Data Communications and Networking **Fourth Edition**

Chapter 12

Multiple Access
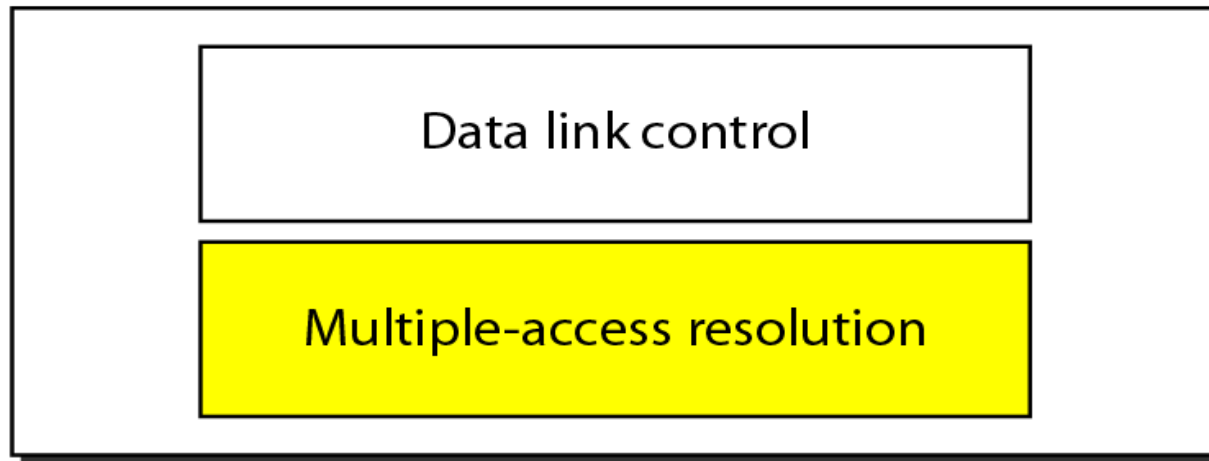
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❑ **Data Link layer divided into two sublayers.**

❖ **The upper sublayer is responsible for datalink control,**

❖ **The lower sublayer is responsible for resolving access to the shared media.**
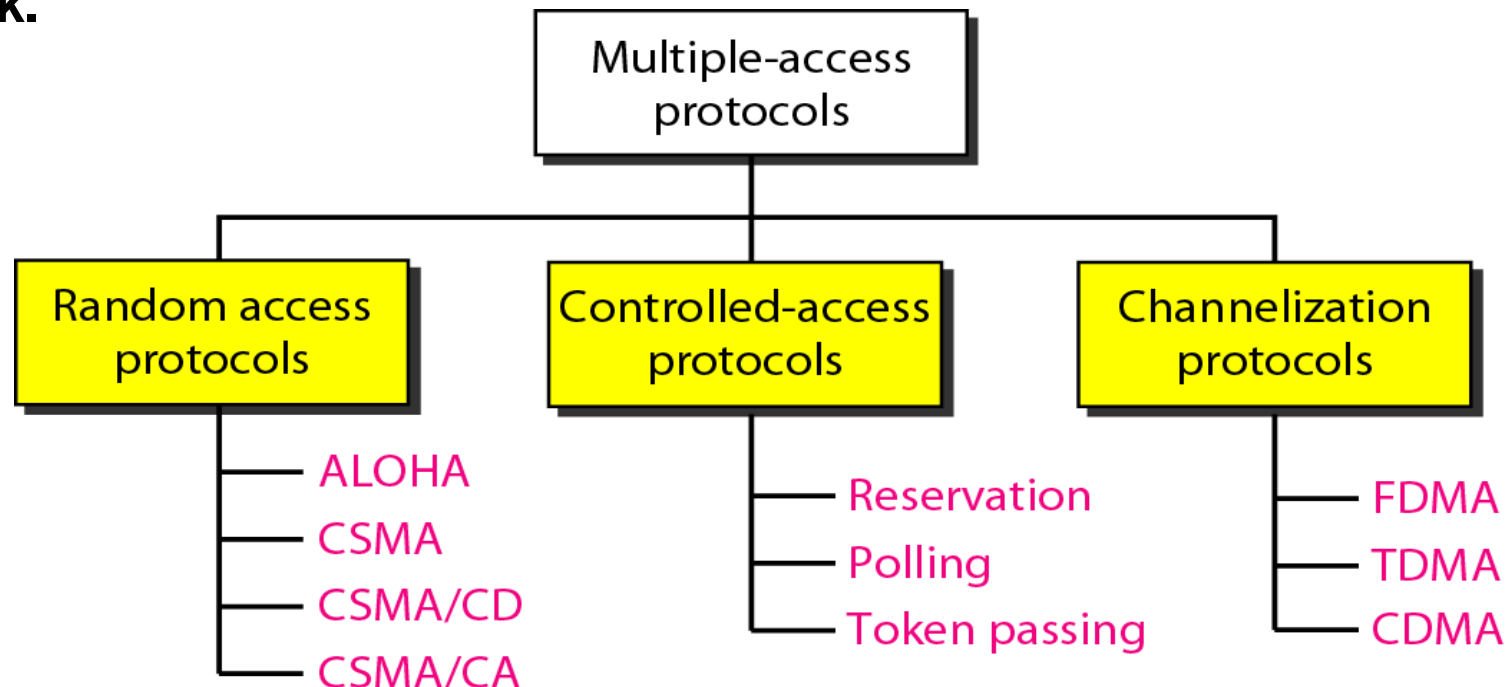
Data link layer

```
┌─────────────────────────────────────┐
│  ┌───────────────────────────────┐  │
│  │       Data link control       │  │
│  └───────────────────────────────┘  │
│  ┌───────────────────────────────┐  │
│  │  Multiple-access resolution   │  │
│  └───────────────────────────────┘  │
└─────────────────────────────────────┘
```

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

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.**

Multiple-access protocols		
Random access protocols	Controlled-access protocols	Channelization protocols
ALOHA	Reservation	FDMA
CSMA	Polling	TDMA
CSMA/CD	Token passing	CDMA
CSMA/CA		

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

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
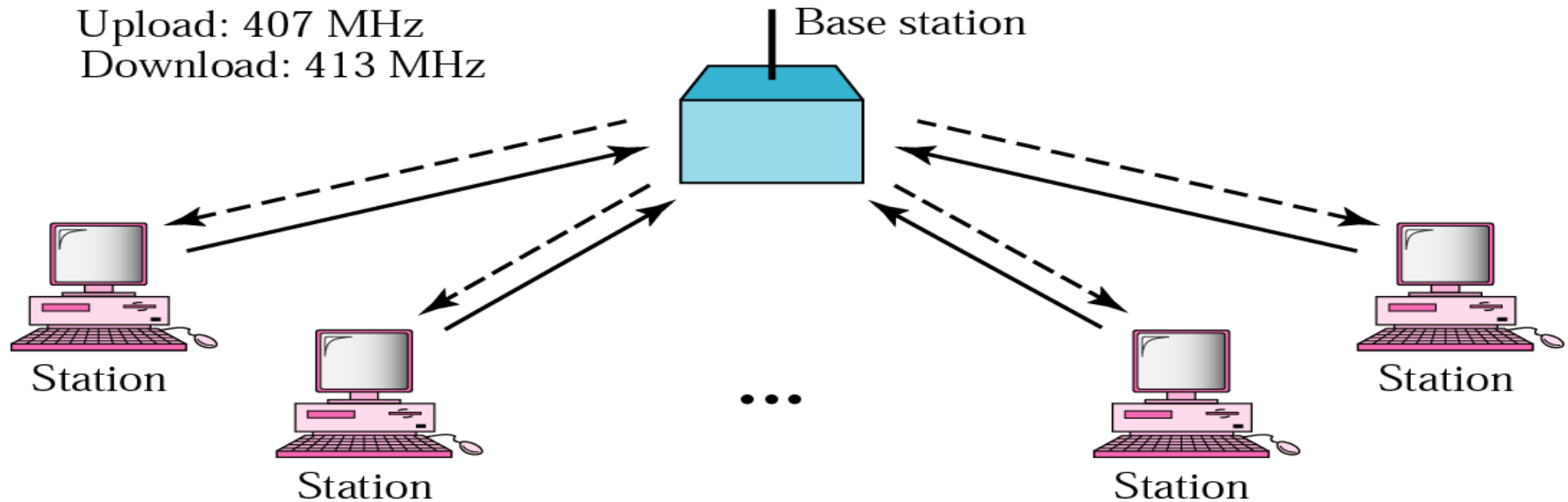
Random Access

❑ **Random Access**

❖ In a Random access method, each station has the right to the medium without being controlled by any other station.

❖ If more than one station tries to send, there is an access conflict – COLLISION – and the frames will be either destroyed or modified.

❑ **To avoid access conflict, each station follows a procedure.**

❖ When can the station access the medium ?

❖ What can the station do if the medium is busy ?

❖ How can the station determine the success or failure of the transmission ?

❖ What can the station do if there is an access conflict ?

ALOHA network – Multiple Access

Upload: 407 MHz
Download: 413 MHz

Base station

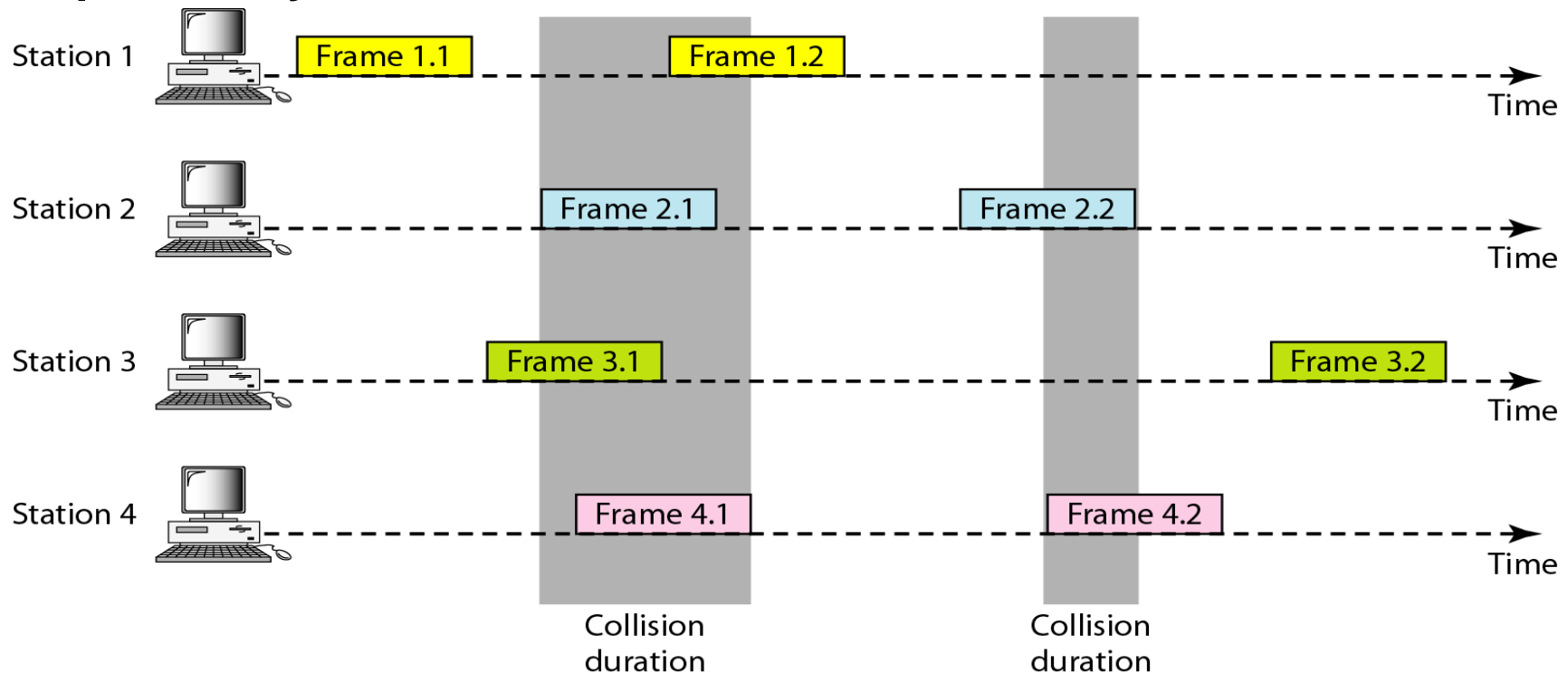Station

Station

Station

Station

- The earliest random-access method, was developed at the Univ. of Hawaii in the early 1970s.

