Paper Reading Assignment I

(Due on September 17th)

- Roscoe, Timothy. "Writing reviews for systems conferences." (2007).
- Mahmood, Aneeq, Reinhard Exel, Henning Trsek, and Thilo Sauter. "Clock synchronization over IEEE 802.11—A survey of methodologies and protocols." IEEE Transactions on Industrial Informatics 13, no. 2 (2016): 907-922.

Review for "Paper Title"

your name, email and student ID

Paper Summary

Objectives of the Paper

Approach, Novelty and Technical Depth

Major Strengths and Weaknesses

Learn from the Paper

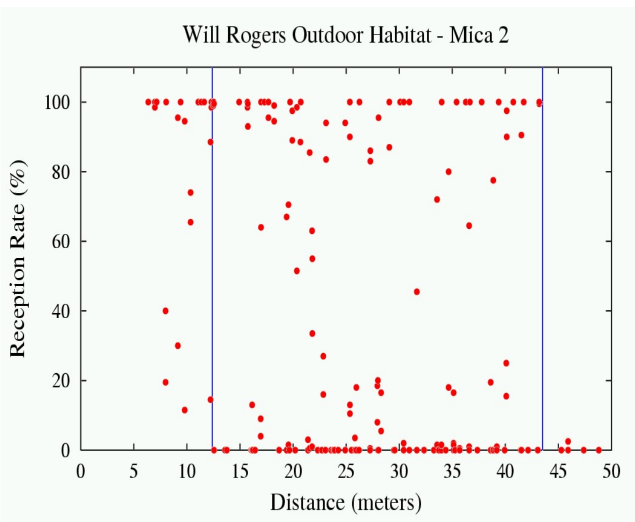
Future Work

CHALLENGES IN WIRELESS NETWORKING RESEARCH

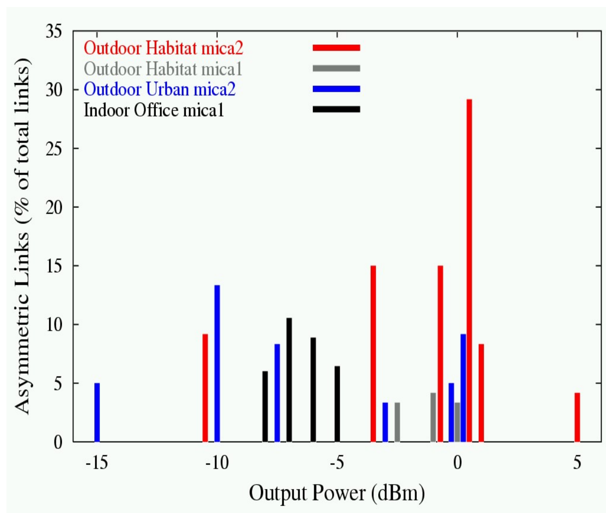
CHALLENGE 1: UNRELIABLE AND UNPREDICTABLE WIRELESS LINKS

- Wireless links are less reliable
- They may vary over time and space

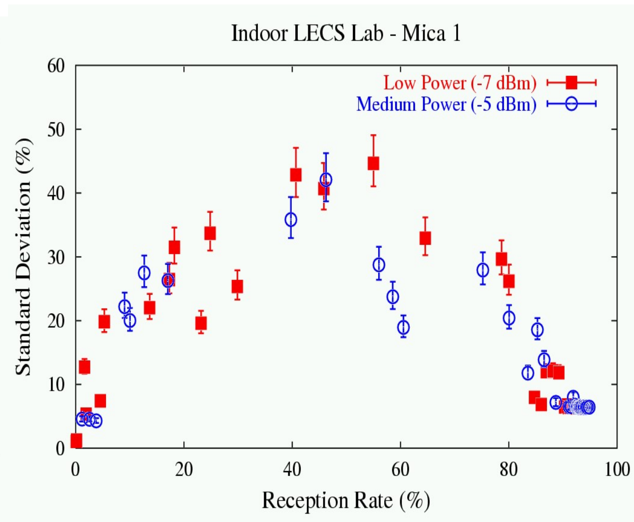
Reception vs. Distance



Asymmetry vs. Power



Standard Deviation vs. Reception rate



*Cerpa, Busek et. al, scale: a tool for simple connectivity assessment in lossy environments
http://www.eecs.harvard.edu/~mdw/course/cs263/papers/scale-tr03.pdf

