CSE 461: Bits and Bandwidth

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Homework

Chapter 1, written problems

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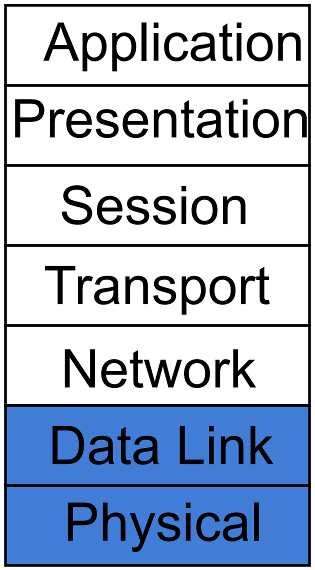
Due 11:59pm next Wednesday, October 8
Submit by mailing it to the TA -- Alper

Next Topic

- Focus: How do we send a message across a wire?

- The physical / link layers:
  1. Different kinds of media
  2. Encoding bits, messages
  3. Model of a link

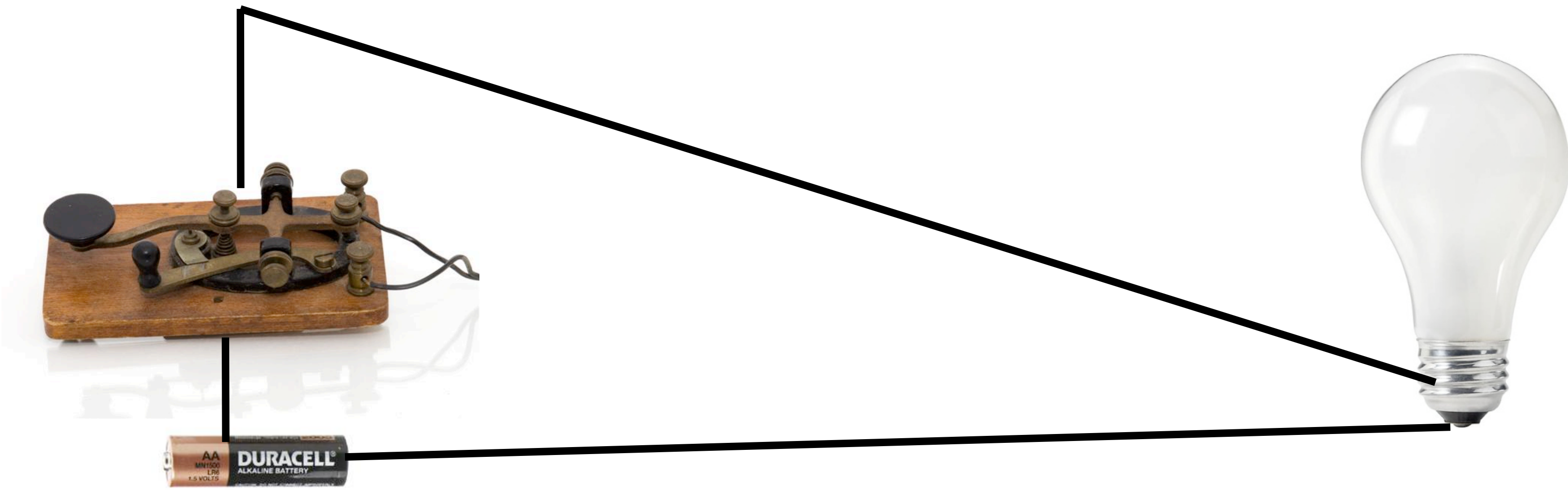


Our Challenge Today: Transmit Bits

- Transmit some bits from A to B
  - How quickly can we transmit them?
  - How far can we transmit them?
  - How are these two questions related?

- Thought Experiment:
  - Why can’t you speak quickly someplace where there is a lot of echo – like in a sauna?
  - Why is it easier to understand someone speaking in your ear quietly than someone speaking from a few feet away – even with equal perceived volume?

