CHAPTER 3

MODEM

DIGITAL MODULATION

In digital modulation, an analog carrier signal is modulated by a digital bit stream. Digital modulation methods can be considered as digital-to-analog conversion, and the corresponding demodulation or detection as analog-to-digital conversion. The changes in the carrier signal are chosen from a finite number of M alternative symbols. For **digital modulation**, which is the main topic in this section, digital data (0 and 1) is translated into an analog signal (baseband signal). Digital modulation is required if digital data has to be transmitted over a medium that only allows for analog transmission. One example for wired networks is the old analog telephone system – to connect a computer to this system a modem is needed. The modem then performs the translation of digital data into analog signals and vice versa. Digital transmission is used, for example, in wired local area networks or within a computer (Halsall, 1996), (Stallings, 1997). In wireless networks, however, digital transmission cannot be used. Here, the binary bit-stream has to be translated into an analog signal first. The three basic methods for this translation are **amplitude shift keying (ASK)**, **frequency shift keying (FSK)**, and **phase shift keying (PSK)**. These are discussed in more detail in the following sections.

DIGITAL MODULATION METHODS (ASK, PSK, FSK)

Encoding Techniques

We mentioned that modulation involves operation on one or more of the three characteristics of a carrier signal: amplitude, frequency, and phase. Accordingly, there are three basic encoding or modulation techniques for transforming digital data into analog signals, as illustrated in Figure 4.7:

Amplitude-shift keying (ASK)

Frequency-shift keying (FSK)

Phase-shift keying (PSK)

In all these case;, the resulting signal occupies a bandwidth centered on the carrier frequency.

In **ASK**, the two binary values are represented by two different amplitudes of the carrier frequency. Commonly, one of the amplitudes is zero; that is, one binary digit is represented by the presence, at constant amplitude, of the carrier, the other by the absence of the carrier. The resulting signal is

$$s(t) = \begin{cases} A\cos(2\pi f_c t) & \text{binary 1} \\ 0 & \text{binary 0} \end{cases}$$

where the carrier signal is A cos(2n-jct). ASK is susceptible to sudden gain changes and is a rather inefficient modulation technique. On voice-grade lines, it is typically used only up to 1200 bps.

The ASK technique is used to transmit digital data over optical fiber. For

LED transmitters, the equation above is valid. That is, one signal element is represented by a light pulse while the other signal element is represented by the absence of light. Laser transmitters normally have a fixed "bias" current that causes the device to emit a low light level. This low level represents one signal element, while a higher-amplitude lightwave represents another.

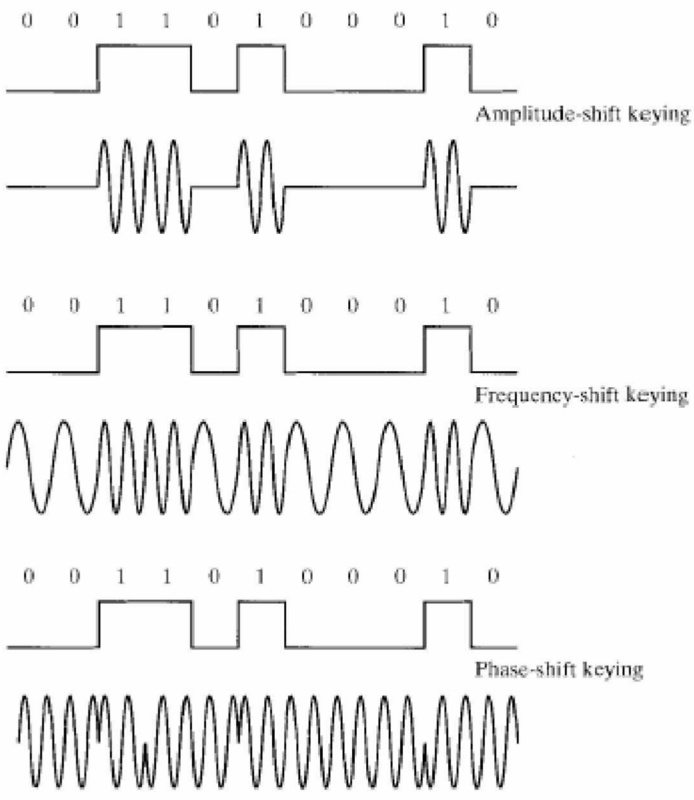


FIGURE 4.7 Modulation of analog signals for digital data.

