10

Wide Area Networks

Terms you'll need to understand:

- Analog and digital connections
- Packet and circuit switching
- Public Switched Telephone Network (PSTN)
- Dial-up lines and dedicated (leased) lines
- X.25 Network
- Integrated Services Digital Network (ISDN)
- Frame relay
- T1 and T3 lines
- Switched 56 lines
- Switched Multimegabit Data Services (SMDS)
- Asynchronous Transfer Mode (ATM)
- Fiber Distributed Data Interface (FDDI)
- Synchronous Optical Network (SONET)

Techniques you'll need to master:

- Understanding the differences among WAN technologies
- Implementing various WAN technologies

Sometimes, a local area network (LAN) is not sufficient to completely blanket an organization with communications capabilities. This condition generally occurs when multiple LANs in different geographical areas must be interconnected, or on large campuses or in industrial parks where distance limitations for conventional LAN technologies prevent their use. This chapter discusses wide area network (WAN) technologies used to interconnect such geographically dispersed systems. In this chapter, we concentrate on those WAN issues that are most commonly used in modern networks.

WAN Terminology

As your local area network matures, you will probably notice a decrease in its responsiveness. Excessive use causes printers to slow down, email to take longer, and applications that move large amounts of data across the network to bog down. When this happens to your LAN (not *if*), you should plan for expansion, especially if your company covers a wide geographical area. You can usually interconnect multiple smaller LANs within a single building by using routers, which we'll cover later in this chapter, and bridges, which we introduced in Chapter 5. Likewise, if you have several buildings located close together, you can convert a collection of smaller LANs into one large internetwork using the same kind of equipment. But, when offices are located in multiple cities or across international borders, you must make other arrangements. You are now ready to consider introducing a WAN into the mix.

A wide area network can span a city, a state, a continent, or even the globe. The technologies used to accomplish such a feat are usually quite similar to those used to build LANs, despite their differences in distance and scope. Typically, WANs consist of several LANs interconnected through high-speed communications links, usually called "WAN links." Such WAN links may rely on telephone carriers, cable TV companies, long-haul fiber optic cables, line-of-sight or satellite microwave systems, or long-haul packet-switched networks. Routers and bridges can also work together with other connectivity devices to ensure that data is transmitted quickly, safely, and securely across WAN links. Amazingly, if a WAN is constructed correctly, most users may not even notice that a WAN is involved in the network.

Owning and operating the physical links that comprise a WAN is usually beyond the financial means of most companies, so they typically lease services (and, sometimes, equipment) from communications service providers, also known as communications carriers. Such carriers include local and long-distance telephone companies such as BellSouth or AT&T, cable operators such as Time Warner, and companies that operate long-haul fiber optic networks such as MCI WorldCom. The longer the distance a WAN link spans, in fact, the higher the probability that more than one communications carrier is involved in transporting the signals between the linked sites. Companies pay for such connections—often called leased lines or leased WAN links—month to month.

Leased WAN links generally use one of the following technologies to make the necessary connections:

- Analog connections These use conventional telephone lines, with voice-signaling (modem) technologies
- Digital connections These use digital-grade telephone lines, with digital technologies all the way
- Switched connections These use multiple sets of links between sender and receiver to move data

Switching (as in switched connections) refers to finding a path for data transmission across a number of potential links between sender and receiver. On the other hand, analog and digital connections require a fixed connection to exist, at least for the duration of each communication session. Switching methods include both circuit switching and packet switching. Essentially, when data is received on an incoming line, the switching device must find an appropriate outgoing line on which to forward it. These switching devices are usually called routers, based on the functions they perform.

Circuit Switching

The most common example of circuit switching is a typical telephone conversation. When you call someone, the phone company maps out and reserves a single communications line between you and the person you are calling. This may involve allocating lines in several central offices (and through multiple long-distance carriers, in the case of a long-distance call). These lines remain allocated for the duration of a call. When your conversation is done, the lines that the various central offices reserved for your call (as well as the long-distance carriers, if your call used them), are freed, and other callers can use those resources.

However, if you call the same party numerous times in a day, you probably won't be connected through the same set of lines. In fact, it's highly unlikely. This points out one of the weaknesses of circuit switching: The

United States and other first-world countries enjoy reliable telephone-line service. But the same is not true of emerging and third-world countries. If you try to connect regularly with one of these countries, the chances of a reliable, clear connection decrease dramatically.

Data transmission through circuit switching is an all-or-nothing process. It either succeeds or fails. A popular analogy of circuit-switched transmissions is the transportation of goods by train. All of the merchandise is loaded on one train, which takes it from Point A to Point B. During this journey, many detours or mishaps may occur. Any deviation in the delivery affects the entire shipment. On a train, everything moves, or it all stands still.

