CSCI-1680
Physical Layer

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Based partly on lecture notes by David Mazières, Phil Levis, John Jannotti

Administrivia

- **Signup for Snowcast milestone**
  - Make sure you signed up
  - Make sure you are on the mailing list!
- **Return signed policy sheet**

Today

- **Physical Layer**
  - Modulation
  - Encoding
- **Link Layer I**
  - Framing

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

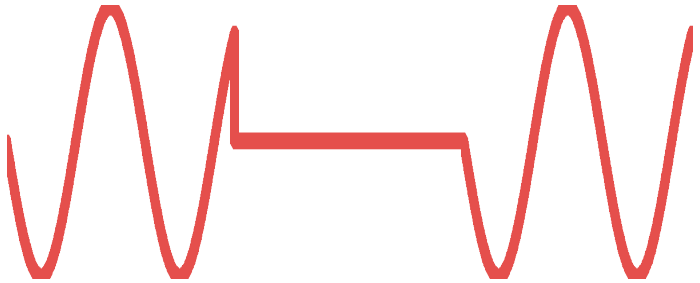
- **Specifies mapping between digital signal and some variation in analog signal**
- **Why not just a square wave (1v=1; 0v=0)?**
  - Not square when bandwidth limited
- **Bandwidth – frequencies that a channel propagates well**
  - Signals consist of many frequency components
  - Attenuation and delay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

Use Carriers

- **Idea: only use frequencies that transmit well**
- ***Modulate* the signal to encode bits**

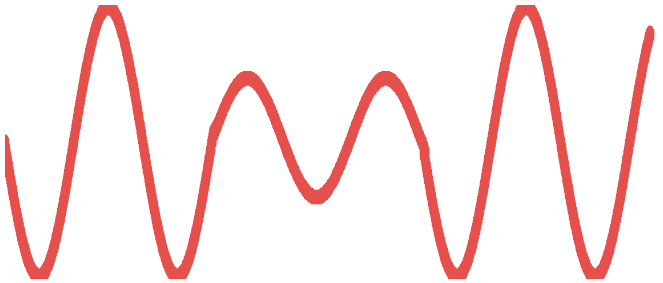
OOK: On-Off Keying

1 0 1



ASK: Amplitude Shift Keying

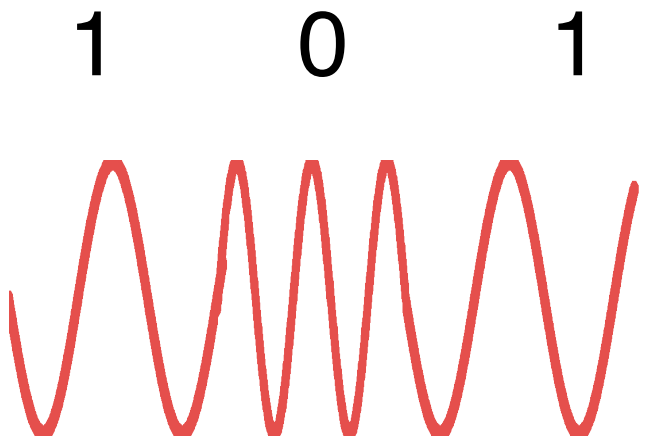
1 0 1



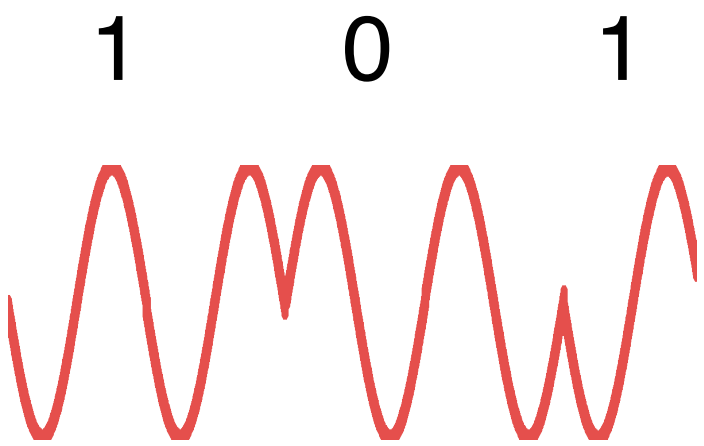
Use Carriers

- **Idea: only use frequencies that transmit well**
- ***Modulate* the signal to encode bits**

FSK: Frequency Shift Keying



PSK: Phase Shift Keying



How Fast Can You Send?

