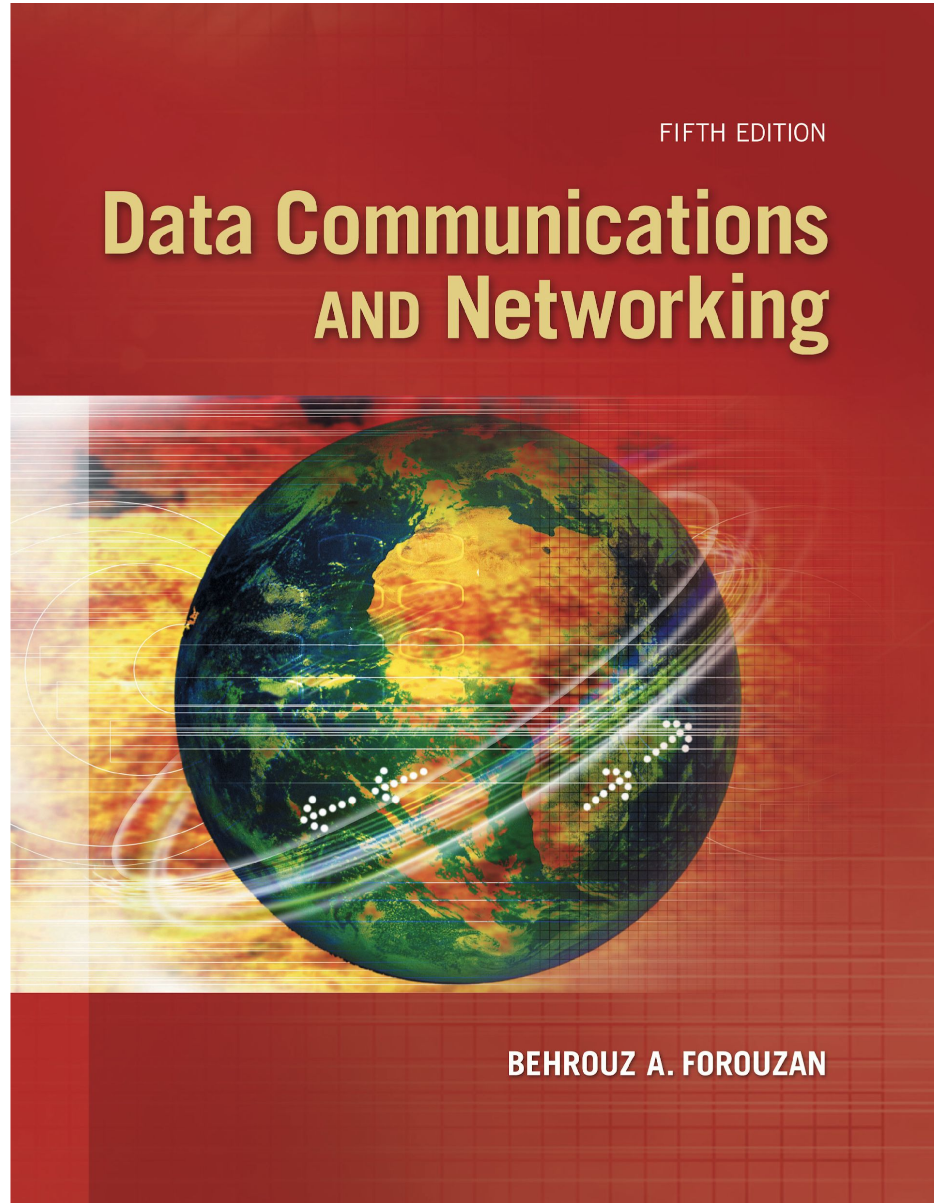
The McGraw-Hill Companies

Chapter 12

Media Access Control (MAC)



Chapter 5: Outline

12.1 RANDOM ACCESS

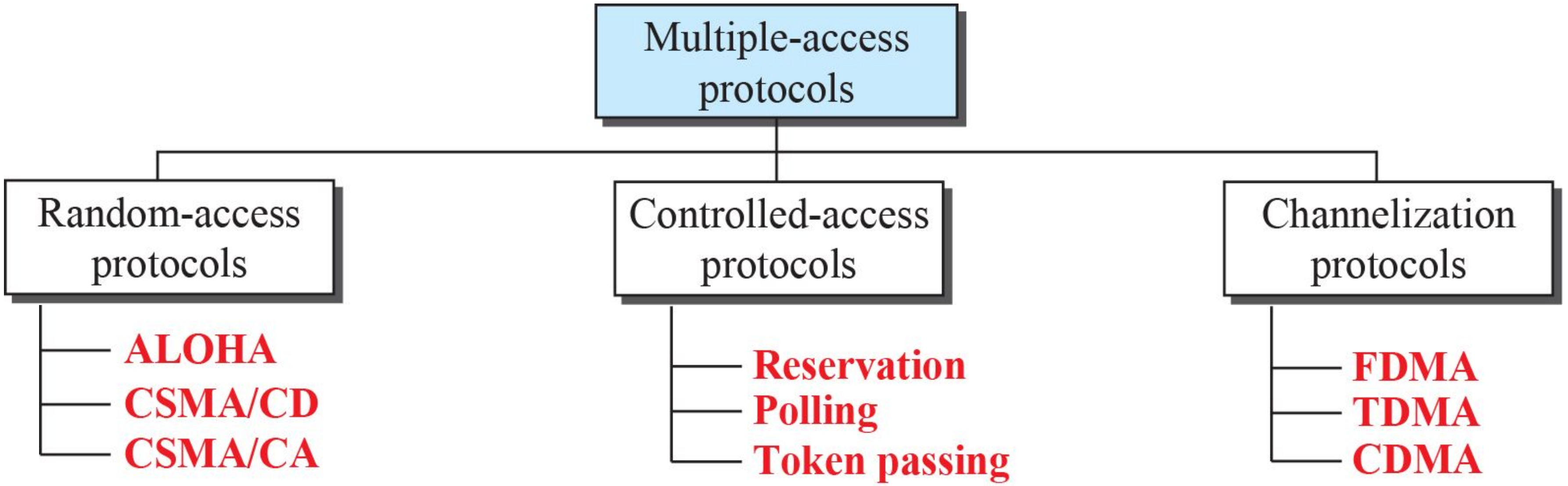
12.2 CONTROLLED ACCESS

12.3 CHANNELIZATION

Chapter 12: Objective

- ***The first section discusses random-access protocols. Four protocols, ALOHA, CSMA, CSMA/CD, and CSMA/CA, are described in this section. These protocols are mostly used in LANs and WANs, which we discuss in future chapters.***
- ***The second section discusses controlled-access protocols. Three protocols, reservation, polling, and token-passing, are described in this section. Some of these protocol are used in LANs, but others have some historical value.***
- ***The third section discusses channelization protocols. Three protocols, FDMA, TDMA, and CDMA are described in this section. These protocols are used in cellular telephony, which we discuss in Chapter 16.***

Figure 12.1: Taxonomy of multiple-access protocols



12-1 RANDOM ACCESS

In random-access or contention no station is superior to another station and none is assigned control over another. At each instance, a station that has data to send uses a procedure defined by the protocol to make a decision on whether or not to send. This decision depends on the state of the medium (idle or busy).

12.12.1 ALOHA

ALOHA, the earliest random access method, was developed at the University of Hawaii in early 1970. It was designed for a radio (wireless) LAN, but it can be used on any shared medium. It is obvious that there are potential collisions in this arrangement. The medium is shared between the stations. When a station sends data, another station may attempt to do so at the same time. The data from the two stations collide and become garbled.

Figure 12.2: Frames in a pure ALOHA network

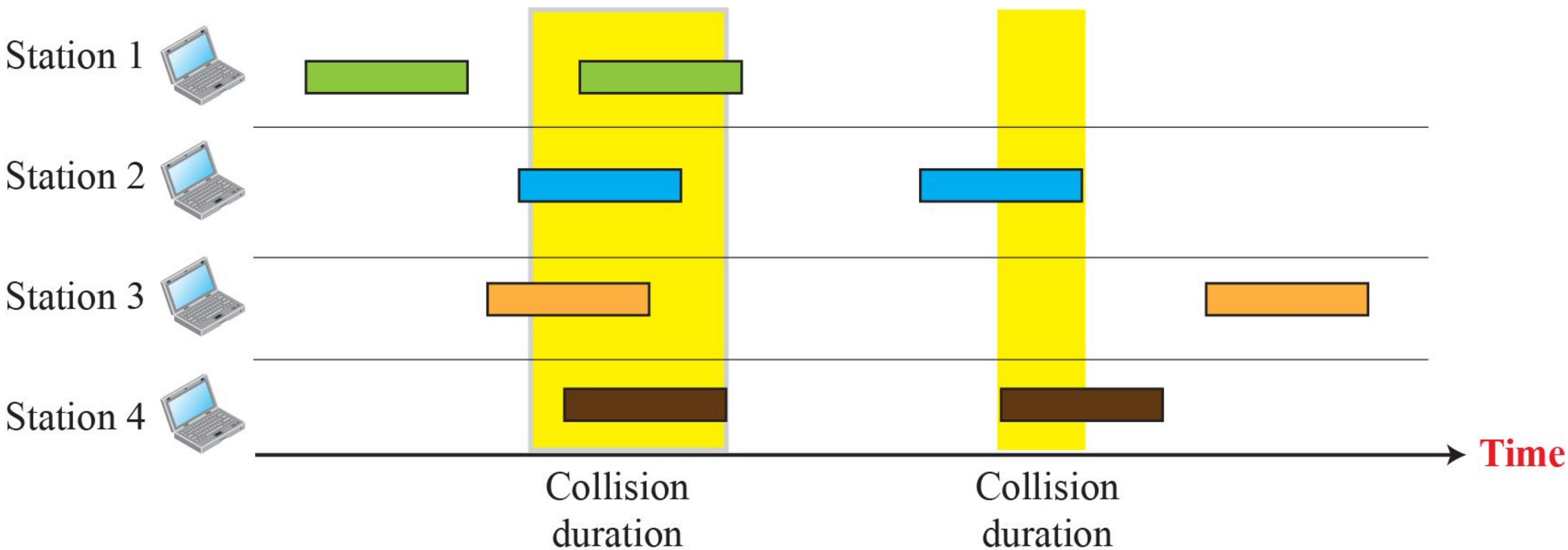
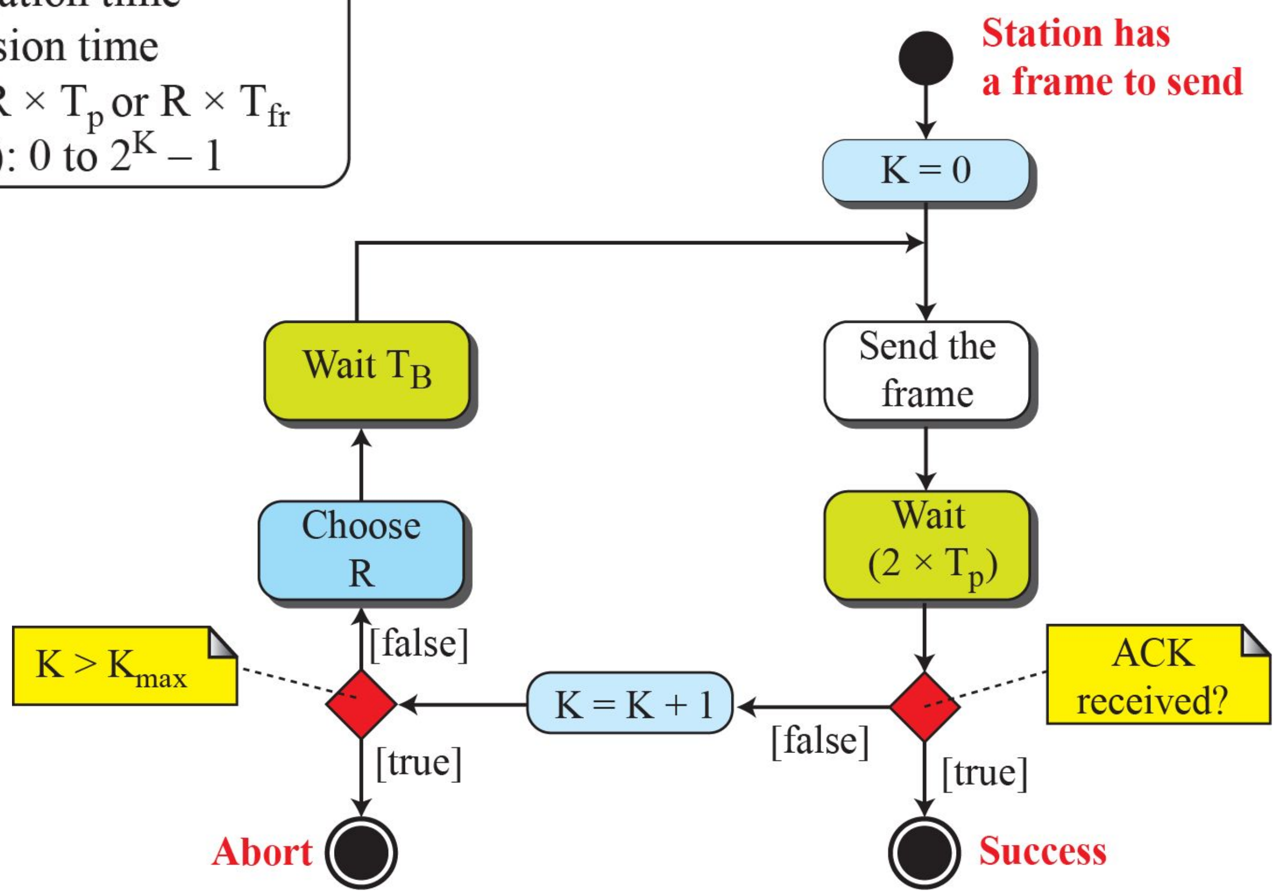


