



Media Access Protocols

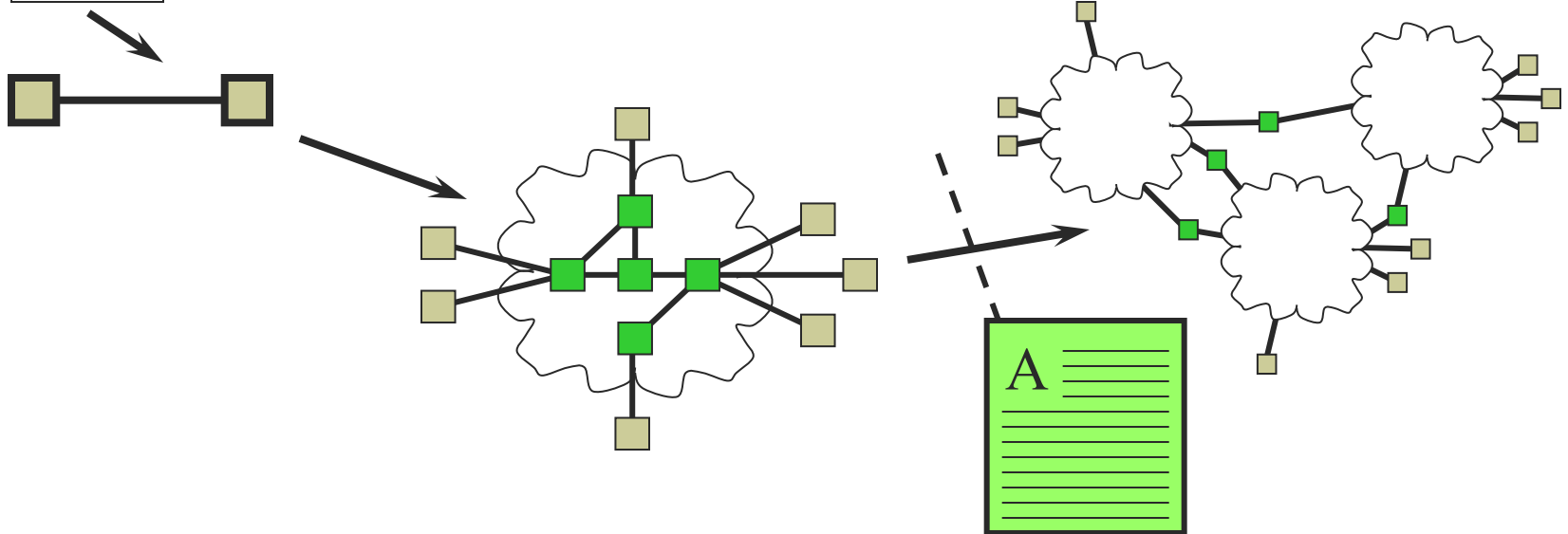


[Where are We?

you are here



00010001
11001001
00011101



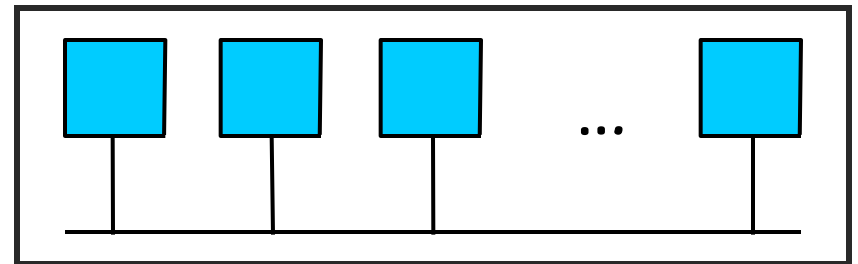
midterm is here





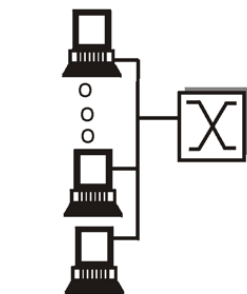
[Multiple Access Media

- Multiple senders on some media
 - Buses (Ethernet)
 - Radio, Satellite
 - Token Ring
- Need methods to mediate access
 - Fair arbitration
 - Good performance



Point-to-Point vs. Broadcast Media

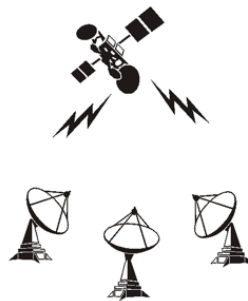
- Point-to-point: dedicated pairwise communication
 - Long-distance fiber link
 - Point-to-point link between Ethernet switch and host
- Broadcast: shared wire or medium
 - Traditional Ethernet
 - 802.11 wireless LAN



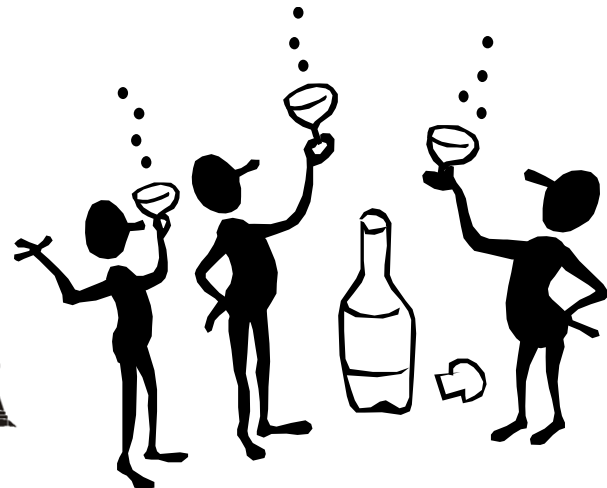
shared wire
(e.g. Ethernet)



shared wireless
(e.g. Wavelan)

