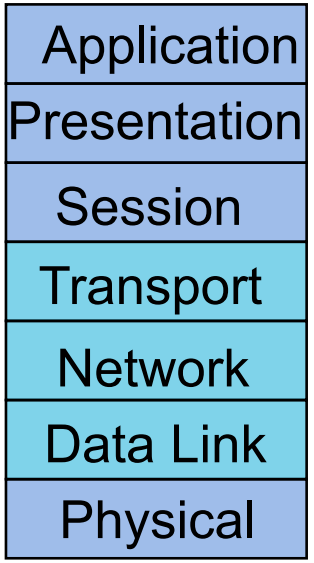
CSE 461: Framing, Error Detection and Correction

Next Topics

- Framing
  - Focus: How does a receiver know where a message begins/ends
- Error detection and correction
  - Focus: How do we detect and correct messages that are garbled during transmission?
  - The responsibility for doing this cuts across the different layers

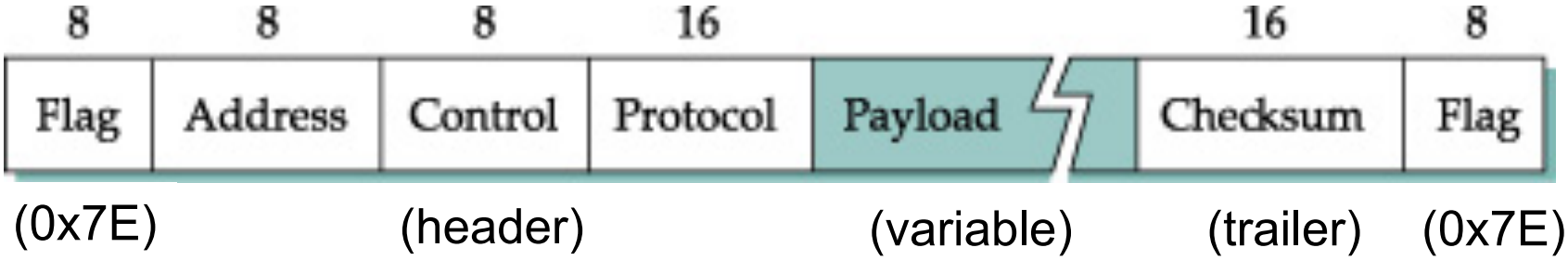


Framing

- Need to send message, not just bits
  - Requires that we synchronize on the start of message reception at the far end of the link
  - Complete Link layer messages are called frames
- Common approaches: Sentinels, lengths, clock-based
  - Sentinels: Look for special control code that marks start of frame and escape or "stuff" this code within the data region
  - Lengths: additionally, tell receiver how large the frame is going to be
  - Clocks: agree on when frames ought to begin/end

Example: Point-to-Point Protocol (PPP)

- IETF standard, used for dialup and leased lines



- Flag is special and indicates start/end of frame
- Occurrences of flag inside payload must be "stuffed"
  - Like an "escape" character:
    - " → \"
  - Replace 0x7E with 0x7D, 0x5E
  - Replace 0x7D with 0x7D, 0x5D
- Problems?
- Why not use a length field?

Example: SONET

- Standard for long distance transmission over optical networks
  - Base rate STS-1 of 51.84 Mbps
  - STS-192 in use

- All packets are 125 μs long → start frame synch bytes just used for synchronization
- No character stuffing, no need for length field to find end of frames
  - Why not always do things SONET style?

Error Detection and Redundancy

- Noise can flip some of the bits we receive
  - We must be able to detect when this occurs!
  - Who needs to detect it? (links/routers, OSs, or apps?)

- Basic approach: add redundant data
  - Error detection codes allow errors to be recognized
  - Error correction codes allow errors to be repaired too

Motivating Example

- A simple error detection scheme:
  - Just send two copies. Differences imply errors.