- Base station is central controller

- Base station acts as a hop

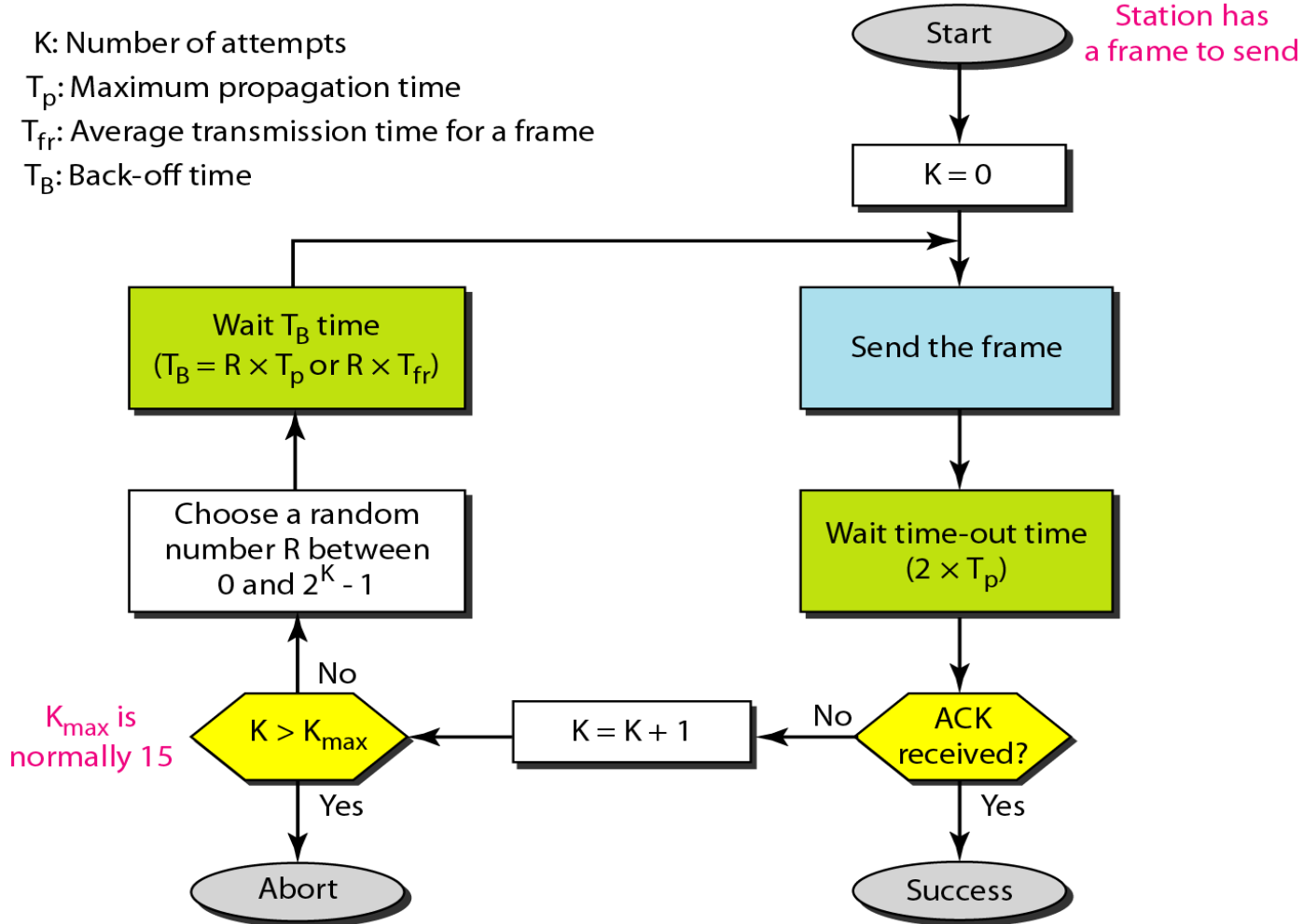- Potential collisions, all incoming data is @ 407 MHz

ALOHA

Pure ALOHA Random Access

❖ **Each station sends a frame whenever it has a frames to send.**

❖**However, there is only one channel to share and there is the possibility of collision between frames from different stations.**

Figure 12.3 *Frames in a pure ALOHA network*

ALOHA

K: Number of attempts
T_p: Maximum propagation time
T_{fr}: Average transmission time for a frame
T_B: Back-off time

Start

Station has a frame to send

K = 0

Send the frame

Wait T_B time
$(T_B = R \times T_p \text{ or } R \times T_{fr})$

Wait time-out time
$(2 \times T_p)$

Choose a random number R between 0 and 2^K - 1

No

K_{max} is normally 15

K > K_{max}

No

K = K + 1

No

ACK received?

Yes

Yes

Abort

Success

Figure 12.4 *Procedure for pure ALOHA protocol*

ALOHA Protocol Rule

❑ **Acknowledgement**

  ❖ **After sending the frame, the station waits for an acknowledgment**

  ❖ **If it does not receive an acknowledgement during the**

   2 times the maximum propagation delay between the two widely separated stations (2 x T_p)

  ❖ **It assumes that the frame is lost; it tries sending again after**

   a random amount of time (T_B =R x T_P , or R x T_{fr}).

   - **T_p (Maximum propagation time)= distance / propagation speed**
   - **T_B (Back off time) : common formula is binary exponential back-off**
     – **R is random number chosen between 0 to 2^k - 1**
     – **K is the number of attempted unsuccessful transmissions**
   - **T_{fr} (the average time required to send out a frame)**

ALOHA

Figure 12.5 *Vulnerable time for pure ALOHA protocol*
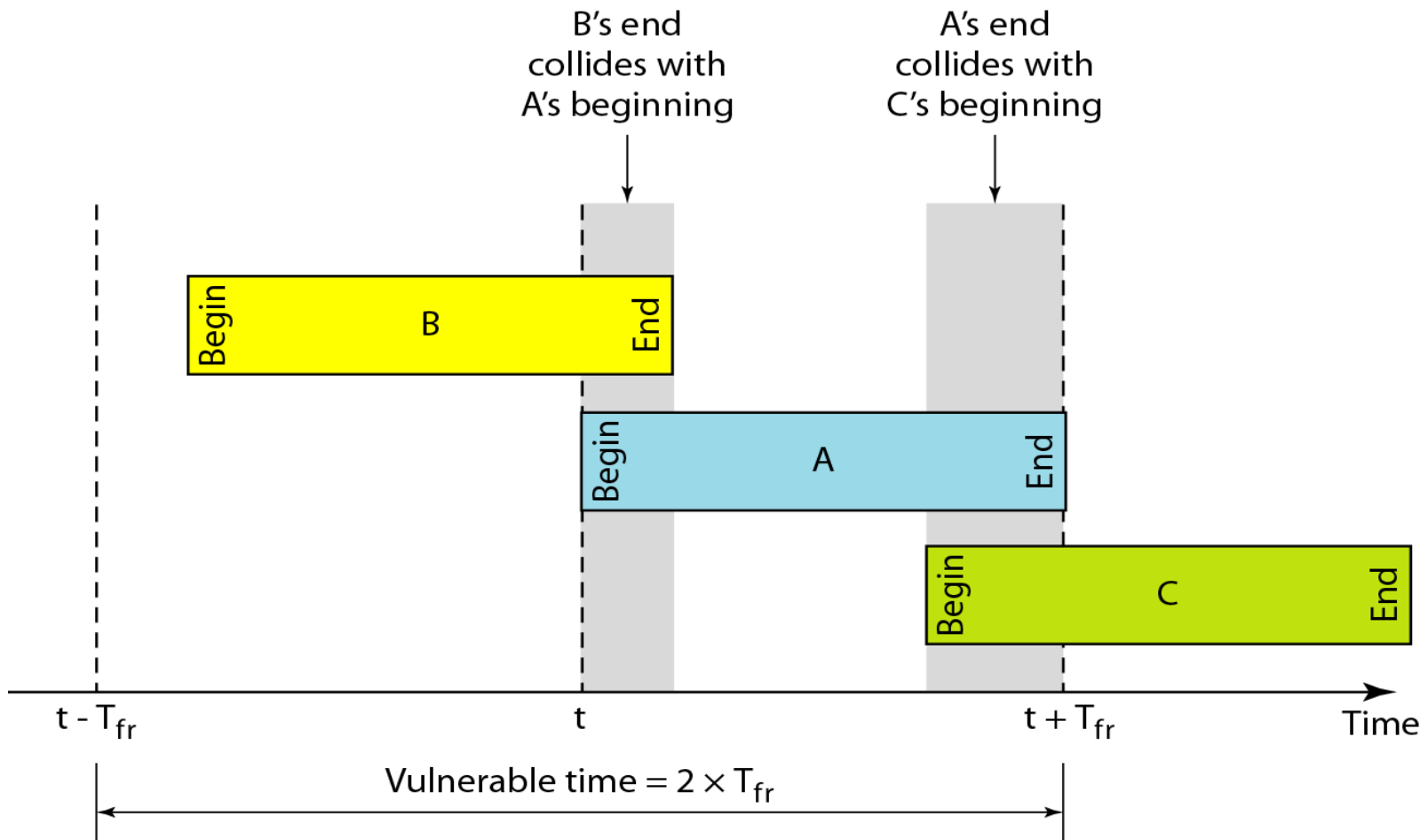
The throughput for pure ALOHA is
$$S = G \times e^{-2G}$$
The maximum throughput
$$S_{max} = 0.184 \text{ when } G = (1/2).$$

* If one-half a frame is generated during one frame transmission time, then 18.4 percent of these frames reach their destination successfully.
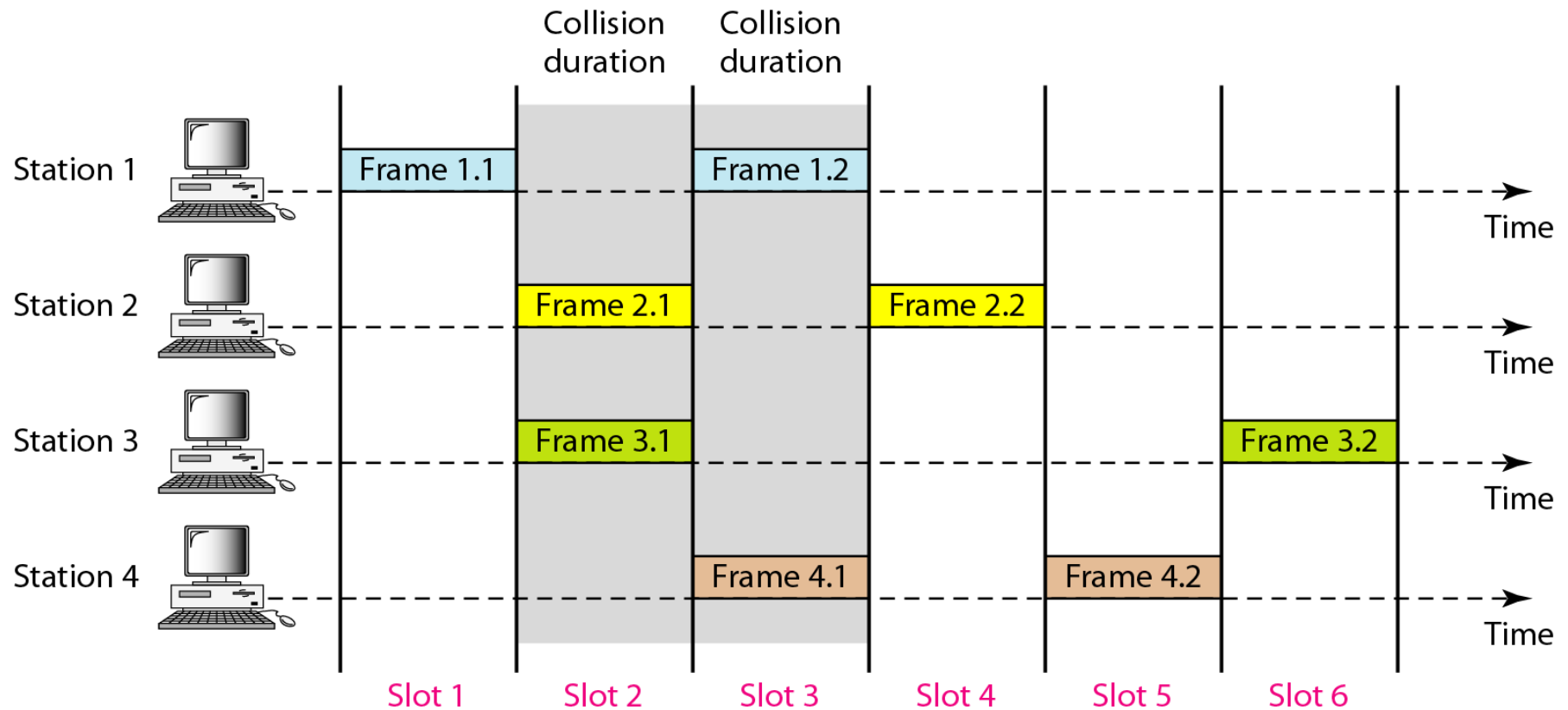
❖ **S is the average number of successful transmissions, called throughput.**

❖ **G is the average number of frames generated by the system during one frame transmission time.**

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Slotted ALOHA

❑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.**

Figure 12.6 *Frames in a slotted ALOHA network*

Slotted ALOHA

Note

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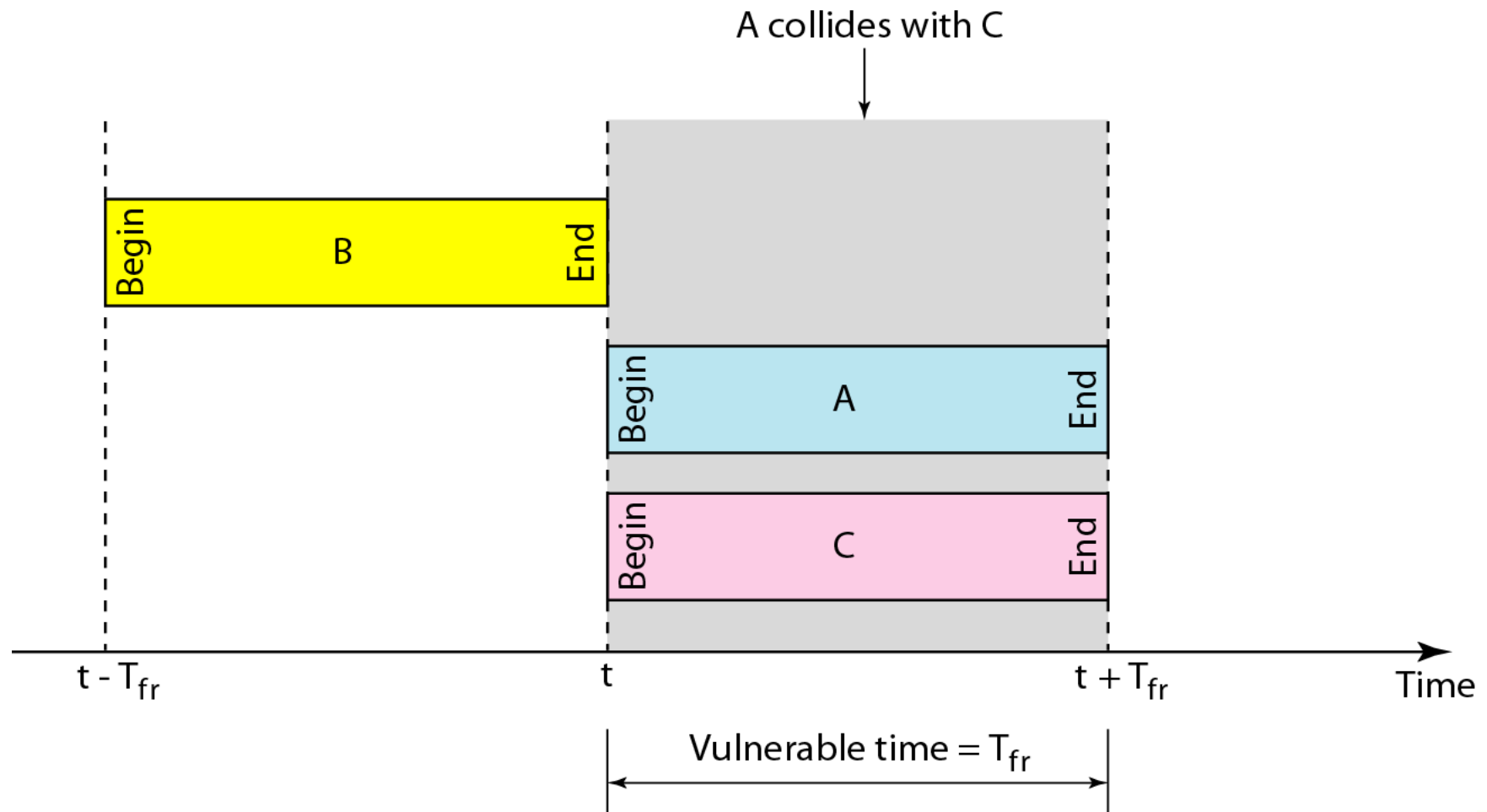$$S = G \times e^{-G}.$$
The maximum throughput
$$S_{max} = 0.368 \text{ when } G = 1.$$

- If a frame is generated during one frame transmission time, then 36.8 percent of these frames reach their destination successfully.

