Chapter 10

Carrier Wide Area Networks (WANs)

LEARNING OBJECTIVES

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

- Contrast LANs and WANs in terms of technology, diversity, economics, speed, and need for optimization.
- Describe the three carrier WAN components and the two typical business uses for carrier WANs.
- Describe how the telephone system is organized, including its hierarchy of switches. (Most carrier WAN networks use the public switched telephone network for some or all of their communication.)
- Explain and compare the ADSL and cable modem residential Internet access services.
- Discuss trends in cellular data transmission speeds.
- Distinguish between access lines and leased lines. Select a leased line for a given application speed requirement. Explain how companies use leased lines in Internet access.
- Explain how networks of leased lines, public switched data networks (PSDNs), and MPLS can be used for site-to-site communication in a firm. Discuss the relative advantages and disadvantages of each.
- Explain carrier Ethernet and MPLS in some detail.
- Explain the capabilities of WAN optimization devices.
- Explain key concepts in software-defined networking.

Albert Einstein was reportedly asked how the telegraph worked. He said it was like a very long cat with its head in one city and its tail in another. When you pull on the tail in one city, it howls in the other city. Wireless transmission is the exactly the same but without the cat.

LANs AND WANs (AND MANs)

One of the most fundamental distinctions in networking is the one between local area networks (LANs) and wide area networks (WANs). Figure 10-1 shows how these two types of networks differ. We will also see how they compare to intermediate-distance networks called metropolitan area networks (MANs).

LANs versus MANs and WANs

On and Off the Customer Premises Some authors base the difference between LANs and WANs on physical distance. For instance, some say that the dividing line between LANs and WANs is one mile or one kilometer. However, the real distinction appears to be that **local area networks (LANs)** exist within a company's site, while **wide area networks (WANs)** connect different sites within an organization or between organizations.

Category	Local Area Network	Metropolitan Area Network	Wide Area Network
Abbreviation	LAN	MAN	WAN
Service Area	*On customer premises* (home, apartment, office, building, campus, etc.)	*Between sites* in a metropolitan area. (city and its suburbs) A Type of WAN	*Between sites* in a region, a country, or around the world.
Implementation	Self	Carrier	Carrier
Ability to Choose Technology	High	Low	Low
Who Manages the Network?	Self	Carrier	Carrier
Price	Highly related to cost	Based on pricing strategy. Highly unpredictable	Based on pricing strategy. Highly unpredictable
Cost per Bit Transmitted	Low	Medium	High
Typical Transmission Speed	1 Gbps and more	10 Mbps to 1 Gbps	1 to 100 Mbps
Diversity of Technologies	Low: 802.3 and 802.11	Medium	High

FIGURE 10-1 LANs versus WANs (and MANs)

Local area networks (LANs) exist within a company's site, while wide area networks (WANs) connect different sites within an organization or between organizations.

For LANs, then, the company owns the property and can do anything it wants. It can choose any LAN technology it wishes, and it can implement it any way it wishes.

There is no such freedom for WANs. A company cannot legally lay wires between two of its sites. (Consider how your neighbors would feel if you started laying wires across their yards.) The government gives certain companies called **carriers**[1] permissions (**rights of way**) to lay wires in public areas and offer service to customers. In return, carriers are subject to government regulation.

When you deal with carriers, you can only get the services they offer, and you must pay their prices. Although there may be multiple carriers in an area, the total number of service choices is likely to be quite limited.

On the positive side, you do not need to hire and maintain a large staff to deal with WANs because carriers handle nearly all of the details. In contrast, if you install a LAN, you also have to maintain it. As the old saying goes, anything you own ends up owning you.

Economics Another fundamental difference between LANs and WANs stems from economics. You know that if you place a long-distance call, this will cost more than a local call. An international call will cost even more. As distance increases, the price of transmission increases. The cost per bit transmitted therefore is higher in WANs than in LANs.

You know from basic economics that as unit price increases, fewer units are demanded. Or, in normal English, when the price for an item increases, you usually buy less of it. Consequently, companies tend to purchase lower-speed WAN links than LAN links. Typically, LANs bring 1 Gbps to each desktop. WAN speeds more typically vary from 1 Mbps to about 100 Mbps. MAN speeds fall between the two.

In addition, companies spend more time optimizing their expensive WAN traffic than their relatively inexpensive LAN traffic. For example, companies may be somewhat tolerant of looking at YouTube videos on LANs, but they usually clamp down on this type of information on their WAN links. They also tend to compress data before sending across a WAN so that it can be handled with a lower-capacity WAN link.

Another aspect of economics is pricing. For LANs, you have a good idea of what installing and using a wired or wireless LAN will cost you. In carrier WANs, however, the price of services is only somewhat related to costs. Carriers change their prices

[1] Carriers were originally called common carriers. The name reflected the fact that these carriers were required by law to provide service to anyone or any organization requesting services. Regulation was originally instituted in the railroad industry because many companies that owned railroads also owned other companies and refused to provide services to competitors of these other companies.

strategically, for example, to encourage users to switch from one service to another. Consequently, price changes for WANs are less predictable than they are for customer-owned LAN technology.

Technologies Another difference between LANs and WANs is that LAN technology has largely settled on two related families of standards—Ethernet (802.3) for wired LANs and Wi-Fi (802.11) for wireless LANs. As we saw in Chapter 6, 802.11 WLANs are primarily used today to extend corporate Ethernet wired LANs to mobile devices.

The technological situation is more complex in wide area networking. Multiple technologies are used, including leased line data networks, public switched data networks, and wireless networks. Within these categories are multiple options. Furthermore, WAN technologies are at different stages in their life cycles, with some increasing rapidly in use and others declining.

Test Your Understanding

1. a) Distinguish between LANs and WANs. b) What are rights of way? c) What are carriers? d) Why do you have more flexibility with LAN service than with WAN service? Why?
2. a) Why are typical WAN speeds slower than typical LAN speeds? Give a clear and complete argument. b) Why are future WAN prices difficult to predict? c) Compare the diversity of technologies in LANs and WANs.

Other Aspects of WANs

Metropolitan Area Networks (MANs) All WANs connect sites between customer premises and cost more per bit transmitted than LANs. However, WANs differ considerably in the distances they span. Some are international and others span single nations. At the small end, some WANs are **metropolitan area networks (MANs)**, which connect sites in a city and its suburbs.

Although MANs are WANs, their relatively short distance span means that the cost per bit transmitted is lower than it is in national and international WANs. Consequently, typical transmission speeds are faster. If you have a smartphone or tablet with 3G or 4G cellular access, then you already use a MAN. Cellular networks almost always span a single MAN or even a single city. However, we will see that wired MANs are important for corporations because site-to-site traffic is large and is more efficiently transmitted over wires.

Single Networks versus Internets Some people think that LANs are single networks, while WANs are internets. However, as Figure 10-2 shows, that is not the case. Small LANs usually will be single networks, but a larger LAN, such as one on a university campus, is likely to be a local internet.

For WANs, there can also be single networks or internets. Of course, the global Internet is a WAN, and we will see that many companies use it extensively for data transmission among their premises. We will also see that companies also use wide area single switched networks. These are large networks, but they are still switched single networks.

Technology	LAN	WAN
Can be a single switched or wireless network?	Yes	Yes
Can be an internet?	Yes	Yes

FIGURE 10-2 Single Networks versus Internets

Test Your Understanding

3. a) Why do MANs have higher typical speeds than broader-scope WANs? b) Are LANs single networks or internets? c) Are WANs single networks or internets? d) Is the Internet a WAN?

Carrier WAN Components and Business Uses

Figure 10-3 shows that there are three basic components to carrier wide area networks:

- First comes the customer premises with the **customer premises equipment (CPE)** needed to connect to the WAN. With mobile devices, your customer premises is wherever you are, and your mobile device is your customer premises equipment. For connecting corporate sites to wired access lines, the customer premises equipment is likely to be a border router.
- **Access links** connect the customer premises to the network core of the WAN. We will focus on wired access links because they are so prevalent. Later in the chapter, we will look at wireless access links.
- The **network core** connects access links to other access links. Again, we show it as a cloud because customers do not have to understand how it works in detail. The carrier takes care of the network core. Of course, as an IT professional, you have to understand what happens inside the cloud, and we will spend time looking at network core technologies.

The Internet connects everyone to everyone else. In contrast, **carrier WANs** primarily see two business uses. As Figure 10-3 shows, companies use carrier WANs to

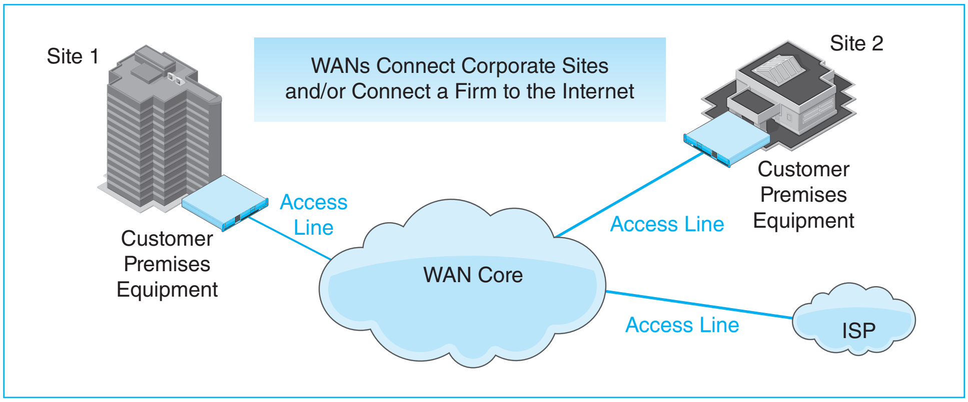

FIGURE 10-3 Basic WAN Components and Business Uses

link their sites to the Internet and to connect their own sites together. Carrier WANs are not frequently used to connect multiple companies together because all must be customers of the same carrier WAN. When multiple companies connect with a carrier WAN, it is generally because they need more security than the Internet provides.

