MAC sublayer

- broadcast channel: single channel shared by many senders and receivers
- two or more simultaneous transmissions by nodes: interference
  - collision if node receives two or more frames at the same time ---> frames are lost

---> **necessary to somehow coordinate the transmissions of active nodes**

multiple access protocol

- algorithm that determines how nodes share channel, i.e., determine when a node can transmit
- communication about channel sharing must use channel itself!
  - no out-of-band channel for coordination

Ideal broadcast channel with a transmission 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 over some time interval
3. fully decentralized:
   - no special node to coordinate transmissions ---> no single point of failure
   - no synchronization of clocks, slots
4. simple, efficient and cheap

MAC Protocols: a taxonomy

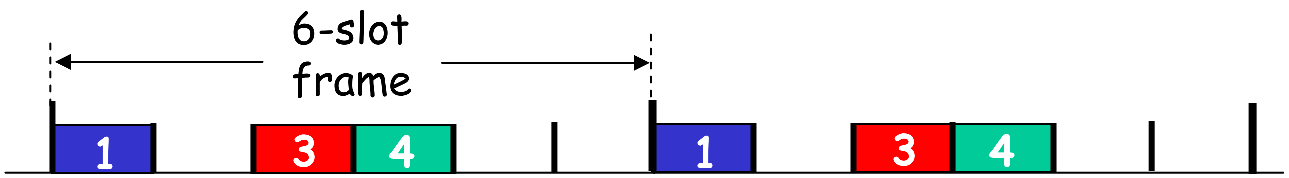
Three broad classes:

- 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
- "Taking turns" (dynamic TDMA)
  - nodes take turns, but nodes with more to send can take longer turns

Channel Partitioning MAC protocols: TDMA

TDMA: time division multiple access

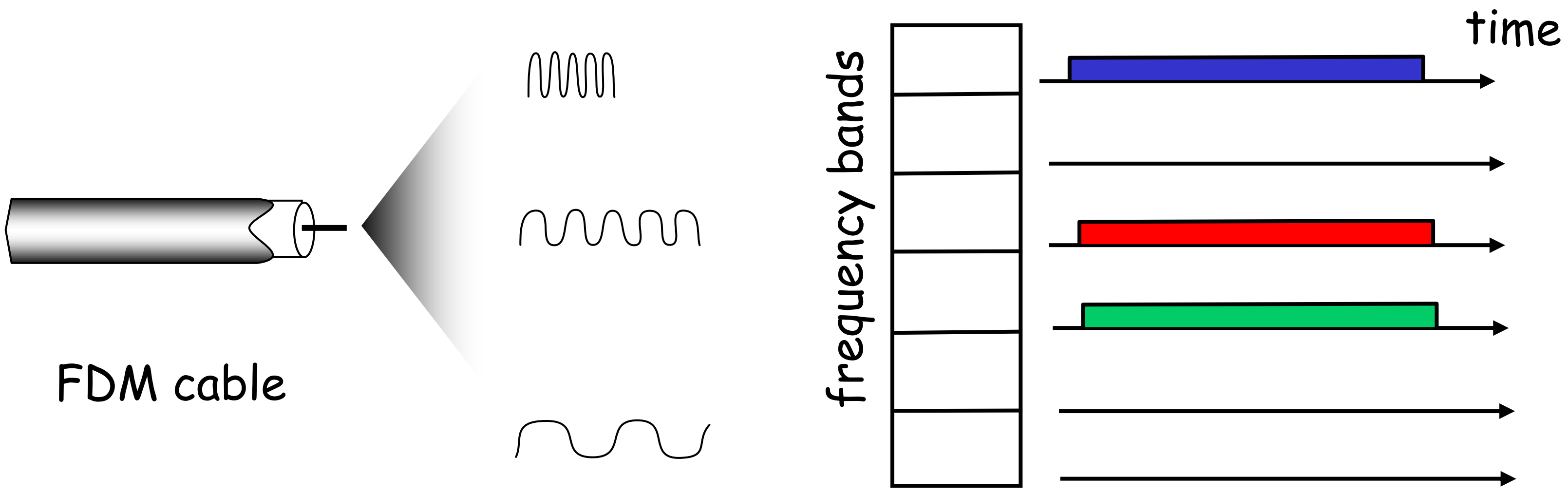
- access to channel in "rounds" called frames
- each station gets fixed slot (length of slot = pkt trans time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have pkt, slots 2,5,6 idle



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



Random Access Protocols

- When node has packet to send
  - transmit at full channel data rate R.
  - no *a priori* coordination among nodes

- two or more transmitting nodes “collision”

