Last Time …

- Error detection and correction
- Redundant bits are added to messages to protect against transmission errors.
- Two recovery strategies are retransmissions (ARQ) and error correcting codes (FEC).
- The Hamming distance tells us how much error can safely be tolerated.

This Lecture

- Key Focus: How do multiple parties share a wire? We want the benefits of statistical multiplexing …
- This is the Medium Access Control (MAC) portion of the Link Layer
- Randomized access protocols:
  1. Aloha
  2. CSMA variants
  3. Classic Ethernet
1. ALOHA

- Wireless links between the Hawaiian islands in the 70s
- Want distributed allocation
  - no special channels, or single point of failure
- Aloha protocol:
  - Just send when you have data!
  - There will be some collisions of course …
  - Detect errored frames and retransmit a random time later
- Simple, decentralized and works well for low load
  - For many users, analytic traffic model, max efficiency is 18%

2. Carrier Sense Multiple Access

- We can do better by listening before we send (CSMA)
  - good defense against collisions only if "a" is small (LANs)

  \[
  a = \text{bandwidth} \times \text{delay} / \text{packet size}
  \]
  - Small (<<1) for LANs, large (>>1) for satellites

What if the Channel is Busy?

- 1-persistent CSMA
  - Wait until idle then go for it
  - Blocked senders can queue up and collide
- non-persistent CSMA
  - Wait a random time and try again
  - Less greedy when loaded, but larger delay
- p-persistent CSMA
  - If idle send with prob p until done; assumed slotted time
  - Choose p so p^* # senders < 1; avoids collisions at cost of delay
CSMA with Collision Detection

• Even with CSMA there can still be collisions. Why?

Time for B to detect A’s transmission

![Diagram](wire)

• For wired media we can detect all collisions and abort (CSMA/CD):
  – Requires a minimum frame size (“acquiring the medium”)
  – B must continue sending (“jam”) until A detects collision

3. Classic Ethernet

• IEEE 802.3 standard wired LAN (1-persistent CSMA/CD)
  – Classic Ethernet: 10 Mbps over coaxial cable
    – Baseband signals, Manchester encoding, preamble, 32 bit CRC

• Newer versions are much faster
  – Fast (100 Mbps), Gigabit (1 Gbps)
• Modern equipment isn’t one long wire
  – Hubs and switches

Modern (Ethernet II) Frames

<table>
<thead>
<tr>
<th>Preamble (8)</th>
<th>Dest (6)</th>
<th>Source (6)</th>
<th>Type (2)</th>
<th>Payload (var)</th>
<th>Pad (var)</th>
<th>CRC (4)</th>
</tr>
</thead>
</table>

• Min frame 64 bytes, max 1500 bytes
• Max length 2.5km, max between stations 500m (repeaters)
• Addresses unique per adaptor; 6 bytes; globally assigned
• Broadcast media is readily tapped:
  – Promiscuous mode; multicast addresses
Binary Exponential Backoff

- Build on 1-persistent CSMA/CD
- On collision: jam and exponential backoff
  - Jamming: send 48 bit sequence to ensure collision detection
- Backoff:
  - First collision: wait 0 or 1 frame times at random and retry
  - Second time: wait 0, 1, or 3 frame times
  - Nth time (N<10): wait 0, 1, …, $2^{N-1}$ times
  - Max wait 1023 frames, give up after 16 attempts
  - Scheme balances average wait with load

Ethernet Capture

- Randomized access scheme is not fair
- Stations A and B always have data to send
  - They will collide at some time
  - Suppose A wins and sends, while B backs off
  - Next time they collide and B’s chances of winning are halved!

Ethernet Performance

- Much better than Aloha or CSMA!
  - Works very well in practice
- Source of protocol inefficiency: collisions
  - More efficient to send larger frames
    - Acquire the medium and send lots of data
  - Less efficient as the network grows in terms of frames
    - recall $a = \text{delay} \times \text{bandwidth} / \text{frame size}$
    - $a$ grows as the path gets longer (satellite)
    - $a$ grows as the bit rates increase (Fast, Gigabit Ethernet)
Key Concepts

- Ethernet (CSMA/CD): randomness can lead to an effective distributed means of sharing a channel