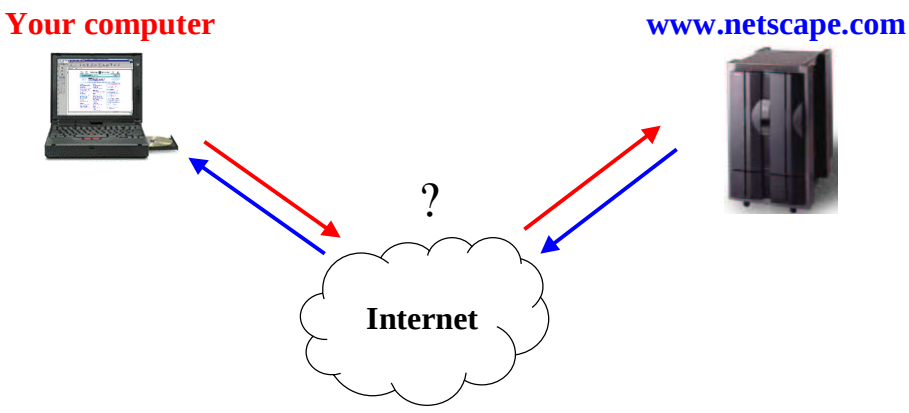
CSE/EE 461
Lecture 2: Link Layer

Tom Anderson
tom@cs.washington.edu

What happens when you click on a Web link?



Finding the right IP address: Domain Naming System (DNS)

Your computer (128.95.1.24)

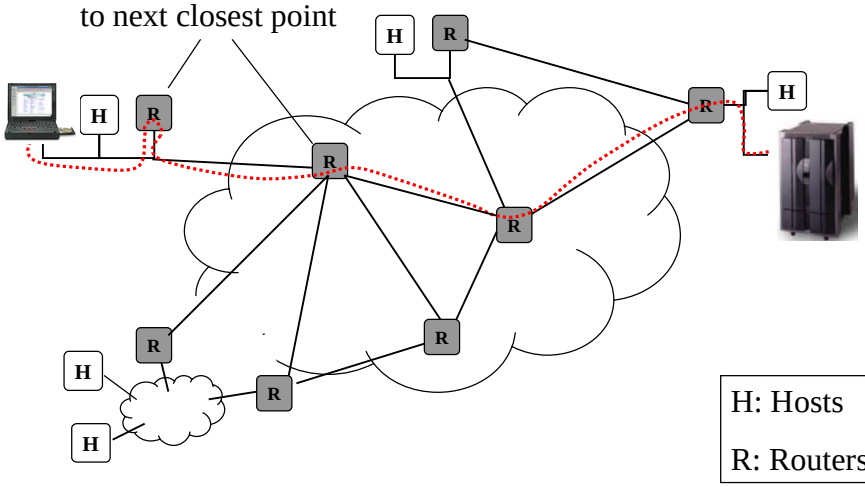
Local DNS server (128.95.1.4)

What's the IP address for www.netscape.com?

Oh, you can find it at 207.200.73.8

How does a packet get through the Internet?

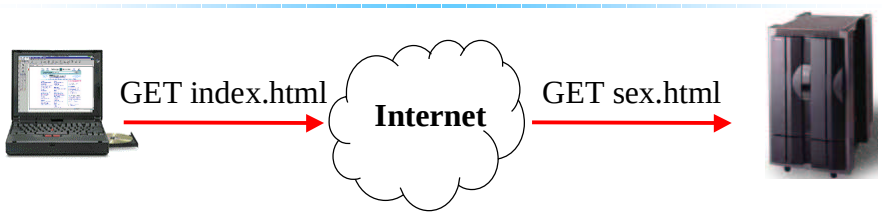
Routers send packet to next closest point



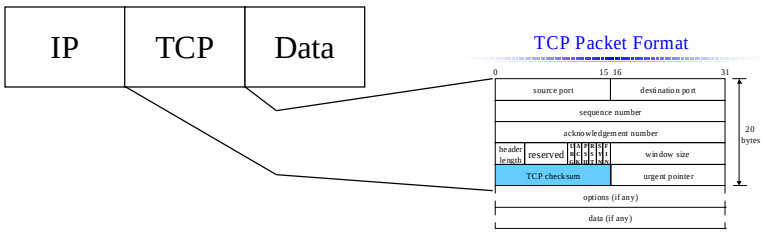
Have address, now send data?

