

CSCI-1680
Physical Layer
Link Layer I

Rodrigo Fonseca



Administrivia

- **Snowcast milestone today!**
- **HW0 due today.**
- **All the long list of signups from last class 😊**



Today

- **Physical Layer**
 - Modulation and Channel Capacity
 - Encoding
- **Link Layer I**
 - Framing



Layers, Services, Protocols

Application	Service: user-facing application. Application-defined messages
Transport	Service: multiplexing applications Reliable byte stream to other node (TCP), Unreliable datagram (UDP)
Network	Service: move packets to any other node in the network IP: Unreliable, best-effort service model
Link	Service: move frames to other node across link. May add reliability, medium access control
Physical	Service: move bits to other node across link



Physical Layer (Layer 1)

- **Responsible for specifying the physical medium**
 - Type of cable, fiber, wireless frequency
- **Responsible for specifying the signal (modulation)**
 - Transmitter varies *something* (amplitude, frequency, phase)
 - Receiver samples, recovers signal
- **Responsible for specifying the bits (encoding)**
 - Bits above physical layer -> *chips*

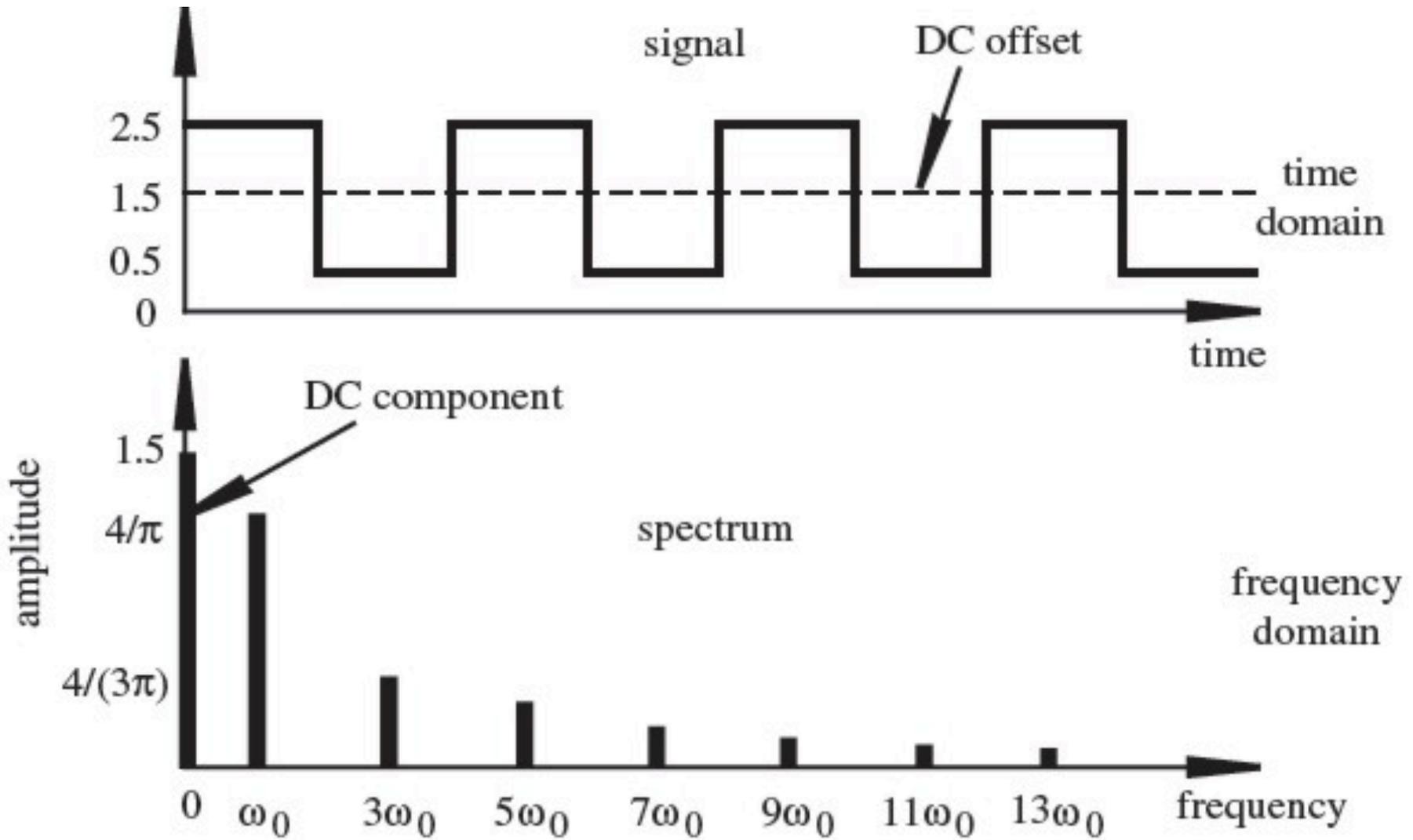


Modulation

- **Specifies mapping between digital signal and some variation in analog signal**
- **Why not just a square wave ($1v=1$; $0v=0$)?**
 - Not square when bandwidth limited
- **Bandwidth – frequencies that a channel propagates well**
 - Signals consist of many frequency components
 - Attenuation and delay frequency-dependent

