Administrivia

- Midterm!
  - Monday, November 6th
Network Components

- Parts of a Network
- Types of Links
- Protocols and Layers
- Encapsulation
Parts of a Network

- Parts of a Network

- Types of Links

  - Simplex
  - Full-duplex
  - Half-duplex
## Protocols and Layers

<table>
<thead>
<tr>
<th>Layer</th>
<th>Purpose</th>
<th>Protocols</th>
<th>Unit of Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Programs that use network service</td>
<td>HTTP, DNS</td>
<td>Message</td>
</tr>
<tr>
<td>Transport</td>
<td>Provides end-to-end data delivery</td>
<td>TCP, UDP</td>
<td>Segment</td>
</tr>
<tr>
<td>Network</td>
<td>Sends packets across multiple networks</td>
<td>IP</td>
<td>Packet</td>
</tr>
<tr>
<td>Link</td>
<td>Sends frames across a link</td>
<td>Ethernet, Cable</td>
<td>Frame</td>
</tr>
<tr>
<td>Physical</td>
<td>Transmit bits</td>
<td></td>
<td>Bit</td>
</tr>
</tbody>
</table>
Protocols and Layers

ADVANTAGES

● Use information hiding to connect different systems
● Information reuse to build new protocols

DISADVANTAGES

● Adds overhead
● Hides information
Encapsulation
Physical Layer

- Coding: Clock Recovery
- Modulation
- Latency
- Media and Theoretical Limits
Coding: Clock Recovery

One answer - 4B/5B
- map every 4 data bits to 5 data bits
- such that there are no more than 3 zeros in a row
- invert signal level on a 1 to break up long runs of 1s
Modulation

- Baseband modulation allows signal to be sent directly on
  NRZ signal of bits

- Passband modulation carries a signal by modulating a
  Amplitude shift keying
  Frequency shift keying
  Phase shift keying
Latency

- Latency = Transmission Delay + Propagation Delay
- Transmission Delay = $M$ (bits) / $R$ (bits/sec) = $M/R$ (sec)
- Propagation Delay = Length / Speed of Signals = Length / $\frac{2}{3}c = D$ (sec)

- Bandwidth-Delay Product = $R$ (bits/sec) x $D$ (sec) = BD (bits)
- RTT = round-trip time
Media and Theoretical Limits

- **Media**
  - Wire, Fiber
  - Wireless: radiates signal over a region

- **Channel Limits**: how rapidly can we send information over a link?
  - Bandwidth ($B$), Signal Power ($S$), Noise Power ($N$)
  - Shannon Capacity - maximum lossless info carrying rate
    $$C = B \log_2(1 + S/N) \text{ bits/sec}$$
Link Layer

- Framing
- Error detection and correction
- Retransmissions
- Multiple Access
- Switching
Framing
Framing Methods

- How do we know where a bit sequence (frame) begins and ends?
  - Byte count
  - Byte stuffing
  - Bit stuffing

- Byte Count
Framing Methods

- **Byte Stuffing**
  - Replace ESC in data with ESC ESC, and replace FLAG in data with ESC FLAG

- **Bit Stuffing**
  - Sequences of 1s as flag, and then add 0 after each flag within data
    - Data bits: 011011111111111110010
    - Transmitted bits with stuffing: 011011111011111011111010010
Error Detection and Correction
Error Detection and Correction

- Add check bits to the message bits to let some errors be detected
- Add more check bits to let some errors be corrected
Hamming Distance

- HD between two codes (D1, D2)
  - the number of bit flips needed to change D1 to D2
  - D1 = 0110110101001
  - D2 = 0100000100001

- HD of a coding
  - the minimum error distance between any pair of codewords that cannot be detected

- For a Hamming distance of $d + 1$, up to $d$ errors will be detected
- For a Hamming distance of $2d + 1$, up to $d$ errors can be corrected
# Error Detection Methods

