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
4. simple, efficient and cheap

MAC Protocols: a taxonomy

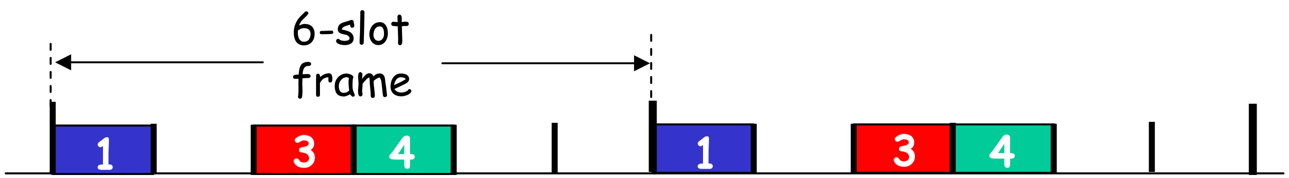
Three broad classes:

- Channel Partitioning
  - divide channel into smaller "pieces" (e.g. time slots)
  - 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 transmission time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have pkt, slots 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)

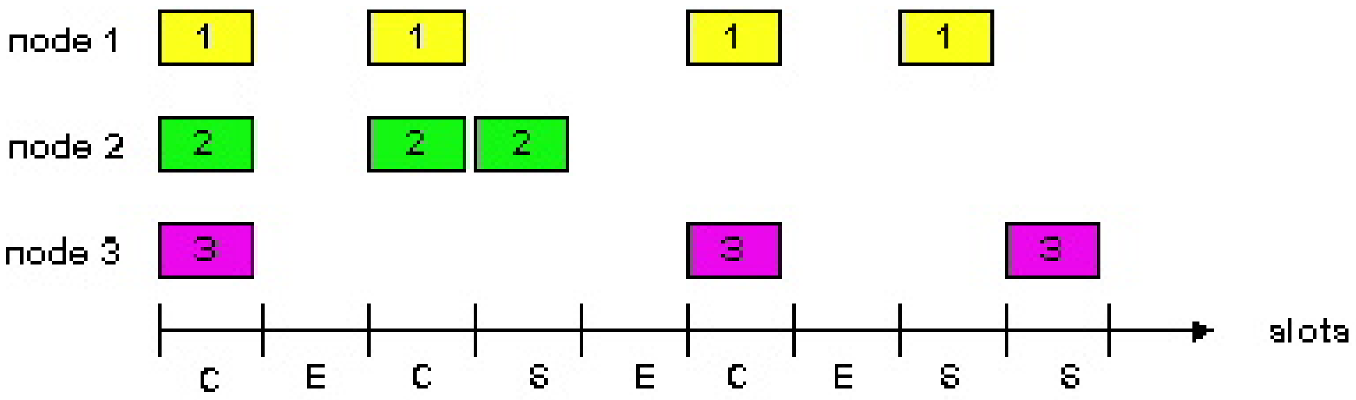
Assumptions:

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

Operation:

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

Slotted ALOHA (2)



Pros

- single active node can continuously transmit at full rate of channel
- 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 packets to send)

- *suppose:* N nodes with many packets 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

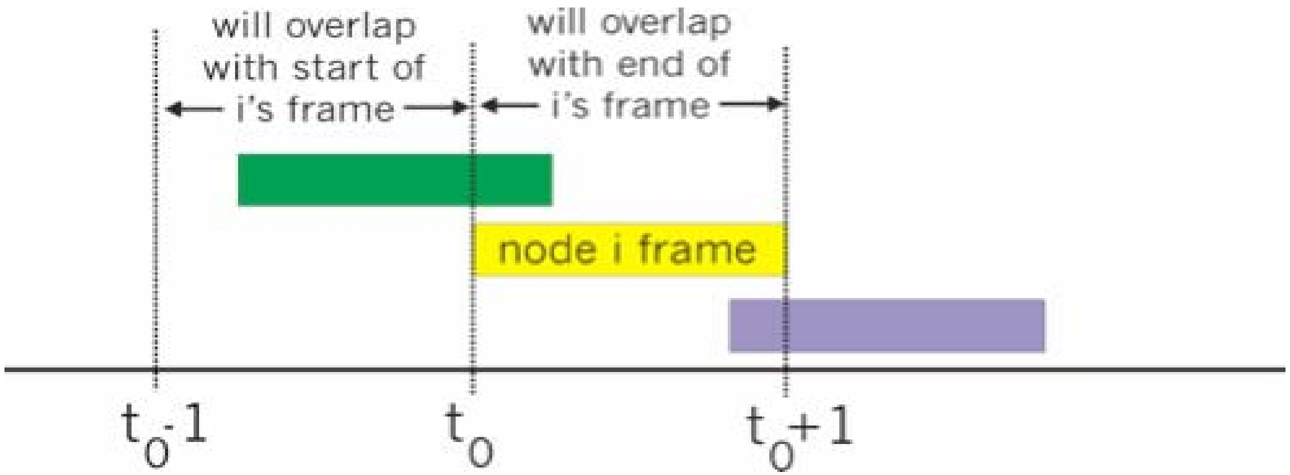
In a worst case situation, i.e. a large # of nodes has many packets to transmit and all with equal probability, efficiency is:

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

Pure (unslotted, fully decentralized) ALOHA

- unslotted Aloha: simpler, no synchronization
- when packet first arrives
  - transmit immediately

- collision probability increases:
  - packet sent at t_0 collides with other packets sent in $[t_0-1, t_0+1]$



Max efficiency = 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

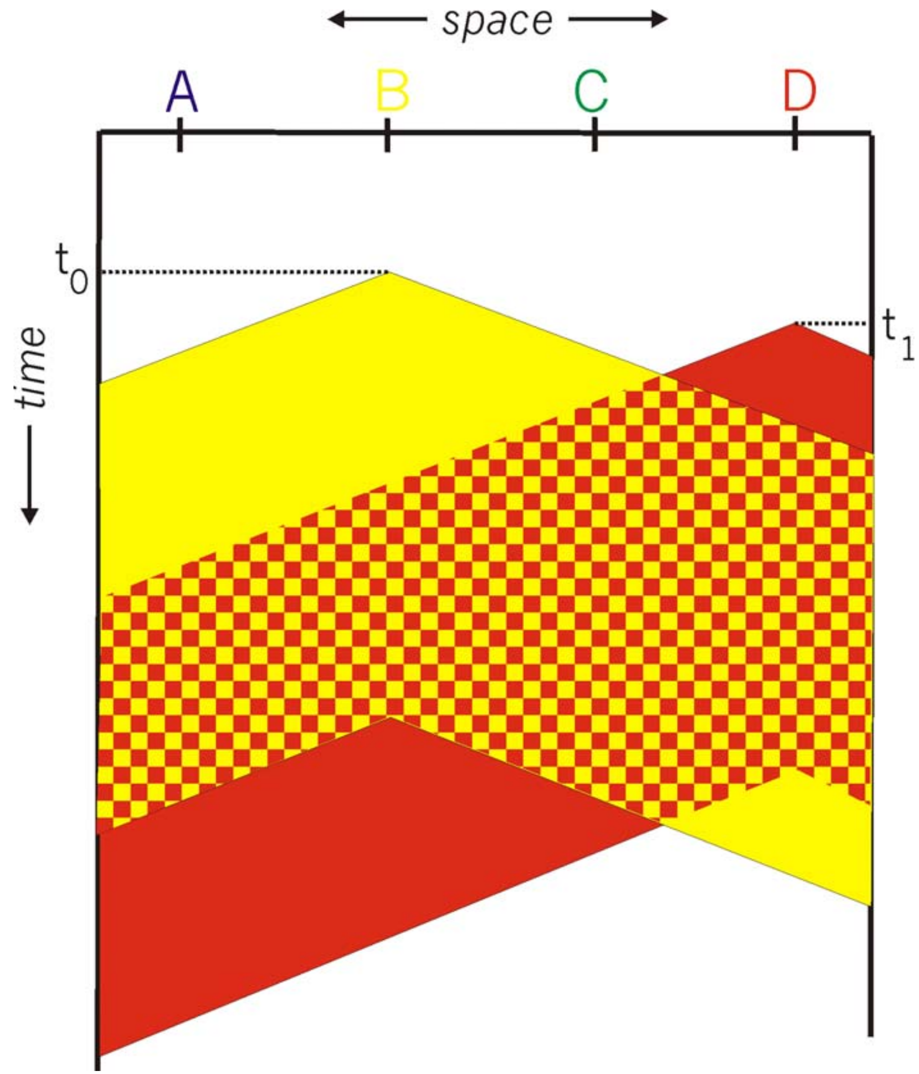
CSMA collisions

spatial layout of nodes

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



