The Link Layer and Local Area Networks: Multiple Access Protocol

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Lecture 05

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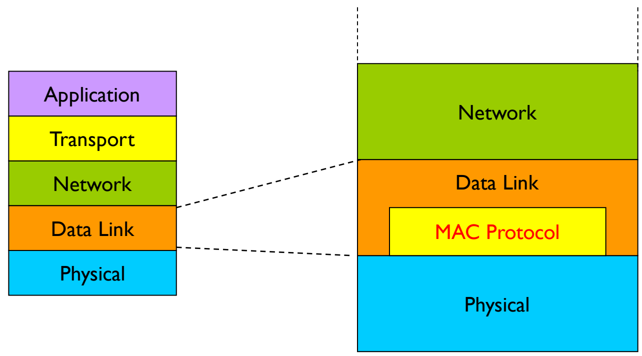
Overview: Medium Access Control (MAC) Protocol

- For example,
  - Crossing intersection
  - How to control vehicles without collision?
  - What is shared?
- MAC protocol:
  - Decide when competing nodes may access the shared medium
- In the event of collision?
  - A MAC protocol deals with through some contention resolution algorithm
  - For example,
    - Resending the packet later at a randomly selected time
    - Simply discard the packet and leave the retransmission to upper layer

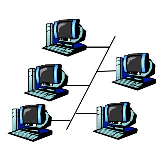
Medium Access Layer

- Where is medium access layer?
- Part of the data link layer:
  - Medium Access Control (MAC) Protocol



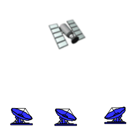
Multiple Access Links and Protocols

- two types of "links":
  - point-to-point
    - PPP for dial-up access
    - point-to-point link between Ethernet switch and host
  - broadcast (shared wire or medium)
    - old-fashioned Ethernet
    - 802.11 wireless LAN



shared wire (e.g., cabled Ethernet)

shared RF (e.g., 802.11 WiFi)



shared RF (satellite)

humans at a cocktail party (shared air, acoustical)

Multiple Access Protocols

- single shared broadcast channel
- two or more simultaneous transmissions by nodes: **interference**
  - collision if a 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

Ideal Multiple Access Protocol

- broadcast 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 synchronization of clocks, slots
  - 4. simple

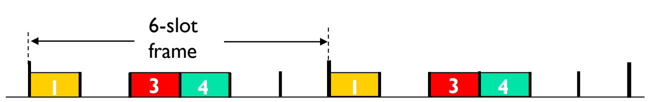
MAC Protocols: a taxonomy

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

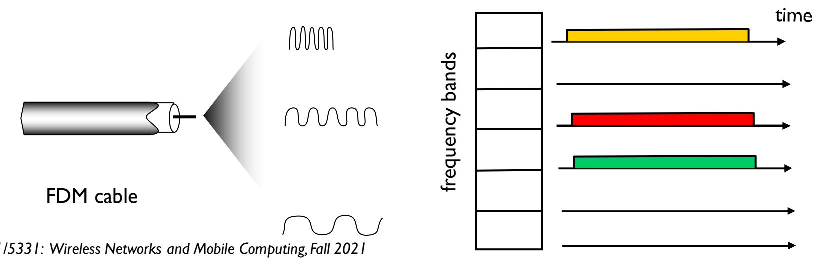
Channel Partitioning MAC Protocols: TDMA

- TDMA: time division multiple access
  - access to channel in "rounds"
  - each station gets fixed length slot (length = pkt trans time) in each round
  - unused slots go idle
  - no collision and perfectly fair
    - a node is limited to an average rate of R/N
  - 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
  - no collision and perfectly fair
    - a node is limited to an average rate of R/N
  - example: 6-station LAN, 1,3,4 have pkt, frequency bands 2,5,6 idle