Circuit-switched networks can be inexpensive but they are generally slow and not exceptionally efficient for transmitting data, especially in large amounts, or when delivery time is a serious concern (for voice or video traffic, for instance).

Analog Connectivity

The Public Switched Telephone Network (PSTN) can provide data communications as well as voice communications. PSTNs exist worldwide and are usually run by government agencies or private organizations. The PSTN is not new; it has been around for about 100 years. At PSTN's inception, it handled only voice communications over analog lines. As such, the PSTN was not well equipped to provide data transmission. But, with new technologies like high-bandwidth fiber optic cables, microwave transmissions, and satellite relays, the PSTN has become much more reliable for data transmission.

Analog transmission consists of sending streams of continuously modulated data, rather than two signals (one for zeros and another for ones), as with digital transmissions. Such continuity is important to permit phones to reproduce the human voice intelligibly; however, this signaling method must essentially be worked around for data transmission. Here's a tidbit of information: "Modem" stands for "modulator/demodulator," which explains the technology used to convert a digital signal to its analog equivalent for transmission, and then to convert that analog signal back to its digital form upon reception.

There are two predominant types of analog lines used for data communications: Dial-up lines work like ordinary phone lines in that a connection is made on demand, by dialing; dedicated lines act more like regular network cables in that once the connection is brought up, it's left up and running pretty much all the time.

Dial-Up Lines

Dial-up lines are voice-grade lines for which you use a modem to connect to another modem that is attached to another computer. These lines are usually limited to a 56 Kbps rate, and frequently you will have to contend with noise on the line. There is no consistent quality because the line is being allocated from the PSTN's pool of voice lines. Thus, a dial-up session is only as good as the circuits it contains.

Dedicated/Leased Lines

As an organization grows, dial-up service may no longer suffice for its communication needs. Ordinary phone lines must handle voice, modem, and fax traffic, with varying results. When demand begins to outstrip the supply of available outside lines, when you try to connect, the line may be busy more often than not. Assuming that the computer is under your control, and you can cover the extra costs involved, you can change this situation by signing up for a dedicated (or leased) analog line that you can use just for data communications. A leased line is faster and more reliable than a dial-up line, but is also more expensive because it's always available whether it's in use or not. Line conditioning (a service that reduces delay and noise on the line, allowing for better transmissions) can make the leased lines even more reliable, and is often part of a leased-line package, or you can obtain it from the service provider at an additional cost.

How, then, can you decide whether to use dial-up or dedicated lines for data communications? Cost is certainly a factor, as is frequency of use and reliability. If your users need to connect only occasionally, dial-up lines make the most sense because they're inexpensive; slow connections or busy signals that occasionally inconvenience usually persist for only a short time. But, if your users need greater reliability, guaranteed access, or higher bandwidth, the benefits that a leased line can deliver will usually be worth the added expense (figure about two to three times the monthly cost of a normal business line, plus some additional fees for line conditioning and setup).

Digital Connectivity

There will come a time when even the enhanced capabilities of a leased analog line won't be able to satisfy your data-transmission needs. Fortunately, there are numerous digital alternatives available. When you need a faster, more secure method of data transmission, take a look at Digital Data Service (DDS) lines. DDS lines use a point-to-point synchronous method that can transmit at 2.4, 4.8, 9.6, and 56 Kbps. DDS is available from most large communications carriers.

For even higher bandwidth—and higher monthly expenses—high-speed digital lines offer nearly error-free transmission. Such lines are available in numerous forms, including full and fractional T1, T3, and Switched 56. They don't require modems but they do require different devices for each end. These are called channel service units/data service units (CSU/DSU), and they make the necessary changes from the digital signals used on network media to that which is in use on digital telephony media for transmission, and reverse the process upon reception.

Packet Switching

Data sent via packet switching is broken down into small pieces of information called packets. Each packet consists of a piece of the data to be transmitted and certain header information that contains the destination address. Packets are sent one at a time, and rely on special network protocols to find a path between sender and receiver, and to deliver them to their proper destinations. It's highly likely that not all packets will travel the same route from source to destination, nor will they arrive in the same order as they were sent. If a packet gets lost or damaged during transmission, it is a relatively easy task to ship out a replacement. But, it is pretty certain that all packets will ultimately arrive at their proper destinations, and be reassembled into whatever original form the sent data may have taken.

Although the analogy for circuit switching is one of loading goods onto a train, packet switching is more like using a fleet of trucks. Goods are broken down into truckload lots, printed on a shipping manifest, and sent to the destination. Each driver is free to choose his or her route, but is expected to attempt to deliver each shipment in a safe and timely manner. As each truck arrives at the destination, the particular lot is checked off a master list. If a truck breaks down or loses its way, a phone call to the source ensures reshipment of an identical lot of goods. As soon as all lots have arrived, they are reassembled into their original configuration and handed over to the receiver. Packet-switching networks, which work as in the truck example, are fast and efficient, yet fairly economical, because they use high-speed transmission lines on a per-transaction basis.

