CHAPTER 9

Using Telephone and Cable Networks for Data Transmission

Telephone networks were originally created to provide voice communication. The need to communicate digital data resulted in the invention of the dial-up modem. With the advent of the Internet came the need for high-speed downloading and uploading; the modem was just too slow. The telephone companies added a new technology, the *digital subscriber line* (DSL). Although dial-up modems still exist in many places all over the world, DSL provides much faster access to the Internet through the telephone network. In this chapter, we first discuss the basic structure of the telephone network. We then see how dial-up modems and DSL technology use these networks to access the Internet.

Cable networks were originally created to provide access to TV programs for those subscribers who had no reception because of natural obstructions such as mountains. Later the cable network became popular with people who just wanted a better signal. In addition, cable networks enabled access to remote broadcasting stations via microwave connections. Cable TV also found a good market in Internet access provision using some of the channels originally designed for video. After discussing the basic structure of cable networks, we discuss how cable modems can provide a high-speed connection to the Internet.

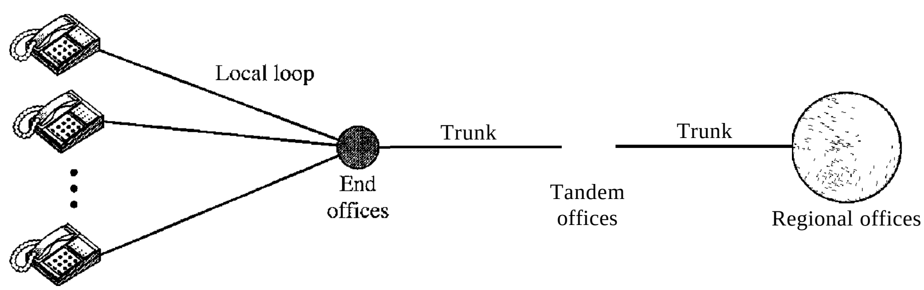
9.1 TELEPHONE NETWORK

Telephone networks use circuit switching. The telephone network had its beginnings in the late 1800s. The entire network, which is referred to as the plain old telephone system (POTS), was originally an analog system using analog signals to transmit voice. With the advent of the computer era, the network, in the 1980s, began to carry data in addition to voice. During the last decade, the telephone network has undergone many technical changes. The network is now digital as well as analog.

Major Components

The telephone network, as shown in Figure 9.1, is made of three major components: local loops, trunks, and switching offices. The telephone network has several levels of switching offices such as end offices, tandem offices, and regional offices.

Figure 9.1 *A telephone system*



Local Loops

One component of the telephone network is the local loop, a twisted-pair cable that connects the subscriber telephone to the nearest end office or local central office. The local loop, when used for voice, has a bandwidth of 4000 Hz (4 kHz). It is interesting to examine the telephone number associated with each local loop. The first three digits of a local telephone number define the office, and the next four digits define the local loop number.

Trunks

Trunks are transmission media that handle the communication between offices. A trunk normally handles hundreds or thousands of connections through multiplexing. Transmission is usually through optical fibers or satellite links.

Switching Offices

To avoid having a permanent physical link between any two subscribers, the telephone company has switches located in a switching office. A switch connects several local loops or trunks and allows a connection between different subscribers.

LATAs

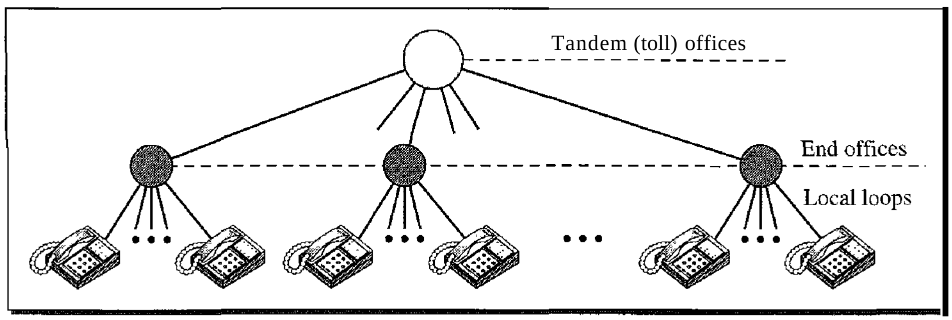
After the divestiture of 1984 (see Appendix E), the United States was divided into more than 200 local-access transport areas (LATAs). The number of LATAs has increased since then. A LATA can be a small or large metropolitan area. A small state may have one single LATA; a large state may have several LATAs. A LATA boundary may overlap the boundary of a state; part of a LATA can be in one state, part in another state.

Intra-LATA Services

The services offered by the common carriers (telephone companies) inside a LATA are called *intra-LATA* services. The carrier that handles these services is called a local exchange carrier (LEC). Before the Telecommunications Act of 1996 (see Appendix E), intra-LATA services were granted to one single carrier. This was a monopoly. After 1996, more than one carrier could provide services inside a LATA. The carrier that provided services before 1996 owns the cabling system (local loops) and is called the incumbent local exchange carrier (ILEC). The new carriers that can provide services are called competitive local exchange carriers (CLECs). To avoid the costs of new cabling, it was agreed that the ILECs would continue to provide the main services, and the CLECs would provide other services such as mobile telephone service, toll calls inside a LATA, and so on. Figure 9.2 shows a LATA and switching offices.

Intra-LATA services are provided by local exchange carriers. Since **1996,** there are two types ofLECs: incumbent local exchange carriers and competitive local exchange carriers.

Figure 9.2 *Switching offices in a LATA*



Communication inside a LATA is handled by end switches and tandem switches. A call that can be completed by using only end offices is considered toll-free. A call that has to go through a tandem office (intra-LATA toll office) is charged.

Inter-LATA Services

The services between LATAs are handled by interexchange carriers (IXCs). These carriers, sometimes called long-distance companies, provide communication services between two customers in different LATAs. After the act of 1996 (see Appendix E), these services can be provided by any carrier, including those involved in intra-LATA services. The field is wide open. Carriers providing inter-LATA services include AT&T, MCI, WorldCom, Sprint, and Verizon.

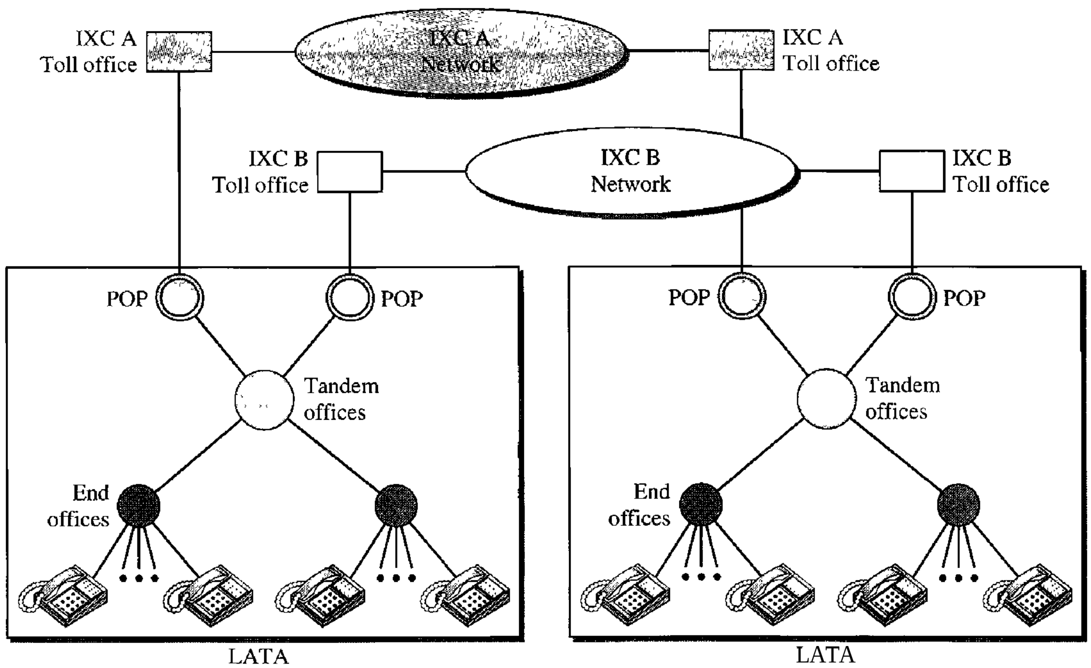
The IXCs are long-distance carriers that provide general data communications services including telephone service. A telephone call going through an IXC is normally digitized, with the carriers using several types of networks to provide service.