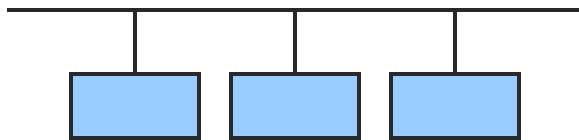


satellite

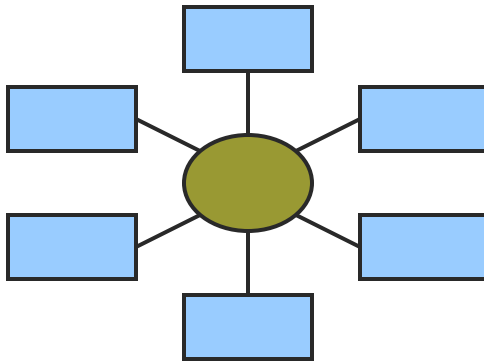


cocktail party

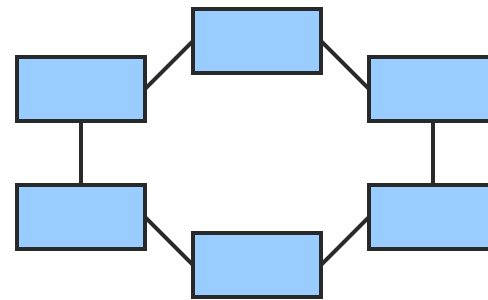
Types of Shared Link Networks



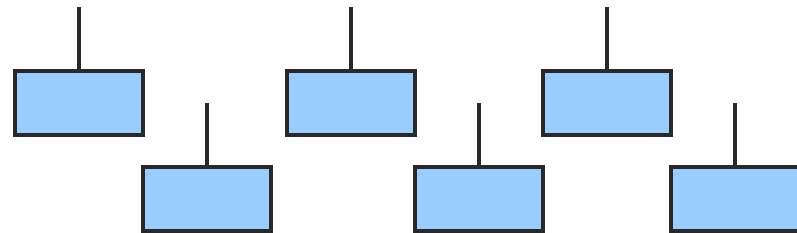
Bus Topology: Shared
Ethernet, Token Bus



Star Topology: Active or Passive Hub
ATM



Ring Topology: Multihop
FDDI, IEEE 802.5



Wireless: Shared
IEEE 802.11

[Multiple Access Algorithm]

- Single shared broadcast channel
 - Must avoid having multiple nodes speaking at once
 - Otherwise, collisions lead to garbled data
 - Need distributed algorithm for sharing the channel
 - Algorithm determines which node can transmit
- Typical assumptions
 - Communication needs vary
 - Over time
 - Between hosts
 - Network is not fully utilized



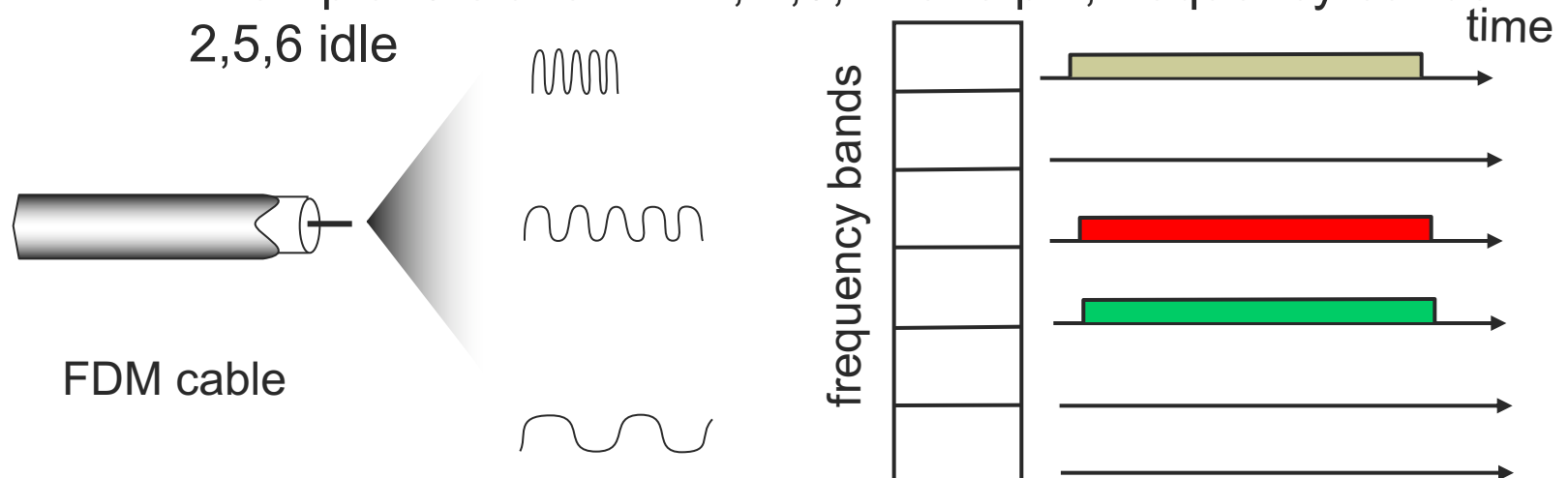
Multiple Access Media

- Which kind of multiplexing is best?
 - Channel partitioning: divide channel into pieces
 - Frequency-division multiplexing (FDM, separate bands)
 - Taking turns: scheme for trading off who gets to transmit
 - Time-division multiplexing (TDM, synchronous time slots)
 - Statistical time-division multiplexing (STDM, time slots on demand)
 - Random access: allow collisions, and then recover



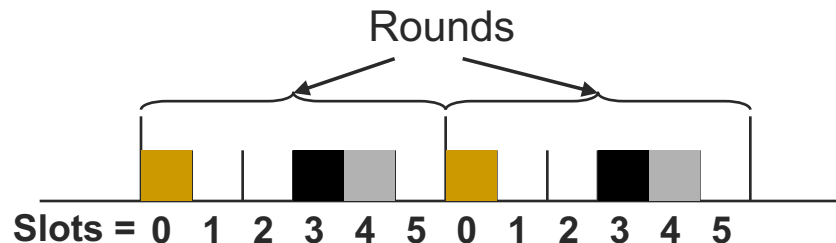
Channel Partitioning: FDMA

- FDMA: Frequency Division Multiple Access
 - Channel spectrum divided into frequency bands
 - Each station assigned fixed frequency band
 - Unused transmission time in frequency bands go idle
 - Example: 6-station LAN, 1,3,4 have pkt, frequency bands 2,5,6 idle



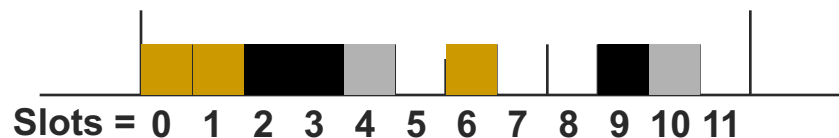
Channel Partitioning: TDMA

- TDMA: Time Division Multiple Access
 - Access to channel in "rounds"
 - Each station gets fixed length slot in each round
 - Time-slot length is packet transmission time
 - Unused slots go idle
 - Example: 6-station LAN with slots 0, 3, and 4



