

Ethernet

by

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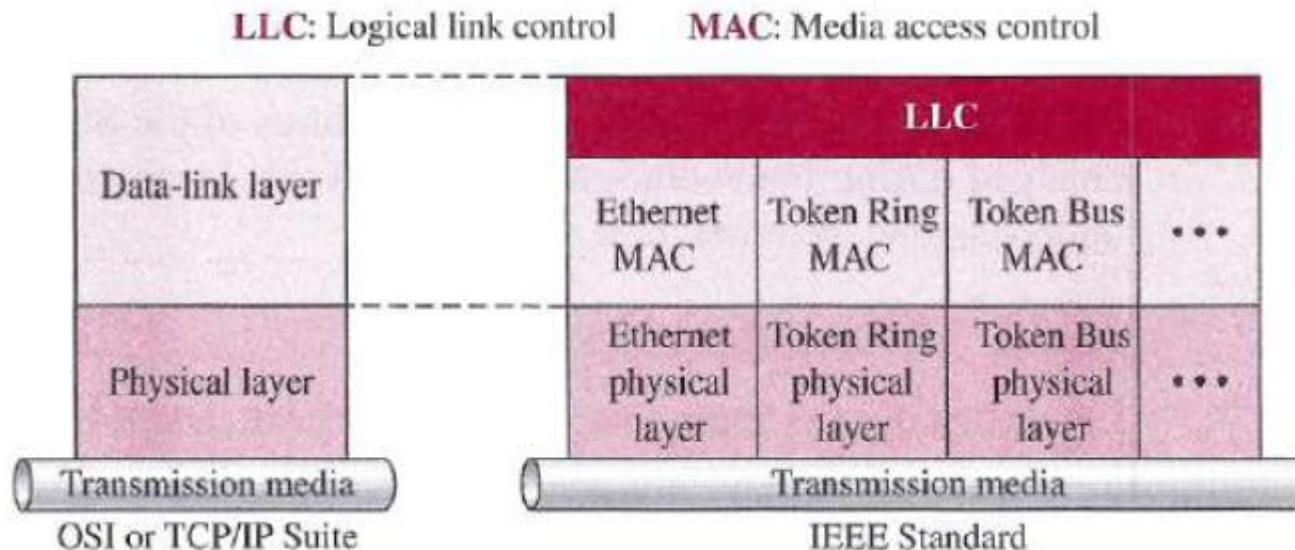
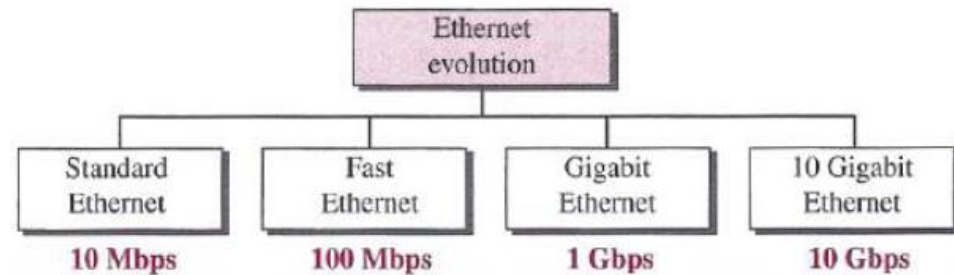
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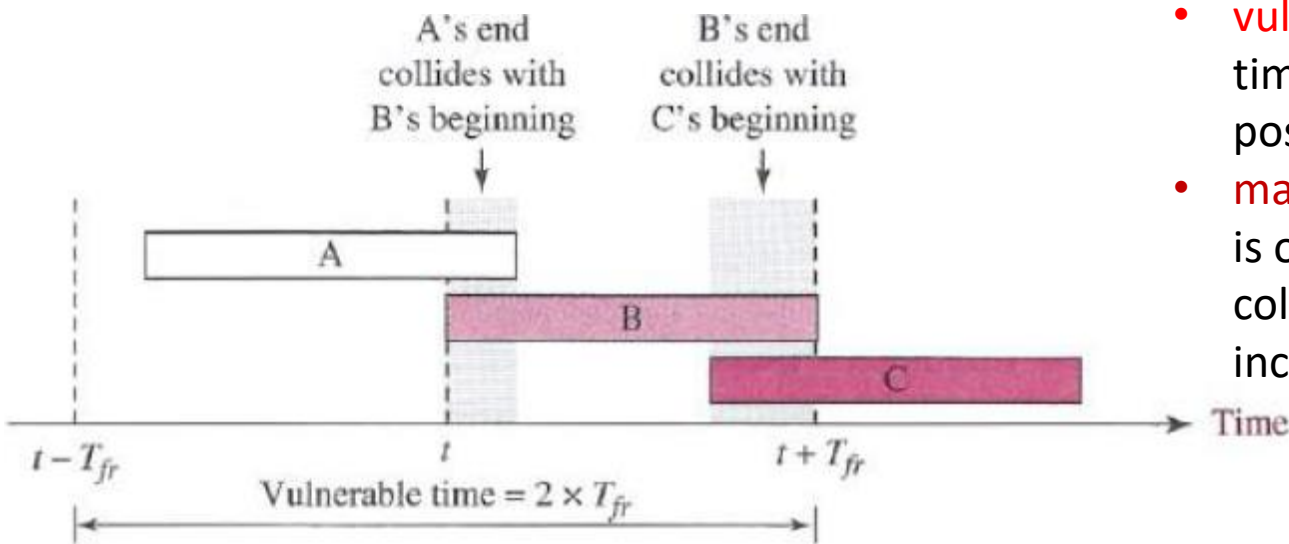
Introduction

