CSE 561 – Bits and Links

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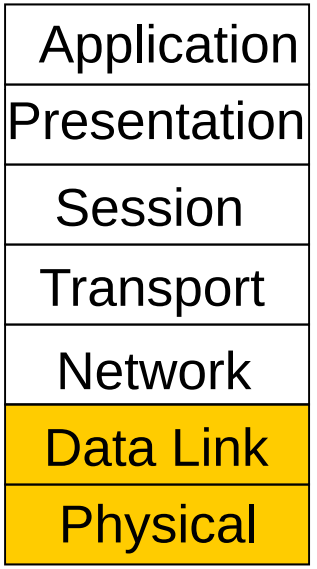
Topic

- How do we send a message across a wire?

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



The Shannon Limit (1948)

- Define Signal to Noise Ratio (SNR):

  $SNR = 10\log_{10}(signal / noise)$ decibels (dB)

  e.g, 30 dB means signal 1000 times noise

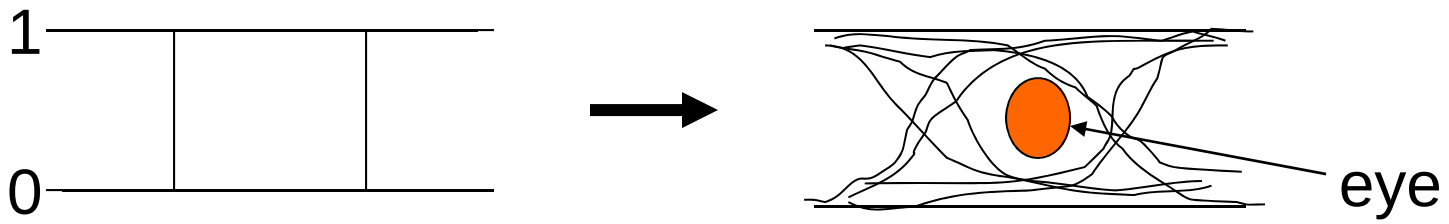
- For a noisy channel with bandwidth B (Hz) and given SNR, the maximum rate at which it is possible to send information, the channel capacity, is:

  $C = B \log_2(1 + SNR)$ (bits/sec)

  e.g 3KHz and 30dB SNR → 30Kbps

Nyquist Limit (~1924)

- For a noiseless channel with bandwidth B
- Symbols will be distorted, and sending too fast leads to Inter-symbol Interference (ISI)



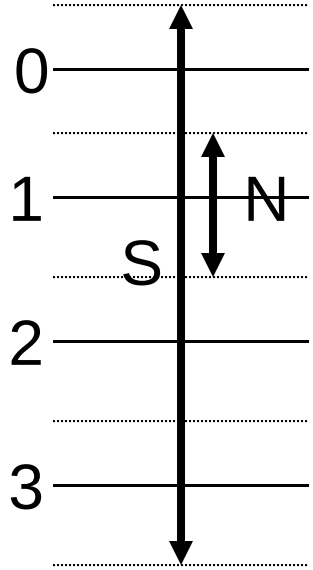
- The maximum rate at which it is possible to send:

  R = 2B symbols/sec

  e.g., 3KHz → 6Ksym/sec

Taking Noise into Account

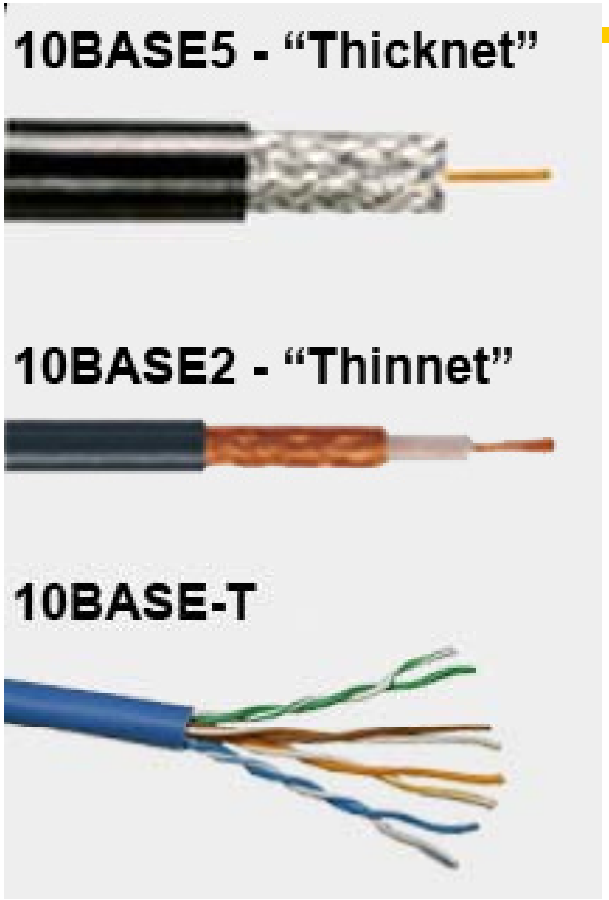
- Noise limits how many signal levels we can safely distinguish between
  - S = max signal amp., N = max noise amp.
- The number of bits per symbol depends on the number of signal levels
  - E.g, 4 levels implies 2 bits / symbol



1. Different kinds of media

- Wire
  - Twisted pair, e.g., CAT5 UTP, 10 → 100Mbps, 100m
  - Coaxial cable, e.g, thin-net, 10 → 100Mbps, 200m
- Fiber
  - Multi-mode, 100Mbps, 2km
  - Single mode, 100 → 2400 Mbps, 40km
- Wireless
  - Infra-red, e.g., IRDA, ~1Mbps
  - RF, e.g., 802.11 wireless LANs, Bluetooth (2.4GHz)
  - Microwave, satellite, cell phones, …

Wires

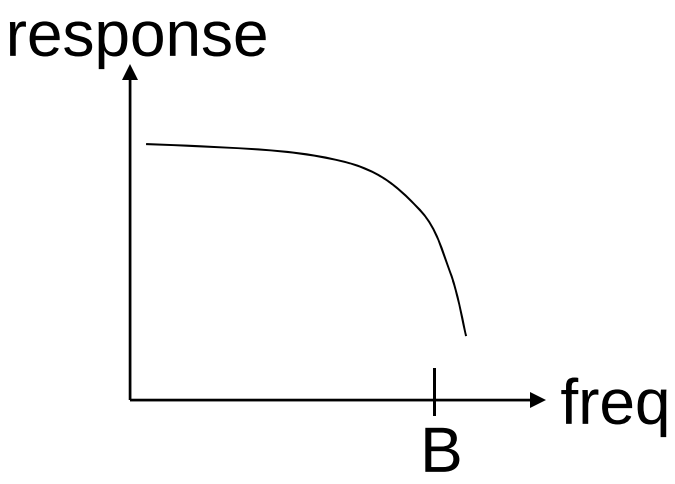


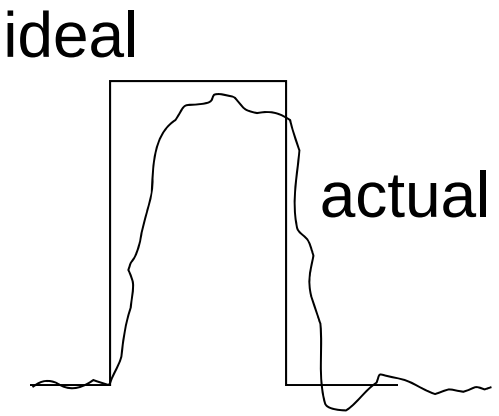
Now Cat 6, Cat 7 for GigE, four pairs

- Twisted pairs: twists reduce RF emission / crosstalk; also shielding can be added
- Coaxial cable: inner and outer ring conductor for superior noise immunity
- Many different specs/grades depending on application
- 100s of MHz for 100s of meters

