CS 525M – Mobile and Ubiquitous Computing Seminar

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Wireless Physical Layer

- Overview
  - Introduction to radio waves
  - Electromagnetic spectrum
  - Spectrum regulation
  - Physics of radio propagation (diffraction, fading, ISI)
  - Differences between indoor and outdoor propagation
  - Analog Vs digital
  - Modulation
  - CDMA/Spread spectrum
  - Performance increasing techniques (diversity, coding, equalization, power control, etc)

Introduction to Waves

- Radio signals are a form of electromagnetic radiation
- Usually thought of as waves with ***frequency, wavelength*** and ***amplitude***

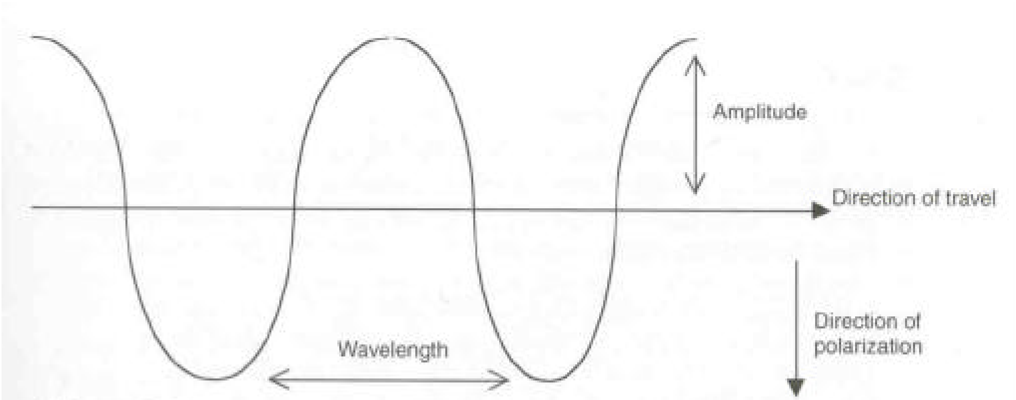


Figure 2.1
A transverse wave.

- Amplitude is wave height, represents power, decreases with distance
- Frequency is how long to complete 1 cycle, then repeat
- Unit of frequency is Hertz (Hz), cycles per second

Introduction to Waves

- 1000 Hz = 1 kiloHertz (kHz)
- 1000000 Hz = 1 megaHertz (MHz)
- 10^9 = 1 gigaHertz (GHz)
- 10^{12} = 1 teraHertz (THz)
- All waves travel at speed of light in vacuum = 3×10^8 m/s
- Speed = *l* ***f***, inverse relationship, high freq = short wavelength
- Most media (e.g. air, clouds) slow down wave speed by a factor
- Radio waves also suffer from attenuation (reduction in power) over distance

Electromagnetic Spectrum

- Can classify radio waves based on either wavelength or frequency
- Infra-red also used for data transmission, LOS, affected by sun

