

데이터통신시스템

서강대학교

소재우

6. Multiple Access



■ 학습개요

- 다중 접속 방식 프로토콜의 동작을 이해한다.

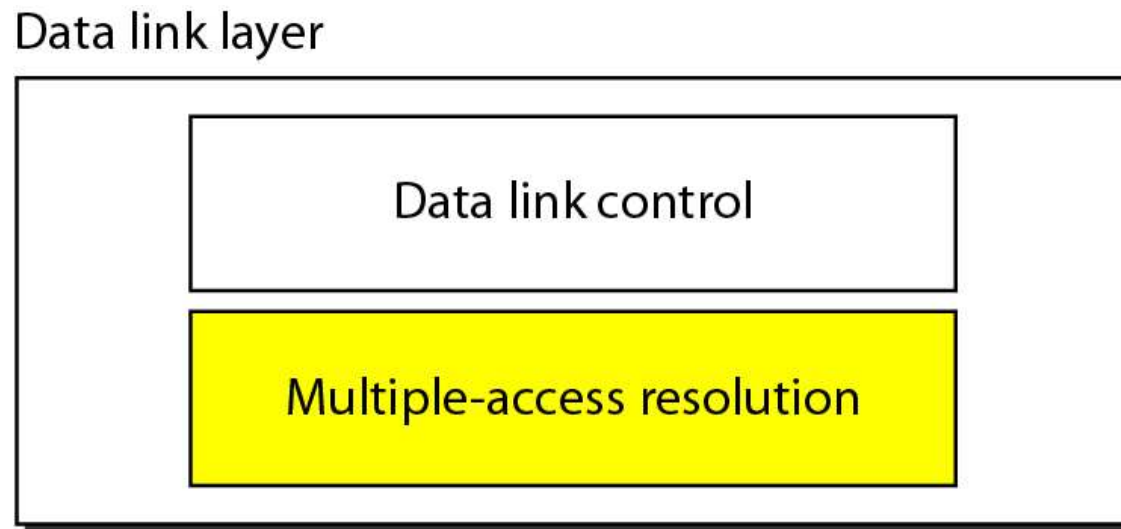
■ 학습목표

- 다중 접속 프로토콜의 동작을 학습하고, 성능을 분석한다.
- ALOHA 동작 및 성능을 분석할 수 있어야 한다.
- CSMA, CDMA 프로토콜 동작을 설명할 수 있어야 한다.

1. Noisy Channels

- The data link layer has two sublayers
 - The upper sublayer is responsible for data link control.
 - The lower sublayer is responsible for resolving access to the shared media.
 - If the channel is dedicated, we do not need the lower sublayer.

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

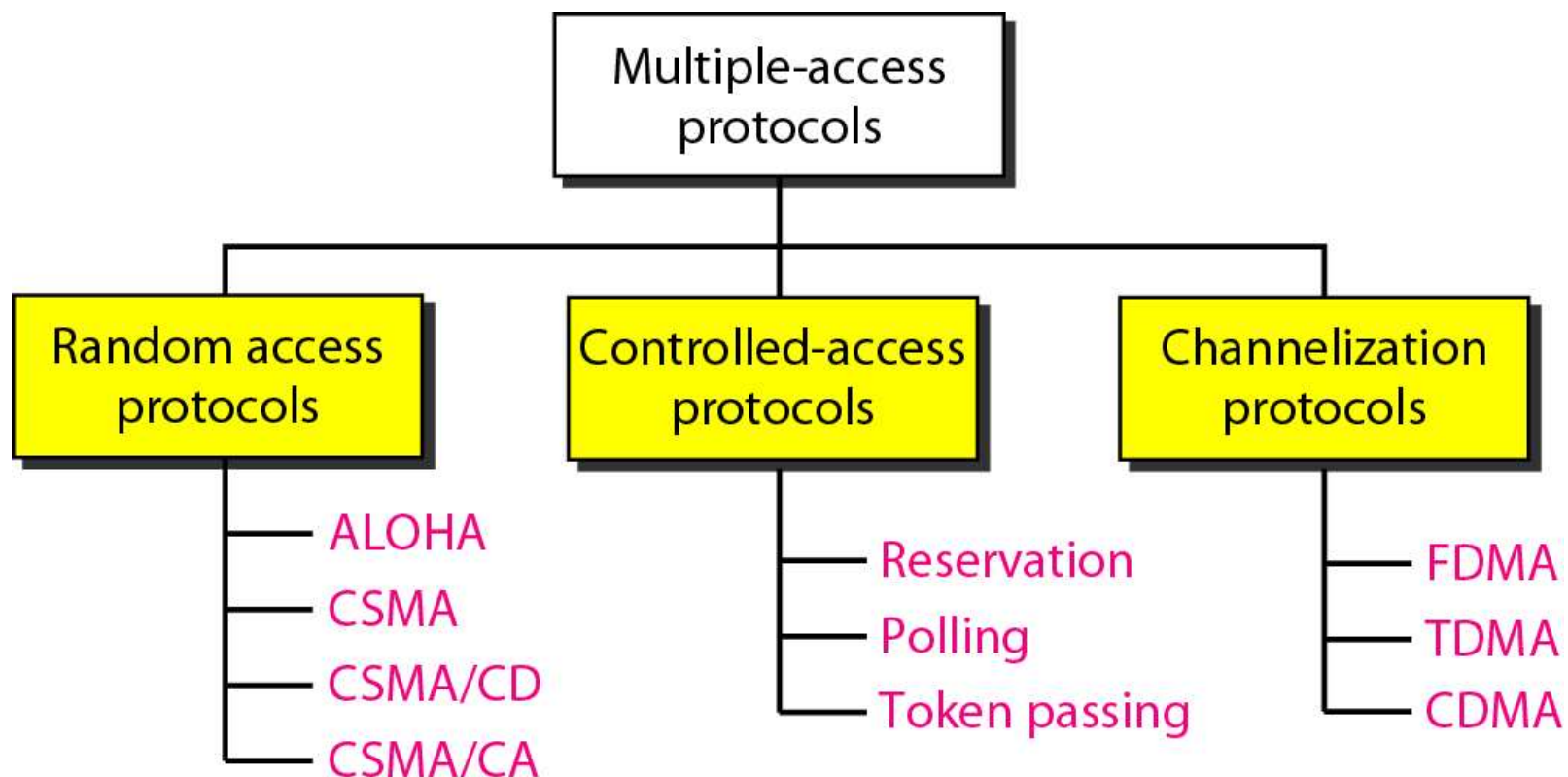


1. Noisy Channels

■ Multiple-access protocol

- When nodes or stations are connected and use a common link, called a multipoint or broadcast link, we need a multiple-access protocol to coordinate access to the link.

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



2. 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

2. Random Access

- Random access or contention methods
 - Random → There is no scheduled time for a station to transmit.
Transmission is random among the stations.
 - Contention → Stations compete with one another to access the medium.
- Each station has the right to access the medium without being controlled by any other station.
- If more than one station tries to send at the same time,
 - there is an access conflict (collision)
 - frames will be either destroyed or modified
- To avoid access conflict or to resolve it when it happens, each station follows a procedure that answers the following questions:
 - When can the station access the medium?
 - What can the station do if the medium is busy?
 - How to determine the success or failure of the transmission?
 - What can the station do if an access conflict?

2. Random Access

ALOHA

- The earliest random access method
 - It was developed at the University of Hawaii in early 1970.
 - Designed for a radio (wireless) LAN, but it can be used on any shared medium

- **Pure ALOHA**
 - very simple, but elegant protocol
 - The original ALOHA protocol is called pure ALOHA.
 - Multiple access
 - Each station sends a frame whenever it has a frame to send.
 - Since there is only one channel to share, there is the possibility of collision between frames from different stations.

2. Random Access

– Acknowledgement

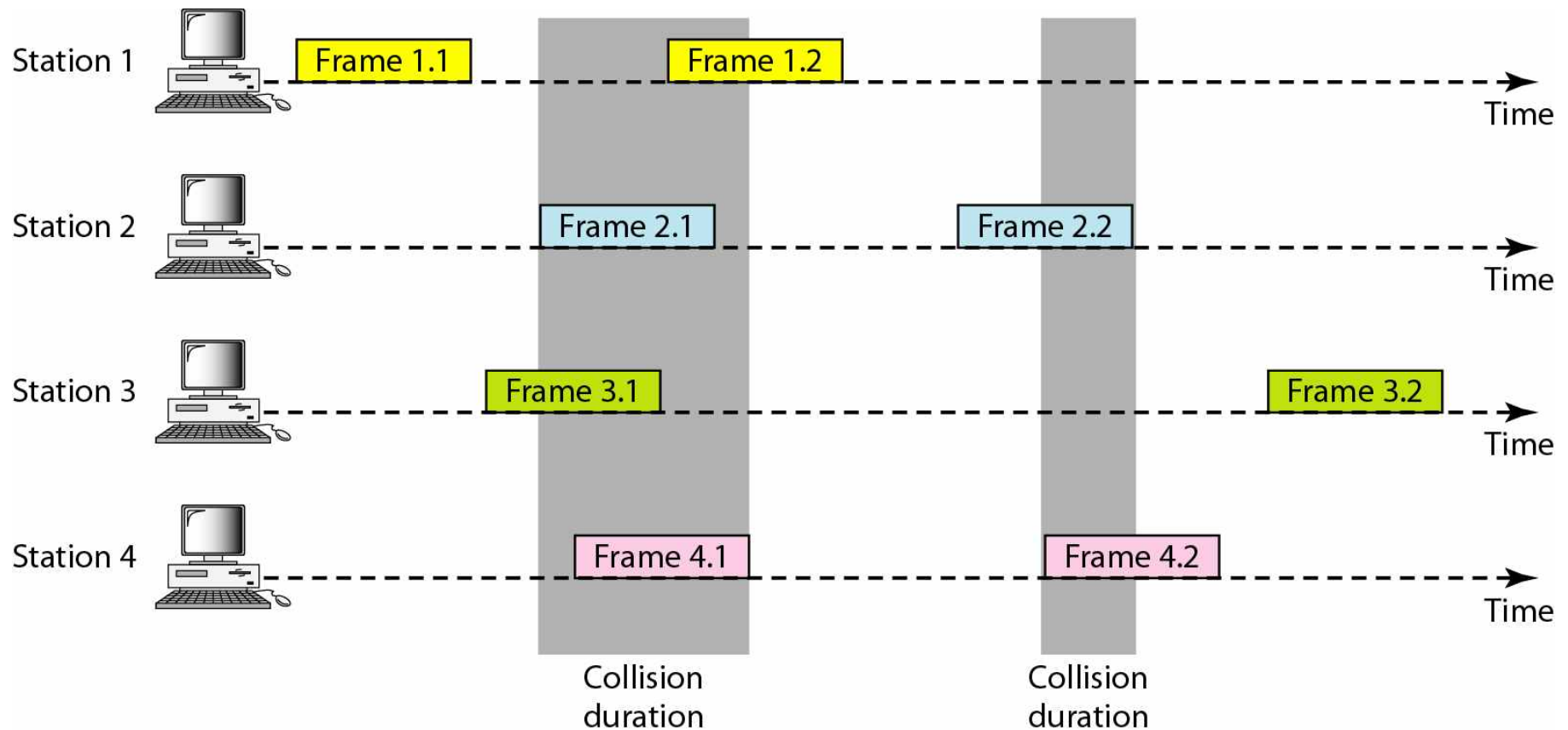
- After sending the frame, the station waits for an ACK.
- If the ACK does not arrive during a time-out period, ($2 \times T_p$), the station
 - assume that the frame is lost
 - tries to resend after a random amount of time, T_B : back-off
 - if fails for several times (limit), it gives up
- One common formula to determine T_B is the binary exponential back-off.
 - $T_B = T_p \times \text{random}[0, 2^K - 1]$ or $T_{fr} \times \text{random}[0, 2^K - 1]$

where

- K : the number of attempts
- T_p : the maximum propagation delay
- T_{fr} : Average transmission time for a frame
- T_B : the back-off time

