CS3640

Link Layer (1): L2 Services, MAC Protocols

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Based on feedback from students, I’m considering switching the finals from **technical interviews** to a pen-and-paper **written exam**.

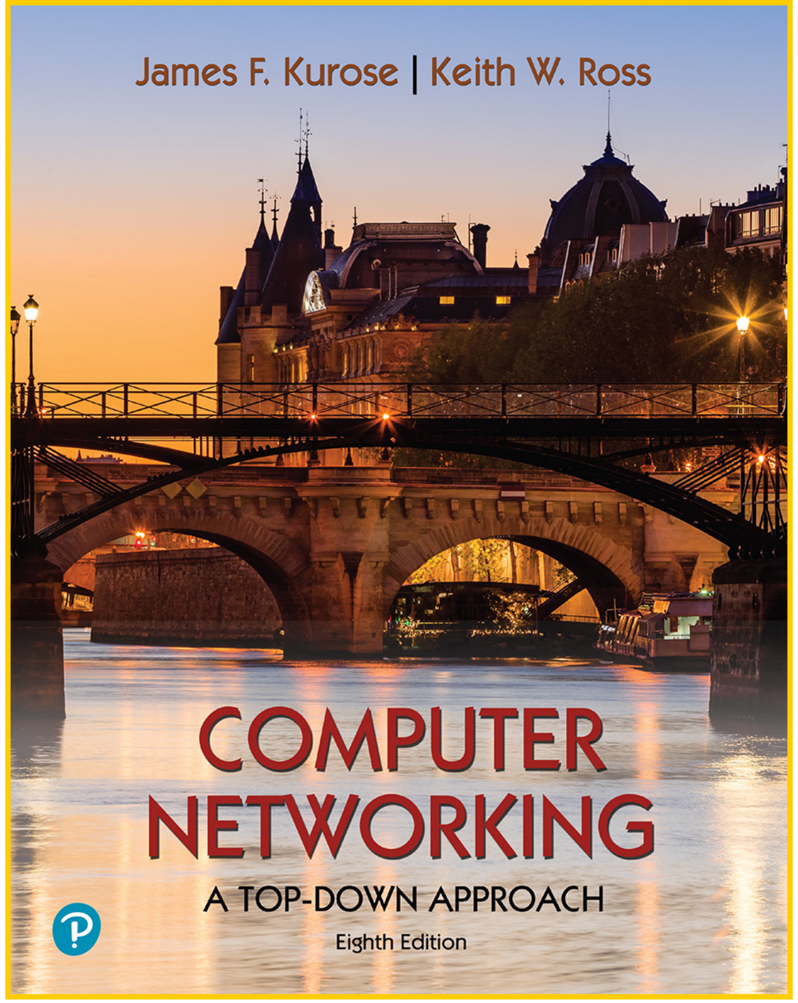
I want to hear from everyone!

Spot Quiz (ICON)

