Announcements

- Reading
  - Today:3.1-3.3
  - Tuesday: 3.5-3.6
  - section 3.4 was covered before (during session)

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
l	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

Error Detection

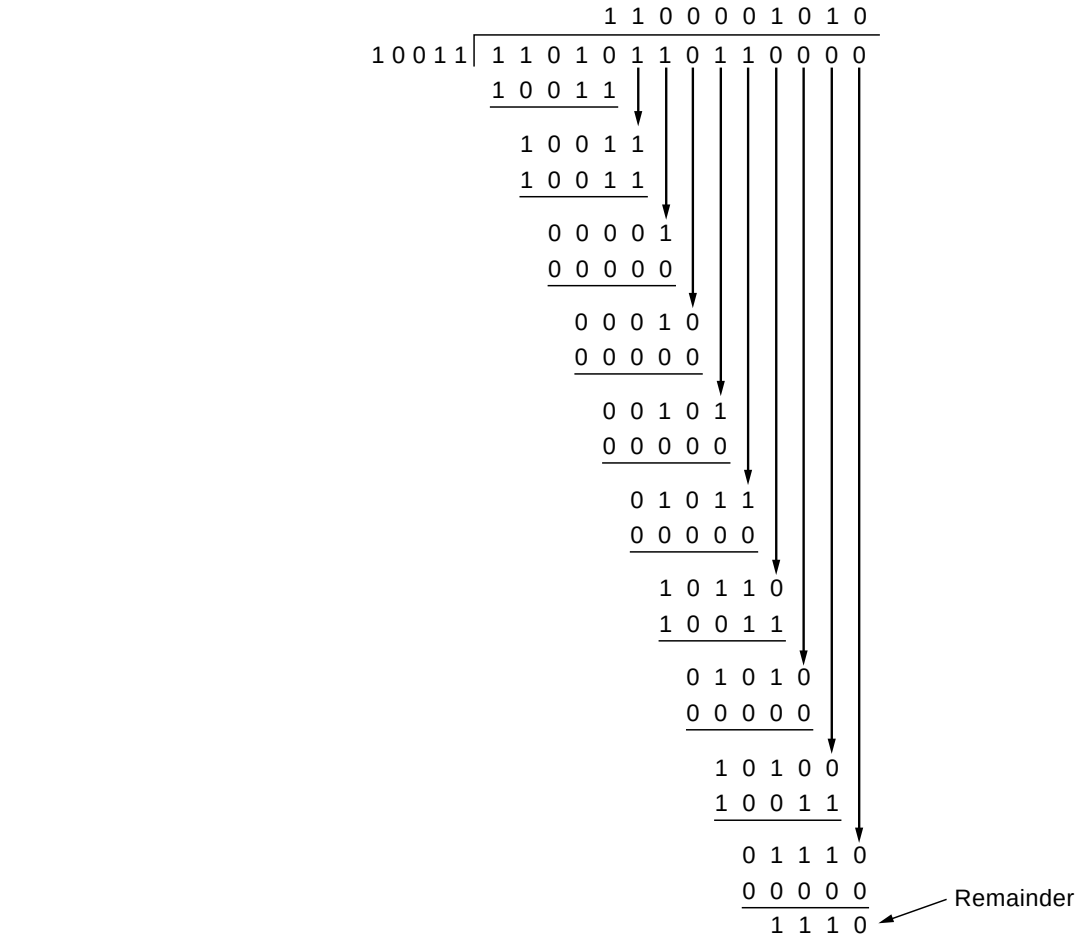
- Less bits are required
  - if errors are infrequent, then then this works better
  - assumes that re-transmission is possible
- Cyclic Redundancy Codes (CRC)
  - Use a generator function G(x) of degree r
  - let M' be the message with r 0's on the end of it
  - divide M' into G(x) and compute remainder
    - use this as the r bit CRC code
  - a code with r bits will detect all burst errors less than r bits
  - several G's are standardized
    - CRC-12 = $x^{12} + x^{11} + x^3 + x^2 + x + 1$
    - CRC-16 = $x^{16} + x^{15} + x^2 + 1$
    - CRC-CCITT = $x^{16} + x^{12} + x^5 + 1$
  - 16 bit CRC will catch
    - all single and double bit errors
    - all errors with an odd number of bits
    - all burst errors of length less than 16

CRC Example

Frame : 1 1 0 1 0 1 1 0 1 1

Generator: 1 0 0 1 1

Message after appending 4 zero bits: 1 1 0 1 0 1 1 0 0 0 0



Transmitted frame: 1 1 0 1 0 1 1 0 1 1 1 1 1 0

Data Link Protocols

- Stop And Wait
  - send a frame
  - wait for ACK
  - need sequence number to tell re-transmission from next packet
    - lost ACK vs. lost frame
- Sliding Window
  - sequence numbers
  - can send up to window size number frames
  - Retransmission
    - Go Back N
    - Selective repeat