CS311: Data Communication

Medium Access Control - I

by

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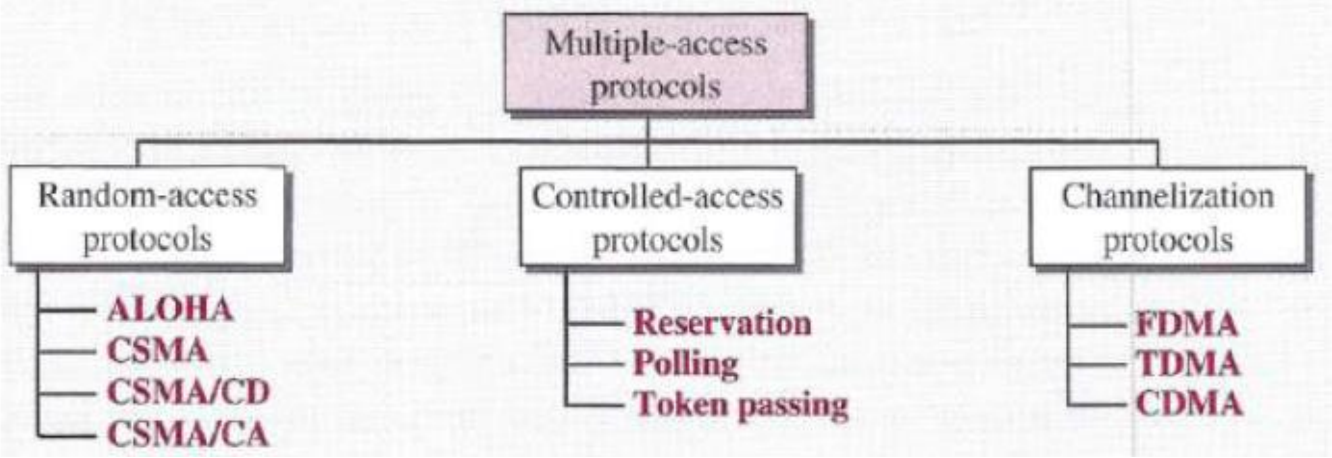
Introduction to MAC

- Types of network
  - Switched communication networks
    - Users are interconnected by means of transmission lines, multiplexers and switches
  - Broadcast networks
    - A single transmission media is shared by all the users and information is broadcast by an user into the medium
- Two types of network links:
  - point-to-point links
    - protocol => PPP, HDLC
  - broadcast links
    - protocol => multiple access protocols
- Issues in MAC
  - The question is “who goes next?” – The proposed scheme are MAC protocols
  - The key issues involved : where and how the control is exercised

Where & How ?

- Where?
  - Centralized : a designated station has an authority to grant access to the network.
    - Simple logic at each station
    - Greater control to provide features like priority, overrides and guaranteed bandwidth
    - Easy coordination
    - Lower reliability
  - Distributed: stations can dynamically determine transmission order.
    - Complex, reliable and scalable
- How?
  - Synchronous: dedicated specific capacity to a connection.
  - Asynchronous: allocates capacity dynamically

Multiple Access Protocols



- Random Access
  - No station is superior to another station
  - None is assigned control over another
  - No scheduled time for transmission
  - Station compete with one another to access the medium

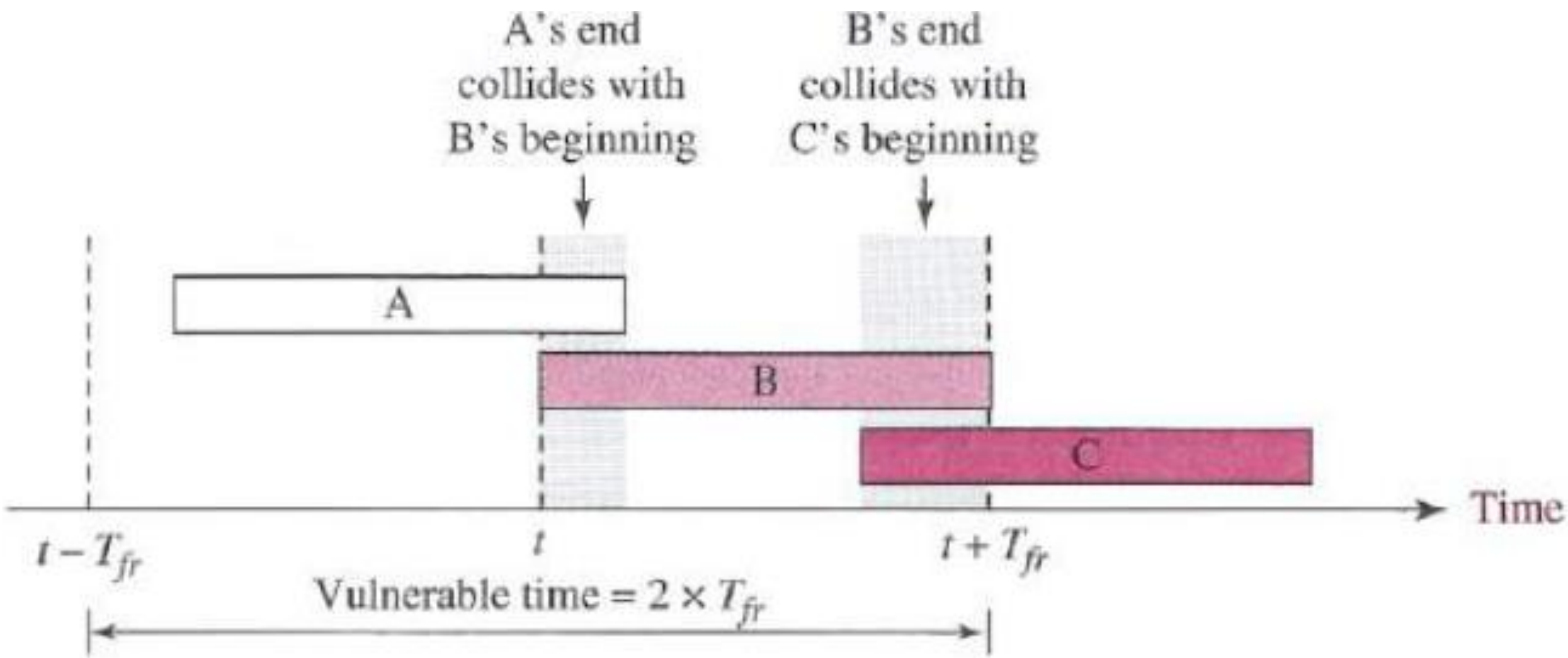
  - It is better than other types as
    - Very large number of stations can be fitted easily
    - In the network, a station can be added/removed dynamically