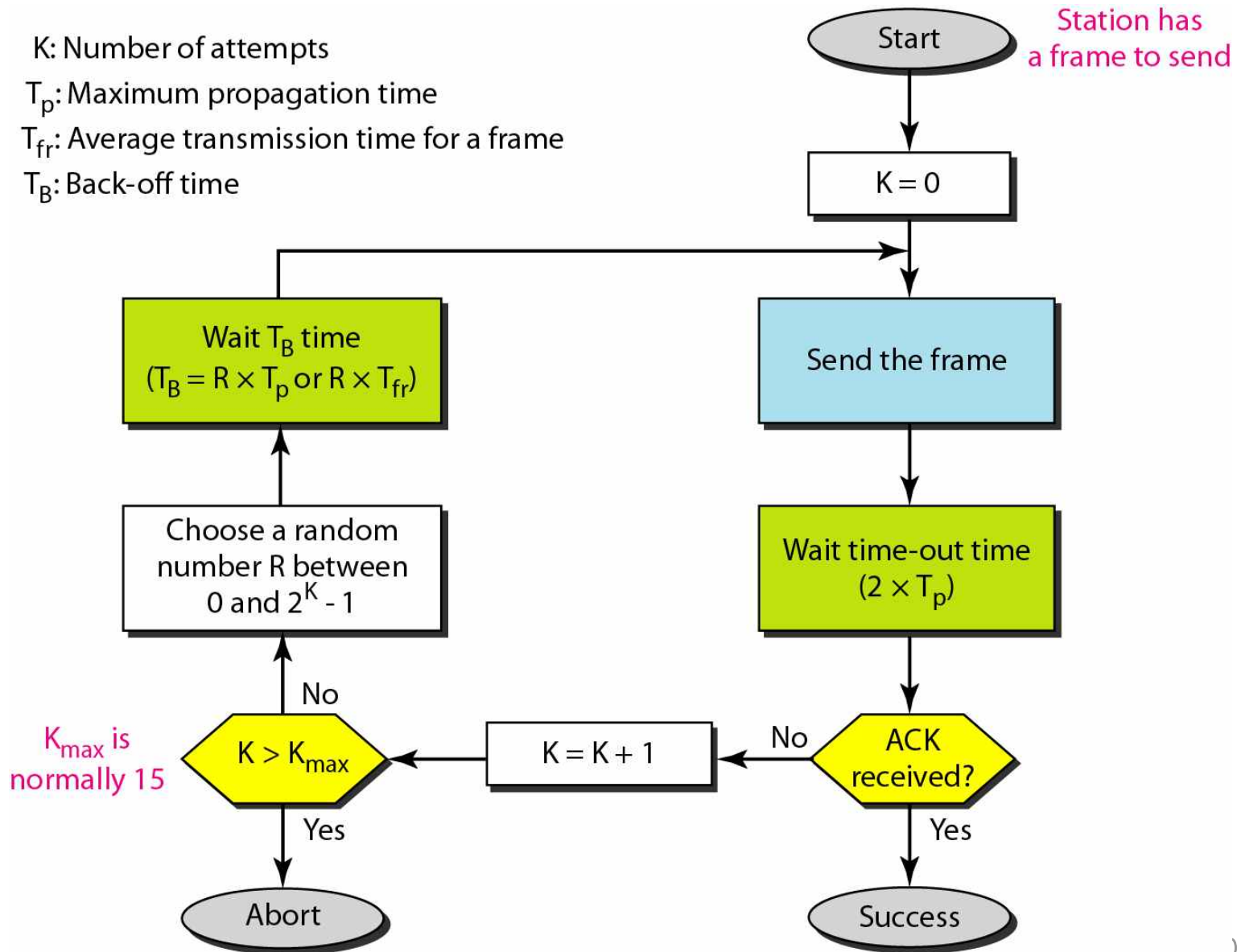
2. Random Access

Figure 12.3 Frames in a pure ALOHA network



2. Random Access

Figure 12.4 Procedure for pure ALOHA protocol



2. Random Access

■ Poisson Process

- The Poisson process is a collection $\{N(t): t \geq 0\}$ of random values, where $N(t)$ is the number of events that have occurred up to time t (starting from time 0).
- The number of events in time interval $(t, t+T]$ follows a Poisson distribution:

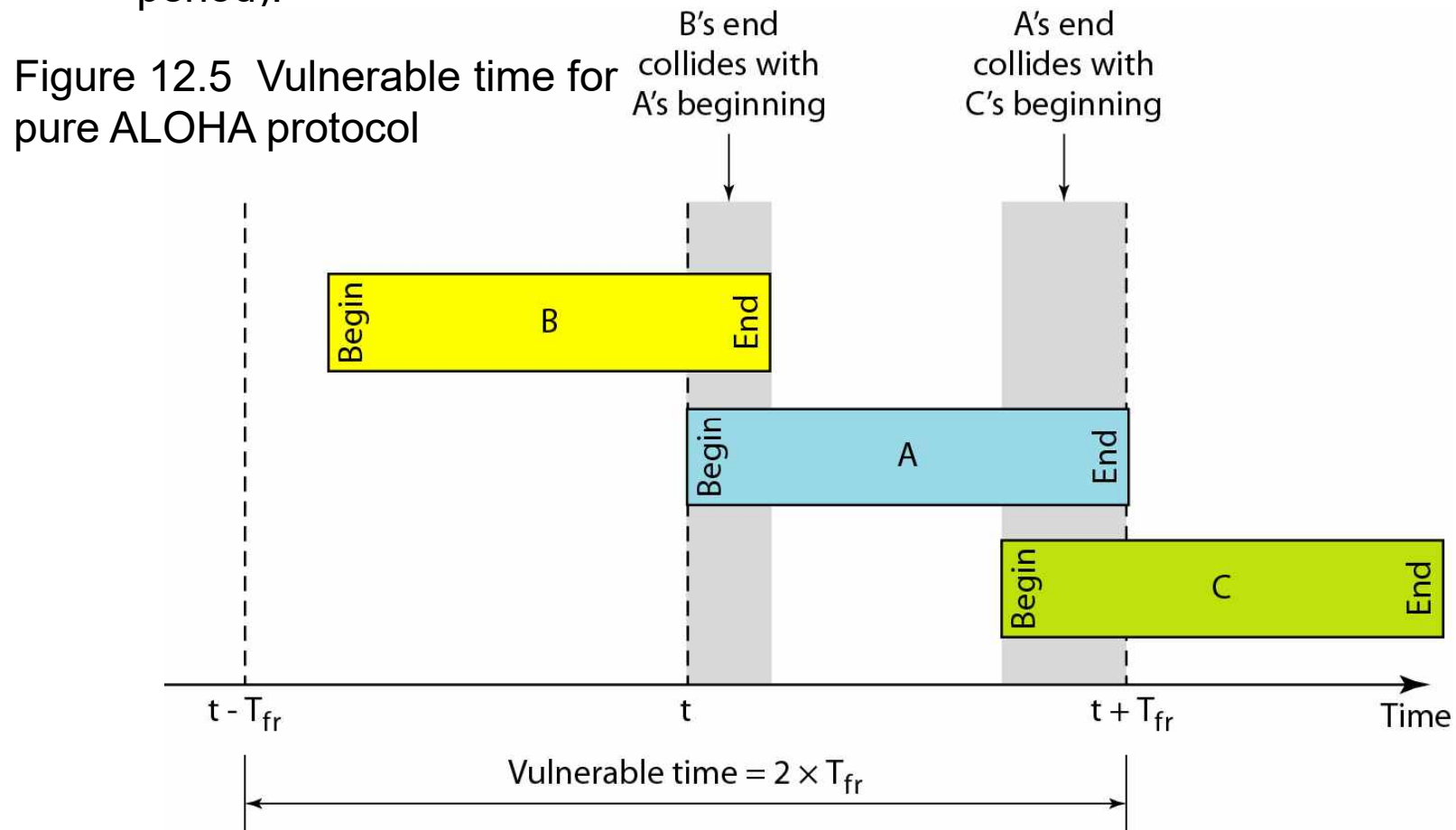
$$P[(N(t+T) - N(t)) = k] = \frac{e^{-\lambda T} (\lambda T)^k}{k!}, \quad k = 0, 1, \dots$$

- Where
 - $N(t+T) - N(t)$: the number of events in time interval $(t, t+T]$.
 - λ : the arrival rate, which is the expected number of “events” or “arrivals” that occur per unit time.

2. Random Access

■ Vulnerable time

- We assume that the stations send fixed-length frames with T_{fr} frame time.
- Consider a packet scheduled for transmission at some time t in Fig. 12.5.
- The packet A will be successful if no other packet is scheduled in the interval $(t - T_{fr}, t + T_{fr})$. (this period of duration $2T_{fr}$ is called the *vulnerable period*).