Figure 12.3: Procedure for pure ALOHA protocol

Legend

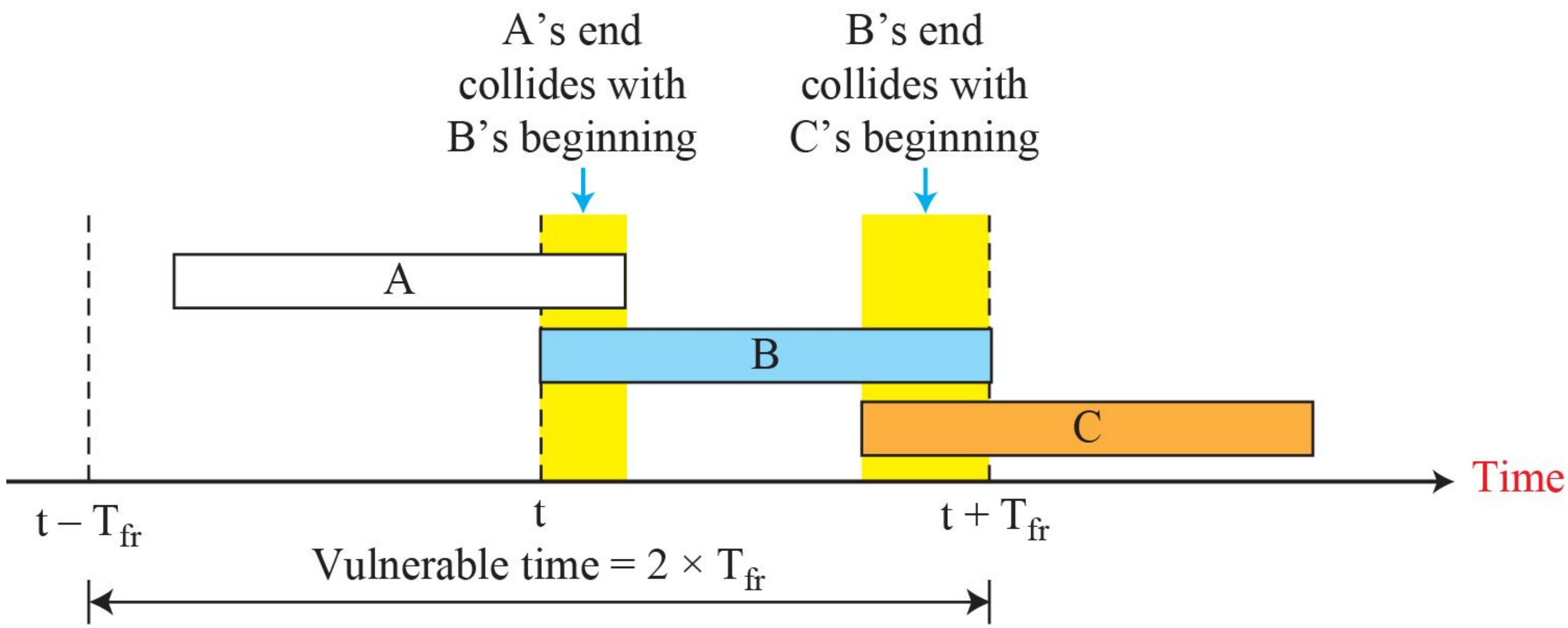
K : Number of attempts
T_p : Maximum propagation time
T_{fr}: Average transmission time
T_B: (Back-off time): $R \times T_p$ or $R \times T_{fr}$
R : (Random number): 0 to $2^K - 1$



Example 12. 1

The stations on a wireless ALOHA network are a maximum of 600 km apart. If we assume that signals propagate at 3×10^8 m/s, we find $T_p = (600 \times 10^3) / (3 \times 10^8) = 2$ ms. For $K = 2$, the range of R is $\{0, 1, 2, 3\}$. This means that T_B can be 0, 2, 4, or 6 ms, based on the outcome of the random variable R.

Figure 12.4: Vulnerable time for pure ALOHA protocol



Example 12.2

A pure ALOHA network transmits 200-bit frames on a shared channel of 200 kbps. What is the requirement to make this frame collision-free?

Solution

Average frame transmission time T_{fr} is 200 bits/200 kbps or 1 ms. The vulnerable time is 2×1 ms = 2 ms. This means no station should send later than 1 ms before this station starts transmission and no station should start sending during the period (1 ms) that this station is sending.

Example 12. 3

A pure ALOHA network transmits 200-bit frames on a shared channel of 200 kbps. What is the throughput if the system (all stations together) produces

a. 1000 frames per second?

b. 500 frames per second?

c. 250 frames per second?

Solution

The frame transmission time is 200/200 kbps or 1 ms.

a. If the system creates 1000 frames per second, or 1 frame per millisecond, then $G = 12$. In this case $S = G \times e^{-2G} =$ 0.135 (13.5 percent). This means that the throughput is $1000 \times 0.135 = 135$ frames. Only 135 frames out of 1000 will probably survive.

Example 12. 3 (continued)

b. If the system creates 500 frames per second, or 1/2 frames per millisecond, then $G = 1/2$. In this case $S = G \times e^{-2G} = 0.184$ (18.4 percent). This means that the throughput is $500 \times 0.184 = 92$ and that only 92 frames out of 500 will probably survive. Note that this is the maximum throughput case, percentage-wise.

c. If the system creates 250 frames per second, or 1/4 frames per millisecond, then $G = 1/4$. In this case $S = G \times e^{-2G} = 0.152$ (15.2 percent). This means that the throughput is $250 \times 0.152 = 38$. Only 38 frames out of 250 will probably survive

Figure 12.5: Frames in a slotted ALOHA network

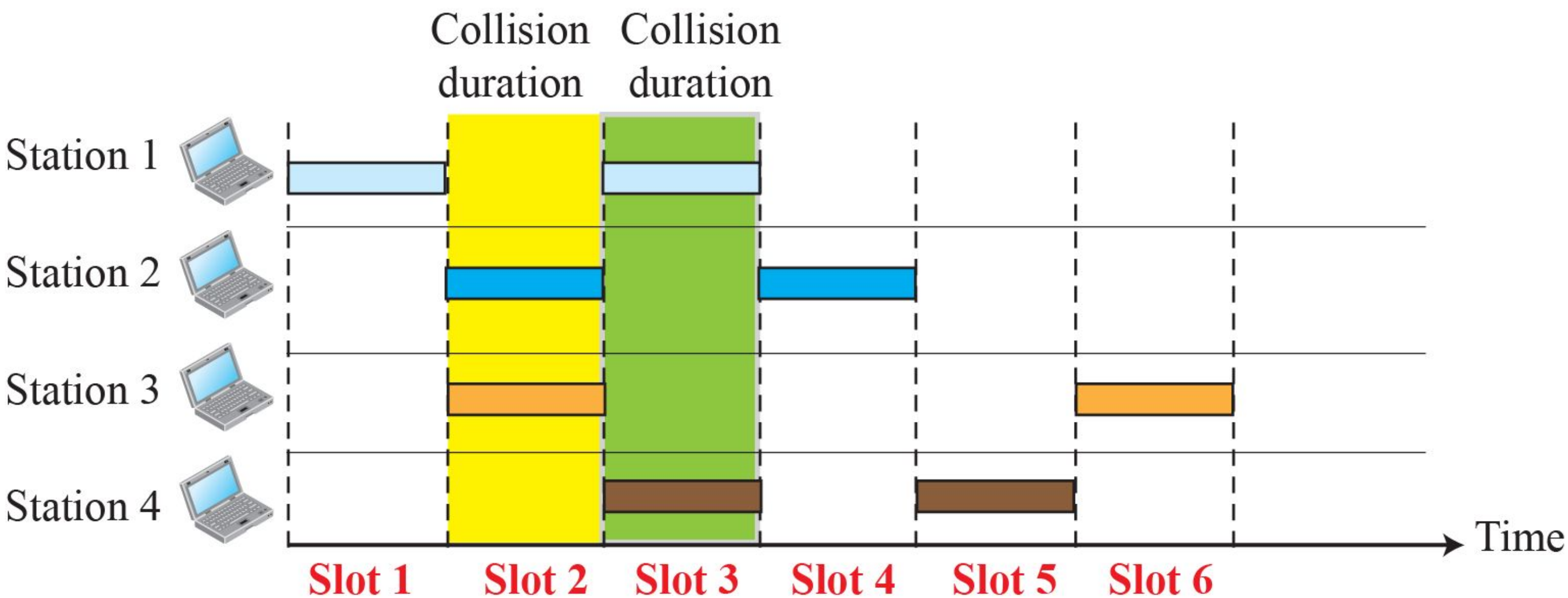
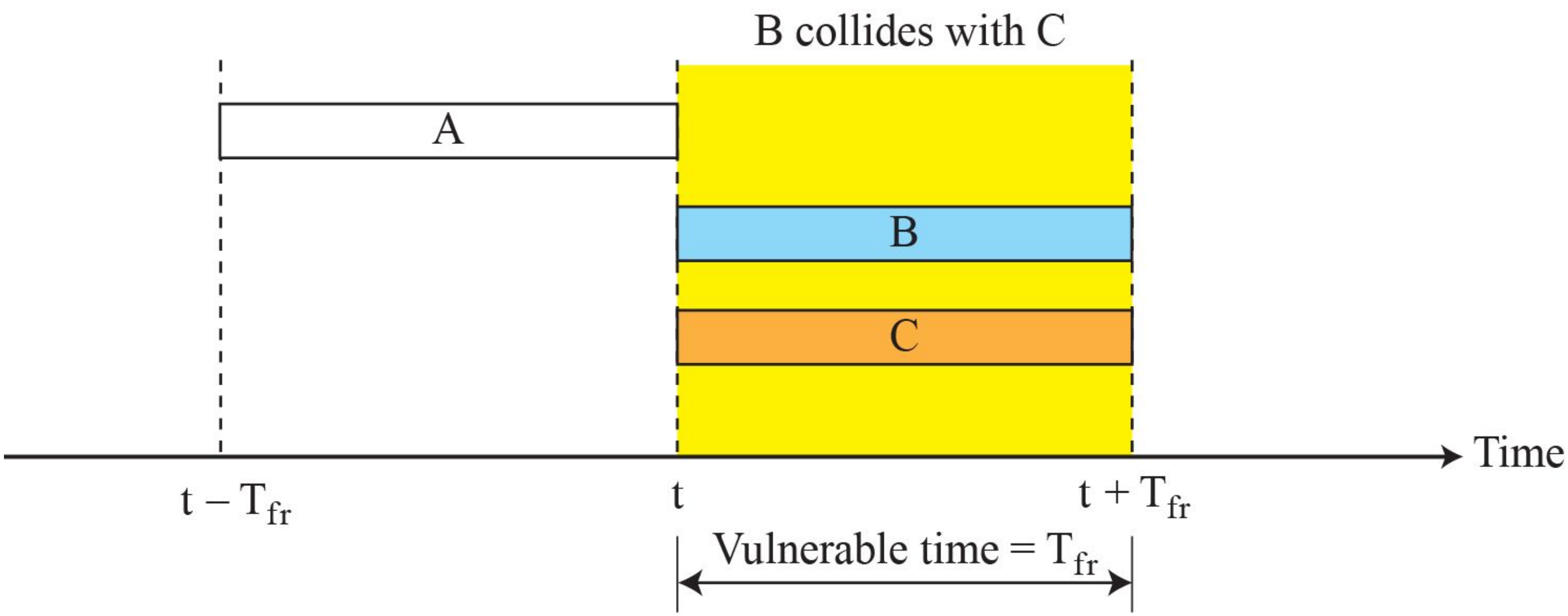


Figure 12.6: Vulnerable time for slotted ALOHA protocol



Example 12. 4

A slotted ALOHA network transmits 200-bit frames using a shared channel with a 200-kbps bandwidth. Find the throughput if the system (all stations together) produces

a. 1000 frames per second.
b. 500 frames per second.
c. 250 frames per second.