Test Your Understanding

4. a) List the three basic components of wide area networks. b) Are access links wired or wireless? c) What is CPE? d) What are the two common business uses for carrier WANs? e) Distinguish between the Internet and carrier WANs. f) Why are carrier WANs not often used to link multiple firms together?

The Telephone System

The worldwide telephone system was created by voice. However, telephone carriers now provide data service to residential and business customers. In addition, other WAN carrier providers typically find it attractive to lease their transmission lines from telephone companies. This allows WAN providers to focus on data switching.

Figure 10-4 shows the **Public Switched Telephone Network (PSTN)**, which is the official name of the telephone system. Per our discussion earlier, there is a central core, and there are access lines. The access portion of the PSTN is the **local loop**. It extends from the final telephone company switch to the customer premises.

The **PSTN Core** is a modified hierarchy of switches. **End office switches** connect the PSTN to the customer. These are usually **Class 5 switches**—the lowest in the hierarchy. For perspective, there are about 100 Class 5 end office switches in the state of Hawaii. There are fewer switches at each subsequent level. For example, Hawaii has a single Class 3 switch.

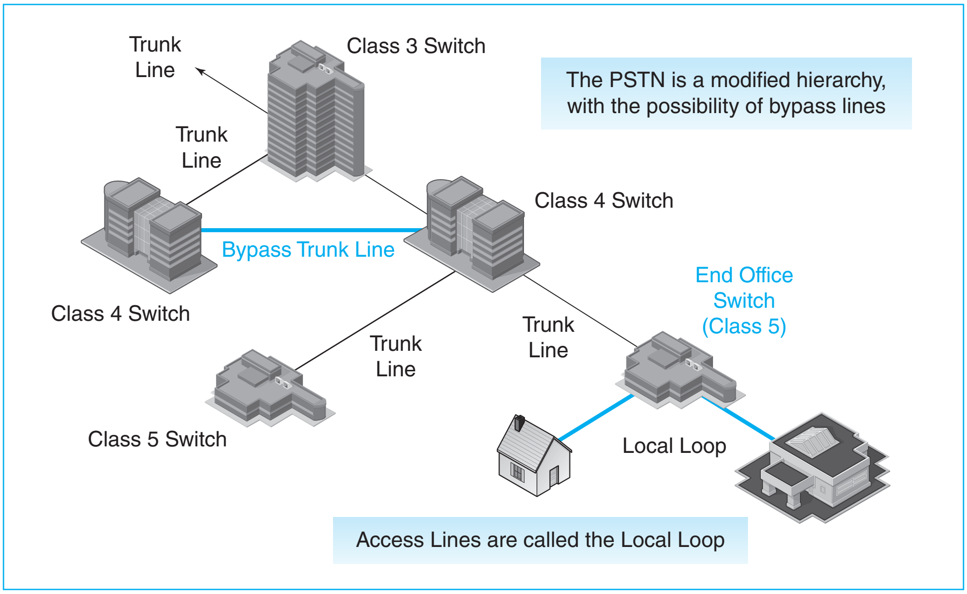

FIGURE 10-4 The Public Switched Telephone Network (PSTN)

The PSTN is a modified hierarchy in the sense that unlike Ethernet, the PSTN includes bypass trunk lines between switches that are at the same level if there is an unusually large volume of traffic between those switches. It is more efficient for such pairs of switches to communicate directly instead of having to involve a higher-level switch.

Test Your Understanding

5. a) Why is the PSTN important in WAN data transmission? b) What is the local loop? c) What class of switches are most end office switches? d) What is the structure of the PSTN core?

RESIDENTIAL WIRED INTERNET ACCESS

We will begin our discussion of WAN technology with residential Internet access. This will permit us to start with something familiar to most readers. This will give us a base of knowledge for looking at corporate WAN technologies.

Residential Asymmetric Digital Subscriber Line (ADSL) Service

Some readers are directly familiar with residential ADSL services. Figure 10-5 shows **asymmetric digital subscriber line (ADSL)** services provide simultaneous voice and data to residential customers. Data transmission speed is asymmetric, with faster download speed than upload speed. This is reasonable. Website downloading often requires a great deal of downstream speed. So does video streaming. In contrast, few residential applications require full two-way high-speed service.

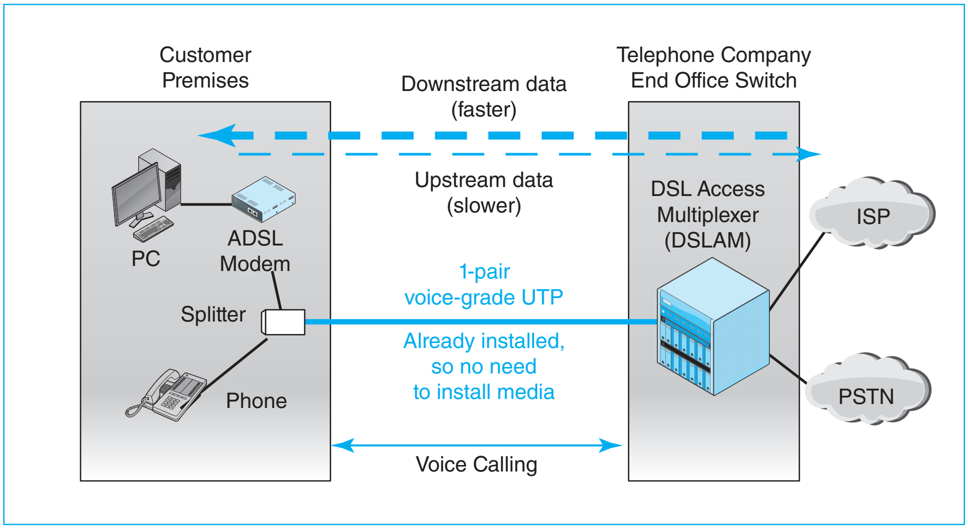

FIGURE 10-5 Asymmetric Digital Subscriber Line (ADSL) for Residential Access

Digital Subscriber Lines Telephone companies have traditionally served residential customers with **one-pair voice-grade (1PVG) UTP** in the local loop. This single unshielded pair was created for voice, not data. It is only twisted about once a foot. However, advances in signaling algorithms have allowed telephone companies to transmit data at high speeds over these lines—while continuing to deliver voice at the same time.

The line between the end office switch and the customer is called the subscriber line. When the telephone company transmits digital signals over it, it is called a **digital subscriber line (DSL)**. These are also called DSL lines, despite the fact that expanding the acronym gives digital subscriber line lines.

Sending data over 1-pair voice grade UTP is important because subscriber lines using this technology already run to every home and business. They have been used since the 1880s to deliver voice telephone service. There is no need to run new subscriber lines to homes in order to provide data transmission. In contrast, the business-focused leased lines that we will see later require carriers to run new transmission lines to each organization. This is extremely expensive.

Residential Customer Equipment and Service For ADSL service, a residential customer installs **ADSL modems**, although it is best to install splitters in each outlet. These **splitters** have two jacks—one for voice and one for data. Splitters separate voice and data signals, preventing possible transmission impairment.

How fast are transmission speeds in ADSL? The answer changes by the minute. In mid-2004, the first author was getting downstream speeds of just under 10 Mbps and upstream speeds a little over 2 Mbps. This is fast enough even for a high-definition movie download. ADSL vendors hope to raise downstream speeds to 100 Mbps or more in the near future. This will permit several high-definition telephone streams into the house. Faster upstream speeds will make online backup for hard disks reasonably painless.

Carrier End Office Equipment To provide ADSL, the carrier has to install a new piece of equipment at the end office switch. This is a **DSL access multiplexer (DSLAM)**. When the customer transmits, the DSLAM directs voice signals to the public switched telephone. However, when data signals arrive, the DSLAM sends it on to an ISP. The DSLAM multiplexes incoming voice and data signals onto the subscriber line.

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. Although 1-pair voice-grade UTP is already installed, its limits are being reached. For speeds beyond about 100 Mbps, carriers are beginning to bring **fiber to the home (FTTH)**—running optical fiber from the end office switch to residential households.

Running new fiber to each household is expensive, so implementation will take time. 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

6. a) Does residential DSL offer simultaneous voice and data service? b) Why is asymmetric speed acceptable in residential ADSL service? c) What is beneficial

about transmitting data over 1-pair voice-grade UTP? d) What equipment does the customer need in his or her home? e) What is the purpose of the DSLAM? f) Why is FTTH attractive? g) How are carriers attempting to reduce the cost of installing FTTH?

