


FIGURE 25.10
Signal transmission in the Verizon home fiber network.

Both the upstream and downstream data transmission capacities are shared among the users connected to the branched fibers. Voice signals are included in the digital data streams. Figure 25.10 illustrates the arrangement used by Verizon.

Video transmission in the Verizon system is in the standard 860-MHz band used for cable television networks, which can carry data plus analog and digital video signals. The FTTH system uses the downstream channel only for video transmission. You'll learn more about this format in Chapter 27.

Verizon transmits both upstream and downstream data as 53-byte ATM cells, a format widely used by local telephone companies because it can guarantee a fixed data rate for voice, as well as carry packets from data networks. At this writing, phone companies have not yet specified what data speeds they will offer, although they will likely be a series of levels carrying different prices. The system can offer multiple circuit-switched phone lines. In practice, each fiber on the splitter can carry a different data rate, determined by the customer's needs and budget.

The splitter in 32-channel PON attenuates signals by 15 dB.

Alternatively, data signals can be transmitted in Ethernet or Internet Protocol formats. The ITU G.984 standard specifies this for Gigabit PONs, while the IEEE 803.2 AH standard specifies it for EPONs. The two systems differ in detail, with more splitting possible in GPON networks, which unlike EPONs can support ATM transmission.

The splitting of signals among 32 potential output lines in BPON corresponds to a 15-dB drop, and requires higher-power transmitters at the switching office than at the home. Input video signals come in optical format and are amplified optically; all homes receive the same video signals, although special decoders are required to view premium channels. Data signals are generated locally by the optical line terminal, which combines input data streams from voice and data networks and addresses the signals to individual home terminals.

Fiber loss is much lower in the upstream direction because the signals are not split, so home terminals—called *optical network terminals*—need lower-power data transmitters. The optical line terminal serves as the central controller for all home terminals on a group of branching fibers. It assigns each home terminal its own time slot for upstream transmission using the *time-division multiple-access* (TDMA) protocol. Each home terminal switches on during its assigned time slot, then switches off so the next can begin transmitting. Clock signals transmitted downstream synchronize the subscriber terminals, dividing upstream capacity among users and preventing transmitters from sending signals at the same time. Each home terminal is at a different distance from the central transmitter, so the system measures those distances and programs appropriate delays into its control signals. The need to control these delays limits maximum transmission distance to 20 km.

Different fiber arrangements are possible. The BPON and GPON standards allow for either one or two fibers to serve each home; in single-fiber systems signals are transmitted in opposite directions simultaneously, but at different wavelengths. A single fiber can be split into up to 32 output fibers, but splitters with fewer ports can be used when data rates or attenuation are high. Two small splitters can be arranged in series, so each output of a 1×4 splitter could be followed by a 1×8 splitter, yielding a total of 32 possible outputs.

Point-to-Point Ethernet in the First Mile

The leading alternative to the PON is point-to-point Gigabit Ethernet transmission through interface units that connect to each home. As shown in Figure 25.11, signals travel through an Ethernet node that receives input signals from the outside world and distributes them to the proper destinations through single fibers linked to separate homes. The figure shows how the system can work in a rural area where large distances separate subscribers, making the high losses of PON splitters a problem.

Point-to-point links are between Ethernet nodes and terminal boxes.

Like Ethernet PON, point-to-point Ethernet transmission is defined in the IEEE 802.3 AH EFM standard. Like the standard, the industry jargon lumps both networks together as *Ethernet in the first mile*, reflecting the idea that the network starts in the home. Yet the two have important distinctions in network structure and transmission capabilities.

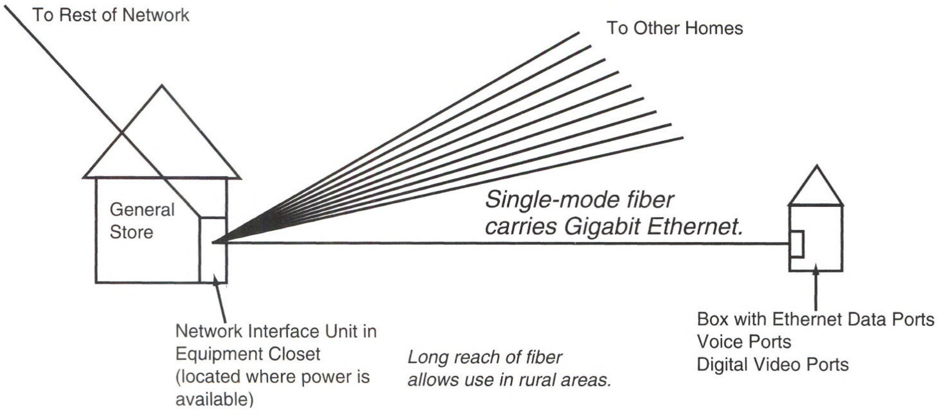


FIGURE 25.11
Gigabit Ethernet to the subscriber.