So far, we have been dealing with basic networking technologies. Let's move on to more advanced technologies that are required to meet the demand for faster, more efficient data transmissions. At first, such technologies were built atop existing media such as telephone lines, but later on, new methods and media—such as fiber optic cable, microwave, and satellite—emerged.

The following sections cover a number of such advanced technologies, including X.25 networks, Integrated Services Digital Networks (ISDNs), frame relay, T-connector services (T1 and T3), Switched 56, Asynchronous Transfer Mode (ATM), Fiber Distributed Data Interfaces (FDDIs), Synchronous Optical Networks (SONETs), and Switched Multimegabit Data Services (SMDS).

X.25 Networks

The X.25 specification was written in the mid-1970s to provide an interface between public packet-switched networks and their customers. It specifies how devices connect over an internetwork. Early X.25 networks transmitted data over analog telephone lines, an unreliable medium that introduced numerous transmission errors. This led the designers of X.25 to incorporate extensive error-checking and packet-retransmission mechanisms to compensate for damaged or missing data. This improved reliability to acceptable levels, but it also resulted in relatively slow transmission speeds that peaked at 64 Kbps. Although a 1992 revision to the X.25 specification increases its maximum throughput to 2 Mbps, this faster version is not yet widely deployed.

Although the X.25 specification was written for use with public or private networks, it has become strongly associated with public data networks (PDNs), marketing as a service by large commercial providers such as AT&T, General Electric, and Tymnet (and most of the PSTNs outside the United States). PDNs were originally used to provide connections between remote terminals and mainframe computers, but now provide relatively low-cost LAN connections. Such links have proved to be particularly useful for credit card processing and other applications where the amount of data is small, and a variable response rate does not pose severe difficulties.

X.25 is not responsible for describing how data moves through the network. It is only responsible for delivering data up to the WAN and receiving it from somewhere else on the WAN. You can imagine the WAN as an amorphous cloud—an ever-changing environment with no standard set of circuits, nor fixed paths between any two points. The best path is determined as needed.

Connection of a LAN to an X.25 network usually requires customers to lease lines that reach between the LAN and a commercial PDN. The actual PDN connection may pass through a computer with an X.25 interface, or through a standalone device called a packet assembler/disassembler (PAD). Whatever type of attachment is used, X.25 networks provide proven, reliable, and nearly error-free connections, but their popularity is waning because of their slow speeds and the evolution of newer and faster technologies such as frame relay and ATM.

TIP Because of its error checking and retransmission of erroneous or lost data packets, X.25 is one of the slowest of the advanced WAN technologies, but it is also one of the most broadly available and affordable options. It remains pervasive outside Europe and the United States.

ISDN Networks

In 1984, a new kind of network called the Integrated Services Digital Network (ISDN) was specified. Although it was heavily hyped and received lots of attention in the 1980s, it hasn't been until the 1990s that ISDN has staked out a measurable piece of the communication-services marketplace.

By design, ISDN's primary goal is to integrate voice and data services by replacing analog telephone lines with digital equivalents that are suited for both voice and all kinds of digital traffic, including data, video, and other digital data streams. Although ISDN is available in many locations, it is used considerably less than PSTN lines. This is due in part to the higher costs of ISDN connections, but also because ISDN does not always offer a sufficient boost to bandwidth compared to PSTN lines (which can support data throughput as high as 115 Kbps including compression). ISDN offers nominal bandwidth of 64 Kbps per channel, and most ISDN lines offer nominal bandwidth of 128 Kbps, because channels are often used in pairs (with compression, some vendors claim throughput as high as 400-plus Kbps across two ISDN bearer channels).

The ISDN specification process took several years; because networking technology moved so rapidly simultaneously, by the time the ISDN standard was finalized, it was already out of date. Today's LANs offer speeds of at least 10 Mbps and are being replaced with 100-Mbps technologies. Offering 64-Kbps service to businesses in the 1980s was a serious proposition. In the 1990s, ISDN might have been completely bypassed, had it not been for individuals and small businesses that need to connect to the Internet.

Although some users are lucky enough to have Internet access at their workplaces, many users are relegated to home or office Internet access via modem, at speeds of 56 Kbps or slower. Because of the cost of ISDN devices, a twofold speed increase is helpful for individuals, but may not be fast enough for LAN-to-Internet connections.