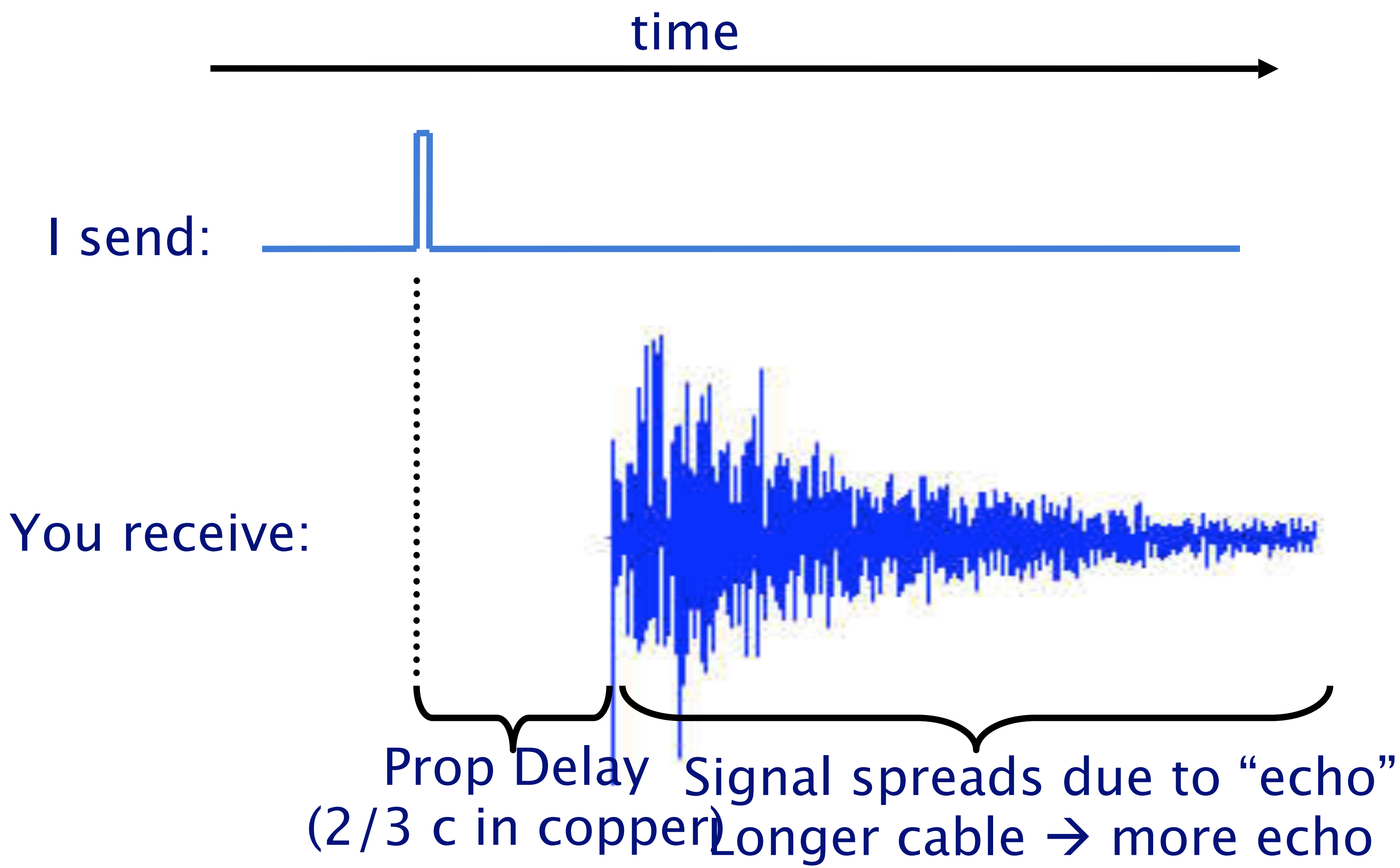
A Very Simple Digital Network



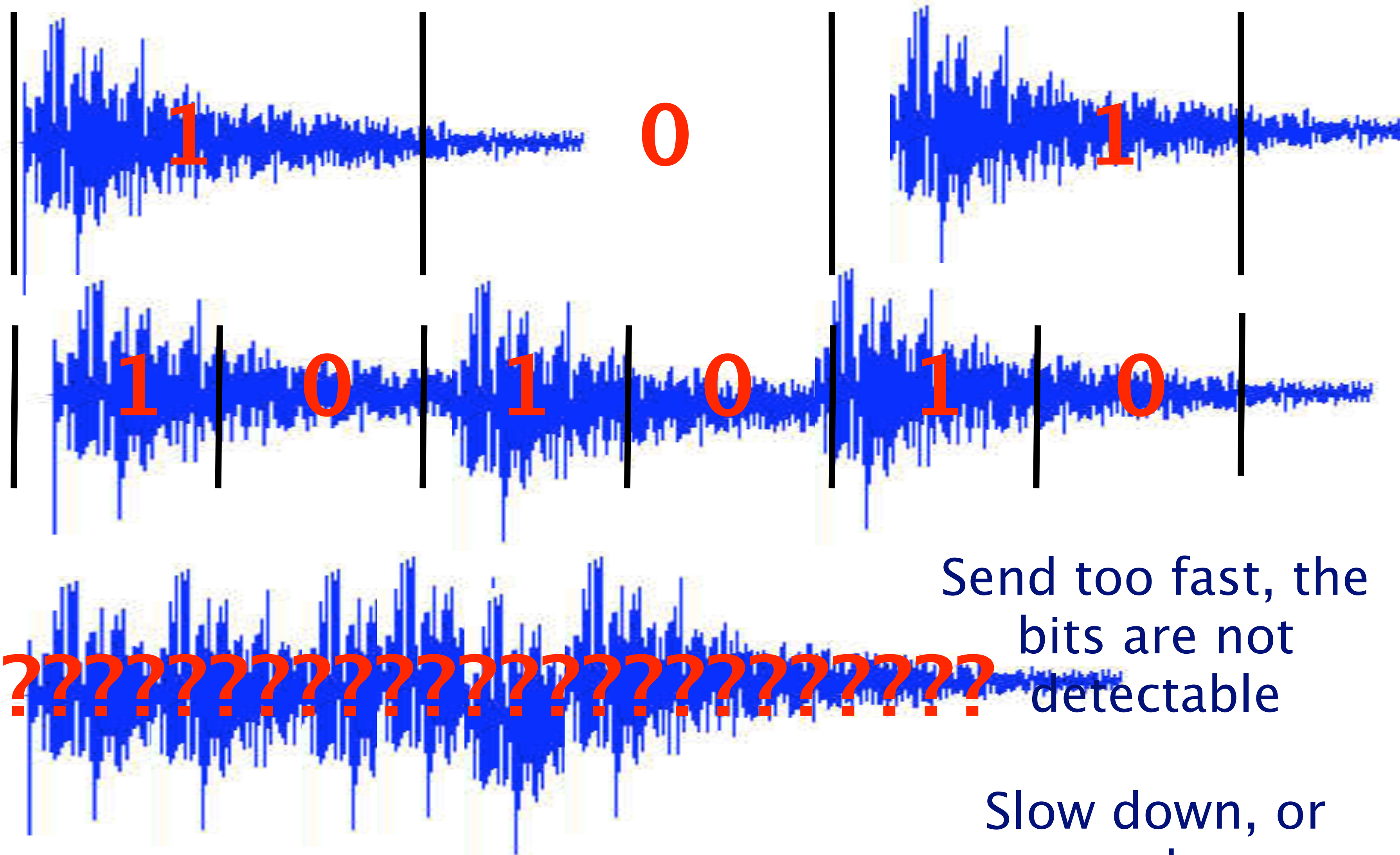
We agree that once per second, you should look at the bulb.
If it flashes, I sent a 1. If it doesn't, I sent a 0.

How quickly can we transmit bits?
What happens when we transmit too quickly?