CHALLENGE 2: OPEN WIRELESS MEDIUM

- Wireless interference

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- Hidden terminals

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- Wireless security
  - Eavesdropping, Denial of service, …

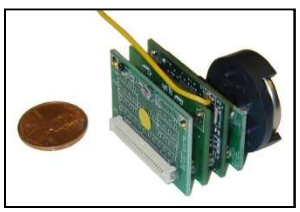
CHALLENGE 3: INTERMITTENT CONNECTIVITY

- Reasons for intermittent connectivity
  - Mobility
  - Environmental changes
- Existing networking protocols assume always-on networks
- Under intermittent connected networks
  - Routing, TCP, and applications all break
- Need a new paradigm to support communication under such environments

CHALLENGE 4: LIMITED RESOURCES

- Limited battery power
- Limited bandwidth
- Limited processing and storage power

Sensors,
embedded
controllers



Mobile phones
• voice, data
• simple graphical displays
• GSM

PDA
• data
• simpler graphical displays
• 802.11

Laptop
• fully functional
• standard applications
• battery; 802.11

Outline

- Introduction to Networked Embedded Systems
  - Embedded systems ➜ Networked embedded systems ➜ Embedded Internet
  - Network properties
- Layered Network Architectures
  - OSI framework – descriptions of layers
  - Internet protocol stack
- Physical Layer Options
  - Guided transmission media
  - Wireless transmission media
- Data Link Layer Services and MAC Protocols
- Embedded System Communication Protocols
  - Wired protocols: Ethernet, CAN, TTP, BACnet
  - Wireless protocols: Wi-Fi, ZigBee, WirelessHART
- TCP/IP Stack and 6LoWPAN Stack
- Modeling and Analysis of Communication Protocols

DATA LINK LAYER SERVICES

- Framing, link access:
  - encapsulate datagram into frame, adding header, tailer
  - channel access if shared medium
  - "MAC" addresses used in frame headers to identify source, destination
- Reliable delivery between adjacent nodes
  - Seldom used on low bit-error link (fiber, some twisted pair)
  - wireless links: high error rates
- Flow control:
  - Pacing between adjacent sending and receiving nodes
- Error detection:
  - Errors caused by signal attenuation, noise.
  - Receiver detects presence of errors: signals sender for retransmission or drops frame
- Error correction:
  - Receiver identifies and corrects bit error(s) without resorting to retransmission
- Half-duplex and full-duplex
  - with half duplex, nodes at both ends of link can transmit, but not at same time

MULTIPLE ACCESS PROTOCOLS

- Single shared broadcast channel
- Two or more simultaneous transmissions by nodes: interference
  - *Collision* if node receives two or more signals at the same time

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.
  - no out-of-band channel for coordination

AN IDEAL MULTIPLE ACCESS PROTOCOL

given: broadcast channel of rate *R* bps

desiderata:

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 synchronization of clocks, slots
4. simple

MAC PROTOCOLS: TAXONOMY

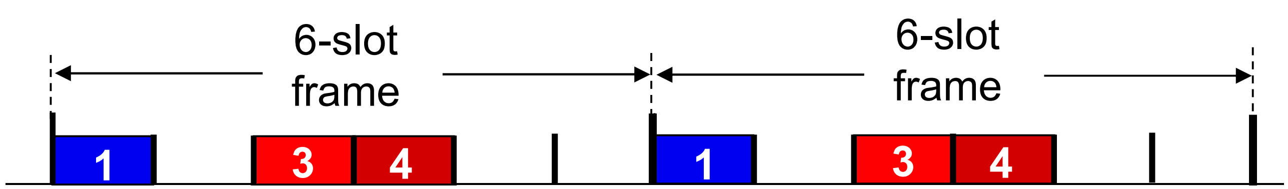
Three broad classes:

- 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”
  - nodes take turns, but nodes with more to send can take longer turns

CHANNEL PARTITIONING MAC PROTOCOLS: TDMA

TDMA: time division multiple access

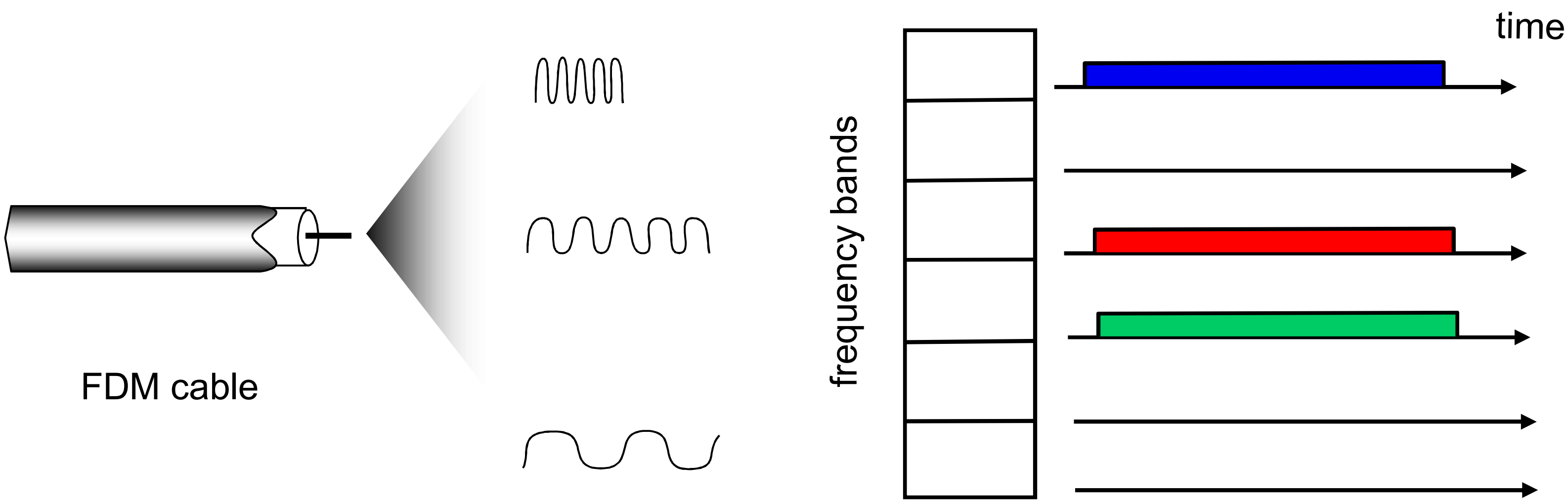
- Access to channel in "rounds"
- Each node gets fixed length slot (length = packet trans time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have packets, slots 2,5,6 idle



CHANNEL PARTITIONING MAC PROTOCOLS: FDMA

FDMA: frequency division multiple access

- Channel spectrum divided into frequency bands
- Each node 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 recover from collisions (e.g., via delayed retransmissions)
- Examples of random access MAC protocols:
  - Slotted ALOHA
  - ALOHA
  - CSMA, CSMA/CD, CSMA/CA

SLOTTED ALOHA

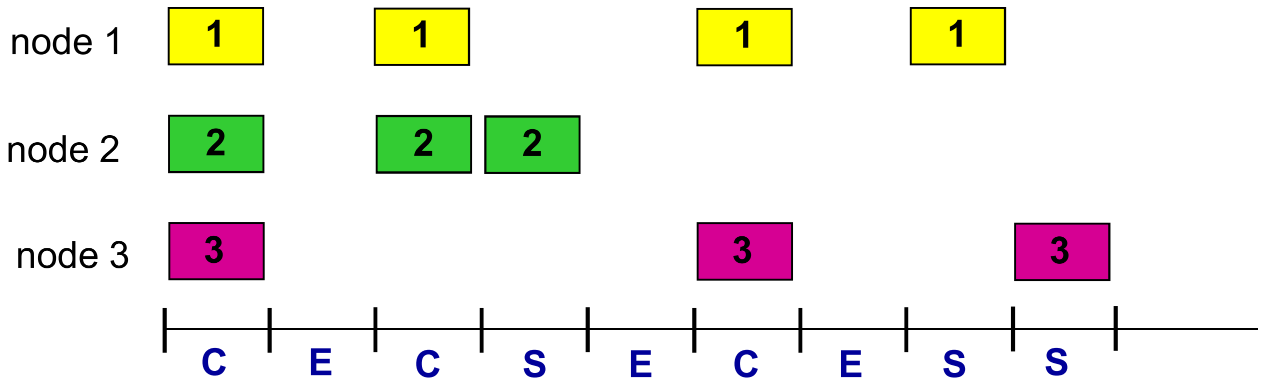
assumptions:

- All frames same size
- Time divided into equal size slots (time to transmit 1 frame)
- Nodes start to transmit only slot beginning
- Nodes are synchronized
- If two or more nodes transmit in slot, all nodes detect collision

operation:

- When node obtains fresh frame, transmits 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



Pros:

- Single active node can continuously transmit at full rate of channel
- Highly decentralized: only slots in nodes need to be in sync
- Simple

Cons:

- Collisions, wasting slots
- Idle slots
- Nodes may be able to detect collision in less than time to transmit packet
- 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 = $Np(1-p)^{N-1}$

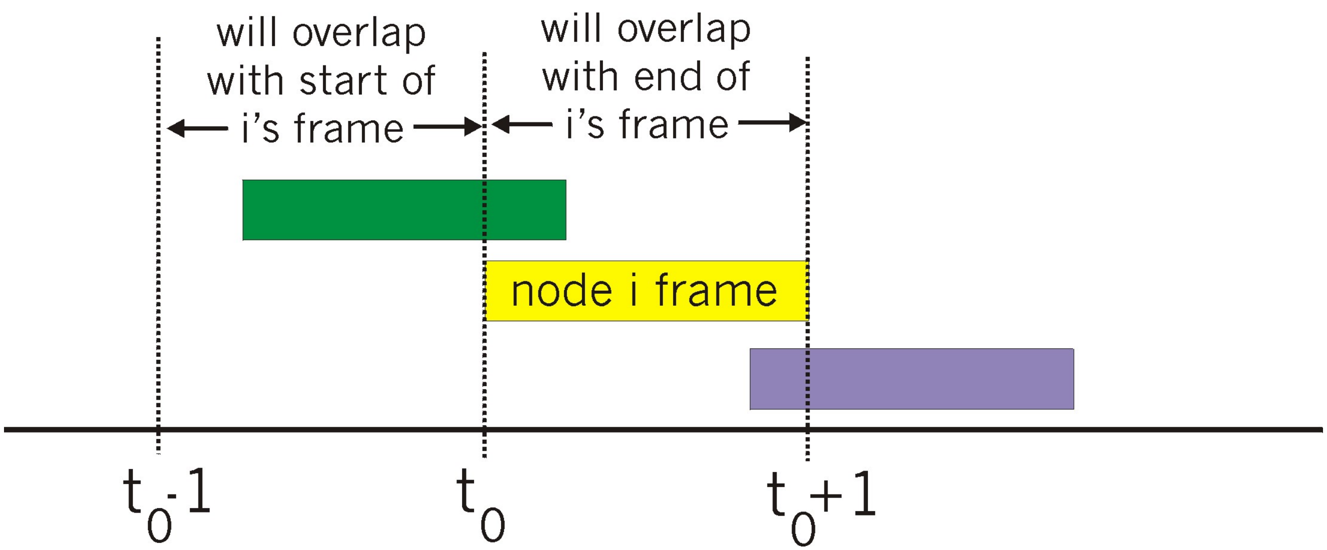
- max efficiency: find p* that maximizes $Np(1-p)^{N-1}$
- for many nodes, take limit of $Np^*(1-p^*)^{N-1}$ as N goes to infinity, gives:

max efficiency = 1/e = .37

at best: channel used for useful transmissions 37% of time!