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.[2]

Figure 10-6 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 are the two wires in a pair. Figure 10-7 shows that in coaxial cable, the first conductor is a wire running through the center of a coaxial cable. The second

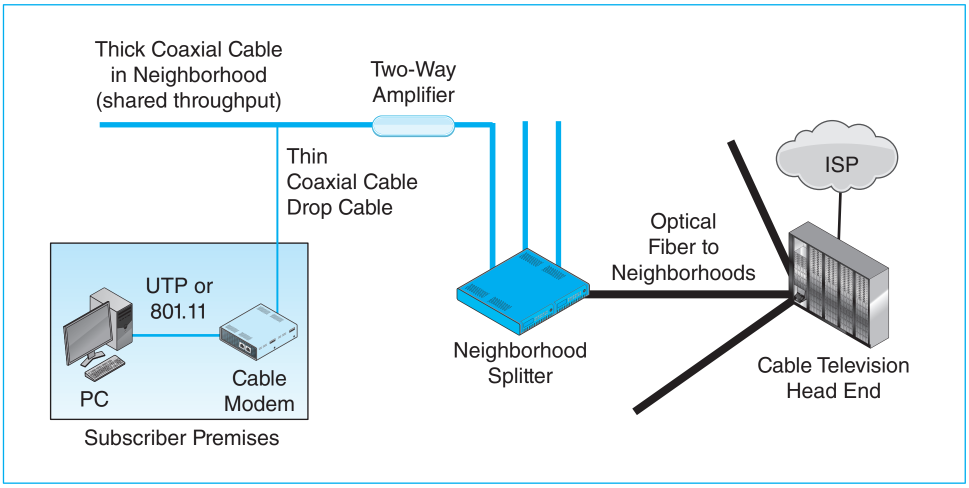

FIGURE 10-6 Cable Modem Service

[2] 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 doctorate.

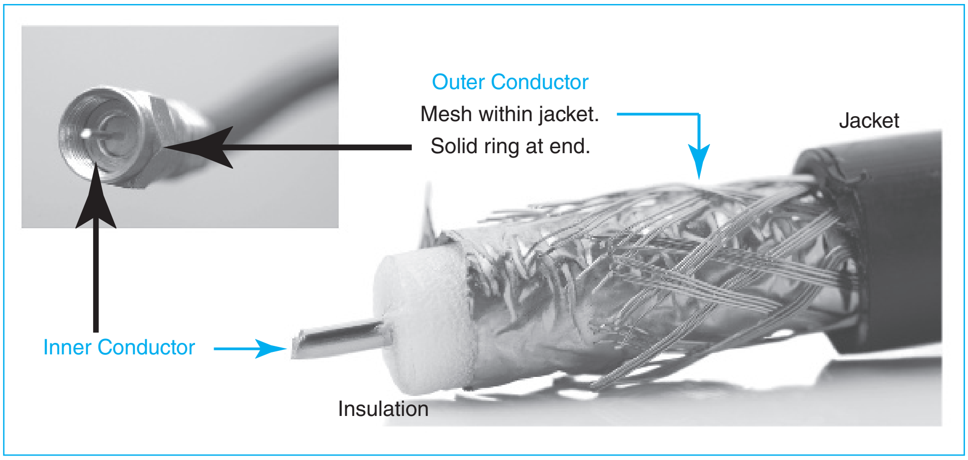

FIGURE 10-7 Coaxial Cable

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 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.

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

7. 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?

ADSL versus Cable Modem Service

Telephone carriers and cable television companies constantly argue about the relative advantages of their two technologies. In reality, however, things boil down to speed and cost. The situation is changing rapidly. Both are increasing speeds frequently, and both are moving to FTTH. At most points in time, ADSL has been a little cheaper and a little slower. It will be interesting to see how competition drives them to improve in the future.

Test Your Understanding

8. a) What are the important things to consider when deciding between ADSL and cable modem service for your residence? b) In the past, how has ADSL compared to cable modem service? c) Which of these two services are moving toward FTTH?

CELLULAR DATA SERVICE

ADSL and cable modem service provide wired access to the Internet by linking users to their ISPs. Cellular telephony now connects users to their ISPs while they are away from home, in the office, or in hotspots. Businesses use cellular telephone service the same way.

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. Many now have *only* a cellular telephone and no traditional *wireline* public switched telephone network phone.

Cells and Cellsites Figure 10-8 shows that cellular telephony divides a metropolitan service area into smaller geographical areas called **cells**. A city the size of Honolulu will have a few hundred 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).

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.[3]

[3] Several cellsites may hear the initial request at different loudness levels; if so, the MTSO selects a service cellsite based on signal strength, not physical distance.

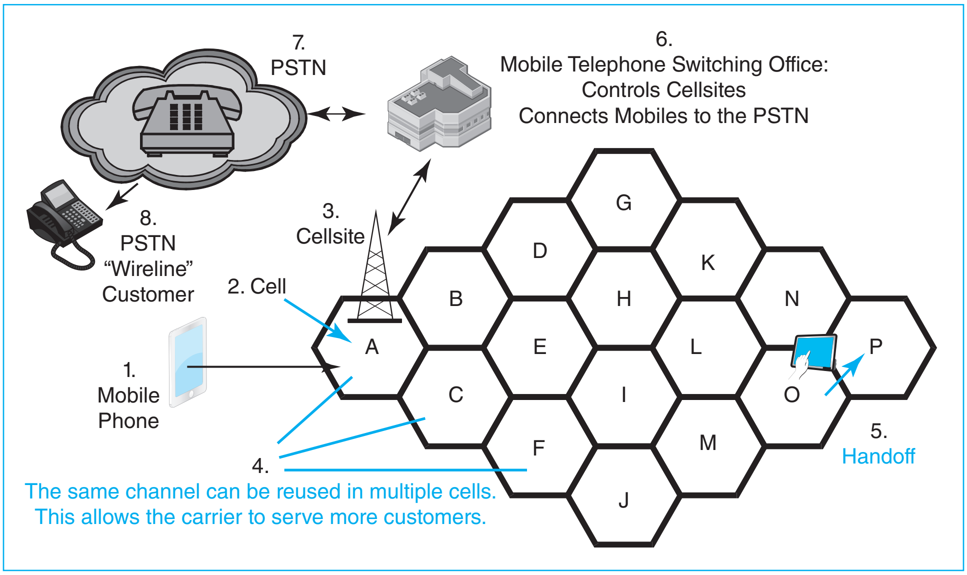

FIGURE 10-8 Cellular Telephone Service

Cellsite Figure 10-9 shows a typical small cellsite on top of a residential building. The three large “paddles” are cellular antennas.

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 10-8 shows a handoff from Cell O to Cell P. The mobile phone will change its

FIGURE 10-9 Cellsite with Paddle Antennas

sending and receiving channels during the handoff, but this occurs too rapidly for users to notice.[4]

Test Your Understanding

9. a) In cellular technology, what is a cell? b) What is a cellsite? c) What are the two functions of the MTSO? d) In cellular system, distinguish between handoffs and roaming.

Why Cells?

Why not use just one central transmitter/receiver in the middle of a metropolitan area? Early pre-cellular radio telephone systems did use a single antenna, and this was much cheaper than using multiple cellsites.

The answer is **channel reuse**. The number of channels permitted by regulators is limited, and subscriber demand is heavy. Cellular 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.[5]

Test Your Understanding

10. a) Why does cellular telephony use cells? b) What is the benefit of channel reuse?

Cellular Data Speeds

Cellular data speeds have increased steadily since about 2000, when speeds jumped from about 20 kbps to a few hundred kilobits per second. Today, most carriers deliver peak downstream speeds of up to 5 to 10 Mbps, and the best carriers provide 15 to 20 Mbps. On the horizon is 100 Mbps. Nearly all carriers today follow the **LTE** (long-term evolution) standard. The **LTE Advanced** standard that most carriers are planning to implement next currently defines a peak downstream speed of 3 Gbps and a peak upstream speed of half that amount.[6]

Although speeds will continue to increase, making new applications attractive and older applications better, price is becoming a barrier to using high speeds. Many residential consumers have found to their shock that downloading a few high-definition movies can put them over the monthly maximums in their contracts. Companies too have to balance high speeds with high bills.

We did not talk about the difference between 3G and 4G because "G" has become meaningless. The International Telecommunications Union defined 4G service as

[4] In contrast, if a subscriber leaves a metropolitan cellular system and goes to another city or country, this is roaming. To confuse matters, many carriers only call going to another city roaming if the home carrier does not offer service there.

[5] 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.

[6] The 3G Partnership Project (3GPP) defines the LTE and LTE Advanced standards. The Partnership frequently adds new "user equipment" categories that permit higher speeds. The "maximum" LTE or LTE Advanced is a constantly moving target.

Speeds

Early cellular systems were limited to about 20 kbps

Today, most carriers give peak download speeds of 5 to 10 Mbps with the best giving 15 to 20 Mbps

100 Mbps is on the horizon

Nearly all carriers now use LTE (long-term evolution) technology

LTE Advanced

The next generation of LTE

Currently, speeds are required to be 3 Gbps downstream, half of that upstream

3G, 4G, and 5G

The ITU creates definitions of generations

Marketers are using the terms in a meaningless manner

Throughput Differs Widely from Rated Speeds

There is extensive overhead in cellular transmission. The data transmission rate is always less than the bit transmission rate.

If the user is riding in a car, throughput will fall.

If more customers use a cellsite, the cellsite may have to decrease the transmission speed to each.

In particular, speed will depend on the time of day.

If the user travels into an area with an overloaded cellsite, speed will be lower.

At greater distances from a cellsite, speed falls, just as in Wi-Fi.

Weakened signal strength caused by transmission through buildings will also reduce speed.

FIGURE 10-10 Cellular Data Speeds (Study Figure)

having a downstream speed of at least one gigabit per second for stationary or walking customers and 100 Mbps for customers in cars or trains. No current offering meets the ITU's 4G standards, but carriers are marketing their systems as 4G and even 5G. It is actual speed that matters.

One problem in evaluating the speeds of different cellular carriers is that throughput is always considerably lower than advertised speed and varies widely within a system. There are several reasons for this.

