Chapter 7

WAN technologies

7.1 Introduction

Compared to data on your local area network (LAN), the information traveling on your wide area network (WAN) traverses longer distances and encounters a wider variety of physical and logical environments en route. WAN technologies, including 56 *Kbps* circuits, ISDN, *leased lines* (including *T1 lines*), and frame relay, are optimized for these lengthy journeys. In technical language, wide area networks utilize protocols at levels 1-3 of the OSI reference model that are optimized, both physically and logically, for extended travel. Schools use WAN technologies to connect their school buildings to each other and to the Internet.

When you select a LAN technology, Ethernet is the obvious choice. However, when you select a WAN technology, you will be faced with many confusing options. The choices vary widely in the amount of data they can deliver, the speed at which they operate, their initial and recurring costs, their management requirements, and their flexibility to include new locations or new technologies such as voice or video. Additionally, some WAN technologies are not widely available.

Furthermore, you are likely to mix a number of different WAN technologies to create your wide area network—a practice that is discouraged for local area networks. For example, you may use ISDN lines for some connections and T1 lines for others, and you may include wireless connections for buildings that are difficult or expensive to connect in other ways.

The next section lists important questions to ask yourself when you are planning a wide area network.

7.2 Planning the network

To begin the planning process, you should draw a sketch of the buildings you wish to connect. For each building, draw a line to all the other buildings with which it must share information, and label each line with the following information:

- the distance between buildings
- the kinds of information that will be exchanged. For example, if School Building A must exchange email with School Building B, then draw a line between these two buildings and label the line *email*. If School Building A must also receive cable TV transmissions, draw a

line labeled *TV* to the cable provider. Be sure to plan for kinds of information you'll use in the future as well as the kinds you exchange today.

- the number of computers in each building
- the number of people who will use those computers at various times of day
- the tasks that will engage these people at various times of day. For example, will your staff and students primarily use electronic mail? Will they use the World Wide Web—and do so more at some times of day than others? Do you have a student learning system in one building which must accommodate 30 simultaneous logins at the beginning of class periods during the day? Will your classrooms collaborate on building Web pages, including large graphics? Do you need to share video or voice transmissions? There are many such questions, and it is critically important that you think carefully through them. You should describe every action that will take place, including its duration and number of participants.

Once you've developed your drawing, you should work with a wide area network integrator to convert this functional description into a technical specification. Remember that your integrator's network plan is only as good as your description. If you omit services or misjudge its usage, then your network may not deliver reliable or sufficient services.

The final network map created by your integrator may not look exactly like the map you drew. For example, imagine a wide area network that includes four school buildings. You may have connected each building with all others. However, your network integrator may link each of these buildings to a central one (instead of each to the other). In many ways, the physical shape of the network is less important than its performance. Your job as technology leader requires not so much that you understand the physical design of your WAN as that you verify its capabilities. You should discuss with your integrator the details of each service as well as the performance levels that you expect from the network.

7.3 Investigating WAN technologies

Besides discussing your network's functional requirements, you should also raise the following questions with your wide area network integrator.

What technologies are available in your geographic area? To make wide area connections, you will use the services of local telephone companies and other communications vendors such as MCI, Sprint, or AT&T. Different vendors offer different technologies. When you plan your WAN, you should check with you local telephone company and other communications providers to see what they support.

What are the installation and recurring costs for each technology? WAN technologies vary in their startup and recurring costs. Startup costs include installation fees and equipment to be purchased. Recurring costs include service contracts for the equipment and connections as well as communications line charges and per-call connection charges. Some technologies cost more as the distance between connections increases (just as long-distance telephone calls cost more than local calls), while others are distance insensitive. Some technologies cost more as the amount of data you send increases, while others charge a flat rate regardless of the amount of data. You'll need to think carefully about the placement, frequency, and duration of your connections and choose a technology that gives you a good balance of cost and performance.

What kinds of data does each technology carry? Some technologies are suited best to carrying data like electronic mail and documents you create. More powerful technologies carry both data and video or voice transmissions. You should determine what kinds of data you need to exchange and select an appropriate technology.

How fast is the connection? WAN technologies vary significantly in their transmission rates. The slowest technologies run at about the same speed as fast modems—56 *Kbps*—and can provide connections for just a few simultaneous users to exchange data (not voice or video). The fastest technologies run many times faster than Ethernet and can service hundreds of simultaneous users exchanging any kind of information. Some WAN technologies carry data at two different transmission rates—they send *downstream* (*to* the user) faster than they send *upstream* (*from* the user). You must make sure that the transmission rates accommodate the kinds of information you wish to share and the number of users you support.

Are there distance limitations for the technology? Some WAN technologies impose limits on the distances that they can carry data. Make sure that the WAN technology you choose can negotiate the distances between your sites.

Does the technology support dial-up connections or permanent connections? Permanent connections between sites are preferable to dial-up connections because they are easier to manage and provide more durable service. In addition, dial-up connections may be inadequate for video, voice, and other kinds of data that must travel in continuous streams. However, dial-up connections may be substantially less expensive than permanent connections. You should confer with your wide area network integrator to determine whether the price of permanent connections is worth the benefit they bring for your particular situation.

7.4 WAN technologies

7.4.1 Plain Old Telephone Service (POTS)

If you have a very small number of simultaneous users (5 or fewer), you may consider using plain old telephone service (*POTS*) and a modem to provide your connections. POTS connects computers using exactly the same technology that you use on the telephone everyday at home and work.

You should *not* consider POTS connections for WANs of even moderate size. For example, POTS connections are too slow to support a WAN that includes several buildings with a shared Internet connection.

7.4.1.1 Technical definition

POTS provides analog, dial-up services over regular telephone wire. *Analog* signals are the opposite of *digital signals*. *Analog signals* are understood as continuous variations in voltage, while *digital signals* are understood as signals that are either on- or off. Both analog and digital signals carry WAN information successfully. For technology planners, one important distinction between the two involves the different kinds of equipment they require (we discuss this equipment in a moment). Additionally, digital signals generally incur a much lower error rate than analog signals.

7.4.1.2 Implementing POTS

To send information using POTS, you attach a modem to the sending computer and a compatible modem to the receiving computer. The sending modem dials, and the receiving modem answers the call. The sending modem then converts digital signals from its computer into an analog representation, and sends them along the telephone line to the receiving computer. The receiving computer converts the incoming analog signals into digital representations, and passes them along to its computer.