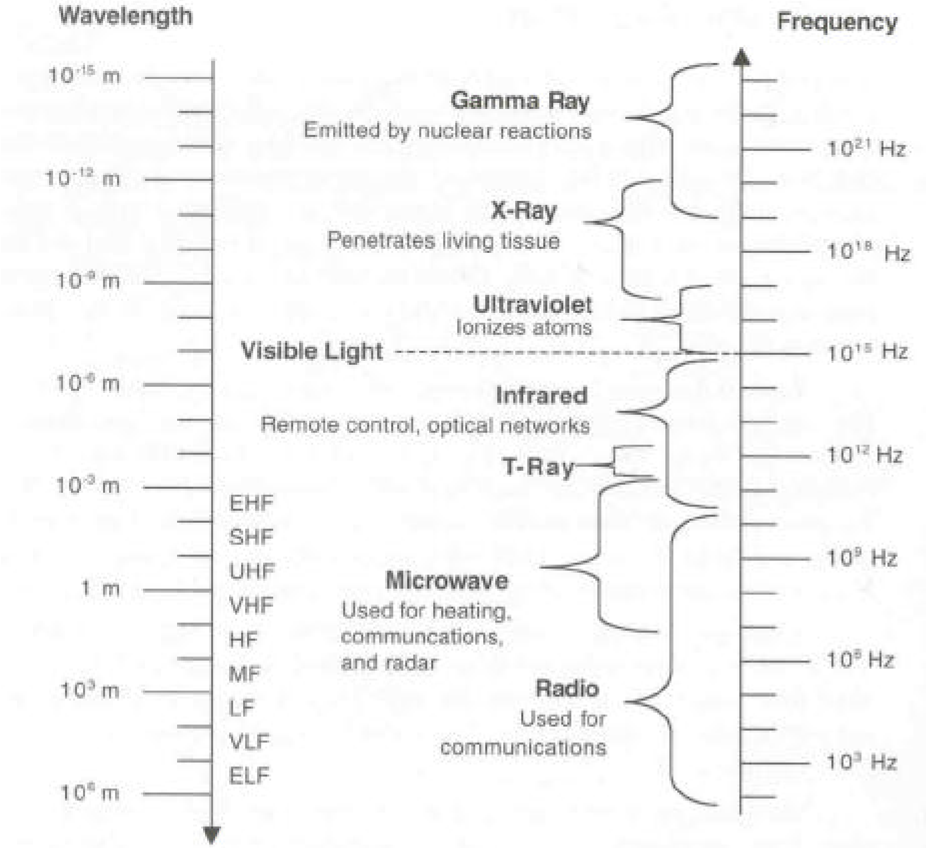


Figure 2.2
The electromagnetic spectrum.

Wave Bands

- Radio spectrum can be sub-divided into regions called wavebands

Table 2.1 Radio Wavebands

Wavelength	Frequency	Common Name	Main Purposes
Above 100 km	Below 3 kHz	Extremely Low Frequency (ELF)	Submarine communications
10–100 km	3–30 kHz	Very Low Frequency (VLF)	Maritime communications
1–10 km	20–300 kHz	Low Frequency (LF) or Long Wave (LW)	AM broadcasting
100–1,000 m	300–3,000 kHz	Medium Frequency (MF) or Medium Wave (MW)	AM broadcasting
10–100 m	3–30 MHz	High Frequency (HF) or Short Wave (SW)	AM broadcasting, amateur radio
1–10 m	30–300 MHz	Very High Frequency (VHF)	FM broadcasting, TV
0.1–1 m	300–3,000 MHz	Ultra High Frequency (UHF)	TV, cell phones
10–100 mm	3–30 GHz	Super High Frequency (SHF)	Fixed wireless, satellites
1–10 mm	30–300 GHz	Extra High Frequency (EHF)	Satellites, radar

Electromagnetic Spectrum

- Higher freq.,
  - shorter wavelength, more bandwidth
  - More blockage
- Lower freq.,
  - attenuated more
  - Can bend round obstacles
- Example:
  - AM radio can span entire country with 1 transmitter
  - VHF can only span 1 city

Interference

- Radio waves at different freq: no interference
- Radio waves at same freq can **interfere,** result:
  - 1 signal drowns the other (capture effect)
  - 2 signals enhance each other (constructive)
  - 2 signals cancel out each other (destructive)

