Link Layer
Multiple Access Protocols

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Assignment #1

- Web proxy server
  - users want to anonymize themselves from the Web server
  - a corporation wants to monitor or restrict employees' Web surfing
  - cache data to reduce the amount of global traffic
- HTTP protocol
- Multithreading
- Persistent connection

Recap of Last Class

- Link layer: handle data transfer between neighboring network elements
  - Encoding: encode binary data into electromagnetic signals
  - Framing: encapsulate data into frame, adding header, trailer
  - Error detection and correction: receiver identifies and corrects bit error(s)

Multiple Access Links

- Two types of “links”:
  - point-to-point duplex and shared wire or medium
- Multiple access link:
  - single shared broadcast channel
  - two or more simultaneous transmissions by nodes ⇒ interference
  - only one node can send successfully at a time

Application
Transport
Network
Link
Physical
**Multiple Access Protocol**

Multiple access protocol:
- distributed algorithm that determines how nodes share channel, i.e., determine when nodes can transmit
- communication about channel sharing must use channel itself!

Objectives:
- Performance – for a multiple access channel of rate R bps:
  - when one node wants to transmit, it can send at rate R
  - when M nodes want to transmit, each can send at average rate R/M
- Robustness
  - no special node to coordinate transmissions
  - no synchronized clocks

**Types of Multiple Access Protocols**

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
- **Centrally controlled/coordinated**
  - centrally coordinate shared access to avoid collisions

**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

**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, freq. bands 2,5,6 idle
**Channel Partitioning MAC protocols:**

**C (code) DMA**
- Use coding to partition channel
- Each user has its unique code
  - Encoded signal: (original data) X (code)
  - Decoding: (encoded signal) X (code)
- Inner product
  - All codes consist of 1, -1 bits
  - Any bit sequence multiplying itself becomes 1

**CDMA: Two-sender Interference**
- Allow multiple users to transmit simultaneously (if code1 X code2 = 0).
- Combined signal is "data1 X code1 + data2 X code2"

**How good are Channel Partitioning Protocols?**
- Performance – for a multiple access channel of rate R bps:
  - When all M nodes want to transmit, each can send at rate R/M
  - When one node wants to transmit, it can send at rate R/M inefficient!
- Robustness
  - No special node to coordinate transmissions
  - Synchronized clocks for all but FDMA

**Random Access Protocols**
- When node has data to send
  - Transmit at full channel data rate R.
  - No a priori coordination among nodes.
- Two or more transmitting nodes -> "collision"
- Random access protocol specifies:
  - How to detect collisions
  - How to recover from collisions (e.g., via delayed retransmissions)
Slotted ALOHA (Abramson)

**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 probability $p$ until success
- **why not retransmit right away?**

**Pros**
- single active node can continuously transmit at full rate of channel

**Cons**
- wasting slots (collisions, idle slots)
- require nodes to be synchronized

Slotted ALOHA Efficiency

**Efficiency** is the long-run fraction of successful slots (assuming each node always has frames to send)

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

- For max efficiency with $N$ nodes, find $p^*$ that maximizes $Np(1-p)^{N-1}$
  - find $p^*$ for $N=1$ and $N=2$?
  - find $p^*$ for any $N$?

- For many nodes, take limit of $Np^*(1-p^*)^{N-1}$ as $N$ goes to infinity, gives $1/e = .37$
  - successful channel transmissions at 37% of the time!

Pure (unslotted) ALOHA

- Unslotted Aloha: no synchronization
- When frame first arrives, transmit immediately
- Collision probability increases:
  - frame sent at $t_c$ collides with other frames sent in $[t_c-1,t_c+1]$
Pure Aloha Efficiency

\[
P(\text{success by given node}) = P(\text{node transmits}) \times P(\text{no other node transmits in } [t_0-1, t_0]) \times P(\text{no other node transmits in } [t_0, t_0+1])
\]

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

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

choosing optimum \( p \) and then letting \( n \to \infty \) ...

\[
= 1/(2e) = .18
\]

Half as efficient as slotted Aloha!

CSMA (Carrier Sense Multiple Access)

CSMA: listen before transmit:
- If channel sensed idle: transmit entire frame
- If channel sensed busy: defer transmission

Human analogy: listen before speaking!

CSMA Collisions

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

Chance of collision: depends on distance & propagation speed

Collision: entire packet transmission time wasted

CSMA/CD (Collision Detection)

CSMA/CD: carrier sensing, same as in CSMA
- collisions detected within short time
- colliding transmissions aborted, reducing channel wastage

Human analogy: if too many people are talking so no one can hear clearly, stop talking.

What if your packet transmission completes before signal from another packet arrives?
How good are Random Access Protocols?

- Performance – for a multiple access channel of rate $R$ bps:
  - when one node wants to transmit, it can send at full rate $R$.
  - when all $M$ nodes want to transmit, each can send at average rate less than $R/M$. Not ideal but sometimes close!

- Robustness (decentralization):
  - no special node to coordinate transmissions
  - no synchronized clocks except for slotted ALOHA

“Centrally Controlled” MAC protocols

Polling:
- control node “invites” regular nodes to transmit in turn
- concerns:
  - single point of failure (control node)
  - polling overhead (bandwidth & latency)

Token passing:
- control token passed from one node to next sequentially.
- transmit only when holding the token
- concerns:
  - single point of failure (token)
  - token overhead (bandwidth & latency)

Summary of MAC protocols

- Channel partitioning
  - Time Division, Frequency Division, Code Division
- Random access
  - ALOHA, S-ALOHA, CSMA, CSMA/CD
- Centrally controlled
  - polling from a central site, controlled by a token

- Comparison on performance and robustness

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