Channel Partitioning: STDMA

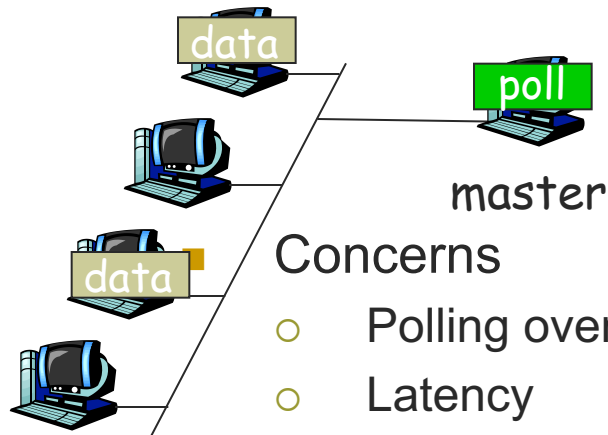
- STDMA: Statistical Time Division Multiple Access
 - Access to channel as needed
 - Each station gets fixed length on transmission
 - Time-slot length is packet transmission time
 - Unused slots go idle only if no station has data to send
 - Example



Channel Partitioning: Taking Turns

■ Polling

- Master node “invites” slave nodes to transmit in turn



Concerns

- Polling overhead
- Latency
- Single point of failure (master)

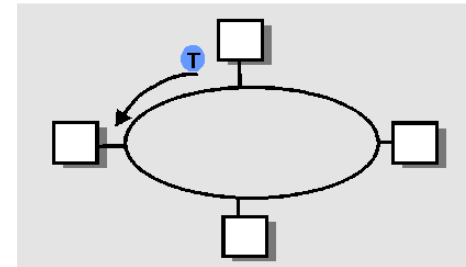
■ Token passing

- Control token passed from one node to next sequentially

■ Node must have token to send

■ Concerns

- Token overhead
- Latency
- At mercy of any node



Multiple Access Media: Random Access

- Random access
 - Optimize for the common case (no collision)
 - Don't avoid collisions, just recover from them....
- When node has packet to send
 - Transmit at full channel data rate
 - No a priori coordination among nodes
- Two or more transmitting nodes \Rightarrow collision
 - Data lost
- Random access MAC protocol specifies
 - How to detect collisions
 - How to recover from collisions



[Multiple Access Media to Discuss]

- Two solutions (of many)
 - Carrier sense multiple access with collision detection (CSMA/CD)
 - Send only if medium is idle
 - Stop sending immediately if collision detected
 - Carrier sense multiple access with collision Avoidance (CSMA/CA)
 - Send only if medium is idle
 - Design send algorithm to avoid collisions
- Tanenbaum Sec. 4.2 covers many others



Carrier Sense Multiple Access with Collision Detection (CSMA/CD)

■ Used by Ethernet

- Xerox and IEEE 802.3 (10Mbps standards)
- IEEE 802.3u (Fast Ethernet, 100Mbps standard)
- IEEE 802.3z,ab (1Gbps Ethernet)
- IEEE 802.3-2005/8 (10 Gbps Ethernet, no shared bus)

■ Outline

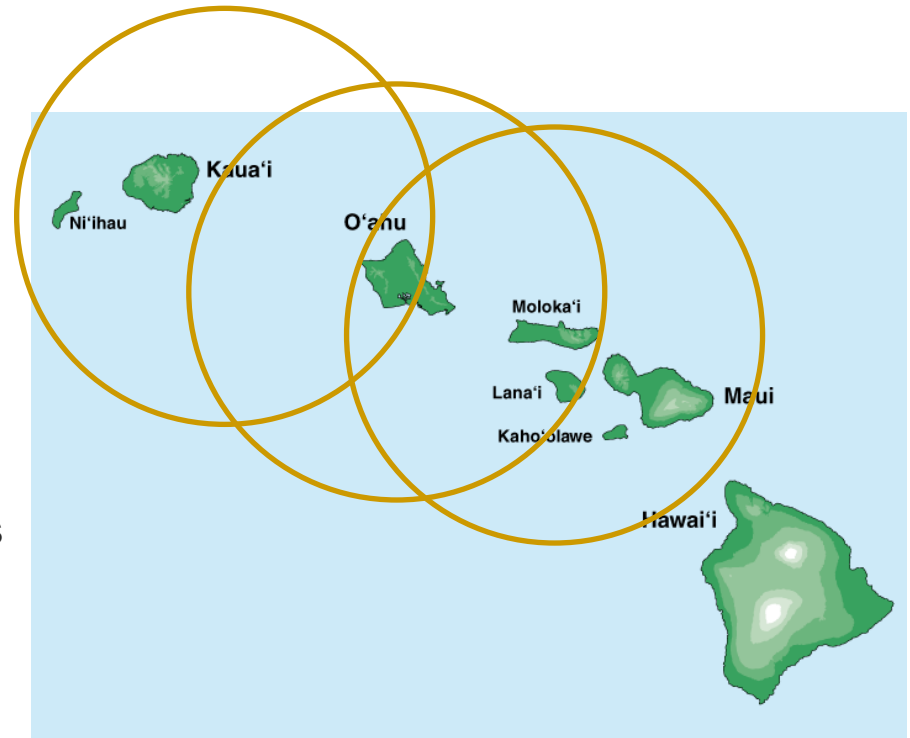
- Historical development
- Topologies and components
- MAC algorithm
- Collision detection limitations
- Lessons learned



[Aloha, Networking!]

■ Aloha Packet Radio Network

- Norm Abramson left Stanford to surf
- Set up first data communication system for Hawaiian islands
- Hub at U. Hawaii, Oahu
- Two radio channels:
 - Random access: for sites sending data
 - Broadcast for hub rebroadcasting data



[Pure ALOHA]

- Keep it simple
 - User transmits at will
 - If two or more messages overlap in time → collision
 - Receiver cannot decode packets
 - Wait roundtrip time plus a fixed increment → collision
 - Lack of ACK
 - After a collision
 - Colliding stations retransmit
 - Stagger attempts randomly to reduce repeat collisions
 - After several attempts, senders give up
- Simple but wasteful
 - Max efficiency of at most $1/(2e) = 18\%$!