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Slotted ALOHA

❖ **Slotted ALOHA vulnerable time = T_{fr}**

Figure 12.7 *Vulnerable time for slotted ALOHA protocol*

Carrier Sense Multiple Access (CSMA)

❑ **To minimize the chance of collision and, therefore, increase the performance, the CSMA method was developed.**

❑ **CSMA is based on the principle "sense before transmit" or "listen before talk."**

❑ **CSMA can reduce the possibility of collision, but it cannot eliminate it.**

   ❖ **The possibility of collision still exists because of propagation delay; a station may sense the medium and find it idle, only because the first bit sent by another station has not yet been received.**

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Carrier Sense Multiple Access (CSMA)
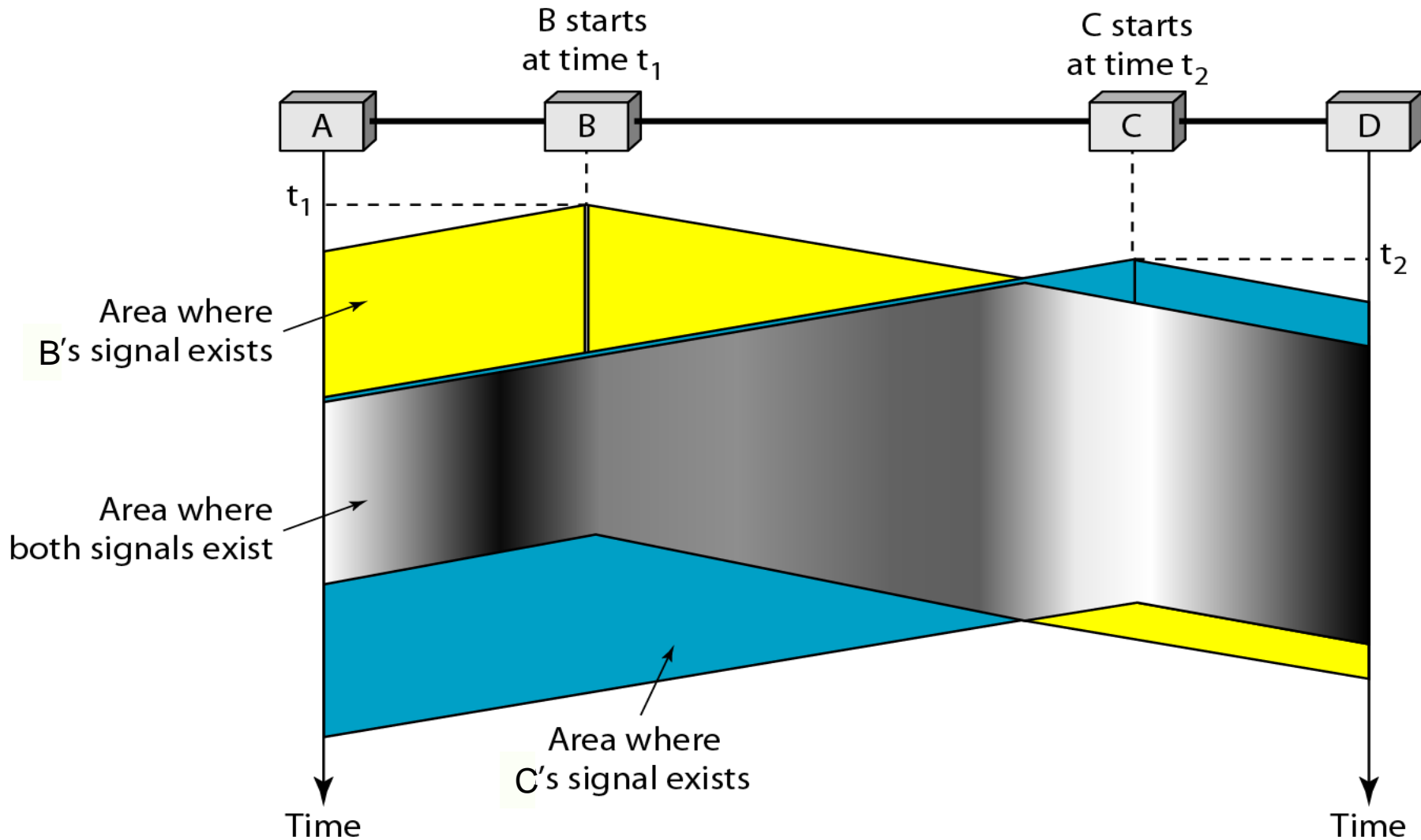
Figure 12.8 *Space/time model of the collision in CSMA*
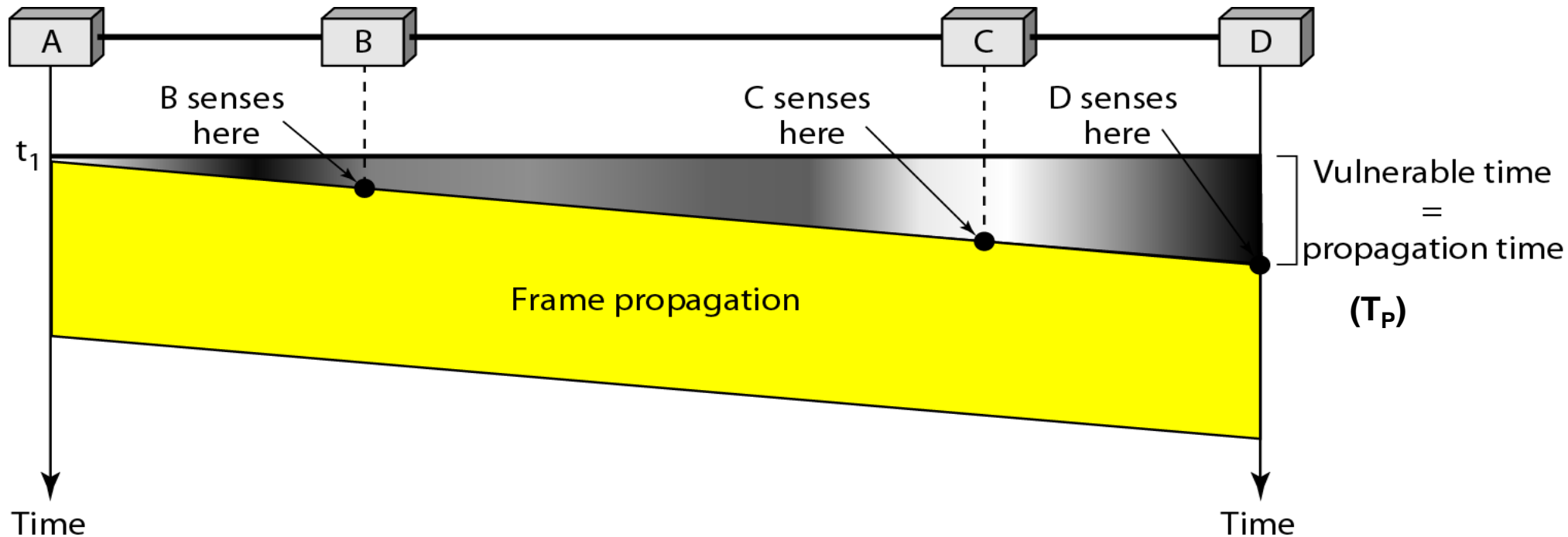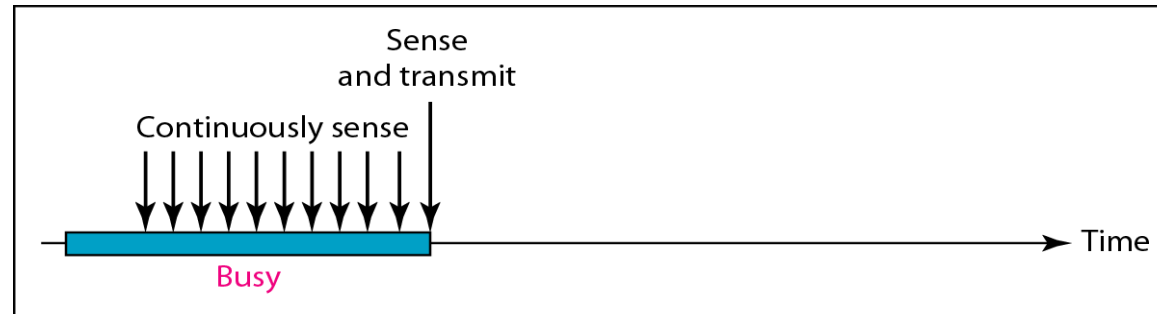
Carrier Sense Multiple Access (CSMA)

**Figure 12.9** *Vulnerable time in CSMA*

Persistence methods

❑ **Persistence strategy defines the procedures for a station that senses a busy medium.**

❑ **Three strategies have been developed;**

❖ **1-persistent method : after the station finds the line idle, it sends its frame immediately (with probability 1)**

❖ **non-persistent 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.**

❖ **_p_-persistent method : After the station finds the line idle,**

- **With probability p, the station sends its frames**
- **With probability q=1-p, the station waits for the beginning of the next time slot and checks the line again.**
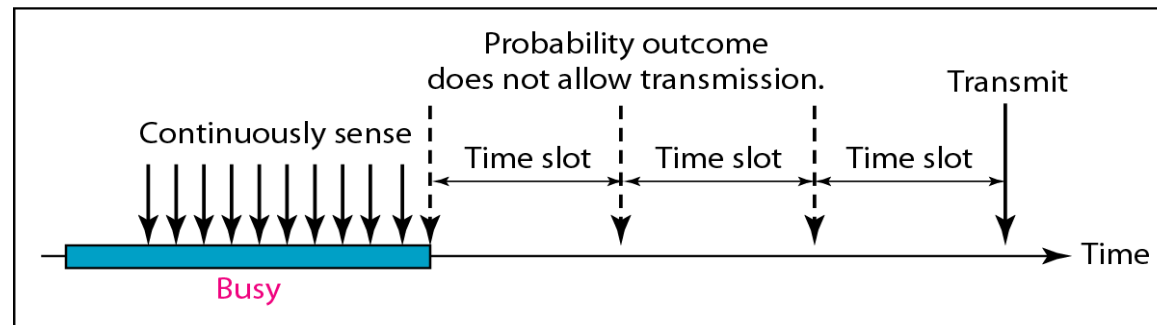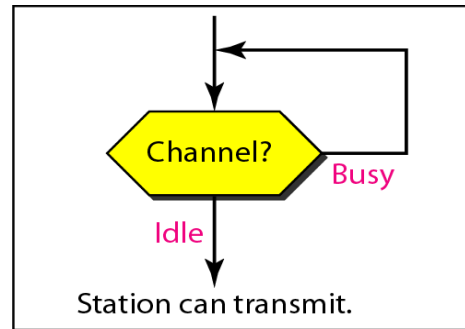
Carrier Sense Multiple Access (CSMA)
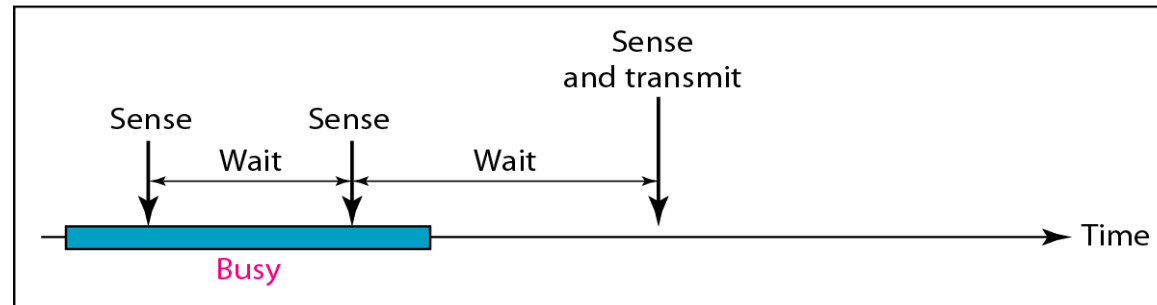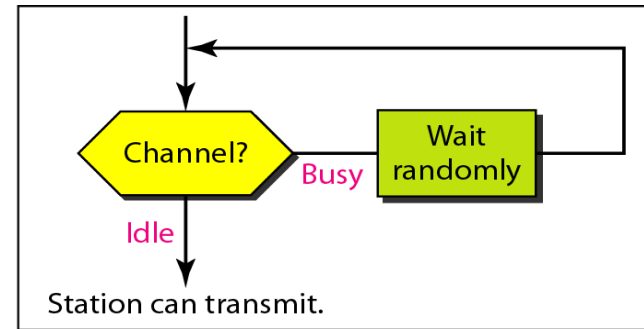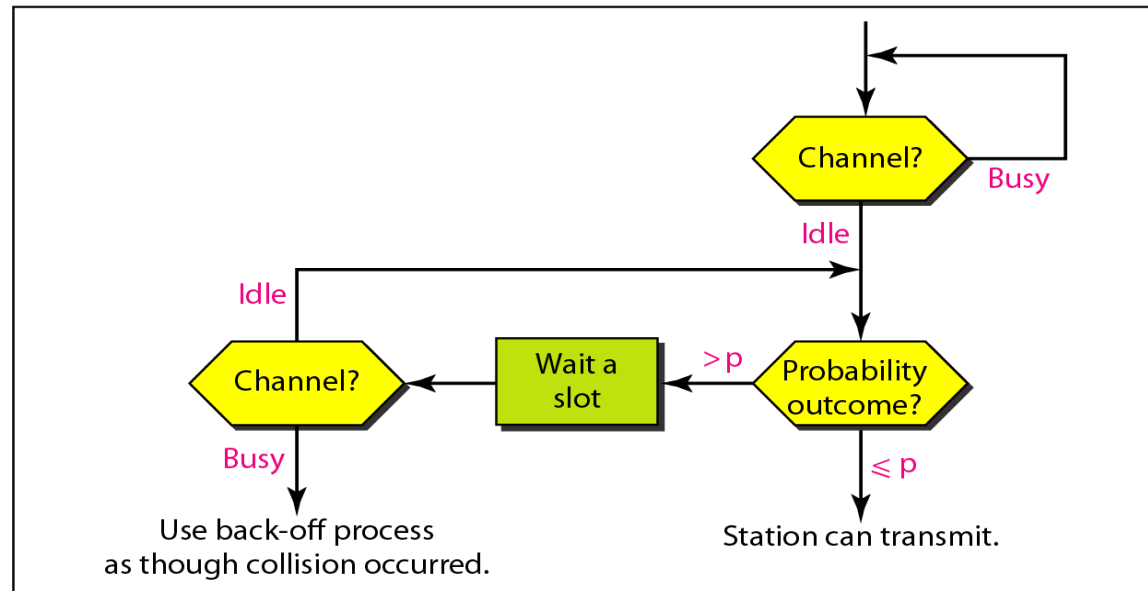