Pure ALOHA

- Developed in early 1970 at University of Hawaii
- Principle:
  - each station sends a frame whenever it has a frame to send
  - relies on acknowledgments from the receiver
  - if time-out occurs, then wait for random backoff time before retransmission
  - after a maximum number of retransmission, a station must give up and try later
  - Time-out
    - maximum round-trip time
  - Backoff time
    - random value generated by backoff algorithm (e.g. binary exponential backoff)

Problem in Pure ALOHA

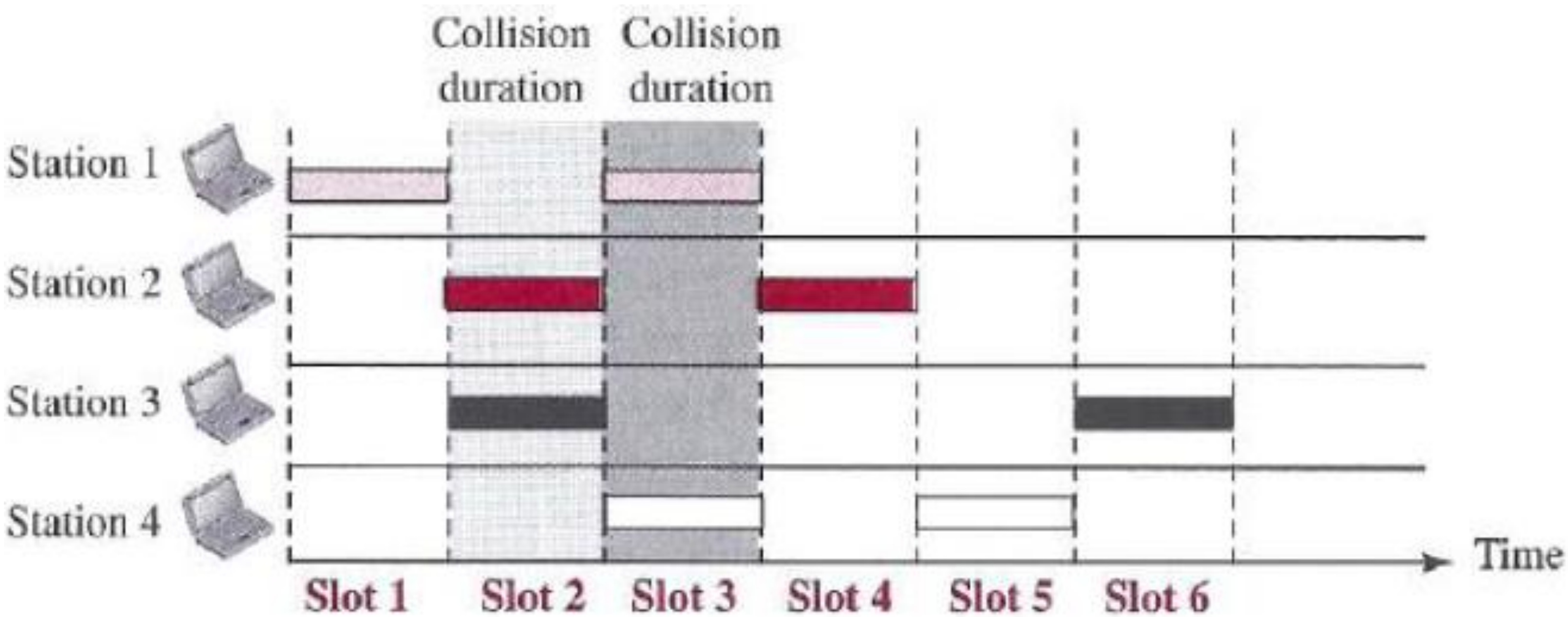
- Frame Collision



- vulnerable time: the length of time in which there is a possibility of collision.

