ECE 435 – Network Engineering
Lecture 25

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Announcements

- HW#8 was posted (due Friday)
- Remember project topics were due
- Demo of modem / coax / infiniband / fiber / ethernet cables

The Physical Layer

- Deals with “transmission media”
- Digital signal into a waveform
- Modulation/Demodulation
- Sometimes referred to as “PHY” in device drivers

Physical Layer Limitations

- Fourier analysis – (see diagram from Tanenbaum, Figure 2-12 (p112)
- Transmit an ASCII binary signal down the line, made up of harmonics
- The various harmonics attenuate differently, causing noise

Physical Layer – Bandwidth

- Note: EEs measure bandwidth in Hz, CEs in bits/s
- Range of frequencies that can be transmitted w/o attenuation is the bandwidth (usually quoted as power by 1/2)
- Bandwidth often artificially limited to provide channels.
- For example, telephone wire might have bandwidth of 1MHz but limited by filter to 3.1kHz
- Starting at 0 is the `baseband`, shifted to another channel `passband`

Sampling

- Digital signal converted to analog
- Sometimes modulate carrier for long distance
- How to get back digital signal? Sample
- How often do you need to sample?
- Quantization: A/D conversion. Can add noise
- Reconstruction is interpolation

Coding Theory

- There's a whole area of study of getting maximum bandwidth out of a medium
- Most of it is way beyond this class
- We will touch on in some more at the Link Layer
- Used to be ECE 583 for this, but possibly not offered anymore
  Maybe ece 484 instead?

Nyquist/Shannon Theorem

- Harry Nyquist, 1932, based on earlier work by Whittaker. Shannon wrote it up, often Nyquist gets most credit.
- If arbitrary signal run through low-pass filter of bandwidth H, can be reconstructed with 2H samples. Sampling faster pointless, as higher frequencies already gone. If V discrete levels:
  $maximumrate = 2Hlog_2Vbits/sec$
- This assumes noiseless channel
- Thermal noise is always present

- Example: binary signal (2-level), 3kHz channel, max 6000bps
  $2(3000)log_2 2 = 6000 bits/sec$
- Bonus question: Why are CDs 44.1kHz?

Signal-to-Noise Ratio

- Signal power = S, Noise power = N, S/N
- Usually logarithmic, presented in dB
  - S/N of 10 = 10dB
  - S/N of 100 = 20dB
  - S/N of 1000 = 30dB

Shannon

- Max data rate of a noisy channel with bandwidth H Hz and S/N is
  $maxbps = Hlog_2(1 + S/N)$
- Example 1: 3000Hz bw with 30dB (typical of old POTS, limited to 30kbps)
  $30dB = 10log(S/N)$, $S/N = 10^3$
  $3000 * log_2(1 + 10^3) = 29.9kbps$
  Why is this different from previous example? Previous limited to two voltages.

- Example 2: 3000Hz bw with 33dB
  $33dB = 10log(S/N)$, $S/N = 1995$
  $3000 * log_2(1 + 1995) = 32.9kbps$

Medium

Media Types

- Guided (copper wire, fiber)
- Unguided (radio, microwaves)
- Persistent Storage (magnetic media)

Highest Bandwidth – Magnetic Media

- To quote AST: *Never underestimate the bandwidth of a station wagon full of tapes hurtling down the highway.*

- Sneakernet

- See xkcd comic about sd-cards `https://what-if.xkcd.com/31/` "Those thumbnail-sized flakes have a storage density of up to 160 terabytes per kilogram, which means a FedEx fleet loaded with MicroSD cards could transfer about 177 petabits per second, or two zettabytes per day — a thousand times the internet's current traffic level."

- High bandwidth but high latency

Guided Media

Twisted Pair

- Two wires, twisted together
- Can be shielded too, usually isn't due to expense
- Why twisted? Parallel wires make antenna
- POTS
- Several kilometers, several Mb/s over such distances

Twisted Pair Cabling

- Cat3 = phone lines (16MHz)
- Cat4 = up to 20MHz
- Cat5 = more twists (up to 100MHz)
- Cat6 and higher (250MHz) gigabit
- Cat7 = up to 600MHz (pairs shielded)
- Cat8 = ????

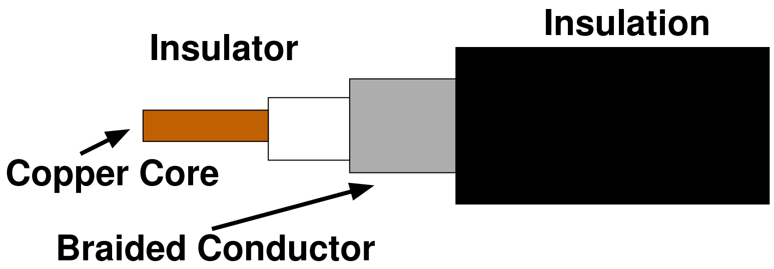
More Twisted Pair Cabling

- Not only faster cables, but use more than one set of twisted pairs. 8 wires in typical Ethernet. Two pairs used 10/100, four pairs for gigabit
- Plenum (fire resistant) and shielded cables
- Can have solid or stranded wires. Stranded bends around corners better
- Cat5 the four different pairs have differing numbers of twists to avoid crosstalk
- Cat6 originally had "spline" to separate cables but now

most don't

- Mostly there are specifications that you have to meet (resistance, cross-talk, inductance, delay) and as long as you test to that you are fine. Standards documents but have to pay to see.