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 $[t_0-1,t_0]$ ·

P(no other node transmits in $[t_0,t_0+1]$

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

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

… choosing optimum p and then letting $n \longrightarrow \infty$

$$= 1/(2e) = .18$$

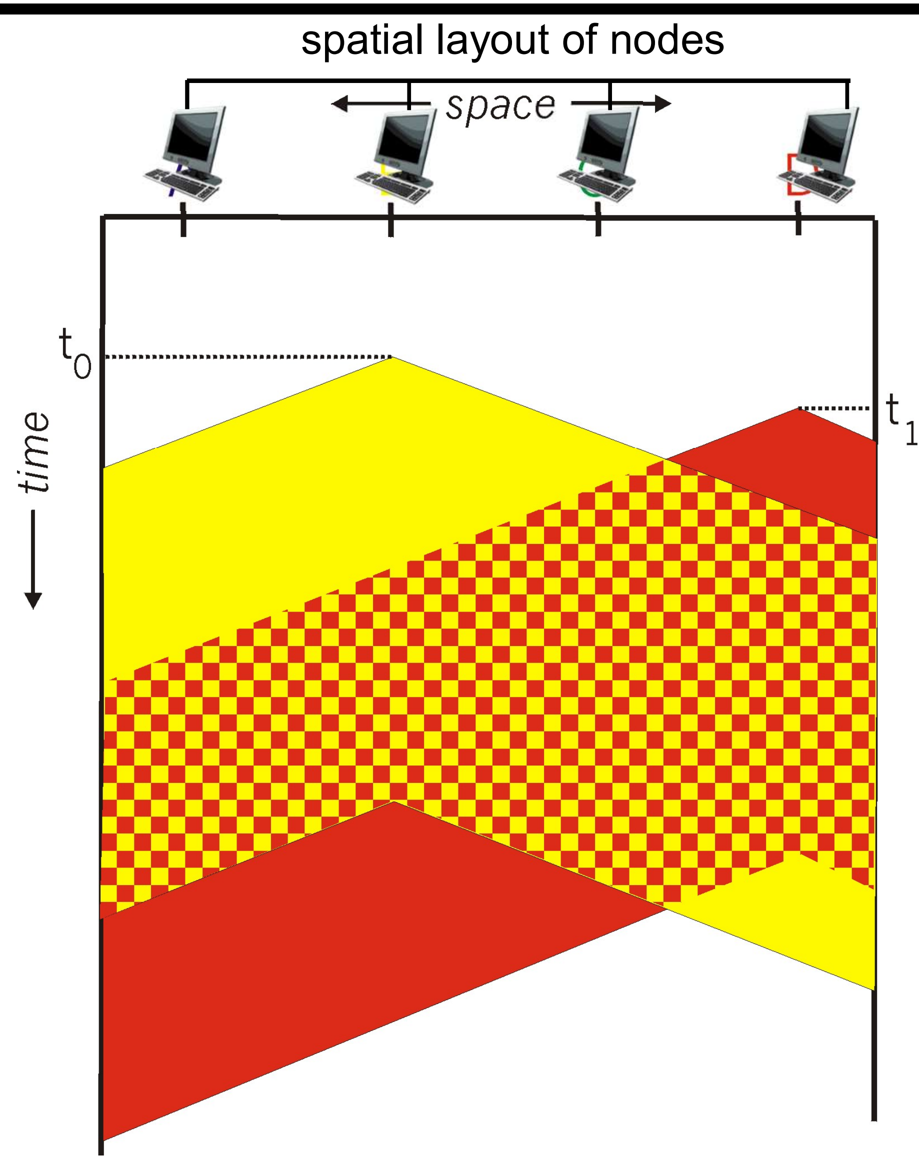
even *worse* than slotted Aloha!

CSMA: listen before transmit

- If channel sensed idle: transmit entire frame
- If channel sensed busy: defer transmission
- Human analogy: don’t interrupt others!

