ECE453 – Introduction to Computer Networks
Lecture 4 – Data Link Layer (I)

Design Issues

- Provide a well-defined service interface
- Group bits (PHY) into frames (DL)
- Deal with transmission errors
- Regulate the flow of frames

Link Layer: Setting the Context

- Two physically connected devices: host-router, router-router, host-host
- Unit of data: frame
- Protocols implemented in "adapter"
Framing
- Character count
- Flag bytes with byte stuffing
- Starting and ending flags with bit stuffing

Framing - Byte Stuffing

Tightly tied to the used of 8-bit characters
Framing – Bit Stuffing
- Flag pattern: 01111110
- Sender stuff: add 0 after 11111
- Receiver destuff: delete 0 after 11111

Error Detection and Correction
- Use redundancy
  - Error detection and retransmission
    - Over low error rate media
  - Error correction
    - Over high error rate media

The Hamming Distance
- Codewords (n bits): message (m bits) + check bits (r bits)
- Complete list of codewords?
- Hamming distance: the number of positions in which two codewords differ
- Hamming distance of the complete code: two codewords with the minimum Hamming distance
- To detect \(d\) errors, Hamming distance of the code: \((d+1)\)
- To correct \(d\) errors, Hamming distance of the code: \(2(d+1)\)
Parity Bit

- Even parity
- Odd parity

A code with a single parity bit has a Hamming distance of ???.
It can be used to detect ?? errors.

Example

<table>
<thead>
<tr>
<th>Arrival</th>
<th>Original</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000000011</td>
<td>0000011111</td>
</tr>
<tr>
<td>0000000111</td>
<td>0000000000</td>
</tr>
</tbody>
</table>

The code has a Hamming distance of ???.
It can detect ?? errors.
It can correct ?? errors.

The Hamming Code

- Theorem: Given a code with \( m \) message bits and \( r \) check bits \( (n=m+r) \) which allows all single errors to be corrected, the lower limit on \( r \) is \( (m+r+1) \leq 2^r \).

- Hamming code (the bits that are power of 2 are check bits, others are message bits, each check bit forces the parity of some collection of bits, including itself).

- Can only correct single bit error.
Example - Hamming Code

10010000

How to Correct Burst Errors

- Uses \( kr \) check bits to make blocks of \( km \) data bits immune to a single burst error of length \( k \) or less

Error Detecting Code - I

- Uses \( kr \) check bits to make blocks of \( km \) data bits immune to a single burst error of length \( k \) or less
Error-Detecting Codes

- Polynomial code (CRC - Cyclic Redundancy Check)
  - Generator polynomial G(x)
  - Message polynomial M(x)
  - Method: append a checksum of r bits to the end of M(x) such that the appended polynomial T(x) is divisible by G(x)

\[ Q(x) \cdot R(x) = x^r M(x) / G(x) \]

\[ T(x) = x^r M(x) + R(x) \]

More on Polynomial Code

- Single error detection?
- Double error detection?
- No polynomial with an odd number of terms is divisible by x + 1
- A polynomial code with r check bits will detect all burst errors of length \( \leq r \)
  - Burst error: at least the first and the last bits of a bit stream are wrong
- Hardware implementation: shifted register circuit
- International standard of G(x)
  - \( x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1 \)