

Link Layer Multiple Access Protocols



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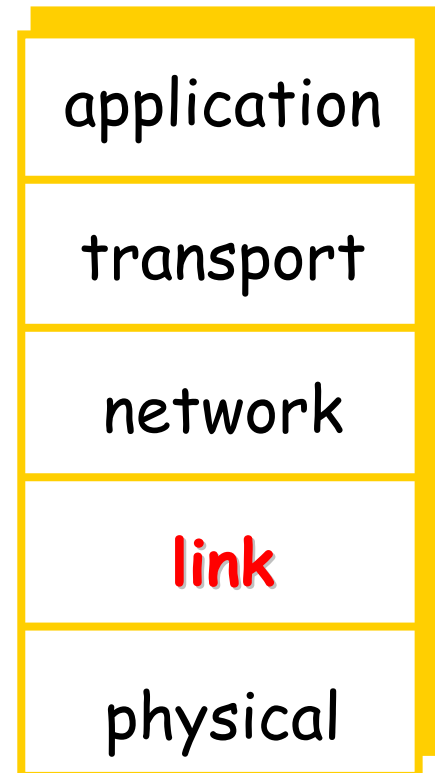
Recap of Last Class

Link layer

- handle data transfer between neighboring network elements

Link layer services:

- **Encoding**
 - encode binary data into electromagnetic signals
- **Framing**
 - encapsulate data into frame, adding header, trailer
- **Error detection and correction**
 - receiver identifies and corrects bit error(s)



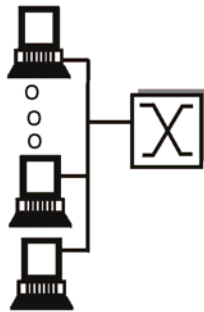
Multiple Access Links

Two types of "links":

- point-to-point and shared wire or medium

Multiple access link:

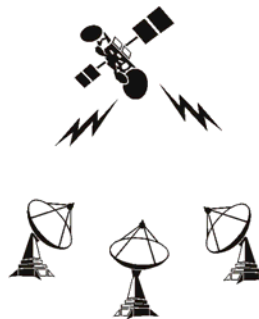
- single shared broadcast channel
- two or more simultaneous transmissions by nodes \Rightarrow interference
 - only one node can send successfully at a time



shared wire
(e.g. Ethernet)



shared wireless
(e.g. Wavelan)



satellite



cocktail party



Multiple Access Protocol

Multiple access protocol:

- distributed algorithm that determines how nodes share channel, i.e., determine when node can transmit
- communication about channel sharing must use channel itself!

Ideal multiple access protocol:

For a multiple access channel of rate R bps

1. When one node wants to transmit, it can send at rate R .
2. When M nodes want to transmit, each can send at average rate R/M .
3. Fully decentralized:
 - no special node to coordinate transmissions
 - no synchronized clocks

⇒ fault-tolerant/robust



Types of Multiple Access Protocols

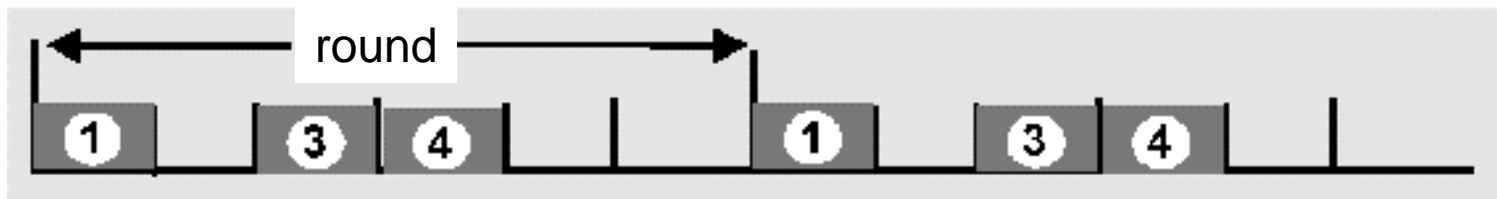
Three broad classes:

- **Channel partitioning**
 - divide channel into smaller "pieces" (time slots, frequency, code)
 - allocate piece to node for exclusive use
- **Random access**
 - channel not divided, allow collisions
 - "recover" from collisions
- **Centrally controlled/coordinated**
 - tightly coordinate shared access to avoid collisions