- random access MAC protocol specifies:
  - how to detect collisions
  - how to prevent further collisions (e.g., via delayed retransmissions)

- Examples of random access MAC protocols:
  - slotted ALOHA
  - ALOHA
  - CSMA, CSMA/CD, CSMA/CA

Slotted ALOHA (1)

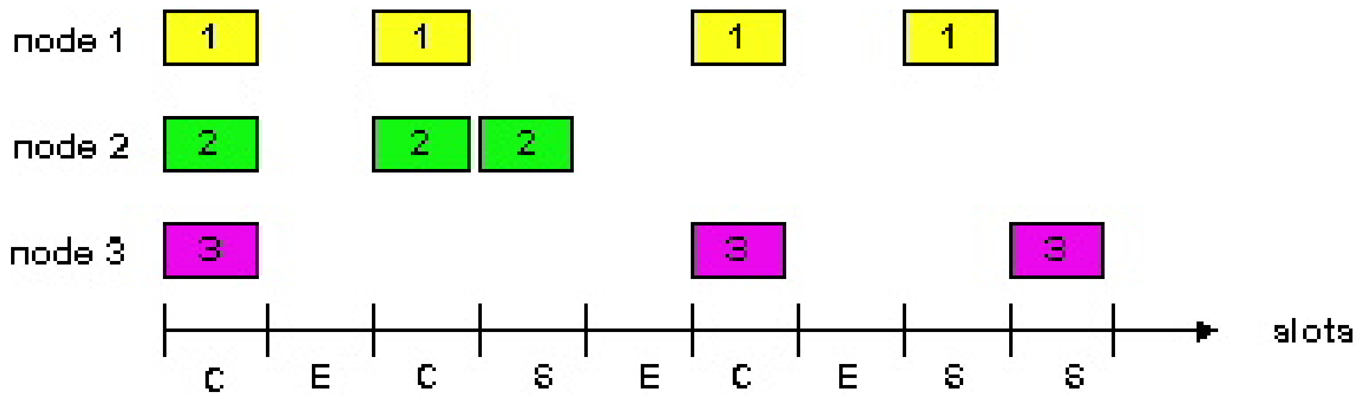
Assumptions:

- all frames same size(*L* bits)
- time divided into equal size slots
  (time to transmit 1 frame:= L/R sec)
- nodes start to transmit only at slot beginning --->needs synchronization

Operation:

- when node obtains fresh frame, it is transmitted in next slot
  - *if no collision:* node can send new frame in next slot
  - *if collision:* node retransmits frame in each subsequent slot with prob. p until success

Slotted ALOHA (2)



Pros

- single active node can continuously transmit at full rate of channel
- (highly?) decentralized: only slots need to be in synchronized
- simple

Cons

- collisions ---> wasting slots
  - empty slots
  - collision slots
- clock synchronization

Slotted Aloha efficiency

Efficiency : long-run fraction of successful slots (many nodes, all with many frames to send)

- *suppose:* N nodes with many frames to send, each transmits in slot with probability *p*
- prob that given node has success in a slot $= p(1-p)^{N-1}$
- prob that *any* node has a success = $Np(1-p)^{N-1}$

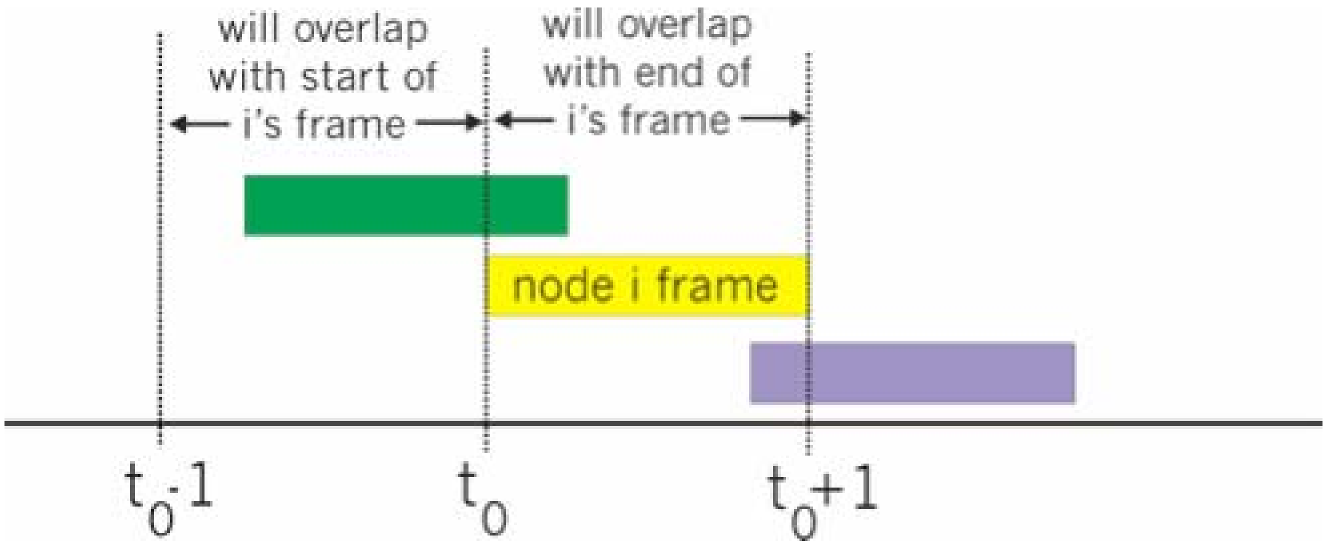
- max efficiency: find p* that maximizes $Np(1-p)^{N-1}$
- Max efficiency = 1/e = 0,37