[From Aloha comes Ethernet]

- Ethernet
 - Developed by Xerox PARC, 1974
 - Standardized by Xerox, DEC and Intel in 1978
 - Later, IEEE 802.3 standard
 - Fast Ethernet (100 Mbps) - IEEE 802.3u standard
 - Switched Ethernet now popular
- Numerous standards with increasing bandwidth over the years
 - 10 Mbps – 100 Mbps – 1 Gbps – 10 Gbps



Xerox Alto, first machine networked with ethernet



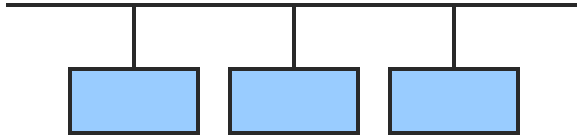
[Ethernet - CSMA/CD]

- CS – Carrier Sense
 - Nodes can distinguish between an idle and a busy link
- MA - Multiple Access
 - A set of nodes send and receive frames over a shared link
- CD – Collision Detection
 - Nodes listen during transmission to determine if there has been interference

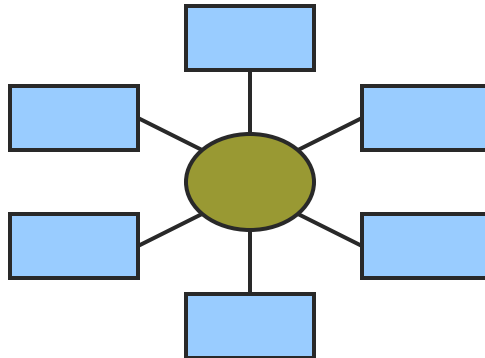




[Ethernet Topologies



Bus Topology: Shared
All nodes connected
to a wire

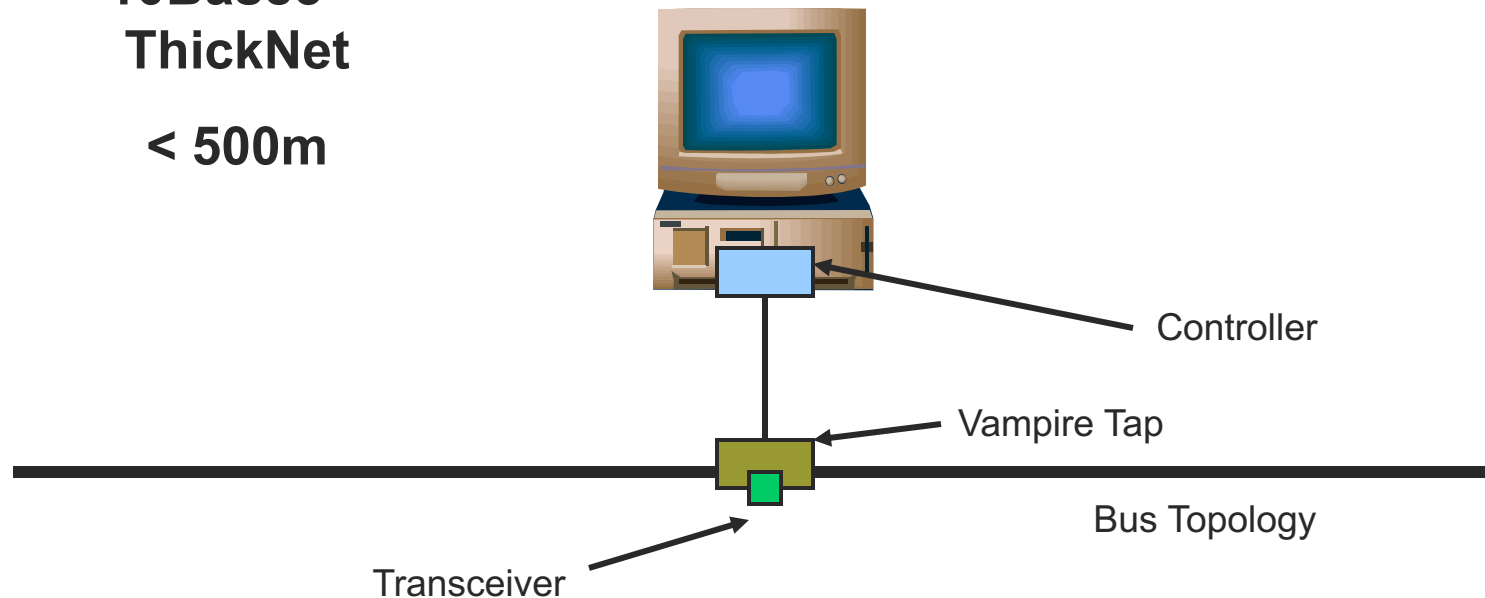


Star Topology:
All nodes connected to a
