Physical and Data Link Layer Overview

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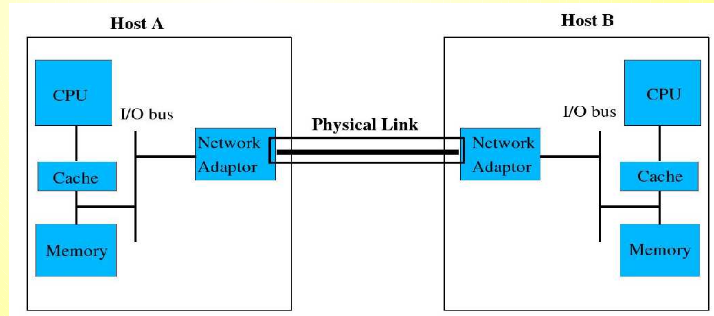
Problem Statement

- Make two computers talk to each other

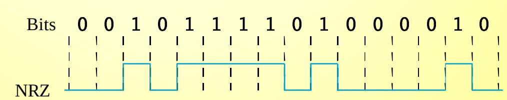


Five Tasks

- Encoding
  - Convert bits to signals
- Framing
  - Delineating sequence of bits into individual messages
- Error Detection
  - Need to ensure that the receiver sees the same copy as sender
- Error Recovery
  - Make a link appear reliable in spite of errors
- Media Access
  - Sharing a single physical medium across more then two computers

Encoding

- Physical media transmit ***Analog*** signals
  - Modulate/demodulate the electromagnetic waves
- Encode binary data into signals
  - E.g. Non-return to Zero (NRZ)
    - 0 as low signal and 1 as high signal



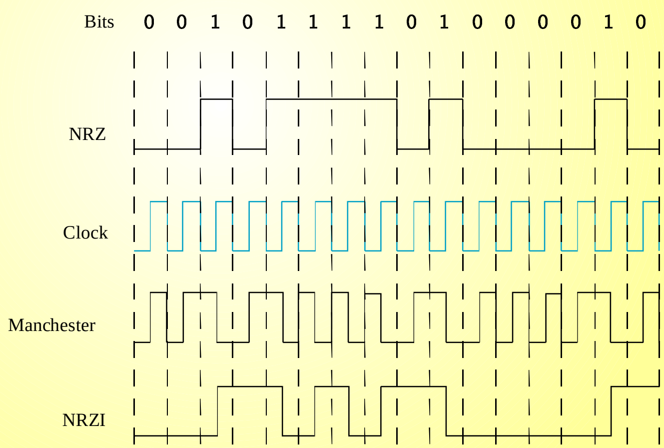
Problems with NRZ

- Consecutive 1s and 0s
  - Changes the average making it difficult to detect signals (*baseline wander*)
  - Clock Recovery
    - Sender's and receiver clocks have to be precisely synchronized
    - Receiver derives the clock from the received signal vis signal transition
    - Lesser number of transitions leads to clock drift

Alternative Encodings

- Non-return to Zero Inverted (NRZI)
  - To encode a 1, make a transition
  - To encode a 0, stay at the current signal
  - Solves problem of consecutive 1's but not 0's
- Manchester Encoding
  - Transmits XOR of the NRZ encoded data and the clock
    - 0 is encoded as low-to-high transition, 1 as high-to-low transition
  - Only 50% efficient

Example



4B/5B Encoding

- Every 4 bit of actual data is encoded into a 5 bit code
- The 5 bit code words have
  - No more than one leading 0
  - No more than two trailing 0s
  - Solves consecutive zeros problem
- The 5 bit codes are sent using NRZI
- Achieves 80% efficiency

4B/5B Encoding

0	11110	0000
1	01001	0001
2	10100	0010
3	10101	0011
4	01010	0100
5	01011	0101
6	01110	0110
7	01111	0111
8	10010	1000
9	10011	1001
A	10110	1010
B	10111	1011
C	11010	1100
D	11011	1101
E	11100	1110
F	11101	1111

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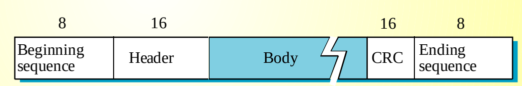
Framing

- Framing breaks bit streams into *frames* of smaller sizes
- Challenge: What sets of bits constitute a frame
  - Where is the beginning and the end of frame?
- Framing Protocols
  - Examples: PPP, HDLC, DDCMP

Theory behind Framing

- Delineate a frame with a special pattern
  - HDLC uses an 8 bit pattern: 01111110



- Problem: Special pattern may appear in payload
- Solution: Bit Stuffing
  - Sender inserts a 0 after 5 consecutive 1's
  - Receiver removes the 0 that follows 5 1's