- There is extensive overhead in cellular transmission. The data transmission rate is always less than the bit transmission rate.
- If the user is riding in a car, throughput will fall.
- If more customers use a cellsite, the cellsite may have to decrease the transmission speed to each. In particular, speed will depend on time of day.
- If the user travels into an area with an overloaded cellsite, speed will be lower.
- At greater distances from a cellsite, speed falls, just as in Wi-Fi.
- Weakened signal strength caused by transmission through buildings will also reduce speed.

Test Your Understanding

11. a) How fast can the best systems today download data? b) What speed is on the horizon? c) What is today's dominant cellular technology? d) What speed does the LTE Advanced standard currently require? e) Why does the book not distinguish between 3G and 4G service? f) What factors affect what throughput an individual user will receive?

WIRED BUSINESS WANs

To communicate with customers and for access to remote employees, companies use the Internet. However, they still need to use carrier WANs to reach the Internet and to connect their sites to one another. Figure 10-11 illustrates this situation.

Leased Lines

To connect to the Internet, Figure 10-11 shows that companies typically use leased lines from a carrier, most commonly the local telephone company. **Leased lines** are fast, point-to-point, always-on connections. As the name suggests, if a company wishes to use a leased line, it must sign a lease for a specified duration. Specifying the wrong speed when a leased line is ordered creates a persistent problem.

Figure 10-12 shows that a leased line is really a complex transmission path between the two points it connects. This path passes through customer access lines at the two ends and trunk lines between carrier switches along the path. To the user, however, the access line seems to be a simple data pipe all their own.

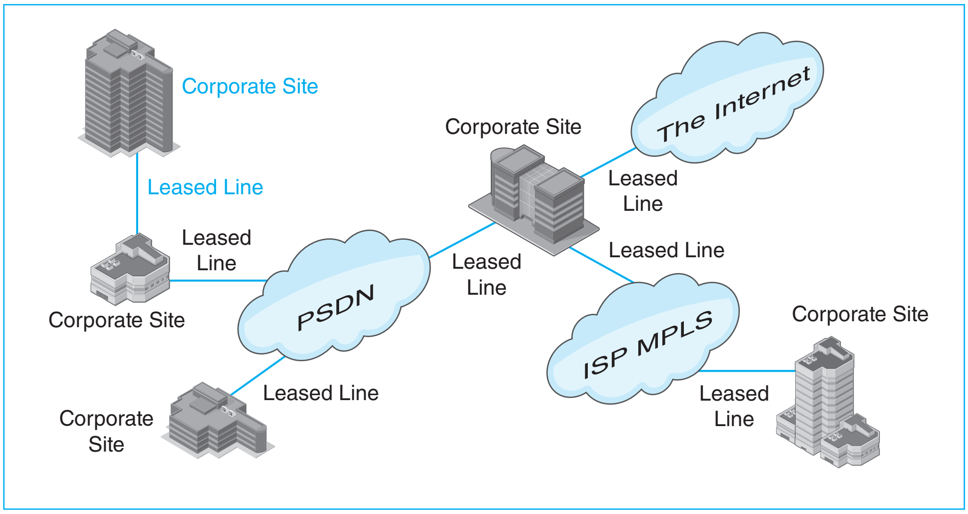

FIGURE 10-11 The Internet and Wired Carrier WANs for Business

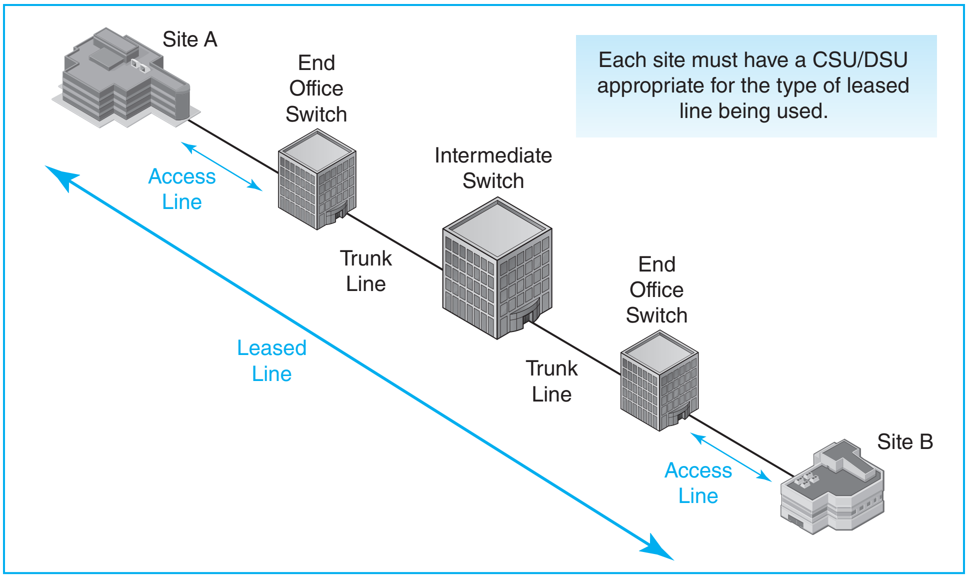

FIGURE 10-12 Leased Line, Trunk Lines, and Access Lines

To use a leased line, a company needs a piece of customer premises equipment called a **CSU/DSU**.[7] The purpose of this device is to translate the physical layer signals of network devices on the customer premises into physical layer signals in a format that leased lines require.

Test Your Understanding

12. a) What are the characteristics of leased lines? b) Distinguish between leased lines and access lines. c) What device must a customer have at its site to connect to a leased line?

Reaching the ISP via a Leased Line

A company needs to connect to its ISP. The simplest way to do this is to run a leased line from the company to the ISP's nearest access location. We know that this access line will pass through several transmission lines and switches, but networking professionals usually draw leased lines as they appear to be, namely a point-to-point transmission link. Figure 10-11 illustrates this approach.

Test Your Understanding

13. When a customer uses a leased line to connect to its ISP, what two points does the leased line connect?

[7] Channel Service Unit/Data Service Unit. Not very informative.

Leased Line Private Corporate WANs

Companies need to communicate with their ISPs. If they have multiple sites, they also need to connect these sites into a coherent network for internal communication. Figure 10-13 shows that they can do this by building a leased line network that will create a private internal WAN. Site routers route packets among the sites.

Figure 10-14 shows that leased line speeds vary widely. Under 50 Mbps, leased line speed standards were set regionally. The United States and Canada use the North American Digital Hierarchy Standard. Europe uses the CEPT Hierarchy. Other countries may use different standards. Fortunately, it is possible to translate between different leased line hierarchies, but the diversity of standards does cause minor problems.

Above 50 Mbps, carriers have standardized on a single standard that is called Synchronous Optical Network (SONET)[8] or Synchronous Digital Hierarchy (SDH). SONET and SDH use different naming conventions for their lines. For example, SONET labels its lines with OC (optical carrier) numbers, while SDH uses STM (synchronous transport module) designations. Other than naming differences, their services are identical and compatible.[9]

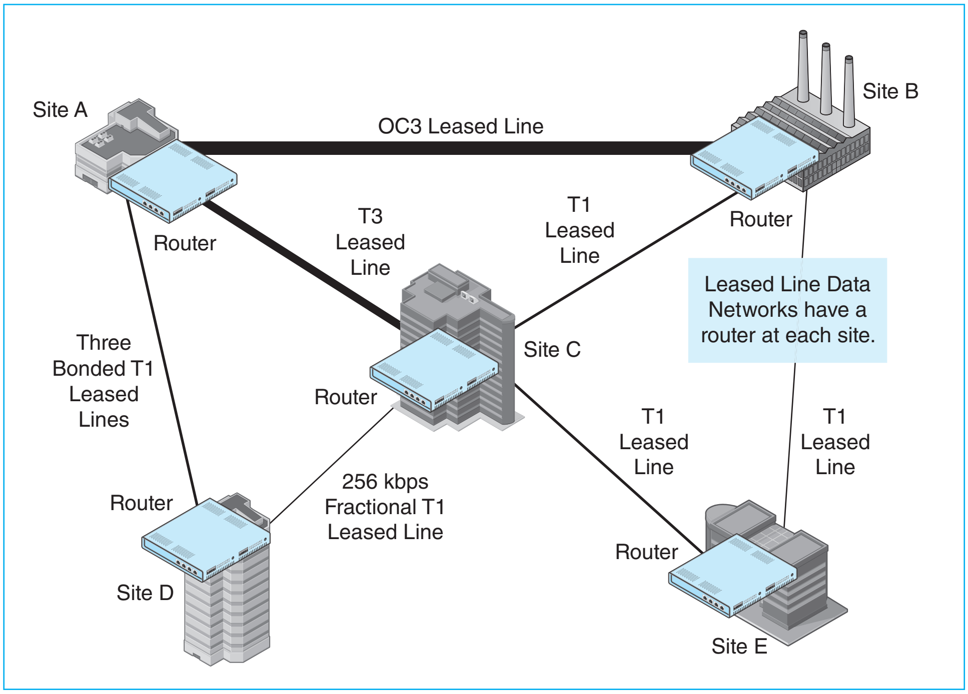

FIGURE 10-13 Leased Line Private Corporate WAN

[8] SONET is the terminology used in the United States and Canada. The rest of the world uses the SDH nomenclature.

[9] Apart from a few unimportant differences.

North American Digital Hierarchy		
Line	Speed	Typical Transmission Medium
T1*	1.544 Mbps	2-Pair Data-Grade UTP
T3	44.736 Mbps	Carrier Optical Fiber
CEPT Hierarchy		
Line	Speed	Typical Transmission Medium
E1*	2.048 Mbps	2-Pair Data-Grade UTP
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

*Often offer synchronous DSL over existing 1-pair voice grade UTP rather than offering traditional T1 and E1 service over 2-pair data grade UTP, which must be pulled to the customer's premises.

