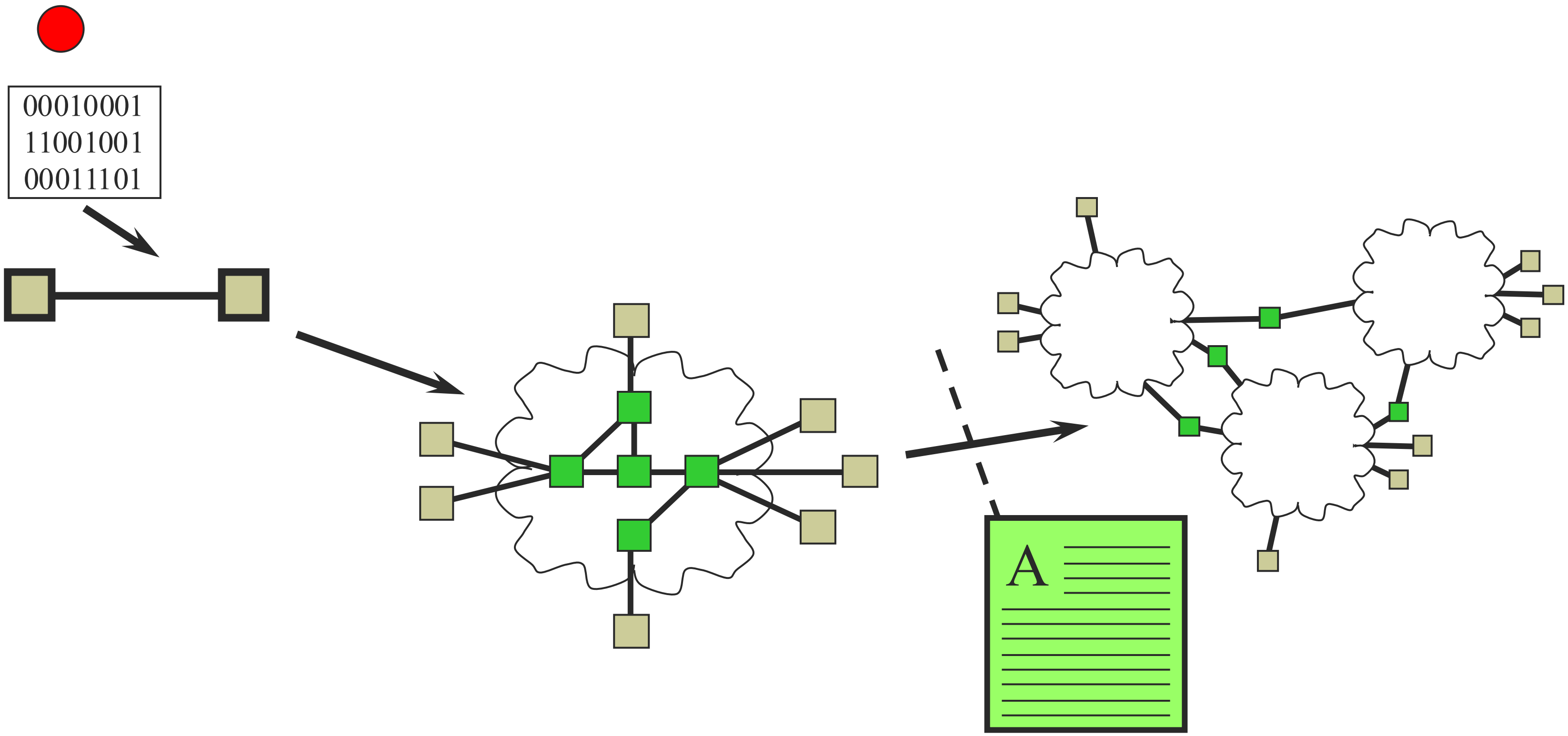
Media Access Protocols

Where are We?

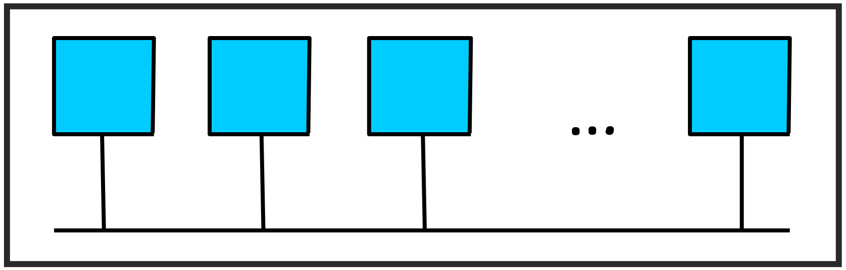
you are here



midterm is here

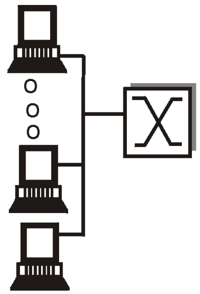
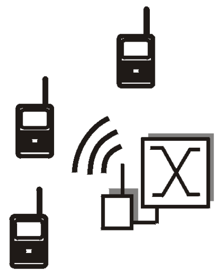
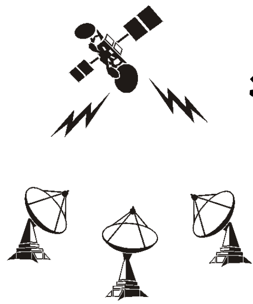
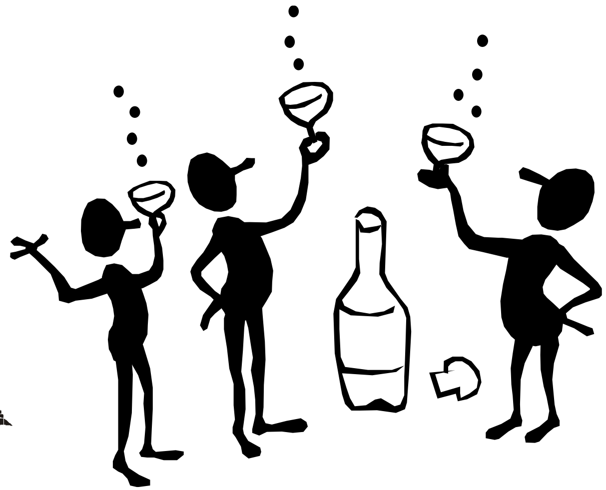
Multiple Access Media