Fortunately, you may purchase ISDN in two different forms:

- The Basic Rate Interface (BRI) targets home users or small businesses. A BRI consists of two bearer channels, also called B-Channels (64 Kbps), and a data channel, also called a D-Channel (16 Kbps), for a total of 144 Kbps of bandwidth. Each of the B-Channels may be used to transmit and receive either voice or data. The D-Channel is used for call setup and control (and sometimes for X.25 or fax communications). With the proper equipment and software, both B-Channels may be combined into a single virtual channel with a data transmission speed of 128 Kbps.
- The Primary Rate Interface (PRI) targets service providers and large organizations. A PRI uses a full T-1 line with 23 B-Channels and a single 64-Kbps D-Channel. Users with access to a PRI can use B-Channels individually, in pairs (typically for incoming BRI connections), or aggregated in any combinations up to all 23 channels together.

ISDN makes it possible to access the Internet at nearly three times the current speed of a modem. Home and small-business users have shown themselves to be willing to use ISDN to enjoy the rapid downloading of Web graphics, files, and email. Essentially, ISDN can be a cost-effective way to connect remote sites where occasional connections are required, and bandwidth needs remain relatively modest.

Remember, though, that ISDN is a type of dial-up service. In most cases, if an ISDN connection is to be used as a dedicated line, Internet Service Providers charge significantly more for such service. On-demand ISDN access is as cheap as $20 a month at some ISPs, but it's rare to find monthly fees for a dedicated line with two B-Channels at less than $300. Because communications carriers often charge per-minute usage fees, in addition to basic service charges, the carrier costs for a dedicated ISDN line can range from a low of $70 per month, to a high of $876 per month (at 2 cents per minute of connect time).

TIP

ISDN is a dial-up technology that furnishes voice and data at speeds up to 128 Kbps. Although it took a long time to get to the marketplace, it now enjoys widespread use as a source for Internet connectivity.

Frame Relay

Frame relay evolved from X.25 and ISDN technology. Like X.25, frame relay is a packet-switching network service, but unlike X.25, it doesn't perform error checking or accounting functions. Frame relay expects that the media it traverses will deliver high-quality transmission characteristics, and that error checking will be handled at either end of a connection, most likely in hardware.

Frame relay uses variable-length packets in a packet-switching environment. It establishes a logical path that's called a Permanent Virtual Circuit (PVC) between end-points. PVCs take fixed paths, so a PVC is the equivalent of a dedicated line in a packet-switched network. The path is fixed, so network nodes don't have to waste time calculating routes. Frame relay connections operate at speeds between 56 Kbps and 1.544 Mbps because they use PVCs, and there is no built-in error checking. Frame relay services are gaining popularity: They are much faster than other networking systems at performing basic packet-switching operations, and customers can specify exactly what amount of bandwidth they want to pay for.

You can establish frame relay services to meet any bandwidth requirement. When an organization arranges for a frame relay connection with a provider, it contracts for a Committed Information Rate (CIR), a guaranteed minimum data-transmission rate for the connection. CIRs are available in 64-Kbps increments. Frame relay connections are also popular because they are one of the least expensive types of medium-speed WAN connections. A frame relay connection costs significantly less than a dedicated leased line or an ATM connection.

Frame relay connections to a network require you to use a frame relay-compatible CSU/DSU to create the physical connection to the WAN, and a router or bridge to move traffic from the LAN to the WAN, and the WAN to the LAN, as needed.

TIP

Frame relay costs less than a dedicated line or an ATM connection and provides data transmission rates of up to 1.544 Mbps over conventional or fiber optic media.

T1 And T3 Lines

In the early days of the PSTN, a single telephone line could only carry a single telephone conversation. As the use of telephones increased, and demand for more lines grew, the telephone companies desperately sought a solution. In the 1960s, Bell Labs developed a process called multiplexing (or muxing) that could take several transmissions, aggregate them across one high-speed cable, transmit them, and then separate them at their destinations. This process gave birth to the T-carrier system.

The basic unit of the T-carrier system is the T1 line, perhaps the most widely used type of all high-speed digital lines. T1 is a point-to-point transmission technology that consists of 24 64-Kbps channels for a total transmission capability of 1.544 Mbps. Each of the channels may be used as a separate voice or data communications channel, or channels may be combined to provide higher transmission rates. For example, combining 3 channels yields 192 Kbps, and combining 22 channels yields 1.31 Mbps.

A faster commercial T-carrier line is called a T3. It is the equivalent of 28 T1 lines and handles a data rate of 44.736 Mbps. A T3 is the highest-capacity leased-line service available from most communications carriers, and is designed to transport large amounts of data at high speeds between two points. T3 lines can also be horrendously expensive; prices of $30,000 per month or higher are the norm. T1 lines use standard copper wire, whereas T3 lines require fiber optic cables or microwave-transmission equipment.

Installation and monthly service charges for leased T-carrier lines are high; for those reasons, service providers allow customers to lease portions of a T-carrier line's bandwidth through services called Fractional T1 (FT1) and Fractional T3 (FT3). For example, a customer could lease from 1 to 24 of the 24 64-Kbps channels of a T1 line; or anywhere from 2 to 27 T1-width channels of a T3 line.