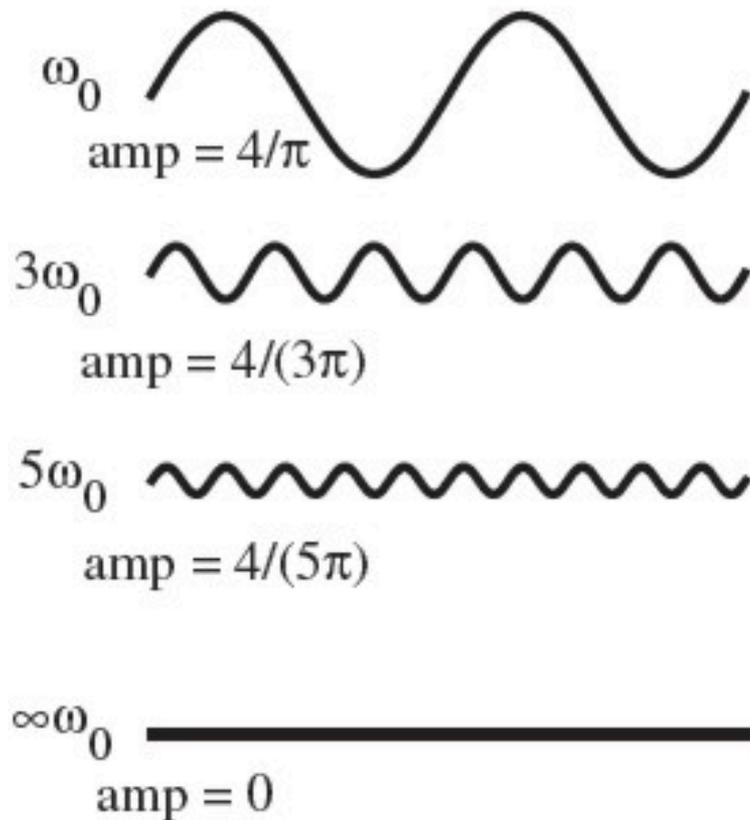


Components of a Square Wave

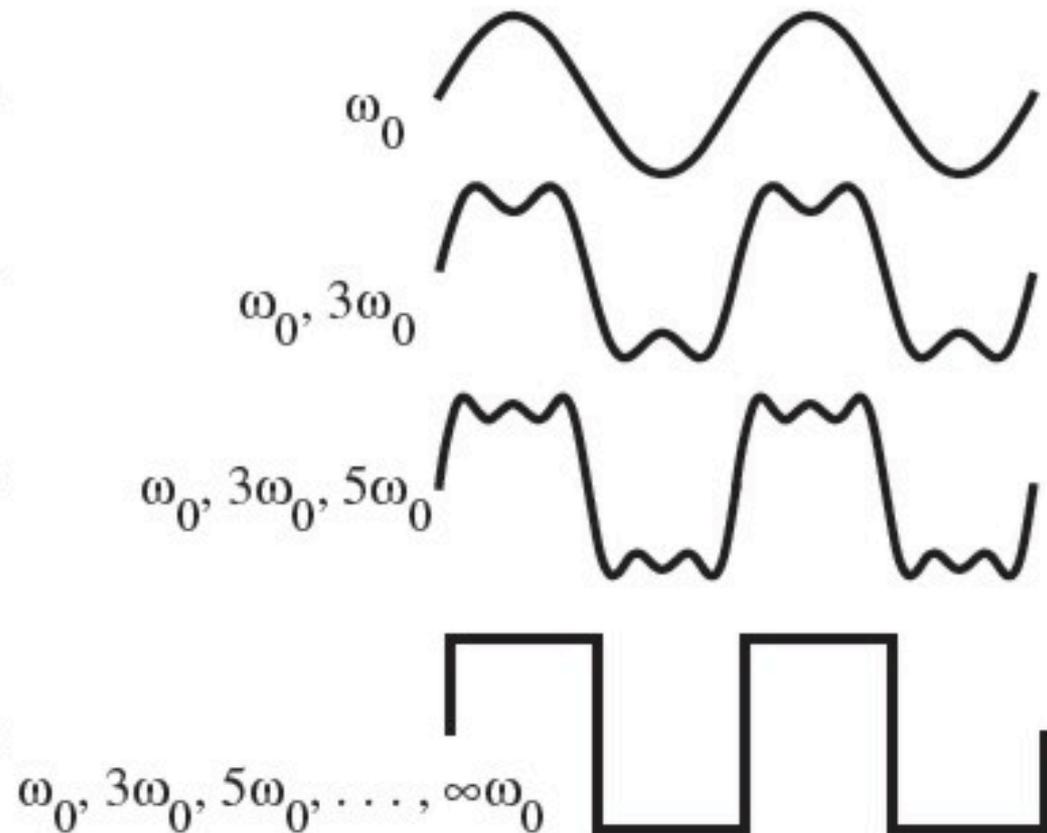


Approximation of a Square Wave

individual harmonics



combined harmonics

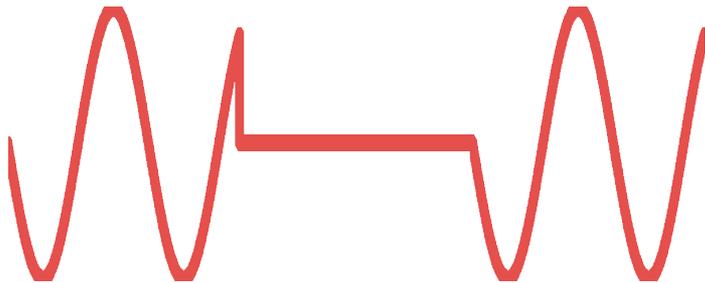


Idea: Use Carriers

- Only use frequencies that transmit well
- *Modulate* the signal to encode bits

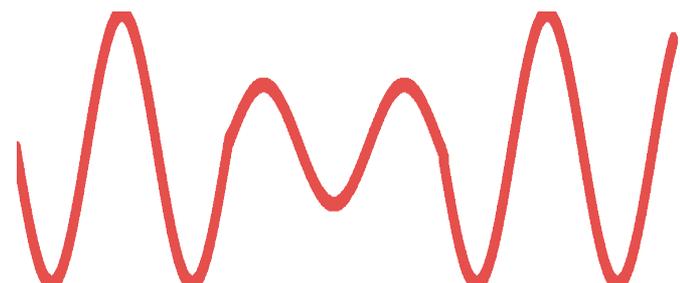
OOK: On-Off Keying

1 0 1



ASK: Amplitude Shift Keying

1 0 1