Solution

This situation is similar to the previous exercise except that the network is using slotted ALOHA instead of pure ALOHA. The frame transmission time is 200/200 kbps or 1 ms.

Example 12. 4 (continued)

a) In this case G is 12. So $S = G \times e^{-G} = 0.368$ (36.8 percent). This means that the throughput is $1000 \times 0.0368 = 368$ frames. Only 368 out of 1000 frames will probably survive. Note that this is the maximum throughput case, percentage-wise.

b) Here G is 1/2. In this case $S = G \times e^{-G} = 0.303$ (30.3 percent). This means that the throughput is $500 \times 0.0303 = 1512$. Only 151 frames out of 500 will probably survive.

c) Now G is 1/4. In this case $S = G \times e^{-G} = 0.195$ (19.5 percent). This means that the throughput is $250 \times 0.195 = 49$. Only 49 frames out of 250 will probably survive.

12.12.2 CSMA

To minimize the chance of collision and, therefore, increase the performance, the CSMA method was developed. The chance of collision can be reduced if a station senses the medium before trying to use it. Carrier sense multiple access (CSMA) requires that each station first listen to the medium (or check the state of the medium) before sending. In other words, CSMA is based on the principle "sense before transmit" or "listen before talk."

Figure 12.7: Space/time model of a collision in CSMA

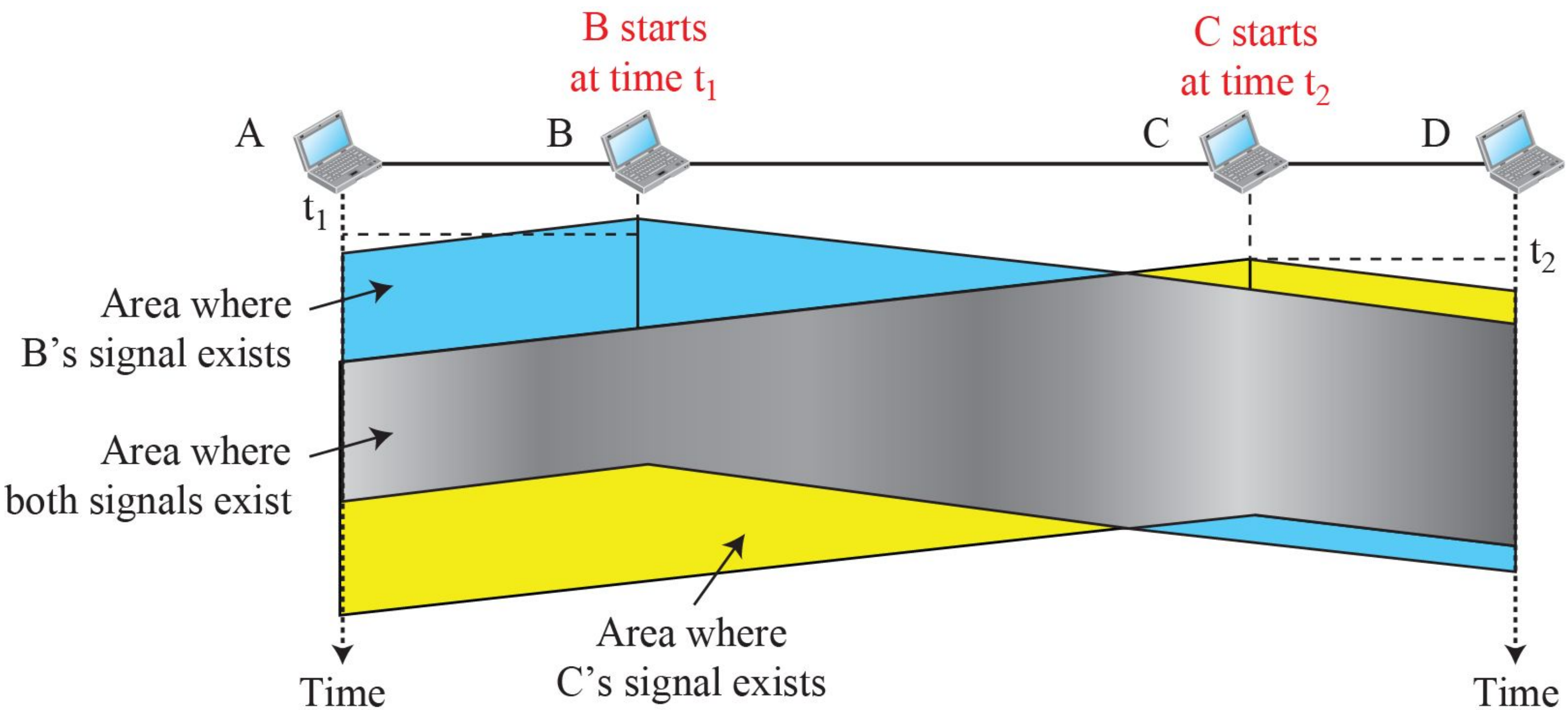


Figure 12.8: Vulnerable time in CSMA

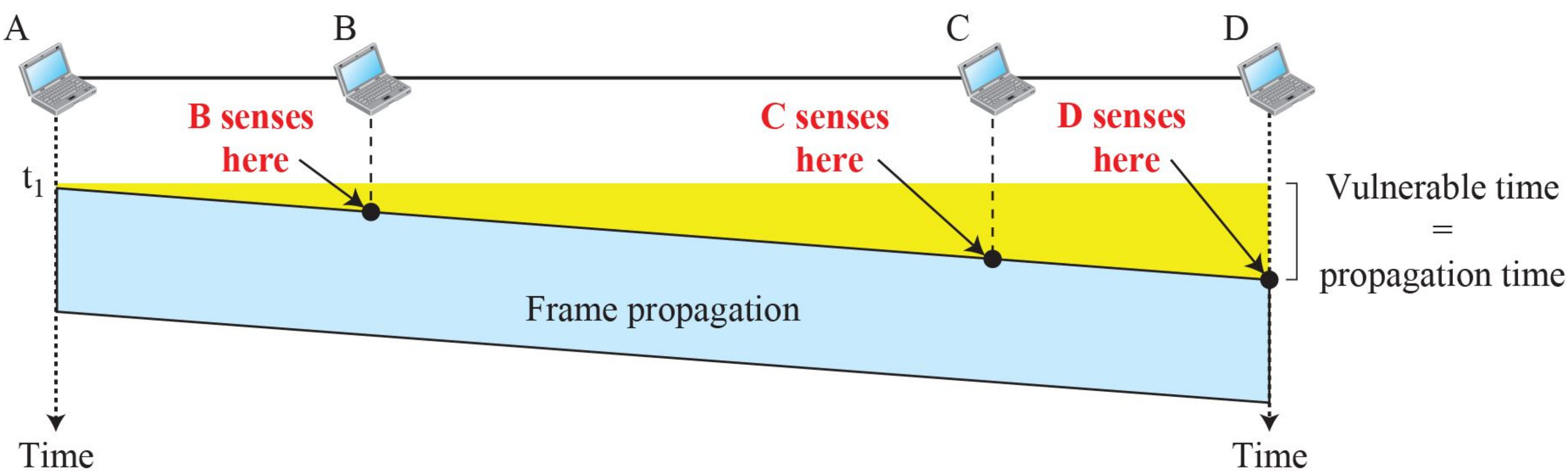


Figure 12.9: Behavior of three persistence methods

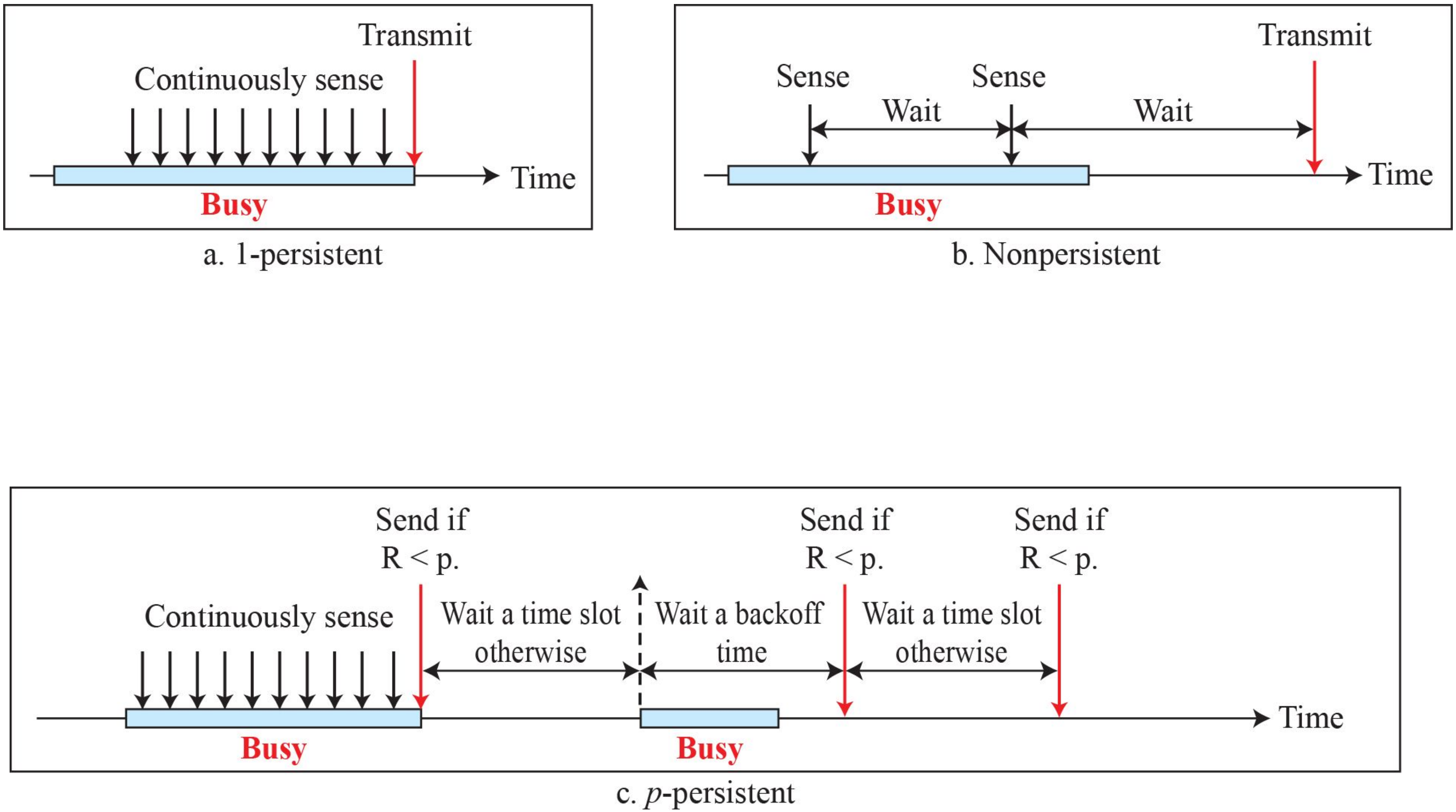
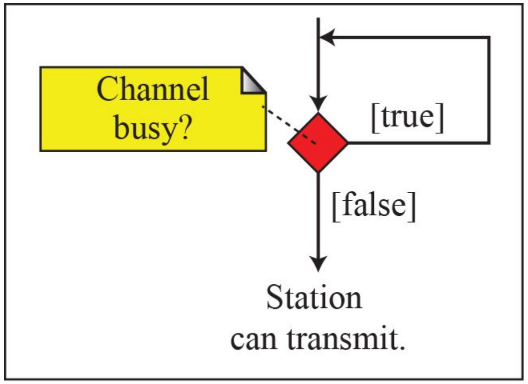
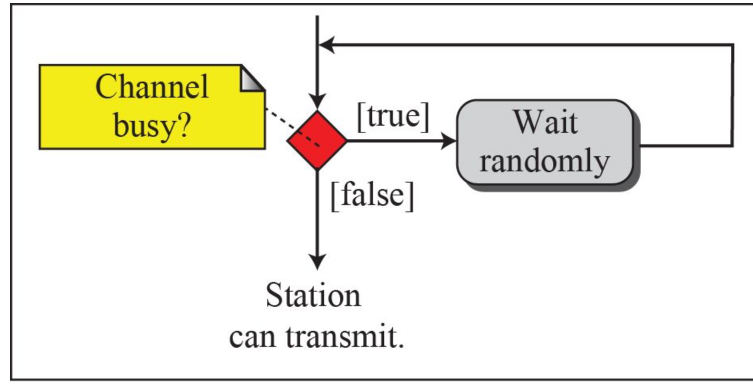


