Data Communication and Computer Network

MAC Sub Layer

"Technically, the MAC sublayer is the bottom part of the data link layer, so logically we should have studied it before examining all the point-to-point protocols in Chap. 3. Nevertheless, for most people, it is easier to understand protocols involving multiple parties after two-party protocols are well understood. For that reason we have deviated slightly from a strict bottom-up order of presentation."

From - Computer Networks,

Andrew S. Tanenbaum and David J. Wetherall

Medium Access Control (MAC) Protocols

- Also called Random Access or Contention Protocols
- Protocol followed by nodes to decide **who should transmit when**
- 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
- Any node may have data to transmit at any point of time
- Needs to avoid collision, i.e. two or more stations transmitting through the medium at the same time

Random Access Protocol Types

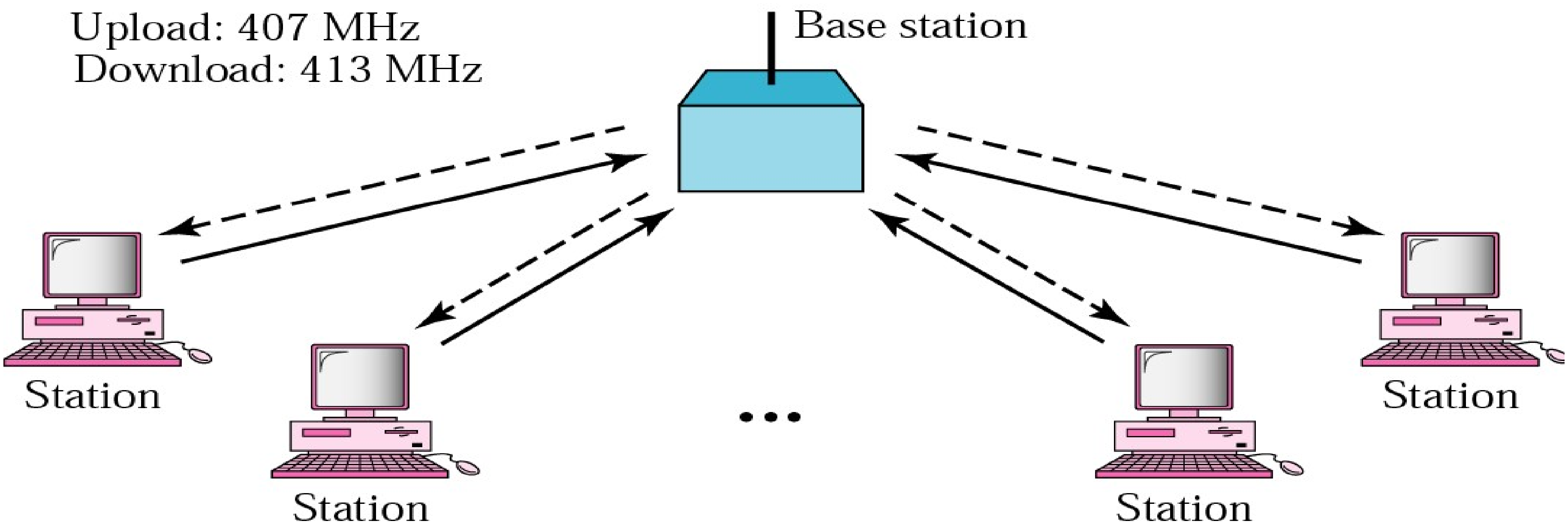
- ALOHA
- Carrier Sense Multiple Access (CSMA)
- Carrier Sense Multiple Access with Collision Detection (CSMA-CD)
- Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA)

ALOHA

ALOHA

- Developed in University of Hawaii in early 70s
  - Originally developed for packet radio networks
  - Transmission to and from a central station
  - All other sources transmit using same frequency, central station uses another frequency
- Whenever a station has a frame, it sends immediately
  - Station listens for maximum round trip time (plus small increment) for ACK
  - If ACK, fine. If not, wait for a random time and then retransmit frame
  - If no ACK after repeated transmissions, give up

