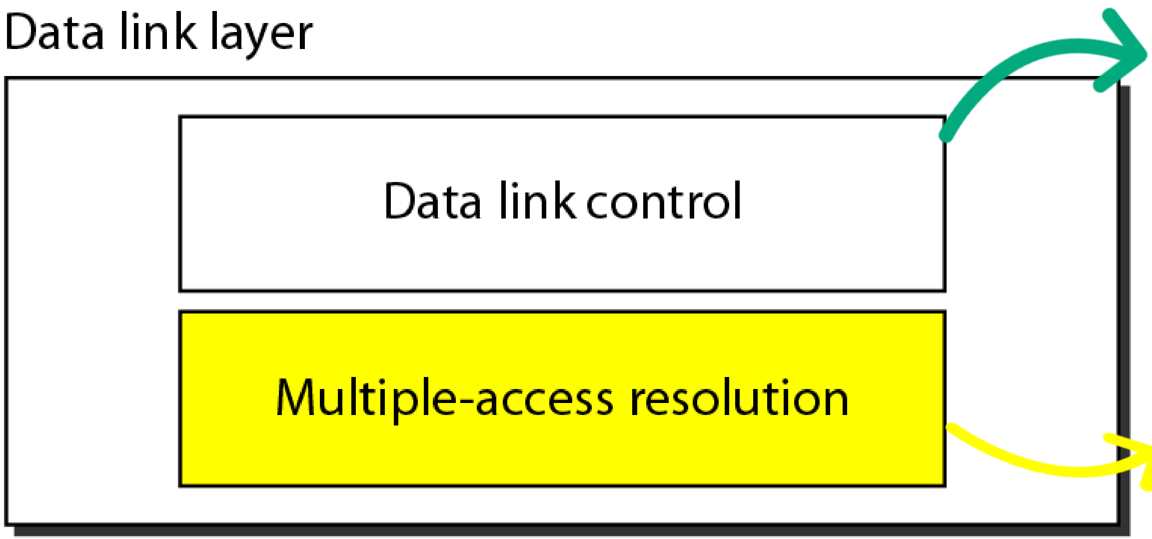
Chapter 12

Multiple Access

Figure 12.1 *Data link layer divided into two functionality-oriented sublayers*

Till now, we assumed that there is an available dedicated link (or channel) between the sender and the receiver.



A mechanism which provides a link with reliable communication.

responsible for resolving access to the shared media.

Figure 12.2 *Taxonomy of multiple-access protocols discussed in this chapter*

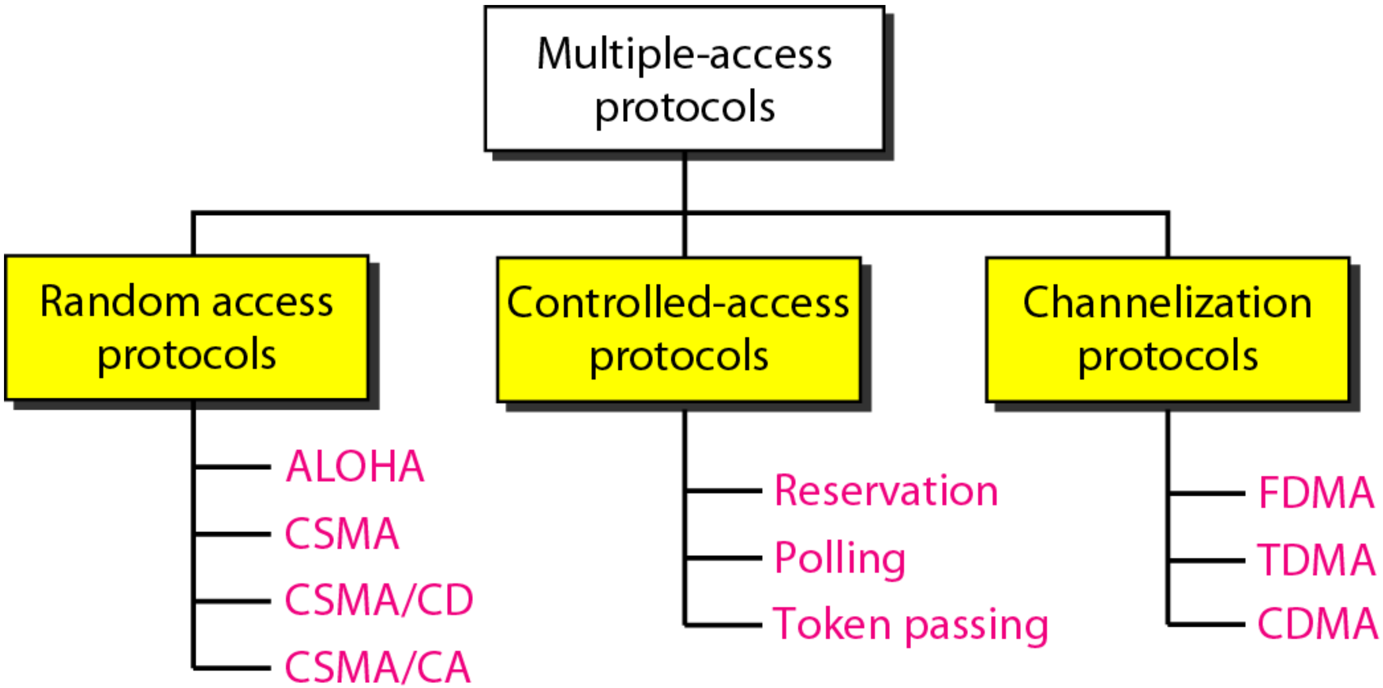


Figure 12.2 *Taxonomy of multiple-access protocols discussed in this chapter*

- **In random access** or contention methods, no station is superior to another station and none is assigned the control over another.

- **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.

- **Channelization** is a multiple-access method in which the available bandwidth of a link is shared in time, frequency, or through code, between different stations.

12-1 RANDOM ACCESS

In random access or contention methods, **no station is superior to another station** and none is assigned the control over another. No station permits, or does not permit, another station to send. 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.

Topics discussed in this section:

ALOHA
Carrier Sense Multiple Access
Carrier Sense Multiple Access with Collision Detection
Carrier Sense Multiple Access with Collision Avoidance

12-1 RANDOM ACCESS

Two features give this method its name.

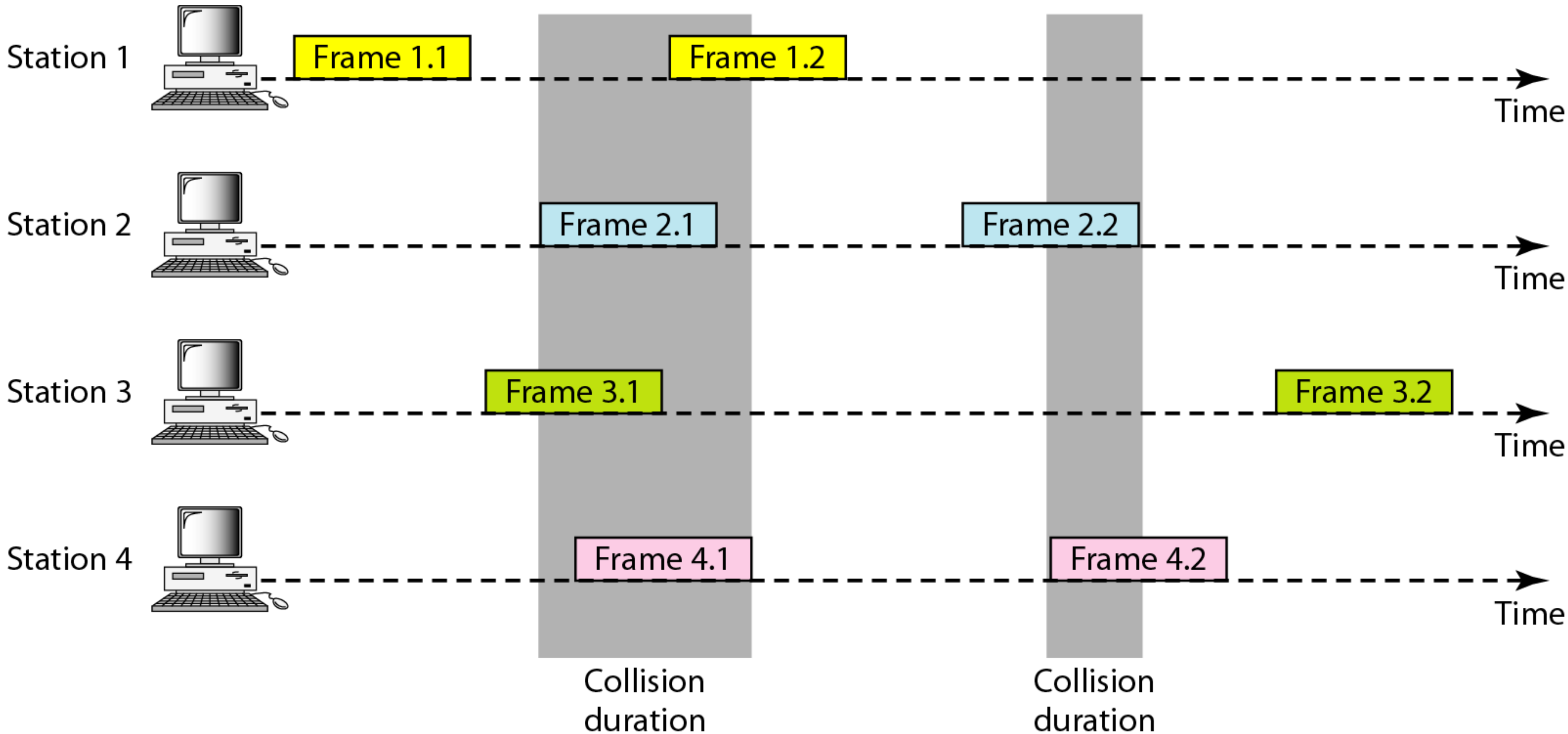
First, there is no scheduled time for a station to transmit. Transmission is random among the stations. That is why these methods are called *random access*.

Second, no rules specify which station should send next. Stations compete with one another to access the medium. That is why these methods are also called *contention* methods.

Versions of ALOHA

- Pure ALOHA
- Slotted ALOHA

Figure 12.3 *Frames in a pure ALOHA network*



Even if one bit of a frame coexists on the channel with one bit from another frame, there is a collision and both will be destroyed.

Pure Aloha:

- It allows the stations to transmit data at any time whenever they want.
- After transmitting the data packet, station waits for some time.

Then, following 2 cases are possible-

Case-01:

- Transmitting station **receives an acknowledgement** from the receiving station.
- In this case, transmitting station assumes that the transmission is successful.

