MAC protocols: taxonomy

Three broad classes:

- channel partitioning

  divide channel into smaller "pieces" (time slots, frequency, code) allocate piece to node for exclusive use

- random access

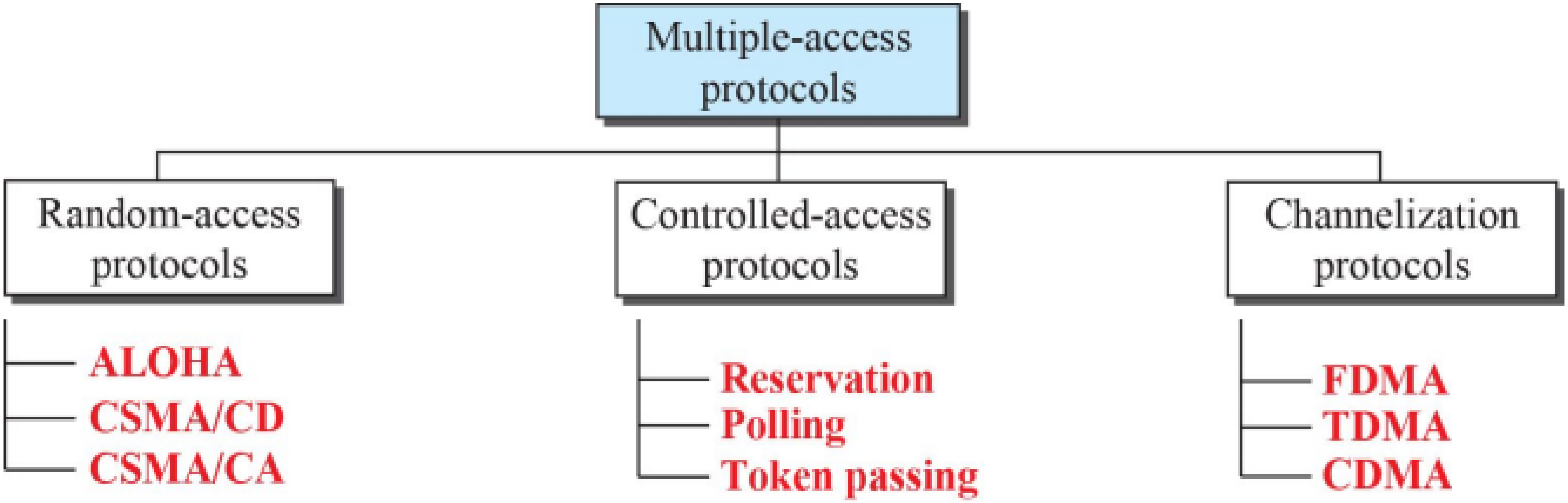
  channel not divided, allow collisions

  "recover" from collisions

- "taking turns"

  nodes take turns, but nodes with more to send can take longer turns

Figure 12.1: Taxonomy of multiple-access protocols



Channel partitioning MAC protocols: TDMA

TDMA: time division multiple access

- access to channel in "rounds"

- each station gets fixed length slot (length = pkt trans time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have pkt, slots 2,5,6 idle

frame

6-slot
fram
e

6-slot

1 3 4 1 3 4

Channel partitioning MAC protocols: FDMA

FDMA: frequency division multiple access

- channel spectrum divided into frequency bands
- each station assigned fixed frequency band
- unused frequency bands go idle

- example: 6-station LAN, 1,3,4 have pkt, frequency bands 2,5,6 idle

Random access protocols

- When node has packet to send
  - transmit at full channel data rate R
  - no *a priori* coordination among nodes
  - Two or more transmitting nodes ➜ "collision",
- Random access MAC protocol specifies:
  - how to detect collisions
  - how to recover from collisions (e.g., via delayed retransmissions)

- Examples of random access MAC protocols:
  - slotted ALOHA and (pure) ALOHA
  - CSMA, CSMA/CD, CSMA/CA