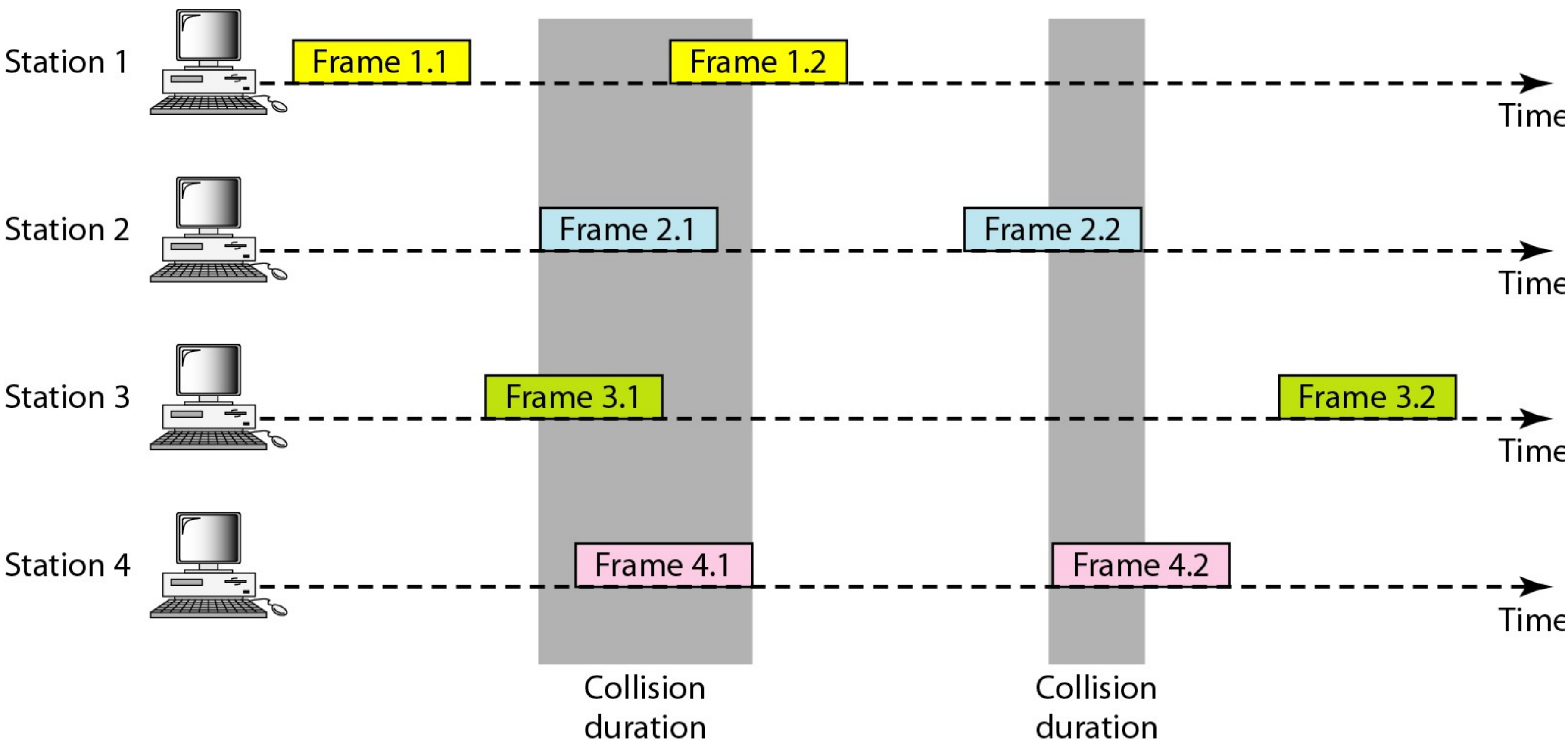
ALOHA network



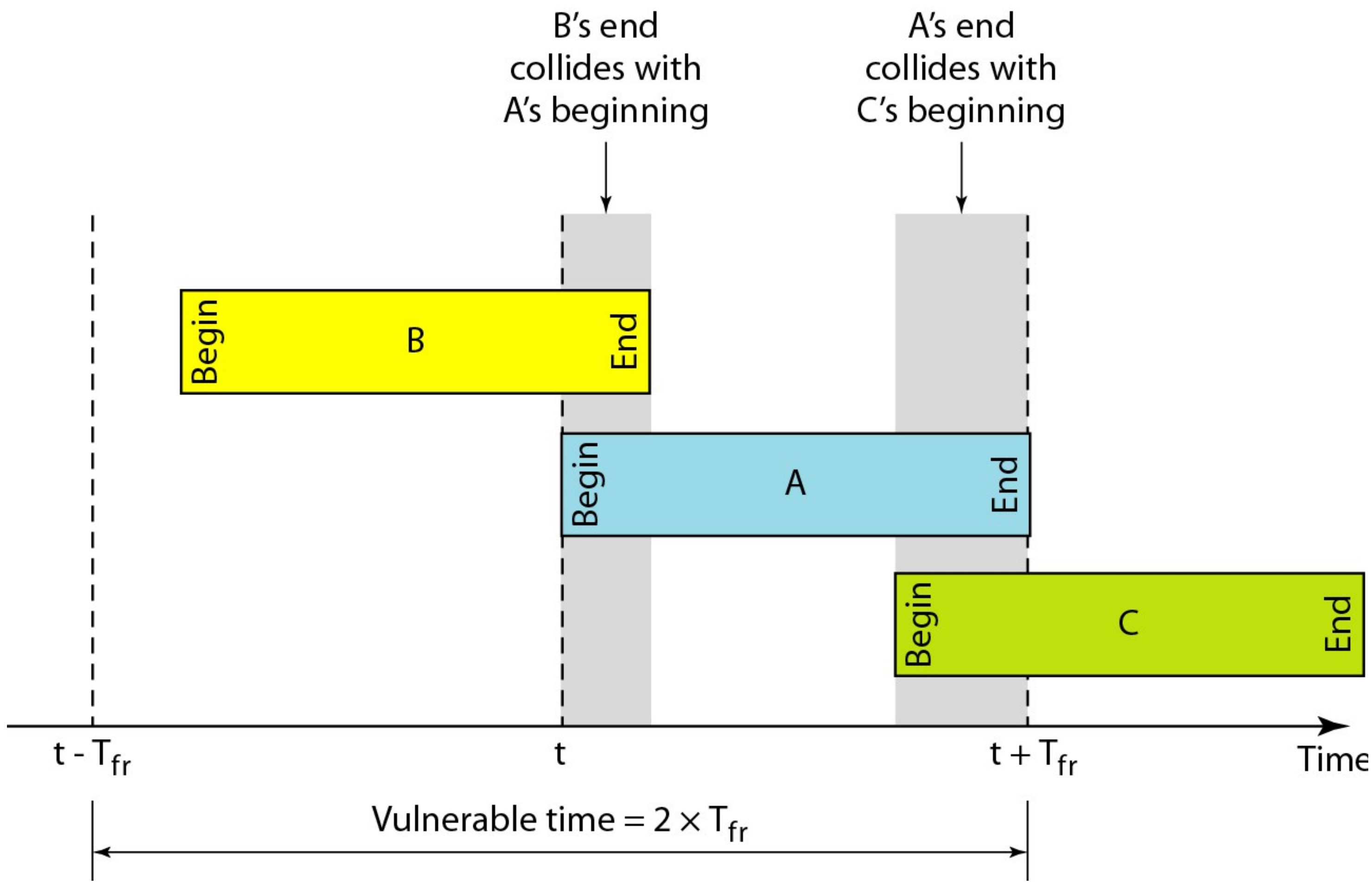
ALOHA (contd.)

- When a station receives a frame:
  - If frame ok (using FCS) and address matches this station, send ACK frame immediately
  - ACK frames sent on a different frequency
- Frame may become invalid due to noise, or because another station transmitted a frame at about the same time: collision
- How is collision detected?
  - If frame found to be invalid, receiver NOT send ACK
  - If no ACK received within some time, sender assumes collision
- Max utilization 18%, very low for large nos. of nodes or for higher transmission rates

Frames in a pure ALOHA network

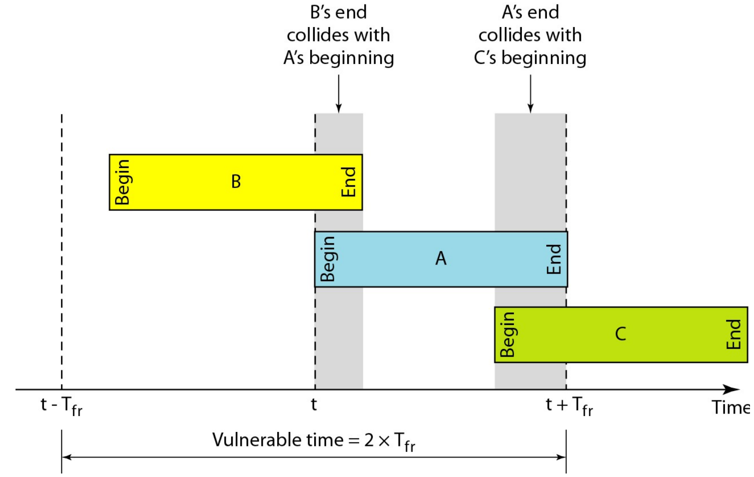


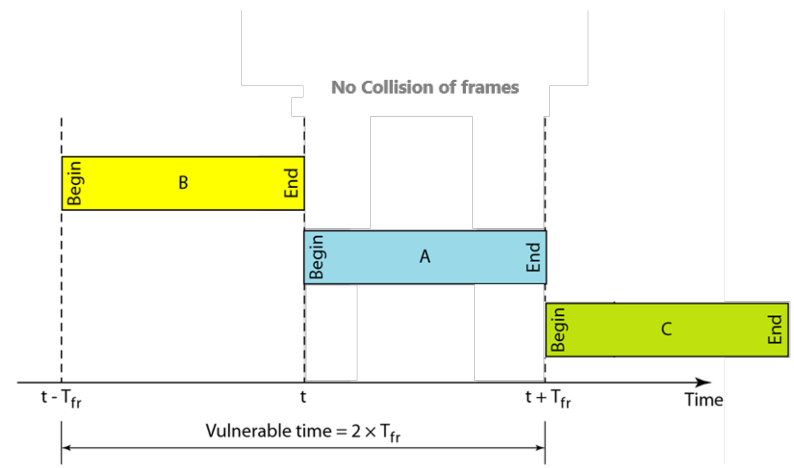
Vulnerable time for pure ALOHA protocol



Vulnerable time for pure ALOHA protocol

- Station A sends a frame at time t.
- Now imagine station B has already sent a frame between (t – Tfr) and t. This leads to a collision between the frames from station A and station B. The end of B's frame collides with the beginning of A's frame.
- On the other hand, suppose that station C sends a frame between t and (t + Tfr). Here, there is a collision between frames from station A and station C. The beginning of C's frame collides with the end of A's frame.
- Hence, the vulnerable time, during which a collision may occur in pure ALOHA, is 2 times the frame transmission time.