Lecture goals

a technical overview of the data link layer

- *Link-layer Services*
- *Network Interface Controller (NIC)*
- *MAC Protocols*



Chapters 6.1, 6.3

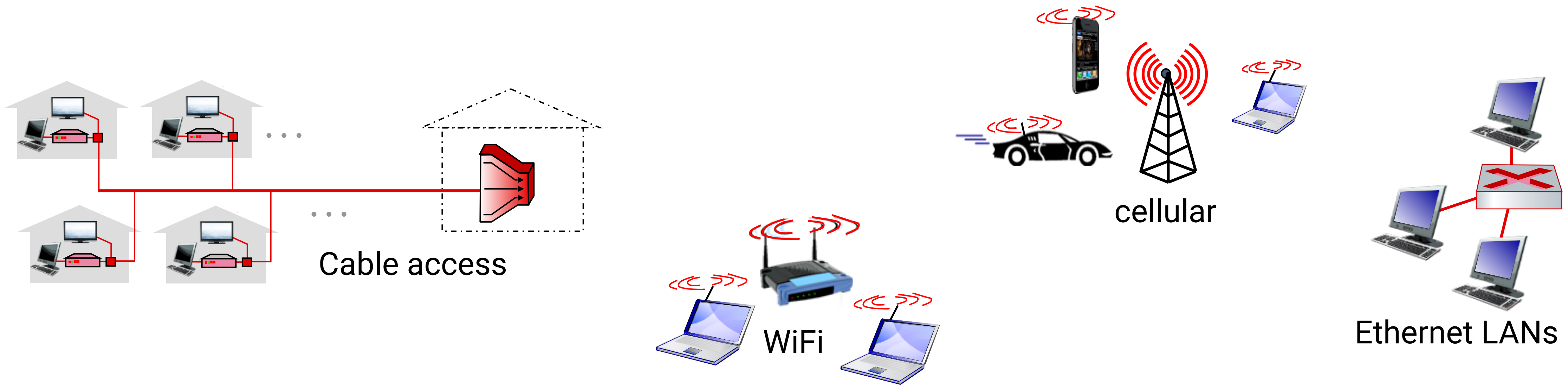
IOWA

Link-layer Overview

Goals

- Transfer IP datagrams from one node to its *physically adjacent* node over a link
- Serve as an interface to the physical layer networking devices

Link layer technologies



Link-layer Services

Framing

- encapsulate network datagram into link-layer frame, adding header and trailer

Link sharing

- protocols that govern how multiple nodes share a broadcast medium
- identify source and destination nodes via MAC address (a link-layer exclusive ID)

Error detection and correction

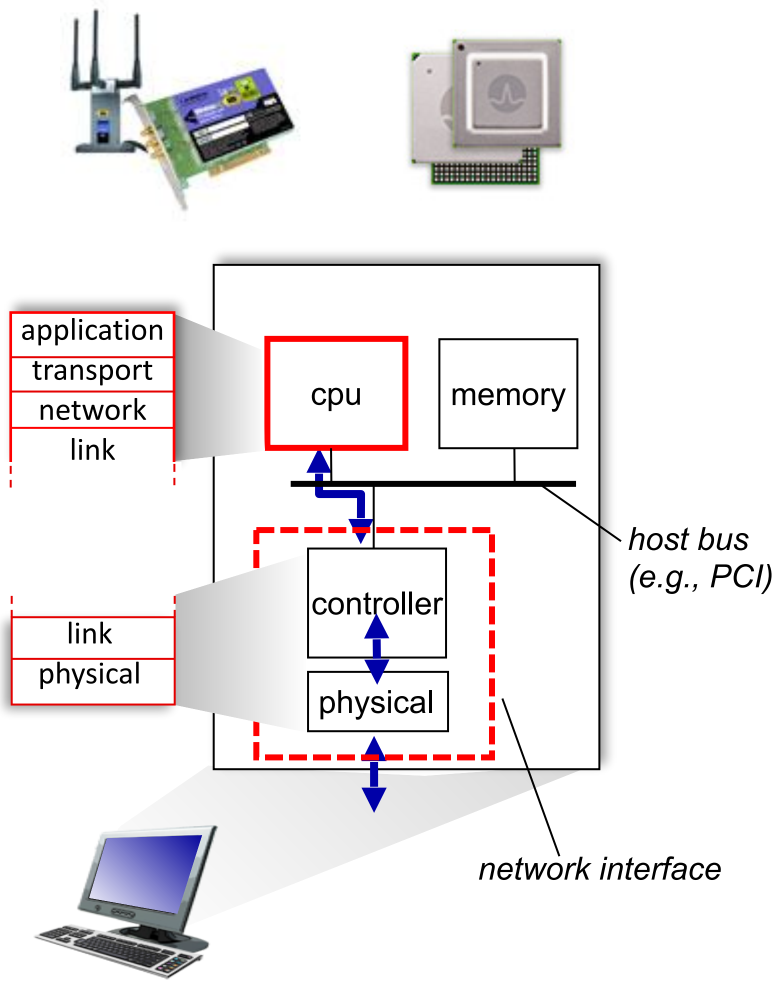
- mechanisms to detect errors, drop frames, and signal retransmission
- techniques to correct errors without the need for retransmission