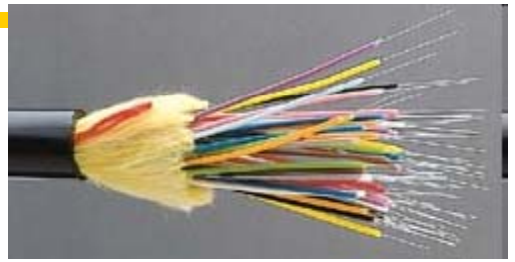
Wires

- Frequencies beyond a cutoff highly attenuated
- Signal also subject to:
  - Attenuation (frequency dependent)
  - Distortion (frequency and delay)
  - Noise (thermal, crosstalk, impulse)

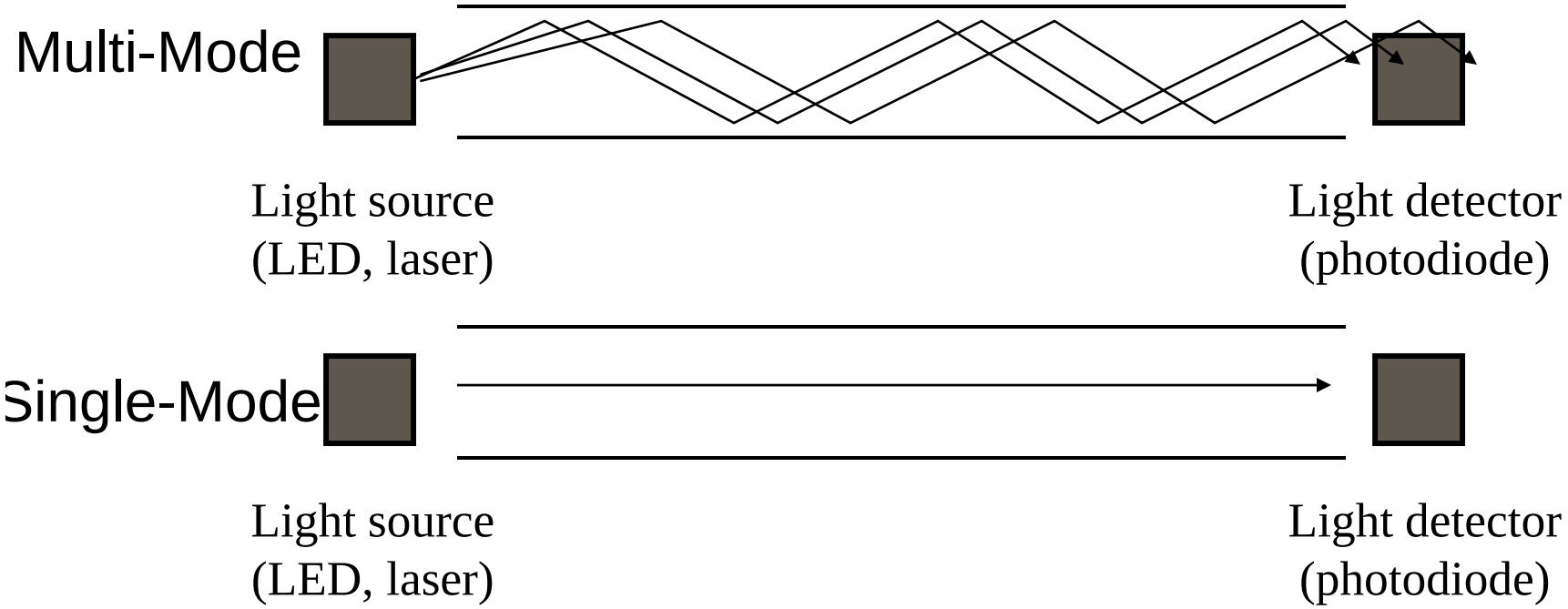




Fiber Optic Cable

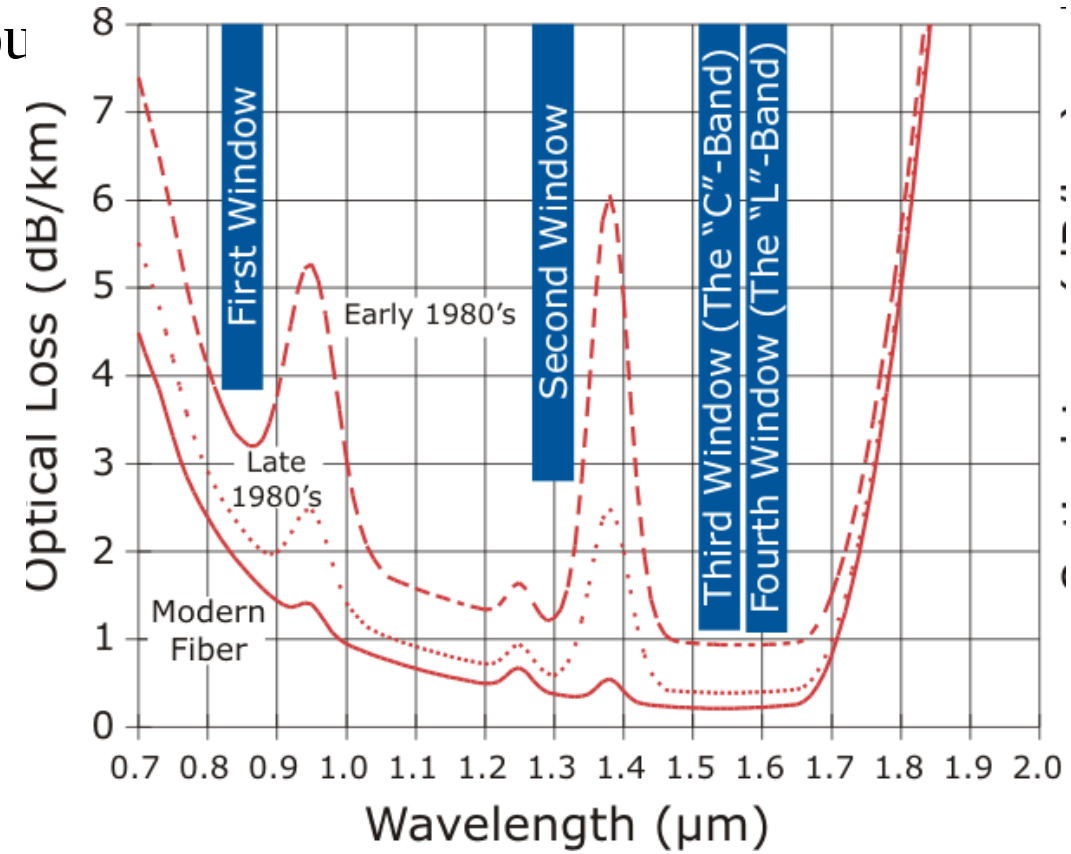


- Long, thin, pure strand of glass
  - light propagated with total internal reflection
  - enormous bandwidth available (terabits)