a. 1-persistent

b. Nonpersistent

c. p-persistent

Figure 12.10 **Behavior of three persistence methods**

Carrier Sense Multiple Access (CSMA)

a. 1-persistent

b. Nonpersistent

c. p-persistent

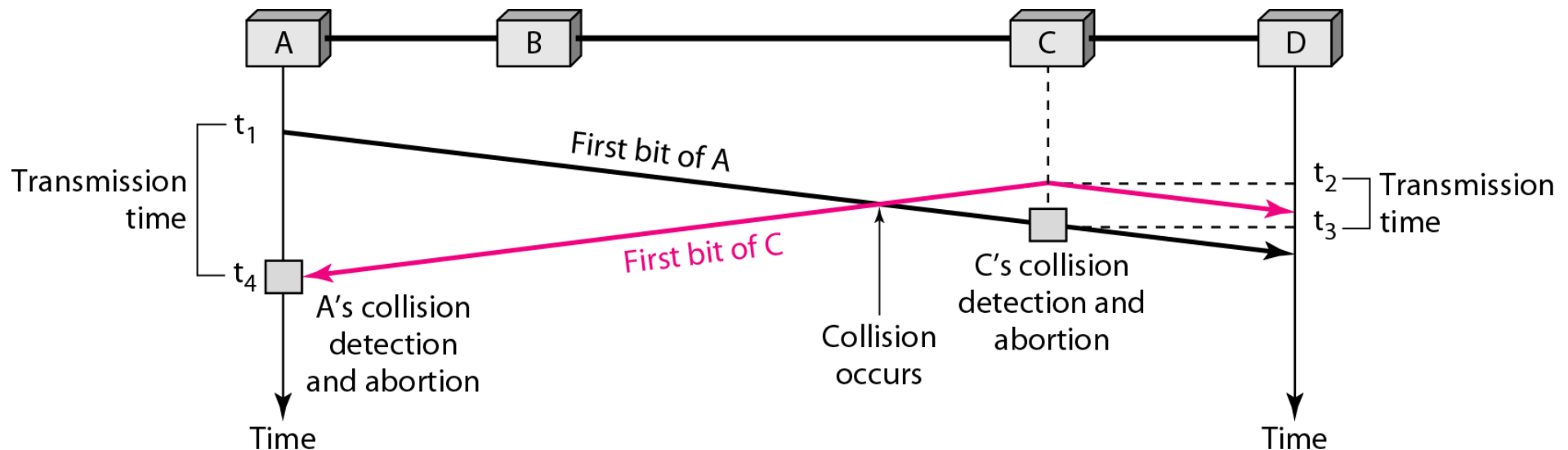**Figure 12.11** Flow diagram for three persistence methods

CSMA with Collision Detection (CSMA/CD)

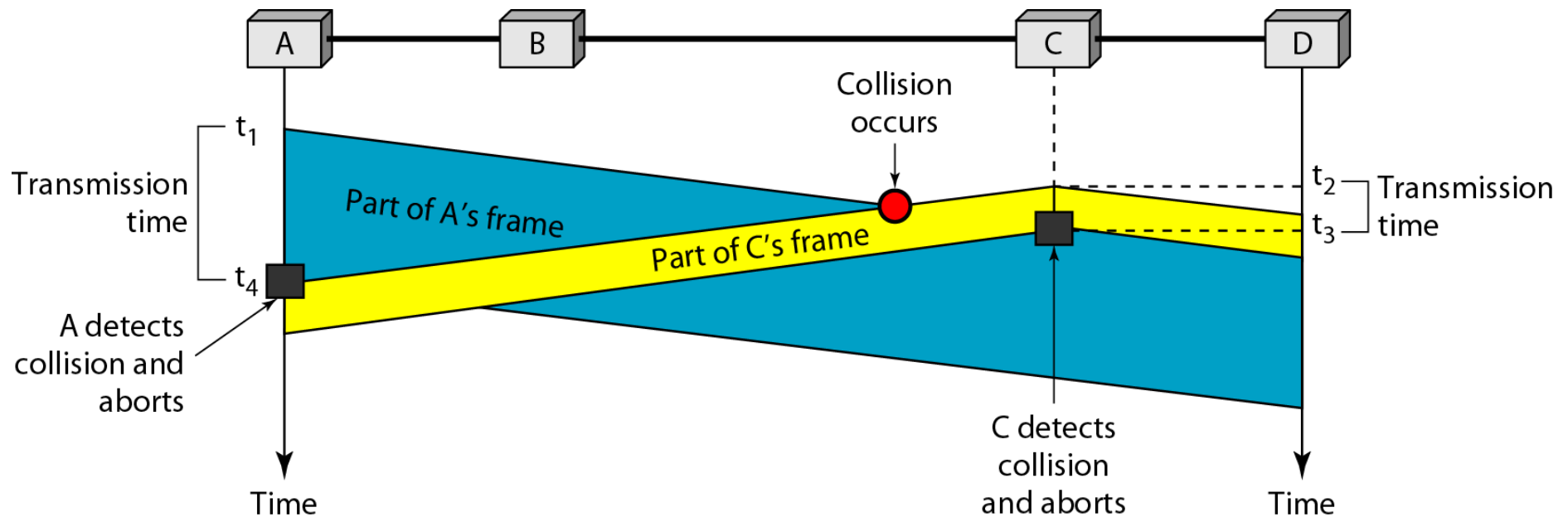❑ **CSMA/CD adds a procedure to handle the collision.**

❖ **A station monitors the medium after it sends a frame to see if the transmission was successful.**

- **If so, the station is finished.**
- **If there is a collision, the frame is sent again.**

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

CSMA with Collision Detection (CSMA/CD)

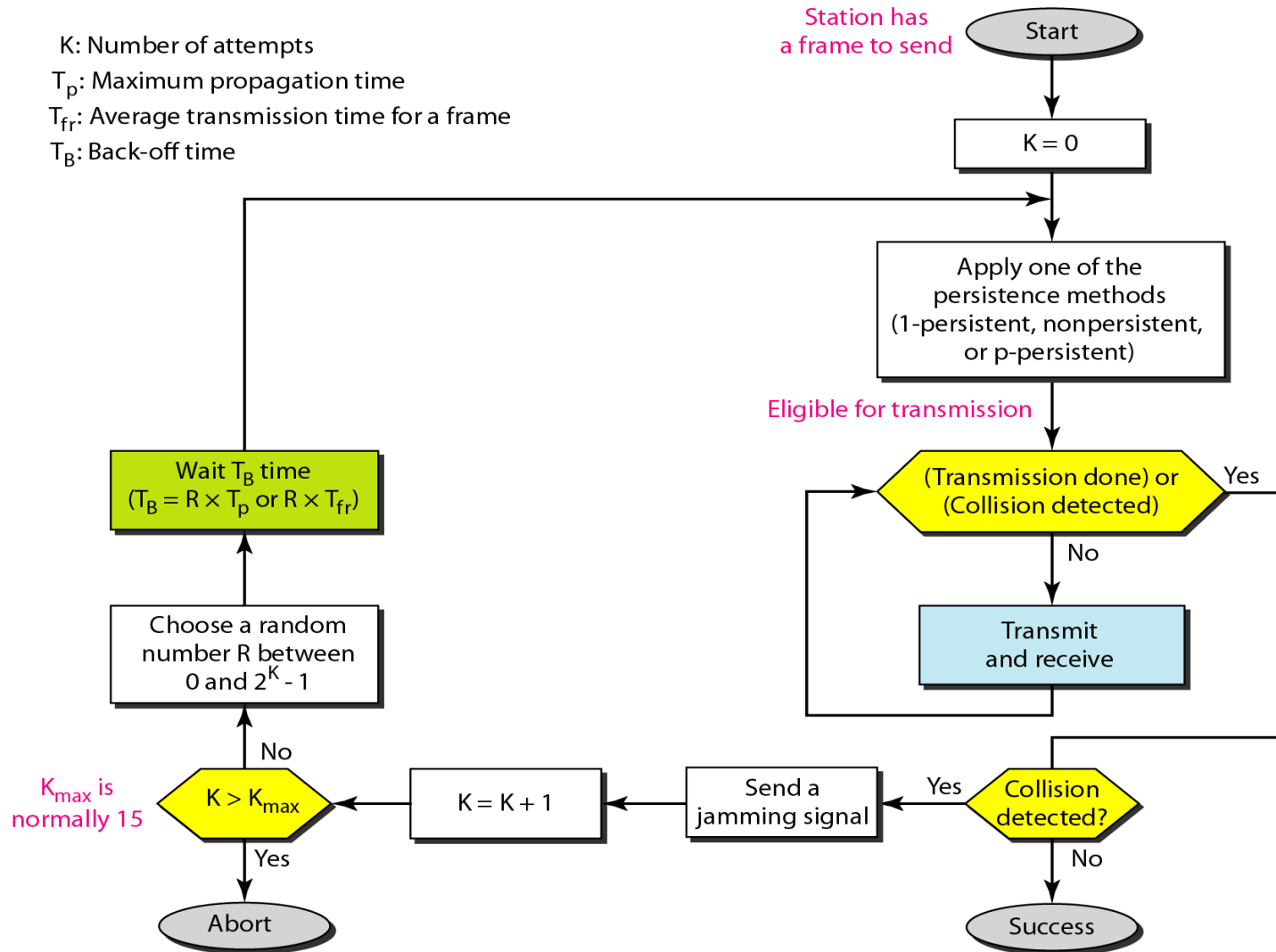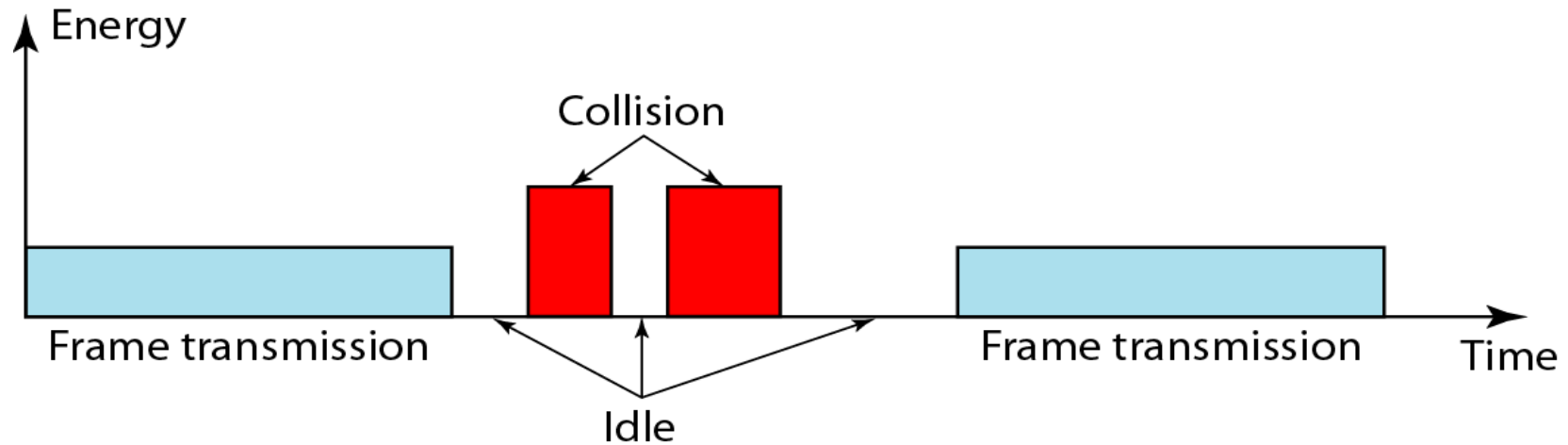Figure 12.13 *Collision and abortion in CSMA/CD*

❑Minimum Frame Size

❖**For CSMA/CD to work, we need a restriction on the frame size.**

❖**The frame transmission time T_{fr} must be at least two times the maximum propagation time T_p .**

CSMA with Collision Detection (CSMA/CD)

K: Number of attempts
T_p: Maximum propagation time
T_{fr}: Average transmission time for a frame
T_B: Back-off time

Station has a frame to send

Start

K = 0

Apply one of the persistence methods (1-persistent, nonpersistent, or p-persistent)

Eligible for transmission

(Transmission done) or (Collision detected)   Yes

No

Transmit and receive

Wait T_B time
($T_B = R \times T_p$ or $R \times T_{fr}$)

Choose a random number R between 0 and $2^K - 1$

No

K_{max} is normally 15

$K > K_{max}$

K = K + 1

Send a jamming signal   Yes   Collision detected?