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

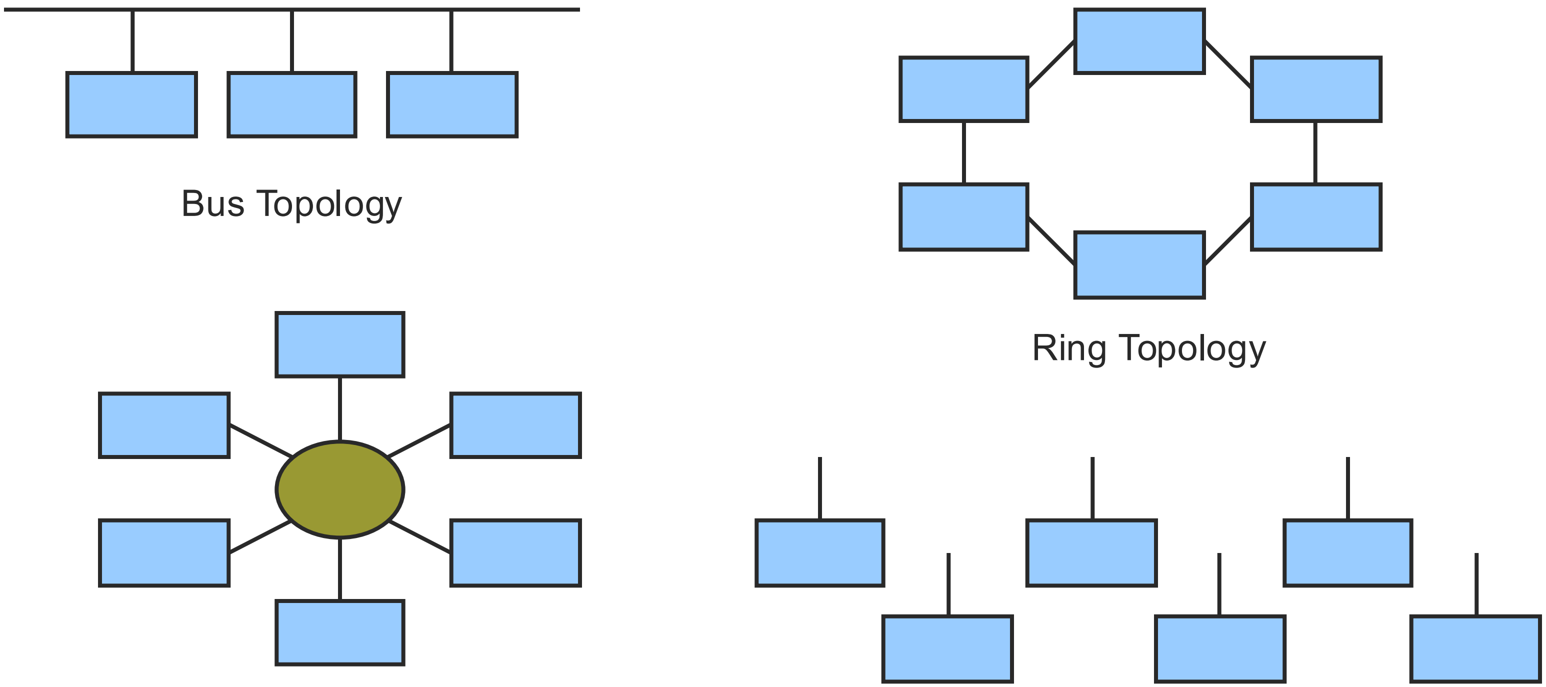


Point-to-Point vs. Broadcast Media

- 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

Types of Shared Link Networks



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

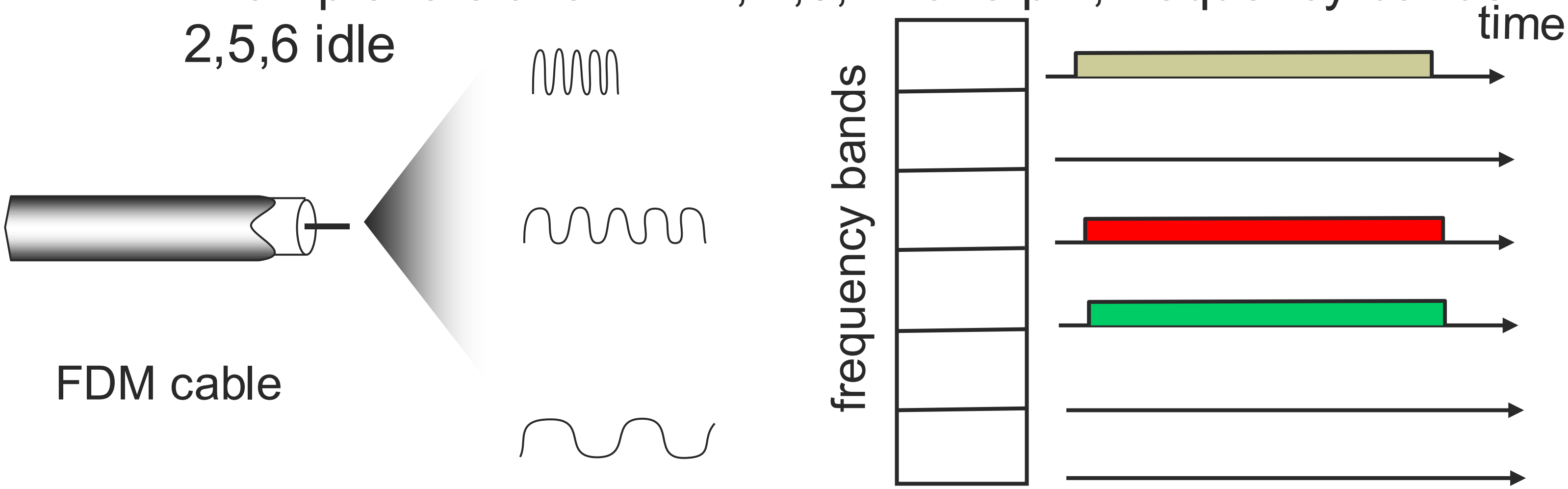
- Typical assumptions
  - Communication needs vary
    - Over time
    - Between hosts
  - Network is not fully utilized

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

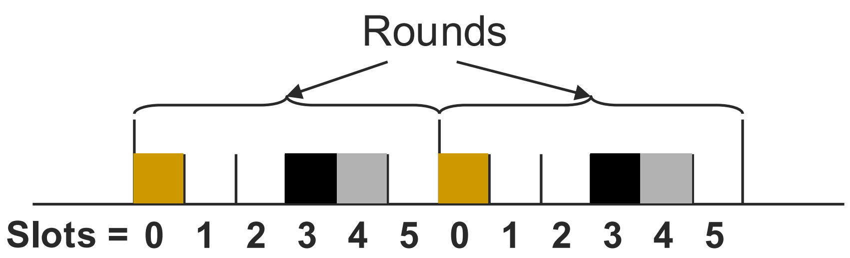
Channel Partitioning: FDMA

- 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



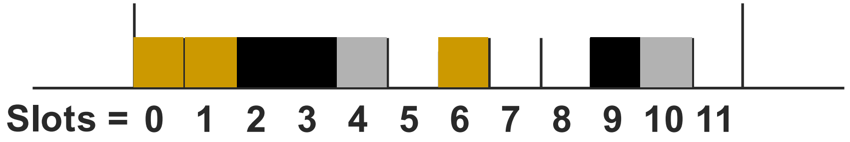
Channel Partitioning: TDMA

- 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



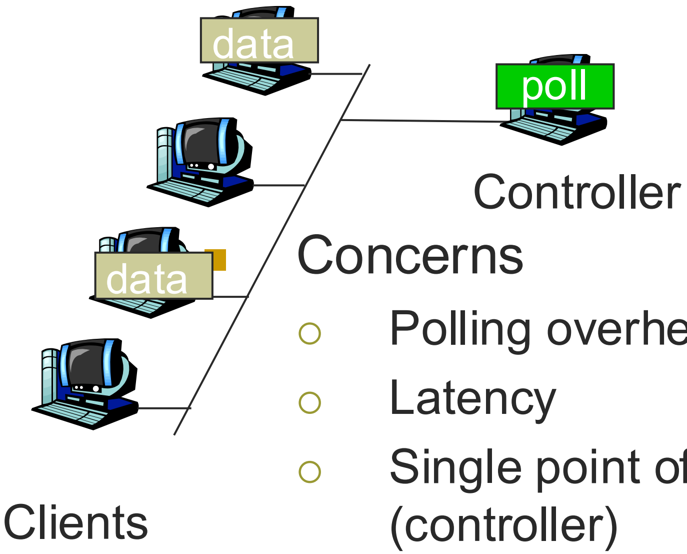
Channel Partitioning: STDMA

- 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



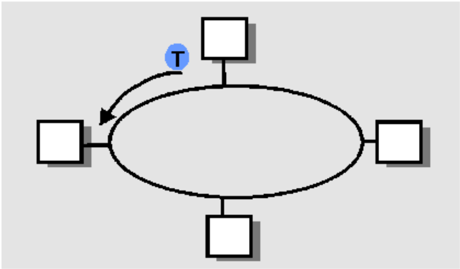
Channel Partitioning: Taking Turns

- Polling
  - Controller node “invites” client nodes to transmit in turn



- Concerns
  - Polling overhead
  - Latency
  - Single point of failure (controller)