Channel Partitioning MAC protocols: TDMA

TDMA: time division multiple access

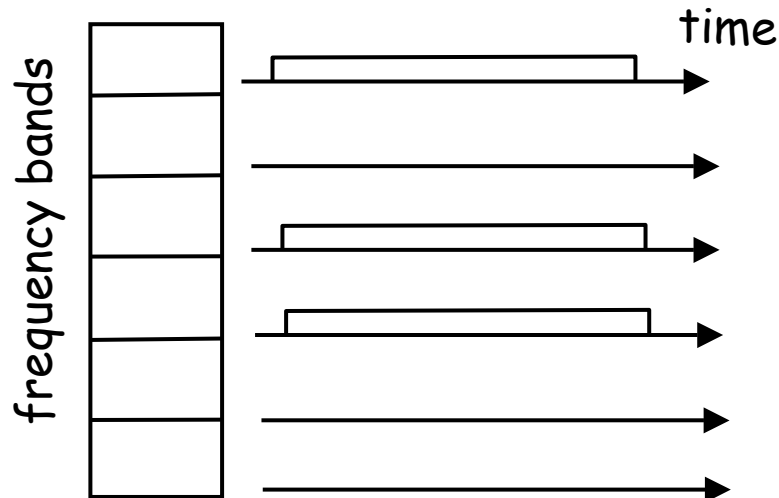
- access to channel in "rounds"
- each station gets fixed length slot (length = pkt trans time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have pkt, slots 2,5,6 idle



Channel Partitioning MAC protocols: FDMA

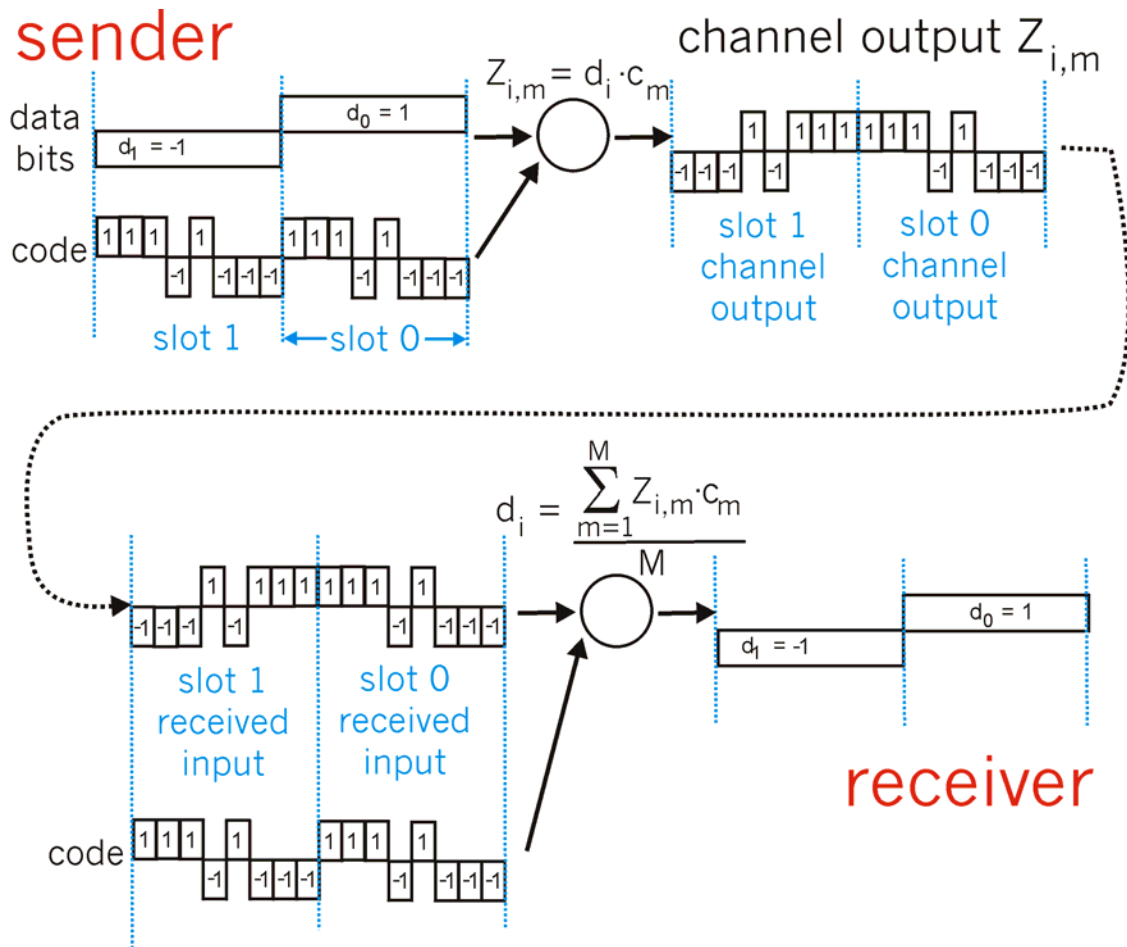
FDMA: frequency division multiple access