12.12.1 ALOHA

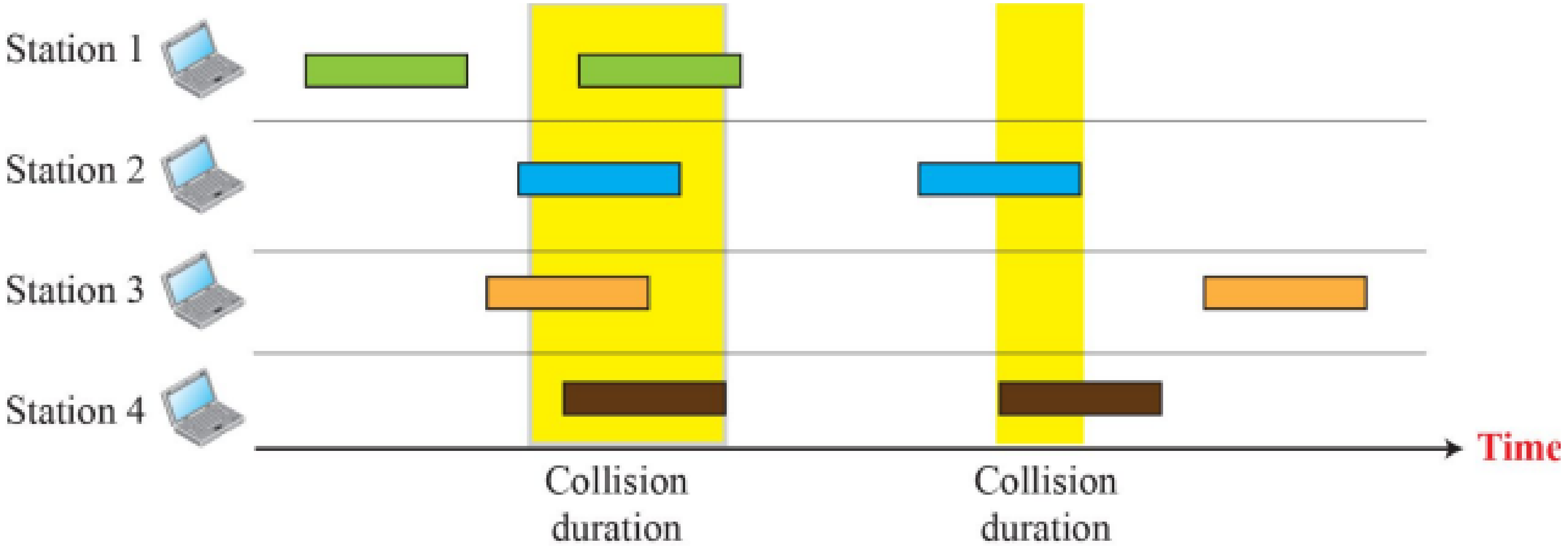
- ALOHA, the earliest random access method, was developed at the University of Hawaii in early 1970.

- It was designed for a radio (wireless) LAN, but it can be used on any shared medium.

- potential collisions - The medium is shared between the stations. When a station sends data, another station may attempt to do so at the same time. The data from the two stations collide and become garbled.

Pure ALOHA

- The idea is that each station sends a frame whenever it has a frame to send (multiple access).
- Since there is only one channel to share, there is the possibility of collision between frames from different