You may attach a modem directly to an individual computer or to your local area network. If you attach a modem to an individual computer, then that computer (or anyone sharing its resources via a peer network) can initiate or receive calls from another computer or network.

Most sites attach modems to their local area networks rather than to individual computers. LAN modems may be standalone devices that connect directly to your LAN wiring, or they may be attached to (or inside of) your servers. LAN modems can respond to requests from any user inside your LAN to connect outward. They can also receive calls from an external computer or network. LAN modems enable students, teachers, and community members to dial your network from home, download or upload files, and connect to electronic mail as if they were doing so within your school buildings.

Before you decide to offer modem connections to students, teachers, and community members, however, you must weigh the costs against these significant benefits. Many schools find that supporting dial-up connections requires significant staff time; people calling from home often experience difficulties with such connections and call for assistance. Because of these difficulties, some school systems have chosen to offer connections to their networks only via the Internet. (To be sure, Internet connections also encounter problems, but such problems occur somewhat less frequently than do modem connections.) These school systems require that students, teachers, community members each have his or her own Internet Service Provider; once connected to an ISP, a student, teacher, or community member can use a Web browser or other communications software to connect to the school’s network resources. You should consider, however, that Internet connections are inherently less secure than dial-up connections; dial-up connections use a private telephone line while Internet connections travel on a public network. As a corollary, your school may have decided to restrict Internet connections to specific servers and documents; some resources may therefore be accessible via dial-up connections but not via the Internet. In summary, the decision concerning how students, teachers, and community members will access your school network is complex and should be considered carefully.

To use the modems, you must also install software that dials your connections, answers incoming calls, and provides other modem configuration services. Most modems include software when you purchase them; alternatively, you can purchase modem software from computer stores or from your server manufacturer. (Some servers automatically include software for modems.)

If you use POTS, you must ensure that each building, as well as your Internet provider, is equipped with a compatible modem. Many network managers try to purchase modems from the same manufacturer for all their buildings to ensure compatibility.

The fastest modems (56 *Kbps* to the user and 28.8-33.3 Kbps from the user) have appeared only recently, and there is one major problem associated with them. Many of them were sold before the final 56 Kbps modem standards (*V.90* standards) were issued by the International Telecommunications Union (ITU, formerly CCITT), the international standards body that defines modem standards. As a result, modems from different manufacturers may operate by different rules and may not be able to connect with one another. If you plan to use 56 Kbps modems, you must purchase V.90 modems and make sure that everyone to whom you will connect—including your Internet provider—supports V.90 service. If you have previously purchased a non-standard modem, you may be able to upgrade it to V.90 standards. Call your modem manufacturer.

For most schools, POTS service won't provide adequate data delivery capacity to provide responsive connections to the Internet.

7.4.1.3 References

You can see diagrams of school networks that incorporate telephone lines at the following links:
http://wsd3.k12.co.us/ (click the link entitled *WSD3Net Diagram* at the bottom of the page, and then look for the area marked “8 analog phone lines”)
http://www.att.com/communityguide/d2.html
http://www.att.com/communityguide/d6.html

Section 7.4.1Technical Information Summary

Plain old telephone service (POTS)

POTS (plain old telephone service) provides a way for computers to communicate over regular telephone lines. POTS provides slow connections, however, and should not be used for WANs of even modest size.

To create a POTS connection, you install modems at each site. Modems can be attached to individual computers or to your LAN and can be shared by many users. Once you have installed your modems and configured the associated software, the users at each site can dial or receive calls from anywhere in the world.

The fastest modems (56 Kbps *to* the user and 28.8-33.3 Kbps *from* the user), termed V.90 modems after the telecommunications standard that defines their before, are still too slow to provide robust connections for wide area networks.

7.4.2 Integrated Services Digital Network (ISDN)

7.4.2.1 Technical definition

Integrated Services Digital Network (*ISDN*) connections provide half- or full duplex digital data communications on a dial-up basis between two points over regular telephone wire. By *half duplex* we mean that the communications channel can carry signals in only one direction at a time (although the direction may switch back and forth instantaneously, effectively transmitting data in both directions). By *full duplex* we mean that the communications channel can carry signals in both directions simultaneously. (Regular telephone connections are also full duplex.) By *digital* we mean that the data are received as a series of on-off signals, and we distinguish them from the continuous variations in voltage that constitute analog signals. Digital connections generally incur a much lower error rate than analog connections.

ISDN services can be purchased at many different speeds, including 64 Kbps, 128 Kbps, 256 Kbps, and 512 Kbps. The most common ISDN service offers 128 Kbps and can support several dozen simultaneous users with reasonable response rates. ISDN services at 128 Kbps are now available in most geographic areas. ISDN carries both voice and data.

Basic rate ISDN provides two 64 Kbps channels (called B channels or bearer channels) which carry data between two callers as well as a 16 Kbps channel (called a D or data channel) to carry control signals (for example, "dial these digits", "ring the telephone"). Because the D channel initiates calls digitally, the time to establish the call is much shorter than that required by analog modems. The two B channels may be used separately for full duplex services, or they may be bonded (joined) to produce one, half duplex 128 Kbps channel (which carries data in a single direction at any given moment). When the B channels are bonded, the ISDN equipment allows you the option to accept incoming calls by switching one B channel to service the call temporarily; the equipment can automatically rejoin the channels when the incoming call is complete. You may upgrade from basic rate to higher speeds if your telephone company supports them.

It is possible to achieve ISDN speeds approaching 230.4 Kbps if your modem and ISDN provider both support data compression. To take advantage of the speeds achieved through compression, you must also purchase a high speed serial card for your computer. High speed serial cards fit inside your computer and connect to your modem. The cards include a special chip, called a 16750 UART (universal asynchronous receiver transmitter), which includes a faster clock as well as more memory than the standard serial circuitry of new computers. While standard circuitry transmit data at a maximum rate of 115 Kbps, high speed serial cards can transmit data at speeds of nearly 1 Mbps (1000 Kbps).

7.4.2.2 Implementing ISDN

ISDN services require a special telephone connection to be installed by your telephone company. This connection, called the *U-loop*, consists of 2 copper wires and has a maximum length of 5.5 km (18000 ft) between your connection and the central telephone office. The equipment on both sides of the U loop has to be carefully designed to deal with the long length and the noisy environment it operates in.

