CS343: Data Communication

Ethernet

by

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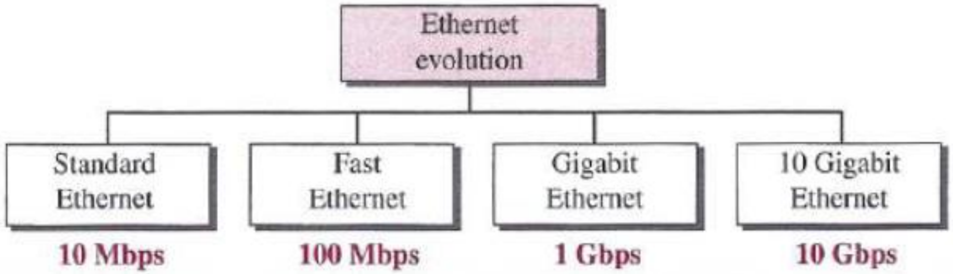
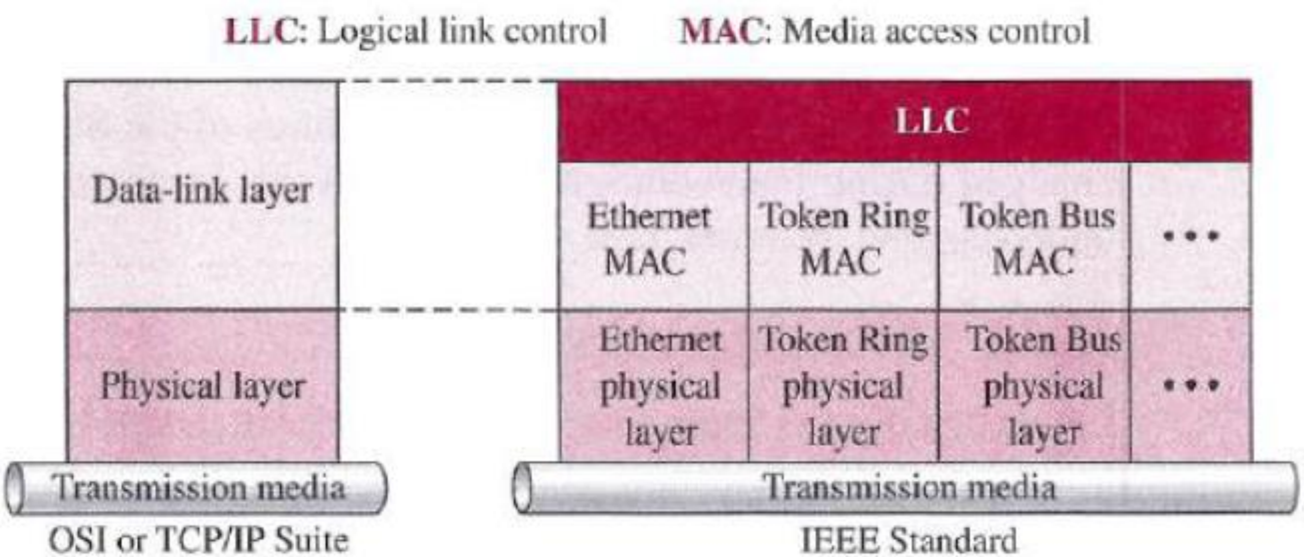
Introduction

- The most widely used high-speed LANs today are based on Ethernet.

- Following CSMA/CD approach
  - Ethernet
- Following token-passing approach
  - Token Ring
  - Token Bus
  - FDDI (Fiber Distribution Data Interface)

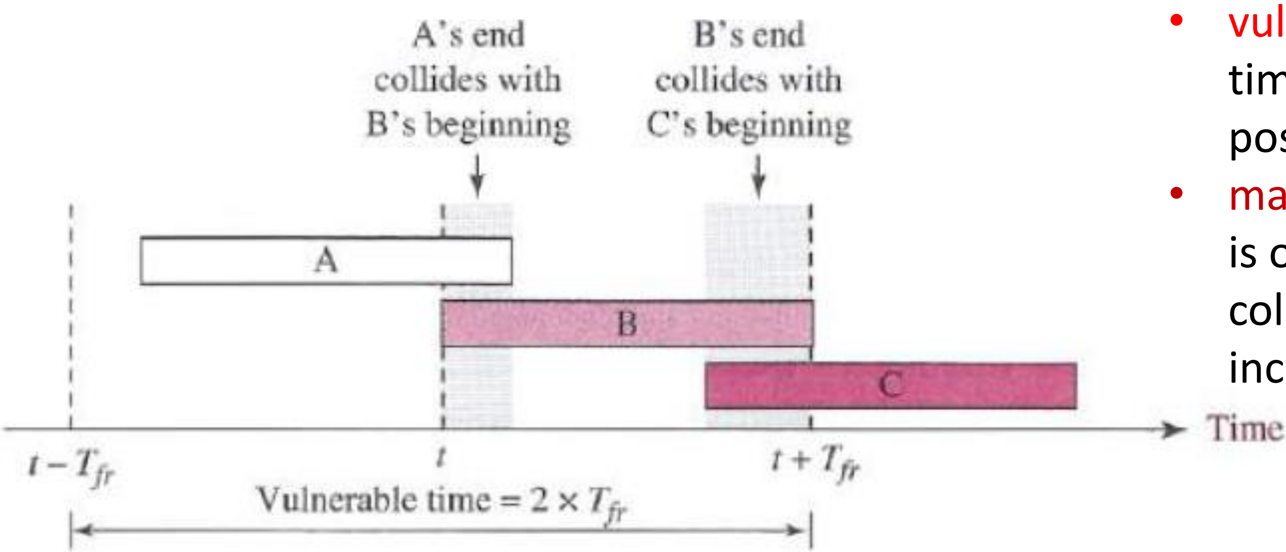




Pure ALOHA

- Developed in early 1970 at University of Hawaii for packet radio networks.
- 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 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. BEB)