stations. ***Figure 12.2:* Frames in a pure ALOHA network**

Pure ALOHA

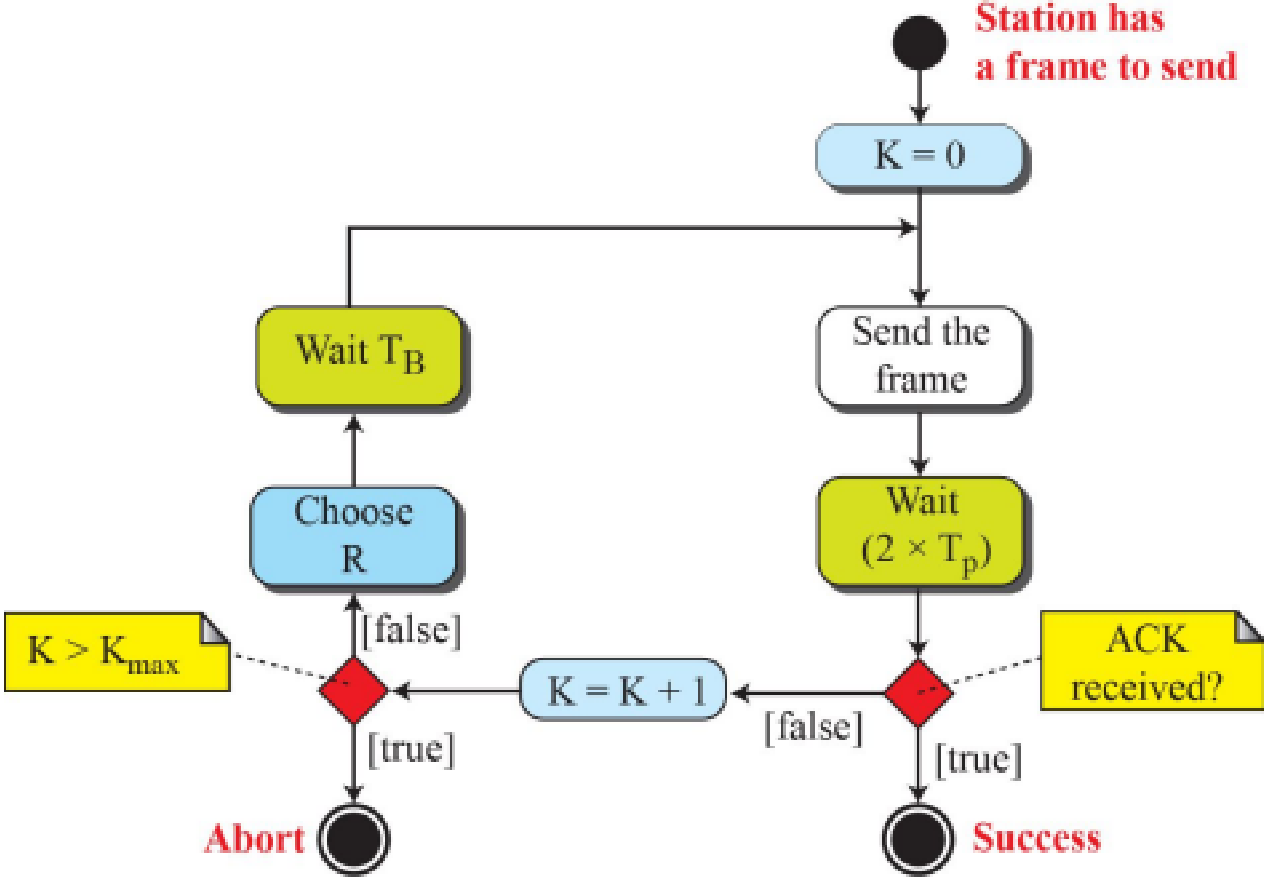
- The pure ALOHA protocol relies on acknowledgments
- If the acknowledgment does not arrive (time-out), the station assumes that the frame (or the acknowledgment) has been destroyed and resends the frame.

- Pure ALOHA dictates that when the time-out period passes
  - each station waits a random amount of time before resending its frame.
  - The randomness will help avoid more collisions.
  - Named *backoff time* T_B.

***Figure 12.3:* Procedure for pure ALOHA protocol**

Legend

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


Station has
a frame to send
K = 0
Send the
frame
Wait
(2 × T_p)
ACK
received?
[true]
Success
[false]
K = K + 1
$K > K_{max}$
[true]
Abort
[false]
Choose
R
Wait T_B