Yes

No

Abort

Success

Figure 12.14 *Flow diagram for the CSMA/CD*

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CSMA with Collision Detection (CSMA/CD)

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

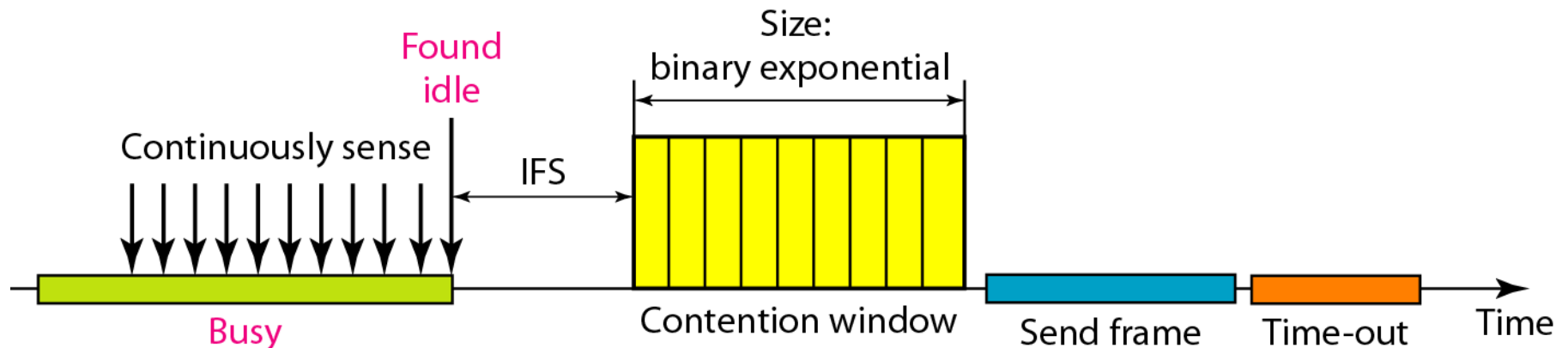❑ **CSMA/CA was invented for the wireless networks to avoid collisions.**

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

● **The interframe space, the contention window, and acknowledgments.**

Figure 12.16 *Timing in CSMA/CA*

CSMA with Collision Detection (CSMA/CD)

Note

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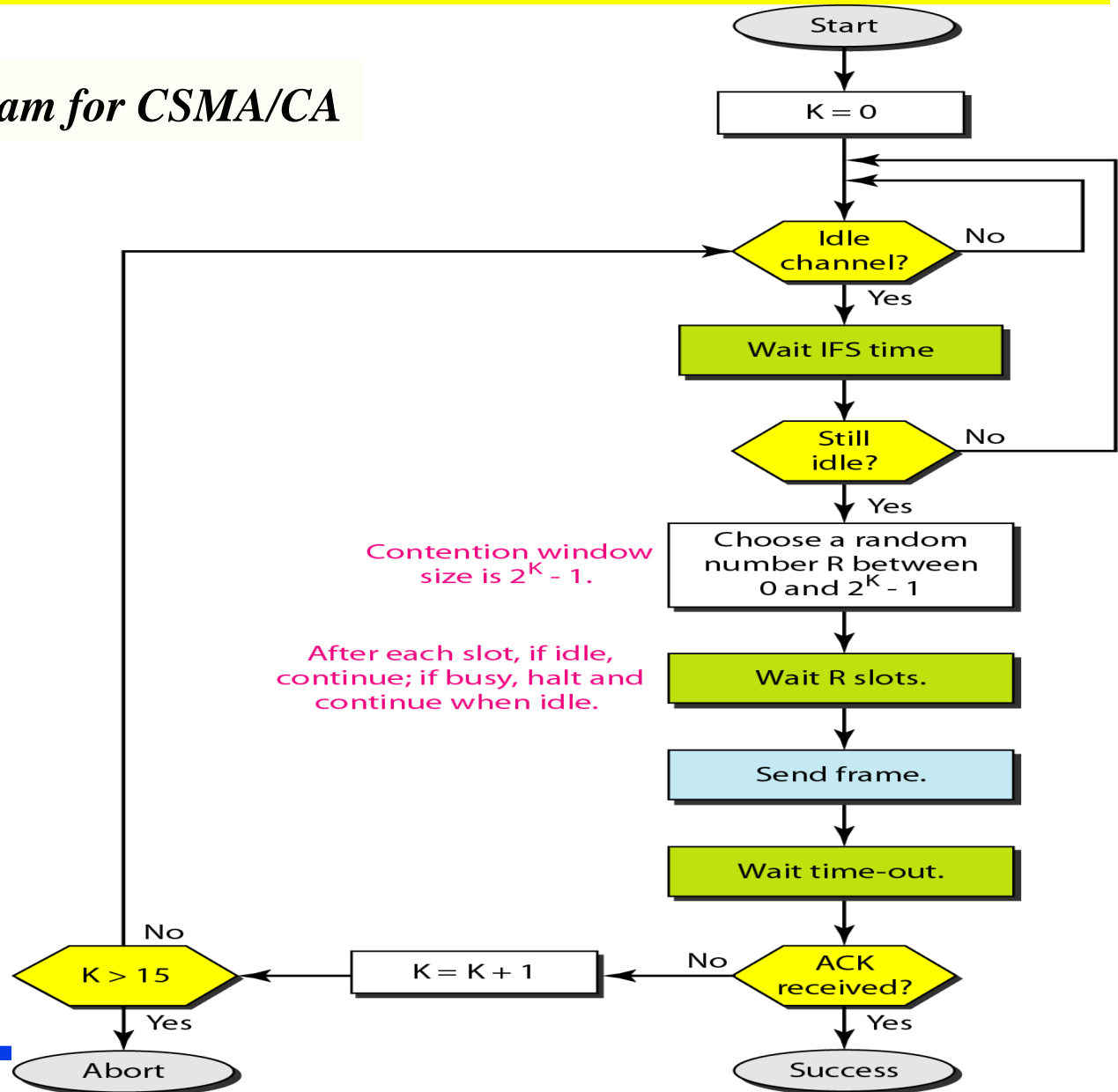
Note

**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.**

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CSMA with Collision Detection (CSMA/CD)

Figure 12.17 *Flow diagram for CSMA/CA*

Start

K = 0

Idle channel? — No

Yes

Wait IFS time

Still idle? — No

Yes

Choose a random number R between 0 and 2^K - 1

Contention window size is $2^K - 1$.

After each slot, if idle, continue; if busy, halt and continue when idle.

Wait R slots.

Send frame.

Wait time-out.

ACK received? — No

Yes → Success

K = K + 1

K > 15 — No

Yes → Abort

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

Reservation

□ **A station need to make a reservation before sending data**

❖ **In each interval, a reservation frame precedes the data frames sent in that interval.**

❖ **If there are N stations in the system, there are exactly N reservation minislots in the reservation frame. Each minislot belongs to a station.**

❖**When a station needs to send a data frame, it makes a reservation in its own minislot.**

❖**The stations that have made reservations can send their data frames after the reservation frame.**


Figure 12.18 *Reservation access method*
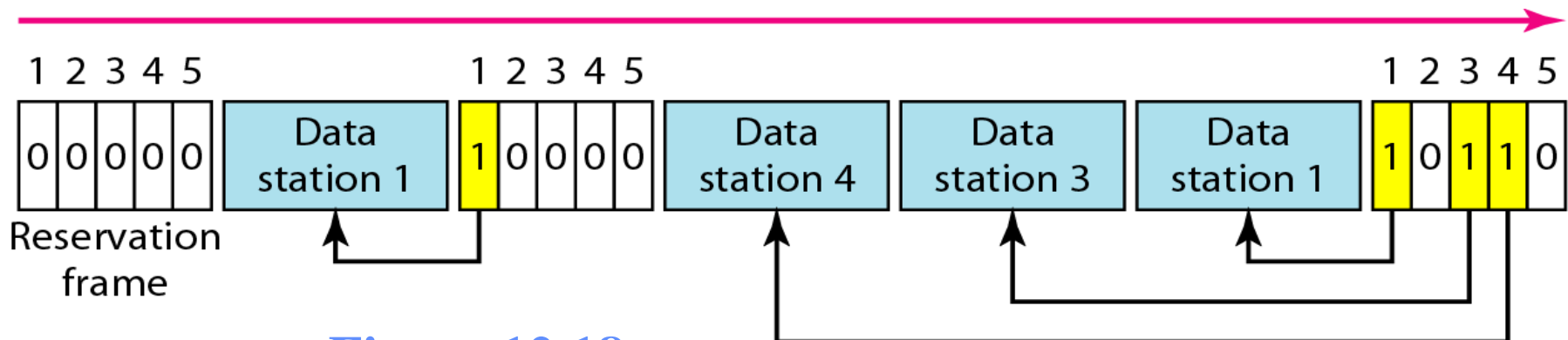
Polling

❑ **Polling works with topologies in which one device is designed as a Primary Station and the other devices are Secondary Station.**

❖ **The primary device controls the link;**

❖ **The secondary devices follow its instruction.**

❑ **Poll function : If the primary wants to receive data, it asks the secondaries if they have anything to send.**

❑ **Select function : If the primary wants to send data, it tells the secondary to get ready to receive.**
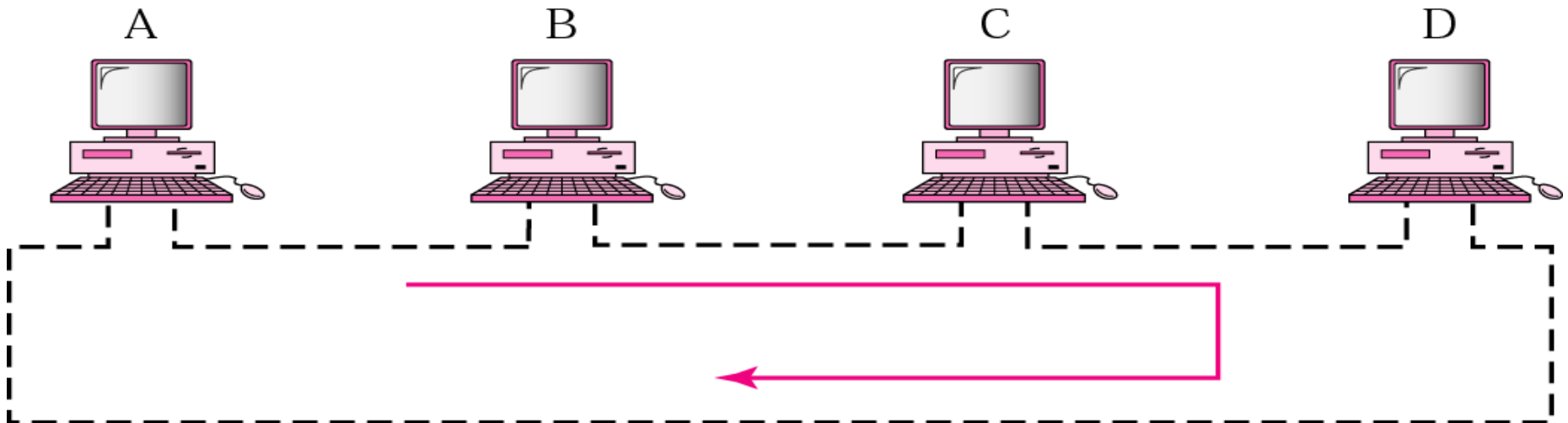
Polling
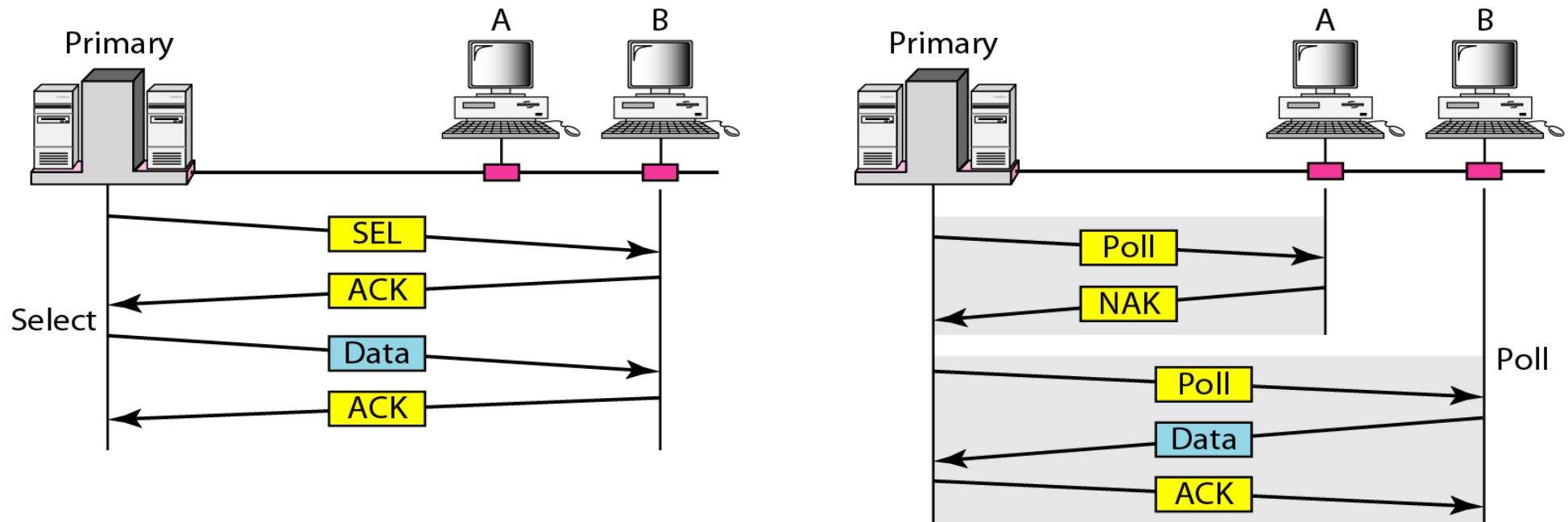
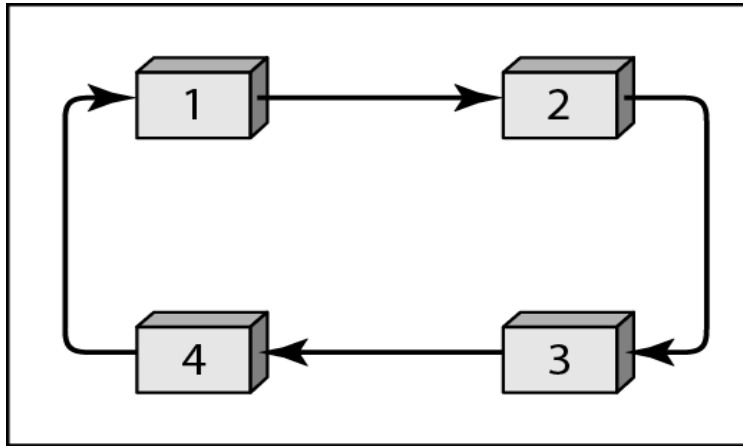**Figure 12.19** *Select and poll functions in polling access method*
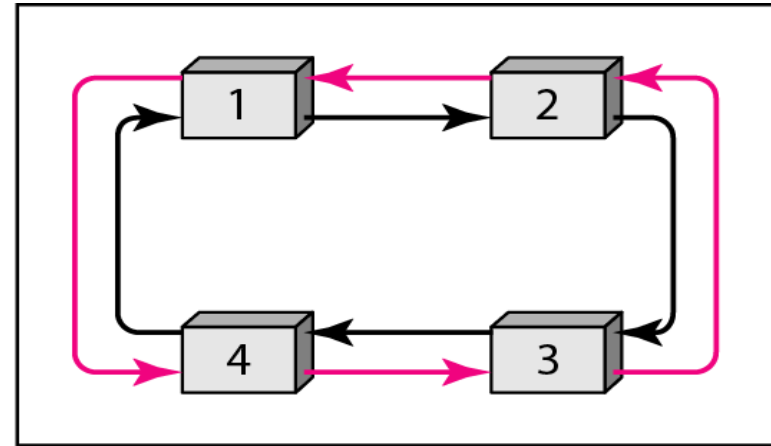
Token-passing network

