Medium Access Control

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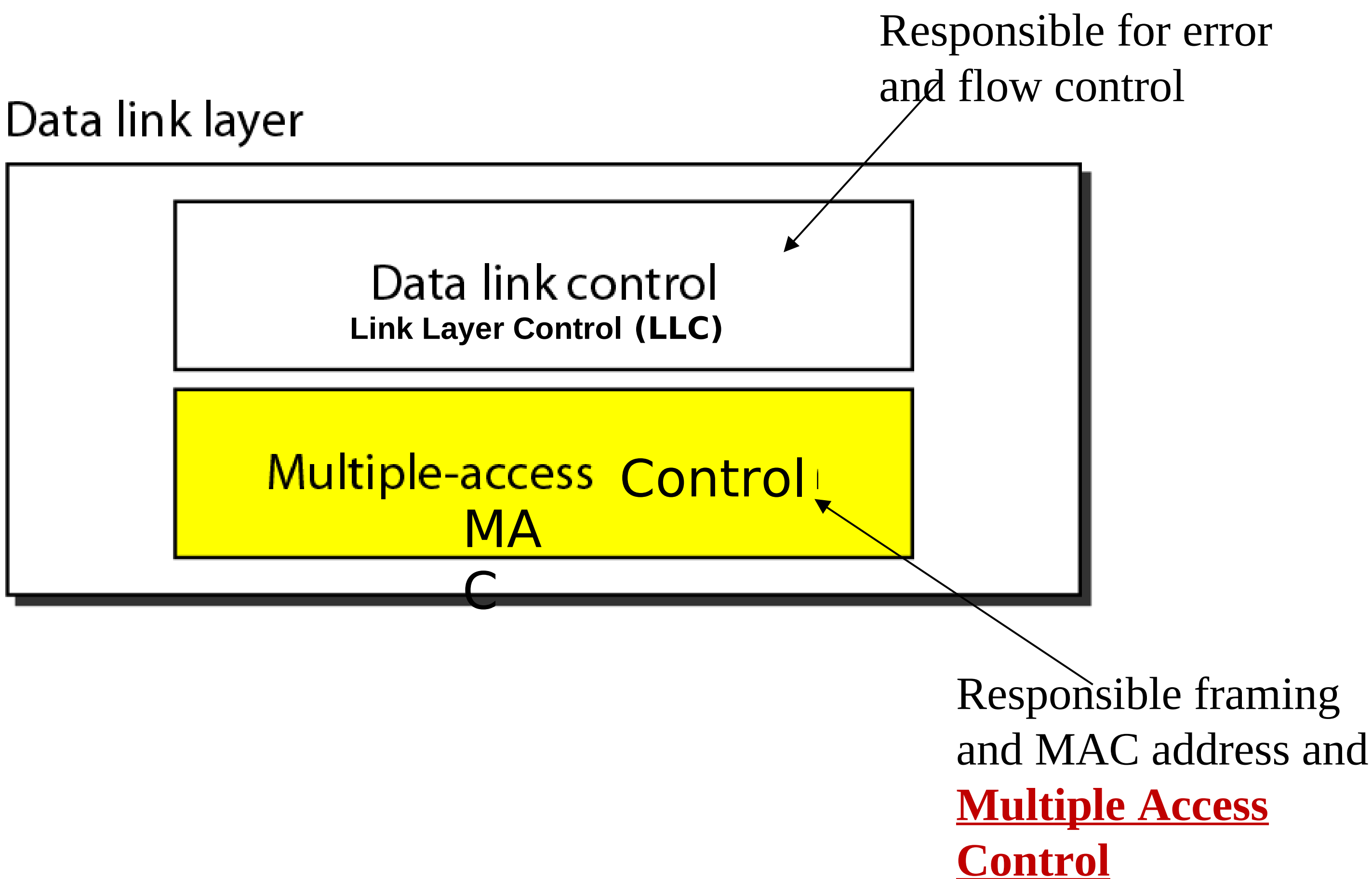
- Medium access control
- Taxonomy of multiple access protocols
- Random access protocols
- Controlled access protocols
- Channelization protocols

Multiple Access - Introduction

- Broadcast link used in LAN consists of multiple sending and receiving nodes connected to or use a single shared link
- Broadcast link examples
  - Ethernet
  - Wireless network
  - Satellite network

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



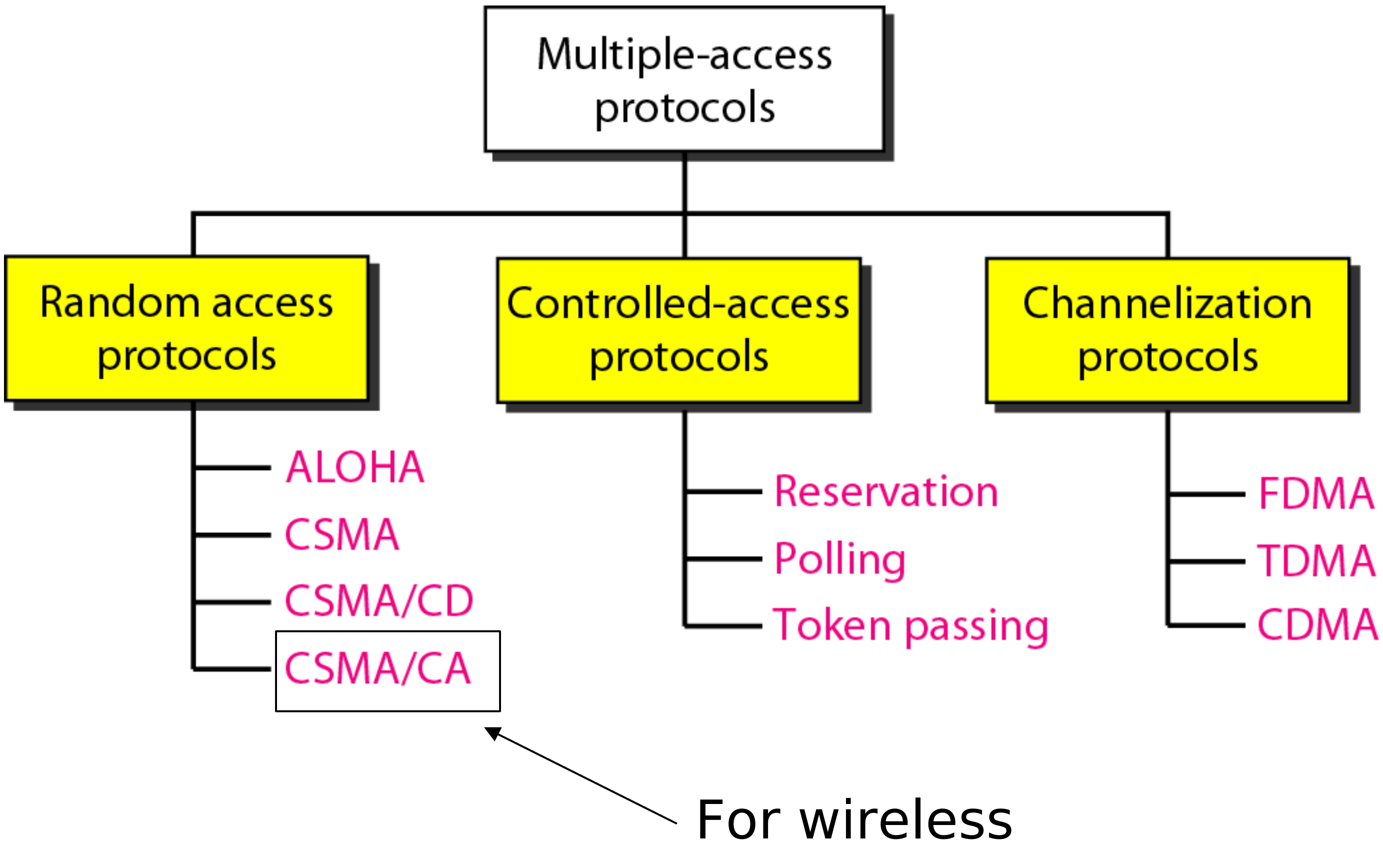
Multiple Access

- **Problem**: When two or more nodes transmit at the same time, their frames <u>will collide</u> and the link bandwidth is **wasted** during collision
  - How to coordinate the access of multiple sending/receiving nodes to the shared link**???**
- **Solution**: We need a **protocol** to coordinate the transmission of the active nodes

Multiple Access

- These protocols are called **Medium or Multiple Access Control (MAC) Protocols**
- Belong to a **sublayer** of the data link layer called **MAC** (Medium Access Control)
- Main task is to **minimize collisions** in order to **utilize the bandwidth** by:
  - Determining **when** a station can use the link (medium)
  - **what** a station should do when the link is **busy**
  - **what** the station should do when it is involved in **collision**

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



Random Access

- **Random Access (or contention) Protocols:**
  - No station is superior to another station
  - No station is assigned the control over another.
  - A station with a frame to be transmitted **can use the link directly based** on a procedure defined by the protocol to make a decision on whether or not to send.

- **ALOHA Protocols**
- Was designed for **wireless LAN** and can be used for **any shared medium**

Random Access – Pure Aloha

- **Pure ALOHA** Protocol Description
  - All frames are fixed length(**L bits**)
  - Stations transmit at equal **transmission time (*all stations produce frames with equal frame lengths*)**.
  - A station that has data **can transmit at any time.**
  - **After transmitting a frame**, the sender **waits** for an **acknowledgment** for an amount of time (time out) equal to the **maximum round-trip propagation delay** = $2^* t_{prop}$
  - If **no ACK** was received, sender assumes that the **frame or ACK** has been destroyed and **resends** that frame after it **waits for a *random* amount of time**
  - If station fails to receive an ACK after repeated transmissions, **it gives up**

Random Access – Pure Aloha

- **Channel utilization or efficiency or Throughput** is the **percentage** of the transmitted frames that arrive **successfully** (without collisions) **or** the **percentage** of the **channel bandwidth** that will be used for transmitting frames without collisions

- ALOHA Maximum channel utilization is **18%** (i.e, if the system produces **F frames/s**, then **0.18 * F** frames will arrive **successfully on average without the need of retransmission**).

Maximum Propagation Delay

- **Maximum propagation delay**(t_{prop}): time it takes for a bit of a frame to travel between the two most widely separated stations.
- Time to wait for detection of collision

