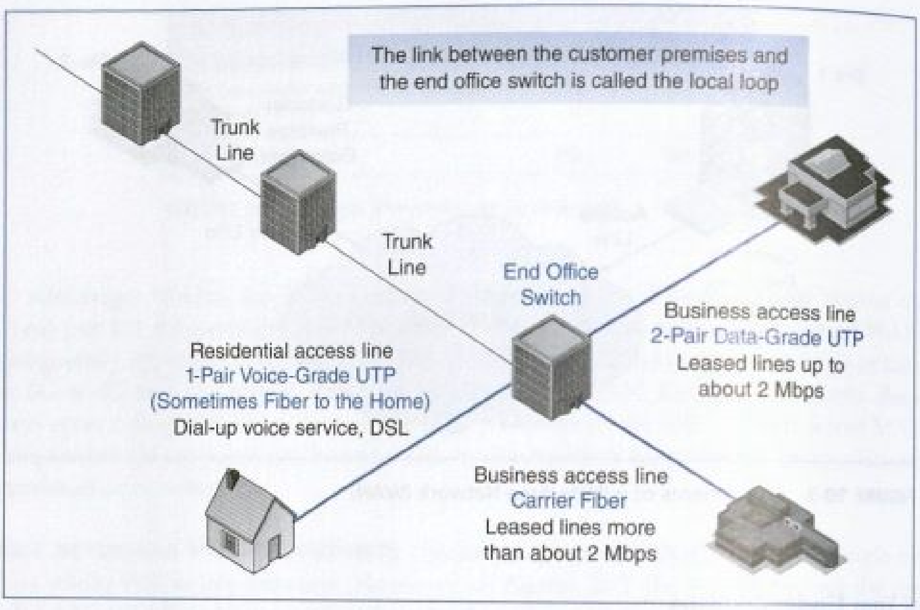

FIGURE 10-4 The Public Switched Telephone Network Local Loop

Purpose	Local Loop Technology	Considerations
Business Local Loop	2-pair data-grade UTP	For leased lines up to about 2 Mbps Must be pulled to the customer premises Not limited to 100 meters
	Optical fiber (carrier fiber)	For leased lines more than about 2 Mbps Must be pulled to the customer premises
Residential Local Loop	1-pair voice-grade UTP	Designed only for voice transmission Can be used for digital subscriber line (DSL) service Not limited to 100 meters Already installed; avoids cost of pulling media
	Optical fiber (carrier fiber)	Fiber to the home New Installed in entire neighborhoods to reduce cost
Internal Data Wiring	4-pair UTP (Category 3-6A)	For inside a site Usually limited to 100 meters
	Multimode optical fiber	Limited to about 300 meters

FIGURE 10-5 Local Loop Technologies

This is **2-pair data-grade UTP**. As the name suggests, this type of UTP wiring uses *two* twisted pairs instead of four. Each pair is for transmission in one direction. *Data grade* means that this wire was designed to carry data instead of voice. Two-pair data-grade UTP is used in the slowest leased lines—those up to about 2 Mbps.

Local loops, of course, are longer than 100 meters. Often, there can be 1 or 2 km between the customer premises and the nearest end office switch. The 100 meter limit on UTP cords that we saw earlier in this chapter is specific to 4-pair UTP and LANs.

The 100 meter limit on UTP cords that we saw earlier in this chapter is specific to 4-pair UTP and LANs. It does not apply to other types of UTP.

Carrier Fiber Two-pair data-grade UTP is fine for leased lines up to about 2 Mbps. For all faster leased lines, carriers use carrier-grade optical fiber. This means single-mode fiber and higher wavelengths of light—1310 and 1550 nm.

THE RESIDENTIAL LOCAL LOOP

One-Pair Voice-Grade UTP While businesses needing leased lines may use 2-pair data-grade UTP, the lines running to all residential premises are **1-pair voice-grade UTP**. As its name suggests, this type of wiring was designed to carry voice, not high-speed data. However, it can carry data up to moderate speeds.

Fiber to the Home (FTTH) Although 1-pair voice-grade UTP can carry data, this is not an ideal medium for transmission. Subscribers want to bring high-definition video into their homes, and they want multiple channels at a time. We cannot do this with digital subscriber lines using 1-pair voice-grade UTP copper wire. To provide extremely high speeds, a number of carriers are beginning to bring **fiber to the home (FTTH)** by running carrier-grade fiber from the end office switch to residential households.

Running new fiber to each household is very expensive, so implementation has been slow. However, by converting entire neighborhoods to FTTH, carriers have been able to lower their per-house installation costs.

LAN VERSUS WAN UTP We first looked at unshielded twisted pair (UTP) wiring in Chapter 5, in the context of Ethernet LANs. A key point that almost all students remember from that discussion is that Ethernet can normally carry signals over a maximum distance of 100 meters. However, this is an Ethernet limit, not an inherent UTP limit. In the local loop of the telephone system, voice and data signals typically need to travel a kilometer or more. However, while 4-pair UTP with high-category numbers can carry signals over a gigabit per second or more, 1-pair voice-grade UTP and even two-pair data-grade UTP can only carry data signals at much lower speeds.

Test Your Understanding

5. a) What two technologies are used in business local loops? b) What two technologies are used in residential local loops? c) Compare the two local loop UTP technologies in terms of number of pairs and voice-grade versus data-grade wiring quality. d) Compare the types of UTP used in corporate buildings and in low-speed PSTN leased lines. e) Is all UTP wiring limited to 100 meters? Explain.

Business Leased Lines

As Figure 10-6 shows, access lines run from the customer premises to the nearest end office switch. In contrast, leased lines run from one customer premises to another. Leased "lines" are really transmission paths that travel over access lines, through switches, and over trunk lines between switches. They seem like a physical line because there is reserved capacity on each access line, switch, and trunk line along the way. To users, the service is a simple point-to-point connection.

You personally use dial-up connections when you place a call to someone over a landline phone. Leased lines are different from dial-up connections.

- You can dial up any other number, but leased line transmission can only occur between the two customer premises the leased line connects.
- Dial-up connections exist only for the duration of the call. In contrast, leased lines are always-on connections for the duration of the lease.
- You pay for long-distance calls by the minute. In contrast, a leased line has a fixed payment for the term of the lease, typically with an additional cost that depends on use.
- Leased lines are leased. As in mobile telephone service, the lease has a term during which fees must be paid. Installing a leased line is a long-term commitment.
- Leased lines can carry data much faster than residential telephone lines, which require the use of either telephone modems or DSL service (which we saw earlier in this chapter).

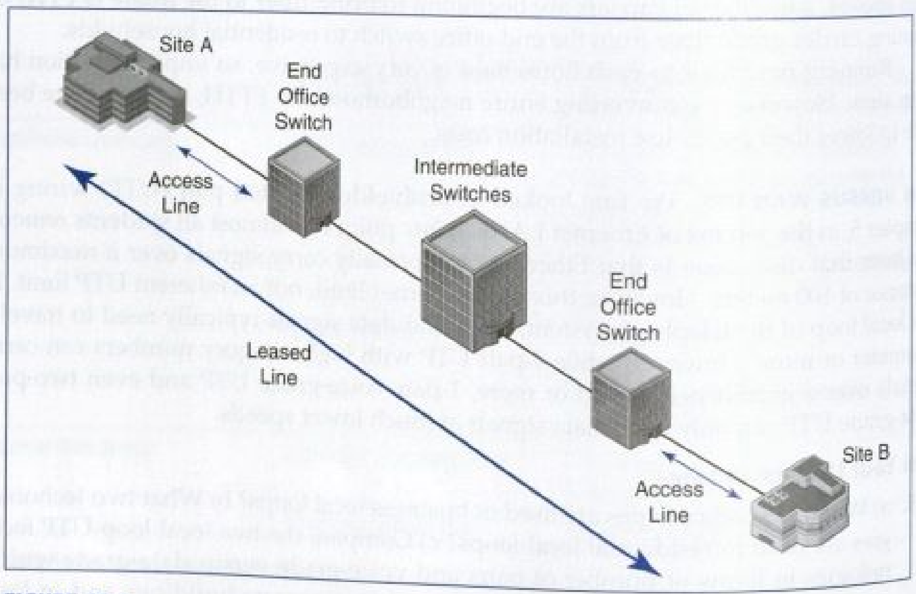

FIGURE 10-6 Access Lines versus Leased Lines

Characteristic	Dial-Up Connections	Leased Lines
Connectivity	Point-to-any-point	Point-to-point
Connection Period	Duration of a call	Duration of lease (always on)
Payment	By the minute for long-distance calls	Flat rate plus per-use changers
Commitment	None (except for cellular plans)	Duration of the lease
Data Transmission Speed	Low to moderate	Moderate to high

FIGURE 10-7 Leased Lines versus Dial-Up Lines (Study Figure)

Test Your Understanding

6. a) Explain the difference between access lines and leased lines. b) Compare dial-up connections with leased line connections along the dimensions shown in Figure 10-7.

Leased Line Speeds

Leased line speeds vary from about one megabit per second to tens of gigabits per second. Figure 10-8 shows that different parts of the world use different standards for leased lines below 50 Mbps. The figure shows lower-speed leased lines in the United States and Europe. There also are differences in other countries.

T1/E1 LEASED LINES The **T1 leased line** in the United States operates at 1.544 Mbps. The comparable European (CEPT) **E1 leased line** operates at 2.048 Mbps.

T1 and E1 lines require 2-pair data-grade UTP access lines. The lines are expensive because when a business needs a T1 or E1 line, the carrier typically must run a new 2-pair data-grade UTP access line to the customer premises.

For faster leased line speeds, optical fiber access links are required. These too typically must be pulled to the customer premise when a new leased line is established.

FRACTIONAL T1/E1 LEASED LINES Many leased line connections do not require T1 or E1 speeds. Many carriers offer **fractional T1/E1** leased lines. Fractional T1 lines typically operate at 128 kbps, 256 kbps, 384 kbps, 512 kbps, or 768 kbps. Fractional T1/E1 lines are slower than full T1/E1 lines, but they are less expensive.

BONDED T1/E1 LINES Sometimes, a firm needs slightly more than a single T1/E1 line but does not need the much higher speed of T3/E3 lines (discussed next). Often, a company can **bond** a few T1/E1 lines, that is, use them as a single connection. This will give a few multiples of 1.544 Mbps or 2.048 Mbps. This is similar to link aggregation in Ethernet, which we saw in Chapter 5. Bonding requires one 2-pair DG access line for each bonded T1 or E1 line.

THE T1/E1 FAMILY IN PERSPECTIVE T1/E1, fractional T1/E1, and bonded T1/E1 lines provide speeds in the range of greatest corporate demand for WAN transmission. Consequently, T1/E1, fractional T1/E1, and bonded T1/E1 lines are the most widely used leased lines.