- **Nyquist's theorem limits how fast we can send on a bandwidth-limited channel**

  If a signal has been through a low-pass filter of bandwidth B, the signal can be reconstructed by making 2B samples per second.

- **Maximum data rate: 2B**

But wait…

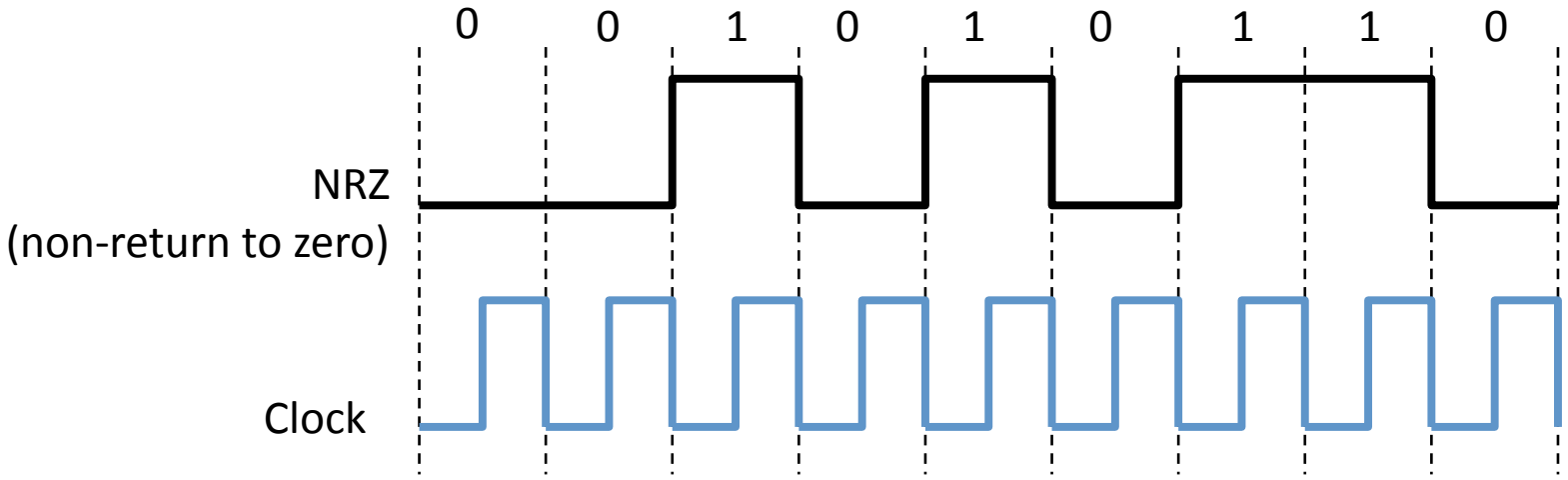
- **So we can only change 2B/second, what if we encode more bits per sample?**
  - Baud is the frequency of changes to the physical channel
  - Not the same thing as bits!
- **Suppose channel passes 1KHz to 2KHz**
  - 1 bit per sample: alternate between 1KHz and 2KHz
  - 2 bits per sample: send one of 1, 1.33, 1.66, or 2KHz
  - n bits: choose among 2^n frequencies!
- **Sorry, channels are *noisy***

How Fast Can You Really Send?

- **Depends on frequency and signal/noise ratio**
- **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
- **Example: Telephone Line**
  - 3KHz b/w, 30dB S/N = 10^(30/10) = 1000
  - C ≈ 30 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: Non-return to Zero (NRZ)**
  - Transmit 0 as low, 1 as high!