Slotted ALOHA

- we divide the time into slots of T_{fr} seconds and force the station to send only at the beginning of the time slot
- If collision occurs, the node retransmit frame in next slot with probability *p*



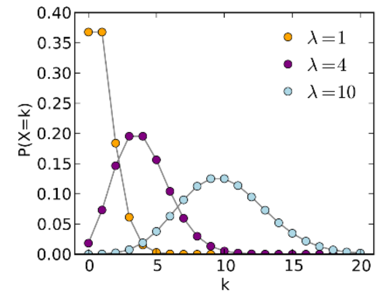
- Vulnerable time= T_{fr}

Random Access - Performance

- Let all packet consists of exactly N bits, transmission rate = R bits/sec
- Let a slot equals the time to transmit a packet

  τ = slot size = transmission time of a packet = N/R sec.

- Each nodes are synchronized
- Let there are n nodes



- Random access schemes assume that a node generate packets according to a Poisson process at a rate of λ frames per unit time,
- i.e., λ is the average number of packets that arrive in any time interval [0, t] divided by t.
- Equivalently, λN is the average number of bits generated in any time interval [0, t]

- For a Poisson process, the probability that the number of packet arrivals in a time period [0, t], denoted as $X(t)$, is equal to some integer k is given by

$$p(X(t) = k) = \frac{(\lambda t)^k}{k!} e^{-\lambda t}$$

- Poisson processes are memoryless,
  - so that the number of packet arrivals during any given time period does not affect the distribution of packet arrivals in any other time period.

Cont…

- The **traffic load** on the channel, given Poisson packet arrivals at rate λ and a packet transmission duration τ, is defined as $L = \lambda\tau$.

- In other words, L is the ratio of the packet arrival rate divided by the packet rate that can be transmitted over the channel at the channel's data rate R. So, L is unitless.

- If $L > 1$ then on average more packets (or bits) arrive in the system over a given time period than can be transmitted in that period,
  - so systems with $L > 1$ are unstable.

- **Performance** of random access techniques is typically characterized by **throughput** T of the system

- The throughput is defined as the ratio of the average number of packets successfully transmitted in any given time interval divided by the number of attempted transmissions in that interval. So, it is unitless.

- In other words, Throughput equals the offered traffic load multiplied by the probability of successful packet reception,
- *So,* $T = L \times p$(successful packet reception)

Throughput in ALOHA

- In pure or unslotted ALOHA users transmit data packets as soon as they are formed
- we assume no capture effect, no channel distortion or noise
- So, throughput = offered load times the probability of no collisions

  $T = L \times p(\text{no collisions})$

- Vulnerable time in Pure ALOHA = 2τ
- So, the probability that no packets are generated during the time [$-\tau, \tau$] is given by Poisson distribution with $t = 2\tau$

$$p(X(t) = 0) = e^{-2\lambda\tau} = e^{-2L}$$

- *So, the throughput* $T = Le^{-2L}$
- Now, to get Maximum throughput dT/dL = 0 => $T_{max} = e^{-1}/2 = 0.1839$
- Vulnerable time in Slotted ALOHA = τ
- So, theoretical maximum throughput $T_{max} = e^{-1} = 0.3679$ => 37%

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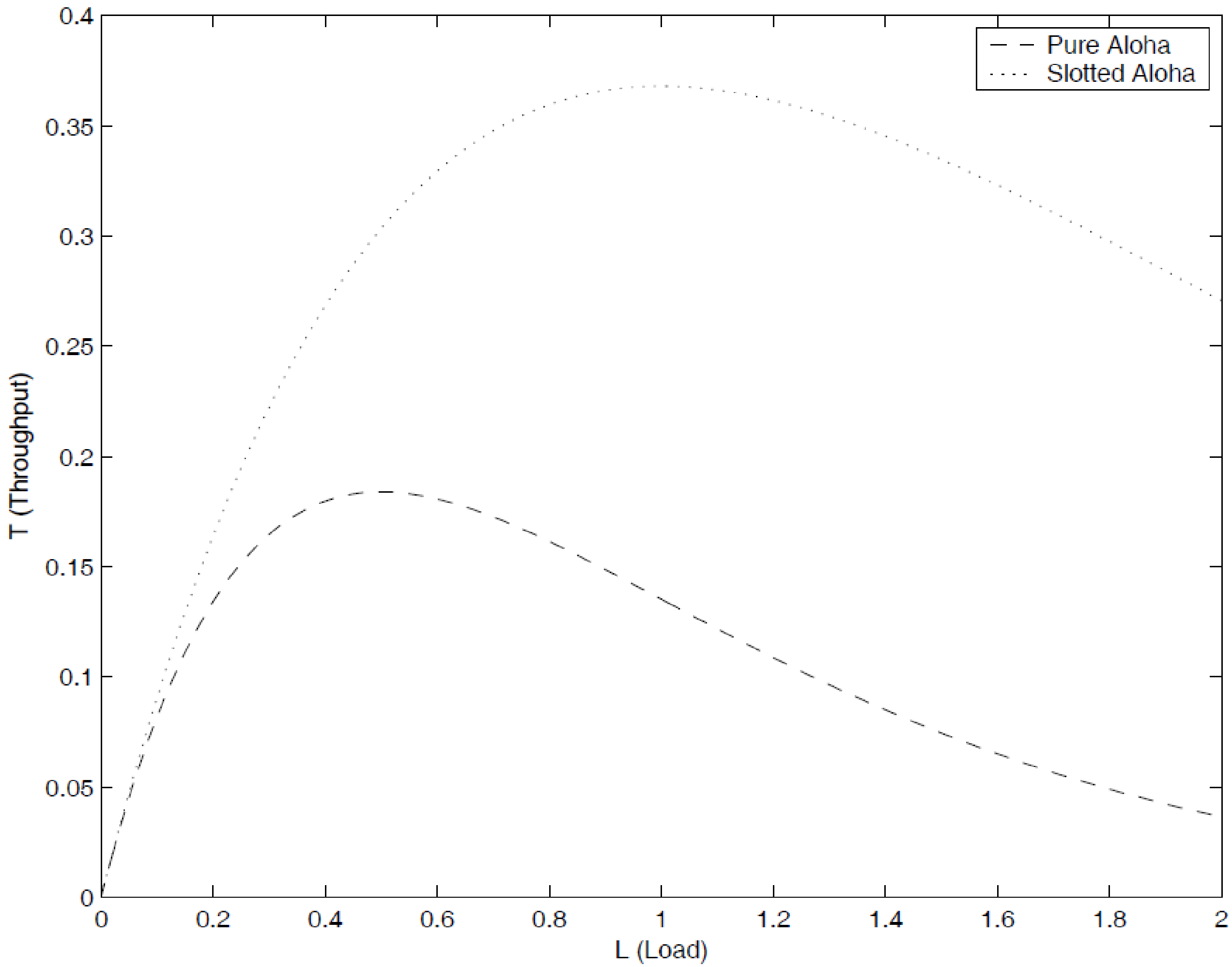