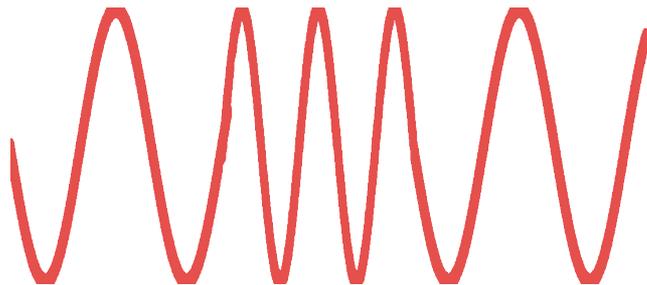


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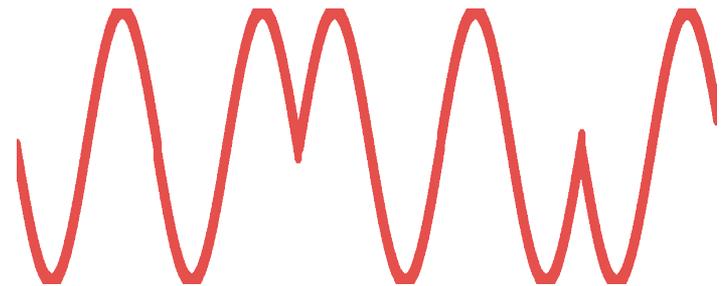
FSK: Frequency Shift Keying

1 0 1



PSK: Phase Shift Keying

1 0 1



How Fast Can You Send?

- **Encode information in some varying characteristic of the signal.**
- **If B is the maximum frequency of the signal**

$$C = 2B \text{ bits/s}$$

(Nyquist, 1928)



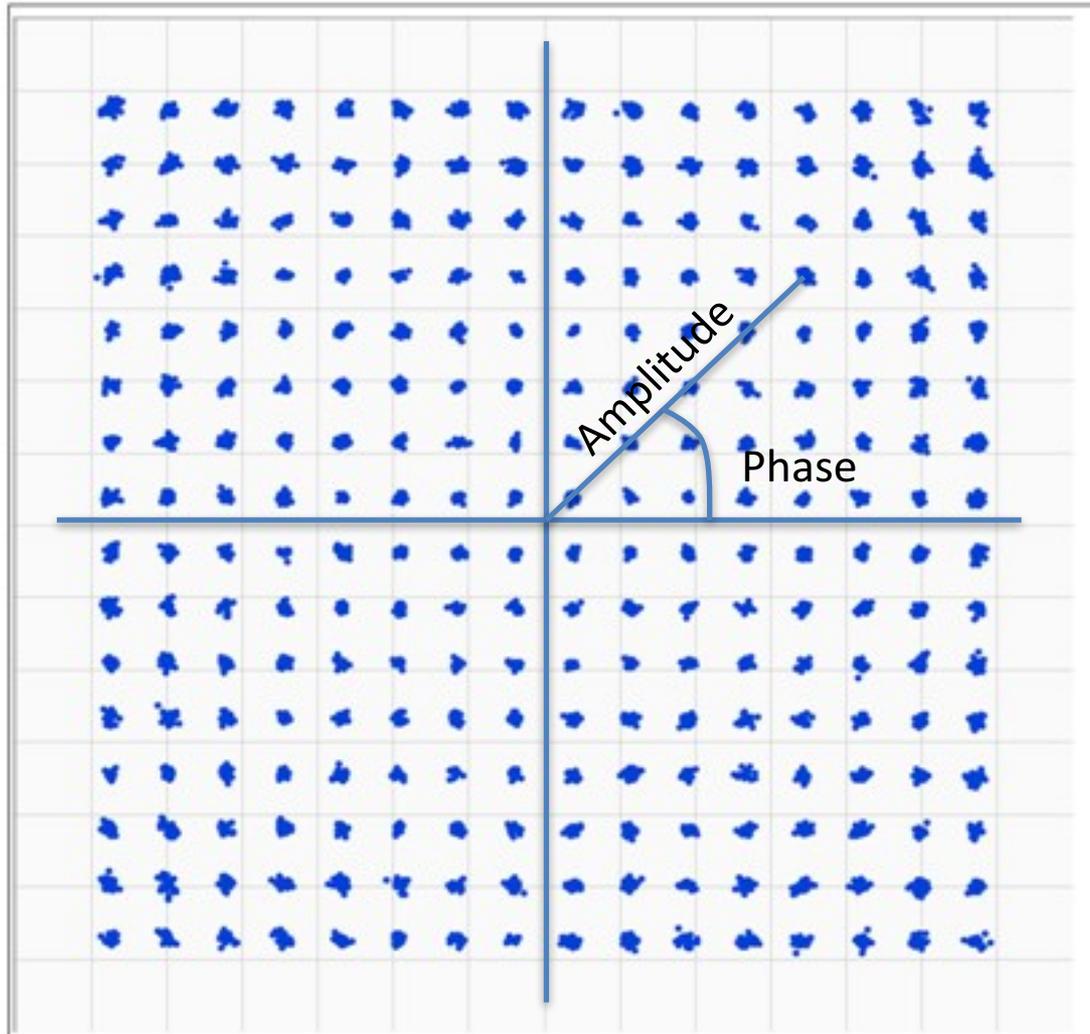
Can we do better?