In the point-to-point network, all fiber links are strictly point-to-point, between Ethernet nodes and terminal points. No splitters divide optical signals; all signals go between pairs of electro-optic boxes. This is the architecture used in office local-area networks, and it allows the use of standard low-cost mass-produced Ethernet equipment. Ethernet nodes are active components that require electrical power, but they can be placed in utility closets in buildings, with long single-mode fiber connections running to individual homes that could be kilometers away. As Figure 25.11 shows, an Ethernet node serving a small town can be installed in a closet or storage area in a general store or municipal building.

As in PON networks, all subscribers attached to that node share a single input data stream. However, a pure Ethernet system is far more flexible in handling variations in the data rate. If nobody else is using the system, a Gigabit Ethernet system can deliver data to a single home at 1 Gbit/s. In contrast, PONs limit the maximum data transfer rate to a lower level, and must reserve fixed capacities for some users.

Large telephone companies have been slow to use point-to-point Ethernet, but some smaller companies and public utility districts have chosen it for their home fiber networks. With its high bandwidth, point-to-point Ethernet has the capacity to handle video transmission, security monitors, video cameras, and Internet links to appliances, as shown in Figure 25.12. Time and market reaction will be the acid tests of point-to-point Ethernet technology.

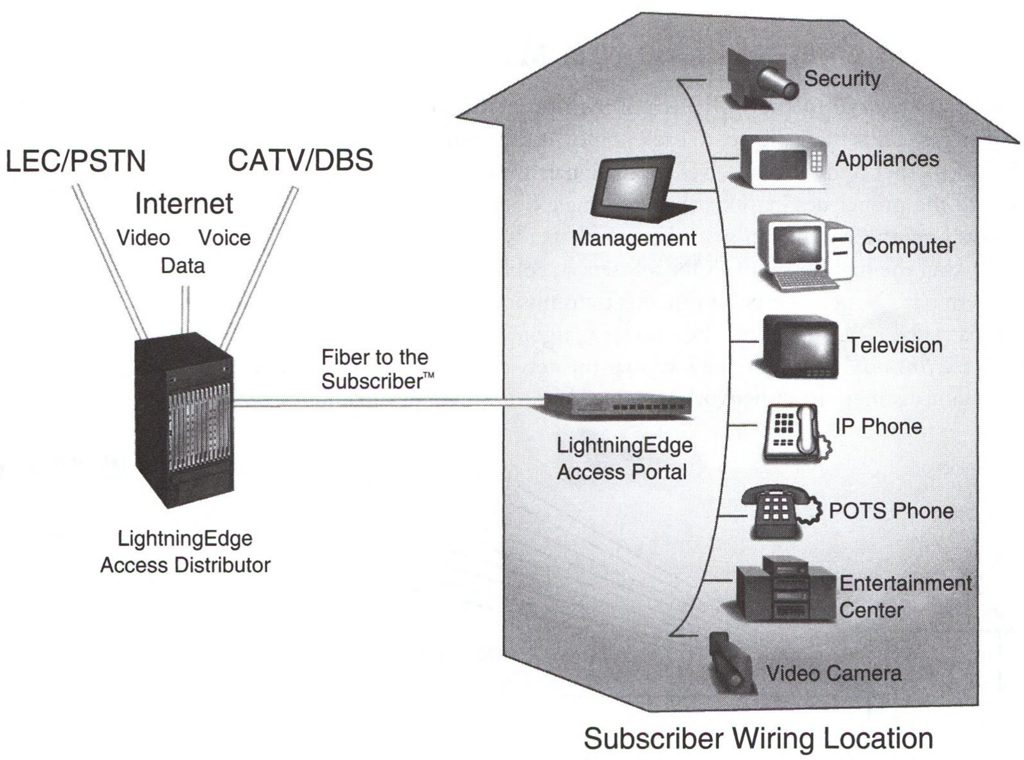


FIGURE 25.12
Multiple services delivered over Gigabit Ethernet link. (Courtesy of World Wide Packets)

THINGS TO THINK ABOUT

Timing of Fiber to the Home

In the March/April 2000 issue of *Technology Review* magazine, I described how fiber to the home might be used—but I set my example in the year 2020. Was I way off in my estimate of when fiber would be installed at homes?

Not really, for various reasons that are worth thinking about.

First, I described a family using technology that had become common by 2020. They could have been using it for years, taking advantage of improvements as we have taken advantage of improvements in personal computers.