Random Access Protocols

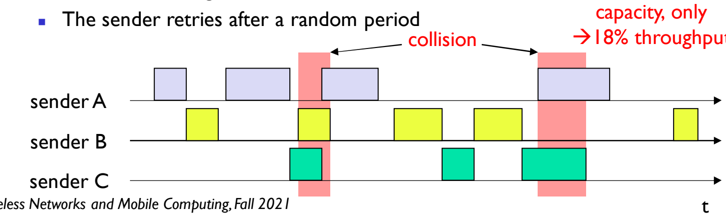
- When a node has a packet to send
  - transmit at full channel data rate R
  - no *a* ***priori*** coordination among nodes
- two or more transmitting nodes ➜ "**collision**"
  - wait a **random delay** before re-transmitting the frame
  - each node will choose independent random delay

- 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

TDMA-based Medium Access: ALOHA

- In the classic (pure) ALOHA protocol,
  - Developed for packet radio networks in the 1970s
  - A node simply transmits a packet, when it is generated
    - Random access (no central arbiter), and time-multiplex
  - If no other node is sending at the same time?
    - The data transmission succeeds
    - The receiver responds with an ACK
  - In case of a collision?
    - No ACK will be generated
    - The sender retries after a random period

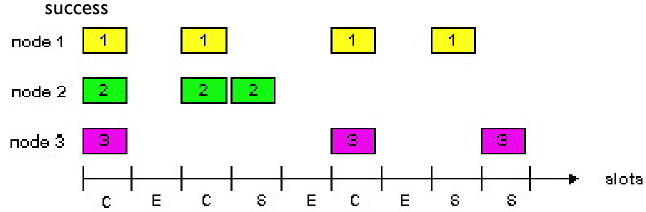
What is a potential problem here?
poor use of channel capacity, only →18% throughput



CS4331/5331: *Wireless Networks and Mobile Computing, Fall 2021*

Slotted ALOHA

- assumptions:
  - all frames same size (L bits)
  - time divided into equal size slots (time to transmit 1 frame, L/R secs)
  - nodes start to transmit only slot beginning
  - nodes are synchronized – each node knows when the slots begin
  - if 2 or more nodes transmit in slot, all nodes detect collision before the slot ends
- 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



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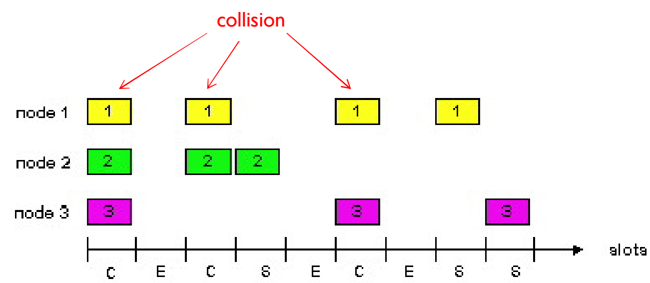
Slotted ALOHA (cont.)

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



CSMA (Carrier Sense Multiple Access)

- **CSMA**: listen before transmit:
  - if channel is sensed **idle**, transmit entire frame
  - if channel is sensed **busy**, defer transmission
    - wait a random amount of time (**back off**) and again sense the channel
- human analogy: don't interrupt others!
  - listen before speaking
    - node listen to the channel before transmitting, **carrier sensing**
  - if someone else begins talking at the same time, stop talking
    - **collision detection**

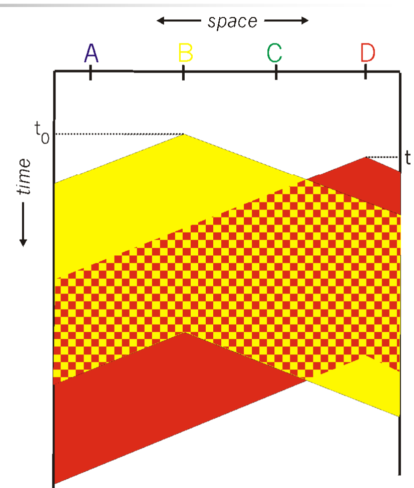
CSMA Collisions

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

channel propagation delay

collision:
entire packet transmission time wasted

note: role of distance & propagation delay in determining collision probability
→ Longer propagation delay, larger the chance that a carrier-sensing node is not yet able to sense a transmission