- 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

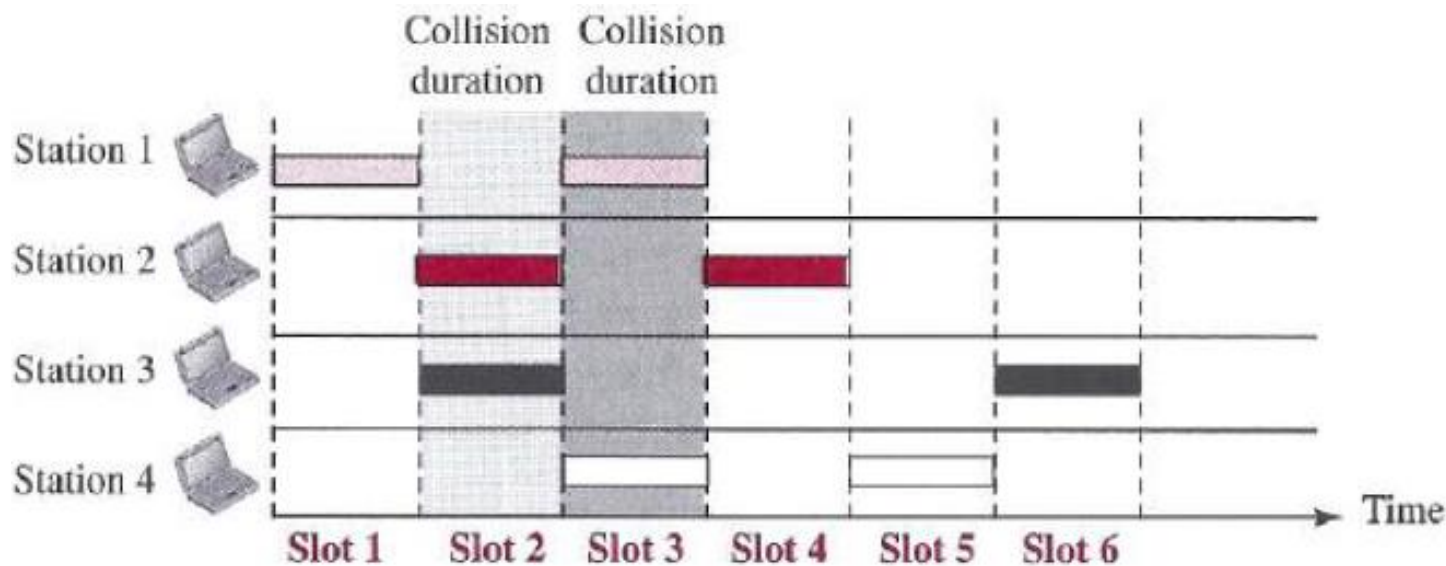
- Developed in early 1970 at University of Hawaii for packet radio networks.
- Principle:
 - each station sends a frame **whenever** it has a frame to send
 - relies on **acknowledgments** from the receiver
 - if **time-out** occurs, then wait for **backoff time** before **retransmission**
 - after a **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

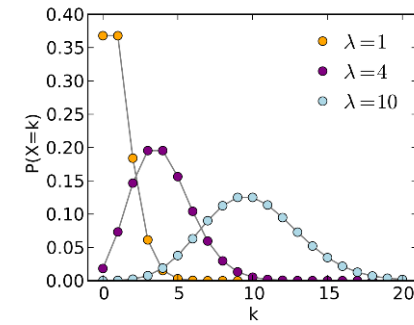
- To improve efficiency, a modification of ALOHA was proposed.
- we divide the time into **slots of T_{fr} seconds** and
- force the station to send only **at the beginning** of the time slot
- If **collision** occurs, the node **retransmit** frame in next slot **with probability p**



