ECE 435 – Network Engineering
Lecture 25

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Announcements

- Show Wireless Spectrum Allocation Poster
- HW#8 due Friday
- Responded to all project groups. We have 14 groups so should be able to have presentations last week of classes

Physical Layer – Wireless

- First some Physics review
- c=speed of light in vacuum $3 \times 10^8 m/s$ (roughly 1 foot/ns) (Hopper)
- 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)
- Note: VLF transmitter near Machaias, for submarines in Atlantic
- 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, 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.
- 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
  - ITU (international telecommunication union)
  - FCC (federal communications commission) – US
- 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 relay 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
- atmosphere thicker so orbits can decay faster

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
- 7000 in orbit now, plan for 12k to 42k total
  literally launching more each week
- 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
- SpaceSail (China) 15k planned
- Europe Eutelsat

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

- Satellite benefits
  - Satellite anyone with a dish can tap in anywhere, Fiber: point to point.
  - Satellite works for mobile (airplanes, ships, etc)
  - Satellite allows broadcast: send once, receive by many
  - Satellite works in difficult landscapes where it is hard to lay fiber. It's uneconomical to lay fiber to every house in distant regions
  - Rapid deployment – just launch a satellite (though you

have to have it ready to go and a rocket ready to go. That's become easier recently)

- Fiber benefits
  - Lower latency than geostationary satellites (benefit not as pronounced with low-earth orbit)
  - Satellite can be blocked by trees, weather (heavy rain), solar storms
  - Harder to jam. Satellites can be zapped from a wide area, with fiber need to physically go and dig up
  - Harder to hack (maybe tell Hughes satellite story)
  - Privacy – harder to intercept fiber?

- Unclear benefit
  - Harder to destroy? Varies. Accidental satellite collisions. Accidental backhoes.
    Militaries have ways for taking out satellites (though they can make a huge mess in orbit)
  - Cost: be careful with this one. Depends a lot on the situation.