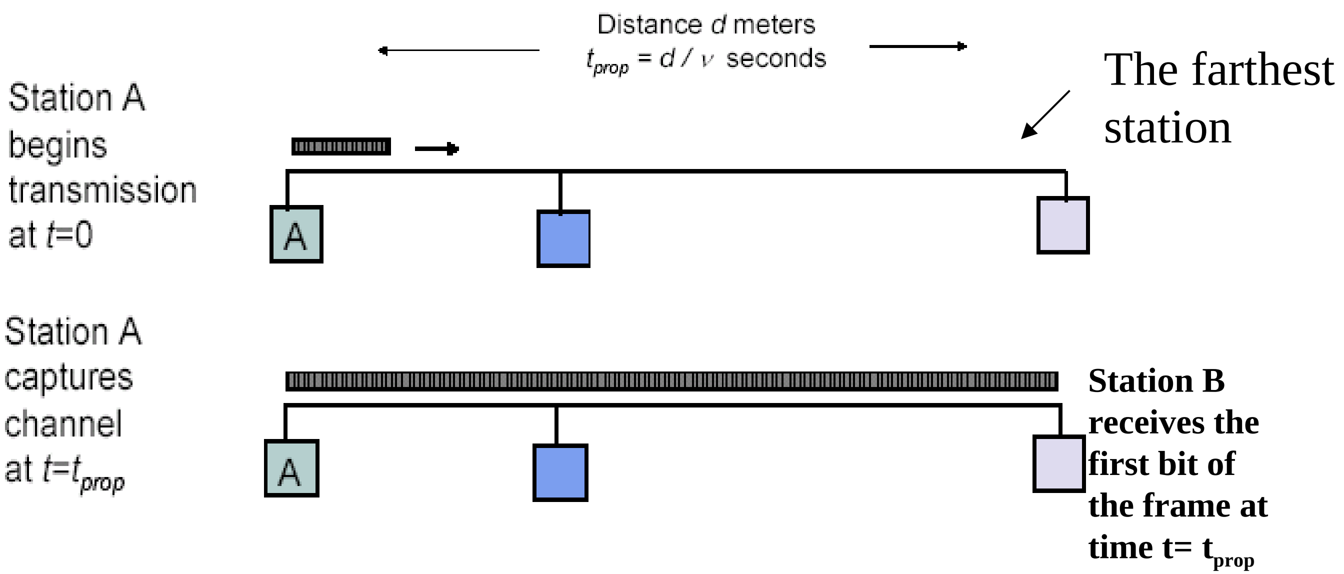


Figure 13.4 Procedure for ALOHA protocol

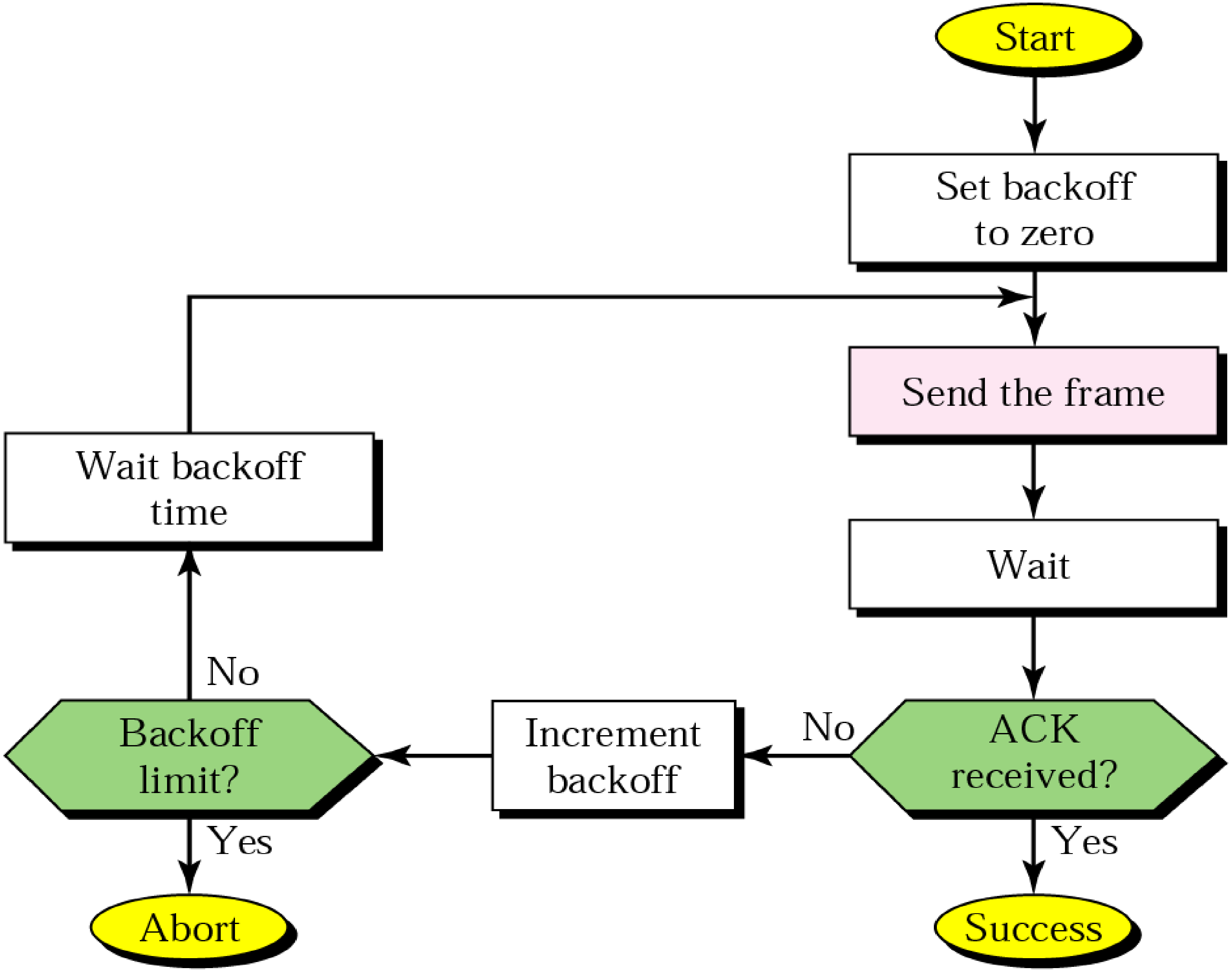
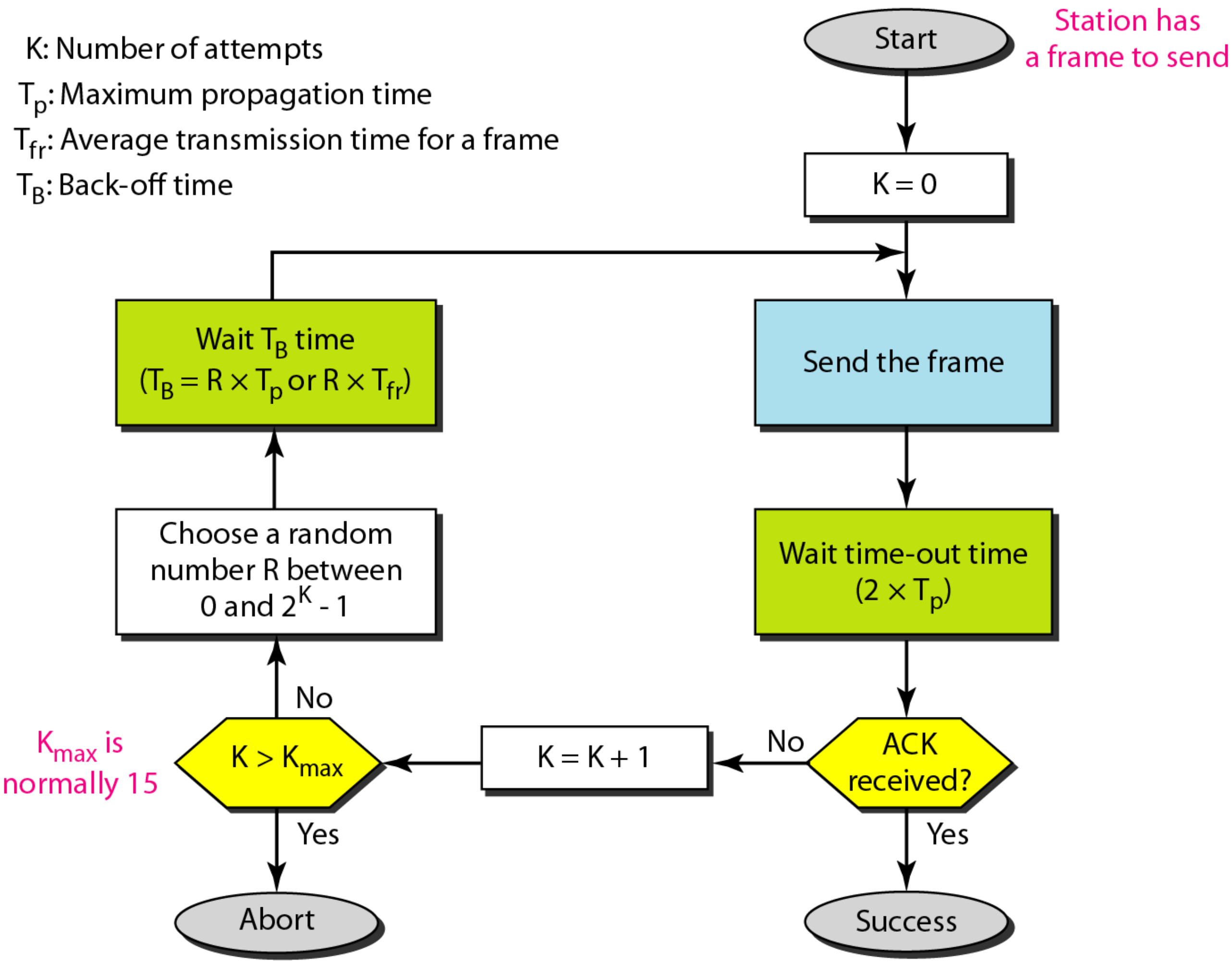


Figure 13.4 Procedure for pure ALOHA protocol



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

$$T_p = (6 \times 10^5) / (3 \times 10^8) = 2 \text{ ms}.$$

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.

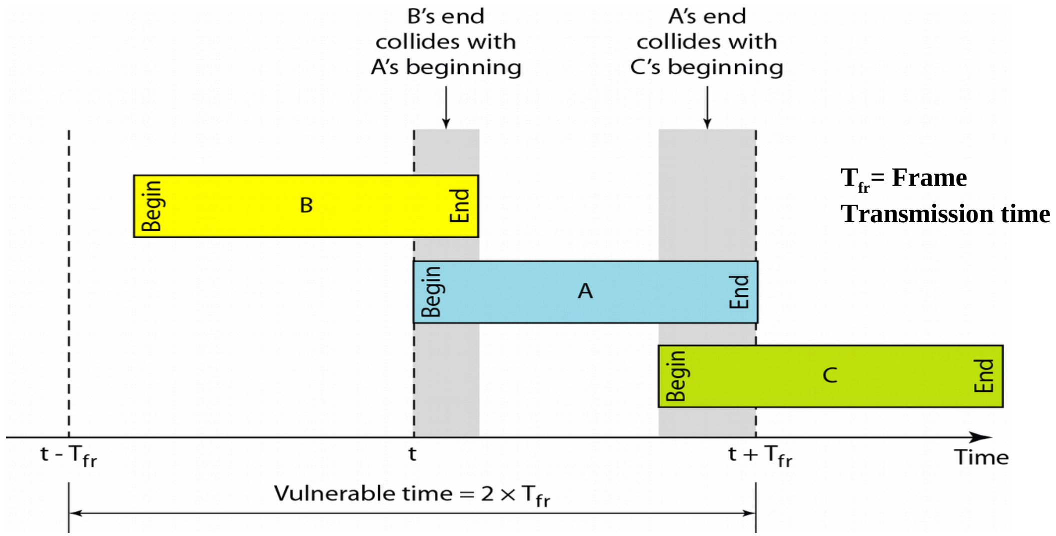
Example 12.1 (continued)

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.

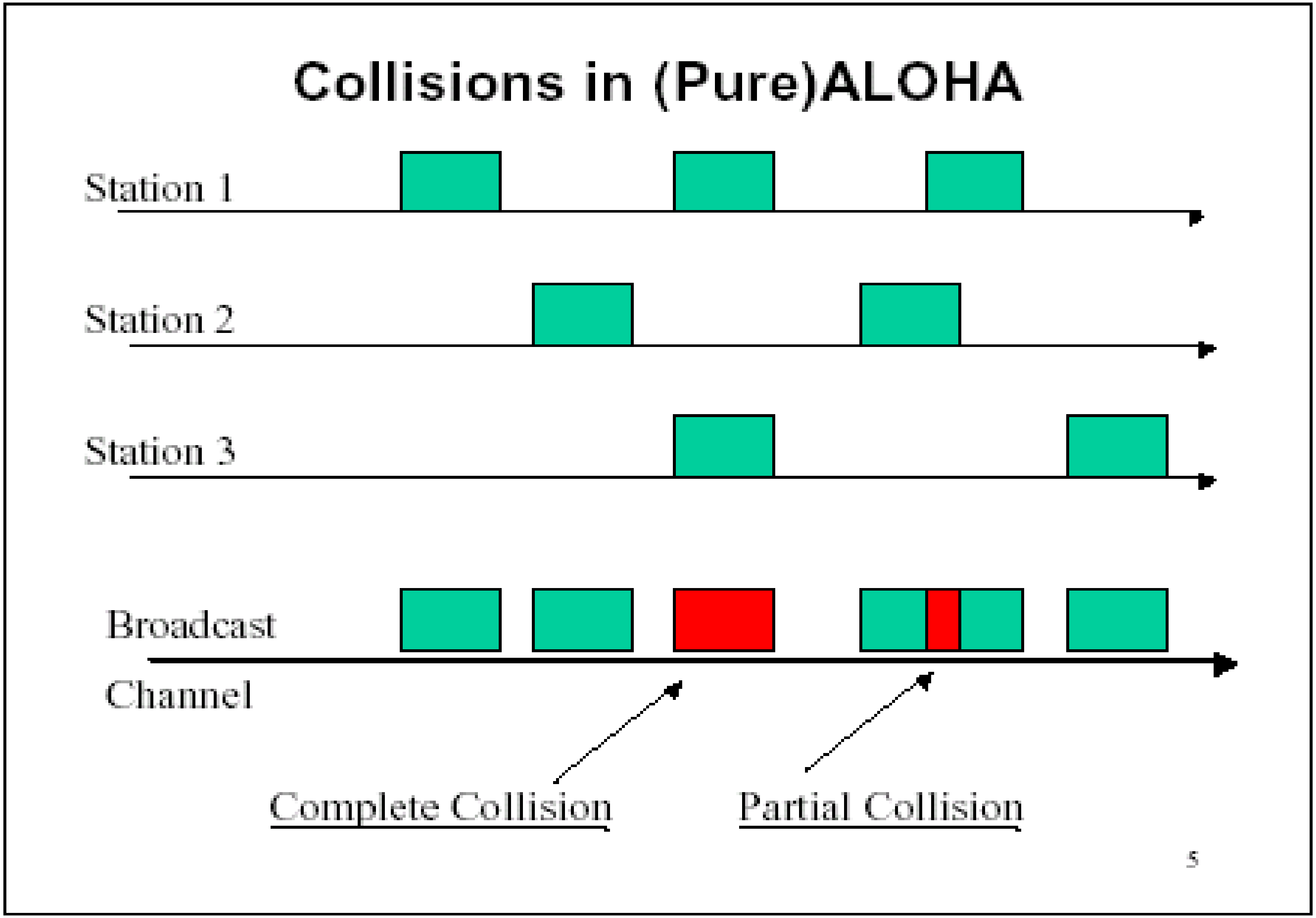
d. We need to mention that if K > 10, it is normally set to 10.

Critical time for pure ALOHA protocol



If the frame <u>transmission time</u> is T sec, then the vulnerable time is = 2 T sec.
This means no station should send during the T-sec before this station starts transmission and no station should start sending during the T-sec period that the current station is sending.

Pure ALOHA



In pure ALOHA, frames are transmitted at completely arbitrary times.

Note

The throughput (S) for pure ALOHA is

$$S = G \times e^{-2G}.$$

The maximum throughput

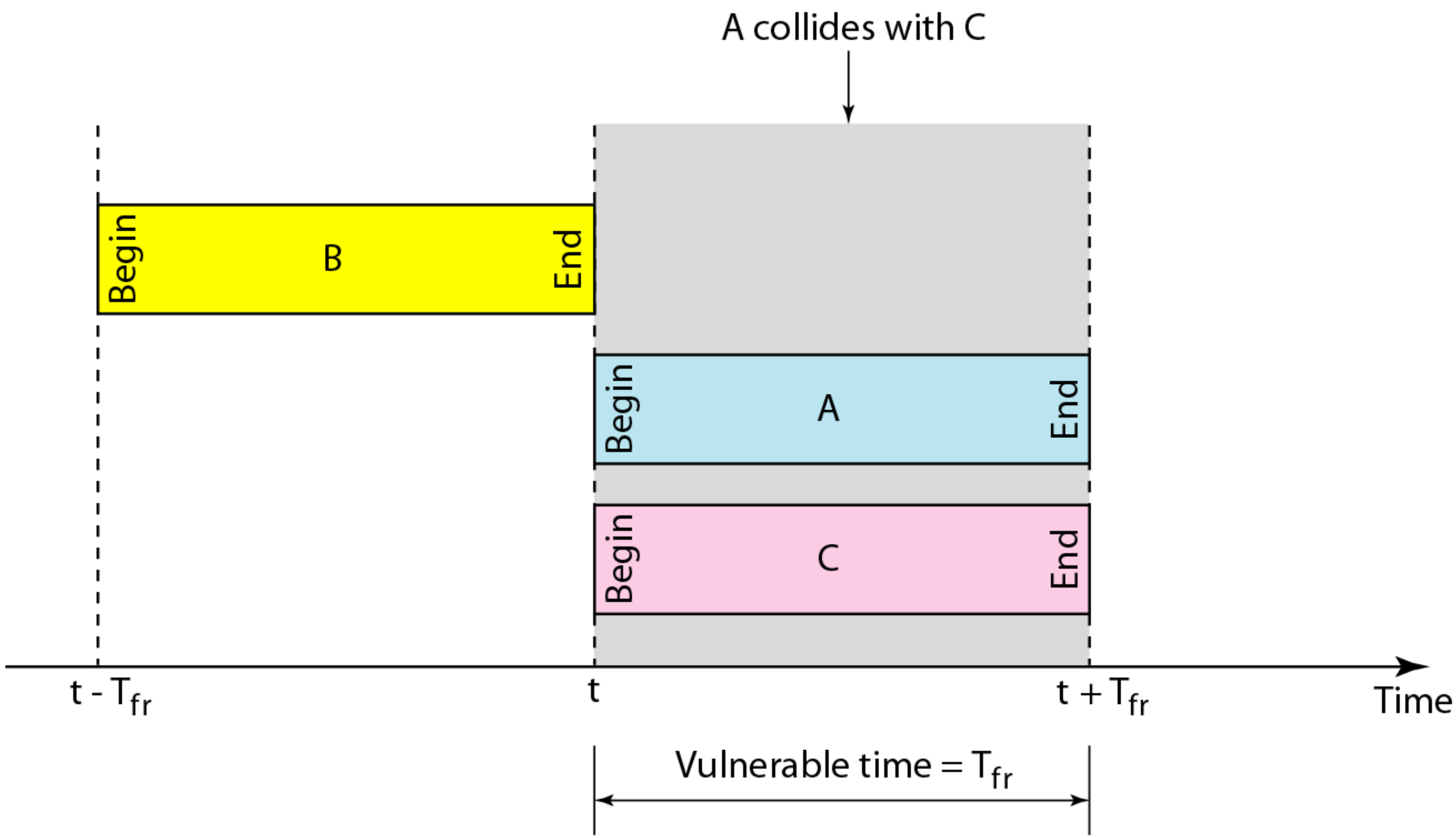
$S_{max} = 0.184$ when G= (1/2).