❑ **A station is authorized to send data when it receives a special frame called a token**
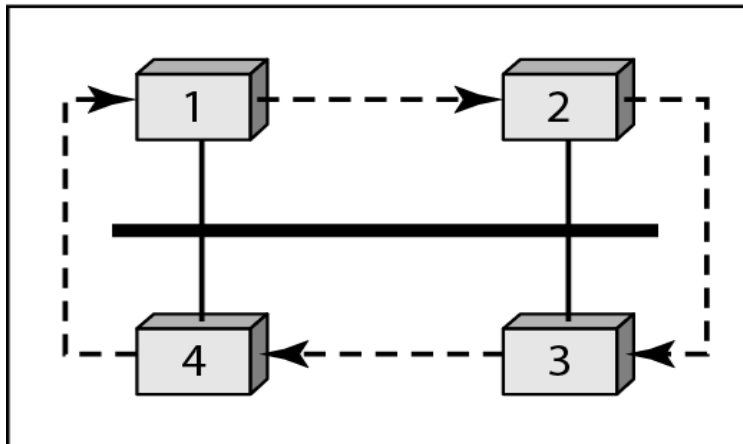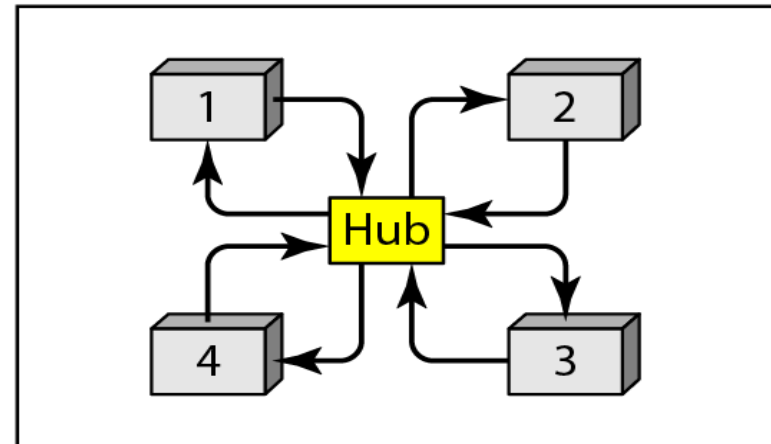
a. Physical ring

b. Dual ring

c. Bus ring

d. Star ring

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

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)

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FDMA

❑ **The available bandwidth is shared by all stations.**

❑ **The FDMA is a data link layer protocol that uses FDM at the physical layer**

In FDMA, the available bandwidth of the common channel is divided into bands that are separated by guard bands.
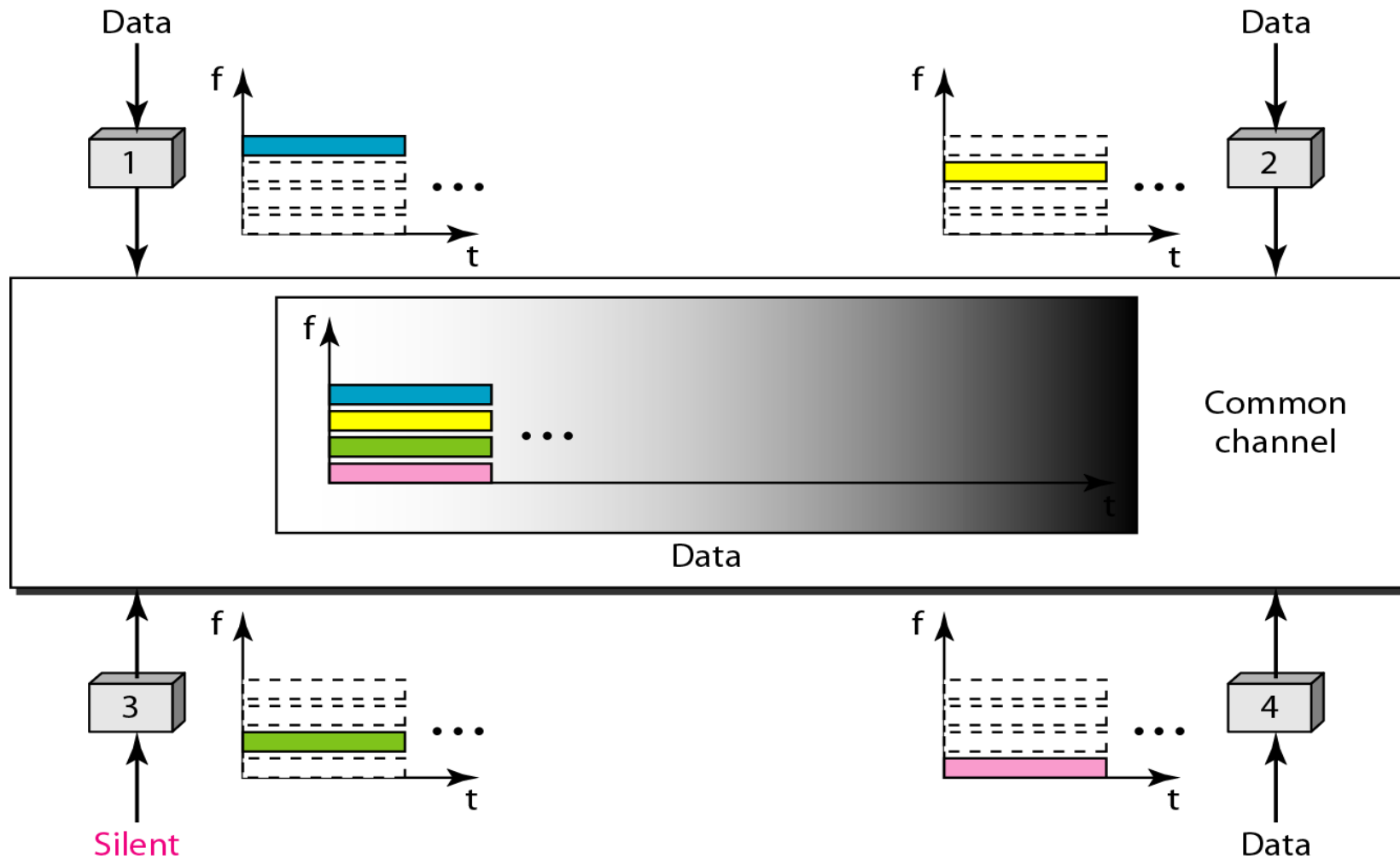
Figure 12.21 *Frequency-division multiple access (FDMA)*

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TDMA

❑ **The entire bandwidth is just one channel.**

❑ **Stations share the capacity of the channel in time**

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

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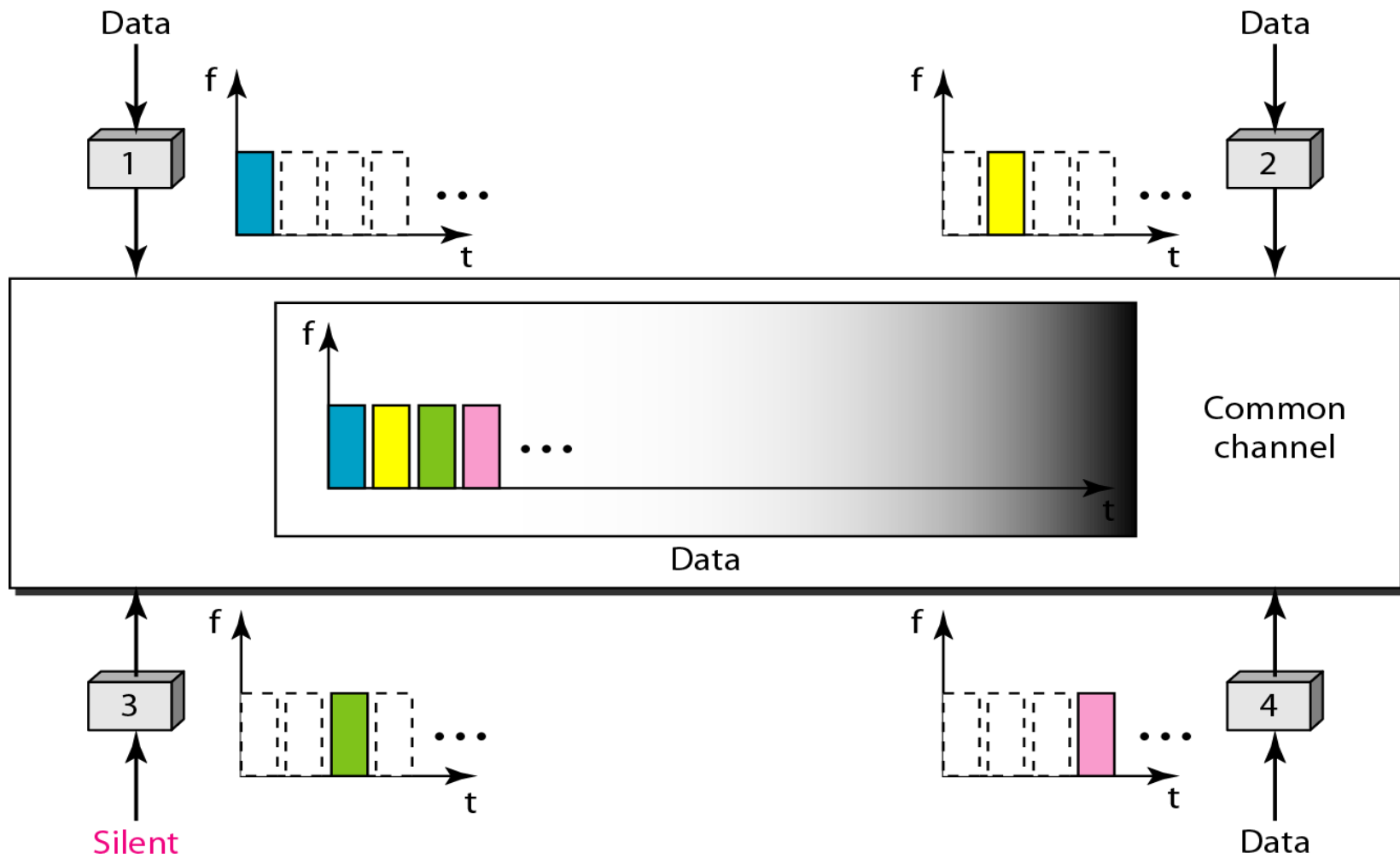
CDMA

❑ **CDMA differs from FDMA because only one channel occupies the entire bandwidth of the link.**

❑ **It differs from TDMA because all stations can send data simultaneously; there is no time sharing.**

In CDMA, one channel carries all transmissions simultaneously.