In **FSK**, the two binary values are represented by two different frequencies near the carrier frequency. The resulting signal is

$$s(t) = \begin{cases} A\cos(2\pi f_1 t) & \text{binary 1} \\ A\cos(2\pi f_2 t) & \text{binary 0} \end{cases}$$

where fi and *fi* are typically offset from the carrier frequency *f,* by equal but opposite amounts. FSK is less susceptible to error than ASK.

In **PSK** , the phase of the carrier signal is shifted to represent data. The bottom of Figure 4.7 is an example of a two-phase system. In this system, a binary 0 is represented by sending a signal burst of the same phase as the previous signal burst. A binary 1 is represented by sending a signal burst of opposite phase to the preceding one; this is known as differential PSK, as the phase shift is with reference to the previous bit transmitted rather than to some constant reference signal. The resulting signal is

$$s(t) = \begin{cases} A\cos(2\pi f_c t + \pi) & \text{binary 1} \\ A\cos(2\pi f_c t) & \text{binary 0} \end{cases}$$

with the phase measured relative to the previous bit interval.
More efficient use of bandwidth can be achieved if each signaling element represents more than one bit. For example, instead of a phase shift of 180G, as allowed in PSK, a common encoding technique, known as quadrature phase-shift keying (QPSK) uses phase shifts of multiples of 90":

$$s(t) = \begin{cases} A\cos(2\pi f_c t + 45°) & 11 \\ A\cos(2\pi f_c t + 135°) & 10 \\ A\cos(2\pi f_c t + 225°) & 00 \\ A\cos(2\pi f_c t + 315°) & 01 \end{cases}$$

Thus, each signal element represents two bits rather than one.
This scheme can be extended. It is possible to transmit bits three at a time using eight different phase angles. Further, each angle can have more than one amplitude.

MODEM AND STANDARDS

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.

MULTIPLEXING

Multiplexing describes how several users can share a medium with minimum or no interference. A common application of multiplexing is in long-haul communications. Trunks on long-haul networks are high-capacity fiber, coaxial, or microwave links. These links can carry large numbers of voice and data transmissions simultaneously using multiplexing.
Figure 7.1 depicts the multiplexing function in its simplest form. There are n inputs to a multiplexer. The multiplexer is connected by a single data link to a demultiplexer. The link is able to carry n separate channels of data. The multiplexer combines (multiplexes) data from the *n* input lines and transmits over a highercapacity data link. The demultiplexer accepts the multiplexed data stream, separates (demultiplexes) the data according to channel, and delivers them to the appropriate output lines.

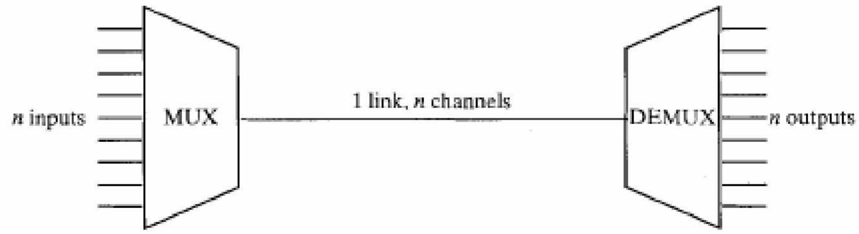


FIGURE 7.1 Multiplexing.

MULTIPLEXING TECHNIQUES

Frequency division multiplexing

Frequency division multiplexing (FDM) describes schemes to subdivide the frequency dimension into several non-overlapping frequency bands as shown in Figure 2.17. Each channel ki is now allotted its own frequency band as indicated. Senders using a certain frequency band can use this band continuously. Again, **guard spaces** are needed to avoid frequency band overlapping (also called **adjacent channel interference**). This scheme is used for radio stations within the same region, where each radio station has its own frequency. This very simple multiplexing scheme does not need complex coordination between sender and receiver: the receiver only has to tune in to the specific sender. However, this scheme also has disadvantages. While radio stations broadcast 24 hours a day, mobile communication typically takes place for only a few minutes at a time. Assigning a separate frequency for each possible communication scenario would be a tremendous waste of (scarce) frequency resources. Additionally, the fixed assignment of a frequency to a sender makes the scheme very inflexible and limits the number of senders.

