ECE 435 – Network Engineering Lecture 18

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Announcements

- Show Wireless Spectrum Allocation Poster
- Don't forget project topics/groups due
- HW#8 was posted, due Friday
- Monday's faculty interview moved at last minute to Wednesday; Wednesday office hours canceled now

Some Last Notes on HW#7

- People seeing Apogee Telecom in their traceroutes; I hadn't realized campus had outsourced the internet in the dorms
- If you have Spectrum it's possible all your packets to campus go via Chicago
- Note TTL is in hops, not seconds

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 lines 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.
- Up to 10GHz used, but above 4GHz absorbed by water (only few inches long)
- Issues: Absorbed by water, as in microwave oven. Multipath Fading

Microwave Infrastructure

- Climb many hills in Maine, will be a microwave tower at top
- Popular before fiber for long-distance data communication, relaying from hill to hill
- 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
- How is it distributed?
- Modern times auction off
  - When analog TV discontinued, freed up frequency ranges
  - auction, lead to crazy large fees but then companies can't actually pay them

Could we live without Government Spectrum Regulation

- Would be lots of interference, strongest signal would win
- Many bands might be unusable
- Some ways to try to avoid this
  - "spread spectrum"
  - frequency hop until find one that's free.

ISM (Industrial/Scientific/Medical) Ranges

- Mostly unregulated bands
  - 902-928MHz (1W in US)

    Garage doors, old cordless phones (what happened when people would listen in on calls?)
  - 2.4 - 2.4835 GHz

    Old wifi, new cordless phones, bluetooth, poorly shielded microwave ovens
  - 5.735 - 5.860GHz

    New wifi

Communications Satellites

- Put satellite in space, can relays signals from ground stations on earth
- The earliest ones were just reflectors
- Later ones would receive, amplify, and retransmit
  Could in theory be hacked if you could overwhelm groundstation signal
- Modern ones properly encrypted and stuff, can still be jammed?
- 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.

Geostationary Satellites

- At 35,800km orbital period is 24 hours, so satellite always above same place on earth
- If above equator essentially fixed (though do need some stationkeeping)
- Can aim fixed satellite dish at it
- 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
- 250 to 300ms latency

Medium-earth Orbit (MEO) Satellites

- closer than GEO (between the radiation belts).
- Not widely used, but GPS is here.
- Less powerful transmitter needed.

Low-earth Orbit (LEO) Satellites

- LEO gives best latency (25ms)
- Need a lot of them (field of view), only few hundred miles up so can't see all of earth
- Move fast so have to aim antenna
- Require less power on both sender and receiver

Iridium

- First example of large LEO constellation for satellite phones
- Iridium (77) not Dysprosium (66)
- Went bankrupt, bailed out by government because useful

Starlink

- SpaceX Starlink is a sudden but overwhelming contender
- 6000 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
- Special phase-array antennas, essentially steer signal in software/DSPs rather than moving it

Other Constellations

- OneWeb
- Amazon Kuiper new competitors

Issues with Large Constellations

- Space Debris / Kessler Syndrome
- Astronomers not like it (streaks in photos)
- Who regulates these? FCC still controls all US related launches

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 (tell anecdote on 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