- 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

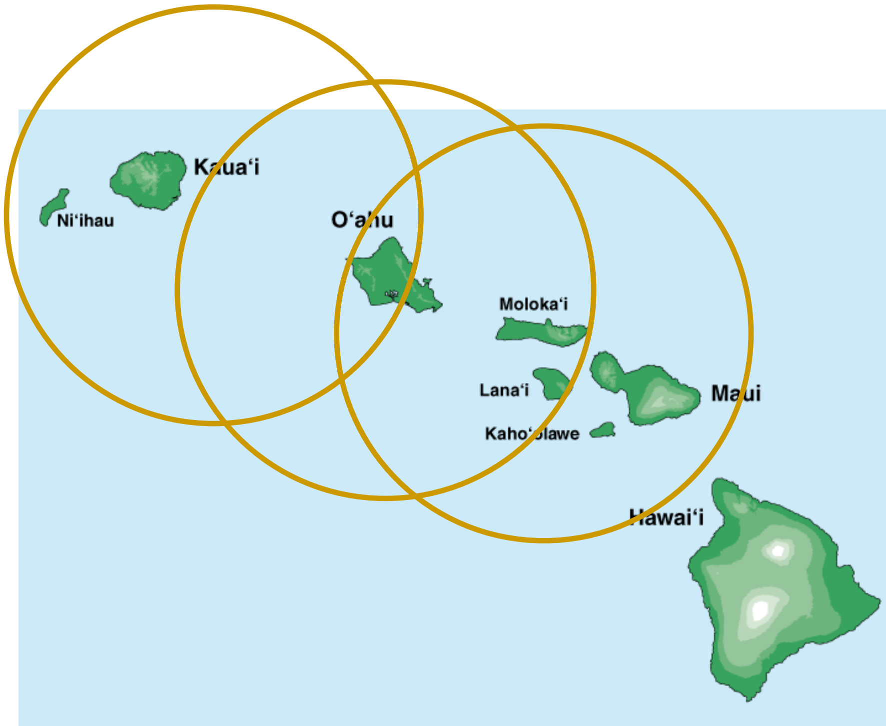


Multiple Access Media: Random Access

- 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 ⇒ collision
  - Data lost
- Random access MAC protocol specifies
  - How to detect collisions
  - How to recover from collisions

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

- 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



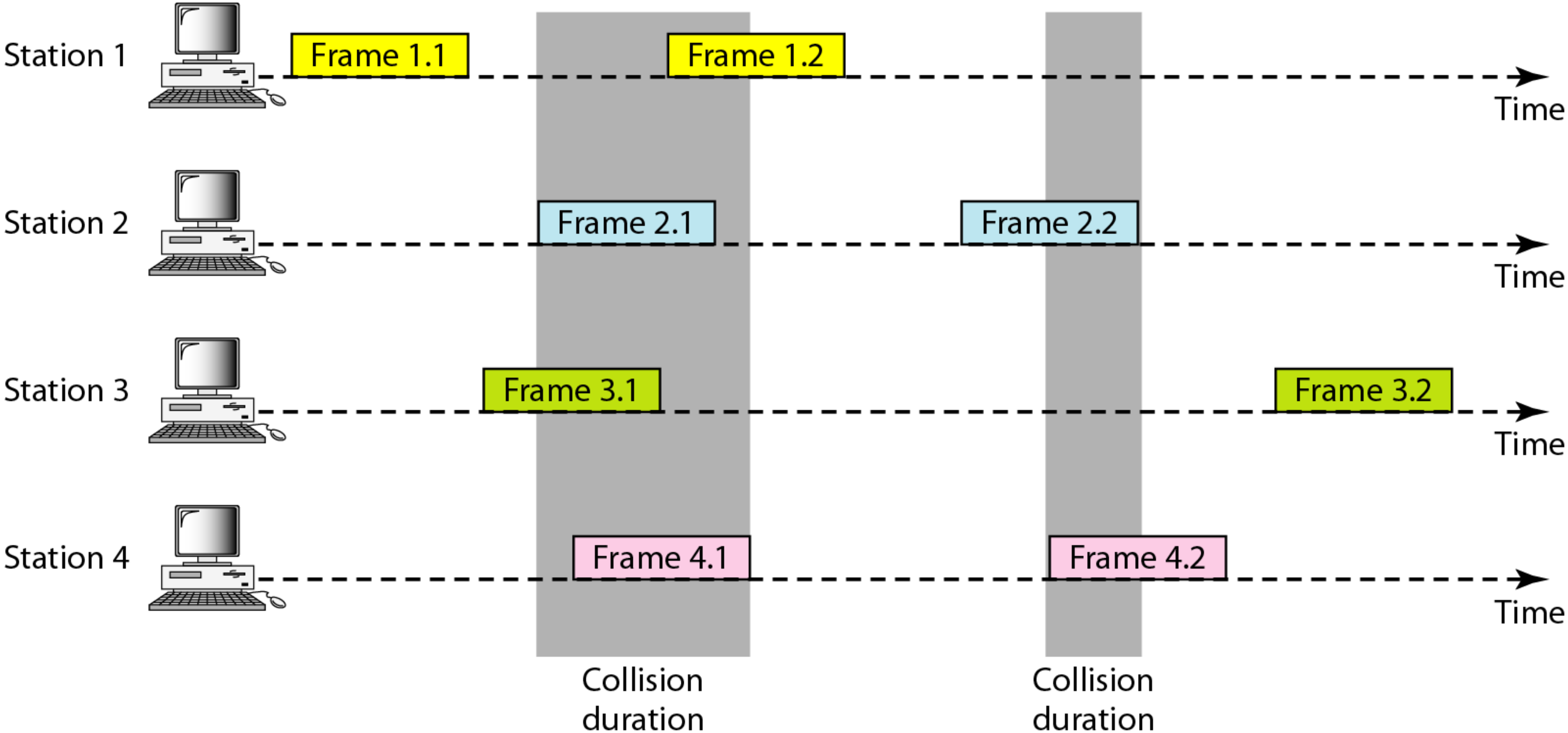
Pure ALOHA

- 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%!

Pure ALOHA

- User model
  - N transmitters
    - Each transmitter hooked to one terminal
    - One person at each terminal
  - Person types a line, presses return
    - Transmitter sends line
    - Each station transmits λ packets/sec on average based on a Poisson arrival process
  - Checks for success (no interference)
  - If collision occurred, wait random time and resend