North American Digital Hierarchy

Line	Speed	Typical Transmission Medium
T1	1.544 Mbps	2-Pair Data-Grade UTP
Fractional T1	128 kbps, 256 kbps, 384 kbps, 512 kbps, 768 kbps	2-Pair Data-Grade UTP
Bonded T1s (multiple T1s acting as a single line)	Small multiples of 1.544 Mbps	2-Pair Data-Grade UTP
T3	44.736 Mbps	Carrier Optical Fiber

CEPT Hierarchy

Line	Speed	Typical Transmission Medium
Fractional E1		2-Pair Data-Grade UTP
E1	2.048 Mbps	2-Pair Data-Grade UTP
Bonded E1	Small multiples of 2.048 Mbps	
E3	34.368 Mbps	Carrier Optical Fiber

SONET/SDH Speeds

Line	Speed (Mbps)	Typical Transmission Medium
OC3/STM1	155.52	Carrier Optical Fiber
OC12/STM4	622.08	Carrier Optical Fiber
OC48/STM16	2,488.32	Carrier Optical Fiber
OC192/STM64	9,953.28	Carrier Optical Fiber
OC768/STM256	39,813.12	Carrier Optical Fiber

FIGURE 10-8 Leased Line Speeds in the United States and Europe

T1/E1, fractional T1/E1, and bonded T1/E1 lines are the most widely used leased lines.

T3/E3 LEASED LINES The next level of the hierarchy is the T3 line in the United States.[2] It operates at 44.736 Mbps. The comparable E3 line operates at 34.368 Mbps. At this speed, optical fiber access lines are required.

SONET/SDH Beyond T3/E3 lines, the world has nearly standardized on a single technology or, more correctly, on two compatible technologies. These are **SONET (Synchronous Optical Network)** in North America and **SDH (Synchronous Digital Hierarchy)** in Europe. Other parts of the world select one or the other. As the North American name suggests, SONET/SDH lines all require optical fiber access lines.

SONET/SDH speeds are multiples of 51.84 Mbps, which is close to the speed of a T3/E3 line. Figure 10-8 shows that SONET speeds are given by OC **(optical carrier)** numbers, while SDH speeds are given by **STM (synchronous transfer mode)** numbers.

[2]Although there are T2 and E2 standards, they are not offered commercially.

The slowest offered SONET/SDH speed is 155.52 Mbps. From this speed, SONET/SDH speeds range up to several gigabits per second. The SONET speed nearest to 10 Gbps is 9,953.28 Mbps. Ethernet uses this speed for "10 Gbps" WAN usage so that it can transmit data over physical layer SONET lines. (We will see later in this chapter how Ethernet has begun to move outside the corporation.)

Test Your Understanding

7. a) Below what speed are there different leased line standards in different parts of the world? b) What is the exact speed of a T1 line? c) What are the speeds of comparable leased lines in Europe? d) What access link transmission media do T1 and E1 lines use? e) What access link transmission medium do all higher-speed leased lines require? f) Why are fractional T1 and E1 speeds desirable? g) List common fractional T1 speeds. h) What is T1/E1 bonding, and why is it attractive? i) What are the most widely used leased lines?
8. a) What leased line standards are used above 50 Mbps? b) What is the lowest-speed SONET/SDH leased line? c) Why does 10 Gbps Ethernet use a speed of 9,953.28 Mbps on "10 Gbps" WAN links?

Business Digital Subscriber Line (DSL) Service

The problem with T1/E1 lines is that their provisioning typically requires a new pair of data-grade UTP lines to be run from the nearest end office switch to the customer premises. This is expensive. However, until recently, only 2-pair data-grade UTP could carry data signals, so there was no choice.

However, one-pair voice-grade lease lines run to both residential and business locations. They are already in place, so if they could be used for data transmission, there would be no need to run new lines to the customer premises. Potentially, this means that they could offer services similar to leased line services but at a much lower price because there would be no need to pull new 2-pair data-grade UTP lines to the customer premises.

In the past, the inferior 1-pair voice-grade UTP line could only carry voice signals. However, advances in signaling technology allows them to carry data at moderate speed, up to a few tens of megabytes per second. In other words, they can be used for connections that use T1/E1 speeds. Given that 1-pair voice-grade UTP is already installed, they can offer these speeds at prices considerably below those of T1/E1 leased lines. When 1-pair VG UTP lines are used to carry data, carriers call them **digital subscriber lines** because they send and receive digital signals over these traditional subscriber lines designed for non-digital voice signals. Figure 10-9 shows that carriers offer several types of DSL lines.[3]

As discussed in the next subsection, consumers receive asymmetric digital subscriber line service over 1-pair VG UTP lines. The term *asymmetric* means that speeds are different in the two directions (downstream to the subscriber and upstream from the subscribers). Businesses, however, require *symmetric speeds* on their transmission lines—the same speed in both directions. They require *symmetric digital subscriber lines*.

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[3]OK, "DSL line" technically means "digital subscriber line line." No, it doesn't make grammatical sense, but that's the terminology that people in the field use.

Feature	ADSL	VDSL	HSDL	HSDL2	SHDSL
Name	Asymmetric DSL	Very-High-Bit-Rate DSL	High-Rate Symmetric DSL	High-Rate Symmetric DSL Version 2	Super-High Rate Symmetric DSL
Uses Existing 1-Pair Voice-Grade UTP?	Yes*	Yes	Yes*	Yes*	Yes*
Target Market	Residences	Residences, multi-tenant units	Business	Business	Business
Downstream Rated Speed	Initially, 1.5 Mbps; now up to 12 Mbps	52 to 100 Mbps	768 kbps	1.544 Mbps	192 kbps to 2.3 Mbps
Upstream Rated Speed	Initially, up to 0.5 Mbps; now up to 3.3 Mbps	16 to 100 Mbps	768 kbps	1.544 Mbps	192 kbps to 2.3 Mbps
Speed Symmetry	Asymmetrical	Asymmetric or Symmetric	Symmetrical	Symmetrical	Symmetrical
Quality-of-Service Guarantees?	No	No	Yes	Yes	Yes

*By definition, digital subscriber lines use 1-pair voice-grade UTP.

FIGURE 10-9 Digital Subscriber Lines (DSLs)

Business also needs guarantees that the line will be able to carry these speeds. These guarantees are spelled out in service level agreements (SLAs). If the carrier fails to meet these guarantees for more than a very brief amount of time, the carrier must pay a penalty. Paying a penalty is not attractive, so carriers over-engineer symmetric DSLs for business. As a consequence, while consumer asynchronous DSL lines cost only about $50 per month, business SDSL lines are more expensive.

As Figure 10-9 shows, several business-oriented DSL standards are available. The most popular business DSL is the **high-rate symmetric digital subscriber line (HDSL)**. This standard allows symmetric transmission at 768 kbps (approximately half of a T1's speed) in both directions. A newer version, **HDSL2**, transmits at 1.544 Mbps in both directions. Like all DSLs, both use a single voice-grade twisted pair. Businesses find HDSL and HDSL2 attractively priced compared with T1 and fractional T1 lines.[4]

Growing in popularity is **SHDSL (super-high-rate symmetric DSL)**, which can operate symmetrically over a single voice-grade twisted pair and over a speed range of 384 kbps–2.3 Mbps. In addition to offering a wide range of speeds and a higher top speed than HDSL2, SHDSL also can operate over somewhat longer distances.

Carriers are now beginning to introduce VDSL (Very-High-Rate DSL) and VDSL2 service. VDSL offers downstream speeds up to 52 Mbps and upstream speeds up to 16 Mbps. VDSL2 offers up to 100 Mbps symmetrically. These standards are difficult to

[4]In fact, most T1 lines provided to businesses are double-bonded HDSL lines or HDSL2.

categorize because they bridge the asymmetric-symmetric distinction and the business-residential distinction. In addition, although they offer ultrahigh speeds, they require a pristine wiring plant and rather short distances. Even more importantly, many carriers see this as a technology to offer over fiber rather than 1-pair VG UTP. Consequently, it is only a DSL standard in some senses.

Test Your Understanding

9. a) Why are DSL connections likely to be less expensive than traditional leased line connections? b) Are business DSL service speeds symmetric or asymmetric? Explain. c) What are the downstream and upstream speeds of HDSL, HDSL2, and SHDSL? d) Do business, residential, or both DSL services offer quality-of-service guarantees? e) What is the fastest DSL standard? f) Why is VDSL difficult to compare to the other standards?

Residential DSL Service

Most readers are only directly familiar with residential DSL services. As Figure 10-9 shows, these are **asymmetric DSL (ADSL)** services, which means there are different speeds for downloading and uploading. These services have much faster download speed than upload speeds. This is reasonable because website downloading often requires a great deal of speed and because video download and streaming service also need a great deal of speed. Few consumer applications require full two-way high-speed service.

Asymmetric service saves money because upstream speeds are lower and so use a lower-cost transmission technology. In addition, Figure 10-9 shows that residential DSL services do not receive service level agreement guarantees for speed. This means that signaling systems do not have to be over-engineered. This further saves money.

ELEMENTS OF RESIDENTIAL ADSL SERVICE Figure 10-10 shows the main technical elements of ADSL service. The customer needs a DSL modem, which plugs into a wall

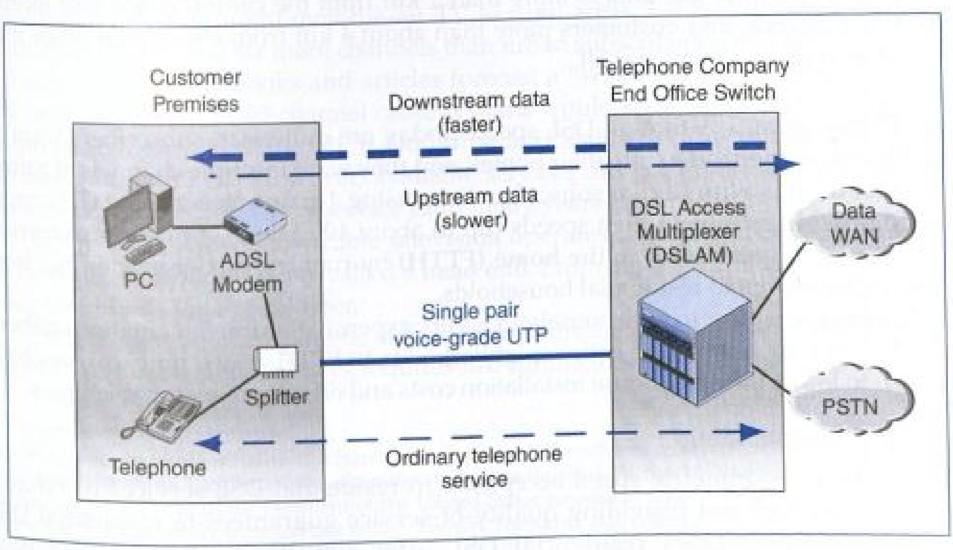


FIGURE 10-10 Asymmetric Digital Subscriber Line (DSL) Service

jack via a home telephone cord. A computer can plug into the DSL modem for digital transmission service. At the same time, the customer can plug his or her telephones into wall jacks and use them while the line is used for data transmission.