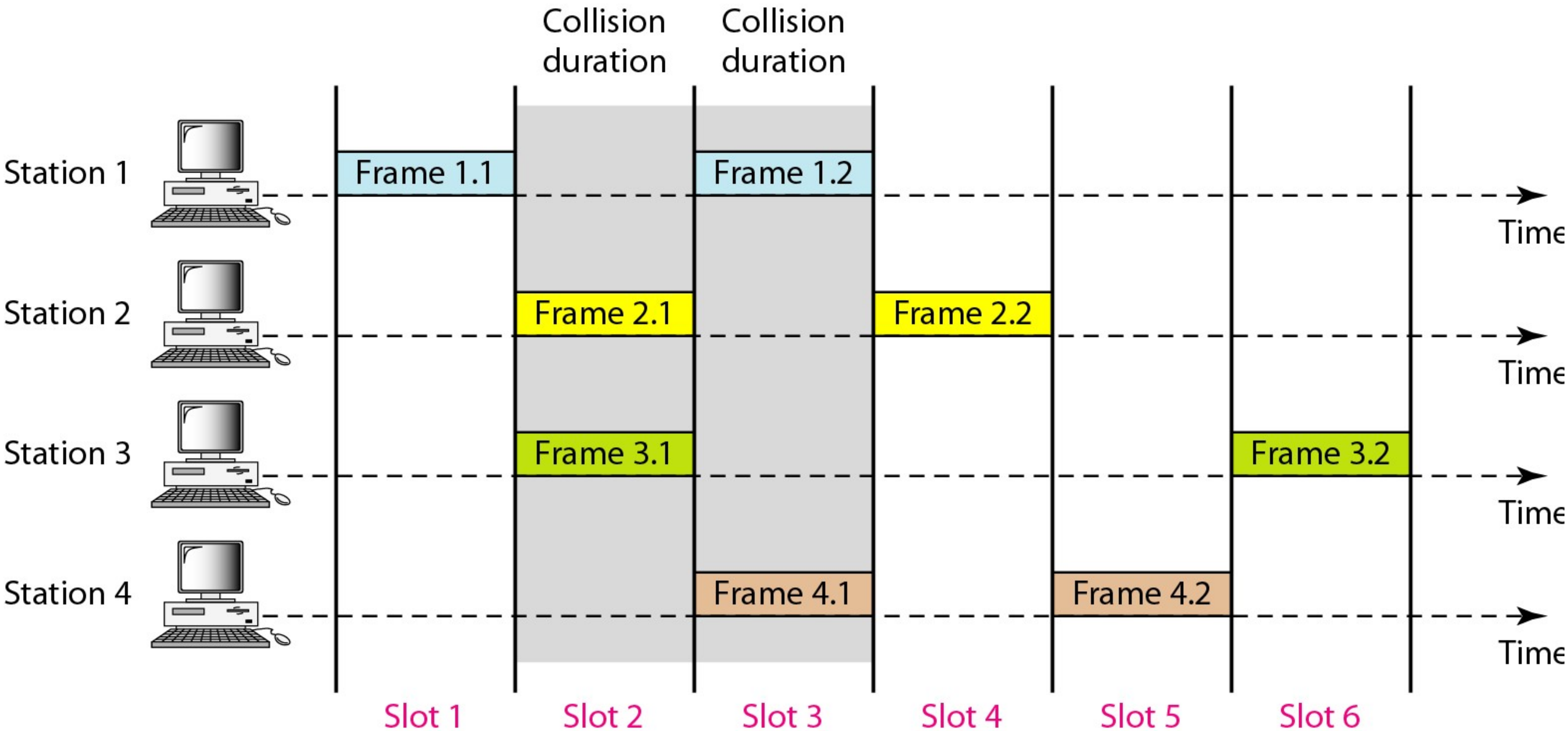




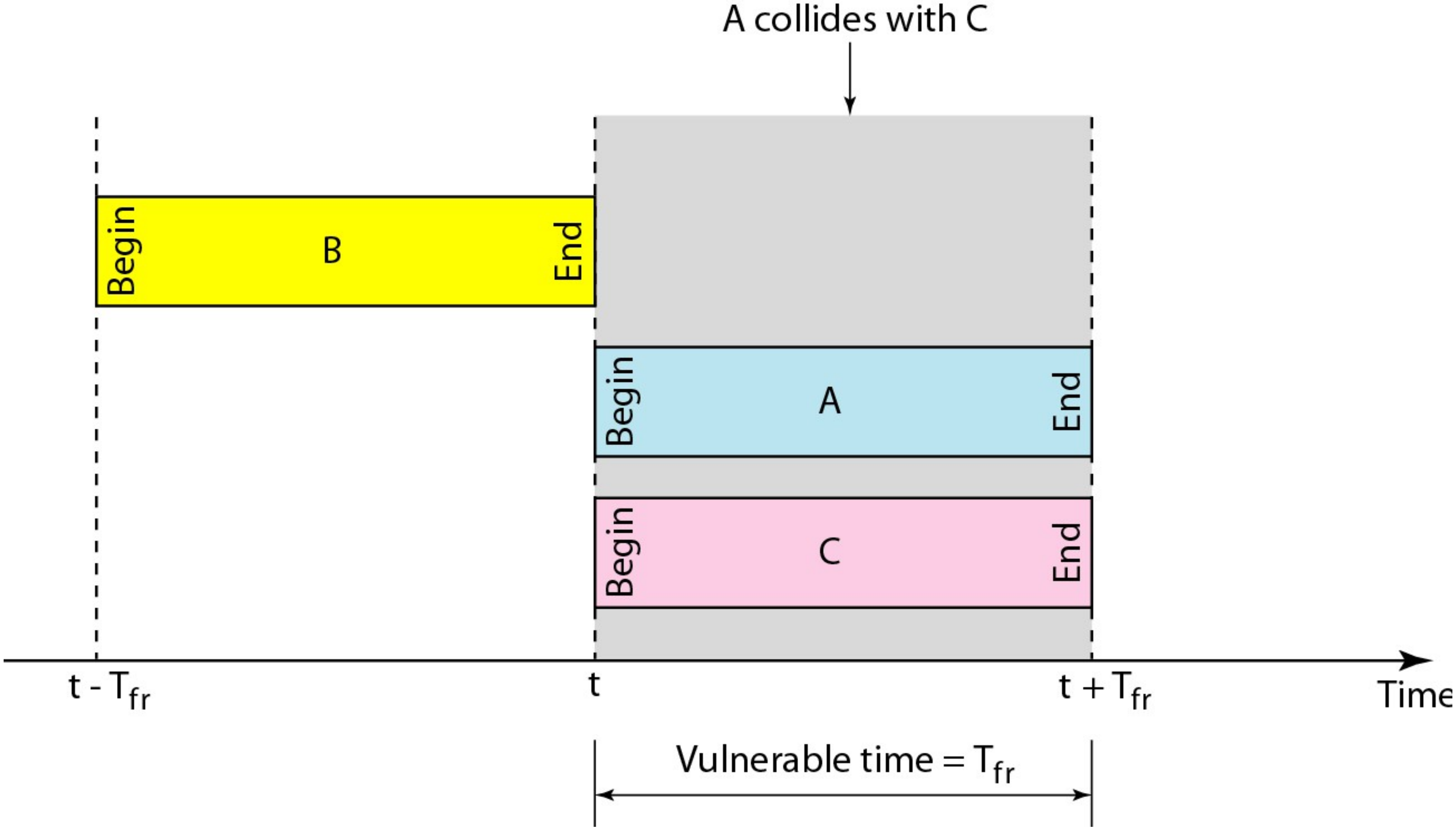
Slotted ALOHA

- Time on the channel **divided into slots** equal to frame transmission time
  - Needs central clock to synchronize all nodes
  - A source can start sending only at the beginning of a slot
- Reduces number of collisions over ALOHA
  - Contention period (time interval in which frames can overlap or collide) is halved compared to ALOHA
  - Collision possible only if more than 1 sources become ready to transmit within the same slot
- Max utilization 37%