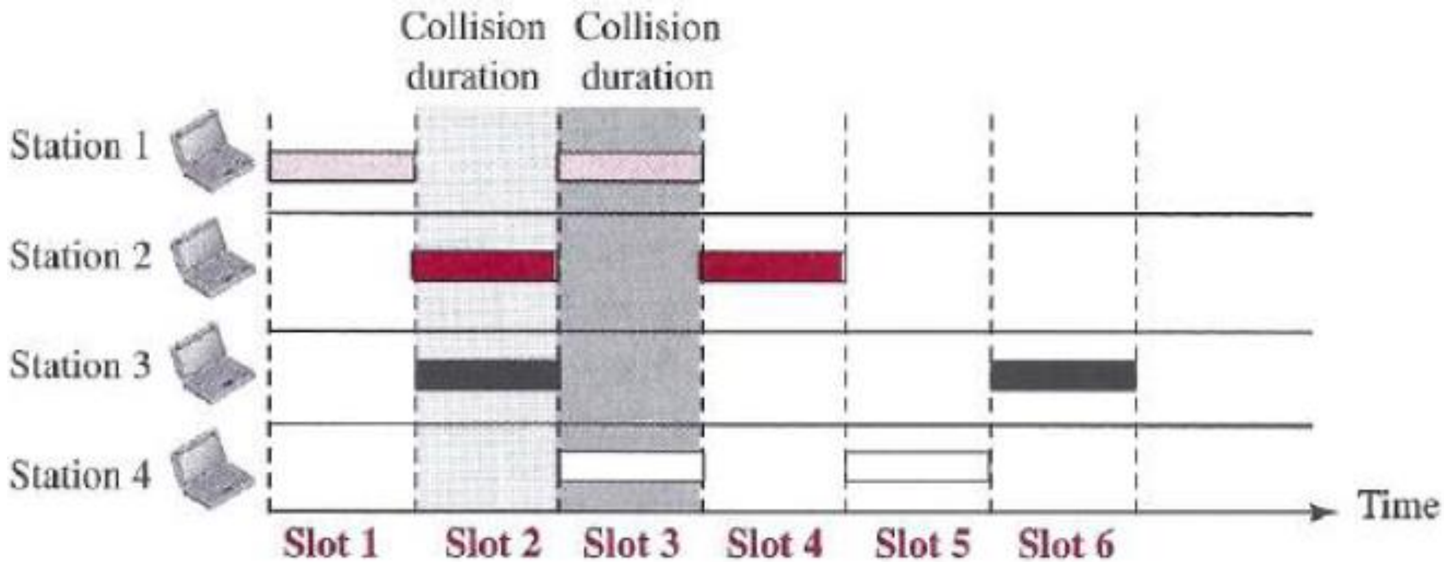


- vulnerable time: the length of time in which there is a possibility of collision
- maximum utilization of channel is only **18%,** because number of collisions rises rapidly with increased load

Slotted ALOHA

- To improve efficiency, a modification of ALOHA was proposed.

- 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*

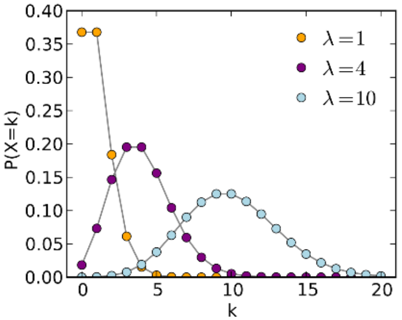


- Vulnerable time = T_{fr}
- This increases the maximum utilization of the system to about **37%**.

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.
- Let there are *n* nodes. Each nodes are synchronized



- Random access schemes assume that
  - a node generate packets according to a Poisson process at a rate of λ packet per unit time,
  - i.e., λ is the average number of packets that arrive in any time interval [0, *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 (L) is defined as 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.
- given that, Poisson packet arrivals at rate λ and a packet transmission duration τ, we have $L = \lambda\tau$

- 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.

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

Throughput of ALOHA & Slotted ALOHA

- In pure 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 multiplied with probability of no collision