To use DSL service effectively, the user must plug a **splitter** into each telephone jack. The splitter separates the voice signal from the data signal so that they cannot interfere with each other. Phones plug into the voice port of a splitter. A DSL modem, if one is present, plugs into the data port on the splitter.

At the telephone company end office switch, the carrier needs to install a **DSL access multiplexer (DSLAM)**. This device separates voice and data traffic. It links voice traffic to the traditional voice part of the public switched telephone network. It links data traffic to a data network.

ADSL SPEED As in most transmission standards, there is a wide gap between ADSL rated speeds and actual throughput. Initially, there were two common ADSL standards. One offered a rated download speed of 1.5 Mbps and a rated upstream speed of 0.5 Mbps and was widely used. By today's standards, it was painfully slow, but compared to a telephone modem limited to 56 kbps downstream and 33 kbps upstream, it was wonderful. Today, the fastest ADSL standard (ADSL2+M) offers a rated download speed of 24 Mbps and a rated upload speed of 3.3 Mbps.

In addition, as we just saw, VDSL can offer far higher speeds to residential customers. Common offerings are 20 to 40 Mbps downstream and 10 to 20 Mbps upstream. VDSL is sufficient for multiple HDTV transmissions to multiple HDTV televisions in a home.

These are not the speeds that users receive. First, there is the usual large gap between rated speeds and throughput under the best of conditions. In addition, remember that all DSL services use existing 1-pair VG UTP access lines that were not designed for high-speed data. Real throughput depends heavily on the quality of the residential wiring plant. It depends even more heavily on the distance between the customer and the central office. Speed starts out fairly high near the central office switch but falls off rapidly with distance. Customers more than 2 km from the central office will receive much lower speeds, and customers more than about 4 km from the central office may not be able to receive service at all.

FIBER TO THE HOME Although DSL speeds today are quite fast, subscribers want to bring high-definition video into their homes, and they want multiple channels at a time. We cannot do this with digital subscriber lines using 1-pair voice-grade UTP copper wire. To provide extremely high speeds (up to about 100 Mbps), a number of carriers are beginning to bring **fiber to the home (FTTH)** by running carrier-grade fiber from the end office switch to residential households.

Running new fiber to each household is very expensive, so implementation has been slow. However, by converting entire neighborhoods to FTTH at one time, carriers have been able to lower their per-house installation costs and offer more reasonable prices.

Test Your Understanding

10. a) Why is asymmetric speed acceptable in residential DSL service? b) What is the benefit of not providing quality-of-service guarantees to residential DSL customers? c) Does residential DSL offer simultaneous voice and data

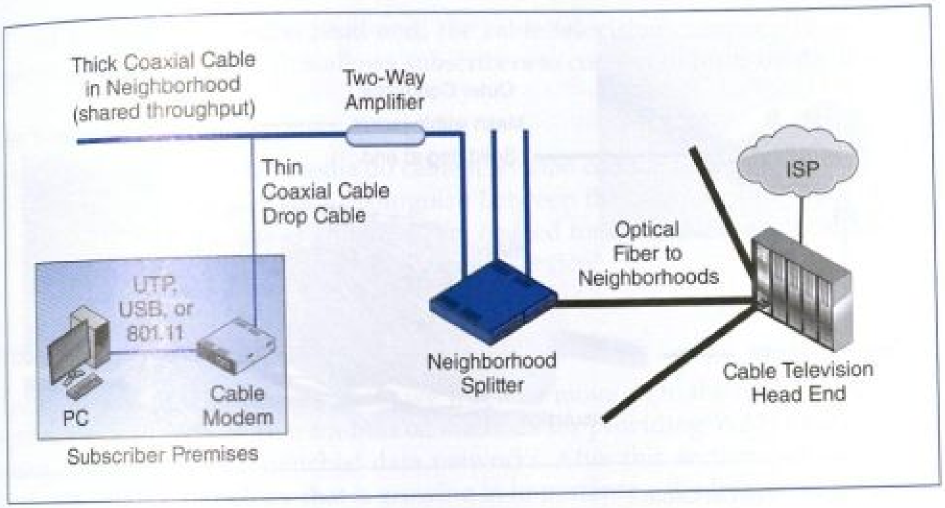


FIGURE 10-11 Cable Modem Service

service? d) What equipment does the customer have to add to his or her home? e) What is the purpose of the DSL access multiplexer? f) Compare rated *downstream* speeds for ADSL initially and today. g) Compare rated *upstream* speeds for ADSL initially and today. h) What three factors reduce actual user throughput? i) Why is fiber to the home attractive? j) Compare fiber to the home installation with pulling optical fiber to firms for high-speed leased lines.

Cable Modem Service

TELEPHONE SERVICE AND CABLE TV In the 1950s, **cable television** companies sprang up in the United States and several other countries, bringing television into the home. Initially, cable only brought over-the-air TV to rural areas. Later, it began to penetrate urban areas by offering far more channels than urban subscribers could receive over the air. In the 1970s, many books and articles forecast a "wired nation" in which two-way cable and the advent of 40-channel cable systems would soon turn cable into an information superhighway. (After all, it would be impossible to fill 40 channels just with television, wouldn't it?) However, available services did not justify the heavy investment to make cable a two-way service until many years later.[5]

Figure 10-11 shows how cable television operates. The cable television operator has a central distribution point, called a **head end**. From the head end, signals travel out to neighborhoods via optical fiber.

From neighborhood splitters, signals travel through coaxial cable. The transmission of an electrical signal always requires *two* conductors. In UTP, the two conductors

[5]This was proven in the dissertation of a Stanford PhD student. The student received a contract from the White House to do the study. Unfortunately, when the study was finished, Richard Nixon was being impeached, and the Executive Office of the President of the United States refused to release the study—despite the fact that the results of the study were already widely known. The study was released a year later, and the student was able to get his PhD.

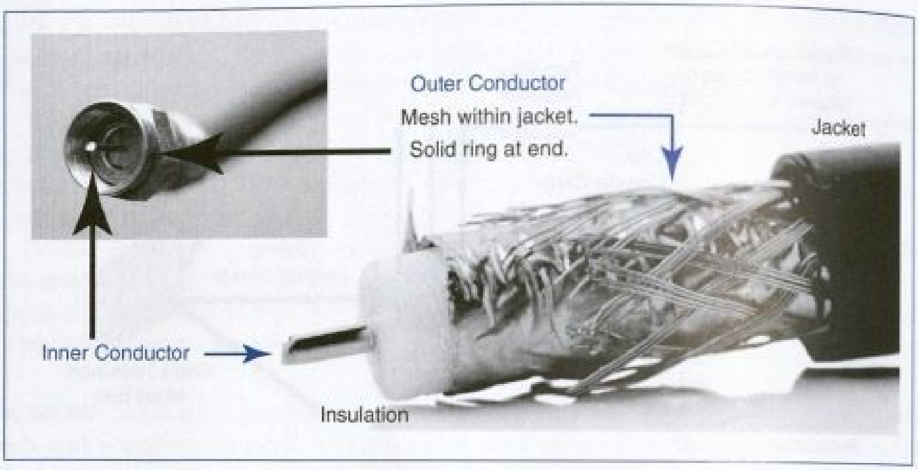


FIGURE 10-12 Coaxial Cable

Source: © Yury Minaev/iStockphoto; © Mark Coffey/iStockphoto

are the two wires in a pair. Figure 10-12 shows that in coaxial cable, the first conductor is a wire running through the center of a coaxial cable. The second conductor is a mesh wire tube running along the cable. The two conductors have the same axis, so the technology is called **coaxial cable**. Before the advent of high-definition HDMI cables, you typically connected your VCR to your television with coaxial cable.

The cable television company runs signals through the neighborhood using *thick coaxial cable* that looks like a garden hose. The access line to individual homes is a *thin coaxial cable* **drop cable**. The resident connects the drop cable to his or her television.

CABLE MODEM SERVICE[6] Cable television companies eventually moved beyond one-way television service to two-way broadband (fast) data service. For television, the repeaters that boost signals periodically along the cable run only had to boost television signals traveling downstream. Data transmission required cable companies to install **two-way amplifiers**, which could carry data in both directions. Although this was expensive, it allowed cable companies to compete in the burgeoning market for broadband service. As in the case of ADSL, cable television service was asymmetric, offering faster downstream speeds than upstream speeds.

Instead of having a DSL modem, the subscriber has a **cable modem**. In general, this cable data service is called **cable modem service**. The coaxial cable drop line goes into the cable modem. The cable modem has a USB port and an Ethernet RJ-45 connector. The subscriber plugs a computer or access router into one of the two ports.

[6]Which is better—ADSL service or cable modem service? ADSL services tout the fact that ADSL access lines are not shared, while coaxial cable trunk lines passing through neighborhood are shared. However, DSLAMs are shared in ADSL and often lack full capacity to serve all subscribers simultaneously. In both ADSL and cable modem service, the trunk line leading back to the data network is shared. More importantly, service providers often do not give the highest possible speed at lower monthly prices. In general, cable modem has tended to be somewhat faster and also somewhat more expensive than ADSL service.

At the cable television head end, the cable television company connects to an Internet service provider. This allows subscribers to connect to hosts on the Internet.

Test Your Understanding

11. a) What transmission media do cable television companies use? b) Why is coaxial cable called "coaxial"? c) Distinguish between the coaxial trunk cable and drop cable. d) What types of amplifiers are needed for cable data service? e) What device do customers need for cable modem service?

THE NETWORK CORE

Having looked at wired access links, we will now move on to the network core. In this section, we will look at two traditional methods for providing WAN cores. These are leased lines and public switched data networks. After this section, we will look at a third core WAN technology that is growing in importance—the Internet.

Leased Line Wide Area Networks

LEASED LINE NETWORK TECHNOLOGY When leased lines appeared in the 1960s, companies realized that they could build their own internal telephone networks to link their sites together. Figure 10-13 shows that companies need two pieces of technology to build leased line WANs.