- Murphy's Law applies to networks
  - Data can be corrupted
  - Data can get lost
  - Data might not fit in a single packet
  - Data can be delivered in the wrong order
  - etc...

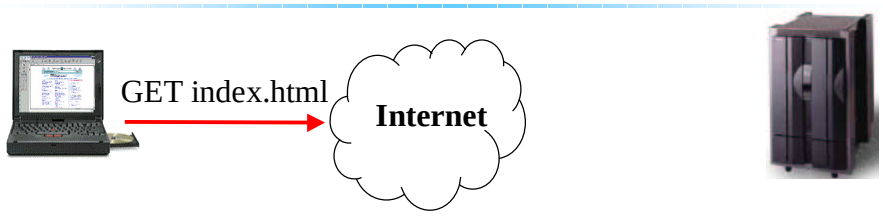
What if the data gets corrupted?



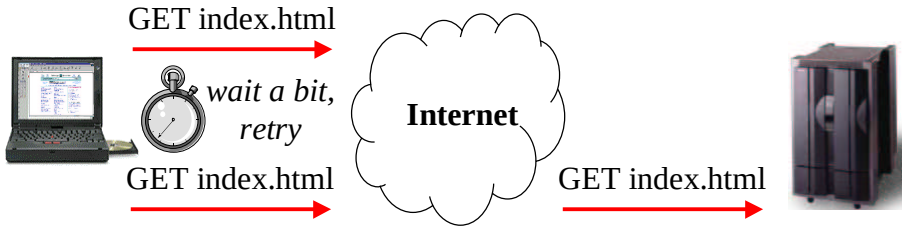
Solution: Add a *checksum*



What if the data gets lost?



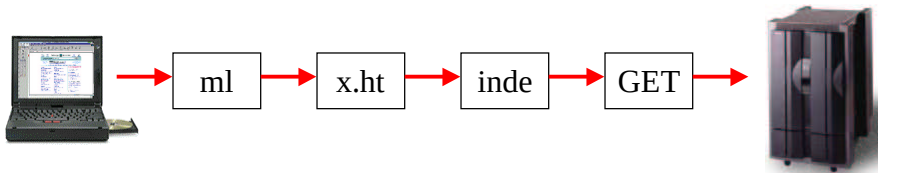
Solution: *Timeout* and *retransmit*



What if the data doesn't fit?

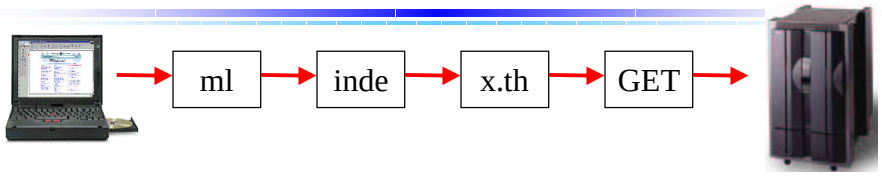
- On Ethernet, max IP packet is 1.5kbytes
- Typical web page is 10kbytes

Solution: *Fragment* data across packets



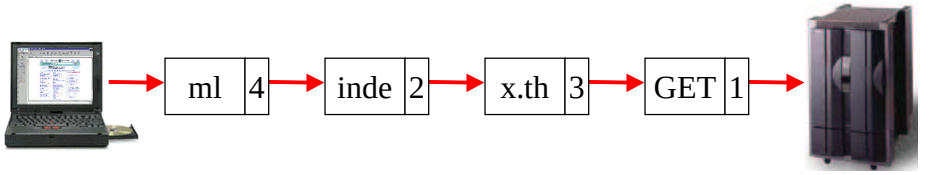
GET index.html

What if the data is out of order?



GET x.thindeml
???

- Solution: Add sequence numbers

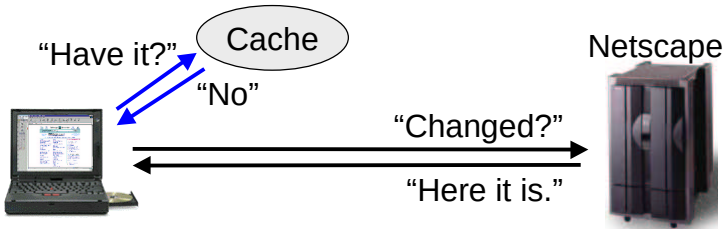


GET index.html

What if network is overloaded?