CSMA COLLISIONS

- collisions *can* still occur: propagation delay means two nodes may not hear each other's transmission
- Collision: entire packet transmission time wasted
  - Distance & propagation delay play role in determining collision probability



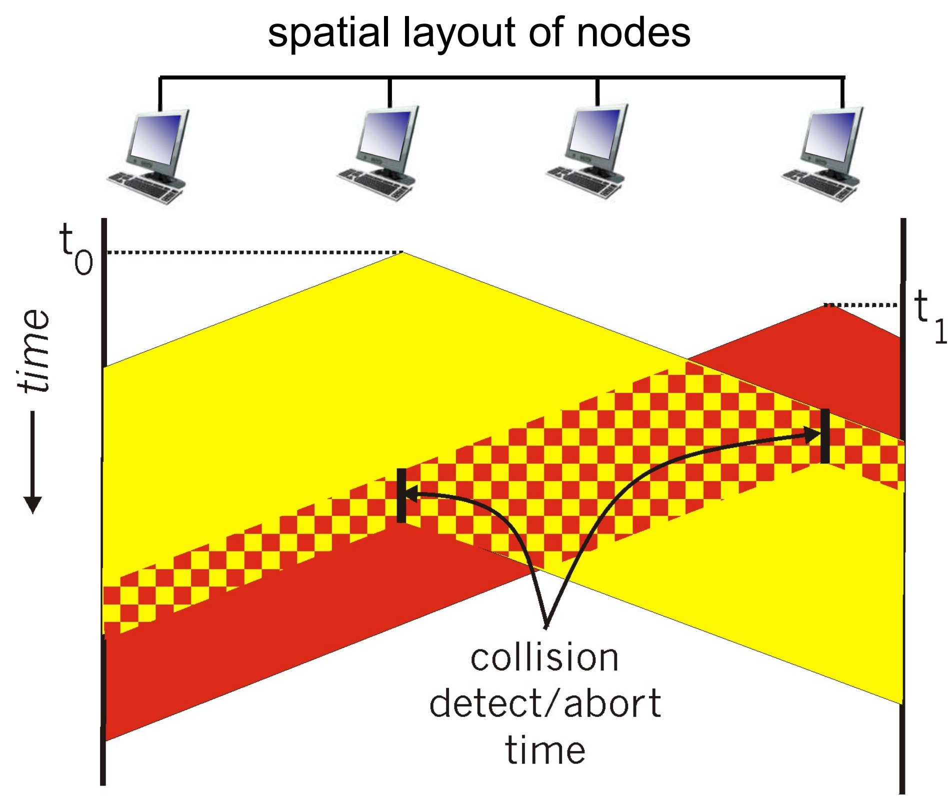
CSMA/CD (COLLISION DETECTION)

CSMA/CD: carrier sensing, deferral as in CSMA

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

- Collision detection:
  - easy in wired media: measure signal strengths, compare transmitted, received signals
  - difficult in wireless media: received signal strength overwhelmed by local transmission strength
- Human analogy: the polite conversationalist

CSMA/CD (COLLISION DETECTION)



CSMA/CA (COLLISION AVOIDANCE)

- CSMA/CA:
  - Wireless MAC protocols often use collision avoidance techniques, in conjunction with a (physical or virtual) carrier sense mechanism
  - To be discussed more in WiFi and 802.15.4 protocols
- Collision avoidance
  - Nodes hearing RTS or CTS stay silent for the duration of the corresponding transmission.
  - Once channel becomes idle, the node waits for a randomly chosen duration before attempting to transmit.
- Carrier sense
  - Nodes stay silent when carrier sensed (physical/virtual)
  - Physical carrier sense: carrier sense threshold
  - Virtual carrier sense using Network Allocation Vector (NAV): NAV is updated based on overheard RTS/CTS/DATA/ACK packets

“TAKING TURNS” MAC PROTOCOLS

Channel partitioning MAC protocols:

- Share channel *efficiently* and *fairly* at high load
- Inefficient at low load: delay in channel access, 1/N bandwidth allocated even if only 1 active node!