At best: channel used for useful transmissions 37% of time, i.e. 37% successful slots!

Pure (unslotted) ALOHA

- unslotted Aloha: simpler, 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

P(success by given node) = P(node transmits) ·

P(no other node transmits in $[t_0\text{-}1,t_0]$ ·

P(no other node transmits in $[t_0,t_0\text{+}1]$

$= p \cdot (1-p)^{\mathbf{N-1}} \cdot (1-p)^{\mathbf{N-1}}$

$= p \cdot (1-p)^{\mathbf{2(N-1)}}$

… choosing optimum p and then letting N -> infinity ...

= 1/(2e) = 0,18

double worse than slotted Aloha!

CSMA (Carrier Sense Multiple Access)

human analogy: the polite conversationalist

- don't interrupt others! If, unintentionally, it still happens:
- stop talking immediately

CSMA: listen before transmit:
If channel sensed idle: transmit entire frame

- If channel sensed busy, defer transmission

- In case of a detected collision, stop transmitting immediately

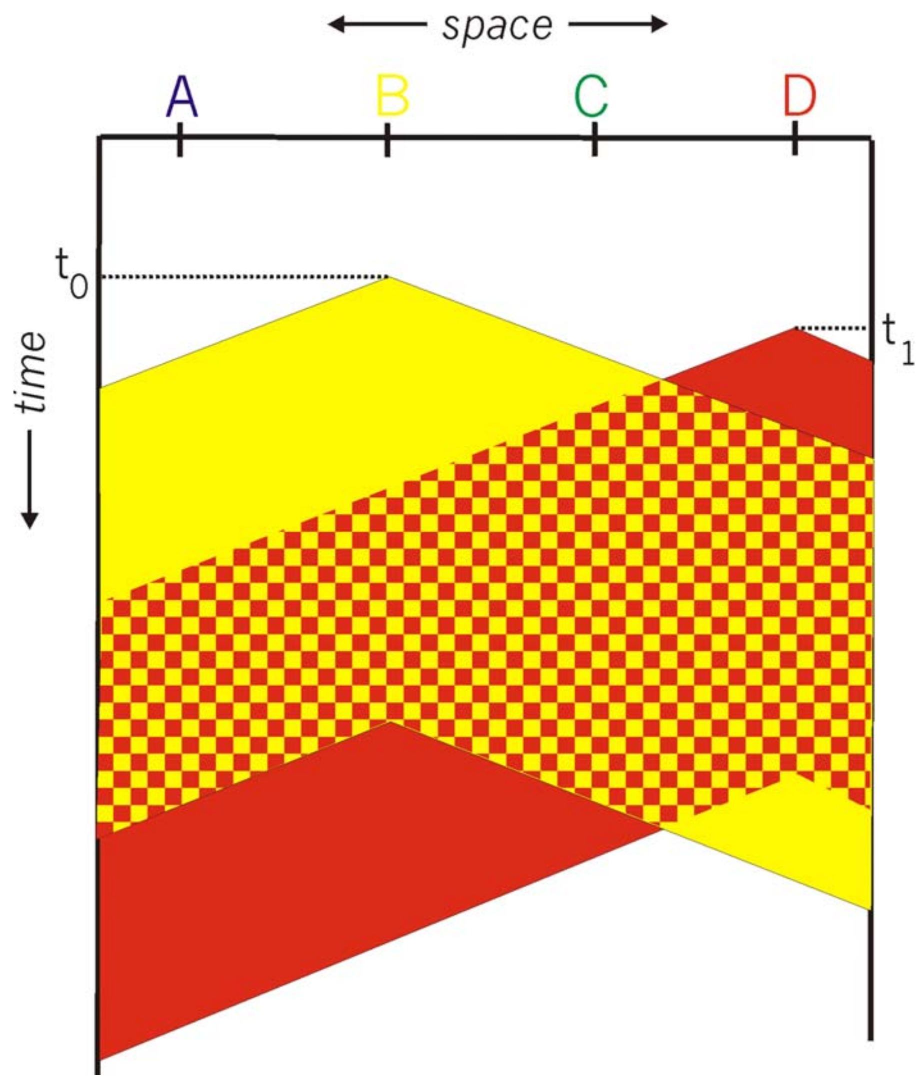
CSMA collisions

collisions *can* still occur:
propagation delay means two nodes may not hear each other's transmission