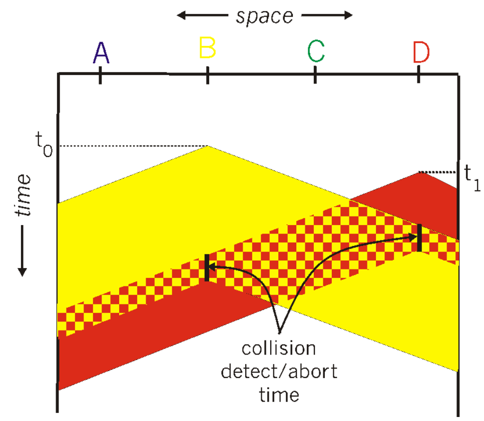
spatial layout of nodes

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
  - difficult in **wireless LANs**: received signal strength overwhelmed by local transmission strength
    - CSMA/CA (**Collision Avoidance**)

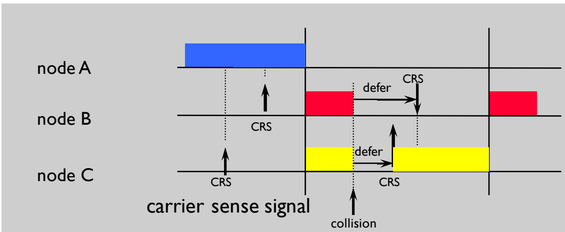
CSMA/CD (Collision Detection) (cont.)

Perform collision detection:
two nodes each abort their transmission a short time after detecting a collision



CSMA/CD (Collision Detection) (cont.)

- for example,
  - if channel is sensed **idle**, transmit entire frame
  - if channel is sensed **busy**, defer transmission
    - wait a random amount of time (**back off**) and again sense the channel

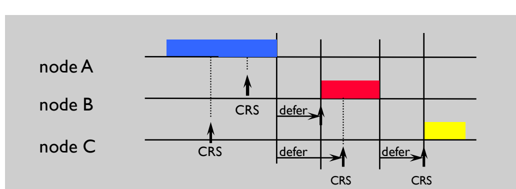


CSMA/CD (Collision Detection) (cont.)

- Why not CSMA/CD in wireless networks?
  - In wired networks,
    - The sender is the one detecting collision
    - If a collision happens somewhere in the wire, everybody will notice it
  - In wireless networks,
    - The sender can detect an idle medium, but a collision happens at the receiver
    - Most radios are half-duplex,
      - Send or receive, not simultaneously
  - Hidden terminal problem
  - Exposed terminal problem

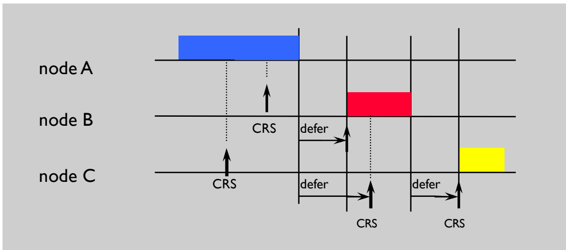
Contention-based Medium Access: CSMA/CA

- Carrier Sense Multiple Access/ Collision Avoidance (CSMA/CA):
  - Similar to CSMA,
    - Carrier sensing:
      - First, listen to the media to determine if it is free
    - Collision avoidance:
      - Minimize chance for collision by **starting** (random) back-off timer, when medium is sensed free, and prior to transmission



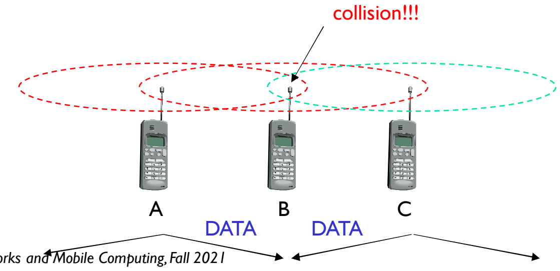
Contention-based Medium Access: CSMA/CA (cont.)