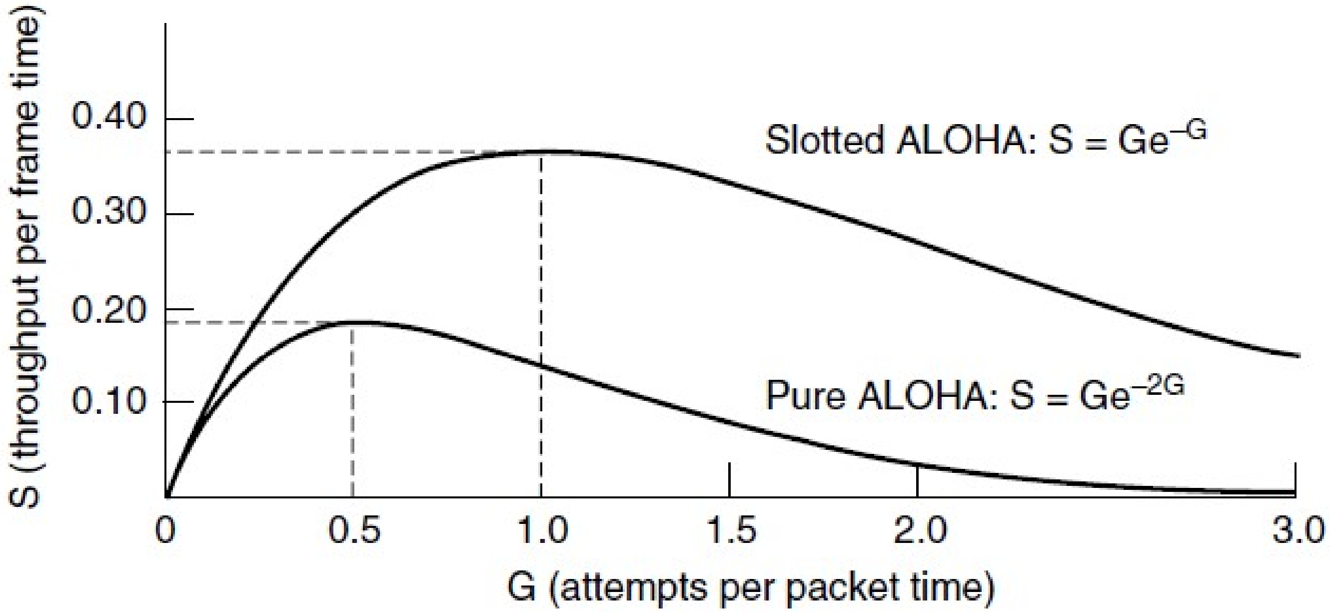
Frames in a slotted ALOHA network



Vulnerable time for slotted ALOHA protocol



Channel utilization of ALOHA and slotted ALOHA



Throughput versus offered traffic for ALOHA systems.

Carrier Sense Multiple Access (CSMA)

Carrier Sense Multiple Access (CSMA)

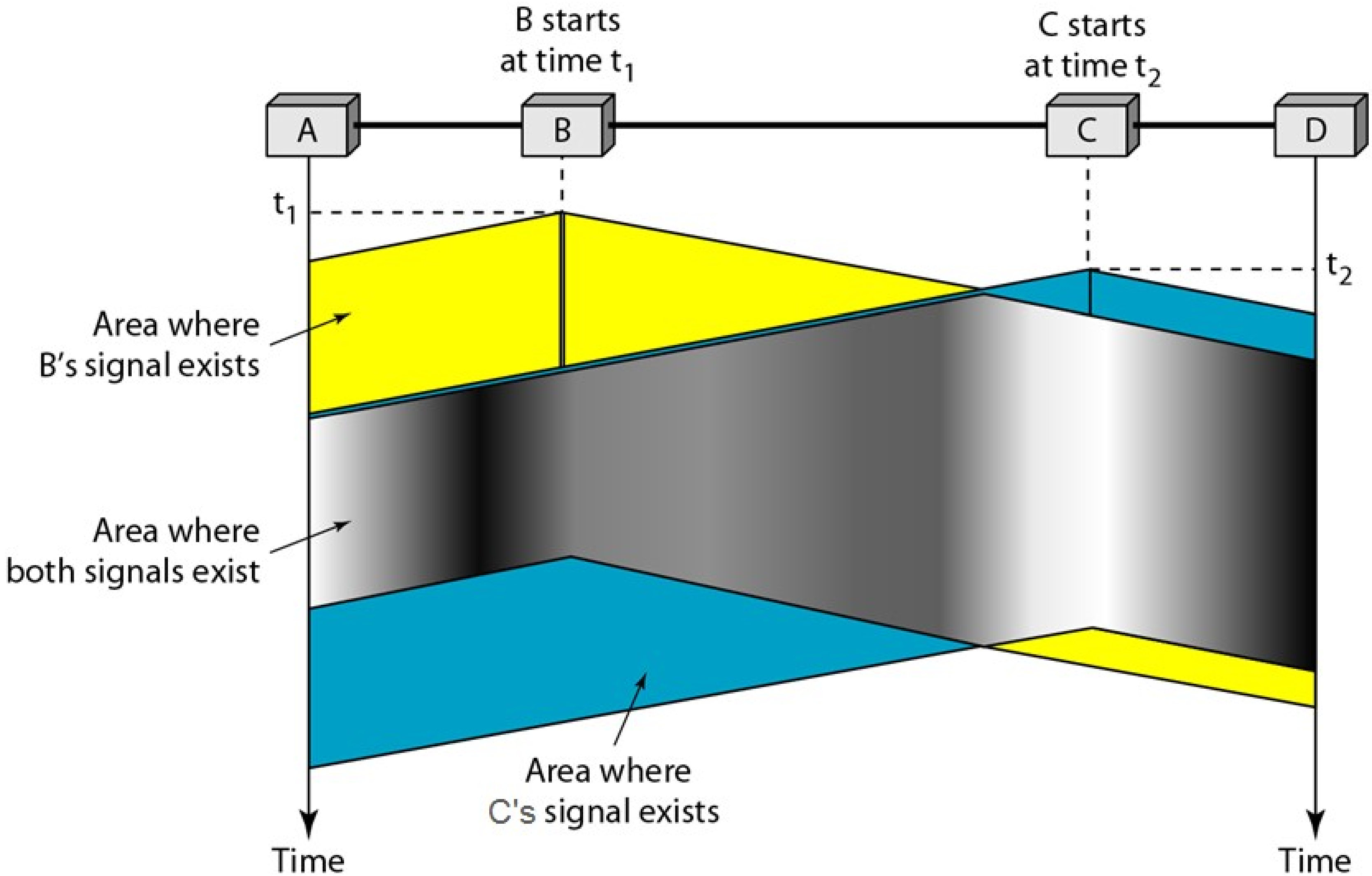
- Motivation
  - In most small networks, **propagation time** is much smaller compared to **frame transmission time**
- Whenever node N becomes ready to transmit a frame, sense the medium (carrier sense)
- If line idle, N <u>may</u> transmit frame immediately
- If line not idle
  - Alternatives: (1) non-persistent, (2) 1-persistent, (3) p-persistent
  - Tradeoff between line utilization and chance of collision

CSMA: collisions

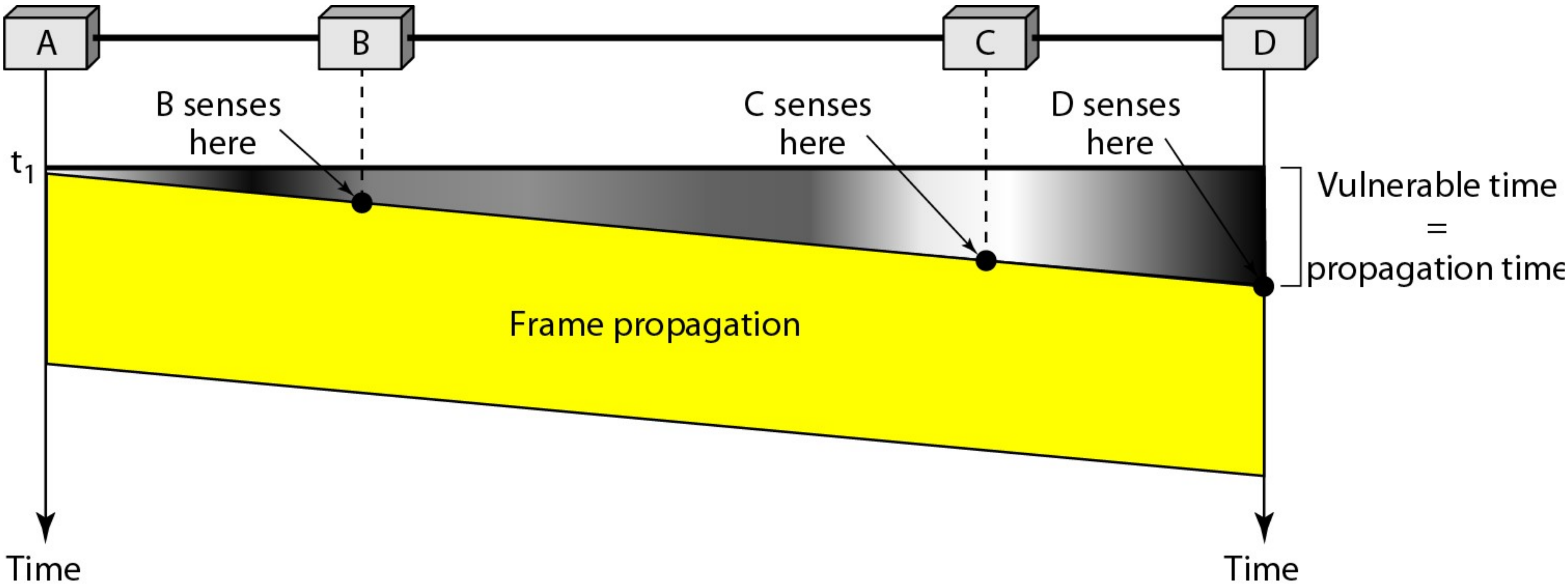
- After transmitting, station waits for ACK for a reasonable time
  - RTT + some allowance (because Rx must also contend for the channel in order to send ACK)
- If no ACK, then repeat process for transmitting
  - Sense medium; if idle, transmit; else wait …