- **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
 $\tau = \text{slot size} = \text{transmission time of a packet} = N/R$ 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

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

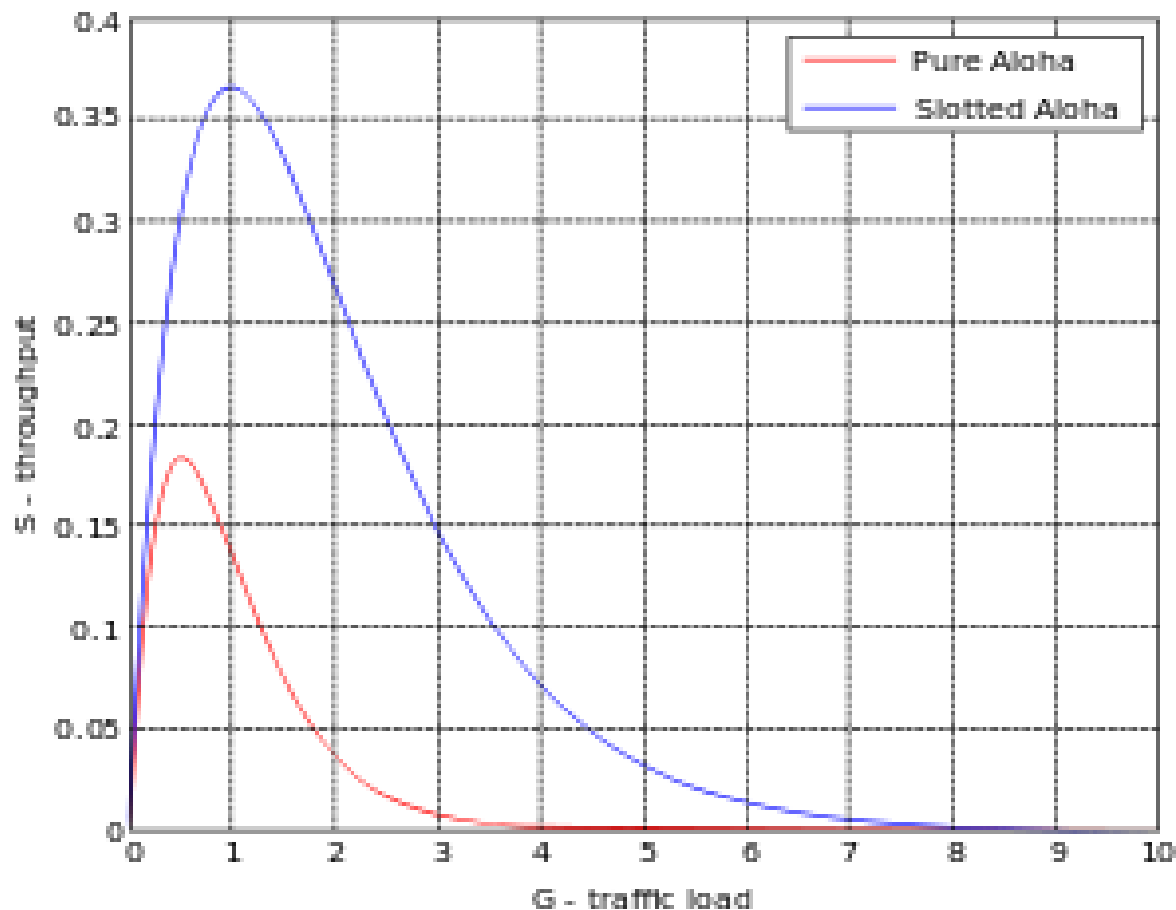
- Vulnerable time in **Pure ALOHA** = 2τ
- So, the probability that **no packets are generated during** the time $[-\tau, \tau]$ is given by Poisson distribution with $t = 2\tau$

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

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

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, $dE/dp = 0 \Rightarrow p^* = 1/n$
- Now, to obtain the **maximum efficiency** for a **large number of active nodes**, we take the limit $np^*(1-p^*)^{n-1}$
So, $\lim_{n \rightarrow \infty} np^*(1-p^*)^{n-1} = \lim_{n \rightarrow \infty} (1-1/n)^{n-1} = 1/e = 0.3678$