On your premises, the U-loop connects to an NT1 (network termination 1) device. The NT1 serves several purposes. First, it connects the two-wire twisted pairs used by telephone companies to the four wire connectors commonly found in telephones, fax machines, and other telecommunications equipment. It also translates between the signal encoding schemes used on the telephone company network and your local area network, provides power for the telephone and fax machine if necessary, and allows more than one device to access to the two B-channels provided by ISDN (each device connects to one of the B channels when it identifies a message requesting its services).

The NT1 connects to an ISDN terminal device such as an ISDN router, digital telephone, or direct ISDN connection in a computer or server. Alternatively, the NT1 may connect to terminal adapter; terminal adapters enable serial devices such as regular modems to connect to ISDN circuits. The terminal adapter translates the ISDN signals into a form that the serial device can use, and adjusts the differing transmission rates between the two devices (usually according to a protocol termed V.120). Many terminal adapters have NT1 devices built in so that you can purchase a single piece of equipment to connect both ISDN and serial devices to you ISDN connection.

NT1 and terminal adapters may be internal or external to your computer or server. For PC-type computers, internal modems may be capable of reaching faster speeds than external modems (unless the external modem is connected through a special, high speed circuit board) because internal connections, or buses, that service the modem are faster than standard serial port connections that service external modems.

Whether you purchase an internal or an external modem, you must make sure that its switch type is the same as that used by your telephone company's central office There are three main switch types in the United States—AT&T 5ESS, Northern Telecom DMS-100, and National ISDN-1. There are additional telecommunications provider compatibility requirements as well. For example, each piece of ISDN equipment on your premises—your fax machine, router, or digital telephone—is associated with a unique identifier which your provider may ask you to specify in your equipment setup procedures; likewise, you may need to specify the data link protocol, such as PPP, to be used atop the ISDN physical connection. To ensure compatibility, you should ask your telephone company to indicate what equipment (such as an NT1 or terminal adapter) you must purchase and the brands and models they recommend.

To purchase ISDN services, you generally place an order with your local telephone company. Be sure to inquire about both installation costs (including the cost of installing your ISDN telephone line) and recurring charges. Recurring charges include a monthly charge plus an additional per-minute connection charge. ISDN lines may be configured differently depending on whether they will transmit voice or data, whether they accept call waiting, providing call forwarding, and so forth; be sure that your telephone company provides detailed ordering instructions. You may also wish to ask about the number of telephone numbers that are included in your package (two numbers are sometimes included), whether your ISDN basic rate supports multiple simultaneous calls (one on hold, another active), call forwarding, conference calling, and call transfer.

Although most ISDN connections are dial-up, some ISDN connections can be left on at all times (creating a permanent connection); you should ask your ISDN provider about these services if you need permanent connections. ISDN technology is also called *digital subscriber line* technology. Its major competitors are its younger siblings—more advanced, faster technologies known collectively as DSL. Cable modem is also a competitor. These technologies are discussed later in this chapter.

7.4.2.3 References

You can read an article about ISDN modems and services at: http://www.cnet.com/Content/Reviews/Compare/Isdn2/ (This article is several years old. Its background information is still quite relevant, but its recommendations for particular modem models are outdated.) Alternatively, you'll find a second good tutorial on ISDN at: http://www.networkmagazine.com/magazine/tutorial/internetworking/9506tut.htm .

You can see a diagram of a school network that incorporates ISDN lines at: http://wsd3.k12.co.us/ (click the link entitled *WSD3Net Diagram* at the bottom of the page).

Section 7.4.2 Technical Information Summary

ISDN

Integrated Services Digital Network (*ISDN*) connections provide digital data communications on a dial-up basis between two points over regular telephone wire. ISDN services can be purchased at many different speeds, including 64 Kbps, 128 Kbps (actually 230.4 Kbps if you also use data compression), 256 Kbps, and 512 Kbps. The most common ISDN service offers 128 Kbps and can support several dozen simultaneous users with reasonable response rates. ISDN services at 128 Kbps are now available in most geographic areas. ISDN carries both voice and data.

Connections are billed as a monthly charge plus an additional per-minute connection charge. ISDN services are available in most United States communities, and the technology is increasingly common. The major competitors to ISDN are its younger siblings—more advanced, faster technologies known collectively as DSL. Cable modem is also a competitor. These technologies are discussed later in this chapter.

Example

Suppose your school district consists of 4 buildings that are connected to each other. In addition, each building has its own connections to the Internet. If these connections to the Internet are via ISDN…

- Your local telephone company and your Internet provider must support ISDN services.
- Each building must be no further than 5.5 km from the central telephone office, must procure ISDN services from the telephone company, and must purchase compatible equipment (NT1, terminal adapter). If you add a building to your ISDN WAN, it must also conform to these rules.
- Connections are billed as a monthly charge plus an additional per-minute connection charge. If your buildings reside in locations that are subject to long-distance rates, your ISDN calls will also be charged at these higher rates.

7.4.3 Leased lines (including T1)

7.4.3.1 Technical definition

Leased lines, as the name suggests, are telephone communications lines that you rent for your private use. Leased lines provide constant (as opposed to dial-up) digital connections between two sites over copper wire. You may lease lines at many different speeds—from 56 Kbps to 274 Mbps—with the most common connections being *T1* (1.544 Mbps) and *fractional T1* (various speeds that are all multiples of 64 Kbps). Recently, telecommunications providers have begun to offer *burstable T1* (speeds which vary with the momentary demands of your network, up to 1.544 Mbps). For rates of 128 Kbps and above, you can upgrade your service relatively easily. To increase your transmission rate you simply provision new services from the telecommunications provider, and you need not change your network connection equipment. T1 services provide very good response rates for hundreds of simultaneous users. Of all the LAN technologies in this chapter, T1 lines constitute the most common technology for connecting schools to the Internet.

Leased line communications are defined by a series of standards that the American National Standards Institute issued in the 1980's. Common standards include:

Standard	*Transmission rate*
DS-0 (digital signal level 0)	64 Kbps
DS-1 (digital signal level 1)	1.544 Mbps
DS-3 (digital signal level 3)	44.736 Mbps

Telephone circuits implement these standards. For example, telephone lines called T1 lines conform to DS-1 standards, while T3 lines conform to DS-3 standards. You can use these T-carrier circuits to transmit/receive data, voice, and video simultaneously (the signals are combined, or multiplexed, onto the line).

