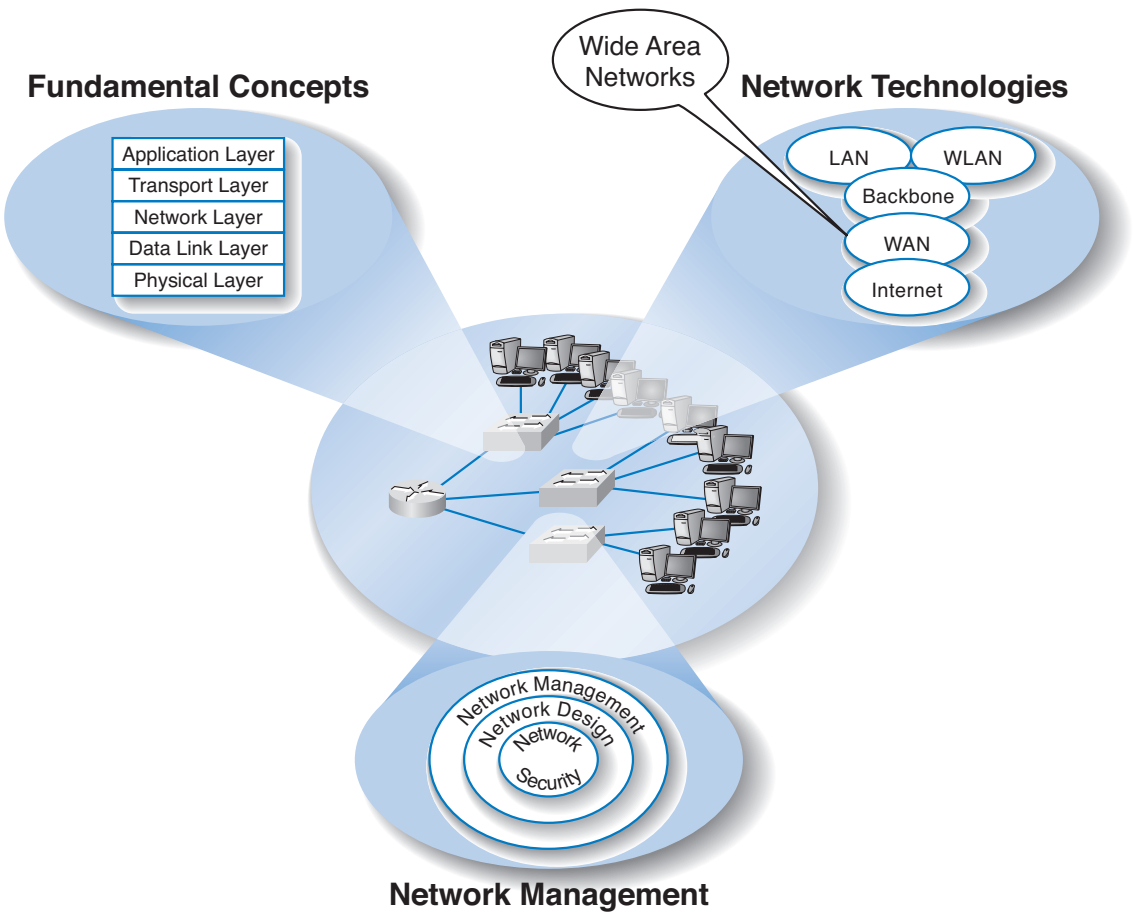
CHAPTER 9

# METROPOLITAN AND WIDE AREA NETWORKS




## The Three Faces of Networking

**MOST ORGANIZATIONS** do not build their own metropolitan or long-distance communication circuits, preferring instead to lease them from common carriers or to use the Internet. Therefore, this chapter focuses on the MAN/WAN architectures and telecommunications services offered by common carriers for use in MANs and WANs, not the underlying technology that the carriers use to provide them. We discuss the four principal types of MAN and WAN services that are available: circuit-switched services, dedicated-circuit services, packet-switched services, and virtual private network (VPN) services. We conclude by discussing how to improve MAN and WAN performance and how to select services to build MANs and WANs.

## OBJECTIVES

- Understand circuit-switched services and architectures
- Understand dedicated-circuit services and architectures
- Understand packet-switched services and architectures
- Understand VPN services and architectures
- Understand the best practice recommendations for MAN/WAN design
- Be familiar with how to improve MAN and WAN performance

## CHAPTER OUTLINE

## INTRODUCTION

Metropolitan area networks (MANs) typically span between 3 and 30 miles and connect BNs and LANs. MANs also provide dial-in and dial-out capability to LANs, BNs, and mainframes and access to the Internet. WANs connect BNs and MANs across longer distances, often hundreds or thousands of miles.

The communication media used in MANs and WANs were described in Chapter 3 (e.g., twisted-pair, wire coaxial cable, fiber optics, microwave, satellite, infrared). Although some organizations build their own MANs and WANs using these media, most do not. Most organizations cannot afford to lay long stretches of cable, build microwave towers, or lease satellites. Instead, most rent or lease circuits from *common carriers,* private companies such as AT&T, Bell Canada, Sprint, BellSouth, and so on that sell or lease communication services and facilities to the public. As a customer, you do not lease physical cables per se; you simply lease circuits that provide certain transmission characteristics. The carrier decides whether it will use twisted-pair, coaxial, fiber optics, or other media for its circuits.

In this chapter, we examine the MAN and WAN architectures and technologies from the viewpoint of a network manager, rather than that of a common carrier. We focus less on internal operations and how the specific technologies work, and more on how these services are offered to network managers and how they can be used to build networks because network managers are less concerned with how the services work and more concerned with how they can use them effectively.

Likewise, we will focus on MAN and WAN services in North America because the majority of our readers are in North America. Although there are many similarities in the

way data communications networks and services have evolved in different countries, there also are many differences. Most countries have a federal government agency that regulates data and voice communications. In the United States, the agency is the *Federal Communications Commission (FCC);* in Canada, it is the *Canadian Radio-Television and Telecommunications Commission (CRTC).* Each state or province also has its own *public utilities commission (PUC)* to regulate communications within its borders.

Common carriers are profit oriented, and their primary products are services for voice and data transmissions, both over traditional wired circuits as well as cellular services. Common carriers often supply a broad range of computer-based services, such as the manufacturing and marketing of specialized communication hardware and software. A common carrier that provides local telephone services (e.g., BellSouth) is commonly called a *local exchange carrier (LEC),* whereas one that provides long-distance services (e.g., AT&T) is commonly called an *interexchange carrier (IXC).* As the LECs move into the long-distance market and IXCs move into the local telephone market, this distinction may disappear.

## CIRCUIT-SWITCHED NETWORKS

Circuit-switched networks are the oldest and simplest approach to MAN and WAN circuits. These services operate over the *public switched telephone network (PSTN);* that is, the telephone networks operated by the common carriers such as AT&T, BellSouth, and so on. When you telephone someone, you are using the PSTN. The first service we will discuss is the standard dial-up service you use when you call an ISP with a dial-up modem—but first we need to discuss the basic architecture shared by all circuit-switched services.

### Basic Architecture

*Circuit-switched services* use a *cloud architecture.* The users lease connection points (e.g., telephone lines) into the common carrier's network, which is called the *cloud*[1] (Figure 9.1). A person (or computer) dials the telephone number of the destination computer and establishes a temporary circuit between the two computers. The computers exchange data, and when the task is complete, the circuit is disconnected (e.g., by hanging up the phone).

This architecture is very flexible. Circuits can be established as needed between any computers attached to the cloud at any point. However, data can be transmitted only while a circuit is established, and only to the one location it connects to. If a computer needs to send data to a number of other locations, a series of temporary circuits must be established with and later disconnected from each location, one after another. In general, only a limited number of circuits can be established from or to any one location at a time (e.g., each location has only so many telephone lines).

[1]It is called a cloud because what happens inside the common carrier's network is hidden from view. Network managers really don't care how the common carrier switches the circuit inside their network, just as long as the network is fast, accurate, and reliable.

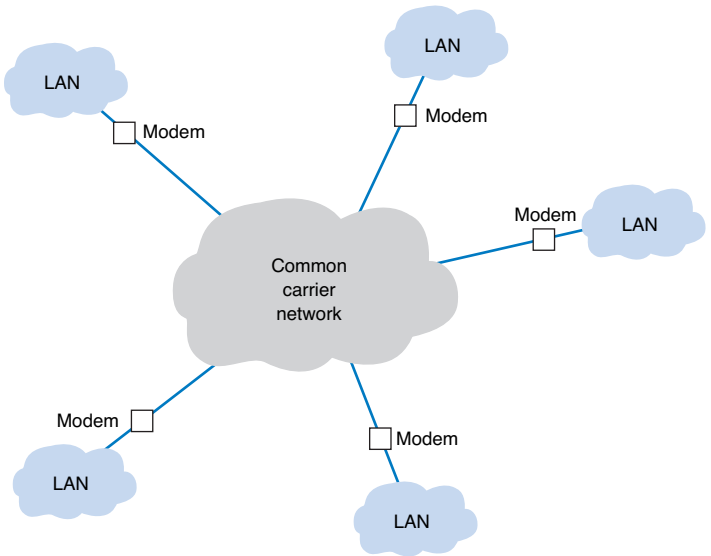



**FIGURE 9.1** Dialed circuit services. LAN = local area network.

Cloud-based designs are simpler for the organization because they move the burden of network design and management inside the cloud from the organization to the common carrier. Network managers do not need to worry about the amount of traffic sent between each computer; they just need to specify the amount of traffic entering and leaving each computer and buy the appropriate size and number of connections into the PSTN. However, this comes at a price. Cloud-based designs can be more expensive because users must pay for each connection into the network and pay on the basis of the amount of time each circuit is used. Cloud-based designs are often used when network managers are uncertain of network demand, particularly in a new or rapidly growing network.

There are two basic types of switched-circuit services in use today: POTS and ISDN.

## Plain Old Telephone Service

*Plain old telephone service* (POTS) is the name for the dial-up services you or your parents used at one time. To use POTS, you need to lease a circuit into the network (i.e., a telephone line) and install special equipment (i.e., a modem) to enable your computer to talk to the PSTN. To transfer data to and from another computer on the network, you instruct your modem to dial the other computer's telephone. Once the modem in your computer connects to the modem at the other end, you can transfer data back and forth. When you are done, you hang up and can then call another computer if you wish. Today, POTS is most commonly used to connect to the Internet, but you can also use it to communicate directly with a private non-Internet server.

POTS may use different circuit paths between the two computers each time a number is dialed. Some circuits have more noise and distortion than others, so the quality and maximum data transmission rate can vary.

Charges for direct dialing are based on the distance between the two telephones (in miles) and the number of minutes the connection is used. Data communications users pay the same rate as voice communications users. In general, most local calls are free, but this depends on the type of local telephone service you have purchased. Long-distance calls are charged at the rate for which you have contracted with your long-distance carrier.

*Wide area telephone services (WATSs)* are special-rate services that allows calls for both voice communications and data transmission to be purchased in large quantities. For example, you might purchase 100 hours of usage per month for one fixed rate and be charged so many dollars per hour thereafter.

## ISDN

The first generation of *integrated services digital network (ISDN)* combines voice, video, and data over the same digital circuit. Because there is a newer version of ISDN, the original version is occasionally called *narrowband ISDN,* but we will just use the term ISDN. ISDN is widely available from a number of common carriers in North America.

To use ISDN, users first need to lease connection points in the PSTN, which are telephone lines just like POTS. Next, they must have special equipment to connect their computers (or networks) into the PSTN. Users need an ISDN *network terminator* (NT-1 or NT-2) that functions much like a hub, and a NIC (called a *terminal adapter [TA]* or even an "ISDN modem") in all computers attached to the NT-1/NT-2. In most cases, the ISDN service appears identical to the regular dialed telephone service, with the exception that usually (but not always) each device attached to the NT-1/NT-2 needs a unique *service profile identifier (SPID)* to identify it. To connect to another computer using ISDN, you dial that computer's telephone number using the ISDN NIC in much the same way as you would with a modem on a regular telephone line.