- **So we can only change $2B/\text{second}$, what if we encode more bits per sample?**
 - Baud is the frequency of changes to the physical channel
 - Not the same thing as bits!
- **Suppose channel passes 1KHz to 2KHz**
 - 1 bit per sample: alternate between 1KHz and 2KHz
 - 2 bits per sample: send one of 1, 1.33, 1.66, or 2KHz
 - Or send at different amplitudes: $A/4$, $A/2$, $3A/4$, A
 - n bits: choose among 2^n frequencies!
- **What is the capacity if you can distinguish M levels?**



Example

256-QAM Constellation



Hartley's Law

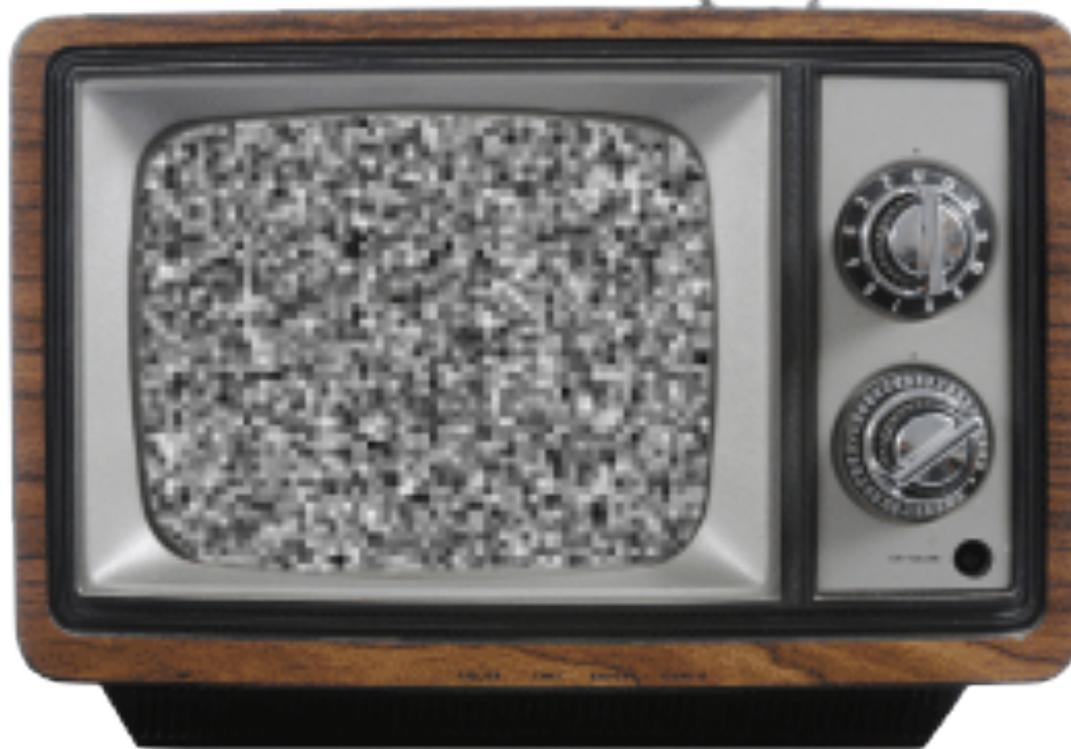
$$C = 2B \log_2(M) \text{ bits/s}$$

Great. By increasing M , we can have as large a capacity as we want!

Or can we?



The channel is noisy!



The channel is noisy!

- **Noise prevents you from increasing M arbitrarily!**
- **This depends on the signal/noise ratio (S/N)**
- **Shannon: $C = B \log_2(1 + S/N)$**
 - C is the channel capacity in bits/second
 - B is the bandwidth of the channel in Hz
 - S and N are average signal and noise power
 - Signal-to-noise ratio is measured in dB = $10\log_{10}(S/N)$