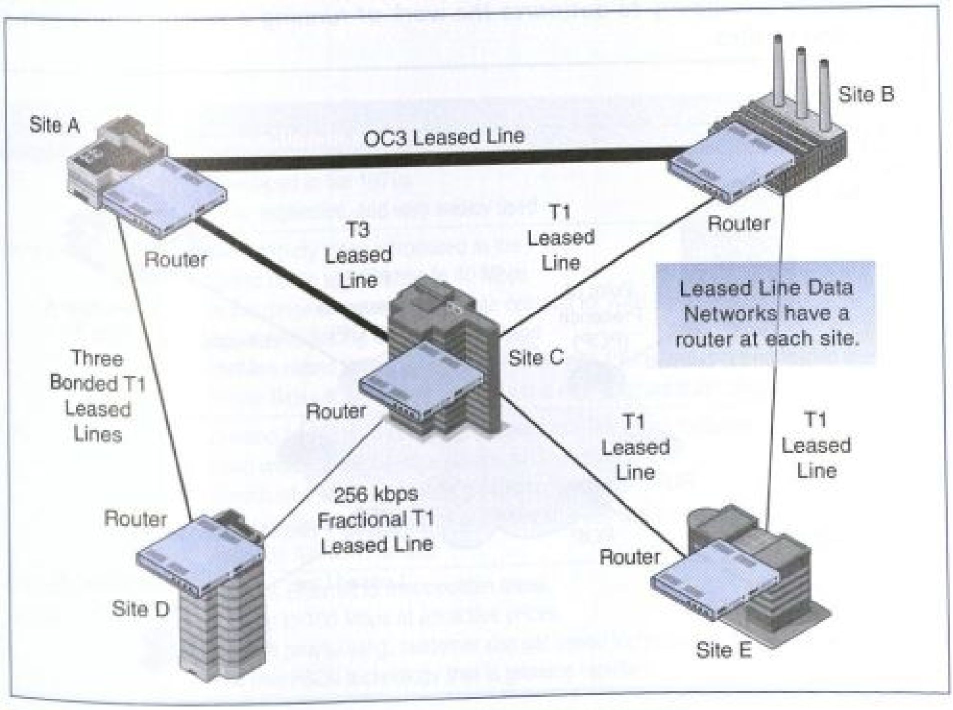


FIGURE 10-13 Leased Line Network

- First, they needed leased lines to connect their sites to one another.
- Second, they needed a router at each site.

LABOR COSTS Designing a leased line network was a considerable task. As Chapter 4 discussed, a firm must first discover the traffic volumes between each pair of sites. In a leased line data WAN, the company must decide which sites to connect and what leased line speeds they need to connect the sites together. It must then contract with the telephone company for leased lines, install the switches, and test the network.

However, the real work begins after the leased line network is installed. Switched data networks in LANs often work with little day-to-day intervention. This is not true for switched WANs. The networking staff in the company must manage the network constantly. The labor costs are substantial.

Test Your Understanding

12. a) What two technologies are needed for leased line switched WANs? b) What are the cost elements in networks of leased lines?

Public Switched Data Network (PSDN)

Companies that build their own leased line WANs must design, install, configure, and manage their leased lines. This is expensive. In contrast, many companies use **public switched data networks (PSDNs)**, which are shown in Figure 10-14. PSDNs allow a company to outsource the work of running a switched data network connecting its sites.

PSDNs allow a company to outsource the work of running a switched data network connecting its sites.

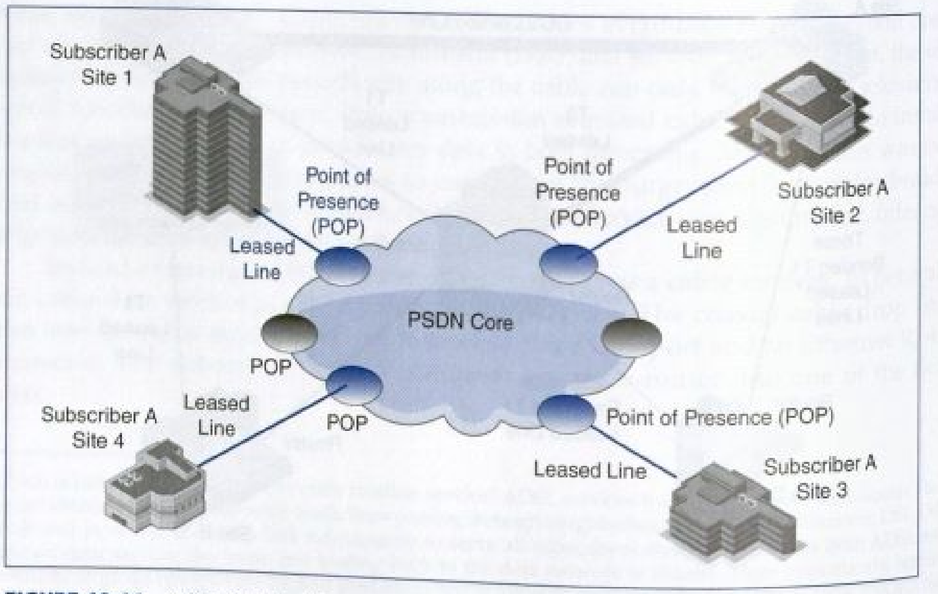


FIGURE 10-14 Public Switched Data Network (PSDN)

PUBLIC SWITCHED DATA NETWORK (PSDN) ACCESS LINES With a PSDN, the corporation needs only one leased line per site. This leased line has to run only from the site to the PSDN's nearest access point. These access points are called **points of presence (POPs)**.

This means that if you have ten sites, you only need ten leased lines. Furthermore, most PSDN carriers have many POPs, so the few leased lines that are needed tend to span only short distances.

THE PSDN CLOUD The PSDN's transport core usually is represented graphically as a **cloud**. This symbolizes the fact that although the PSDN has internal switches and trunk lines, the customer does not have to know how things work inside the PSDN cloud. The PSDN carrier handles almost all of the management work that customers have to do when running their own leased line networks. Customers merely have to send data to and receive data from the PSDN cloud, in the correct format. Although PSDN carrier prices reflect their management costs, there are strong economies of scale in managing very large PSDNs instead of individual corporate leased line networks. Quite simply, it is proportionally cheaper to manage the traffic of many firms than of one firm. There also are very large economies of scale in switching and leased line technologies. These economies of scale allow PSDN prices to remain relatively low.

PSDN STANDARDS There are several standards for PSDN services. They have different speed ranges and also different prices.

X.25 The original PSDN standard was **X.25**. This was a 1970s technology that was slow, expensive, and never widely used. It is completely gone today, but it pioneered PSDN service.

Standard	Characteristics
X.25	Developed in the 1970s Slow, expensive, and very widely used
Frame Relay	Grew rapidly when introduced in the 1990s Speed range of 256 kbps to 40 Mbps In the range of greatest corporate demand for WAN service Aggressive pricing also drives demand Carriers raised Frame Relay prices in the late 1990s and dropped leased line prices Frame Relay is still widely used, but it is now a legacy technology
ATM	Created for the core of the Public Switched Telephone Network Used widely there but also offered to customers Speeds of 1 Mbps to several gigabits per second However expensive in terms of carrier charges and customer management cost Adoption has been limited
Metropolitan Area Ethernet	Extends Ethernet to metropolitan areas 1 Mbps to 100 Mbps at attractive prices Flexible provisioning; customer can get speed increases or decreases in days The only PSDN technology that is growing rapidly

FIGURE 10-15 Public Switched Data Network (PSDN) Standards (Study Figure)

Frame Relay In the 1990s, **Frame Relay** burst onto the scene. Frame Relay was much less expensive than X.25. Its speed range of 256 kbps to about 40 Mbps was not blindingly fast. However, as noted earlier in this chapter, companies have lower speed requirements for WAN service than for LAN service. Frame Relay had exactly the speed range that corporations needed. In addition, only telephone companies offered leased lines, but new data networking companies could offer Frame Relay service. These new companies offered very low prices.

Frame Relay grew meteorically during the 1990s. Soon, it was used as widely as leased line networks. However, Frame Relay providers had very low profit margins because of their low prices. During the late 1990s, Frame Relay vendors began raising their prices while leased line prices fell precipitously because of improving technology. Frame Relay is still widely used, but it is a now a legacy technology.

ATM Another PSDN standard is **ATM**.[7] ATM actually was created as a new technology for the entire core of the worldwide Public Switched Telephone Network. In fact, it has already replaced much of the traditional PSTN core, especially on international connections.

ATM offers higher speeds than X.25—from about 1 Mbps up to hundreds of gigabits per second. This makes ATM the fastest PSDN service. However, ATM is extremely expensive in terms of both carrier charges and customer management cost, so ATM prices have also been very high. Consequently, ATM PSDN adoption has been very limited.

Metropolitan Area Ethernet Ethernet is a switched technology designed for LANs. However, many PSDN carriers have introduced metropolitan area Ethernet to extend Ethernet beyond the LAN. A **metropolitan area network (MAN)** is a WAN that is limited to a metropolitan area, such as a major city and its suburbs. MAN distances are shorter than national and international WAN distances, so MAN prices are lower, and typical speeds are higher. "Metro Ethernet" offers speeds of 1 Mbps to 100 Mbps at a very attractive price.

Metro Ethernet has several attractions beyond high speed and low price. Perhaps the most important is that corporations are already familiar with Ethernet. There is little learning with metro Ethernet compared to Frame Relay or ATM. Many people believe that in the future, companies will primarily use IP over Ethernet for nearly all connections.

Another advantage of metro Ethernet is provisioning. **Provisioning** is providing a service or changing a service. In metro Ethernet, service providers normally can reprovision the speed of a service within a day or so. This is much greater flexibility than companies have traditionally enjoyed with PSDNs.

Provisioning is providing a service or changing a service.

Given the promise of metro Ethernet, it is not surprising that metropolitan area Ethernet is the only PSDN service that is growing rapidly.

[7] It stands for Asynchronous Transport Mode. Not very enlightening, is it? Fortunately, nobody ever spells it out.

Test Your Understanding

13. a) List the physical components of PSDN technology. b) Do customers need leased lines if they use PSDNs? c) What is a POP? d) Why do you want a WAN with many POPs? (The answer is not in the text. It requires you to think about POPs.) e) If a company has seven sites, how many leased lines will it need if it uses a PSDN? f) Why are PSDNs fairly inexpensive? g) Why is the PSDN transport core drawn as a cloud?
14. a) What is the speed range of Frame Relay? b) Why is this speed range attractive? c) Why has ATM not been popular? d) What is metro Ethernet? e) For what reasons is it attractive? f) What PSDN service is growing?

Virtual Circuit Operation

Figure 10-16 shows that the PSDN switches that sit inside the cloud are connected in a mesh topology. In any mesh topology, whether partial or full, there are multiple alternative paths for frames to use to go from a source POP to a destination POP.

Selecting Best Possible Paths through Meshes

Selecting the best possible path for each frame through a PSDN mesh would be complex and, therefore, expensive. In fact, if the best possible path had to be computed for each frame at each switch along its path, PSDN switches would have to do so much work that they would be prohibitively expensive.

