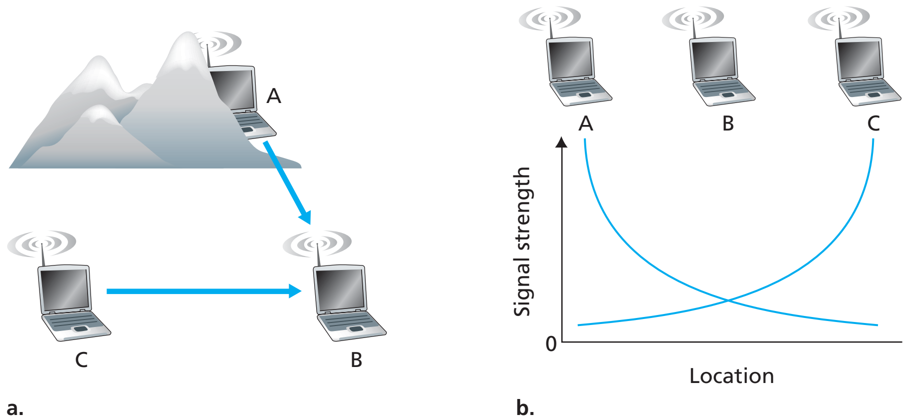

Figure 6.4 ♦ Hidden terminal problem caused by obstacle (a) and fading (b)

make multiple access in a wireless network considerably more complex than in a wired network.

6.2.1 CDMA

Recall from Chapter 5 that when hosts communicate over a shared medium, a protocol is needed so that the signals sent by multiple senders do not interfere at the receivers. In Chapter 5 we described three classes of medium access protocols: channel partitioning, random access, and taking turns. Code division multiple access (CDMA) belongs to the family of channel partitioning protocols. It is prevalent in wireless LAN and cellular technologies. Because CDMA is so important in the wireless world, we'll take a quick look at CDMA now, before getting into specific wireless access technologies in the subsequent sections.

In a CDMA protocol, each bit being sent is encoded by multiplying the bit by a signal (the code) that changes at a much faster rate (known as the **chipping rate**) than the original sequence of data bits. Figure 6.5 shows a simple, idealized CDMA encoding/decoding scenario. Suppose that the rate at which original data bits reach the CDMA encoder defines the unit of time; that is, each original data bit to be transmitted requires a one-bit slot time. Let d_i be the value of the data bit for the ith bit slot. For mathematical convenience, we represent a data bit with a 0 value as –1. Each bit slot is further subdivided into M mini-slots; in Figure 6.5, M = 8, although in practice M is much larger. The CDMA code used by the sender consists of a sequence of M values, c_m, m = 1, . . . , M, each taking a +1 or –1