Clean Signal In, Dirty Signal Out



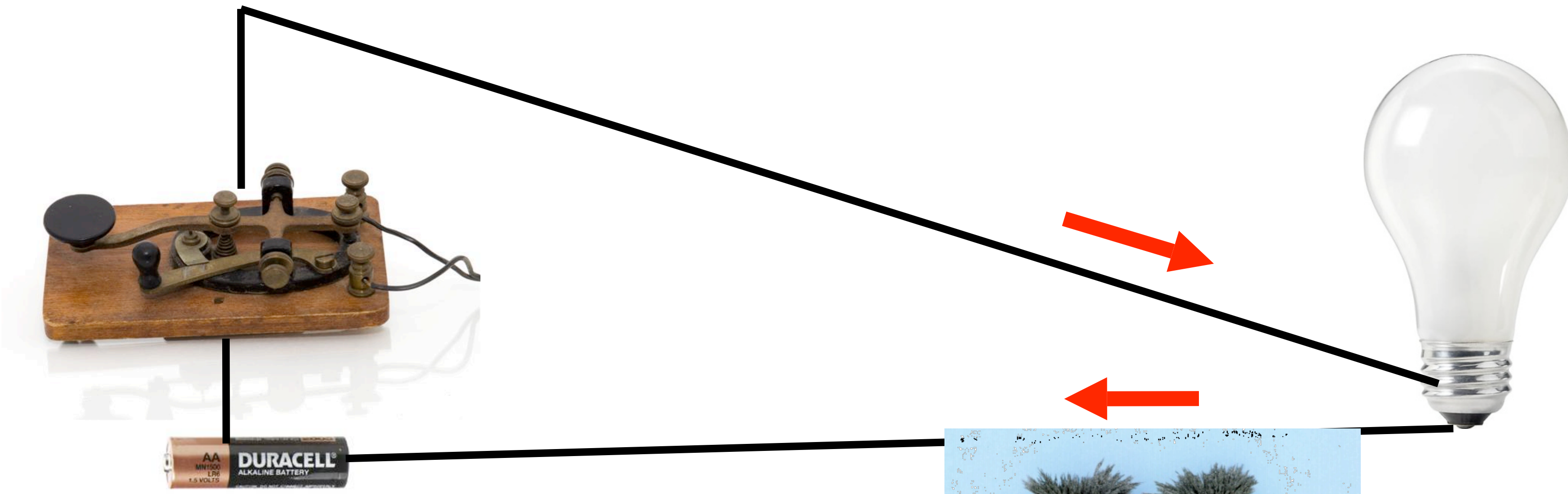
Slow bits vs. Fast bits



Send too fast, the bits are not detectable

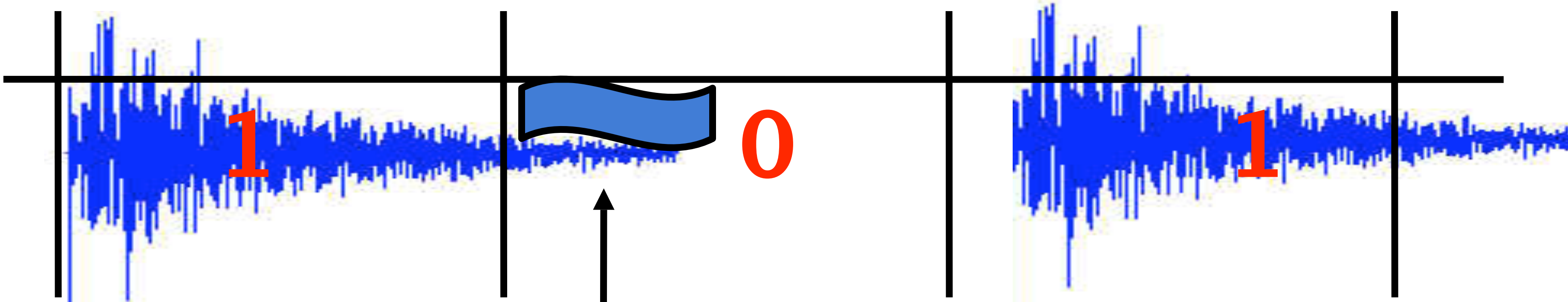
Slow down, or make

Problem 2: Noise

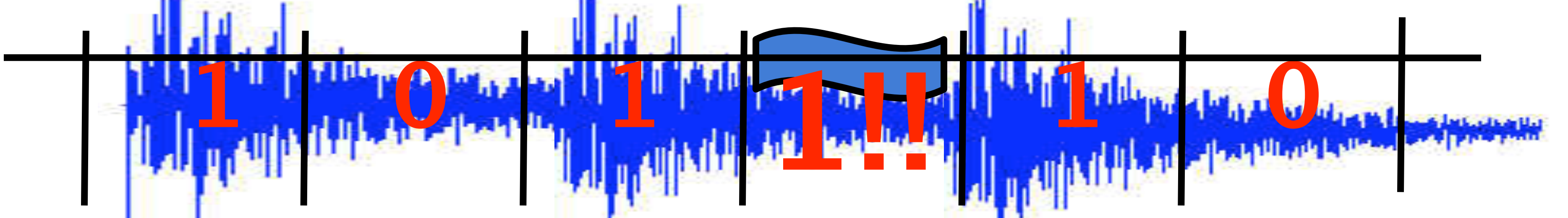


What happens when a magnetic field comes near a loop of copper wire?

Noise from the Environment



Despite a burst of noise,
the bit is still under the “0” detection threshold.

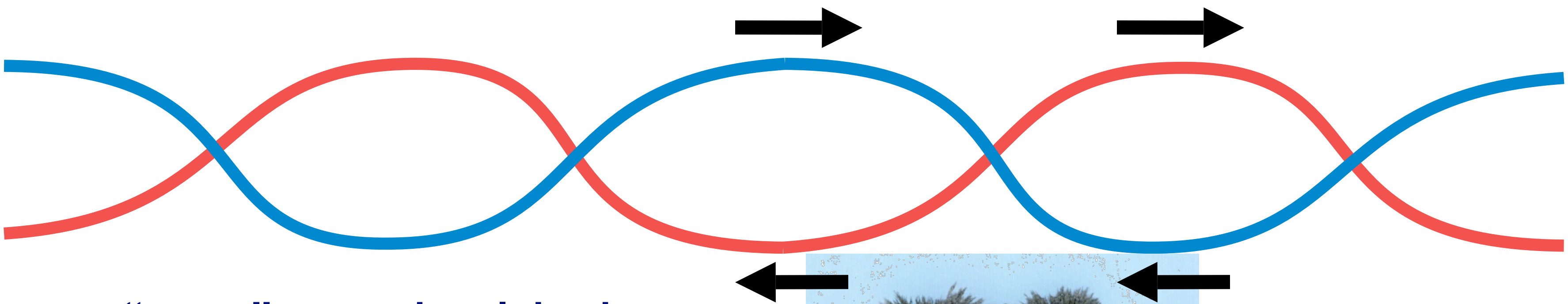


This bit wasn’t so lucky.
Bits transmitted faster are closer to the detection threshold, and are therefore more susceptible to noise.