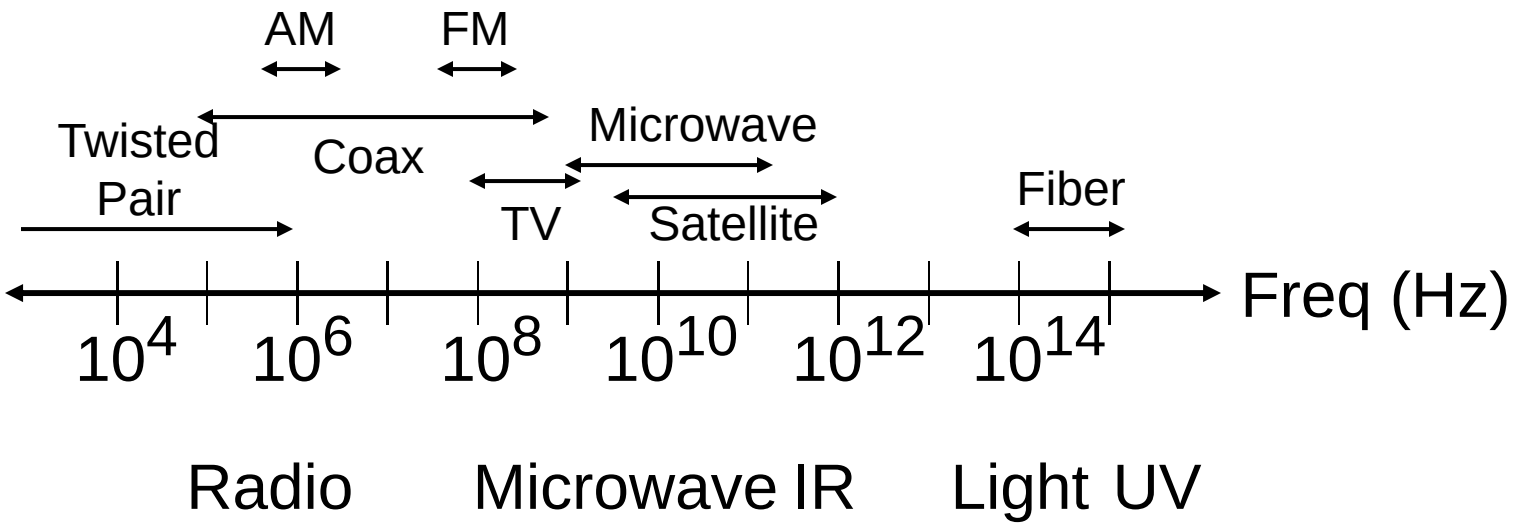
Attenuation of optic fiber

- Enormou



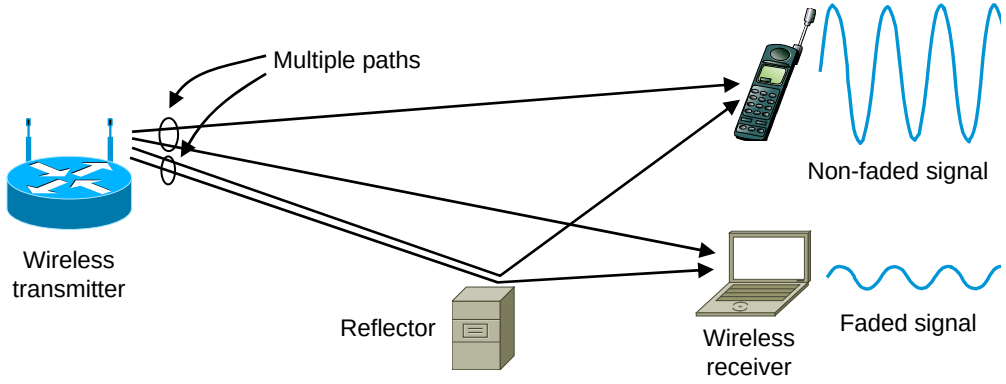
Wireless

- Different frequencies have different properties
- Signals subject to atmospheric/environmental effects



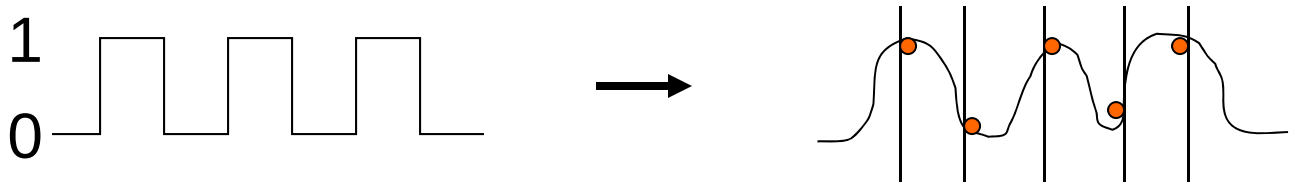
Wireless propagation

- Not as simple as wired …
- Signal spreads out as it propagates: path loss > d^2
- Signal obstructed: shadowing, e.g., buildings
- Reflected signals combine: freq. dependent multipath
  - OFDM: use channel as many parallel narrowband channels



2. Encoding Bits with Signals

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

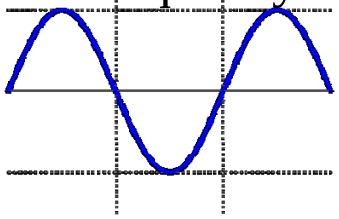


- We send/recover symbols that are mapped to bits
  - Signal transition rate = baud rate, versus bit rate
- This is baseband transmission … take a signals course!