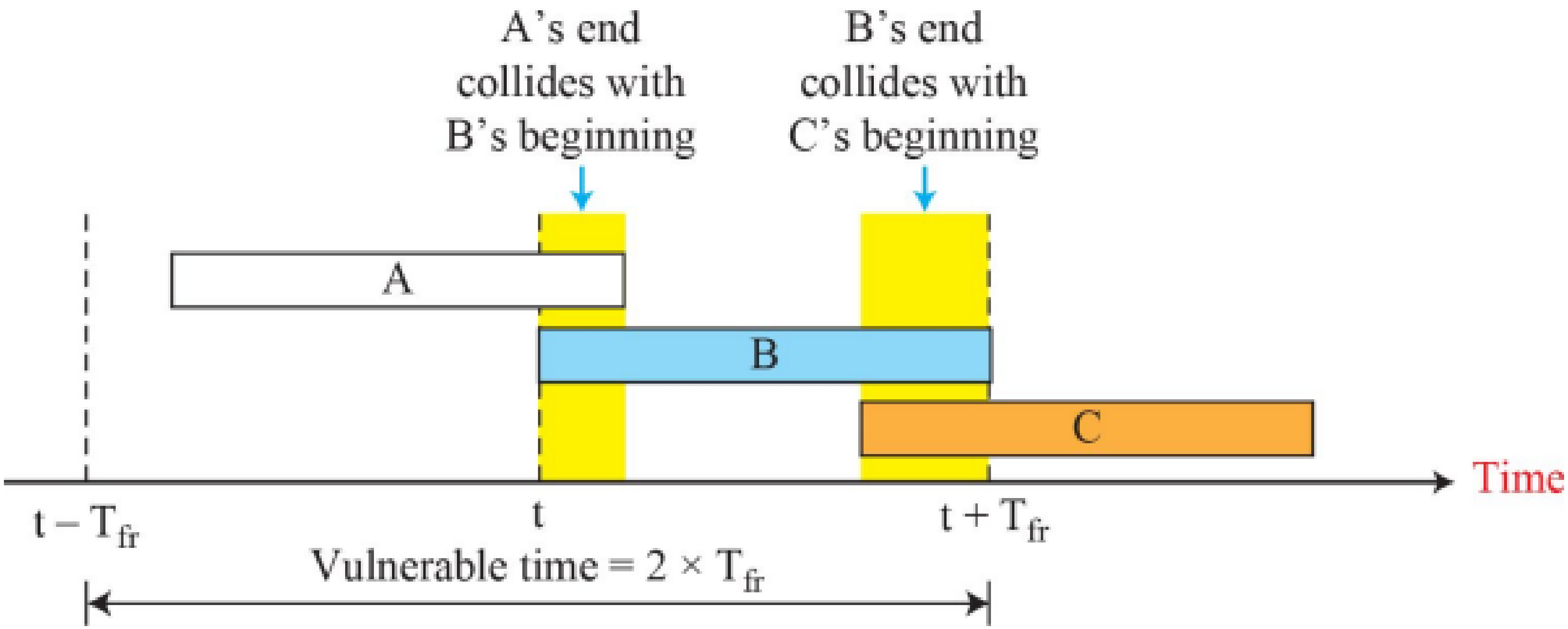
- The stations on a wireless ALOHA network are a maximu
600 km apart.

- If we assume that signals propagate at 3×10^8 m/s, we find

$$T_p = (600 \times 10^3) / (3 \times 10^8) = 2\ ms$$

- For $K = 2$, the range of R is $\{0, 1, 2, 3\}$. This means that T
be 0, 2, 4, or 6 ms, based on the outcome of the random vari
R.

Figure 12.4: Vulnerable time for pure ALOHA protocol



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

Solution

Average frame transmission time T_{fr} is 200 bits/200 kbps or 1 ms. The vulnerable time is 2×1 ms $= 2$ ms.

This means no station should send later than 1 ms before this station starts transmission and no station should start sending during the period (1 ms) that this station is sending.

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

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

Solution

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

If the system creates 1000 frames per second, or 1 frame per millisecond, then G = 1 [**G the average number of frames generated bythe system during one frame transmission time**.]. In this case $S = G \times e^{-2G}$ = 0.135 (13.5 percent). This means that the throughput is 1000 × 0.135 = 135 frames. Only 135 frames out of 1000 will probably survive.

b. If the system creates 500 frames per second, or 1/2 frames per millisecond, then G = 1/2. In this case $S = G \times e^{-2G}$ =

0.184 (18.4 percent). This means that the throughput is 500 × 0.184 = 92 and that only 92 frames out of 500 will probably survive. Note that this is the maximum throughput case, percentage-wise.