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

- 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 $t = 2\tau$

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

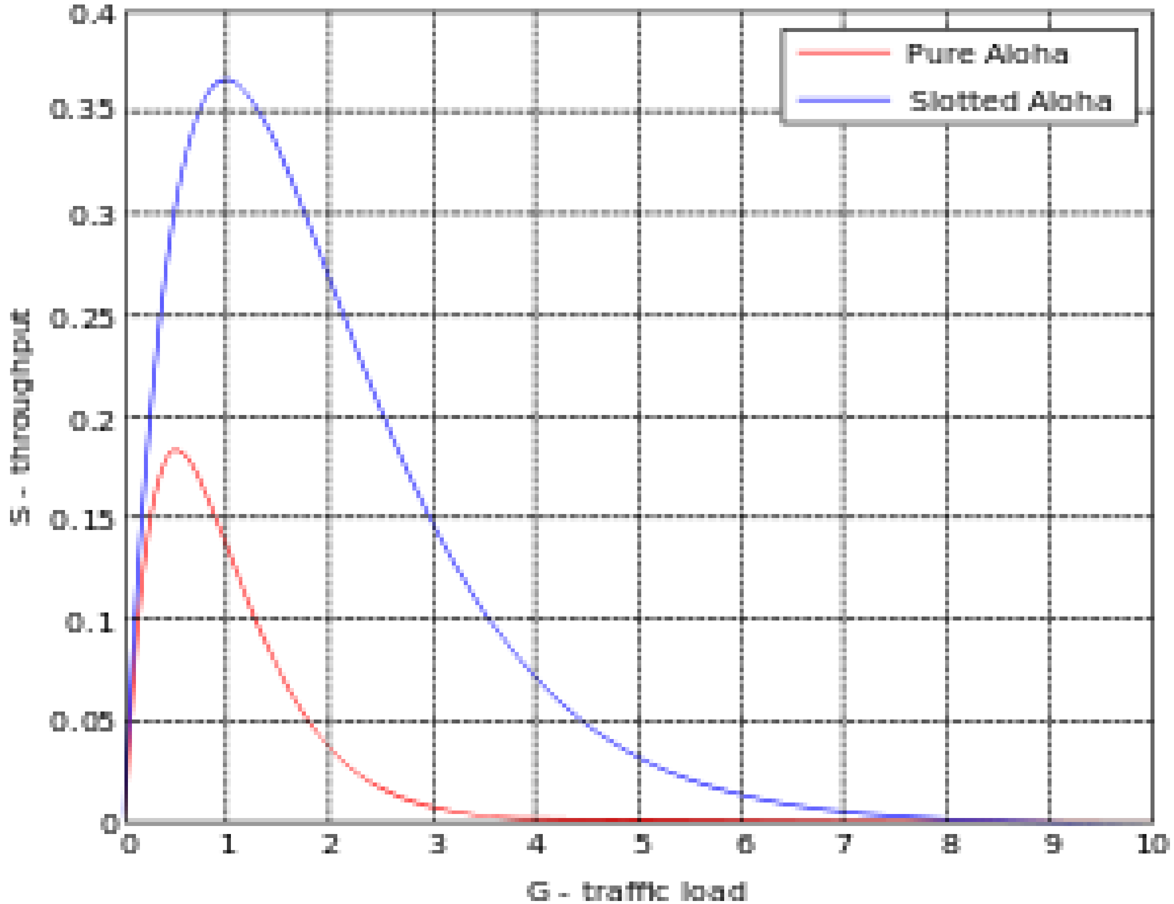
- *So, the throughput* $T = Le^{-2L}$

- 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%

Cont…

Comparison of Pure Aloha and Slotted Aloha shown on
Throughput vs. Traffic Load plot



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 node always having a large number of frames to send.

- Let transmission probability p
- 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, $dE/dp = 0 \quad \Rightarrow p^* = 1/n$

- 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

- Let transmission probability *p.*
- 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 = $(1-p)^{n-1}$
- So, 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*

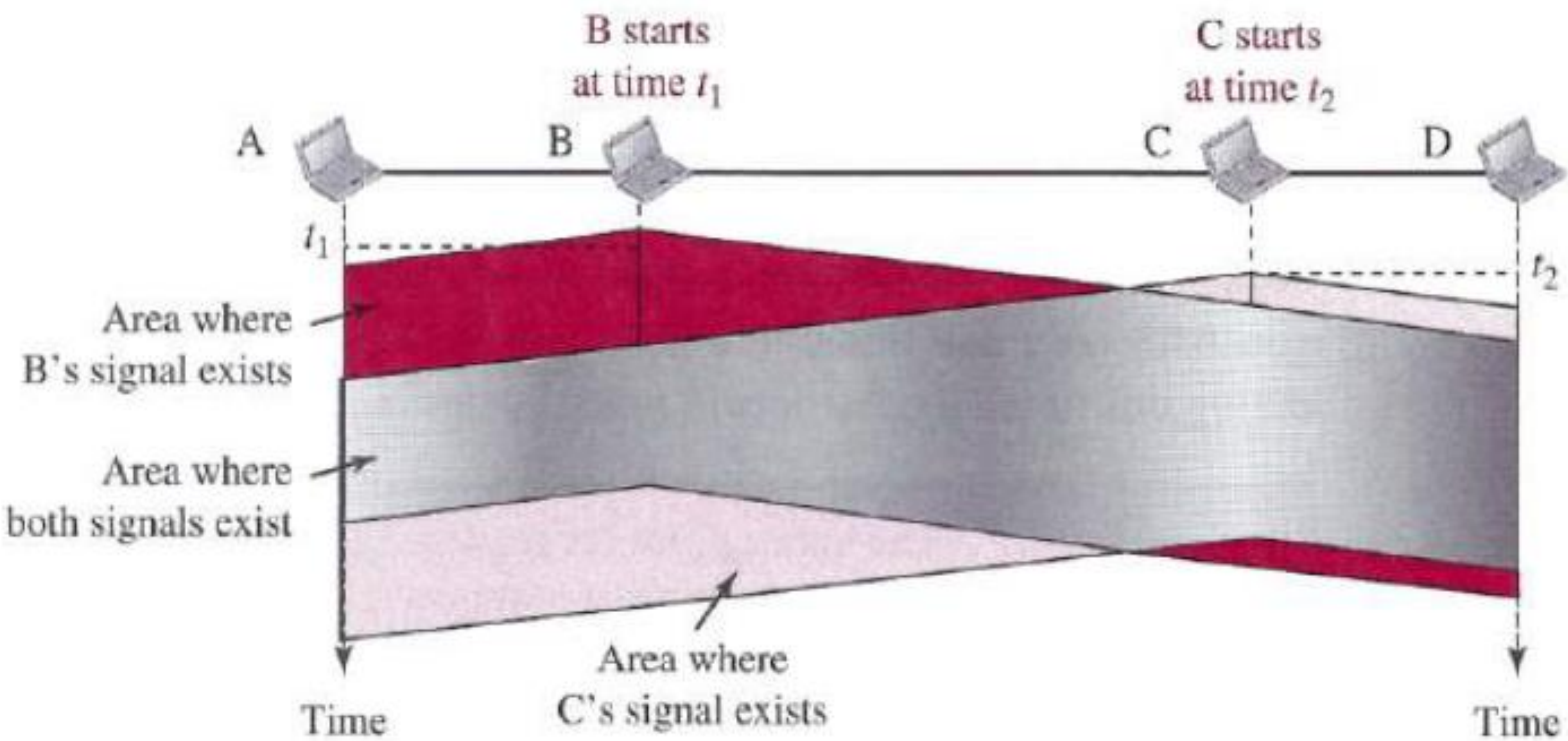
  So, $dE/dp = 0 \quad\quad => p^* = 1/(2n-1)$