Signal to Noise Ratio is strongly related to channel capacity (Shannon)

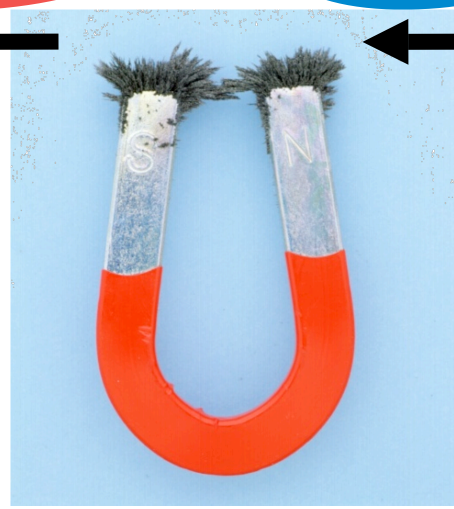
Twisted Pair

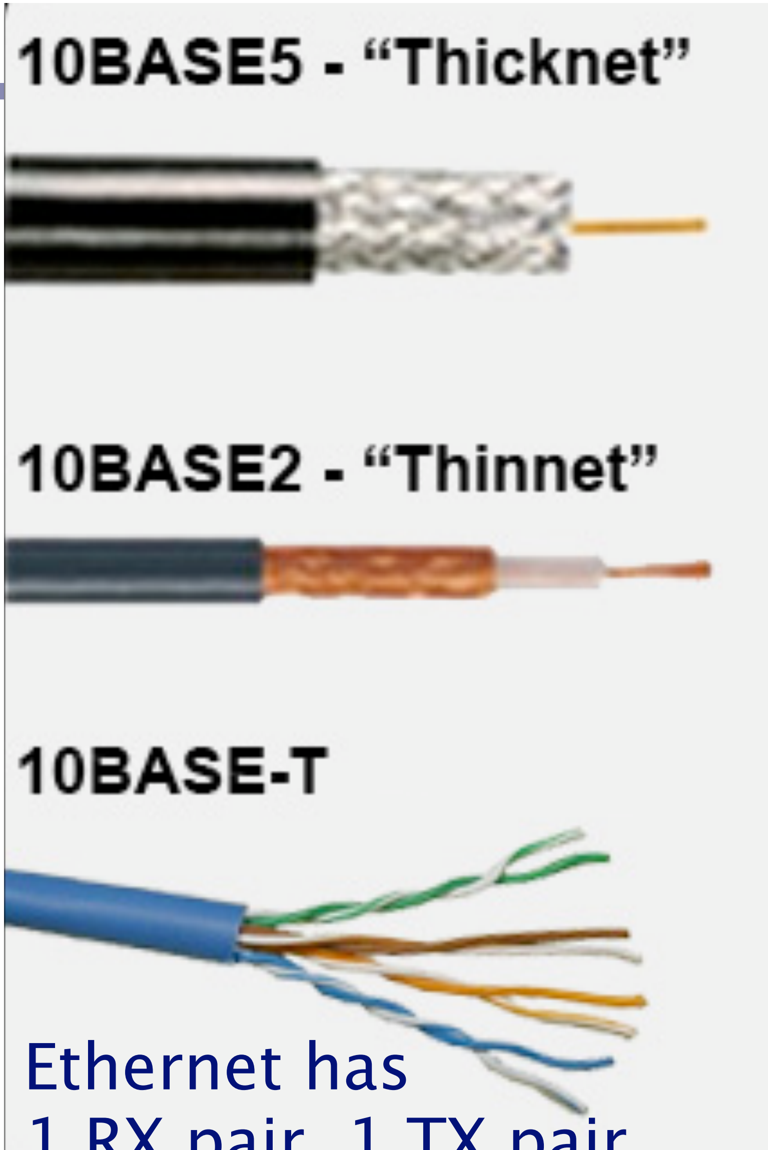
Why does it work?
Why should the twists be spaced closely together?



"UTP": Unshielded Twisted Pair

"Cat 5": Category 5, relates to required impedance, prop delay, twist density, etc





Ethernet has
1 RX pair, 1 TX pair,
2 unused pairs

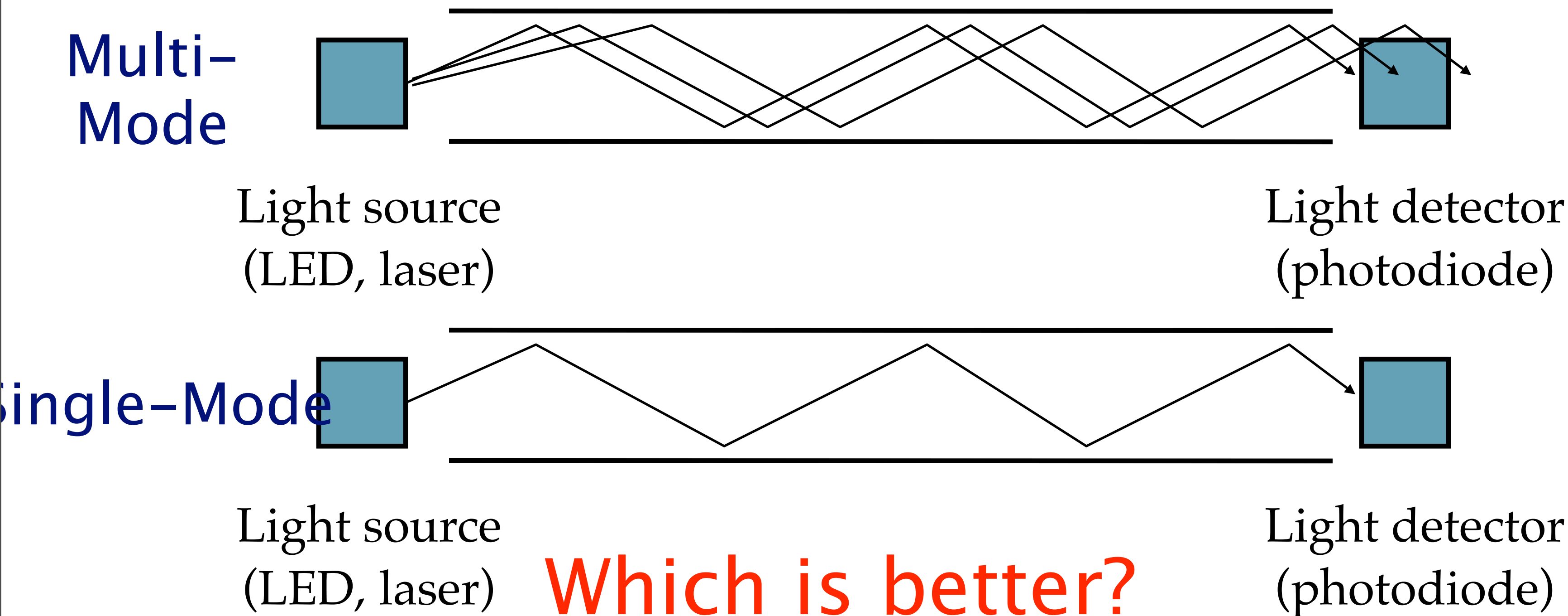
Early types of Ethernet tried to reduce noise purely through shielding