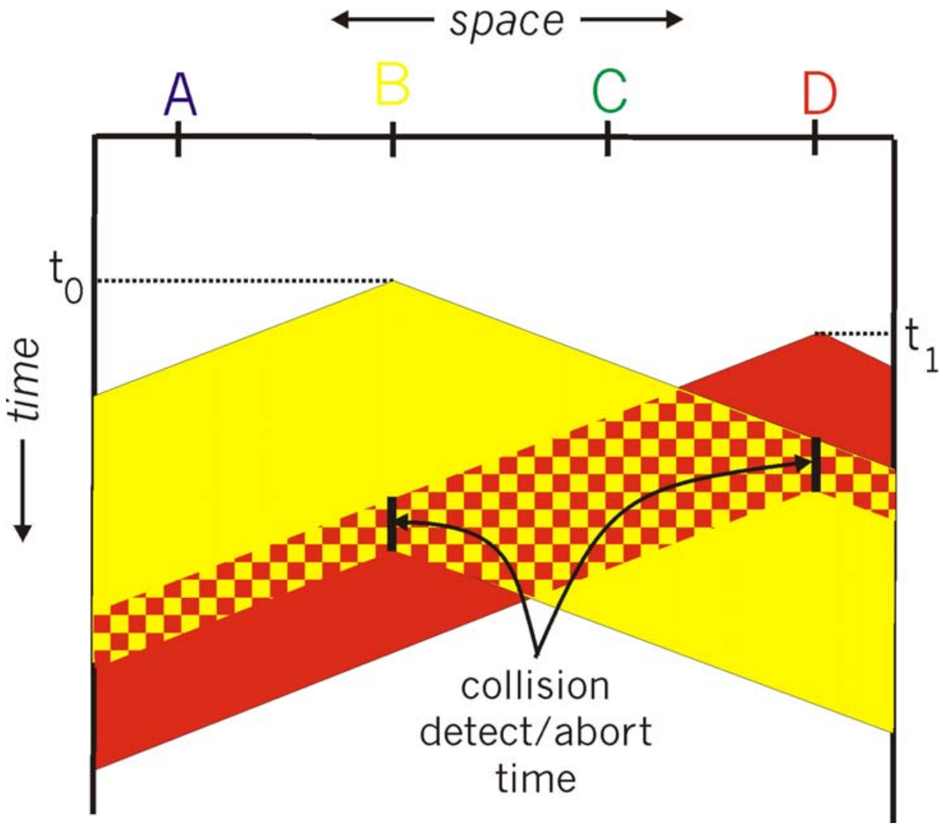
CSMA/CD (Collision Detection)

CSMA/CD: carrier sensing, deferral as in CSMA

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

- collision detection:
  - A transmitting node listens constantly while transmitting --->
    In case of a detected collision, stop transmitting immediately
  - easy in wired LANs: measure signal strengths, compare transmitted and 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 (back-off time).

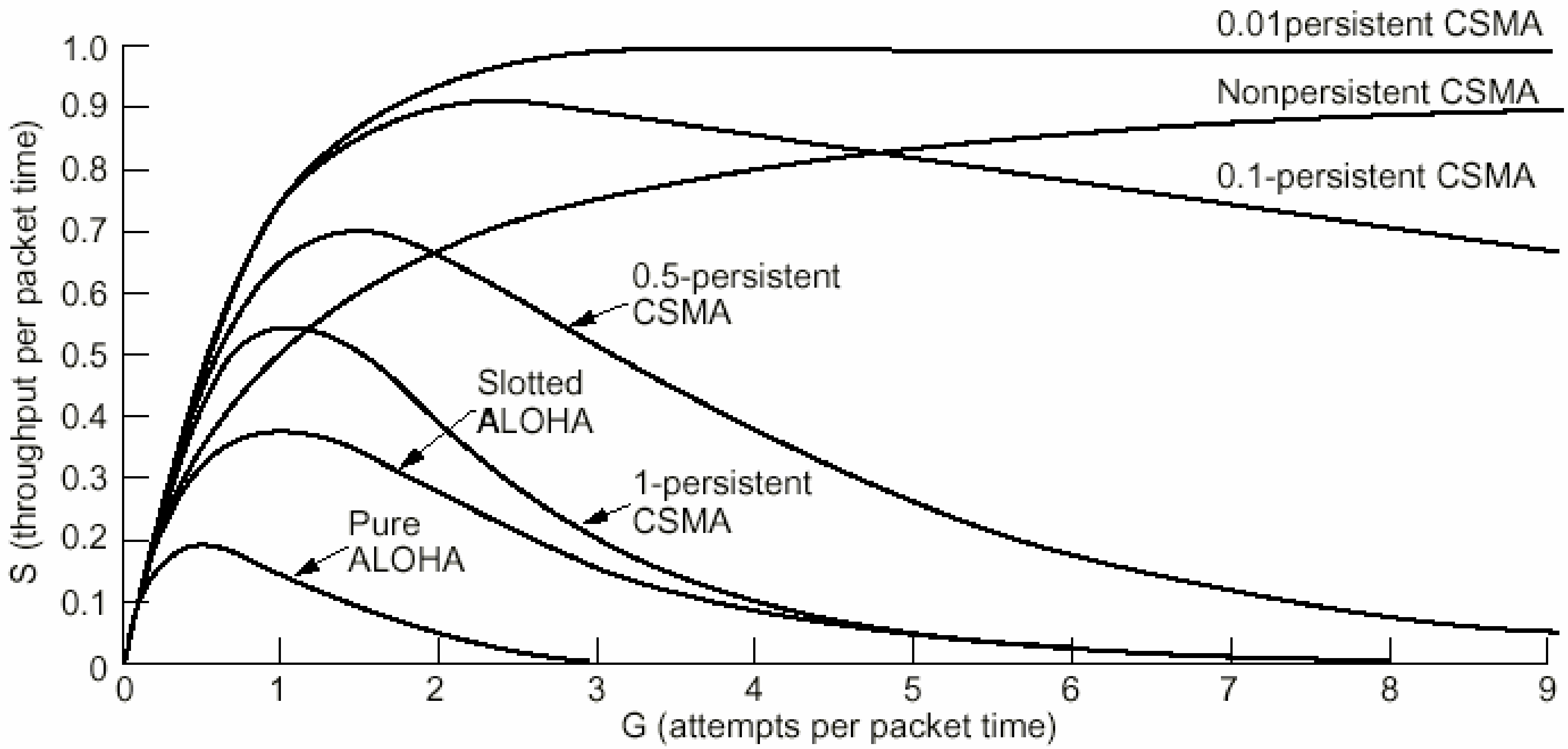
- *p-persistent* (applies to slotted channels)