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

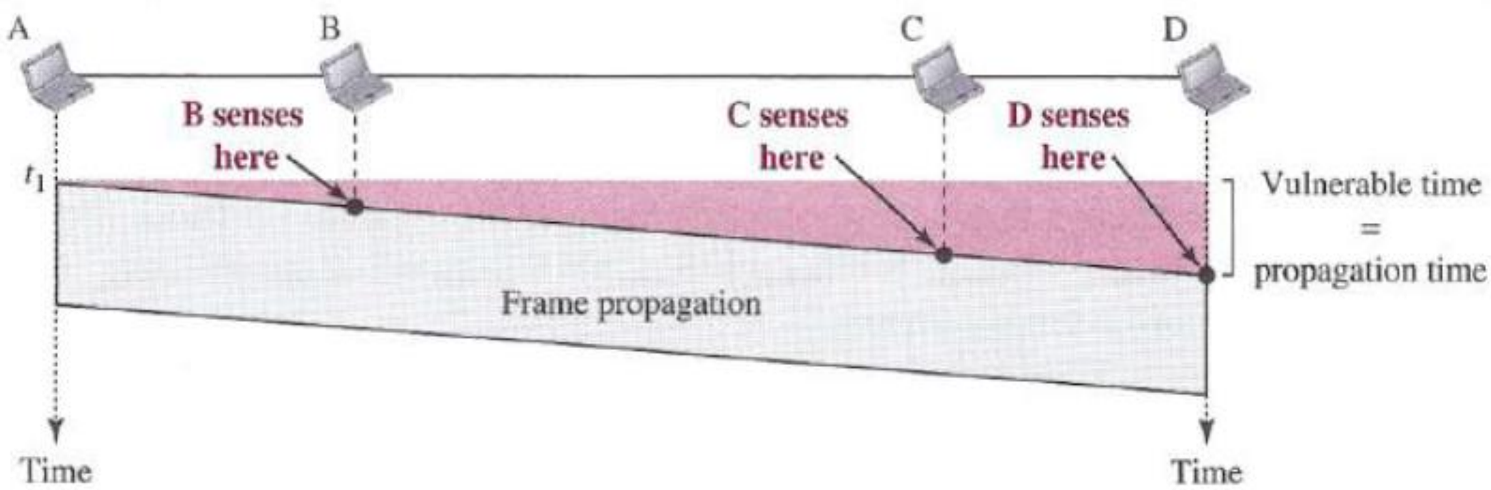
  So, $\lim_{n\to inf} np^*(1-p^*)^{2(n-1)} = 1/2e = 0.18$

Carrier Sense Multiple Access (CSMA)

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



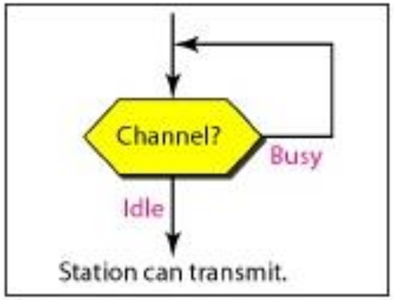
CSMA vulnerable time



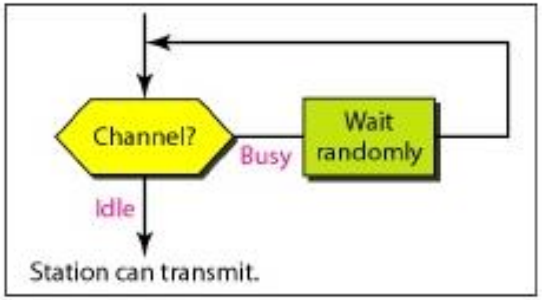
- Vulnerable period = t(prop) (i.e, propagation time to travel maximum distance)