G = Average number of frames generated by the system (all stations) during one frame transmission time

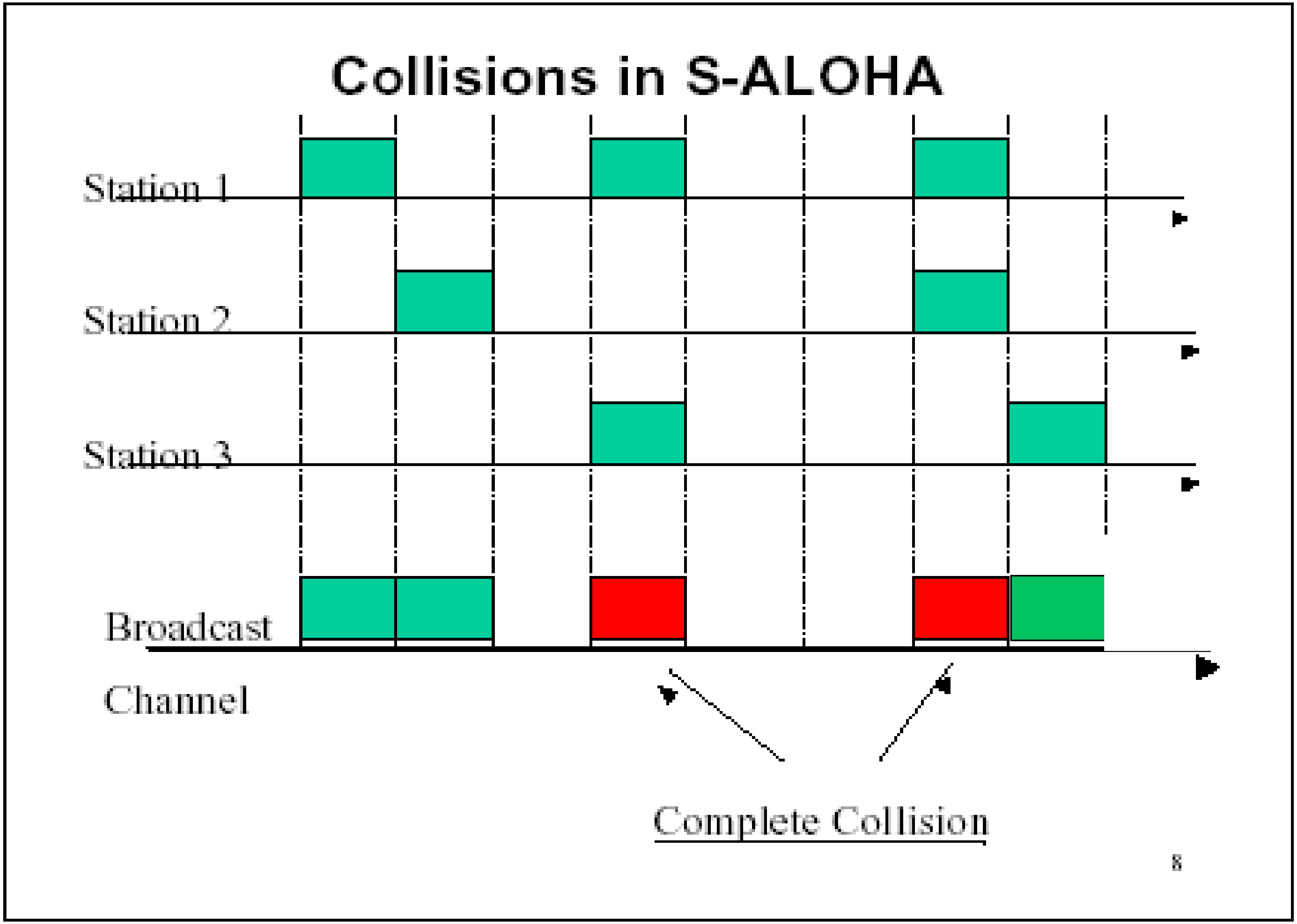
Random Access – Slotted ALOHA

- Time is divided into slots equal to a **frame transmission time (T_{fr})**
- A station can transmit at the beginning of a slot only
- If a station misses the beginning of a slot, it has to wait until the beginning of the next time slot.
- **A central clock** or station informs all stations about the start of a each slot
- Maximum channel utilization is **37%**

In danger time for slotted ALOHA protocol



Random Access – Slotted



Note

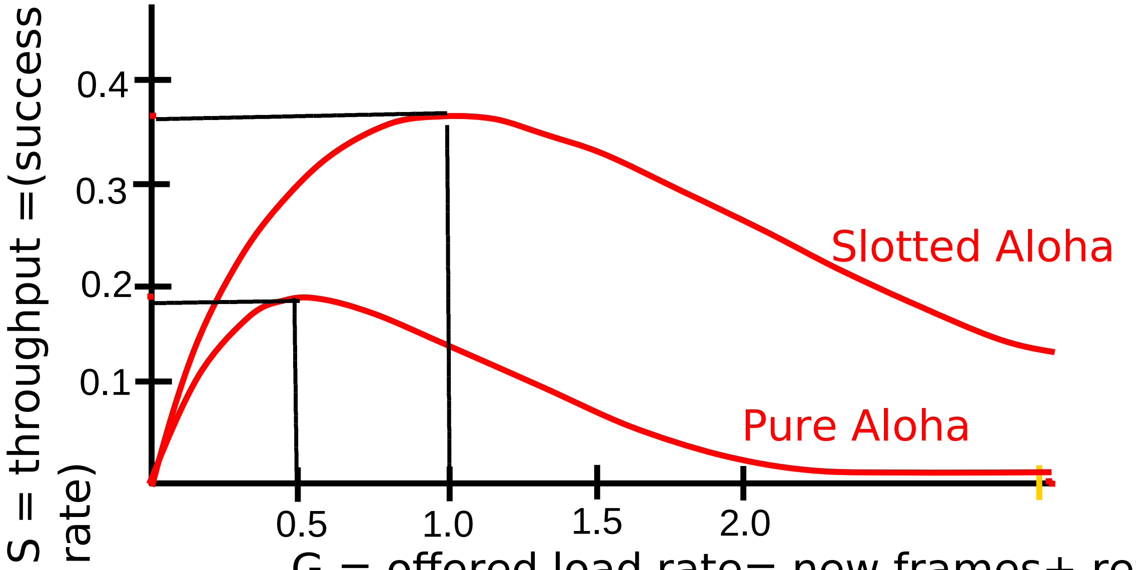
The throughput for slotted ALOHA is

$$S = G \times e^{-G}.$$

The maximum throughput

$S_{max} = 0.368$ when G = 1.

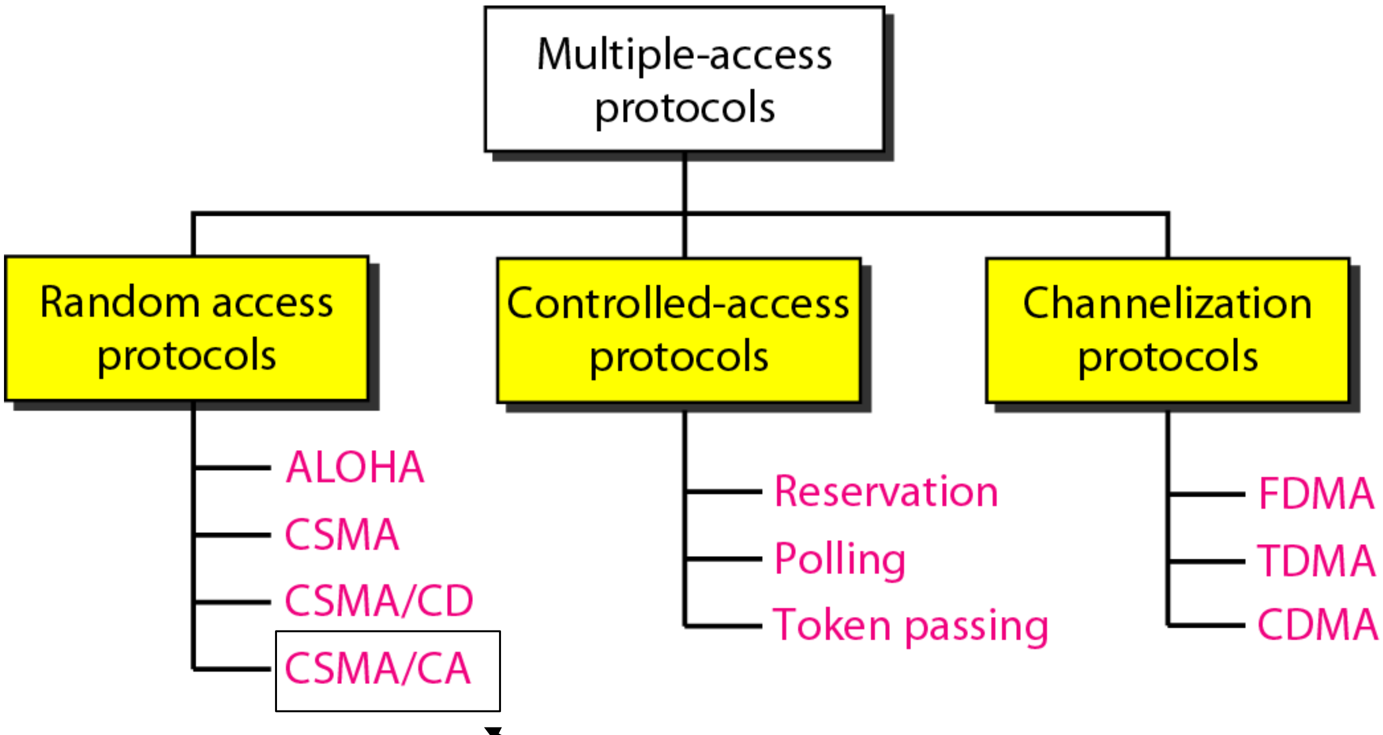
Efficiency of Aloha



G = offered load rate= new frames+ retransmitted
= Total frames presented to the link per the transmission time of a single frame

- **Advantage of ALOHA protocols**
  - A node that has frames to be transmitted can **transmit continuously** at the **full rate of channel (R bps)** if it is the <u>only node</u> with frames
  - Simple to be implemented
  - No master station is needed to control the medium
- Disadvantage
  - If (M) nodes want to transmit, many collisions can occur and the rate allocated for each node will **not be on average R/M bps**
  - This causes low channel utilization

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

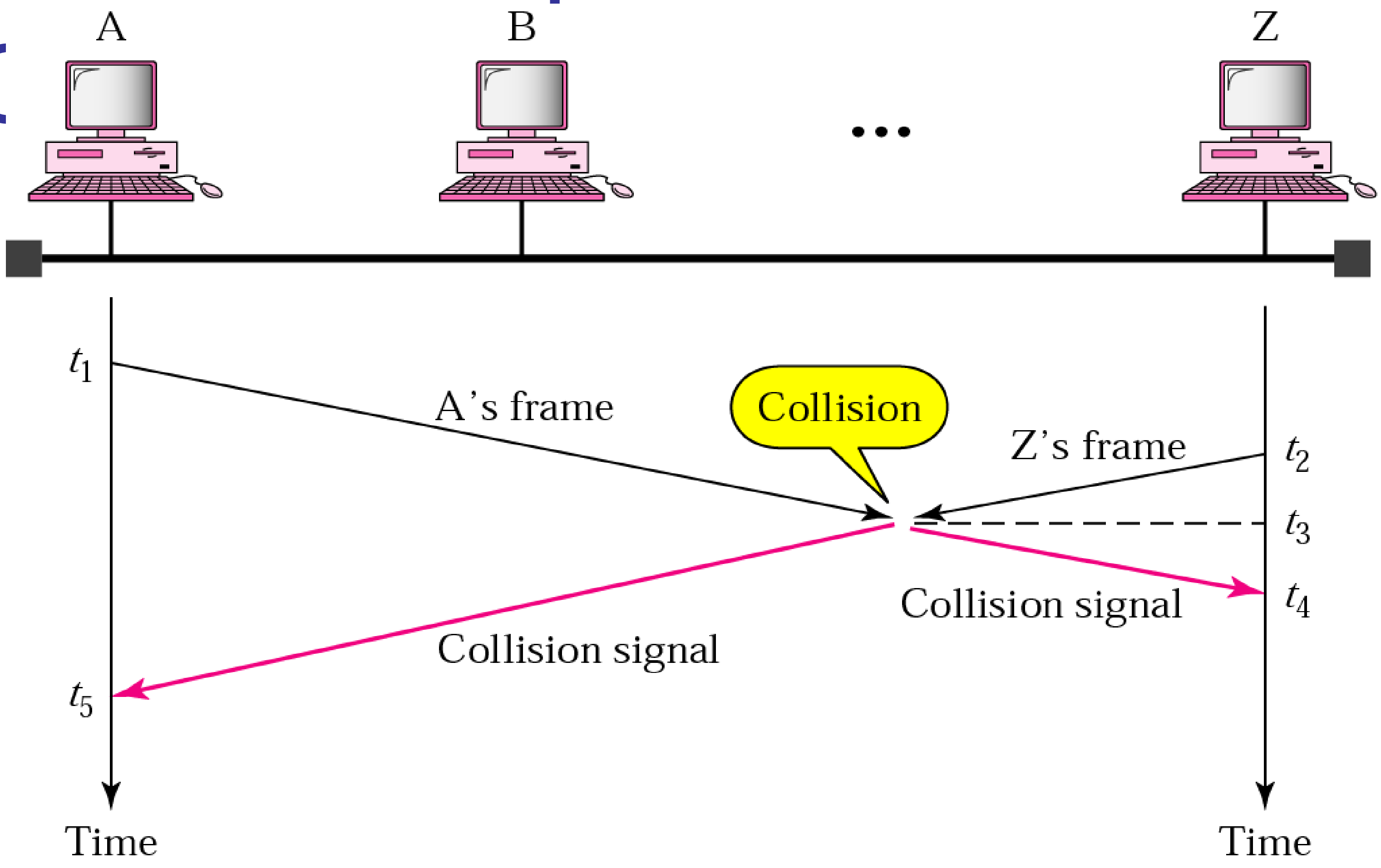


For wireless not included with us

Random Access : Carrier Sense Multiple Access (CSMA)