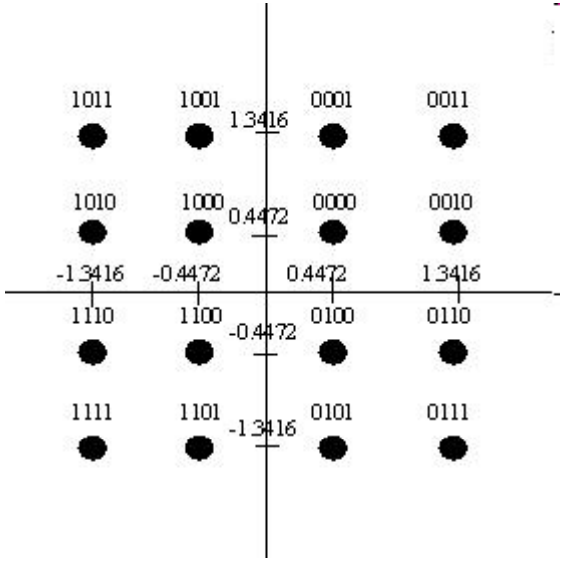
Modulation

- For wireless, fiber, need to encode signal by modulating carrier wave … can't propagate at baseband

- Modulate: can change
  - Amplitude
  - Phase/frequency

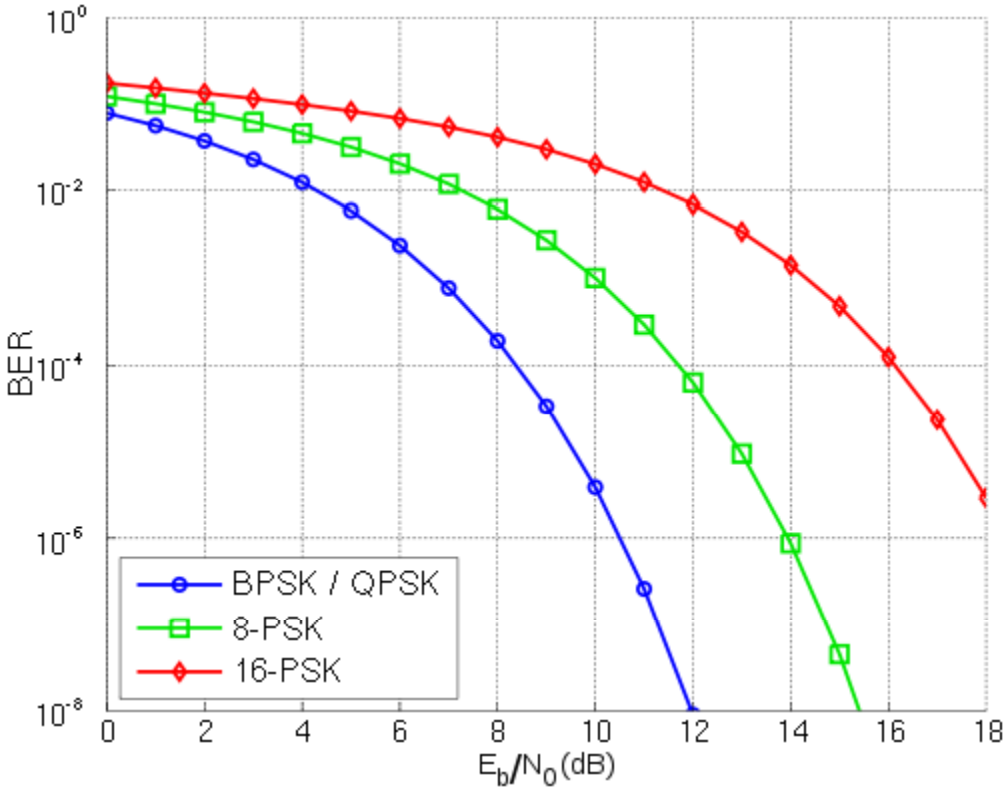


  - BPSK, QPSK … QAM
  - Express as constellation



QAM 16 constellation in HSPDA

BER versus SNR



3. Model of a Link

- Abstract model is typically all we will need
  - What goes in comes out altered by the model
- Other parameters that are important:
  - The kind and frequency of errors
  - Whether the media is broadcast or not

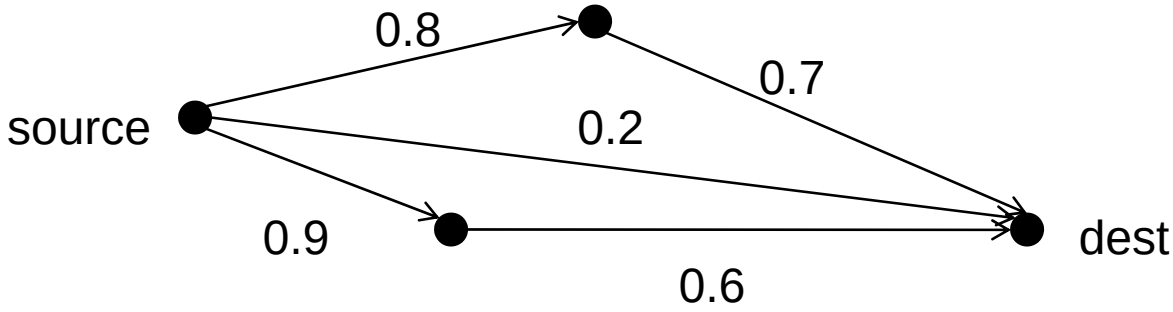
Wireless link

- Broadcast channel – interference effects
- Capacity changes as endpoints move (and SNR changes)
- Error rate changes with conditions
- Which “links” are “up” changes too!

- Wired is about engineering the right link properties
- Wireless is all about adapting to the channel properties