Connecting a T1 line to your network is similar to connecting a DDS or frame relay line. You will need a T1-compatible CSU/DSU, and a bridge or router. To distribute the T1's bandwidth between voice and data traffic, you will need a multiplexer/demultiplexer to combine voice and data signals for transmission, and separate them upon reception. You can lease T1 or T3 lines, either full or fractional, from telephone companies, long-distance carriers, or other service providers, and you are billed at a flat monthly rate, once you pay for installation and equipment.

TIP

T1 lines are the most common high-speed connectivity in use today. They can transmit up to 1.544 Mbps. One nice feature is that a user can lease a fraction of the T1 line as needed. T3 lines are 28 times the size of a T1 (roughly 45 Mbps), and can be consumed in fractions as well.

Switched 56

When customers demanded 56-Kbps dial-up service that was less expensive than dedicated lines, telephone companies and service providers began offering the Switched 56 service. In reality, a Switched 56 line is nothing more than a circuit-switched version of a standard 56-Kbps DDS leased line. As customers pay only for connection time, resulting costs are usually significantly lower than those of a dedicated line.

Both ends of a connection must be equipped with Switched 56-compatible CSU/DSUs that can dial and connect to each other on demand. In many areas where ISDN is not yet available, Switched 56 offers an attractive alternative. In areas where both services are available, it's often wise to make a cost comparison between ISDN and Switched 56, and choose the one that's cheaper (especially in areas where per-minute ISDN-usage charges can contribute significantly to line-operation costs).

TIP

Switched 56 is merely a circuit-switched version of a standard 56-Kbps line. This is good for customers because they only have to pay for what they use.

Asynchronous Transfer Mode (ATM)

ATM is an advanced packet-switching technology that transmits data over LANs or WANs in fixed-length 53-byte chunks, called cells, at speeds of up to 622 Mbps. ATM can accommodate voice, data, fax, realtime video, CD-quality audio, imaging, and multimegabit data transmission.

Unlike frame relay, which uses variable-sized packets, ATM cells have a fixed length of 53 bytes. Of these 53 bytes, 48 bytes contain data and 5 contain header information. Because data packets of uniform length are much easier to transport than random-sized packets, ATM can use network equipment to switch, route, and move cells much more quickly than the same equipment could handle randomly sized frames.

ATM is like frame relay because it assumes noise-free lines and leaves error checking to devices at either end of a connection. Also, ATM creates a PVC between two points across an ATM network as part of setting up a communication session. The primary speeds for ATM networks are 155 Mbps and 622 Mbps. The 155-Mbps speed was chosen because high-definition television signals are transmitted at this speed. The 622-Mbps speed was chosen to permit four 155-Mbps channels to be sent simultaneously through the same connection.

You can use ATM with existing media designed for other communications systems such as coaxial, twisted-pair, and fiber optic cable. Because these traditional network media do not support all of ATM's capabilities, you can also use ATM with T-3 (45 Mbps), FDDI (100 Mbps), Fiber Channel (155 Mbps), and OC-3 SONET (155 Mbps)—we'll discuss these last three and OC shortly. ATM can even interface with frame relay and X.25.

ATM offers theoretical throughput speeds of up to 2.4 Gbps (OC-48) but is usually constrained to 622 Mbps because of the type of fiber optic cable used for current long-haul cable installations. Experimental fiber optic technologies have already surpassed transmission rates of 10 Gbps in laboratory environments, so ATM has obviously not reached its "speed limit"—it's just waiting for faster transport equipment and improved media!

TIP

ATM is a packet-switched technology that transmits data in fixed-length, 53-byte cells. Theoretically capable of speeds of 1.2 (OC-24) and even 2.4 Gbps (OC-48), it usually transmits in the 155 Mbps (OC-3) to 622 (OC-12) Mbps range.

About Optical Carrier Levels, T-Carrier Rates, And More

The Optical Carrier rating level for standard ATM technologies is customarily abbreviated as OC-n, where n is a multiplier applied to the basic OC level 1 rate (OC-1) of 51.84 Mbps. OC-1 describes the basic transmission rate for SONET communications. Table 10.1 (seen later in this chapter) summarizes most of the WAN service types that we cover in this chapter, along with their common abbreviations, basic characteristics, maximum throughput rates, and associated transmission technologies.

FDDI

Fiber Distributed Data Interface (FDDI) is not really a WAN technology but is used to connect LANs via a high-speed, token-passing, one- or two-way counter-rotating ring. FDDI supports both LED- and laser-generated LAN communications across fiber optic cable. FDDI networks are quite reliable because fiber optic cable doesn't break as easily as other cable types, is difficult to wiretap because the cable doesn't emit any signals, and is immune to electrical interference.