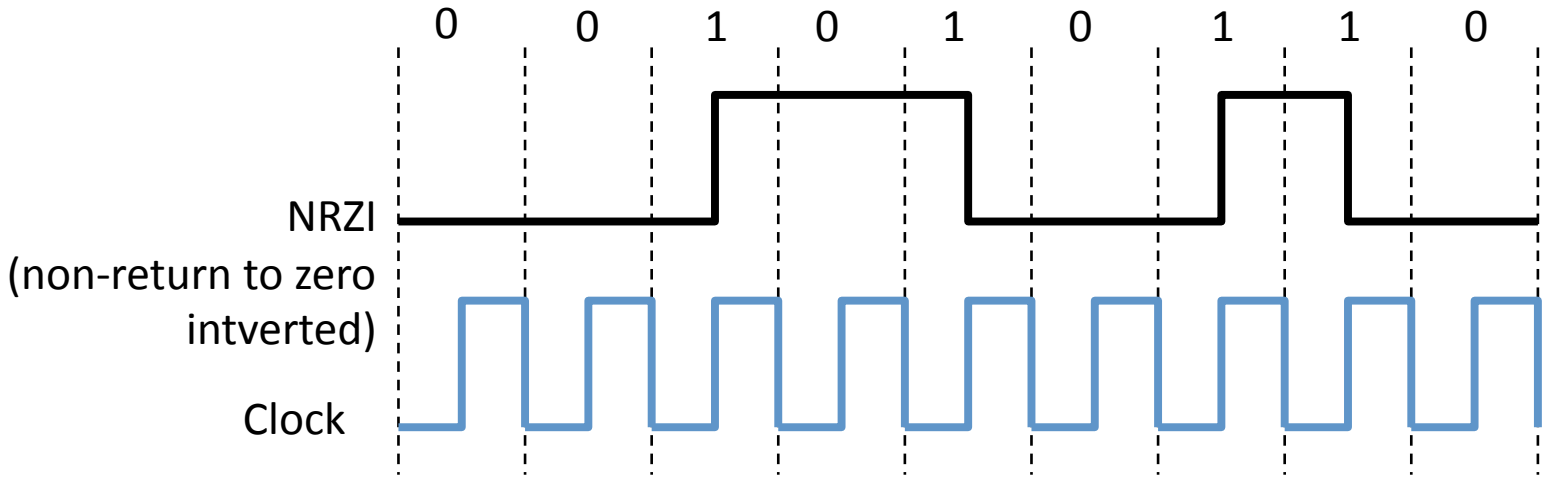


Drawbacks of NRZ

- **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

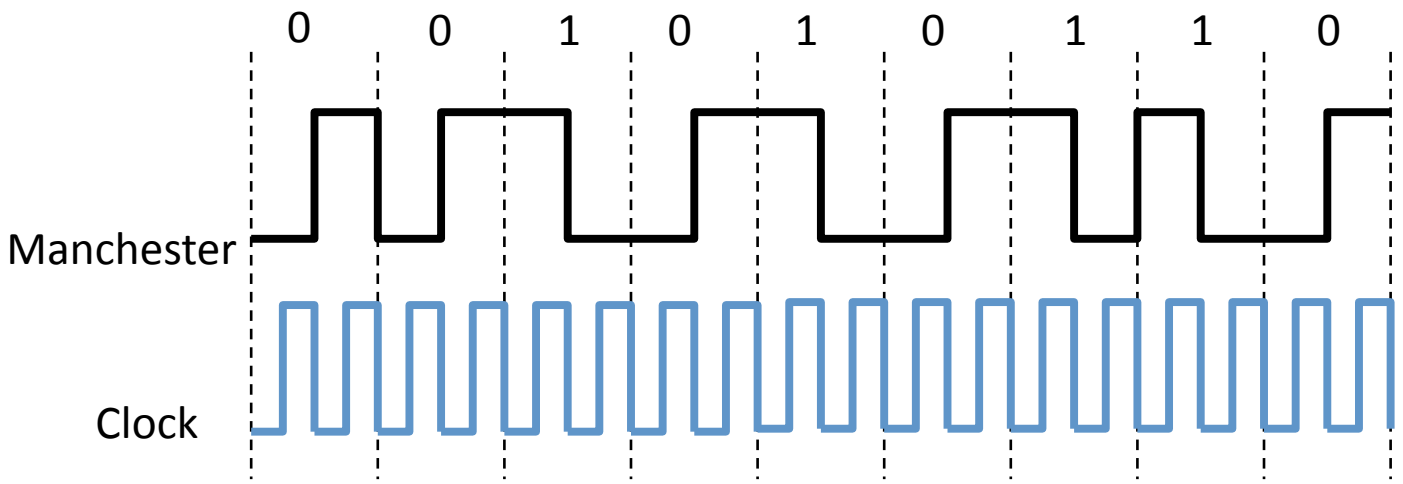
Alternative Encodings

- **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

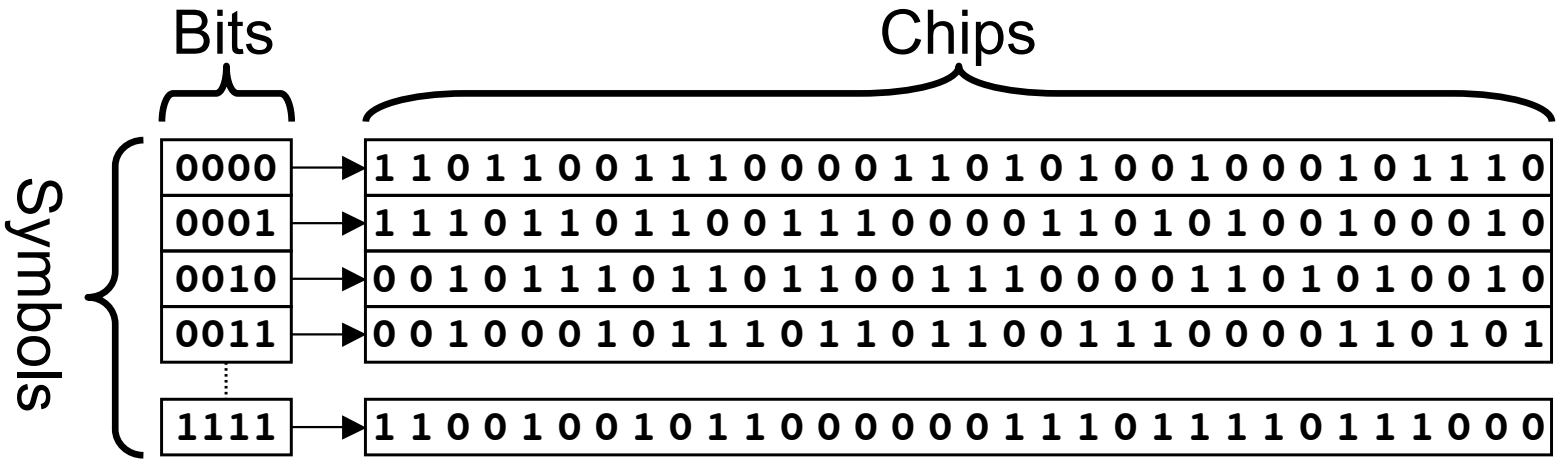
- **Can we have a more efficient encoding?**
- **Every 4 bits encoded as 5 *chips***
- **Need 16 5-bit codes:**
  - selected to have no more than one leading 0 and no more than two trailing 0s
  - Never get more than 3 consecutive 0s
- **Transmit chips using NRZI**
- **Other codes used for other purposes**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