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Error Detection

- Basic Idea: Add redundant information to a frame
  - Add k bits of redundant data to a n bit message
  - k << n; k = 32; n = 12,000
  - k derived from original message through some algorithm
- Examples: CRC, checksum, two-dimensional parity

Checksum

- View data in a frame to be transmitted as a sequence of 16-bit integers.
- Add the integers using 16 bit one's complement arithmetic.
- Take the one's complement of the result – this result is the checksum

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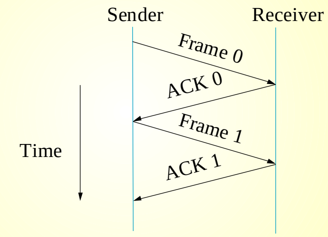
Error Recovery

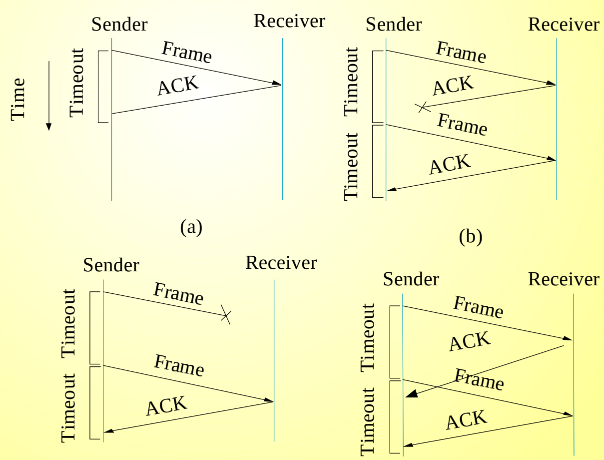
- Two forms of error recovery:
  - Automatic Repeat reQuest (ARQ)
  - Forward Error Correction (FEC)
- ARQ relies on two mechanisms
  - Acknowledgments
  - Timeout

Stop and Wait ARQ



- Problem: Can't keep pipe full
- Example: Consider a 1.5 Mbps link with a 45ms round trip time; Frame size is 1024 bytes
  - Utilization is 1024*8/0.045 = 182kbps

Stop and Wait ARQ Cont...

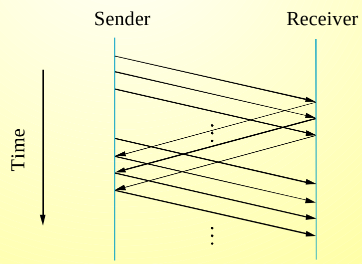


Bandwidth-Delay Product (BDP)

- View a link as a hollow pipe
  - Latency corresponds to the length of the pipe
  - Bandwidth gives diameter of the pipe
  - BDP gives the volume of the pipe – the number of bits it holds
  - E.g. a transcontinental link with bandwidth 45Mbps and latency 50ms can hold $2.25 * 10^6$ bits
- BDP represents #bits the sender can transmit before the sender gets acknowledgment of the first bit
- If the sender does not send BDP's worth of data, it is under utilizing the link

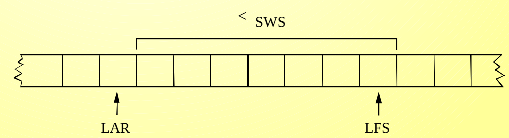
Sliding Window

- Allow multiple outstanding (un-Acked) frames
- Place an upper bound on un-Acked frames, called window



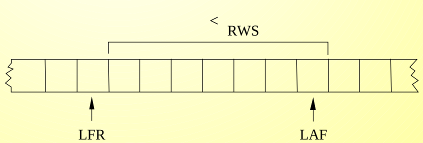
Sender Side

- Assign a sequence number to each frame (SeqNum)
- Maintain 3 variables:
  - Send Window Size (SWS): upper bound on the number of unacked frames that sender can transmit
  - LAR denotes sequence number of Last Acknowledgment Received; Advance LAR when ACK arrives
  - LFS denotes sequence number of Last Frame Sent
- Maintain Invariant: LFS-LAR <= SWS



Receiver Side

- Maintains the following three variables
  - Received Window Size (RWS): upper bound on the number of out of order frames
  - LAF denotes sequence number of last acceptable frame
  - LFR denotes sequence number of last frame received
- Maintain invariant: LAF – LFR <= RWS



Receiver Side cont..

- Frame SeqNum arrives
  - If SeqNum <= LFR or SeqNum > LAF, discard
  - If LFR< SeqNum <= LAF, accept
- Send cumulative Acks

Summary

- Five key problems have to be solved for two computers to talk with each
- We covered four of these problems
  - Encoding
  - Framing
  - Error Detection
  - Error Recovery
- The fifth problem and our topic of next session is ***Media Access Protocols***