- 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 MAC protocols: C (code) DMA

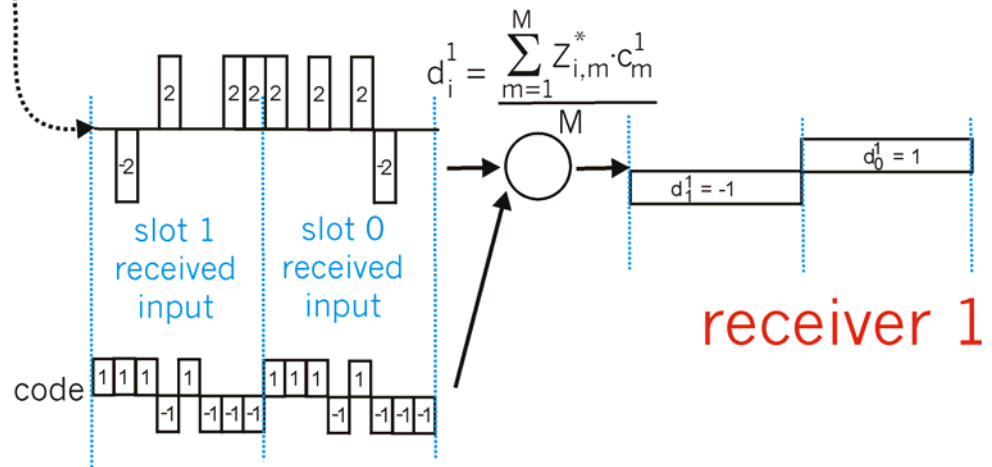
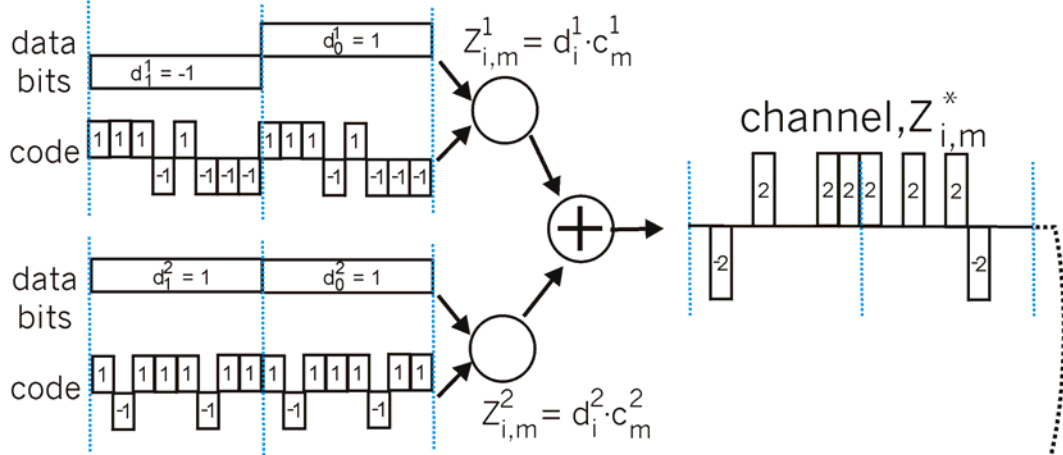
- use coding to allow multiple simultaneous transmission without interference
- each user has its unique code
 - **encoded signal:** (original data) \times (code)
 - **decoding:** (encoded signal) \times (code)
- inner product
 - all codes consist of 1, -1 bits
 - any bit sequence multiplying itself becomes 1



CDMA: Two-sender Interference

- allows multiple users to transmit simultaneously (if $\text{codex} \times \text{code}_y = 0$).
- combined signal is "data_x X code_x + data_y X code_y"

senders



What is really good about it compared to TDMA?



