

7.2.1 CDMA

Recall from Chapter 6 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 6, 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 7.5 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 i th 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 7.5, $M = 8$, although in practice M is much larger. The CDMA code used by the sender consists of a sequence of M values, c_m , $m = 1, \dots, M$, each taking a $+1$ or -1 value. In the example in Figure 7.5, 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 i th data bit, d_i . For the m th 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 m th bit in the assigned CDMA code, c_m :

$$Z_{i,m} = d_i \cdot c_m \quad (7.1)$$

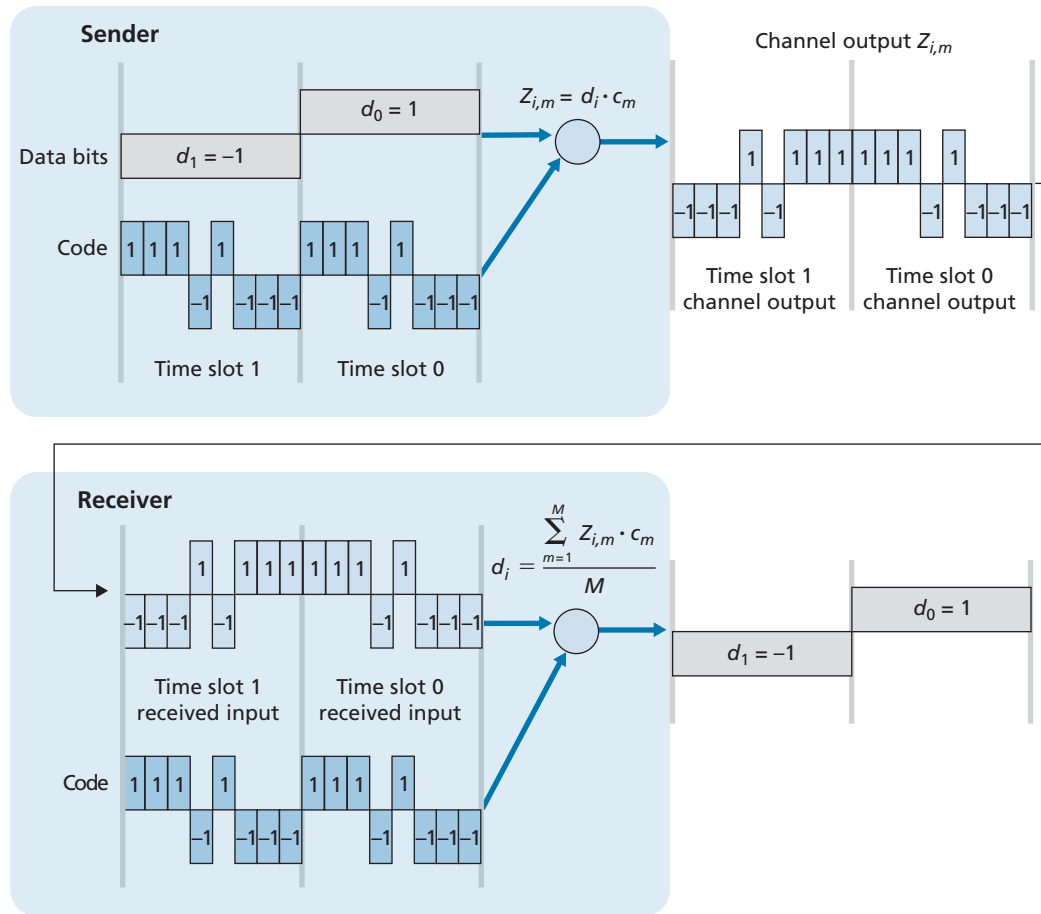


Figure 7.5 ♦ A simple CDMA example: Sender encoding, receiver decoding

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:

$$d_i = \frac{1}{M} \sum_{m=1}^M Z_{i,m} \cdot c_m \tag{7.2}$$

The reader might want to work through the details of the example in Figure 7.5 to see that the original data bits are indeed correctly recovered at the receiver using Equation 7.2.