Figure 14.6: Throughput of Pure and Slotted ALOHA.

Efficiency of Slotted ALOHA

- The **efficiency** of a slotted multiple access protocol is defined to be the long-run fraction of successful slots in the case when there are a large number of active nodes, each always having a large number of frames to send.

- Let transmission probability *p. (modified version)*
- The probability that 'a given slot is a successful slot' is the probability that one of the nodes transmits and that the remaining (n – 1) nodes do not transmit = $p(1-p)^{n-1}$
- the probability that any one of the n nodes has a success is $E = n\,p\,(1-p)^{n-1}$

- Thus, when there are n active nodes, the efficiency of slotted ALOHA is = $np(1-p)^{n-1}$
- Let slotted ALOHA achieves maximum efficiency at p*

  So, $dE/dp = 0 \Rightarrow np = 1 \quad \Rightarrow p^* = 1/n$

- Now, to obtain the maximum efficiency for a large number of active nodes, we take the limit $np^*(1-p^*)^{n-1}$

  So, $\lim_{n\to\inf} np^*(1-p^*)^{n-1} = \lim_{n\to\inf} (1-1/n)^{n-1} = 1/e = 0.3678$

Efficiency of Pure ALOHA

- The **efficiency** of a slotted multiple access protocol is defined to be the long-run fraction of successful slots in the case when there are a large number of active nodes, each always having a large number of frames to send.

- Let transmission probability *p. (modified version)*
- The probability that 'a given slot is a successful slot' is the probability that one of the nodes transmits and that the remaining (n – 1) nodes do not transmit = $p(1-p)^{n-1}$
- In pure ALOHA, we have one more condition – no one else has started transmission in previous slot. Probability of this is = $(1-p)^{n-1}$
- the probability that any one of the n nodes has a success in a slot is $E = np(1-p)^{2(n-1)}$

- Thus, when there are n active nodes, the efficiency of slotted ALOHA is = $np(1-p)^{2(n-1)}$
- Let slotted ALOHA achieves maximum efficiency at p*

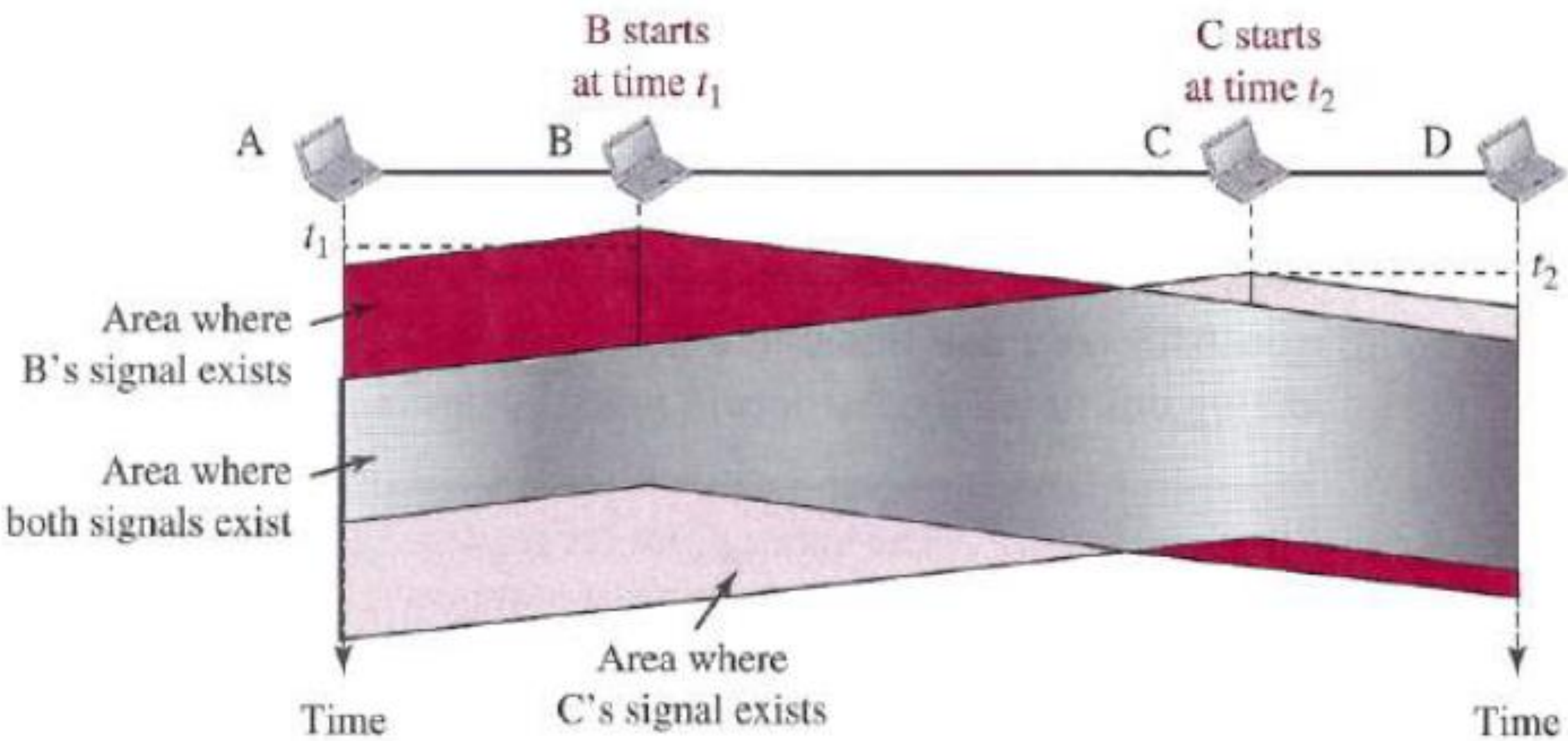
  So, $dE/dp = 0$ $\Rightarrow p^* = 1/(2n-1)$