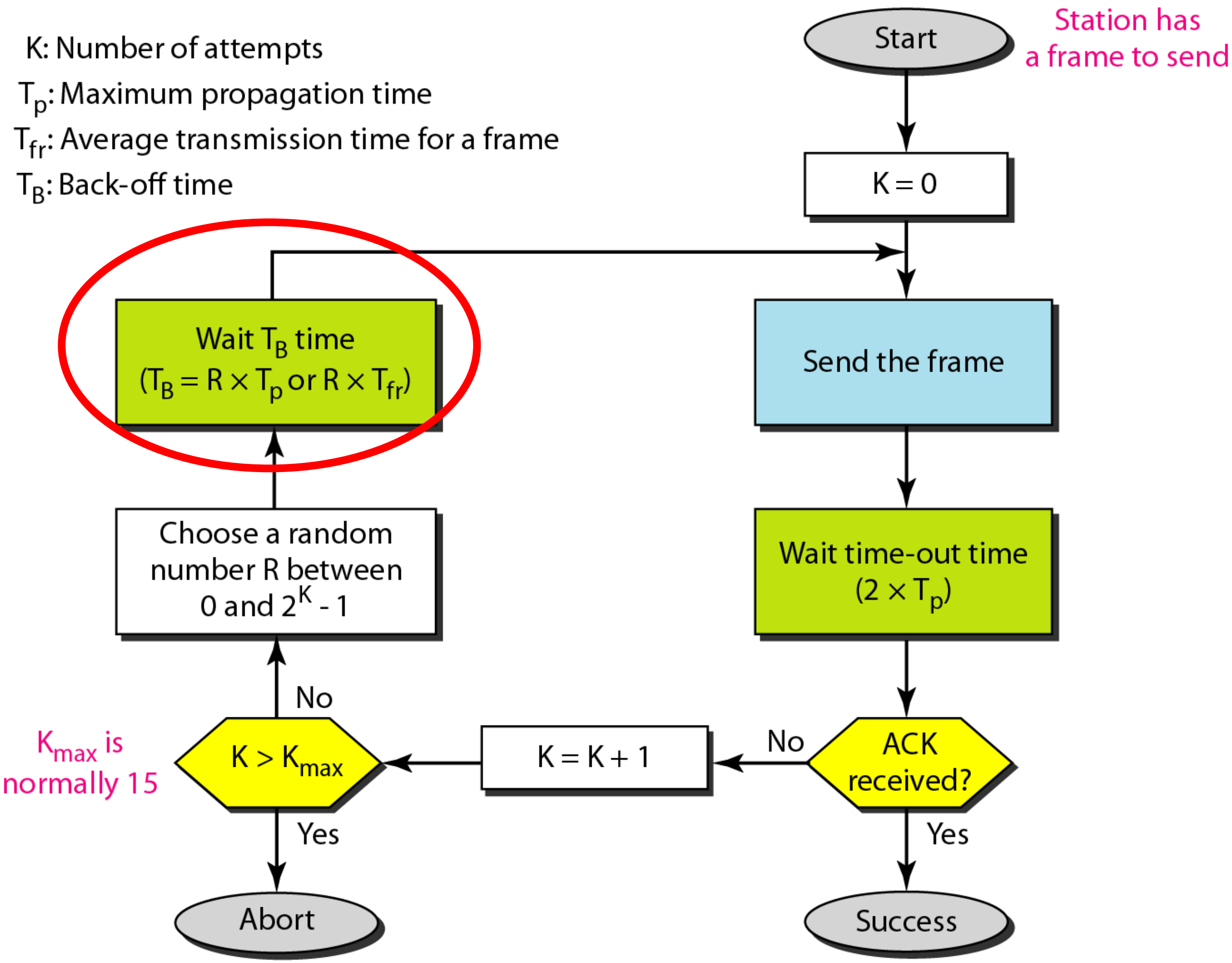
Case-02:

- Transmitting station **does not receive any acknowledgement** within specified time from the receiving station.
- In this case, transmitting station assumes that the transmission is unsuccessful.

Then,

- Transmitting station uses a Back Off Strategy and waits for some random amount of time. (This is what reduces the collision)
- After back off time, it transmits the data packet again.
- It keeps trying until the back off limit is reached after which it aborts the transmission.

Figure 12.4 *Procedure for pure ALOHA protocol*



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

$$T_p = (600 \times 10^5) / (3 \times 10^8) = 2 \text{ ms.}$$

Now we can find the value of T_B for different values of K.

a. For $K = 1$, the range is {0, 1}. The station needs to generate a random number with a value of 0 or 1. This means that T_B is either 0 ms (0×2) or 2 ms (1×2), based on the outcome of the random variable.

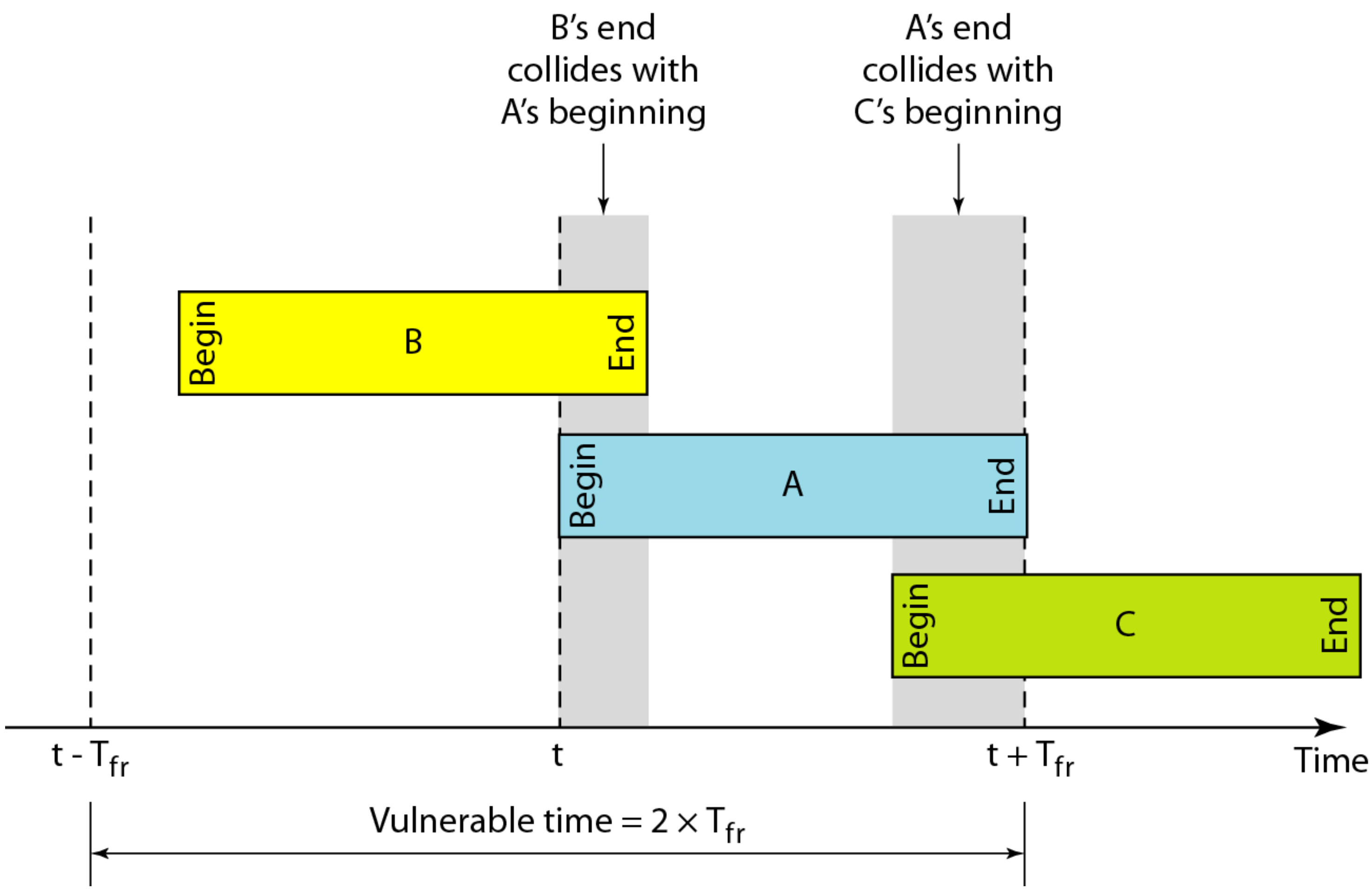
Example 12.1 (continued)

b. For K = 2, the range 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.

c. For K = 3, the range is {0, 1, 2, 3, 4, 5, 6, 7}. This means that T_B can be 0, 2, 4, . . . , 14 ms, based on the outcome of the random variable.

d. We need to mention that if K > 10, it is normally set to 10.

Figure 12.5 *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 one 1-ms period that this station is sending.

Note

The throughput for pure ALOHA is $S = G \times e^{-2G}$.
The maximum throughput $S_{max} = 0.184$ when G= (1/2).

G=Number of Stations wish to transmit at the same time/ Number of frame generated during one frame transmission time

So, $G = \frac{1}{2}$ means one-half a frame is generated during one frame transmission time (in other words, one frame during two frame transmission times)

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

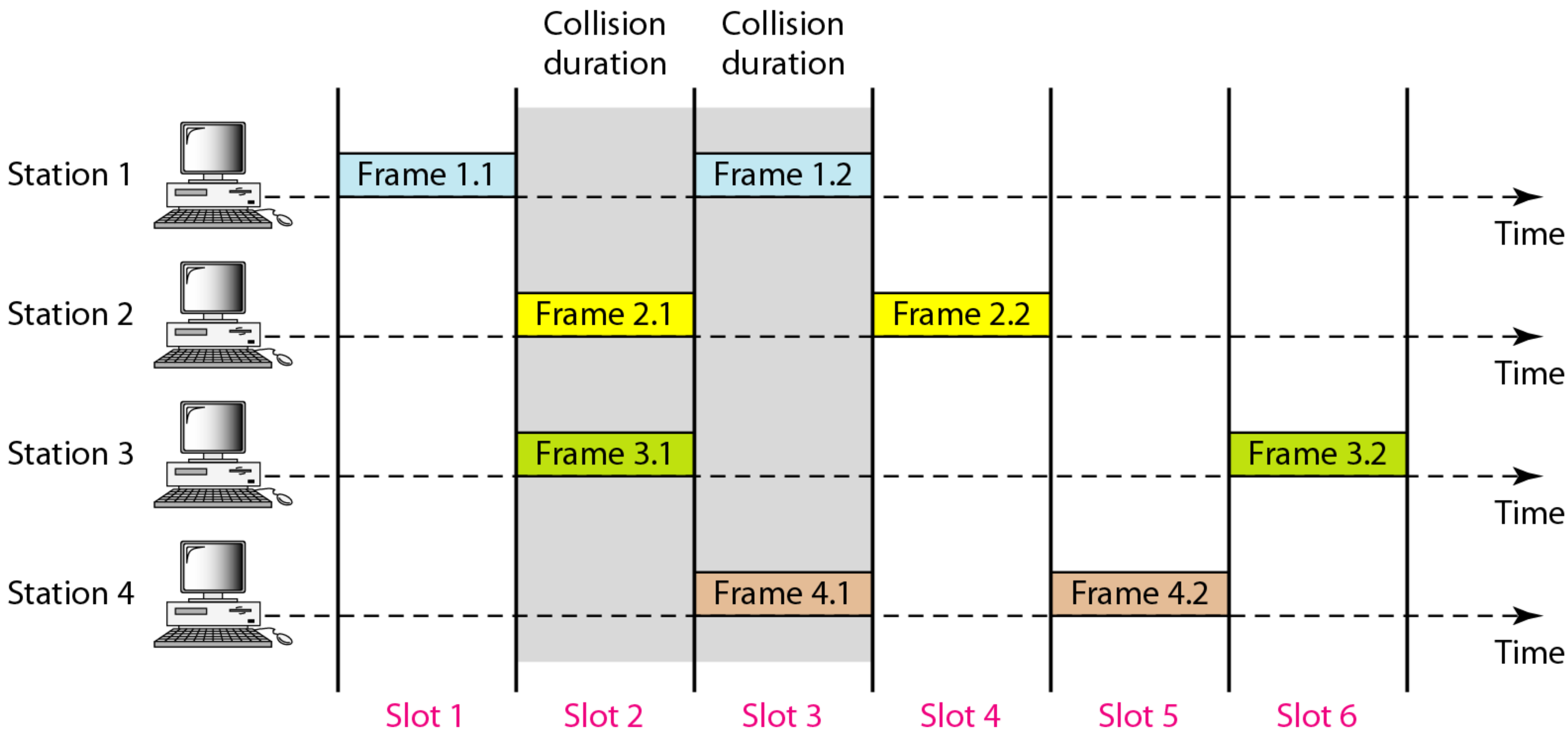
Example 12.3 (continued)

b. *If the system creates 500 frames per second, this is (1/2) frame per millisecond. The load is (1/2). In this case $S = G \times e^{-2G}$ or $S = 0.184$ (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, percentagewise.*

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

Figure 12.6 *Frames in a slotted ALOHA network*

In slotted ALOHA we divide the time into slots of T_{fr} s and force the station to send only at the beginning of the time slot.