EXOR

- Setting is multihop wireless (broadcast) routing



EXOR questions

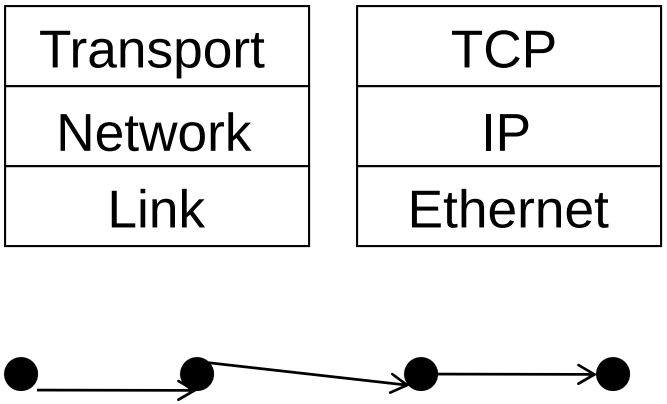
- What is the key idea?
- What is assumed about links?
- How do we model this as a layered protocol stack?

EXOR

- Key idea is lazy choice of path – broadcast tried many links at once, you pick the one that worked best for that packet.
- Relies on independent loss over links, and partially working links
- Does not easily decompose into protocol layers – integrated MAC/routing/transport.

E2E exercise

- Goal: reliably transport messages across network
- Q: in what layer should we check for errors?



E2E exercise

- E2E argument pushes functionality to the ends: the transport layer
- But lower layers help with performance, so add reliability to links too.
- And there are limits to the ends too, e.g., don't check the write to disk
- Plus reuse pushes down