- Question: Can we do any better?
  - With less overhead
  - Catch more kinds of errors
- Answer: Yes – stronger protection with fewer bits
  - But we can't catch all inadvertent errors, nor malicious ones

- We will look at basic block codes
  - K bits in, N bits out is a (N,K) code
  - Simple, memoryless mapping

The Hamming Distance

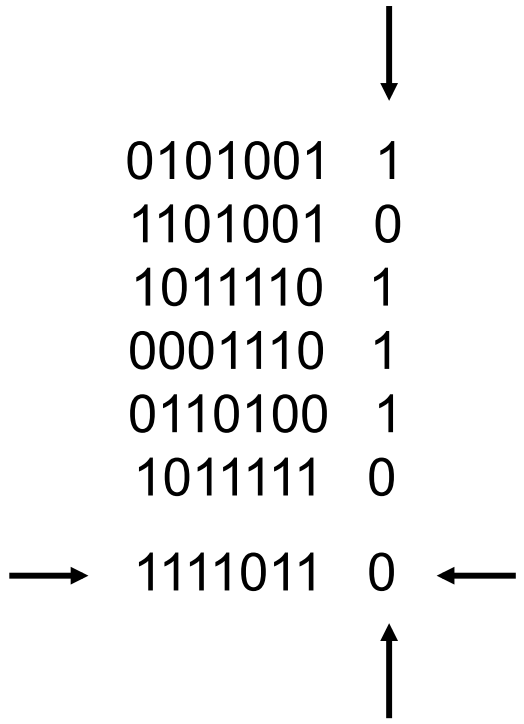
- Errors must not turn one valid codeword into another valid codeword, or we cannot detect/correct them.
- Hamming distance of a code is the smallest number of bit differences that turn any one codeword into another
  - e.g, code 000 for 0, 111 for 1, Hamming distance is 3
- For code with distance d+1:
  - d errors can be detected, e.g, 001, 010, 110, 101, 011
- For code with distance 2d+1:
  - d errors can be corrected, e.g., 001 → 000

Parity

- Start with n bits and add another so that the total number of 1s is even (even parity)
  - e.g. 0110010 → 01100101
  - Easy to compute as XOR of all input bits
- Will detect an odd number of bit errors
  - But not an even number
- Does not correct any errors

2D Parity

- Add parity row/column to array of bits
- How many simultaneous bit errors can it detect?
- Which errors can it correct?



Checksums

- Used in Internet protocols (IP, ICMP, TCP, UDP)
- Basic Idea: Add up the data and send it along with sum

- Algorithm:
  - checksum is the 1s complement of the 1s complement sum of the data interpreted 16 bits at a time (for 16-bit TCP/UDP checksum)
- 1s complement: flip all bits to make number negative
  - Consequence: adding requires carryout to be added back

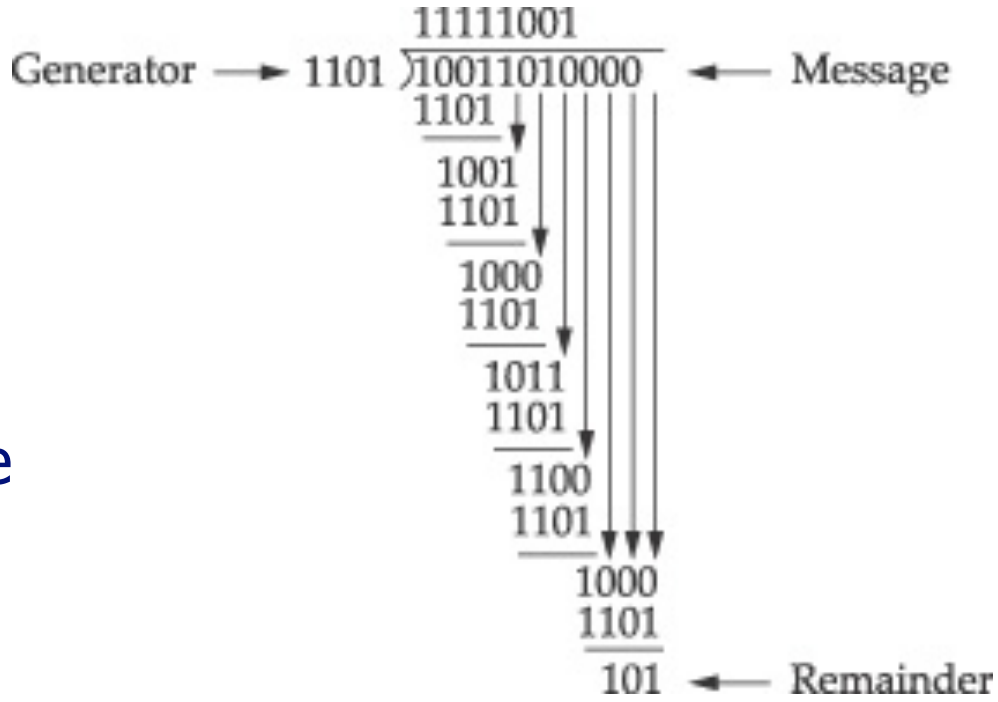
CRCs (Cyclic Redundancy Check)