Fractional T1 speeds are often offered by carriers. These typically include some subset of the speeds 128 kbps, 256 kbps, 384 kbps, 512 kbps, and 768 kbps.

T1 and E1 lines can be bonded to provide double, triple, or quadruple the capacity of a single line.

FIGURE 10-14 Leased Line Speeds

The line naming conventions and speeds are easier to understand if you understand that all SONET/SDH speeds are multiples of 51.84 Mbps. The slowest OC line that carriers offer is OC-3, which is three times the base speed. SDH carriers call this STM-1 because it is the first (slowest) speed they offer.

Applying Figure 10-14 Applying the information in Figure 10-14 is straightforward. If you have a requirement for a particular speed between two points, you select a leased line sufficient for that speed. For example, if you require a speed of 100 Mbps, you select an OC-3 or STM-1 line.

Carriers often offer more choices, predominantly at lower speeds. WAN line speeds traditionally were slow, around one to two megabits per second. This was roughly T1/E1 speed. Given frequent demand for a fraction of a T1 or E1 line, carriers typically offer fractional T1/E1 speeds for a fraction of the cost of a full T1/E1 line. If you need 200 kbps, you could get a fractional T1 line running at 256 kbps, which is 16.5% of a T1 line. As you might suspect, carriers will charge more than 16.5% of what they charge for a full T1 line.

Carriers also allow a customer to bond two or more T1/E1 lines together between a pair of sites. For example, if you need 2.8 Mbps between a pair of sites, you might bond two T1 or E1 lines.

Traditionally, T1/E1 leased lines required running a new 2-pair data grade UTP line to the customer's premises. This is expensive. In addition, the telephone system already runs 1-pair voice grade UTP to all premises, including business premises. We saw earlier in this chapter that carriers run digital subscriber line (ADSL) services over these lines. We also saw that ADSL today is much faster than T1/E1 speeds. Consequently, many carriers who offer "T1" and "E1" lines today are really offering DSL service over 1-pair VG UTP.

However, carriers do not offer asymmetric DSL service because businesses need symmetric speed—the same speed in both directions. Consequently, carriers offer **synchronous DSL** services to businesses. Businesses also require QoS guarantees, so these synchronous DSL lines come with service level agreements. SLAs mean that the DSL services offered to businesses are more expensive per bit transmitted than residential ADSL service.

Managing the WAN Leased line corporate WANs do not design and operate themselves. A company that uses leased line networks to connect its sites faces substantial labor and customer premises equipment costs.

Test Your Understanding

14. a) If you need a speed of 1.2 Mbps between two points in the United States, what leased line would you specify in the United States and in Europe? b) Repeat for 160 Mbps. c) Repeat for 3 Mbps. d) Why do carriers offer low-speed "leased lines" that are really DSL lines? e) How do business DSL lines differ from residential DSL lines? f) Why is the need to manage the leased line network an issue?

Public Switched Data Network (PSDN) Carrier WANs

As packet switching matured in the 1970s, carriers began to create **public switched data networks (PSDNs)** that absorbed most of the corporate burden of managing WAN connections. As Figure 10-15 shows, the customer only needs to run a leased line from each of its corporate sites to the PSDN's nearest **point of presence (POP)**. The PSDN is shown as a cloud to signify that the PSDN handles all switching and forwarding tasks without concerning customers about the details.

The customer only needs to run a leased line from each of its corporate sites to the PSDN's nearest point of presence (POP).

Carriers have economies of scale in management costs because they manage the PSDN services of many customers. Consequently, PSDNs usually are cheaper than deploying a network of leased lines to link corporate sites together.

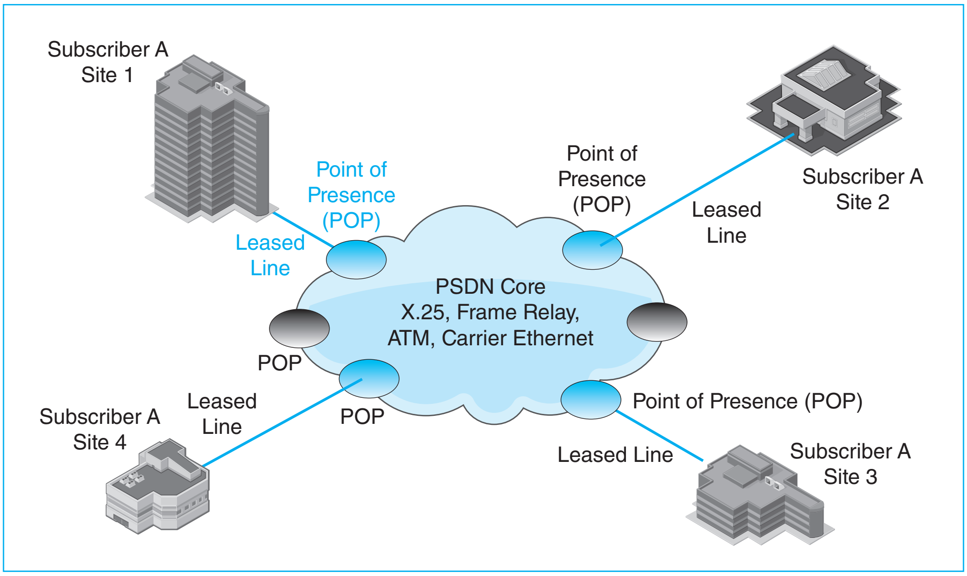

FIGURE 10-15 Public Switched Data Network (PSDN)

Due to economies of scale, PSDNs usually are cheaper than deploying a network of leased lines to link corporate sites together.

Historical PSDN Technologies PSDNs are switched, which means that they operate at Layer 2, the data link layer. (This is why one PSDN technology is called *Frame* Relay.) There have been several PSDN technologies to date.

- The first, **X.25**, emerged in the 1980s but never grew large. It was too expensive for what it provided.
- Things changed in the 1990s, when **Frame Relay** began to grow rapidly. Around the turn of the century, Frame Relay and leased line data networks each accounted for about 40% of WAN traffic. However, part of this growth was due to aggressive Frame Relay pricing, which resulted in poor profit margins. Around 2000, carriers began raising their Frame Relay prices, and market share dropped considerably.
- Another PSDN technology, **ATM**,[10] was created to replace the core of the public switched telephone network and has to a considerable extent done so. It offers very high speeds and many expected it to replace Frame Relay as WAN speeds increased. However, ATM was expensive and never grew as expected. As one pundit said, "ATM is the wave of the future and always will be."

[10] Asynchronous Transfer Mode. This is not very illuminating, so the acronym is rarely spelled out.

Carrier Ethernet (CE) In the 1980s, there were several competing LAN technologies. However, Ethernet became the only survivor thanks to its low-cost switch operation and its ability to grow to ever faster speeds. One reason why carriers raised the price of Frame Relay dramatically in the early 2000s was that they wanted to move customers to either MPLS IP networks, which we will see a little later in this chapter, or to **carrier Ethernet (CE)**. As the name applies, this is Ethernet for WAN service offered by carriers. Carrier Ethernet was originally limited to metropolitan area network, so it was originally called *metro Ethernet*. However, when Ethernet began to span distances beyond metropolitan area networks, MEF (formerly called the Metropolitan Ethernet Forum) which standardizes Ethernet services in WANs, changed the name to carrier Ethernet.[11]

Although CE is relatively new, it is growing rapidly—the only PSDN technology to be doing so. Many carriers have told their customers that Frame Relay service will soon be discontinued, and this is accelerating carrier Ethernet's growth even faster.

MEF has standardized eight Carrier Ethernet services. Figure 10-16 shows the two that have dominated so far.

- **E-LINE** service is a site-to-site service. It competes directly with leased lines but offers other benefits.
- **E-LAN** service essentially extends the LAN to the wide area. Sites can use Ethernet to communicate back and forth as if the Carrier Ethernet PSDN was simply a set of trunk lines between switches.

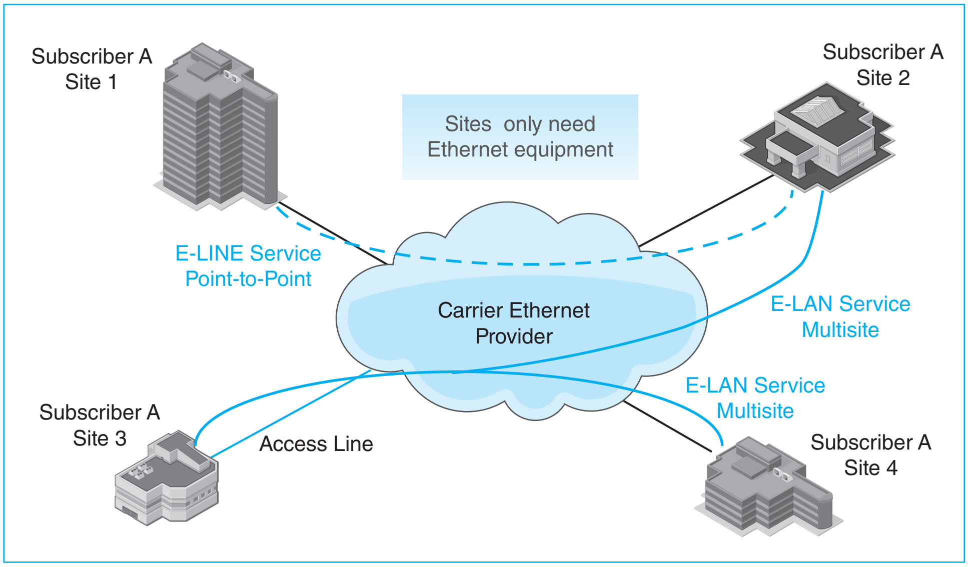

FIGURE 10-16 Carrier Ethernet Services

[11] MEF has long worked closely with the 802.3 Working Group. Knowing that carrier Ethernet would run over SONET/SDH lines, 802.3 developed two standards for its fastest speeds. For instance, short-reach versions of 10 Gbps were designed for LANs and operate at exactly 10 Gbps. In turn, long-reach versions of 10 Gbps Ethernet operate at 9,953 Gbps to run over OC192/STM64 lines. The 802.3 Working Group has defined a number of standards specifically designed for transmitting Ethernet over the local loop, including both carrier optical fiber and 1-pair voice-grade UTP.