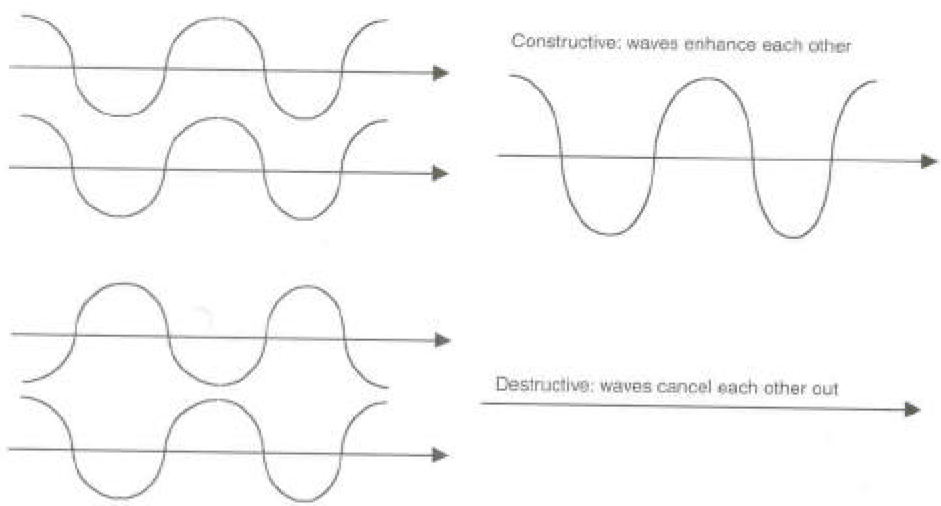


Figure 2.3
Constructive and destructive interference.

Multipath Interference

- Radio transmitter sends signals in all directions
- Signals bounce off various objects, arrive at destination through many alternate paths
- At object surfaces, reflection, diffraction or scattering can happen
- Different path lengths, net effect of multiple paths

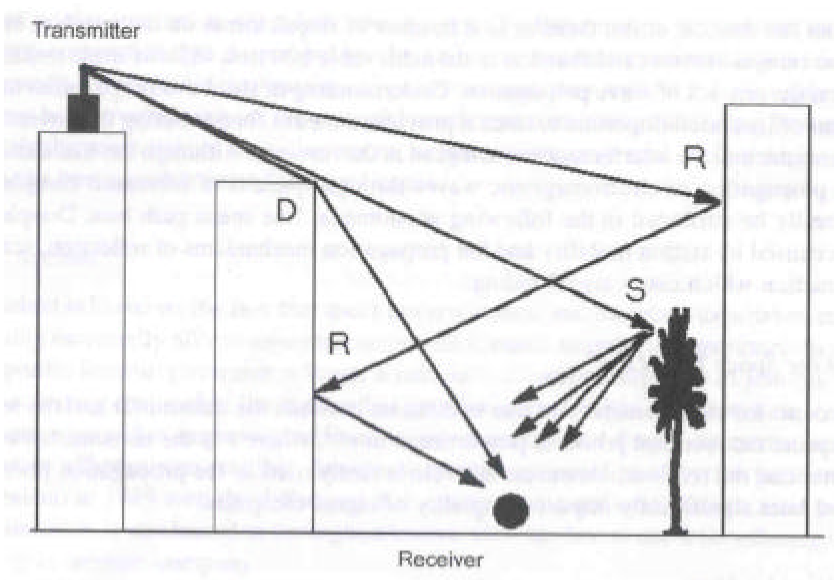


Figure 2.5 Reflection (R), diffraction (D) and scattering (S)

Multipath Fading

- **Multipath Fading (or fast fading):** shortest path signal arrives first, echos from longer paths follow
- Echos distort original signal
- Even receiver movements of a fraction of wavelength causes large changes in net rcvd signal
- Variation in local average, computed over recvr movements of 10-40 wavelengths is small (slow fading)

