

ECE 435 – Network Engineering

Lecture 23

Vince Weaver

`https://web.eece.maine.edu/~vweaver`

`vincent.weaver@maine.edu`

26 March 2025

Announcements

- HW#8 was posted (due Friday)
- Remember project topics are due March 28th (Fri)
- 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



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:

$$\text{maximumrate} = 2H \log_2 V \text{ bits/sec}$$

- This assumes noiseless channel
- Thermal noise is always present



- Example: binary signal (2-level), 3kHz channel, max 6000bps

$$2(3000)\log_2 2 = 6000 \text{ bits/sec}$$

- 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

$$\text{maxbps} = H \log_2(1 + S/N)$$

- Example 1: 3000Hz bw with 30dB (typical of old POTS, limited to 30kbps)

$$30dB = 10 \log(S/N), S/N = 10^3$$

$$3000 * \log_2(1 + 10^3) = 29.9kbps$$

Why is this different from previous example? Previous limited to two voltages.



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



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

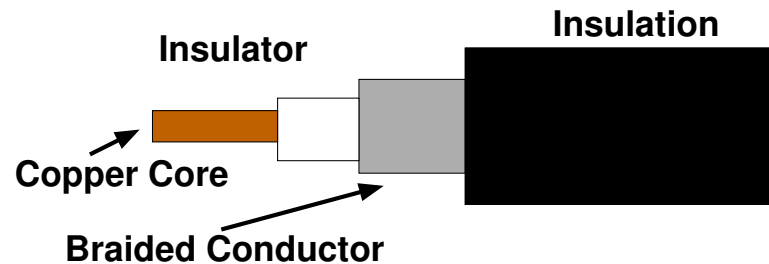


most don't

- 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

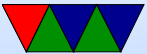


Power Line internet

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



Infiniband



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 = $10\log_{10}\frac{\text{transmitted power}}{\text{received power}}$
- Three common wavelength bands, 0.85, 1.30 and 1.55 microns
25,000 GHz bandwidth
- chromatic dispersion. pulse spreads out as it travels.
special 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?
 - 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
 - Bandwidth: fiber generally more because light has high frequency
 - Latency: complex. Generally both roughly $2/3$ speed of light but copper can at times be faster, it depends