ISDN has long been more of a concept than a reliable service in North America. It has been available since the late 1970s, although it has not been widely adopted. Its largest problems are a lack of standards and a lack of interest from common carriers. Acceptance of ISDN has also been slowed because equipment vendors and common carriers have conflicting interpretations of the ISDN standards and because the data rates it offers are low compared with newer services. Skeptics claim that ISDN actually stands for "I still don't know," "I still don't need it" or "It still does nothing." ISDN offers two types of "normal" or narrowband service, plus one higher-speed broadband service.

### Basic Rate Interface

*Basic rate interface (BRI)* (sometimes called basic access service or 2*B*+*D*) provides a communication circuit with two 64-Kbps digital transmission channels (called B channels) and one 16-Kbps control signaling channel (called a D channel). The two B channels handle digitized voice, data, and image transmissions, providing a total of 128 Kbps. The D channel is used for control messages such as acknowledgments, call setup and termination, and other functions such as automatic number identification. Some common carriers sell just one single 64-Kbps channel to those customers needing less capacity than full BRI.

One advantage of BRI is that it can be installed in many existing telephone locations without adding any new cable. If the connection from the customer's telephone to the common carrier's end office is less than 3.5 miles, the ISDN line can use the existing two

pairs of twisted-pair wires. The only changes are the end connections at the customer's location and at the carrier's end office. If the connection is longer than 3.5 miles, then new cable will have to be laid.

***Primary Rate Interface*** *Primary rate interface (PRI)* (also called primary access service or 23*B*+*D*) is typically offered to commercial customers. It consists of 23 64-Kbps B channels plus 1 64-Kbps D channel. PRI has almost the same capacity as a T1 circuit (1.544 Mbps). In Europe, PRI is defined as 30 B channels plus 1 D channel, making interconnection between America and Europe difficult.

***Broadband Integrated Services Digital Network*** *Broadband ISDN (B-ISDN)* is very different from narrowband ISDN—so different, in fact, that it really is not ISDN. It is a circuit-switched service, but B-ISDN uses ATM to move data from one end point to the other. B-ISDN is backward-compatible with narrowband ISDN, which means it can accept narrowband BRI and PRI transmissions. B-ISDN currently defines three services. The first is a full-duplex channel that operates at 155.52 Mbps; the second provides a full-duplex channel that operates at 622.08 Mbps; and the third is an asymmetrical service with two simplex channels, one from the subscriber at 155.52 Mbps and one from the host to the subscriber at 622.08 Mbps. The first two services are intended for normal bidirectional information exchange. The third (asymmetrical) service is intended to be used for information distribution services such as digital broadcast television.

## DEDICATED CIRCUIT NETWORKS

There are three main problems with POTS and ISDN circuit-switched networks. First, each connection goes through the regular telephone network on a different circuit. These circuits may vary in quality, meaning that although one connection will be fairly clear, the next call may be noisy. Second, the data transmission rates on these circuits are usually low. Generally speaking, transmission rates range from 28.8 Kbps to 56 Kbps for dialed POTS circuits to 128 Kbps to 1.5 Mbps for ISDN circuits. Third, you usually pay per use for circuit-switched services. One alternative is to establish a dedicated circuit network, in which the user leases circuits from the common carrier for his or her exclusive use 24 hours per day, 7 days per week.

### Basic Architecture

With a dedicated circuit network, you lease circuits from common carriers. All connections are point to point, from one building in one city to another building in the same or a different city. The carrier installs the circuit connections at the two end points of the circuit and makes the connection between them. The circuits still run through the common carrier's cloud, but the network behaves as if you have your own physical circuits running from one point to another (Figure 9.2).

Once again, the user leases the desired circuit from the common carrier (specifying the physical end points of the circuit) and installs the equipment needed to connect computers and devices (e.g., routers or switches) to the circuit. This equipment may include multi-

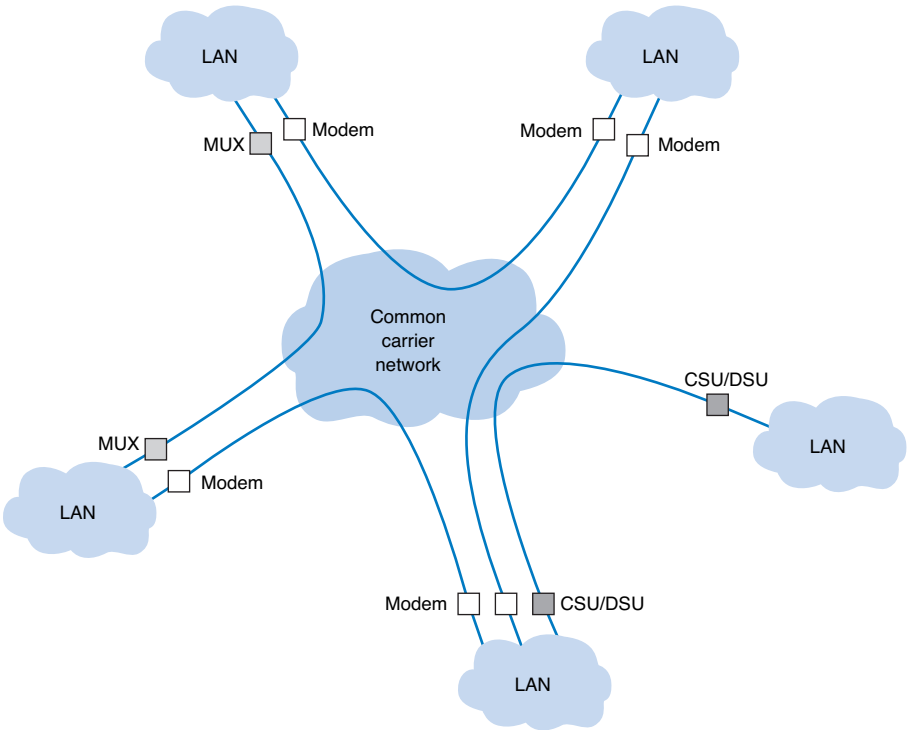



**FIGURE 9.2** Dedicated circuit services. CSU = channel service unit; DSU = data service unit; MUX = multiplexer.

plexers or a *channel service unit* (CSU) and/or a *data service unit (DSU);* a CSU/DSU is the WAN equivalent of a NIC in a LAN.

Unlike circuit-switched services that typically use a pay-per-use model, dedicated circuits are billed at a flat fee per month, and the user has unlimited use of the circuit. Once you sign a contract, making changes can be expensive because it means rewiring the buildings and signing a new contract with the carrier. Therefore, dedicated circuits require more care in network design than do switched circuits, both in terms of locations and the amount of capacity you purchase.

There are three basic architectures used in dedicated circuit networks: ring, star, and mesh. In practice, most networks use a combination of architectures. For example, a *distributed star architecture* has a series of star networks that are connected by a mesh or ring architecture.

***Ring Architecture*** A *ring architecture* connects all computers in a closed loop with each computer linked to the next (Figure 9.3). The circuits are full-duplex or half-duplex circuits, meaning that messages flow in both directions around the ring. Computers in the ring may send data in one direction or the other, depending on which direction is the shortest to the destination.

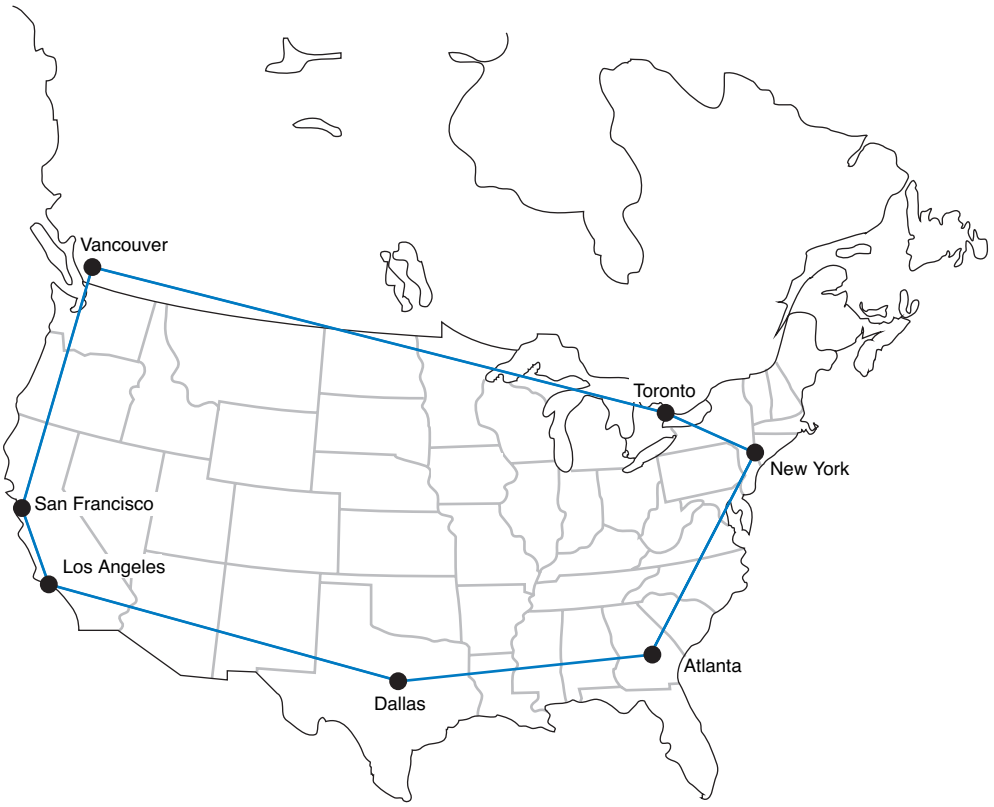



**FIGURE 9.3** Ring-based design.

One disadvantage of the ring topology is that messages can take a long time to travel from the sender to the receiver. Messages usually travel through several computers and circuits before they reach their destination, so traffic delays can build up very quickly if one circuit or computer becomes overloaded. A long delay in any one circuit or computer can have significant impacts on the entire network.

In general, the failure of any one circuit or computer in a ring network means that the network can continue to function. Messages are simply routed away from the failed circuit or computer in the opposite direction around the ring. However, if the network is operating close to its capacity, this will dramatically increase transmission times because the traffic on the remaining part of the network may come close to doubling (because all traffic originally routed in the direction of the failed link will now be routed in the opposite direction through the longest way around the ring).