central repeater



Ethernet Connectivity

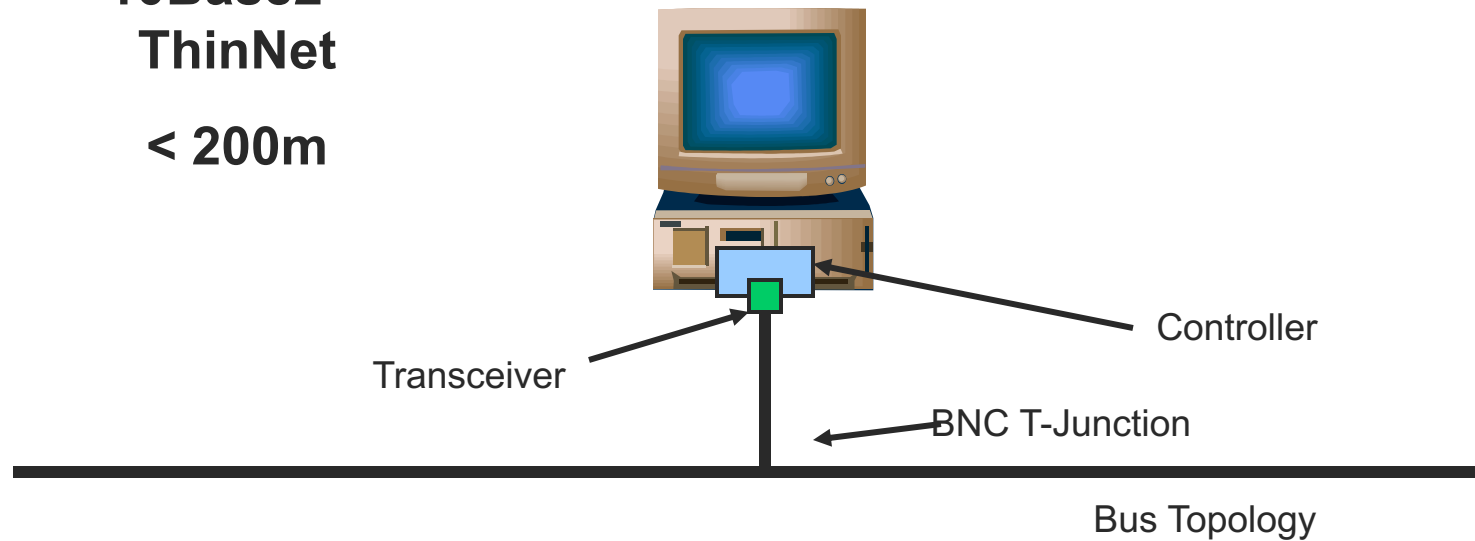
**10Base5 –
ThickNet**
< 500m





[Ethernet Connectivity

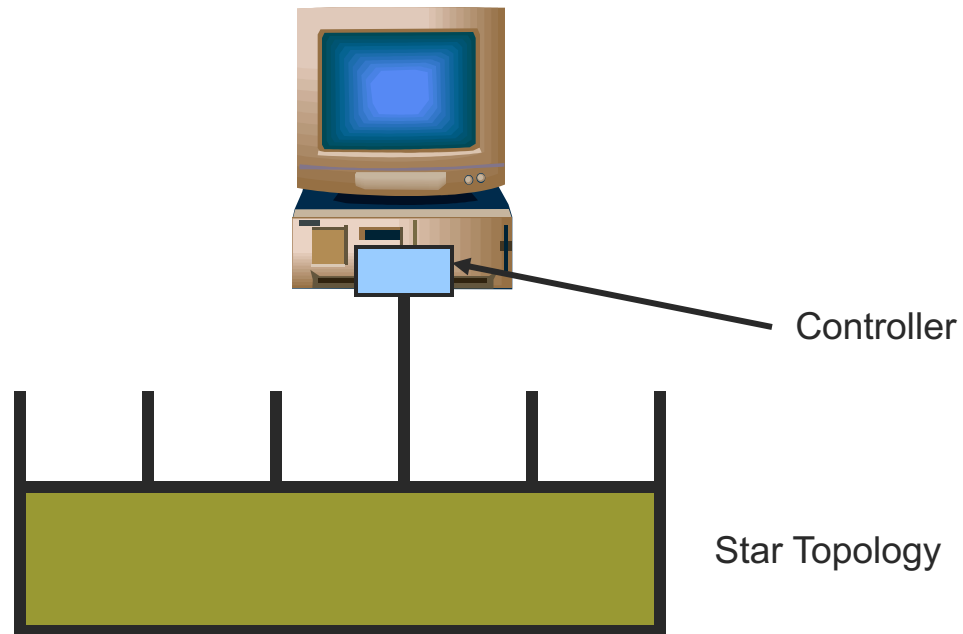
**10Base2 –
ThinNet**
< 200m



[Ethernet Connectivity

10BaseT

< 100m



Ethernet Specifications

- Coaxial Cable
 - up to 500m
- Taps
 - > 2.5m apart
- Transceiver
 - Idle detection
 - Sends/Receives signal
- Repeater
 - Joins multiple Ethernet segments
 - < 5 repeaters between any two hosts
- < 1024 hosts

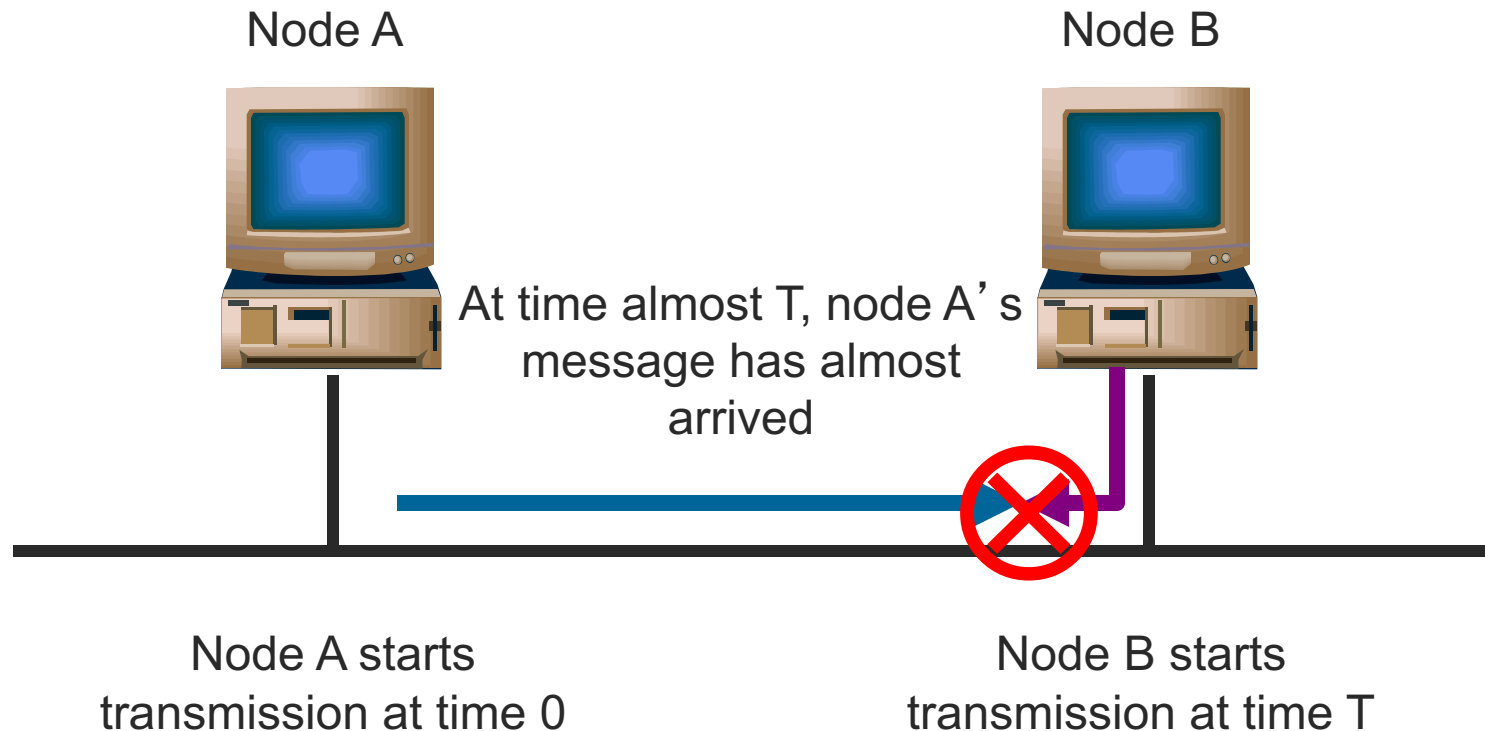


[10Mb Ethernet Specifications]

- Broadcast
- Encoding
 - Manchester
 - 10 Mbps \Rightarrow Transmission at 20Mhz
 - Faster Ethernet standards use more efficient encodings
- Framing
 - Preamble marks beginning, sentinel marks end of frame
 - Bit oriented (similar to HDLC)
 - Data-dependent length
- Error Detection
 - 32-bit CRC



Ethernet MAC Algorithm



How can we ensure that A knows about the collision?