7.4.3.2 Implementing leased lines

The leased line usually consists of two twisted pairs of copper conductors. These wires terminate at your site in a jack. The jack is connected, in turn, to a *channel service unit/data service unit* (CSU/DSU), which provides digital connection services similar to those provided by a modem for analog connections. Generally, the CSU/DSU receives incoming signals from the telephone company's central office via one- or two-pairs of wires, processes the signals, and passes them onto a router on your local area network. (A router connects your local area network to other networks, such as the Internet. We discuss routers in more detail in Chapter 5.) For outgoing signals, the CSU/DSU receives information from the router, encodes it for travel over the telephone company line, and sends it onto its destination.

To provision a leased line, you must call your local telephone company or telecommunications carrier. For each pair of buildings you wish to connect, you must install a leased line and a CSU/DSU at each location. The CSU/DSUs must be compatible with each other, and with equipment at the telephone company central office (for example, they must use the same encoding schemes when sending/receiving information). There are no restrictions on the distance between the two points connected by a leased line. However, leased line charges vary directly with the distance between connected points as well as with the speed of the line.

DSL, cable modem, and radio waves are competitor technologies to leased lines. They can carry data, video, and voice information over long distances at reasonable rates. Frame relay services are also a competitor to T1 leased lines with regard to data, but frame relay cannot carry video with equivalent reliability. Other competitor technologies include asynchronous transfer mode (ATM) and low-level satellite technologies.

7.4.3.3 References

You can see a diagram of a school network that incorporates T1 lines at: http://wsd3.k12.co.us/ (click the link entitled *WSD3Net Diagram* at the bottom of the page—we looked at this network in the POTS and ISDN sections of this chapter, as well).

Section 7.4.3 Technical Information Summary

Leased lines (including T1)

Leased lines, as the name suggests, are telephone communications lines that you rent for your private use. Leased lines provide constant (as opposed to dial-up) digital connections between two sites over copper wire. You may lease lines at many different speeds—from 56 Kbps to 274 Mbps—with the most common connections being *T1* (1.544 Mbps) and *fractional T1* (various speeds that are all multiples of 64 Kbps).

Leased lines provide very fast, robust communication services and are perhaps the most common way that schools connect to the Internet. They are also relatively expensive and require weeks of advance notice to provision. DSL, cable modem, and radio waves are competitor technologies to leased lines. They can carry data, video, and voice information over long distances at reasonable rates. Frame relay services are also a competitor to T1 leased lines with regard to data, but frame relay cannot carry video with equivalent reliability.

Example

Suppose your school district consists of 3 school buildings that are connected to a 4th building, the district office. In addition, all buildings share a single Internet connection through the district office. If all of these connections are via T1 leased lines…

- Your Internet service provider must support T1 services. In the district office, you must install a leased line and CSU/DSU that is compatible with your Internet service provider's equipment.
- You must provision 3 leased lines and purchase 3 pairs (that is, 6 total) CSU/DSUs to connect each school building to the district office. (One CSU/DSU resides in each school, and its matching CSU/DSU resides in the district office. In addition, the district office includes a CSU/DSU that connects to its partner at the ISP.) You must also install a router in the district office to connect the CSU/DSUs and bind the leased lines into a wide area network.
- Leased lines create a permanent connection between buildings. Charges are based on distance between buildings and the speed of the connection.

7.4.4 Digital Subscriber Lines (ADSL)

7.4.4.1 Technical definition

Digital subscriber line technologies (DSL) use standard phone lines to deliver high-speed data communications. The fastest DSL transmissions are fast enough—up to 52 Mbps downstream (*to* the user) and 2.3 Mbps upstream (*from* the user)—to support full motion video, telephony, and interactive multimedia applications delivered directly from the Internet. The most common form of DSL, called ADSL (Asynchronous Digital Subscribe Line), offers speeds similar to leased T1 lines, and can support dozens of simultaneous users of voice and data communications.

The interest in DSL technology arose in part from the prohibitive cost of the competitive technologies. It also grew as a result of the Telecommunications Reform Act of 1996, which allowed local and long-distance carriers, cable companies, radio/television broadcasters, Internet/online service providers, and telecommunications equipment manufacturers to compete in one another’s markets. Since late 1998, the number of telephone companies offering DSL services has increased significantly. The DSL family includes several different technologies of increasing power:

Digital subscriber line technologies

DSL technology	*Speed*	*Distance*	*Applications*
Asynchronous Digital Subscriber Line Lite (ADSL Lite)	Up to 1 Mbps downstream Up to 384 Kbps upstream	22,000–25,000 ft	Internet/intranet access, Web browsing, voice telephony, video telephony
Asynchronous Digital Subscriber Line (ADSL) & Rate-Adaptive Digital Subscriber Line (R-ADSL)	1.5–8 Mbps downstream Up to 1.544 Mbps upstream	18,000 feet (12,000 ft for fastest speeds)	Internet/intranet access, video-on-demand, remote LAN access, virtual private networks, voice telephony
High Bit-Rate Digital Subscriber Line (HDSL)	1.544 Mbps full duplex (T1) (uses 2–3 wire pairs)	12,000–15,000 ft	Local, repeated T1 trunk replacement, PBX or LAN interconnect, Frame Relay traffic aggregator
Single-Line Digital Subscriber Line (SDSL)	1.544 Mbps full duplex (T1) (uses 1 wire pair)	10,000 ft	Local, repeated T1 trunk replacement, collaborative computing, LAN interconnect
Very High Bit-Rate Digital Subscriber Line (VDSL)	13–52 Mbps downstream 1.5–2.3 Mbps upstream	1,000–4,500 ft	(depending on speed) Multimedia Internet access, high-definition television program delivery

Source: 3Com, March 1998
*(*http://www.3com.com/technology/tech_net/white_papers/500624.html#What*)*

7.4.4.2 Implementing DSL

DSL services are not yet available in all areas of the United States. You should check with your local telecommunications companies to determine their offerings. If your telecommunications companies offer DSL, you should inquire about their installation procedures, compatible brands of modems and other hardware, and rates. Like cable, DSL installations usually require that the vendor (your telecommunications company) install the connection at your site.