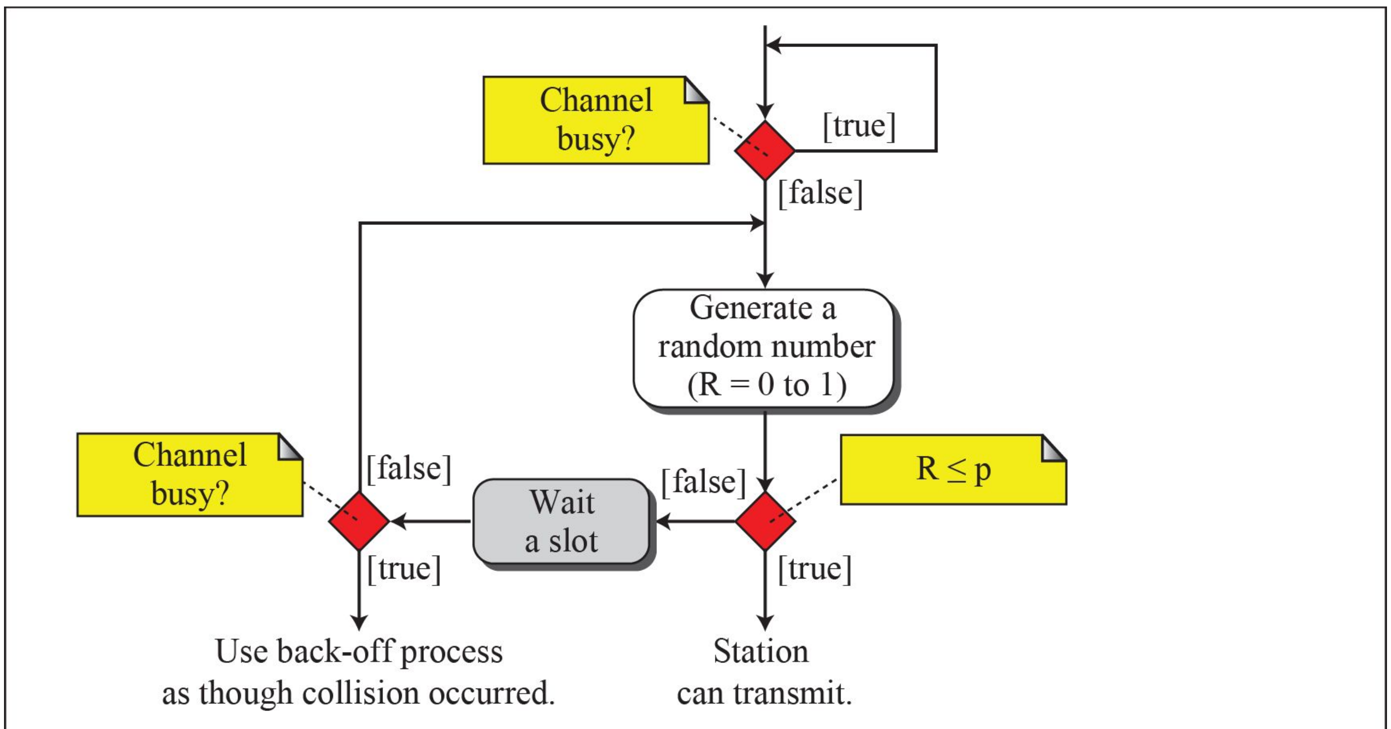
Figure 12.10: Flow diagram for three persistence methods



a. 1-persistent



b. Nonpersistent



c. *p*-persistent

12.12.3 CSMA/CD

The CSMA method does not specify the procedure following a collision. Carrier sense multiple access with collision detection (CSMA/CD) augments the algorithm to handle the collision.

In this method, a station monitors the medium after it sends a frame to see if the transmission was successful. If so, the station is finished. If, however, there is a collision, the frame is sent again.

Figure 12.11: Collision of the first bits in CSMA/CD

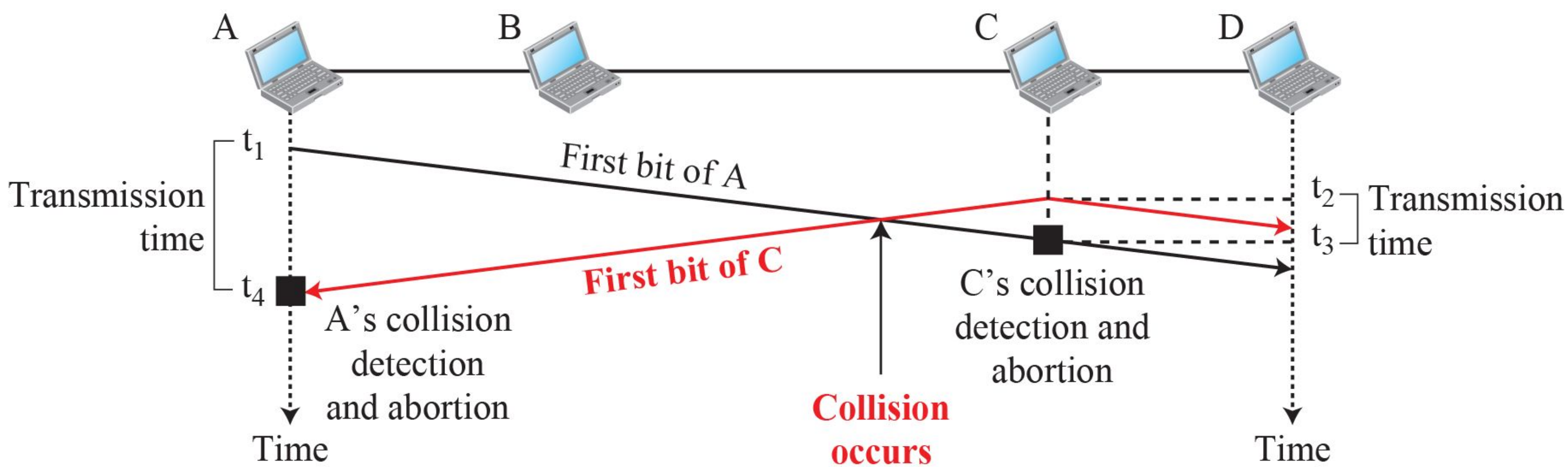
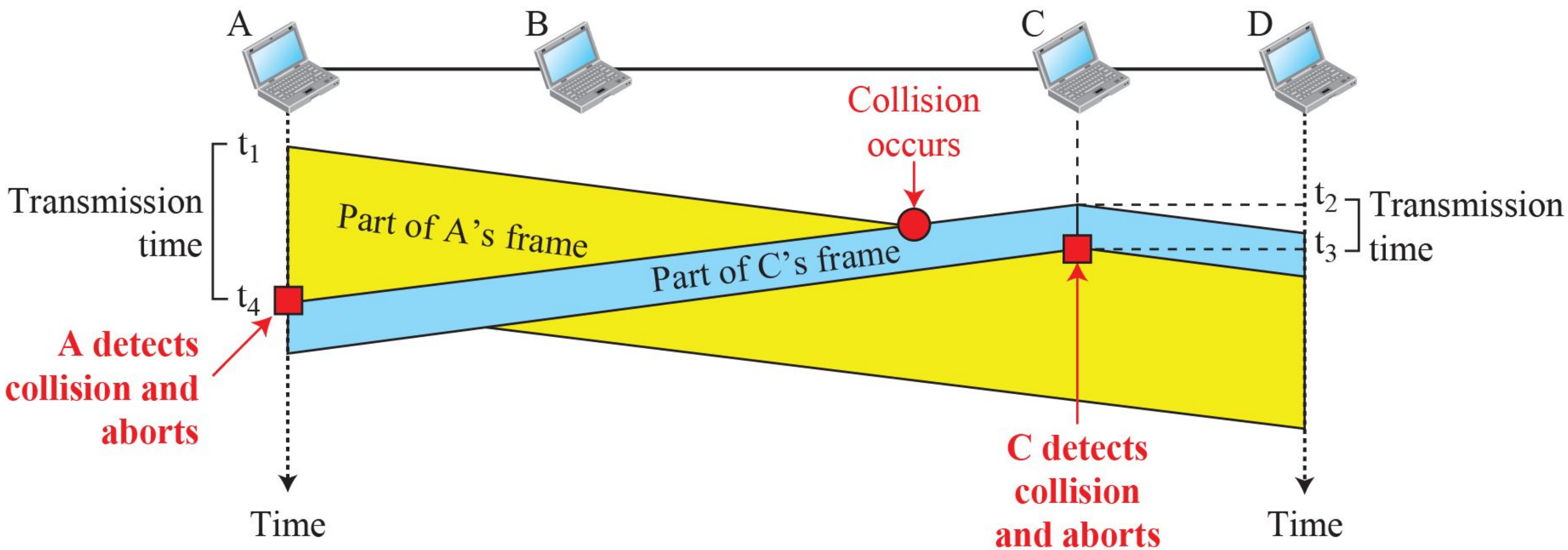


Figure 12.12: Collision and abortion in CSMA/CD



Example 12. 5

A network using CSMA/CD has a bandwidth of 10 Mbps. If the maximum propagation time (including the delays in the devices and ignoring the time needed to send a jamming signal, as we see later) is 25.6 μs, what is the minimum size of the frame?

Solution

The minimum frame transmission time is $T_{fr} = 2 \times T_p = 512.2\ \mu s$. This means, in the worst case, a station needs to transmit for a period of 512.2 μs to detect the collision. The minimum size of the frame is 10 Mbps × 512.2 μs = 512 bits or 64 bytes. This is actually the minimum size of the frame for Standard Ethernet, as we will see later in the chapter.

Figure 12.13: *Flow diagram for the CSMA/CD*

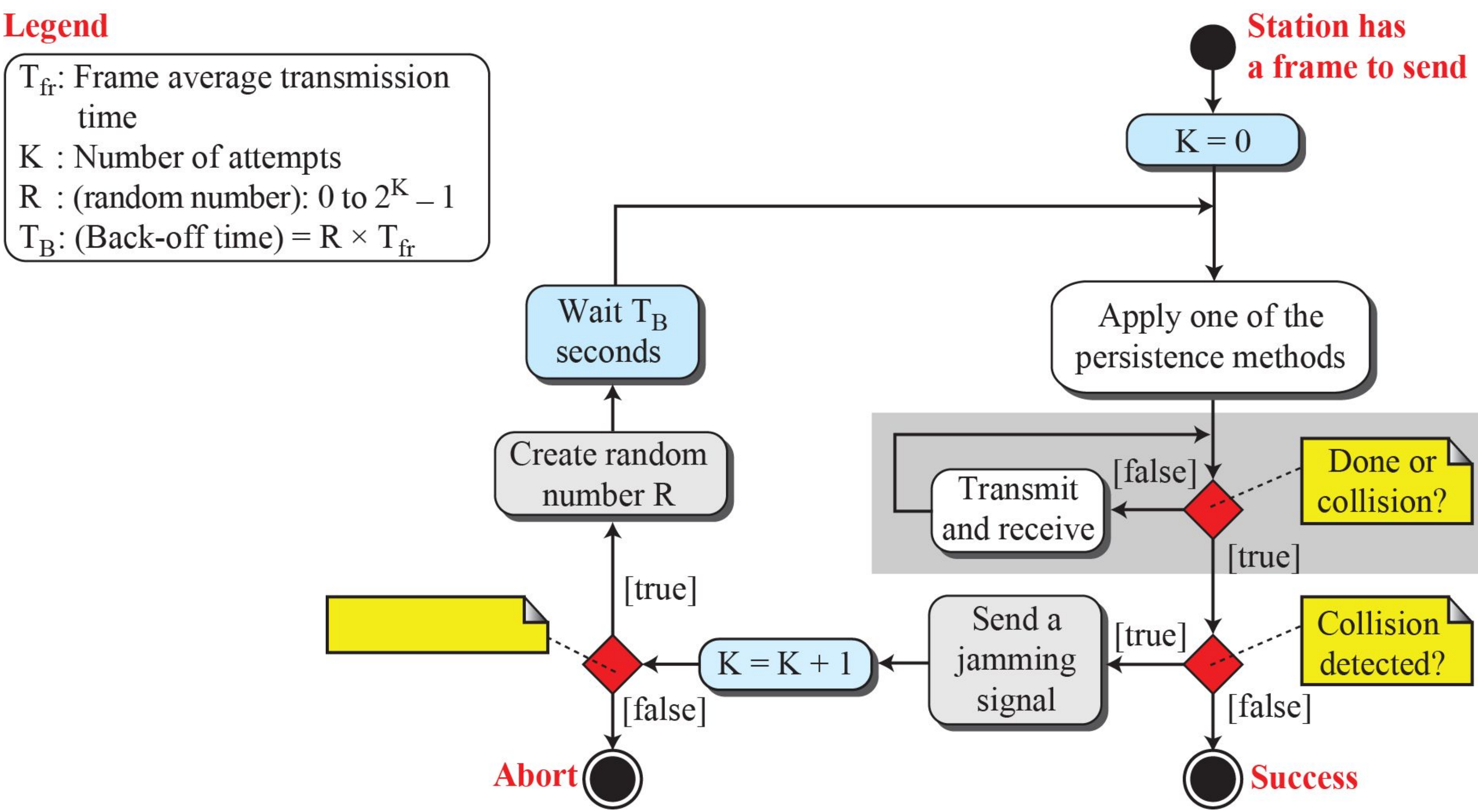
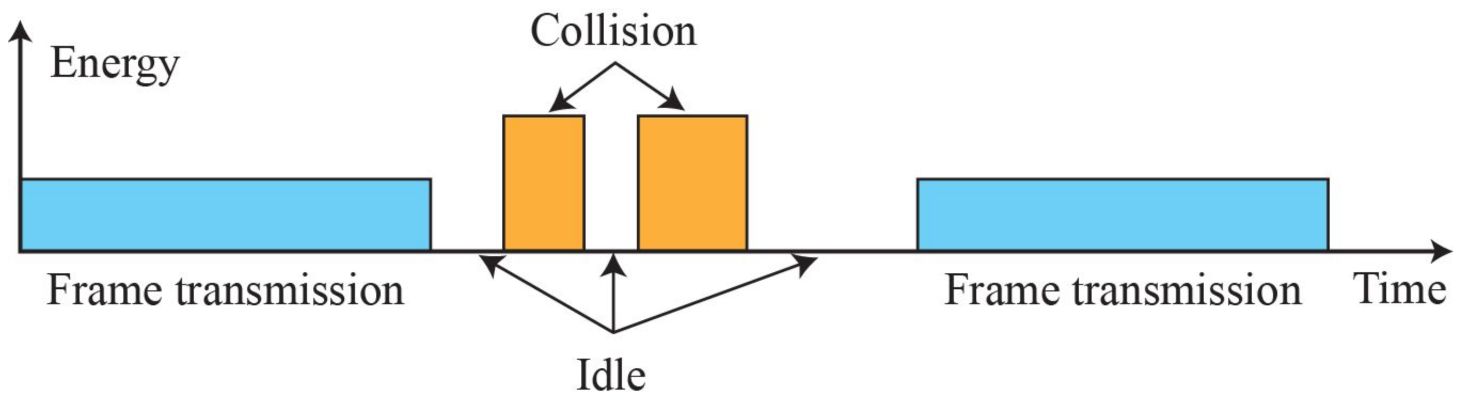