- Collision occurs if another node N′ starts transmitting within the time it takes for the first bit sent by N to reach this node N′ (within the propagation delay)

Space/time model of the collision in CSMA



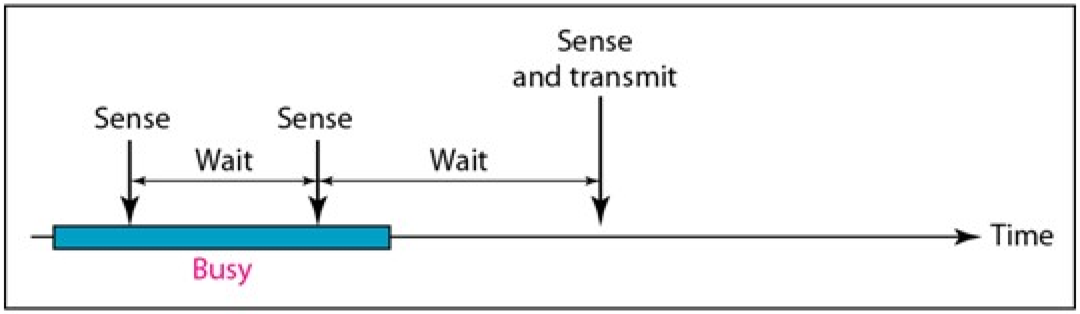
Vulnerable time in CSMA

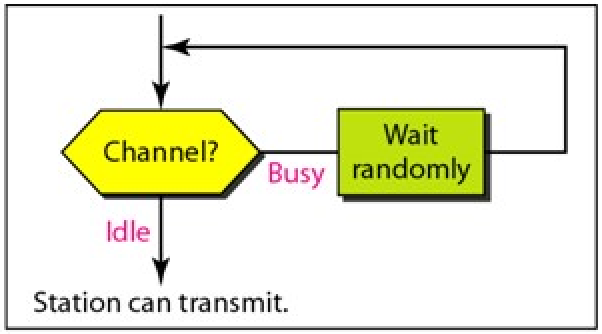


CSMA – what must a node do if line is busy

Non-persistent CSMA

1. sense medium
2. if medium idle
   - ✓ transmit frame
3. else (if medium busy)
   - ✓ wait for a random time
   - ✓ repeat from step 1

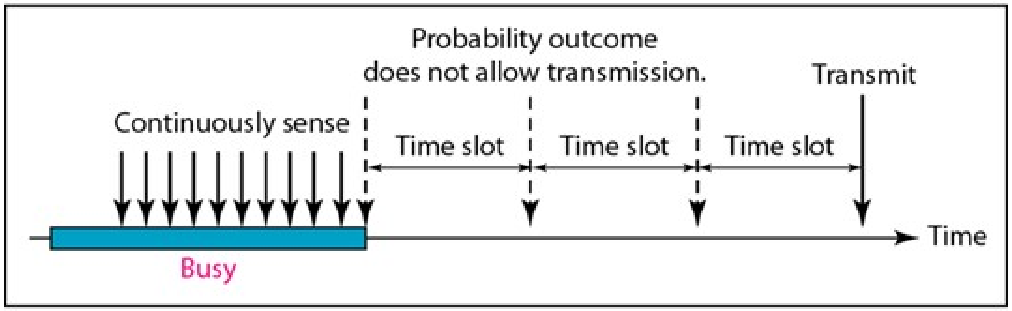


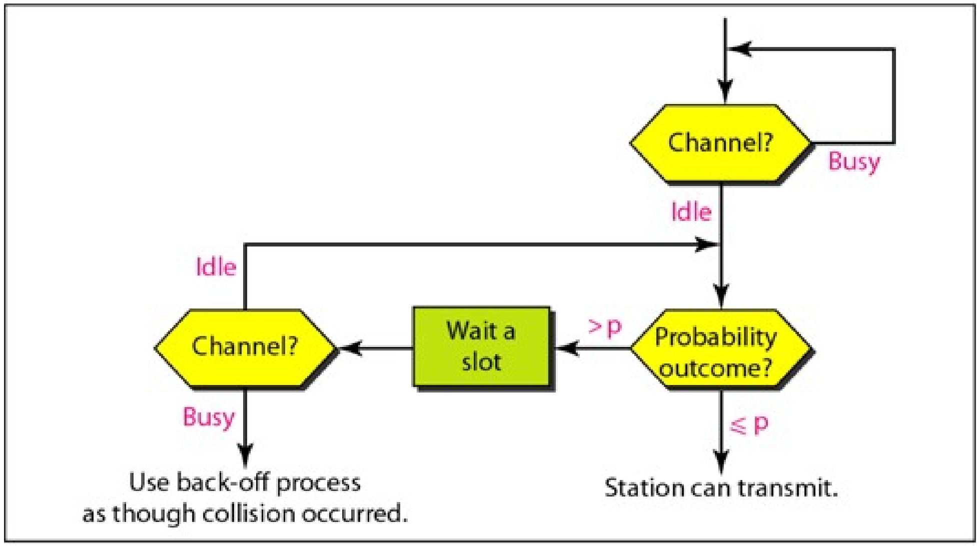


CSMA – what must a node do if line is busy (Contd)

p-persistent CSMA, $0 \leq p \leq 1$

1. sense medium
2. if medium idle,
   - ✓transmit frame with probability p, or
   - ✓Delay one time slot with probability q = 1-p and repeat from step 1
3. else (if medium busy)
   - ✓continue to sense medium until it is idle
   - ✓after medium becomes idle, repeat from step 2



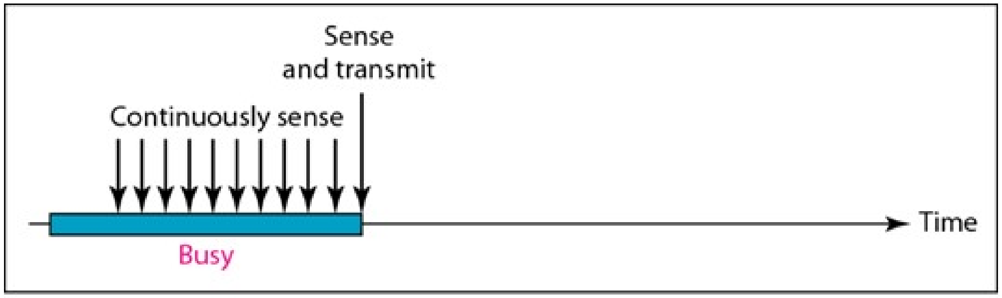


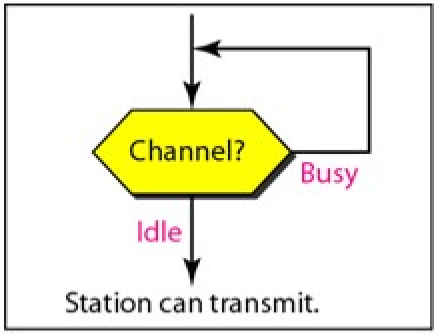
CSMA – what must a node do if line is busy (Contd 2)