Second, and more important, it will take time for fiber to reach homes all across the country. It's a huge job to rebuild a network serving over 100 million households. Verizon is starting by running fiber past a million homes in 2004 and plans to pass 2 million homes in 2005. But all those homes won't automatically be connected to the fiber network. Individual subscribers will have to sign up for video and/or data services that require the fiber connection, and they will need time to decide whether the service is worth the price. And cable companies may decide to run fiber to homes if they see a market for the extra bandwidth.

People don't sign up automatically for all new services. It has taken years for broadband Internet links over cable modems and DSL to reach about a third of American households, although they are available to most of the population. Cable television has been widely available for 25 years, but the fraction of households that subscribe is stuck below 70% (not counting satellite television), compared to more than 90% who have VCRs.

For now, I'm happy with my guess of 2020. How do you expect fiber to the home to grow?

Ethernet to the subscriber will compete with passive optical networks for other types of signal distribution as well as fiber to the home. Some of the earliest Gigabit Ethernet networks were installed by Canadian school systems as part of a program to enhance Internet connectivity to schools.

What Have You Learned?

1. The subscriber loop distributes telephone signals to individual users. The access network is a new term for the network that distributes services to business users.
2. The subscriber loop distributes signals from a switching office or central office to individual users over copper and fiber cables. The switching office is the interface between individual phone lines and the global network.
3. Twisted pairs of copper wires are widely used in the subscriber loop. They can carry voice signals several miles, but DSL is limited to shorter distances.
4. Traditional phone lines were designed to carry only analog voice signals at 300 to 3000 Hz called Plain Old Telephone Service (POTS).
5. Fax machines and dial-up modems transmit digital data by converting the data to analog tones and transmitting the tones over voice phone lines.

6. Digital Subscriber Line (DSL) transmits data on twisted-pair phone lines at frequencies above the normal voice range.
7. Several types of DSL transmission have been developed; they differ in nominal data rate and maximum transmission distance. The maximum speed drops with total transmission distance, measured along the cable route.
8. Voice over Internet Protocol (VoIP) sends digitized voice as packets over the Internet. This cuts costs and allows new services, but packet delays can degrade voice quality.
9. Cell phones are replacing wireline phones for some people.
10. Local cable and phone companies want to offer "triple-play" services that combine voice, video, and data.
11. FTTX is a family of services that run fiber in the subscriber loop, including fiber to the neighborhood (FTTN), fiber to the curb (FTTC), and fiber to the home (FTTH) or premises (FTTP).
12. FTTN nodes serve hundreds of subscribers in a neighborhood. They can distribute DSL to subscribers if the data signals are transmitted to the nodes separately from the phone calls.
13. FTTC runs fiber to nodes on each block, with short connections to homes that can carry high-speed VDSL.
14. Early fiber-to-the-home installations were in rural areas that lacked broadband service and large new developments where fiber was laid along with new utility services.
15. Demand for Internet bandwidth and interest in offering "triple-play" services led large phone companies to start installing fiber to the home. The fiber is being overlaid, with the old copper lines remaining in place. Customers are hooked up to fiber if they sign up for new services.
16. Passive optical networks distribute FTTH services. They have no active components between switch and subscriber, reducing operation and maintenance costs. Passive splitters distribute signals to up to 32 output fibers.
17. ITU G.983 and G.984 standards cover two types of passive optical networks, specifying how they transmit downstream data, upstream data, and video overlays at separate wavelengths.
18. Point-to-point Gigabit Ethernet systems also can transmit signals to homes, with distribution through neighborhood Ethernet nodes. This allows use of inexpensive Ethernet components.

What's Next?

In Chapter 26, you will learn about data transmission and local-area networks.

Further Reading

DSL Reports: *http://www.dslreports.com*

Ethernet in the First Mile Alliance: *http://www.efmalliance.org*

Fiber to the Home Council: *http://www.ftthcouncil.org*

Gary M. Miller, *Modern Electronic Communication,* 6th ed. (Prentice Hall, 1999)

Questions to Think About

1. A switching office serves 5000 voice telephone lines. It is designed so that at peak usage 20% of the lines can be connected—a total of 1000 phone lines. Residents discover the Internet and 500 of them buy dial-up modems and install new phone lines so they can leave their modems on all of the time. How much more switching capacity does the phone company have to install, both in number of lines and percent?
2. Suppose that instead of installing new phone lines, the residents of the town in Question 1 hooked their modems up to existing phone lines. If 500 people buy modems and half of them go on the Internet in the evening at a time of peak residential calling, how much does the phone company have to increase its switching capacity? How much must switching capacity be increased to accommodate half of the households buying modems and half of the modem users going on the Internet in the evening? Assume the rate of voice calling does not change.
3. Check to find how far your residential phone line is from your local phone company's switching office at *http://www.dslreports.com.* What DSL rates are available? If you're in a class, compare the rates and distance with those of other students.
4. A fiber-to-the-curb system is installed on a street. It serves 10 homes with copper drop cables less than 1000 feet long, which carry one phone line plus VDSL service at the maximum possible speed. If all voice and data services to the curbside interface are digitized and transmitted on a fiber, what is the minimum data rate on the fiber needed to serve all homes.
5. A passive optical network serves 32 subscribers with 622 Mbit/s downstream and 155 Mbit/s upstream. Two customers buy premium service, which guarantees 50 Mbit/s downstream and 10 Mbit/s upstream. What speed can the other customers get if the remaining capacity is divided equally among them?
6. The transmitter for a passive optical network generates a 1-mW signal that is divided equally among 32 users. If the cable loss is 10 dB and the couplers have no excess loss, what is the signal that reaches each user?
7. A Gigabit Ethernet signal is split among 32 subscribers. Neglecting losses arising from congestion, what is the maximum data rate if all are receiving signals at equal capacity?