How Good are Channel Partitioning Protocols

Broadcast channel of rate R bps

1. When all M nodes want to transmit
 - each can send at average rate R/M
2. When one node wants to transmit
 - it can send at rate R/M . **Inefficient!**
3. Decentralization/fault tolerance:
 - no special node to coordinate transmissions
 - synchronized clocks for all but FDMA



Random Access Protocols

- When node has data to send
 - transmit at full channel data rate R .
 - no *a priori* coordination among nodes
- Two or more transmitting nodes -> "collision",
- **Random access protocol** specifies:
 - how to detect collisions
 - how to recover from collisions (e.g., via delayed retransmissions)
- Examples of random access protocols:
 - slotted ALOHA
 - ALOHA
 - CSMA, CSMA/CD



Slotted ALOHA

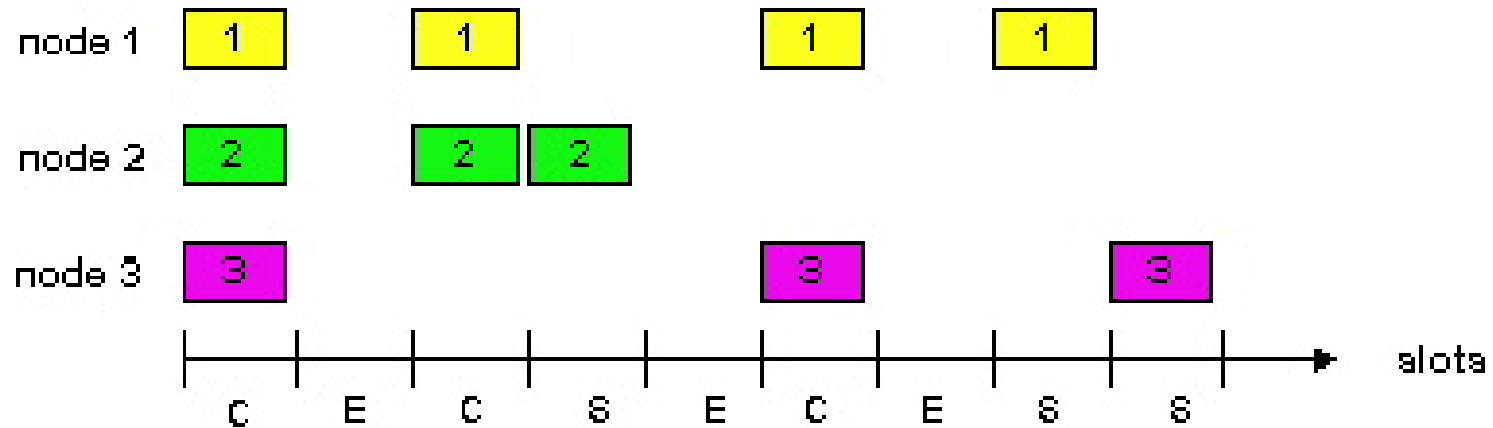
Assumptions

- all frames same size
- time is divided into equal size slots, time to transmit 1 frame
- nodes start to transmit frames only at beginning of slots (nodes are synchronized!)
- if 2 or more nodes transmit in slot, all nodes detect collision

Operation

- when node obtains fresh frame, it transmits in next slot
- no collision, node can send new frame in next slot
- if collision, node retransmits frame in each subsequent slot with probability p until success
- why not retransmit right away?