Efficiency of Pure ALOHA

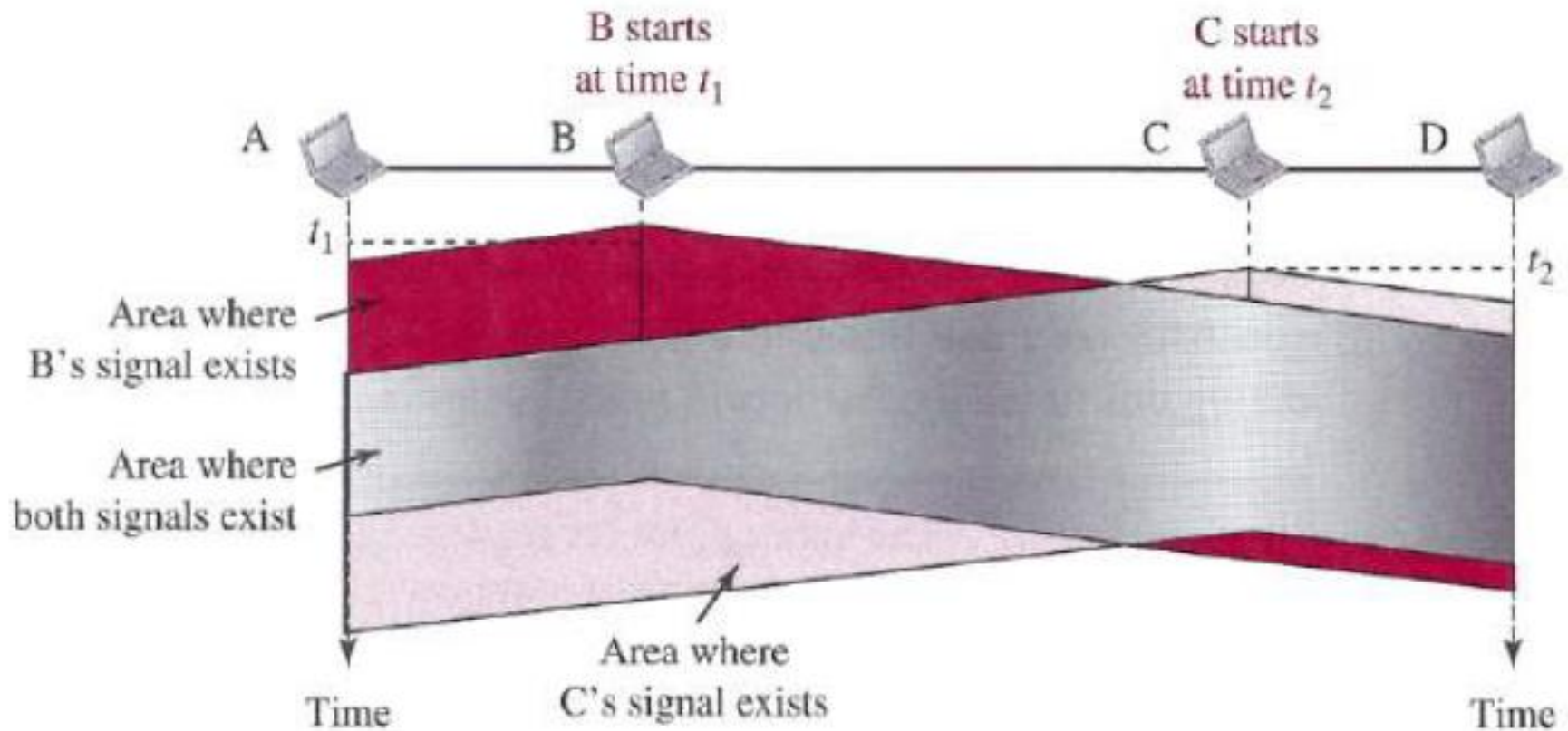


- Let **transmission probability** p .
- The probability that 'a given slot is a successful slot' is the probability that one of the nodes transmits and that the remaining $(n - 1)$ nodes do not transmit $= p(1-p)^{n-1}$
- In pure ALOHA, we have **one more condition** – no one else has started transmission 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, $dE/dp = 0 \quad \Rightarrow p^* = 1/(2n-1)$
- Now, to obtain the **maximum efficiency** for a large number of active nodes, we take the limit $np^*(1-p^*)^{2(n-1)}$
So, $\lim_{n \rightarrow \infty} np^*(1-p^*)^{2(n-1)} = 1/2e = 0.18$