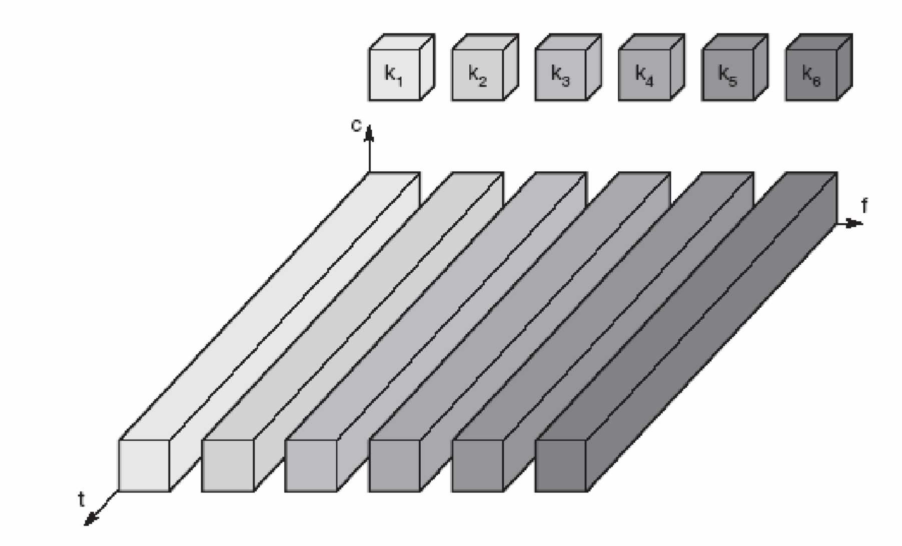
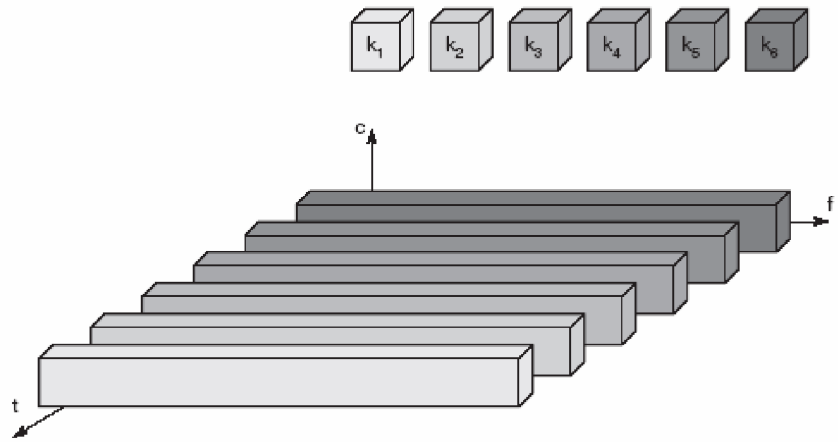


Figure 2.17
Frequency division multiplexing (FDM)

Time division multiplexing

A more flexible multiplexing scheme for typical mobile communications is **time division multiplexing (TDM)**. Here a channel ki is given the whole bandwidth for a certain amount of time, i.e., all senders use the same frequency but at different points in time (see Figure 2.18). Again, **guard spaces**, which now represent time gaps, have to separate the different periods when the senders use the medium. In our highway example, this would refer to the gap between two cars. If two transmissions overlap in time, this is called co-channel interference. (In the highway example, interference between two cars results in an accident.) To avoid this type of interference, precise synchronization between different senders is necessary. This is clearly a disadvantage, as all senders need precise clocks or, alternatively, a way has to be found to distribute a synchronization signal to all senders. For a receiver tuning in to a sender this does not just involve adjusting the frequency, but involves listening at exactly the right point in time. However, this scheme is quite flexible as one can assign more sending time to senders with a heavy load and less to those with a light load.