Pure ALOHA

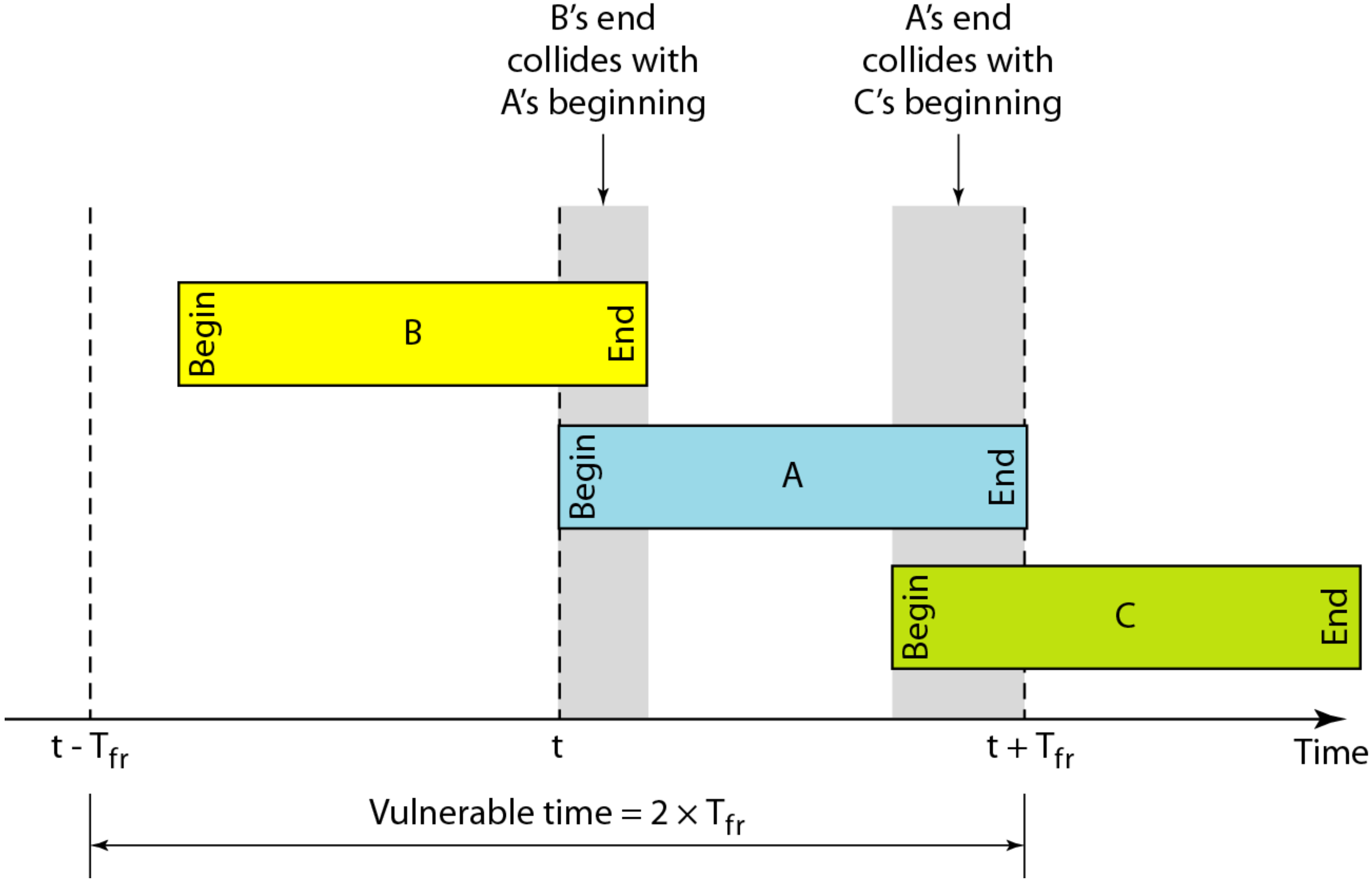


Station 1
Frame 1.1
Frame 1.2
Time
Station 2
Frame 2.1
Frame 2.2
Time
Station 3
Frame 3.1
Frame 3.2
Time
Station 4
Frame 4.1
Frame 4.2
Time
Collision duration
Collision duration

Pure ALOHA

- Collisions
  - A frame will not suffer a collision if no other frames are sent within one frame time of its start
  - Let t = time to send a frame
  - If any other user has generated a frame between time t_0 and time $t_0 + t$, the end of that frame will collide with the beginning of our frame
  - Similarly, any other frame started between time $t_0 + t$ and time $t_0 + 2t$ will collide with the end of our frame

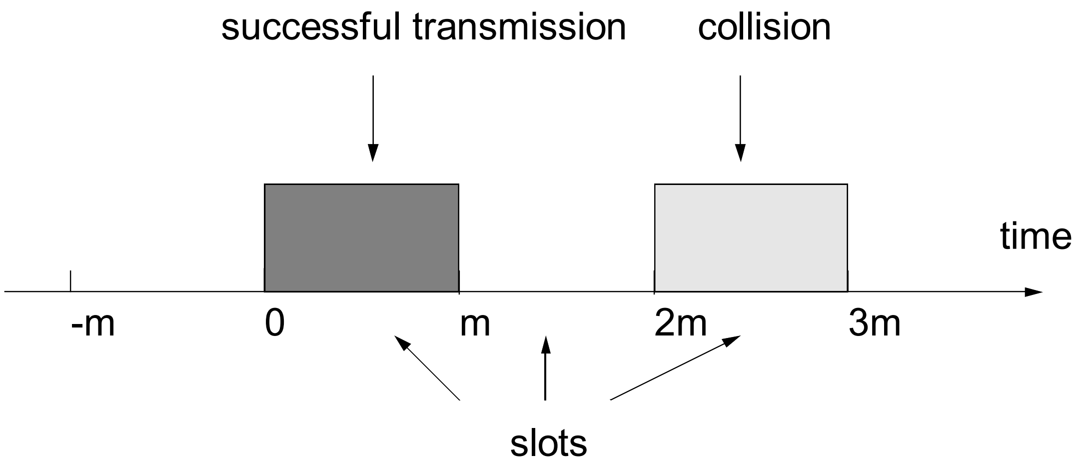
Pure ALOHA



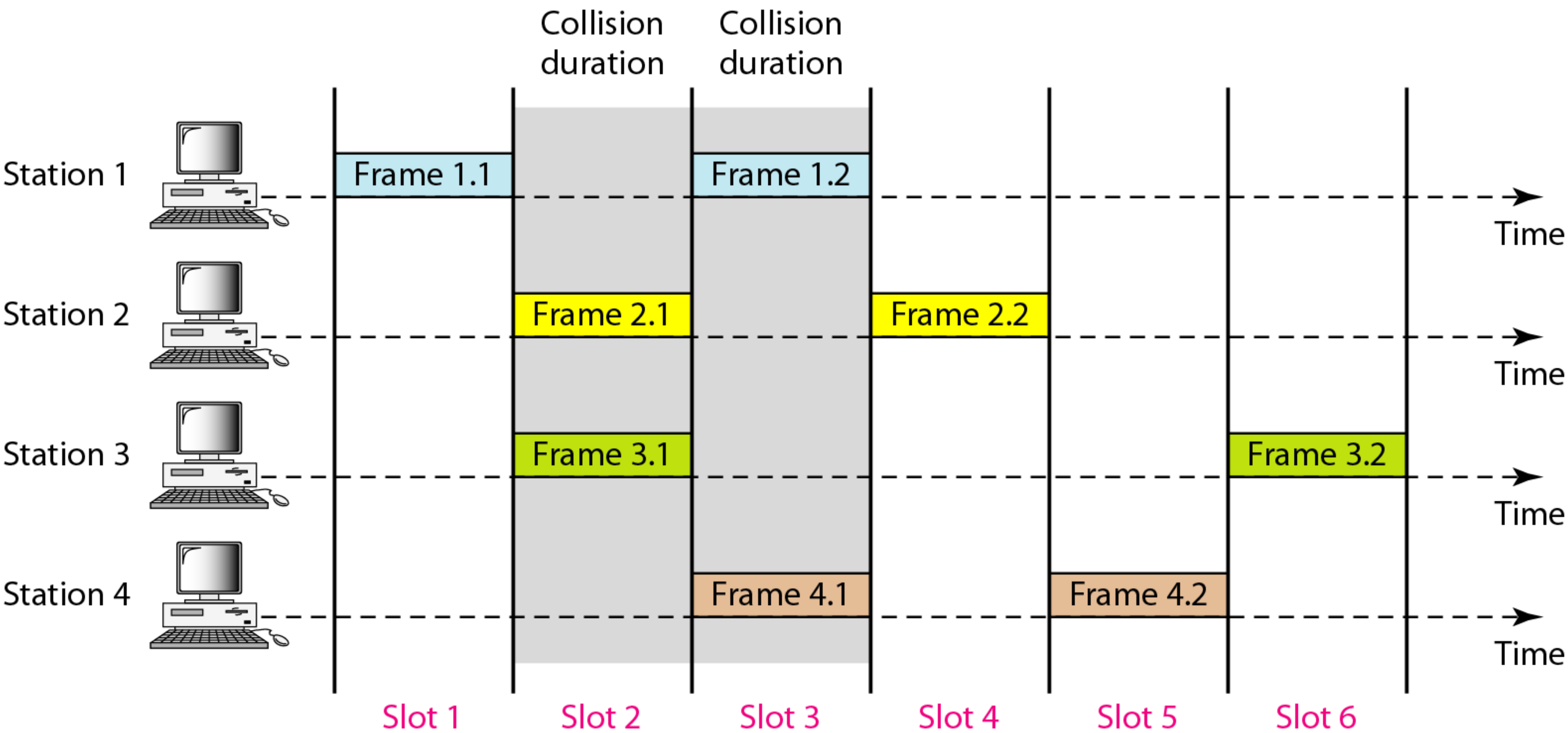
B's end collides with A's beginning
A's end collides with C's beginning
Begin
B
End
Begin
A
End
Begin
C
End
t - T_{fr}
t
t + T_{fr}
Time
Vulnerable time = $2 \times T_{fr}$