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

12.25

Slotted ALOHA

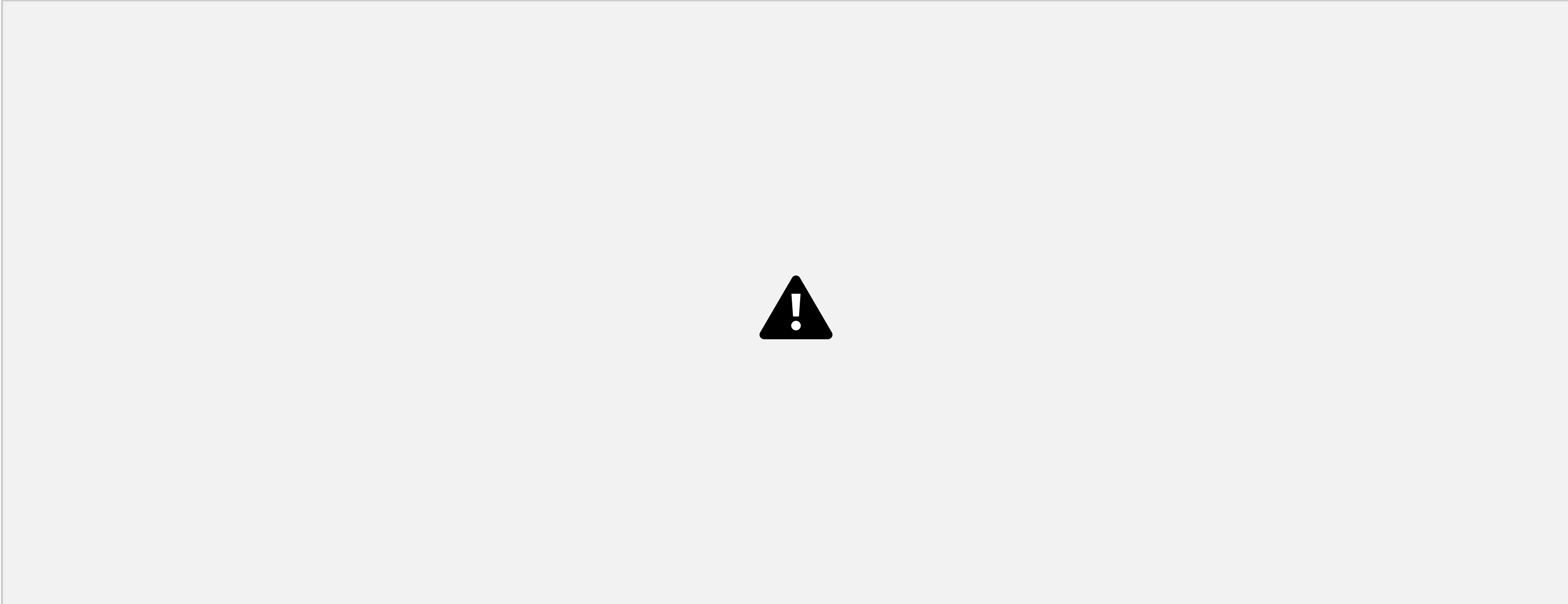
Assumptions:

- Same sized frames (L bits)
- Time divided into equal size slots (time to transmit 1frame)
- The nodes are synchronized so that each node knows when the slots begin.
- Nodes start to transmit only slot beginning
- If 2 or more nodes transmit in slot, [redacted]

Slotted ALOHA

Figure 12.5: ***Frames in a slotted ALOHA network***

Figure 12.6: ***Vulnerable time for slotted ALOHA protocol***



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

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

Solution

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

12.30

a) In this case G is 1. So $\mathbf{S = G \times e^{-G}}$ = 0.368 (36.8 percent). This means that the throughput is 1000 × 0.368 = 368 frames. Only 368 out of 1000 frames will probably survive. Note that this is the maximum throughput case, percentage-wise.

b) Here G is 1/2. In this case $S = G \times e^{-G} = 0.303$ (30.3 percent). This means that the throughput is $500 \times 0.303 = 151.2$. Only 151 frames out of 500 will probably survive.

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

12.12.2 CSMA

(Carrier Sense Multiple Access)

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

- [redacted].
- Carrier sense multiple access (CSMA) requires that each station first listen to the medium (or check the state of the medium) before sending.

CSMA collisions

- collisions *can* still occur: two nodes may not hear each other's transmission
- collision: entire packet transmission time wasted