- Carrier Sense Multiple Access/ Collision Avoidance (CSMA/CA): (cont.)
  - Overview



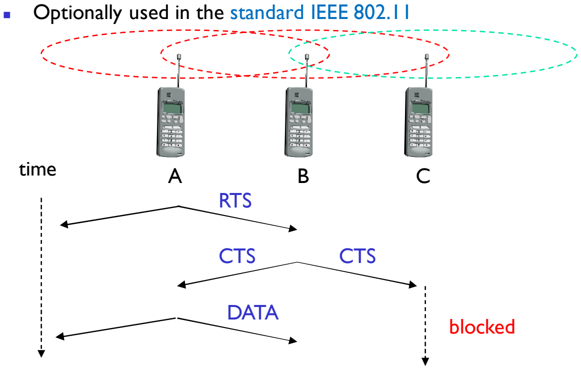
Multiple Access with Collision Avoidance (MACA)

- Multiple Access with Collision Avoidance (MACA)
  - Use short signaling packets for collision avoidance
- RTS (Request To Send)
  - Sender requests the right to send from a receiver with a short RTS packet before it sends a data packet
- CTS (Clear To Send)
  - Receiver grants the right to send as soon as it is ready to receive



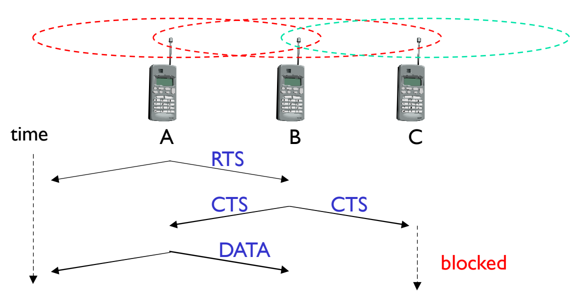
MACA: Hidden Terminal Problem (cont.)

- Hidden terminal problem,
  - Resolved through RTS/CTS signaling
  - What if both A and C sends a RTS?
    - Optionally used in the standard IEEE 802.11



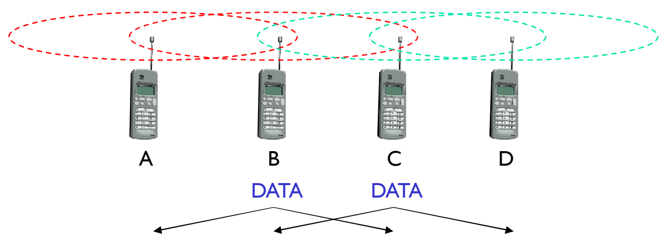
MACA: Hidden Terminal Problem (cont.)

- Hidden terminal problem, (cont.)
  - When the data is received correctly?
    - An explicit ACK is sent back to the sender
  - If the sender does not receive the ACK in due time?
    - Initiate a retransmission to account for the corrupted or lost data



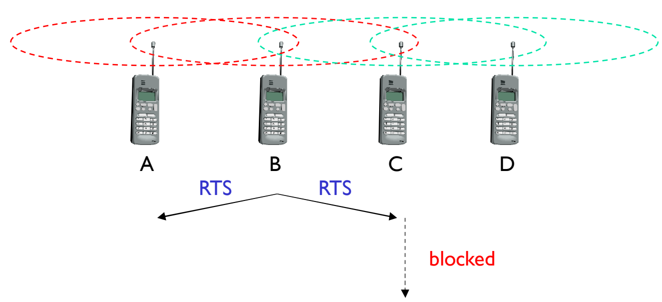
MACA: Exposed Terminal Problem

- Exposed terminal problem,
  - B wants to send to A, and C wants to send to D, concurrently
    - The signals from B cannot disturb the reception at D
    - C senses a busy medium caused by the transmission from B
      - → C defers, although C could never cause a collision at A