- Stronger protection than checksums
  - Used widely in practice, e.g., Ethernet CRC-32
  - Implemented in hardware (XORs and shifts)
- Algorithm: Given n bits of data, generate a k bit check sequence that gives a combined n + k bits that are divisible by a chosen divisor C(x)
- Based on mathematics of finite fields
  - "numbers" correspond to polynomials, use modulo arithmetic
  - e.g, interpret 10011010 as $x^7 + x^4 + x^3 + x^1$

CRC Example

- Extend message with *k* 0's, when using a *k* -degree generator
- Divide message by generator (XOR)
- Discard result
- Subtract remainder from original message

- On reception, check that message is divisible by generator



How is C(x) Chosen?

- Mathematical properties:
  - All 1-bit errors if non-zero x^k and x^0 terms
  - All 2-bit errors if C(x) has a factor with at least three terms
  - Any odd number of errors if C(x) has (x + 1) as a factor
  - Any burst error < k bits
- There are standardized polynomials of different degree that are known to catch many errors
  - Ethernet CRC-32: 100000100110000010001110110110111

Error Correction

- Two strategies to correct errors:
  - Detect and retransmit, or Automatic Repeat reQuest. (ARQ)
  - Error correcting codes, or Forward Error Correction (FEC)
- Retransmissions typically at higher levels (Network+). Why?

- Question: Which should we choose?

