

ECE 435 – Network Engineering

Lecture 21

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Announcements

- Wireless Spectrum Allocation Poster
- Don't forget project status update due
- HW#10 will be out soon



Question from Last time: Cable Differences

- Cat5e cables – can handle gigabit. No real changes, just have been tested to make sure can handle gigabit
- Cat6 – gigabit, can do 10 gigabit for 150 feet or so
Cat6a – can do 10 gigabit for 300 feet or so.



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



Wireless

- Speed of light in vacuum $3 \times 10^8 m/s$ (roughly 1 foot/ns)
- In wire/fiber more like 2/3 of value, freq dependent
- $\lambda f = c$, can get roughly 8bits/Hz
- See chart below. Why aren't UV, x-ray and gamma rays used much?
- bandwidth calc $\Delta f = \frac{c\Delta\lambda}{\lambda^2}$

Rough table, based on one found on Wikipedia



Type	Name	Freq	Wavelength
Ionizing	Gamma	300EHz	1pm
	Hard X	30EHz	10pm
		3EHz	100pm
	Soft X	300PHz	1nm
	Extreme UV	30PHz	10nm
Visible	Near UV	3PHz	100nm
	Visible	300THz	1 μ m
	Near IR	30THz	10 μ m
	Mid IR	3THz	100 μ m
	Far IR	300GHz	1mm
Radio/Microwave	EHF	30GHz	1cm
	SHF	3GHz	10cm
	UHF		
	VHF	300MHz	1m
	HF	30MHz	10m
		3MHz	100m
	MF	300kHz	1km
	LF	30kHz	10km
	VLF	3kHz	100km
	ULF	300Hz	1Mm
	SLF	30Hz	10Mm
	ELF	3Hz	100Mm



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)
- Even lower? ELF (3Hz) submarines?
- 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 lines and bounce off



things and absorbed by rain

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



Microwaves

- Digression about optics class at UMD
- 1GHz to 300GHz (overlap with UHF)
- GPS at 1.2 and 1.6GHz, 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)



Infrared

- 300GHz-400THz, cannot penetrate walls



Visible Light

- Networks that modulate the lightbulbs in a room?
- Laser links between roofs of buildings (cannot penetrate fog well)



Electromagnetic Spectrum

- Government regulated
- Hard to decide to allocate. Recently auction, lead to crazy large fees but then companies can't actually pay them
- alternative is “spread spectrum” frequency hop until find one that's free.
- ISM (Industrial/Scientific/Medical) Mostly unregulated bands
 - 902-928MHz (1W in US)



- 2.4 - 2.4835 GHz
- 5.735 - 5.860GHz



Communications Satellites

- geostationary – 35,800km. Need to be at least 2 degrees apart to avoid interference, so only 180 slots. But can use tricks to avoid this (different frequencies, polarization). ITU regulates slots
- Certain frequencies allocated to avoid microwave interference L (1.5Ghz), S (1.9GHz) C (4.0GHz) Ku (11GHz) Ka (20GHz). Higher bands have problems with rain.



- Originally just transponders, signals that wait on a certain frequency, amplify, rebroadcast at another. Modern ones can do more processing
- geostationary 250 to 300ms latency
- medium-earth-orbit – closer than GEO (between the radiation belts). drift though. Not widely used, but GPS is here
- LEO – low Earth orbit. Only few ms latency, low power. Iridium (77) not Dysprosium (66)



Satellite vs Fiber

- Fiber: point to point. Satellite anyone with a dish can tap in anywhere
- Mobile: airplanes and such
- Broadcast: send once, receive by many
- Difficult landscape. Uneconomical to lay fiber to every house in distant regions
- Rapid deployment – just launch a satellite
- Harder to destroy? Varies. Accidentally satellite collisions. Accidental backhoes.



- Cost: be careful with this one. Depends a lot on the situation.



Wired Phone Network

- Originally all analog. Point-to-point
- Switching offices, operator manually jumper
- Later automatic dialing involved (story of that, Stowager gear)
- Wires connecting to your house “local loop”



Data over Phone lines

- Rent your own local loop
- Modems on both ends. Before 1984 not allowed to, acoustic couplers
- Modem doesn't send raw binary, it uses sine wave carrier
Max a perfect phone line can do about 3000Hz, so max is 2400bps. Instead change the "baud" which is *symbols* per second. Say four different voltages. Also say different phase shifts. Quadrature Phase Shift



Keying

- Interesting to me as I used to do all of this
- Duplex – simplex or full duplex
- Hit Shannon limit about 33.6kbps
- how do you hit 56k? need ISP equipment at the exchange, can bypass some restrictions. Also different rates up/down



DSL

- Normal phone lines have a filter from 300 – 4000Hz or so
- For DSL they remove the filter
- You need to put own filter on your actual phones in house
- Speed depends on distance to the facility
- Often asymmetric. Could split 50/50, but people usually



download more so make it favor download

- 250 channels of data coming down. Modem has a DSP to convert this to data



Cable Modems

- Cable typically a broadcast medium
- Single cable shared by many users; download a large file and you slow everyone else (not a problem with DSL)
- Bandwidth of co-ax higher than twisted pair
- TV stations up to 550MHz, data down above to 750MHz, data up 5-42MHz. Smaller so asymmetric
- QAM-256, QPSK



- encrypted



FIOS

- Fiber to the home. One fiber line sent to neighborhood, split for 32 subscribers
- 50Mbps-500Mbps symmetric
- VOIP