***Star Architecture*** A *star architecture* connects all computers to one central computer that routes messages to the appropriate computer (Figure 9.4). The star topology is easy to manage because the central computer receives and routes all messages in the network. It can also be faster than the ring network because any message needs to travel through at most two circuits to reach its destination, whereas messages may have to travel

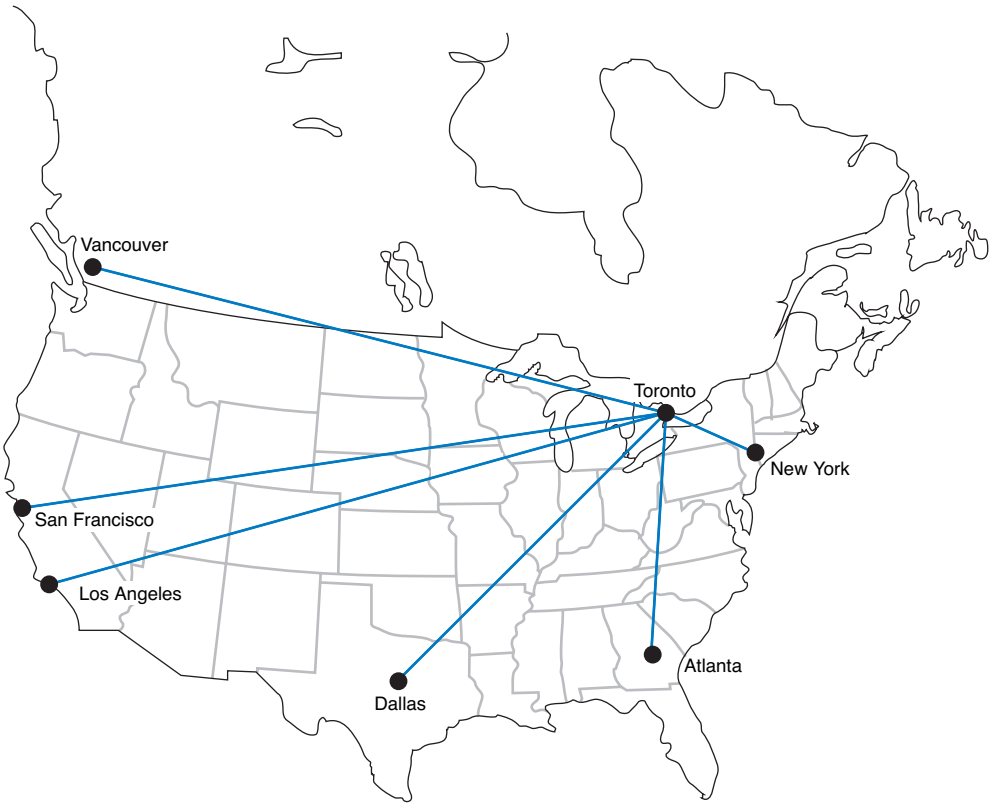


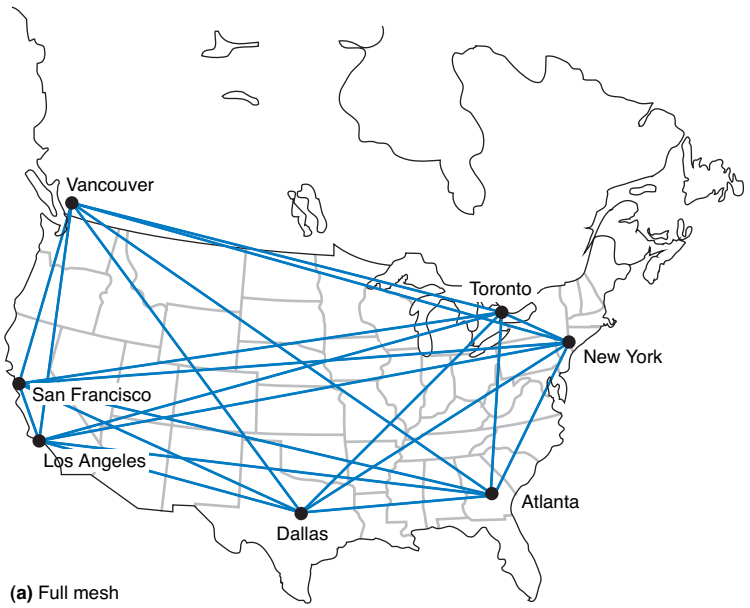

**FIGURE 9.4** Star-based design.

through far more circuits in the ring network. However, the star topology is the most susceptible to traffic problems because the central computer must process all messages on the network. The central computer must have sufficient capacity to handle traffic peaks, or it may become overloaded and network performance will suffer.

In general, the failure of any one circuit or computer affects only the one computer on that circuit. However, if the central computer fails, the entire network fails because all traffic must flow through it. It is critical that the central computer be extremely reliable.

***Mesh Architecture*** In a *full-mesh architecture,* every computer is connected to every other computer (Figure 9.5a). Full-mesh networks are seldom used because of the extremely high cost. *Partial-mesh architecture (*usually called just *mesh architecture),* in which many, but not all, computers are connected, is far more common (Figure 9.5b). Most WANs use partial-mesh topologies.

The effects of the loss of computers or circuits in a mesh network depend entirely on the circuits available in the network. If there are many possible routes through the network, the loss of one or even several circuits or computers may have few effects beyond the specific computers involved. However, if there are only a few circuits in the network, the loss of even one circuit or computer may seriously impair the network.




**(a)** Full mesh


**(b)** Partial mesh

**FIGURE 9.5** Mesh design.

In general, mesh networks combine the performance benefits of both ring networks and star networks. Mesh networks usually provide relatively short routes through the network (compared with ring networks) and provide many possible routes through the network to prevent any one circuit or computer from becoming overloaded when there is a lot of traffic (compared with star networks in which all traffic goes through one computer).

The drawback is that mesh networks use decentralized routing so that each computer in the network performs its own routing. This requires more processing by each computer in the network than in star or ring networks. Also, the transmission of network status information (e.g., how busy each computer is) "wastes" network capacity.

There are two types of dedicated-circuit services in common use today: T carrier services and synchronous optical network (SONET) services. Both T carrier and SONET have their own data link protocols, which are beyond the focus of this chapter.

## T Carrier Services

*T carrier circuits* are the most commonly used form of dedicated circuit services in North America today. As with all dedicated circuit services, you lease a dedicated circuit from one building in one city to another building in the same or different city. Costs are a fixed amount per month, regardless of how much or how little traffic flows through the circuit. There are several types of T carrier circuits (Figure 9.6).

A *T1 circuit* (also called a DS1 circuit) provides a data rate of 1.544 Mbps. T1 circuits can be used to transmit data but often are used to transmit both data and voice. In this case, inverse TDM provides 24 64-Kbps circuits.[2] Digitized voice using PCM requires a 64-Kbps circuit (see Chapter 3), so a T1 circuit enables 24 simultaneous voice channels. Most common carriers make extensive use of PCM internally and transmit most of their voice telephone calls in digital format using PCM, so you will see many digital services offering combinations of the standard PCM 64-Kbps circuit.

A *T2 circuit,* which transmits data at a rate of 6.312 Mbps, is an inverse multiplexed bundle of four T1 circuits. A *T3 circuit* allows transmission at a rate of 44.736 Mbps although most articles refer to this rate as 45 megabits per second. This is equal to the capacity of 28 T1 circuits. T3 circuits are becoming popular as the transmission medium for corporate MANs and WANs because of their higher data rates. At low speed, these T3 circuits can be used as 672 different 64-Kbps channels or voice channels. A *T4 circuit* transmits at 274.176 Mbps, which is equal to the capacity of 178 T1 circuits.

*Fractional T1,* sometimes called *FT1,* offers portions of a 1.544-Mbps T1 circuit for a fraction of its full cost. Many (but not all) common carriers offer sets of 64 Kbps DS-0

| T Carrier Designation | DS Designation | Speed |
|---|---|---|
| FT1 | DS0 | 64 Kbps |
| T1 | DS1 | 1.544 Mbps |
| T2 | DS2 | 6.312 Mbps |
| T3 | DS3 | 44.376 Mbps |
| T4 | DS4 | 274.176 Mbps |

**FIGURE 9.6** T carrier services.

[2]If you multiply 24 circuits by 64 Kbps per circuit, you will get 1.536 Mbps, not 1.544 Mbps. This is because some of the 1.544-Mbps circuit capacity is used by the common carrier for control signals used to frame the data (i.e., mark the start and stop of packets).

| SONET Designation | SDH Designation | Speed |
|---|---|---|
| OC-1 | | 51.84 Mbps |
| OC-3 | STM-1 | 155.52 Mbps |
| OC-9 | STM-3 | 466.56 Mbps |
| OC-12 | STM-4 | 622.08 Mbps |
| OC-18 | STM-6 | 933.12 Mbps |
| OC-24 | STM-8 | 1.244 Gbps |
| OC-36 | STM-12 | 1.866 Gbps |
| OC-48 | STM-16 | 2.488 Gbps |
| OC-192 | STM-24 | 9.953 Gbps |

**FIGURE 9.7** SONET (synchronous optical network) and SDH (synchronous digital hierarchy) services. OC = optical carrier (level); STM = synchronous transport module.

channels as FT1 circuits. The most common FT1 services provide 128 Kbps, 256 Kbps, 384 Kbps, 512 Kbps, and 768 Kbps.

### Synchronous Optical Network

The *synchronous optical network (SONET)* is the American standard (ANSI) for high-speed dedicated circuit services. The ITU-T recently standardized an almost identical service that easily interconnects with SONET under the name *synchronous digital hierarchy (SDH).*

SONET transmission speeds begin at the OC-1 level (optical carrier level 1) of 51.84 Mbps. Each succeeding rate in the SONET fiber hierarchy is defined as a multiple of OC-1, with SONET data rates defined as high as OC-192, or about 10 Gbps. Figure 9.7 presents the other major SONET and SDH services. Each level above OC-1 is created by an inverse multiplexer. Notice that the slowest SONET transmission rate (OC-1) of 51.84 Mbps is slightly faster than the T3 rate of 44.376 Mbps.

## PACKET-SWITCHED NETWORKS

*Packet-switched networks* are quite different from the two types of networks discussed previously. For both circuit-switched and dedicated circuit networks, a circuit was established between the two communicating computers. This circuit provided a guaranteed data transmission capability that was available for use by only those two computers.

For example, if computer A is to transmit data using an ISDN BRI connection to computer B, the connection at both A and B must be available. Once in use for this transmission, it is assigned solely to that transmission. No other transmission is possible until the circuit is closed. So, for example, if computer C attempts to reach computer B, it will have to wait until the circuit is closed. In contrast, packet-switched services enable multiple connections to exist simultaneously between computers over the same physical circuit, just like LANs and BNs.

**MANAGEMENT FOCUS** **9-1 CAREGROUP'S DEDICATED CIRCUIT NETWORK**

CareGroup Healthcare System operates six hospitals in the Boston area and uses a metropolitan area network (MAN) and wide area network to connect them together to share clinical data (Figure 9.8). The three major hospitals have relatively high data needs and therefore are connected to one another and the main data center via a MAN that uses a set of SONET OC-1 circuits in a ring architecture.

The other three hospitals, with lower data needs, are connected to the data center via a set of T3 circuits in a star architecture. The data center also has a T3 connection into the Internet to enable its 3,000 or so doctors to access clinical data from their private practice offices or from home.

SOURCE: "Using the Web to Extend Patient Care," *Network World,* May 29, 2000.

## Basic Architecture

With packet-switched services, the user again buys a connection into the common carrier cloud (Figure 9.9). The user pays a fixed fee for the connection into the network (depending on the type and capacity of the service) and is charged for the number of packets transmitted.