Additionally, *unless your telecommunications company has specific experience interconnecting buildings with DSL*, you should plan to use DSL only to connect your school buildings to the Internet; you should *not* use DSL to interconnect school buildings with one another. Current DSL technologies do not generally use dedicated, and therefore secure, connections between buildings. Instead, most DSL implementations send your data from the point of origin (for example, one school building) to your telecommunications carrier, where Internet-style routing directs the data onto the recipient (another school building). Like all Internet connections, data on these connections travel on a public (insecure) network. The most common alternative to DSL—leased lines—have the advantage that they are private connections and therefore much more secure.

DSL connections carry both voice and data on the same copper wires that traditionally carried only voice; they accomplish this magic by leaving alone the bandwidth used by voice transmissions (below 4 KHz), and sending computer data using modern digital processing techniques at other frequencies. (DSL is classified as a *broadband* connection because it carries data on multiple frequencies at the same time. Cable connections are also broadband.) At the telephone company central office, the voice transmissions are routed to the regular telephone switch, and the data are passed directly to an Internet Service Provider or other Internet server. Happily, the voice portion of the signal remains active even if power is lost (unlike ISDN voice transmissions).

In order for data and voice to coexist peaceably, DSL technologies make use of a device called a *splitter*. Splitters generally work in pairs, with one splitter in the telephone company central office and the other installed by the telephone company at your home or school. The splitter at your home or school connects the telephone company line to your telephone and, over separate wires, to your ADSL equipment. The splitter at the telephone company office channels your telephone voice transmissions to the public telephone network, and your data transmissions to ATM networks, Ethernets, T1 lines, serial lines, or frame relay (depending on the DSL services you negotiate with your telecommunications carrier).

ADSL enthusiasts (and modem manufacturers), who would prefer that ADSL modems be as easy to install as regular modems, have agitated for a modification to the DSL standard that would make it unnecessary for the telephone company to install each DSL connection. Accordingly, they have proposed the G.lite standard, which allows ADSL modems and telephones to share existing telephone lines without a splitter. The G.lite specification was formally endorsed by the International Telecommunications Union in October 1998 (a strong first step towards complete acceptance among manufacturers and telecommunications vendors).

Some recent news reports indicate the G.lite, splitterless technologies achieved neither of their goals—neither robust connections nor telephone company-free installations. Particularly, some reports mention interference between voice and data communications on G.lite lines. G.lite is brand new, and you should watch the computer press in the near future, as well as the experience of your colleagues, to determine its true potential before you implement it.

Like ISDN modems, DSL modems may be installed internally or externally. If you install an internal modem, you simply insert the modem card into your computer and connect the modem card to the telephone company wall jack with an ADSL cable. External modems sport at least 3 connections: one for the DSL cable connected to your DSL telephone line, another for a plain old telephone connection, and a third for an Ethernet connection. If the external DSL modem will be used by just one person, you can connect the DSL modem's Ethernet port to the Ethernet network interface in your computer. Alternatively, if you wish to share your ADSL modem among a number of users, you must connect every user (including the DSL modem) to an Ethernet hub. As another alternative, you can employ a DSL router (instead of a DSL modem) to connect your local area network to the Internet.

Like T1 and cable technologies (and unlike ISDN), DSL connections are permanent, dedicated between two points, and billed at a flat rate for unlimited Internet access. In general, DSL connections are considerably cheaper than T1 connections at similar speeds.

Widespread use of DSL technologies depends on how well the telephone companies market and implement the services. A number of telecommunications vendors offer DSL services now, and you can expect more in the near future. Because ADSL is considered an “overlay” technology—

one which uses existing telephone wires and whose other required components can be added quickly to the telephone company network as needed—most analysts expect rapid deployment.

7.4.4.3 References

You can see a diagram of a traditional ADSL network as well as a G.lite network at http://www.orckit.co.il/fr_newsa.html?/glite.html (the traditional ADSL network is at the bottom of the page).

You can read an excellent (technical) tutorial about DSL technologies at http://www.data.com/tutorials/dsl.html . The tutorial includes a diagram of a DSL wide area network at http://www.data.com/tutorials/images/dsl_figure.html .

Section 7.4.4 Technical Information Summary

Digital subscriber line (ADSL)

Digital subscriber line technologies use standard phone lines to deliver high-speed data communications. The most common form of DSL, called ADSL (Asynchronous Digital Subscriber Line), offers speeds similar to leased T1 lines, and can support dozens of simultaneous users of voice and data communications.

At this time, *unless your telecommunications company has specific experience interconnecting buildings with DSL*, you should plan to use DSL only to connect your school buildings to the Internet and not to interconnect them with one another. Current DSL technologies do not generally use dedicated, and therefore secure, connections between buildings. The most common alternative to DSL—leased lines—have the advantage that they are private connections and therefore secure.

DSL technologies are relatively new and are not yet available in all areas of the United States. Where they are available, your school building must be within 12,000-18,000 feet of the telephone company central office to utilize most DSL technologies.

7.4.5 Cable modems

7.4.5.1 Technical definition

Primarily intended for Internet access from customers' homes, *cable modems* deliver up to 30 Mbps information downstream and up to 10 Mbps upstream (although much slower rates of 10 Mbps downstream and 128 Kbps upstream are more common).

7.4.5.2 Implementing cable modems

To implement cable modem connections, you must first determine whether your local cable company offers networking services. If they do, you should inquire whether they offer an interbuilding network (called an institutional loop), Internet services, or both. An institutional loop allows you to create connections among your school buildings; Internet services allow you to connect with the Internet. You should also inquire about your cable company's recommended installation procedures, costs, and restrictions. As with DSL technologies, you should only use cable technologies for interbuilding communication *if your cable company has explicit experience with such installations.* Otherwise, you may wish to use cable connections only for traffic to and from the Internet.

To connect a site via cable, the cable company installs coaxial cable (just like the cable that connects your television) and rents you a cable modem. You connect the coaxial cable to the cable modem, and the cable modem via an Ethernet cable to an Ethernet network interface in one of your computers, servers, hubs, or routers. Cable connections are classified as *broadband* because they carry data on multiple frequencies at the same time. DSL connections are also broadband.)

Like T1 and DSL, cable modems create a permanent connection to the Internet. Once you've connected your computer to your cable modem, and your cable modem to the cable company wall jack, your connection to the Internet is active and remains always ready for your use.

Cable modems deliver data at remarkable speeds with high reliability, and many schools and individuals are queuing up for these services. Nonetheless, you should be cautious of implementing them for several reasons.