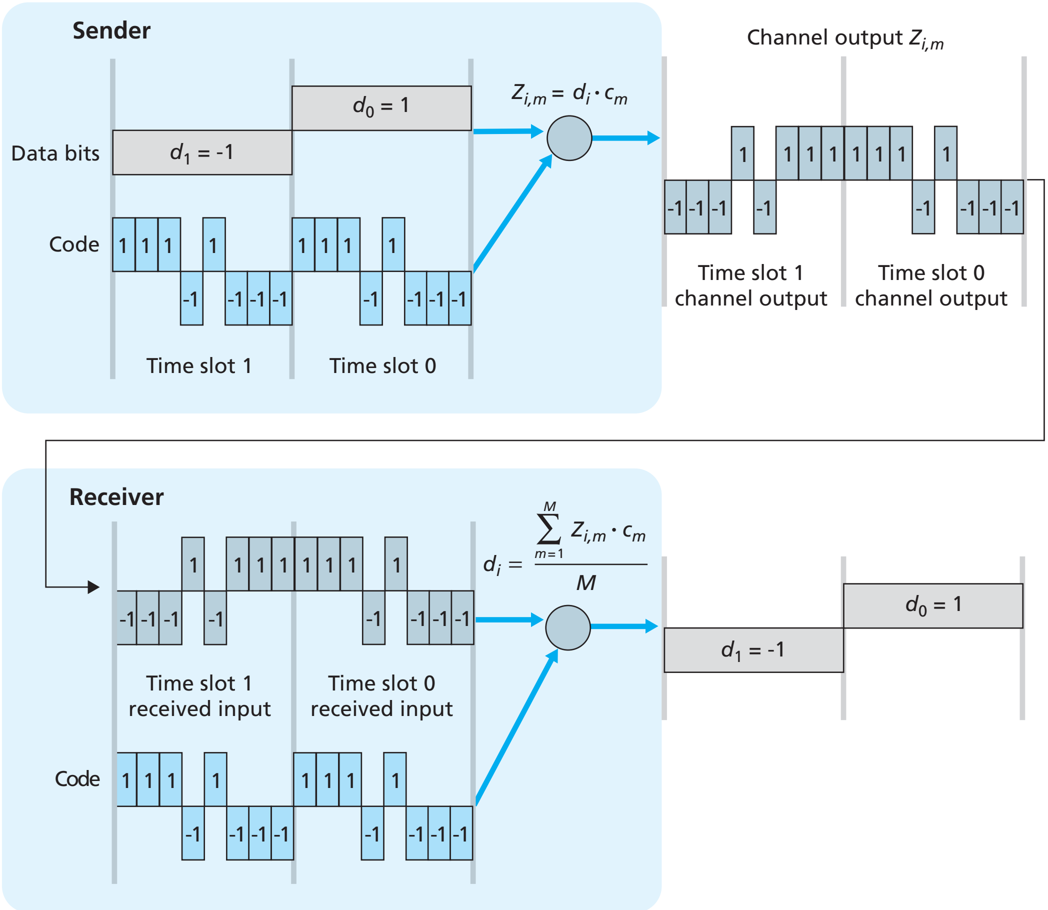

Figure 6.5 ♦ A simple CDMA example: sender encoding, receiver decoding

value. In the example in Figure 6.5, the M-bit CDMA code being used by the sender is (1, 1, 1, –1, 1, –1, –1, –1).

To illustrate how CDMA works, let us focus on the ith data bit, d_i. For the mth mini-slot of the bit-transmission time of d_i, the output of the CDMA encoder, $Z_{i,m}$, is the value of d_i multiplied by the mth bit in the assigned CDMA code, c_m:

$$Z_{i,m} = d_i \cdot c_m \tag{6.1}$$

In a simple world, with no interfering senders, the receiver would receive the encoded bits, $Z_{i,m}$, and recover the original data bit, d_i, by computing:

$$d_i = \frac{1}{M}\sum_{m=1}^{M} Z_{i,m} \cdot c_m \tag{6.2}$$

The reader might want to work through the details of the example in Figure 6.5 to see that the original data bits are indeed correctly recovered at the receiver using Equation 6.2.

The world is far from ideal, however, and as noted above, CDMA must work in the presence of interfering senders that are encoding and transmitting their data using a different assigned code. But how can a CDMA receiver recover a sender's original data bits when those data bits are being tangled with bits being transmitted by other senders? CDMA works under the assumption that the interfering transmitted bit signals are additive. This means, for example, that if three senders send a 1 value, and a fourth sender sends a –1 value during the same mini-slot, then the received signal at all receivers during that mini-slot is a 2 (since $1 + 1 + 1 - 1 = 2$). In the presence of multiple senders, sender s computes its encoded transmissions, $Z^s_{i,m}$, in exactly the same manner as in Equation 6.1. The value received at a receiver during the mth mini-slot of the ith bit slot, however, is now the *sum* of the transmitted bits from all N senders during that mini-slot:

$$Z^*_{i,m} = \sum_{s=1}^{N} Z^s_{i,m}$$

Amazingly, if the senders' codes are chosen carefully, each receiver can recover the data sent by a given sender out of the aggregate signal simply by using the sender's code in exactly the same manner as in Equation 6.2:

$$d_i = \frac{1}{M}\sum_{m=1}^{M} Z^*_{i,m} \cdot c_m \tag{6.3}$$

as shown in Figure 6.6, for a two-sender CDMA example. The M-bit CDMA code being used by the upper sender is (1, 1, 1, –1, 1, –1, –1, –1), while the CDMA code being used by the lower sender is (1, –1, 1, 1, 1, –1, 1, 1). Figure 6.6 illustrates a receiver recovering the original data bits from the upper sender. Note that the receiver is able to extract the data from sender 1 in spite of the interfering transmission from sender 2.

Recall our cocktail analogy from Chapter 5. A CDMA protocol is similar to having partygoers speaking in multiple languages; in such circumstances humans are actually quite good at locking into the conversation in the language they understand, while filtering out the remaining conversations. We see here that CDMA is a partitioning protocol in that it partitions the codespace (as opposed to time or frequency) and assigns each node a dedicated piece of the codespace.