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

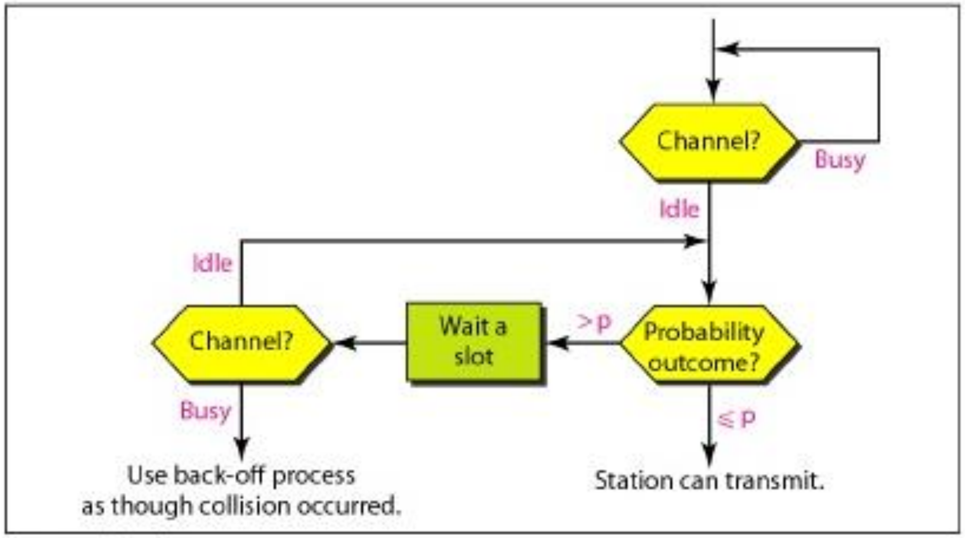
Persistent Methods of CSMA



a. 1-persistent



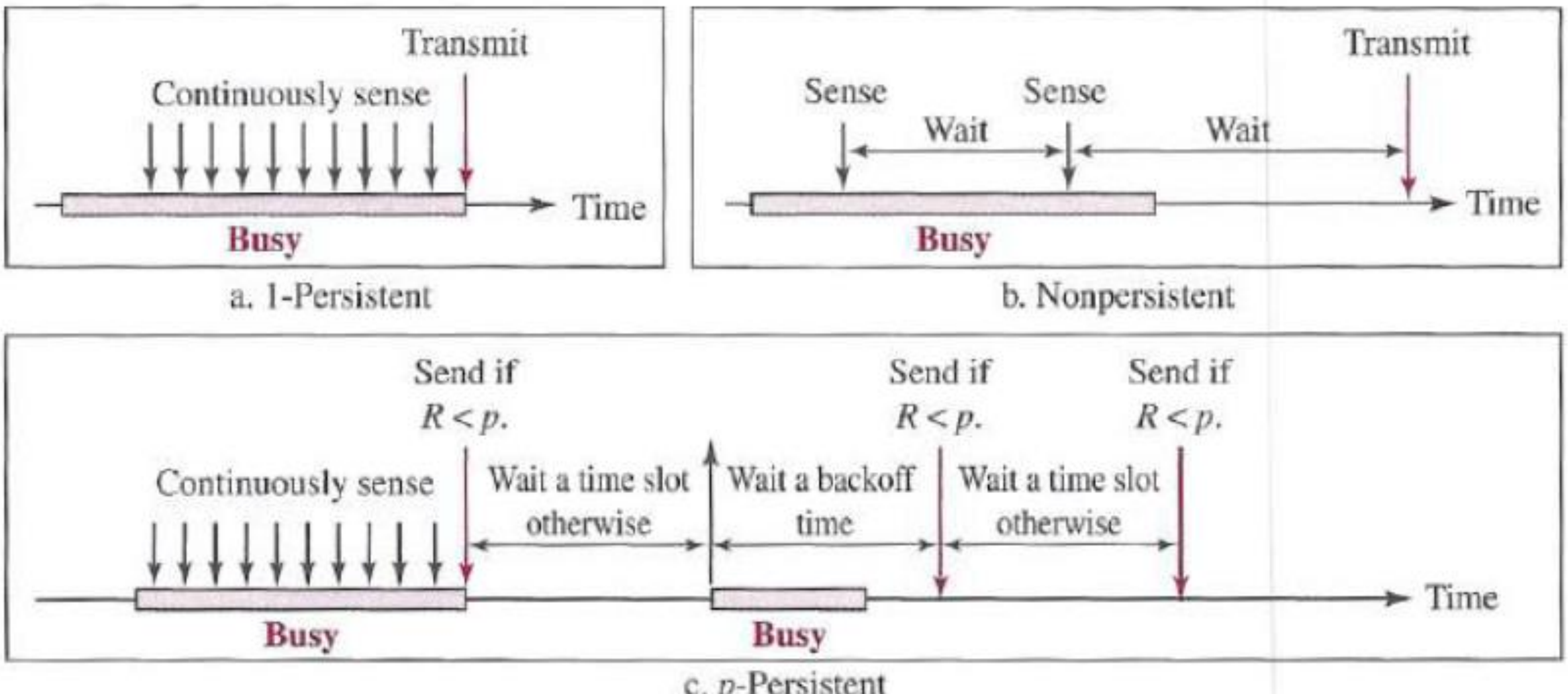
b. Nonpersistent



c. p-persistent

- 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, although more efficient than ALOHA or slotted ALOHA, still has one glaring inefficiency
  - When two frames collide, the medium remains unusable for the duration of transmission of both damaged frames.
  - This waste can be reduced if a station continues to listen to the medium while transmitting to sense collision