The user's connection into the network is a *packet assembly/disassembly device (PAD),* which can be owned and operated by the customer or by the common carrier. The PAD converts the sender's data into the network layer and data link layer packets used by the packet network and sends them through the packet-switched network. At the other end, another PAD

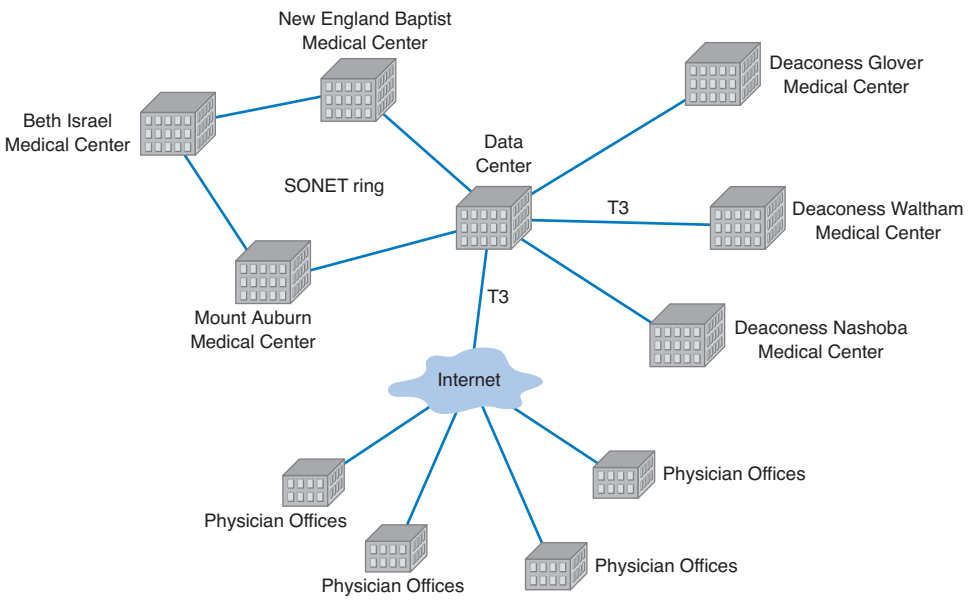



**FIGURE 9.8** CareGroup's metropolitan and wide area networks. SONET = synchronous optical network.

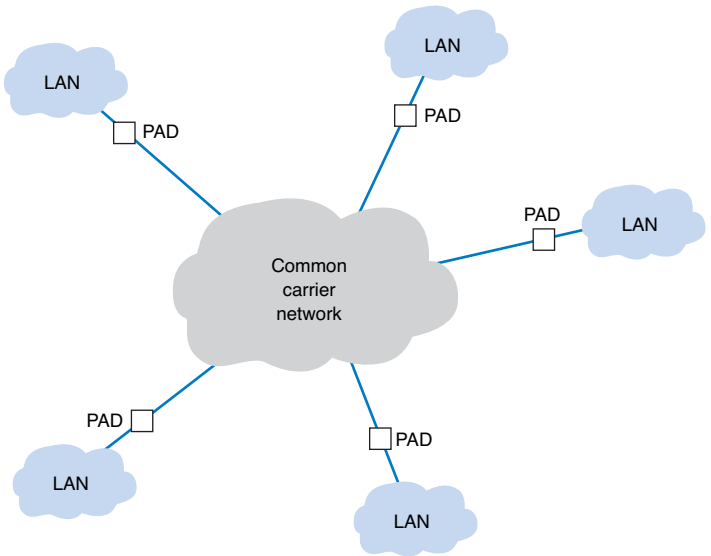



**FIGURE 9.9** Packet-switched services. LAN = local area network; PAD = packet assembly/disassembly device.

reassembles the packets back into the network layer and data link layer protocols expected by the destination and delivers it to the appropriate computer. The PAD also compensates for differences in transmission speed between sender and receiver; for example, the circuit at the sender might be 1.5 Mbps whereas the receiver only has a 64-Kbps circuit.

Packet-switched networks enable packets from separate messages with different destinations to be *interleaved* for transmission, unlike switched circuits and dedicated circuits. Packet switching is popular because most data communications consist of short bursts of data with intervening spaces that usually last longer than the actual burst of data. Packet switching takes advantage of this characteristic by interleaving bursts of data from many users to maximize use of the shared communication network. Figure 9.10 shows a packet-switching connection between six different cities. The little boat-shaped figures (shown on the communication circuits) represent individual packets from separate messages.

Although the packets in one data stream may mix with several other data streams during their journey, it is unlikely that packets from two different data streams will travel together during the entire length of their transmission. The two communicating computers do not need to know through which intermediate devices their data are routed because the packet network takes care of it by either of two methods.

The first method, called *datagram,* is a connectionless service. It adds a destination address and sequence number to each packet, in addition to information about the data stream to which the packet belongs. In this case, a route is chosen for each packet as it is accepted into the packet network. Each packet may follow a different route through the network. At the destination address, the sequence number tells the network how to reassemble the packets into a continuous message. The sequence number is necessary because different routes may deliver packets at different speeds, so data packets often arrive out of sequence. Few networks today use datagrams for data transfer.

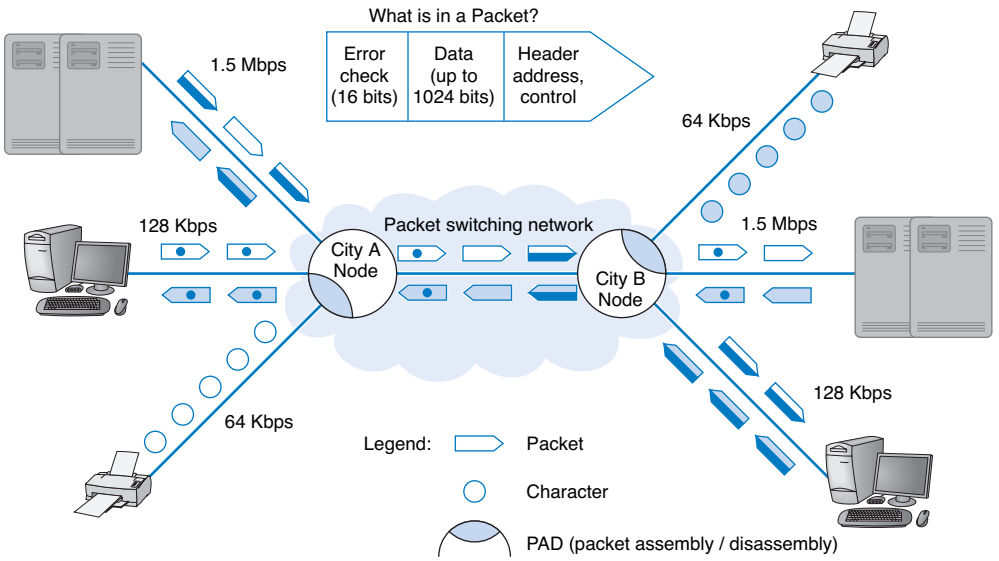



**FIGURE 9.10** Packet-switching concepts.

The second and more common routing method is a connection-oriented approach called a *virtual circuit.* In this case, the packet-switched network establishes what appears to be one end-to-end circuit between the sender and receiver. All packets for that transmission take the same route over the virtual circuit that has been set up for that particular transmission. The two computers believe they have a dedicated point-to-point circuit, but in fact, they do not.

Virtual circuits are usually *permanent virtual circuits (PVCs),* which means that they are defined for frequent and consistent use by the network. They do not change unless the network manager changes the network. Some common carriers also permit the use of *switched virtual circuits (SVCs)* although this is not usual. Changing PVCs is done using software, but common carriers usually charge each time a PVC is established or removed. It often takes days or weeks to create or take down PVCs although this is mostly due to poor management by common carriers rather than due to technology issues, so this may change.

Because most network managers build packet-switched networks using PVCs, *most packet-switched networks behave like dedicated circuit networks.* At first glance, the basic architecture in Figure 9.9 looks very similar to the cloud mesh of switched-circuit services, and in fact, they are very similar because data can move from any computer attached to the cloud to any other on the cloud. However, because virtually all data-intensive networks use PVCs, this means that the network is actually built using virtual circuits that are the software equivalent of the hardware-based dedicated circuits.

Most common carriers permit users to specify two different types of data rates that are negotiated per connection and for each PVC as it is established. The *committed information rate (CIR)* is the data rate the PVC must guarantee to transmit. If the network accepts the connection, it guarantees to provide that level of service. Most connections also specify a *maximum allowable rate (MAR),* which is the maximum rate that the network will attempt to provide, over and above the CIR. The circuit will attempt to transmit all packets up to the

MAR, but all packets that exceed the CIR are marked as *discard eligible (DE).* If the network becomes overloaded, DE packets are discarded. So although users can transmit more data than the CIR, they do so at a risk of lost packets and the need to retransmit them.

Packet-switched services are often provided by different common carriers than the one from which organizations get their usual telephone and data services. Therefore, organizations often lease a dedicated circuit (e.g., T1) from their offices to the packet-switched network *point of presence (POP).* The POP is the location at which the packet-switched network (or any common carrier network, for that matter) connects into the local telephone exchange.

There are five types of packet-switched services: X.25, ATM, frame relay, switched multimegabit data service, and Ethernet service. Several common carriers (e.g., Sprint) have announced that they intend to stop offering all services except Ethernet and Internet services (see Chapter 10). Other carriers have hinted at the same decision. Over the next few years these technologies may disappear.

## X.25

The oldest packet-switched service is *X.25,* a standard developed by ITU-T. X.25 offers datagram, SVC, and PVC services. X.25 uses the LAP-B data link layer protocol and the PLP network-layer protocol. When packets arrive at the PAD, connecting the user's network to the packet-switched network, their data link (e.g., Ethernet) and network layer (e.g., IP) packets are removed and PLP and LAP-B packets are substituted. Packets are moved through the X.25 network in much the same way as in TCP/IP networks, with the LAP-B packet error checked and replaced at each hop in the network. When they arrive at the edge of the X.25 network, new destination protocols (e.g., Ethernet, IP) are created and the message is sent on its way. X.25 is sometimes called a *reliable packet service* because it provides complete error checking and guaranteed delivery on all packets transmitted.

Although common in Europe, X.25 is not widespread in North America. The primary reason is its transmission speed. For many years, the maximum speed into North American X.25 networks was 64 Kbps, but this has increased to 2.048 Mbps, which is the European standard for ISDN. However, for many users, 2.048 Mbps is still not fast enough.

## Asynchronous Transfer Mode

*Asynchronous transfer mode (ATM),* also standardized, is a newer technology than X.25. ATM for BNs was discussed in the previous chapter. ATM for the MAN and WAN is essentially the same.

ATM is similar to X.25 in that it provides packet-switched services, but it has four distinct operating characteristics that differ from X.25. First, ATM performs encapsulation of packets, so packets are delivered unchanged through the network.

Second, ATM provides no error control in the network; error control is the responsibility of the source and destination. (ATM is considered an *unreliable packet service.*) Because the user's data link packet remains intact, it is simple for the devices at the edge of the ATM network to check the error-control information in the packet to ensure that no errors have occurred and to request transmission of damaged or lost packets. Figure 9.11 illustrates the difference in error control between X.25 networks and ATM networks. The left side shows that when an X.25 packet leaves its source A and moves through node B,

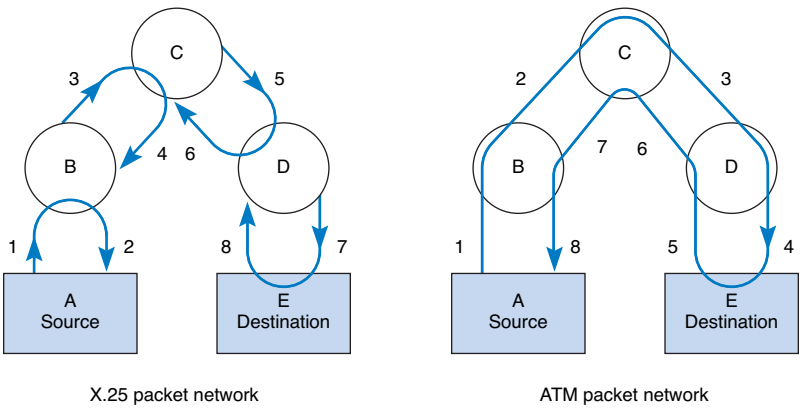



**FIGURE 9.11** Asynchronous transfer mode (ATM) compared with X.25 packet switching. With X.25, each node sends an acknowledgment immediately on receiving a packet. With ATM, the final destination sends an acknowledgment, making this technique faster than the X.25 technique.

to node C, to node D, and finally to destination E, each intermediate node acknowledges the packet as it passes. The right side of the figure shows how an ATM packet moves through node B, node C, node D, and on to destination E. When destination E receives the packet correctly, a single acknowledgment is sent back through the nodes to source A, as shown by the numbers *5, 6, 7,* and *8.* Some common carriers have started using the term *fast packet services* instead to refer to these services that do not provide error control—it sounds better for marketing!

Third, ATM provides extensive QoS information that enables the setting of very precise priorities among different types of transmissions: high priority for voice and video, lower priority for e-mail.

Finally, ATM is scalable; it is easy to multiplex basic ATM circuits into much faster ATM circuits. Most common carriers offer ATM circuits that provide the same data transmission rates as SONET: 51.84 Mbps, 466.56 Mbps, 622.08 Mbps, and so on up to 39 Gbps (OC-768). New versions called T1 ATM (1.544 Mbps) and T3 ATM (45 Mbps) are also available.