Collision Detection

■ Problem

- How can A detect a collision?

■ Solution

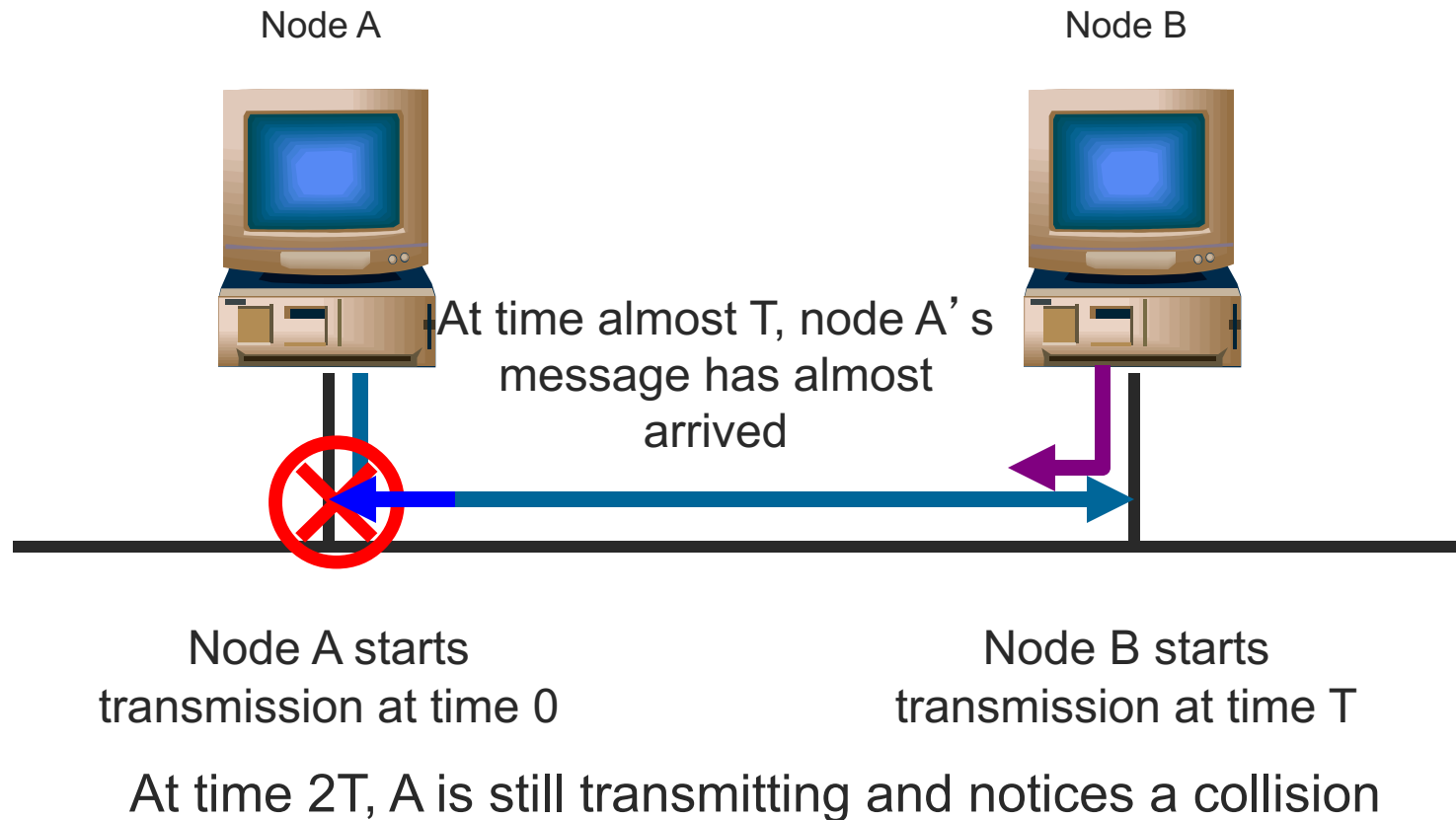
- A must still be transmitting when it receives B's transmission!

■ Example

- Node A's message reaches node B at time T
- Node B's message reaches node A at time $2T$
- For node A to detect a collision, node A must still be transmitting at time $2T$



Ethernet MAC Algorithm



[Collision Detection]

- IEEE 802.3
 - $2T$ is bounded to $51.2\mu\text{s}$
 - At 10Mbps $51.2\mu\text{s} = 512\text{b}$ or $64 = 512\text{b}$ or 64B
 - Packet length $\geq 64\text{B}$
- Jam after collision
 - Ensures that all hosts notice the collision



Ethernet MAC Algorithm

■ Sender/Transmitter

- If line is idle (carrier sensed)
 - Send immediately
 - Send maximum of 1500B data (1527B total)
 - Wait 9.6 μ s before sending again
- If line is busy (no carrier sense)
 - Wait until line becomes idle
 - Send immediately (1-persistent)
- If collision detected
 - Stop sending and jam signal
 - Try again later

Why have a max size?

Want to prevent one node from taking over completely

Why 9.6 μ s?