Figure 12.14: Energy level during transmission, idleness, or collision



12.12.4 CSMA/CA

Carrier sense multiple access with collision avoidance (CSMA/CA) was invented for wireless networks. Collisions are avoided through the use of CSMA/CA's three strategies: the interframe space, the contention window, and acknowledgments, as shown in Figure 12.15. We discuss RTS and CTS frames later.

Figure 12.15: Flow diagram for CSMA/CA

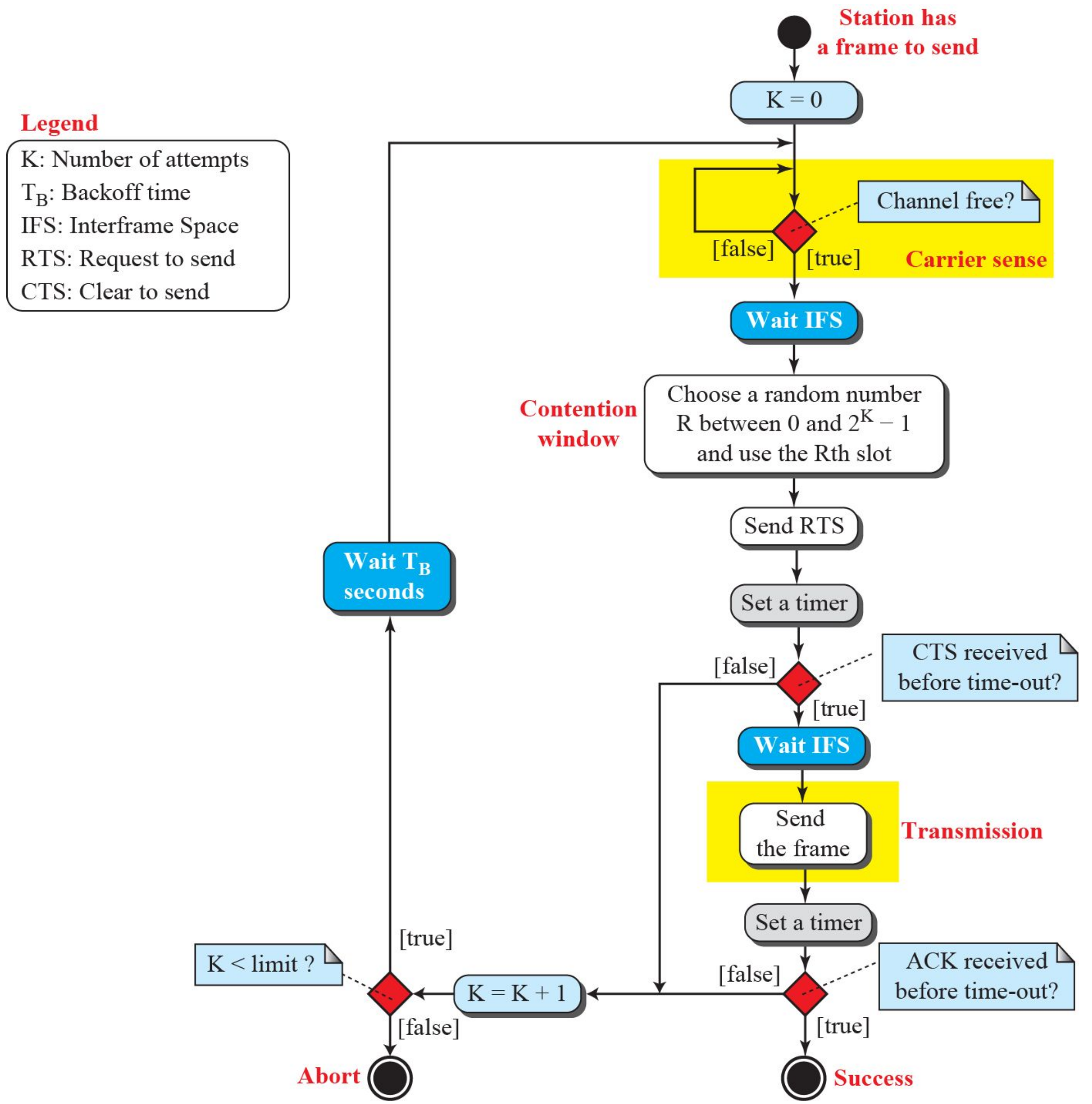


Figure 12.16: Contention window

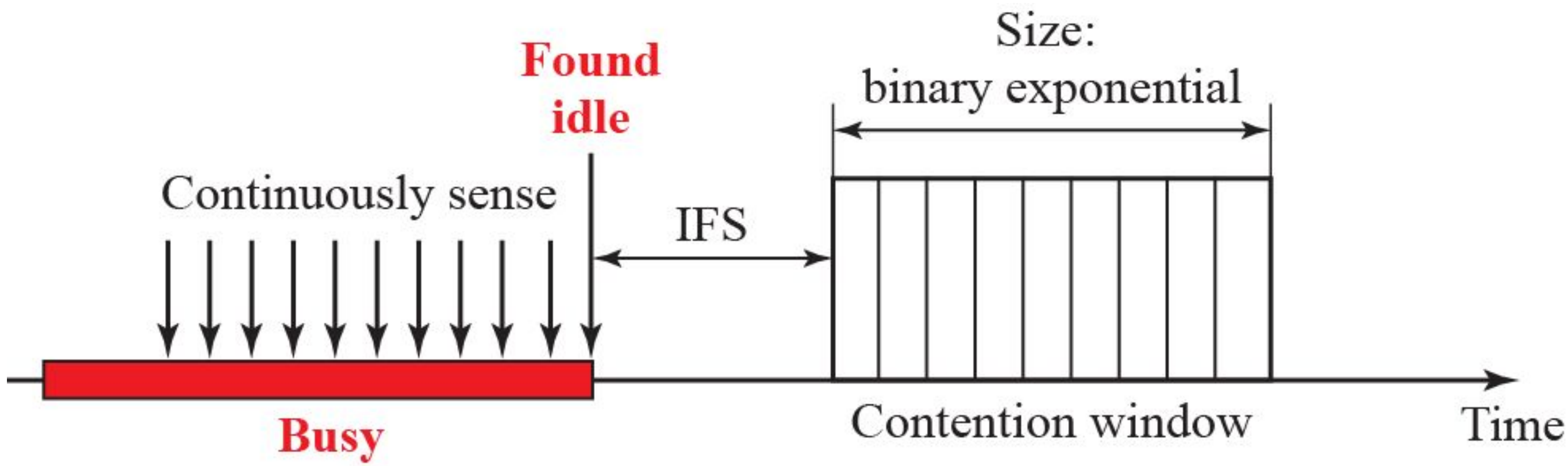
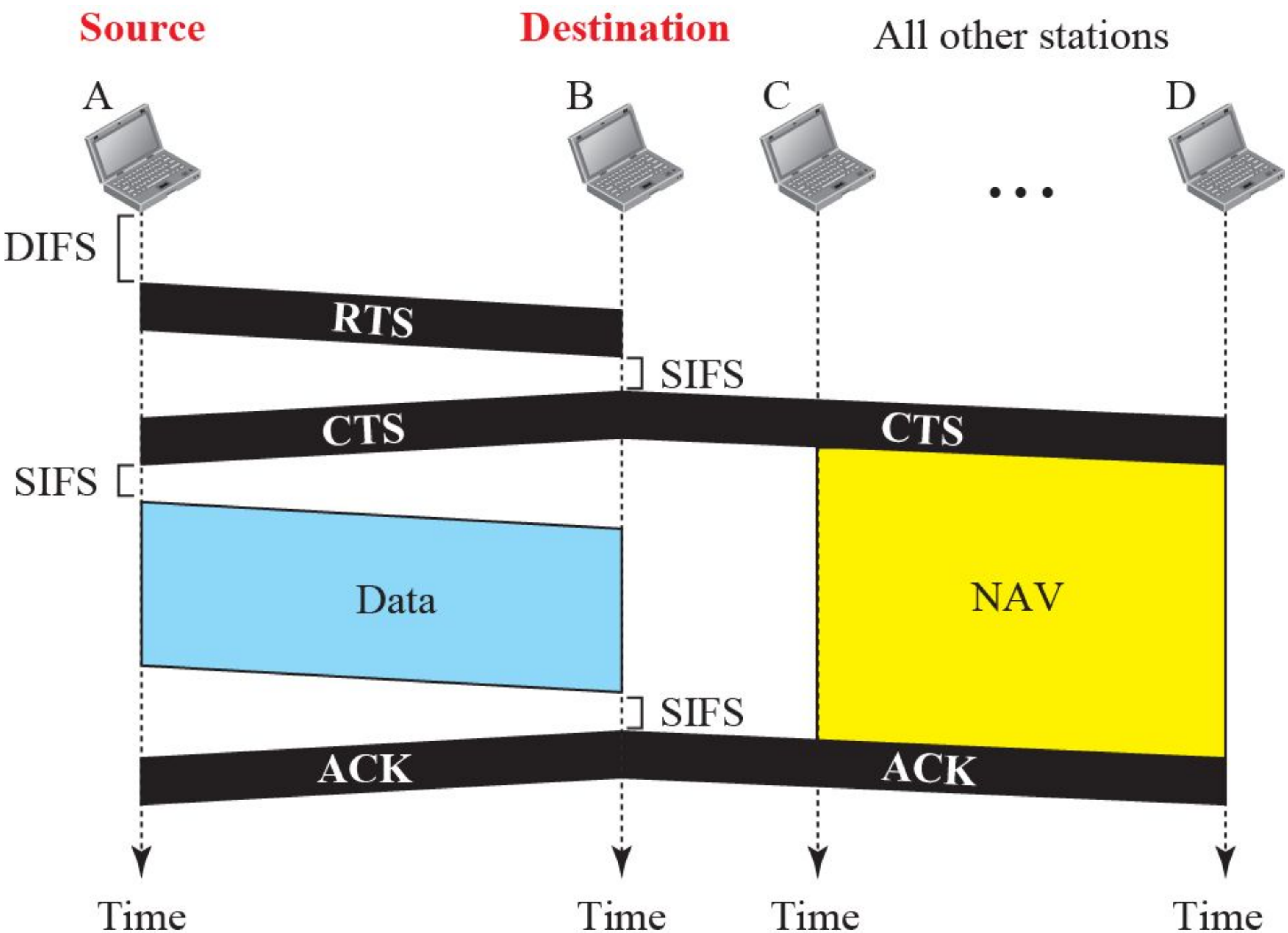