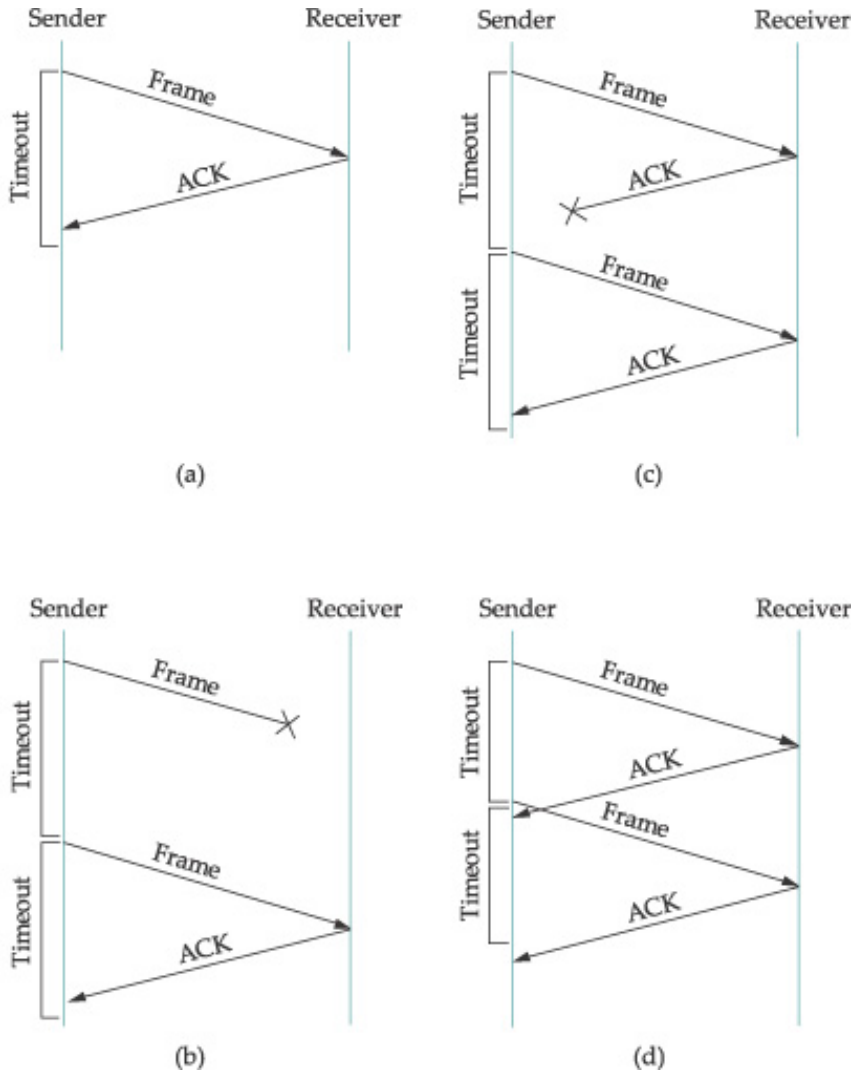
Retransmissions vs. FEC

- The better option depends on the kind of errors and the cost of recovery
- Example: Message with 1000 bits, Prob(bit error) 0.001
  - Case 1: random errors
  - Case 2: bursts of 1000 errors
  - Case 3: real-time application (teleconference)

ARQ: Stop-and-Wait

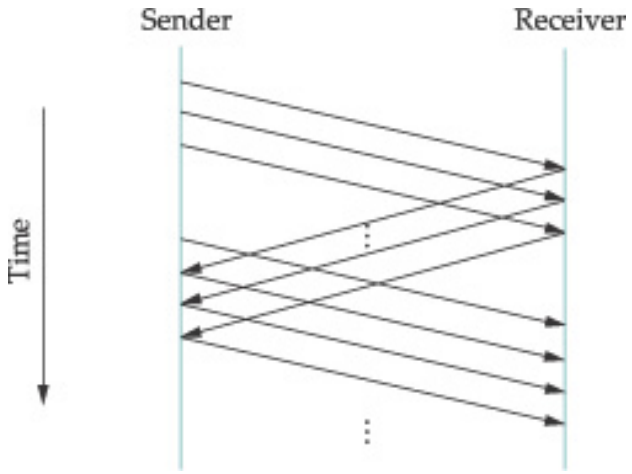
- Idea: transmit and wait for an ACK
  - Sender sets a timer
  - He retransmits if doesn't hear an ACK before the timer expires
  - What should the timeout be?
  - Do we need sequence numbers?

- Efficiency?
  - E.g., 1.5 Mbps link with 45ms RTT, 1500 byte frame → 1500 * 8 / .045 = 267 Kbps

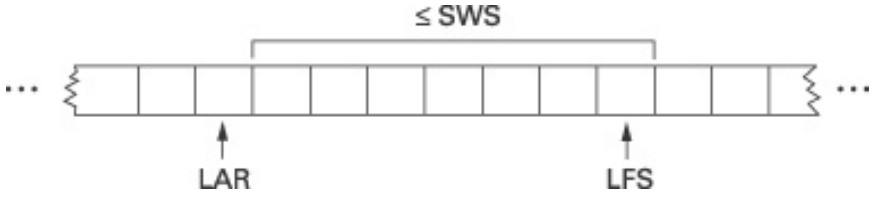


ARQ: Sliding Window

- Idea: have more than one outstanding packet
- LFS – LAR ≤SWS, LAF – LFR ≤ RWS
- How big should SWS and RWS be?
- Sequence numbers?
- Flow Control?
- Cumulative ACKS
- Selective ACKs? NACKs?



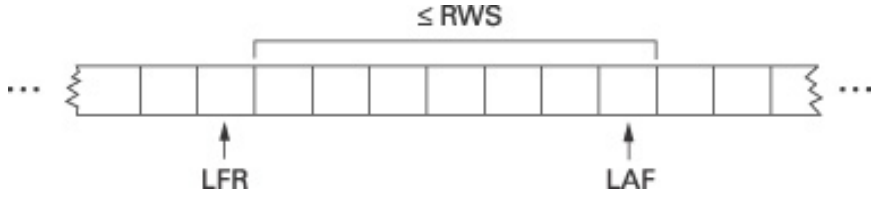
Send Window Size



Last Acknowledged Received

Last Frame Sent

Receive Window Size



Last Frame Received

Largest Acceptable Frame

FEC: Reed-Solomon / BCH Codes

- Developed to protect data on magnetic disks
- Used for CDs and cable modems too
- Property: 2t redundant bits can correct <= t errors
- Mathematics somewhat more involved …

Key Concepts

- Senders "frame" messages with sentinels, length fields, and clock synch, so receivers can determine where they start and end
- Redundant bits are added to messages to protect against transmission errors.
- Two recovery strategies are retransmissions (ARQ) and error correcting codes (FEC)