distance & propagation delay play role in determining collision probability

spatial layout of nodes

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

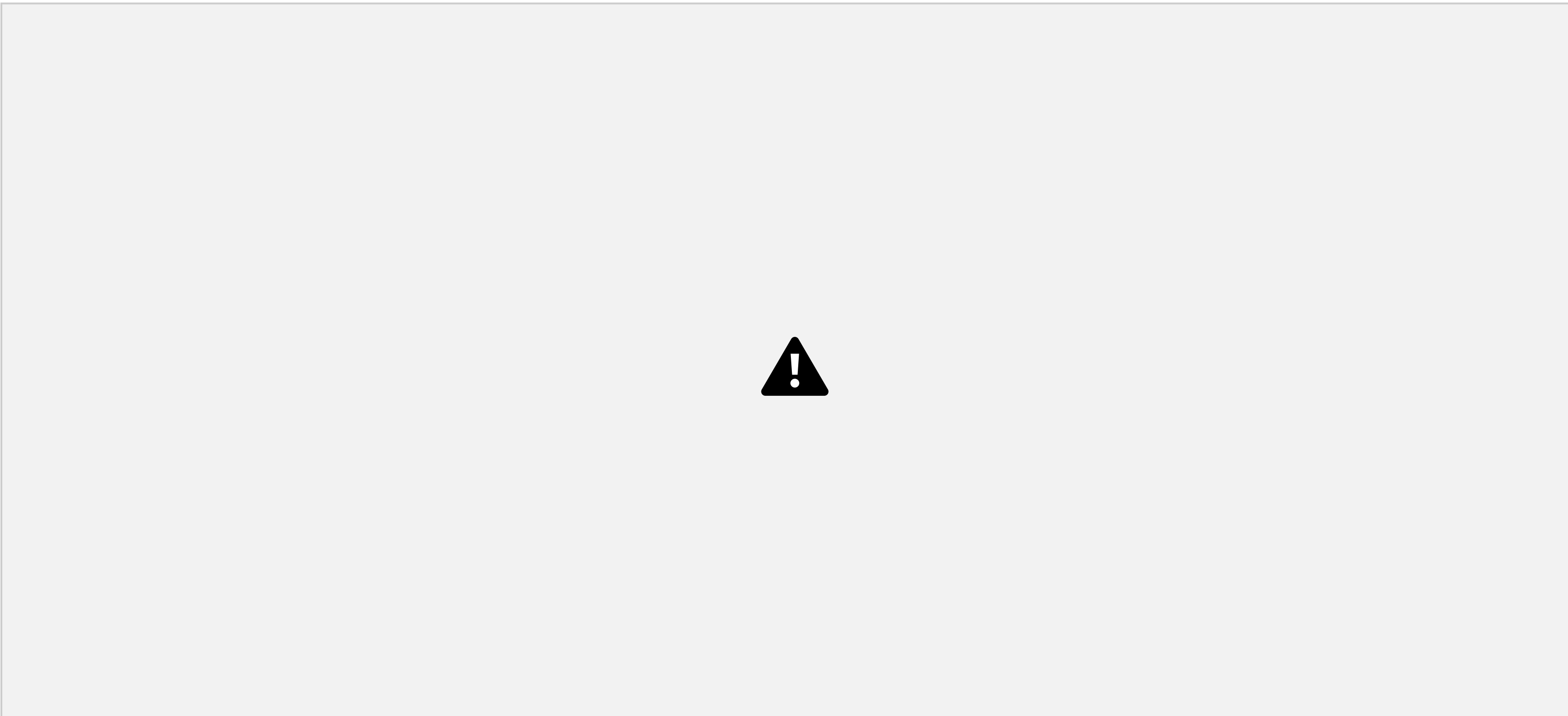


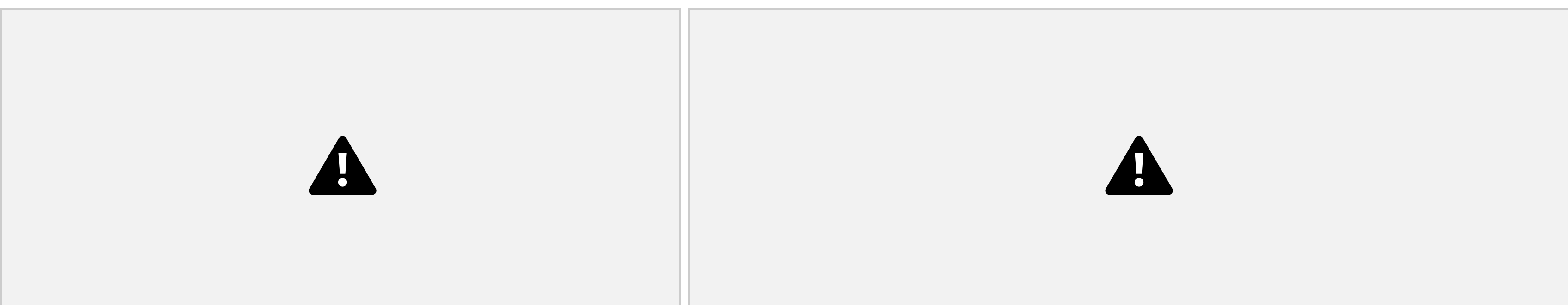
***Figure 12.8:* Vulnerable time in CSMA**

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

• When a station sends a frame and any other station tries to send a frame during this time, a collision will result. • But if the first bit of the frame reaches the end of the medium, every station will already have heard the bit and will refrain from sending.