➢ CSMA with Collision Detection (CSMA/CD)

- If channel idle:
  - Packet is transmitted for non-persistent and 1-persistent modes
  - Packet is transmitted with probability p OR delayed by end-to-end propagation delay with probability ($1-p$) for p-persistent mode

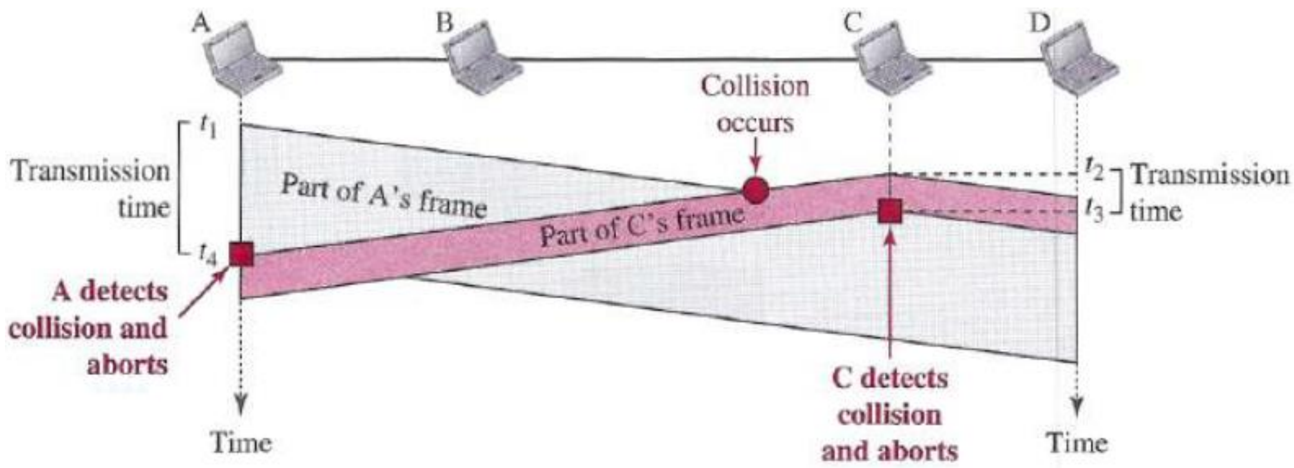
- If channel is busy:
  - The packet is *backed off* and the algorithm is repeated for non-persistent mode
  - The station *defers transmission* until the channel is sensed idle and then immediately transmits in 1-persistent mode
  - The station *defers transmission* until the channel is sensed idle and then follow the channel idle procedure for p-persistent mode

- If a collision is detected during transmission
  - transmit a jamming signal to assure that all stations know that there has been a collision
  - And, then cease transmission.

Collision Detection and Abort

- There must be a mechanism by which sender get to know whether a packet is reached at the receiver or not.
- To check this, the sender wants the head of the packet to transit from one end of the wire and back again before the tail of the packet finished transmission.

- The IEEE standard dictates that the transmitter will detect a collision if the signal on the cable at the transmitter tap point exceeds the maximum that could be produced by the transmitter alone.
- So, the IEEE standard restricts the maximum length of coaxial cable to 500 m for 10BASE5, 200 m for 10BASE2.



Flowchart of CSMA/CD

1) If the medium is idle, transmit; otherwise, go to step 2.

2) If the medium is busy, continue to listen until the channel is idle, then transmit immediately.

3) If a collision is detected during transmission, transmit a brief jamming signal to assure that all stations know that there has been a collision and then cease transmission.

4) After transmitting the jamming signal, wait a random amount of time, referred to as the backoff, then attempt to retransmit (repeat from step 1).

5) A station attempts to transmit repeatedly in the face of repeated collisions. For the first 10 retransmission attempts, the mean value of the random delay is doubled. This mean value then remains the same for 6 additional attempts. After 16 unsuccessful attempts, the station gives up and reports an error.

- The persistent algorithm used in the IEE 802.3 standard (Ethernet) is 1-persistent.
- The beauty of the 1-persistent algorithm with binary exponential backoff (BEB) is that
  - it is efficient over a wide range of loads.
  - At low loads, 1-persistence guarantees that a station seizes the channel as soon as it goes idle.
  - At high loads, it is at least as stable as the other techniques.

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 4 to 6 byte fixed binary pattern
  - The maximum jam-time:
    - The **diameter** of an Ethernet is the maximum distance between any pair of stations.
    - 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 Standard Ethernet is 512 bits, the difference between slot time and round-trip-time is 48 bits (6 bytes), which is the maximum "jam-time".
  - The purpose of this is :
    - To ensure that any other node which may currently be receiving a frame will receive the jam signal in place of the correct 32-bit MAC CRC, this causes the other receivers to discard the frame due to a CRC error.
    - To ensure source knows of collision before it completes transmitting the full frame!

Cont...

- **Slot time** is at least twice the time it takes for an electronic pulse to travel the length of the maximum theoretical distance between two nodes.