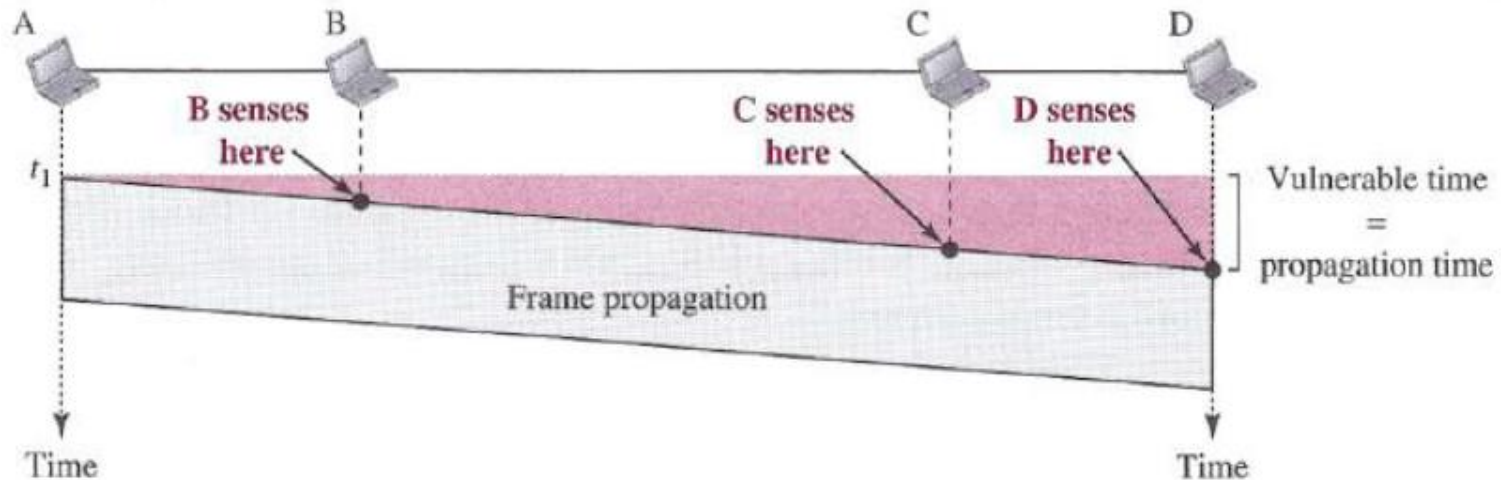
Carrier Sense Multiple Access (CSMA)



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

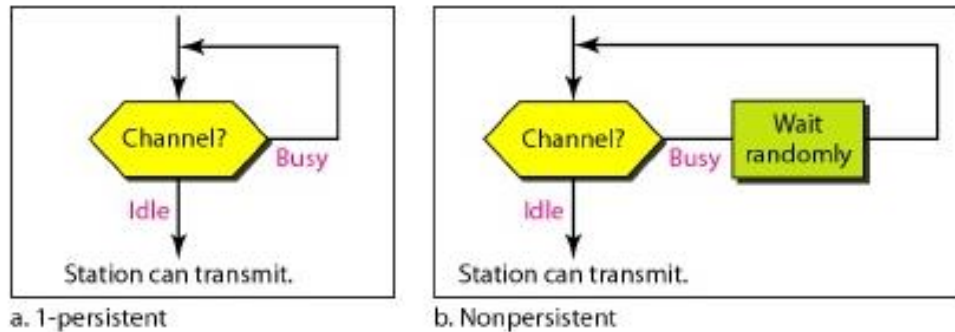


CSMA vulnerable time



- **Vulnerable period** = $t(\text{prop})$ (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

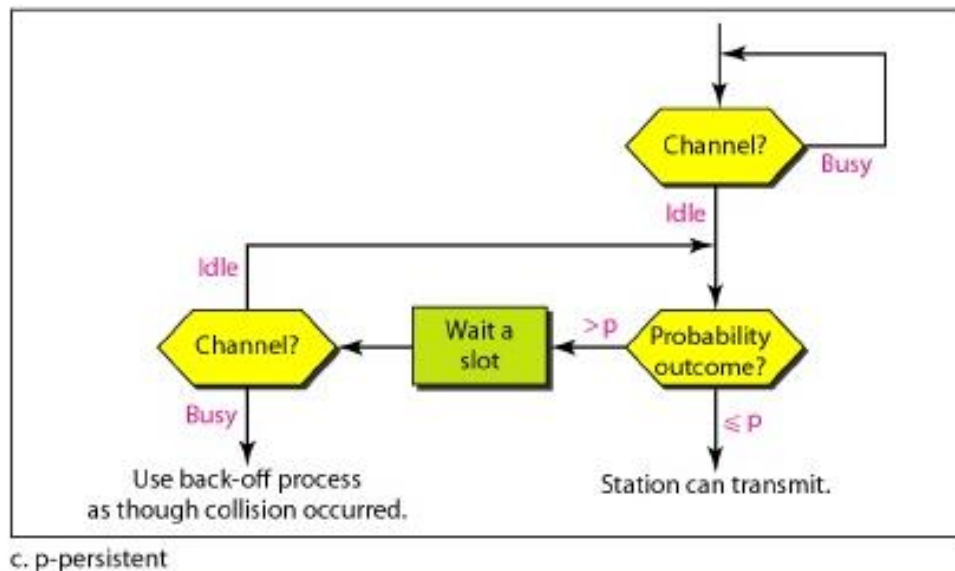


1-persistent

- Continuously sense the channel
- if idle, transmit frame (with probability 1)