Points ofPresence

As we discussed, intra-LATA services can be provided by several LECs (one ILEC and possibly more than one CLEC). We also said that inter-LATA services can be provided by several IXCs. How do these carriers interact with one another? The answer is, via a switching office called a **point** of presence (POP). Each IXC that wants to provide inter-LATA services in a LATA must have a POP in that LATA. The LECs that provide services inside the LATA must provide connections so that every subscriber can have access to all POPs. Figure 9.3 illustrates the concept.

A subscriber who needs to make a connection with another subscriber is connected first to an end switch and then, either directly or through a tandem switch, to a POP. The

Figure 9.3 *Point of presences (POPs)*



call now goes from the POP of an IXC (the one the subscriber has chosen) in the source LATA to the POP of the same IXC in the destination LATA. The call is passed through the toll office of the IXC and is carried through the network provided by the IXC.

Signaling

The telephone network, at its beginning, used a circuit-switched network with dedicated links (multiplexing had not yet been invented) to transfer voice communication. As we saw in Chapter 8, a circuit-switched network needs the setup and teardown phases to establish and terminate paths between the two communicating parties. In the beginning, this task was performed by human operators. The operator room was a center to which all subscribers were connected. A subscriber who wished to talk to another subscriber picked up the receiver (off-hook) and rang the operator. The operator, after listening to the caller and getting the identifier of the called party, connected the two by using a wire with two plugs inserted into the corresponding two jacks. A dedicated circuit was created in this way. One of the parties, after the conversation ended, informed the operator to disconnect the circuit. This type of signaling is called in-band signaling because the same circuit can be used for both signaling and voice communication.

Later, the signaling system became automatic. Rotary telephones were invented that sent a digital signal defining each digit in a multidigit telephone number. The switches in the telephone companies used the digital signals to create a connection between the caller and the called parties. Both in-band and out-of-band signaling were used. In in-band signaling, the 4-kHz voice channel was also used to provide signaling. In out-of-band signaling, a portion of the voice channel bandwidth was used for signaling; the voice bandwidth and the signaling bandwidth were separate.

As telephone networks evolved into a complex network, the functionality of the signaling system increased. The signaling system was required to perform other tasks such as

1. Providing dial tone, ring tone, and busy tone
2. Transferring telephone numbers between offices
3. Maintaining and monitoring the call
4. Keeping billing information
5. Maintaining and monitoring the status of the telephone network equipment
6. Providing other functions such as caller ID, voice mail, and so on

These complex tasks resulted in the provision of a separate network for signaling. This means that a telephone network today can be thought of as two networks: a signaling network and a data transfer network.

The tasks of data transfer and signaling are separated in modern telephone networks: data transfer is done by one network, signaling by another.

However, we need to emphasize a point here. Although the two networks are separate, this does not mean that there are separate physical links everywhere; the two networks may use separate channels of the same link in parts of the system.

Data Transfer Network

The data transfer network that can carry multimedia information today is, for the most part, a circuit-switched network, although it can also be a packet-switched network. This network follows the same type of protocols and model as other networks discussed in this book.

Signaling Network

The signaling network, which is our main concern in this section, is a packet-switched network involving the layers similar to those in the OSI model or Internet model, discussed in Chapter 2. The nature of signaling makes it more suited to a packet-switching network with different layers. For example, the information needed to convey a telephone address can easily be encapsulated in a packet with all the error control and addressing information. Figure 9.4 shows a simplified situation of a telephone network in which the two networks are separated.

The user telephone or computer is connected to the signal points (SPs). The link between the telephone set and SP is common for the two networks. The signaling network uses nodes called signal transport ports (STPs) that receive and forward signaling messages. The signaling network also includes a service control point (SCP) that controls the whole operation of the network. Other systems such as a database center may be included to provide stored information about the entire signaling network.

Signaling System Seven (5S7)

The protocol that is used in the signaling network is called Signaling System Seven (SS7). It is very similar to the five-layer Internet model we saw in Chapter 2, but the layers have different names, as shown in Figure 9.5.

Figure 9.4 *Data transfer and signaling networks*

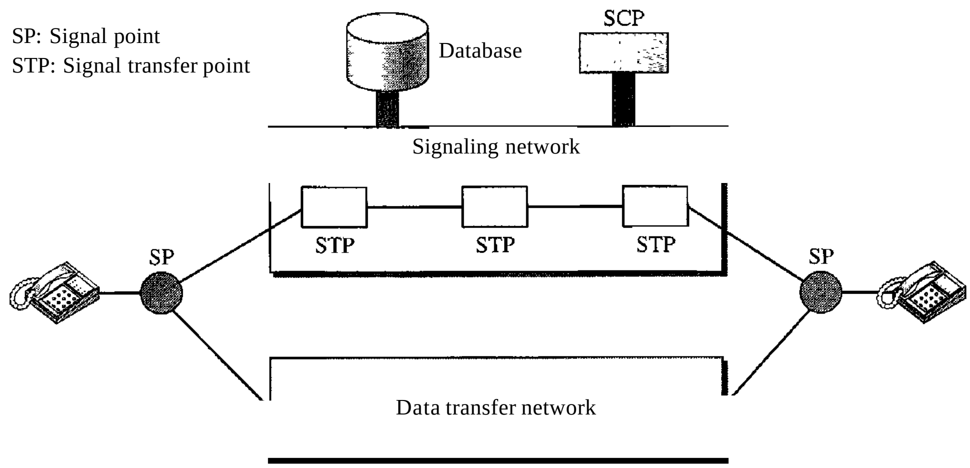
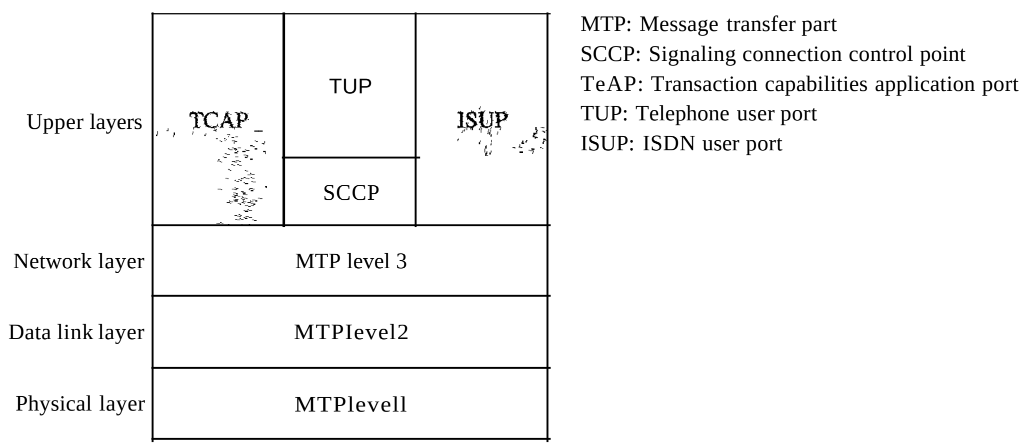


Figure 9.5 *Layers in SS7*



Physical Layer: MTP Level 1 The physical layer in SS7 called message transport part (MTP) level I uses several physical layer specifications such as T-l (1.544 Mbps) and DCa (64 kbps).

Data Link Layer: MTP Level 2 The MTP level 2 layer provides typical data link layer services such as packetizing, using source and destination address in the packet header, and CRC for error checking.

Network Layer: MTP Level 3 The MTP level 3 layer provides end-to-end connectivity by using the datagram approach to switching. Routers and switches route the signal packets from the source to the destination.

Transport Layer: SCCP The signaling connection control point (SCCP) is used for special services such as SaO-call processing.