Shielded twisted pair exists; Sometimes used in hostile buildings (e.g., factory)

“Solid” vs “Stranded” cable: Conductors are made of a single, thick strand of copper (inflexible, but low dispersion) or a copper braid (more flexible, but higher dispersion)

Fiber Optic Cable

- Long, thin, pure strand of glass
  - light propagated with total internal reflection
  - enormous bandwidth available (terabits)



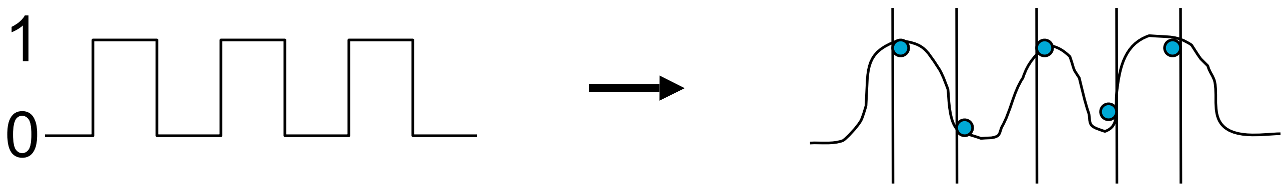
Which is better?

Summary: media

- Copper Wire
  - +Cheap, +Easy to handle, +Mech. Robust, –Noisy
  - Coaxial cable, e.g, thin-net, 10 → 100Mbps, 200m –Bus
  - Twisted pair, e.g., CAT5 UTP, 10 → 100Mbps, 100m +Star
- Fiber
  - +Noise-immune, +Low-dispersion,
  - –Expensive, –Difficult, –Fragile
  - Multi-mode, 100Mbps, 2km
  - Single mode, 100 → 10 Gbps, 60km
  - Single mode with amplifiers & other fanciness 1000km
- Wireless
  - Infra-red, e.g., IRDA, ~1Mbps
  - RF, e.g., 802.11 wireless LANs, Bluetooth (2.4GHz)

2. Real Encodings

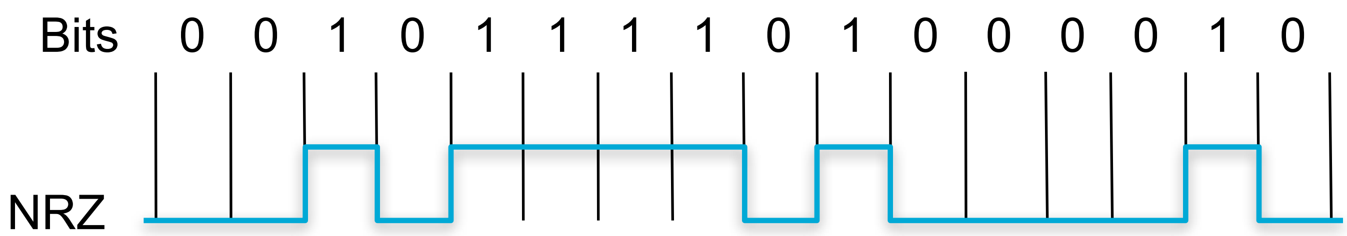
- Generate analog waveform (e.g., voltage) from digital data at transmitter and sample to recover at receiver



- We send/recover symbols that are mapped to bits

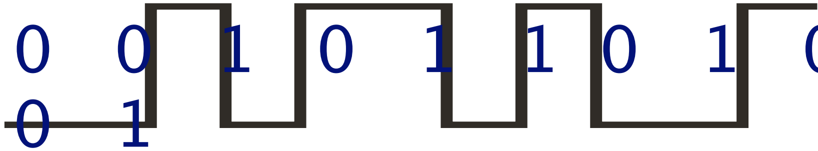
NRZ

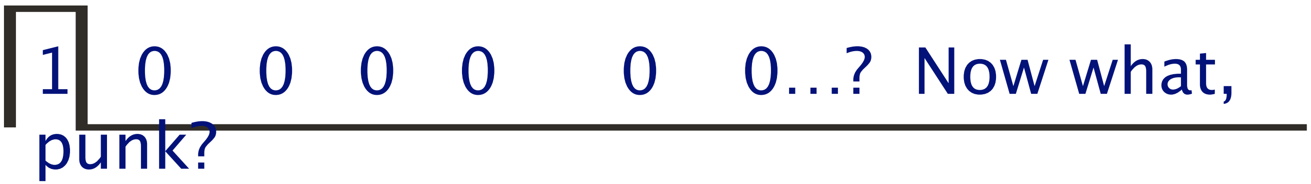
- Simplest encoding, NRZ (Non-return to zero)
  - Use high/low voltages, e.g., high = 1, low = 0



Clock Recovery

- How do we distinguish consecutive 0s or 1s? Easy, right?





