Announcements

- Homework #2 was returned
- Reading
  - Today: 3.1-3.2

Data Link Layer

- Goal: transmit error free frames over the physical link
- Sample Issues:
  - how big is a frame?
  - can I detect an error in sending the frame?
  - what demarks the end of the frame?
  - how to control access to a shared channel?
- Examples:
  - Ethernet framing

Frames

- Slice Raw bit stream up into frames
  - need to have manageable unit of transmission
- Frame Boundary
  - How do we know when a frame ends?
  - Character count
    - header indicates number of bytes
    - problem: what if the header is corrupt, can't tell end of frame
  - Special character
    - ASCII: DLE STX … DLE STE
    - need to use character stuffing to send DLE characters
      - send two DLE to indicate a DLE
  - Special bit pattern - no longer tied to ASCII
    - 01111110 - indicates end of frame
    - need to use bit stuffing to send 01111110 as data
      - insert 0 after 5 1's
  - use link level invalid bit patterns
    - some bits may not be valid

Other Link Functions

- Error Control
  - may want to do sequence numbers and re-transmission
  - this introduces overhead, but useful if probability of failure is high
- Flow Control
  - provide rate matching between sender and receiver
  - sender has rules about when it can send: credits, etc.

Error Correcting Codes

- Idea: add redundant information to permit recovery
  - this is the dual of data compression (remove redundancy)
- Hamming distance (n)
  - number of bit positions that differ in two words
  - key idea: need n single bit errors to go from one word to the other
  - to detect d errors, need a hamming distance of d+1 from **any other valid word.**
  - to recover d errors, need a hamming distance of 2d + 1
    - any error of d bits is still closer to correct word
- Parity bit
  - ensure that every packet has an odd (or even) # of 1's
  - permits detection of one 1 bit error

Error Codes (cont.)

- Error Recovery
  - Given m bits of data and r bits of error code
  - Want to correct any one bit error
  - There are n words one bit from each valid message
    - so need n+1 words for each valid message
    - thus $(n + 1)\ 2^m <= 2^n$
    - but $n = m + r$ so $(m + r + 1) <= 2^r$
- Hamming Code
  - recovers from any one bit error
  - number bits from left (starting at 1)
    - power of two bits are parity
    - rest contain data
  - bit is checked by all parity bits in its sum of power expansion
    - bit 11 is used to compute parity bits 1, 2, and 8v

Hamming Code Example

Char	ASCII	Hamming
H	1001000	00110010000
a	1100001	10111001001
m	1101101	11101010101
I	1101001	01101011001

- Burst Errors
  - can send hamming codes by column rather than row
  - if use k rows, then can detect any burst error up to k bits
    - uses kr bits to check a block km bits long