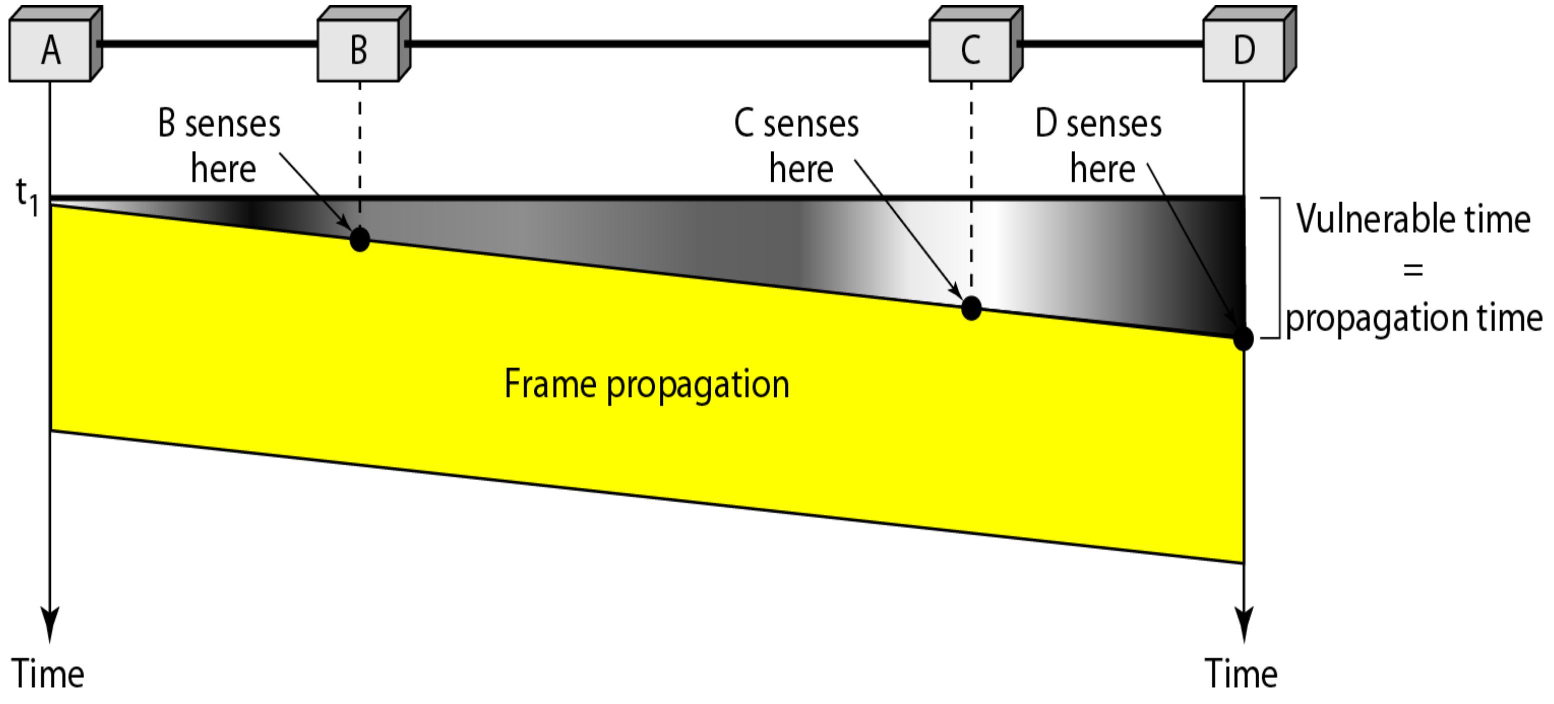
- To improve performance, avoid transmissions that are certain to cause collisions
- Based on the fact that in LAN propagation time is **very small**
- ➔ If a frame was sent by a station, All stations knows immediately so they can **wait before start sending**
  - ➔ **A station with frames to be sent, should sense the medium for the presence of another transmission (carrier) before it starts its own transmission**
- This can **reduce** the possibility of collision but it cannot eliminate it.
  - Collision can only happen when more than one station begin transmitting within a short time (the **propagation time** period)

Random Access – Carrier Sense Multiple Access (C



Random Access – Carrier Sense Multiple Access (CSMA)

- Vulnerable time for CSMA is the **maximum propagation time**
- The longer the propagation delay, the worse the performance of the protocol because of the above case.



Types of CSMA Protocols

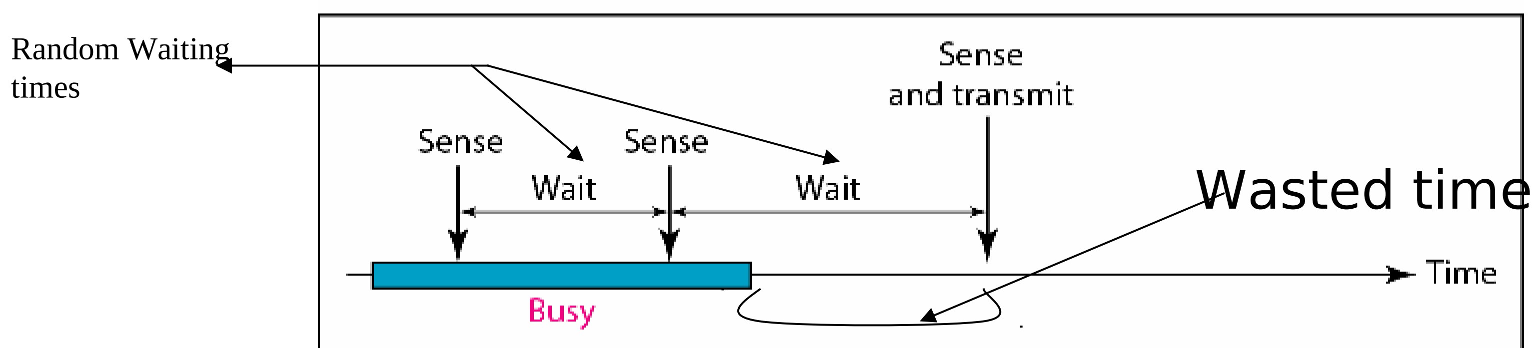
Different CSMA protocols that determine:

- **What a station should do when the medium is idle?**
- **What a station should do when the medium is busy?**

1. **Non-Persistent CSMA**
2. **1-Persistent CSMA**
3. **p-Persistent CSMA**

Nonpersistent CSMA

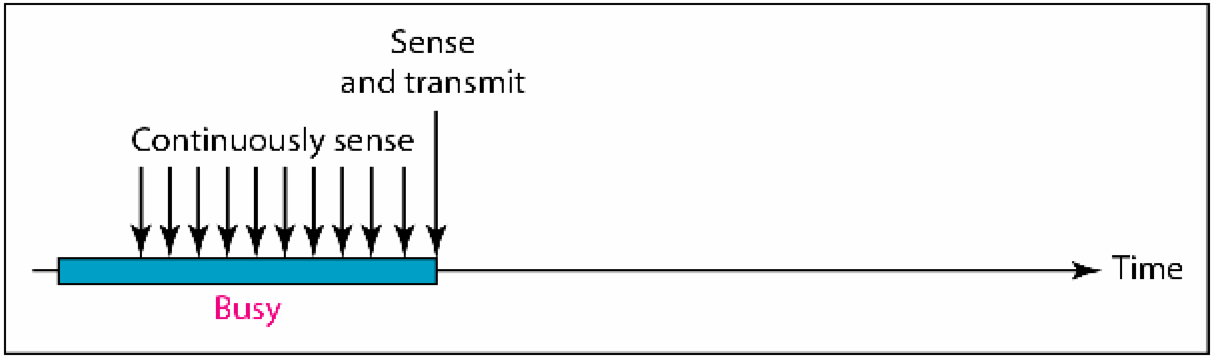
- A station with frames to be sent, should sense the medium
  1. If medium is idle, **transmit**; otherwise, go to 2
  2. If medium is busy, (**backoff**) wait a ***random*** **amount of time** and repeat **1**
- Non-persistent Stations are **deferential (respect others)**
- Performance:
  - Random delays reduces probability of collisions because two stations with data to be transmitted will wait for different amount of times.
  - Bandwidth is **wasted** if waiting time (backoff) is large because medium will remain idle following end of transmission even if one or more stations have frames to send



b. Nonpersistent

1-persistent CSMA

- To avoid idle channel time, 1-persistent protocol used
- Station wishing to transmit listens to the medium:
  1. If medium idle, **transmit** immediately;
  2. If medium busy, **continuously listen** until medium becomes idle; then transmit immediately with probability 1
- Performance
  - 1-persistent stations are **selfish**
  - If two or more stations becomes ready at the same time, **collision guaranteed**

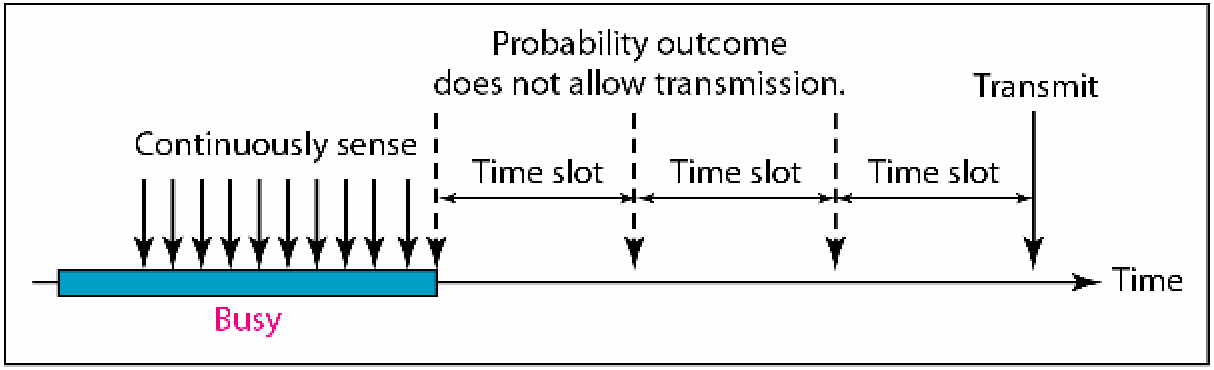


a. 1-persistent

P-persistent CSMA

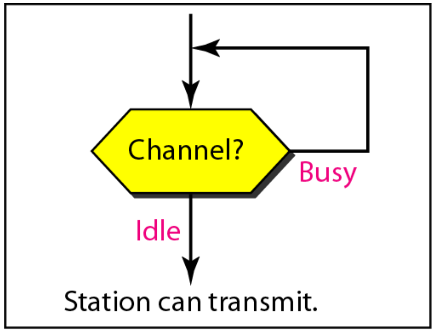
- Time is divided to slots where each Time unit (slot) typically equals **maximum propagation delay**
- Station wishing to transmit listens to the medium:

1. If medium idle,
   - transmit with probability (**p**), OR
   - wait **one time unit (slot)** with probability (**1 – p**), then repeat 1.
2. If medium busy, **continuously listen until idle** and repeat step **1**
3. Performance
   - Reduces the possibility of collisions like **nonpersistent**
   - Reduces channel idle time like **1-persistent**

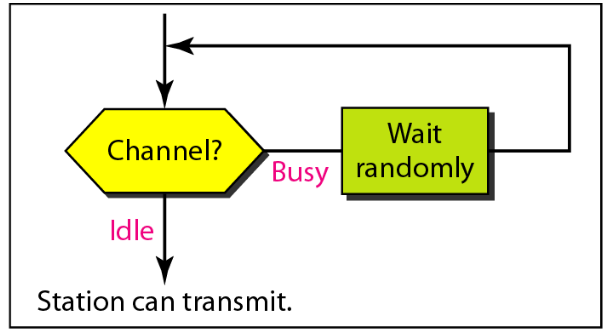


c. p-persistent

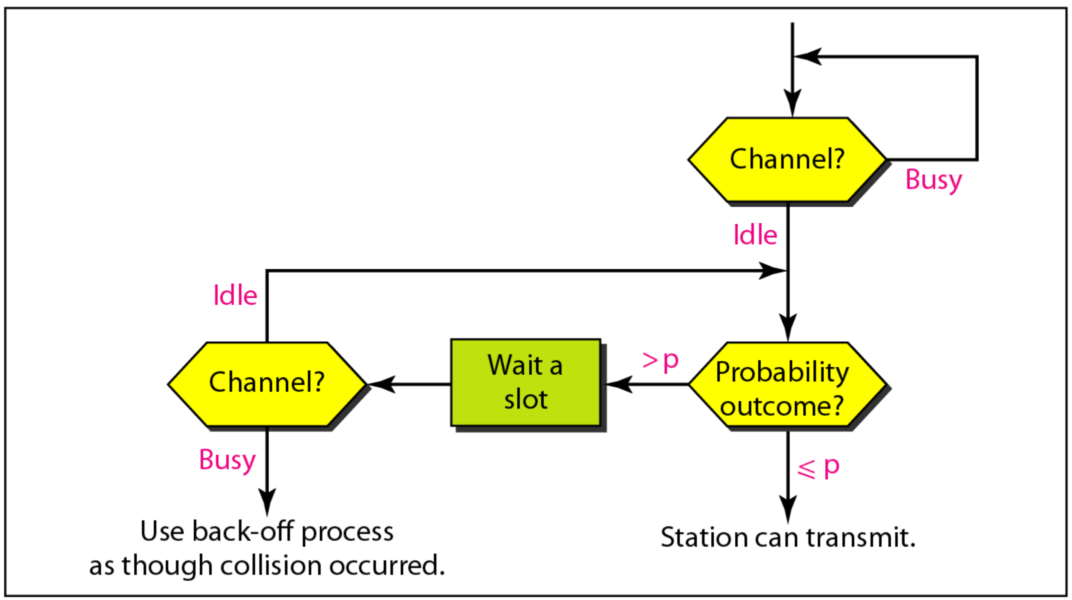
Flow diagram for three persistence methods