Upper Layers: TUP, TCAP, and ISUP There are three protocols at the upper layers. Telephone user port (TUP) is responsible for setting up voice calls. It receives the dialed digits and routes the calls. Transaction capabilities application port (TCAP) provides remote calls that let an application program on a computer invoke a procedure on another computer. ISDN user port (ISUP) can replace TUP to provide services similar to those of an ISDN network.

Services Provided by Telephone Networks

Telephone companies provide two types of services: analog and digital.

Analog Services

In the beginning, telephone companies provided their subscribers with analog services. These services still continue today. We can categorize these services as either analog switched services or analog leased services.

Analog Switched Services This is the familiar dial-up service most often encountered when a home telephone is used. The signal on a local loop is analog, and the bandwidth is usually between 0 and 4000 Hz. A local call service is normally provided for a flat monthly rate, although in some LATAs, the carrier charges for each call or a set of calls. The rationale for a non flat-rate charge is to provide cheaper service for those customers who do not make many calls. A toll call can be intra-LATA or inter-LATA. If the LATA is geographically large, a call may go through a tandem office (toll office) and the subscriber will pay a fee for the call. The inter-LATA calls are long-distance calls and are charged as such.

Another service is called 800 service. If a subscriber (normally an organization) needs to provide free connections for other subscribers (normally customers), it can request the 800 service. In this case, the call is free for the caller, but it is paid by the callee. An organization uses this service to encourage customers to call. The rate is less expensive than that for a normal long-distance call.

The wide-area telephone service (WATS) is the opposite of the 800 service. The latter are inbound calls paid by the organization; the former are outbound calls paid by the organization. This service is a less expensive alternative to regular toll calls; charges are based on the number of calls. The service can be specified as outbound calls to the same state, to several states, or to the whole country, with rates charged accordingly.

The 900 services are like the 800 service, in that they are inbound calls to a subscriber. However, unlike the 800 service, the call is paid by the caller and is normally much more expensive than a normal long-distance call. The reason is that the carrier charges *two* fees: the first is the long-distance toll, and the second is the fee paid to the callee for each call.

Analog Leased Service An analog leased service offers customers the opportunity to lease a line, sometimes called a *dedicated line,* that is permanently connected to another customer. Although the connection still passes through the switches in the telephone network, subscribers experience it as a single line because the switch is always closed; no dialing is needed.

Digital Services

Recently telephone companies began offering digital services to their subscribers. Digital services are less sensitive than analog services to noise and other forms of interference.

The two most common digital services are switched/56 service and digital data service (DDS). We already discussed high-speed digital services-the T lines-in Chapter 6. We discuss the other services in this chapter.

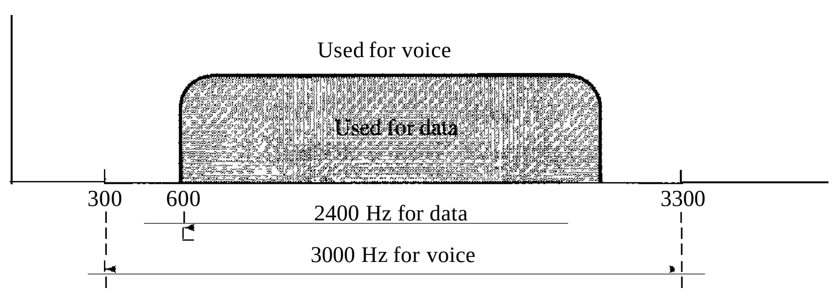
Switched/56 Service Switched/56 service is the digital version of an analog switched line. It is a switched digital service that allows data rates of up to 56 kbps. To communicate through this service, both parties must subscribe. A caller with normal telephone service cannot connect to a telephone or computer with switched/56 service even if the caller is using a modem. On the whole, digital and analog services represent two completely different domains for the telephone companies. Because the line in a switched! 56 service is already digital, subscribers do not need modems to transmit digital data. However, they do need another device called a digital service unit (DSU).

Digital Data Service Digital data service (DDS) is the digital version of an analog leased line; it is a digital leased line with a maximum data rate of 64 kbps.

9.2 DIAL-UP MODEMS

Traditional telephone lines can carry frequencies between 300 and 3300 Hz, giving them a bandwidth of 3000 Hz. All this range is used for transmitting voice, where a great deal of interference and distortion can be accepted without loss of intelligibility. As we have seen, however, data signals require a higher degree of accuracy to ensure integrity. For safety's sake, therefore, the edges of this range are not used for data communications. In general, we can say that the signal bandwidth must be smaller than the cable bandwidth. The effective bandwidth of a telephone line being used for data transmission is 2400 Hz, covering the range from 600 to 3000 Hz. Note that today some telephone lines are capable of handling greater bandwidth than traditional lines. However, modem design is still based on traditional capability (see Figure 9.6).

Figure 9.6 *Telephone line bandwidth*



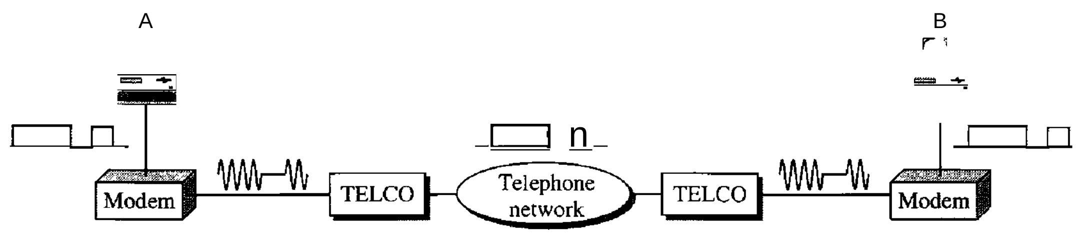
The term modem is a composite word that refers to the two functional entities that make up the device: a signal modulator and a signal demodulator. A modulator creates a bandpass analog signal from binary data. A demodulator recovers the binary data from the modulated signal.

Modem stands for modulator/demodulator.

Figure 9.7 shows the relationship of modems to a communications link. The computer on the left sends a digital signal to the modulator portion of the modem; the data are sent as an analog signal on the telephone lines. The modem on the right receives the analog signal, demodulates it through its demodulator, and delivers data to the computer on the right. The communication can be bidirectional, which means the computer on the right can simultaneously send data to the computer on the left, using the same modulation/demodulation processes.

Figure 9.7 *Modulation/demodulation*

TELCO: Telephone company



Modem Standards

Today, many of the most popular modems available are based on the V-series standards published by the ITU-T. We discuss just the most recent series.

V.32 and V.32bis

The V.32 modem uses a combined modulation and encoding technique called trellis-coded modulation. Trellis is essentially QAM plus a redundant bit. The data stream is divided into 4-bit sections. Instead of a quadbit (4-bit pattern), however, a *pentabit* (5-bit pattern) is transmitted. The value of the extra bit is calculated from the values of the data bits. The extra bit is used for error detection.

The Y.32 calls for 32-QAM with a baud rate of 2400. Because only 4 bits of each pentabit represent data, the resulting data rate is 4 x 2400 = 9600 bps. The constellation diagram and bandwidth are shown in Figure 9.8.

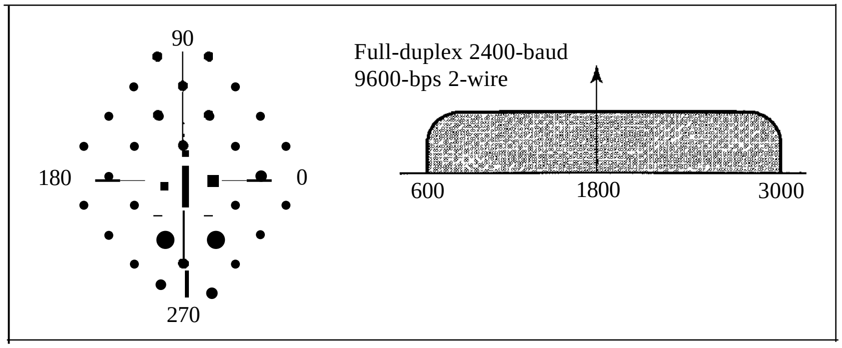
The V.32bis modem was the first of the ITU-T standards to support 14,400-bps transmission. The Y.32bis uses 128-QAM transmission (7 bits/baud with I bit for error control) at a rate of 2400 baud (2400 x 6 = 14,400 bps).