Random access MAC protocols

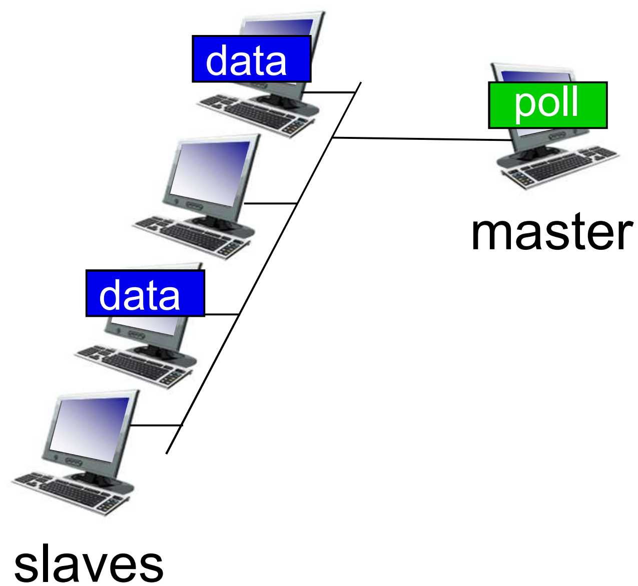
- Efficient at low load: single node can fully utilize channel
- High load: collision overhead

“taking turns” protocols

- Look for best of both worlds.

Polling:

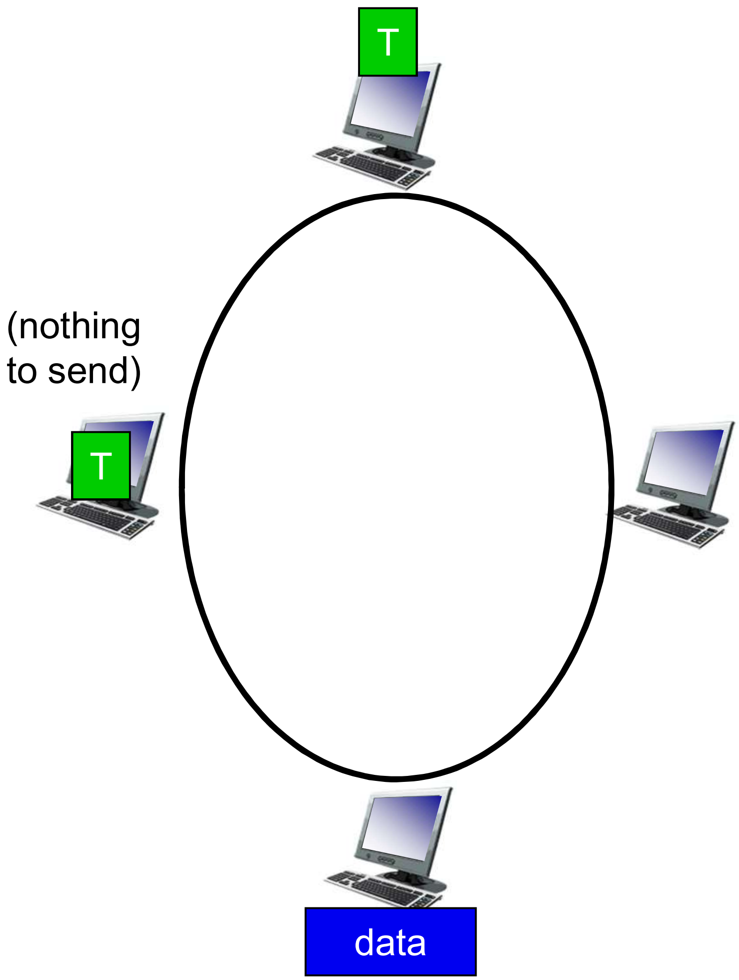
- Master node "invites" slave nodes to transmit in turn
- Typically used with "dumb" slave devices
- Concerns:
  - polling overhead
  - Latency
  - single point of failure (master)



“TAKING TURNS” MAC PROTOCOLS

Token passing:

- Control token passed from one node to next sequentially.
- Token message
- Concerns:
  - Token overhead
  - Latency
  - Single point of failure (token)



SUMMARY OF MAC PROTOCOLS

- Channel partitioning, by time, frequency or code
  - Time Division, Frequency 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, token ring