The diagram shows four stations connected to a common channel:

- Station 1: input d_1, output $d_1 \cdot c_1$
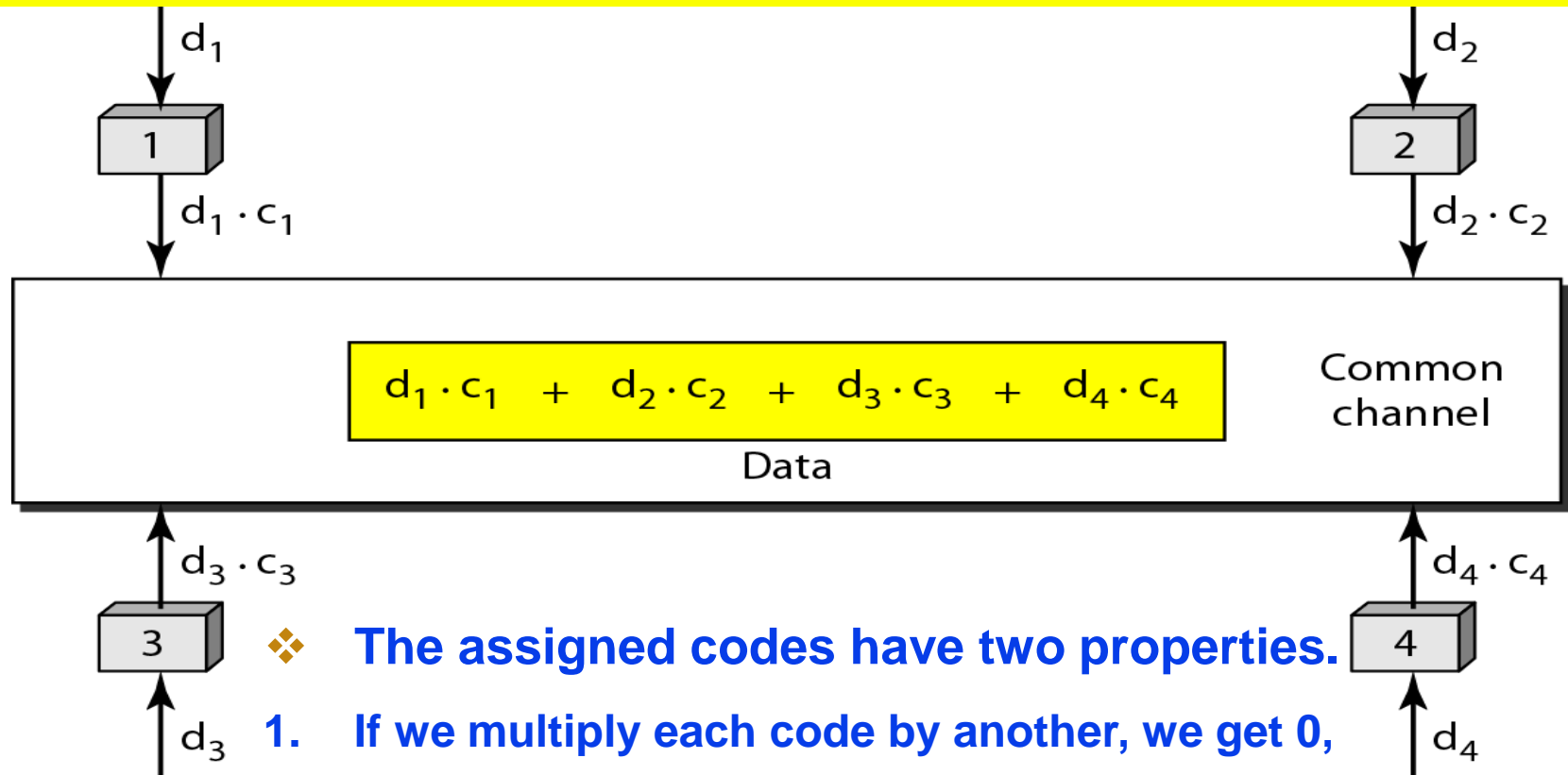- Station 2: input d_2, output $d_2 \cdot c_2$
- Station 3: input d_3, output $d_3 \cdot c_3$
- Station 4: input d_4, output $d_4 \cdot c_4$

Common channel Data:

$$d_1 \cdot c_1 \;+\; d_2 \cdot c_2 \;+\; d_3 \cdot c_3 \;+\; d_4 \cdot c_4$$

❖ **The assigned codes have two properties.**

1. **If we multiply each code by another, we get 0,**
2. **If we multiply each code by itself, we get 4**
   (the number of stations)

ex) Data = ($d_1 c_1 + d_2 c_2 + d_3 c_3 + d_4 c_4$) x c_1 = 4 x d_1

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Figure 12.23 *Simple idea of communication with code*

CDMA

❑ **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*

C_1

[+1 +1 +1 +1]

C_2

[+1 -1 +1 -1]

C_3

[+1 +1 -1 -1]

C_4

[+1 -1 -1 +1]
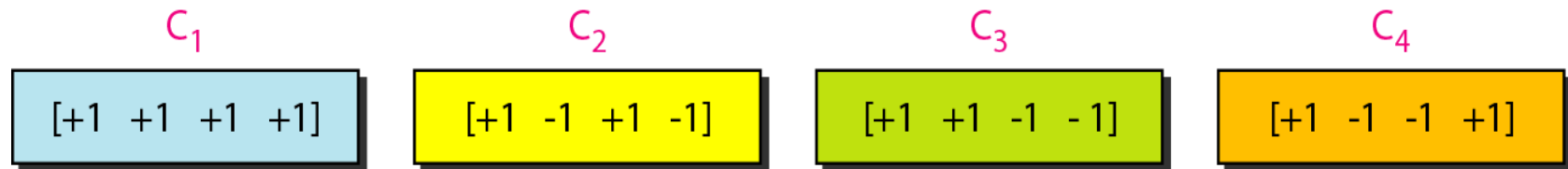
❑ **Orthogonal sequences**

   (1) Inner-product of two equal sequences

     ○ **A•A = N**

     ○ **If we multiply two different sequences, element by element, and add the results, we get 0.**
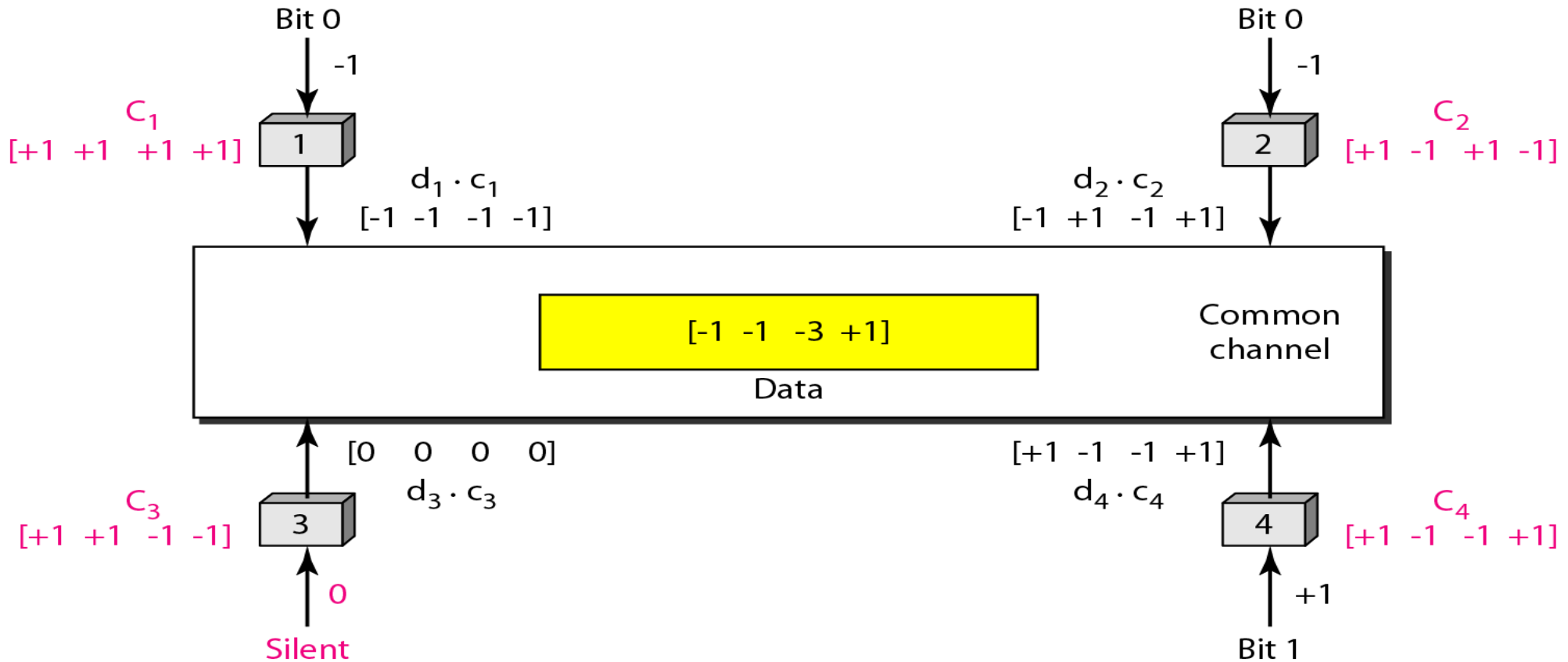
       A•B = 0

   (2) A•(-A) = -N

CDMA – Data Representation

❑ **When a station is idle, it sends no signal, which is represented by a 0.**

Figure 12.25 *Data representation in CDMA*

Data bit 0 ⟶ -1	Data bit 1 ⟶ +1	Silence ⟶ 0

Encoding and Decoding

Bit 0
-1

C_1
[+1 +1 +1 +1]

1

$d_1 \cdot c_1$
[-1 -1 -1 -1]

Bit 0
-1

C_2
[+1 -1 +1 -1]

2

$d_2 \cdot c_2$
[-1 +1 -1 +1]

[-1 -1 -3 +1]

Data

Common
channel

[0 0 0 0]
$d_3 \cdot c_3$

[+1 -1 -1 +1]
$d_4 \cdot c_4$

C_3
[+1 +1 -1 -1]

3

0

Silent

C_4
[+1 -1 -1 +1]

4

+1

Bit 1

Figure 12.26 *Sharing channel in CDMA*

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Encoding and Decoding

Bit 0 → 1 → [-1 -1 -1 -1]

Bit 0 → 2 → [-1 +1 -1 +1]

Silent → 3 → [0 0 0 0]