Figure 12.9: ***Behavior of three persistence methods***

❑ What should a station do if the channel is busy? ❑ What should a station do if the channel is idle? ❑ Three methods have been devised to answer these questions: the 1- persistent method, the Nonpersistent method, and the p- persistent method.



1- Persistent

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.

Nonpersistent

Senses the line

- 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.

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. reduces the efficiency of the network

- because the medium remains idle when there may be stations with frames to send.

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.

P-persistent

P-persistent

CSMA/CD (Collision Detection)

- The CSMA method does not specify the procedure following a collision.
- *Carrier sense multiple access with collision detection* (CSMA/CD)
    - augments the algorithm to handle the collision.
- 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, there is a collision, the frame is sent again.

CSMA/CD (Collision Detection)

❖ ***Collision detection*?**

- easy in wired LANs: measure signal strengths, compare transmitted and received signals
- difficult in wireless LANs: received signal strength overwhelmed by local transmission strength

***Figure 12.14:* Energy level during transmission, idleness, or collision**
***Figure 12.11:* Collision of the first bits in CSMA/CD**

- A transmits for the duration t4 - t1; C transmits for the duration t3 - t2.

Figure 12.12: ***Collision and abortion in CSMA/CD***

CSMA/CD (Collision Detection)

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) is 25.6 μs, what is the minimum size of the frame?

Solution

The minimum frame transmission time is $T_{fr} = 2 \times T_p = 51.2$ μs. 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.

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

Ethernet CSMA/CD algorithm

1. NIC receives datagram

from network layer, creates frame.

2. If NIC senses channel idle, starts frame transmission. If NIC senses channel busy, waits until channel idle, then transmits.

3. If NIC transmits entire frame without detecting another transmission,

CSMA/CD efficiency

- T_{prop} = max prop delay between 2 nodes in LAN
- t_{trans} = time to transmit max-size frame

- efficiency goes to 1
  - as t_{prop} goes to 0
  - as t_{trans} goes to infinity
    - better performance than ALOHA: and simple, cheap, decentralized!

“Taking turns” MAC protocols

Channel partitioning MAC protocols:

share channel *efficiently* and *fairly* at high load

inefficient at low load: delay in channel access, 1/N bandwidth allocated even if only 1 active node!

Random access MAC protocols

efficient at low load: single node can fully utilize channel high load: collision overhead

"Taking turns" protocols

look for best of both worlds!

12.2.2 Polling

- Polling works with topologies in which one device primary station and many secondary stations.

- A[redacted] must be made through the primary.
  - The primary device controls the link; - the secondary devices follow its instructions. - the primary device determines which device is allowed to use the channel

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

- The select (SEL) function used
  - whenever the primary device has something to send.
- If the primary is neither sending nor receiving data, it knows the

link is available.

- The primary must alert the secondary to the upcoming transmission and wait for an acknowledgment of the secondary's ready status.
  - Before sending data, the primary creates and transmits a select (SEL) frame, one field of which includes the address

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

- The poll function
  - used to solicit transmissions from the secondary devices.
- The primary must ask (poll) each

device in turn.

- When the first secondary is approached, it responds either with a NAK frame if it has nothing to send or with data.
- When the response is positive (a data frame), the primary reads the frame and returns an acknowledgment (ACK frame), verifying its receipt.

“Taking turns” MAC protocols

- Polling Concerns:
  - polling overhead
  - latency
  - single point of failure

12.2.3 Token Passing

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

station which is after the station in the ring.

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

The problem with this topology is that if one of the links— the medium between two adjacent stations— fails, the whole system fails.

The high-speed Token Ring networks called FDDI (Fiber Distributed Data Interface) and CDDI (Copper Distributed Data Interface) use this topology.

“Taking turns” MAC protocols

- Token passing:
- control token passed from one node to next sequentially.
- token message
- concerns:

 token overhead

 latency

 single point of failure (token)