- Now, to obtain the maximum efficiency for a large number of active nodes, we take the limit $np^*(1-p^*)^{2(n-1)}$

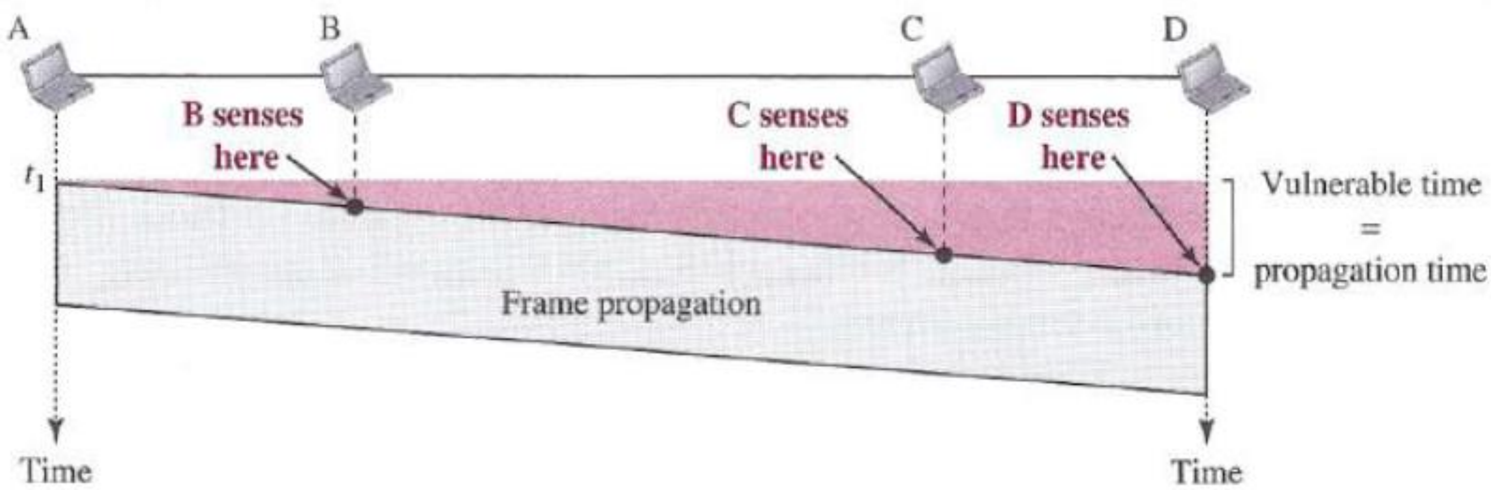
  So, $\lim_{n \to inf} np^*(1-p^*)^{2(n-1)} = 1/2e = 0.18$

Carrier Sense Multiple Access

- Sense the medium before trying to use it
- “sense before transmit” or “listen before talk”