- Collision detection may take $2t_{prop}$ (one slot)
  - Station A begins transmission at time t_A
  - Worst case: B begins `just before` (t_A+t_{prop})
  - B detects collision at t_A+t_{prop} (too late...)
  - A detects collision only at t_A+2t_{prop}

- Consider 10Mbps Ethernet (`classical`)
  - Max length allowed 2500m and up to 4 repeaters
  - Assuming each repeater takes $t_{repeater} < 4\ \mu sec$
- So, $t_{prop} = 2500/(3*10^8) + 4*t_{repeater} < 25\ \mu sec$

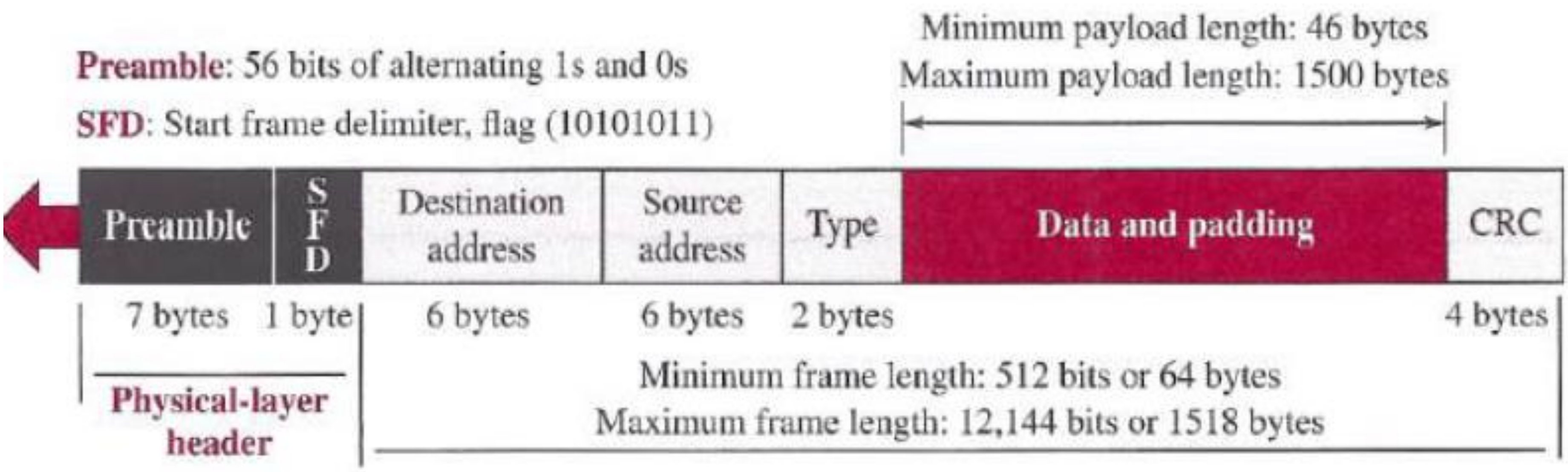
- With 10Mbps, one bit takes 0.1μsec

- So, minimal frame size = 2*25/0.1 = 500b ≈ 512b = 64 Bytes

Points to remember in CSMA/CD

- Points to remember:
  - Use of the 1-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 re-transmission limit (for Ethernet it is 16)

Frame Format



- Type: defines the upper-layer protocol whose packet is encapsulated
- The maximum frame length was later increased to 1522 bytes to allow VLAN tagging.

- Reason for minimum frame length
  - To achieve collision detection

- Reason for maximum frame length
  - Longer frames increases the probability that one or more bits in the frame will be received in error, necessitating retransmission of the frame
  - longer maximum frame increases the memory requirement for a NIC (network interface card)

Efficiency of Ethernet

- Closed from approximation of the efficiency of Ethernet using CSMA/CD:
  Efficiency (E) = the fraction of the transmission capacity of a communication channel that contains data (frame) transmissions = $1/(1 + 4.4\,a)$; $a = t_{prop}/t_{tran}$

  Where, t_{prop}: maximum propagation time between two adapters in LAN
  t_{tran}: time to transmit a maximum size frame
  (max size 1518 bytes - frame takes approx. 1.2 msec for 10 Mbps Ethernet)

- Let n nodes,
- all send with probability p during each time slot ($2t_{prop}$)
- Success probability during a slot is $A=np(1-p)^{n-1}$
- For max success probability, we get $p=1/n$
- So, maximum success probability during a slot $A \rightarrow 1/e$ as $n \rightarrow \infty$
- Probability that a node waits j slots until success is: $(1-A)^{j-1} \cdot A$
- Average number of slots till success is:

$$\sum_{j=1}^{\infty} jA(1-A)^{j-1} = A\sum_{i=0}^{\infty}(i+1)(1-A)^{i}$$

Cont…

Taylor Series: representation of a function as an infinite sum

$$x = f(x) = f(a) + \frac{f'(a)}{1!}(x-a)^1 + \frac{f''(a)}{2!}(x-a)^2 + \frac{f'''(a)}{3!}(x-a)^3 + \dots$$

$$\Rightarrow x = \sum_{i=0}^{\infty} \frac{f^{i}(a)}{i!}(x-a)^i$$

Let, *$f(A) = 1/A^2$*

Then, $f^{i}(A) = (-1)^{i \bmod 2}\,(i+1)!\,A^{-2-i}$

Now, at $a=1$

$$\frac{1}{A^2} = f(A) = \sum_{i=0}^{\infty} \frac{f^{i}(a)}{i!}(A-a)^i = \sum_{i=0}^{\infty} \frac{(-1)^{i \bmod 2}(i+1)!}{i!}(A-1)^i = \sum_{i=0}^{\infty} (i+1)(1-A)^i$$

