ECE 435 – Network Engineering Lecture 17

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Announcements

- Wireless Spectrum Allocation Poster
- Don't forget project topics/groups due Tuesday
- HW#8 will be posted

Physical Layer – Wireless

- First some Physics review
- c=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
- f = frequency, oscillations per second
- λ=wavelength, distance between two peaks
- $\lambda f = c$
- Bandwidth varies with f, but can get roughly 8bits/Hz
- bandwidth calc $\Delta f = \frac{c\Delta\lambda}{\lambda^2}$

Electromagnetic Spectrum

See chart below. Why aren't UV, x-ray and gamma rays used much?

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	1μm
	Near IR	30THz	10μm
	Mid IR	3THz	100μm
	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 (80Hz) submarines?
  - Hard to transmit to submarines, high frequencies can't go under water
  - You can transmit at 80Hz or so, but slow 1 bit per minute / 17mbps (mili-bits)
  - Need extremely long (km-scale) fancy arrays. Cold war

US (UP-MI) (decommissioned), Russia, India, China

- Higher: Above 30GHz air stops after 1km, above 300GHz after few meters (until you get to visual range)

Radio Propagation

- Can travel long distances, omni-directional (go in all directions)
  why is omni bad? interference, everyone can hear
- Inverse square law at lower frequencies
- High frequencies go in straight lights and bounce off things and absorbed by rain
- VLF, LF and MF follow ground
- MF (AM radio) pass through buildings easily, but low bandwidth

- VHF can bounce off ionosphere

Bandwidth Regulation

- Government regulated
- ITU (international telecommunication union)
- FCC (federal communications commission) – US

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)
- Recently new, shorter paths built for high-frequency trading. Saving a few ms in latency worth it for them

Infrared

- 300GHz-400THz
- cannot penetrate walls (is that good or bad?)
- IrDA

Visible Light

- Networks that modulate the lightbulbs in a room?
- Laser links between roofs of buildings (cannot penetrate fog well)
- No need for FCC license
- Hard to tap

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) Ranges

- 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. Less powerful transmitter needed.
- LEO (see next)

Low-earth Orbit (LEO) Satellites

- LEO would give best latency, but need a lot of them (field of view) and they move fast so hard to steer antennas. Require less power
- Iridium
  - Iridium (77) not Dysprosium (66)
  - Satellite phone, went bankrupt
- SpaceX Starlink is a sudden but overwhelming contender
  - 3000 in orbit now, plan for 12k to 42k total
  - Different shells/inclinations for global coverage

- Currently just bounce your signal to local ground station, eventual goal is laser links between satellites to expand coverage range

- OneWeb and Amazon Kuiper new competitors

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.
- Privacy – harder to intercept fiber?

The Last Mile (to your House)

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

Broadband

- Sort of a generic (marketing?) term meaning "faster than a landline modem"

DSL

- Normal phone lines have a filter from 300 – 4000Hz
- 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
- Pair bonding (up to 1GBps) by using two pairs (for historical reasons used to get two pairs to your house in case you wanted two numbers)

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 in US typically 54-550MHz
  So for cable modem, uplink in 5-42MHz
  Downlink 550MHz-750MHz
  Asymmetric

- QAM-256, QPSK
- encrypted
- Originally hundreds of houses per run, but now fiber getting closer and closer and fewer shared resources

FIOS

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