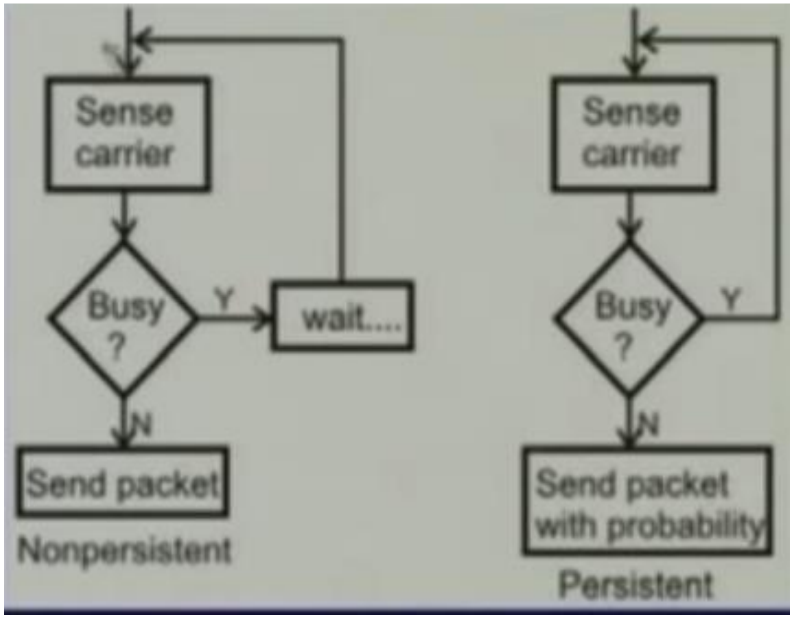
CSMA vulnerable time



- Vulnerable period = t(prop) (i.e, one propagation time)

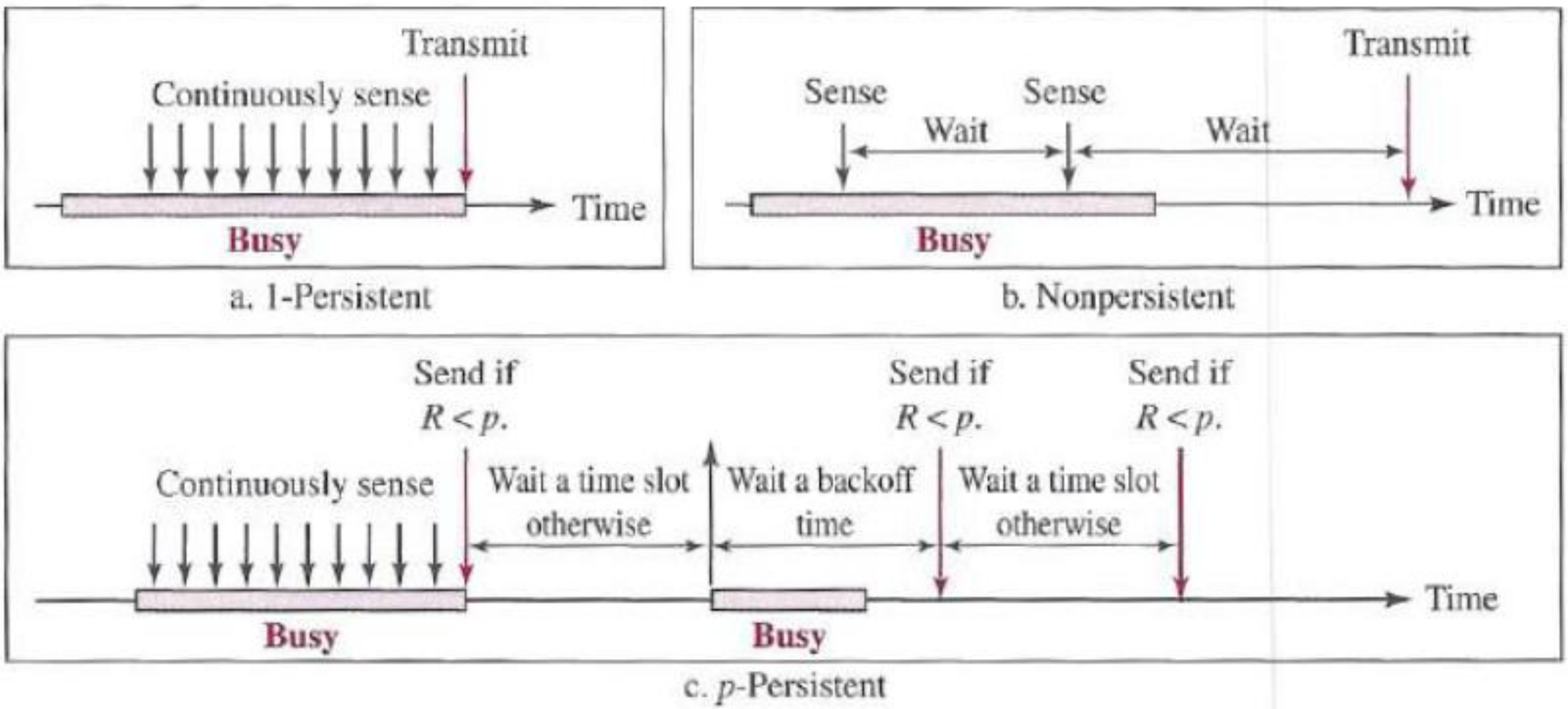
- What should a station do if channel is busy/idle?
  - 1-persistent
  - Non-persistent
  - p-persistent

Persistent Methods



- 1-persistent
  - Continuously sense the channel
  - if idle, transmit frame (with probability 1)
- Non-persistent
  - Sense the channel
  - If idle, transmit frame (with probability 1)
  - If busy, wait a random amount of time and then sense the channel again
- *p*-persistent
  - Non-persistent , but transmit frame (with probability *p)*

Cont…



Transmit
Continuously sense
Time
Busy
a. 1-Persistent
Transmit
Sense
Sense
Wait
Wait
Time
Busy
b. Nonpersistent
Send if
R < p.
Send if
R < p.
Send if
R < p.
Continuously sense
Wait a time slot otherwise
Wait a backoff time
Wait a time slot otherwise
Time
Busy
Busy
c. p-Persistent

CSMA/CD (Collision Detection)