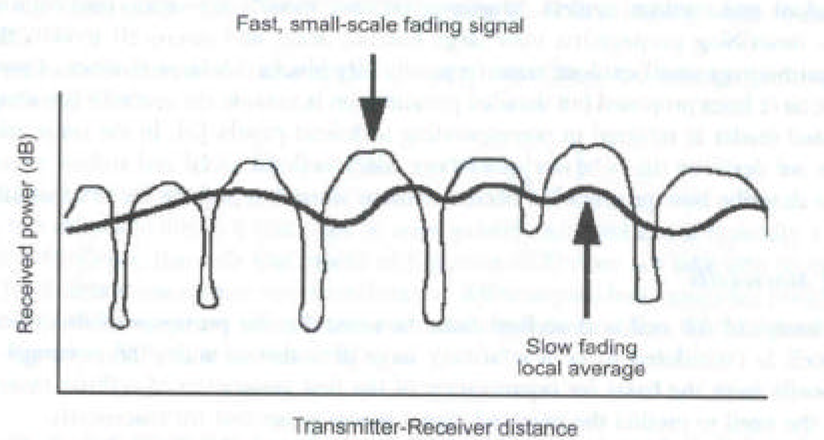


Figure 2.7 Variation of signal level according to transmitter–receiver distance

Multipath Fading

- Time duration between first signal and last echo is called **delay spread** of the channel
- ***Fading causes most bit errors in wireless (10^{-3})***!!
- Ricean fading: LOS exists between Xsmitter, Rcvr
- Rayleigh fading: LOS does NOT exist
- Echos from previous signal may continue to arrive while detecting new symbol causing ***intersymbol interference (ISI)***

Radio Propagation

- A few technical details to chew on:
- **Shannon's formula** for upper bound on bit rate, *W* of channel of bandwith, *H* Hz with given *S/N* ratio:

$$W = H \log_2\left(1 + \frac{S}{N}\right)$$

- ***W*** decreases with higher error, lower ***S/N*** ratio
- **Attenuation** proportional to $1/r^2$ (free space path loss)
- **Two-way ground:** 1 direct ray, 1 bounces of ground
- **Doppler shift:** Xmitter, Receiver moving towards each other, received signal freq. increases, (e.g ambulance), … moving away, freq. decreases

Indoor Vs. Outdoor

- Indoor (wireless LANs) propagation is different from outdoor (cellular) propagation for many reasons:
  - Dependence on building type: architecture, materials, movement of people, etc
  - Classes of buildings: suburban homes, urban homes, office buildings, factories, grocery stores, etc.
  - Table below parametrized a proposed model

Building type	Frequency (MHz)	n	σ dB
Retail stores	914	2.2	8.7
Grocery stores	914	1.8	5.2
Office with fixed walls	1500	3.0	7.0
Office with soft panels	900	2.4	9.6
Office with soft panels	1900	2.6	14.1
LOS Textile/chemical factories	4000	2.1	7.0
OBS Textile/chemical factories	4000	2.1	9.7

Figure 2.10 Values for exponent n and σ for various building types

Indoor Vs. Outdoor

- Delay spread: objects that cause scattering are usually on LOS path so smaller delay spread
- Propagation between floors: depends on materials between floors
- Signals from outdoors or other systems penetrate indoor channel and cause interference

Analog Vs Digital

- Original radio waves transmitted voice
- Voice is ***analog*** signal, continuous waveform
- Digital: restrict legal set of values
- E.g. for radio waves, restrict legal sets of amplitudes, frequencies or phase

Figure 2.5
Analog and digital wave forms.

Why Digital?

- Most modern radio systems are becoming digital
- Note: Can convert from digital to analog and vice versa. But lose information everytime you convert
- **Quantization:** sample continuous analog waveform periodically, return value, converts to digital pulses
- Digital communication has advantages
  - Noise reduction
  - Can checksum and encrypt, etc.

Modulation

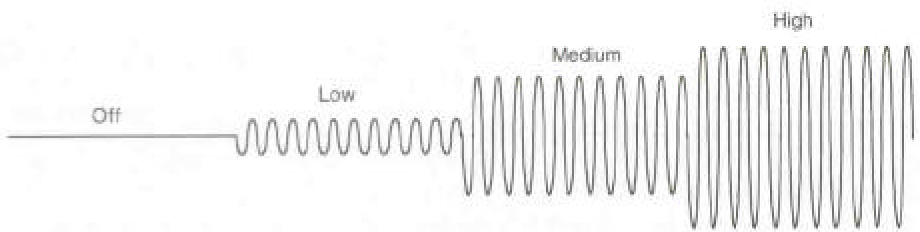
- **Modulation:** convert original information signal (**baseband)** into a form ready for transmission
- During modulation, combine original signal with high frequency waveform called carrier
- Basically, let information signal vary or **modulate** carrier signal
- Output is high frequency waveform **(broadband)**
- Types of modulation:
  - Amplitude modulation
  - Frequency modulation
  - Phase-shift keying

Amplitude Modulation (AM)

- Output waveform amplitude (height) varies in proportion to information signal

Figure 2.6
Amplitude modulation.

