ECE 435 – Network Engineering
Lecture 2

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Announcements

- URL on the website in syllabus is wrong, replace “www” with “web”
- Homework will be posted, due Wed before class
- No class on Monday (Labor Day)

The Physical Layer

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

The Physical Layer

- Fourier analysis?
- Transmit an ASCII binary signal down the line, made up of harmonics
- The various harmonics are attenuated differently, causing noise
- Range of frequencies that can be transmitted w/o attenuation is the bandwidth

- For example, telephone wire might have bandwidth of 1MHz but limited by filter to 3.1kHz

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

Nyquist Theorem

- 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 always present
- Signal-to-noise ratio

- Signal power = S, N power =N, S/N

- Usually logarithmic, presented in dB

- Shannon: max data rate of a noisy channel with bandwidth H Hz and S/N is $maxbps = H log_2(1 + S/N)$

- Example 1: 3000Hz bw with 30dB (typical of old POTS, limited to 30kbps)
  $30dB = 10 log(S/N)$, $S/N = 10^3$
  $3000 * log_2(1 + 10^3) = 29.9kbps$

- Example 2: 3000Hz bw with 33dB

$$33dB = 10log(S/N),\ S/N = 1995$$
$$3000 * log_2(1 + 1995) = 32.9kbps$$

- Why are CDs 44.1kHz?

Baseband vs Broadband

- Baseband is a digital signal that can be put directly on the wire
- Broadband requires modulation. Often modulated to use a higher frequency so that multiple channels can share same medium (cable TV, radio, etc)

Line Coding

- Goals of line coding:
  - prevent baseline wandering
  - eliminate DC components (waste energy)
  - self-synchronization: (Synchronization: what if send long stream of zeros)
  - error detection/correction
  - avoid noise/interference

Transmission Impairments

- Attenuation: gradual loss of energy. How to fix? Amplification
- Fading: time varying source of attenuation (varies with time, location, etc). Multipath fading (reflections), shadow fading (obstacle)
- Distortion: different frequency components have different propagation delay
- Interference: unwanted signals added to desired signal
- Noise: random fluctuations of an analog signal Often

“white”, that is uniformly distributed

Medium

Media Types

- Guided (copper wire, fiber)
- Unguided (radio, microwaves)

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
- Cat3 = phone lines (16MHz)

- Cat4 = up to 20MHz
- Cat5 = more twists (up to 100MHz)
- Cat6 and higher (250MHz) gigabit
- Cat7 = up to 600MHz
- 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

- TODO: diagram?
- 50 or 75 ohm
- copper core, insulating material, outer conductor, outer insulator
- Bandwidth close to 1GHz - 3GHz
- Used in old Ethernet, as well as cable modems

Fiber Optics

- TODO: diagram
- Light source, transmission medium, detector
- Total internal reflection/refraction. Bend too much and light will leak out. Straight can go for kilometers with no loss
- How do they do sub-sea cables? Pump recharge lasers down

- Single mode (narrow, more like wave guide, faster) vs multimode (lots bouncing around) fibers
- attenuation in dB $= 10log_{10}\frac{transmittedpower}{receivedpower}$
- Three common wavelength bands, 0.05, 1.30 and 1.44 microns
- chromatic dispersion. pulse spreads out as it travels. special cosh solitons to avoid this
- Often packed with fiber, glass with different index of refraction, plastic protection

- Often dug up by backhoes. How to fix? Sockets, lost 20% of light. Mechanical splice, 10%. Can fuse and melt for smaller
- Sources: LED or laser. LEDs worse at rate, and distance, but are cheaper and last longer
- Maine 3-ring binder
- Network, a ring. Passive tap (no regeneration) active (reads and re-sends)

Fiber vs Copper

- Fewer repeaters
- No power surges or power failures
- No corrosion
- Thin and lightweight: more room in ducts
- Difficult to wiretap
- Downside (often one-way, can't bend too sharp, more skills to make)

Magnetic

- 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

Wireless

- Speed of light in vacuum $3 \times 10^8 m/s$ (foot/ns)
- In wire/fiber more like 2/3 of value, freq dependent
- $\lambda f = c$
- Include chart? Radio, microwave, infrared, visible, UV, X-ray, gamma ray why aren't UV, x-ray and gamma rays used much?
- bandwidth calc

Radio Transmission

- Radio from 3kHz to 1GHz. VLF (3-30kHz) LF (30-300kHz) MF (300kHz-3MHz) HF (3-30MHz) VHF (30MHz-300MHz) UHF (300MHz-3GHz)
- Can travel long distances, omni-directional (go in all directions)
  why is omni bad? interference, everyone can hear
- Inverse square law
- High frequencies go in straight lights and bounce off

things and absorbed by rain

- Government regulated
- VLF, LF and MF follow ground
- MF (AM radio) pass through buildings easily, but low bandwidth
- VHF can bounce off ionosphere

Microwaves

- 1GHz to 300GHz (overlap with UHF)
- GPS at 1.2-1.6Hz, Wifi 2.4GHz and 5GHz
- Microwaves, above 100MHz travel in nearly straight lines, can be focused. Before fiber optics transmitted across country like this. Multipath fading. Up to 10GHz used, but above 4GHz absorbed by water (only few inches long)
- Absorbed by water, as in microwave oven.
- Benefits: no need to dig up right of way (MCI, microwave

towers. Sprint Southern Pacific railroad fiber)