## Frame Relay

*Frame relay,* just recently standardized, is an even newer packet-switching technology that transmits data faster than X.25 but slower than ATM; it has sometimes been called a poor man's ATM. Like ATM, frame relay performs encapsulation of packets, so packets are delivered unchanged through the network. Like ATM, it is an unreliable packet service because it does not perform error control. Frame relay checks for errors but simply discards packets with errors. It is up to the software at the source and destination to control for lost messages.

Frame relay does not yet provide QoS capabilities, but this is under development. Different common carriers offer frame relay networks with different transmission speeds.

**MANAGEMENT FOCUS 9-2** **DIGITAL ISLAND'S GLOBAL NETWORK**

Digital Island was formed in 1995 to provide network services for global e-business applications. Its clients include many large global corporations, such as MasterCard, Sega, AOL, MTV, ZDNet, and Cisco.

Digital Island's network is organized as a distributed star network (Figure 9.12). Its six major data centers (Silicon Valley, New York, London, Hong Kong, Tokyo, and Honolulu) are connected via a global ATM network using a mesh architecture of OC-3 and higher permanent virtual circuits. Each of the data centers in turn is connected to a variety of other sites and networks, both client sites and Digital Island offices, over a mix of dedicated lines, including FT1, T1, and T3.

SOURCE: "Digital Island," Cisco Systems, Inc., www.cisco.com.

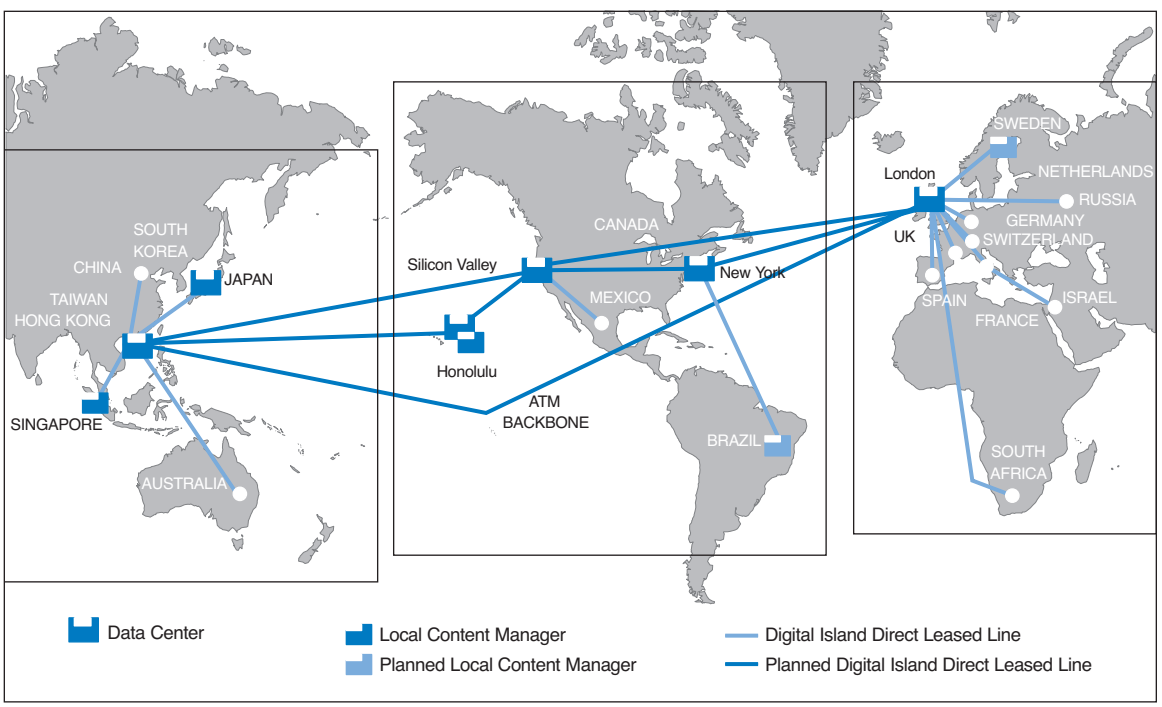



**FIGURE 9.12** Digital Island's wide area network. ATM = asynchronous transfer mode.

Most offer a range of CIR speeds that include 56 Kbps, 128 Kbps, 256 Kbps, 384 Kbps, 1.5 Mbps, 2 Mbps, and 45 Mbps.

## Switched Multimegabit Data Service

*Switched multimegabit data service (SMDS)* is an unreliable packet service like ATM and frame relay. Like ATM and frame relay, SMDS does not perform error checking; the user

### A DAY IN THE LIFE: NETWORKING AND TELECOMMUNICATIONS VICE PRESIDENT

A vice president is a person in an executive-level position whose focus is to set the strategic direction for the organization. A vice president has a very little to do with the day-to-day operations; much like an Admiral in a Navy fleet, he or she defines the direction, but the individual captains running each ship actually make sure that everything that needs to happen gets done.

The vice president works with the chief information officer (CIO) and other executive leadership of the organization to identify the key organizational goals that have implications for the network. The vice president works with his or her staff to revise the strategic networking plan to ensure that the network is capable of supporting the organization's goals. The key elements of the strategic plan are the networking architectures, key technologies, and vendors. Once the strategy has been set, the vice president's job is to instruct the senior managers to execute the strategy and then let them do their jobs.

In most cases, the changes to the networking strategic plan are relatively minor, but sometimes there are dramatic changes that require a major shift in strategic direction. For example, in recent years, we've seen a major change in the fundamental capabilities of network tools and applications. Our architecture strategy during the 1990s was driven by the fact that network management tools were poor and maintenance costs per server were high; the fundamental architecture strategy was to minimize the number of servers. Today, network management tools are much better, maintenance costs per server are significantly lower, and network traffic has changed both in volume and in the number and complexity of services supported (e.g., Web, e-mail, H.323, IPv6); the strategy today is to provide a greater number of servers, each of which is dedicated to supporting one specific type of traffic.

*With thanks to Brian Voss*

is responsible for error checking. As with ATM and frame relay, SMDS encapsulates incoming packets.

SMDS is not yet standardized. At present, not all common carriers offer it. SMDS was originally aimed at MANs, particularly the interconnection of LANs. Recently, it has also made its way into the WAN environment. Regional Bell Operating Companies (RBOCs) offer SMDS at a variety of transmission rates, ranging from 56 Kbps up to 44.376 Mbps. There are no widely accepted standards, so transmissions rates vary by carrier. The future of SMDS is uncertain because it is not standardized and offers no clear advantages over frame relay.

## Ethernet Services

Although we have seen rapid increases in capacities and sharp decreases in costs in LAN and BN technologies, changes in MAN and WAN services offered by common carriers saw only modest changes in the 1990s. That changed in 2000 with the introduction of several Internet startups (e.g., Yipes) offering *Ethernet services.*

Most organizations today use Ethernet and IP in the LAN and BN environment, yet, the MAN/WAN packet network services (X.25, ATM, frame relay, and SMDS) discussed above use different layer-2 protocols. Any LAN or BN traffic, therefore, must be translated or encapsulated into a new protocol and destination addresses generated for the new protocol. This takes time, slowing network throughput. It also adds complexity, meaning

that companies must add staff knowledgeable in the different MAN/WAN protocols, software, and hardware these technologies require. This is one reason many common carriers are starting to call these four technologies "legacy technologies," signaling their demise.

Each of the four preceding packet services uses the traditional PSTN provided by the common carriers such as AT&T and BellSouth. In contrast, Ethernet services bypass the PSTN; companies offering Ethernet services have laid their own gigabit Ethernet fiber-optic networks in large cities. When an organization signs up for service, the packet network company installs new fiber-optic cables from their citywide MAN backbone into the organization's office complex and connects it to an Ethernet switch. The organization simply plugs its network into its Ethernet switch and begins using the service. All traffic entering the packet network must be Ethernet, using IP or MPLS (see Chapter 8).

Currently, Ethernet services offer CIR speeds of 1 Mbps to 40 Gbps, in 1-Mbps increments at about one quarter the cost of traditional packet-switched networks. Because this is an emerging technology, we should see many changes in the next few years.

## VIRTUAL PRIVATE NETWORKS

A *virtual private network (VPN)* provides the equivalent of a private packet-switched network over the public Internet.[3] It involves establishing a series of PVCs that run over the Internet so that the network acts like a set of dedicated circuits over a private packet network.

### Basic Architecture

With a VPN, you first lease an Internet connection at whatever access rate and access technology you choose for each location you want to connect. For example, you might lease a T1 circuit from a common carrier that runs from your office to your *Internet service provider (ISP)*. You pay the common carrier for the circuit and the ISP for Internet access. Then you connect a VPN device (a specially designed router or switch) to each Internet access circuit to provide access from your networks to the VPN. The VPN devices enable you to create PVCs through the Internet that are called *tunnels* (Figure 9.13).

The VPN device at the sender takes the outgoing packet and encapsulates it with a protocol that is used to move it through the tunnel to the VPN device on the other side (see "Virtual Private Network Encapsulation" later in this chapter for a detailed description of this process). The VPN device at the receiver strips off the VPN packet and delivers the packet to the destination network. The VPN is transparent to the users; it appears as though a traditional packet-switched network PVC is in use. The VPN is also transparent to the ISP and the Internet as a whole; there is simply a stream of Internet packets moving across the Internet.

VPNs operate either at layer 2 or layer 3. A *layer-2 VPN* uses the layer-2 packet (e.g., Ethernet) to select the VPN tunnel and encapsulates the entire packet, starting with

[3] Some common carriers and third-party vendors are now providing VPN services that use their own networks rather than the Internet, but by far the majority of VPN services are Internet-based. In the interest of simplicity, we will focus on Internet-based VPN services.

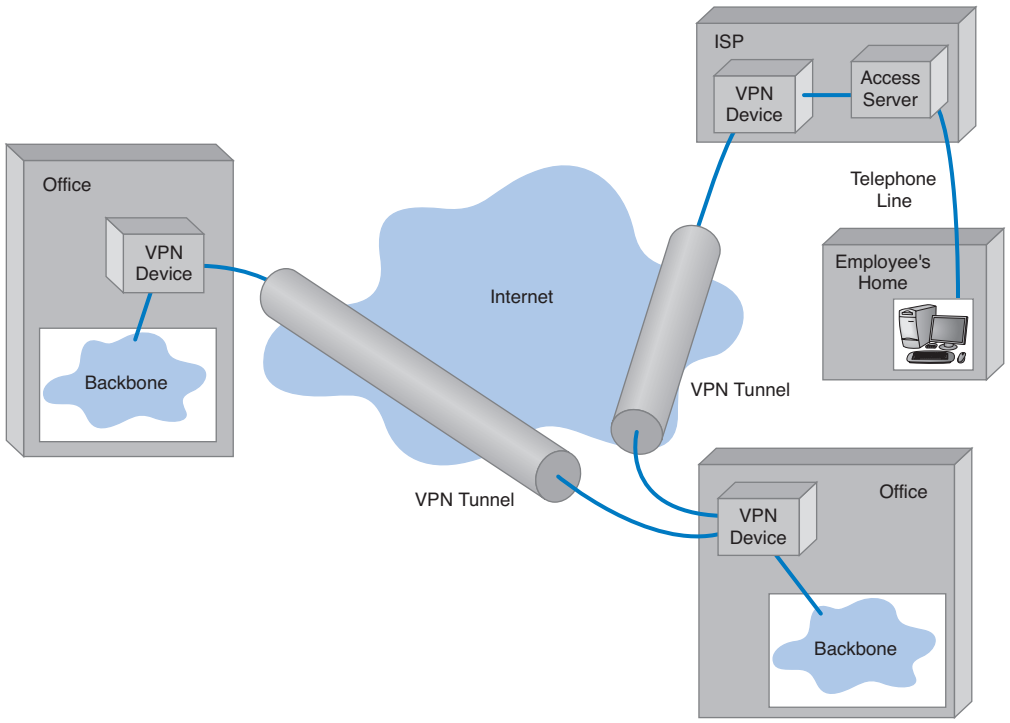



**FIGURE 9.13** A virtual private network (VPN). ISP = Internet service provider.

the layer-2 packet. A *layer-3 VPN* uses the layer-3 packet (e.g., IP) to select the VPN tunnel and encapsulates the entire packet, starting with the layer-3 packet; it discards the incoming layer-2 packet and generates an entirely new layer-2 packet at the destination.