- Unlike leased lines and ISDN, cable modems are shared among all users in a neighborhood, so that actual data delivery rates vary according to the number of users on the system. As the cable companies add subscribers to your segment—and some expect to support as up to 2,000 residences on a single subnet—you can expect to see performance decline.
- A more serious implication of shared subnets is lack of privacy. Cable modem users essentially shared a large public LAN with all other users on their subnet. Credit card information, personal information, and other sensitive data are vulnerable to malicious individuals who use electronic sniffers to watch the contents of each packet on the subnet. Only data that is encrypted is truly safe from other local cable users.

- Finally, the widespread introduction of cable modems depends on how well cable providers negotiate the learning curve involved with creating data networks, whether they develop and install complex, two-way transmission systems (traditional cable systems deliver data in one direction only), and the accuracy of their management and billing systems. In 1998, more than 70 percent of cable connections consisted of one-way, downstream data (to you from the cable company). Upgrading such systems is very expensive, and many cable companies (already in debt) balk at spending large sums of money without knowing if they will live to see an adequate return on their investment.

Cable vendors generally charge a flat, monthly rate for unlimited service. In some communities, cable services are provided to schools at no charge. Like DSL, cable in the context of Internet connectivity is relatively new. You should watch the computer press and the experience of your colleagues before you implement it.

7.4.5.3 References

You can see a diagram of a school network that uses cable technologies at: http://www.att.com/communityguide/d7.html .

You can read a comparison of ISDN, cable, and ADSL technologies at: http://www.networkmagazine.com/magazine/archive/1998/09/9809mkt.htm

Section 7.4.5 Technical Information Summary

Cable modems

Cable modems deliver up to 30 Mbps information downstream (to the user) and up to 10 Mbps upstream (from the user). Much slower rates of 10 Mbps downstream and 128 Kbps upstream are more common.

Cable modems carry data on the same copper wires that traditionally carried only television signals. These wires have large capacities, servicing hundreds of simultaneous connections. Cable connections are faster than ISDN (roughly the same speed as ADSL), and they are permanent. Once you've connected your computer to your cable modem, and your cable modem to the cable company jack, your connection to the Internet is active and remains always ready for your use. Unlike DSL, however, cable modem connections are shared among all users on a segment (local area); security breaches are possible if malicious users employ decoding devices to peer into private information.

Cable modem technologies are relatively new and are not yet available in all areas of the United States. Cable modem services are charged at a flat fee, and generally include the services of an Internet Provider (electronic mail, Web pages, and so forth). As with DSL technologies, you use cable technologies primarily to connect to the Internet; you should use cable technologies for *interbuilding* communication *only if your cable company has explicit experience with such installations.*

7.4.6 Frame Relay

7.4.6.1 Technical definition

Frame relay connections provide constant (as opposed to dial-up) digital data communications service within a network cloud. When we use the term network cloud, we mean any network whose connections you do not maintain and whose physical configuration is immaterial to you. In the case of frame relay networks, your telecommunications carrier maintains the frame relay connections between your sites.

In general, frame relay networks span large geographical areas (for example, whole states in the United States). For networks that do not cover large geographical areas, WAN technologies discussed earlier in this chapter may be less costly.

7.4.6.2 Implementing frame relay

To create a frame relay network, you must connect each building in your WAN to a frame relay network cloud at the site maintained by your telecommunications provider. These connections may use any WAN physical link technology—for example, T1 lines. Once you have connected to the frame relay network cloud, you must provision circuits (connections) within the cloud. For example, imagine a school district that consists of four buildings each connected to all others. You must provision 4 connections (T1 lines, perhaps) to the frame relay network, and then 6 circuits within the network cloud to bind these connections into a wide area network. (You can envision the configuration of the 6 circuits if you connect the vertices of an imaginary square in every possible way.) Frame relay services can be purchased at many different speeds, including 56 Kbps, 128 Kbps, and 1.544 Mbps.

Frame relay networks operate by sending your information along a circuit—a path that is established for the duration of a connection. These circuits may be either *permanent virtual circuits* (PVCs) or *switched virtual circuits* (SVCs). In a permanent virtual circuit, the path from one point on your WAN to every other point is defined at the time of configuration. In a switched virtual circuit, the path is defined when the connection is initiated (like a phone call); switched paths may or may not traverse the same interim connections for each call. Permanent virtual circuits reduce call setup delays and other disturbances in data delivery, and they are the most common circuit offered by frame relay vendors.

When you purchase frame relay services, you have the option to request a guaranteed level of service, called the *committed information rate* (*CIR*). You may exceed the CIR by a second rate, called the *committed burst rate* (*Bc*), up to a maximum specified by a third rate, the *burst excess rate* (*Be*). For example, you might select a CIR of 1.0 Mbps, a Bc of 1.25 Mbps, and a Be of 1.5 Mbps. If you exceed your CIR when the frame relay network is congested (regardless of the other rates you may have specified), then the network may discard some of your data temporarily and signal your sending system to retransmit.

If your network traffic consists mainly of electronic mail and shared documents—data which can tolerate small delays with no loss of integrity—then frame relay may produce adequate throughput with no committed information rate. However, if your network information consists mainly of services such as Web browsing or voice, then you should plan carefully. Describe your network operations to your frame relay vendor and purchase the appropriate rates.

Frame relay and leased line networks are, perhaps, the most common WAN technologies in current use. Frame relay networks have some advantages when compared to leased line technologies.

- Under some circumstances, you need to install and maintain fewer components for frame relay networks than for leased line networks. For example, a 4-building wide area network with each building connected to all others would require 6 leased lines and 12 CSU/DSUs—all your own equipment to maintain. However, an equivalent frame relay network requires only 4 leased lines and 8 CSU/DSUs. It also requires 6 frame relay circuits—but you are not responsible for maintaining the frame relay equipment or connections.
- It is easier to expand frame relay networks than leased line networks. For example, if you add a 5th building to a 4-building leased line network and wish to connect it to each of the others, you must purchase 4 additional leased lines. If you add a 5th building to a frame relay network, however, you need only 1 leased line as well as 4 additional circuits within the cloud. Since it is considerably easier to provision circuits than leased lines, you may find that it is easier to grow frame relay networks than leased line networks.
- Frame relay networks provide redundant paths for data. Unlike leased lines, if one path is damaged the network automatically switches to another path.
- Frame relay sets its price based on your average throughput rather than on your maximum throughput, as do most leased lines. And the costs of frame relay do not increase with distance. Frame relay services may be more expensive than leased lines at short distances (especially if you purchase a committed information rate), but you should check with your local vendors to determine the distance/data rate at which they become cheaper.