2. Random Access

■ Throughput

- The probability of success, P_{succ} , is the probability that no packet is scheduled in an interval of length of $2T_{fr}$. Since the scheduling points correspond to a Poisson process, we have

$$P_{succ} = e^{-2gT_{fr}}$$

- Hence, the throughput, which is defined the fraction of time that useful information is carried on the channel, is

$$S = gT_{fr}P_{succ} = gT_{fr}e^{-2gT_{fr}}$$

- Defining $G = gT_{fr}$, the normalized offered load, we have

$$S = Ge^{-2G}$$

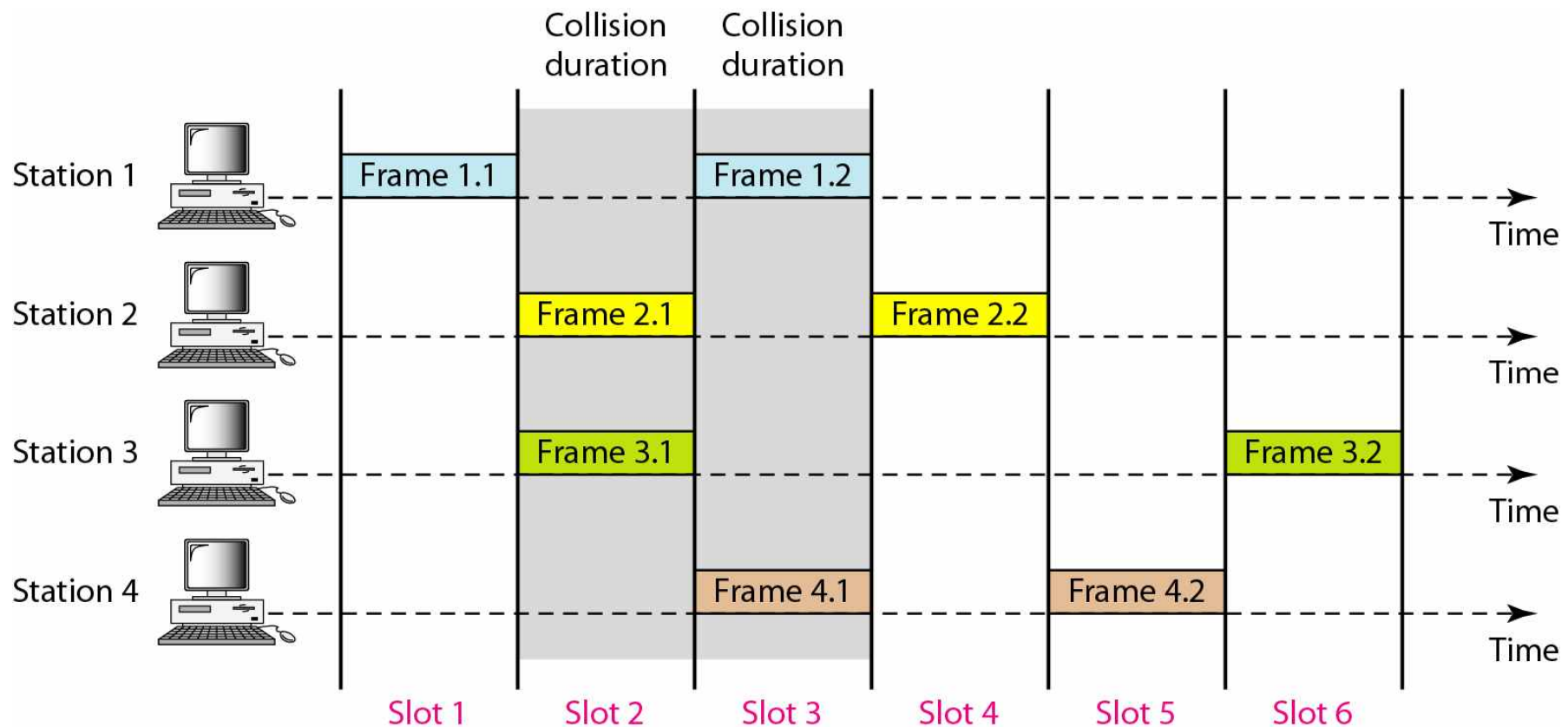
The throughput for pure ALOHA is $S = G \times e^{-2G}$.
The maximum throughput $S_{max} = 0.184$ when $G = (1/2)$.

2. Random Access

■ Slotted ALOHA

- We divide the time into slots of T_{fr} .
- **The station sends only at the beginning of the time slot.** Hence, the vulnerable period is reduced to a single slot.

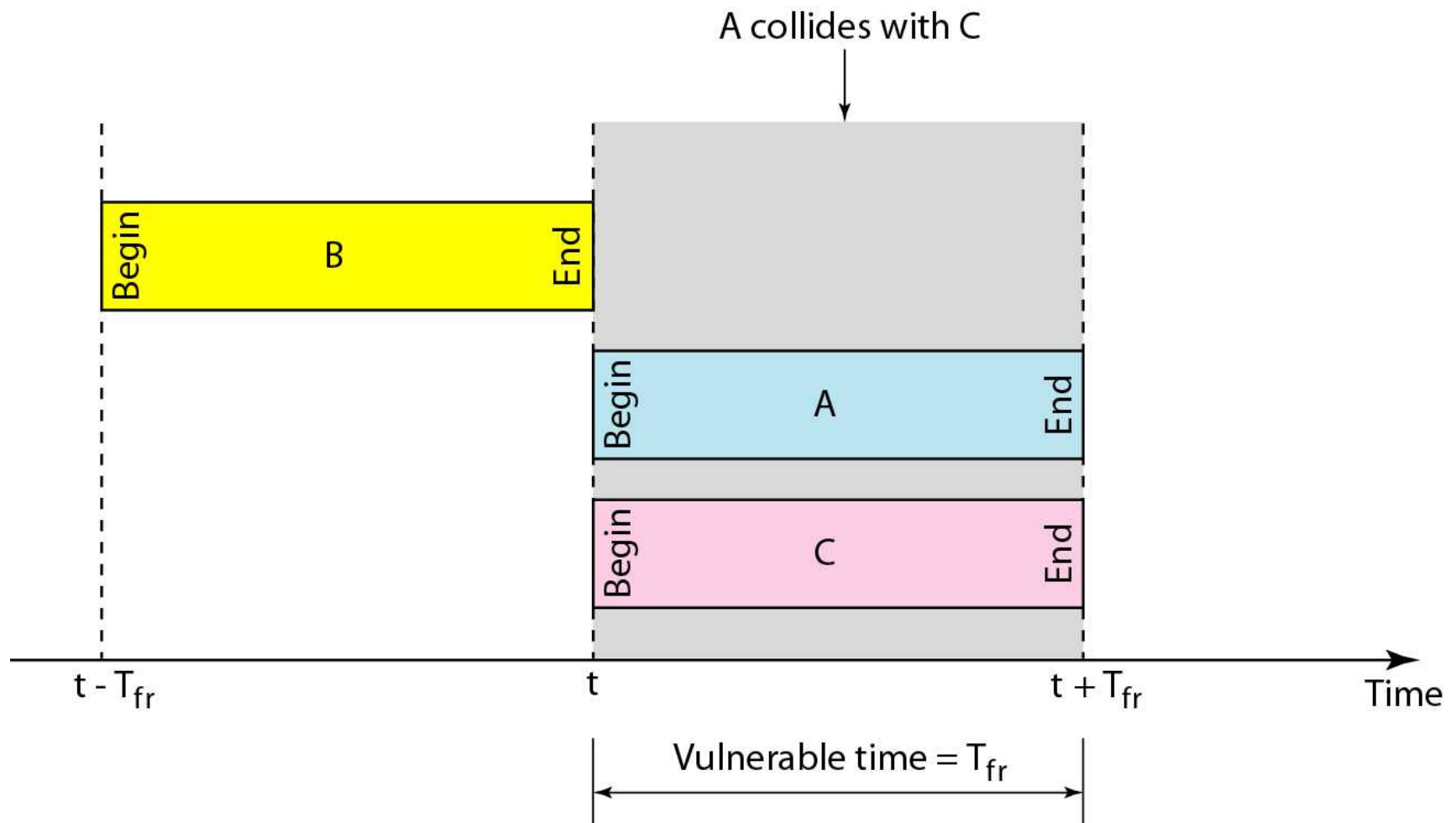
Figure 12.6 Frames in a slotted ALOHA network



2. Random Access

- Vulnerable time
 - the period of duration T_{fr}

Figure 12.7 Vulnerable time for slotted ALOHA protocol



2. Random Access

■ Throughput

- In other words, a slot will be successful if and only if exactly one packet was scheduled for transmission sometime during the previous slot.

$$S = gT_{fr}e^{-gT_{fr}}$$

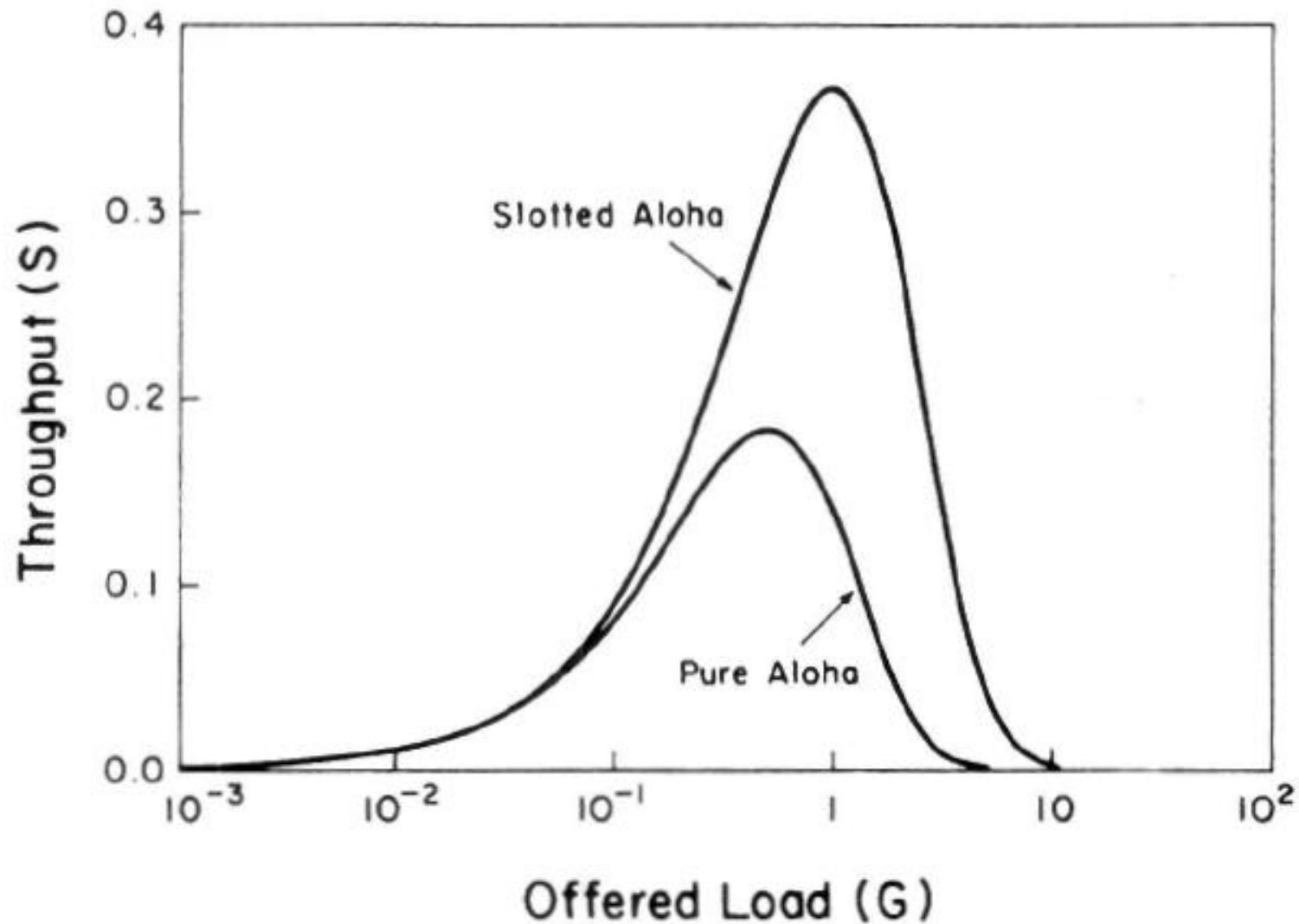
- The throughput is

$$S = Ge^{-G}$$

The throughput for slotted ALOHA is $S = G \times e^{-G}$.
The maximum throughput $S_{\max} = 0.368$ when $G = 1$.