- CSMA with Collision Detection (CSMA/CD)
- Stations listens to the medium while transmitting; Listen while talking (LWT).
- Closed from approximation of the efficiency of Ethernet:

  E =1/ (1+5 d_prop/d_trans)

  Where, d_prop: maximum propagation time between two adapters

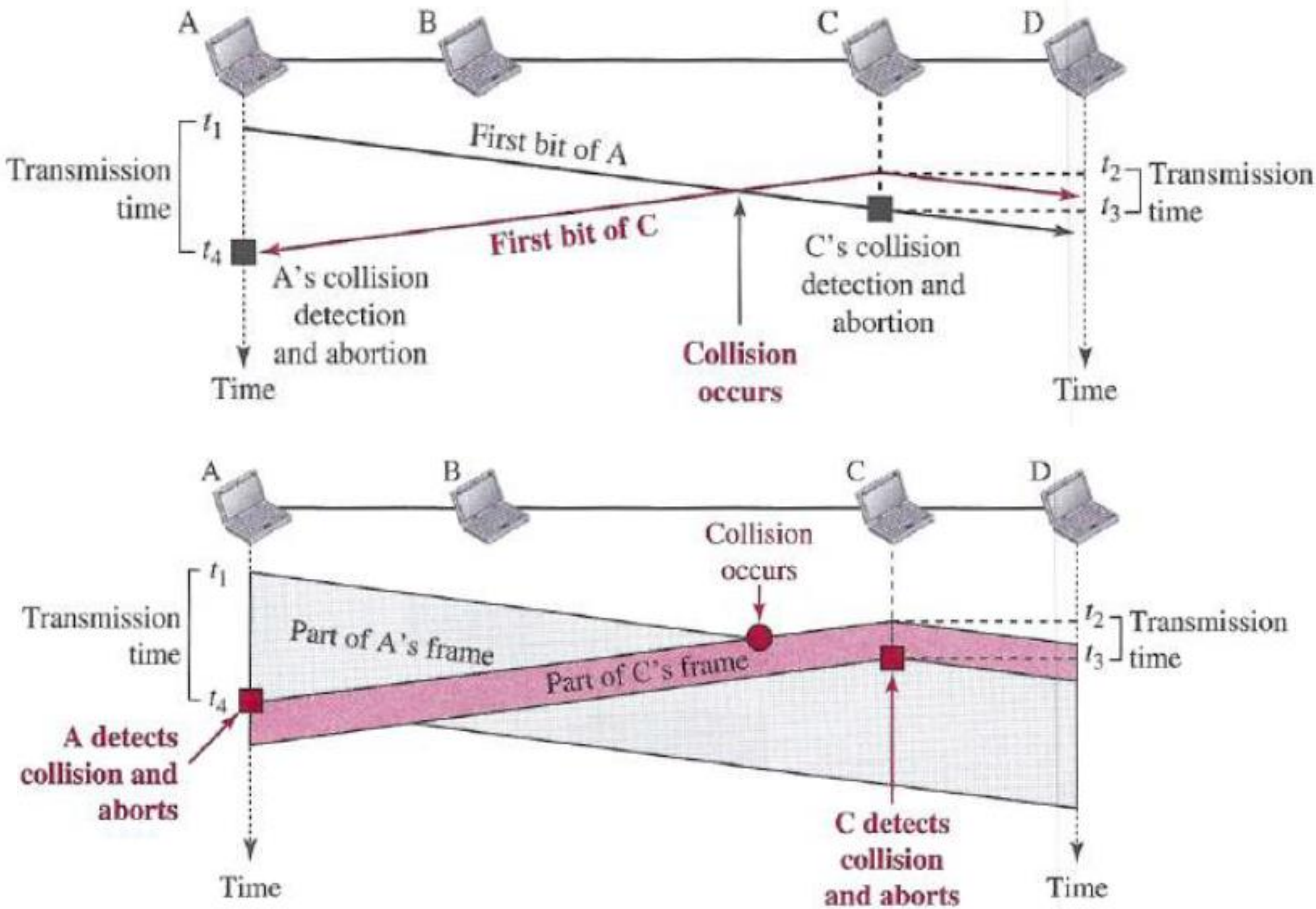
  d_trans: time to transmit a maximum size frame

  (approx. 1.2 msec for 10 Mbps Ethernet)