Coaxial Cable



- 50 ohm (computer) or 75 ohm (TV, but also cable modem) (differences for historical reasons)
- copper core, insulating material, outer conductor, outer insulator
- Bandwidth close to 1GHz - 6GHz (old TV channels 3.5MHz)

- Used in old Ethernet, as well as cable modems

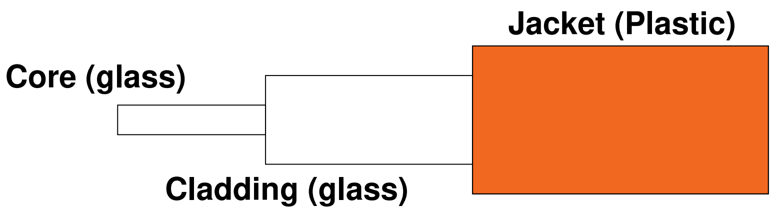
Power Line internet

- Can run network over existing power lines in your house
- High frequench signal overlain on 60Hz power distribution
- Various issues with this

Infiniband

- High-performance computers (supercomputers) often have special high-speed interconnects
- Often optimized for high speed over short distances

Fiber Optics



- Light source, transmission medium, detector
- Traditional explanation: Total internal reflection/refraction. Bend too much and light will leak out. Straight can go for kilometers with no loss
- More modern single mode more of a wave guide, less bouncing

Fiber Optic Types

- Single mode
  - narrow (few wavelengths of light), more like wave guide
  - faster, 50x further distance
  - more expensive
- Multimode
  - lots of bouncing around
  - cheaper, but shorter distances

Fiber Optics – Background

- Glass used is exceedingly clear
- attenuation in dB $= 10log_{10}\frac{transmittedpower}{receivedpower}$
- Three common wavelength bands, 0.05, 1.30 and 1.44 microns

  25,000 GHz bandwidth
- chromatic dispersion. pulse spreads out as it travels. special cosh solitons to avoid this

Fiber Optics – Sending / Receiving

- Often packed with fiber, glass with different index of refraction, plastic protection
- Sources: LED or laser. LEDs worse at rate, and distance, but are cheaper and last longer
- Receiver: photo-diode

Fiber Optics – Reliability

- Often dug up by backhoes.
- Can buy redundant links, only to have them end up in same conduit
- How to fix breaks?
  - Sockets, lose 20% of light
  - Mechanical splice, 10%.
  - Can fuse and melt for almost perfect fix, require big equipment and skilled worker

Fiber Optics – Other things of Note

- Maine 3-ring binder https://digitalcommons.library.umaine.edu/cgi/viewcontent.cgi?article=1575&context=mpr
- Network, a ring. Passive tap (no regeneration) active (reads and re-sends)
- Dark fiber?
- Multiplexing vs multiple colors
- "snowshoe" on utility poles

Long-distance Fiber

- Fascinating to read up on, “Mother Earth, Mother Board” in Wired magazine 1996

  `https://www.wired.com/1996/12/ffglass/`
- Sub-ocean cables
- Problems: ships dragging anchors, undersea landslides, sharks?
- How do they repair?
- How do they power sub-sea cables? Need repeaters every 50km? One way is to run power along copper.

Another is specially doped cables can be recharged by laser light pumped at a different frequency

Fiber Attakcs

- Undersea cables vulnerable
- Current events: (March 2024) due to cable breaks in East Africa and West Africa a lot of Africa currently has very spotty internet

  https://www.kentik.com/blog/what-caused-the-red-sea-submarine-cable
- Lots of breaks in Baltic Sea with Russian ships nearby? Accidental anchor drag or intentional?
- Takes a while to fix things
- Storms can break cables in Pacific Ocean leaving island

territories w/o internet for long spans

Fiber vs Copper

- Fiber Benefits
  - Fewer repeaters (50km vs 5km)
  - No power surges or power failures
  - No corrosion
  - Thin and lightweight: more room in ducts
  - Difficult to wiretap
- Fiber Downsides
  - Often one-way
  - Can't bend around sharp corners

- Takes more skills to fix breaks
- Power use of lasers (TODO: find some numbers)

- What about speed? Remember latency vs bandwidth **BE CAREFUL SAYING FIBER IS FASTER.** It's complicated
  - Bandwidth: fiber generally more because light has high frequency
  - Latency: complex. Generally both roughly 2/3 speed of light but copper can at times have lower latency, it depends