2. Random Access

Throughput-Load of Pure and Slotted ALOHA



2. Random Access

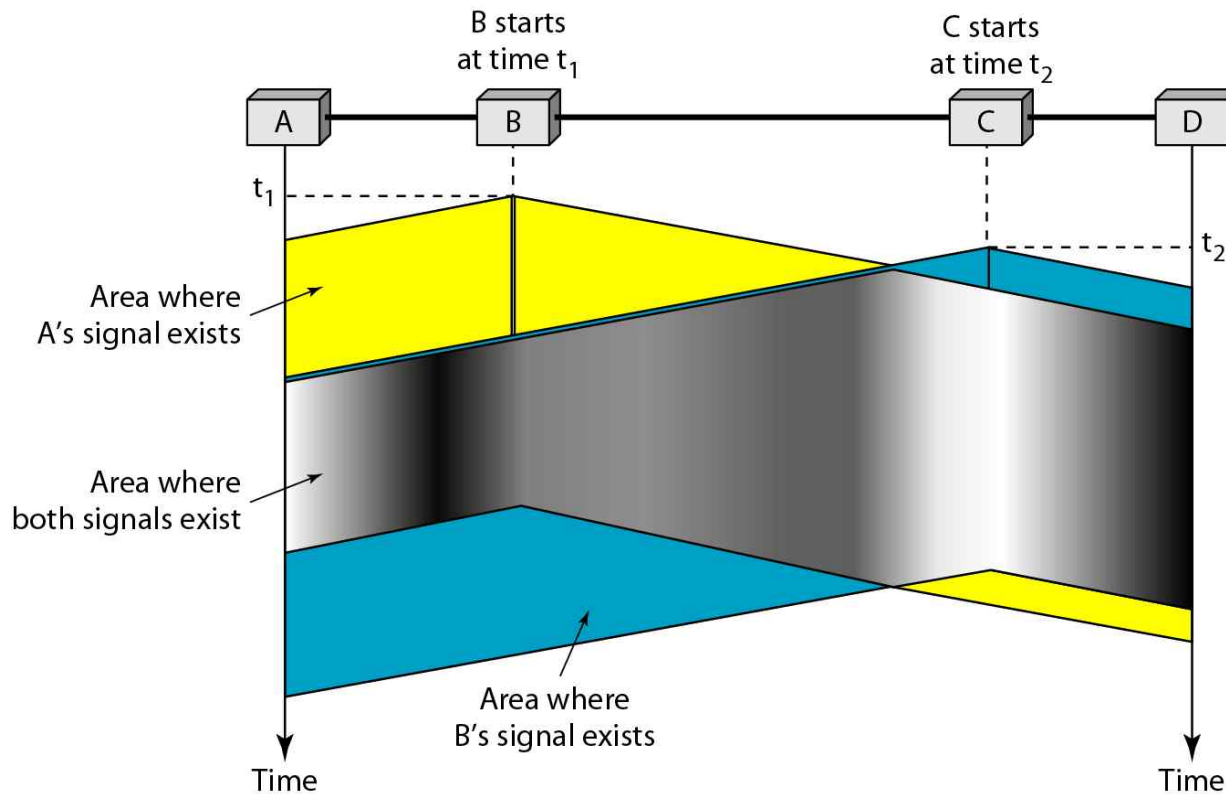
Carrier Sense Multiple Access (CSMA)

- To minimize the chance of collision and, therefore, increase the performance, the CSMA method was developed.
- Operation
 - Each station first **listen** to the medium (or check the state of the medium) before sending.
 - In other words, “sense before transmit” or “listen before talk”.
 - CSMA can reduce the possibility of collision.
 - However, the possibility of collision still exists because of the propagation delay.

2. Random Access

- At time t_1 , station B senses the medium and finds it idle, so it sends a frame.
- At time t_2 , station C senses the medium and finds it idle because the first bits from station B have not reached station C. Station C also sends a frame.
- The two signals collide and both frames are destroyed.

Figure 12.8 Space/time model of the collision in CSMA

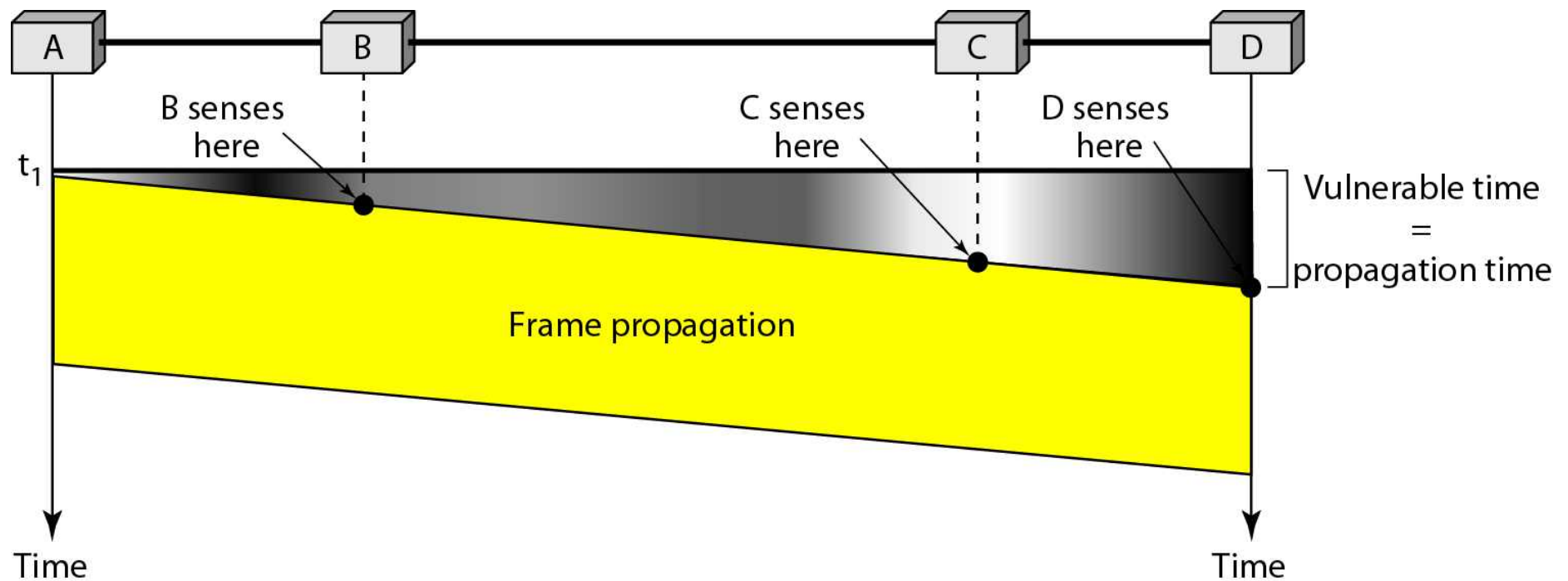


2. Random Access

■ Vulnerable Time

- The vulnerable time for CSMA is the propagation time T_p .
- This is the time needed for a signal to propagate from one end of the medium to the other.

Figure 12.9 Vulnerable time in CSMA

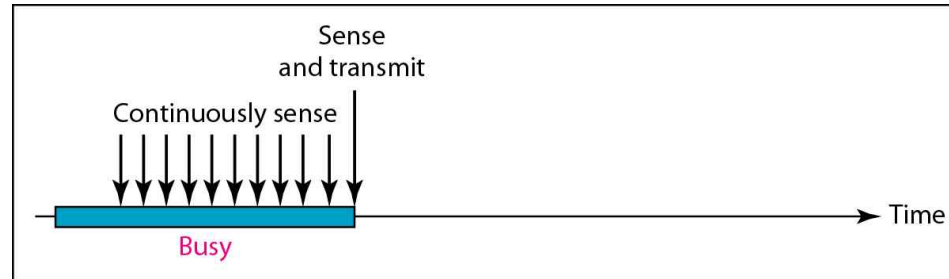


2. Random Access

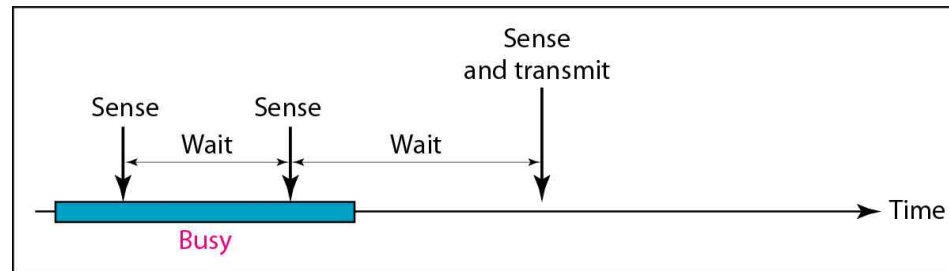
■ Persistence Methods

- What should a station do if the channel is busy?
- What should a station do if the channel is idle?