- Data can arrive at router faster than it can be forwarded!
- Short bursts: buffer at router
- What if buffer overflows?
  - Packets dropped and retransmitted
  - Sender adjusts rate until load = resources
- Called “Congestion control”
  - Broadcast network: bus arbitration

What if we need the same data again?



Caching cuts down on transfers:

- Check cache (local or proxy) for a copy
- Check with server for a new version
- Local DNS server caches too!

What if data has a deadline?

- Ex: multimedia, teleconferencing
- Original Internet: out of luck!
- To provide guarantees, need
  - admission control
  - resource management at routers
- Ex: Telephone network has busy signals + explicit schedules at each switch
- How do we add this to the Internet?

What if multiple receivers?

- Send a separate packet to each?
  - what if zillions of receivers?
- Multicast
  - routers form distribution tree
- What if data is dropped?
  - Acks would overwhelm sender
  - Naks? if drop is early in the tree -> overwhelm sender!

What if sender is malicious?

- Every packet has source, destination IP addresses
- But! Host can put *anything* in IP header
  - packet may have come from anywhere
  - firewalls to enforce sanity checks
    - ex: source must be from other side of wall
    - ex: only allow reply packets
  - encryption/digital signatures for authentication/privacy

Bottom Line

- No magic!
- No revealed wisdom!

Announcements

- Sections start this week
  - Thursdays at 1:30, 2:30, 4:30
- First assignment due Tuesday, January 22 @ 5pm
  - 4 slip days, to be used anytime during quarter on programming assignments

a

Link Layer Outline

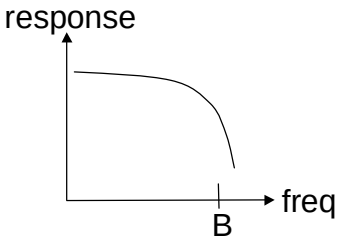
- Fundamental communication limits
- Coding and clock recovery
- Framing
- Error detection/correction

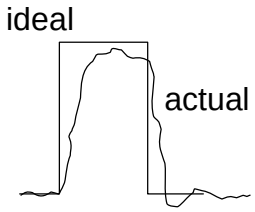
Different kinds of media

- 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

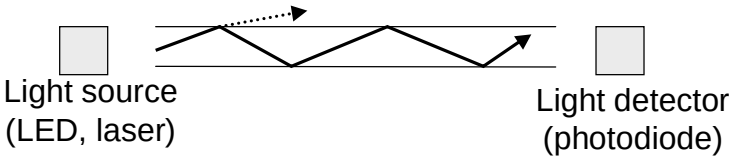
- Signal subject to:
  - Attenuation (repeaters)
  - Distortion (frequency and delay)
  - Noise (thermal, crosstalk, impulse)





Fiber

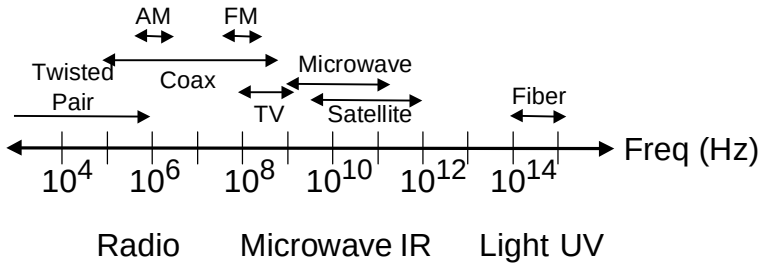
- Long, thin, pure strand of glass
  - Enormous bandwidth available (terabits)



- Multi-mode allows many different paths, dispersion
- Chromatic dispersion if multiple frequencies

