CS3600 — SYSTEMS AND NETWORKS
FALL 2012

Lecture 18: Data-link layer

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Slides used with permissions from Edward W. Knightly, T. S. Eugene Ng, Ion Stoica, Hui Zhang
Bit Stream Encoding

• Specify how bits are represented in the analog signal
  – This service is provided by the physical layer
• Challenges:
  – Efficiency: ideally, bit rate is maximized
  – Robust: avoid de-synchronization between sender and receiver when there is a large sequence of 1’s or 0’s
Assumptions

• We use two discrete signals, high and low, to encode 1 and 0
• The transmission is synchronous, i.e., there is a clock used to sample the signal
• If the amplitude and duration of the signals is large enough, the receiver can do a reasonable job of looking at the distorted signal and estimating what was sent.
Non-Return to Zero (NRZ)

- 1 → high signal; 0 → low signal
Non-Return to Zero (NRZ)

- 1 → high signal; 0 → low signal
Non-Return to Zero (NRZ)

- $1 \rightarrow$ high signal; $0 \rightarrow$ low signal
- Disadvantages: when there is a long sequence of $1$'s or $0$'s
  - Sensitive to clock skew, i.e., difficult to do clock recovery
**Non-Return to Zero Inverted (NRZI)**

- 1 → make transition; 0 → stay at the same level
- Solve previous problems for long sequences of 1’s, but not for 0’s
Non-Return to Zero Inverted (NRZI)

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Manchester

Clock
Manchester

Clock

Manchester

0 0 1 0 1 0 1 1 1 0
Manchester

• 1 $\rightarrow$ high-to-low transition; 0 $\rightarrow$ low-to-high transition
Manchester

- 1 → high-to-low transition; 0 → low-to-high transition
- Addresses clock recovery problems
- Disadvantage: signal transition rate doubled
Manchester

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- Disadvantage: signal transition rate doubled
  - I.e. useful data rate on same physical medium halved

![Manchester diagram](image-url)
Manchester

- 1 → high-to-low transition; 0 → low-to-high transition
- Addresses clock recovery problems
- Disadvantage: signal transition rate doubled
  - I.e. useful data rate on same physical medium halved
  - Efficiency of 50%
4-bit/5-bit (100Mb/s Ethernet)

- Goal: address inefficiency of Manchester encoding, while avoiding long periods of low signals
- Solution:
  - Use 5 bits to encode every sequence of four bits such that no 5 bit code has more than one leading 0 and two trailing 0’s
  - Use NRZI to encode the 5 bit codes
  - Efficiency is 80%
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<thead>
<tr>
<th>4-bit</th>
<th>5-bit</th>
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<td>01110</td>
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<td>0111</td>
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<table>
<thead>
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<th>5-bit</th>
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<td>11100</td>
</tr>
<tr>
<td>1111</td>
<td>11101</td>
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Framing

• Specify how blocks of data are transmitted between two nodes connected on the same physical media
  – This service is provided by the data link layer

• Challenges
  – Decide when a frame starts/ends
  – If use special delimiters, differentiate between the true frame delimiters and delimiters appearing in the payload data
Byte-Oriented Protocols: Sentinel Approach

8

STX  Text (Data)  ETX

8
Byte-Oriented Protocols: Sentinel Approach

- STX – start of text
Byte-Oriented Protocols: Sentinel Approach

- STX – start of text
- ETX – end of text
Byte-Oriented Protocols: Sentinel Approach

- STX – start of text
- ETX – end of text
- Problem: what if ETX appears in the data portion of the frame?
Byte-Oriented Protocols: Sentinel Approach

- STX – start of text
- ETX – end of text
- Problem: what if ETX appears in the data portion of the frame?
- Solution
  - If ETX appears in the data, introduce a special character DLE (Data Link Escape) before it
  - If DLE appears in the text, introduce another DLE character before it

  – Like in C programming, “Say \"Hello\"”, (\ is the escape character)
Byte-Oriented Protocols: Byte Counting Approach

- **Sender**: insert the length of the data (in bytes) at the beginning of the frame, i.e., in the frame header.
- **Receiver**: extract this length and decrement it every time a byte is read. When this counter becomes zero, we are done.
Bit-Oriented Protocols

- Both start and end sequence can be the same
  - E.g., 01111110 in HDLC (High-level Data Link Protocol)
- Sender: in data portion inserts a 0 after five consecutive 1s
  - “Bit stuffing”
- Receiver: when it sees five 1s makes decision on the next two bits
  - If next bit 0 (this is a stuffed bit), remove it
  - If next bit 1, look at the next bit
    - If 0 this is end-of-frame (receiver has seen 01111110)
    - If 1 this is an error, discard the frame (receiver has seen 01111111)
Clock-Based Framing (SONET)

• SONET (Synchronous Optical NETwork)
• Developed to transmit data over optical links
  – Example: SONET STS-1: 51.84 Mbps
• SONET maintains clock synchronization across several adjacent links to form a path
STS-1 Frame

- First two bytes of each frame contain a special bit pattern that allows to determine where the frame starts
- No bit-stuffing is used, frame is fixed size
- Receiver looks for the special bit pattern every 810 bytes
  - Size of frame = 9x90 = 810 bytes
Clock-Based Framing (SONET)

Details:
- Bits are encoded using NRZ
- To avoid long sequences of 0’s or 1’s the payload is XOR-ed with a special 127-bit pattern with many transitions from 1 to 0
Error detection

• How to determine if errors (via noise) were introduced?

• Could send 2 copies of data
  – Has poor efficiency
  – Poor protection against errors

• Will discuss three approaches
  – Two-dimensional parity
  – Checksum
  – CRCs
Two-dimensional parity

• Add extra bits to keep number of 1s even
  – Add parity bits and parity bytes

<table>
<thead>
<tr>
<th></th>
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<th>Parity bit for each 7 bits</th>
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<tbody>
<tr>
<td>0101001</td>
<td>1</td>
<td></td>
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<tr>
<td>1101001</td>
<td>0</td>
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<td>1011110</td>
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<td>0110100</td>
<td>1</td>
<td></td>
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<tr>
<td>0110100</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1011111</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1111011</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Parity byte for each frame
Two-dimensional parity

• Add extra bits to keep number of 1s even
  – Add parity bits and parity bytes
    
    | 0101001 | 1 | Parity bit for each 7 bits |
    | 1101001 | 0 |
    | 1011110 | 1 |
    | 0001110 | 1 |
    | 0110100 | 1 |
    | 1011111 | 0 |

    | 1111011 | 0 | Parity byte for each frame |

• Can detect all 1-, 2-, and 3- bit errors!
  – But with at least 14% overhead
Checksums

• Simple: add up bytes of messages, include the sum
  – Hence check-sum

• View data as series of unsigned 16-bit integers
  – Use ones-complement arithmetic

• Much lower overhead (16 bits/frame)
• But, not resilient to errors
  – Why? Error which increments/decrements any two ints

• Used in UDP, TCP, and IP, though
CRCs

- Cyclic redundancy check (CRC)

- Addresses limitations of prior approaches
  - Uses field theory

- Much better performance
  - Fixed overhead per frame
  - Only 1 in $2^{32}$ chance of missed error with 32-bit CRC

- Details in the book, if you’re curious