Virtual Circuits

Instead, most PSDNs select the best possible path between two sites *before transmission begins.* The actual transmission will flow along this path, called the virtual circuit. As Figure 10-16 shows, the switch merely makes a switching decision according to the virtual circuit number

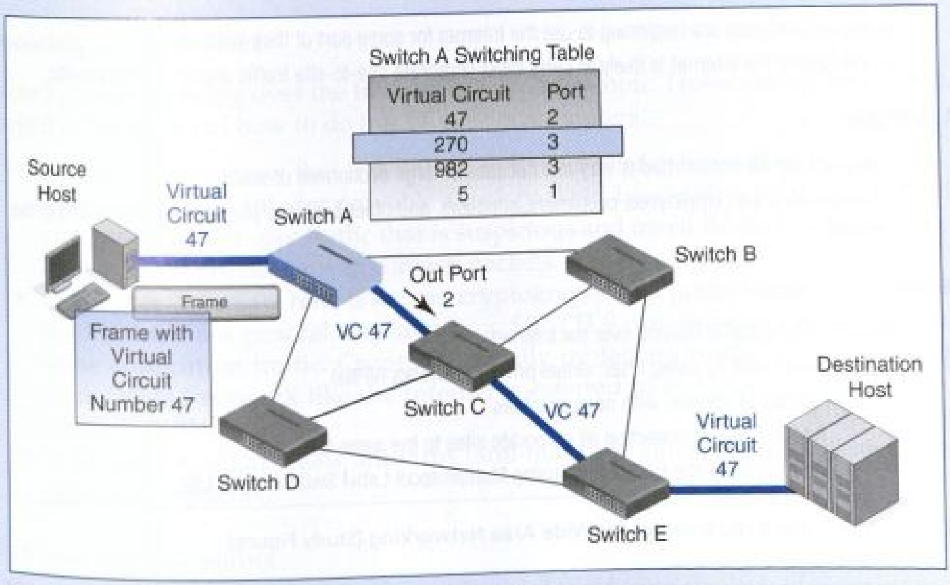


FIGURE 10-16 Virtual Circuit Operation

(continued)

in the frame's header. This virtual circuit lookup is much faster than finding the best alternative path every time a frame arrives at the switch. The "heavy work" of selecting the best alternative path is only done once, before the beginning of communication.

PSDN Frame Headers Have Virtual Circuit Numbers Rather Than Destination Addresses

Note that PSDNs that use virtual circuits do not have destination addresses in their frame headers. Rather, each frame has a virtual circuit number in its header.

This virtual circuit number in Frame Relay is the **Data Link Control Identifier** or **DLCI** (pronounced "DULL-see"). A DLCI typically is 10 bits long.[8] The switch looks up this DLCI in its virtual circuit switching table and sends the frame out through the indicated port.

Test Your Understanding

15. a) Why are virtual circuits used? b) With virtual circuits, on what does a switch base its forwarding decision when a frame arrives? c) Do PSDN frames have destination addresses or virtual circuit numbers in their headers? d) What is the name of the Frame Relay virtual circuit number? e) How long, typically, is a DLCI? f) How many virtual circuits does this number of bits allow? (The answer is not specifically in the text.)

USING THE INTERNET FOR WIDE AREA NETWORKING

The Internet is a wide area network. Many organizations are beginning to use the Internet for some of their WAN traffic. In the future, the Internet is likely to carry most corporate site-to-site traffic and other WAN traffic.

The Internet Is a Wide Area Network

- Many corporations are beginning to use the Internet for some part of their WAN traffic.
- In the future, the Internet is likely to carry most corporate site-to-site traffic and other WAN traffic.

Attractions

- The price per bit transmitted is very low because of large economies of scale
- All corporate sites, employees, customers, suppliers, and other business partners are connected to the Internet

Issues

- The security of traffic flowing over the Internet
  - Addressed by using IPsec virtual private networks (VPNs)
- Variable quality of service, with no guarantees
  - Addressed by connecting all corporate sites to the same ISP
  - Addressed by the ISP (or firm) using Multiprotocol Label Switching (MPLS)

FIGURE 10-17 Using the Internet for Wide Area Networking (Study Figure)

[8]Hosts also have true Frame Relay addresses governed by the E.164 standard. These addresses are used to set up virtual circuits. Consequently, if an equipment failure renders a virtual circuit inoperable, a new virtual circuit can be set up using the E.164 addresses.

Attractions and Issues

ATTRACTIONS For wide area networking, corporations would like to use the global Internet because of its very low price per bit transmitted compared to Public Switched Data Networks. The Internet's enormous size creates strong economies of scale. These lead to extremely low costs per bit transmitted compared to other WAN technologies. This alone is driving corporations heavily to the Internet for their WAN traffic.

Another attraction of the Internet is that nearly all of a corporation's sites are already connected to the Internet. So are its sites, employees, buyers, suppliers, and every other firm the company needs to communicate with. In contrast, networks of leased lines can only connect a corporation's sites. Public switched data networks are similarly limited to corporate use, apart from whatever other corporations are using the same PSDN the company uses. There are many PSDNs, and if a company has many other companies to work with, it would have to join many PSDNs, which would be highly uneconomical and unwieldy.

ISSUES However, there are two issues with the Internet. The first is security. The Internet teems with sniffers, hackers, malware, and other threats. These need to be addressed at least in part through cryptographic protections.

The second issue is quality of service. The Internet has always been a best-effort network. For many corporations, this is a serious issue. Companies that depend heavily on the Internet cannot tolerate its variable service quality from day to day.

Test Your Understanding

16. a) What are the two attractions of using the Internet as a WAN? b) What are the two issues that companies must overcome to do so.

Securing the Internet

Securing traffic flowing over the Internet is a complex topic. However, we have already looked at the basics of how to do this in previous chapters.

- In Chapter 3, we saw that it is critical to have a border firewall at each site to inspect incoming traffic for provable attack packets. In addition, intrusion detection systems can often spot traffic that is suspicious and merit further inspection, even if the packets are not provable attack packets.
- In Chapter 9, we saw how IPsec can cryptographically protect traffic passing over the Internet in a general way and how SSL/TLS can cryptographically protect some application traffic. Cryptographically protecting traffic traveling through an untrusted network like the Internet is referred to as having a virtual private network (VPN).
- In Chapter 3, we also saw antivirus (anti-malware) filtering. We will look at this again in Chapter 11.

Test Your Understanding

17. a) List the three protections that can be used to address the lack of security on the Internet. b) Based on what you learned in the first chapter, how can the second approach make the first approach less effective?

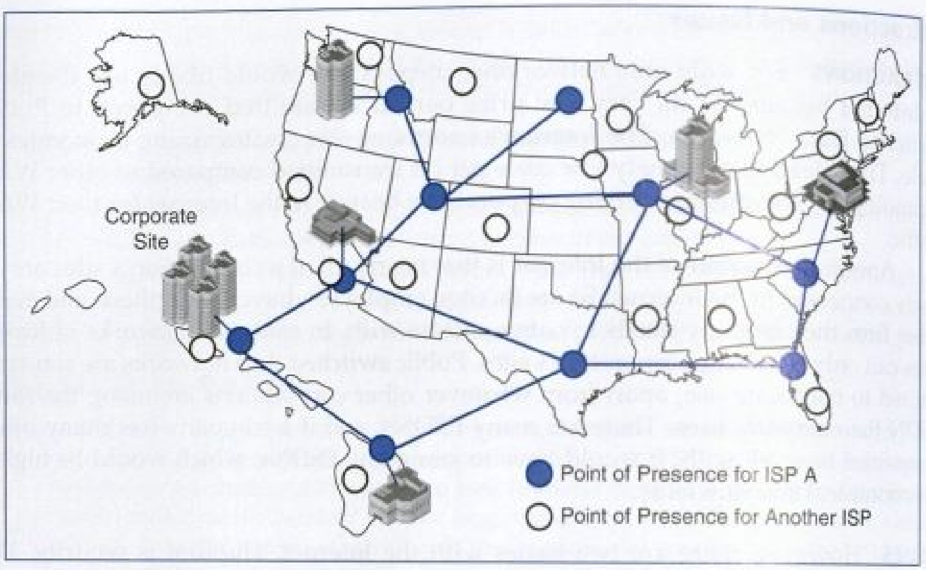


FIGURE 10-18 Connecting All Corporate Sites to a Single ISP

Using a Single ISP

An Internet service provider's network looks like a PSDN, with routers replacing switches. Many ISPs offer nationwide or even worldwide service. This means that a corporation can usually connect all of its sites to a single ISP, as indicated in Figure 10-18.

Why would they do so? The answer is that the Internet, which consists of many ISPs who cooperate to deliver packets, cannot provide quality-of-service guarantees because no one owns or manages the entire Internet. However, individual ISPs do own all of their routers and either own or control the transmission lines connecting each pair of routers. This allows them to control the quality of service they offer to anyone who communicates only through them.

In Chapter 9, we looked at Multiprotocol Label Switching (MPLS). When all routers and transmission lines are under the control of one company, the company can use MPLS to drastically cut costs and to provide quality-of-service guarantees. Most ISPs offer this, as an extra-fee service, to customers who connect all of their sites to the ISP. Connecting all sites to a single ISP that offers quality-of-service guarantees can mitigate service quality problems with the Internet.

Of course, this only provides quality-of-service improvements for traffic between corporate sites. When the firm communicates with a party connected to a different ISP, there are no guarantees.

Test Your Understanding

18. a) How may connecting all of a company's sites to a single ISP mitigate quality-of-service issues for traffic flowing over the Internet? b) What technology do ISPs use to provide quality-of-service guarantees? c) Do these guarantees work for site-to-site traffic within a firm, for traffic with other firms, or both?

CELLULAR DATA SERVICE

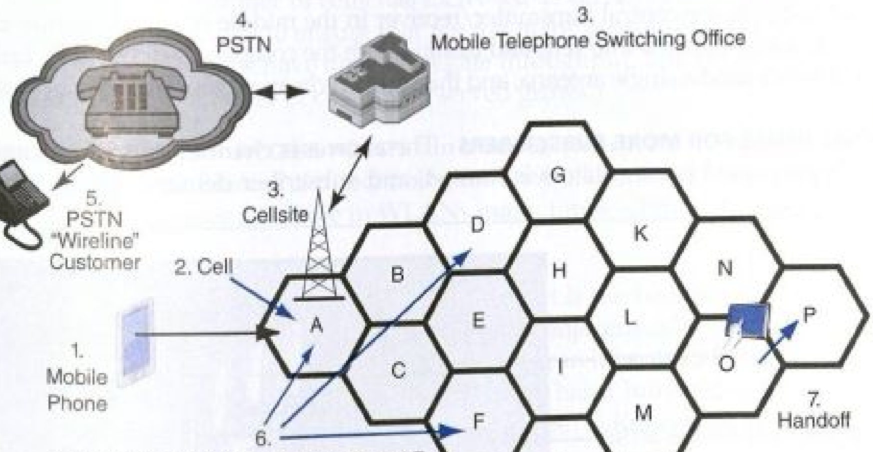
Cellular Service

Nearly everybody today is familiar with cellular telephony. In most industrialized countries, well over half of all households now have a cellular telephone.[9] Many people now have *only* a cellular telephone and no traditional *wireline* public switched telephone network phone.