1-persistent CSMA : Special case of p-persistent (with p=1)

1. Sense medium
2. if medium idle
   - transmit frame
3. else (if medium busy)
   - continue to sense medium until it is idle
   - transmit frame as soon as medium found idle

If two or more stations waiting to transmit, surely collision

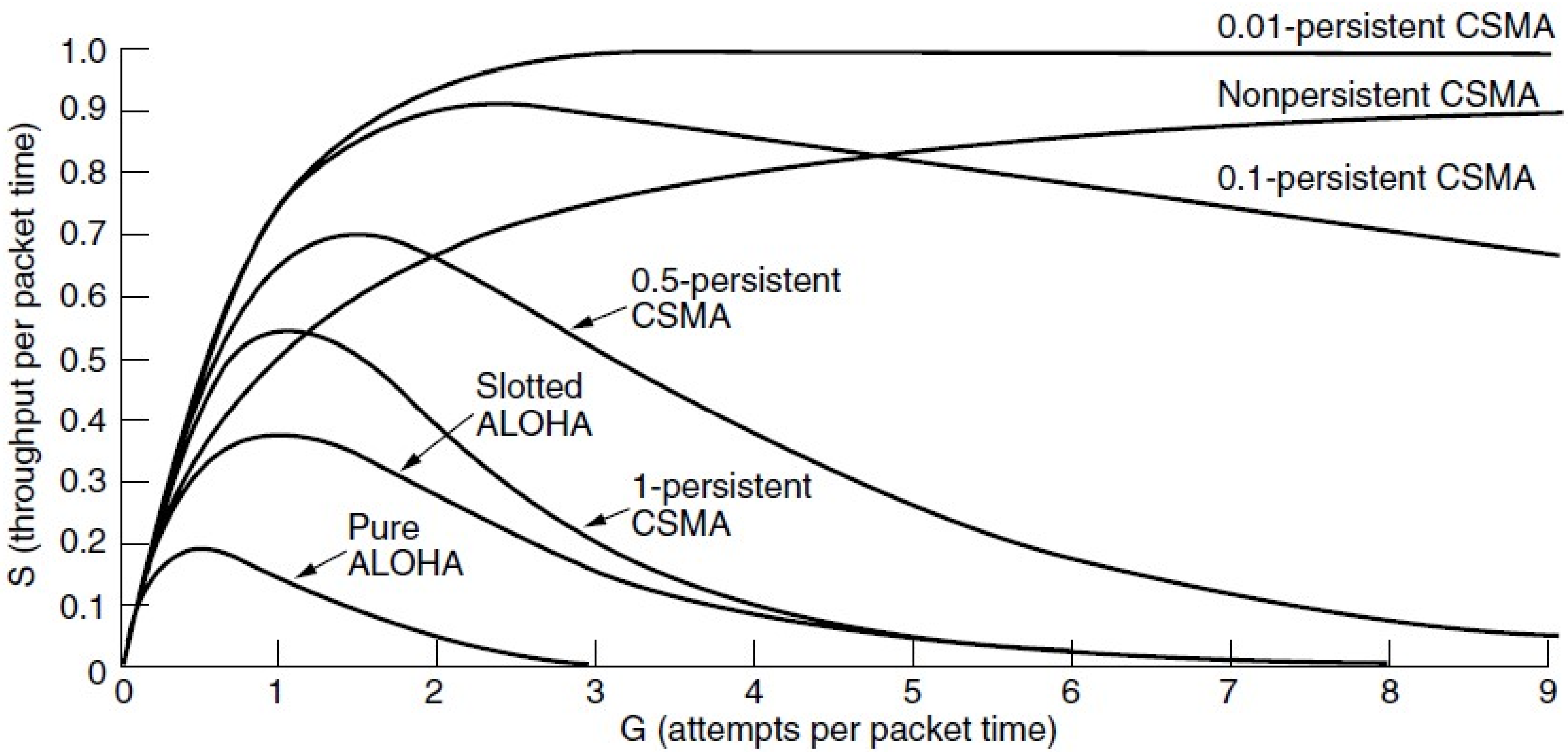




Evaluation of CSMA

- Low values of p
  - Lower chances of collision
  - But, lower channel utilization - medium will generally remain idle after the end of a transmission even if there are one or more stations ready to transmit
- Higher values of p
  - Good channel utilization
  - But, more chances of collision
- 1-persistent
  - Low load: good - prevents unnecessary wait without sensing medium
  - High load: higher chances of collision

Channel utilization of MAC protocols



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

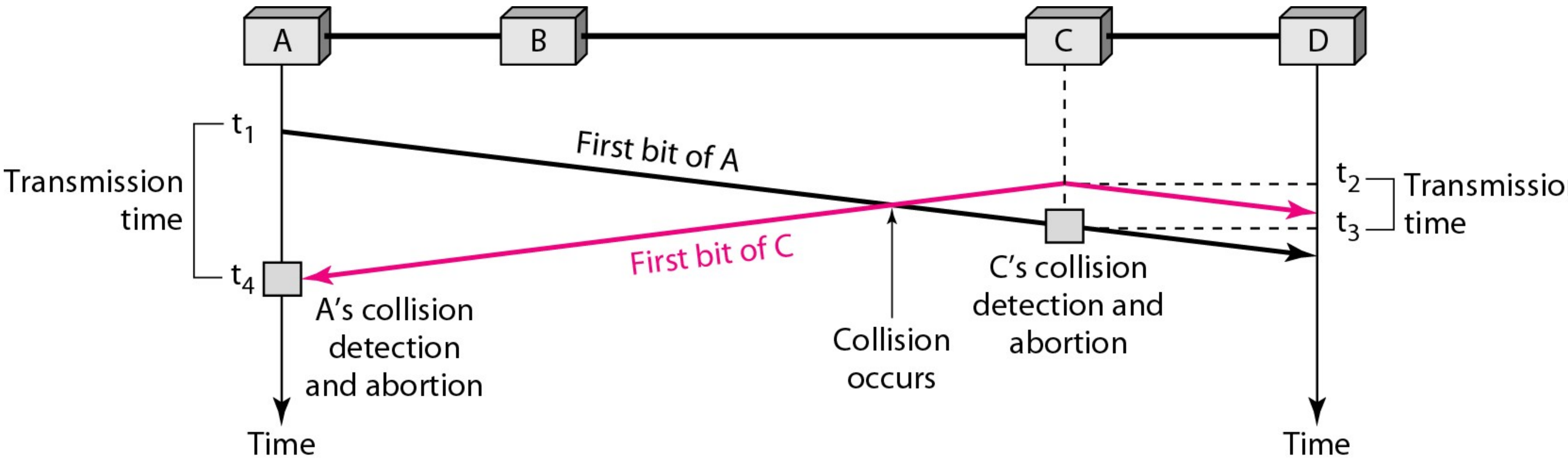
Carrier Sense Multiple Access – Collision Detection (CSMA-CD)