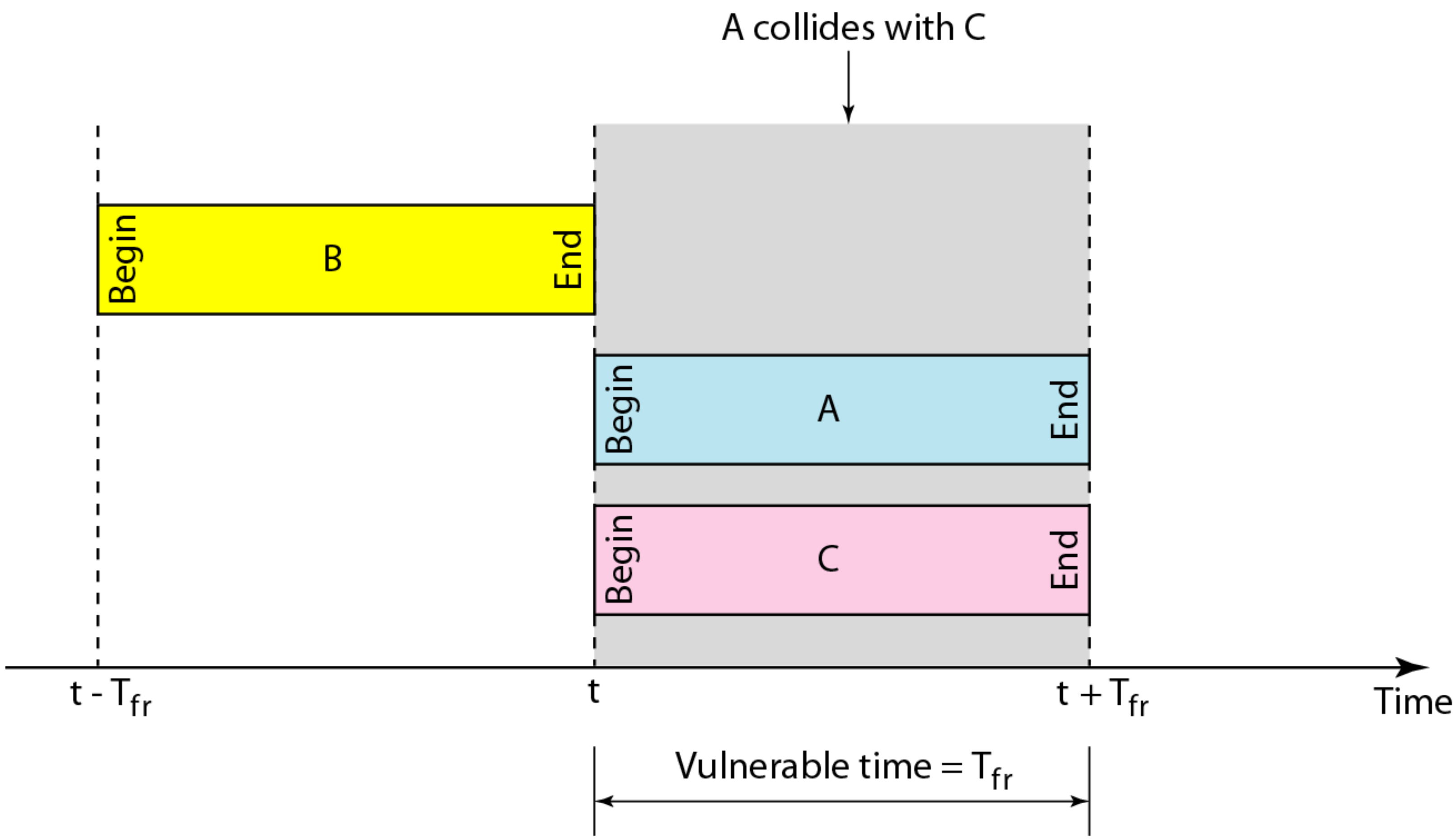


Note

The throughput for slotted ALOHA is $S = G \times e^{-G}$.

The maximum throughput $S_{max} = 0.368$ when $G = 1$.

Figure 12.7 *Vulnerable time for slotted ALOHA protocol*



Example 12.4

A slotted 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, this is 1 frame per millisecond. The load is 1. In this case $S = G \times e^{-G}$ or $S = 0.368$ (36.8 percent). This means that the throughput is $1000 \times 0.0368 = 368$ frames. Only 386 frames out of 1000 will probably survive.

Example 12.4 (continued)

b. ***If the system creates 500 frames per second, this is (1/2) frame per millisecond. The load is (1/2). In this case $S = G \times e^{-G}$ or $S = 0.303$ (30.3 percent). This means that the throughput is $500 \times 0.0303 = 151$. Only 151 frames out of 500 will probably survive.***

c. ***If the system creates 250 frames per second, this is (1/4) frame per millisecond. The load is (1/4). In this case $S = G \times e^{-G}$ or $S = 0.195$ (19.5 percent). This means that the throughput is $250 \times 0.195 = 49$. Only 49 frames out of 250 will probably survive.***

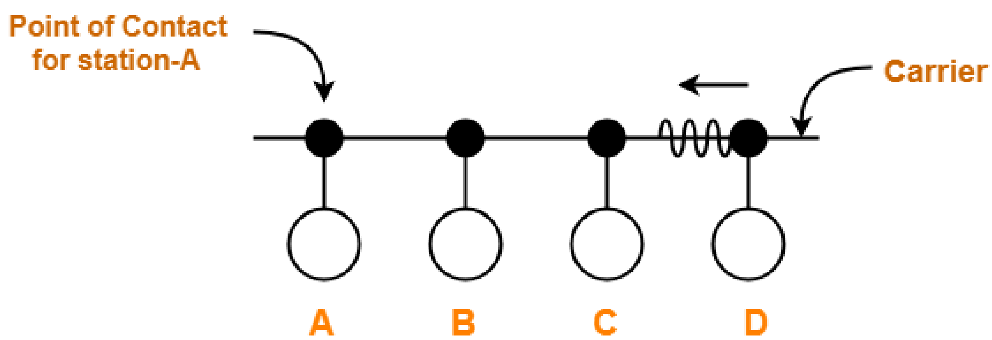
Carrier Sense Multiple Access (CSMA)

- 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."

Carrier Sense Multiple Access (CSMA)

❑ Sensing the Carrier:

- Each station can sense the carrier only at its point of contact with the carrier.
- It is not possible for any station to sense the entire carrier.
- Thus, there is a huge possibility that a station might sense the carrier free even when it is actually not.



(Bus Topology)

CSMA can reduce the possibility of collision, but it cannot eliminate it. The possibility of collision still exists because of propagation delay.

Figure 12.8 *Space/time model of the collision in CSMA*

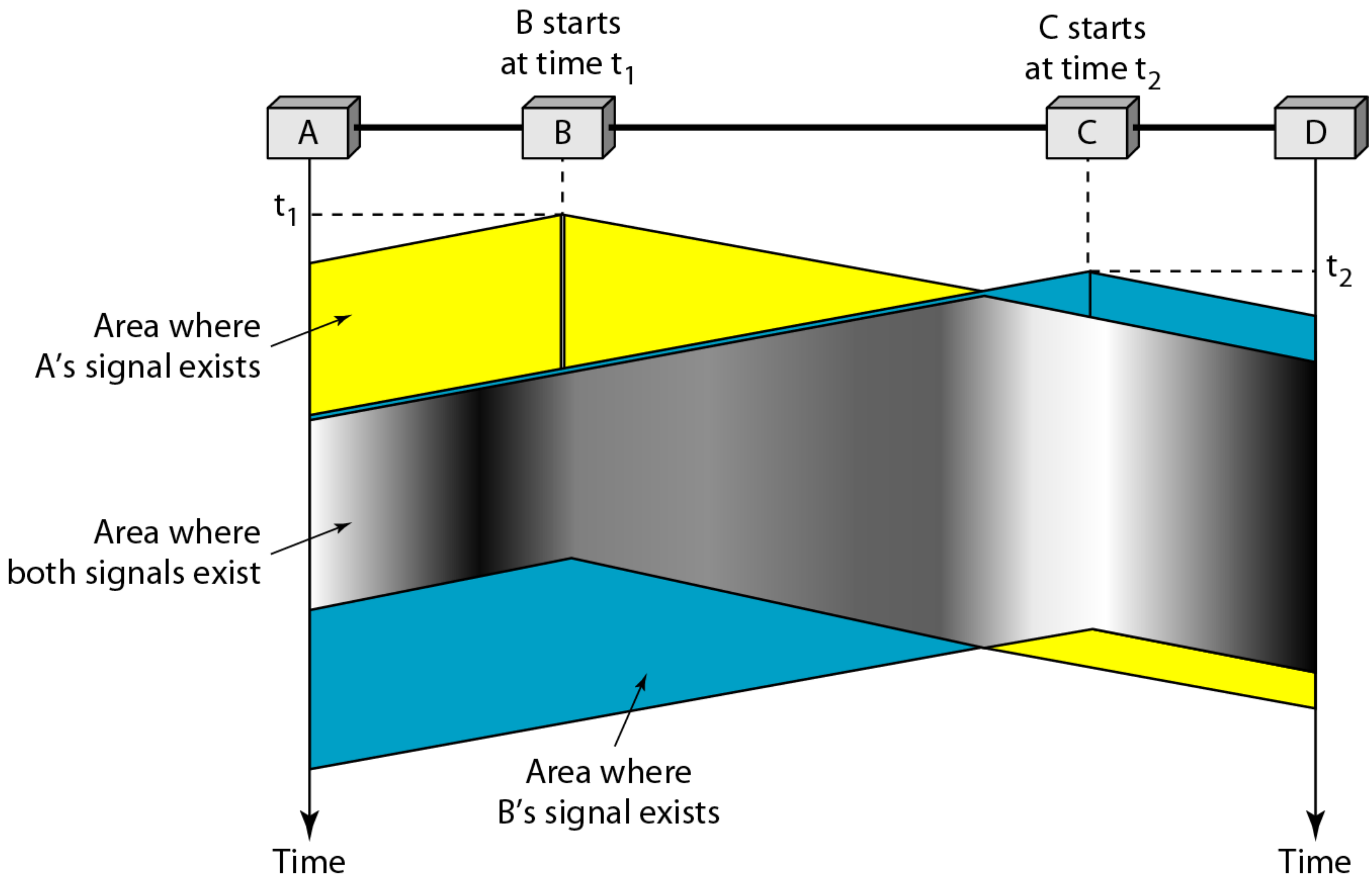
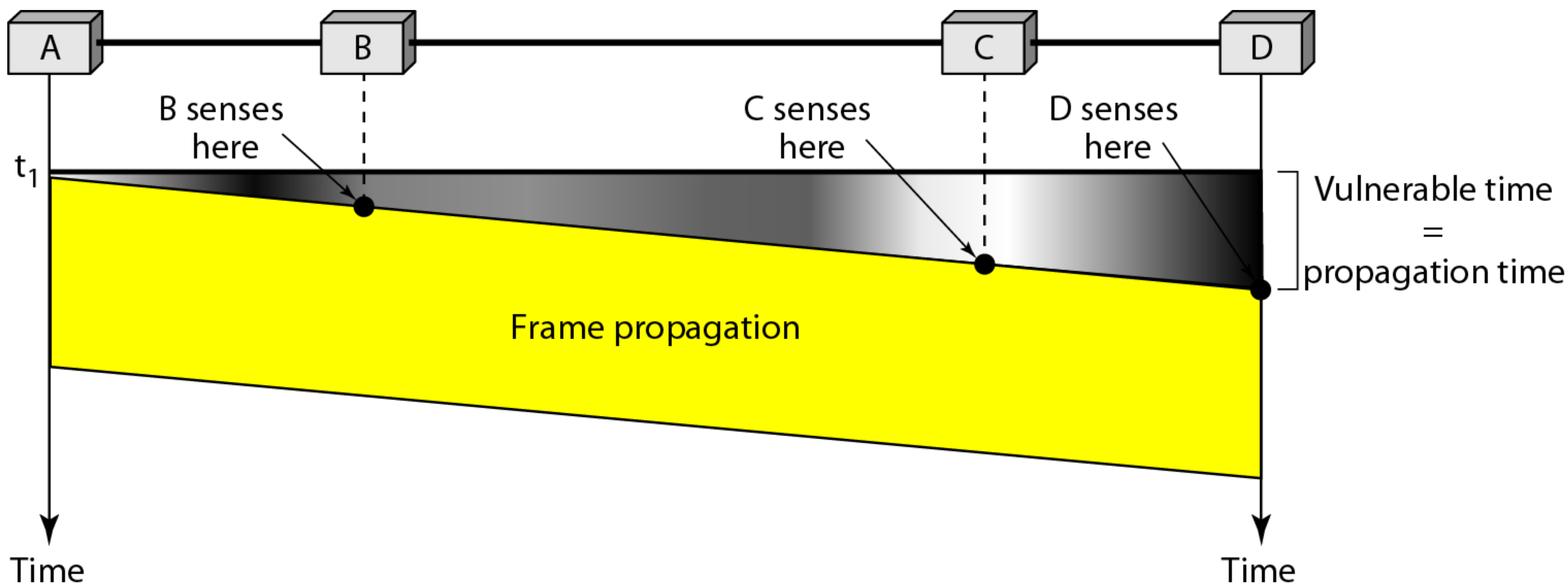
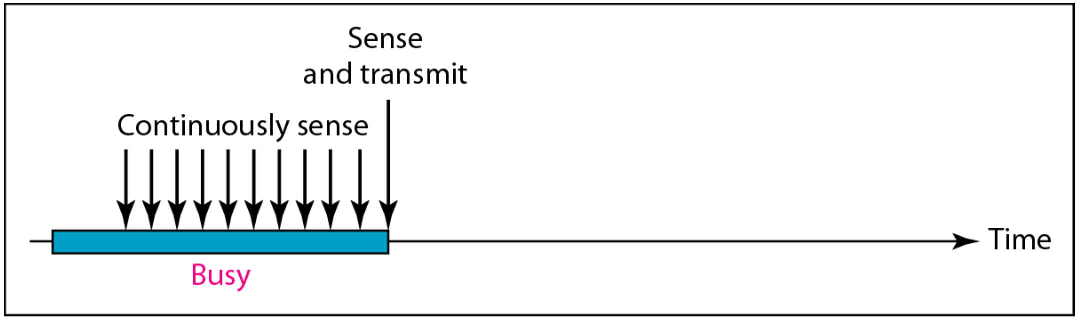