Other services

- flow control, reliable frame transfer, directionality (half or full duplex)

Link-layer Implementation

- Link layer exists in each-and-every host
- Typically, implemented as a combination of hardware, software, and firmware
- Example: network interface card (NIC)
  - NIC implements physical layer and parts of link-layer
  - NIC attaches into host's system buses
  - Some link-layer functionalities are implemented in TCP/IP software stack



Multiple Access Protocols

sharing a single broadcast channel amongst multiple nodes

1 Channel Partitioning Protocols

divide channel into small pieces (e.g., time slots, frequency), and allocate each piece to one node

2 Random Access Protocols

do not divide the channel, and allow nodes to transmit at any time, but detect/ recover from collisions

3 Taking-turns Protocols

nodes take turn to send frames; this dynamism achieves balance between the first two class of protocols

Characterizing MAC Protocols

- MAC protocols are distributed algorithms that determine how nodes share a channel, *i.e., determine when nodes transmit*
- all communications about channel sharing must use channel itself, *i.e, no out-of-band channel for coordination*

An ideal MAC protocol

For a broadcast channel with a rate R bits/sec, it should be/enable the following:

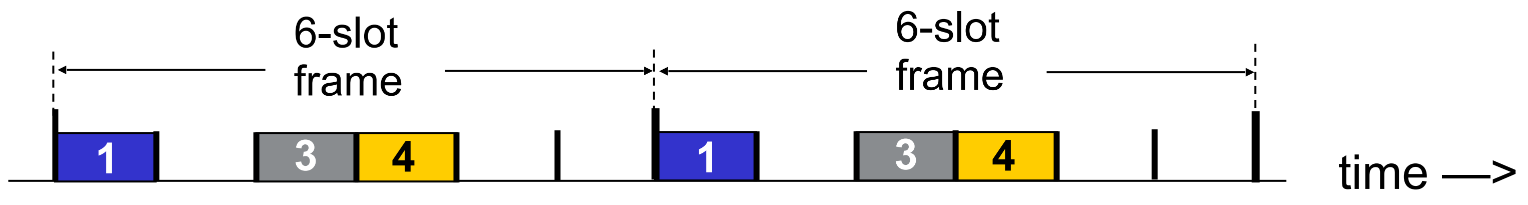
1. if only one node wants to transmit, it can send at rate R
2. if M nodes want to transmit, each can send at average rate R/M
3. be fully decentralized i.e., no centralized controller, no sync of clocks amongst nodes
4. be simple