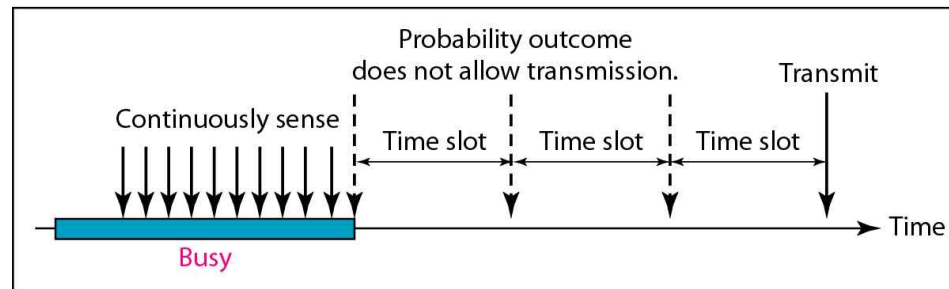
Figure 12.10 Behavior of three persistence methods



a. 1-persistent



b. Nonpersistent

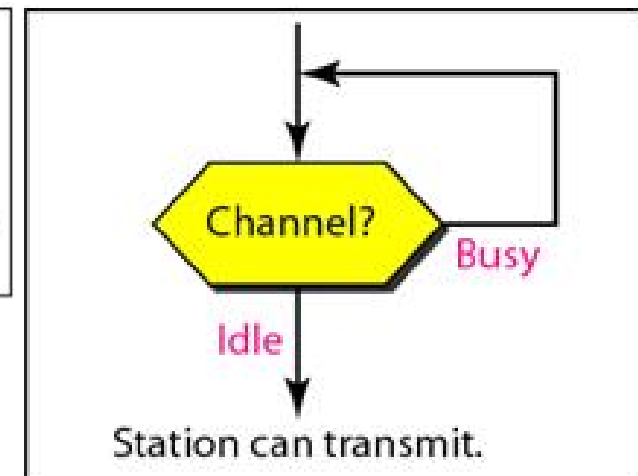
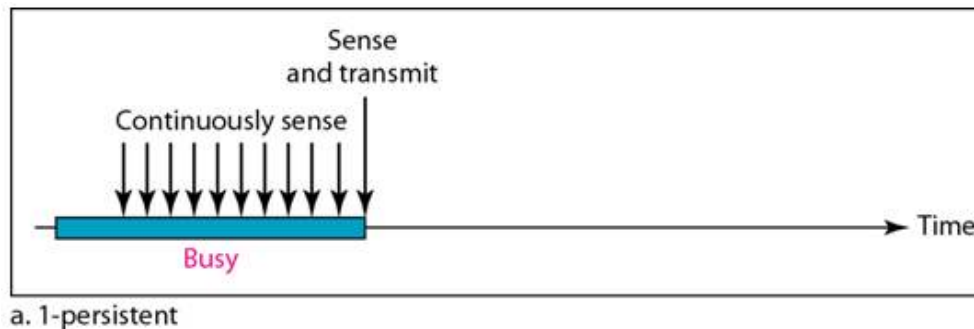


c. p-persistent

2. Random Access

■ 1-Persistent

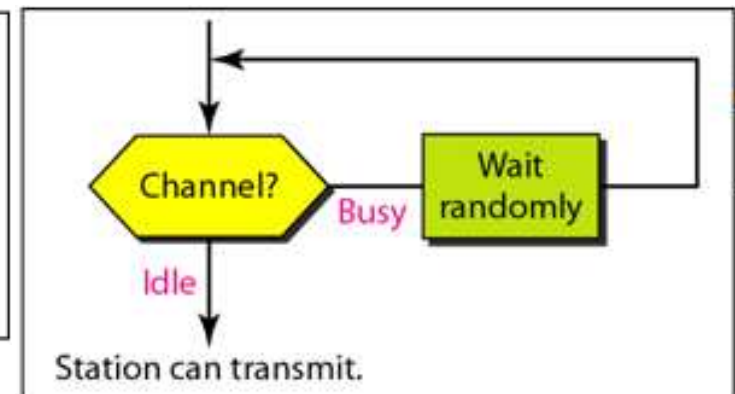
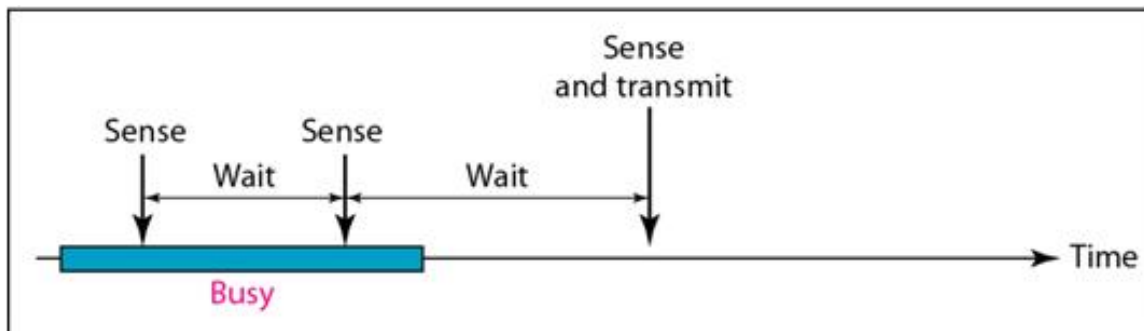
- After the station finds the line idle, it sends its frame immediately (with probability 1).
- The highest chance of collision because two or more stations may find the line idle and send their frames immediately.
- Ex. Ethernet



2. Random Access

■ Nonpersistent

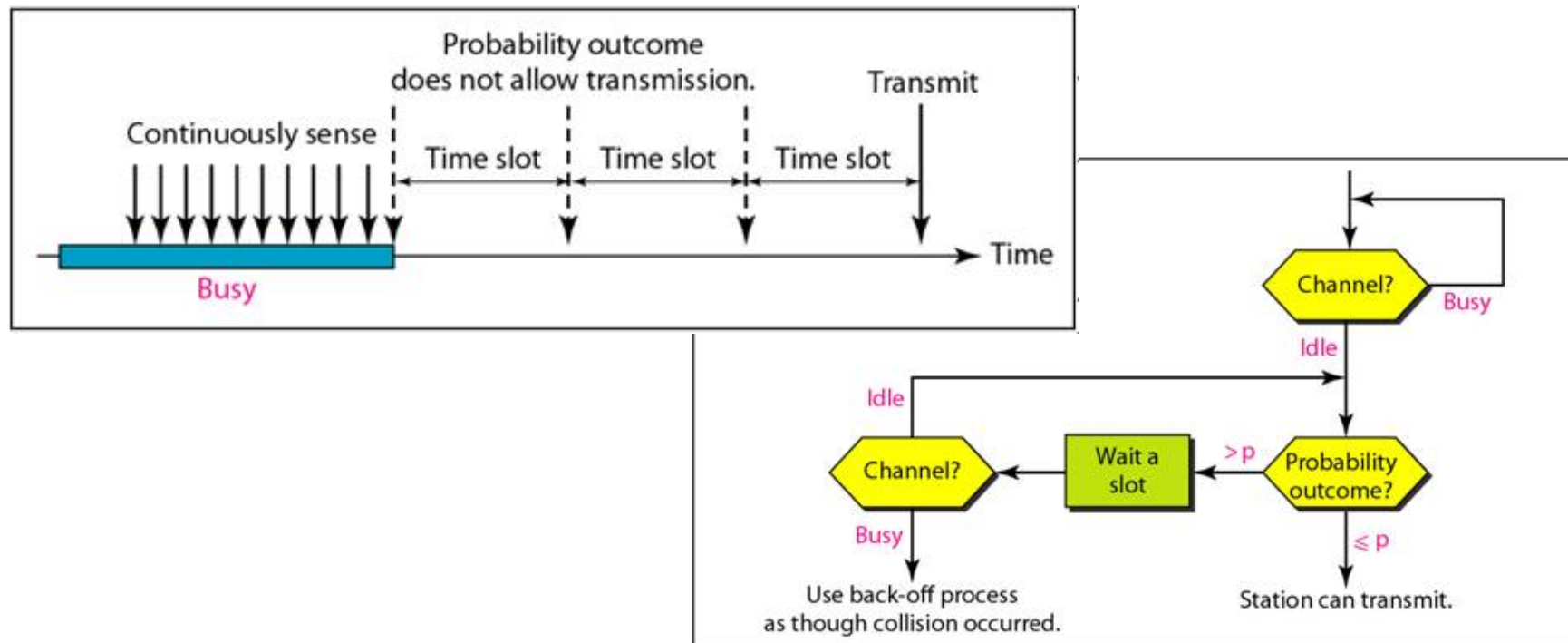
- If the line is not idle, it waits a random amount of time and then senses the line again.
- If the line is idle, it sends immediately.
- Adv: The nonpersistent approach reduces the chance of collision because it is unlikely that two or more stations will wait the same amount of time and retry to send simultaneously.
- Dis: This method reduces the efficiency because the medium remains idle when there may be stations with frames to send.



2. Random Access

■ p-Persistent

- Adv.: Reduces the chance of collision and improves efficiency.
 - STEP 1: With probability p , the stations sends its frame.
 - STEP 2: With probability $q = 1 - p$, the station waits for the beginning of the next time slot and checks the line again.
 - If the line is idle, it goes to step 1.
 - If the line is busy, it acts as though a collision has occurred and uses the back-off procedure.