Non-persistent

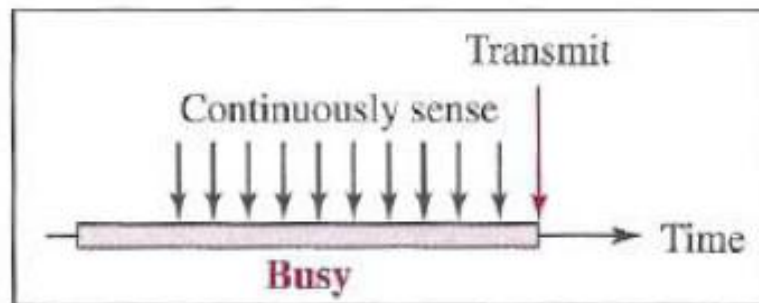
- Sense the channel
- If idle, transmit frame (with probability 1)
- If busy, wait a random amount of time and then sense the channel again



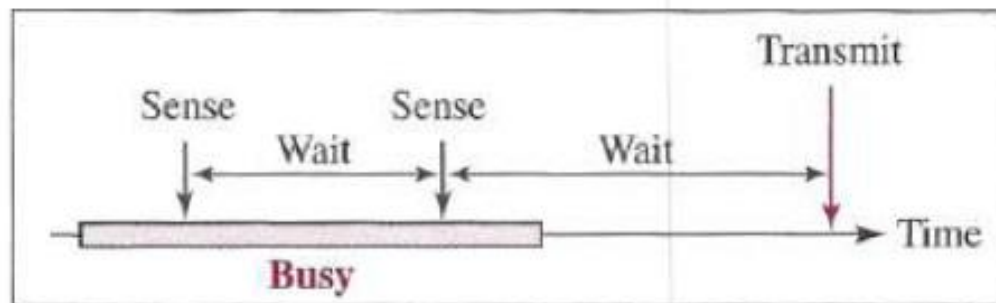
p-persistent

- Non-persistent , but transmit frame with probability p

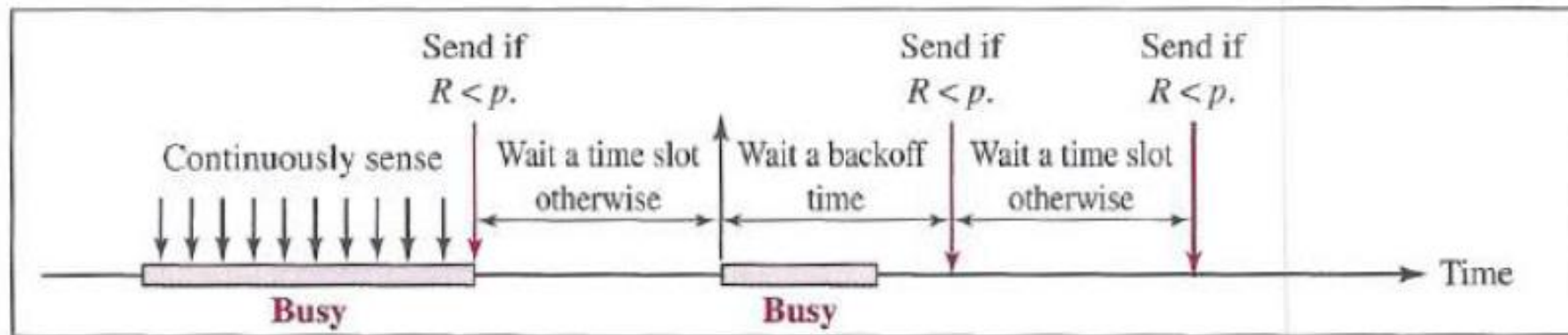
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a. 1-Persistent