collision:
entire packet transmission time wasted

note:
role of distance & propagation delay in determining collision probability

spatial layout of nodes



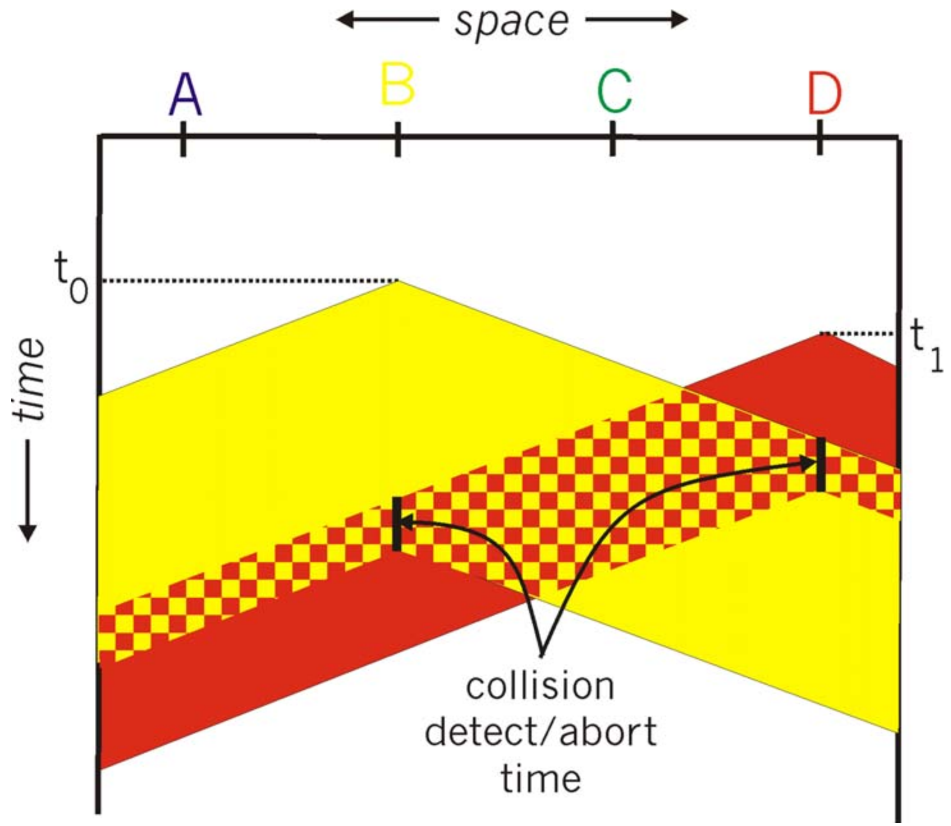
CSMA/CD (Collision Detection)

CSMA/CD: carrier sensing, deferral as in CSMA

- collisions *detected* within short time
- colliding transmissions aborted, reducing channel wastage

- collision detection:
  - easy in wired LANs: measure signal strengths, compare transmitted, received signals

CSMA/CD collision detection



MAC Sublayer(6)

Types of CSMA protocols

- *1-persistent*

Behavior:

When a station has data to send, it transmits with a probability of 1 whenever it finds the channel idle. If the channel is busy, the station waits until it becomes idle (greedy approach).

- *nonpersistent*

Behavior:

It differs from 1-persistent w.r.t. the case where the channel is busy.Then, the station deliberately waits a random period of time before sensing the channel again.