Figure 12.9 *Vulnerable time in CSMA*



The gray area shows the vulnerable area in time and space.

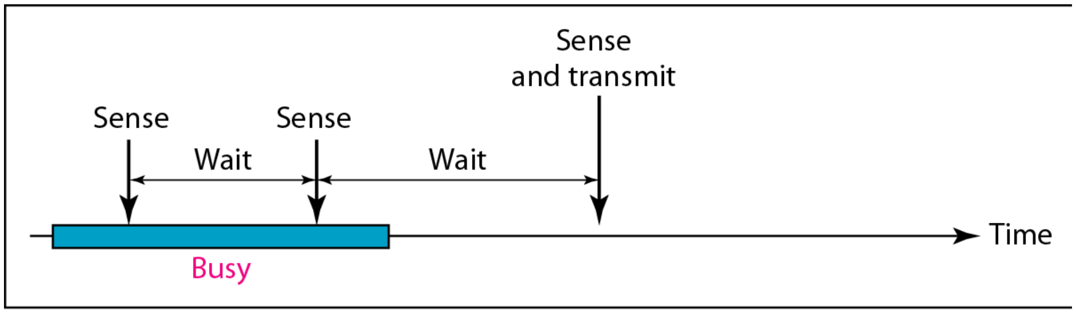
Figure 12.10 *Behavior of three persistence methods*



a. 1-persistent

1-Persistent: The 1-persistent method is simple and straightforward. In this method, after the station finds the line idle, it sends its frame immediately **(with probability 1).** This method has the **highest chance of collision** because two or more stations may find the line idle and send their frames immediately. Ethernet uses this method.

Figure 12.10 *Behavior of three persistence methods*



b. Nonpersistent

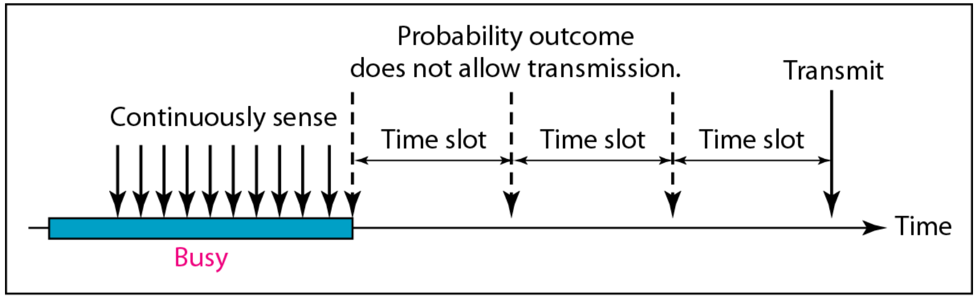
Nonpersistent: In the nonpersistent method, a station that has a frame to send senses the line.

- If the line is idle, it sends immediately.
- If the line is not idle, it waits a **random amount of time** and then senses the line again.

The nonpersistent approach reduces the chance of collision because it is **unlikely** that two or more stations **will wait the same amount** of time and retry to send simultaneously.

However, this method reduces the efficiency of the network because the medium remains idle when there may be stations with frames to send.

Figure 12.10 *Behavior of three persistence methods*



c. p-persistent

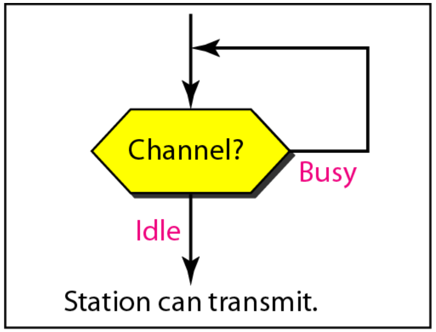
p-Persistent: The **p-persistent** method is used if the channel has **time slots** with a slot duration equal to or greater than the maximum propagation time. The p-persistent approach combines the advantages of the other two strategies. It reduces the chance of collision and improves efficiency. In this method, after the station finds the line idle it follows these steps:

1. With probability p, the station sends its frame.
2. With probability q = 1 - p, the station waits for the beginning of the next time slot and checks the line again.

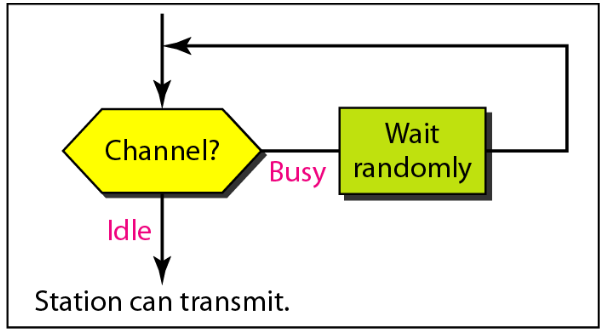
   a. If the line is idle, it goes to step 1.

   b. If the line is busy, it acts as though a collision has occurred and uses the backoff procedure

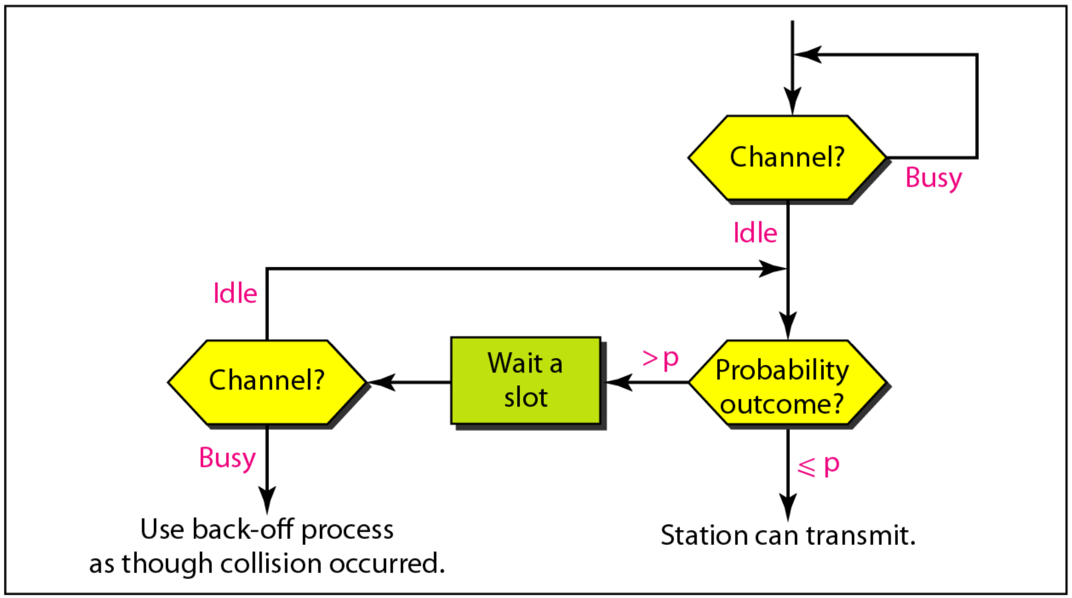
Figure 12.11 *Flow diagram for three persistence methods*