Figure 12.17: CMACA and NAV



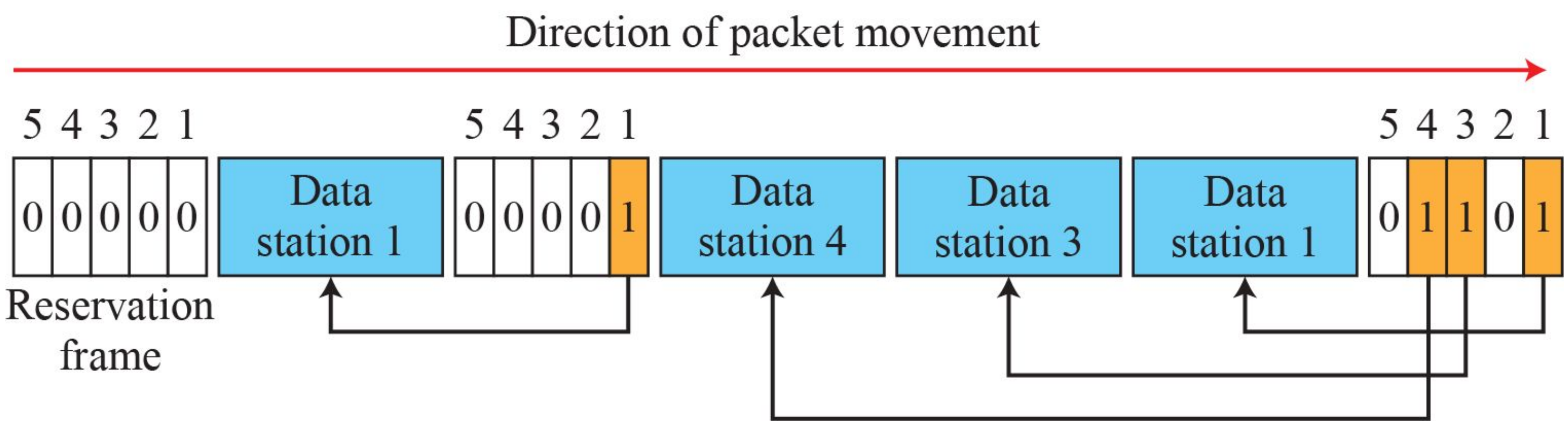
12-2 CONTROLLED ACCESS

In controlled access, the stations consult one another to find which station has the right to send. A station cannot send unless it has been authorized by other stations. We discuss three controlled-access methods.

12.2.1 Reservation

In the reservation method, a station needs to make a reservation before sending data. Time is divided into intervals. In each interval, a reservation frame precedes the data frames sent in that interval.

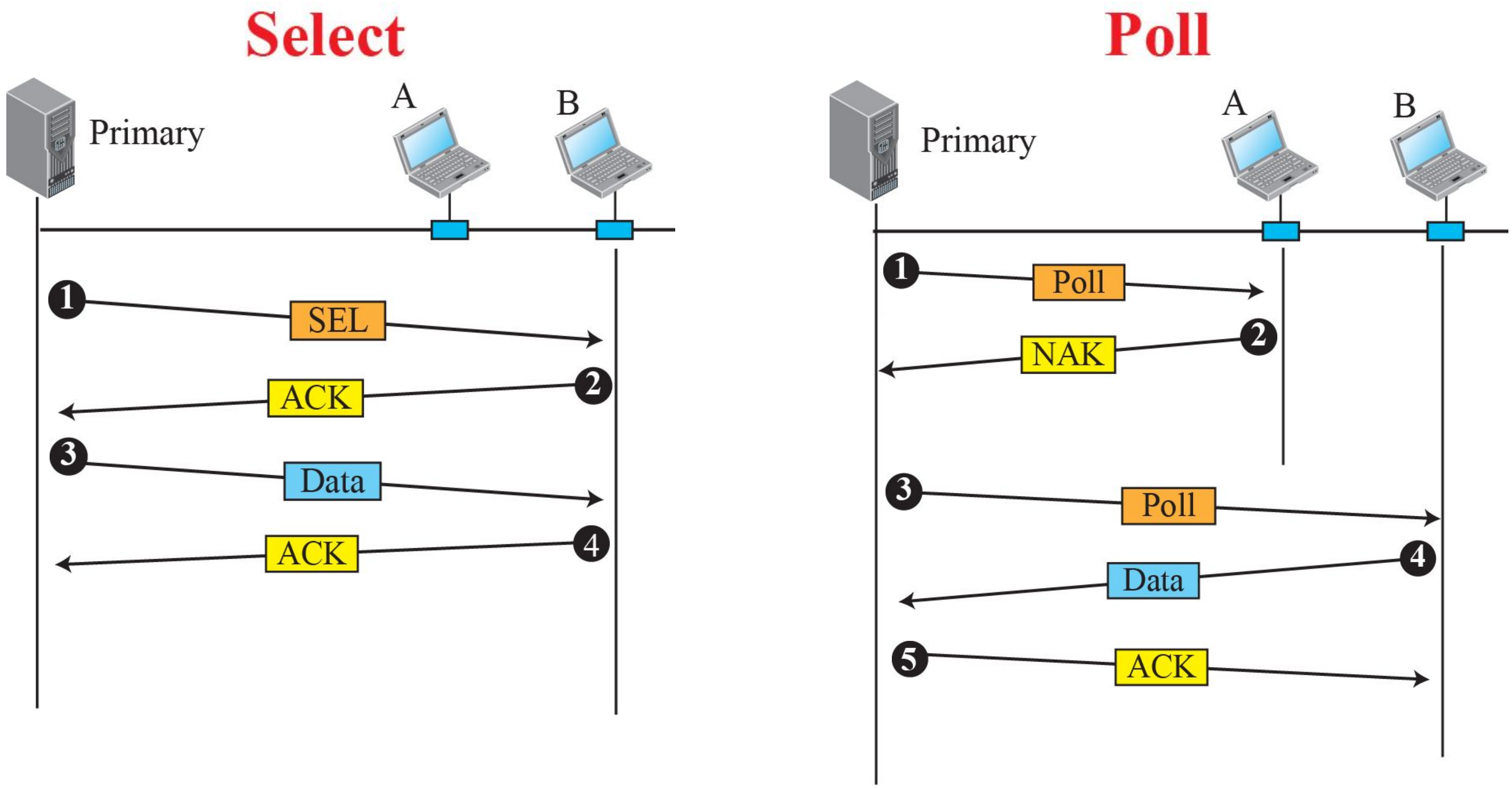
Figure 12.18: ***Reservation access method***



12.2.2 Polling

Polling works with topologies in which one device is designated as a primary station and the other devices are secondary stations. All data exchanges must be made through the primary device even when the ultimate destination is a secondary device. The primary device controls the link; the secondary devices follow its instructions. It is up to the primary device to determine which device is allowed to use the channel at a given time.

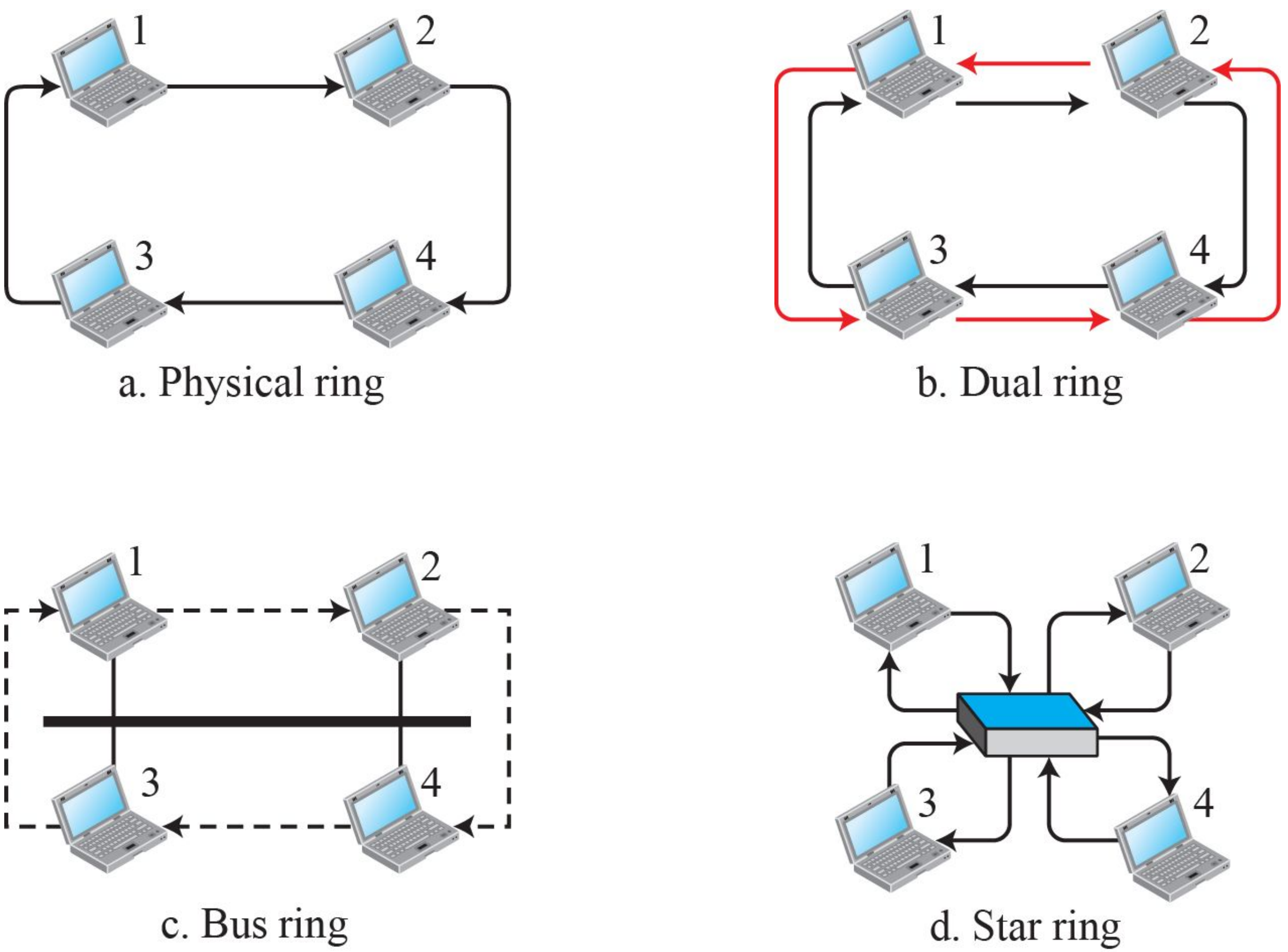
Figure 12.19: Select and poll functions in polling-access method



12.2.3 Token Passing

In the token-passing method, the stations in a network are organized in a logical ring. In other words, for each station, there is a predecessor and a successor. The predecessor is the station which is logically before the station in the ring; the successor is the station which is after the station in the ring.

Figure 12.20: *Logical ring and physical topology in token-passing access method*



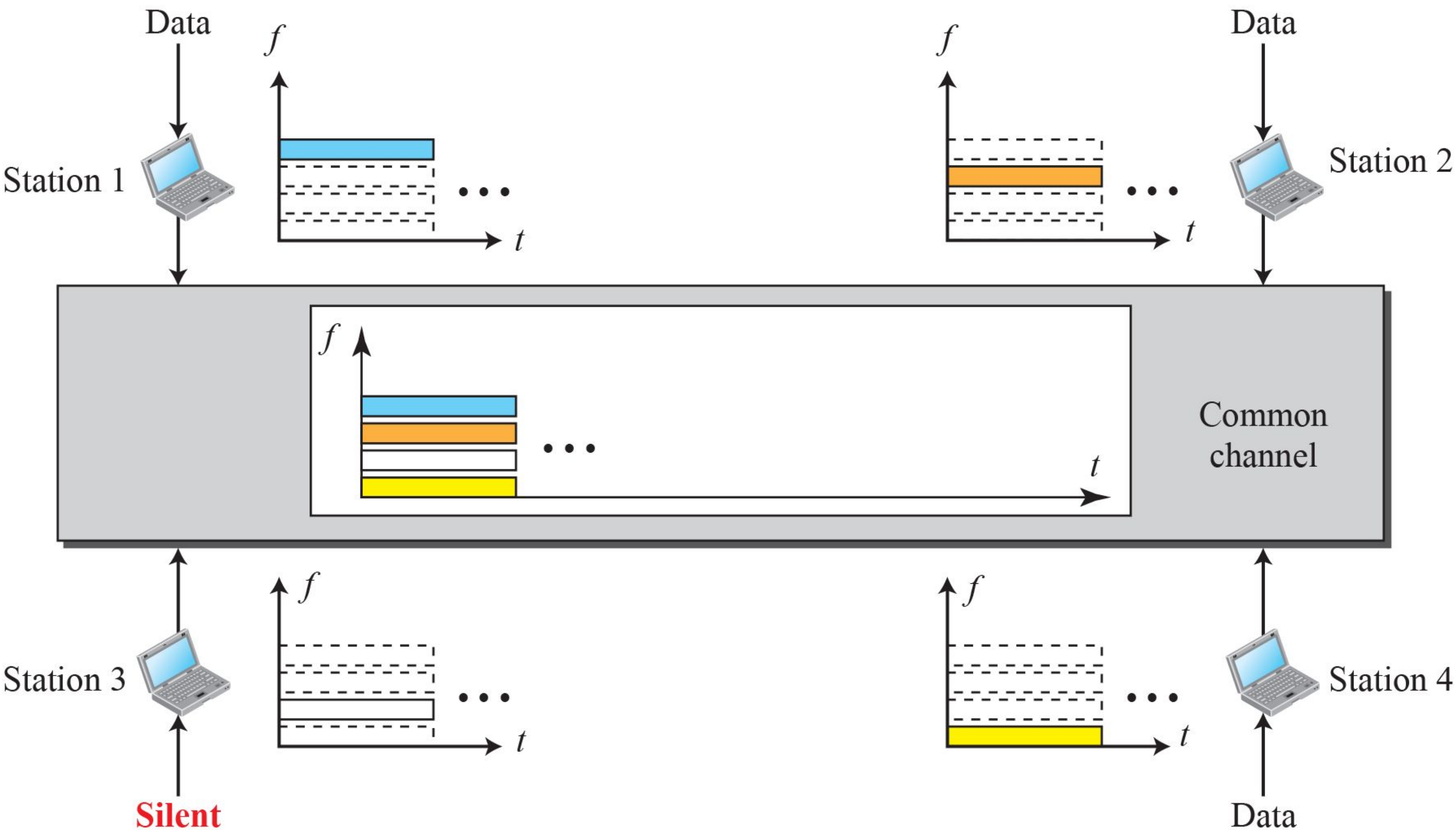
12-3 CHANNELIZATION

Channelization (or channel partition, as it is sometimes called) is a multiple-access method in which the available bandwidth of a link is shared in time, frequency, or through code, among different stations. In this section, we discuss three protocols: FDMA, TDMA, and CDMA.