An additional enhancement provided by Y.32bis is the inclusion of an automatic fall-back and fall-forward feature that enables the modem to adjust its speed upward or downward depending on the quality of the line or signal. The constellation diagram and bandwidth are also shown in Figure 9.8.

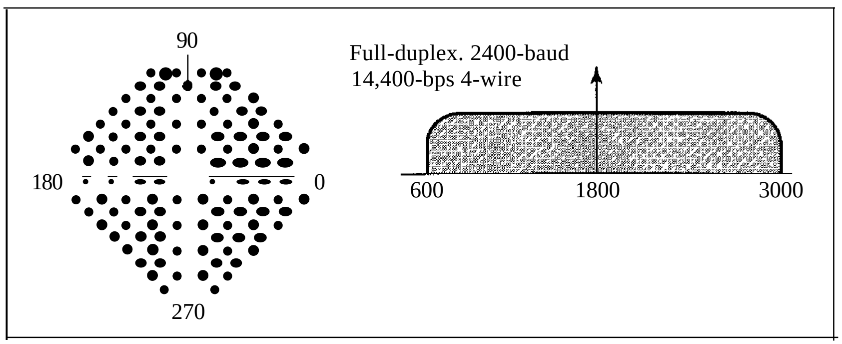
V.34bis

The V.34bis modem provides a bit rate of 28,800 with a 960-point constellation and a bit rate of 33,600 bps with a 1664-point constellation.

Figure 9.8 *The V.32 and V.32bis constellation and bandwidth*



a. Constellation and bandwidth for V.32



b. Constellation and bandwidth for V.32bis

V.90

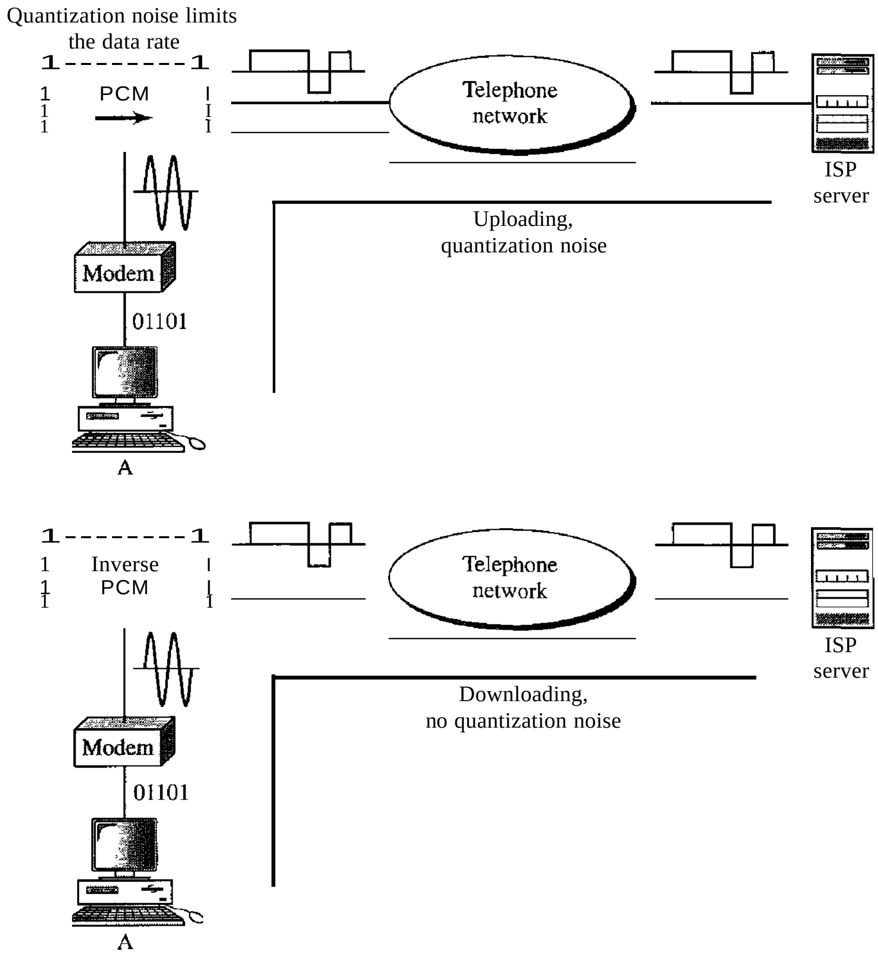
Traditional modems have a data rate limitation of 33.6 kbps, as determined by the Shannon capacity (see Chapter 3). However, V.90 modems with a bit rate of 56,000 bps are available; these are called 56K modems. These modems may be used only if one party is using digital signaling (such as through an Internet provider). They are asymmetric in that the downloading rate (flow of data from the Internet service provider to the PC) is a maximum of 56 kbps, while the uploading rate (flow of data from the PC to the Internet provider) can be a maximum of 33.6 kbps. Do these modems violate the Shannon capacity principle? No, in the downstream direction, the SNR ratio is higher because there is no quantization error (see Figure 9.9).

In uploading, the analog signal must still be sampled at the switching station. In this direction, quantization noise (as we saw in Chapter 4) is introduced into the signal, which reduces the SNR ratio and limits the rate to 33.6 kbps.

However, there is no sampling in the downloading. The signal is not affected by quantization noise and not subject to the Shannon capacity limitation. The maximum data rate in the uploading direction is still 33.6 kbps, but the data rate in the downloading direction is now 56 kbps.

One may wonder how we arrive at the 56-kbps figure. The telephone companies sample 8000 times per second with 8 bits per sample. One of the bits in each sample is used for control purposes, which means each sample is 7 bits. The rate is therefore 8000 x 7, or 56,000 bps or 56 kbps.

Figure 9.9 *Uploading and downloading in 56K modems*



V.92

The standard above V90 is called **V.92.** These modems can adjust their speed, and if the noise allows, they can upload data at the rate of 48 kbps. The downloading rate is still 56 kbps. The modem has additional features. For example, the modem can interrupt the Internet connection when there is an incoming call if the line has call-waiting service.

9.3 DIGITAL SUBSCRIBER LINE

After traditional modems reached their peak data rate, telephone companies developed another technology, DSL, to provide higher-speed access to the Internet. Digital subscriber line (DSL) technology is one of the most promising for supporting high-speed digital communication over the existing local loops. DSL technology is a set of technologies, each differing in the first letter (ADSL, VDSL, HDSL, and SDSL). The set is often referred to as xDSL, where *x* can be replaced by A, V, H, or S.

ADSL

The first technology in the set is asymmetric DSL (ADSL). ADSL, like a 56K modem, provides higher speed (bit rate) in the downstream direction (from the Internet to the resident) than in the upstream direction (from the resident to the Internet). That is the reason it is called asymmetric. Unlike the asymmetry in 56K modems, the designers of ADSL specifically divided the available bandwidth of the local loop unevenly for the residential customer. The service is not suitable for business customers who need a large bandwidth in both directions.

ADSL is an asymmetric communication technology designed for residential users; it is not suitable for businesses.

Using Existing Local Loops

One interesting point is that ADSL uses the existing local loops. But how does ADSL reach a data rate that was never achieved with traditional modems? The answer is that the twisted-pair local loop is actually capable of handling bandwidths up to 1.1 MHz, but the filter installed at the end office of the telephone company where each local loop terminates limits the bandwidth to 4 kHz (sufficient for voice communication). If the filter is removed, however, the entire 1.1 MHz is available for data and voice communications.

The existing local loops can handle bandwidths up to 1.1 MHz.

Adaptive Technology

Unfortunately, 1.1 MHz is just the theoretical bandwidth of the local loop. Factors such as the distance between the residence and the switching office, the size of the cable, the signaling used, and so on affect the bandwidth. The designers of ADSL technology were aware of this problem and used an adaptive technology that tests the condition and bandwidth availability of the line before settling on a data rate. The data rate of ADSL is not fixed; it changes based on the condition and type of the local loop cable.