Low cost and familiarity of the technology to the firm's networking staff
High speeds are available
Speed agility: Increases in speed can be provisioned rapidly
Quality of service
Security

FIGURE 10-17 Carrier Ethernet Attractions (Study Figure)

Carrier Ethernet has a number of attractions.

- *Cost.* Using Ethernet's familiar low-cost MAC layer functionality, CE is inexpensive. In addition, sites only have to plug carrier termination equipment into an Ethernet switch port. There is no need to learn a new technology.
- *Speed.* Companies that need fast connections can get 100 Mbps, 1 Gbps, or 10 Gbps at attractive cost.
- *Speed Agility.* If companies need extra capacity for a limited period of time, such as a year-end crunch, CE carriers can usually reprovision their services quickly.
- *Quality of Service.* CE carriers can offer quality of service guarantees for speed, availability, frame delay, frame jitter, and frame loss.
- *Security.* Although Carrier Ethernet does not include cryptographic protections, the traffic of different customers is kept separate to prevent eavesdropping.

Test Your Understanding

15. a) If a firm has ten sites, how many leased lines will it need to use a PSDN? b) Between what two points will a leased line run for PSDN access? c) Which PSDN technology grew rapidly in the 1990s? d) Which PSDN technology is growing rapidly today? e) What organization is standardizing carrier Ethernet? f) What is the former name for carrier Ethernet? g) Distinguish between E-Line and E-LAN service. h) For what reasons is CE attractive? i) Is the 802.3 Working Group working with MEF?

Multiprotocol Label Switching (MPLS)

Making Routing More Efficient In Chapter 8, we saw that routers look at an incoming packet's destination IP address. They compare that IP address to every row in the routing table, select the best match, and send the packet back out a certain port to a certain IP address. The next packet to arrive gets the same treatment—even if it goes to the same IP address.

Many routers can do decision caching, in which they remember their decisions for certain IP address ranges. We saw that this is dangerous. Fortunately, there is a more robust way to avoid having to look at all rows for all packets. This is **Multiprotocol Label Switching (MPLS)**, which Figure 10-18 illustrates.

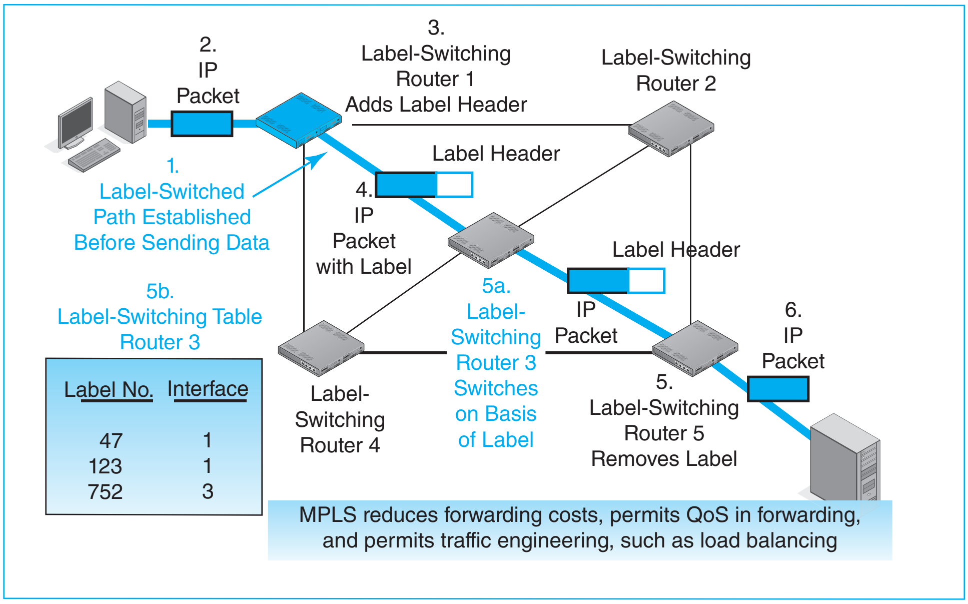

FIGURE 10-18 Multiprotocol Label Switching (MPLS)

Operation When two hosts start to converse, an MPLS network first determines the best path for the packets. This is the **label switched path**. Routers will send all packets along this path rather than making traditional routing decisions for each packet at each router.

As Figure 10-18 shows, after the label switched path is established, the source host transmits packets normally. The first router is a **label switching router**. It inserts a 32-bit **label header** in front of the IP header and after the frame header. The IP packet syntax and the frame syntax are unchanged.

The label header's **label number** identifies the label switched path selected for this conversation. The first label switched router and all others along the label switched path have MPLS look-up tables. These tables allow routers to look up the label number, read the corresponding interface, and send the packet out the indicated interface. For example, if the label number is 47, the router in Figure 10-18 will send it out Interface 1. Table lookups are fast because only one row will match the destination IP address. There is no need to look at all routing table rows to select the best interface to send a packet back out. The hard work was done when the label switched path was created. The last label switching router removes the label. Note that neither the source host nor the destination host knows that label switching was done. MPLS operation is transparent to hosts.

Often, all traffic between two sites is assigned a single label number. Or, traffic between two sites might receive one of a handful of label numbers. Different label numbers might correspond to label switched paths with different quality of service characteristics.

Benefits MPLS offers three major benefits.

- First, MPLS slashes the work each router must do and therefore slashes a company's router costs.
- Second, as we just noted, MPLS can be used to assign paths based on the QoS requirements of different packets.
- Third, MPLS can do **traffic engineering**, that is, to manage how traffic will travel through the network. One traffic engineering capability is **load balancing**, that is, to move some traffic from a heavily congested link between two routers to an alternative route that uses different and less-congested links.

Carrier MPLS Companies can create their own MPLS networks, but they typically use carriers to provide MPLS for their WAN communication. Many of these carriers are Internet service providers who already use MPLS within their own internets. They extend the benefits of MPLS to their customers. That is impossible for the Internet as a whole because there is no central control organization for the Internet.

Extendibility If MPLS is so good, why not use it everywhere on the Internet? The answer is that MPLS requires a single administrator to manage the entire network of label switched routers.

Test Your Understanding

16. a) In MPLS, is selecting the best interface for each packet at each router done when the packet enters the network or before? b) Why is this beneficial? c) What is the name of the path selected for a particular conversation? d) When a source host first transmits to a destination host after a label switched path is established, what will happen? e) Do label switching routers along the MPLS path look at the packet's IP address? The answer is not explicitly in the text. Explain your reasoning. f) On what basis does each label switched router base routing decisions? g) Why is MPLS transparent to the source and destination hosts? h) What are MPLS's attractions? i) What is traffic engineering? j) Can MPLS provide traffic load balancing? k) Is it possible to implement MPLS across the entire Internet? Explain.

WAN Optimization

Given the high cost of long-distance transmissions, companies need to squeeze out every bit of performance improvement they can find for data over WANs. Figure 10-19 shows that one approach is to install **WAN optimization devices** at each end of important shared lines between sites.

Compression The most important action that the WAN optimization devices take is to compress all data being transmitted into the line and decompress the data at the other end. **Compression** is possible because almost all data contains redundancy that can be reduced through encoding. For movies and voice, compression can be substantial. For word processing documents and spreadsheets, compression will be less effective. In the figure, the WAN optimization devices can provide an average of 10:1 compression. Source A is transmitting at 3 Gbps, and Source B is transmitting at

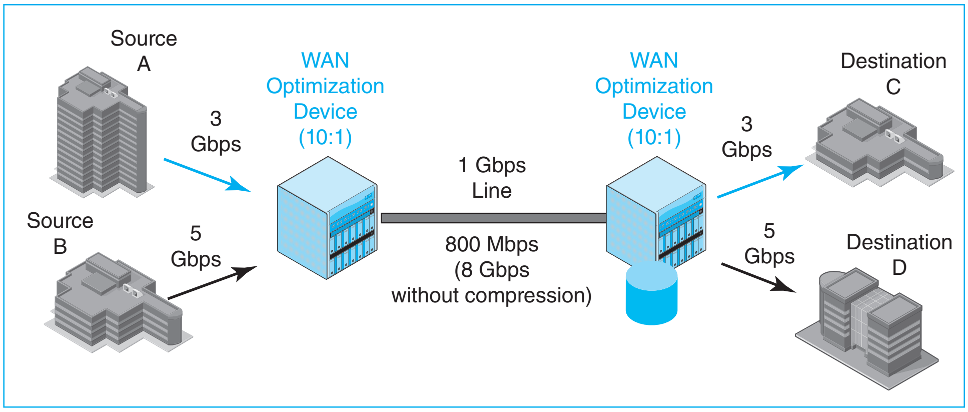

FIGURE 10-19 WAN Optimization: Compression

5 Gbps. This is a total of 8 Gbps arriving at the WAN optimization device. However, with 10:1 compression, the transmission line only has to carry 0.8 Gbps. This will fit in a 1 Gbps transmission line. Without compression, the company would need a much more expensive 10 Gbps transmission line.