Putting it all together

- **Noise limits M!**

$$2B \log_2(M) \leq B \log_2(1 + S/N)$$

$$M \leq \sqrt{1+S/N}$$

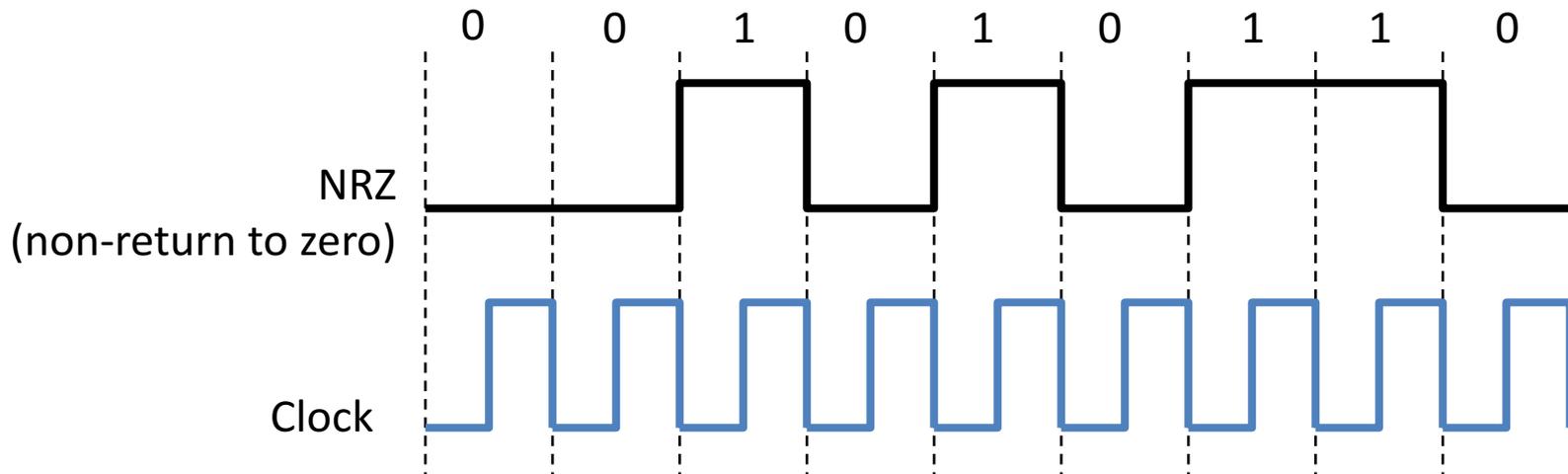
- **Example: Telephone Line**

- 3KHz b/w, 30dB S/N = $10^{(30/10)} = 1000$
- $C = 3\text{KHz} \log_2(1001) \approx 30\text{Kbps}$



Encoding

- **Now assume that we can somehow modulate a signal: receiver can decode our binary stream**
- **How do we encode binary data onto signals?**
- **One approach: 1 as high, 0 as low!**
 - Called Non-return to Zero (NRZ)



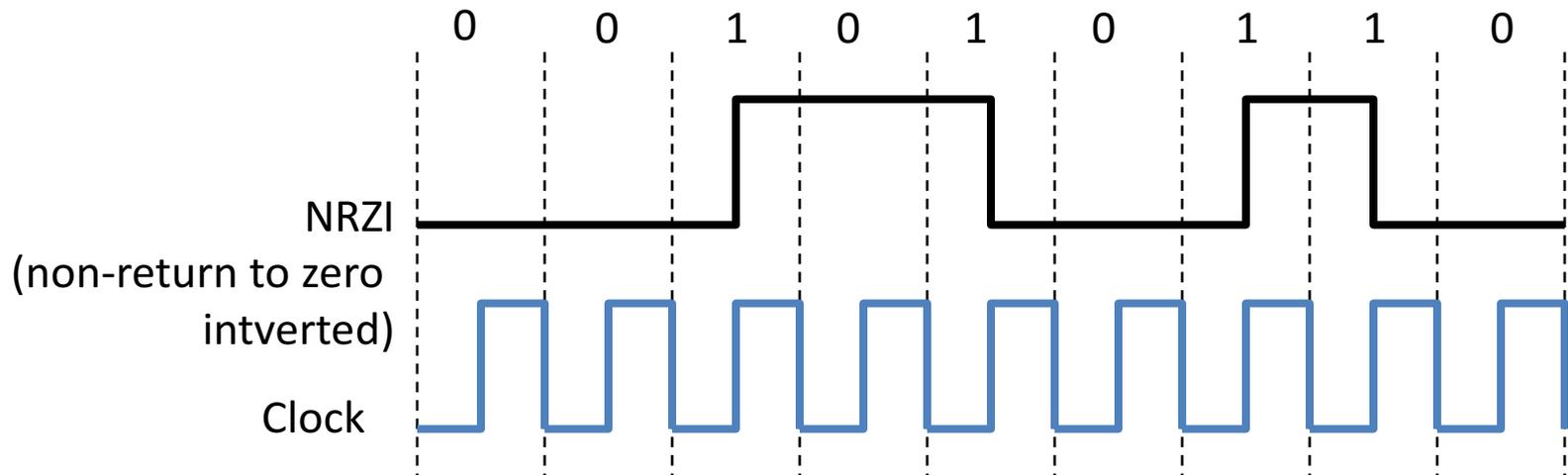
Drawbacks of NRZ

- **No signal could be interpreted as 0 (or vice-versa)**
- **Consecutive 1s or 0s are problematic**
- **Baseline wander problem**
 - How do you set the threshold?
 - Could compare to average, but average may drift
- **Clock recovery problem**
 - For long runs of no change, could miscount periods