Figure 2.18
Time division
multiplexing (TDM)



Code division multiplexing

While SDM and FDM are well known from the early days of radio transmission and TDM is used in connection with many applications, **code division multiplexing (CDM)** is a relatively new scheme in commercial communication systems. First used in military applications due to its inherent security features (together with spread spectrum techniques, see section 2.7), it now features in many civil wireless transmission scenarios thanks to the availability of cheap processing power (explained in more detail in section 3.5). Figure 2.20 shows how all channels ki use the same frequency at the same time for transmission. Separation is now achieved by assigning each channel its own 'code', **guard spaces** are realized by using codes with the necessary 'distance' in code space, e.g., **orthogonal codes**. The technical realization of CDM is discussed in section 2.7 and chapter 3 together with the medium access mechanisms. An excellent book dealing with all aspects of CDM is Viterbi (1995).The typical everyday example of CDM is a party with many participants from different countries around the world who establish communication channels, i.e., they talk to each other, using the same frequency range (approx. 300–6000 Hz depending on a person's voice) at the same time. If everybody speaks the same language, SDM is needed to be able to communicate (i.e., standing in groups, talking with limited transmit power).But as soon as another code, i.e., another language, is used, one can tune in to this language and clearly separate communication in this language from all the other languages. (The other languages appear as background noise.) This explains why CDM has built-in security: if the language is unknown, the signals can still be received, but they are useless. By using a secret code (or language), a secure channel can be established in a 'hostile' environment. (At parties this may cause some confusion.) Guard spaces are also of importance in this illustrative example. Using, e.g., Swedish and Norwegian does not really work; the languages are too close. But Swedish and Finnish are 'orthogonal' enough to separate the communication channels.

The main advantage of CDM for wireless transmission is that it gives good protection against interference and tapping. Different codes have to be assigned, but code space is huge compared to the frequency space. Assigning individual codes to each sender does not usually cause problems. The main disadvantage of this scheme is the relatively high complexity of the receiver (see section 3.5). A receiver has to know the code and must separate the channel with user data from the background noise composed of other signals and environmental noise. Additionally, a receiver must be precisely synchronized with the transmitter to apply the decoding correctly. The voice example also gives a hint to another problem of CDM receivers. All signals should reach a receiver with almost equal strength, otherwise some signals could drain others. If some people close to a receiver talk very loudly the language does not matter. The receiver cannot listen to any other person. To apply CDM, precise power control is required.

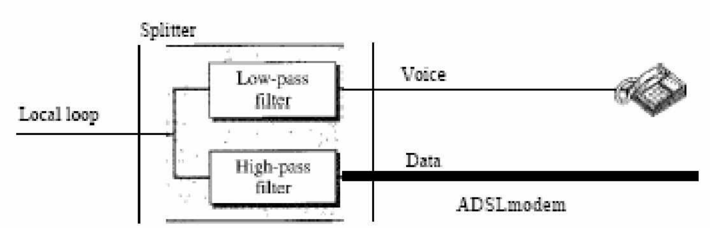
DIGITAL SUBSCRIBER LINE

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.

Figure 9.12 *ADSL modem*



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
ofADSL 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

SECTION 9.3 *DIGITAL SUBSCRIBER LINE 255*

(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.

RADSL

Rate-adaptive DSL (**RADSL**) is a variation of ADSL technology. With RADSL the modem adjusts the upstream speed of the connection (in an upstream/downstream speed tradeoff) depending upon the length and quality of the line between the DCE (Telephone Exchange) or DSLAM and the DTE (Modem), in an attempt to maintain a certain downstream speed.When the modem connects using RADSL the upstream bandwidth is adjusted to create a greater frequency band for the downstream traffic. Using this technique the line is more tolerant of errors caused by noise and signal loss.As the frequency is adjusted, the upstream bandwidth may be markedly decreased if there is a large amount of line noise or signal degradation - this may reduce the upstream bit rate to as little as 64 kbit/s - the same speed as a single ISDN B channel.