Caching Another way to reduce the number of bits flowing through the transmission line is **caching**. (See Figure 10-20.) Suppose the company produces a large annual report. The server holding the report is in Source A. The annual report is likely to be transmitted multiple times from Source A to recipients in Source C and Source D. With a WAN optimization device that has caching, when the annual report is first delivered, it is copied onto the receiving WAN optimization device's disk **cache**. Later, when the annual report is to be transmitted again, the WAN optimization device near Source A and Source B will not transmit the entire file. Instead, it will send a brief message to the WAN optimization device near Source C and Source D. This message asks the WAN optimization device on the right to retrieve the annual report from the cache and send it to the receiver. Avoiding the retransmission of frequently transmitted files can reduce traffic considerably.

Traffic Shaping In many cases, unfavored applications take up too much capacity. Unfavored applications may include YouTube, Netflix, and BitTorrent for file sharing. Some WAN optimization devices do **traffic shaping**. (See Figure 10-21.) When undesired traffic reaches an optimization device, the device may simply prohibit it. The device can also take a less drastic action—limiting the application to a small percentage of the total traffic. Both can dramatically reduce overall traffic, allowing the firm to avoid upgrading its transmission lines.

Application and Network Protocol Acceleration (Tuning) Many applications and network protocols are somewhat inefficient when they transmit over long-distance lines. TCP, for example, tends to have conservative transmission

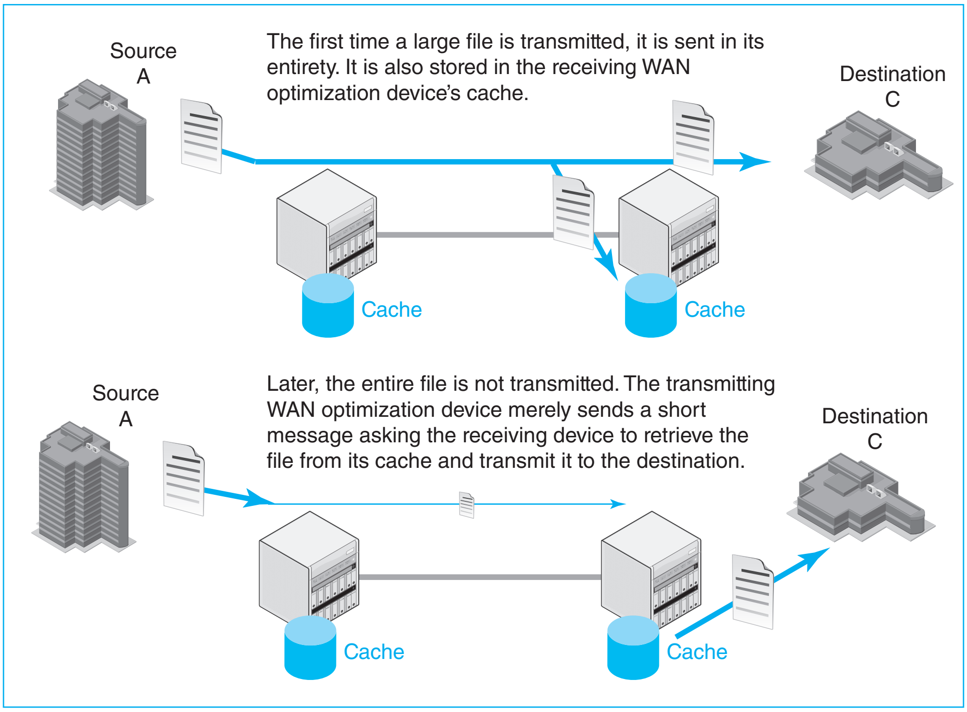

FIGURE 10-20 WAN Optimization: Caching

defaults that slow transmission. It may be possible to tune TCP by adjusting such things spent waiting for acknowledgments. To give another example, when a WAN optimization device receives a TCP SYN segment, it may send back an ACK even before it passes the segment on to its intended host. Application and network acceleration is a family of tactics the WAN optimization devices can use to reduce *latency*,

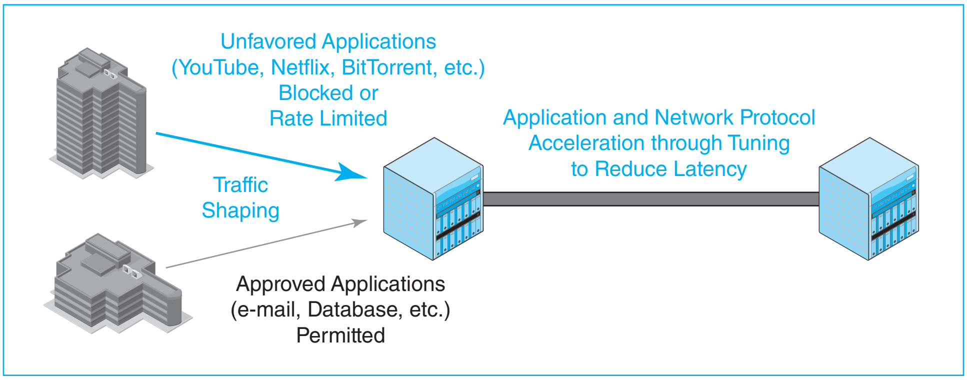

FIGURE 10-21 WAN Optimization: Traffic Shaping and Application and Network Protocol Acceleration

which tends to be a problem when signals must travel long distances. Although tuning can take place on hosts, WAN optimization devices provide a central point for tuning and tuning tools.

Application and network acceleration is a family of tactics the WAN optimization devices can use to reduce latency, *which tends to be a problem when signals must travel long distances.*

Test Your Understanding

17. a) Where are WAN optimization devices found? b) List the four mechanisms we discussed for optimizing transmission over a transmission link. c) How does compression reduce traffic? d) How does caching reduce traffic? e) Explain traffic shaping. f) How does traffic shaping reduce traffic? g) What is the main benefit of application and network protocol acceleration?

SOFTWARE DEFINED NETWORKING (SDN)

Having covered both LANs and WANs, we have finished looking at the transmission parts of networking. Although we still need to look at applications, this is a good time to cover an overall aspect of data transmission. This is **software defined networking (SDN)**, which may permit a vast expansion in our ability to manage entire corporate networks. The word "may" is key. The future of SDN is uncertain, but its potential importance makes it critical to cover.

Concepts and Benefits

Figure 10-22 shows SDN in more detail. It shows that software defined networking has three layers—individual switches and routers, the SDN controller, and SDN applications.

We saw in Chapter 4 that switches and routers traditionally both did forwarding and handled control—managing the rules for deciding how to forward specific frames or packets. **Control** involves routing protocols for exchanging routing table information in routers, Ethernet switch administrative frames for the Rapid Spanning Tree Protocol and other matters, and other administrative chores beyond the forwarding of each message as it arrives.

Placing the control function in individual routers allowed the Internet to scale because one can simply add more routers and be confident that they will participate fairly effectively. The same occurs in switched networks. However, each switch and router needs to be configured separately when it is installed. More importantly, it becomes almost impossible to make radical changes in the operation of an Ethernet network or a corporate internet. Administrators have to configure most or all individual devices to make such radical changes.

The limitations of traditional switching and routing first became serious when large data centers began to add virtual machines. VMs appear suddenly and many last only minutes or hours. A multitenant data center must do **traffic segregation** so that

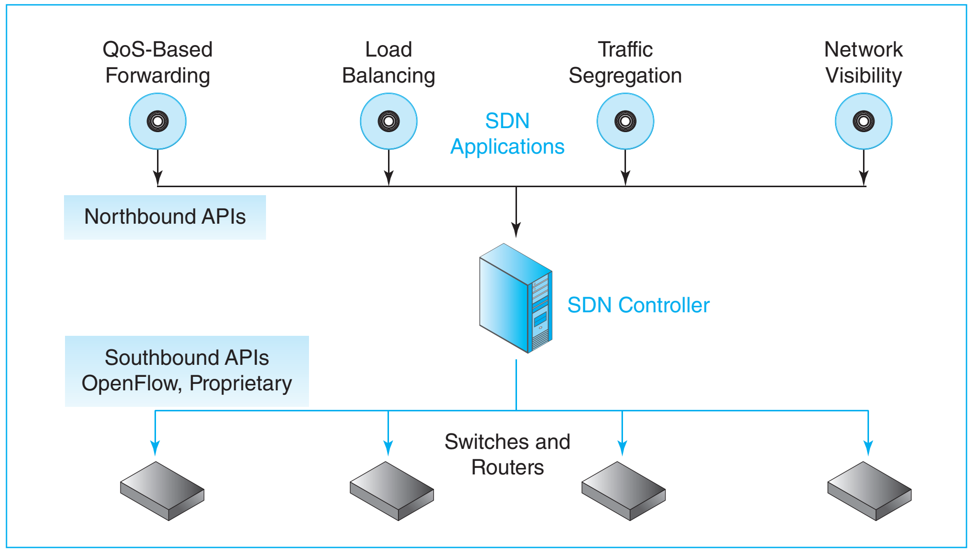

FIGURE 10-22 Software Defined Networking (SDN)

customers cannot reach the VMs of other customers. This and other changes required by growing data center size and an increasing pace of change led to constant router reconfiguration.