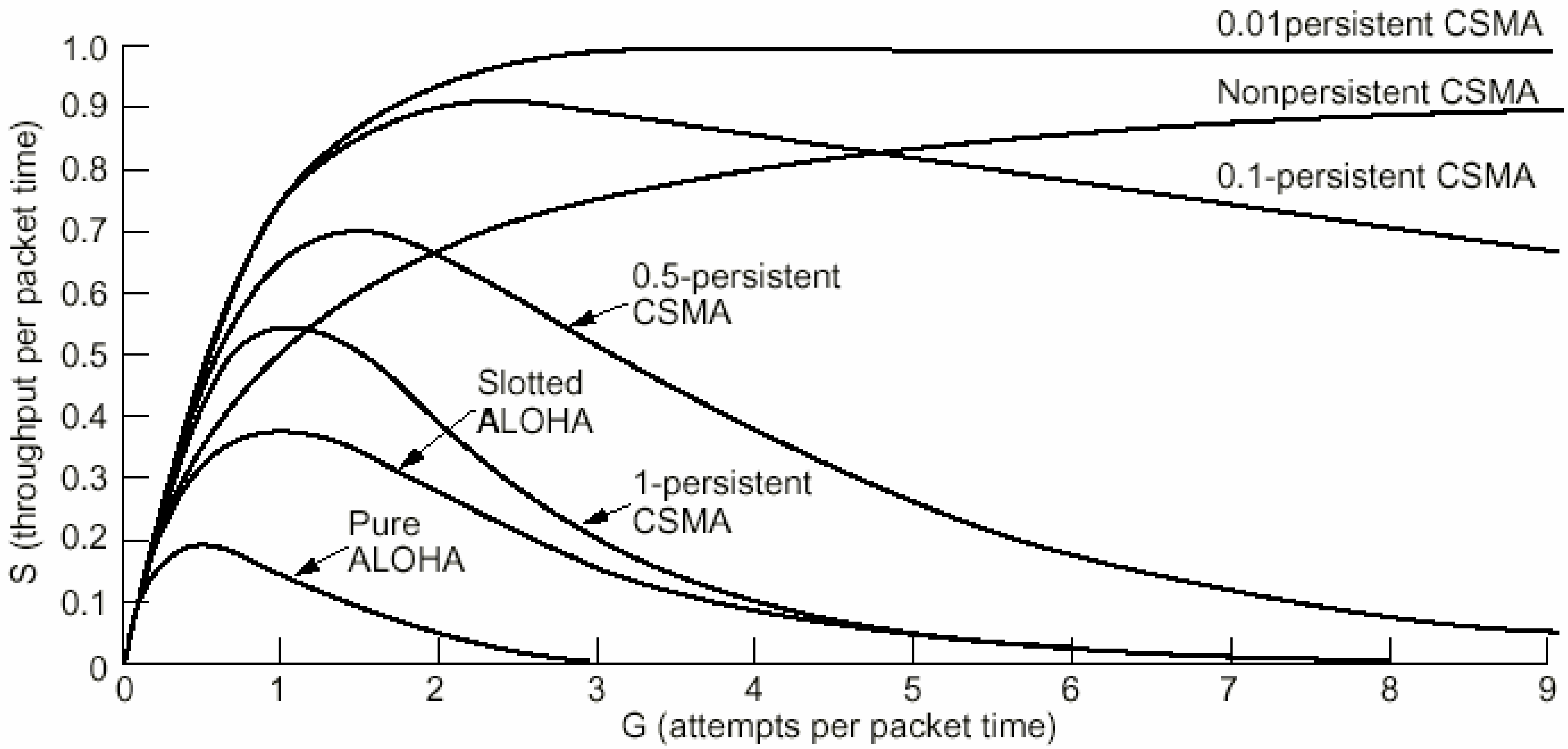
- *p-persistent* (applies to slotted channels)

Behavior:

When a station has data to send, it transmits with a probability of p whenever it finds the channel idle. With a probability of q = 1- p it defers until the next slot and the same procedure iterates. If the channel has become busy meanwhile, the station waits a random time and starts again.If the channel is busy when first sensing it, the station waits until the next slot and repeats the procedure.

MAC Sublayer(7)

Comparison of channel utilization versus load for the various random access protocols:

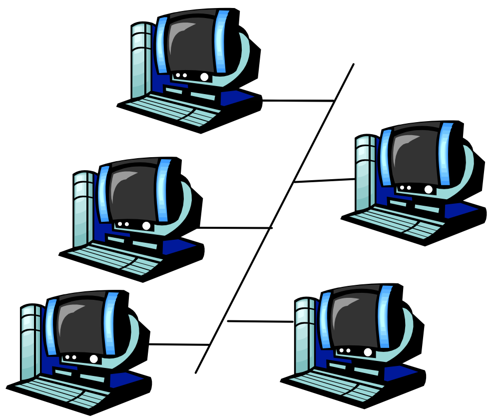


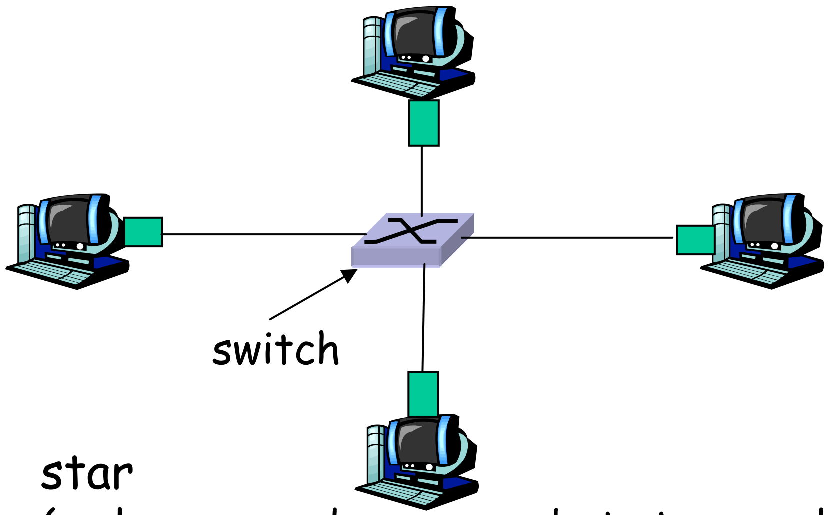
Ethernet

"dominant" wired LAN technology:

- cheap $20 for NIC (Network Interface Controller
- first widely used LAN technology
- simpler, cheaper than token LANs and ATM
- kept up with speed race: 10 Mbps – 10 Gbps

Today: Two topologies used: bus and star (implemented by hub or switch (Switched Ethernet))

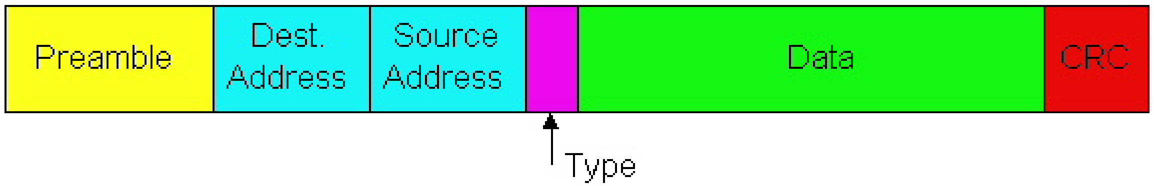




star
(no longer random access but store-and-forward)

Ethernet Frame Structure

Sending node encapsulates IP datagram (or other network layer protocol packet) in Ethernet frame



Preamble:

- 7 bytes with pattern 10101010 followed by one byte with pattern 10101011
- used to synchronize receiver to the sender clock rates of the NIC controlling the target transmission rate (from 10 Mbps to 1Gbps)

Ethernet efficiency

- T_{prop} = max prop delay between 2 nodes in LAN
- t_{trans} = time to transmit max-size frame

$$efficiency = \frac{1}{1 + 5 t_{prop} / t_{trans}}$$

- efficiency goes to 1
  - as t_{prop} goes to 0
  - as t_{trans} goes to infinity
- in general better performance than ALOHA: and simple, cheap, decentralized!

Comparison

channel partitioning MAC protocols:

- share channel *efficiently* and *fairly* at high load
- inefficient at low load: delay in channel access, R/N bandwidth allocated even if only 1 active node! (violating a property of the “ideal” protocol)

Random access MAC protocols

- efficient at low load: single node can fully utilize channel
- high load: collision overhead and violating the fairness property of the “ideal” protocol)

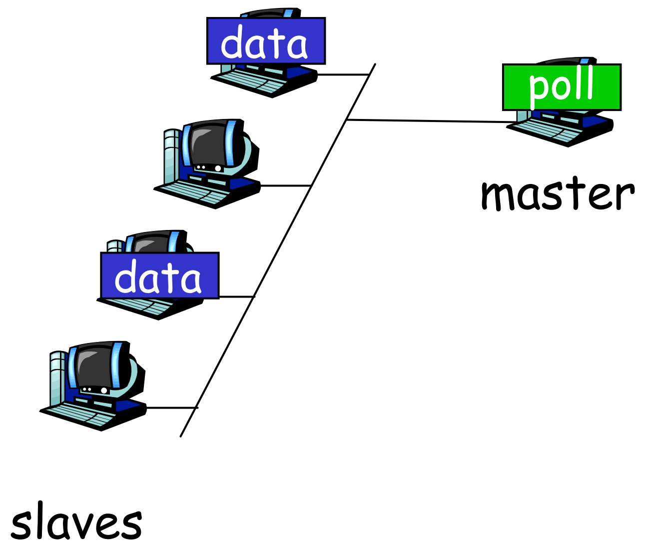
“taking turns” protocols

look for best of both worlds, i.e. not violating both of the “ideal” roperties

"Taking Turns" MAC protocols (1)