Channel Partitioning Protocols

Channel Partitioning Protocols

TDMA: Time Division Multiple Access

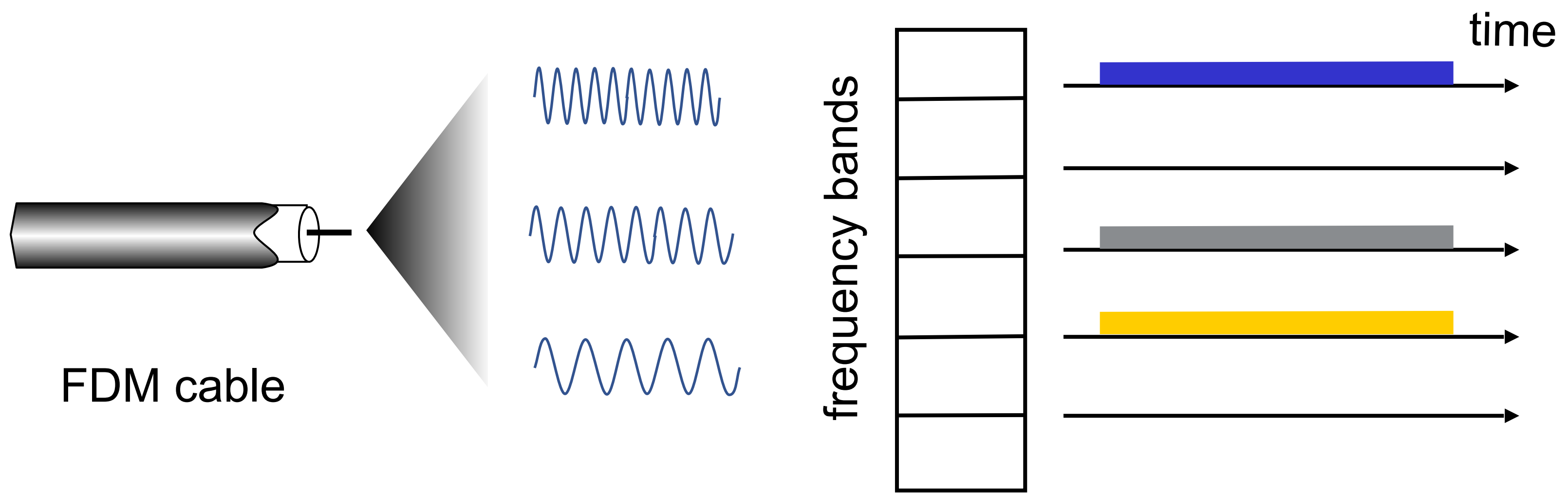
- access to channel in “rounds”
- each station gets fixed length slot (length = packet transmission time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have packets to send, slots 2,5,6 idle



Channel Partitioning Protocols

FDMA: Frequency Division Multiple Access

- channel spectrum is divided into frequency bands
- each station assigned a particular frequency band
- unused transmission time in a frequency band goes idle/waste
- example: 6-station LAN, 1,3,4 have packet to send, and bands 2,5,6 are idle



Random Access Protocols

Random Access Protocols

- When node has packet to send,
  - ➡ it transmits at full channel data rate R
  - ➡ no *a priori* coordination among nodes
- If two or more nodes transmit simultaneously: collision
- Random Access Protocols specify
  - ➡ how to detect collisions
  - ➡ how to recover from collisions
- Examples of random access protocols
  - ➡ ALOHA, slotted ALOHA (impolite speakers)
  - ➡ CSMA, CSMA/CD (more polite speakers)

Slotted ALOHA

Channel assumptions

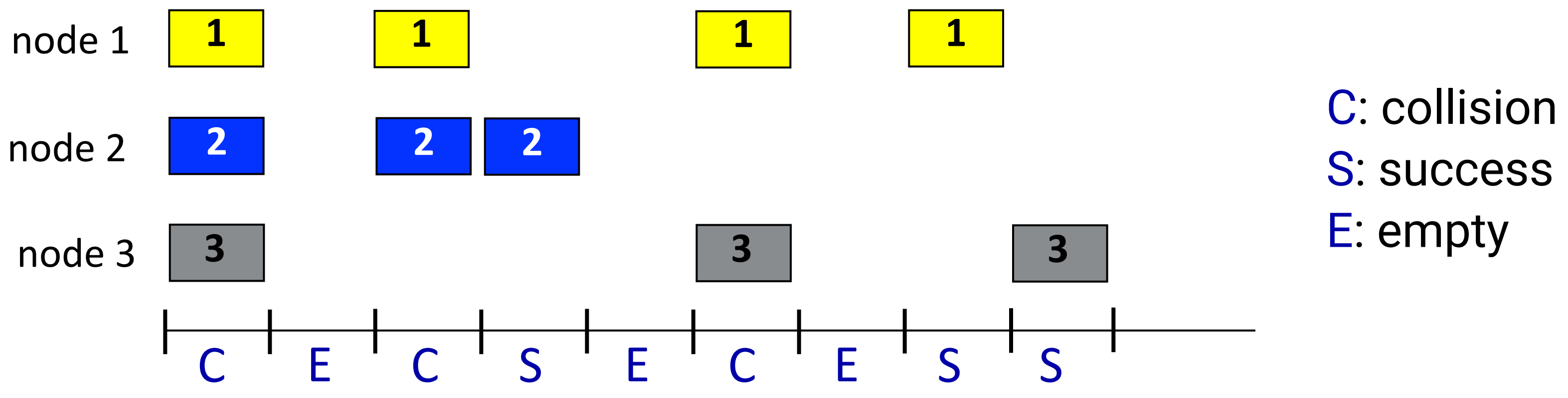
- all frames are of same size
- time is divided into equal length slots *(e.g., time to transmit 1 frame)*
- clocks at all nodes are synchronized
- nodes start to transmit only at the beginning of a slot
- if two or more nodes transmit in slot, all nodes detect collision