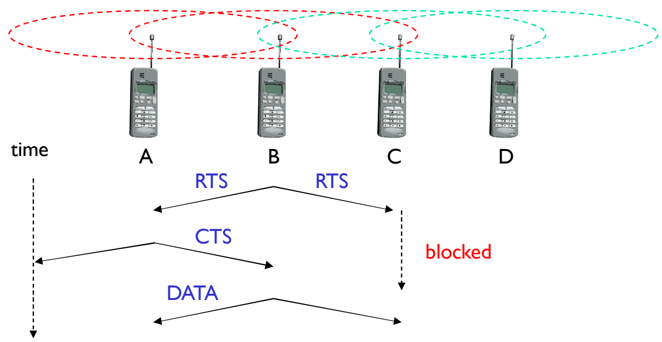
MACA: Exposed Terminal Problem (cont.)

- Exposed terminal problem, (cont.)
  - Since B must be able to receive the CTS by A
    - *All nodes* who can hear B's RTS packet must remain silent, even if they are outside the reach of the receiver A.
  - Now C is "*exposed*" to B's transmission (and vice versa)



MACA: Exposed Terminal Problem (cont.)

- Exposed terminal problem, (cont.)
  - Resolved through RTS/CTS signaling (three-way handshaking)



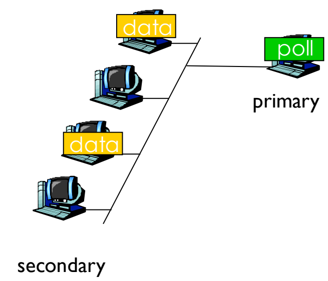
"Taking Turns" MAC Protocols

- 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!

“Taking Turns” MAC Protocols (cont.)

polling:

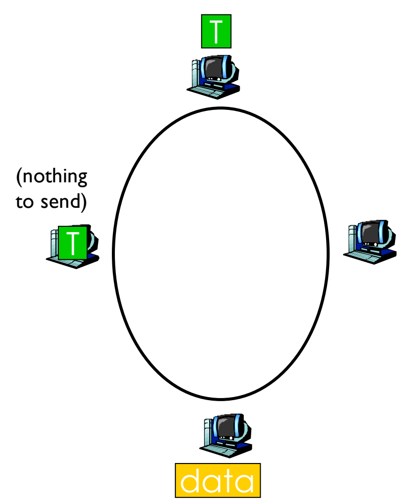
- primary node “**invites**” secondary nodes to transmit in turn
- typically used with “dumb” secondary devices
- eliminate the collisions
- concerns:
  - polling overhead
  - latency
  - single point of failure (primary)



“Taking Turns” MAC Protocols (cont.)

token passing:

- control **token** passed from one node to next sequentially
- token message
- concerns:
  - token overhead
  - latency
  - single point of failure (token)
  - neglect to release the 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, Fiber Distributed Data Interface (FDDI), IBM Token Ring

IEEE 802.11

- IEEE computer society published the IEEE 802.11 wireless LAN standard
  - Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications,
  - http://standards.ieee.org/getieee802/download/802.11-2007.pdf
- Operated in the 2.4 GHz or 5 GHz band
- Dual modes:
  - Infrastructure mode
  - Ad-hoc mode
- Reference papers,
  - S. Choi, "Overview of Emerging IEEE 802.11 Protocols for MAC and Above," SK Telecom Telecommunications Review, Special Issue on Wireless Communications and Broadcasting Standards, November 2003
  - Youngsoo Kim, Jeonggyun Yu, Sunghyun Choi, and Kyunghun Jang, "A Novel Hidden Station Detection Mechanism in IEEE 802.11 WLAN," IEEE Communications Letters, vol. 10, no. 8, pp. 608-610, August 2006