a. 1-persistent

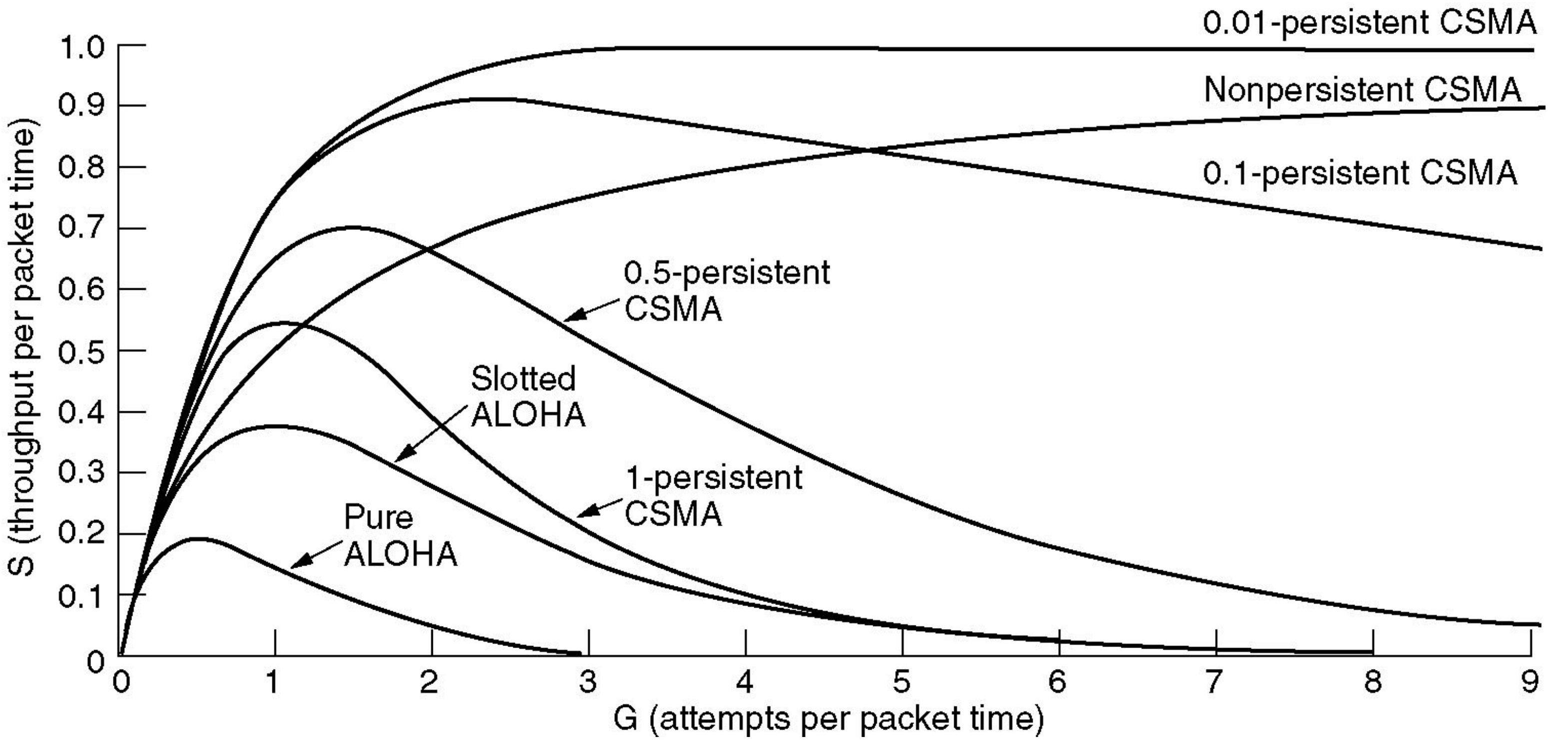


b. Nonpersistent



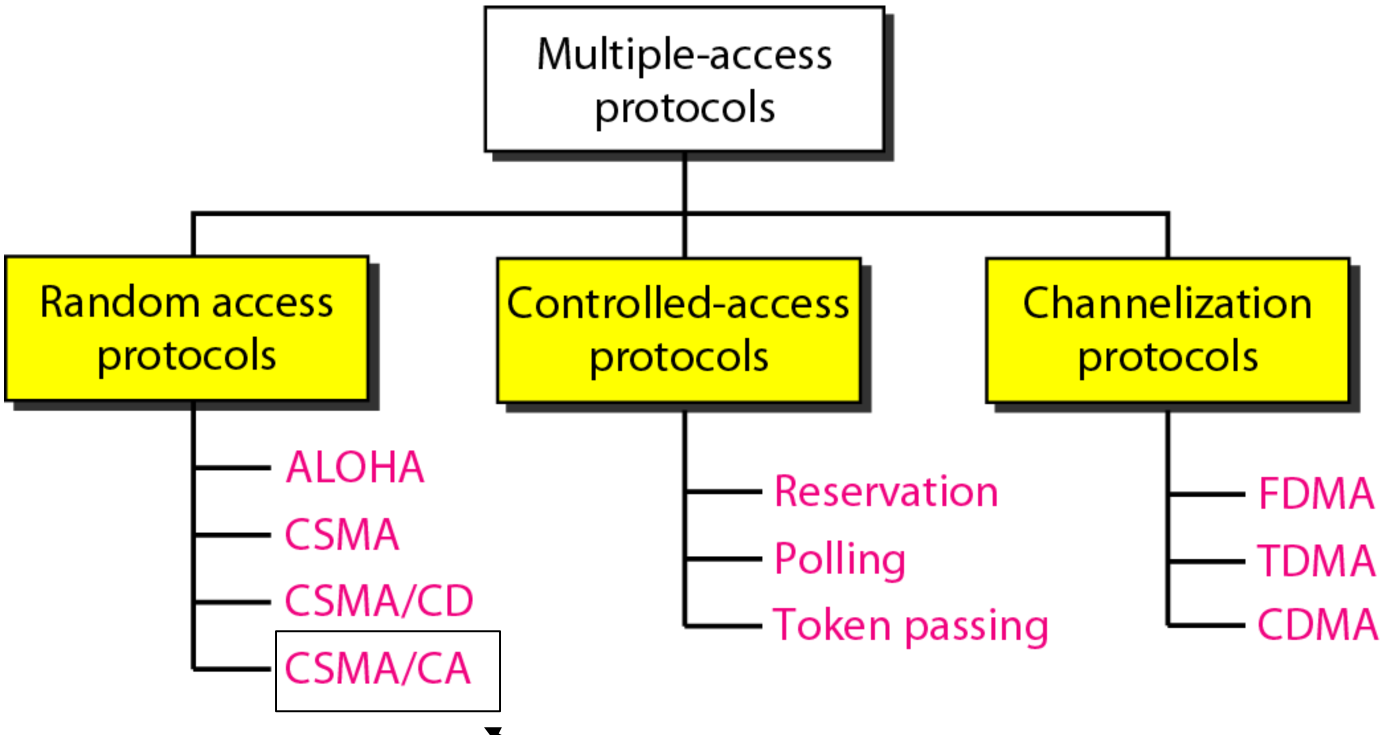
c. p-persistent

Persistent and Nonpersistent CSMA



Comparison of the channel utilization versus load for various random access protocols.

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



For wireless not included with us

CSMA/CD (Collision Detection)

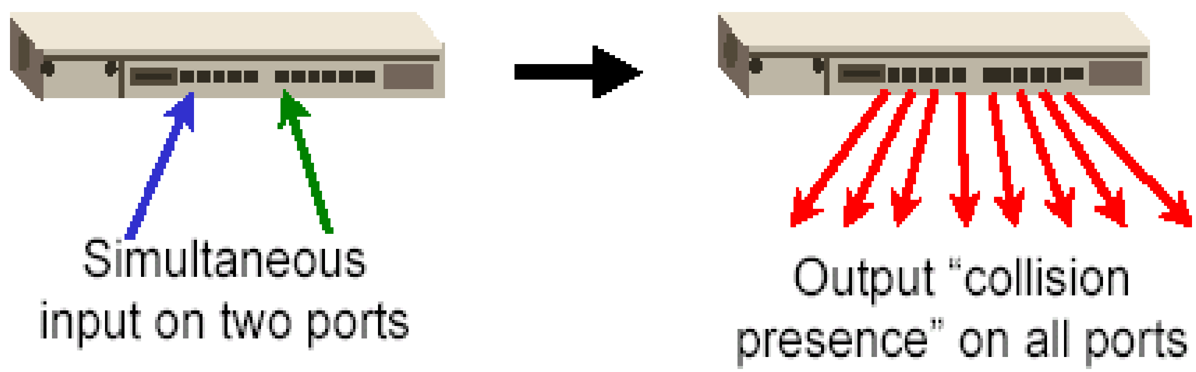
- ***CSMA (all previous methods) has an inefficiency:***
  - If a collision has occurred, the channel is **unstable** until colliding packets have **<u>been fully transmitted</u>**
- ***CSMA/CD*** *(Carrier Sense Multiple Access with Collision Detection)* ***overcomes this as follows:***
  - While transmitting, the sender is **listening to medium** for collisions.
  - Sender **stops transmission** if collision has occurred **reducing channel wastage** .

CSMA/CD is Widely used for **bus topology LANs** (IEEE 802.3, Ethernet).

How does a node detect a collision?

Transceiver: **A node monitors the media while transmitting. If the observed power is more than transmitted power** of its own signal, it means collision occurred

Hub: **if input occurs simultaneously on two ports, it indicates a collision. Hub sends a collision presence signal on all ports.**



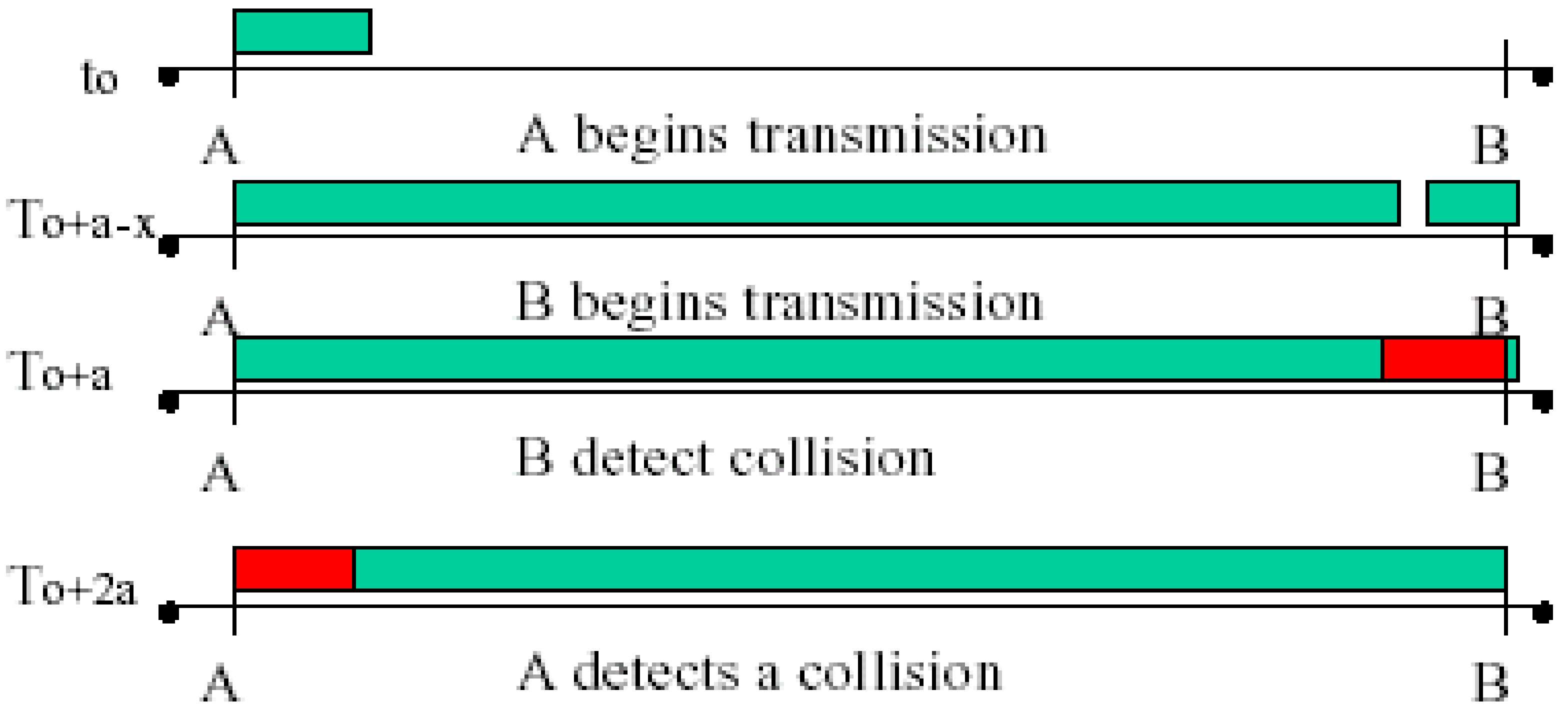
CSMA/CD Protocol

- Use one of the CSMA persistence algorithm ***(non-persistent, 1-persistent, p-persistent)*** for transmission
- If a collision is detected by a station during its transmission then it should do the following:
  - **Abort transmission** and
  - **Transmit** a ***jam signal*** (48 bit) to notify other stations of collision so that they will **discard the transmitted frame** also to make sure that the collision signal will stay until detected by the farthest station
  - After sending the ***jam signal***, **backoff (wait) for a *random*** amount of time, then
  - Transmit the frame again

CSMA/CD

- ***Question:*** How long does it take to detect a collision?
- ***Answer:*** *In the **worst case***, **twice the maximum propagation delay of the medium**