- Can use multiple carrier levels e.g. 4 levels instead of 2 called Quadrature Amplitude Modulation (QAM)



- ***QAM***

Figure 2.7
Quadrature amplitude modulation.

Frequency Modulation (FM)

- FM keeps amplitude constant and modifies frequency instead in proportion to information signal

FM

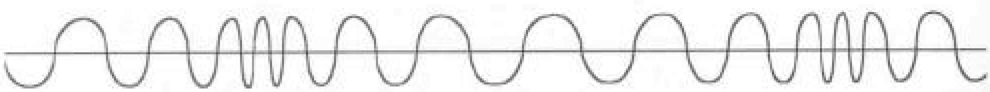


Figure 2.8
Frequency-modulated carrier wave.

- FM is more resistant to noise than AM
- Can hear two AM stations from 1 location
- In FM, (1 station) or noise is completely captured

Phase-Shift Keying (PSK)

- Shift phase of carrier based on information signal
- Phase? Point in waveform's cycle
- Digital modulation: only a few phases are legal
- Transmitter generates phases, receiver detects
- Many variants. E.g to minimize sudden phase shift, pass through filter (GMSK) in GSM
- ***PSK***

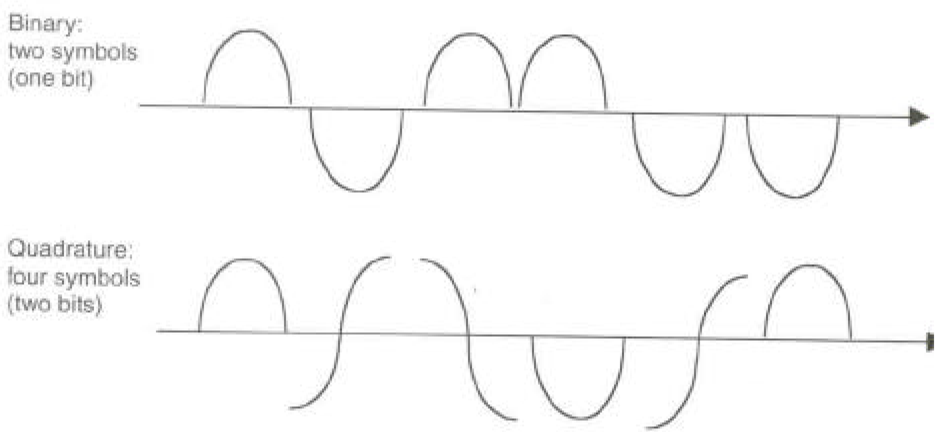


Figure 2.9
Binary and quadrature phase modulation.

Constellation diagrams

- Can increase symbol rate by increasing number of valid phases
- Useful to represent waveform phases on **constellation diagrams**
- **Question:** why not pack a million points in 1 cycle?