a. 1-persistent



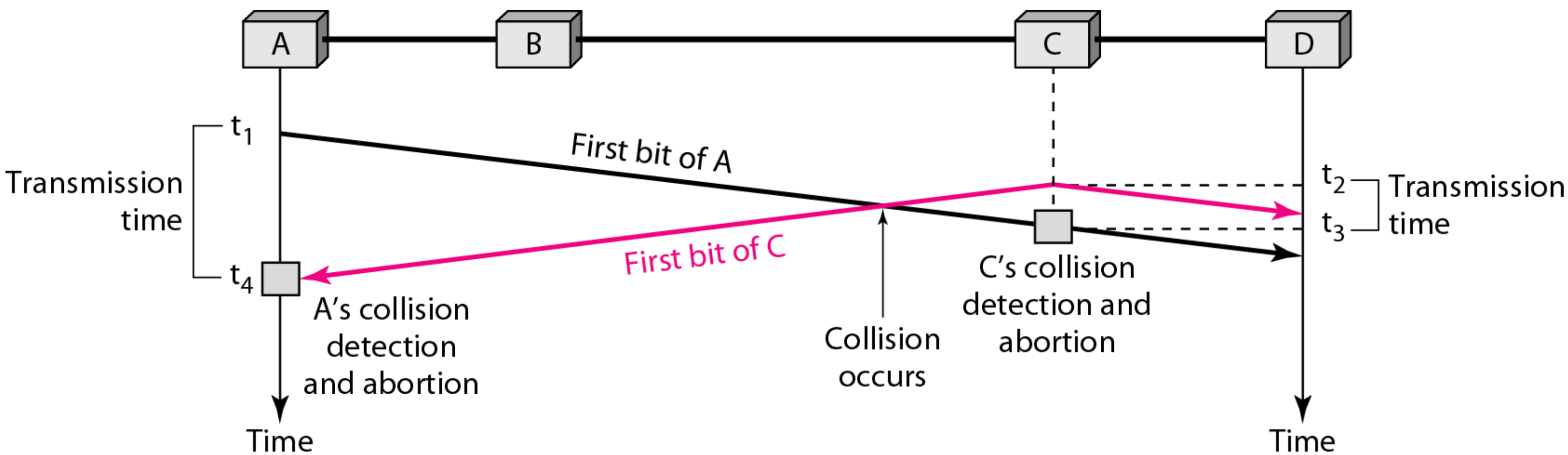
b. Nonpersistent



c. p-persistent

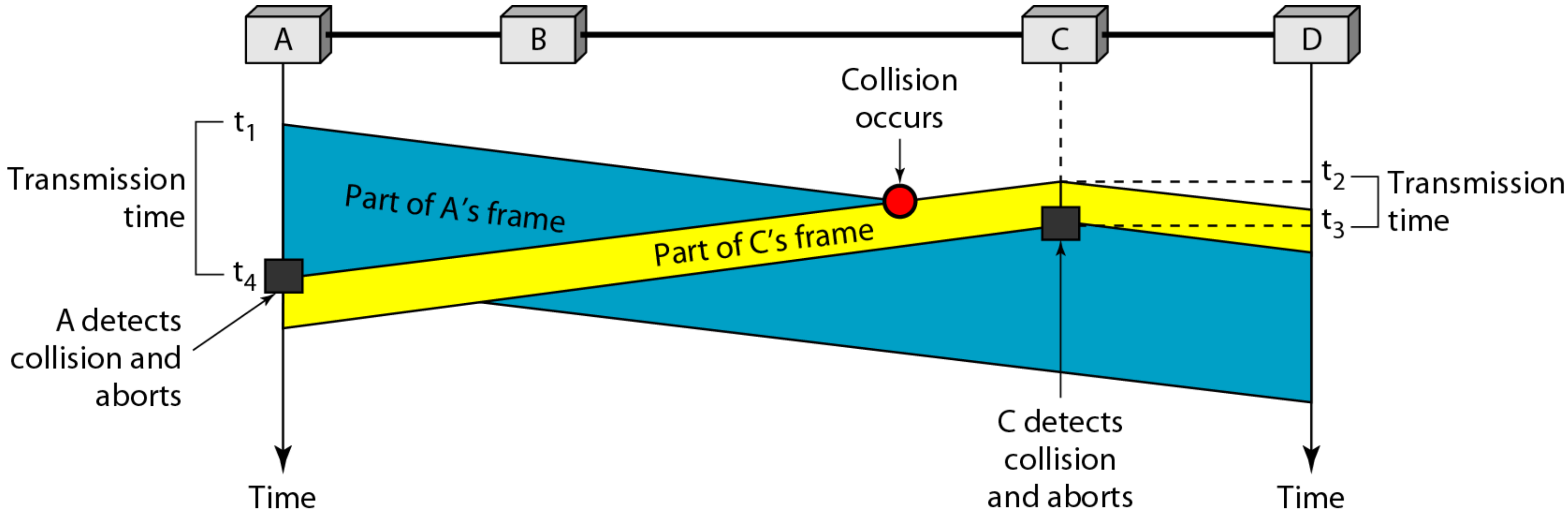
Figure 12.12 *Collision of the first bit in CSMA/CD*

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.



Stations A and C are involved in the collision

Figure 12.13 *Collision and abortion in CSMA/CD*



$$T_{fr} >= 2 \times T_p$$

maximum propagation time,

$$T_{fr} = 2 \times T_p$$

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 frame transmission time is $T_{fr} = 2 \times T_p = 51.2\ \mu s$. This means, in the worst case, a station needs to transmit for a period of 51.2 μs to detect the collision. The minimum size of the frame is 10 Mbps × 51.2 μs = 512 bits or 64 bytes. This is actually the minimum size of the frame for Standard Ethernet.

Figure 12.14 *Flow diagram for the CSMA/CD*

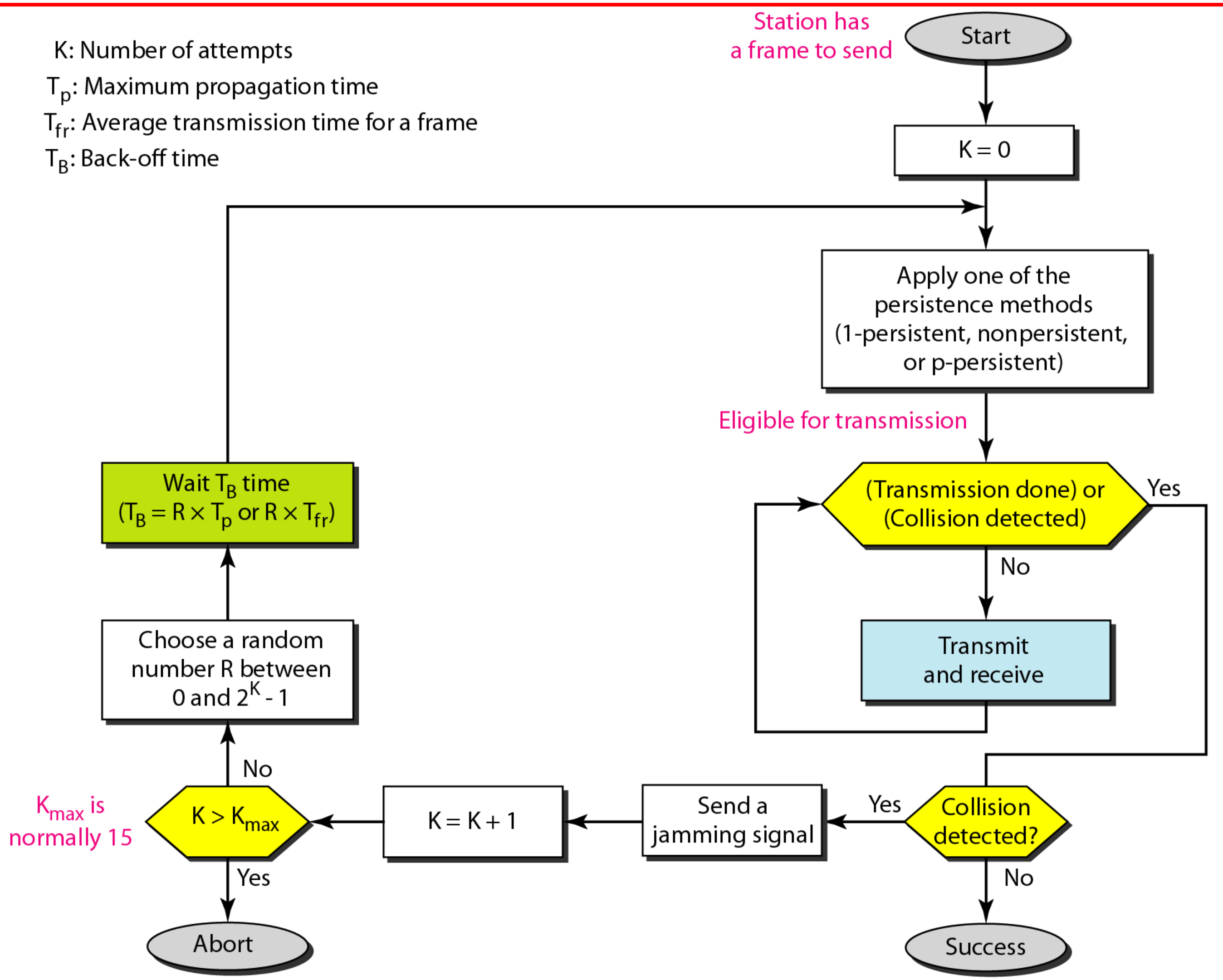


Figure 12.15 *Energy level during transmission, idleness, or collision*

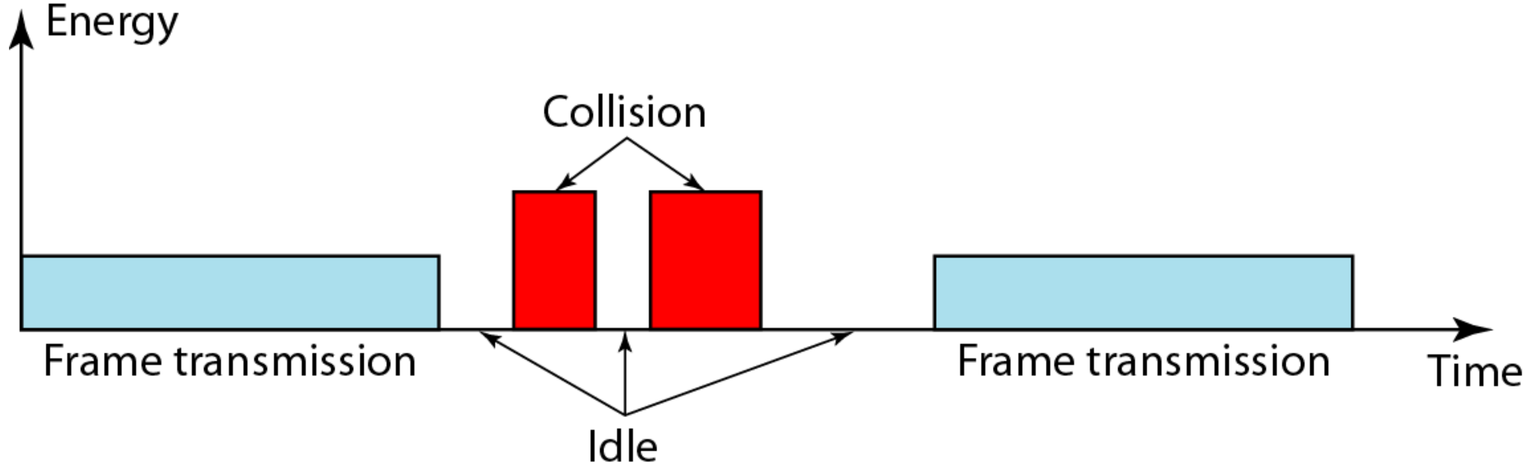
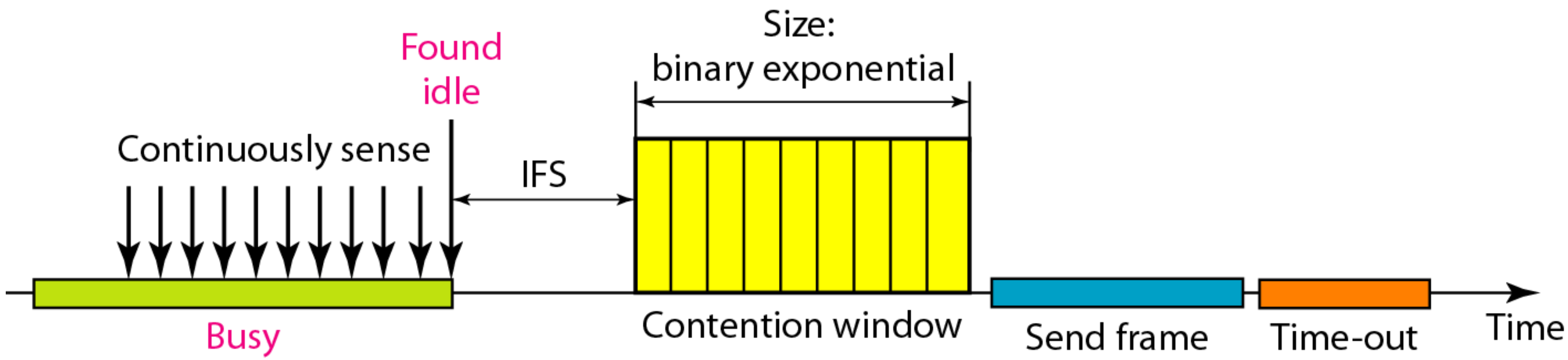


Figure 12.16 *Timing in CSMA/CA*

Collisions are avoided through the use of CSMA/CA's three strategies:

1. the interframe space (IFS)
2. the contention window and
3. acknowledgments



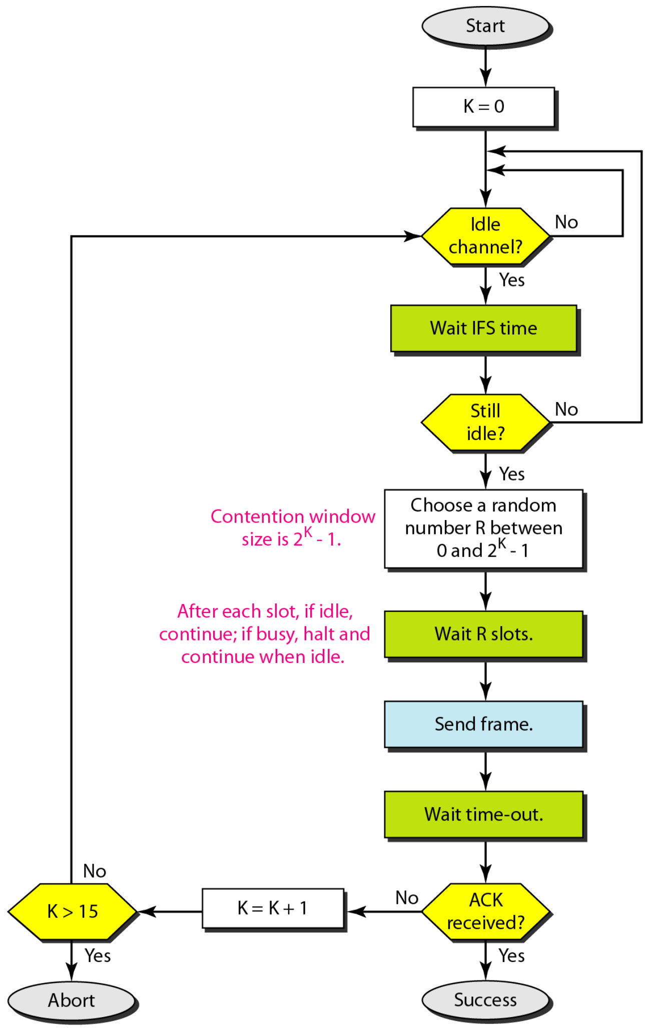
Note

In CSMA/CA, the IFS can also be used to define the priority of a station or a frame.

Note

In CSMA/CA, if the station finds the channel busy, it does not restart the timer of the contention window; it stops the timer and restarts it when the channel becomes idle.

Figure 12.17 *Flow diagram for CSMA/CA*



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 popular controlled-access methods.

Topics discussed in this section:

Reservation
Polling
Token Passing

Figure 12.18 *Reservation access method*

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.

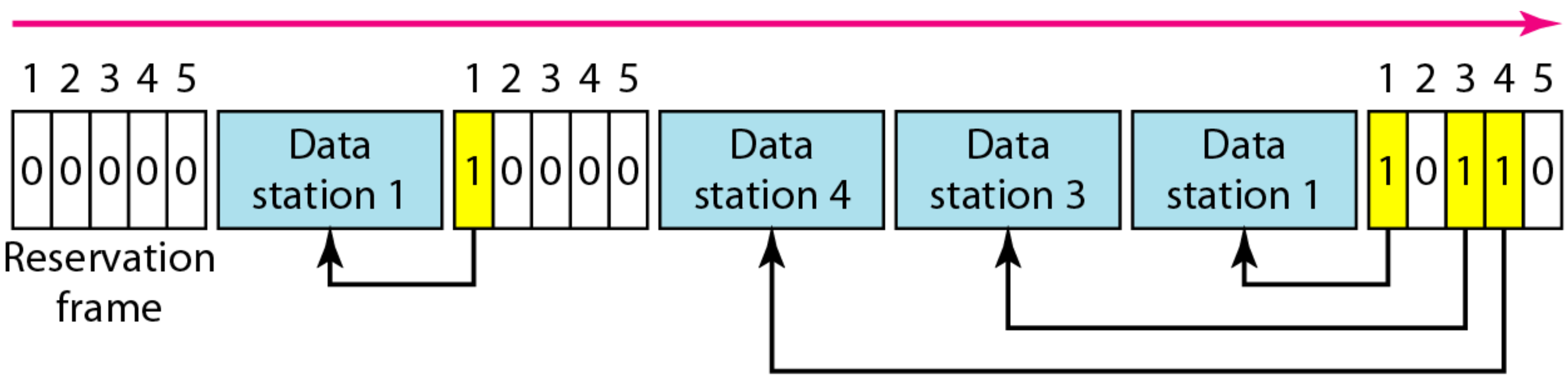


Figure 12.19 *Select and poll functions in polling access method*

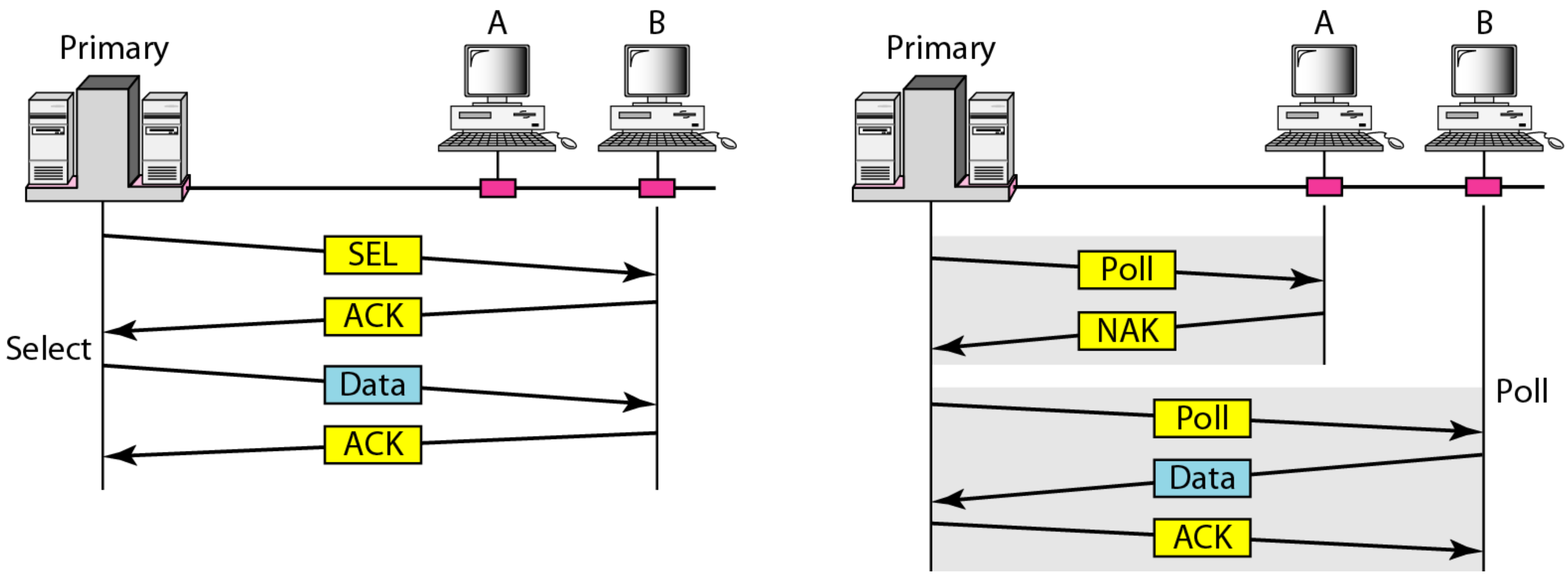
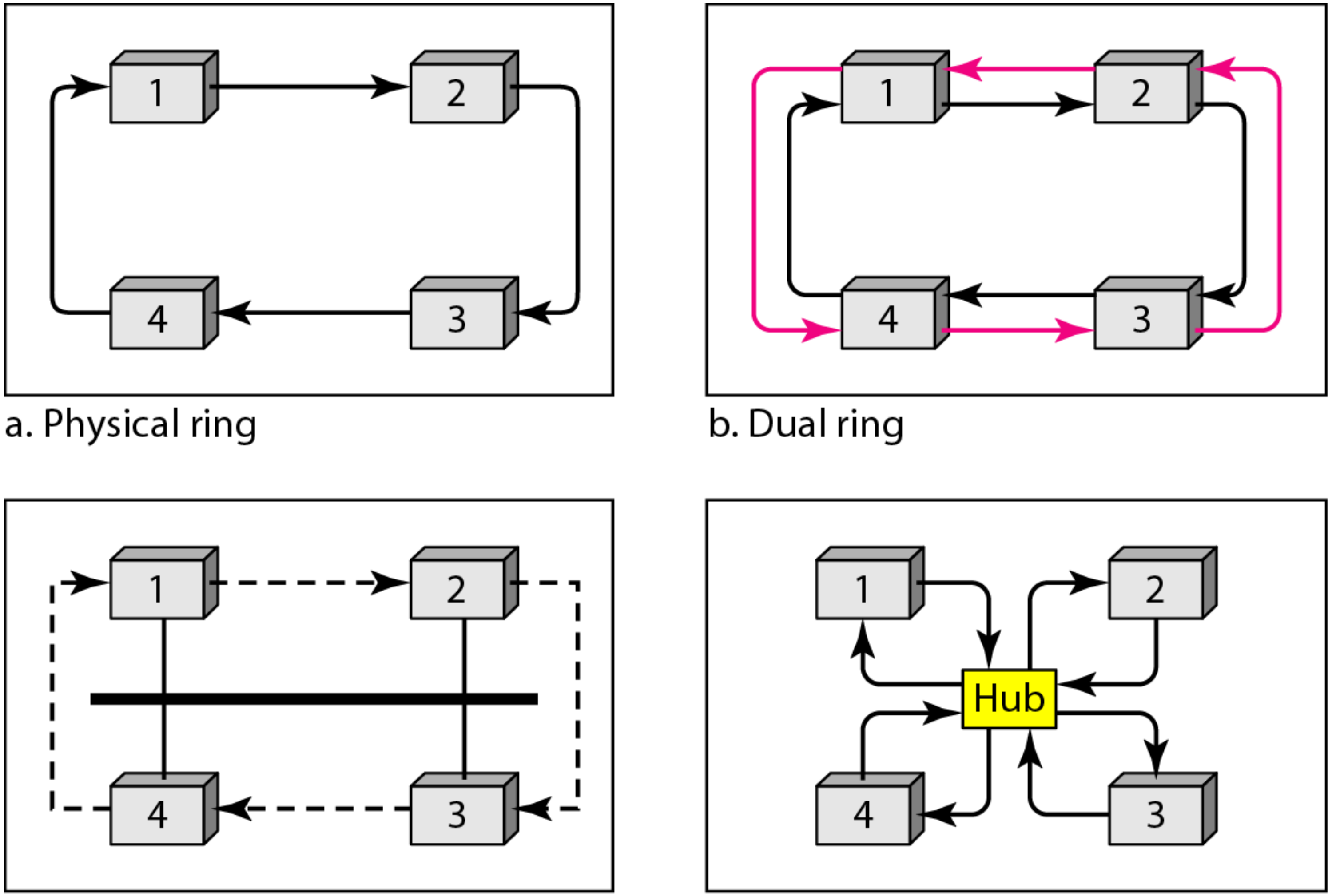


Figure 12.20 *Logical ring and physical topology in token-passing access method*



a. Physical ring
b. Dual ring
c. Bus ring
d. Star ring

12-3 CHANNELIZATION

Channelization is a multiple-access method in which the available bandwidth of a link is shared in time, frequency, or through code, between different stations. In this section, we discuss three channelization protocols.