Note: **a = maximum propagation delay**



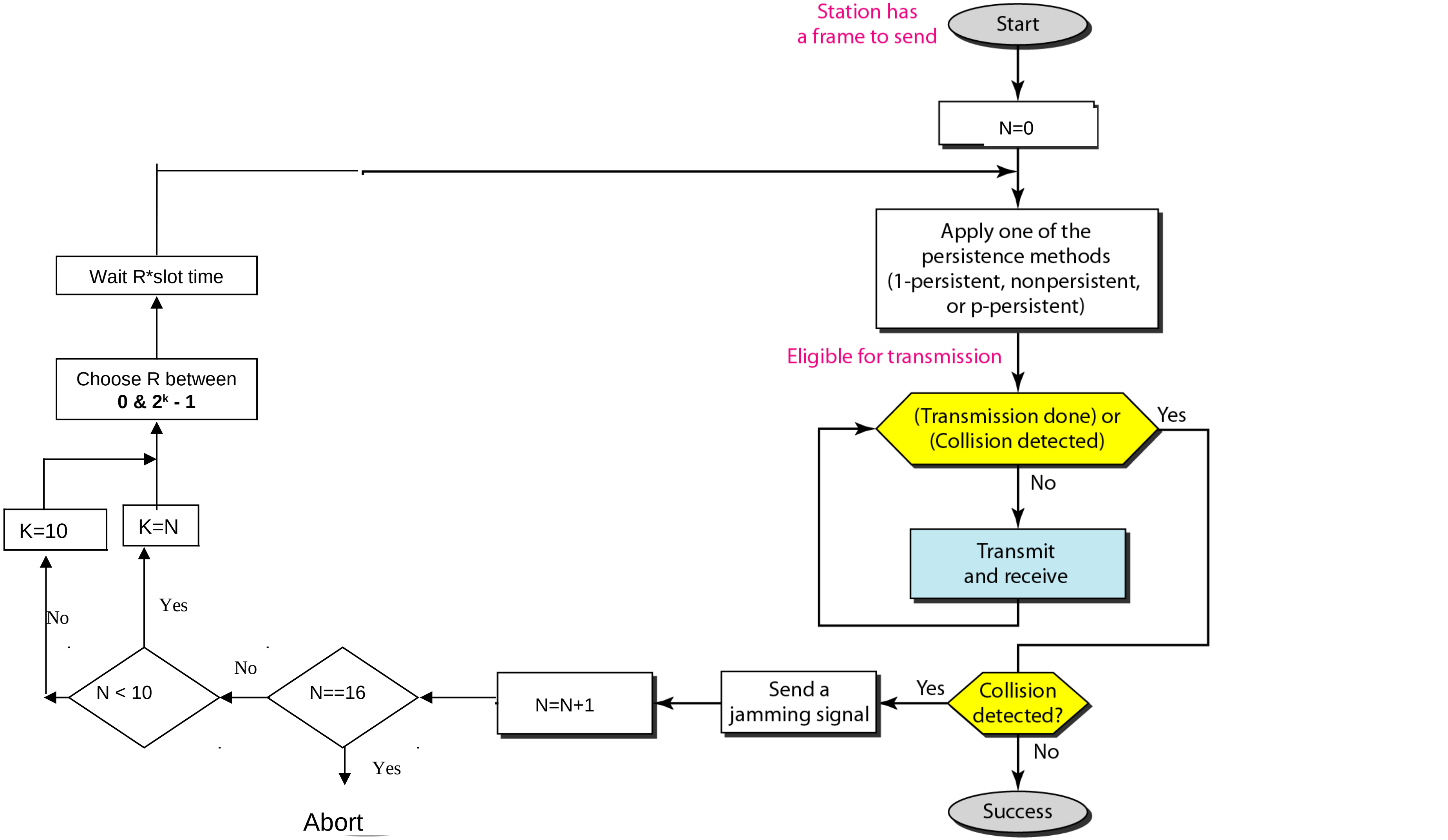
CSMA/CD

- Restrictions of CSMA / CD:
  - **Packet transmission time should be at least as long as the time needed to detect a collision (2 * maximum propagation delay + *jam sequence* transmission time)**
  - Otherwise, CSMA/CD does not have an advantage over CSMA

Exponential Backoff Algorithm

- Ethernet uses the exponential backoff algorithms to determine **the best duration of the random waiting period after the collision happens**
- Algorithm:
  - Set "**slot time**" equal to 2*maximum propagation delay + Jam sequence transmission time (= 51.2 usec for Ethernet **10-Mbps** LAN)
  - After K^{th} collision, select a random number (R) between 0 and $2^k - 1$ and **wait** for a period equal to (R***slot time**) then **retransmit** when the medium is **idle, for example:**
    - After first collision (K=1), select a number (R) between 0 and $2^1 - 1$ {0 ,1} and wait for a period equal to R*slot times (Wait for a period 0 usec or 1x51.2 usec) then retransmit when the medium is idle
  - Do not increase random number range, if K=10
    - ➔ Maximum interval {0 – 1023}
  - Give up after 16 unsuccessful attempts and report failure to higher layers

Figure 12.14 *Flow diagram for the CSMA/CD*



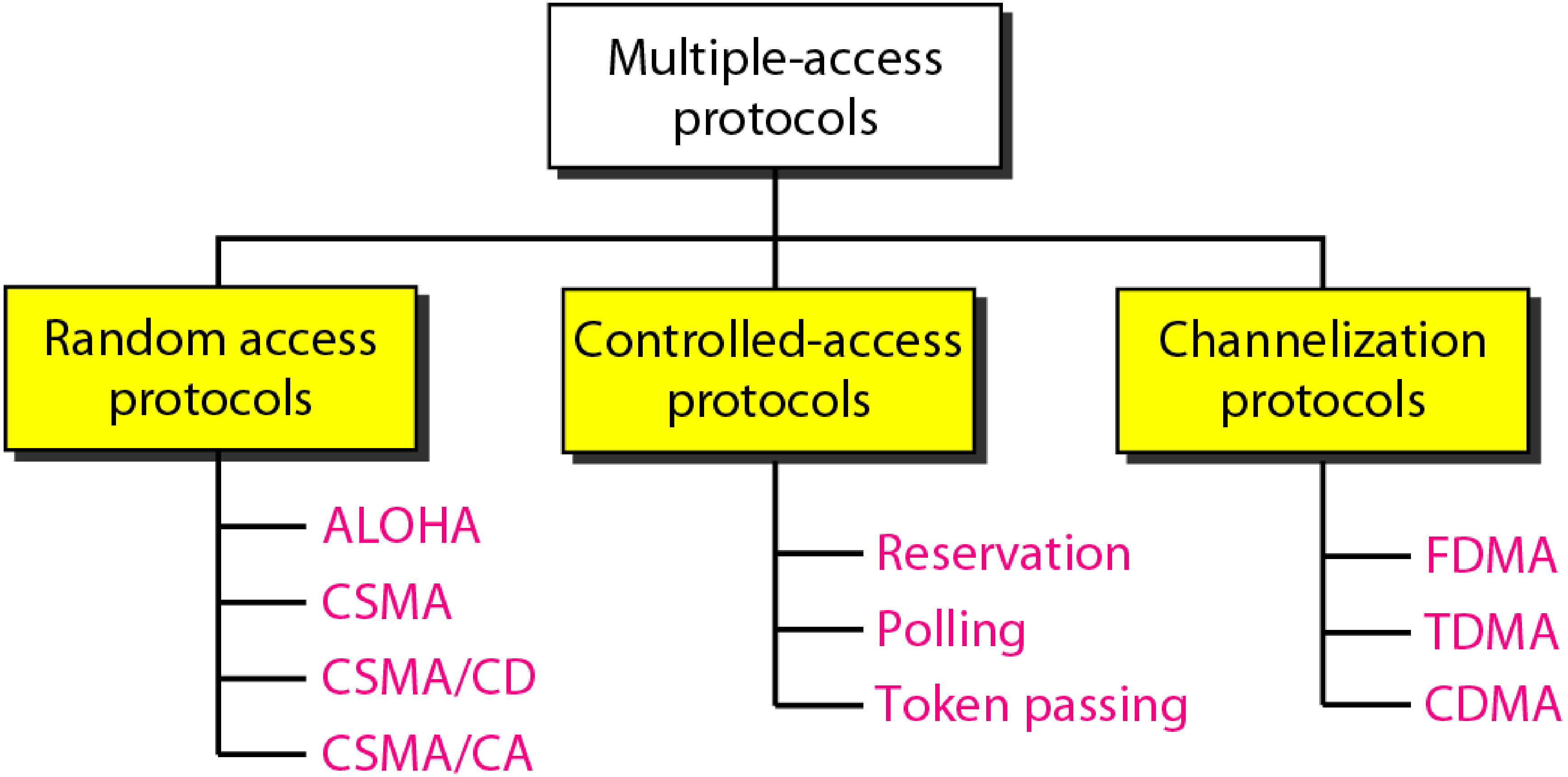
Exponential Backoff Algorithm

- Reduces the chance of two waiting stations picking the same random waiting time
- When network traffic is light, it results in **minimum** waiting time before transmission
- As congestion increases (traffic is high), collisions increase, stations backoff by **larger amounts** to reduce the probability of collision.
- Exponential Back off algorithm gives **last-in, first-out effect**
  - Stations with **no or few collisions** will have the chance to transmit before stations that have waited longer because of their previous unsuccessful transmission attempts.

Performance of Random Access Protocols

- Simple and easy to implement
- Decentralized (no central device that can fail and bring down the entire system)
- In low-traffic, packet transfer has low-delay
- However, limited throughput and in heavier traffic, packet delay has no limit.
- In some cases, a station <u>may never</u> have a chance to transfer its packet. (**unfair protocol**)
- A node that has frames to be transmitted can **transmit continuously** at the **full rate of channel (R)** if it is the **only node with frames**
- If (M) nodes want to transmit, many collisions can occur and the rate for each node will **<u>not be on average R/M</u>**

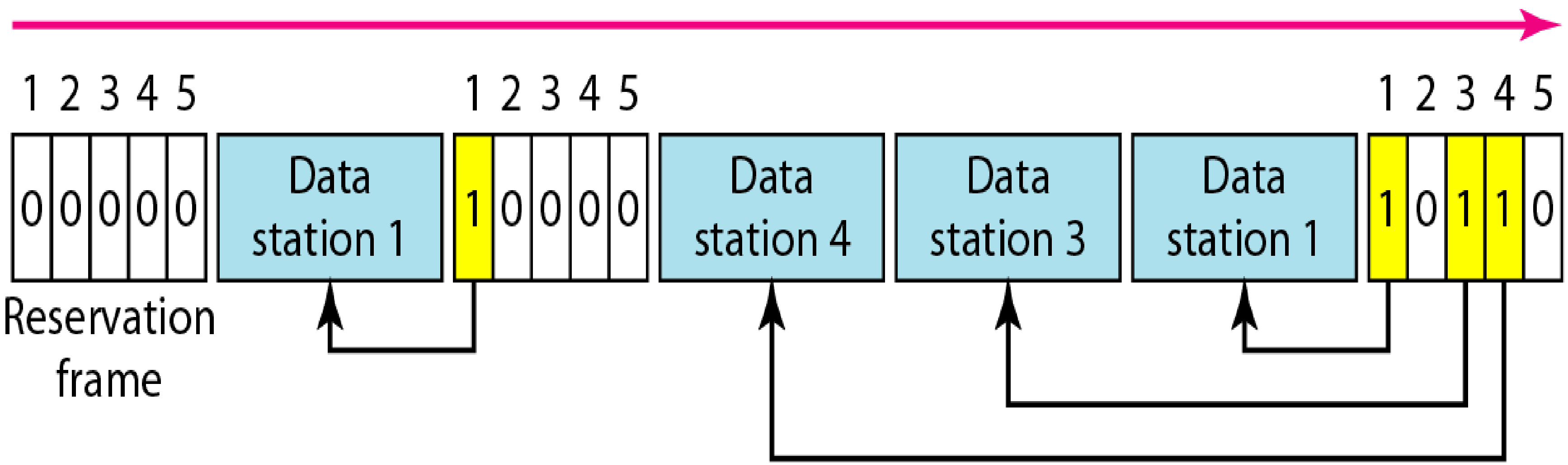
Random Access Protocols



13.2 Controlled Access or Scheduling

- Provides **in order access** to shared medium so that every station has chance to transfer (**fair protocol**)
- ***Eliminates*** collision completely
- **Three methods** for controlled access:
  - Reservation
  - Polling
  - Token Passing

1-Reservation access method



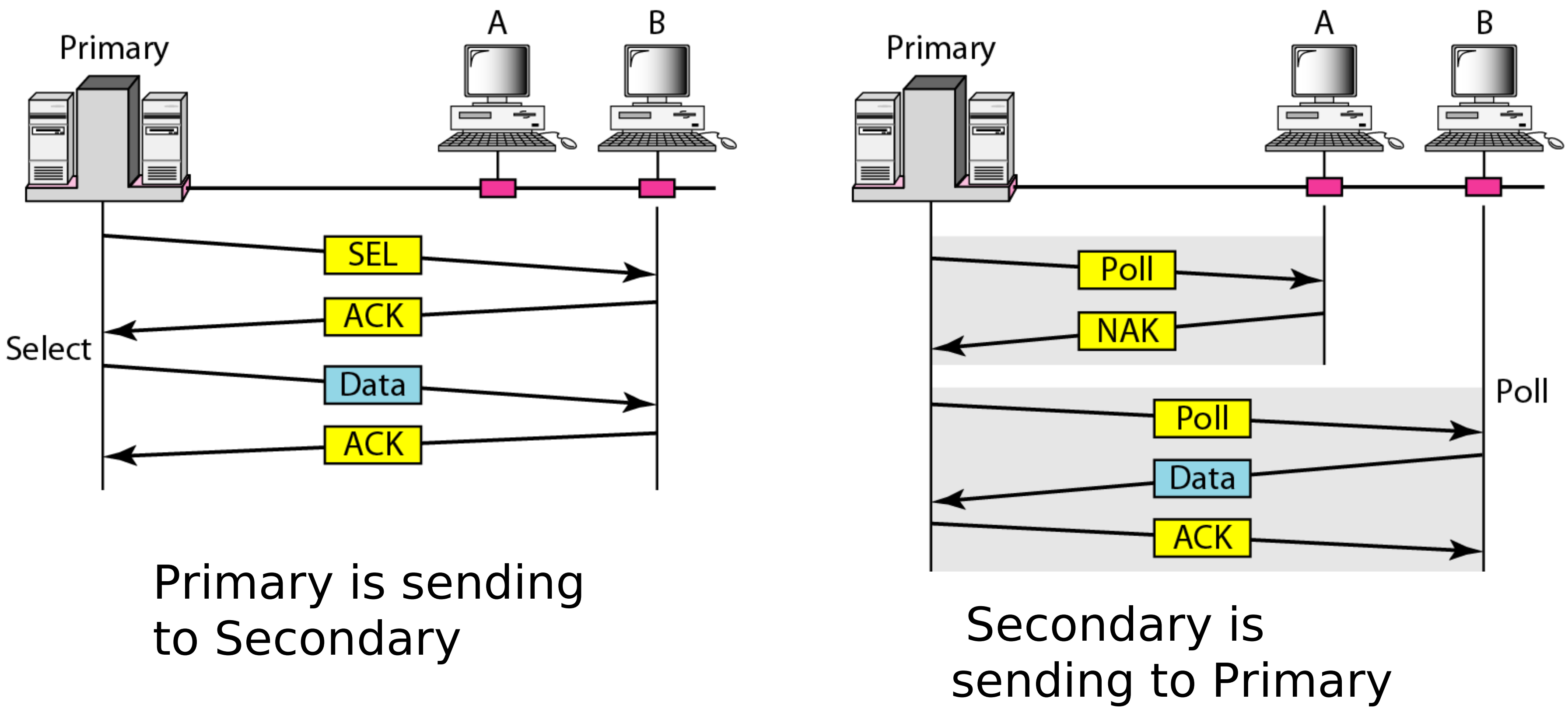
1-Reservation access method

- Stations **take turns transmitting a single frame** at a **full rate (R) bps**
- Transmissions are organized into variable length cycles
- Each cycle begins with a reservation interval that consists of (N) minislots. One minislot for each of the N stations
- When a station needs to send a data frame, it makes a **reservation** in its own minislot.
- By listening to the reservation interval, every station knows which stations will transfer frames, and in which order.
- The stations that made reservations can send their data frames after the reservation frame.