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**

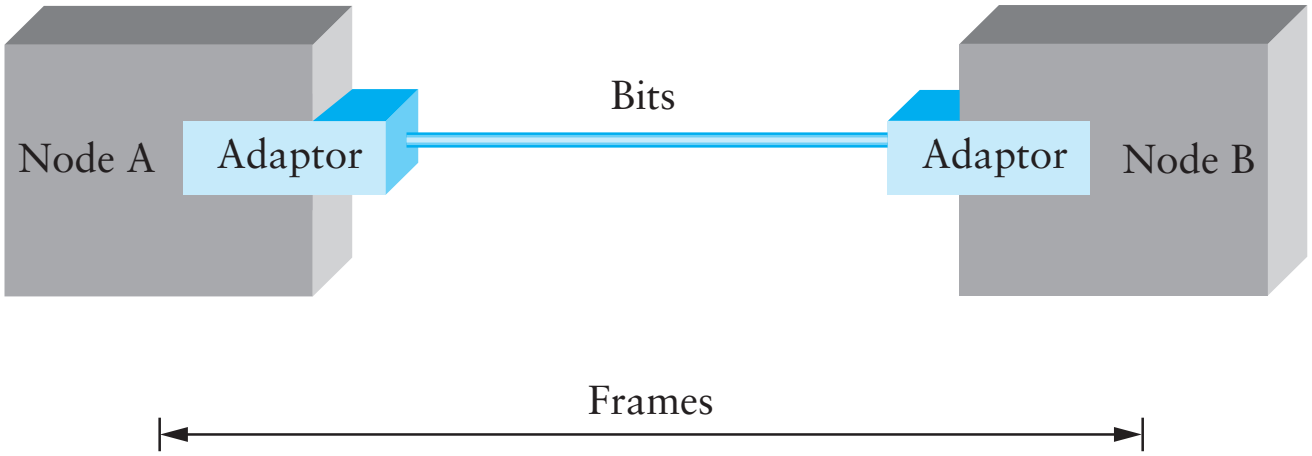


Two-minutes for stretching

Photo: Lewis Hine

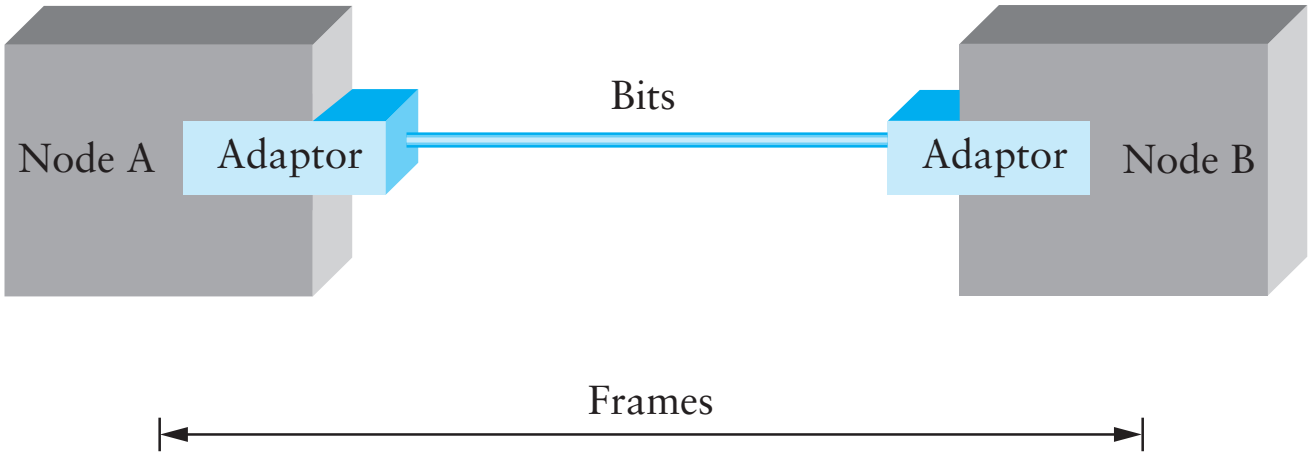
Framing

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



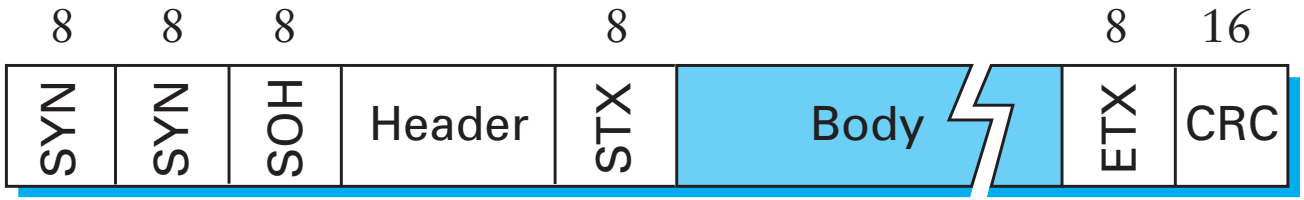
Representing Boundaries

- **Sentinels**
- **Length counts**
- **Clock-based**



Sentinel-based Framing

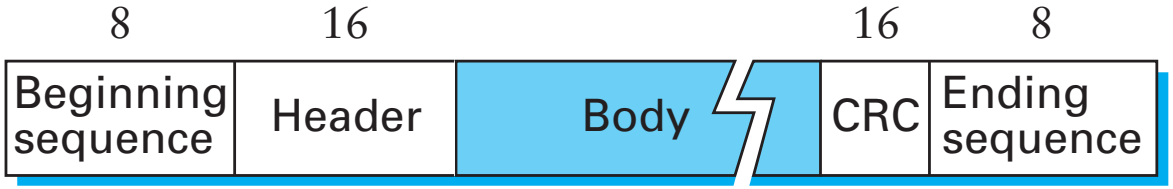
- **Byte-oriented protocols (*e.g.* BISYNC, PPP)**
  - Place special bytes (SOH, ETX,…) in the beginning, end of messages



- **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

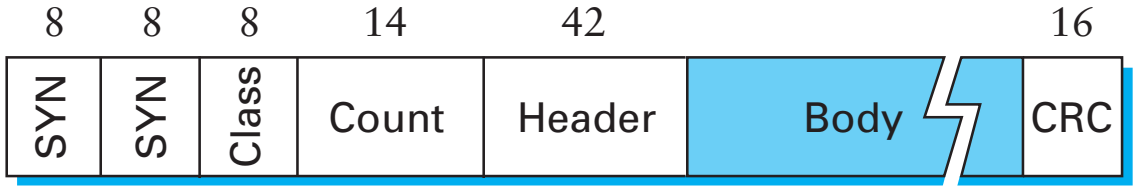