Protocol operation

- When a node has a new frame, it transmits it in next slot
- If no collision is detected: node can send any new frame in next slot
- If collision is detected: node retransmits the frame in each subsequent slot with probability **p** until success

randomization – *why*?

Slotted ALOHA



Pros

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

Cons

- a collision wastes the full slot
- leaves idle slots even when nodes have data to transmit
- clock synchronization

Slotted ALOHA

Efficiency: long run fraction of slots that transmit data successfully (assuming many nodes, and all of them have 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 = $Np(1-p)^{N-1}$
- take limit of $Np(1-p)^{N-1}$ as N goes to infinity, max efficiency = 1/e = .37

At best, only 37% of the slots do useful work!

Carrier Sense Multiple Access (CSMA)

Simple CSMA: listen before transmit

- if channel sensed to be idle: *transmit entire frame*
- if channel sensed to be busy: *defer transmission*

human analogy: don’t interrupt while others are talking!

CSMA/CD: CSMA with collision detection

- collisions detected within short time
- colliding transmissions are immediately aborted, thus reducing channel wastage

human analogy: a polite conversationalist

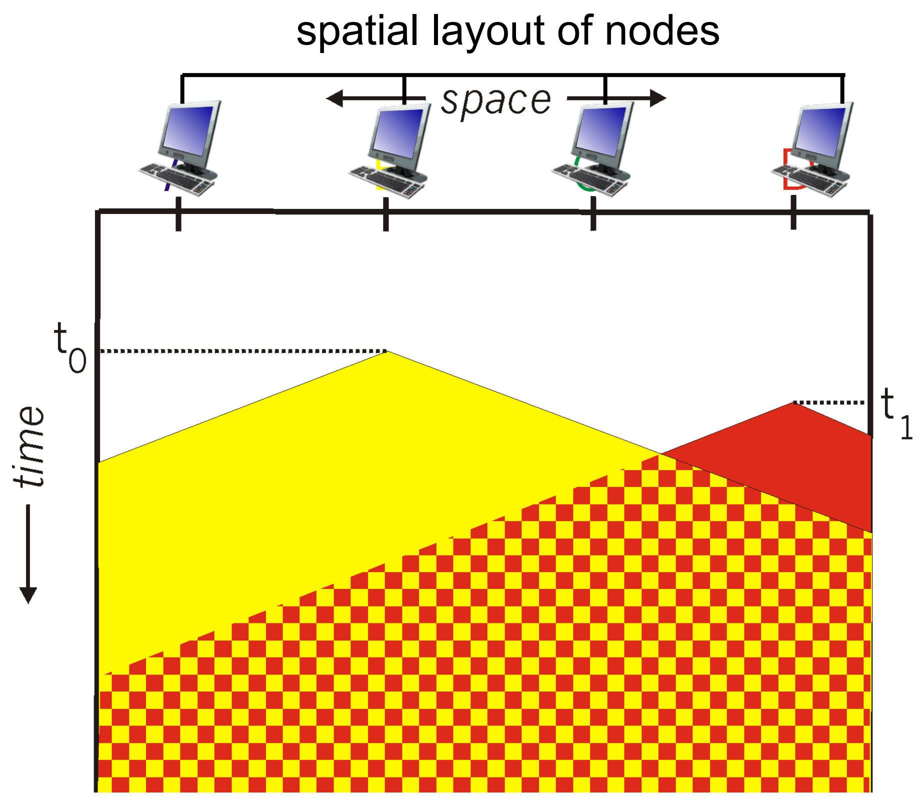
Simple CSMA

Collisions can still occur with carrier sensing:

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

When there is a collision: entire packet transmission time is wasted

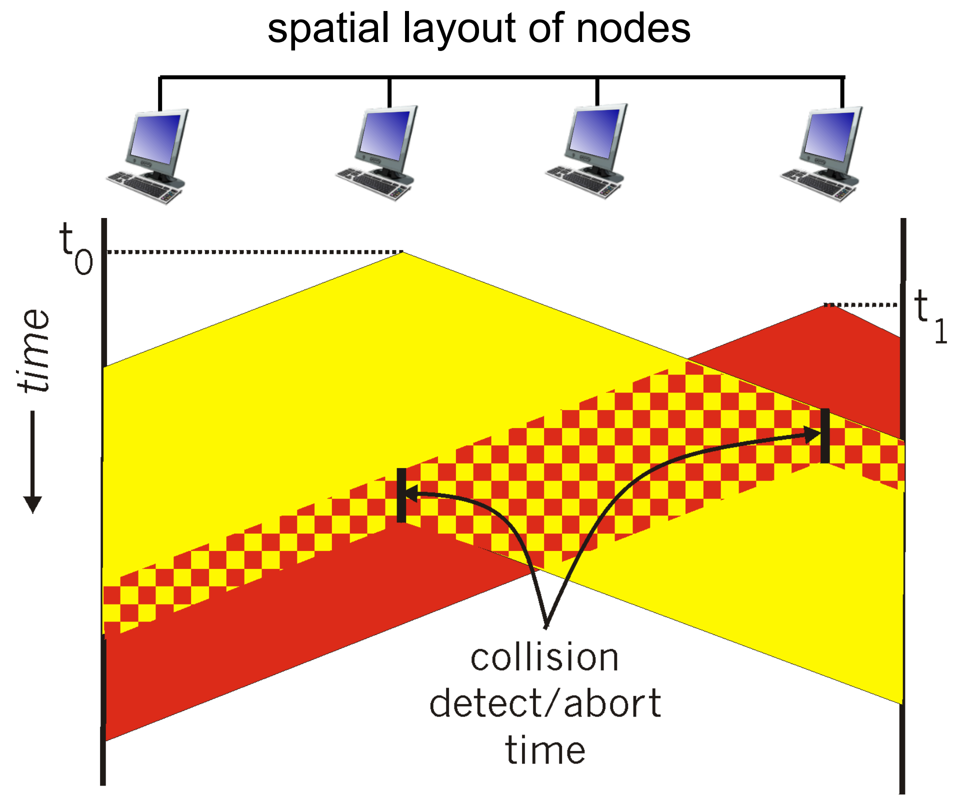
- distance and propagation delay play role in in determining collision probability



CSMA/CD

CSMA/CD reduces the amount of time wasted in collisions

- transmission aborted on collision detection



Ethernet CSMA/CD algorithm

1. Ethernet receives datagram from network layer, creates a frame
2. If Ethernet senses channel:

   if idle: start frame transmission.

   if busy: wait until channel idle, then transmit
3. If entire frame transmitted without collision - done!
4. If another transmission detected while sending: abort, send jam signal
5. After aborting, enter binary exponential backoff
   - ➡ after mth collision, chooses K at random from $\{0,1,2, \ldots, 2^m - 1\}$. Ethernet waits K slots, returns to Step 2
   - ➡ more collisions for the same frame: longer backoff interval