Slotted ALOHA

- Hosts wait for next slot to transmit
  - Slot time units = m (message length)
  - Modify Aloha by allowing users to attempt transmission at the beginning of a time slot only
  - All users need to be synchronized in time.
- Vulnerable period is now cut in half (T)
  - Doubles max throughput



Slotted Aloha



Slotted ALOHA

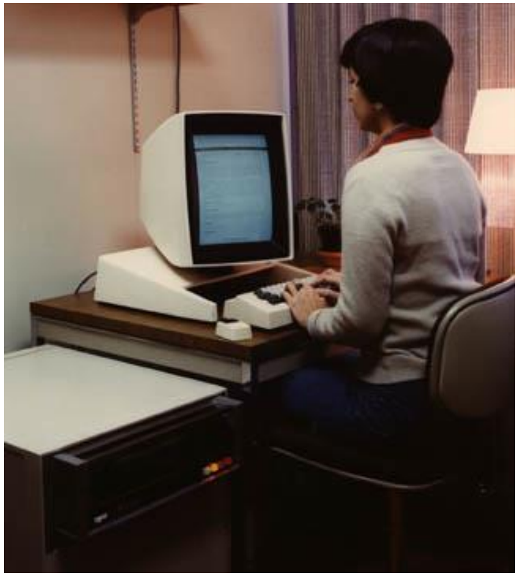
- Pros
  - Single active node can continuously transmit at full rate of channel
  - Highly decentralized: only need slot synchronization
  - Simple
- Cons
  - Wasted slots:
    - Idle
    - Collisions
  - Nodes should detect collision in less than time to transmit packet
  - Clock synchronization

Slotted ALOHA

- Limitations
  - Slotted Alohas has twice the performance of basic Aloha, but performance is still poor
    - Slotted design is also not very efficient when carrying variable sized packets!
    - Also (slightly) longer delay than pure Aloha
  - Still, not bad for an absolutely minimal protocol!
  - How do we go faster?

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

From Aloha comes Ethernet

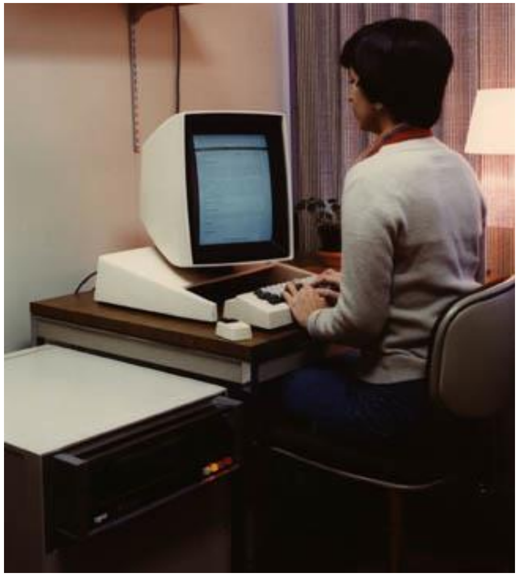
- Et
  - 1974
  - and Intel
  -
  - IEEE
  - lar
- N reasing ba
  - ps – 10


The New York Times

Turing Award Won by Co-Inventor of Ethernet Technology

In the 1970s, Bob Metcalfe helped develop the primary technology that lets you send email or connect with a printer over an office network.

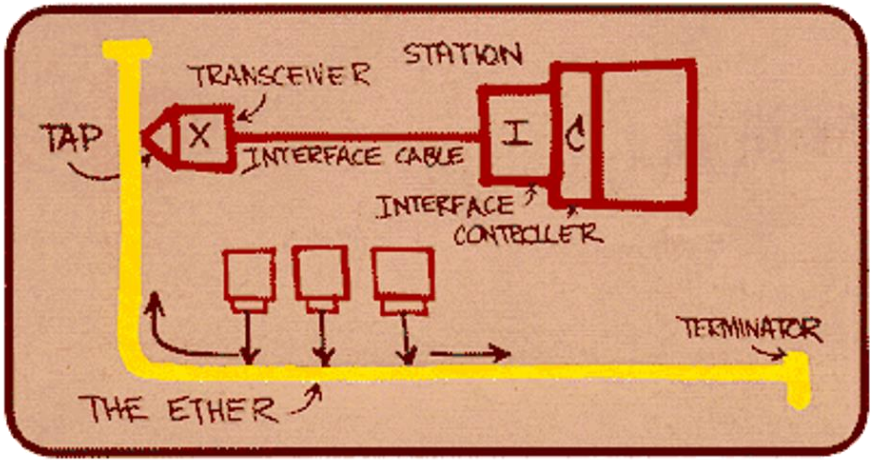
Give this article



Xerox Alto, first machine networked with ethernet

Ethernet

- "dominant" wired LAN technology:
  - Single chip, multiple speeds(e.g., Broadcom BCM5761)
  - First widely used LAN technology
  - Simple, cheap
  - Kept up with speed race: 10 Mbps – 10 Gbps

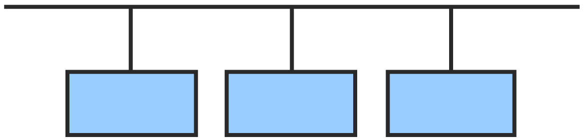


Metcalfe's Ethernet sketch

Ethernet - CSMA/CD

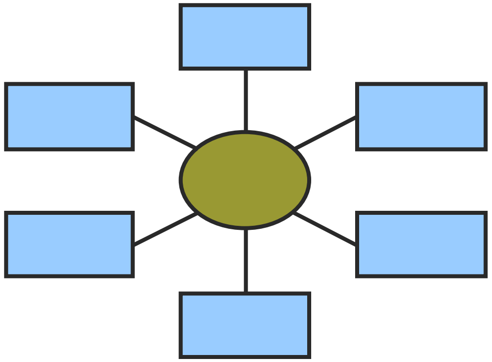
- CS – Carrier Sense
  - Nodes can distinguish between an idle and a busy link
- MA - Multiple Access
  - A set of nodes send and receive frames over a shared link
- CD – Collision Detection
  - Nodes listen during transmission to determine if there has been interference