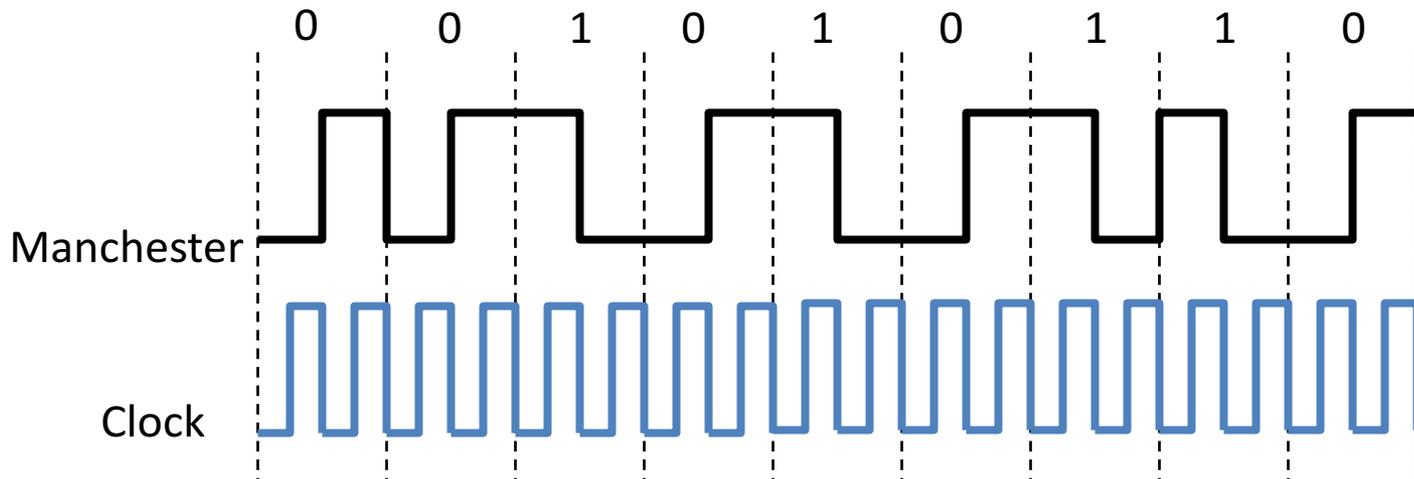
Alternative Encodings

- **Non-return to Zero Inverted (NRZI)**
 - Encode 1 with transition from current signal
 - Encode 0 by staying at the same level
 - At least solve problem of consecutive 1s



Manchester

- **Map 0 → chips 01; 1 → chips 10**
 - Transmission rate now 1 bit per two clock cycles
- **Solves clock recovery, baseline wander**
- **But cuts transmission rate in half**



4B/5B

- **Can we have a more efficient encoding?**
- **Every 4 bits encoded as 5 *chips***
- **Need 16 5-bit codes:**
 - selected to have no more than one leading 0 and no more than two trailing 0s
 - *Never get more than 3 consecutive 0s*
- **Transmit chips using NRZI**
- **Other codes used for other purposes**
 - E.g., 11111: line idle; 00100: halt
- **Achieves 80% efficiency**



4B/5B Table

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



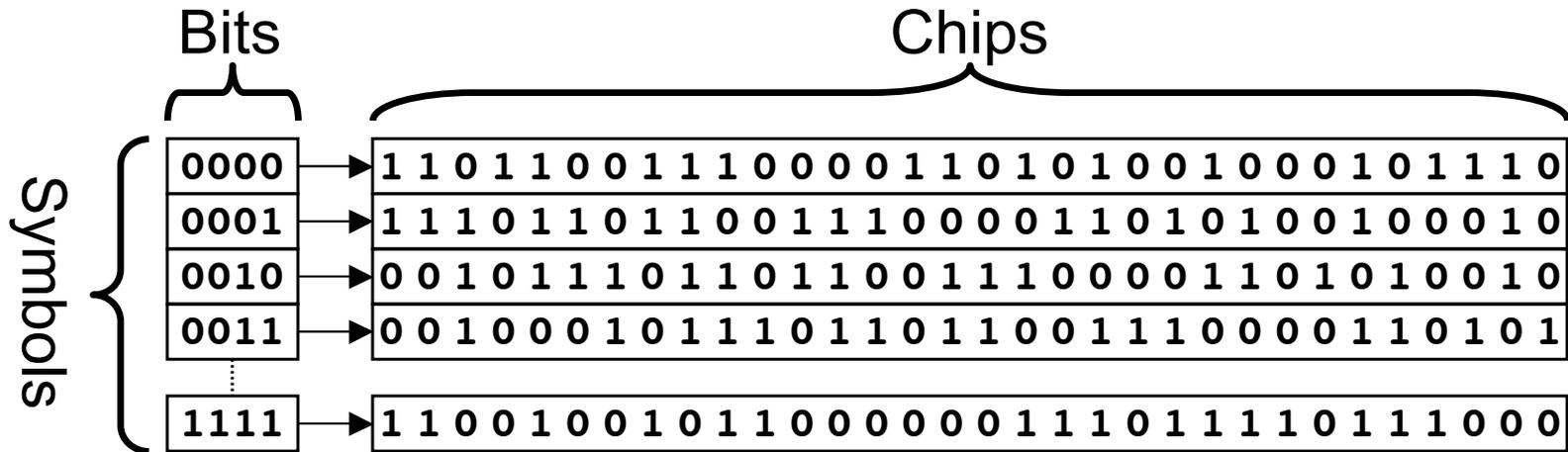
Encoding Goals

- **DC Balancing (same number of 0 and 1 chips)**
- **Clock synchronization**
- **Can recover some chip errors**
- **Constrain analog signal patterns to make signal more robust**
- **Want near channel capacity with negligible errors**
 - Shannon says it's possible, doesn't tell us how
 - Codes can get computationally expensive
- **In practice**
 - More complex encoding: fewer bps, more robust
 - Less complex encoding: more bps, less robust



Last Example: 802.15.4

- **Standard for low-power, low-rate wireless PANs**
 - Must tolerate high chip error rates
- **Uses a 4B/32B bit-to-chip encoding**



Questions so far?