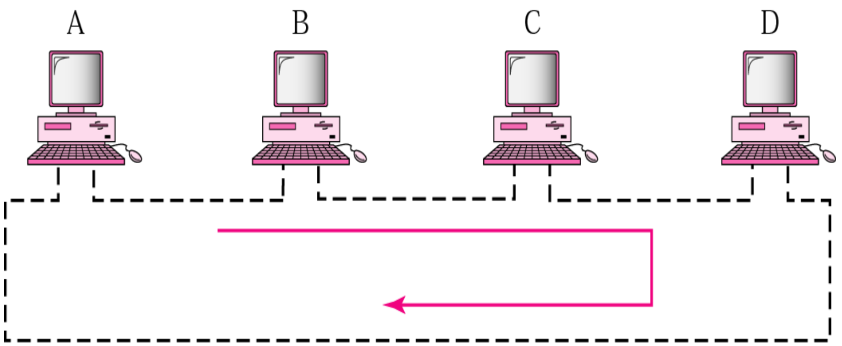
2- Polling

- Stations take turns accessing the medium
- Two models: **Centralized** and **distributed** polling
- **Centralized polling**
  - **Primary and secondary devices**
- **Distributed polling**
  - **No primary and secondary**
  - Stations have a **known polling order** list which is made based on some protocol (can be based on priority)

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

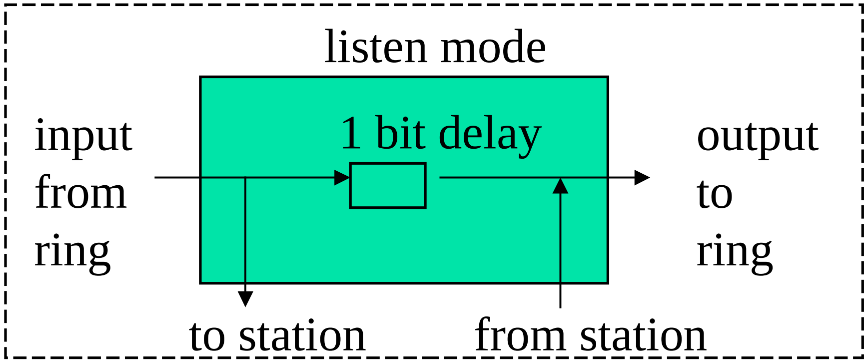


3- Token-Passing network

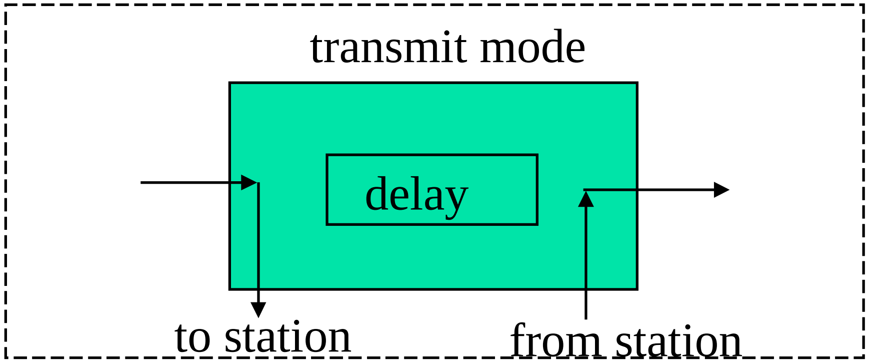


Implements Distributed
Polling System

bits are copied to the output bits with a one bit delay

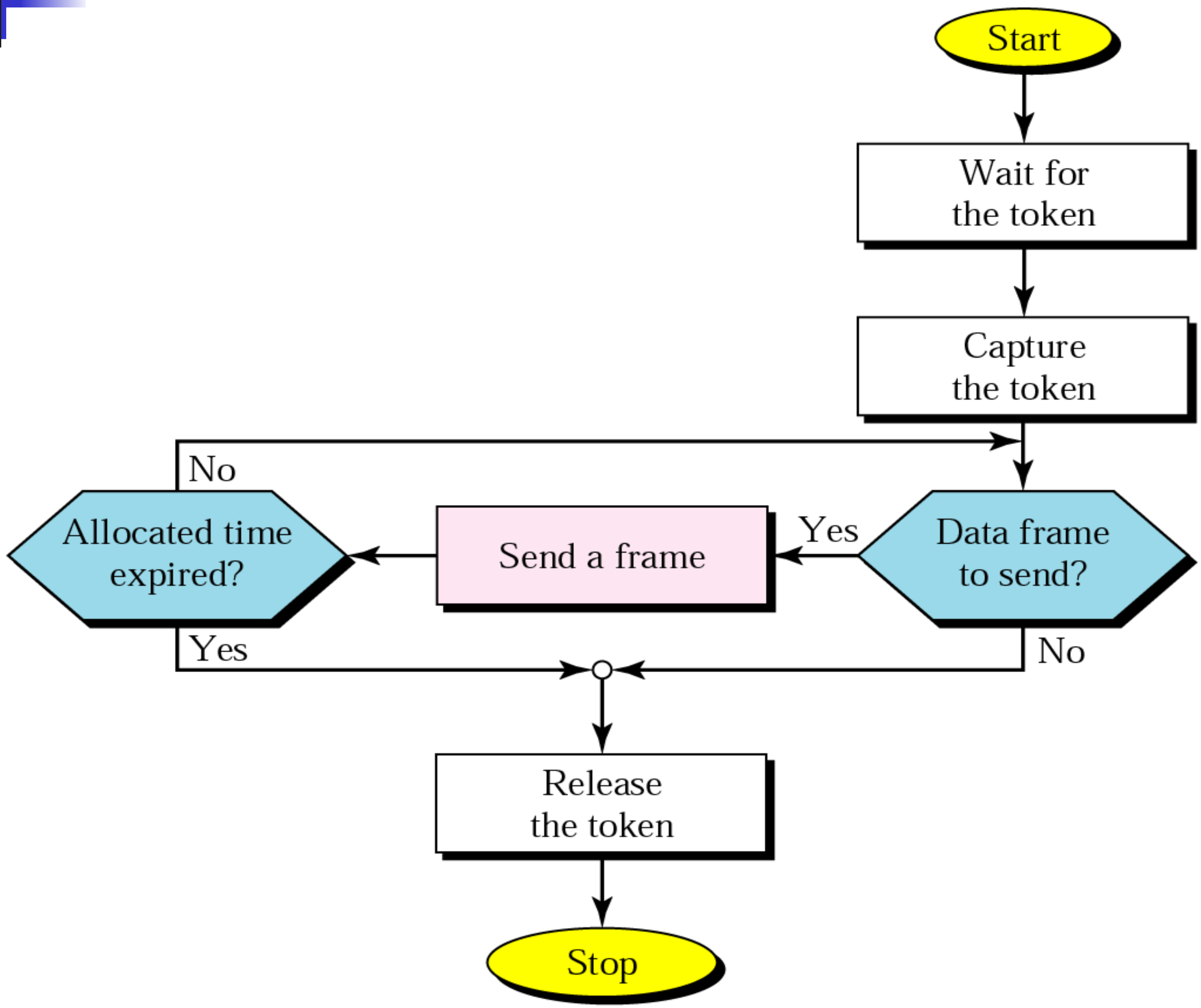


Bits are inserted by the station

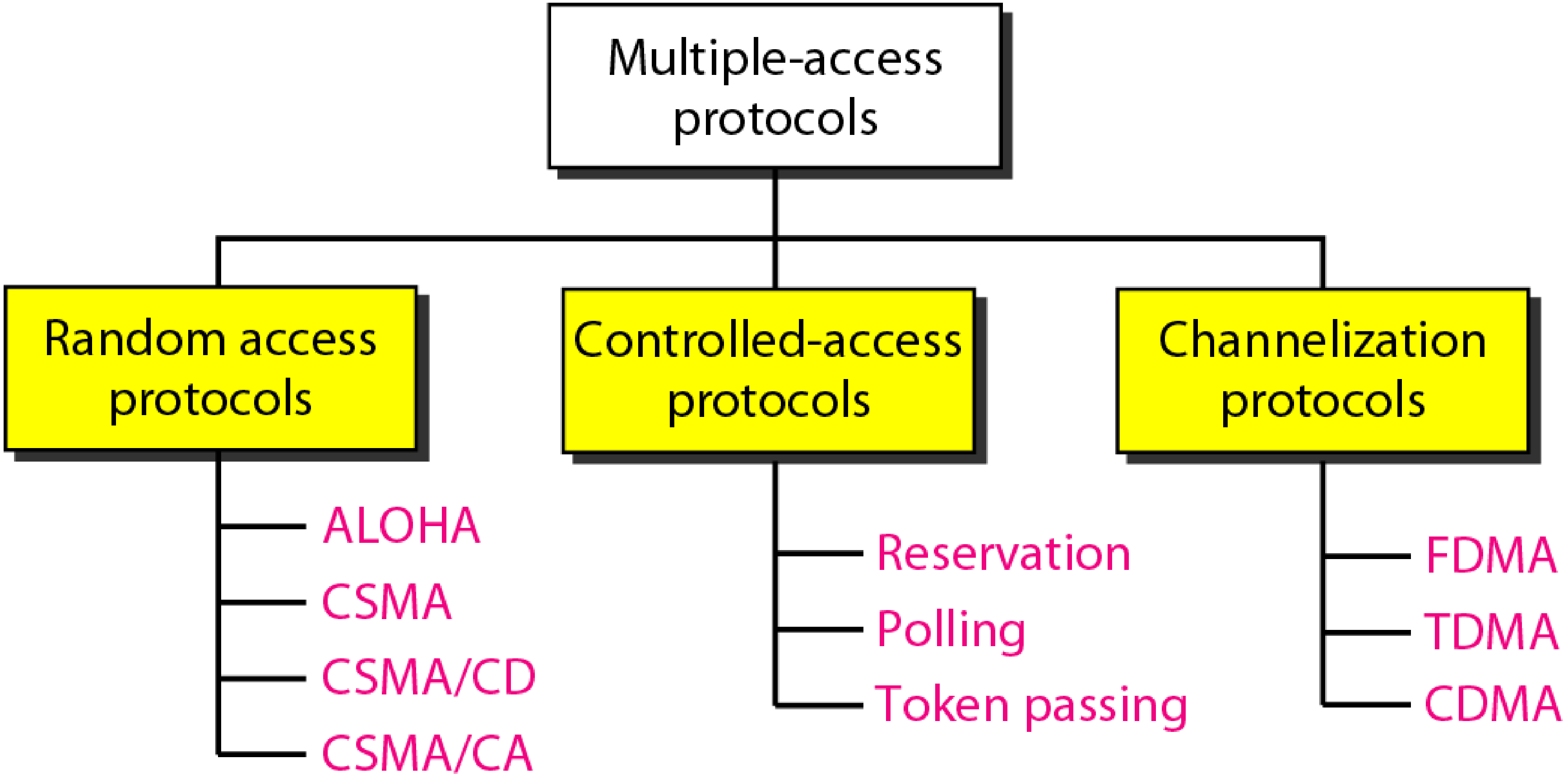


- **Station Interface is in two states**:
  - **Listen state**: Listen to the arriving bits and check the destination address to see if it is its own address. If yes the frame is copied to the station otherwise it is passed through the output port to the next station.
  - **Transmit state**: station captures a special frame called **free token** and transmits its frames. **Sending** station is responsible for **reinserting** the free token into the ring medium and for **removing** the transmitted frame from the medium.