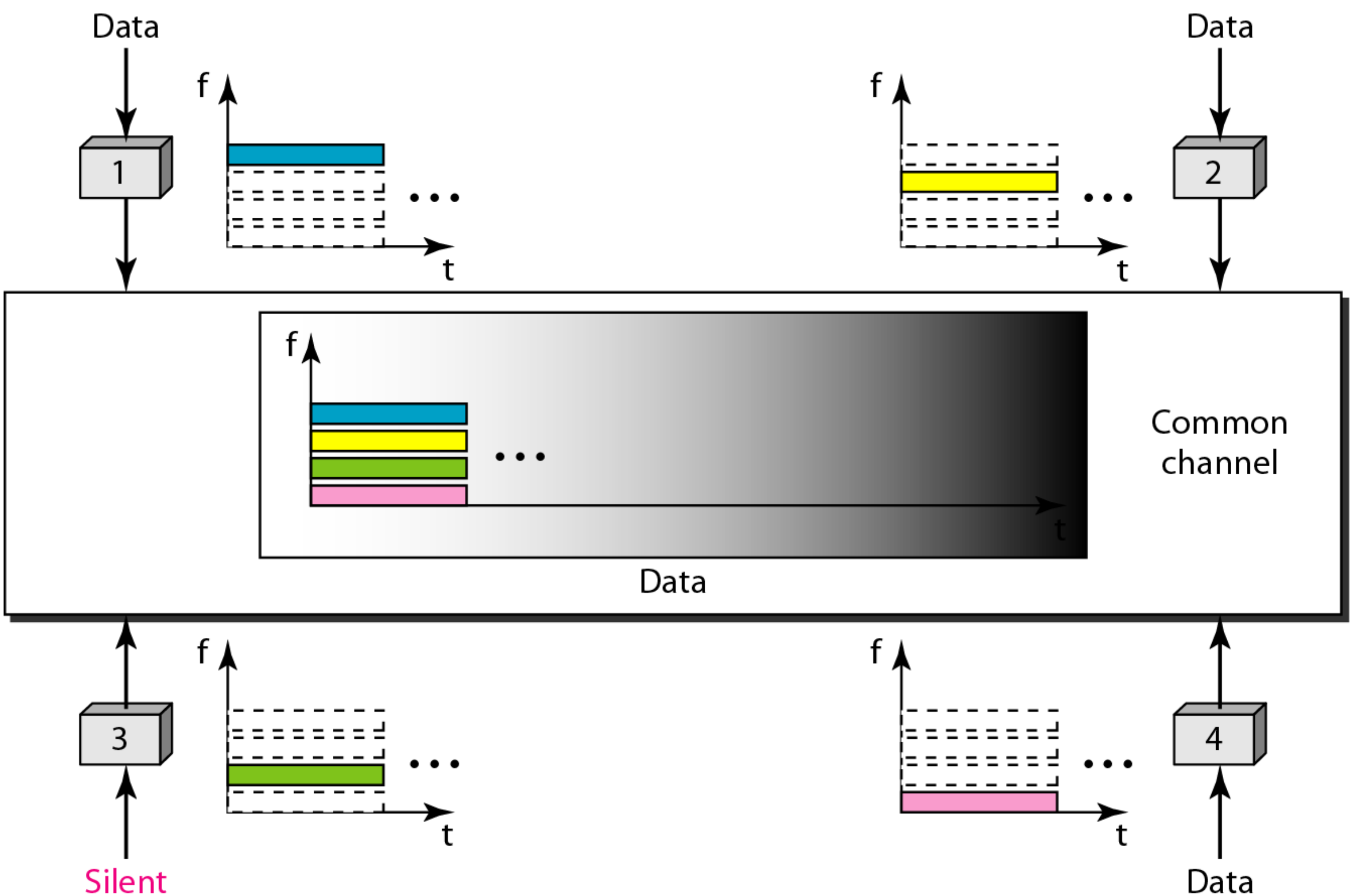
Topics discussed in this section:

Frequency-Division Multiple Access (FDMA)
Time-Division Multiple Access (TDMA)
Code-Division Multiple Access (CDMA)

Note

We see the application of all these methods in Chapter 16 when we discuss cellular phone systems.

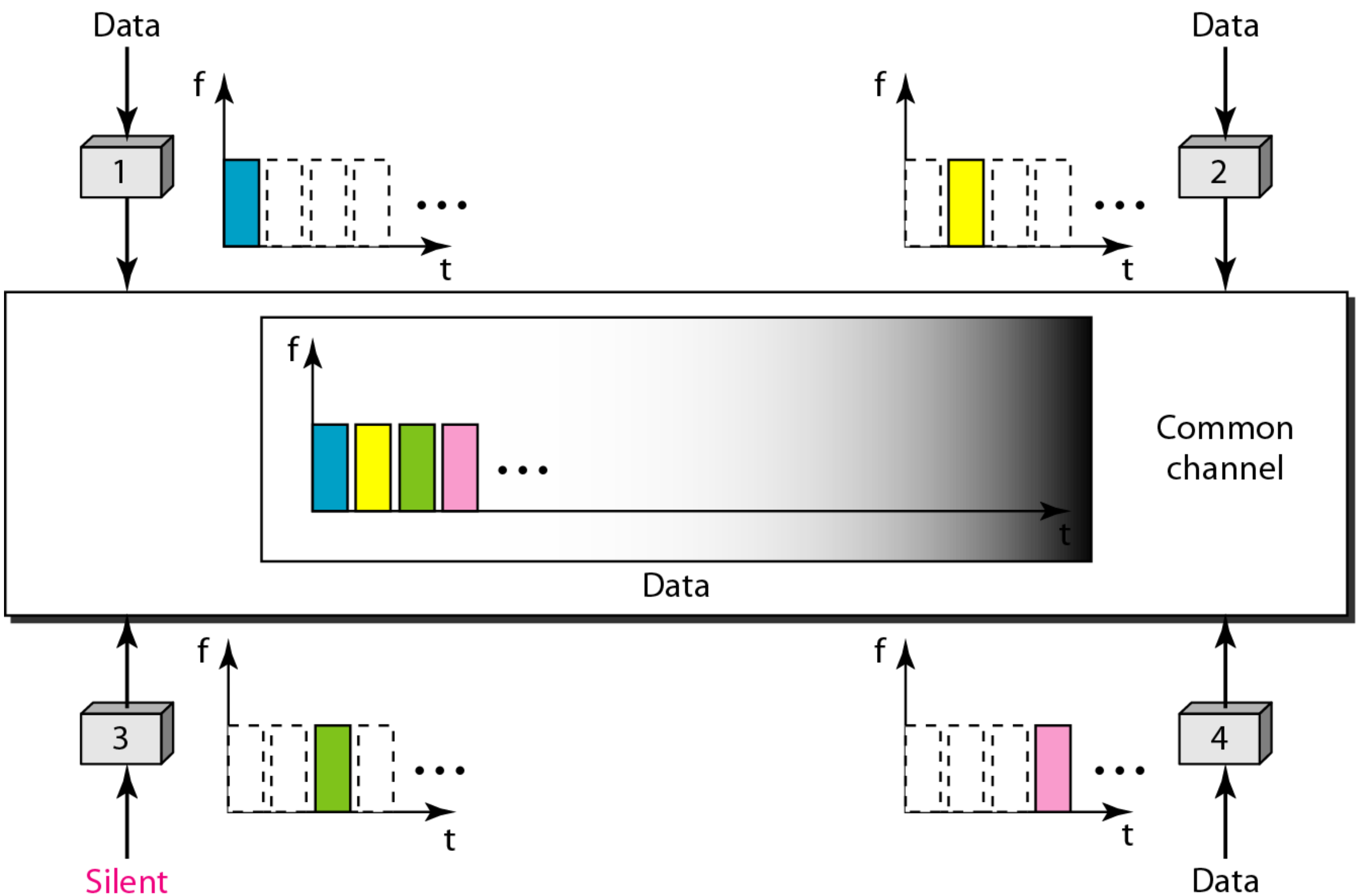
Figure 12.21 *Frequency-division multiple access (FDMA)*



Note

In FDMA, the available bandwidth of the common channel is divided into bands that are separated by guard bands.

Figure 12.22 *Time-division multiple access (TDMA)*



Note

In TDMA, the bandwidth is just one channel that is timeshared between different stations.

Note

In CDMA, one channel carries all transmissions simultaneously.

Figure 12.23 *Simple idea of communication with code*

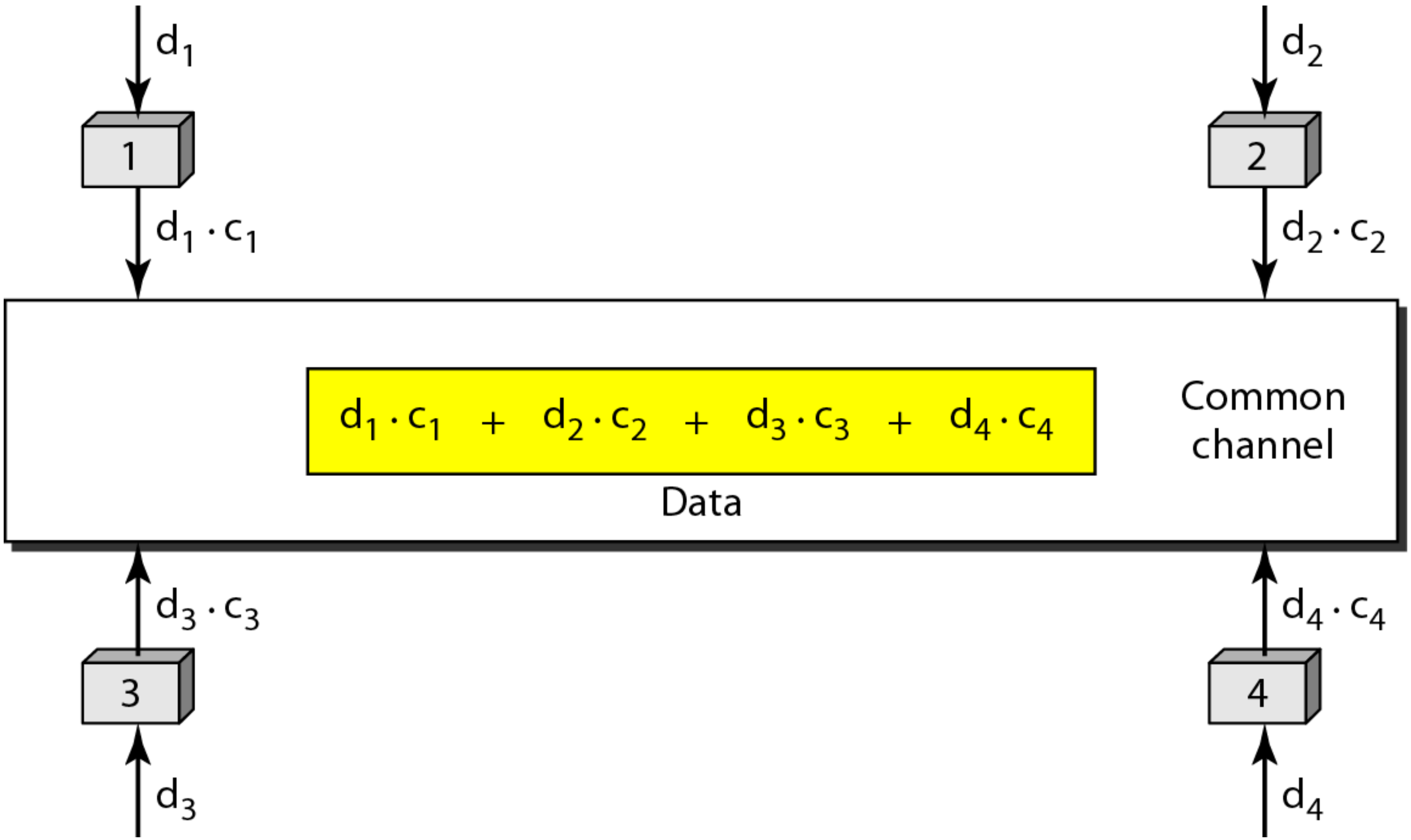


Figure 12.24 *Chip sequences*

C_1	C_2	C_3	C_4
[+1 +1 +1 +1]	[+1 -1 +1 -1]	[+1 +1 -1 - 1]	[+1 -1 -1 +1]