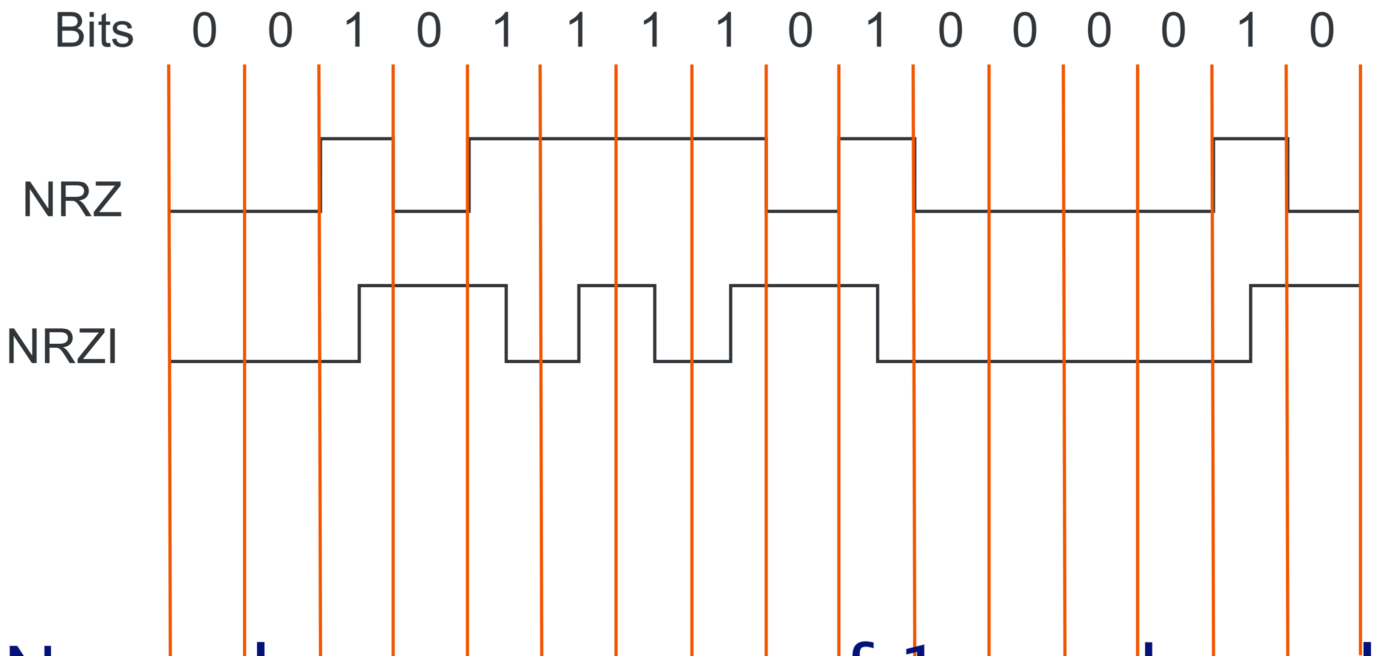
If sender and receiver have exact clocks no problem

  - But in practice they drift slowly

- Possible solutions:
  - Get really good clocks → super expensive (mini-atomic clocks?)
  - Send clock signal (“synchronous”) → huge overhead, expensive
  - Keep messages short → lots of overhead

NRZI

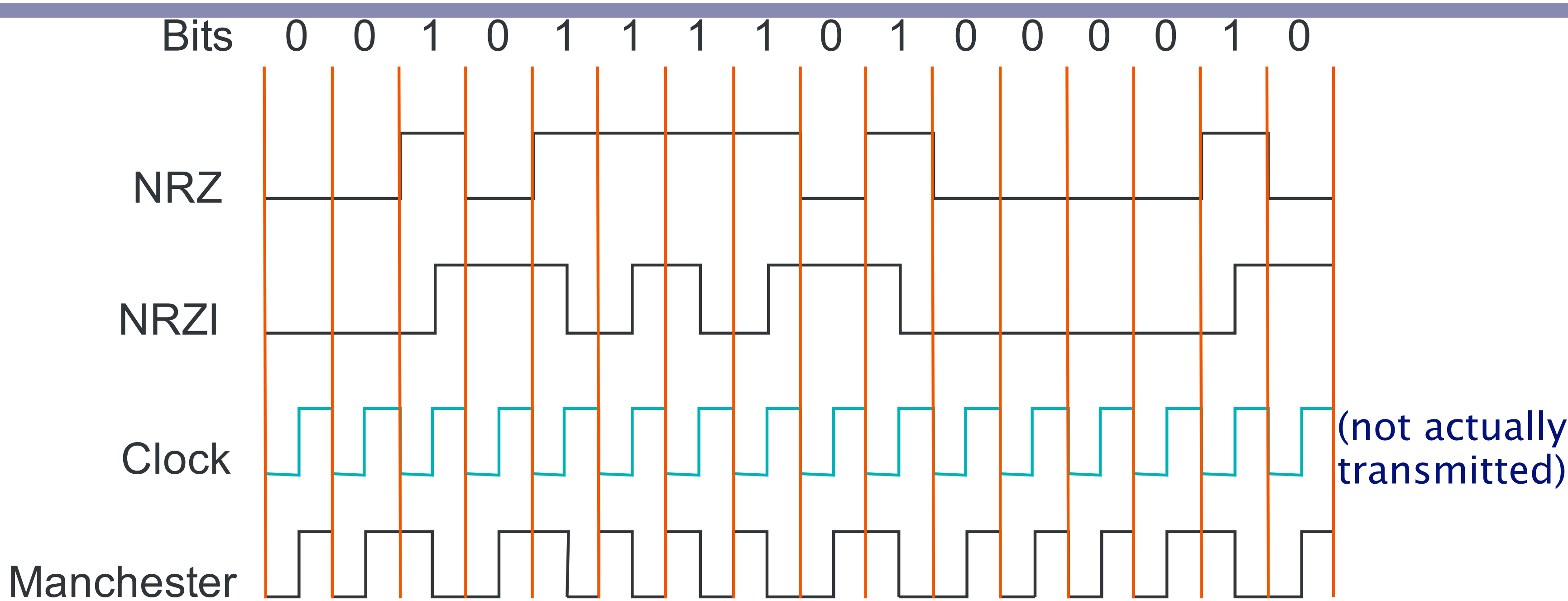
- NRZI (NRZ Inverted):
  - “stay at same voltage” means “0”
  - “voltage change” means “1”



Now a long sequence of 1s works really well.