Cells

CELLS AND CELLSITES Figure 10-19 shows that cellular telephony divides a metropolitan service area into smaller geographical areas called **cells.**

The user has a cellular telephone (also called a **mobile phone, mobile,** or **cellphone**). Near the middle of each cell is a **cellsite,** which contains a **transceiver** (transmitter/receiver) to receive mobile phone signals and to send signals out to the mobiles. The cellsite also supervises each mobile phone's operation (setting its power level, initiating calls, terminating calls, and so forth).



Reuse of Channel 47 in Cells A, D, and F. Allows a cellular operator to serve more customers for each authorized channel.

FIGURE 10-19 Cellular Technology

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[9]Although cellular telephony was first developed in the United States, the United States has slightly lower market penetration than most other countries. One reason is that normal telephony is inexpensive in the United States, so moving to cellular service is an expensive choice. Another reason is that when someone calls a cellular phone in the United States, the cellular owner receiving the call pays; in most other countries, the caller pays. These two factors increase the relative price of using a cellular phone compared with using a landline phone in the United States. A third factor is that U.S. cellular carriers give inadequate coverage, even in large metropolitan areas. In most other countries, dropped calls and dead spots are rare.

MOBILE TELEPHONE SWITCHING OFFICE (MTSO) All of the cellsites in a cellular system connect to a **mobile telephone switching office (MTSO)**, which connects cellular customers to one another and to wired telephone users.

The MTSO also controls what happens at each of the cellsites. It determines what to do when people move from one cell to another, including deciding which cellsite should handle the transmission when the caller wishes to place a call. (Several cellsites may hear the initial request at different loudness levels; if so, the MTSO selects a service cellsite based on signal loudness—not necessarily based on physical proximity.)

CELLSITE Figure 10-20 shows a typical small cellsite on top of a residential building. The three large "paddles" are cellular antennas. The small round antenna is a microwave antenna. Microwave technology provides point-to-point radio transmission. The antenna is pointed at a similar antenna at the mobile telephone switching office.

Test Your Understanding

19. a) In cellular technology, what is a cell? b) What is a cellsite? c) What are the two functions of the MTSO?

Why Cells?

Why not use just one central transmitter/receiver in the middle of a metropolitan area instead of dividing the area into cells and dealing with the complexity of cellsites? Early pre-cellular phones used a single antenna, and this is much cheaper than using multiple cellsites.

CHANNEL REUSE FOR MORE SUBSCRIBERS The answer is **channel reuse**. The number of channels permitted by regulators is limited, and subscriber demand is heavy. Cellular

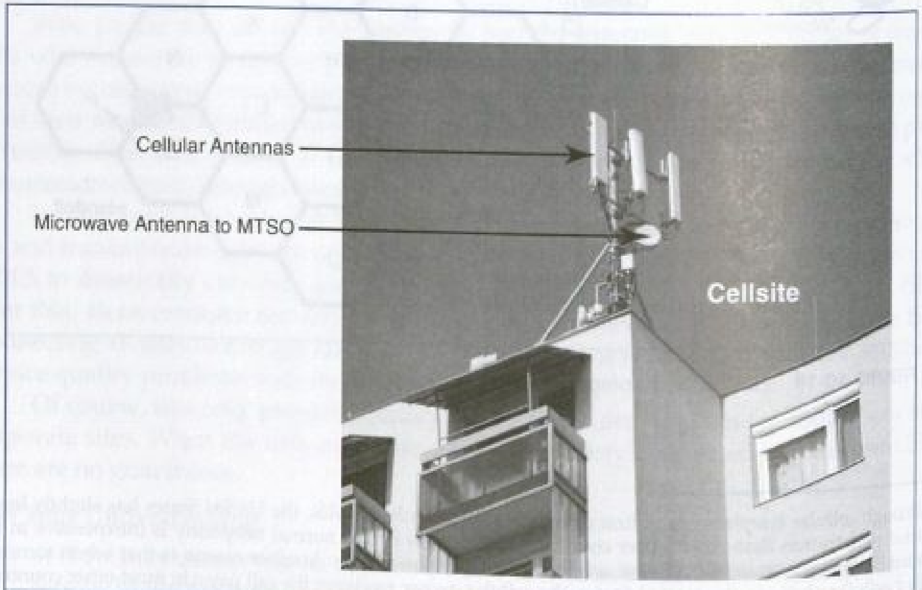

FIGURE 10-20 Cellsite for Mobile Telephones

Source: Courtesy of Raymond R. Panko

telephony uses each channel multiple times, in different cells in the network. This multiplies the effective channel capacity, allowing more subscribers to be served with the limited number of channels available.

Cellular technology is used because it provides channel reuse—the ability to use the same channel in different cells. This allows cellular systems to support more subscribers.

TRADITIONALLY, NO CHANNEL REUSE IN ADJACENT CELLS There are different mobile technologies. Some allow the use of the same channel in adjacent cells. Others do not to avoid interference from signals "leaking" beyond their cell boundaries. Figure 10-19 illustrates the situation for technology that does not permit the use of the same frequency. Suppose that you use Channel 47 in Cell A. Then you cannot use it in Cells B or C. However, you can use it in D and F. In general, the number of times you can reuse a channel is only about the number of cells, divided by seven. In other words, if you have 20 cells, you can reuse each channel only about three (20/7) times. This is a rough calculation, so "about 2.857 times" makes no sense.

How many cells are there in a city? Later, we will discuss generations of cellular technologies. In the first generation, which appeared in the early 1980s, a mid-size city like Honolulu typically had about a hundred cells. In the second generation, which began in the early 1990s, a city like Honolulu would have a hundred cells. For more recent generations, the number of cells has increased as carriers add many cells to improve channel reuse and also to ensure that not too many customers will be in a cell to allow good service. (Cellsites have high aggregate throughput, but individual throughput falls rapidly as the number of customers served grows.)

CELLS AND WIRELESS LAN ACCESS POINTS In a sense, enterprise wireless LANs with many access points are like cellular technologies. They allow users to employ the limited number of frequencies available in WLANs many times within a building.

Test Your Understanding

20. a) Why does cellular telephony use cells? b) What is the benefit of channel reuse? c) In Figure 10-19, channels cannot be reused in adjacent cells, and Channel 47 is being used in Cells A, D, and F. What other cells can it be used in? d) Continuing, how many times is Channel 47 used? e) If a city has a hundred cells, how many times can a channel be used without channel reuse? f) Repeat the last two parts if channel reuse is possible in adjacent cells.

Basic Logic

The same channel can be used in multiple sites

This allows subscribers to use the same channel if they are in different sites

Consequently, the carrier can serve more customers per channel

Example

Without channel reuse: 500 channels, so only 500 simultaneous subscribers can be served

Channel reuse factor (varies): 20

Number of simultaneous subscribers: 10,000

FIGURE 10-21 Cells, Channel Reuse, and Number of Subscribers (Study Figure)

	802.11 WLANs	Cellular Telephony
Relationship	*Handoff* and *roaming* mean the *same thing*	*Handoff* and *roaming* mean *different things*
Handoffs (means the same in both)	Wireless host travels between access points in an organization	Mobile phone travels between cellsites in the *same* cellular system
Roaming (means different things)	Wireless host travels between access points in an organization	Mobile phone travels to a *different* cellular system

FIGURE 10-22 Handoff and Roaming in 802.11 and Cellular Networks

Handoffs versus Roaming

HANDOFFS If a subscriber moves from one cell to another within a city, the MTSO will implement a **handoff** from one cellsite to another. For instance, Figure 10-19 shows a handoff from Cell O to Cell P. The mobile phone will change its sending and receiving channels during the handoff, but this occurs too rapidly for users to notice.

ROAMING In contrast, if a subscriber leaves a metropolitan cellular system and goes to another city or country, this is called **roaming**. Roaming requires the destination cellular system to be technologically compatible with the subscriber's mobile. It also requires administration permission from the destination cellular system. Roaming is as much a business and administrative problem as it is a technical problem.

In cellular telephony, handoffs occur when a subscriber moves between cells in a local cellular system. Roaming occurs when a subscriber moves between cellular systems in different cities or countries.

HANDOFF AND ROAMING IN 802.11 WLANS Recall from Chapter 6 that *handoff* and *roaming* mean the same thing in 802.11 WLANs. They both mean moving from one access point to another within the same WLAN. In other words, the terms *handoff* and *roaming* are used differently in cellular telephony from the way they are used in WLANs.[10] Figure 10-22 shows how the terms *handoff* and *roaming* are used differently in WLANs and cellular telephony.

Test Your Understanding

21. a) Distinguish between handoffs and roaming in cellular telephony. b) Distinguish between handoffs and roaming in 802.11 wireless LANs.

Using Cellular Telephony for Data Transmission

SMARTPHONES Originally, mobile phones were just that—telephones that you could carry with you. Today, however, many new mobile phones are **smartphones** that do far more. Most have cameras, and some even have video cameras. Most importantly, all have web browsers to support web access and can download streaming video.

[10]Wouldn't it be nice if there were a networking terminology court that could punish this sort of thing?

Generation 1 (1G)

- Began in the early 1980s
- Analog signaling
- Data transmission difficult, limited to 10 kbps

Generation 2 (2G)

- Began in the early 1990s
- Digital signaling
- Data transmission difficult, limited to 10 kbps to 20 kbps

Generation 3 (3G)

- Began around 2001
- Designed to give at least 2 Mbps download speeds to fixed customers
- Designed to give at least 384 kbps download speeds to moving customers
- Throughput lower in practice: 100 kbps to 500 kbps initially
- Created an explosion in data use
- Web surfing, etc., low-quality streaming video, etc.

Generation 4 (4G)

- Began around 2010
- Performance
  - Designed to give at least 1 Gbps download speeds to fixed customers
  - Designed to give at least 200 Mbps download speeds to fixed customers
  - Throughput lower in practice but generally equal to wired Internet
  - Needed for high-definition video
- Technology
  - MIMO
  - Bandwidth of 5 to 20 MHz
  - Mandatory to use IP as the transport mechanism
  - Strong quality-of-service management

Moving to 4G

- The situation today
  - HSPA+: rated at 42 Mbps downstream but typically about 7 Mbps down and 1 Mbps up
  - LTE (Long-Term Evolution): generally provides 10 Mbps down and 6 Mbps up
  - WiMAX: Similar to LTE, but fading in the marketplace
  - Overall, LTE is somewhat better, especially in the best systems
  - However, HSPA+ has no growth potential
- LTE and LTE Advanced
  - LTE does not offer speeds anywhere near the 4G requirements
  - However, it will, in an evolutionary form called LTE Advanced
  - The ITU allows LTE vendors to call their systems 4G anyway, because LTE is a *precursor* 4G technology
  - HPSA+ is not a precursor technology to 4G so is only 3G
- Carriers are converging on LTE and LTE advanced

FIGURE 10-23 Generations of Cellular Service (Study Figure)

Smartphones are indicative of a trend in cellular service from voice service to voice and data service. Future cellular technologies will primarily be data transmission technology, with voice transmission being a secondary consideration. Applications like web browsing and streaming video require much higher transmission speeds than voice calls, and cellular vendors have been responding with ever-faster service.