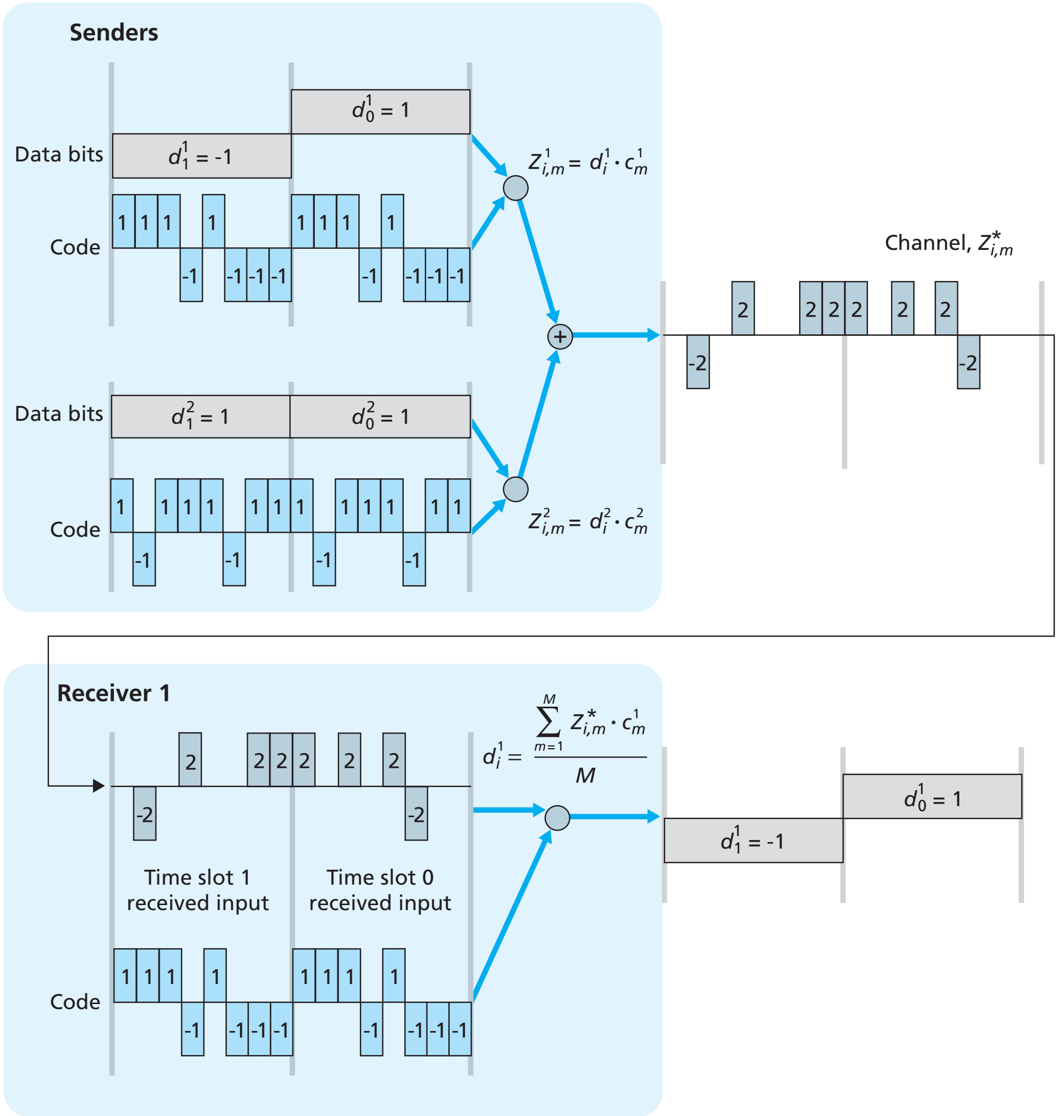

Figure 6.6 ♦ A two-sender CDMA example

Our discussion here of CDMA is necessarily brief; in practice a number of difficult issues must be addressed. First, in order for the CDMA receivers to be able to extract a particular sender's signal, the CDMA codes must be carefully chosen. Second, our discussion has assumed that the received signal strengths from various senders are the same; in reality this can be difficult to achieve. There is a considerable body of literature addressing these and other issues related to CDMA; see [Pickholtz 1982; Viterbi 1995] for details.

6.3 WiFi: 802.11 Wireless LANs

Pervasive in the workplace, the home, educational institutions, cafés, airports, and street corners, wireless LANs are now one of the most important access network technologies in the Internet today. Although many technologies and standards for wireless LANs were developed in the 1990s, one particular class of standards has clearly emerged as the winner: the **IEEE 802.11 wireless LAN**, also known as **WiFi**. In this section, we'll take a close look at 802.11 wireless LANs, examining its frame structure, its medium access protocol, and its internetworking of 802.11 LANs with wired Ethernet LANs.

There are several 802.11 standards for wireless LAN technology, including 802.11b, 802.11a, and 802.11g. Table 6.1 summarizes the main characteristics of these standards. 802.11g is by far the most popular technology. A number of dual-mode (802.11a/g) and tri-mode (802.11a/b/g) devices are also available.

The three 802.11 standards share many characteristics. They all use the same medium access protocol, CSMA/CA, which we'll discuss shortly. All three use the same frame structure for their link-layer frames as well. All three standards have the ability to reduce their transmission rate in order to reach out over greater distances. And all three standards allow for both "infrastructure mode" and "ad hoc mode," as we'll also shortly discuss. However, as shown in Table 6.1, the three standards have some major differences at the physical layer.

The 802.11b wireless LAN has a data rate of 11 Mbps and operates in the unlicensed frequency band of 2.4–2.485 GHz, competing for frequency spectrum with 2.4 GHz phones and microwave ovens. 802.1la wireless LANs can run at

Standard	Frequency Range (United States)	Data Rate
802.11b	2.4–2.485 GHz	up to 11 Mbps
802.11a	5.1–5.8 GHz	up to 54 Mbps
802.11g	2.4–2.485 GHz	up to 54 Mbps

Table 6.1 ♦ Summary of IEEE 802.11 standards