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, $Z_{i,m}^s$, in exactly the same manner as in Equation 7.1. The value received at a receiver during the m th mini-slot of the i th bit slot, however, is now the *sum* of the transmitted bits from all N senders during that mini-slot:

$$Z_{i,m}^* = \sum_{s=1}^N Z_{i,m}^s$$

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 7.2:

$$d_i = \frac{1}{M} \sum_{m=1}^M Z_{i,m}^* \cdot c_m \quad (7.3)$$

as shown in Figure 7.6, 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 7.6 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 6. 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.

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.

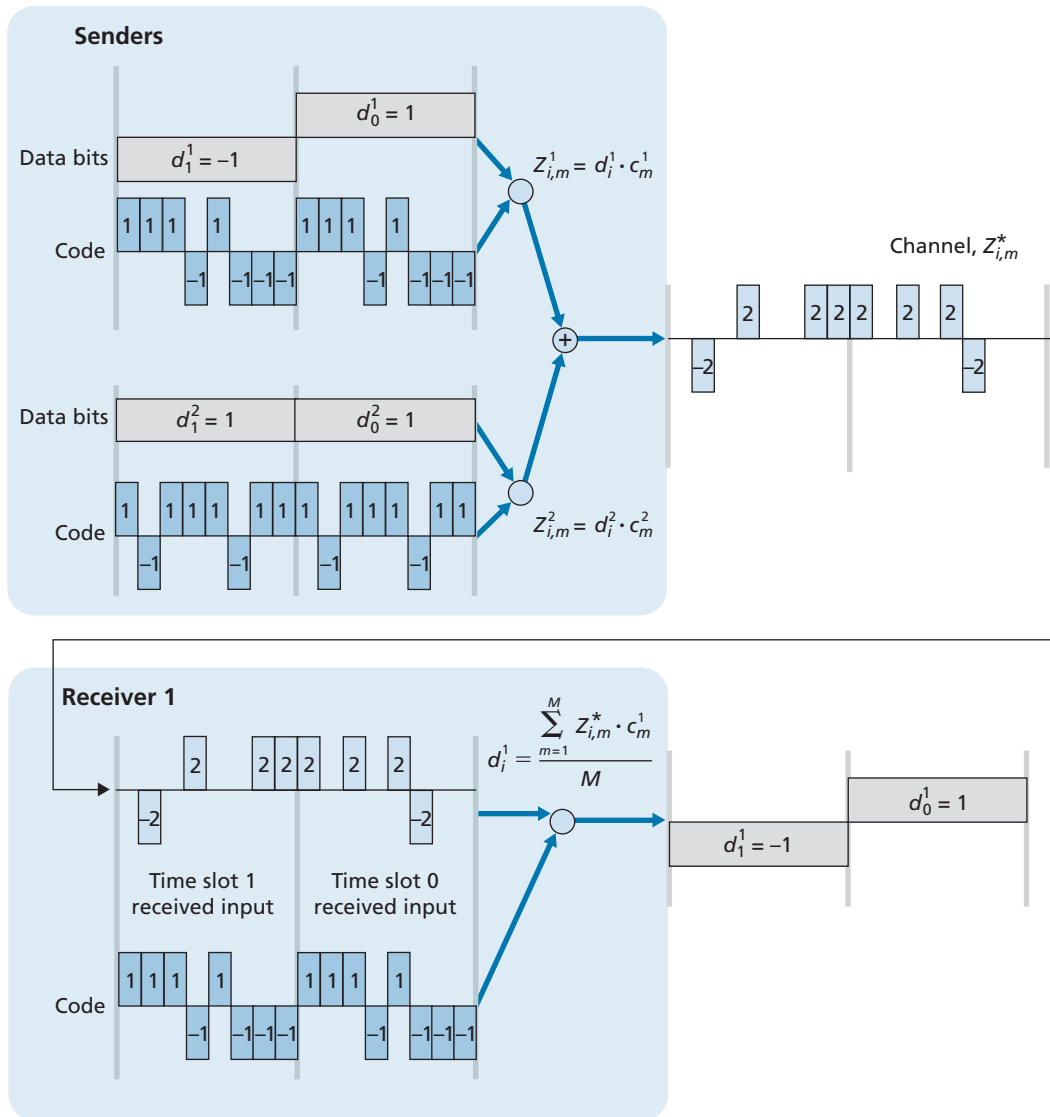


Figure 7.6 ♦ A two-sender CDMA example