CSMA/CD

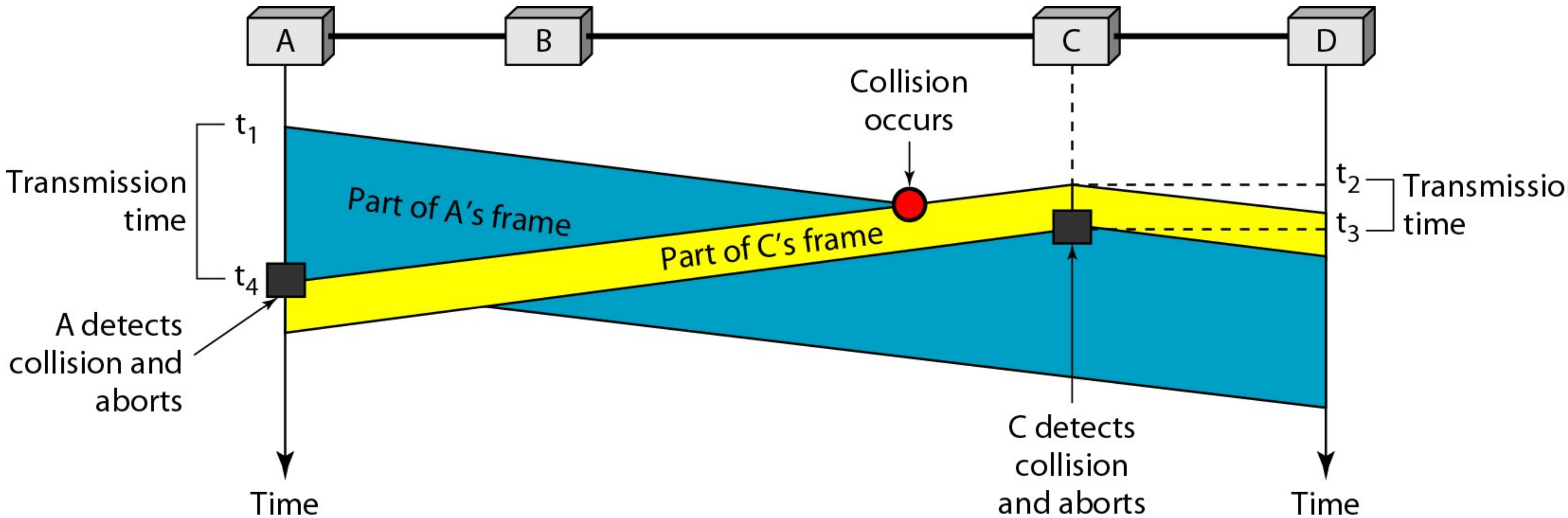
When node N is ready to transmit

1. Sense medium
2. If medium busy
   - apply standard CSMA using value of p set apriori
3. If medium idle
   - transmit, listen while transmitting
   - If collision detected during transmission
     - ✓ Transmit a brief jamming signal (specified by protocol) to ensure that all stations know there has been a collision
     - ✓ After sending jamming signal, wait for a random amount of **time slots** (binary exponential backoff)
     - ✓ Then repeat all above steps starting from step 1

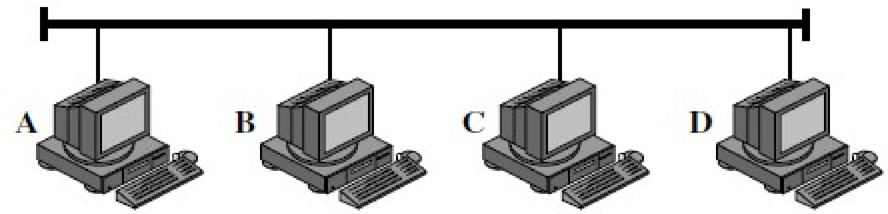
Collision of the first bit in CSMA/CD



Collision and abortion in CSMA/CD



CSMA/CD Operation

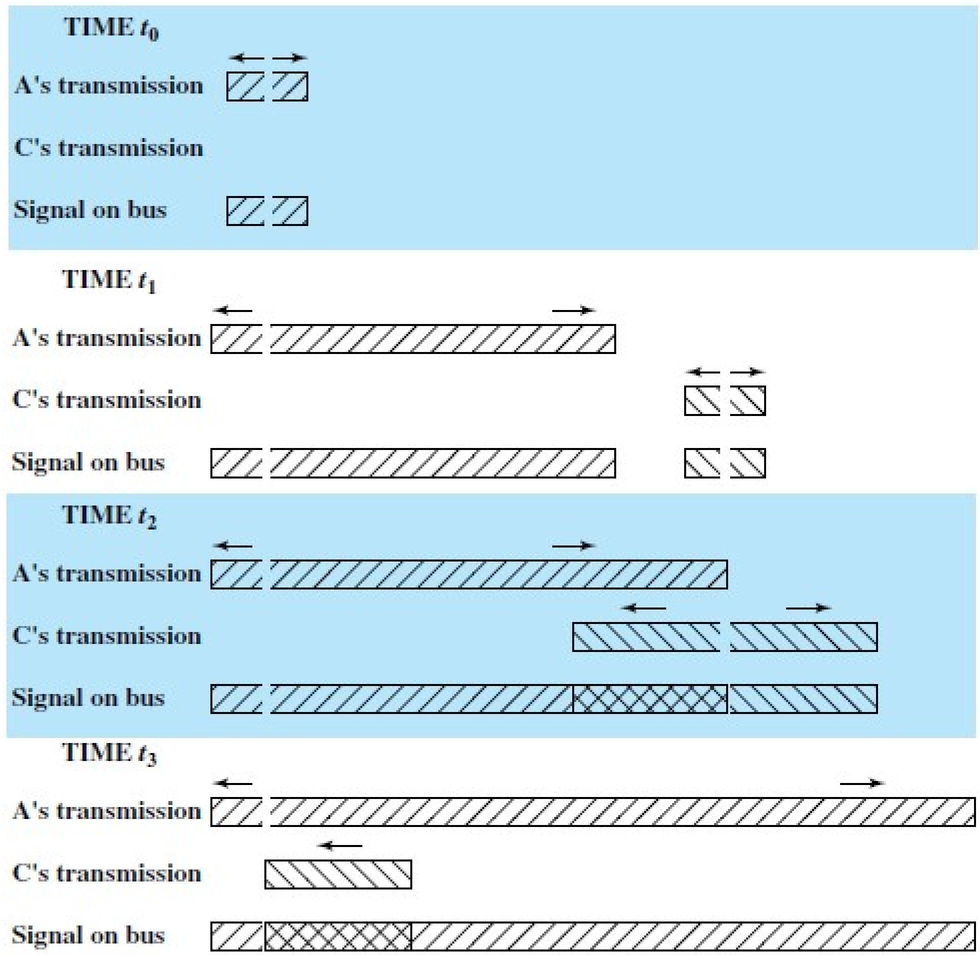


At time ***t0,*** station A begins transmitting a packet addressed to D.

At ***t1***, both B and C are ready to transmit. B senses a transmission and so defers. C, however, is still unaware of A's transmission and begins its own transmission

At ***t2***, when A's transmission reaches C, at C detects the collision and ceases transmission

At ***t3***, the effect of the collision propagates back to A, and then A ceases transmission



Ethernet Frame Format (*to be discussed later*)

<table>
<tr><td>PA</td><td>SFD</td><td>DA</td><td>SA</td><td>LEN</td><td>LLC PDU</td><td>PAD</td><td>FCS</td><td>IEEE 802.3</td></tr>
<tr><td colspan="2">PA</td><td>DA</td><td>SA</td><td>Type</td><td>DATA</td><td>PAD</td><td>FCS</td><td>DIX Ethernet</td></tr>
<tr><td>7</td><td>1</td><td>6</td><td>6</td><td>2</td><td colspan="2">46-1500</td><td>4</td><td></td></tr>
</table>

- PA: Preamble --- 7 bytes 10101010s for synchronization
- SFD: Start of frame delimiter --- 10101011 to start frame
- DA, SA: Destination & source MAC address
- LEN: Length --- number of data bytes
- Type: Identify the higher-level protocol
- LLC PDU + Pad: minimum 46 bytes, maximum 1500
- FCS: Frame Check Sequence, using CRC

CSMA/CD and Minimum Frame Size

For CSMA/CD to work, there is a need a restriction on the frame size

- Before sending the last bit of the frame, the sending station must detect a collision(if any) and abort the transmission, because
  - once the entire frame is sent, sender does not keep a copy of the frame
  - and does not monitor the line for collision detection
- Therefore, the frame transmission time T_{fr} must be at least two times the maximum propagation time T_p. **But Why ?**
  - Consider the worst-case scenario - the two stations involved in a collision are the maximum distance apart
    - ✓ the signal from the first takes time T_p to reach the second
    - ✓ and the effect of the collision takes another time T_p to reach the first
- So the requirement is that the first station must still be transmitting after $2T_p$

CSMA/CD and Minimum Frame Size

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 (micro sec), what is the minimum size of the frame?