FDDI is not like a regular Token Ring network because more than one computer at a time can transmit a token so that multiple tokens can circulate on the ring at any one time. The token-passing system is used in a dual-ring setting. Traffic in the FDDI network consists of two similar data streams moving in opposite directions around two counter-rotating rings. The primary ring usually carries the traffic. If the primary ring fails, FDDI automatically reconfigures the network so that data flows onto the secondary ring, and moves the data in the opposite direction. Redundancy is one of the key advantages of this particular dual-ring topology.

FDDI can achieve data transmission speeds of up to 100 Mbps. FDDI is not suitable for WANs because the maximum ring length is 100 kilometers or about 62 miles; however, it can interconnect LANs that will be connected to form a WAN, and is also clearly suitable for deployment in metropolitan area networks (MANs).

TIP

FDDI networks are very reliable because the cable cannot be wiretapped, and is not susceptible to electromagnetic interference. In addition, FDDI's dual-ring architecture increases its reliability.

SONET

After the breakup of AT&T in 1984, local telephone companies were faced with trying to connect to many long-distance carriers, all with different interfacing schemes. Bell Communications Research developed SONET, the Synchronous Optical Network. SONET is a fiber optic WAN technology used to deliver voice, data, and video at speeds in multiples of 51.84 Mbps (known as OC-1, as documented in Table 10.1). SONET's main goals were to create a method by which all carriers could interconnect, and to unify differing standards used in Europe, the United States, and Asia—especially Japan.

SONET has unified these groups with a new system that defines data rates in terms of Optical Carrier (OC) levels. The basic OC-1 level specifies a data rate of 51.84 Mbps, and is based on the DS1 basic rate defined for SONET. The most common level is OC-3 or 3 multiplied by 51.84 Mbps or 155.52 Mbps. OC-3 is the most common SONET implementation in use today, even though the specification defines OC-48 at 2.48 Gbps.

TIP

SONET is a fiber optic WAN technology used to deliver voice, data, and video at speeds up to 622 Mbps, and beyond.

SMDS

Switched Multimegabit Data Services (SMDS) is a switching WAN technology introduced in 1991 that provides data transmission in the range between 1.544 Mbps (T1 or DS1) to 45 Mbps (T3 or DS3). SMDS offers high bandwidth at reduced network costs. Like ATM, SMDS uses a fixed-length cell of 53 bytes for data transmission. Like ATM and frame relay, it provides no error checking, leaving that up to devices at the connection points.

An SMDS line with appropriate bandwidth can connect to a local carrier and provide connections between all sites without requiring call setup or tear-down procedures to be invoked. ATM and convention digital technologies require that such procedures be enacted for every PVC used, which saves time and money.

Note: SMDS is a competitor to X.25 but is not in widespread use because of high equipment costs.

Table 10.1 Common WAN service types, with salient details.

Abbreviation	Expanded Form	Transmission Rate	Applies To	Remarks
BRI	Basic Rate Interface	2 64-Kbps channels	ISDN	Total bandwidth 144 Kbps (2B +16 Kbps data channel)
DS0	Digital Service, level 0	64 Kbps	Digital telephony	Defines basic digital channel used to classify capacities of digital lines and trunks
DS1	Digital Service, level 1	1.544 Mbps, U.S. 2.048 Mbps, Outside the United States	Digital telephony	In the United States, based on a Bell standard, same as T1; 2.048 speed based on ITU standard
DS3	Digital Service, level 3	44.736 Mbps	Digital telephony	Same as T3, equivalent to 28 T1s.

(continued)

Table 10.1 Common WAN service types, with salient details *(continued)*.

Abbre-viation	Expanded Form	Transmission Rate	Applies To	Remarks
E1	European Trunk Line, level 1	2.048 Mbps	Digital telephony	Equivalent to T1 in most of the world, but the E stands for Europe in the abbreviation
T1	Level 1 Trunk Line	1.544 Mbps	Digital telephony	Uses two pairs of TP phone cable. Used in the United States, Canada, Hong Kong, Japan
T3	Level 3 Trunk Line	44.736 Mbps	Digital telephony	Often rounded to 45 Mbps
OC-1	Optical Carrier level 1	51.840 Mbps	ATM, SONET	Permits direct electrical-to-optical mapping
OC-3	Optical Carrier level 3	155 Mbps	ATM, SONET	
OC-12	Optical Carrier level 12	622 Mbps	ATM, SONET	
OC-24	Optical Carrier level 24	1.2 Gbps	ATM, SONET	
OC-48	Optical Carrier level 48	2.4 Gbps	ATM, SONET	
PRI	Primary Rate Interface	1.544 Mbps	ISDN	23-B + 64 Kbps channel, same overall bandwidth as a T1, DS1
Switched 56	Switched 56	56 Kbps	Digital telephony	On-demand, moderate-speed digital telephone service

Practice Questions

Question 1

What is the most widely used type of high-speed digital link in the United States?

