Wireless Networks
(CSC-7602)
Lecture 3
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Multiple Access Links and Protocols

Two types of "links":
- point-to-point  -> no need to have MAC
  - PPP for dial-up access
  - point-to-point link between Ethernet switch and host
- broadcast (shared wire or medium)
  - traditional Ethernet
  - 802.11 wireless LAN

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
**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

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**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
Classification of Multiple Access Protocols

- **Contention-based**
  - Random access
    - ALOHA, CSMA, BTMA, ISMA, etc
  - Collision resolution
    - TREE, WINDOW, etc

- **Conflict-free**
  - FDMA, TDMA, CDMA, Token Bus, DQDB, etc
  - DQDB: Distributed Queue Dual Bus
  - BTMA: Busy Tone Multiple Access
  - ISMA: Internet Streaming Media Alliance

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
- example: 6-station LAN, 1,3,4 have pkt, slots 2,5,6 idle

- TDM (Time Division Multiplexing): channel divided into N time slots, one per user; inefficient with low duty cycle users and at light load.
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

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<table>
<thead>
<tr>
<th>Frequency bands</th>
<th>Time</th>
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- FDM (Frequency Division Multiplexing): frequency subdivided.

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 $\rightarrow$ "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 is divided into equal size slots, time to transmit 1 frame
- nodes start to transmit frames only at beginning of slots
- nodes are synchronized
- if 2 or more nodes transmit in slot, all nodes detect collision

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

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** is the long-run fraction of successful slots when there are many nodes, each with many frames to send.

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

For max efficiency with $N$ nodes, find $p^*$ that maximizes $Np(1-p)^{N-1}$
- Optimal $p^* = 1/N$

For many nodes, take limit of $Np^*(1-p^*)^{N-1}$ as $N$ goes to infinity, gives $1/e = .37$
- Maximum = $(1-1/N)^{N-1}$
  - $= (1-1/N)^N / (1-1/N)^1$

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

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**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 $[t_0-1, t_0+1]$

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**Graph:**
- Frame overlaps with start or end of node's frame
- Intersection of frames at $t_0$
Pure Aloha efficiency

\[ P(\text{success by given node}) = P(\text{node transmits}) \times \]
\[ P(\text{no other node transmits in } [t_{n-1}, t_n]) \times \]
\[ P(\text{no other node transmits in } [t_n, t_{n+1}]) \]
\[ = p \cdot (1-p) \times (1-p) \]
\[ = p \cdot (1-p)^2 \]
\[ \ldots \]
choosing optimum \( p \) and then letting \( n \to \infty \) ...
\[ = \frac{1}{2e} \approx .18 \]

Even worse!

CSMA (Carrier Sense Multiple Access)

**CSMA**: listen before transmit:
- If channel sensed idle: transmit entire frame
- If channel sensed busy, defer transmission
- Human analogy: don’t interrupt others!
Nonpersistent/x-persistent CSMA Protocols

- **Nonpersistent CSMA Protocol:**
  - **Step 1:** If the medium is idle, transmit immediately
  - **Step 2:** If the medium is busy, wait a random amount of time and repeat Step 1
    - Random backoff reduces probability of collisions
    - Waste idle time if the backoff time is too long

- **1-persistent CSMA Protocol:**
  - **Step 1:** If the medium is idle, transmit immediately (with prob. 1)
  - **Step 2:** If the medium is busy, continue to listen until medium becomes idle, and then transmit immediately
    - There will always be a collision if two nodes want to retransmit (usually you stop transmission attempts after few tries)

- **p-persistent CSMA Protocol:**
  - **Step 1:** If the medium is idle, transmit with probability $p$, and delay for worst case propagation delay for one packet with probability $(1-p)$
  - **Step 2:** If the medium is busy, continue to listen until medium becomes idle, then go to Step 1
  - **Step 3:** If transmission is delayed by one time slot, continue with Step 1
    - A good tradeoff between nonpersistent and 1-persistent CSMA
Efficiency

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

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
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: receiver should shut off while transmitting
“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
- concerns:
  - polling overhead
  - latency
  - single point of failure (master)

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

- What do you do with a shared media?
  - Channel Partitioning, by time, frequency or code
    - Time Division, Frequency Division
  - Random partitioning (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 a central site, token passing