Figure 13.13 Token-passing procedure



Random Access Protocols



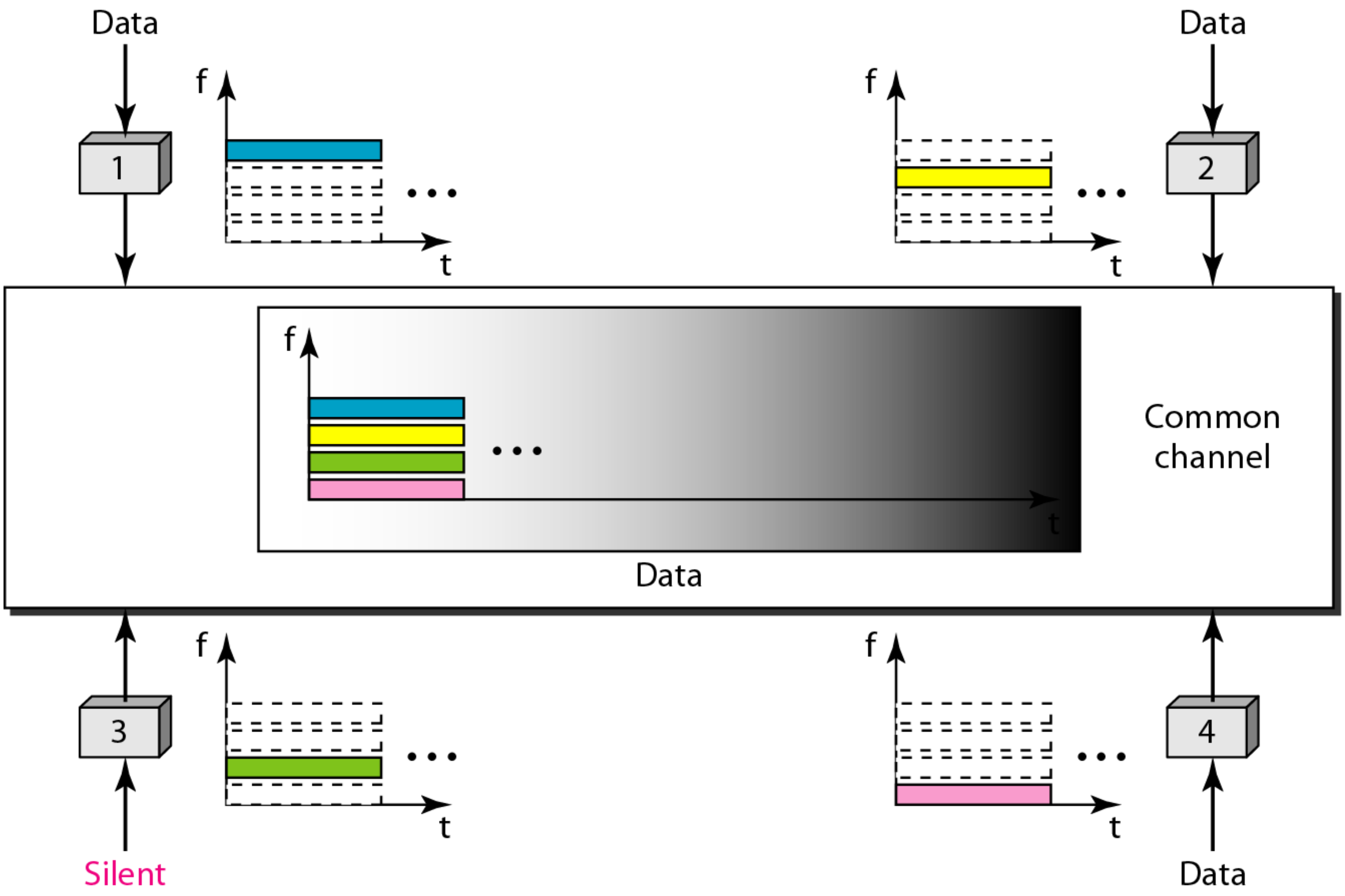
12-3 CHANNELIZATION

***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)

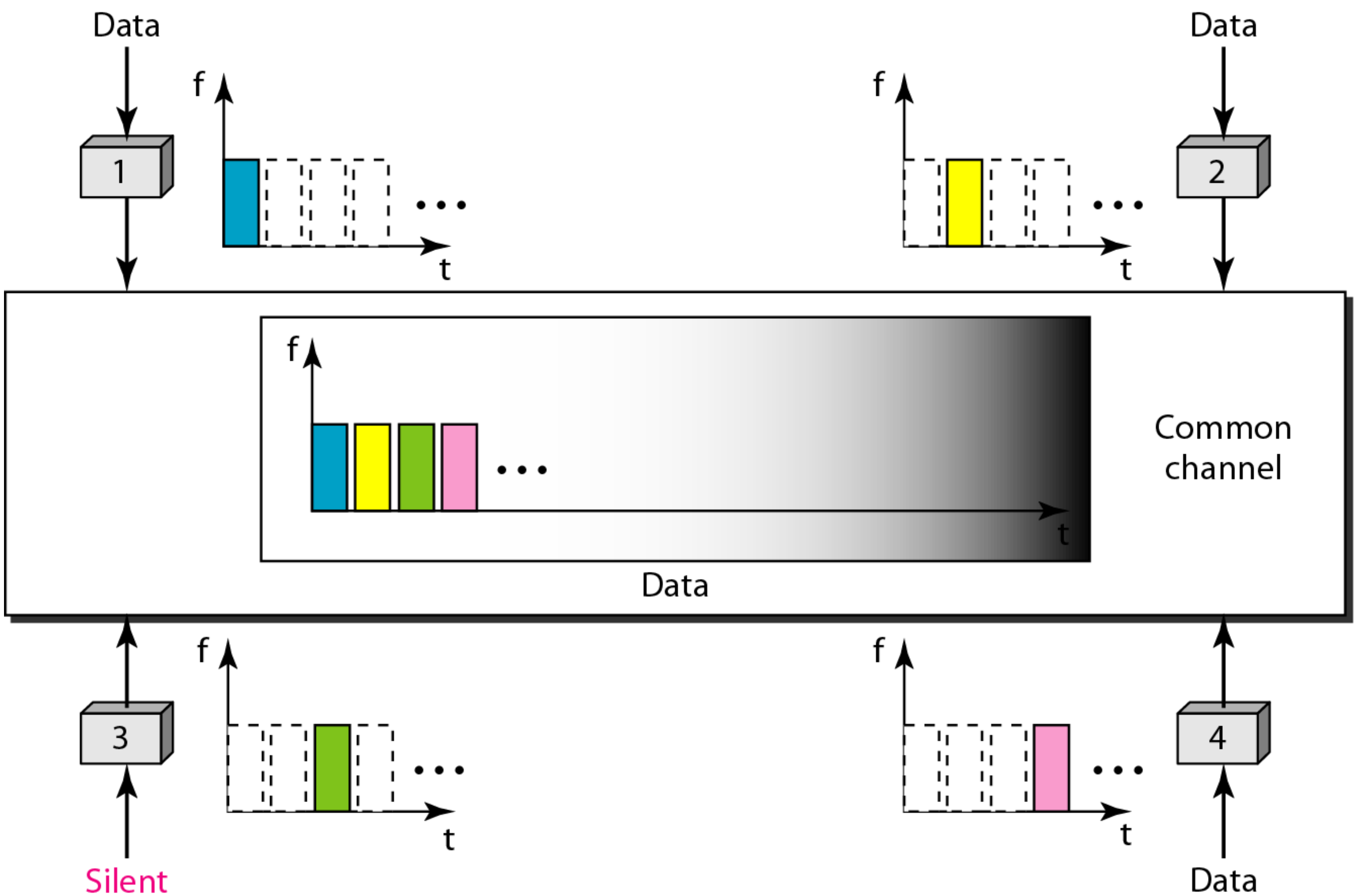
Figure 12.21 *Frequency-division multiple access (FDMA)*



12-3 CHANNELIZATION - FDMA

- **FDMA:** Frequency Division Multiple Access:
  - Transmission medium is divided into **M** separate frequency bands
  - Each station transmits **continuously** on the assigned band at an average rate of **R/M**
  - A node is **limited** to an average rate equal **R/M** (where M is number of nodes) even when it is **the only node with frame** to be sent

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



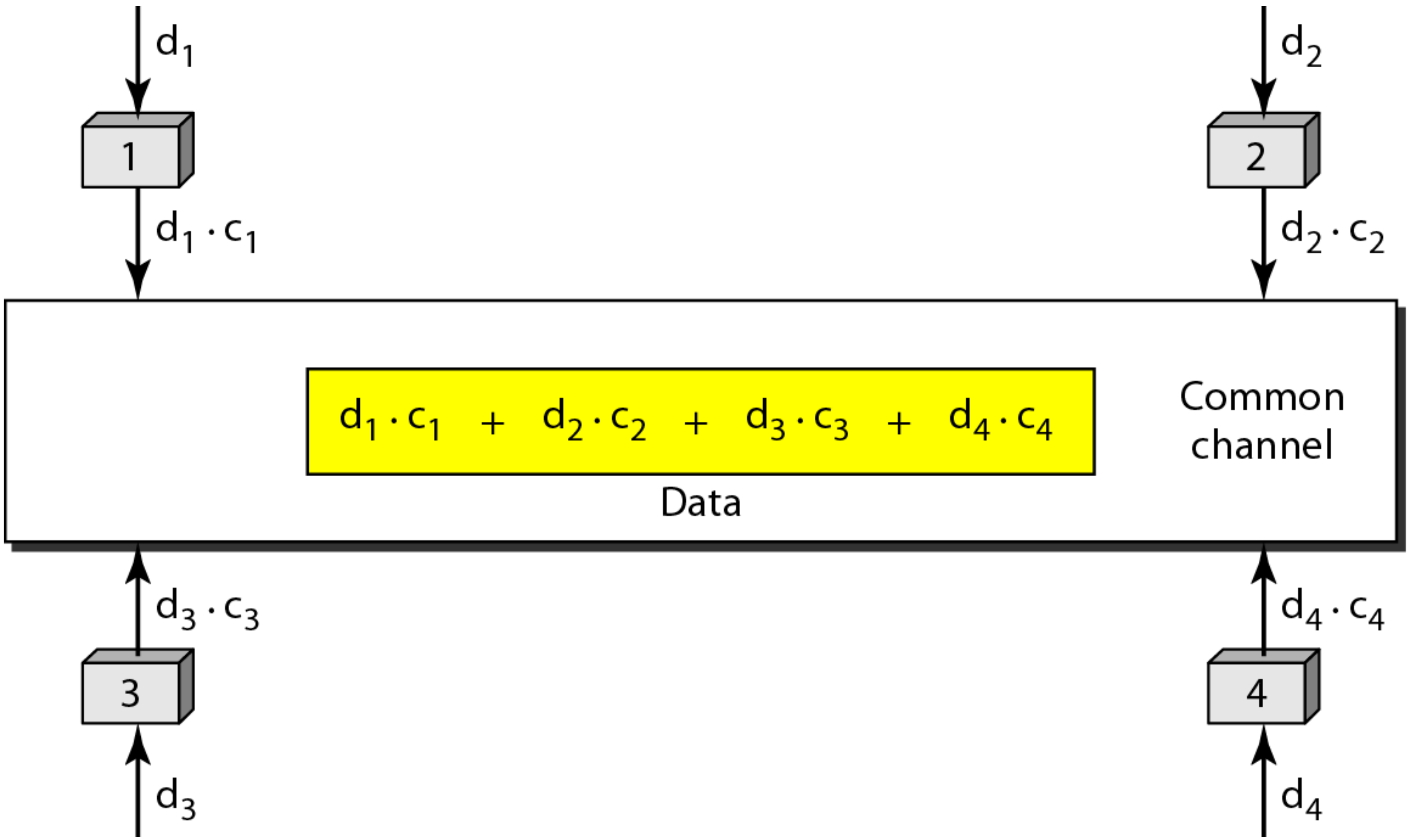
12-3 CHANNELIZATION - TDMA

- **TDMA: Time Division Multiple Access**
  - The entire bandwidth capacity is a **single channel** with its capacity shared **in time** between **M** stations
  - A node must **always wait for its turn** until its slot time arrives even when it is the **only node** with frames to send
  - A node is limited to an average rate equal **R/M** (where M is number of nodes) even when it is the only node with frame to be sent

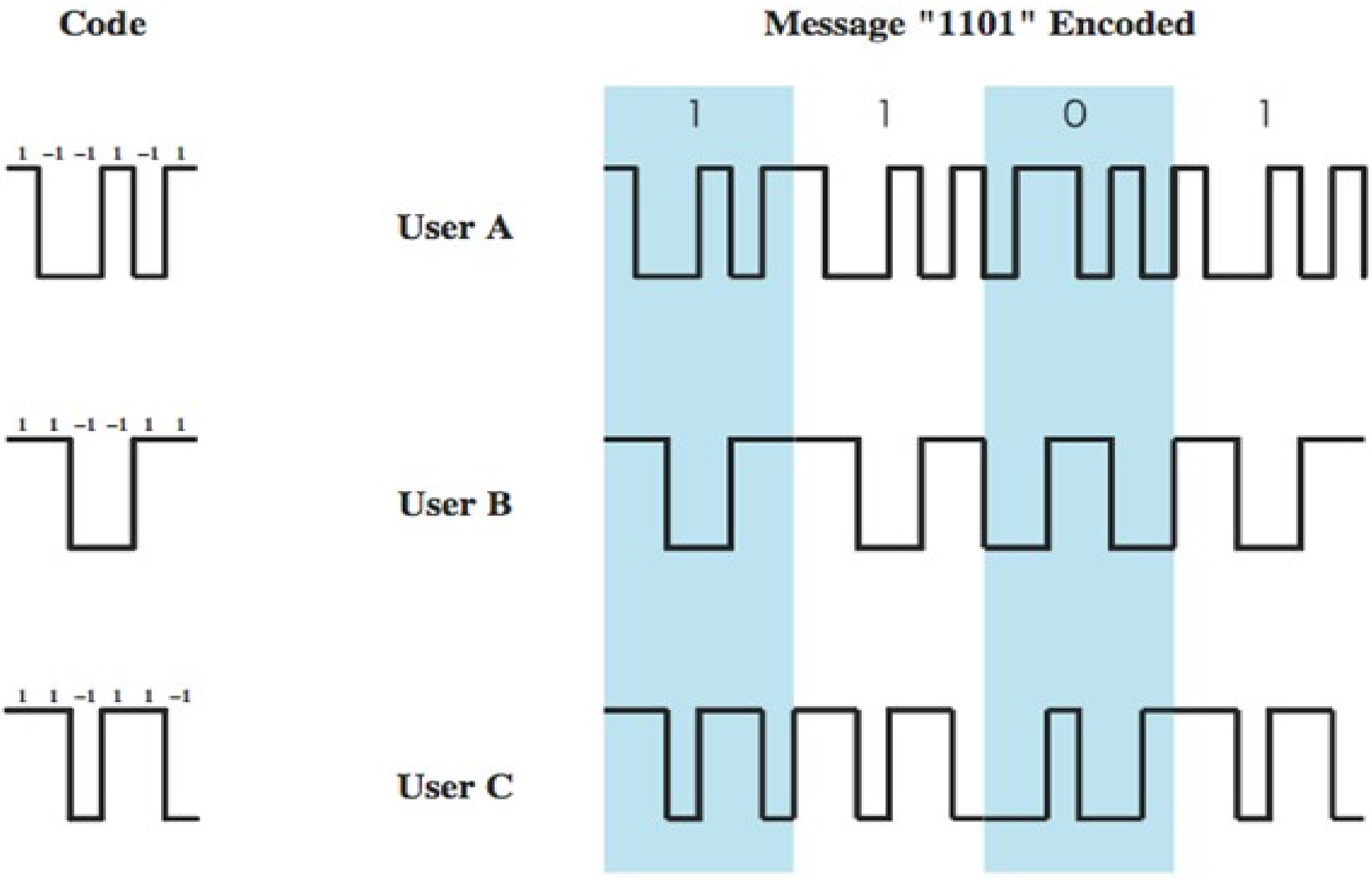
12-3 CHANNELIZATION - CDMA

- **CDMA: Code Division Multiple Access**
  - In CDMA, **one channel** carries all transmissions **simultaneously**
  - Each station codes its data signal by a specific codes before transmission
  - The stations receivers use these codes to recover the data for the desired station

gure 12.23 Simple idea of communication with code



Code Division Multiplexing



Code Division Multiplexing

- Walsh code

$$W_2 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} \qquad W_4 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix} \qquad W_8 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 & 1 \end{bmatrix}$$

Exercise - 1

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

Exercise 1 – Solution (a)

Given: Frame size = 200 bits

BW= 200 Kbps

Find: Throughput

Time per frame = 200 / 200kbps = 1ms

1000 frames/sec => 1frame/ms

We know that Throughput = $S = G \times e^{-2G}$ = $S = 1 \times e^{-2x1}$ =0.135

1000 frames per second

Throughput = 1000 x 0.135 = 135 frames per second

Exercise 1 – Solution (b)

Given: Frame size = 200 bits

BW= 200 Kbps

Find: Throughput

Time per frame = 200 / 200kbps = 1ms

500/sec => ½ frame/ms

We know that Throughput = $\mathbf{S = G \times e^{-2G}}$ =

$\mathbf{S = 0.5 \times e^{-2x0.5}}$ =0.183

1000 frames per second

Throughput = 500 x 0.183 = 92 frames per second

Exercise 2 (HW)

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

Reference

- Behrouz A. **Forouzan** “Data communication and Networking” 4th edition. (chapter 12)

Next Topic

- Ethernet (IEEE 802.3)
- Token Ring (IEEE 802.5)
- Wireless Network (IEEE 802.11)
  - CSMA/CA