ADSL is an adaptive technology. The system uses a data rate based on the condition of the local loop line.

Discrete Multitone Technique

The modulation technique that has become standard for ADSL is called the discrete multitone technique (DMT) which combines QAM and FDM. There is no set way that the bandwidth of a system is divided. Each system can decide on its bandwidth division. Typically, an available bandwidth of 1.104 MHz is divided into 256 channels. Each channel uses a bandwidth of 4.312 kHz, as shown in Figure 9.10. Figure 9.11 shows how the bandwidth can be divided into the following:

- Voice. Channel 0 is reserved for voice communication.
- Idle. Channels 1 to 5 are not used and provide a gap between voice and data communication.

Figure 9.10 *Discrete multitone technique*

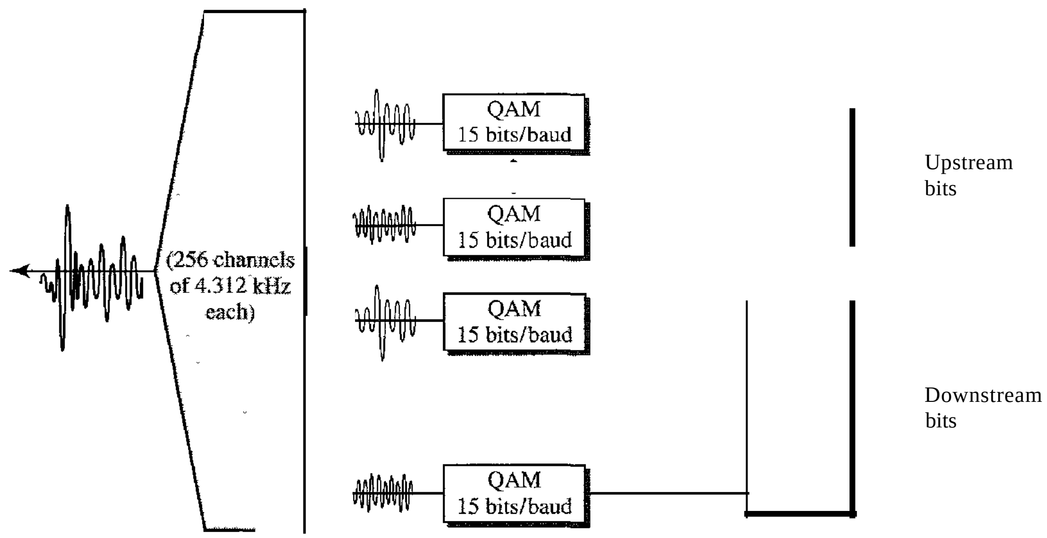
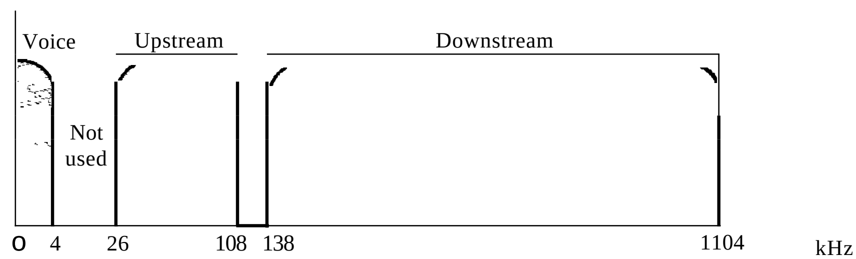


Figure 9.11 *Bandwidth division in ADSL*

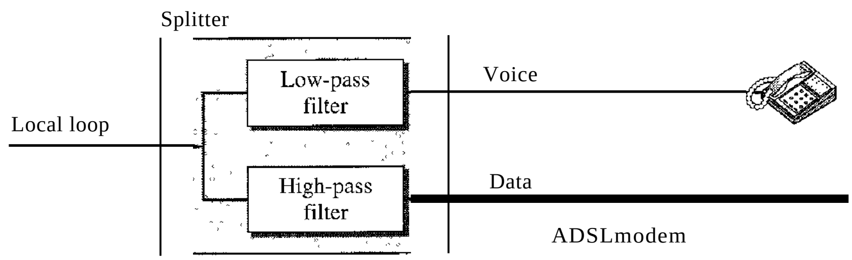


- Upstream data and control. Channels 6 to 30 (25 channels) are used for upstream data transfer and control. One channel is for control, and 24 channels are for data transfer. If there are 24 channels, each using 4 kHz (out of 4.312 kHz available) with QAM modulation, we have 24 x 4000 x 15, or a 1.44-Mbps bandwidth, in the upstream direction. However, the data rate is normally below 500 kbps because some of the carriers are deleted at frequencies where the noise level is large. In other words, some of channels may be unused.
- Downstream data and control. Channels 31 to 255 (225 channels) are used for downstream data transfer and control. One channel is for control, and 224 channels are for data. If there are 224 channels, we can achieve up to 224 x 4000 x 15, or 13.4 Mbps. However, the data rate is normally below 8 Mbps because some of the carriers are deleted at frequencies where the noise level is large. In other words, some of channels may be unused.

Customer Site: ADSL Modem

Figure 9.12 shows an ADSL modem installed at a customer's site. The local loop connects to a splitter which separates voice and data communications. The ADSL modem modulates and demodulates the data, using DMT, and creates downstream and upstream channels.

Figure 9.12 *ADSL modem*

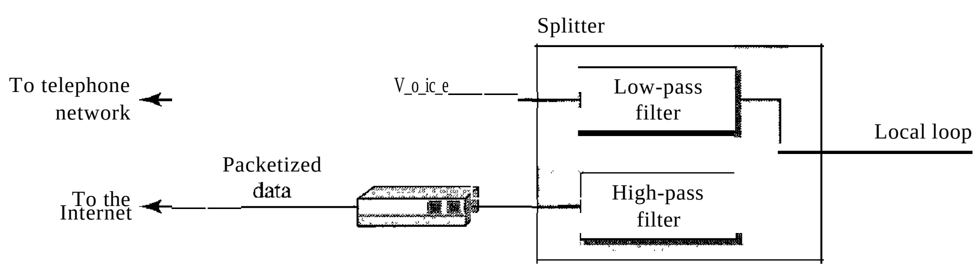


Note that the splitter needs to be installed at the customer's premises, normally by a technician from the telephone company. The voice line can use the existing telephone wiring in the house, but the data line needs to be installed by a professional. All this makes the ADSL line expensive. We will see that there is an alternative technology, Universal ADSL (or ADSL Lite).

Telephone Company Site: DSLAM

At the telephone company site, the situation is different. Instead of an ADSL modem, a device called a digital subscriber line access multiplexer (DSLAM) is installed that functions similarly. In addition, it packetizes the data to be sent to the Internet (ISP server). Figure 9.13 shows the configuration.

Figure 9.13 *DSLAM*



ADSL Lite

The installation of splitters at the border of the premises and the new wiring for the data line can be expensive and impractical enough to dissuade most subscribers. A new version of ADSL technology called ADSL Lite (or Universal ADSL or splitterless ADSL) is available for these subscribers. This technology allows an ASDL Lite modem to be plugged directly into a telephone jack and connected to the computer. The splitting is done at the telephone company. ADSL Lite uses 256 DMT carriers with 8-bit modulation (instead of 15-bit). However, some of the carriers may not be available because errors created by the voice signal might mingle with them. It can provide a maximum downstream data rate of 1.5 Mbps and an upstream data rate of 512 kbps.

HDSL

The high-bit-rate digital subscriber line (HDSL) was designed as an alternative to the T-lline (1.544 Mbps). The T-1line uses alternate mark inversion (AMI) encoding, which is very susceptible to attenuation at high frequencies. This limits the length of a T-l line to 3200 ft (1 km). For longer distances, a repeater is necessary, which means increased costs.