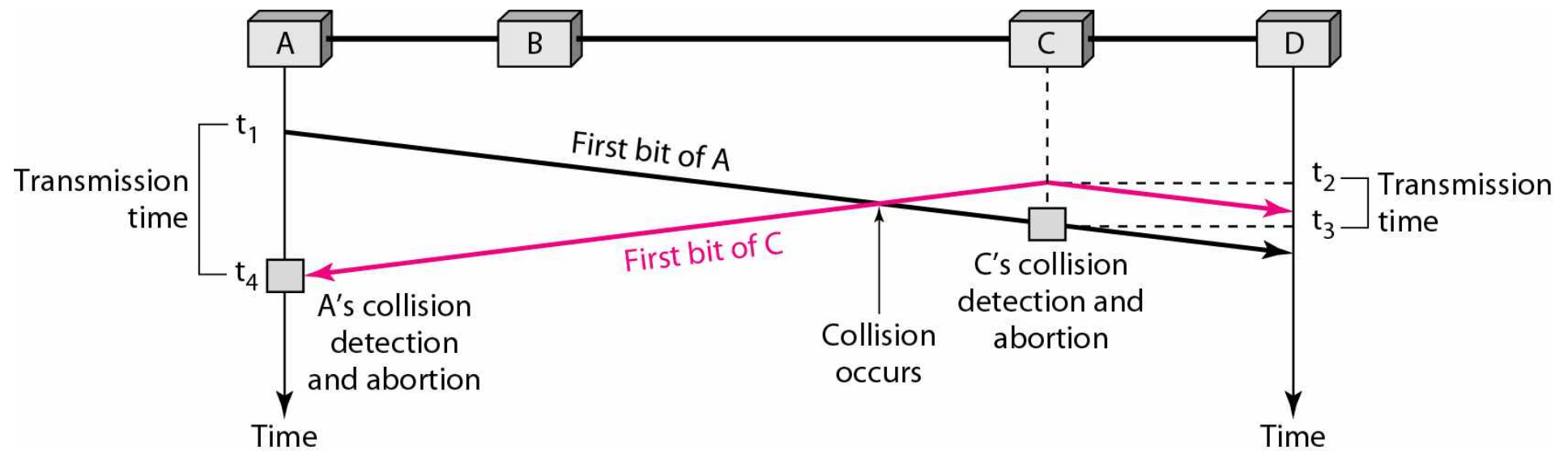
2. Random Access

CSMA with Collision Detection (CSMA/CD)

- The CSMA method does NOT specify the procedure following a collision.
- CSMA/CD augments the algorithm to handle the collision.
 - STEP1: Apply one of the persistent methods and a station sends a frame.
 - STEP2: The station monitors the medium to see if the transmission was successful.
 - STEP3-1: If transmission was successful, the station is finished.
 - STEP3-2: If, however, a collision is detected,
 - The station immediately aborts transmission.
 - Send a **jamming signal** that enforces the collision in case other stations have not yet sensed the collision.
 - Wait T_B time, back-off, and go to STEP 1.
where $T_B = T_p \times \text{random}[0, 2^K-1]$ or $T_{fr} \times \text{random}[0, 2^K-1]$

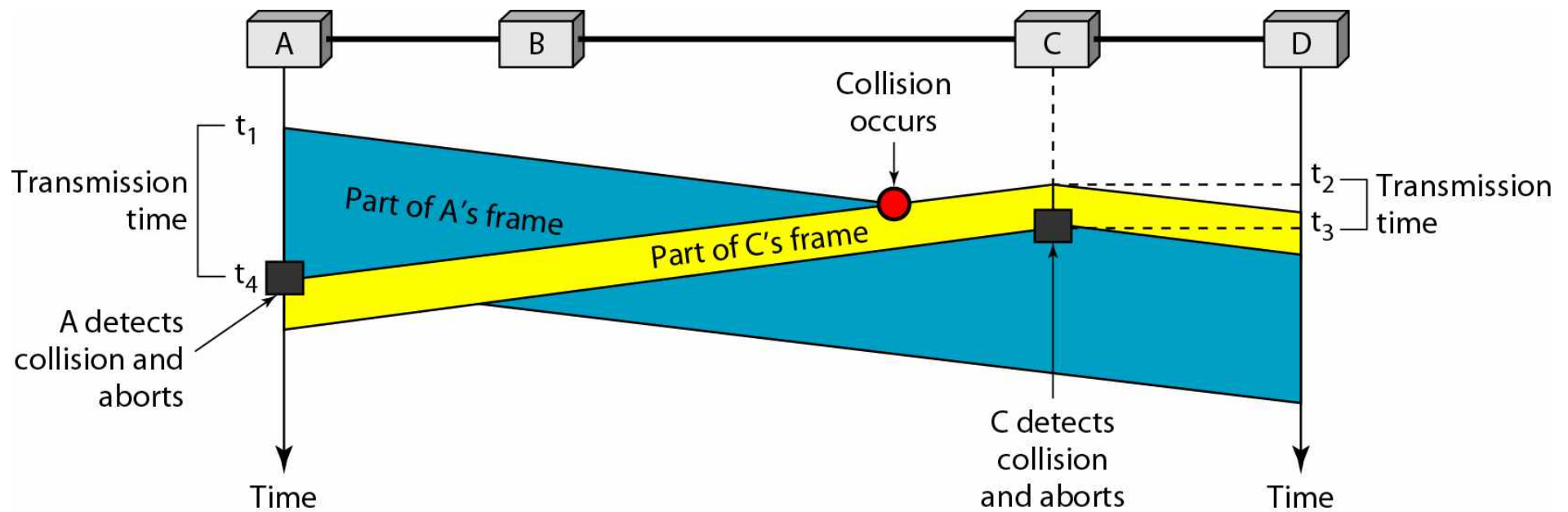
2. Random Access

Figure 12.12 Collision of the first bit in CSMA/CD



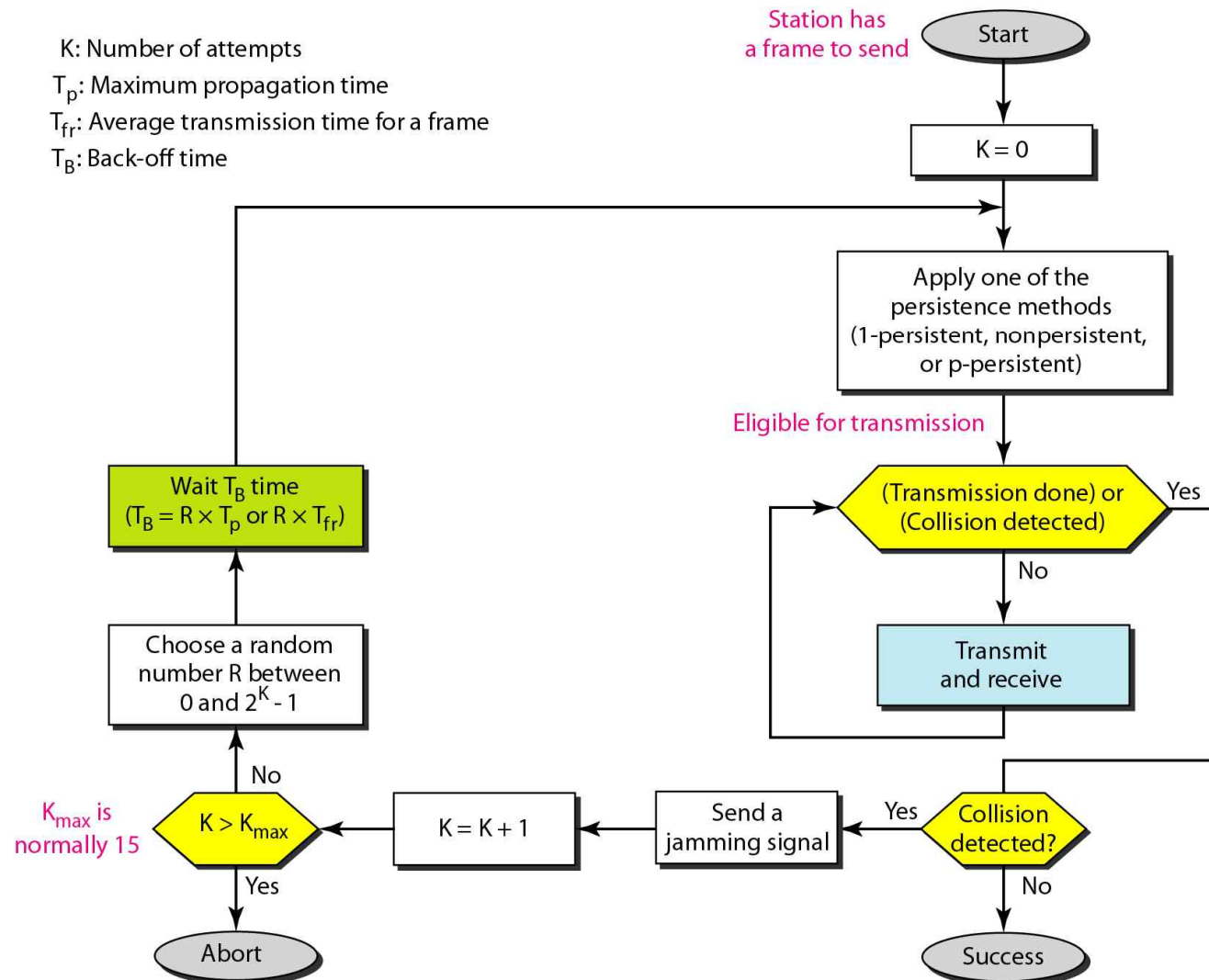
2. Random Access

Figure 12.13 Collision and abortion in CSMA/CD



2. Random Access

Figure 12.14 Flow diagram for the CSMA/CD



2. Random Access

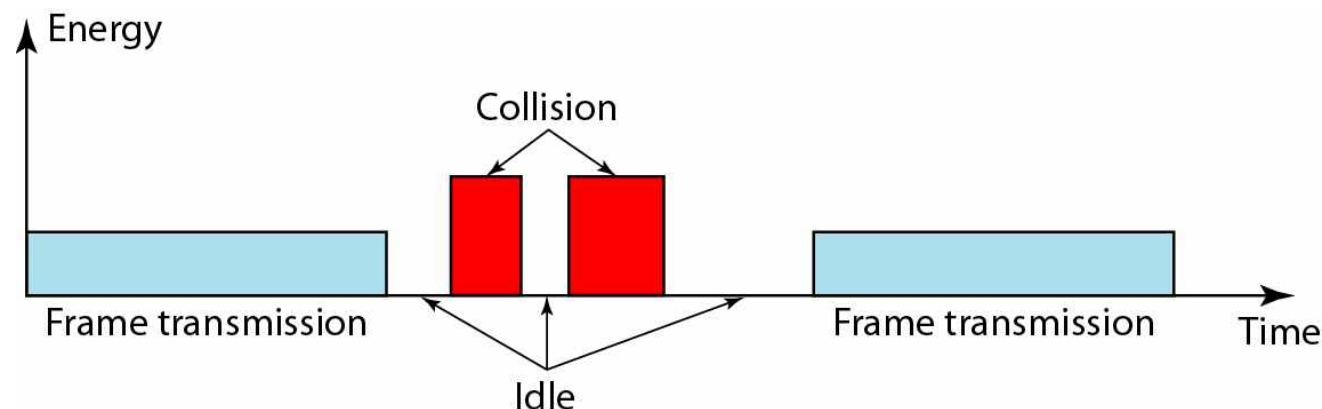
■ Minimum Frame Size

- Before sending the last bit of the frame, the sending station must detect a collision, if any, and abort the transmission.
- Therefore, the frame transmission time T_{fr} must be at least two times the maximum propagation time T_p .
- $T_{fr} \geq 2T_p$.

■ Energy Level

- The level of energy in a channel can have three values: zero, normal, and abnormal.
- At the zero level, the channel is idle.
- At the normal level, a station is sending its frame.
- At the abnormal level, there is a collision and the level of the energy is twice the normal.