FIRST-GENERATION (1G) CELLULAR The early cellular telephones, which appeared in the early 1980s, could only send and receive data at extremely low speeds and with considerable difficulty. **First-generation (1G)** cellular technology used analog radio transmission and could only send and receive data at speeds below 10 kbps—far slower than even a telephone modem.

SECOND-GENERATION (2G) CELLULAR **Second-generation** (2G) technology appeared in the early 1990s. It introduced all-digital transmission, but it too was limited to a painfully slow 10 kbps to 20 kbps. This was inadequate for web access, but it was good enough to introduce texting and the exchange of low-quality photographs.

THIRD-GENERATION (3G) CELLULAR **Third-generation (3G)** technology arrived around the year 2001. Third-generation services were designed to give download speeds of 2 Mbps to stationary customers and 384 kbps to moving customers in cars and busses. (Motion causes serious problems for reading complex radio signals.) Initially, these services only gave speeds of 100 kbps to 500 kbps. This was well below the standard's requirement, but it was a huge leap over 2G speeds. It created an explosion in data use, including web surfing, limited-quality streaming video, file synchronization, and other transmission-intensive tasks. Phones were quickly joined by laptop computers and by eventually tablet computers as consumer devices. Cellular service was not just for phones anymore.

FOURTH-GENERATION (4G) CELLULAR The next step will be **fourth-generation (4G)** cellular technology. This new generation will be required to give at least 1 Gbps download speeds to stationary users and 200 Mbps to moving customers. This will make wireless as good as or better than wired Internet access. This will be sufficient for heavy web downloading and high-definition streaming video.

Fourth-generation cellular will bring advances in underlying technology. Transmission will be entirely packet-switched using IP. Given the dearth of IPv4 addresses, carriers are specifying that IPv6 must be used. Cellsites and mobiles will use MIMO. Fourth-generation systems will offer scalable bandwidth of 5 to 20 MHz, allowing carriers to provide extremely high speeds or still-high but more economical speeds. There will also be strong quality-of-service management. In general, 4G will be a fully "grown up" technology.

TODAY: CLOSING THE GAP BETWEEN 3G AND 4G The gap between 3G and 4G is very large, but 3G systems soon began offering speeds much higher than the 3G requirements. As of 2012, three services are dominant.

- **HSPA+** (High Speed Packet Access plus) has a rated speed of 42 Mbps in the best systems (half that in most). Its actual typical speed in the best systems is 7 Mbps down and 1 Mbps up.

- **LTE** (Long-Term Evolution) provides 10 Mbps downstream in good systems and 6 Mbps up.
- **WiMAX** provides service speeds similar to those of LTE. However, WiMAX is falling out of favor with carriers, and most carriers that use it are in the process of switching to LTE. Consequently, we will not discuss it further.

Overall, the two main systems today are HSPA+ and LTE. They are fairly comparable in performance, although LTE is better in most systems and sharply better in the best. In any case, HSPA+ is a dead end for the future with no growth potential. Most HSPA+ vendors are switching to LTE.

PREPARING FOR 4G Although LTE does not come near ITU specifications for speed, it does embody most of the technology required for 4G systems. It will be extended until it finally reaches full 4G service, at which time it will be called **LTE Advanced**. In 2010, under intense vendor pressure, the ITU allowed systems that are precursors of 4G technology to call themselves 4G. This applies to LTE, which can therefore be called a 4G service. It now appears that nearly all carriers will switch to LTE and LTE Advanced in the near future.

Test Your Understanding

22. a) List the required download speeds for each of the four generations of service. b) With what generation did web surfing become attractive? c) Compare 3G required download speeds with initial 3G actual throughput. d) What throughput do the best 3G services provide today? e) What applications that are difficult or impossible to use with 3G will be easy to use in 4G? f) What are the technical advances required in 4G systems? g) What 4G technology is likely to dominate in the future?
23. a) What generation is HSPA+? b) What generation is LTE in terms of current speed? c) What generation does the ITU allow LTE to be called? Why? d) What is the designation of the version of LTE that will fully meet 4G performance requirements? e) Toward what standards are carriers converging?

Lies, Damned Lies, and Mobile Service Speeds

The speeds we have been discussing were "typical" speeds. However, every 3G user knows that throughputs vary widely by time of day and physical location. In fact, they vary because of several things.

- First, they vary by technology. We have just seen that LTE service is usually faster than HSPA+ service, but cellular technologies have many design options, and these can have a major impact on speed. For instance, most HSPA+ services use 5 MHz channels, while the best use 10 MHz channels. In some technologies, MIMO is possible but optional. Carriers select their specific technology options with an eye toward trade-offs between cost and service speed.
- Second, as noted earlier, cellular throughput is shared by the customers using a cell. As the number of customers increases, service speeds drop roughly linearly with the number of customers. In addition, the presence of even a few very heavy users such as people watching streaming video can reduce individual throughput substantially. The carrier can minimize overcrowding having more cellsites, but this is more expensive for the carrier.

- Third, throughput varies by time of day. During the daytime, there are periods of heavier and lighter use. For example, use tends to increase during commuting time. In addition, use declines an night. Lower use means faster speeds.
- Fourth, throughput varies by location. Not surprisingly, speed are higher at the center of cells and lower at the cells' edges. There may also be buildings or terrain obstructions in certain locations. More subtly, the carrier may have too few cell-sites in some locations, causing overloads that reduce speed.
- Finally, regardless of what the carrier does, the customer cannot have better service than his or her smartphone allows. Most older smartphones cannot handle the latest carrier offerings. In addition, some smartphones are better engineered than others. Better mobiles give faster service than more poorly engineered mobiles, even if they have the same technology and options. Overall, users receive the lower of their carrier technology or their cellphone technology.

Actual Customer Throughput Depends on Many Things

Technology Specifics

Standards have many options such as bandwidth per channel

So two carriers using the same basic standard may offer rather different actual speeds

Sharing

Channels are shared

Individual throughput is only a fraction of total throughput

Throughput tends to fall linearly with the number of users

Even a few heavy users such as HTDV viewers can reduce throughput for everybody

Time of Day

There are fewer customers at night, so throughput to individuals tends to be higher then

Commuting times can congest the carrier system

Location

Greater distance from the cell tower reduces throughput

Buildings and terrain obstacles weaken the signal, causing dropbacks to lower speeds

The carrier may have too few cellsites in an area

Customer Smartphone Limits

The customer's smartphone may not be able to use the carrier's best technology

Customers receive the lowest of their carrier technology and the cellphone technology

Some smartphones are simply faster than others for a given standard

FIGURE 10-24 Lies, Damned Lies, and Service Speeds (Study Figure)

Test Your Understanding

24. a) List the general categories of conditions that may limit user throughput. b) Which can the carrier do something about? c) What can the vendor do for each of these? d) What category is beyond the vendor's control?

Cellular–Wi-Fi Convergence

We looked at cellular in this chapter and Wi-Fi in Chapters 6 and 7. This makes sense because traditionally there has been a simple dichotomy. Wi-Fi 802.11 systems were used as wired LAN extensions for mobile computers while cellular service was used for telephony and metropolitan area data service. However, this situation is changing. We are seeing increasing convergence between cellular and 802.11 service for data and voice calls.

DATA SERVICE For laptop computers, wireless data service has traditionally meant Wi-Fi. Although a small fraction of users equipped their laptops with cellular service modems, this was too much of a rarity to discuss. For laptops, the main use of wireless technology was to connect the user to the corporate LAN or a public hot spot.

Tablets and smartphones changed this. Although many tablets are still sold with Wi-Fi access only, a large fraction already has cellular service as well. To avoid going over their cellular rate limit, users use Wi-Fi as much as possible. In doing so, they get another benefit. Wi-Fi is much faster than cellular data service today. While low-end "feature phones" often continue to offer data only through cellular carriers, most

Data Service

- Laptops
- Smartphones, tablets
- Always provide Wi-Fi access
- Many also offer cellular data access
- Wi-Fi access currently offers much higher speeds
- Cellular access can be used when no accessible Wi-Fi access point is available

Telephone Service

- Traditionally only offered cellular calling
- Some can now offload calling to a Wi-Fi network
- This helps the caller by lowering costs
- This can help the cellular carrier if the customer has a flat-rate plan
- Customers can already receive this benefit if they use Skype or a similar service

Using a Smartphone as an Access Point

- To share the smartphone user's bandwidth

FIGURE 10-25 Cellular–Wi-Fi Convergence (Study Figure) smartphones have had 802.11 access added. In addition, both tablets and smartphones that can use Wi-Fi notify the user if a Wi-Fi access point is available and whether it is secured. Now laptops—especially highly portable laptops such as ultrabooks—are also beginning to offer integral cellular data service.

VOICE CALLING SERVICE For voice calling, 802.11–cellular convergence has been slower to emerge. For voice calling, a mobile phone would normally use cellular service. However, if the caller was in range of a Wi-Fi access point, the phone would ask the caller if he or she preferred to use the WLAN to place the call. Many callers would welcome this as a way not to use up his or her daytime minutes for calls. In turn, the cellular provider might prefer to offload the customer's traffic from its expensive air network to the less expensive Internet for the path between the customer and the MTSO. Unfortunately, convergence for voice calls is still rare.

Of course, a mobile phone user could install Skype or a similar service on his or her smartphone. If the smartphone has Wi-Fi capabilities, as most do today, then he or she could place a Skype call when near an accessible access point.

USING A SMARTPHONE AS AN ACCESS POINT A third pattern in the convergence of 802.11 and cellular service is that some smartphones can be used as access points. This way, if a user has a laptop or other device that only has Wi-Fi capability, the user can access the Internet when no physical access points are nearby. In fact, several users might share the smartphone acting as an access point. With today's cellular speeds, this arrangement is not too exciting. However, as cellular speeds increase, smartphones that can act as access points will be more attractive.

One drawback of using smartphones as access points is that most carriers charge an additional monthly or usage fees for users doing this. This makes sense when groups share the access because it increases carrier traffic. However, this is a strong impediment to use.

Test Your Understanding

25. a) Why is it attractive to a laptop user to have WLAN access? (This is a simple question.) b) Why is it attractive for a laptop user to have cellular data access? c) Why is it good for users that some smartphones can connect to WLAN access points? d) Why is it good for carriers? e) Why is it attractive to users that some smartphones can act as access points? f) Why is it attractive for a smartphone to act as an access point? g) Why should it be more attractive in the future? h) What is unattractive using a smartphone as an access point today?

VIRTUAL WIDE AREA NETWORKS (VIRTUAL WANs)

An important development in WAN management has been the growing availability and sophistication of virtual WAN software. Most companies today have multiple WAN technology components—leased line connections, PSDNs of various types, Internet WAN transmission, cellular services, and so forth. They also deal with multiple types of access lines.