Polling:

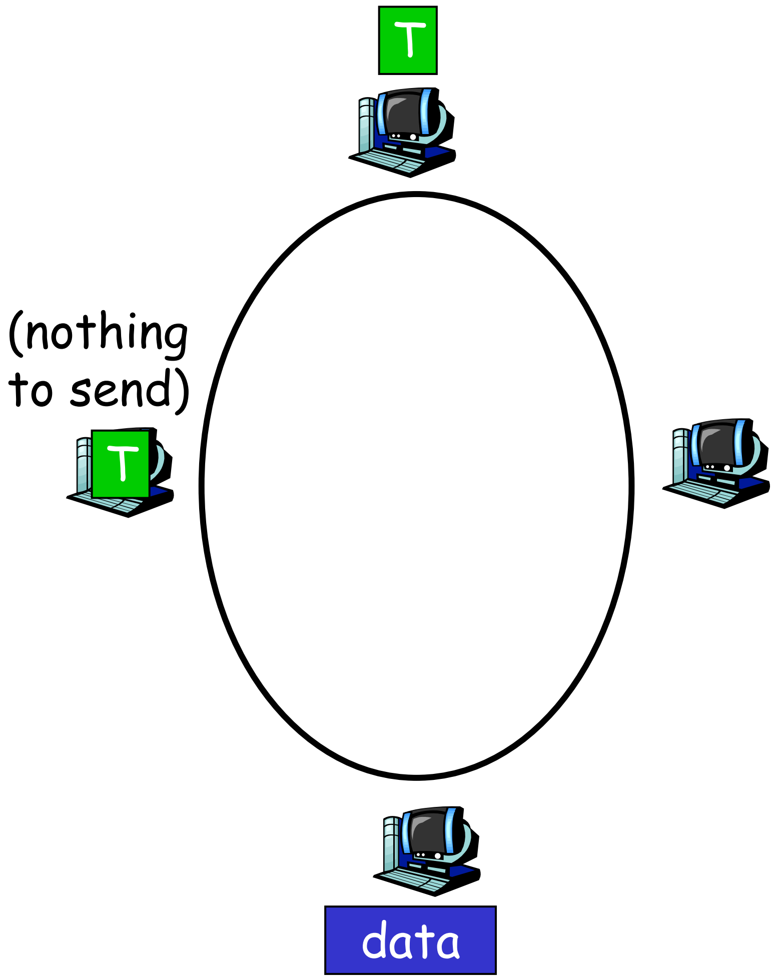
- master node "invites" slave nodes to transmit in turn
- typically used with "dumb" slave devices
- concerns:
  - polling overhead
  - static
  - single point of failure (master)



“Taking Turns” MAC protocols (2)

Token passing:

- control **token** passed from one node to next sequentially.
- token message
- concerns:
  - token overhead
  - token loss
  - single point of failure (token holder)