Cont…

- Finally, the average number of slots till success is: $A.\frac{1}{A^2} = \frac{1}{A} = e$
- Average amount of time between successful packet transmissions is:

  $(e\text{-}1)\cdot 2t_{prop} + t_{tran} + t_{prop}$
- So,

Efficiency $= \dfrac{t_{tran}}{(e-1)2t_{prop} + t_{tran} + t_{prop}} \cong \dfrac{1}{1+4.4a}$ where, $a = t_{prop}/t_{tran}$

- Efficiency goes to 1 as t_{prop} goes to 0
  - Smaller physical network diameter (distance)
- Efficiency goes to 1 as t_{tran} goes to infinity
  - Slower transmission, longer (minimal) frames
- Different tradeoffs → several Ethernet variants…
- Much more efficient at high loads (than ALOHA, Slotted ALOHA protocols), while still decentralized, simple, and cheap.
- E.g., if a= 0.1, the Ethernet efficiency = 69%

Ethernet Evolution

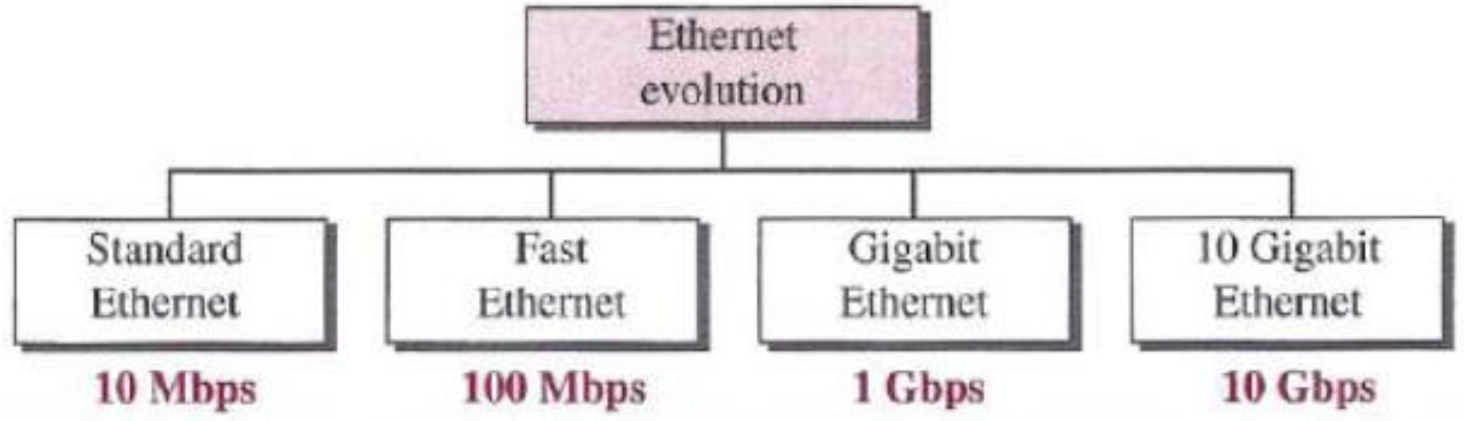


Table 13.1 *Summary of Standard Ethernet implementations*

Implementation	*Medium*	*Medium Length*	*Encoding*
10Base5	Thick coax	500 m	Manchester
10Base2	Thin coax	185 m	Manchester
10Base-T	2 UTP	100 m	Manchester
10Base-F	2 Fiber	2000 m	Manchester

- Common notation:

<data rate in Mbps> <signaling method><maximum segment length >

Cont…

Table 13.2 *Summary of Fast Ethernet implementations*

Implementation	*Medium*	*Medium Length*	*Wires*	*Encoding*
100Base-TX	UTP or STP	100 m	2	4B5B + MLT-3
100Base-FX	Fiber	185 m	2	4B5B + NRZ-I
100Base-T4	UTP	100 m	4	Two 8B/6T

Table 13.3 *Summary of Gigabit Ethernet implementations*

Implementation	*Medium*	*Medium Length*	*Wires*	*Encoding*
1000Base-SX	Fiber S-W	550 m	2	8B/10B + NRZ
1000Base-LX	Fiber L-W	5000 m	2	8B/10B + NRZ
1000Base-CX	STP	25 m	2	8B/10B + NRZ
1000Base-T4	UTP	100 m	4	4D-PAM5

Table 13.4 *Summary of 10 Gigabit Ethernet implementations*

Implementation	*Medium*	*Medium Length*	*Number of wires*	*Encoding*
10GBase-SR	Fiber 850 nm	300 m	2	64B66B
10GBase-LR	Fiber 1310 nm	10 Km	2	64B66B
10GBase-EW	Fiber 1350 nm	40 Km	2	SONET
10GBase-X4	Fiber 1310 nm	300 m to 10 Km	2	8B10B

Thanks!

Figure and slide materials are taken from the following sources:

1. W. Stallings, (2017), Data and Computer Communications, 10th Ed.
2. B. A. Forouzan, (2012), Data Communication and Networking, 5th Ed.
3. Kurose and Ross, (2013), Computer Networking – A Top Down Approach, 6th Ed.