Photo: Lewis Hine

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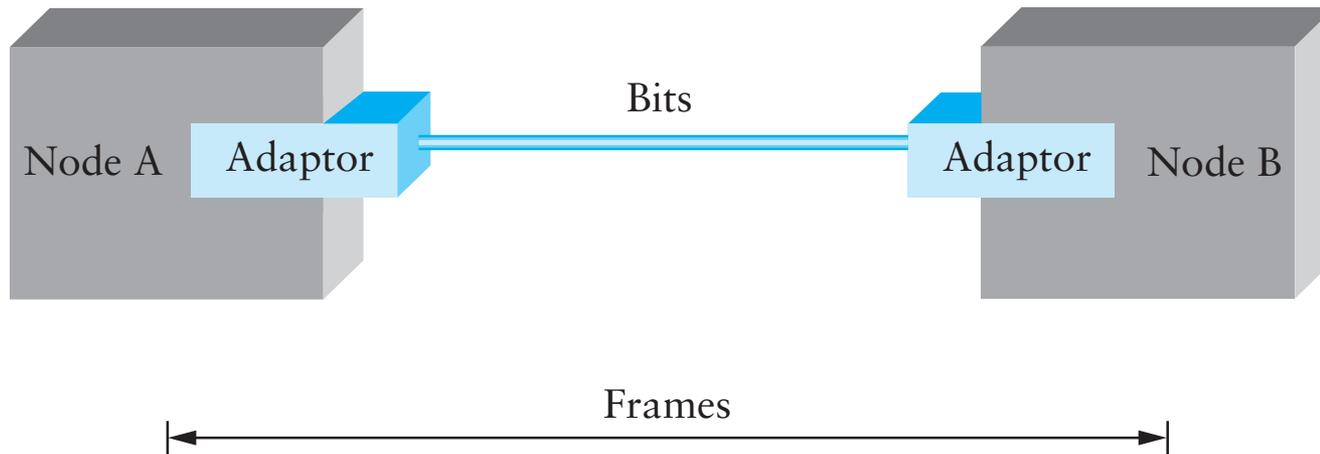
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Framing

- **Given a stream of bits, how can we represent boundaries?**
- **Break sequence of bits into a frame**
- **Typically done by network adaptor**

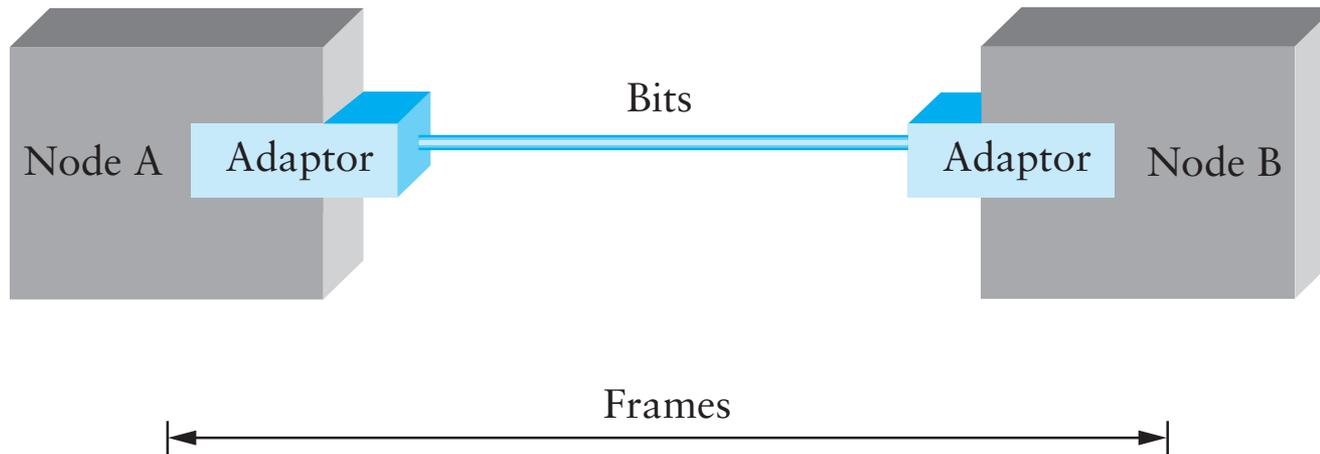


Link Layer Framing



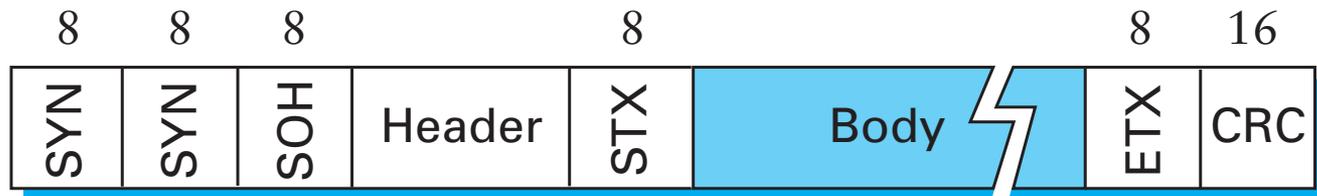
Representing Boundaries

- Sentinels
- Length counts
- Clock-based



Sentinel-based Framing

- **Byte-oriented protocols (e.g. BISYNC, PPP)**
 - Place special bytes (SOH, ETX,...) in the beginning, end of messages