Figure 12.15 Energy level during transmission, idleness, or collision



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)

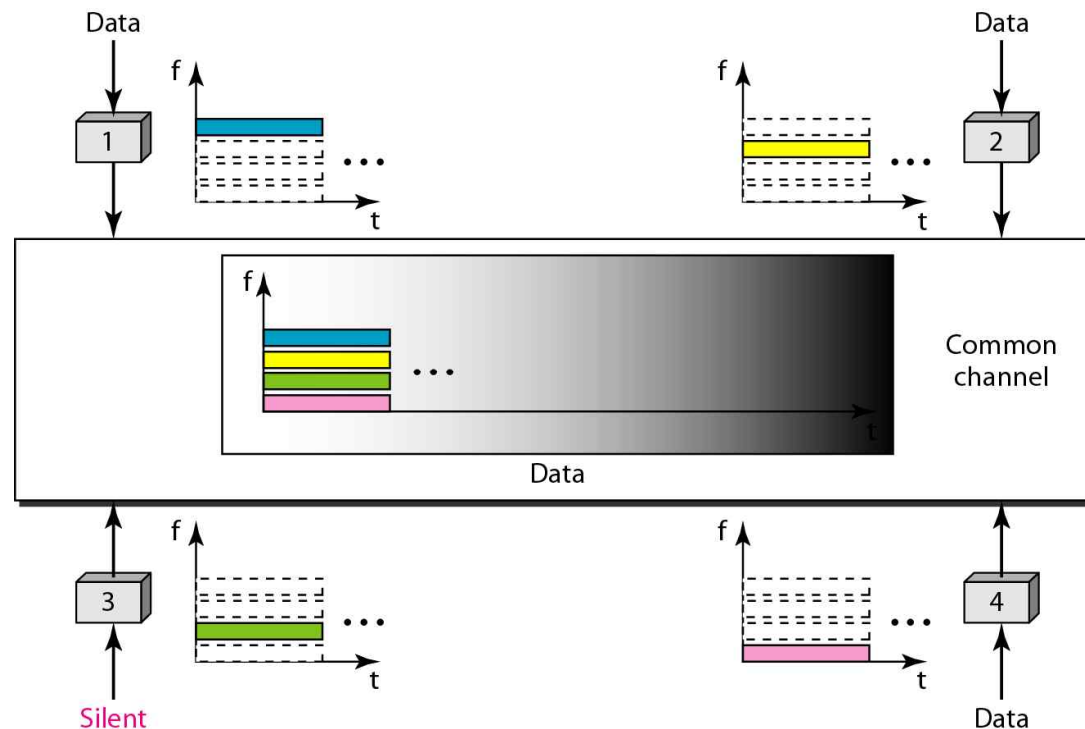
Code-Division Multiple Access (CDMA)

3. Channelization

Frequency-Division Multiple Access (FDMA)

- The available bandwidth is divided into bands that are separated by guard bands.
- Each band is reserved for a specific station, and it belongs to the station all the time.
 - FDM is a physical layer technique.
 - FDMA, on the other hand, is an access method in the data link layer.

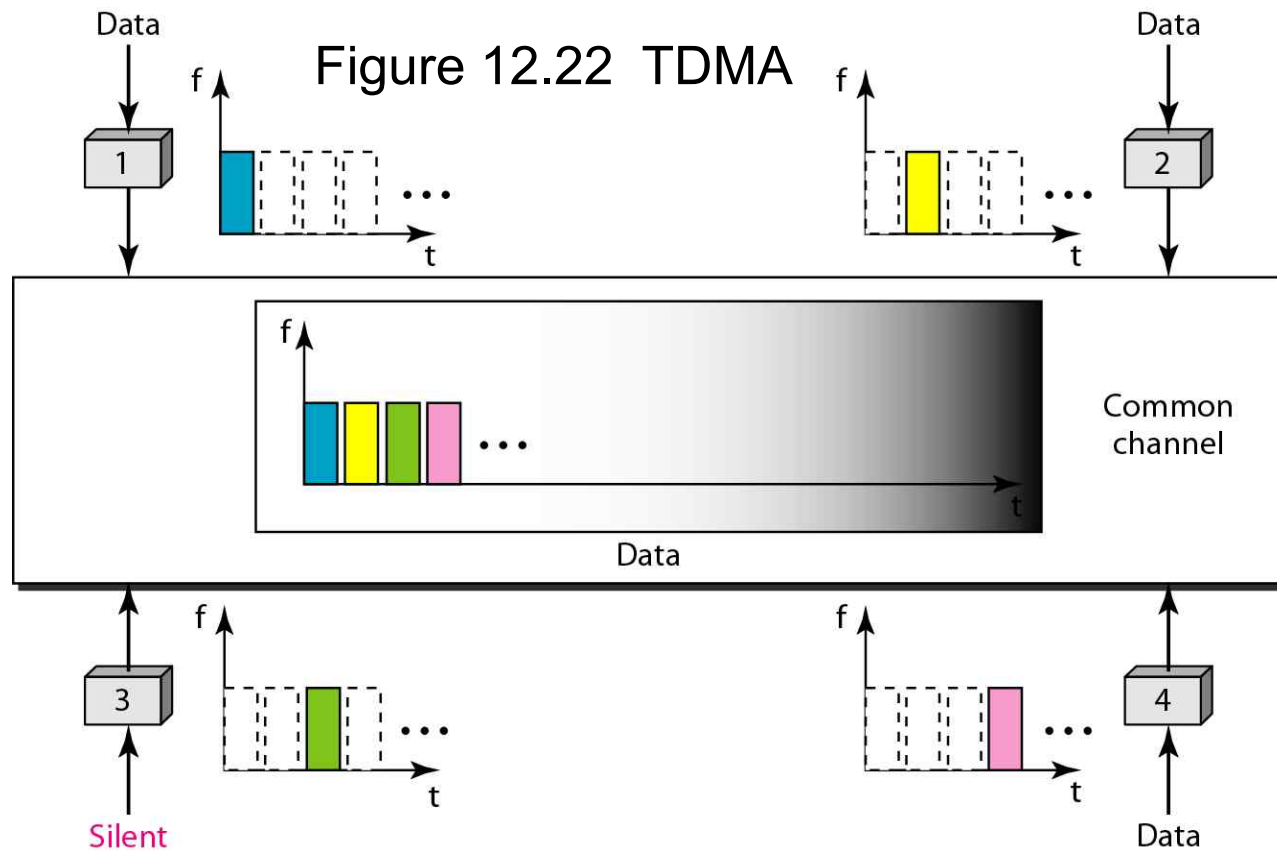
Figure 12.21 FDMA



3. Channelization

Time-Division Multiple Access (TDMA)

- The bandwidth is just one channel that is timeshared between different stations.
- Each station transmits its data in an assigned time slot.
 - TDM is a physical layer technique.
 - TDMA, on the other hand, is an access method in the data link layer.



3. Channelization

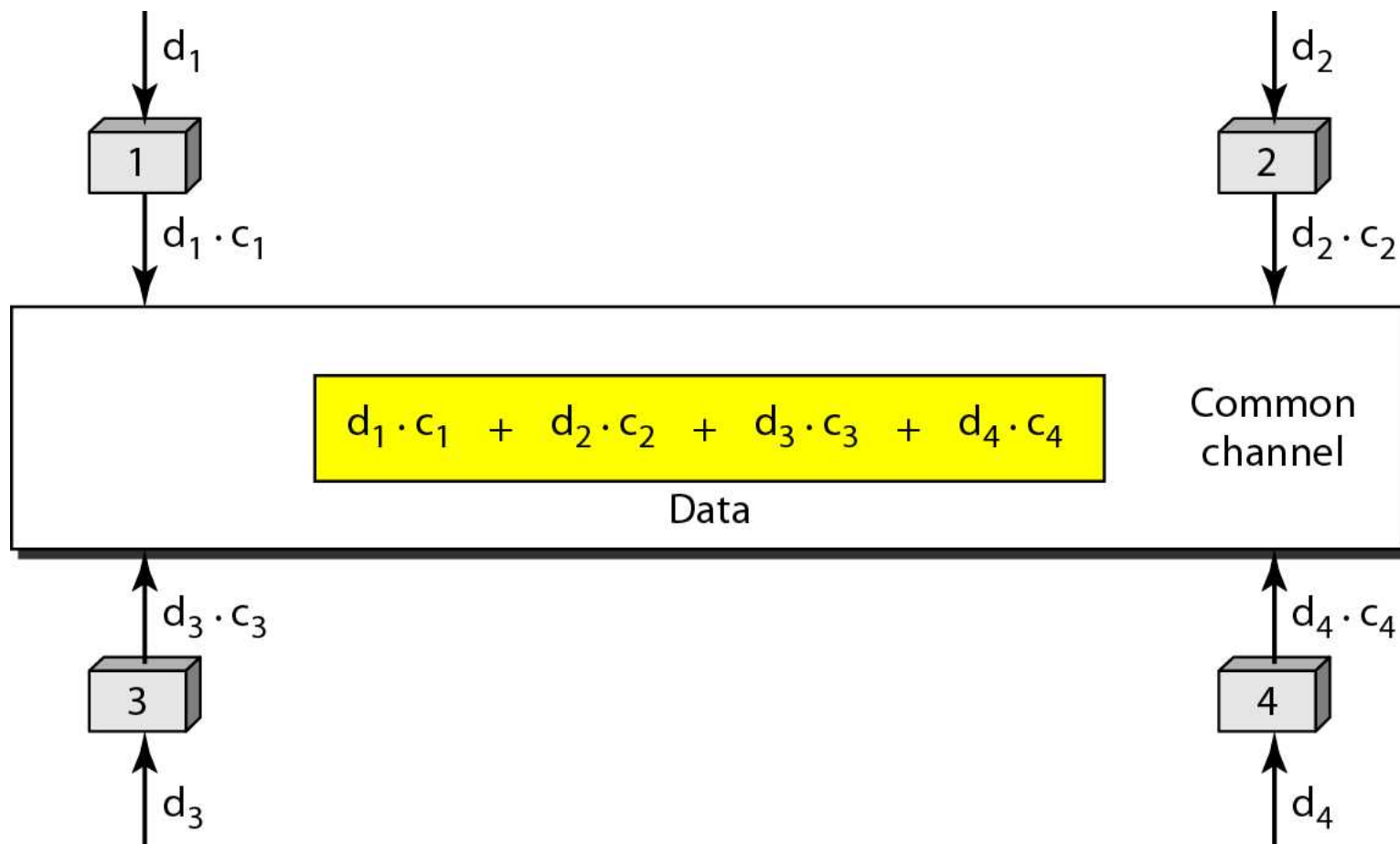
Code-Division Multiple Access (CDMA)