You didn’t really need zeroes, did you?

Manchester Coding



- Make transition in the middle of every bit period
  - Low-to-high is 0; high-to-low is 1
  - Signal rate is twice the bit rate
- Advantage: self-clocking
- Disadvantage: 50% efficiency

4B/5B Codes

- We want self-clocking transitions and efficiency …
- Solution: map data bits (which may lack transitions) into code bits (which are guaranteed to have them)

- 4B/5B code:
  - 0000 → 11110, 0001 → 01001, … 1111 → 11101
  - Never more than three consecutive 0s back-to-back
  - 80% efficiency

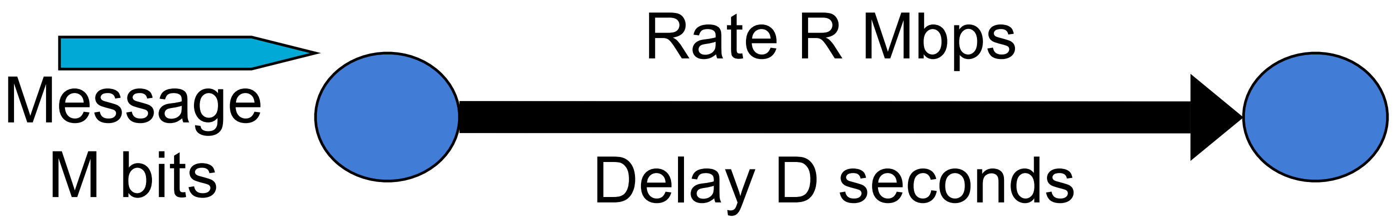
- Many more complex codes are available; some use multiple voltage levels
  - How does a 3-voltage system interact with noise and speed?

Framing

- Need to send message, not just bits
  - Requires that we synchronize on the start of message reception at the far end of the link
  - Complete Link layer messages are called <u>frames</u>

- Common approach: Sentinels
  - Look for special control code that marks start of frame
  - And escape or “stuff” this code within the data region
  - Like a C compiler: A quotation mark (“) is a string sentinel, so (\”) means (“)

4. Model of a Link

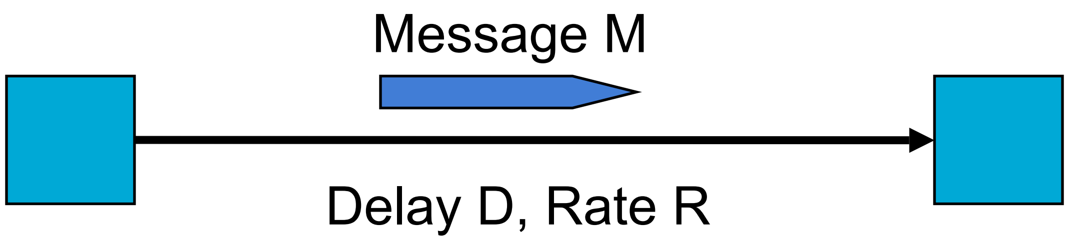


- Abstract model is typically all we will need

- Other parameters that are important:
  - The kind and frequency of errors
  - Whether the media is broadcast or not

Message Latency

- How long does it take to send a message?



- Two terms:
  - Propagation delay = distance / speed of signal in media
    - How quickly a message travels over the wire
    - 2/3c for copper wire
  - Transmission delay = message (bits) / rate (bps)
    - How quickly you can inject the message onto the wire
  - Propagation delay tells you when the FIRST bit arrives, Transmission delay tells you when the LAST bit arrives.
- Later we will see queuing delay …

Relationships

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- Latency = Propagation + Transmit + Queue

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- Propagation Delay = Distance/PropagationSpeed

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- Latency = Propagation + Transmit + Queue
- Propagation Delay = Distance/PropagationSpeed
- Transmit Time = MessageSize/Bandwidth

One-way Latency

Dialup with a modem:

- D = 10ms, R = 56Kbps, M = 1024 bytes
- Latency = 10ms + (1024 x 8)/(56 x 1024) sec = 153ms!

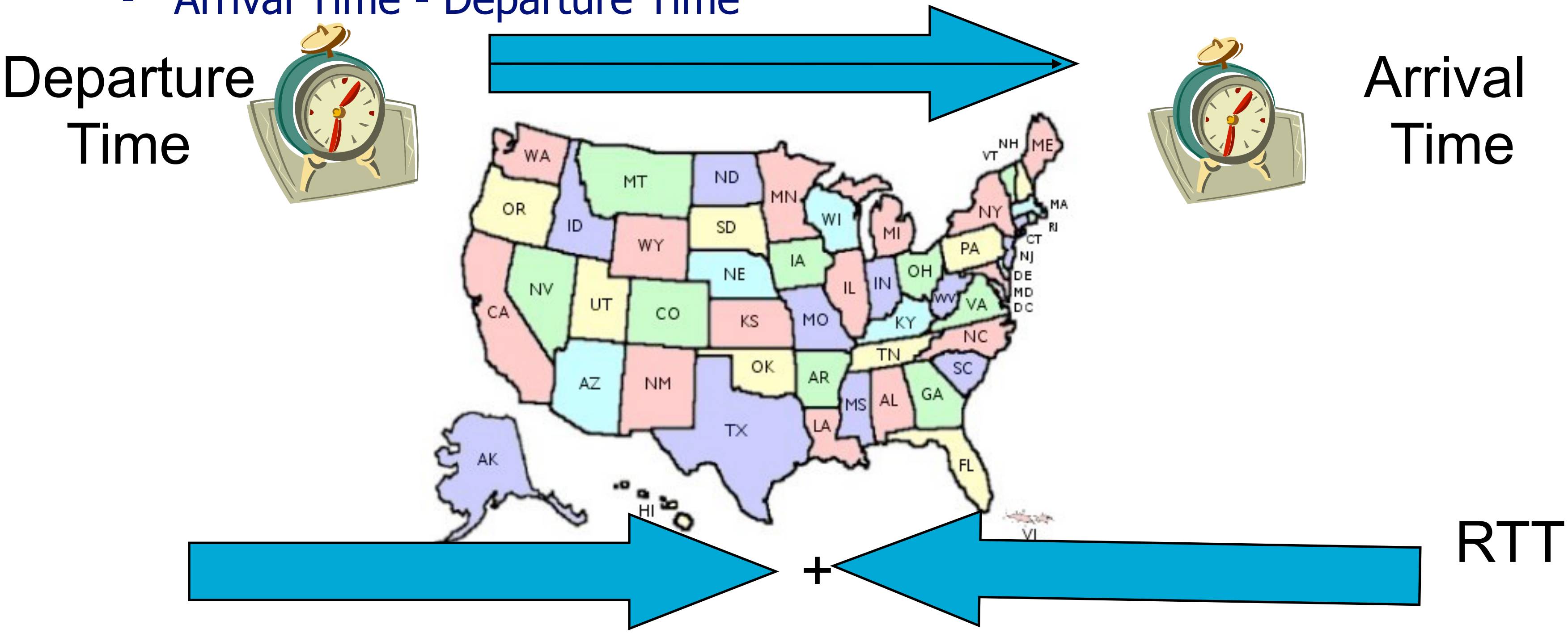
Cross-country with T3 (45Mbps) line:

- D = 50ms, R = 45Mbps, M = 1024 bytes
- Latency = 50ms + (1024 x 8) / (45 x 1024*1024) sec = 50ms!

- Either a slow link or long wire makes for large latency

Latency and RTT

- Latency is typically the one way delay over a link
  - Arrival Time - Departure Time



- The round trip time (RTT) is twice the one way delay
  - Measure of how long to signal and get a response

Throughput

- Measure of system's ability to "pump out" data
  - NOT the same as bandwidth
- Throughput = Transfer Size / Transfer Time
  - E.g., "I transferred 1000 bytes in 1 second on a 100Mb/s link"
    - BW?
    - Throughput?
- Transfer Time = SUM OF
  - Time to get started shipping the bits
  - Time to ship the bits
  - Time to get a response if necessary

Messages Occupy Space On the Wire

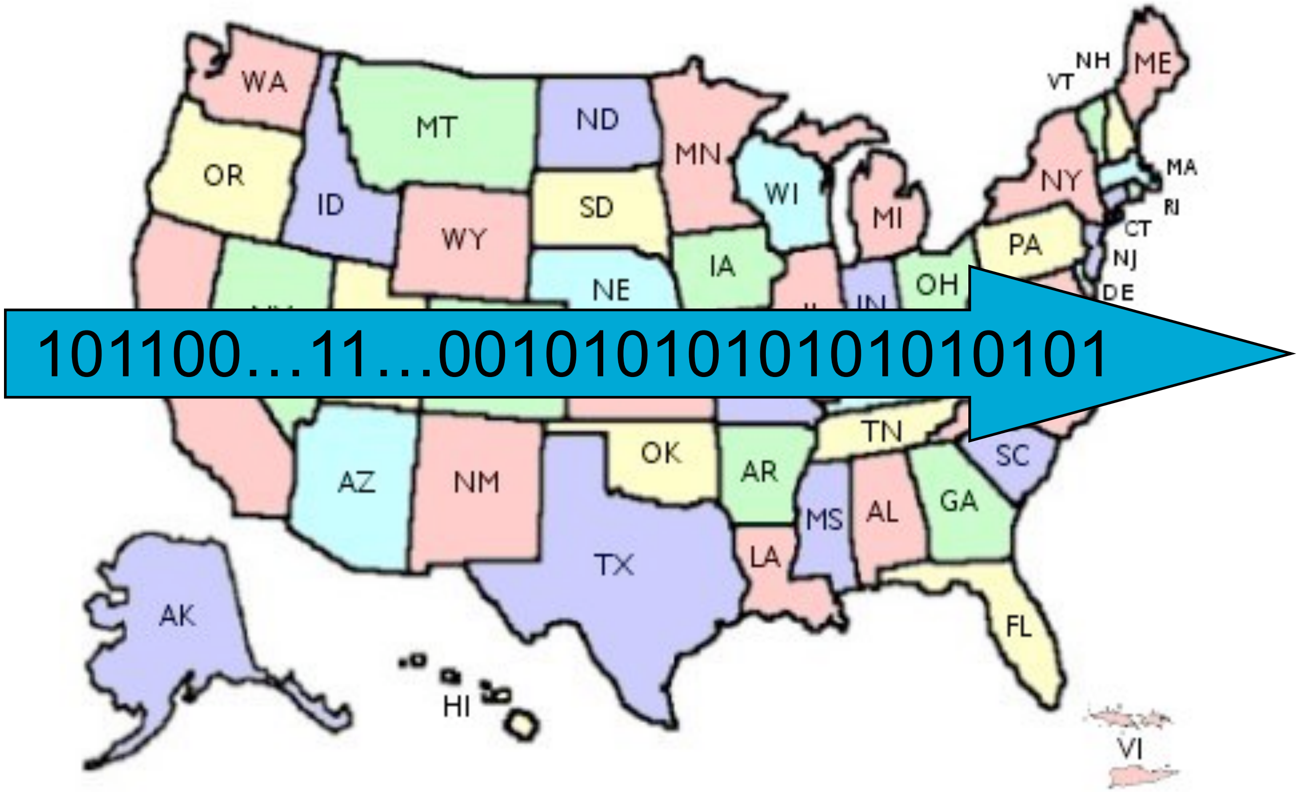
- Consider a 1b/s network.

- Suppose latency is 16 seconds.
  - How many bits can the network "store"
  - This is the BANDWIDTH-DELAY product
  - Measure of "data in flight."
  - 1b/s * 16s = 16b

- Tells us how much data can be sent before a receiver sees any of it.
  - Twice B.D. tells us how much data we could send before hearing back from the receiver something related to the first bit sent.
  - What are the implications of high B.D.?

A More Realistic Example

BD = 50ms * 45Mbps = 2.25 * 10^6 = 280KB



We'll see why this is important when we learn about TCP

Key Concepts

- Transmitting bits is a complex interplay between speed, noise, error rate, media, coding, and other factors
  - Those details are studied in more detail in EE classes – they start here and go down, we start here and go up. There are many modulations (not just on/off) and encodings (not just 4b5, Manchester).
- We typically model links in terms of bandwidth, delay, and error rate, from which we can calculate message latency
- Most of the remainder of the class assumes a link underneath that transmits bits, without us needing to know physical, electrical, or coding details