The primary advantages of VPNs are low cost and flexibility. Because they use the Internet to carry messages, the major cost is Internet access, which is inexpensive compared with the cost of circuit-switched services, dedicated circuit services, and packet-switched services from a common carrier. Likewise, anywhere you can establish Internet service, you can quickly put in a VPN.

There are two important disadvantages. First, traffic on the Internet is unpredictable. Sometimes packets travel quickly, but at other times, they take a long while to reach their destination. Although some VPN vendors advertise QoS capabilities, these apply only in the VPN devices themselves; on the Internet, a packet is a packet (at least until Internet 2 becomes more common—see Chapter 10). Second, because the data travels on the Internet, security is always a concern. Most VPN networks encrypt the packet at the source VPN device before it enters the Internet and decrypt the packet at the destination VPN device. (See Chapter 11 for more on encryption.)

At present, there are several different approaches to providing VPN services, each supported by different sets of companies and each moving down the path to standardiza-

**TECHNICAL FOCUS**

### 9-1 Virtual Private Network Encapsulation

When a virtual private network (VPN) device sends packets through an Internet tunnel, it must first encapsulate (i.e., surround) the existing packet with a VPN packet that provides information to the receiving VPN, so that it knows how to process the packet. This encapsulation is conceptually simple and works in much the same way as ATM or frame relay. However, because the packets must travel over the Internet, things become a bit more complex.

At present, there are several competing approaches to managing VPNs, so there are several incompatible VPN protocols used by different vendors. Layer-2 tunneling protocol (L2TP) is an common standard for use by layer-2 access VPNs.

Suppose a user is sending an e-mail message through an access VPN into the corporate network. The user connects to a VPN device at an Internet service provider via a modem over a dial-up circuit (i.e., plain old telephone service). The e-mail client software on the user's computer generates a Simple Mail Transfer Protocol (SMTP) packet at the application layer. The transport and network layers in the client computer add Transmission Control Protocol (TCP) and Internet Protocol (IP) packets, respectively. Point-to-Point Protocol (PPP) is the most commonly used dial-up data link layer protocol, so the packet that arrives at the VPN device is a PPP packet, containing an IP packet, containing a TCP packet, containing an SMTP packet with the e-mail message (see the upper left corner of Figure 9.14).

The VPN device encrypts the incoming packet and encapsulates it with the VPN protocol, L2TP. Now the packet is ready for transmission on the Internet. The protocol on the Internet is TCP/IP, so the VPN device now encapsulates the VPN packet with an IP packet that specifies the IP address of the destination VPN device. Each circuit on the Internet is simply a T1, T3, ATM OC-48, or some other circuit. Each of these circuits has its own data link protocol. So the VPN device then surrounds the IP packet with the appropriate packet for the specific Internet circuit the message will use (e.g., ATM; see Figure 9.14).

The message travels through the Internet and arrives at the destination VPN device at the corporate network, perhaps arriving with a different data link layer packet, depending on the type of connection the corporation has with the Internet (e.g., T3). The VPN device strips off the data link layer packet and the IP packet and processes the L2TP packet. It then decrypts the PPP packet and sends it to the corporate access server for processing. As far as the access server is concerned, the packet arrived from a directly connected dial-up circuit (Figure 9.14).

tion. For the moment, it is important to build VPNs using equipment and services from one set of vendors.

## VPN Types

Three types of VPNs are in common use: intranet VPN, extranet VPN, and access VPN. An *intranet VPN* provides virtual circuits between organization offices over the Internet. The center section of Figure 9.13 illustrates an intranet VPN. Each location has a VPN device that connects the location to another location through the Internet.

An *extranet VPN* is the same as an intranet VPN, except that the VPN connects several different organizations, often customers and suppliers, over the Internet.

An *access VPN* enables employees to access an organization's networks from a remote location. Employees have access to the network and all the resources on it in the

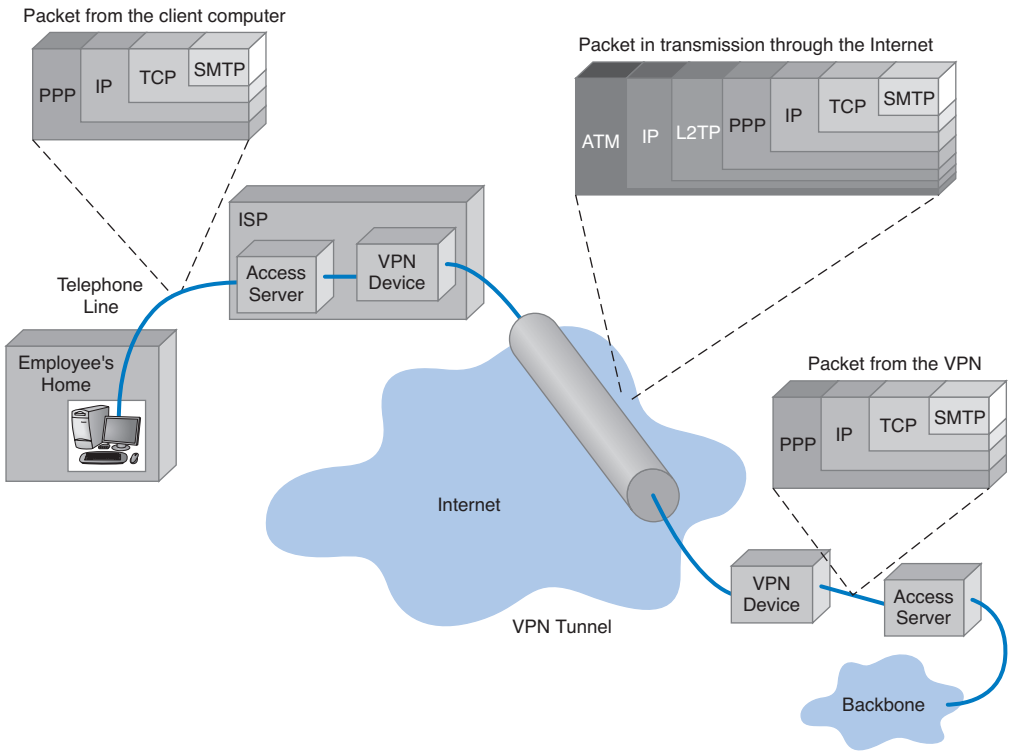



**FIGURE 9.14** Virtual private network (VPN) encapsulation of packets. ATM = asynchronous transfer mode; IP = Internet Protocol; L2TP = layer-2 tunneling protocol; PPP = Point-to-Point Protocol; SMTP = Simple Mail Transfer Protocol; TCP = Transmission Control Protocol.

same way as employees physically located on the network. The upper right part of Figure 9.13 shows an access VPN. The user connects to a local ISP that supports the VPN service via POTS, ISDN, or other circuit. The VPN device at the ISP accepts the user's log-in, establishes the tunnel to the VPN device at the organization's office, and begins forwarding packets over the Internet. An access VPN provides a less expensive connection than having a national toll-free phone number that connects directly into large sets of modems at the organization's office. Compared with a typical ISP-based remote connection, the access VPN is a more secure connection than simply sending packets over the Internet.

## THE BEST PRACTICE MAN/WAN DESIGN

Developing best practice recommendations for MAN and WAN design is more difficult than for LANs and backbones because the network designer is buying services from different companies rather than buying products. The relatively stable environment enjoyed

## MANAGEMENT FOCUS 9-3 ENERGY SCIENCES NETWORK

The Energy Sciences Network serves the U.S. Department of Energy and the thousands of corporate and university scientists doing research for it. It is one of the fastest wide area networks in the world because its users, researching high energy physics, human genomics, and climate modeling, routinely move terabyte-sized files across the network.

The current network uses a mixture of very high speed optical Ethernet services as well as high speed ATM, and moderate speed T3 circuits (see Figure 9.15). The Network has always been an early adopter of new technologies, so the San Francisco ring, currently running at 20 Gbps, will upgrade to 100 Gbps Ethernet within the next 2 years as it becomes available. Likewise, the older ATM portions of the network will gradually move to faster Ethernet services.

SOURCE: "ESnet turns to high-speed optical MANs." *NetworkWorld,* May 23, 2005, p. 12.

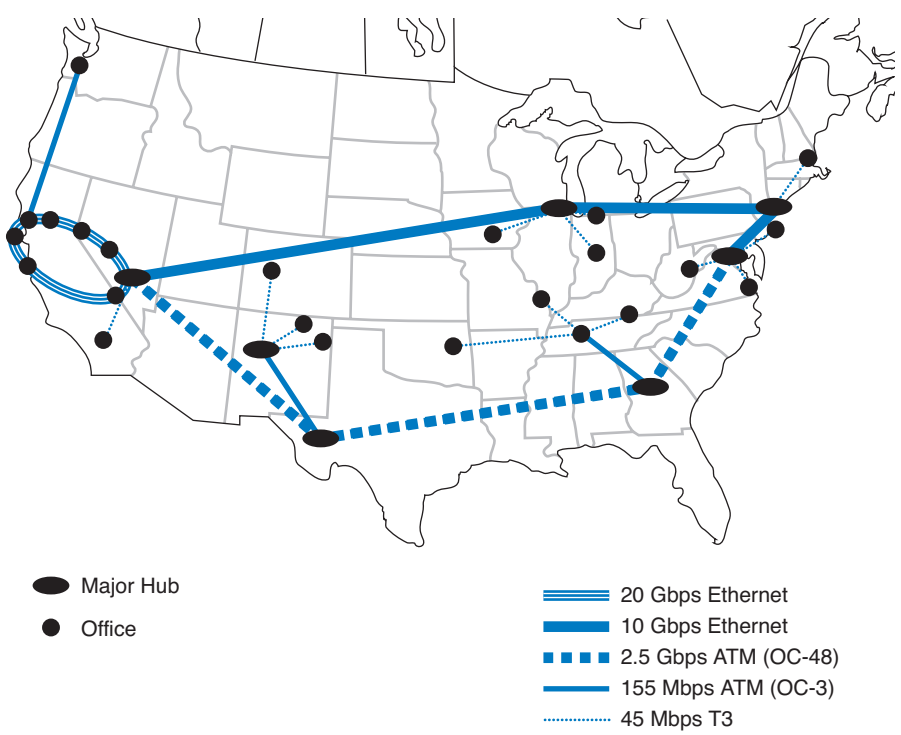



**FIGURE 9.15** Energy Sciences Network.

by the MAN/WAN common carriers is facing sharp challenges by VPNs at the low end and Ethernet services at the high end. As larger IT and equipment firms begin to enter the VPN and Ethernet services markets, we should see some major changes in the industry and in the available services and costs.

We also need to point out that the technologies in this chapter are primarily used to connect different corporate locations. Technologies primarily used for Internet access (e.g., DSL, cable modem) are discussed in the next chapter.

We use the same two factors as we have previously for LANs and backbones (effective data rates and cost), plus add two additional factors: reliability and network integration. Reliability refers to the ability to predictably send messages as expected. Network integration refers to the ease with which the MAN/WAN service can be used to connect LANs and backbones.

