Data Link Layer Overview

First of four classes on the data link layer

Internet Architecture

Bottom-up:
- **physical**: electromagnetic signals "on the wire"
- **link**: data transfer between neighboring network elements
- **network**: host-host multi-hop connectivity
  - routing, addressing
- **transport**: host-host data transport
  - reliable data transport, congestion control, flow control
- **application**: anything you want to do on computer networks

Link Layer: Introduction

Some terminology:
- nodes in the network edge are hosts; nodes in the network core are routers
- communication channels that connect adjacent nodes along communication path are links
  - LANs, modem links, satellite links, wireless radio links

Link layer has responsibility of transferring data from one node to adjacent node over a link.

Link Layer Functions

- **Encoding**
  - encode binary data to/from electromagnetic signals
- **Framing**
  - encapsulate data into frame, adding header, trailer
  - physical addresses used in frame headers to identify source, dest (different from IP address!)
- **Link access control**
  - coordinate access for shared link
- **Flow control**
  - pacing between sending and receiving nodes such that the sender does not overwhelm the receiver
More Link Layer Functions

- **Error detection**
  - errors caused by signal attenuation, electromagnetic noise.
  - receiver detects presence of errors:
    - drops frame or signals sender for retransmission
- **Error correction**
  - receiver identifies and corrects error(s) without resorting to retransmission
- **Reliable delivery over the link**
  - typically mean no data loss and/or in-order delivery

Variety of Link Types

- Data transfer over different links:
  - e.g., first link (local-area cable)
  - intermediate links (long-haul fiber)
  - last link (wireless)
- Different links may demand different functions
  - encoding
  - link access control
  - reliable delivery
  - ... ...

Outline

- Introduction and functions of the data link layer
  - **Encoding**
  - Framing
  - Error detection and correction

Encoding

- Signals propagate over a physical medium
  - modulate electromagnetic waves
  - e.g., vary power
- Encode binary data onto signals
  - e.g., positive voltage as 1 and negative voltage as 0
  - Also known as Non-Return to Zero (NRZ)

<table>
<thead>
<tr>
<th>Bits</th>
<th>High-Low</th>
</tr>
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<tbody>
<tr>
<td>0 0 1 0 1 1 1 0 1 0 0 0 0 1 0</td>
<td></td>
</tr>
</tbody>
</table>

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Problem with Consecutive 1s or 0s

- Clock synchronization
  - both the sender and the receiver maintains a clock
  - clock synchronized at signal change

An Alternative Encoding

- Transition encoding
  - make a transition from current signal to encode a one;
  - stay at current signal to encode a zero
  - only solves the problem of consecutive ones

Manchester Encoding

- Manchester
  - encode 0 into low-to-high transition; encode 1 into high-to-low transition.
  - only 50% efficient.

4B/5B Encoding

- every 4 bits of data encoded in a 5-bit code
  - since there are more 5-bit codes than 4-bit data; some codes are not used; we can design a mapping/encoding such that no data is encoded into 5-bit code with more than one leading 0 or more than two trailing 0s
  - thus, never get more than three consecutive 0s
  - resulting 5-bit codes are transmitted using the transition encoding
  - efficiency?
    - 80%
Outline

- Introduction and functions of the data link layer
- Encoding
- **Framing**
  - break sequence of bits into frames, add protocol headers/trailers
- Error detection and correction

Where each frame begins and ends?

- **Sentinel-based framing**
  - delineate frame with special begin/end patterns
  - e.g.,
  - `|beginning sequence| Header | Body | EDC | ending sequence|
  - problem: end pattern appears in the payload
  - solution: *bit stuffing*
    - for pattern `01111110`
      - Sender - insert 0 after five consecutive 1s
      - Receiver - delete 0 that follows five consecutive 1s
  - similar to escape characters in program languages

Where each frame begins and ends?

- **Counter-based framing**
  - include payload length in header

Outline

- Introduction and functions of the data link layer
- Encoding
- Framing
  - Error detection and correction
Error Detection and Correction

D - Data protected by error checking, may include header fields
EDC - Error Detection and Correction bits (redundancy)

Parity Checking

Single Bit Parity:
Detect single bit errors

Two Dimensional Bit Parity:
Detect and correct single bit errors

Cyclic Redundancy Check

view data bits, D, as a binary number
constant r+1 bit pattern (generator), G
Sender:
- for each D: choose r CRC bits, R, such that <D,R> exactly divisible by G
- d data bits -> r bits

Receiver:
- divides <D',R'> by G. Non-zero remainder: error detected!
- can detect all burst errors fewer than r+1 bits

CRC Example

There is no carries and borrows in modulo-2 arithmetic. Addition, subtraction, and bit-wise XOR are all identical.

Want:
- D \cdot 2^r + R = nG
equivalent to (modulo-2):
\[ D \cdot 2^r = nG + R \]
equivalent to:
\[ R = \text{remainder}[D \cdot 2^r / G] \]
Internet Checksum

Note: used at network/transport layers (IP, TCP/UDP).

**Sender:**
- treat data as sequence of 16-bit integers
- add using 16-bit 1's complement arithmetic; take 1's complement of the result as the checksum
- sender puts checksum value into TCP/UDP checksum field

**Receiver:**
- compute checksum of received segment
- check if computed checksum equals checksum field value:
  - NO - error detected
  - YES - no error detected

1's complement addition - carryout from the most-significant bit adds to the least-significant bit: 1010 + 1100 = 0111

Error Detection Reliability

- Error detection is not 100% reliable!
  - It is possible for corrupted D' to match EDC'
  - what is the chance that a random error escapes detection?
  - larger EDC field yields better detection and correction

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