Chapter 5: The Data Link Layer

Our goals:
- understand principles behind data link layer services:
  - sharing a broadcast channel: multiple access
  - error detection, correction
  - link layer addressing
  - reliable data transfer, flow control: done!
- instantiation and implementation of various link layer technologies

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
  - upstream HFC
  - 802.11 wireless LAN

Ideal Multiple Access Protocol

Broadcast channel of rate $R \text{ bps}$
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

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 divided into equal size slots (time to transmit 1 frame)
- nodes start to transmit only slot beginning
- nodes are synchronized
- if 2 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

**Efficiency**

- Long-run fraction of successful slots (many nodes, all with many frames to send)
- 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 $= \frac{1}{e} = .37$

**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 $[t_0-1,t_0+1]$?
  - Will overlap with start of $i$’s frame
  - Will overlap with end of $i$’s frame

**Efficiency**

- $P(success \ by \ given \ node) = P(node \ transmits)$
- $P(no \ other \ node \ transmits \ in \ [p_0-1,p_0])$
  - $P(success) = p \cdot (1-p) \cdot (1-p)^{N-1}$
  - Choosing optimum $p$ and then letting $n \to \infty$
  - $\Rightarrow 1/(2e) = .18$

Even worse than slotted ALOHA!

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**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!

**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: received signal strength overwhelmed by local transmission strength
- human analogy: the polite conversationalist

**“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!

**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, IBM Token Ring
Chapter 5: Let’s take a breath

- Journey down protocol stack *complete* (except PHY)
- Solid understanding of networking principles, practice
- ..... could stop here .... but *lots* of interesting topics!
  - wireless
  - multimedia
  - security
  - network management