Slotted ALOHA



Pros

- single active node can continuously transmit at full rate of channel

Cons

- wasting slots (collisions, idle slots)
- require nodes to be synchronized

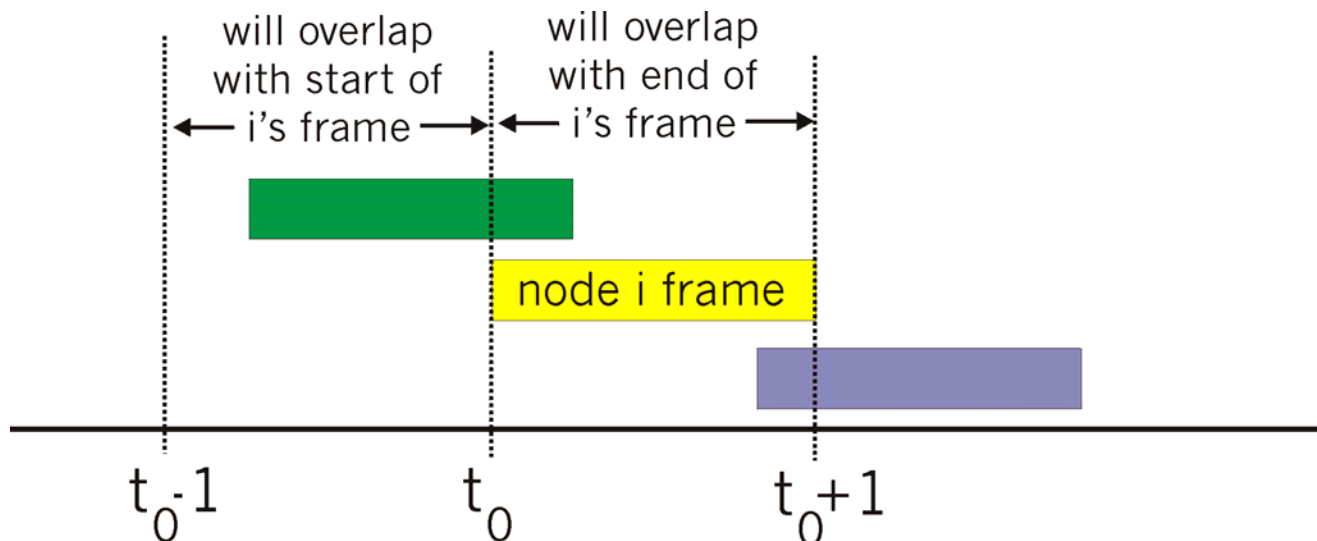
Slotted Aloha Efficiency

Efficiency is the long-run fraction of successful slots when there are many nodes, each with many frames to send

- Suppose N nodes with many frames to send, each transmits in slot with probability p
- prob that one particular node has success in a slot
 - $p(1-p)^{N-1}$
- prob that some node has a success
 - $Np(1-p)^{N-1}$
- For max efficiency with N nodes, find p^* that maximizes $Np(1-p)^{N-1}$
 - find p^* for $N=1$ and $N=2$?
 - find p^* for any N ?
- For many nodes, take limit of $Np^*(1-p^*)^{N-1}$ as N goes to infinity, gives $1/e = .37$
 - **At best:** channel used for useful transmissions 37% of time!

Pure (unslotted) ALOHA

- Unslotted Aloha: no synchronization
- When frame first arrives, transmit immediately
- Collision probability increases:
 - frame sent at t_0 collides with other frames sent in $[t_0-1, t_0+1]$





Pure Aloha Efficiency

$$\begin{aligned} P(\text{success by given node}) &= P(\text{node transmits}) \times \\ &\quad P(\text{no other node transmits in } [p_0-1, p_0]) \times \\ &\quad P(\text{no other node transmits in } [p_0, p_0+1]) \\ &= p \cdot (1-p)^{N-1} \cdot (1-p)^{N-1} \\ &= p \cdot (1-p)^{2(N-1)} \end{aligned}$$

choosing optimum p and then letting $n \rightarrow \infty \dots$
 $= 1/(2e) = .18$

Half as efficient as slotted Aloha!



CSMA (Carrier Sense Multiple Access)

CSMA: listen before transmit:

- If channel sensed idle: transmit entire frame
 - If channel sensed busy: defer transmission
-
- Human analogy: listen before speaking!

CSMA Collisions

collisions can still occur:

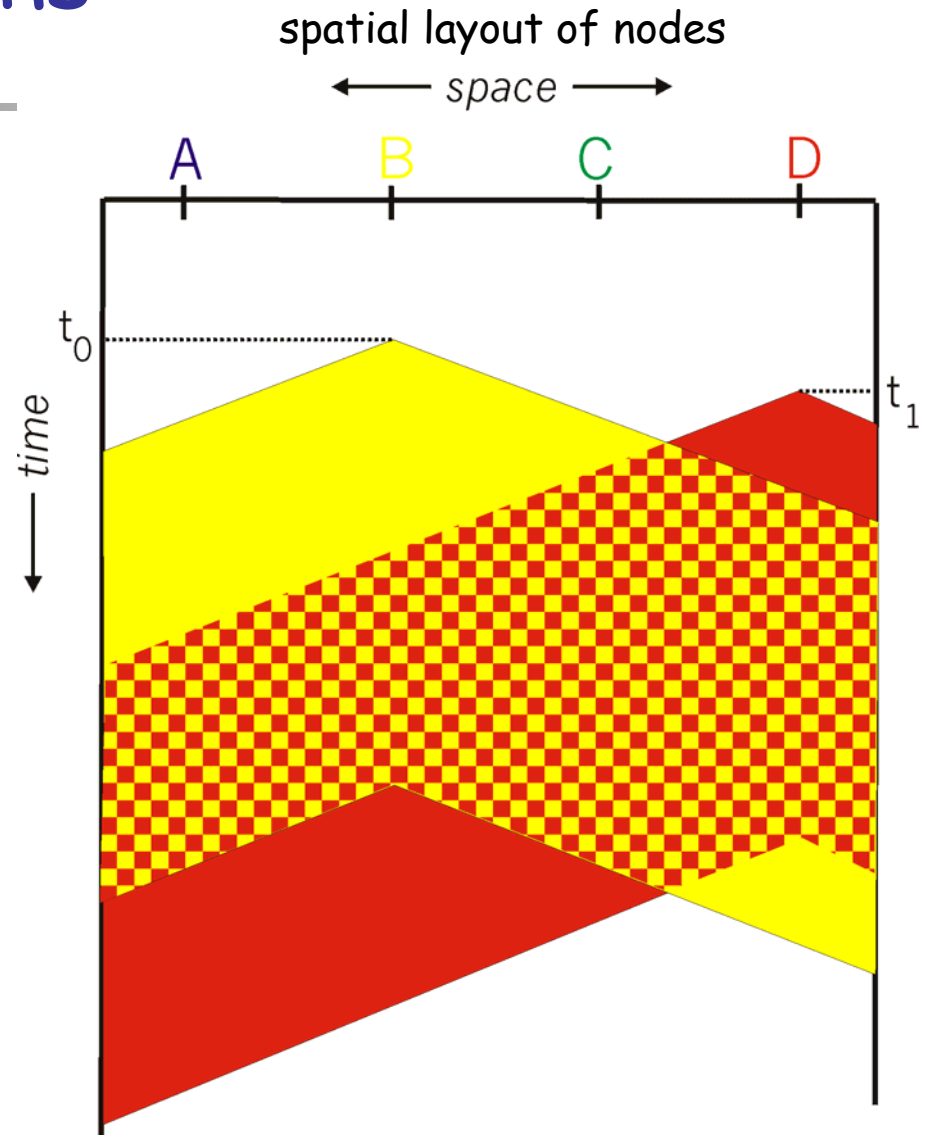
propagation delay means
two nodes may not hear
each other's transmission

collision:

entire packet transmission
time wasted

note:

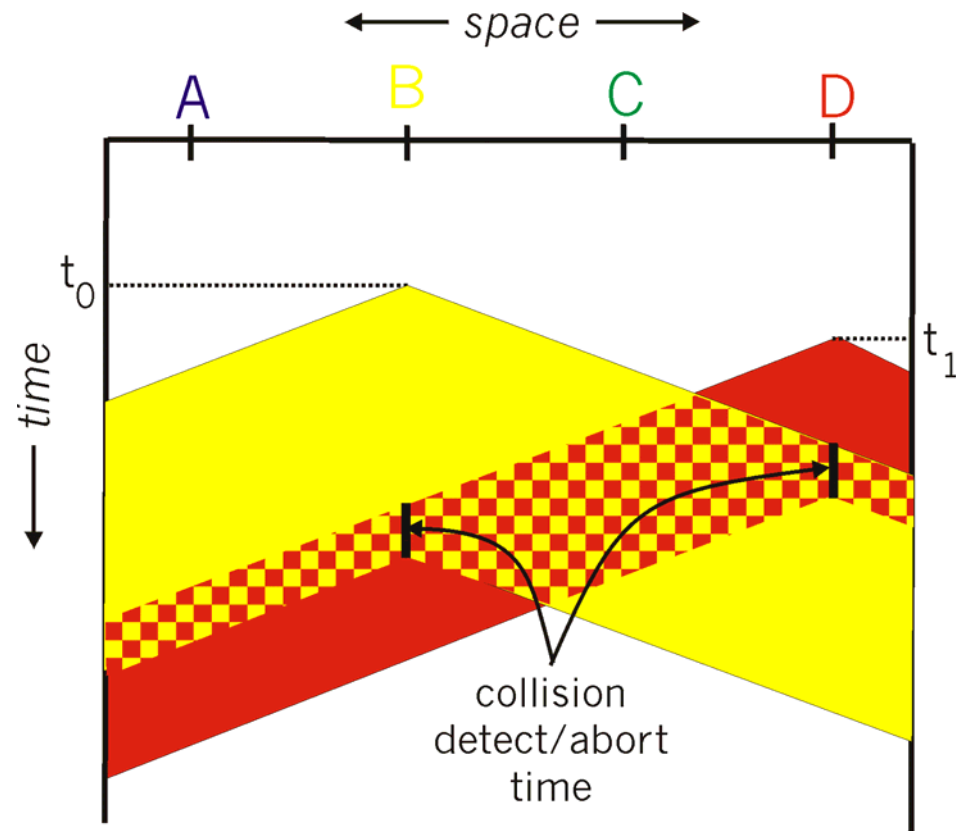
collision probability depends on
distance & propagation speed