In SDN, switches and routers still do the forwarding function as usual. However, an SDN controller decides how switching and routing should be done, then pushes appropriate forwarding table changes out to individual switches and routers. This separation of traditional functionality brings several crucial benefits.

- *Agility*. Changes in forwarding patterns can be made rapidly. When a new VM appears, the information can be added immediately to its aggregation group for processing on all switches and routers. If a firm needs additional bandwidth between its servers and backup facilities overnight, to give another example, it can do so easily although many switches and routers may be involved.
- *Lower OpEx Cost through Automation*. **OpEx** is operating cost. It is primarily labor. By avoiding constant reconfiguration at many devices, SDN can dramatically trim labor costs. This is especially true because SDN controllers are programmable, meaning that many repetitive tasks can be automated.
- *Lower CapEx Cost*. **CapEx** is capital expense. Switches and routers are pricey because of their need to be able to perform control functions. Companies using SDN may be able to buy lower-cost "dumb" switches and routers, although switch and router vendors are trying to make this difficult.
- *Radical Changes*. If a company wishes to drastically change the way it does forwarding or routing or wishes to experiment with a new routing protocol or switch supervisory protocol, the firm can do this for a subset of its forwarding devices to experiment and then roll out innovations. Individual forwarding devices can even run traditional modes of operation for some traffic and new modes of operation for other traffic.

Test Your Understanding

18. a) What are the three layers in SDN? b) Distinguish between forwarding and control. c) Traditionally, where have these functions been located? d) How does this change in SDN? e) What pressing management issues does SDN address? f) Why did SDN begin in large data centers? g) What is the ability to change forwarding tables rapidly called? h) How can SDN reduce OpEx? i) How can it reduce CapEx? j) How can it facilitate radical changes in the network's operation?

Forwarding Tables

We saw Ethernet forwarding tables in Chapter 5 and router forwarding tables in Chapter 8. Actually, forwarding table rules can be considerably more intricate, as Figure 10-23 shows. Each row is a rule. **Forwarding rules** can use considerable information in a frame or packet.

Test Your Understanding

19. a) Was the information we presented about switching and routing tables in earlier chapters complete? b) From where does an SDN switch or SDN router get its forwarding table rules? c) Explain the rule in the first row. An Ethernet VLAN is used to segregate hosts. Hosts in a VLAN can only communicate with hosts on the same VLAN. d) Explain the rule in the second row. e) On what device is the forwarding table—a controller, switch, or router?

SDN Applications

SDN allows controllers to manage many aspects of forwarding on switches and routers. However, these abilities do not come pre-baked in controllers. Each requires the creation or purchase of an SDN application to do a particular thing. The real future of

Row	IP Src Addr	IP Dest Addr	TCP Dest Port	Ethernet Priority	IP Class Number	Action
1	External	128.3.2.8	443	7	Any	Pass with Priority
2	External	128.3.2.8	443	Any	17	Pass Apply Class Rule 17
3	External	128.3.2.8	443	Any	Any	Drop
4	Not Finance	Finance	Any	Any	Any	Drop Log
5	Internal	128.7.65.123	443	Any	Any	Authenticate
6	Internal	External	80	Any	Any	Drop
7	Internal	External	443	Any	Any	Pass
8	Any	Honeypot	Any	Any	Any	Pass Alarm

Note: All, Internal, External, Finance, and Honeypot are ranges of IP addresses.

FIGURE 10-23 Forwarding Table Rules

SDN rests on whether firms and vendors will build the applications that organizations need to administer their networks. Here are four important SDN applications (there are countless more):

- *Quality of Service Applications*. Most obviously, SDN can specify QoS-dependent message forwarding. SDN applications can add new QoS methods.
- *Load Balancing Applications*. When individual routers make routing decisions, they sometimes overload some paths while leaving others only slightly filled. **Load balancing** applications even out traffic on different paths.
- *Traffic Segregation Applications*. For security and other reasons, the traffic flows of different user groups or applications often need to be segregated from one another. Ethernet does this with virtual LANs (VLANs). SDN controllers can use VLAN IDs within Ethernet frames to do this, or they can use more sophisticated and robust methods.
- *Network Visibility*. Communication between the controller and the devices they control takes place in both directions. SDN applications can collect detailed data on forwarding device statistics. They can present this information in coherent form to network administrators.

Test Your Understanding

20. a) What good is a controller without SDN applications? b) List the four application categories listed in the text.

Application Program Interfaces (APIs)

Communication between SDN applications and SDN controllers must be standardized to allow competition among vendors. Communication between controllers and forwarding devices also needs standards. Standards are implemented through **application program interfaces (APIs)**. Each API exposes a function or set of functions to commands from the next higher layer. Figure 10-22 shows that it is common to call SDN APIs between applications and controllers **northbound APIs**. APIs between the controller and forwarding devices are **southbound APIs**.

> *Standards are implemented through* **application program interfaces (APIs)**. *Each API exposes a function or set of functions to commands from the next higher layer.*

For southbound APIs, the **OpenFlow** standards are becoming popular. With OpenFlow, there is theoretically no need to purchase expensive switches and routers. For example, Google uses OpenFlow in its data centers. It built its own "dumb" routers with no internal control mechanisms. This permitted Google to reduce its CapEx considerably.

Naturally, switch and router vendors are disquieted by the prospect of their boxes being turned into low-cost commodities. To address this worry, they are adopting OpenFlow but are also offering their own southbound **proprietary APIs**. In many cases, these functions already existed in the forwarding device. Vendors hope that their proprietary APIs will be more fully featured and therefore more attractive to customers. Some, like Hewlett Packard, even have their own SDN app stores.

Test Your Understanding

21. a) What is an API? b) For SDN, distinguish between northbound and southbound APIs. c) What is OpenFlow, and why is it significant? d) Is OpenFlow a northbound or southbound API? e) What threat does OpenFlow create for switch and router vendors? f) How are vendors responding?

CONCLUSION

Synopsis

In Chapters 5, 6, and 7, we looked at local area networks. The technology picture was simple. Ethernet dominates wired LANs, and 802.11 dominates wireless LANs. In wide area networks, which take transmission beyond the customer premises, 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.

LANs and WANs also differ economically. LAN distances are short, so the cost per bit transmitted is low. In WAN transmission, however, the cost per bit transmitted is comparatively high, so companies need to be more frugal, living with lower transmission speeds and optimizing technology carefully. Metropolitan Area Networks (MANs) are intermediate in cost and speed. Overall, LAN and WAN managers must have different mind-sets. In this chapter, you learned to think like a WAN manager.

The Internet connects nearly everybody. However, it offers no performance guarantees or inherent security. Carrier WAN services, in turn, can offer QoS guarantees and enhanced security, but only companies who use the same carrier WAN service can communicate over carrier WAN technology. WANs are used primarily for connecting sites in the same corporation and connecting an organization to the Internet.

In this chapter, we looked at the main elements of wide area networks. These are the network core and the access link that connects the customer premises to the network core. In many cases, carriers use transmission lines from the public switched telephone network. Customers need customer premises equipment to connect to carrier WANs. For leased lines, the CPE is a CSU/DSU.

We looked first at wired residential Internet access, including ADSL from telephone companies and cable modem service from cable television companies. We also looked at cellular data transmission, which is increasing rapidly in speed.

Companies use the Internet to communicate with their customers. They also use a variety of wired networks to connect them to the Internet and to connect their sites together. These include Layer 1 networks of leased lines, Layer 2 public switched data networks, and Layer 3 MPLS services from ISPs. Companies still use leased lines to connect them to PSDNs and MPLS services from ISPs. Leased lines come in a wide range of speeds. To reduce costs, companies often apply WAN optimization devices at the two ends of a transmission link. These devices can reduce data transmission requirements and reduce latency.

Software defined network (SDN) may revolutionize the way in which we manage our networks. Controllers will allow us to centralize the control function that tells individual switches and routers how to forward arriving frames and packets. This will allow us to make changes rapidly in the way our networks operate, and it may lead to far cheaper switches and routers. The future of SDN depends heavily on how smart developers are at building SDN applications to implement control functions intelligently.

END-OF-CHAPTER QUESTIONS

Thought Questions

10-1. Distinguish between dial-up telephone service you use as a consumer and leased line services used in business. (You will have to extrapolate from your own experience with dial-up lines.)

10-2. If you have a network of leased lines, you have options for how many sites you connect. Sites can communicate directly or through intermediate sites. a) In a full mesh, every pair of sites will be directly linked by a leased line. If there are N sites, there will be $N*(N-1)/2$ connections. In Figure 10-13, how many leased lines would be used in a full mesh? b) In a hub-and-spoke network, there is a central site, and a leased line radiates from it to each other site. In Figure 10-13, how many leased lines would be used in a hub-and-spoke network with the hub located at Site A? c) What is the benefit of full mesh networks over hub-and-spoke networks? d) What is the advantage of hub-and-spoke networks over full mesh networks? e) How would you use this information about advantages to advise a company about what to do when it installs a network of leased lines?

10-3. In ADSL service, there is a single UTP pair running from the end office switch to the individual household. In cable modem service, the thick coaxial cable in the neighborhood is shared by many subscribers. Yet typically, cable modem service provides faster service to individual customers than ADSL. How can this be? Hint: Draw a picture of the entire situation for both ADSL and cable modem service.

10-4. a) What wired WAN technologies are growing? b) Why will leased lines continue to be important even if networks of leased lines are no longer used?

Hands-On

10-5. If you have a smartphone, download an app to tell your data transmission throughput. What did you find?

Perspective Questions

10-6. What was the most surprising thing in this chapter for you?

10-7. What was the most difficult part of this chapter for you?