Too long: wastes time
Too short: doesn't allow other nodes to transmit (fairness)

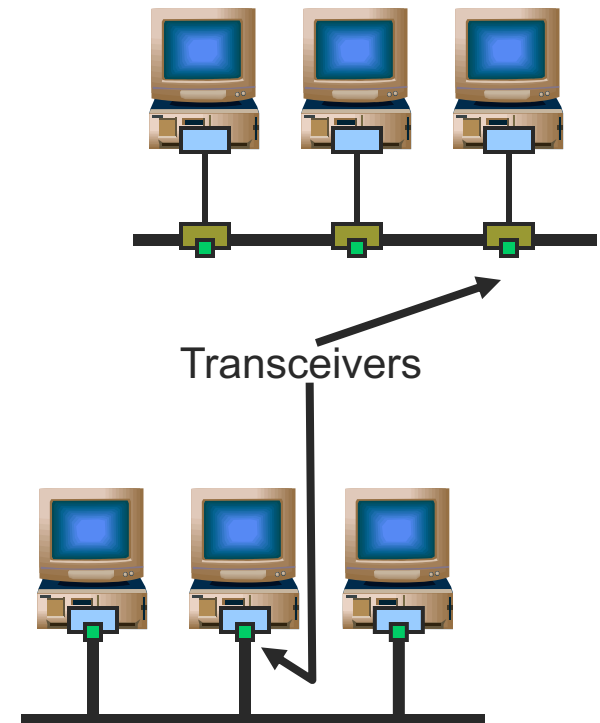
← How do we do this?

← How do we do this?



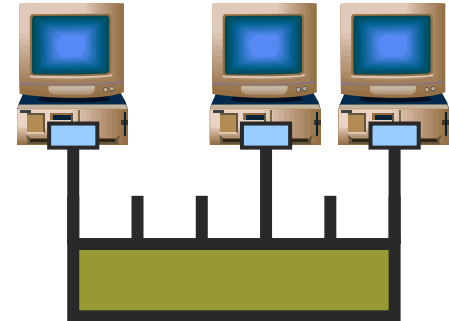
Collision Detection Techniques: Bus Topology

- Transceiver handles
 - Carrier detection
 - Collision detection
 - Jamming after collision
- Transceiver sees sum of voltages
 - Outgoing signal
 - Incoming signal
- Transceiver looks for
 - Voltages impossible for only outgoing



Collision Detection Techniques: Hub Topology

- Controller/Card handles
 - Carrier detection
- Hub handles
 - Collision detection
 - Jamming after collision
- Need to detect activity on all lines
 - If more than one line is active
 - Assert collision to all lines
 - Continue until no lines are active



[Frame Reception]

- Sender handles all access control
- Receiver simply pulls the frame from the network
- Ethernet controller/card
 - Sees all frames
 - Selectively passes frames to host processor
- Acceptable frames
 - Addressed to host
 - Addressed to broadcast
 - Addressed to multicast address to which host belongs
 - Anything (if in promiscuous mode)
 - Need this for packet sniffers/TCPDump

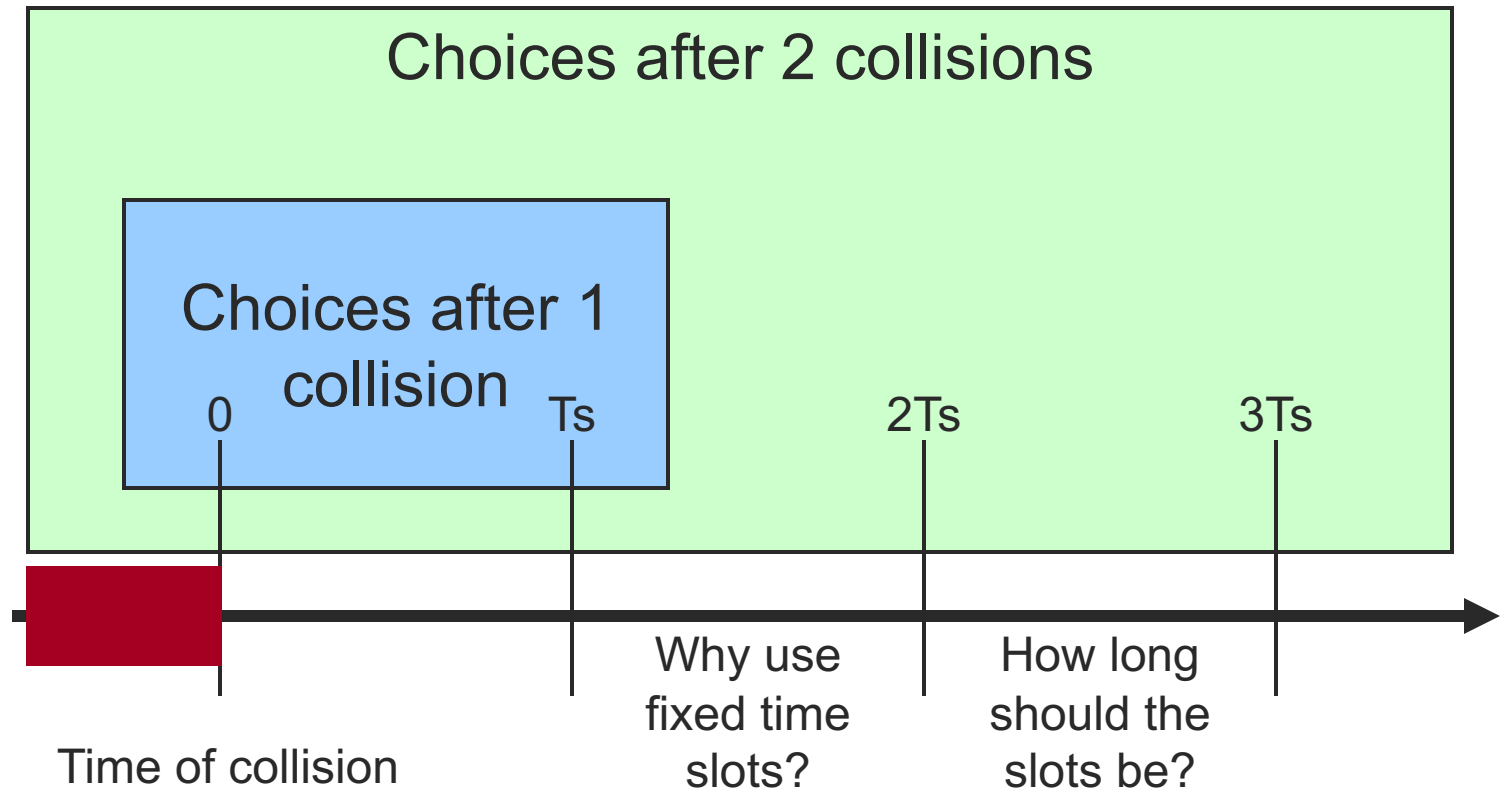


Retransmission

- How long should a host wait to retry after a collision?
- What happens if the host waits too long?
 - Wasted bandwidth
- What happens if the host doesn't wait long enough?
 - More collisions
- Ethernet Solution
 - Binary exponential backoff
 - Maximum backoff doubles with each failure
 - After N failures, pick an N-bit number
 - 2^N discrete possibilities from 0 to maximum