b. Nonpersistent



c. p -Persistent

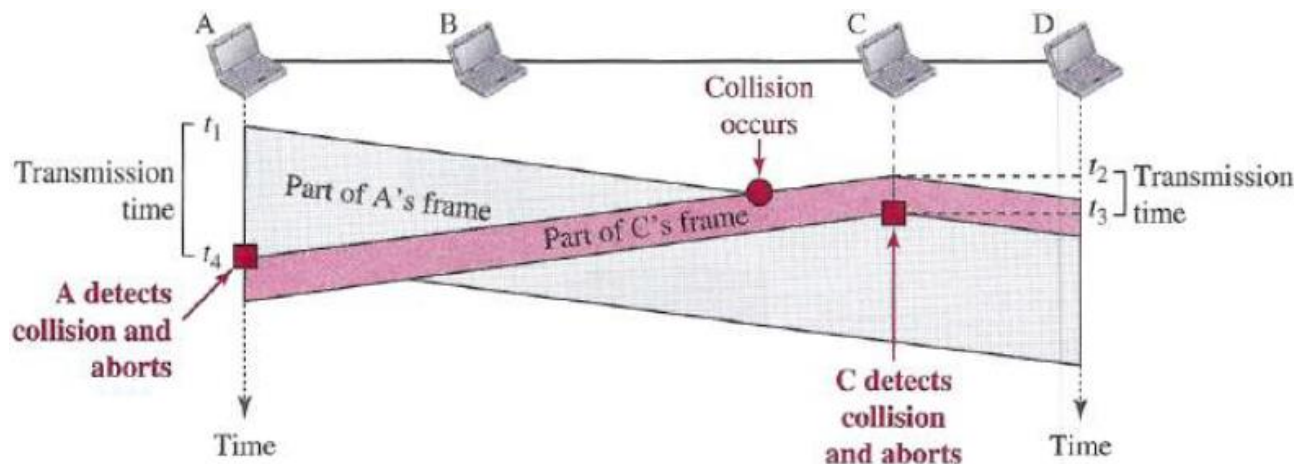
CSMA/CD (Collision Detection)



- 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 IEEE 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!**

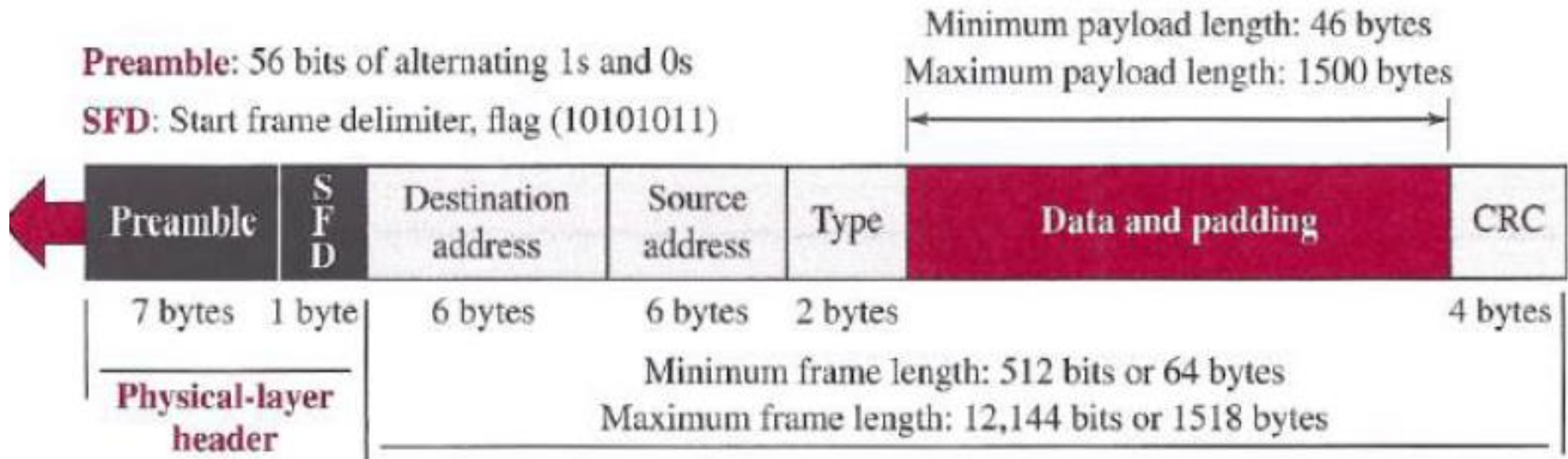
- **Slot time** is at least twice the time it takes for an electronic pulse to travel the length of the maximum theoretical distance between two nodes.
- Collision detection may take $2t_{prop}$ (one slot)
 - Station A begins transmission at time t_A
 - Worst case: B begins `just before` ($t_A + t_{prop}$)
 - 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 $t_{repeater} < 4 \mu\text{sec}$
- So, $t_{prop} = 2500 / (3 * 10^8) + 4 * t_{repeater} < 25 \mu\text{sec}$
- With 10Mbps, one bit takes $0.1 \mu\text{sec}$
- So, minimal frame size = $2 * 25 / 0.1 = 500\text{b} \approx 512\text{b} = 64 \text{ Bytes}$