- ❍ a. T1
- ❍ b. T3
- ❍ c. E1
- ❍ d. Switched 56

The correct answer is a; T1 lines are the most common high-speed digital links used in the United States today. Answer b names the 44.736-Mbps T3 (DS3) service, whose costs start at around $30,000 per month from most carriers—still a bit too expensive for widespread deployment. Answer c, E1, names the most common European digital trunk line, unheard of and unused in the United States. Switched 56 is quite common, but doesn't really qualify as a high-speed digital link, so answer d is also incorrect.

Question 2

What role does the D-Channel play in basic-rate ISDN?

- ❍ a. Signaling and link management data
- ❍ b. 128 Kbps data only
- ❍ c. Voice, data, or videos
- ❍ d. 16 Kbps only

Answer a is correct. The primary function of the data channel in ISDN, whether basic or primary rate, is call management, which literally translates into signaling and link management data. If you recall the ISDN discussion earlier in the chapter, the BRI D-Channel is also sometimes used for fax or X.25 traffic as well. The bandwidth of the D-Channel is 16 Kbps on a BRI, so answer b is clearly incorrect. The D-Channel is only used for call control and some limited types of narrow-bandwidth data transmission. On telephone circuits, digitized voice requires 64 Kbps (or at least one B-channel), data and video usually do best when they can use both B-channels; thus, answer c is also incorrect. Although answer d accurately describes the bandwidth of a D-Channel, it fails to name what it's used for, which explains why that answer is also incorrect.

Question 3

Which of the following WAN technologies was originally intended to replace analog phone lines?

❍ a. ATM

❍ b. T1

❍ c. ISDN

❍ d. Frame relay

❍ e. FDDI

The correct answer to this question is c, the Integrated Services Digital Network, or ISDN. ATM offers bandwidth that typically starts at 155 Mbps; because a digital voice channel needs only 64 Kbps, this is a major case of overkill, and would be way too expensive to replace analog phone lines. Therefore, answer a is incorrect. Even T1, which includes only 24 voice line channels of 64 Kbps is too expensive and offers too much bandwidth for replacing less than a sizable bank of telephone lines. Therefore, answer b is incorrect. Frame relay, answer d, comes in increments of 56 Kbps, and is sometimes used to aggregate voice and data traffic, but was not ever intended to replace analog phone lines either. Finally, FDDI is not a form of digital telephony at all (and is not considered a WAN technology in some circles anyway); also, at 100 Mbps; it's another case of overkill for replacing analog voice channels. Therefore, answer e is incorrect.

Question 4

Which of the following WAN technologies can transmit data at more than 100 Mbps? [Check all correct answers]

❑ a. Switched 56

❑ b. ATM

❑ c. ISDN

❑ d. T1

❑ e. SONET OC-12

Answers b and e are the only correct answers to this question. Although answer b, ATM, comes in many flavors, standard implementations begin at 155 Mbps and increase from there; thus, ATM is a correct answer. Like ATM, SONET comes in many flavors, some of which are slower than 100 Mbps; however, answer e's specification of OC-12 (622 Mbps) specifically states that it transmits faster than 100 Mbps. The key to answering this question lies in knowing the speeds associated with these technologies. Answer a, Switched 56, offers 56-Kbps speeds for each channel; clearly, this is less than 100 Mbps, which makes this answer incorrect. Even ISDN PRI offers only 1.544 Mbps (BRI tops out at 144 Kbps); therefore, answer c is incorrect. T1 lines offer a maximum of 1.544 Mbps (same number of 64 Kbps channels as a PRI, in fact), making answer d incorrect.

Question 5

Which of the following statements best describes frame relay technology?

❍ a. It transmits fixed-length packets at the Physical layer through the most cost-effective path.

❍ b. It transmits variable-length packets at the Physical layer through the most cost-effective path.

❍ c. It transmits fixed-length packets at the Data Link layer through the most cost-effective path.

❍ d. It transmits variable-length packets at the Data Link layer through the most cost-effective path.

Because frame relay uses variable-length, not fixed-length, packets, only answer d is correct. Only the physical interfaces and media operate at the Physical layer of the OSI model. Thus, answers a and b are both incorrect because they situate packet handling where only frames may go.

Question 6

Which of the following WAN technologies is actually a protocol suite that uses packet assemblers and disassemblers (PADs)?

- ❍ a. X.25
- ❍ b. ISDN
- ❍ c. ATM
- ❍ d. Frame relay

Answer a is the only correct answer. The real clue to this question comes from its mention of Packet Assemblers/ Disassemblers (PADs)—of all the technologies mentioned in this question, only X.25 uses PADs. Only X.25, the oldest WAN technology discussed in this chapter, actually incorporates its own specific protocol suite to manage addressing, transport, and delivery of the information that it carries.