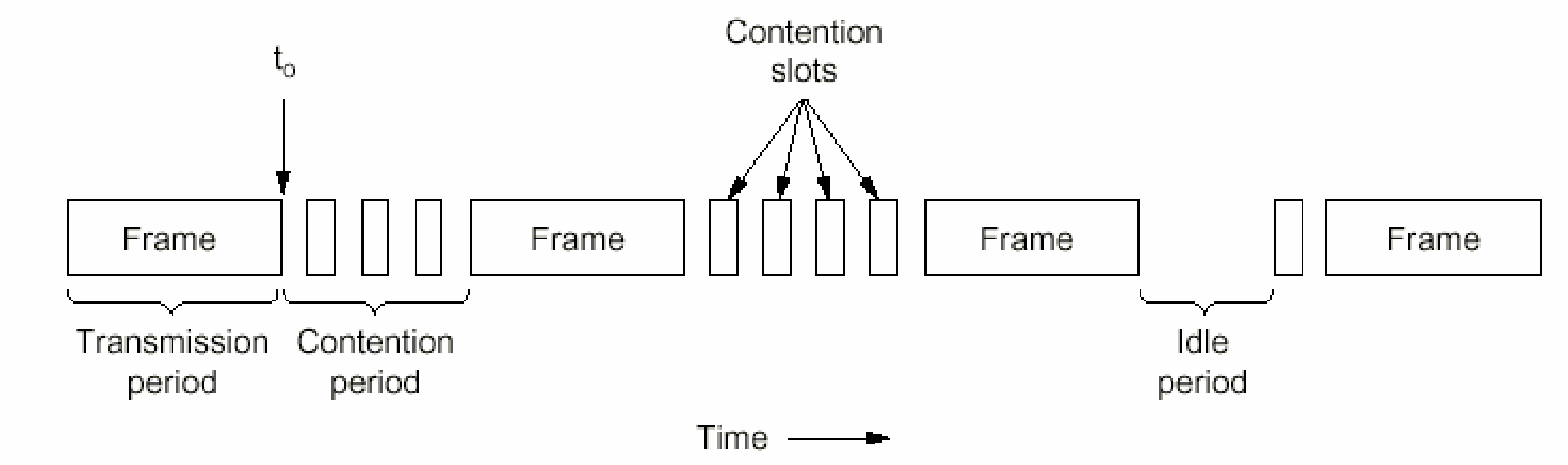


Summary of MAC protocols with so far

- *channel partitioning,* by time, frequency or code
  - Time Division, Frequency Division, Code Division
- *random access* (dynamic),
  - ALOHA, S-ALOHA, CSMA, CSMA/CD
  - carrier sensing: easy in some technologies (wire), hard in others (wireless)
  - CSMA/CD used in Ethernet
  - CSMA/CA used in 802.11
- *taking turns*
  - polling from central site, token passing
  - Bluetooth, FDDI, IBM Token Ring

MAC Sublayer(8)

Conceptual model of CSMA with Collision Detection (CSMA/CD):



How to resolve the contention for the channel without any collisions at all, i.e. including the contention period?

Assumption:

- There are N stations, each with a unique address

Basic question:

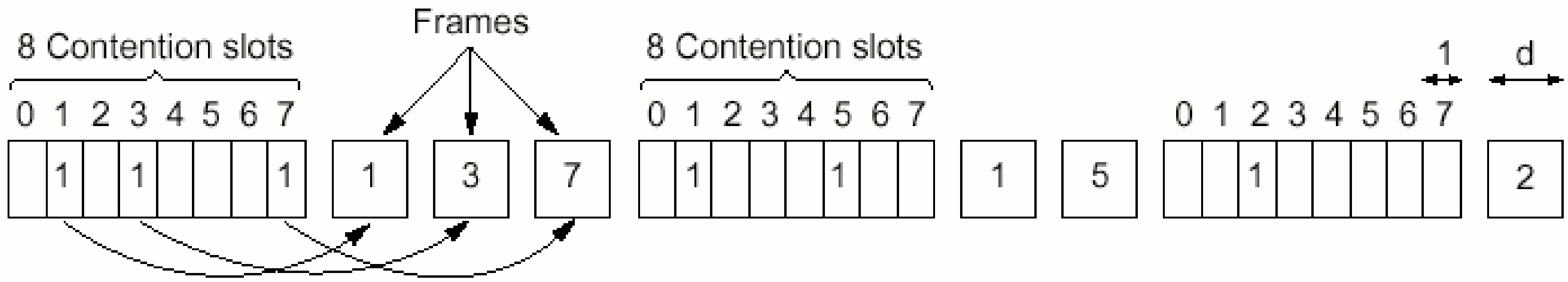
Which station gets the channel after a successful transmission?

Possible Answer:

The contention interval is modeled as N discrete contention slots with slot width := round trip propagation of one bit

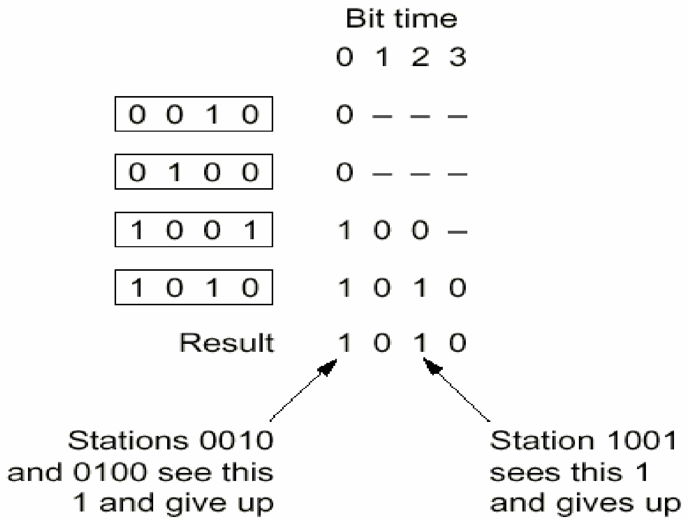
MAC Sublayer (9)

The basic Bit - Map Protocol (N = 8)



This protocol belongs to the class called **reservation protocols.**

The Binary Countdown Protocol



Limited Contention Protocols

Idea:
Combine the best properties of the contention and the collision-free protocols