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 form approximation of the efficiency of Ethernet using CSMA/CD:

$$E = 1 / (1 + 5 t_{\text{prop}} / t_{\text{trans}})$$

Where, t_{prop} : maximum propagation time between two adapters in LAN

t_{trans} : 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 ($2t_{\text{prop}}$)
- Success probability $A = np(1-p)^{n-1}$
- For max success probability, we get $p = 1/n$
- Success probability $A \rightarrow 1/e$ 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

$$\begin{aligned} f(x) &= f(a) + \frac{f'(a)}{1!} (x-a)^1 + \frac{f''(a)}{2!} (x-a)^2 + \frac{f'''(a)}{3!} (x-a)^3 + \dots \\ &= \sum_{i=0}^{\infty} \frac{f^i(a)}{i!} (x-a)^i \end{aligned}$$

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

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

Now, at $a=1$

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

Cont...

- Finally, the **average number of slots till success** is:

$$A \cdot \frac{1}{A^2} = \frac{1}{A} = e$$

- Time till success:** $e \cdot 2t_{prop}$

- So,

$$\text{efficiency} = \frac{t_{trans}}{t_{trans} + 2et_{prop}} \cong \frac{1}{1 + 5t_{prop} / t_{trans}}$$

$$5 \cong 2e$$

- Efficiency goes to 1 as t_{prop} goes to 0
 - Smaller physical network diameter (distance)
- Efficiency goes to 1 as t_{trans} goes to infinity
 - Slower transmission, longer (minimal) frames
- Different tradeoffs \rightarrow several Ethernet variants...
- Much more efficient at high loads (cf. ALOHA, Slotted ALOHA), while still decentralized, simple, and cheap
- E.g., if $t_{prop}/t_{trans} = 0.1$, the Ethernet efficiency = 67%

Ethernet Evolution

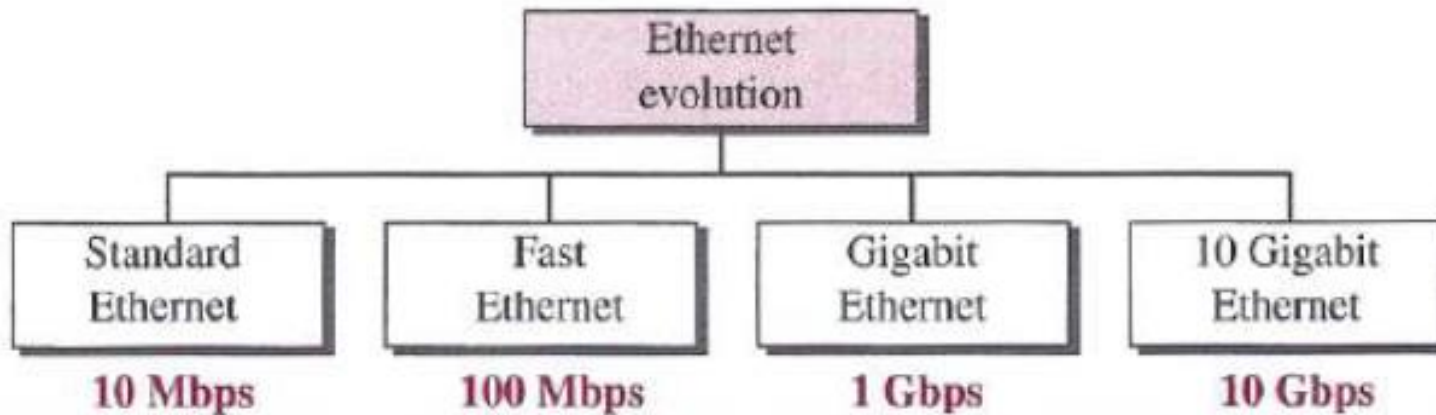


Table 13.1 *Summary of Standard Ethernet implementations*

<i>Implementation</i>	<i>Medium</i>	<i>Medium Length</i>	<i>Encoding</i>
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 >

Table 13.2 *Summary of Fast Ethernet implementations*

<i>Implementation</i>	<i>Medium</i>	<i>Medium Length</i>	<i>Wires</i>	<i>Encoding</i>
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*

<i>Implementation</i>	<i>Medium</i>	<i>Medium Length</i>	<i>Wires</i>	<i>Encoding</i>
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*

<i>Implementation</i>	<i>Medium</i>	<i>Medium Length</i>	<i>Number of wires</i>	<i>Encoding</i>
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.