Question 7

What two ring configurations can be used on an FDDI network? [Check all correct answers]

- ❑ a. Single rotating ring
- ❑ b. Single virtual ring, implemented as a star
- ❑ c. Dual counter-rotating rings
- ❑ d. Dual parallel-rotating rings

Answers a and c are the correct choices. Answer a is the only correct single-ring answer. FDDI can use either a single-ring or a double-ring configuration, where the topology is a true ring. For dual rings, FDDI uses counter-rotating rings to speed delivery times, not parallel-rotating rings (the option for answer d), so only answer c of the two dual-ring possibilities is correct. Answer b is incorrect; even though for most other topologies, the ring is virtual (and the star actual) as with IBM Token Ring networks.

Question 8

Of the following networking technologies, which define data rates in terms of Optical Carrier (OC) levels? [Check all correct answers]

- ❑ a. SMDS
- ❑ b. FDDI
- ❑ c. ATM
- ❑ d. SONET
- ❑ e. ISDN

Answers c and d are correct. Both of the highest-speed technologies listed here—namely ATM and SONET—describe their data rates using Optical Carrier levels. SMDS supports variable data rates up to DS3 levels, and is not described in terms of Optical Carrier levels. Therefore, answer a is incorrect. FDDI is strictly 100 Mbps, and makes no reference to OC levels. Therefore, answer b is incorrect. ISDN describes its data rates in terms of DS0 64-Kbps bearer channels (and for BRI, a 16-Kbps data channel as well; for PRI, the D-Channel is also 64 Kbps). Therefore, answer e is incorrect as well.

Need To Know More?

This chapter covers a huge range of topics. We offer some of our favorite resources, but these only scratch the surface of what's available. Be sure to visit www.amazon.com and check out its "Search by Author, Title, Keyword" capabilities for all these topics—new publications keep showing up all the time, and most of the topics covered in this chapter are hotbeds of publication activity!

Bezar, David D.: *LAN Times Guide to Telephony*, Osborne/McGraw-Hill, Berkeley, 1995. ISBN: 0-07-882126-6. One of the best all-around references on computer telephony, with especially informative coverage of digital telephony, trunk lines, and digital data services.

De Prycker, Martin: *Asynchronous Transfer Mode, 3rd Edition*, Prentice-Hall, London, 1995. ISBN: 0-13-342171-6. Although the material is a bit dated, this book contains one of the best overviews of ATM signaling and cell handling we've ever seen. Recommended for those who need to learn the details of this technology.

Michael, Wendy H., William J. Cronin, Jr., and Karl F. Pieper: *FDDI: An Introduction*, Digital Press, Burlington, MA, 1993. A short, clear, and understandable introduction to FDDI terminology, technology, and hardware.

Parnell, Tere: *LAN Times Guide to Building High-Speed Networks*, Osborne/McGraw-Hill, Berkeley, 1996. Good chapters on ATM, SONET, and SMDS, among numerous other topics of interest to those who seek to construct the fastest networks possible.

Sheldon, Tom: *LAN Times Encyclopedia of Networking, 2nd Edition*, Osborne/McGraw-Hill, Berkeley, 1997. An outstanding all-around reference on networking topics of all kinds, Sheldon's articles on all of the technologies covered in this chapter will make valuable supplements to the information covered in any of the Networking Essentials study guides or training materials available.

Tittel, Ed, and Dawn Rader: *Computer Telephony: Automating Home Offices and Small Businesses*, AP Professional, Boston, 1996. ISBN: 0-12-691411-7. A good review of computer telephony terminology and technology, with good coverage of digital telephony of all kinds.

Tittel, Ed, Steve James, David Piscitello, and Lisa Phifer: *ISDN Clearly Explained, 2nd Edition*, AP Professional, Boston, 1997. ISBN: 0-12-691412-5. A thorough overview of ISDN terminology and technology, coupled with in-depth reviews of SOHO ISDN adapters, modems, and routers.

For more information on any of the technologies covered in this chapter, visit your favorite search engine, or www.search.com, and use its name as a search term to find countless sources of additional information.

The ATM Forum, which operates a Web site at www.atm.forum.com, is the ultimate source of information about ATM online.

Ray LaRocca, of the FDDI Consortium, has written an excellent tutorial on the subject that you can find at www.iol.unh.edu/training/fddi/htmls/index.html.

The folks at Teletutor have put together a terrific online X.25 tutorial that you can download at www.teletutor.com/x25.html.

Lucent has put together a nice tutorial on Internet access that includes significant discussion of SONET, which you will find at www.webproforum.com/lucent/index.html.

Online resources on ISDN abound, but nowhere is there a better place to start than Dan Kegel's truly amazing repository of ISDN pointers and information, which you will find at www.alumni.caltech.edu/~dank/isdn/.