Ethernet Topologies



Bus Topology: Shared

All nodes connected to a wire



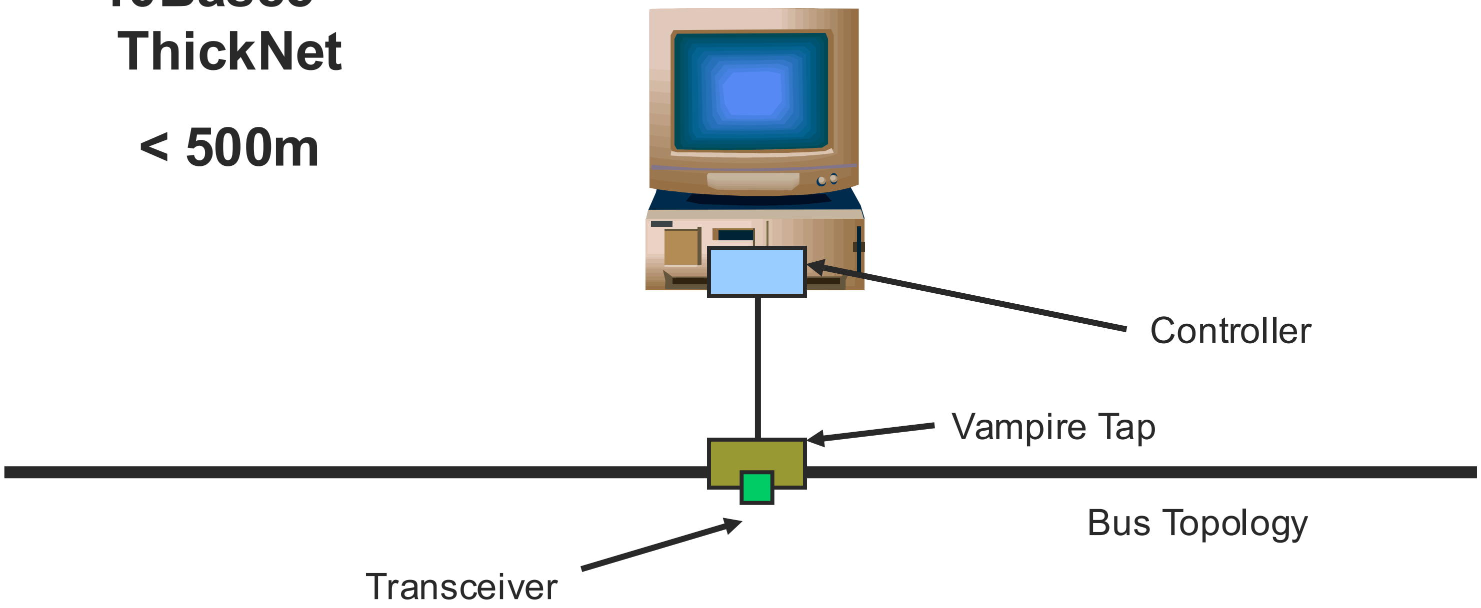
Star Topology:

All nodes connected to a central repeater

Ethernet Connectivity

10Base5 – ThickNet

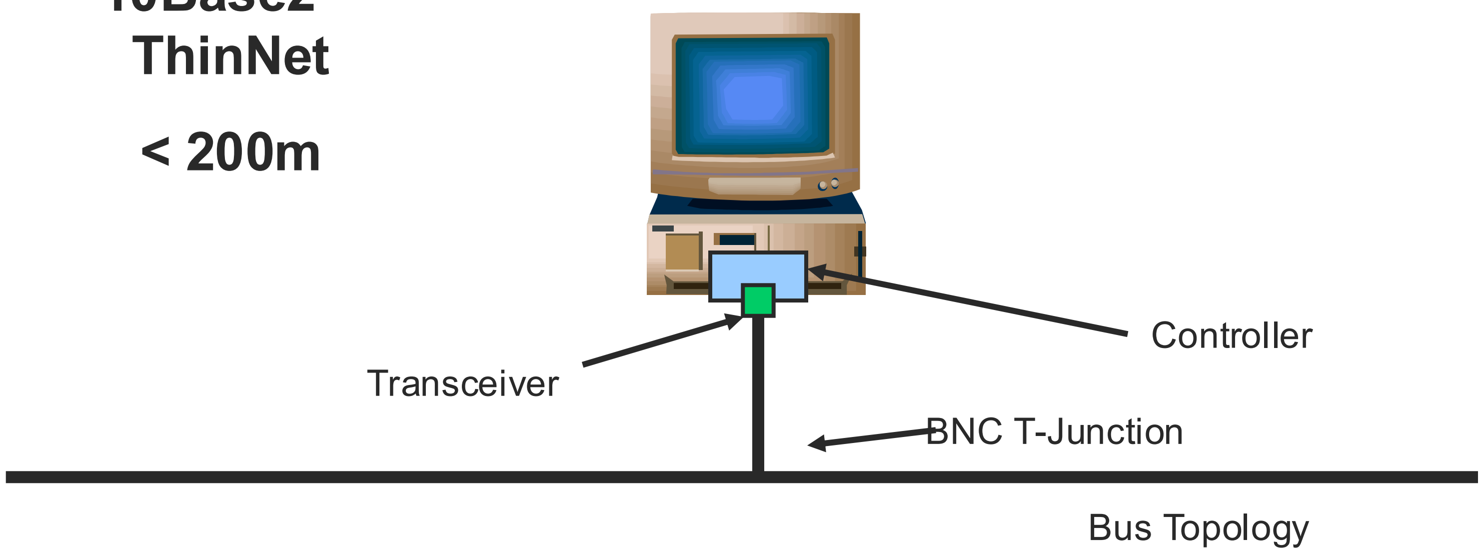
< 500m



Ethernet Connectivity

10Base2 – ThinNet

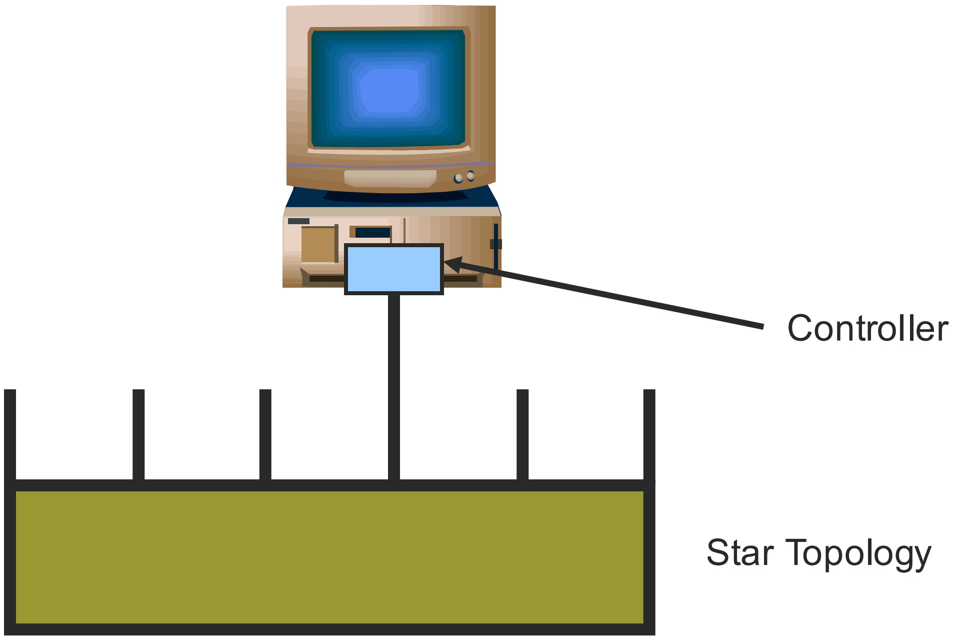
< 200m



Ethernet Connectivity

10BaseT

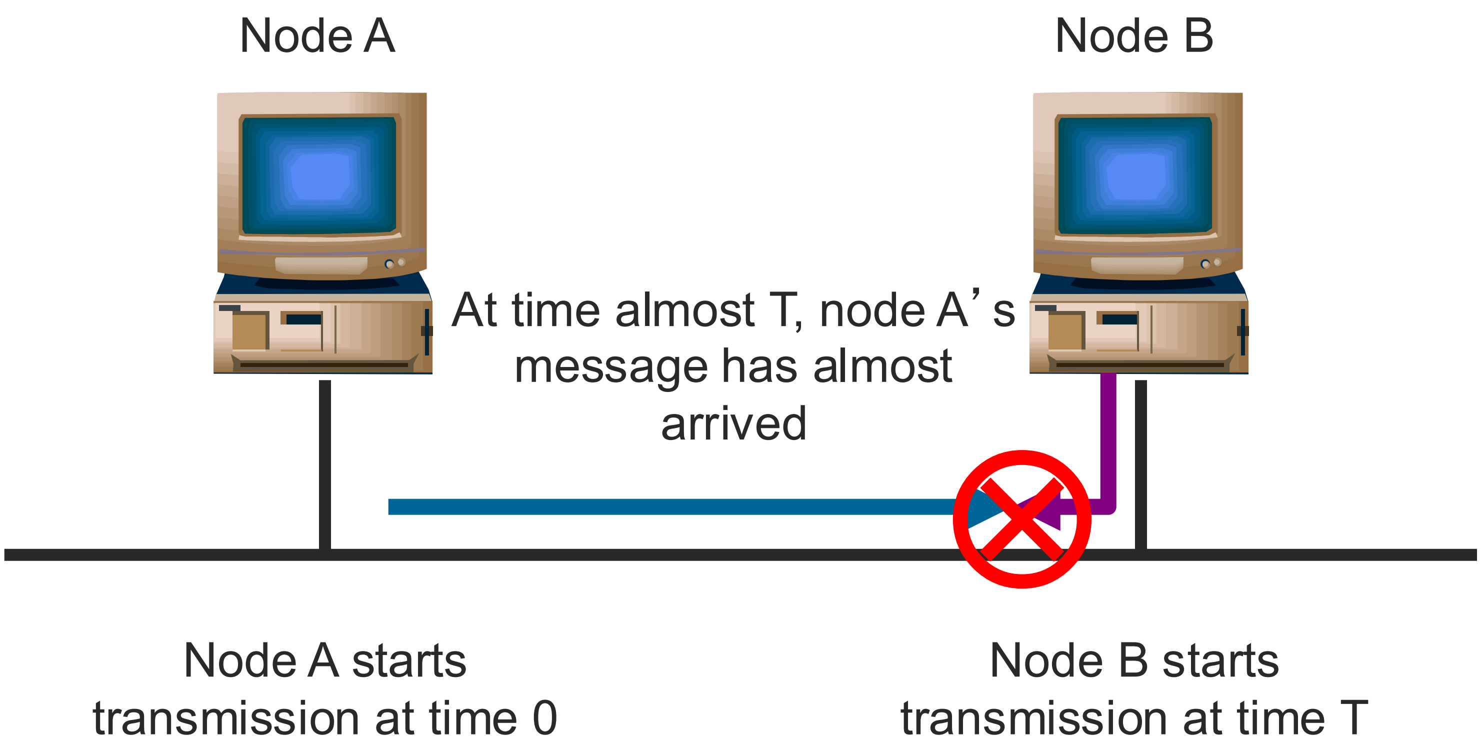
< 100m



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

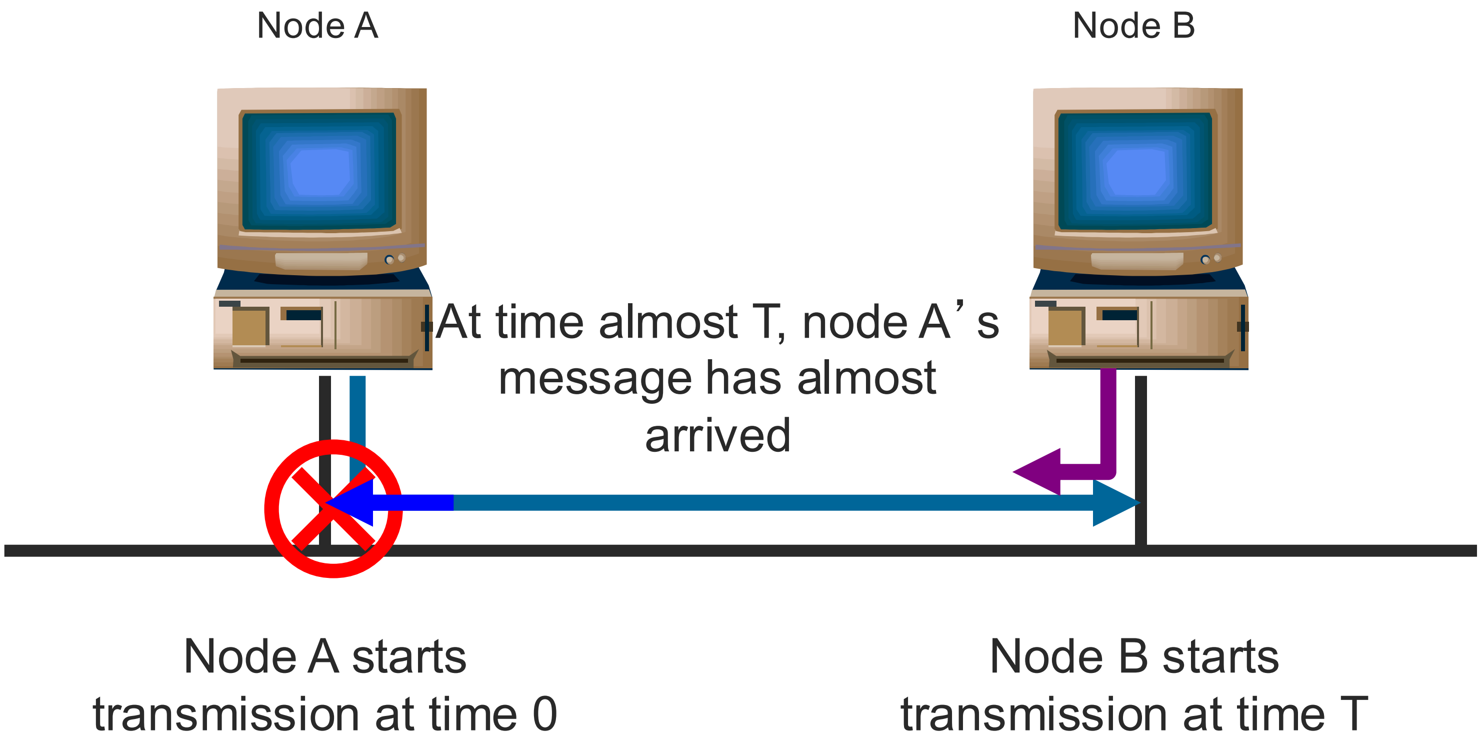


How can we ensure that A knows about the collision?

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



At time 2T, A is still transmitting and notices a collision

Collision Detection

- IEEE 802.3
  - 2T is bounded to 51.2μs
  - At 10Mbps 51.2μs = 512b or 64 = 512b or 64B
  - Packet length ≥ 64B
- 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 μs 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 μs?

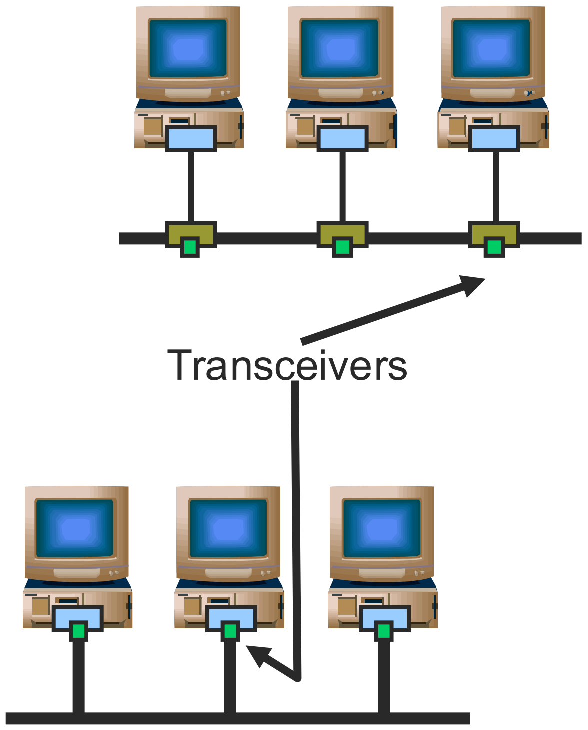
Too long: wastes time
Too short: doesn't allow other nodes to transmit (fairness)