Frame relay networks also have some disadvantages with regard to leased line technologies.

- In a frame relay network, you share bandwidth (data delivery capacity) with others, and their traffic may affect your throughput.
- Additionally, security is a greater issue because you share the frame relay with other clients of the telecommunications vendor. While your circuits are still private, you should discuss security issues with your frame relay vendor.
- The unpredictable retransmissions that sometimes occur with frame relay services make frame relay less desirable than leased lines if your WAN includes voice or video transmissions, which require dependable, steady delivery streams.
- One final drawback of frame relay involves connections between different frame relay clouds (pertinent only when the communicating sites are very far apart). Within any given cloud, your connection is specified by standards for the user-to-network

interface (UNI). However, the complexities of connections between clouds are still being ironed out. Some of these complexities have been addressed in the network-to-network interface—NNI (which defines signal standards), but billing and troubleshooting are not always compatible between different frame relay networks.

7.4.6.3 References

You can see a network diagram of a library network connected by frame relay at: http://198.209.253.70/projects/real/equipment.htm

You can read an article about frame relay networks at: http://www.networkcomputing.com/netdesign/frame1.html

Section 7.4.6 Technical Information Summary

Frame relay

Frame relay connections provide constant (as opposed to dial-up) digital data communications service within a network cloud. When we use the term network cloud, we mean any network whose connections you do not maintain and whose physical configuration is immaterial to you. In the case of frame relay networks, your telecommunications carrier maintains the frame relay connections between your sites. Frame relay services can be purchased at many different speeds, including 56 Kbps, 128 Kbps, and 1.544 Mbps.

Frame relay is a proven WAN technology that may be less expensive to implement than leased lines. It is faster than ISDN, and more commonly available than DSL or cable modem. The costs for frame relay vary with your usage (but are independent of distance).

Example

Suppose your school district consists of 4 buildings that are connected to each other via a frame relay network. In addition, one of these buildings maintains a single Internet connection via a T1 leased line…

- Each building must secure a local connection to the frame relay network (probably purchasing a T1 leased line and CSU/DSU). In addition, each building must secure a circuit within the frame relay network cloud to every other building. In total, your 4-building WAN requires 4 connections to the frame relay network and 6 circuits within the frame relay network.

- Frame relay networks have several advantages over leased line networks. They require that you purchase and maintain less equipment, base their costs on your average throughput (rather than your maximum), and are somewhat easier to expand.
- Frame relay networks have several disadvantages with regard to leased line networks. They are often more expensive at short distances. They provide less desirable service than leased lines if your WAN includes voice or video transmissions, which require dependable, steady delivery streams. Because you share the frame relay network with others, you should discuss security issues with your frame relay network vendor.
- Frame relay creates a permanent (rather than dial-up) connection between buildings. Charges are based on transmission rate provided to each connection.

7.4.7 Wireless

7.4.7.1 Technical definition

Many different technologies—including microwaves, lasers, and radio waves—can be used to create wireless WAN links. Of these technologies, radio waves have gained the most attention recently. Connecting LANs as far as 25 miles apart, radio waves provide an inexpensive if relatively novel kind of wide area network.

Like their local area cousins, wireless wide area radio networks use frequency hopping spread spectrum and direct sequence spread spectrum technologies. (You may remember from earlier chapters that these two radio technologies transmit information by spreading their transmissions across a range, or spectrum, of different radio wave frequencies.) Wireless connections generally offer transmission speeds of 1-2 MHz, although speeds of 10 MHz are becoming increasingly common. Operating in the 2.4 GHz wavelength band of the radio spectrum (which is reserved for unregulated industrial, scientific, and medical use), these wireless connections do not need to be licensed by the FCC.

7.4.7.2 Implementing wireless connections

To create a wireless WAN, you typically purchase a wireless bridge and an antenna for each site. The wireless bridge connects to your local area network, receives Ethernet data, filters the data intended for wide area transmission and sends that data to its internal radio frequency modem. The radio modem changes the Ethernet data into a radio frequency suitable for wireless transmission and sends it via a cable to an antenna, which transmits the signal over long distances.

When you set up a wireless WAN, you must be sure that the equipment is installed properly—particularly that the antennas are within *radio line of sight* and properly aligned to each other. Radio line of sight implies more than just visibility. Since radio waves can be disturbed by obstacles on or near the transmission path, radio line of sight requires not only a clear direct path between sites but also an unobstructed swath above and below the center of the transmission line. One rule of thumb calls for 12 feet of clearance at the center of the path for every mile between the two points you are connecting. Some vendors offer charts that describe the relationship between the clearance required, the distance between the sites, and the height of obstacles in the path.

Unless you are very skilled, you may wish to ask your vendor to conduct a path analysis before you purchase your wireless WAN equipment. A path analysis determines not only the line of sight, but also identifies potential obstacles, calculates the necessary power and requirements for repeaters, and selects the type of antenna that will best suit your site needs.

Because wireless WANs do not incur line charges, they can realize great savings for your school/district. But these technologies are sufficiently new that you should find colleagues with actual experience in situations like yours before your buy.

7.4.7.3 References

You can read about wireless WANs at manufacturer sites:

C-Spec	http://www.c-spec.com/
Solectek	http://www.solectek.com/
Speedcom	http://www.the-wave-wireless.com/wiretut.html

You can read case studies of one manufacturer's experience with several successful school implementations at:
http://www.c-spec.com/ (select the References link on the main page).

You can see diagrams of school networks using wireless technologies at:
http://www.lgsd.k12.ca.us/lemonlink/network_diagram.htm
http://scnc.holt.k12.mi.us/~lachniet/lmb/

Section 7.4.7 Technical Information Summary

Wireless

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7.4.8 Asynchronous Transfer Mode (ATM), SONet & Fiber Distributed Data Interface (FDDI)

Asynchronous Transfer Mode (*ATM*), *SONet (Synchronous Optical Network),* and *Fiber Distributed Data Interface* (*FDDI*) provide powerful but expensive networks sufficient to convey voice, video, and data for large organizations.