HDSL uses 2B1Q encoding (see Chapter 4), which is less susceptible to attenuation. A data rate of 1.544 Mbps (sometimes up to 2 Mbps) can be achieved without repeaters up to a distance of 12,000 ft (3.86 km). HDSL uses two twisted pairs (one pair for each direction) to achieve full-duplex transmission.

SDSL

The symmetric digital subscriber line (SDSL) is a one twisted-pair version ofHDSL. It provides full-duplex symmetric communication supporting up to 768 kbps in each direction. SDSL, which provides symmetric communication, can be considered an alternative to ADSL. ADSL provides asymmetric communication, with a downstream bit rate that is much higher than the upstream bit rate. Although this feature meets the needs of most residential subscribers, it is not suitable for businesses that send and receive data in large volumes in both directions.

VDSL

The very high-bit-rate digital subscriber line (VDSL), an alternative approach that is similar to ADSL, uses coaxial, fiber-optic, or twisted-pair cable for short distances. The modulating technique is DMT. It provides a range of bit rates (25 to 55 Mbps) for upstream communication at distances of 3000 to 10,000 ft. The downstream rate is normally 3.2 Mbps.

Summary

Table 9.1 shows a summary of DSL technologies. Note that the data rate and distances are approximations and can vary from one implementation to another.

Table 9.1 *Summary ofDSL technologies*

Technology	*Downstream Rate*	*Upstream Rate*	*Distance (jt)*	*Twisted Pairs*	*Line Code*
ADSL	1.5-6.1 Mbps	16-640 kbps	12,000	1	DMT
ADSL Lite	1.5 Mbps	500 kbps	18,000	1	DMT
HDSL	1.5-2.0 Mbps	1.5-2.0 Mbps	12,000	2	2B1Q
SDSL	768 kbps	768 kbps	12,000	1	2B1Q
VDSL	25-55 Mbps	3.2 Mbps	3000-10,000	1	DMT

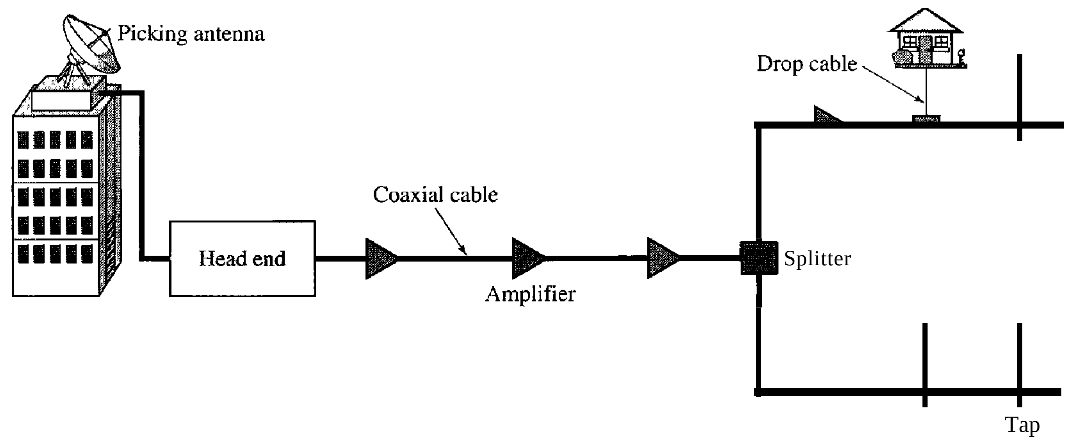
9.4 CABLE TV NETWORKS

The cable TV network started as a video service provider, but it has moved to the business of Internet access. In this section, we discuss cable TV networks per se; in Section 9.5 we discuss how this network can be used to provide high-speed access to the Internet.

Traditional Cable Networks

Cable TV started to distribute broadcast video signals to locations with poor or no reception in the late 1940s. It was called community antenna TV (CATV) because an antenna at the top of a tall hill or building received the signals from the TV stations and distributed them, via coaxial cables, to the community. Figure 9.14 shows a schematic diagram of a traditional cable TV network.

Figure 9.14 *Traditional cable TV network*



The cable TV office, called the head end, receives video signals from broadcasting stations and feeds the signals into coaxial cables. The signals became weaker and weaker with distance, so amplifiers were installed through the network to renew the signals. There could be up to 35 amplifiers between the head end and the subscriber premises. At the other end, splitters split the cable, and taps and drop cables make the connections to the subscriber premises.

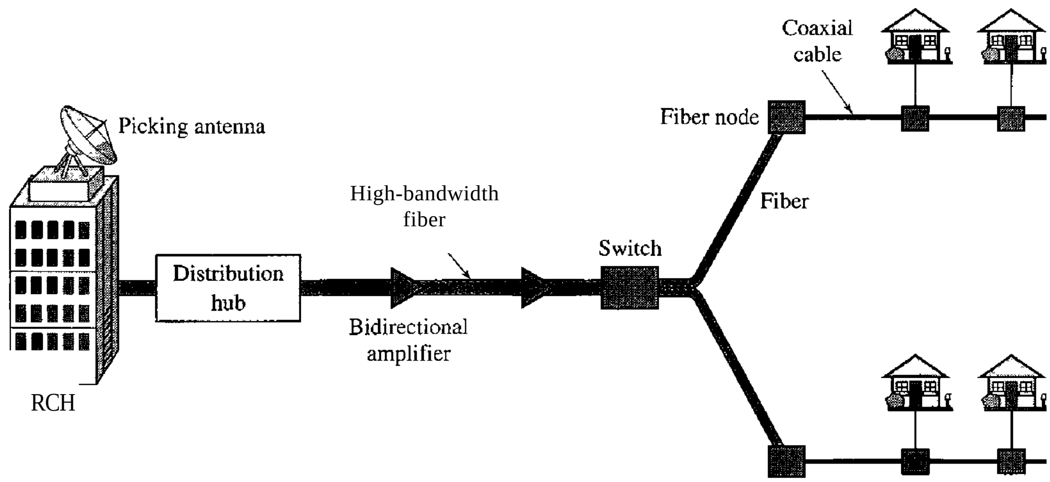
The traditional cable TV system used coaxial cable end to end. Due to attenuation of the signals and the use of a large number of amplifiers, communication in the traditional network was unidirectional (one-way). Video signals were transmitted downstream, from the head end to the subscriber premises.

Communication in the traditional cable TV network is unidirectional.

Hybrid Fiber-Coaxial (HFC) Network

The second generation of cable networks is called a hybrid fiber-coaxial (HFC) network. The network uses a combination of fiber-optic and coaxial cable. The transmission medium from the cable TV office to a box, called the fiber node, is optical fiber; from the fiber node through the neighborhood and into the house is still coaxial cable. Figure 9.15 shows a schematic diagram of an HFC network.

Figure 9.15 *Hybridfiber-coaxial (HFC) network*



The regional cable head (RCH) normally serves up to 400,000 subscribers. The RCHs feed the distribution hubs, each of which serves up to 40,000 subscribers. The distribution hub plays an important role in the new infrastructure. Modulation and distribution of signals are done here; the signals are then fed to the fiber nodes through fiber-optic cables. The fiber node splits the analog signals so that the same signal is sent to each coaxial cable. Each coaxial cable serves up to 1000 subscribers. The use of fiber-optic cable reduces the need for amplifiers down to eight or less.

One reason for moving from traditional to hybrid infrastructure is to make the cable network bidirectional (two-way).

Communication in an HFC cable TV network can be bidirectional.

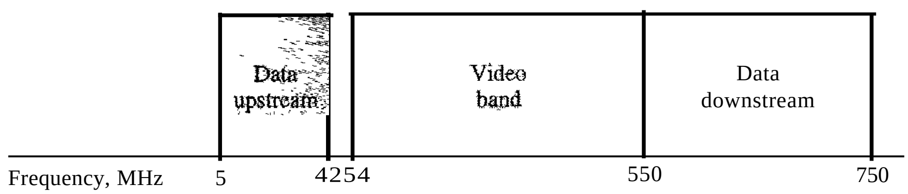
9.5 CABLE TV FOR DATA TRANSFER

Cable companies are now competing with telephone companies for the residential customer who wants high-speed data transfer. DSL technology provides high-data-rate connections for residential subscribers over the local loop. However, DSL uses the existing unshielded twisted-pair cable, which is very susceptible to interference. This imposes an upper limit on the data rate. Another solution is the use of the cable TV network. In this section, we briefly discuss this technology.