<table>
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<tr>
<th>Method</th>
<th>Description</th>
<th>Hamming Distance</th>
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<tbody>
<tr>
<td>Parity Bit</td>
<td>Add 1 check bit that is sum/XOR of d data bits</td>
<td>2</td>
</tr>
<tr>
<td>Internet Checksum</td>
<td>1s complement sum of 16 bit word</td>
<td>2</td>
</tr>
<tr>
<td>Cyclic Redundancy Check (CRC)</td>
<td>For n data bits, generate n+k bits that are evenly divisible by C</td>
<td>4(CRC32)</td>
</tr>
</tbody>
</table>
HD of Internet Checksum

0001  
€204  
€4€5  
€6€7  
+  220c  
-----  
2fff€d  

2fff€d  
+     2  
-----  
fff€f  

fff€f  

0000
Error Correction - Hamming Code

Hamming Distance = 3

Suppose we want to send a message $M$ of 4 bits: 0101
We add $k=3$ check bits, because ($n = 2^k - k - 1 = 2^3 - 3 - 1 = 4$)
So, we will have a $n+k = 7$ bit code, with check bits in positions 1, 2, 4 Each check bit is an XOR of certain positions.
Error Correction - Hamming Code

\[
\begin{array}{cccc}
42 & 1 & 42 & 1 \\
1 & = & 0b001 & 1 & = & 0b001 & 1 & = & 0b001 \\
2 & = & 0b010 & 2 & = & 0b010 & 2 & = & 0b010 \\
3 & = & 0b011 & 3 & = & 0b011 & 3 & = & 0b011 \\
4 & = & 0b100 & 4 & = & 0b100 & 4 & = & 0b100 \\
5 & = & 0b101 & 5 & = & 0b101 & 5 & = & 0b101 \\
6 & = & 0b110 & 6 & = & 0b110 & 6 & = & 0b110 \\
7 & = & 0b111 & 7 & = & 0b111 & 7 & = & 0b111 \\
\end{array}
\]

- Example, continued
  \[0100111\]

\[
\begin{array}{cccccc}
1 & 2 & 3 & 4 & 5 & 6 & 7 \\
p_1 & = & b_3 + b_5 + b_7 & = & 0 + 1 + 1 & = & 0 \\
p_2 & = & b_3 + b_6 + b_7 & = & 0 + 0 + 1 & = & 1 \\
p_4 & = & b_5 + b_6 + b_7 & = & 1 + 0 + 1 & = & 0 \\
\end{array}
\]

Syndrome = \textbf{11} 0, flip position 6
Data = 0101 (correct after flip!)
Retransmissions
ARQ - Automatic Repeat Request

- **ARQ**
  - Wait-Resend
- **Stop-and-wait**
  - Single bit SEQ
- **Sliding window**
Multiple Access
Multiplexing

- Multiplexing is the network word for the sharing of a resource.
- Time Division Multiplexing - high rate at some times.
- FDM - low rate all the time.
Multiple Access

- **ALOHA**: Node just sends when it has traffic; if collision happens, wait for a random amount of time and try again.
  - Huge amount of loss under high load
- **CSMA (Carrier Sense Multiple Access)**: Listen before send.
  - Collision is still possible because of delay; good only when BD is small
- **CSMA/CD (Carrier Sense Multiple Access with Collision Detection)**: CSMA + Aborting JAM for the rest of the frame time
  - Minimum frame length of 2D seconds
- **CSMA “Persistence”**: CSMA + P(send) = 1 / N
  - Reduce the chance of collision
- **Binary Exponential Backoff (BEB)**: Doubles interval for each successive collision
  - Very efficient in practice
Issues with Wireless

Hidden Terminal Problem: nodes A and C are hidden terminals when sending to B

Exposed Terminal Problem: nodes B and C are exposed terminals when sending to A and D

MACA is a potential solution: Sender sends Request to Send(RTS) and receiver replies Clear To Send(CTS).
Switching
Switches

- Backward Learning
  - Learn the sender’s port by looking at the packets

- Spanning Tree
  - Pick a root (Usually the switch with the lowest address)
  - Grow based on the shortest distance from the root
  - Ports not on the spanning tree are turned off