Traditionally, each of these components has been managed separately. However, traffic between two hosts may pass through multiple components. This makes it dif-

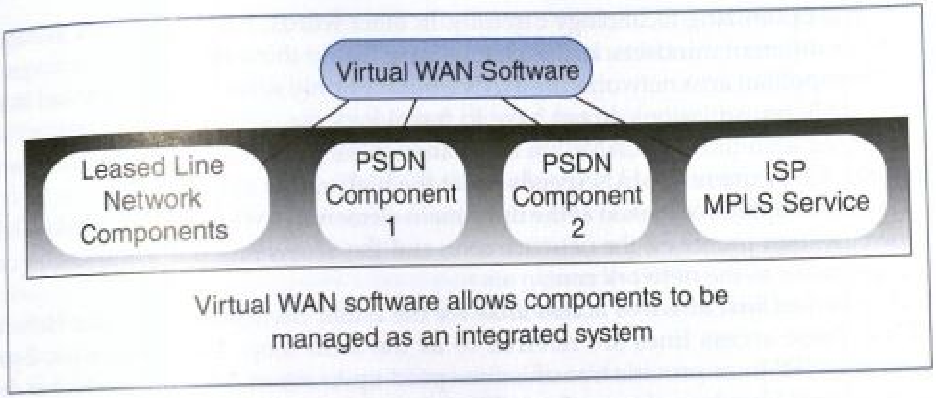

FIGURE 10-26 Virtual WAN

ficult to manage overall performance and efficiency. Optimization is nearly impossible, and it is very difficult to locate the causes of poor transmission quality.

Figure 10-26 shows that virtual WAN technology adds **virtual WAN software** to the corporate network. This software provides overall management of the individual WAN components so that they act as a complete system. This allows overall performance management in terms of efficiency and quality of service.

Once virtual WAN system is in place, it is also relatively easy to change. Individual technology components can be added or dropped with relative ease, and in many systems, the effect of an add or drop can be simulated before the expense of making technological changes is made.

Test Your Understanding

26. a) What technical problem does virtual WAN technology address? b) What must be added to create a corporate virtual WAN? c) What benefits can a virtual WAN system bring?

CONCLUSION

Synopsis

In Chapters 5, 6, and 7, we looked at local area networks. The technology picture was fairly clean. Ethernet dominates for wired LANs, and 802.11 dominates for wireless LANs. We also saw a few niche technologies, such as Bluetooth for personal area networks, but the core technology picture was quite simple.

Now we have switched to wide area networks, which take transmission beyond the customer premises. For WANs, the situation is anything but simple. Most corporations have multiple WAN technologies that must work in an integrated way. In this chapter, we stepped through these technologies, beginning with wired technologies and moving to cellular data transmission in the wireless realm.

LAN transmission distances are short, so the cost per bit transmitted is low. Consequently, companies can afford high transmission speeds and optimization is not an overwhelming concern. In WAN transmission, however, the cost per bit transmitted is relatively high, so companies need to be more frugal, living with lower transmission speeds and optimizing technology carefully. In other words, LAN and WAN managers must have different mindsets. In this chapter, you had to think like a WAN manager.

Metropolitan area networks are WANs, but they only serve a single city and its environs. MAN transmissions do not have to travel very far, so costs per bit transmitted, while higher than those in LANs, are lower than those in WANs that span countries or the world. Consequently, MAN speeds are at the high end of WAN speeds.

In this chapter, we looked at the three main elements of wide area networks. These are the customer premises, the network core, and the access link that connects the customer premises to the network core.

We looked first at wired access links for the Public Switched Telephone Network (PSTN). These access lines are referred to as the local loop. For businesses, 2-pair data-grade UTP lines provide transmission speed up to about 2 Mbps. For higher data speeds, optical fiber is necessary. Typically, the telephone company must run new lines to businesses needing service, and this makes these lines very expensive, leading to high service prices.

Businesses normally receive leased line service over their access lines. Leased lines are high-speed point-to-point lines that are always on. In the United States and Canada, T1 lines have a speed of 1.544 Mbps. In Europe, E1 lines are 2.048 Mbps. T1 and E1 leased lines, fractional T1 and E1 leased lines, and bonded T1 and E1 leased lines dominate leased line usage today. However, companies that need faster leased lines can get them. Above 50 Mbps, leased lines are governed by the SONET/SDH standards. These standards extend to several gigabits per second.

For the residential local loop, 1-pair voice-grade UTP is the norm. These lines were not designed to carry data, but engineers found how to do so. When these lines carry data, they are called digital subscriber lines (DSL lines). Residential customers normally receive asymmetric DSL, with higher downstream speeds than upstream speeds. There is no need to pull new lines to the customer premises. This allows less expensive service. Still, 1-pair VG UTP is not a good data transmission media, and carriers are beginning to serve residential customers with fiber to the home. Businesses also use DSL lines, but they normally receive symmetric speeds and quality-of-service guarantees. These guarantees make business DSL service more expensive than residential DSL service.

In the United States and a few other countries, cable television is widespread. Cable modem service permits the transmission of data over cable television connections. Cable television uses a mixture of optical fiber and coaxial cable, with the final runs to the home consisting of thin coaxial cable. Cable television is a competitor for DSL in most communities. Typically speaking, cable offers somewhat higher throughput at somewhat higher prices.

Access lines connect a company site to the network core at locations called points of presence (POPs). Many companies connect their sites via leased lines, using a router at each site to control the transmission. In addition, carriers offer public switched data networks (PSDNs), which essentially have the customer outsource the work of operating the network core. Customers merely run an access line from each site to the nearest POP. Only metropolitan area Ethernet, which moves Ethernet beyond the LAN, is growing rapidly in use among PSDN technologies.

If you read the box, "Virtual Circuit Operation," you saw how PSDN vendors reduce the work that switches in the network core have to do. These switches are connected in a mesh. This creates alternative routes. As we saw in Chapter 8, this makes routers do a great deal of work for each arriving packet. In virtual circuit operation, the network first establishes a single best path for all frames between two points. Then, when transmission begins, all frames follow that one path.

In the past, leased line networks and PSDNs dominated wide area networking. However, companies are now moving toward use of the Internet as their wide area networking technology. Economies of scale make the Internet inexpensive per bit transmitted. In addition, nearly all suppliers and customers are connected to the Internet.

Unfortunately, the Internet itself has no security. Companies that need to transmit securely across the Internet create virtual private networks (VPNs) using IPsec or SSL/TLS. They also use border firewalls, intrusion detection systems, and antivirus (anti-malware) protection.

The Internet also has service quality issues. To address service quality, a company can connect all sites to a single ISP. The ISP can use multiprotocol label switching (MPLS) to control traffic quality and provide quality-of-service guarantees for traffic between corporate sites.

For metropolitan area networks, companies can turn to wireless transmission. Today, that primarily means sending data over cellular networks. In cellular technology, a city is divided into many geographical cells. Each cell has a cellsite with an antenna and radio equipment to communicate with customers within the site. Cellular channels can be reused in cells that are not too near, increasing the number of possible subscribers in a city. (In an analogous way, the many access points in a large wireless LANs permit channel reuse in different areas and therefore service to more 802.11 users.)

One difference between cellular and Wi-Fi networks is the distinction between handoff and roaming. In 802.11, both terms mean moving to another access point in the same wireless network. In cellular terminology, handoff is moving from one cell to another within a city, while roaming is going to a different city.

Cellular technology has gone through three generations of technology and is entering a fourth. Today, service with HSPA+ and LTE can reach 5 to 10 Mbps in downstream speed, although speeds are frequently lower. Normally, LTE is faster. HSPA+ is a 3G technology. LTE only offers 3G speed, but because it is a precursor to LTE Advanced technology, which is a full 4G technology, it may be referred to as 4G. Full 4G service will bring up to a gigabit per second of download speed, although LTE Advanced will undoubtedly offer far lower speeds when it first appears. Cellular throughput for individuals, of course, is limited by many factors, such as the number of simultaneous users in a cell and limits in both carrier and smartphone technology. As they say in television advertisements, your results will vary.

Today, cellular and 802.11 services are quite separate, but they are beginning to converge. Already, many tablets and smartphones can use an access point when they are near one, instead of using up their cellular data limits. They also receive faster transmission speeds. In addition, for voice calls, it may soon be possible to send those through an access point instead of using up cellular calling minutes. In addition, a smartphone using cellular data service can act as an access point to serve one or more 802.11 devices.

At the beginning of this synopsis, we noted that there are many WAN technologies and that most companies use several to serve their needs. A recent trend is the creation of virtual WAN (VWAN) software that manages all WAN transmission as a single integrated system. Even when the technology for a particular need is changed, the VWAN software continues as it has been doing.

END-OF-CHAPTER QUESTIONS

Thought Questions

1. Why was this chapter so difficult?

Hands-On

1. If you have a smartphone, download an app to tell your data transmission throughput. What did you find?

Perspective Questions

1. What was the most surprising thing in this chapter for you?
2. What was the most difficult part of this chapter for you?

11 NETWORKED APPLICATIONS

LEARNING OBJECTIVES

By the end of this chapter, you should be able to:

- Describe the concept and importance of networked applications.
- Describe how taking over an application can give an attacker the ability to control the computer.
- Describe electronic mail standards and security.
- Describe voice over IP (VoIP) operation and standards.
- Describe the World Wide Web in terms of standards and explain how a webpage with text, graphics, and other elements is downloaded.
- Describe cloud computing (including Software as a Service, utility computing, and virtualization, as well as security issues).
- Describe Service-Oriented Architectures, with an emphasis on Web services and SOAP.
- Explain peer-to-peer (P2P) computing (including BitTorrent, Skype, and SETI@home), which, paradoxically, normally uses servers for part of the work.

PAPA MURPHY'S

Papa Murphy's Take 'N' Bake is one of the largest pizza companies in the United States, having more than 1,150 stores in more than 30 states.[1] Many of its stores are franchised. While the company has enjoyed success and expansion, it also faced a problem: how could it create a centralized management system for all of its franchises?

Rather than designing, building, and hosting its own management system, Papa Murphy's decided to outsource the job to Salesforce, a company that provides cloud computing services. According to Papa Murphy's Director of Business Technology, Brian Fisher, "It took less than three months to build what would have taken a year on other platforms."[2] In addition to its quick implementation, the new franchise management system also brought the benefit of mobile access. Since the system is run as an online application, employees can access the information they need from anywhere, via mobile devices. Also, Papa Murphy's is freed from managing the system and the servers it runs on; these IT jobs are taken care of by Salesforce.[3]

[1] www.papamurphys.com.
[2] "5 Reasons CIOs are Adopting Cloud Computing in 2009." Salesforce.com white paper. Salesforce.com.
[3] http://www.salesforce.com/customers/distribution-retail/papamurphys.jsp, www.salesforce.com/customers/distribution-retail/papamurphys.jsp.