Figure 9.16 summarizes the major services available today for the MAN and WAN, grouped by the type of service. A few patterns should emerge from the table. For small MANs and WANs with low data transmission needs, POTS dial-up services are a reasonable alternative. POTS can be more difficult to integrate with LANs and backbones, so this is a good option only if one is willing to use dial-up connections. Since most of this

| Type of Service | Nominal Data Rates | Effective Data Rates | Relative Cost | Reliability | Network Integration |
|---|---|---|---|---|---|
| Circuit-Switched Services | | | | | |
| POTS | 33.6 Kbps to 56 Kbps | 33 to 300 Kbps[1] | Low | High | Difficult |
| ISDN | 128 Kbps to 1.5 Mbps | 122 Kbps to 1.3 Mbps | Moderate | Moderate | Difficult |
| B-ISDN | 155 Mbps to 622 Mbps | 300 Mbps to 1200 Mbps[2] | High | Low | Difficult |
| Dedicated Circuit Services | | | | | |
| T Carrier | 64 Kbps to 274 Mbps | 53 Kbps to 218 Mbps | Moderate | High | Moderate |
| SONET | 50 Mbps to 10 Gbps | 48 Mbps to 9.1 Gbps | High | High | Moderate |
| Packet-Switched Services | | | | | |
| X.25 | 56 Kbps to 2 Mbps | 50 Kbps to 1.5 Mbps | Moderate | High | Difficult |
| ATM | 52 Mbps to 10 Gbps | 84 Mbps to 16 Gbps[3] | High | Moderate | Moderate |
| Frame Relay | 56 Kbps to 45 Mbps | 56 Kbps to 44 Mbps | Moderate | Moderate | Moderate |
| SMDS | 56 Kbps to 45 Mbps | 45 Kbps to 36 Mbps | Moderate | Low | Difficult |
| Ethernet | 1 Mbps to 40 Gbps | 900 Kbps to 36 Gbps | Low | High | Simple |
| VPN Services | | | | | |
| VPN | 56 Kbps to 2 Mbps | 50 Kbps to 1.5 Mbps | Very Low | Low | Moderate |

Notes:
1. Assuming data compression and no noise
2. B-ISDN is full duplex
3. ATM is full duplex

**FIGURE 9.16** MAN/WAN services.

| Network Needs | Recommendation |
|---|---|
| Low Traffic Needs<br>(64 Kbps or less) | POTS if dial-up is acceptable<br>VPN if reliability is less important<br>Frame relay otherwise |
| Moderate Traffic Needs<br>(64 Kbps to 2 Mbps) | VPN if reliability is less important<br>T1 if network volume is stable and predictable<br>Frame relay otherwise |
| High Traffic Needs<br>(2 Mbps to 45 Mbps) | Ethernet if available<br>T3 if network volume is stable and predictable<br>Frame relay otherwise |
| Very High Traffic Needs<br>(45 Mbps to 10 Gbps) | Ethernet if available<br>SONET if network volume is stable and predictable<br>ATM otherwise |

**FIGURE 9.17** Best practice MAN/WAN recommendations.

type of network is used for Internet access, we really need to wait until the next chapter before drawing conclusions.

For networks with moderate data transmission needs (64 Kbps–2 Mbps) there are several distinct choices. If cost is more important than reliability, then a VPN is probably a good choice. If you need flexibility in the location of your network connections and you are not completely sure of the volume of traffic you will have between locations, frame relay is probably a good choice. If you have a mature network with predictable demands, then T carrier services is probably a good choice (Figure 9.17).

For high-traffic networks (2 Mbps–45 Mbps), the new Ethernet services are a dominant choice. Some organizations may prefer the more mature—and therefore proven—T3 or frame relay services, depending on whether the greater flexibility of packet services provides value or a dedicated circuit makes more sense.

For very-high-traffic networks (45 Mbps–10 Gbps), Ethernet services again are a dominant choice. And again some organizations may prefer the more mature ATM or SONET services, depending on whether the greater flexibility of packet services provides value or a dedicated circuit makes more sense.

Unless their data needs are stable, network managers often start with more flexible packet-switched services and move to the usually cheaper dedicated circuit services once their needs have become clear and an investment in dedicated services is safer. Some packet-switched services even permit organizations to establish circuits with a zero-CIR (and rely entirely on the availability of the MAR) so network managers can track their needs and lease only what they need.

Network managers often add a packet network service as an overlay network on top of a network built with dedicated circuits to handle peak data needs; data usually travels over the dedicated circuit network, but when it becomes overloaded with traffic, the extra traffic is routed to the packet network.

# IMPROVING MAN/WAN PERFORMANCE

Improving the performance of MANs and WANs is handled in the same way as improving LAN performance. You begin by checking the devices in the network, by upgrading the circuits between the computers, and by changing the demand placed on the network (Figure 9.18).

## Improving Device Performance

In some cases, the key bottleneck in the network is not the circuits; it is the devices that provide access to the circuits (e.g., routers). One way to improve network performance is to upgrade the devices and computers that connect backbones to the WAN. Most devices are rated for their speed in converting input packets to output packets (called *latency*). Not all devices are created equal; some vendors produce devices with lower latencies than others.

Another strategy is examining the routing protocol, either static or dynamic. Dynamic routing will increase performance in networks that have many possible routes from one computer to another and in which message traffic is "bursty"—that is, in which traffic occurs in spurts, with many messages at one time, and few at others. But dynamic routing imposes an overhead cost by increasing network traffic. In some cases, the traffic and status information sent between computers accounts for more than 50 percent of all WAN message traffic. This is clearly a problem because it drastically reduces the amount of network capacity available for users' messages. Dynamic routing should use no more than 10 to 20 percent of the network's total capacity.

## Improving Circuit Capacity

The first step is to analyze the message traffic in the network to find which circuits are approaching capacity. These circuits then can be upgraded to provide more capacity. Less-used circuits can be downgraded to save costs. A more sophisticated analysis involves

**Performance Checklist**

**Increase Computer and Device Performance**
- Upgrade devices
- Change to a more appropriate routing protocol (either static or dynamic)

**Increase Circuit Capacity**
- Analyze message traffic and upgrade to faster circuits where needed
- Check error rates

**Reduce Network Demand**
- Change user behavior
- Analyze network needs of all new systems
- Move data closer to users

**FIGURE 9.18** Improving performance of metropolitan and local area networks.

**MANAGEMENT FOCUS**

### 9-4 GIGABIT ETHERNET IN THE NETHERLANDS

SURFnet is the national computer network for education and research in the Netherlands. Demand for network capacity had been rapidly growing as more and more students started using the Internet, so SURFnet began looking for a way to significantly upgrade its WAN that connects more than 50 universities, libraries, and research centers.

SURFnet considered implementing SONET or ATM OC-192, but felt that 10Gbps Ethernet provided similar data rates, was more familiar to their customers, and was more scaleable. SURFnet has leased fiber from Amsterdam to major regional centers around the Netherlands (Figure 9.19). Each of these regional centers is a POP and in turn provides connections to other universities, libraries, and research centers in its region, often via a 1 Gbps or 100 Mbps Ethernet MAN or WAN. Sometimes SONET, ATM, or E-carrier services (the European equivalent to T carrier services) are used for the regional connections, depending upon the demand.

SOURCE: "Cisco Helps SURFnet Provide 10 Gigabit Ethernet to Higher Education and Research Community," www.cisco.com, 2004.

examining *why* circuits are heavily used. For example, in Figure 9.3, the circuit from San Francisco to Vancouver may be heavily used, but much traffic on this circuit may not originate in San Francisco or be destined for Vancouver. It may, for example, be going from Los Angeles to Toronto, suggesting that adding a circuit here would improve performance to a greater extent than upgrading the San Francisco-to-Vancouver circuit.

The capacity may be adequate for most traffic but not for meeting peak demand. One solution may be to add a circuit-switched or packet-switched service that is used only when demand exceeds circuit capacity. The use of a service as a backup for heavy traffic provides the best of both worlds. The lower-cost dedicated circuit is used constantly, and the backup service is used only when necessary to avoid poor response times.

Sometimes a shortage of capacity may be caused by a faulty circuit. As circuits deteriorate, the number of errors increases. As the error rate increases, throughput falls because more messages have to be retransmitted. Before installing new circuits, monitor the existing ones to ensure that they are operating properly or ask the common carrier to do it.

## Reducing Network Demand

There are many ways to reduce network demand. One simple step is to require a network impact statement for all new application software developed or purchased by the organization. This focuses attention on the network impacts at an early stage in application development. Another simple approach is to use data compression techniques for all data in the network.

Another sometimes more difficult approach is to shift network usage from peak or high-cost times to lower-demand or lower-cost times. For example, the transmission of detailed sales and inventory reports from a retail store to headquarters could be done after the store closes. This takes advantage of off-peak rate charges and avoids interfering with transmissions requiring higher priority such as customer credit card authorizations.


**FIGURE 9.19** The SURFnet gigabit Ethernet WAN.

The network can be redesigned to move data closer to the applications and people who use them. This also will reduce the amount of traffic in the network. Distributed database applications enable databases to be spread across several different computers. For example, instead of storing customer records in one central location, you could store them according to region.

## IMPLICATIONS FOR MANAGEMENT

As the amount of digital computer data flowing through MANs and WANs has increased and as those networks have become increasingly digital, the networking and telecommunications vice president role has significantly changed over the past five to ten years. Traditionally this vice president has been responsible for computer communications; today in most companies, this individual is also responsible for telephone and voice services.

T carrier, SONET, and ATM have traditionally dominated the MAN and WAN market. However, with the growing use of VPNs and Ethernet services, we are beginning to see a major change. In the early 1990s, the costs of MANs and WANs were quite high. As these networks have changed to increasingly digital technologies, and as competition has increased with the introduction of new companies and new technologies (e.g., VPNs, Ethernet services), costs have begun to drop. More firms are now moving to implement software applications that depend upon low-cost MANs and WANs.

The same factors that caused the LAN and BN to standardize on a few technologies (Ethernet, wireless Ethernet) are now acting to shape the future of the MAN and WAN. We believe that within 5 years, X.25, ATM, and SMDS will disappear, replaced by Ethernet and IP services. Within 10 years, ISDN, T carrier, and SONET may also disappear.

These changes have also had significant impacts on the manufacturers of networking equipment designed for MANs and WANs. Market shares and stock prices have shifted dramatically over the last 5 years in favor of companies with deep experience in backbone technologies (e.g., Ethernet) and Internet technologies (e.g., IP) as those technologies spread into the MAN and WAN market.

## SUMMARY

***Circuit-Switched Networks*** Circuit-switched services enable you to define the end points of the WAN without specifying all the interconnecting circuits through carrier's cloud. The user dials the number of the destination computer to establish a temporary circuit, which is disconnected when the data transfer is complete. POTS is traditional dial-up service. BRI ISDN provides a communication circuit with two 64-Kbps digital transmission channels and one 16-Kbps control channel. PRI ISDN consists of 23 64-Kbps data channels and one 64-Kbps control channel. Broadband ISDN, not yet widely available, offers much faster data speeds up to 622 Mbps.

***Dedicated Circuit Networks*** A dedicated circuit is leased from the common carrier for exclusive use 24 hours per day, 7 days per week. Faster and more noise-free transmissions are possible, but you must carefully plan the circuits you need because changes can be expensive. The three common architectures are ring, star, and mesh. T carrier circuits have a set of digital services ranging from FT1 (64 Kbps) to T1 (1.544 Mbps) to T4 (274 Mbps). A SONET uses fiber optics to provide services ranging from OC-1 (51 Mbps) to OC-12 (622 Mbps).

***Packet-Switched Networks*** Packet switching is a technique in which messages are split into small segments. The user buys a connection into the common carrier cloud and pays a fixed fee for the connection into the network and for the number of packets transmitted. X.25 is an older, traditional service that provides slower service (up to 2 Mbps) but guarantees error-free delivery. ATM does not perform error control, and it offers data rates up to 622 Mbps. Frame relay is a newer packet-switching service with higher data rates (up to 45 Mbps), but it does not perform error control. SMDS is a nonstandardized service that offers data rates up to 45 Mbps. Ethernet services use Ethernet and IP to transmit packets at speeds between 1 Mbps and 1 Gbps.