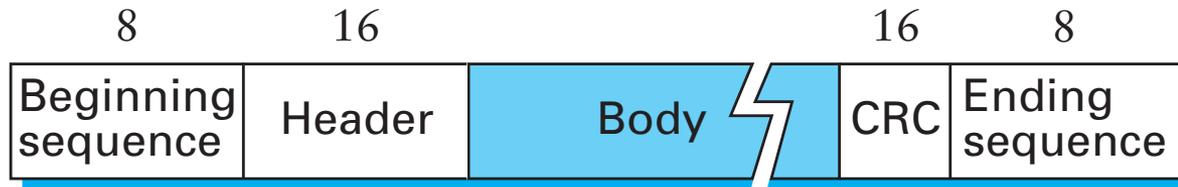


- **What if ETX appears in the body?**
 - **Escape** ETX byte by prefixing DEL byte
 - **Escape** DEL byte by prefixing DEL byte
 - Technique known as *character stuffing*



Bit-Oriented Protocols

- View message as a stream of bits, not bytes
- Can use sentinel approach as well (e.g., HDLC)

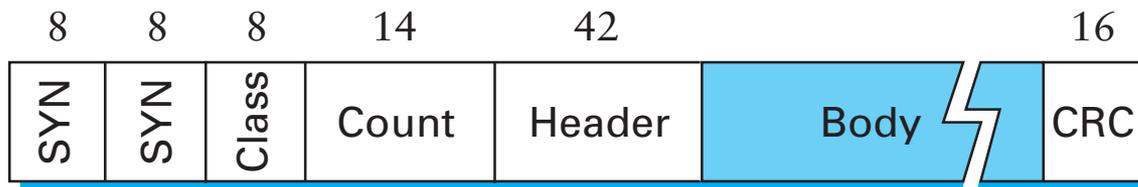


- HDLC begin/end sequence 01111110
- Use *bit stuffing* to escape 01111110
 - Always append 0 after five consecutive 1s in data
 - After five 1s, receiver uses next two bits to decide if stuffed, end of frame, or error.



Length-based Framing

- **Drawback of sentinel techniques**
 - Length of frame depends on data
- **Alternative: put length in header (e.g., DDCMP)**

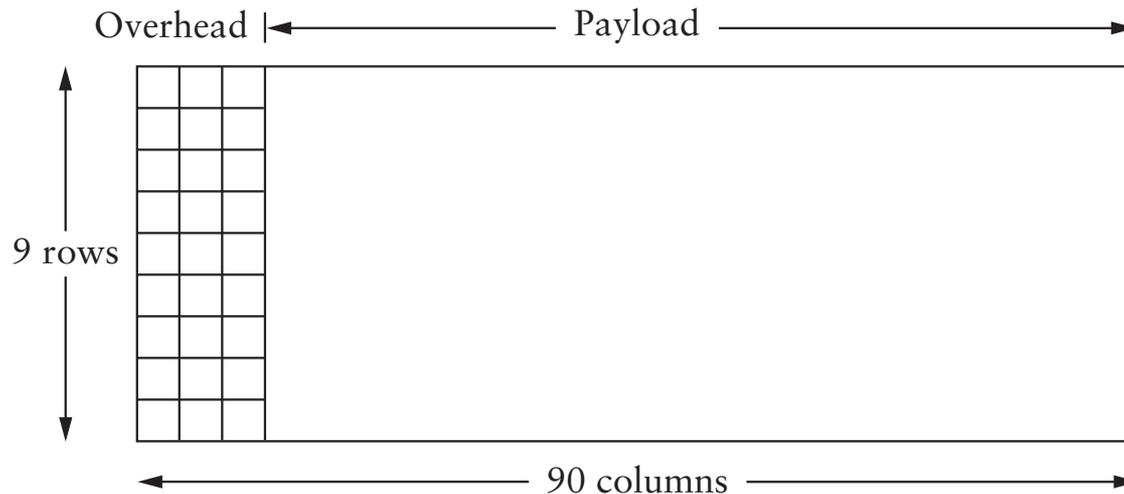


- **Danger: Framing Errors**
 - What if high bit of counter gets corrupted?
 - Adds 8K to length of frame, may lose many frames
 - CRC checksum helps detect error



Clock-based Framing

- ***E.g., SONET (Synchronous Optical Network)***
 - Each frame is 125 μ s long
 - Look for header every 125 μ s
 - Encode with NRZ, but first XOR payload with 127-bit string to ensure lots of transitions



Error Detection

- **Basic idea: use a checksum**
 - Compute small checksum value, like a hash of packet
- **Good checksum algorithms**
 - Want several properties, *e.g.*, detect any single-bit error
 - Details in a later lecture



Next Week

- **Next week: more link layer**
 - Flow Control and Reliability
 - Ethernet
 - Sharing access to a shared medium
 - Switching
- **Next Thursday: Snowcast due, HW1 out**