CSMA/CD (Collision Detection)

CSMA/CD: carrier sensing,
same as in CSMA

- collisions detected within short time
- colliding transmissions aborted, reducing channel wastage
- Human analogy: if someone else begins talking at the same time, stop talking.



How Good are Random Access Protocols

Multiple channel of rate R bps

1. When one node wants to transmit,
 - it can send at full rate R .
2. When M nodes want to transmit,
 - each can send at average rate less than R/M . **Not ideal!**
3. Decentralization:
 - no special node to coordinate transmissions
 - no synchronized clocks except for slotted ALOHA

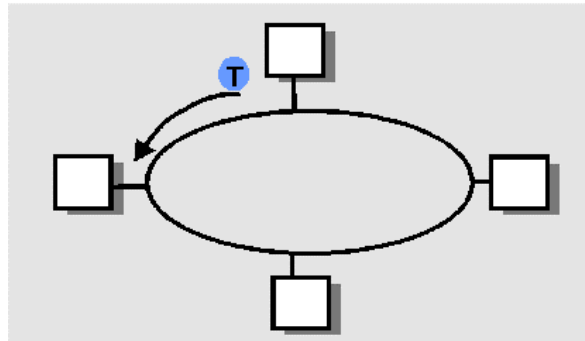
"Centrally Controlled" MAC protocols

Polling:

- master node "invites" slave nodes to transmit in turn
- concerns:
 - polling overhead (bandwidth & latency)
 - single point of failure (master)

Token passing:

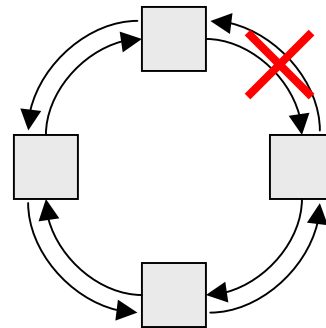
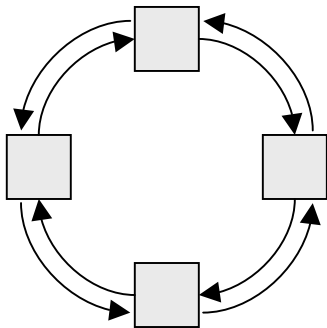
- control **token** passed from one node to next sequentially.
- transmit only when holding the token
- concerns:
 - token overhead (bandwidth & latency)
 - single point of failure (token)



Redundant ring topologies

Networks with ring topologies can quickly failover:

- FDDI (Fiber Distributed Data Interface) is a token ring that can be configured for dual counter-rotating rings.
- SONET (Synchronous Optical Network) is a telecommunications standard for building large-scale TDM (time-division multiplexed) networks, often configured in rings for protection.



Link failures can be identified quickly and traffic redirected to redundant links.



Summary of MAC protocols

- Channel partitioning
 - Time Division, Frequency Division, Code Division
- Random access
 - ALOHA, S-ALOHA, CSMA, CSMA/CD
 - CSMA/CD used in Ethernet
- Centrally controlled
 - polling from a central site
 - controlled by a token



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