Wireless

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

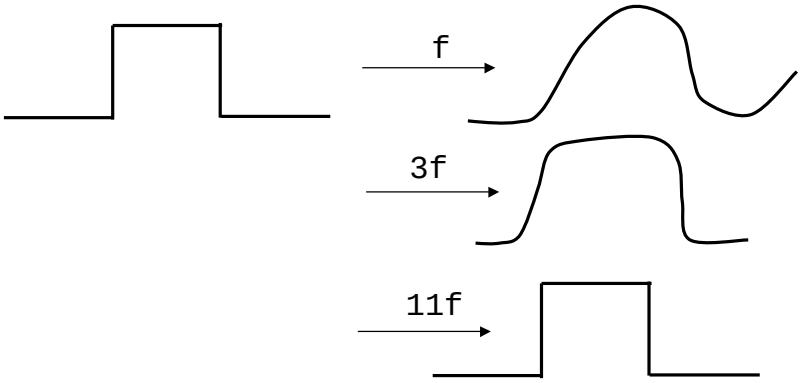


Model of Channel Distortion

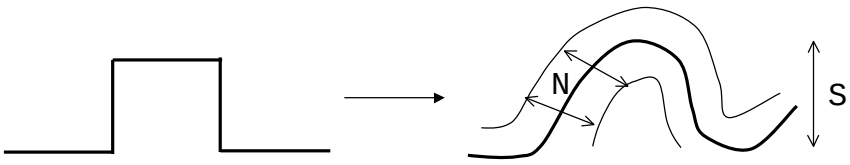
- Behavior of channel on a signal is based on behavior on each component of the signal:
  - g(signal) = g(sum(freq))
    = sum(g'(freq))
  - frequency response (amplitude attenuation)
  - phase response (phase shift)
- Measure channel on pure signals
  => predict impact on each component
  => sum to get output

Signal as f(signalling rate)

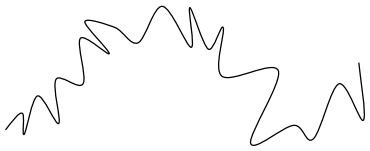
f = channel bw



How does noise affect signal rate?

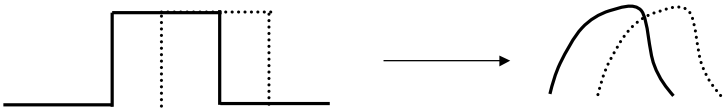


with noise N
amplitude S



Nyquist Limit

- Nyquist limit for channel with B bw
  - can't send faster than 2B symbols per sec
  - why two?



Shannon Limit

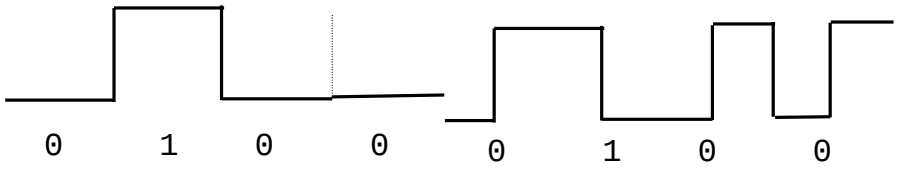
- At most log (S/2N) bits/symbol
- Example:
  - Suppose we encode 4 values:
    - 3V, 2V, 1V, 0V (or in 4 different frequencies)
  - What if noise is > .5V?
    - if get 2.5V, can't tell if it should be 2V or 3V?
- Combining with Nyquist
  - <= 2B log (S/2N) bits/second
  - more realistically, <= B log (1 + S/2N) bits/second
- Applies whether we encode in energy levels (AM) or frequencies (FM)

Clock Recovery

- How does the receiver know when to sample?
  - assume some a priori agreement on rate
  - 1. get in phase: start bit sequence
    - example: start = 01; end = 10
  - 2. stay in phase:
    - try #1: precisely identical clocks
    - what if message was all 0's?

Staying in Phase (contd)

- Try #2:
  - Keep messages short; how short?
- Try #3:
  - embed clock into the signal
  - Manchester encoding: rising = 0; falling = 1



Staying in Phase (contd)

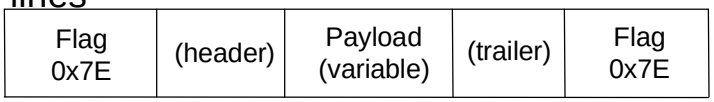
- Try #4: 4-5 code
  - code 4 bits of data into 5 bits of data and clock
  - resync every 5 bits
  - example: 0 0 0 0 => 5 bit code with a transition
- Phase-locked loop to stay in sync
  - speed up/slow down clock (slightly!) based on predicted vs. actual transition

Framing

- Frame is a complete link layer packet
  - need to be able to synchronize sender/receiver on start and end of packet, despite potential bit errors
- Sentinels: special control code that marks start of frame
  - sentinel + fixed sized frames (SONET)
  - sentinel + frame length
  - sentinel + bit stuffing (PPP)
  - physical layer sentinel (4/5 codes, Ethernet, FDDI)

Point-to-Point Protocol (PPP)

- IETF standard, used for dialup and leased lines



- Flag is special and indicates start/end of frame
- Occurrences of flag inside payload must be “stuffed”
  - Replace 0x7E with 0x7D, 0x5E
  - Replace 0x7D with 0x7D, 0x5D