Taking-Turns Protocols

Taking Turns MAC Protocols

Channel Partitioning MAC Protocols

- inefficient at low load: if only one node is active, 1/N bandwidth is allocated to it!
- allows sharing the channel *efficiently and fairly* at high load

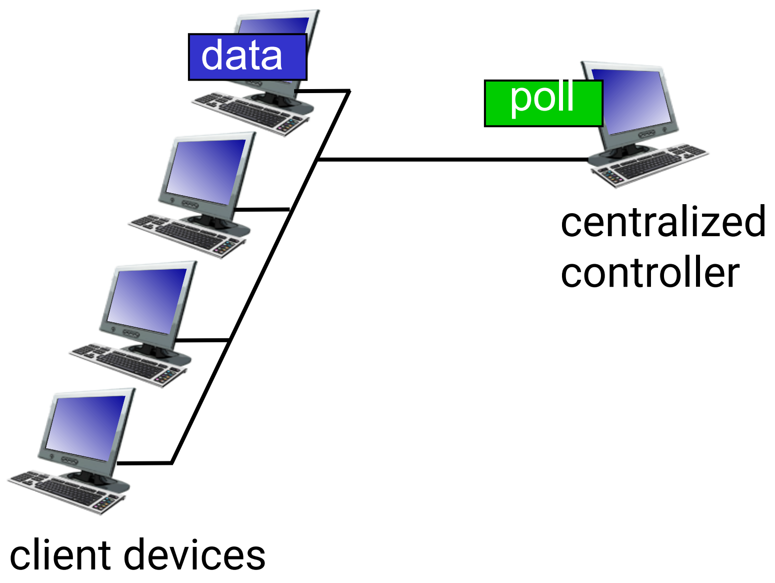
Random Access MAC Protocols

- *efficient at low load*: a single node can fully utilize channel
- experiences overhead at high load due to collisions

Taking Turns Protocols *look for best of both worlds!*

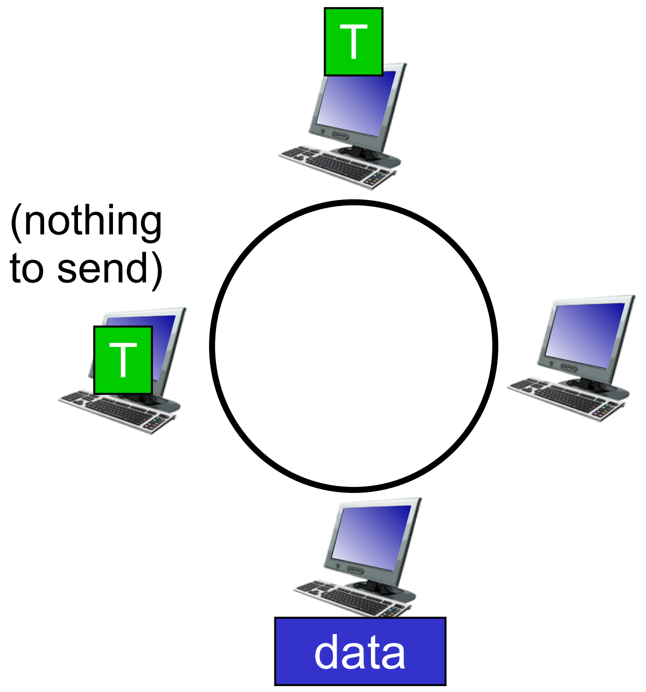
Polling Protocols

- a controller “invites” other nodes to transmit in turn
- typically used with “dumb” devices
- suffers from polling overhead, latency, and single point of failure (controller)



Token Passing Protocols

- control token message explicitly passed from one node to next, sequentially
- transmit while holding token
- suffers from token overhead, latency, and single point of failure (token)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