ATM provides both a LAN and a WAN technology. The current price of installation makes its use on most LANs prohibitive, but it is frequently deployed for wide area connections. Running at speeds from 1.54 Mbps to 622 Mbps with additional capabilities for managing network congestion, ATM provides an astonishing potential to deliver high volumes of video, voice, and data.

ATM divides its operations into several levels (analogous to the levels of the OSI model). The upper levels describe how your network connects to ATM services. Intermediate levels describe how your data is divided for the WAN transmission into small packages (53-bytes each, termed cells). The lowest level defines the connections between ATM and the physical network, including several possible alternative carrier signals with which ATM can be integrated—DS-3 (T3), SONet lines, and Fiber Distributed Data Interface (FDDI).

SONet defines a transmission scheme for fiber-optic cable or copper wire. SONet operates at the following speeds:

SONet		*Transmission rate (Mbits/s)*	*Number of Digitized Voice or 64,000-bits/s Data Circuits*
Optical Fiber	*Copper Wire*		
OC-1	STS-1	51.84	672
OC-3	STS-3	155.52	2,016
OC-12	STS-12	622.08	8,064
OC-48	STS-48	2,488.32	32,256

Source: Schneir, Dictionary of PC Hardware and Data Communications Terms
http://www.oreilly.com/reference/dictionary/terms/S/Synchronous_Optical_Network.htm

You should note that current copper wire technologies are not certified to deliver data at speeds greater than 155 Mbps. Many of these standards therefore exist in theory only. SONet is usually implemented on *single mode fiber optic cable*.

Fiber Distributed Data Interface (FDDI) defines 100 Mbps service over fiber optic cable. FDDI can provide data link and physical communications for ATM or, alternatively, it can provide full LAN or WAN services on its own. As a LAN technology, FDDI is expensive to implement. In some geographic locations, telecommunications carriers provide access to Fiber Network Services (FNS), a public FDDI network that provides very fast wide area connections.

Both SONet and FDDI are widely used, with FDDI more common on the LAN and SONet more common on large WANs (for example, between Internet Service Providers). ATM is the technology of choice for combining video, data, and phone (voice) networks, if you can afford it.

You can read a good article about ATM, 100 Mbps Ethernet, and FDDI at:
http://www.infoworld.com/cgi-bin/displayArchive.pl?/96/41/backbona.dat.htm

Section 7.4.8 Technical Information Summary

Asynchronous Transfer Mode (ATM), SONet & Fiber Distributed Data Interface (FDDI)

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SONet defines a transmission scheme for fiber-optic cable or copper wire. SONet operates at very high speeds, commonly 622 Mbps. ATM services at the upper levels of the OSI model are sometimes run over SONet at the lower levels.

Fiber Distributed Data Interface (FDDI) defines 100 Mbps service over fiber optic cable. FDDI can provide data link and physical communications (lowest OSI levels) for ATM or, alternatively, it can provide full LAN or WAN services on its own.

7.5 WAN technologies and the OSI Reference Model

Throughout our discussion of wide area network technologies, we have omitted any mention of the OSI Reference Model (see Chapter 3). Wide area network technologies implement this model just as do local area networks, but they generally focus on the physical and data link layers only. The chart below summarizes the most common wide area network technologies with regard to the OSI Reference Model.

WAN Technology	*Physical Layer (Layer 1)*	*Data Link Layer (Layer 2)*
POTS	POTS operates at the physical layer (layer 1).	Point-To-Point (PPP) and Serial Line Internet Protocol (SLIP) work with POTS at the data link layer (layer 2). PPP and SLIP, in turn, receive information from the TCP/IP protocol stack (at layers 3 and 4) on your network, encapsulate this information, and then pass it onto your POTS connections.
ISDN	ISDN operates at the physical layer (layer 1).	Point-to-Point Protocol (PPP) or High-Level Data Link protocol (HDLC) work with ISDN at the data link layer (layer 2). PPP and HDLC receive information from the TCP/IP protocol stack (at layers 3 and 4) on your network, encapsulate this information, and then pass it onto your ISDN connections.
Leased Lines	Leased lines operates at the physical layer (layer 1).	Point-to-Point Protocol (PPP), High-Level Data Link protocol (HDLC), and others are common carriers; your telecommunications provider will specify the data link protocol (layer 2) when you provision the line. The links protocols (like PPP and HDLC) receive information from the TCP/IP protocol stack (at layers 3 and 4) on your network, encapsulate this information, and then pass it onto your leased line connections.
Frame Relay	Uses leased lines or ATM at the physical layer (layer 1).	Frame relay defines a data link layer protocol (layer 2) for conveying data over a variety of physical connections, including T1 or ATM. Frame relay receives information from the TCP/IP protocol stack (at layers 3 and 4) on your network, encapsulates this information, and then passes it onto your physical connections.

7.6 Comparison of ISDN, leased lines, & frame relay

The table below summarizes the most important distinctions among ISDN, leased lines, and frame relay—the three most common WAN technologies.

ISDN

Cost	monthly fee + per minute charge cost increases as the distance between points increases
Bandwidth	64 Kbps to 128 Kbps (most common)
Uses	voice, data, video
Advantages	you pay only for the time you are using the connection, so ISDN is cost-effective if your communications are sporadic relatively inexpensive simple installation

Leased Lines (T1)

Cost	fixed cost cost increases as the distance between points increases
Bandwidth	56 Kbps, 128 Kbps, 512 Kbps, 1.544 Mbps (T1)
Uses	voice, data, video
Advantages	• you pay a fixed rate, so leased lines are useful if your communications are continuous and you wish to keep your expenses to a fixed monthly sum • well-known and reliable technology • good security • easy to increase capacity from 128 Kbps to higher bandwidth

Frame Relay

Cost	varies with bandwidth used
	cost does *not* increase as the distance between points increases
Bandwidth	any (depending on the WAN technology—such as T1—that connects you to your frame relay network and the frame relay bandwidth you contract for)
Uses	voice, data
Advantages	can grow to include numerous, geographically dispersed locations
	troubleshooting is handled by the frame relay provider instead of your staff
	easy to increase bandwidth

7.7 Closing Remarks

You can find a few brief case studies of wide area networks in schools at: http://education.3com.com/ecsmenu.html (click links beneath the United States Case Studies).

3Com Corporation provides a set of clickable diagrams which provide an overview of a school network and a means to drill (by clicking) into the details for each element. You can see these diagrams at http://education.3com.com/erc/netdiagram.html