Bandwidth

Even in an HFC system, the last part of the network, from the fiber node to the subscriber premises, is still a coaxial cable. This coaxial cable has a bandwidth that ranges from 5 to 750 MHz (approximately). To provide Internet access, the cable company has divided this bandwidth into three bands: video, downstream data, and upstream data, as shown in Figure 9.16.

Figure 9.16 *Division of coaxial cable band by CATV*



Downstream Video Band

The downstream video band occupies frequencies from 54 to 550 MHz. Since each TV channel occupies 6 MHz, this can accommodate more than 80 channels.

Downstream Data Band

The downstream data (from the Internet to the subscriber premises) occupies the upper band, from 550 to 750 MHz. This band is also divided into 6-MHz channels.

Modulation Downstream data band uses the 64-QAM (or possibly 256-QAM) modulation technique.

Downstream data are modulated using the 64-QAM modulation technique.

Data Rate There is 6 bits/baud in 64-QAM. One bit is used for forward error correction; this leaves 5 bits of data per baud. The standard specifies I Hz for each baud; this means that, theoretically, downstream data can be received at 30 Mbps (5 bitslHz x 6 MHz). The standard specifies only 27 Mbps. However, since the cable modem is normally connected to the computer through a lOBase-T cable (see Chapter 13), this limits the data rate to 10 Mbps.

The theoretical downstream data rate is 30 Mbps.

Upstream Data Band

The upstream data (from the subscriber premises to the Internet) occupies the lower band, from 5 to 42 MHz. This band is also divided into 6-MHz channels.

Modulation The upstream data band uses lower frequencies that are more susceptible to noise and interference. For this reason, the QAM technique is not suitable for this band. A better solution is QPSK.

Upstream data are modulated using the QPSK modulation technique.

Data Rate There are 2 bitslbaud in QPSK. The standard specifies 1 Hz for each baud; this means that, theoretically, upstream data can be sent at 12 Mbps (2 bitslHz x 6 MHz). However, the data rate is usually less than 12 Mbps.

The theoretical upstream data rate is 12 Mbps.

Sharing

Both upstream and downstream bands are shared by the subscribers.

Upstream Sharing

The upstream data bandwidth is 37 MHz. This means that there are only six 6-MHz channels available in the upstream direction. A subscriber needs to use one channel to send data in the upstream direction. The question is, "How can six channels be shared in an area with 1000,2000, or even 100,000 subscribers?" The solution is timesharing. The band is divided into channels using FDM; these channels must be shared between subscribers in the same neighborhood. The cable provider allocates one channel, statically or dynamically, for a group of subscribers. If one subscriber wants to send data, she or he contends for the channel with others who want access; the subscriber must wait until the channel is available.

Downstream Sharing

We have a similar situation in the downstream direction. The downstream band has 33 channels of 6 MHz. A cable provider probably has more than 33 subscribers; therefore, each channel must be shared between a group of subscribers. However, the situation is different for the downstream direction; here we have a multicasting situation. If there are data for any of the subscribers in the group, the data are sent to that channel. Each subscriber is sent the data. But since each subscriber also has an address registered with the provider; the cable modem for the group matches the address carried with the data to the address assigned by the provider. If the address matches, the data are kept; otherwise, they are discarded.

CMandCMTS

To use a cable network for data transmission, we need two key devices: a cable modem (CM) and a cable modem transmission system (CMTS).

CM

The cable modem (CM) is installed on the subscriber premises. It is similar to an ADSL modem. Figure 9.17 shows its location.

CMTS

The cable modem transmission system (CMTS) is installed inside the distribution hub by the cable company. It receives data from the Internet and passes them to the combiner, which sends them to the subscriber. The CMTS also receives data from the subscriber and passes them to the Internet. Figure 9.18 shows the location of the CMTS.

Figure 9.17 *Cable modem (CM)*

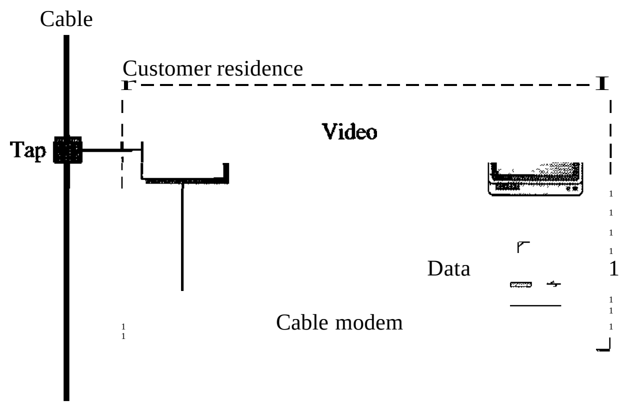
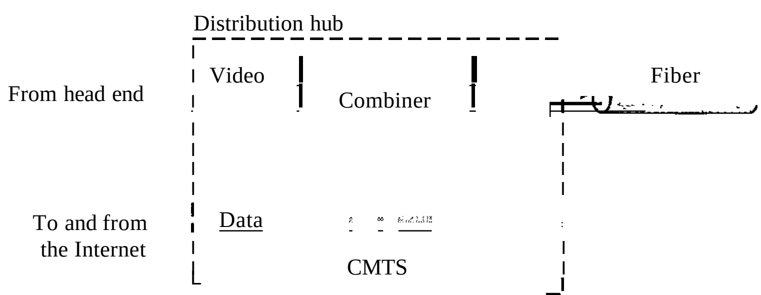


Figure 9.18 *Cable modem transmission system (CMTS)*



Data Transmission Schemes: DOeSIS

During the last few decades, several schemes have been designed to create a standard for data transmission over an HFC network. Prevalent is the one devised by Multimedia Cable Network Systems (MCNS), called Data Over Cable System Interface Specification (DOCSIS). DOCSIS defines all the protocols necessary to transport data from a CMTS to aCM.

Upstream Communication

The following is a very simplified version of the protocol defined by DOCSIS for upstream communication. It describes the steps that must be followed by a CM:

1. The CM checks the downstream channels for a specific packet periodically sent by the CMTS. The packet asks any new CM to announce itself on a specific upstream channel.
2. The CMTS sends a packet to the CM, defining its allocated downstream and upstream channels.
3. The CM then starts a process, called ranging, which determines the distance between the CM and CMTS. This process is required for synchronization between all

CMs and CMTSs for the minislots used for timesharing of the upstream channels. We will learn about this timesharing when we discuss contention protocols in Chapter 12.

4. The CM sends a packet to the ISP, asking for the Internet address.
5. The CM and CMTS then exchange some packets to establish security parameters, which are needed for a public network such as cable TV.
6. The CM sends its unique identifier to the CMTS.
7. Upstream communication can start in the allocated upstream channel; the CM can contend for the minislots to send data.

Downstream Communication

In the downstream direction, the communication is much simpler. There is no contention because there is only one sender. The CMTS sends the packet with the address of the receiving eM, using the allocated downstream channel.

9.6 RECOMMENDED READING

For more details about subjects discussed in this chapter, we recommend the following books. The items in brackets [...] refer to the reference list at the end of the text.

Books

[CouOl] gives an interesting discussion about telephone systems, DSL technology, and CATV in Chapter 8. [Tan03] discusses telephone systems and DSL technology in Section 2.5 and CATV in Section 2.7. [GW04] discusses telephone systems in Section 1.1.1 and standard modems in Section 3.7.3. A complete coverage of residential broadband (DSL and CATV) can be found in [Max99].