12.3.1 FDMA

In frequency-division multiple access (FDMA), the available bandwidth is divided into frequency bands. Each station is allocated a band to send its data. In other words, each band is reserved for a specific station, and it belongs to the station all the time. Each station also uses a bandpass filter to confine the transmitter frequencies. To prevent

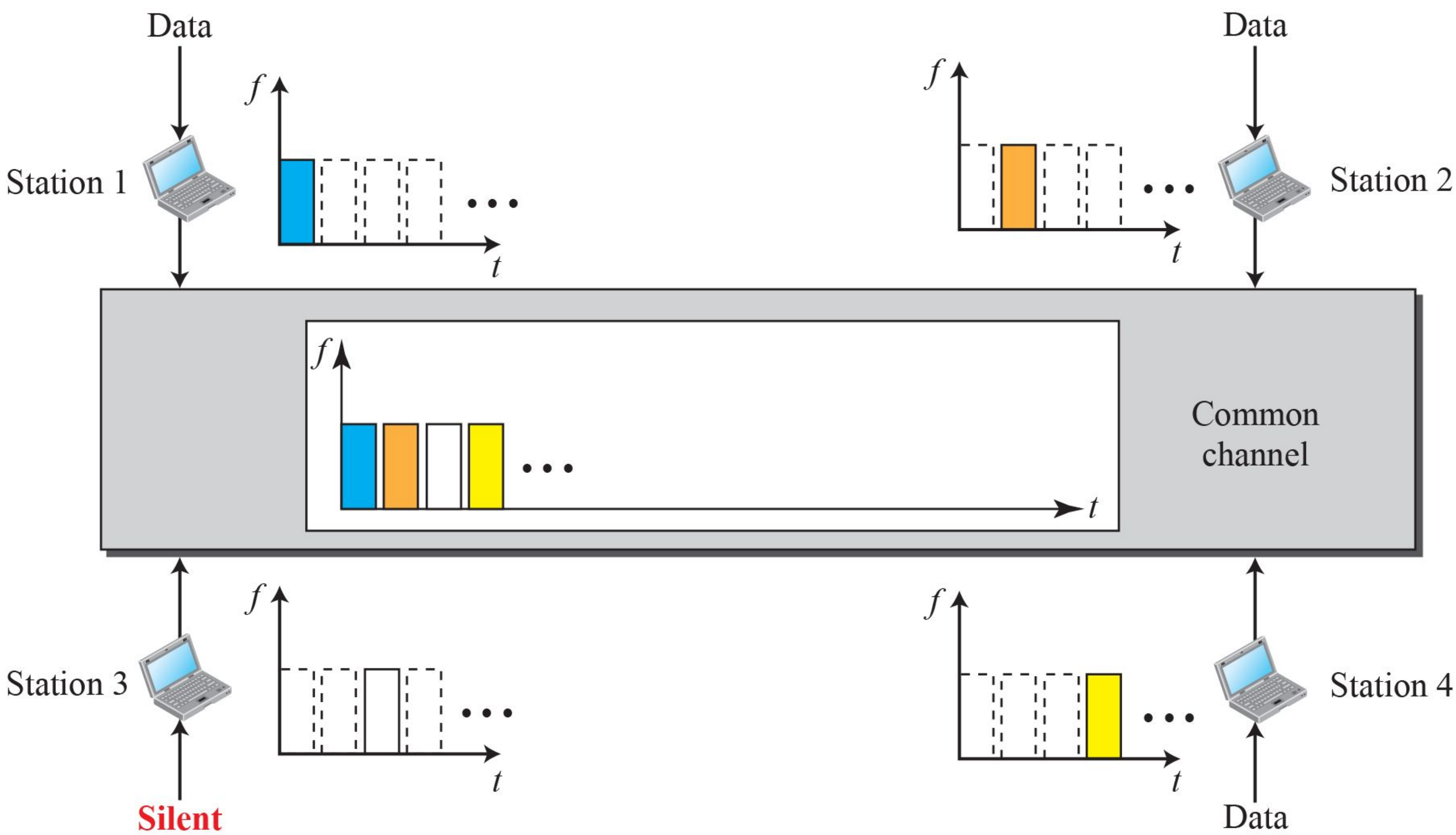
Figure 12.21: Frequency-division multiple access (FDMA)



12.3.2 TDMA

In time-division multiple access (TDMA), the stations share the bandwidth of the channel in time. Each station is allocated a time slot during which it can send data. Each station transmits its data in its assigned time slot. Figure 12.22 shows the idea behind TDMA.

Figure 12.22: Time-division multiple access (TDMA)



12.3.3 CDMA

Code-division multiple access (CDMA) was conceived several decades ago. Recent advances in electronic technology have finally made its implementation possible. CDMA differs from FDMA in that only one channel occupies the entire bandwidth of the link. It differs from TDMA in that all stations can send data simultaneously; there is no timesharing.