Solution:

- The frame transmission time is atleast $T_{fr} = 2 \times T_p = 51.2$ 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.
- This is actually the minimum size of the frame for Standard Ethernet

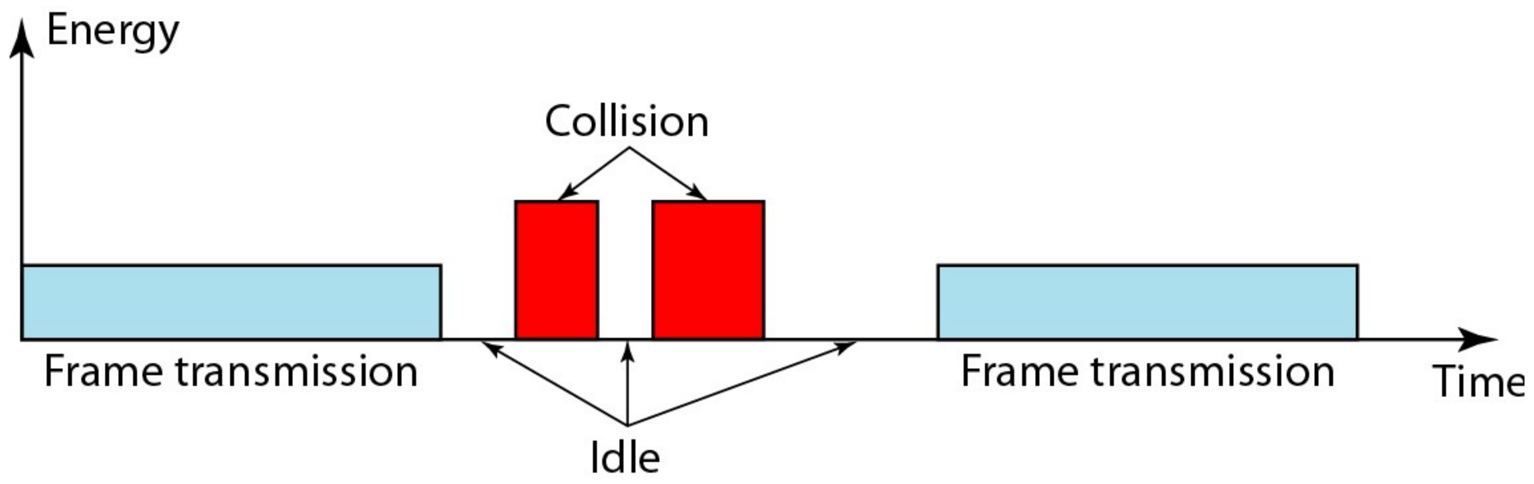
CSMA/CD and Maximum Frame Size

The standard defines the maximum length of a frame (without preamble and SFD field) as 1518 bytes. If we subtract the 18 bytes of header and trailer, the maximum length of the payload is 1500 bytes.

It has two historical reasons

- First, memory was very expensive when Ethernet was designed: a maximum length restriction helped to reduce the size of the buffer.
- Second, the maximum length restriction prevents one station from monopolizing the shared medium, blocking other stations that have data to send.

Contention, transmission, or idle state and their energy level in CSMA/CD

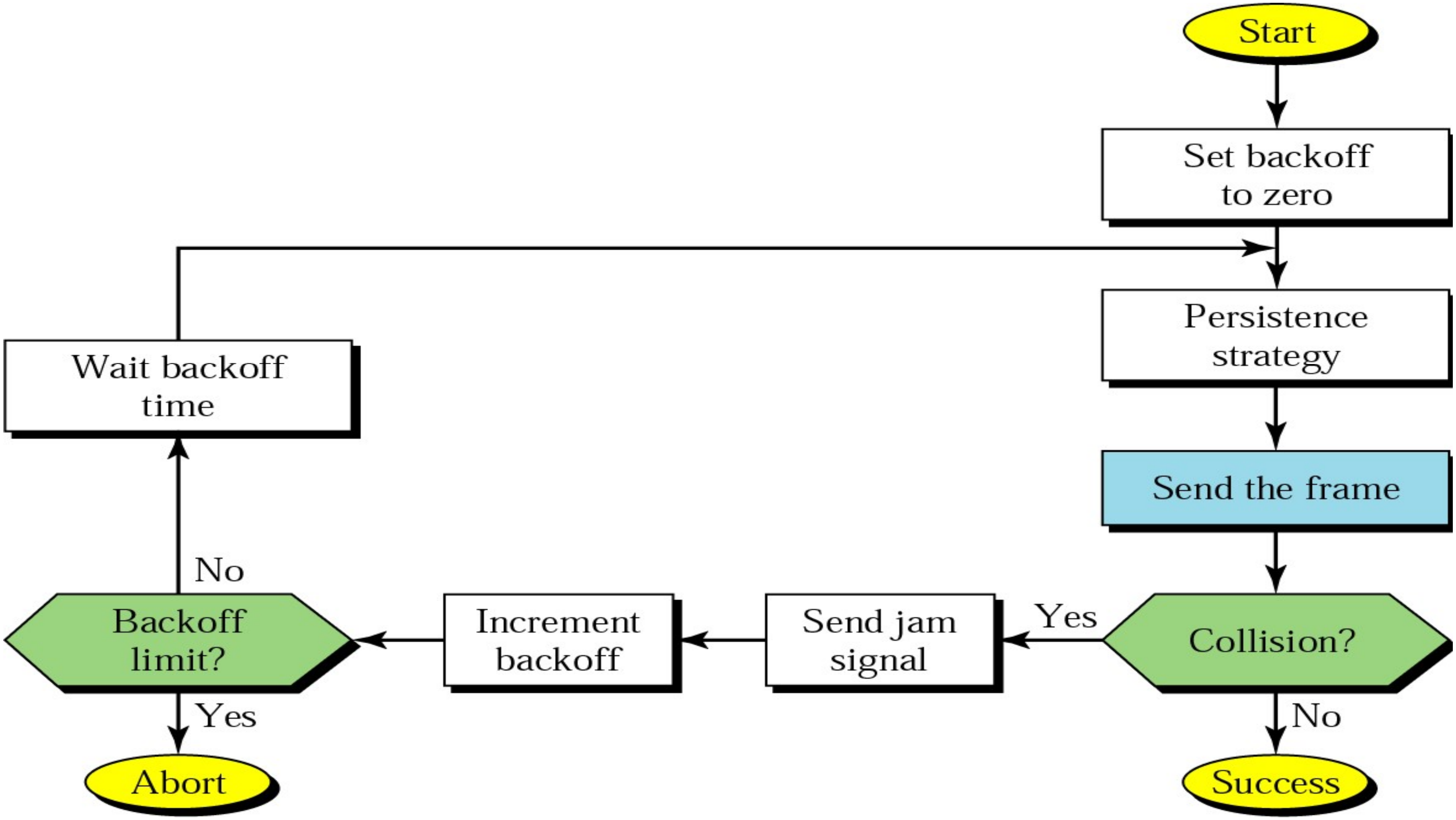


Binary exponential backoff algorithm

- After collision has been detected, waiting time must be adaptive to load
  - Low load => low wait time (high wait time may cause low channel utilization)
  - High load => relatively high wait time (low wait time may cause frequent collisions)

- How to estimate load? By number of repeated collisions
  - After k collisions, choose a waiting time randomly between $0,1,2,\ldots,2^k-1$ **slots**, $k<=10$
    - In the 802.3 ethernet, 51.2μs is considered as fixed slot time
  - After 10 collisions, for $10 <= k <= 16$, choose a waiting time between 0 and $2^{10}-1$
  - After 16 collisions, give up

CSMA/CD with Binary Exponential Backoff



Carrier Sense Multiple Access - Collision Avoidance (CSMA-CA)

For Your Study

References

- *Data Communications & Networking, 5th Edition, Behrouz A. Forouzan*
- *Data and Computer Communication, William Stallings*
- *Computer Networks, Andrew S. Tanenbaum and David J. Wetherall*