9.7 KEY TERMS

56Kmodem
800 service
900 service
ADSL Lite
ADSLmodem
analog leased service
analog switched service
asymmetric DSL (ADSL)
cable modem (CM)
cable modem transmission system (CMTS)
cable TV network
common carrier
community antenna TV (CATV)
competitive local exchange carrier (CLEC)
Data Over Cable System Interface Specification (DOCSIS)
demodulator
digital data service (DDS)
digital service
digital subscriber line (DSL)
digital subscriber line access multiplexer (DSLAM)
discrete multitone technique (DMT)
distribution hub

downloading
downstream data band
end office
fiber node
head end
high-bit-rate DSL (HDSL)
hybrid fiber-coaxial (HFC) network
in-band signaling
incumbent local exchange carrier (ILEC)
interexchange carrier (IXC)
ISDN user port (ISUP)
local access transport area (LATA)
local exchange carrier (LEC)
local loop
long distance company
message transport port (MTP) level
modem
modulator
out-of-band signaling
plain old telephone system (POTS)
point of presence (POP)
ranging
regional cable head (RCH)
regional office
server control point (SCP)
signal point (SP)
signal transport port (STP)
signaling connection control point (SCep)
Signaling System Seven (SS7)
switched/56 service
switching office
symmetric DSL (SDSL)
tandem office
telephone user port (TUP)
transaction capabilities application port (TCAP)
trunk
uploading
upstream data band
Y.32
Y.32bis
Y.34bis
Y.90
Y.92
very-high-bit-rate DSL (VDSL)
video band
V-series
wide-area telephone service (WATS)

9.8 SUMMARY

- The telephone, which is referred to as the plain old telephone system (POTS), was originally an analog system. During the last decade, the telephone network has undergone many technical changes. The network is now digital as well as analog.
- The telephone network is made of three major components: local loops, trunks, and switching offices. It has several levels of switching offices such as end offices, tandem offices, and regional offices.
- The United States is divided into many local access transport areas (LATAs). The services offered inside a LATA are called intra-LATA services. The carrier that handles these services is called a local exchange carrier (LEC). The services between LATAs are handled by interexchange carriers (lXCs).
- In in-band signaling, the same circuit is used for both signaling and data. In out-of-band signaling, a portion of the bandwidth is used for signaling and another portion

for data. The protocol that is used for signaling in the telephone network is called Signaling System Seven (SS7).

- Telephone companies provide two types of services: analog and digital. We can categorize analog services as either analog switched services or analog leased services. The two most common digital services are switched/56 service and digital data service (DDS).
- Data transfer using the telephone local loop was traditionally done using a dial-up modem. The term *modem* is a composite word that refers to the two functional entities that make up the device: a signal modulator and a signal demodulator.
- Most popular modems available are based on the V-series standards. The V.32 modem has a data rate of 9600 bps. The V32bis modem supports 14,400-bps transmission. V90 modems, called 56K modems, with a downloading rate of 56 kbps and uploading rate of 33.6 kbps are very common. The standard above V90 is called V92. These modems can adjust their speed, and if the noise allows, they can upload data at the rate of 48 kbps.
- Telephone companies developed another technology, digital subscriber line (DSL), to provide higher-speed access to the Internet. DSL technology is a set of technologies, each differing in the first letter (ADSL, VDSL, HDSL, and SDSL. ADSL provides higher speed in the downstream direction than in the upstream direction. The high-bit-rate digital subscriber line (HDSL) was designed as an alternative to the T-l line (1.544 Mbps). The symmetric digital subscriber line (SDSL) is a one twisted-pair version of HDSL. The very high-bit-rate digital subscriber line (VDSL) is an alternative approach that is similar to ADSL.
- Community antenna TV (CATV) was originally designed to provide video services for the community. The traditional cable TV system used coaxial cable end to end. The second generation of cable networks is called a hybrid fiber-coaxial (HFC) network. The network uses a combination of fiber-optic and coaxial cable.
- Cable companies are now competing with telephone companies for the residential customer who wants high-speed access to the Internet. To use a cable network for data transmission, we need two key devices: a cable modem (CM) and a cable modem transmission system (CMTS).

9.9 PRACTICE SET

Review Questions

1. What are the three major components of a telephone network?
2. Give some hierarchical switching levels of a telephone network.
3. What is LATA? What are intra-LATA and inter-LATA services?
4. Describe the SS7 service and its relation to the telephone network.
S. What are the two major services provided by telephone companies in the United States?
6. What is dial-up modem technology? List some of the common modem standards discussed in this chapter and give their data rates.

7. What is DSL technology? What are the services provided by the telephone companies using DSL? Distinguish between a DSL modem and a DSLAM.
8. Compare and contrast a traditional cable network with a hybrid fiber-coaxial network.
9. How is data transfer achieved using CATV channels?
10. Distinguish between CM and CMTS.

Exercises

11. Using the discussion of circuit-switching in Chapter 8, explain why this type of switching was chosen for telephone networks.
12. In Chapter 8, we discussed the three communication phases involved in a circuit-switched network. Match these phases with the phases in a telephone call between two parties.
13. In Chapter 8, we learned that a circuit-switched network needs end-to-end addressing during the setup and teardown phases. Define end-to-end addressing in a telephone network when two parties communicate.
14. When we have an overseas telephone conversation, we sometimes experience a delay. Can you explain the reason?
15. Draw a barchart to compare the different downloading data rates of common modems.
16. Draw a barchart to compare the different downloading data rates of common DSL technology implementations (use minimum data rates).
17. Calculate the minimum time required to download one million bytes of information using each of the following technologies:
    a. V32 modem
    b. V32bis modem
    c. V90 modem
18. Repeat Exercise 17 using different DSL implementations (consider the minimum rates).
19. Repeat Exercise 17 using a cable modem (consider the minimum rates).
20. What type of topology is used when customers in an area use DSL modems for data transfer purposes? Explain.
21. What type of topology is used when customers in an area use cable modems for data transfer purposes? Explain.

PART 3

Data Link Layer

Objectives

The data link layer transforms the physical layer, a raw transmission facility, to a link responsible for node-to-node (hop-to-hop) communication. Specific responsibilities of the data link layer include *framing, addressing, flow control, error control,* and *media access control.* The data link layer divides the stream of bits received from the network layer into manageable data units called frames. The data link layer adds a header to the frame to define the addresses of the sender and receiver of the frame. If the rate at which the data are absorbed by the receiver is less than the rate at which data are produced in the sender, the data link layer imposes a flow control mechanism to avoid overwhelming the receiver. The data link layer also adds reliability to the physical layer by adding mechanisms to detect and retransmit damaged, duplicate, or lost frames. When two or more devices are connected to the same link, data link layer protocols are necessary to determine which device has control over the link at any given time.

In Part 3 of the book, we first discuss services provided by the data link layer. We then discuss the implementation of these services in local area networks (LANs). Finally we discuss how wide area networks (WANs) use these services.

Part 3 of the book is devoted to the data link layer and
the services provided by this layer.

Chapters

This part consists of nine chapters: Chapters 10 to 18.

Chapter 10

Chapter 10 discusses error detection and correction. Although the quality of devices and media have been improved during the last decade, we still need to check for errors and correct them in most applications.

Chapter 11

Chapter 11 is named data link control, which involves flow and error control. It discusses some protocols that are designed to handle the services required from the data link layer in relation to the network layer.

Chapter 12

Chapter 12 is devoted to access control, the duties of the data link layer that are related to the use of the physical layer.

Chapter 13

This chapter introduces wired local area networks. A wired LAN, viewed as a link, is mostly involved in the physical and data link layers. We have devoted the chapter to the discussion of Ethernet and its evolution, a dominant technology today.

Chapter 14

This chapter introduces wireless local area networks. The wireless LAN is a growing technology in the Internet. We devote one chapter to this topic.

Chapter 15

After discussing wired and wireless LANs, we show how they can be connected together using connecting devices.

Chapter 16

This is the first chapter on wide area networks (WANs). We start with wireless WANs and then move on to satellite networks and mobile telephone networks.

Chapter 17

To demonstrate the operation of a high-speed wide area network that can be used as a backbone for other WANs or for the Internet, we have chosen to devote all of Chapter 17 to SONET, a wide area network that uses fiber-optic technology.

Chapter 18

This chapter concludes our discussion on wide area networks. Two switched WANs, Frame Relay and ATM, are discussed here.