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 (back-off time).If the channel is busy when first sensing it, the station waits until the next slot and repeats the procedure (no back-off time).

MAC Sublayer(7)

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

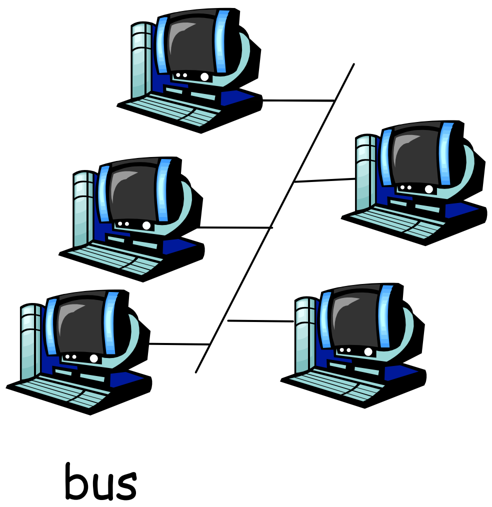


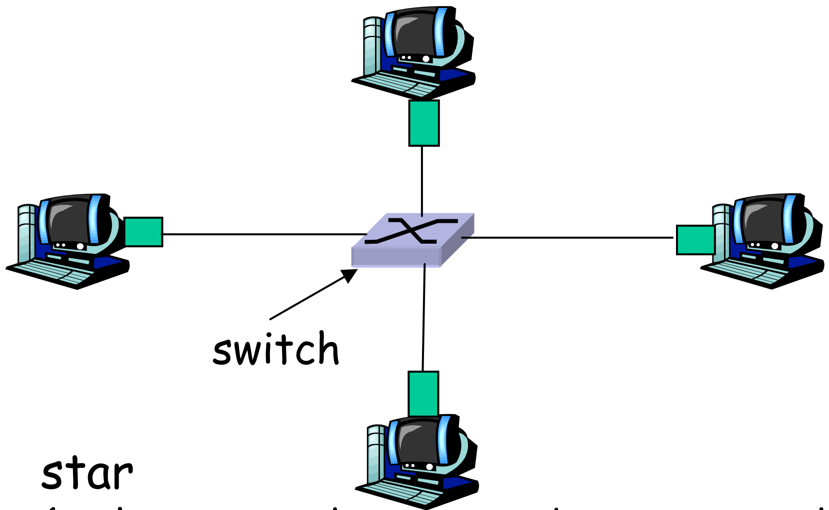
Ethernet

"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

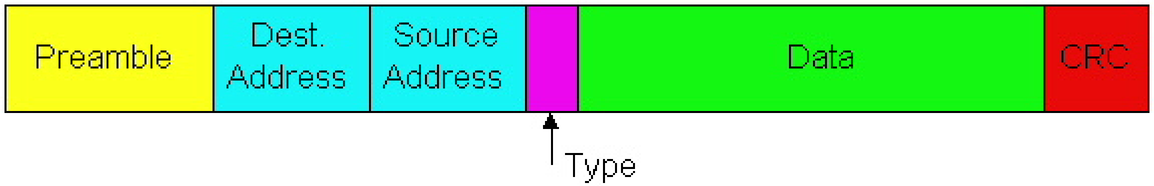
Today: Two topologies used: bus and star (implemented by hub or switch (Switched Ethernet))





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

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

- 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