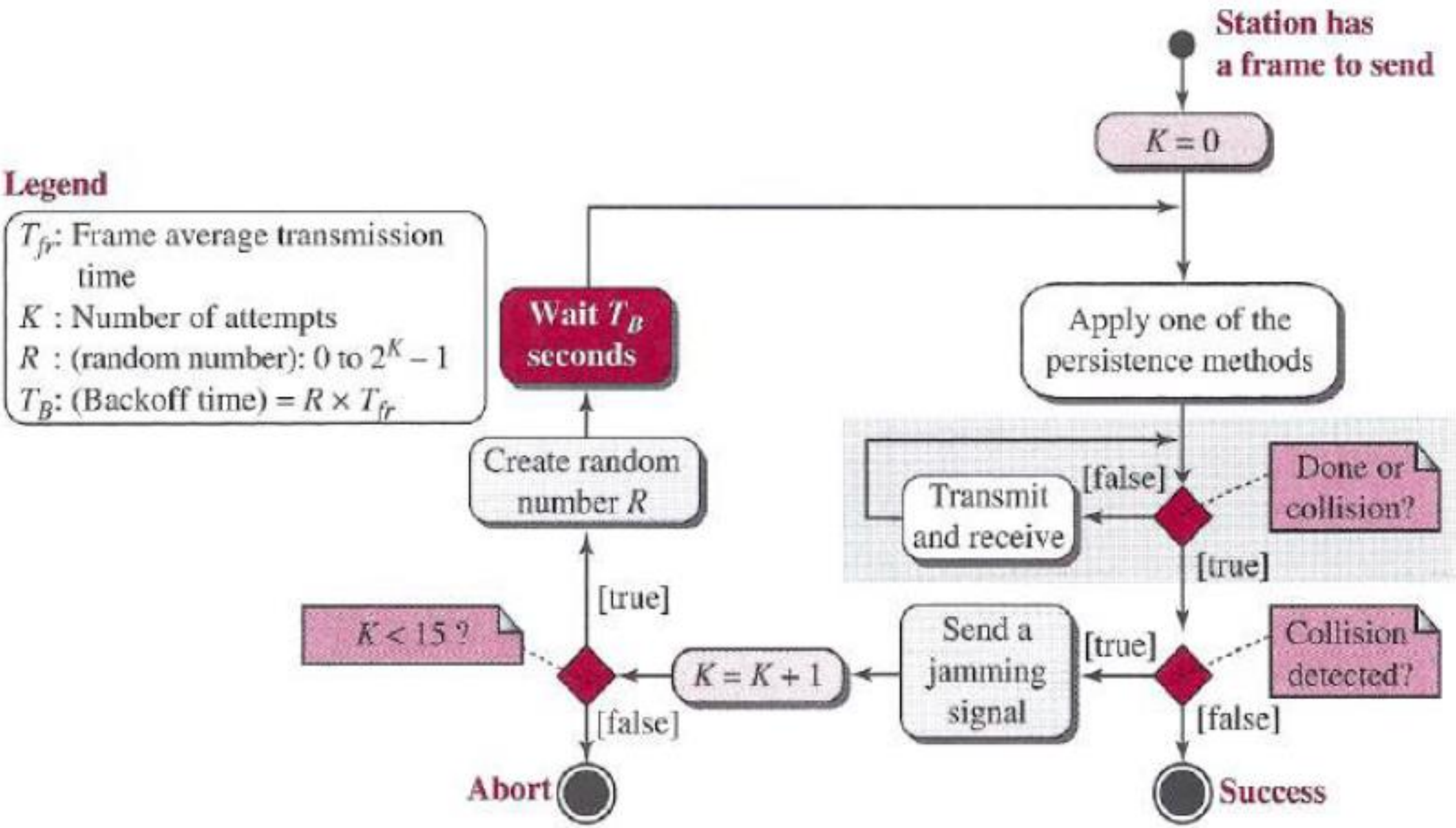
CSMA/CD

- If channel idle:
  - Packet is transmitted if non-persistent or 1-persistent
  - For p-persistent, the packet is sent with probability p or delayed by the end-to-end propagation delay with probability (1-p).
- If channel is busy:
  - The packet is backed off and the algorithm is repeated for non-persistent case
  - The station defers transmission until the channel is sensed idle and then immediately transmits in 1-persistent case
  - For p-persistent CSMA/CD the stations defers until the channel is idle, then follow the channel idle procedure.

CSMA/CD


A
B
C
D
t_1
Transmission time
t_4
First bit of A
First bit of C
t_2
t_3
Transmission time
A's collision detection and abortion
Collision occurs
C's collision detection and abortion
Time
Time
A
B
C
D
Collision occurs
t_1
Transmission time
t_4
Part of A's frame
Part of C's frame
t_2
t_3
Transmission time
A detects collision and aborts
C detects collision and aborts
Time
Time

Cont…



Station has a frame to send
K = 0
Legend
T_{fr}: Frame average transmission time
K : Number of attempts
R : (random number): 0 to $2^K - 1$
T_B: (Backoff time) = $R \times T_{fr}$
Wait T_B seconds
Apply one of the persistence methods
Create random number R
[false]
Transmit and receive
Done or collision?
[true]
[true]
$K < 15$?
Send a jamming signal
[true]
Collision detected?
$K = K + 1$
[false]
[false]
Abort
Success

Cont…

- Points to remember:
  - Use of the persistence process
  - The station transmits and receives continuously and simultaneously (using two different ports or a bidirectional port)
  - We constantly monitor in order to detect one of two conditions: either transmission is finished or a collision is detected
  - sending of a short jamming signal to make sure that all other stations become aware of the collision
  - Use of random backoff mechanism
  - Use of retransmission limit

Jamming Signal in CSMA/CD

- Did a collision occur? If so, go to collision detected procedure.
  - In that procedure, continue transmission (**with a jam signal** instead of frame header/data/CRC) until minimum packet time is reached to ensure that all receivers detect the collision.
  - The **jam signal** is a signal that carries a 32-bit binary pattern
  - The maximum jam-time:
    - The maximum allowed diameter of an Ethernet is limited to 232 bits. This makes a round-trip-time of 464 bits. As the slot time in Ethernet is 512 bits, the difference between slot time and round-trip-time is 48 bits (6 bytes), which is the maximum "jam-time".

Thanks!

Figure and slide materials are taken from the following sources:

1. W. Stallings, (2010), Data and Computer Communications
2. NPTL lecture on Data Communication, by Prof. A. K. Pal, IIT Kharagpur
3. B. A. Forouzan, (2013), Data Communication and Networking