How do we do this? (← If collision detected)

How do we do this? (← Try again later)

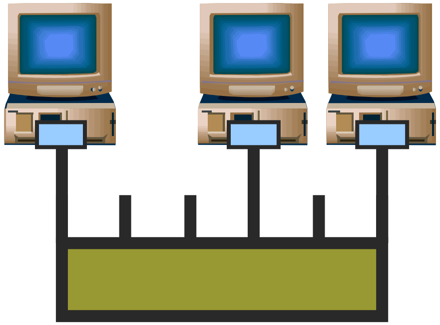
Collision Detection Techniques: Bus Topology

- 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



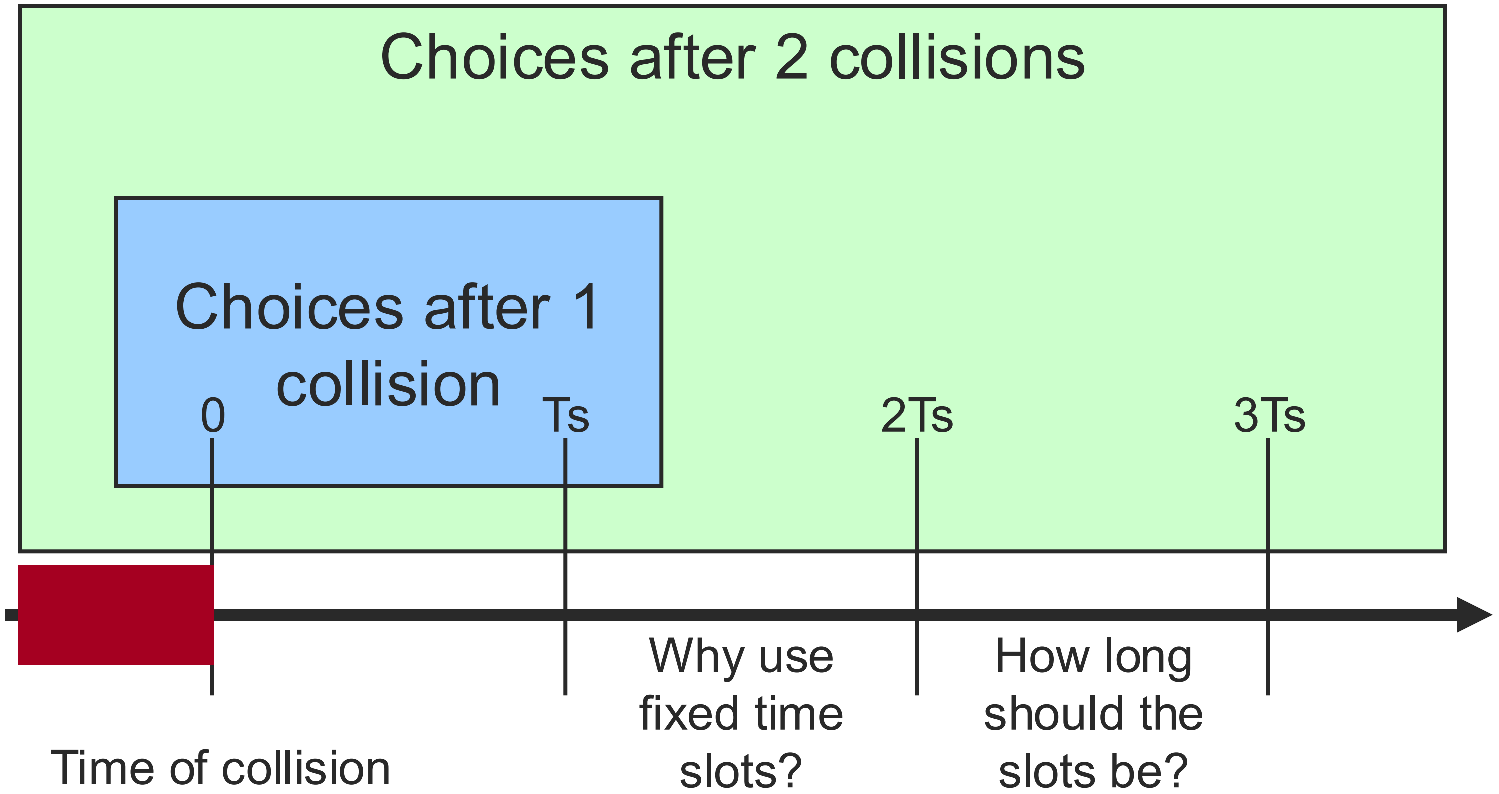
Frame Reception

- 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
    - 2N discrete possibilities from 0 to maximum

Binary Exponential Backoff



Binary Exponential Backoff

- For IEEE 802.3, T = 51.2 μs
- 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 μs
  - 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 $0 \leq k < 2^n$

Ethernet Example

- Two nodes are ready to send a packet at the same time a third ends transmission
- i^{th} round
  - Each nodes wait $[0, 1, \ldots, 2^{(i-1)} - 1]$ 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[collision in the i^{th} round]
  - Assuming collisions in all the previous $i - 1$ rounds

Ethernet Example

- Find q_i as a function of i for all $i \geq 1$
  - There are $2^{(i-1)}$ slots to chose 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

    $q_i = 2^{-(i-1)}$

Ethernet Example

- Find the probability p_i that exactly i rounds are needed for the first success
  - $p_i = q_1 q_2 q_3 \ldots q_{i-1} (1 - q_i)$
- Compute p_1, p_2, p_3, p_4 and p_5
  - $p_1 = 1 - q_1 = 0$
  - $p_2 = q_1 \times (1 - q_2) = 1 \times (1 - ½)$
  - $p_3 = q_1 \times q_2 \times (1 - q_3) = 1 \times ½ \times (1 - ¼)$
  - $p_4 = q_1 \times q_2 \times q_3 \times (1 - q_4) = 1 \times ½ \times ¼ \times (1 - 1/8)$
  - $p_5 = q_1 \times q_2 \times q_3 \times q_4 \times (1 - q_5) = 1 \times ½ \times ¼ \times 1/8 \times (1 - 1/16)$

Ethernet Example

- Give an *upper bound* on the probability it takes more that 20 *ms* until the first success

- Slot duration is 51.2μs
  - 20 ms = 390 slots
- Maximum probability → 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

Ethernet Example

- Give an *upper bound* on the probability it takes more that 20 *ms* until the first success

- At least 8 collisions → delay >= 20 ms
- P(delay >= 20 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			200m	30
10BaseT	(0.5mm)	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)				

The fixed T defines the maximum segment length

100Mbps Ethernet

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
100Bas		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			

Shorter distances, same protocol!

Gbps Ethernet

Name	Cable	Max. Segment Length
1000BASE-T	Cat 5	100m
2.5GBASE-T	Cat 5e	100m
5GBASE-T	Cat 6	100m
10GBASE-T	Cat 6a	100m
All hub based. Other types not allowed. Hubs can be shared or switched		

Gbps Ethernet

Name	Cable	Max. Segment Length
1000BASE-T	Cat 5	100m
2.5GBAS		100m
5GBASE		100m
10GBASE-T	Cat 6a	100m
All hub based. Other types not allowed. Hubs can be shared or switched		

More efficient encoding schemes

Pulse Amplitude Modulation
64B/65B encoding
Forward error correction

..and beyond

- Gigabit ethernet is common
- 25 - 100 GB ethernet
  - Shorter distances ~30m
  - Cat 8 cables
  - standardized, but not yet marketed

Ethernet in Practice

- Number of hosts
  - Limited to 200 in practice, standard allows 1024
- Range
  - Typically much shorter than limit in standard
- Round Trip Time
  - Typically 5 or 10 μs, 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!