- **View message as a stream of bits, not bytes**
- **Can use sentinel approach as well (*e.g.*, HDLC)**



  - 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

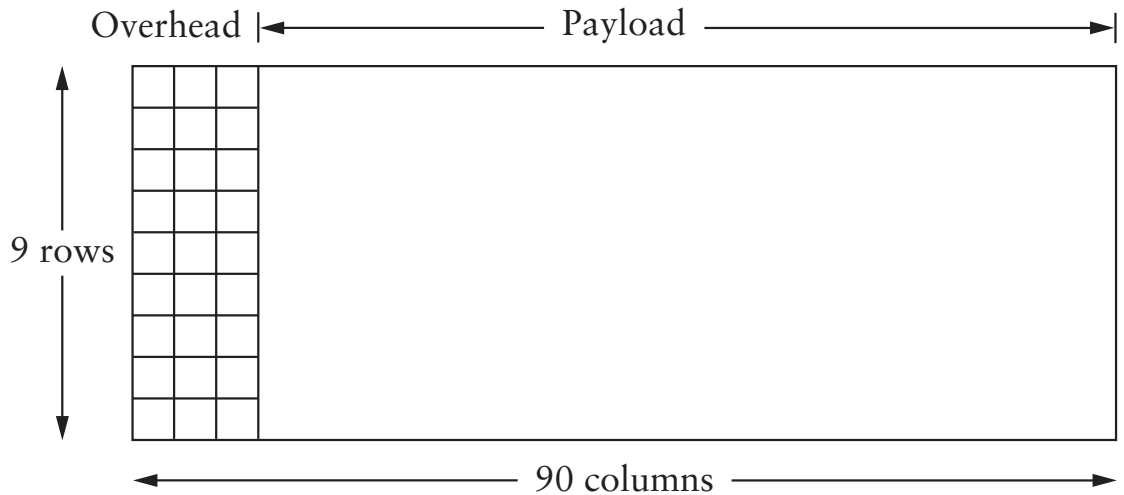
- **Drawback of sentinel techniques**
  - Length of frame depends on data
- **Alternative: put length in header (*e.g.*, DDCMP)**



- **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 125μs long
  - Look for header every 125μs
  - Encode with NRZ, but 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

Coming Up

- **Next week: more link layer**
  - Flow Control and Reliability
  - Ethernet
  - Sharing access to a shared medium
  - Switching
- **Friday 11th: Snowcast due**