***VPN Networks*** A VPN provides a packet service network over the Internet. The sender and receiver have VPN devices that enable them to send data over the Internet in encrypted form through a VPN tunnel. Although VPNs are inexpensive, traffic delays on the Internet can be unpredictable.

***The Best Practice MAN/WAN Design*** For small MANs and WANs with low data transmission needs, POTS dial-up services are a reasonable alternative. For networks with moderate data trans-

mission needs (64 Kbps–2 Mbps), a VPN is a good choice if cost is more important than reliability; otherwise, frame relay or T carrier services are good choices. For high-traffic networks (2 Mbps–45 Mbps), the new Ethernet services are a dominant choice, but some organizations may prefer the more mature—and therefore proven—T3 or frame relay services. For very high-traffic networks (45 Mbps–10 Gbps), Ethernet services are a dominant choice but again some organizations may prefer the more mature ATM or SONET services. Unless their data needs are stable, network managers often start with more flexible packet-switched services and move to the usually cheaper dedicated circuit services once their needs have become clear and an investment in dedicated services is safer.

***Improving MAN/WAN Performance*** One can improve network performance by improving the speed of the devices themselves and by using a better routing protocol. Analysis of network usage can show what circuits need to be increased or decreased in capacity, what new circuits need to be leased, and when additional switched circuits may be needed to meet peak demand. Reducing network demand may also improve performance. Including a network usage analysis for all new application software, using data compression, shifting usage to off-peak times, establishing priorities for some applications, or redesigning the network to move data closer to those who use it are all ways to reduce network demand.

## KEY TERMS

access VPN
asynchronous transfer mode (ATM)
available bit rate (ABR)
basic rate interface (BRI)
broadband ISDN (B-ISDN)
Canadian Radio-Television and Telecommunications Commission (CRTC)
channel service unit/data service unit (CSU/DSU)
circuit-switched services
cloud
cloud architecture
committed information rate (CIR)
common carrier
datagram
dedicated circuit services
discard eligible (DE)
distributed star architecture
Ethernet services
extranet VPN
fast packet services
Federal Communications Commission (FCC)
fractional T1 (FT1)
frame relay
integrated services digital network (ISDN)
interexchange carrier (IXC)
Internet service provider (ISP)
intranet VPN
latency
layer-2 VPN
layer-3 VPN
local exchange carrier (LEC)
maximum allowable rate (MAR)
mesh
mesh architecture
narrowband ISDN
network terminator (NT-1, NT-2)
packet assembly/disassembly (PAD)
packet-switched services
permanent virtual circuit (PVC)
plain old telephone service (POTS)
point of presence (POP)
primary rate interface (PRI)
public switched telephone network (PSTN)
public utilities commission (PUC)
regional Bell operating company (RBOC)
reliable packet services
ring architecture
service profile identifier (SPID)
star architecture
switched multimegabit data service (SMDS)
switched virtual circuit (SVC)
synchronous digital hierarchy (SDH)
synchronous optical network (SONET)
T carrier circuit
T1, T2, T3, T4 circuits
terminal adapter (TA)
2B+D
23B+D
unreliable packet services
virtual circuit
virtual private network (VPN)
wide area telephone service (WATS)
X.25

## QUESTIONS

1. What are common carriers, local exchange carriers, and interexchange carriers?
2. Who regulates common carriers and how is it done?
3. Explain how a cloud architecture works.
4. What is POTS?
5. How does ISDN work?
6. Compare and contrast BRI, PRI, and B-ISDN.
7. What is a 2B+D?
8. How does broadband ISDN differ from narrowband ISDN?
9. Compare and contrast circuit-switched services, dedicated circuit services, and packet-switched services.
10. Is a WAN that uses dedicated circuits easier or harder to design than one that uses dialed circuits? Explain.
11. Compare and contrast ring architecture, star architecture, and mesh architecture.
12. What are the most commonly used T carrier services? What data rates do they provide?
13. Distinguish among T1, T2, T3, and T4 circuits.
14. Describe SONET. How does it differ from SDH?
15. How do packet-switching services differ from other WAN services?
16. How is a virtual circuit distinguished from other circuits?
17. Where does packetizing take place?
18. What does a packet contain?
19. How does a reliable packet service differ from an unreliable packet service?
20. How do datagram services differ from virtual circuit services?
21. How does an SVC differ from a PVC?
22. Compare and contrast X.25, frame relay, ATM, SMDS, and Ethernet services.
23. Which is likely to be the longer-term winner, X.25, frame relay, ATM, SMDS, or Ethernet services?
24. Explain the differences between CIR and MAR.
25. How do VPN services differ from common carrier services?
26. Explain how VPN services work.
27. Compare the three types of VPN.
28. How can you improve WAN performance?
29. Describe five important factors in selecting WAN services.
30. Are Ethernet services a major change in the future of networking or a technology blip?
31. Are there any MAN/WAN technologies that you would avoid if you were building a network today? Explain.
32. Suppose you joined a company that had a WAN composed of SONET, T carrier services, ATM, and frame relay, each selected to match a specific network need for a certain set of circuits. Would you say this was a well-designed network? Explain.
33. It is said that packet-switched services and dedicated circuit services are somewhat similar from the perspective of the network designer. Why?

## EXERCISES

**9-1.** Find out the data rates and costs of T carrier and ISDN services in your area.

**9-2.** Find out the data rates and costs of packet-switched and circuit-switched services in your area.

**9-3.** Investigate the MAN or WAN of a company in your area. Draw a network map.

## MINI-CASES

### I. Cookies Are Us

Cookies Are Us runs a series of 100 cookie stores across the midwestern United States and central Canada. At the end of each day, the stores express-mail a diskette or two of sales and inventory data to headquarters, which uses the data to ship new inventory and plan marketing campaigns. The company has decided to move to a WAN. What type of a WAN architecture and WAN service would you recommend? Why?

### II. MegaCorp

MegaCorp is a large manufacturing firm that operates 5 factories in Dallas, 4 factories in Los Angeles, and 5 factories in Albany, New York. It operates a tightly connected order management system that coordinates orders, raw materials, and inventory across all 14 factories. What type of WAN architecture and WAN service would you recommend? Why?

### III. Sunrise Consultancy

Sunrise Consultancy is a medium-sized consulting firm that operates 17 offices around the world (Dallas, Chicago, New York, Atlanta, Miami, Seattle, Los Angeles, San Jose, Toronto, Montreal, London, Paris, Sao Paulo, Singapore, Hong Kong, Sydney, and Bombay). They have been using Internet connections to exchange e-mail and files, but the volume of traffic has increased to the point that they now want to connect the offices via a WAN. Volume is low but expected to grow quickly once they implement a new knowledge management system. What type of a WAN topology and WAN service would you recommend? Why?

### IV. CareGroup

Reread Management Focus 9-1. What other alternatives do you think that CareGroup considered? Why do you think they did what they did?

### V. Digital Island

Reread Management Focus 9-2. What other alternatives do you think that Digital Island considered? Why do you think they did what they did?

### VI. Energy Sciences Network

Reread Management Focus 9-3. What other alternatives do you think that the Energy Sciences Network considered? Why do you think they did what they did?

### VII. SURFnet

Reread Management Focus 9-4. What other alternatives do you think that SURFnet considered? Why do you think they did what they did?

## CASE STUDY

*NEXT-DAY AIR SERVICE*

See the Web site.

## HANDS-ON ACTIVITY

### Examining Wide Area Neworks

There are millions of WANs in the world. Some are run by common carriers and are available to the public. Others are private networks run by organizations for their internal use only. Thousands of these networks have been documented on the Web.

Explore the Web to find networks offered by common carriers and compare the types of network circuits they have. Now do the same for public and private organizations to see what they have. Figure 9.20 shows the network map for Quest (www.qwest.com/about/qwest/network), a large common carrier in the United States. This shows the services offered in each major city, as well as the size of the ATM and T-carrier circuits connecting cities.

Other interesting WAN maps, including dynamic maps, are available from:

Cable and Wireless: www.cw.com/our_network/network_maps

Cogent: www.cogentco.com/htdocs/map.php

Verizon: www.verizonbusiness.com/about/network/global_presence/global/

Sprint/Nextel: www.sprintworldwide.com/english/maps/

VSNL International: www.vsnlinternational.com

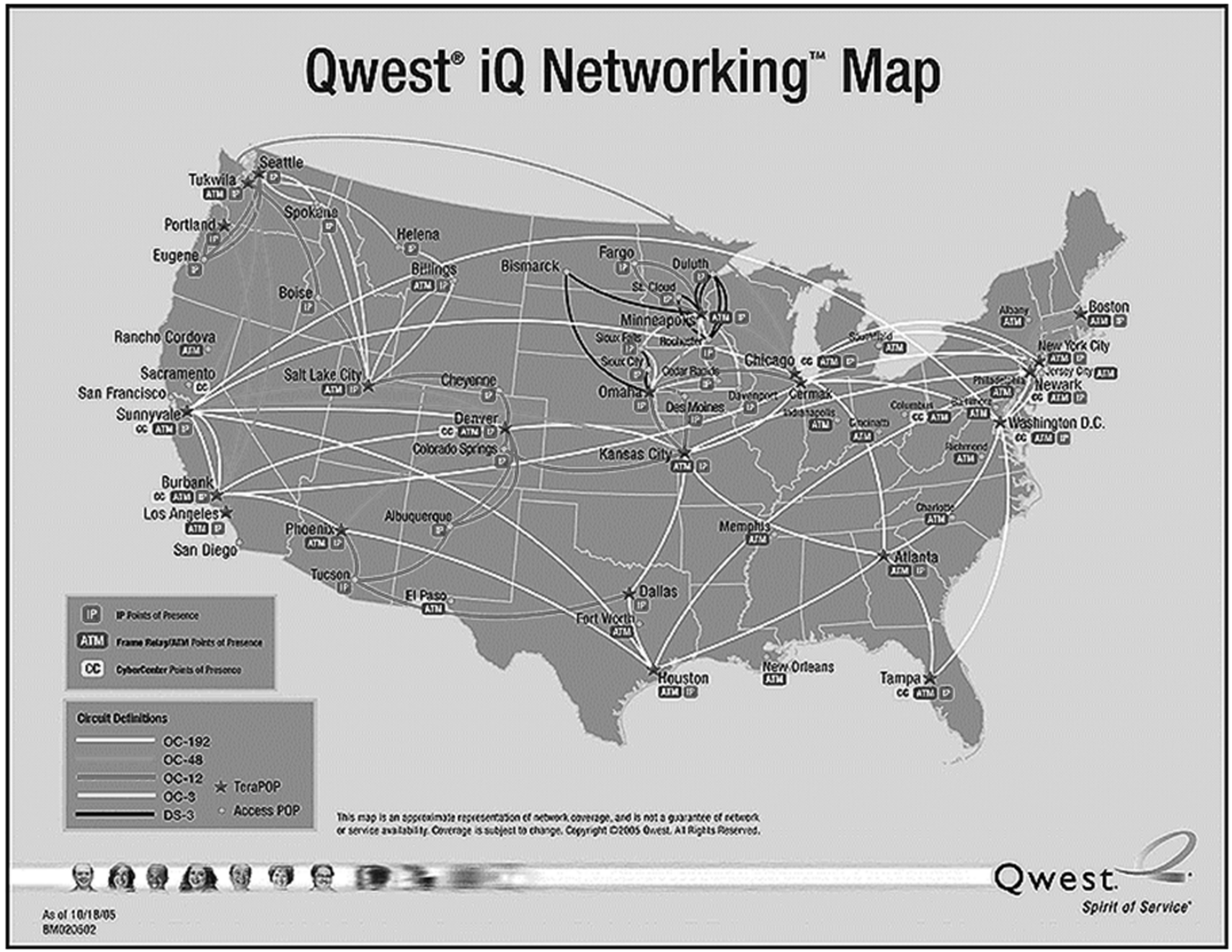



**FIGURE 9.20** The QUEST U.S. WAN.