Binary Exponential Backoff



Binary Exponential Backoff

- For IEEE 802.3, $T = 51.2 \mu\text{s}$
- Consider the following
 - k hosts collide
 - Each picks a random number from 0 to $2^{(N-1)}$
 - If the minimum value is unique
 - All other hosts see a busy line
 - Note: Ethernet RTT $< 51.2 \mu\text{s}$
 - If the minimum value is not unique
 - Hosts with minimum value slot collide again!
 - Next slot is idle
 - Consider the next smallest backoff value



Binary Exponential backoff algorithm

- When collision first occurs
 - Send a jamming signal to prevent further data being sent
- Resend a frame
 - After either 0 or T seconds, chosen at random
- If resend fails, resend the frame again
 - After either 0 , T , $2T$, or $3T$ seconds.
 - In other words, send after kT seconds, where k is a random integer with $0 \leq k < 2^2$
- If that still doesn't work, resend the frame again
 - After kT , where k is a random number with $0 \leq k < 2^3$
- In general, after the n^{th} failed attempt, resend the frame after kT , where k is a random number and $0 \leq k < 2^n$



10 Mbps Ethernet Example

- Two nodes are ready to send a packet at the same time a third ends transmission
- i^{th} round
 - Each nodes wait $[0, 1, \dots, 2^{(i-1)} - 1]$ slots until next attempt
 - 1st round choices: 0
 - 2nd round choices: 0, 1
 - 3rd round choices: 0, 1, 2, 3
 - All 2^{i-1} choices have equal probability
- $q_i = P[\text{collision in the } i^{\text{th}} \text{ round}]$
 - Assuming collisions in all the previous $i - 1$ rounds



10 Mbps Ethernet Example

- Find q_i as a function of i for all $i \geq 1$
 - There are $2^{(i-1)}$ slots to choose from
 - Station A selects a slot with probability $1/2^{(i-1)}$
 - Station B selects a slot with probability $1/2^{(i-1)}$
 - And the same slot is chosen with probability $1/2^{(i-1)}$
 - This probability doesn't depend on the slot the first station selected, so the unconditional probability is
$$q_i = 2^{-(i-1)}$$



[10 Mbps Ethernet Example]

- Find the probability p_i that exactly i rounds are needed for the first success
 - $p_i = q_1 q_2 q_3 \dots q_{i-1} (1 - q_i)$
- Compute p_1, p_2, p_3, p_4 and p_5
 - $p_1 = 1 - q_1 = 0$
 - $p_2 = q_1 \times (1 - q_2) = 1 \times (1 - 1/2)$
 - $p_3 = q_1 \times q_2 \times (1 - q_3) = 1 \times 1/2 \times (1 - 1/4)$
 - $p_4 = q_1 \times q_2 \times q_3 \times (1 - q_4) = 1 \times 1/2 \times 1/4 \times (1 - 1/8)$
 - $p_5 = q_1 \times q_2 \times q_3 \times q_4 \times (1 - q_5) = 1 \times 1/2 \times 1/4 \times 1/8 \times (1 - 1/16)$



[10 Mbps Ethernet Example]

- Give an *upper bound* on the probability it takes more than 20 *ms* until the first success
- Slot duration is $51.2\mu\text{s}$
 - 20 ms = 390 slots
- Maximum probability \rightarrow smallest number of collisions
 - Both stations must wait maximum amount of time
 - Delay for eight collisions =
 $1 + 2 + 4 + 8 + 16 + 32 + 64 + 128 = 255$
 - Delay for nine collisions =
 $1 + 2 + 4 + 8 + 16 + 32 + 64 + 128 + 256 = 511$



[10 Mbps Ethernet Example]

- Give an *upper bound* on the probability it takes more than 20 ms until the first success
- At least 8 collisions \rightarrow delay ≥ 20 ms
- $P(\text{delay} \geq 20 \text{ ms}) = q_1 q_2 q_3 q_4 q_5 q_6 q_7 q_8 = 2^{-(0+1+2+3+4+5+6+7)}$



10Mbps Ethernet Media

Name	Cable	Advantages	Max. Segment Length	Max Nodes on Segment
10Base5	Thick Coaxial (10mm)	Good for backbones	500m	100
10Base2	Thin Coaxial (5mm)	Cheapest system	200m	30
10BaseT	Twisted Pair (0.5mm)	Easy Maintenance	100m	1 (to hub)
10BaseFP	Fiber (0.1mm)	Best between buildings	500m	33
Extended segments may have up to 4 repeaters (total of 2.5km)				



10Mbps Ethernet Media

Name	Cable	Advantages	Max. Segment Length	Max Nodes on Segment
10Base5	Thick Coaxial (10mm)	Good for backbones	500m	100
10Base2	The fixed T defines the maximum segment length (0.5mm)		200m	30
10BaseT		Maintenance	100m	1 (to hub)
10BaseFP	Fiber (0.1mm)	Best between buildings	500m	33
Extended segments may have up to 4 repeaters (total of 2.5km)				



100Mbps Ethernet Media

Name	Cable	Max. Segment Length	Advantages
100BaseT4	4 Twisted Pair	100m	Cat 3, 4 or 5 UTP
100BaseTX	Twisted Pair	100m	Full duplex on Cat 5 UTP
100BaseFX	Fiber Pair	100m	Full duplex, long runs
All hub based. Other types not allowed. Hubs can be shared or switched			



100Mbps Ethernet Media

Name	Cable	Max. Segment Length	Advantages
100BaseT4	4 Twisted Pair	100m	Cat 3, 4 or 5 UTP
100BaseT	Shorter distances, same protocol!	100m	Full duplex on Cat 5 UTP
100BaseFX		100m	Full duplex, long runs
All hub based. Other types not allowed. Hubs can be shared or switched			



[..and beyond

- Gigabit ethernet common in PCs
- 100 GB ethernet standard ratified in June 2010



Ethernet in Practice

- Number of hosts
 - Limited to 200 in practice, standard allows 1024
- Range
 - Typically much shorter than 2.5km limit in standard
- Round Trip Time
 - Typically 5 or 10 μ s, not 50
- Flow Control
 - Higher level flow control limits load (e.g. TCP)
- Topology
 - Star easier to administer than bus
 - Even better: exclusive access rather than shared!