Bit 1 → 4 → [+1 -1 -1 +1]
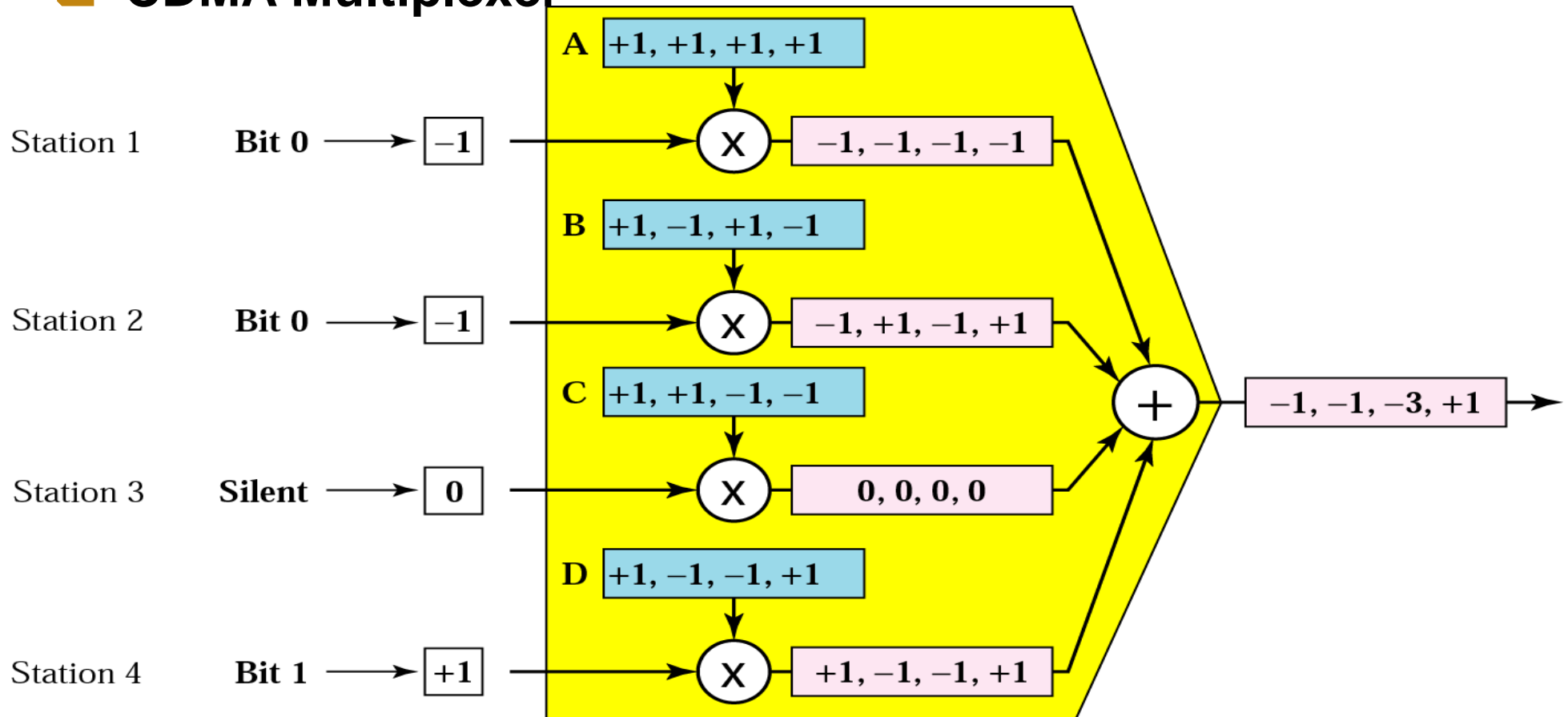
Data on the channel
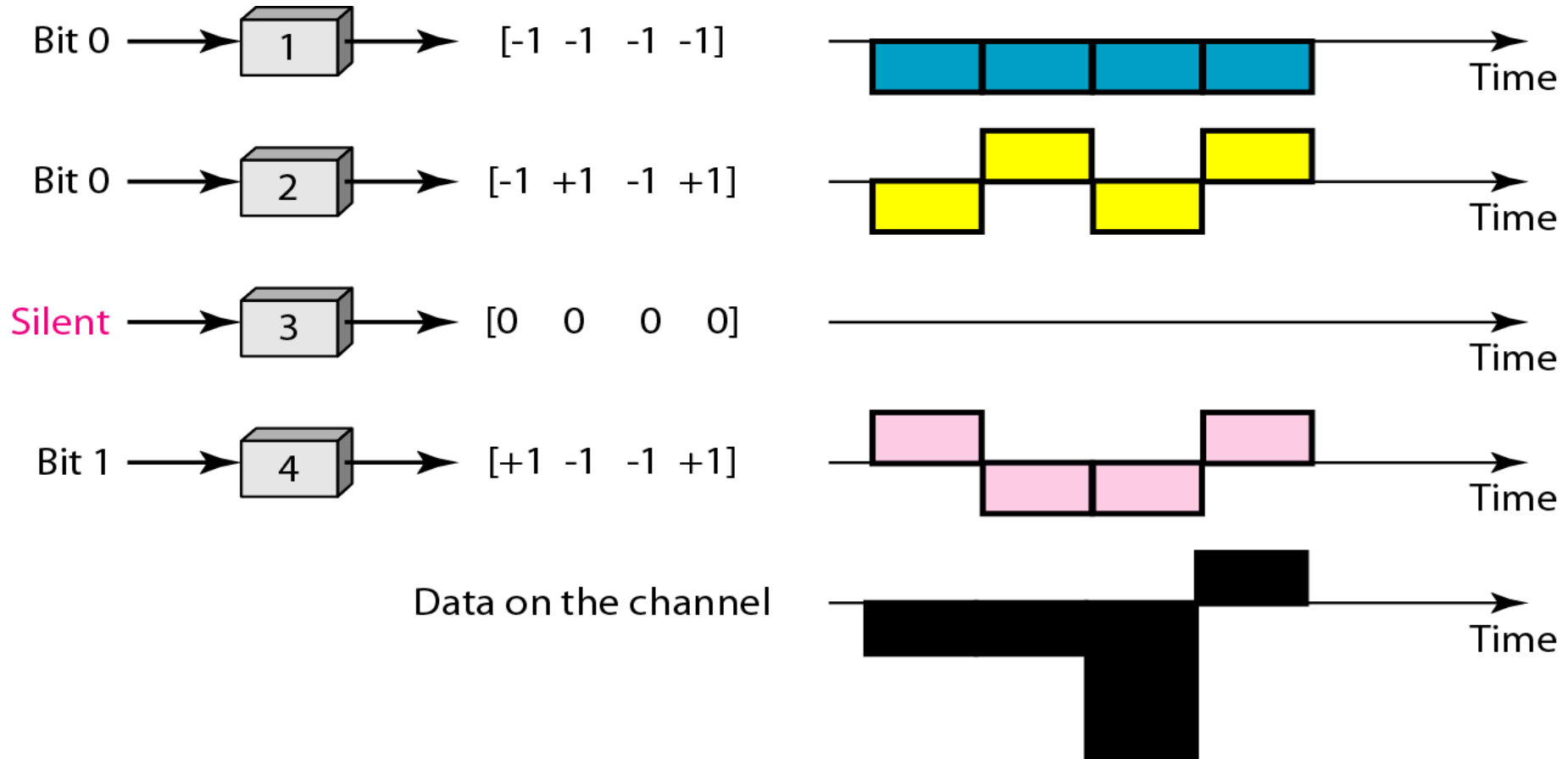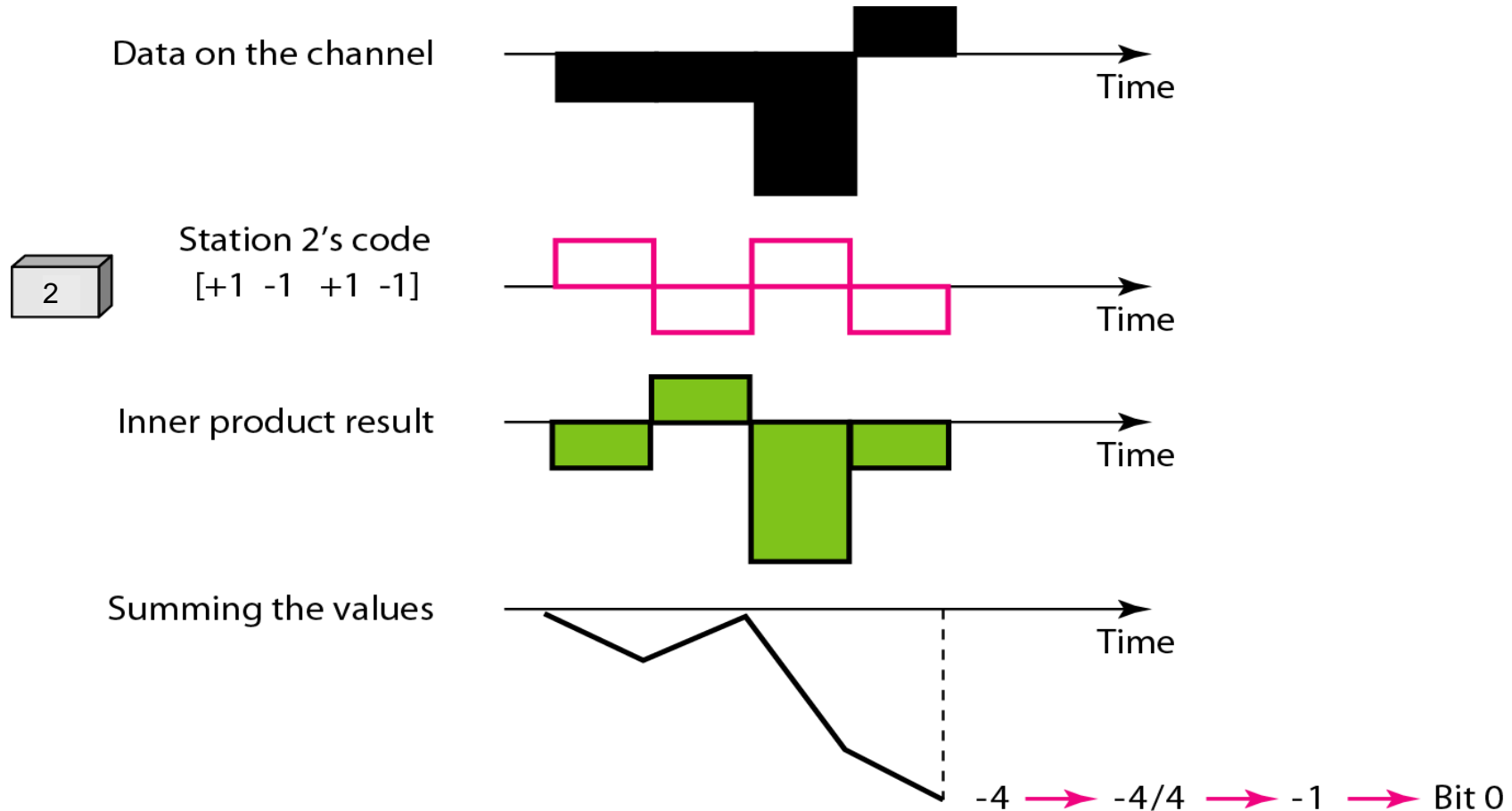
Figure 12.27 *Digital signal created by four stations in CDMA*

CDMA - Encoding Rules

❑ **Showing how four stations share the link during 1-bit interval.**
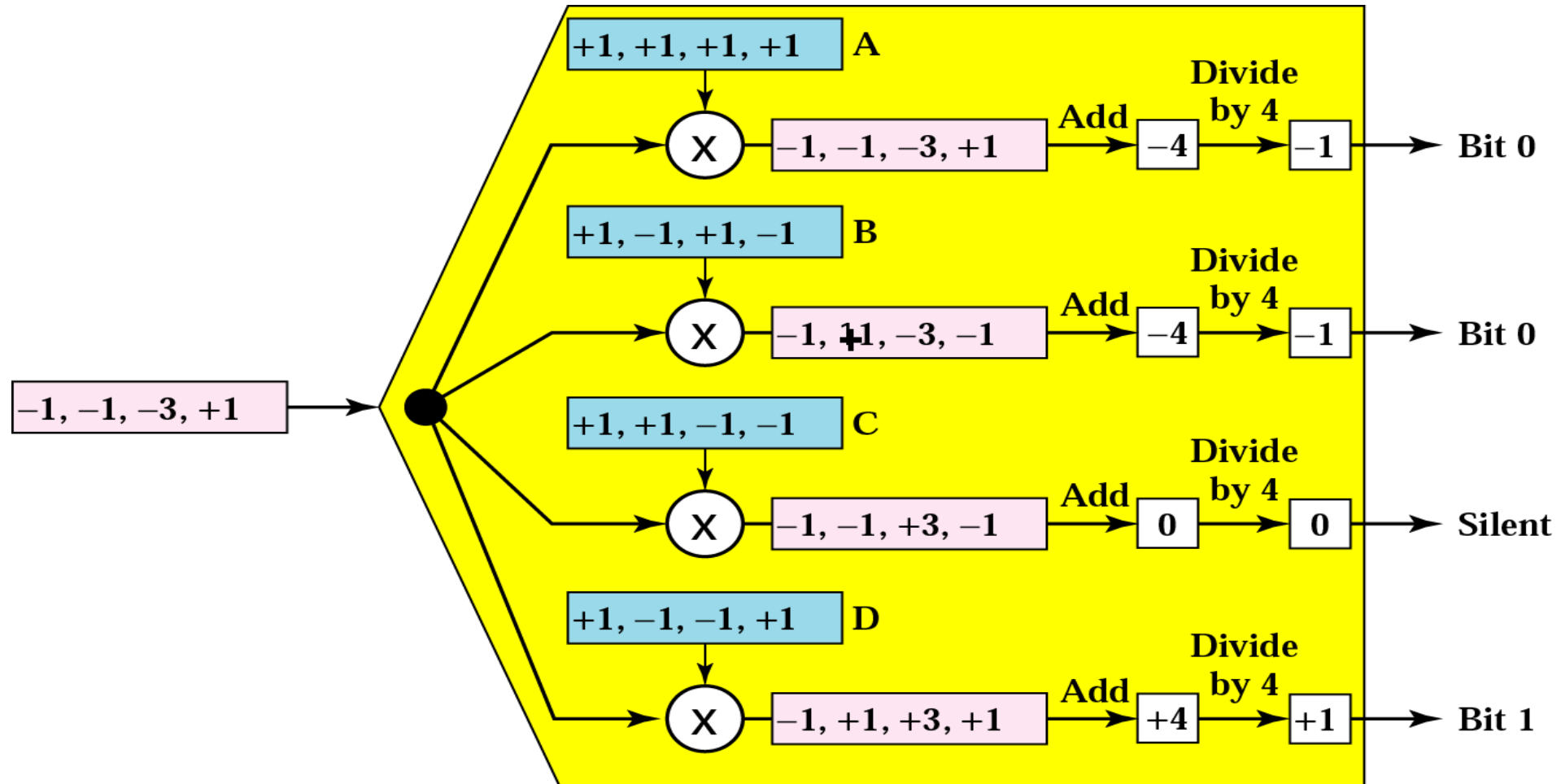
❑ **CDMA Multiplexer**

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

CDMA - Encoding Rules

❑ **CDMA Demultiplexer**

CDMA - Sequence Generation

❑ **To generate sequences, we use a Walsh table, a two-dimensional table with an equal number of rows and columns.**

❑ **Each row is a sequence of chips**

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
$$[+1\ +1]\ \text{and}\ [+1\ -1].$$

b. For a four-station network we have
$$[+1\ +1\ +1\ +1],\ [+1\ -1\ +1\ -1],$$
$$[+1\ +1\ -1\ -1],\ \text{and}\ [+1\ -1\ -1\ +1].$$

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.

• We can consider the data link layer as two sublayers. The upper sublayer is responsible for data link control, and the lower sublayer is responsible for resolving access to the shared media.

•Many formal protocols have been devised to handle access to a shared link. We categorize them into three groups: random access protocols, controlled access protocols, and channelization protocols.

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

•ALOHA allows multiple access (MA) to the shared medium. There are potential collisions in this arrangement. 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.

Summary (2)

• 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 before sending. Three methods have been devised for carrier sensing: 1-persistent, nonpersistent, and p-persistent.

• Carrier sense multiple access with collision detection (CSMA/CD) arguments the CSMA algorithm to handle 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

• To avoid collision on wireless networks, carrier send multiple access with collision avoidance (CSMA/CA) was invented. Collisions are avoided through the use three strategies: the Interframe space, the contention window, and acknowledgments.

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• 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 station. We discussed three popular controlled-access methods: reservation, polling, and token passing.

• In the reservation access 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 send in that interval.

• In the polling method, 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

• In the token-passing method, the stations in a network are organized in a logical ring. Each station has a predecessor and a successor. A special packet called a token circulates through the ring.

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Summary (4)

- 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. We discussed three channelization protocols: FDMA, TDMA, and CDMA.
- 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
- In time-division multiple access (TDMA), the stations share the bandwidth of the cannel in time. Each station is allocated a time slot during which it can send data. Each station transmits its data in its data in its assigned time slot.
- In code-division multiple access (CDMA), the stations use different codes to achieve multiple access. CDMA is based on coding theory and used sequences of numbers called chips. The sequences are generated using orthogonal codes such the Walsh tables.

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Q and A

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