Figure 12.25 *Data representation in CDMA*

Data Representation

Figure 12.26 *Sharing channel in CDMA*

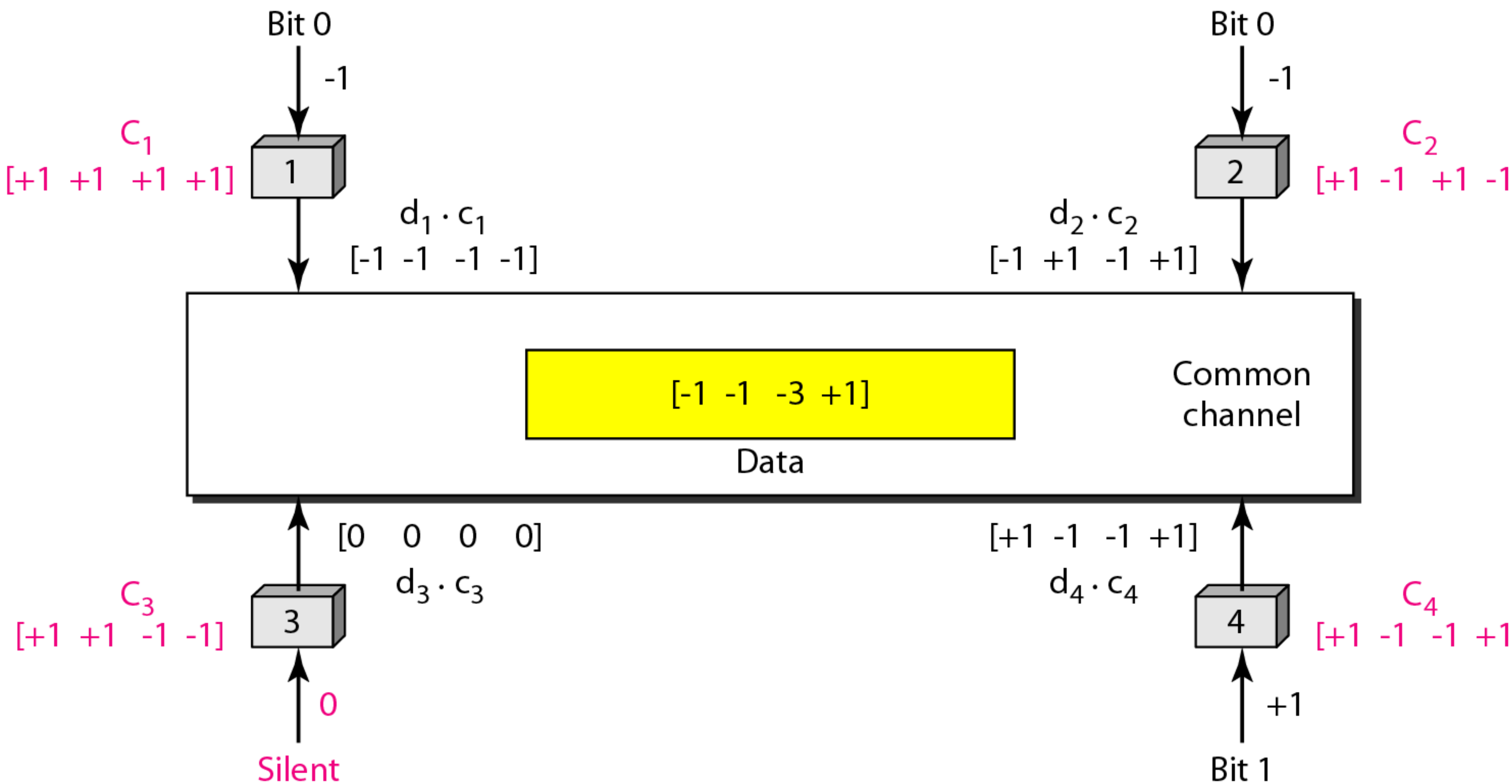


Figure 12.27 *Digital signal created by four stations in CDMA*

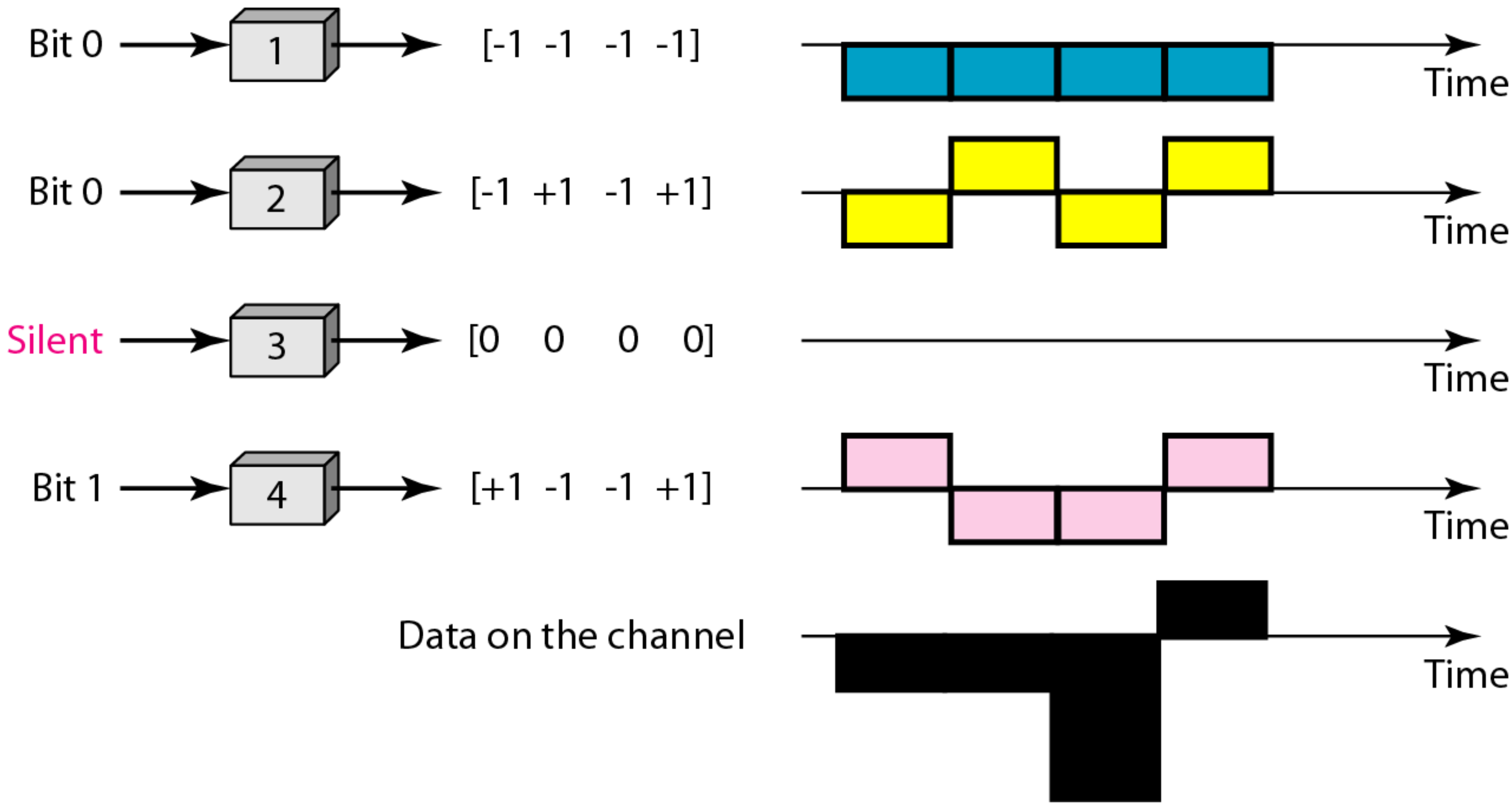


Figure 12.28 *Decoding of the composite signal for one in CDMA*

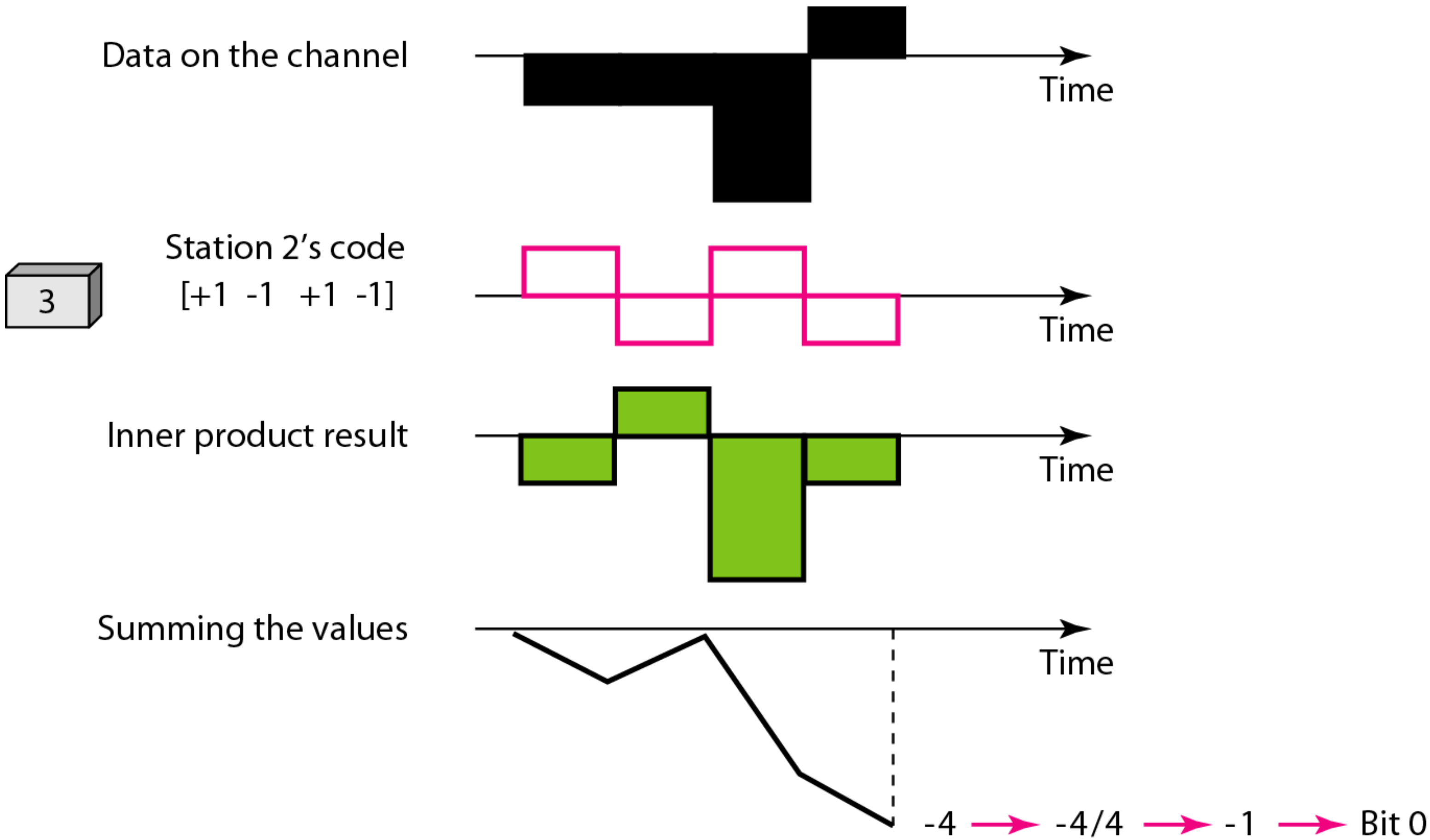


Figure 12.29 *General rule and examples of creating Walsh tables*

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

a. Two basic rules

$$W_1 = \begin{bmatrix} +1 \end{bmatrix}$$

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

b. Generation of W_1, W_2, and W_4

Note

The number of sequences in a Walsh table needs to be $N = 2^m$.

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 12.29:

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.

Example 12.8 (continued)

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

When we divide the result by N, we get d_1.