Chapter Quiz

1. Which of the following is at the network edge?
   a. individual telephone subscribers
   b. Digital Subscriber Line
   c. individual telephones
   d. telephone switching offices
   e. international connections from national telecommunication networks
2. The network edge is the
   a. interface at which calls are directed.
   b. point where digital signals stop.
   c. point where telephone signals stop at a telephone.
   d. point where signals are transferred between regional and long-distance networks.
   e. point where signals are transferred between long-distance and international networks.
3. What connects to standard voice telephones?
   a. optical fibers
   b. twisted-wire pairs
   c. single copper wires
   d. coaxial copper cable
   e. special hybrid cables with one fiber and one copper wire
4. What transmits digital subscriber line (DSL)?
   a. optical fibers
   b. twisted-wire pairs
   c. single copper wires
   d. coaxial copper cable
   e. special hybrid cables with one fiber and one copper wire
5. Which of the following can limit the availability of DSL services?
   a. load coils
   b. distance from the central switching office
   c. quality of phone lines
   d. installation of digital loop carriers
   e. all of the above
6. You are in charge of telephone operations for a resort town. The CEO of your company has bought a vacation home in a new development outside of DSL reach, but wants at least 1.5-Mbit/s ADSL service to keep in touch with

corporate headquarters. What's the best way to upgrade service to the whole new development and please the big boss?

a. run fiber-optic cable to the CEO's door
b. run fiber to the center of the new development and build a new node to distribute DSL and other services there
c. install IDSL because it can reach farther than ADSL
d. run VDSL from your switching office
e. start looking for a new job because you're not going to be able to do it

7. What services besides POTS are transmitted in the low-frequency analog band of copper twisted pair?

a. digital switched video
b. DSL
c. fax and dial-up modem signals
d. Gigabit Ethernet
e. passive optical networks

8. Each node in a fiber-to-the-curb system would serve about how many homes?

a. 1
b. 10
c. 100
d. 500
e. over 1000

9. Each node in a fiber-to-the-neighborhood system would serve about how many homes?

a. 1
b. 10
c. 100
d. 500
e. several thousand

10. What unique service is offered only by fiber to the home?

a. high-definition digital television
b. Internet access at faster than 10 Mbit/s
c. combination of voice, video, and data at speeds faster than cable modems
d. high-definition video telephone
e. none of the above

11. The high cost of installing fiber to the home in communities that already have telephone service on copper wires comes mainly from

a. labor costs of installation.

b. the high cost of optical terminals.
c. the cost of removing old copper phone wires.
d. the need to secure new right of way to lay fiber.
e. lobbying to change regulations affecting telecommunications.

12. What equipment is installed outdoors in a passive optical network?
a. fiber-optic cable only
b. fiber-optic cable and splitters only
c. fiber-optic cable and optical line terminals only
d. fiber-optic cable, splitters, and optical switches only
e. fiber-optic cable, splitters, optical line terminals only

13. Signals transmitted downstream in a single fiber leaving an optical line terminal in an FSAN (ITU G.983) passive optical network can be divided among up to how many fibers going to individual homes?
a. 1
b. 4
c. 8
d. 16
e. 32

14. How do passive optical networks transmit video signals downstream to homes?
a. All video channels are digitized and added to the Internet data stream.
b. as an overlay signal in analog cable television format at the same 1310-nm wavelength as signals transmitted upstream from home terminals
c. as an overlay signal in analog cable-television format at 1550 nm
d. One channel selected by the subscriber is transmitted in the Internet data stream to each television set in the home.
e. All video signals are digitized and transmitted in a separate data stream at 1550 nm.

15. The maximum data rate a point-to-point Gigabit Ethernet system can deliver over a single fiber to the home subscriber is
a. 10 Mbit/s.
b. 52 Mbit/s.
c. 100 Mbit/s.
d. 622 Mbit/s.
e. 1 Gbit/s.