- In CDMA, one channel carries all transmissions simultaneously.
 - CDMA simply means communication with different codes.
- CDMA differs from FDMA because only one channel occupies the entire bandwidth of the link
- CDMA differs from TDMA because all stations can send data simultaneously: there is no timesharing
- Idea
 - Consider four stations 1, 2, 3, and 4; data from station 1 are d_1 , from station 2 are d_2 , and so on. The code assigned to the station 1 is c_1 , to the station 2 is c_2 , and so on.
 - If we multiply each code by another, we get 0.
 - If we multiply each code by itself, we get 4 (the number of stations).
 - For station 1,

$$\begin{aligned} data &= (d_1 \cdot c_1 + d_2 \cdot c_2 + d_3 \cdot c_3 + d_4 \cdot c_4) \cdot c_1 \\ &= d_1 \cdot c_1 \cdot c_1 = 4 \times d_1 \end{aligned}$$

3. Channelization

Figure 12.23 Simple idea of communication with code

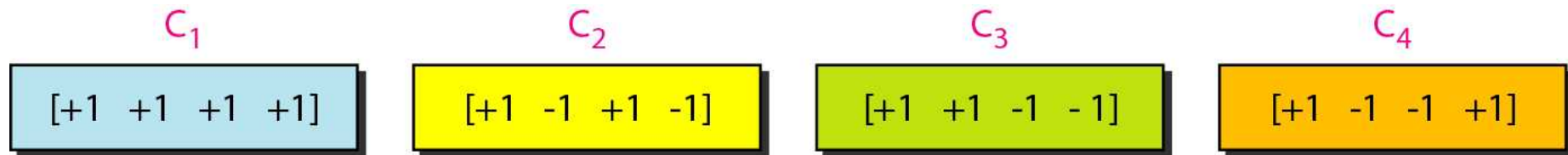


3. Channelization

- Chips

- CDMA is based on coding theory.
- Each station is assigned a code, which is a sequence of numbers called chips.

Figure 12.24 Chip sequences



- Data Representation

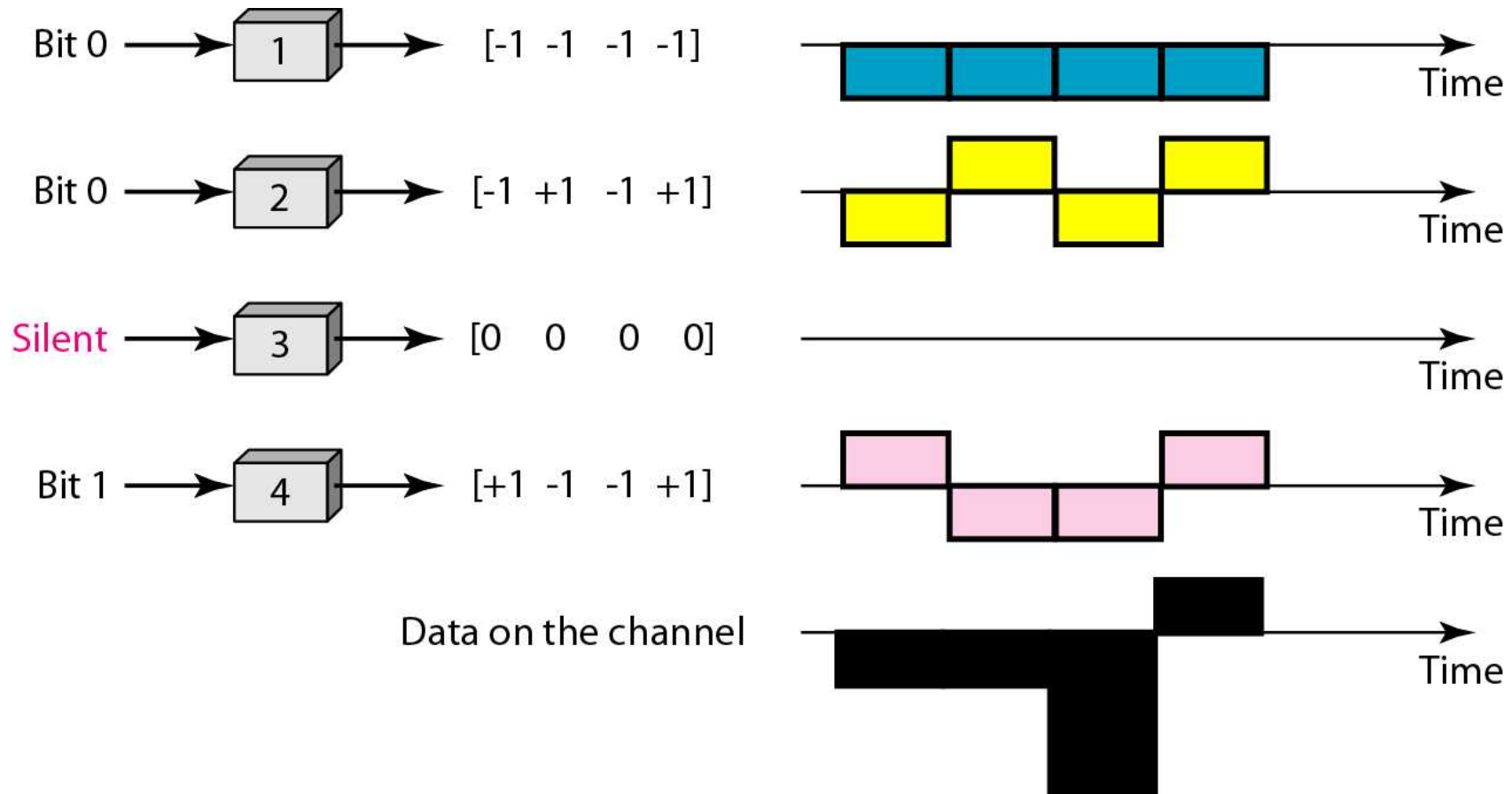
Figure 12.25 Data representation in CDMA



3. Channelization

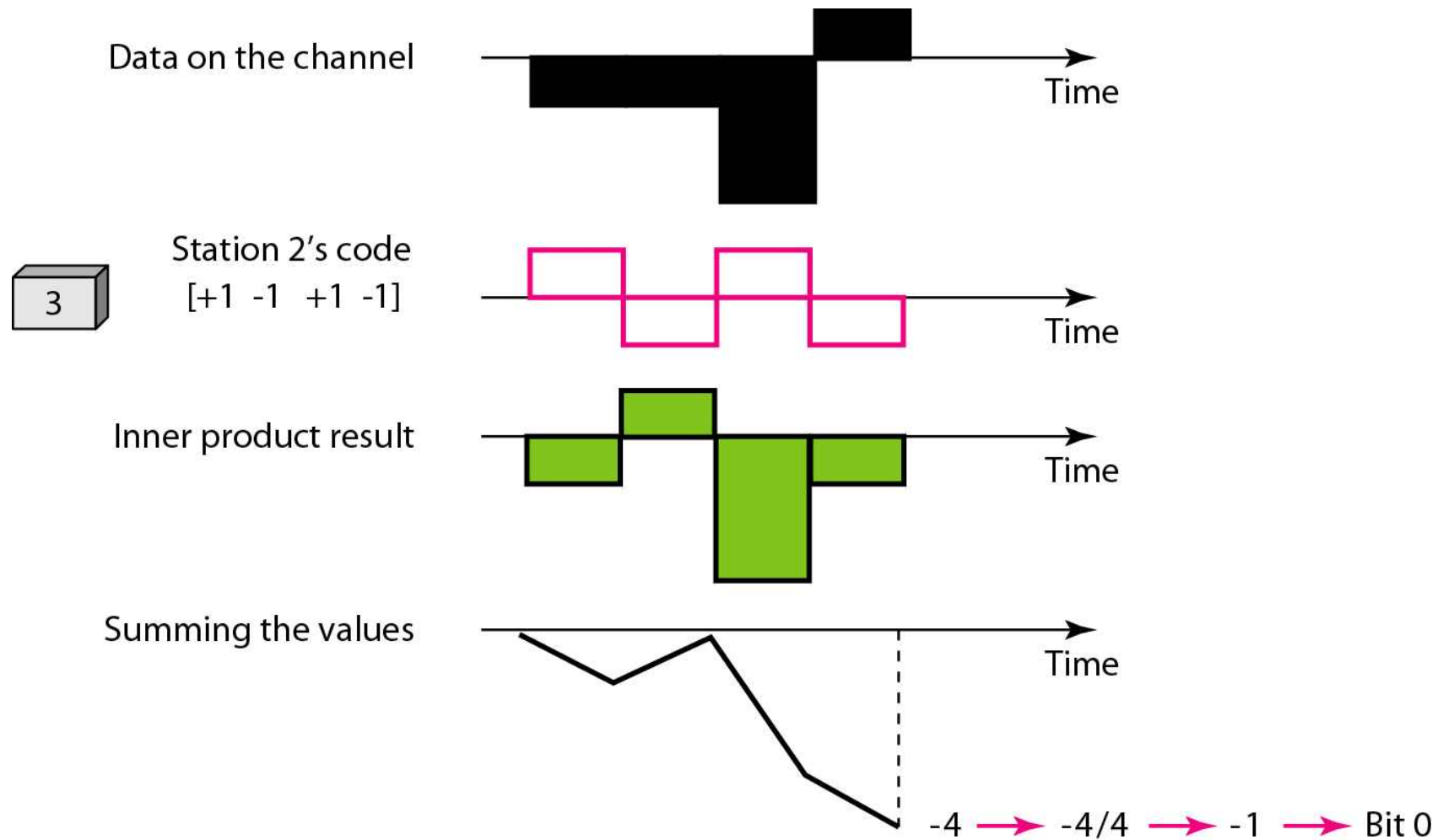
- Signal Level

Figure 12.27 Digital signal created by four stations in CDMA



3. Channelization

Figure 12.28 Decoding of the composite signal for one in CDMA



3. Channelization

■ Sequence Generation

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

Figure 12.29 General rule and examples of creating Walsh tables

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

complementary of W_N

a. Two basic rules

$$W_1 = \begin{bmatrix} +1 \end{bmatrix}$$
$$W_2 = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix}$$
$$W_4 = \begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{bmatrix}$$

b. Generation of W_1 , W_2 , and W_4

3. Channelization



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 .

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

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

Summary

- Medium access methods can be categorized as random, controlled, or channelized.
- In the carrier sense multiple-access (CSMA) method, a station must listen to the medium prior to sending data onto the line.
- FDMA, TDMA, and CDMA are channelization methods.
- In FDMA, the bandwidth is divided into bands; each band is reserved for the use of a specific station.
- In TDMA, the bandwidth is not divided into bands; instead the bandwidth is timeshared.
- In CDMA, the bandwidth is not divided into bands, yet data from all inputs are transmitted simultaneously.