ECE 435 – Network Engineering Lecture 17

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Announcements

- Reminder HW#7 done and graded
- Remember project topics are due 26th (Tues)
- Demo of 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)
- For example, telephone wire might have bandwidth of 1MHz but limited by filter to 3.1kHz
- Bandwidth often artificially limited to provide channels.
- 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

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:

$$maximum\ rate = 2Hlog_2Vbits/sec$$

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

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)

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
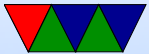
zettabytes per day — a thousand times the internet's current traffic level."

- 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
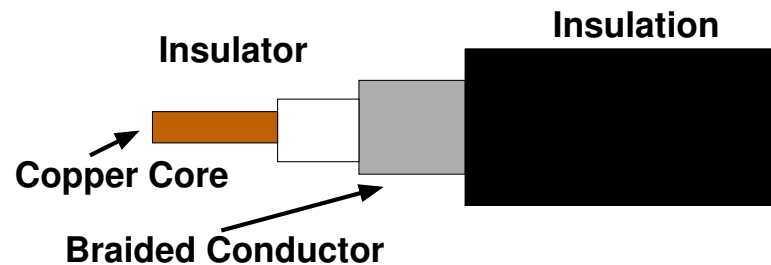- Cat6 originally had "spline" to separate cables but now

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

Insulation

Insulator

Copper Core

Braided Conductor

- 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)

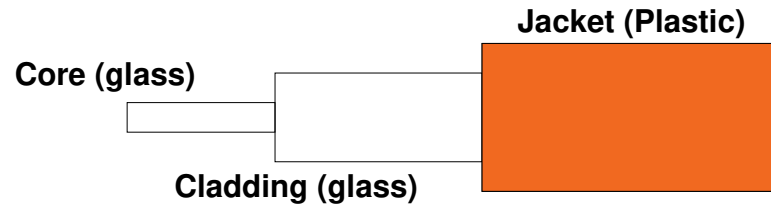- Used in old Ethernet, as well as cable modems

Power Line internet

Infiniband

Fiber Optics

Jacket (Plastic)

Core (glass)

Cladding (glass)

- 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

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 $= 10 log_{10} \frac{transmitted power}{received power}$
- 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?
  - Sockets, lose 20% of light
  - Mechanical splice, 10%.
  - Can fuse and melt for almost perfect fix, require big equipment and skilled worker

Fiber Optics – Implementation

- Maine 3-ring binder
- 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
- Current events: (March 2024) due to cable breaks in East Africa and West Africa a lot of Africa currently has very spotty internet

Fiber Benefits vs Copper

- Fewer repeaters (50km vs 5km)
- No power surges or power failures
- No corrosion
- Thin and lightweight: more room in ducts
- Difficult to wiretap
- Downsides: (often one-way, can't bend too sharp, more skills to make)