Figure 12.23: Simple idea of communication with code

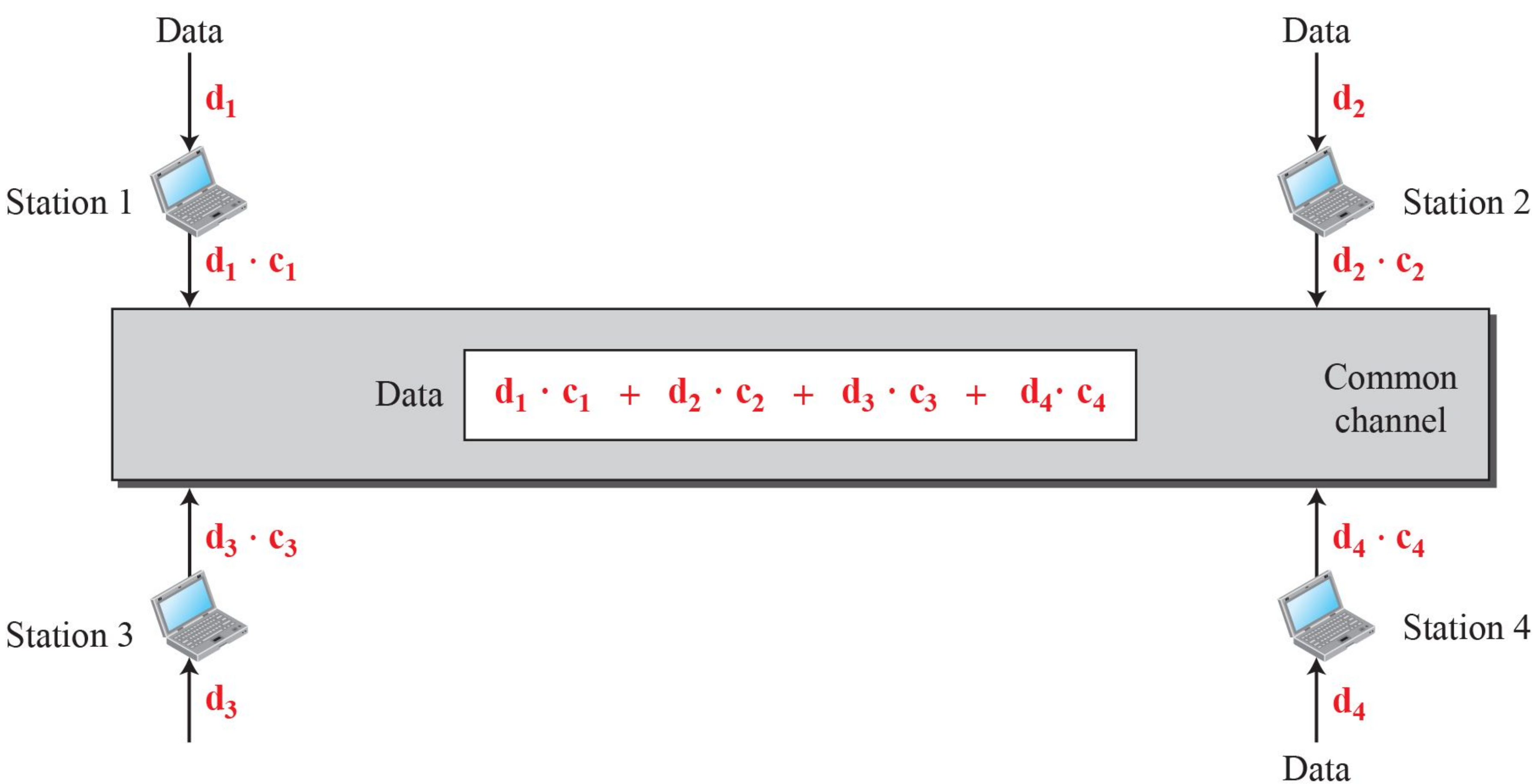


Figure 12.24: Chip sequences

C_1

$[+1 \quad +1 \quad +1 \quad +1]$

C_2

$[+1 \quad -1 \quad +1 \quad -1]$

C_3

$[+1 \quad +1 \quad -1 \quad -1]$

C_4

$[+1 \quad -1 \quad -1 \quad +1]$

Figure 12.25: Data representation in CDMA

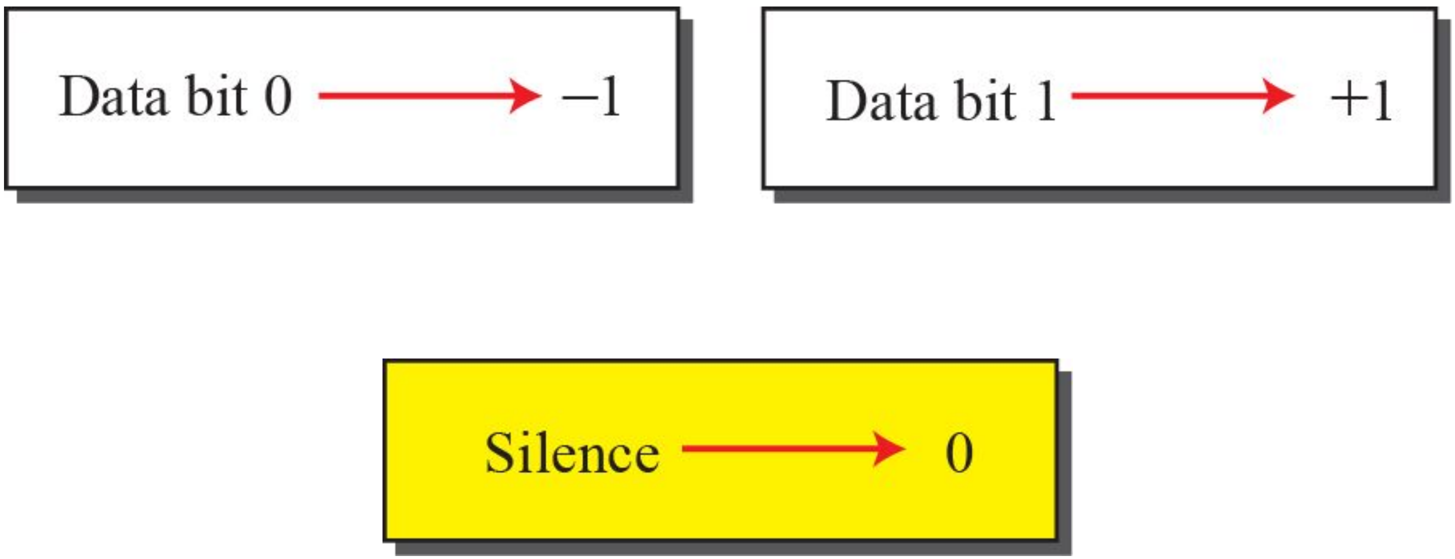


Figure 12.26: Sharing channel in CDMA

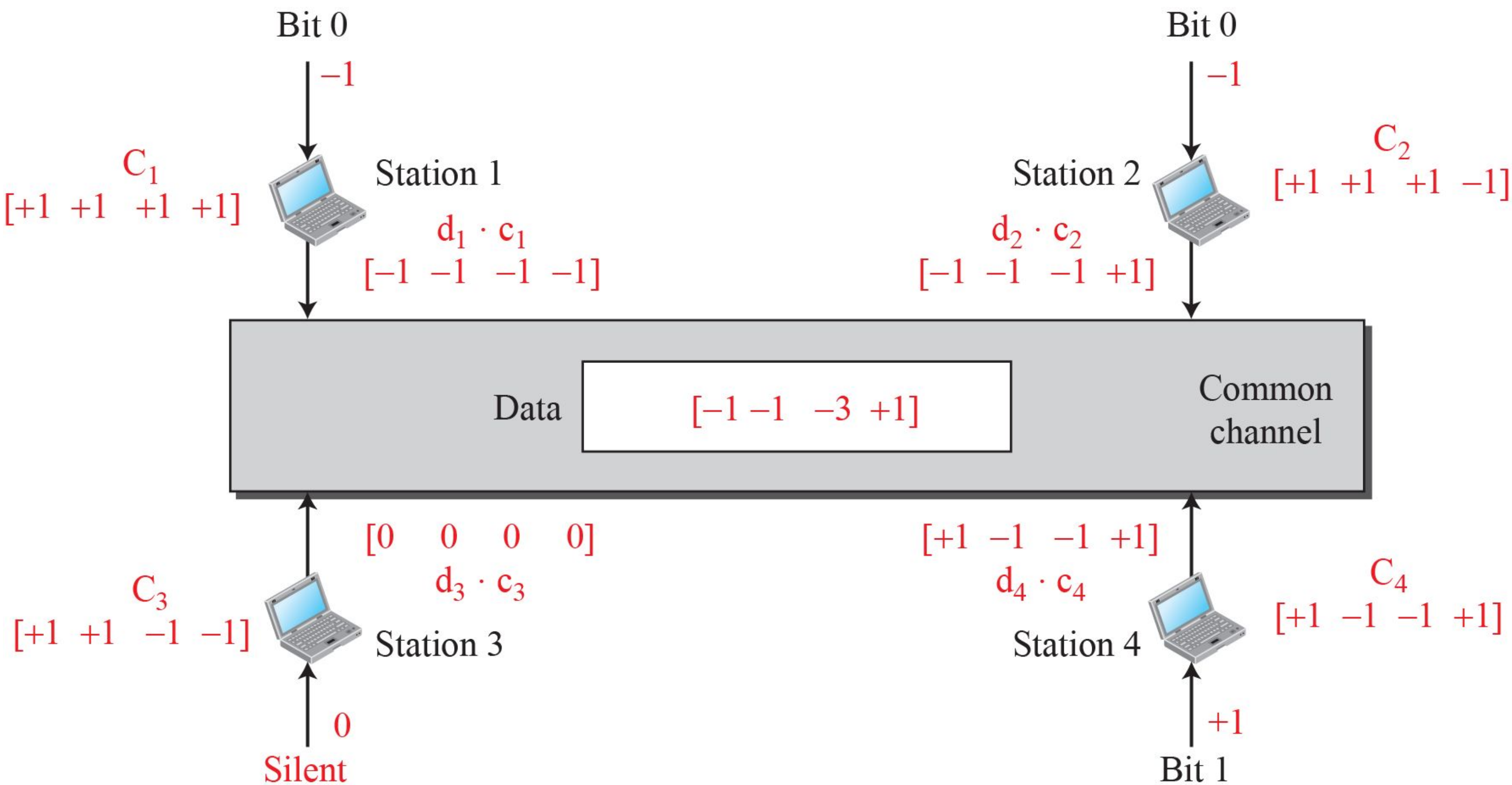


Figure 12.27: Digital signal created by four stations in CDMA

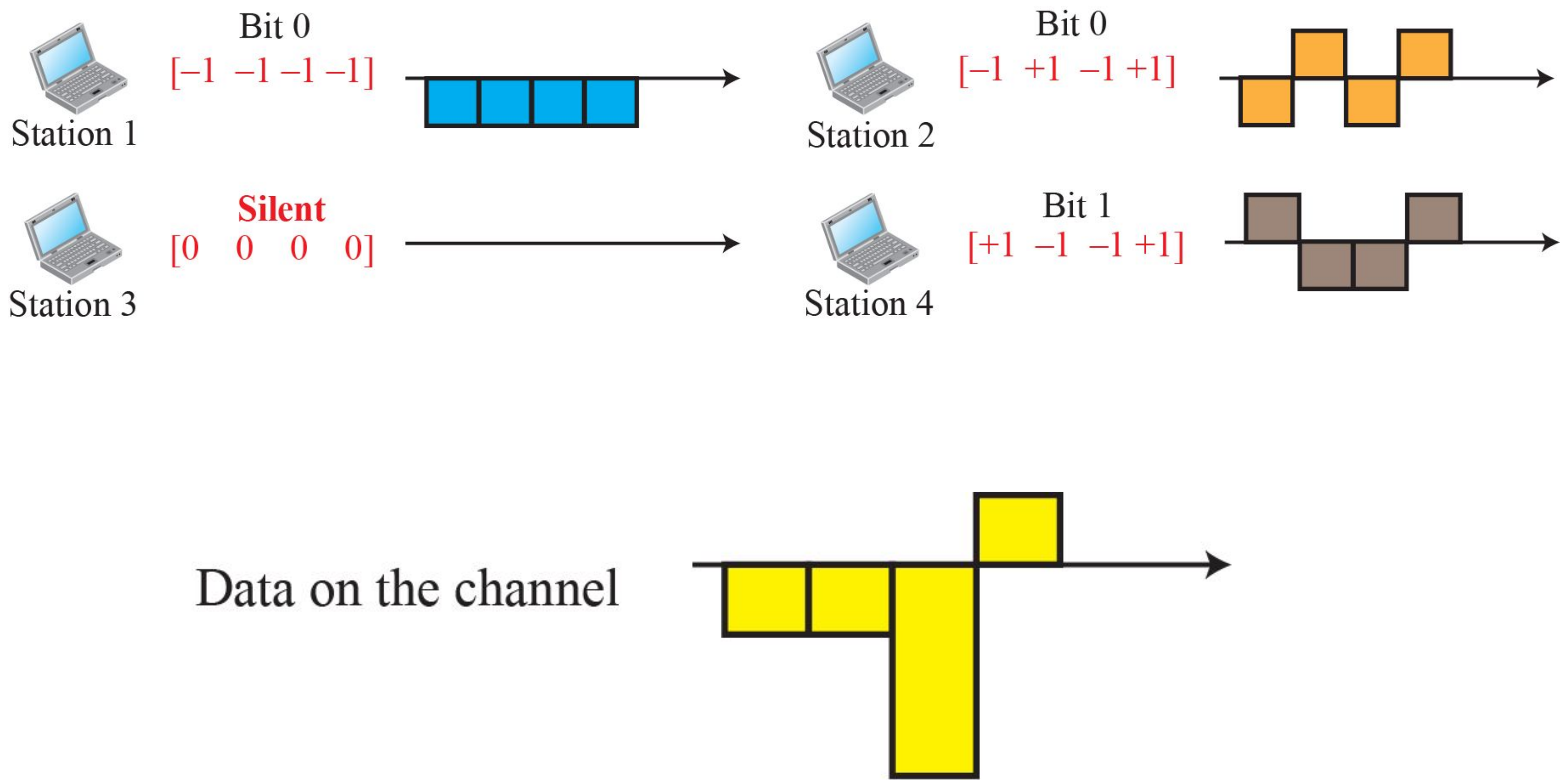
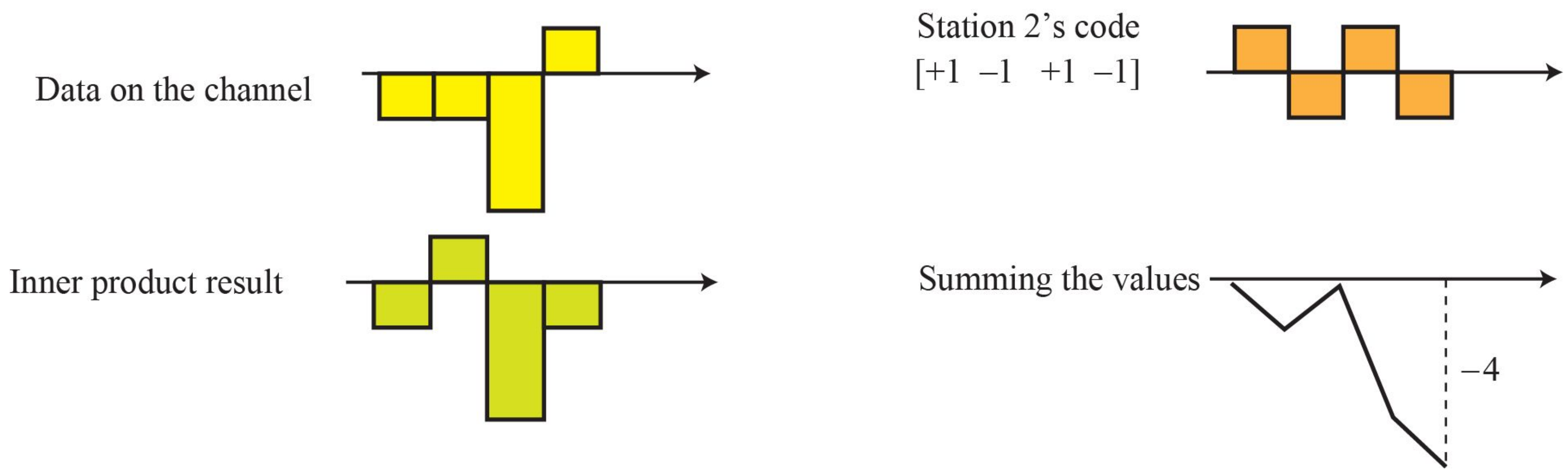


Figure 12.28: Decoding of the composite signal for one in CDMA



–4 → –4/4 → –1 → Bit 0

Figure 12.29: General rules and examples of creating Walsh tables

$$W_1 = \begin{bmatrix} +1 \end{bmatrix} \qquad W_{2N} = \begin{bmatrix} W_N & W_N \\ W_N & \overline{W_N} \end{bmatrix}$$

a. Two basic rules

$$W_2 = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix} \qquad W_4 = \begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{bmatrix}$$

b. Generation of W_1, W_2, and W_4

Example 12.6

Find the chips for a network with

a. Two stations

b. Four stations

Solution

We can use the rows of W_2 and W_4 in Figure 6.34:

a. For a two-station network, we have [+1 +1] and [+1 −1].

b. For a four-station network we have [+1 +1 +1 +1], [+1 −1 +1 −1], [+1 +1 −1 −1], and [+1 −1 −1 +1].

Example 12. 7

What is the number of sequences if we have 90 stations in our network?

Solution

The number of sequences needs to be 2^m. We need to choose $m = 7$ and $N = 2^7$ or 128. We can then use 90 of the sequences as the chips.

Example 12.8

Prove that a receiving station can get the data sent by a specific sender if it multiplies the entire data on the channel by the sender's chip code and then divides it by the number of stations.

Solution

Let us prove this for the first station, using our previous four-station example. We can say that the data on the channel $D = (d_1 \cdot c_1 + d_2 \cdot c_2 + d_3 \cdot c_3 + d_4 \cdot c_4)$. The receiver, which wants to get the data sent by station 1, multiplies these data by c_1.

$$
\begin{aligned}
[D \cdot c_1] / 4 &= [(d_1 \cdot c_1 + d_2 \cdot c_2 + d_3 \cdot c_3 + d_4 \cdot c_4) \cdot c_1] / 4 \\
&= [d_1 \cdot c_1 \cdot c_1 + d_2 \cdot c_2 \cdot c_1 + d_3 \cdot c_3 \cdot c_1 + d_4 \cdot c_4 \cdot c_1] / 4 \\
&= [d_1 \times 4 + d_2 \times 0 + d_3 \times 0 + d_4 \times 0] / 4 = [d_1 \times 4] / 4 = d_1
\end{aligned}
$$