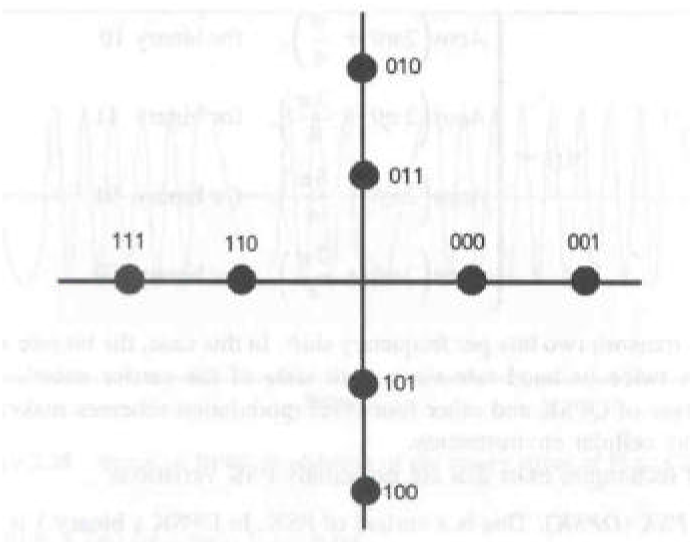


Figure 2.28 8-level QAM constellation encoding 3 bits/baud

Spectrum Regulation

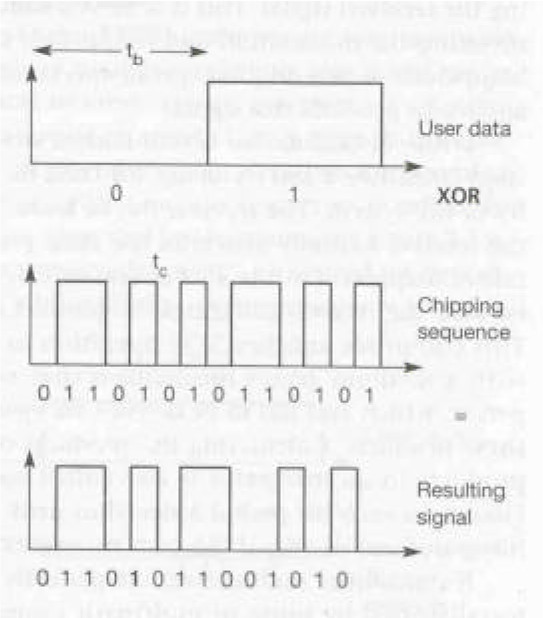
- More users want spectrum than is available
- Each country has governing body that allocates frequencies (e.g. FCC in the US)
- International cooperation helps to make products interoperate in many countries. E.g. 2.4 GHz in 802.11 globally available
- After allocating blocks of frequency, how to allocate to specific companies?
  - **Beauty contests:** comparative bidding, govt. decides, can be corrupt
  - **Lotteries:** Quick, attracts speculators
  - **Auctions:** highest bidder
  - **Free-for-all:** unlicensed use, e.g. ISM bands

Spread Spectrum

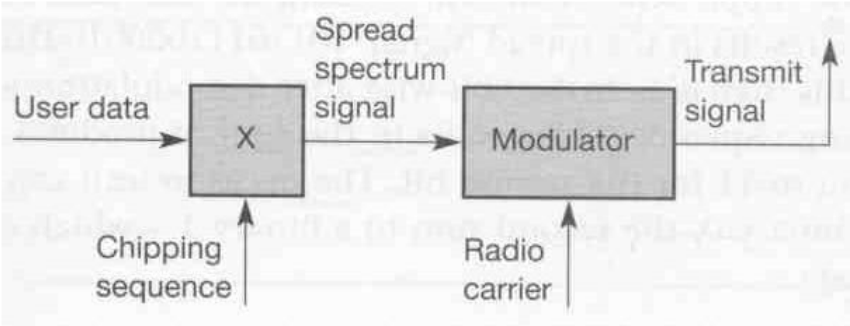
- In free-for-all, ISM bands, need to reduce probability or duration of interference between devices from different manufacturers ***(spread spectrum)***
- SS also reduces effect of fading
- Two key types:
  - **Frequency Hopping (FHSS),** Xmitter and receiver hop on same sub-channels in pseudo-random pattern, interruption for small time, start with series of 1's for synchronization
  - **Direct Sequence (DSSS),** spread original signal over larger spectrum reduces probability of errors (similar to CDMA)

Direct Sequence (DSSS)

- Both sender and receiver decide on pseudo random chip sequence
- E.g. Barker code of 802.11 wireless LANs
- XOR code and original data, then send
- Xsmit random code (1) or compliment (0)



Direct Sequence (DSSS)



- So, apply chip sequence, modulate then transmit
- Receiver recovers original data by XOR with pseudo-random code
- Fading or errors affect only a few bits, Codes chosen **(orthogonal)** such that receiver can still guess or fix few bit errors

Improving Wireless Performance

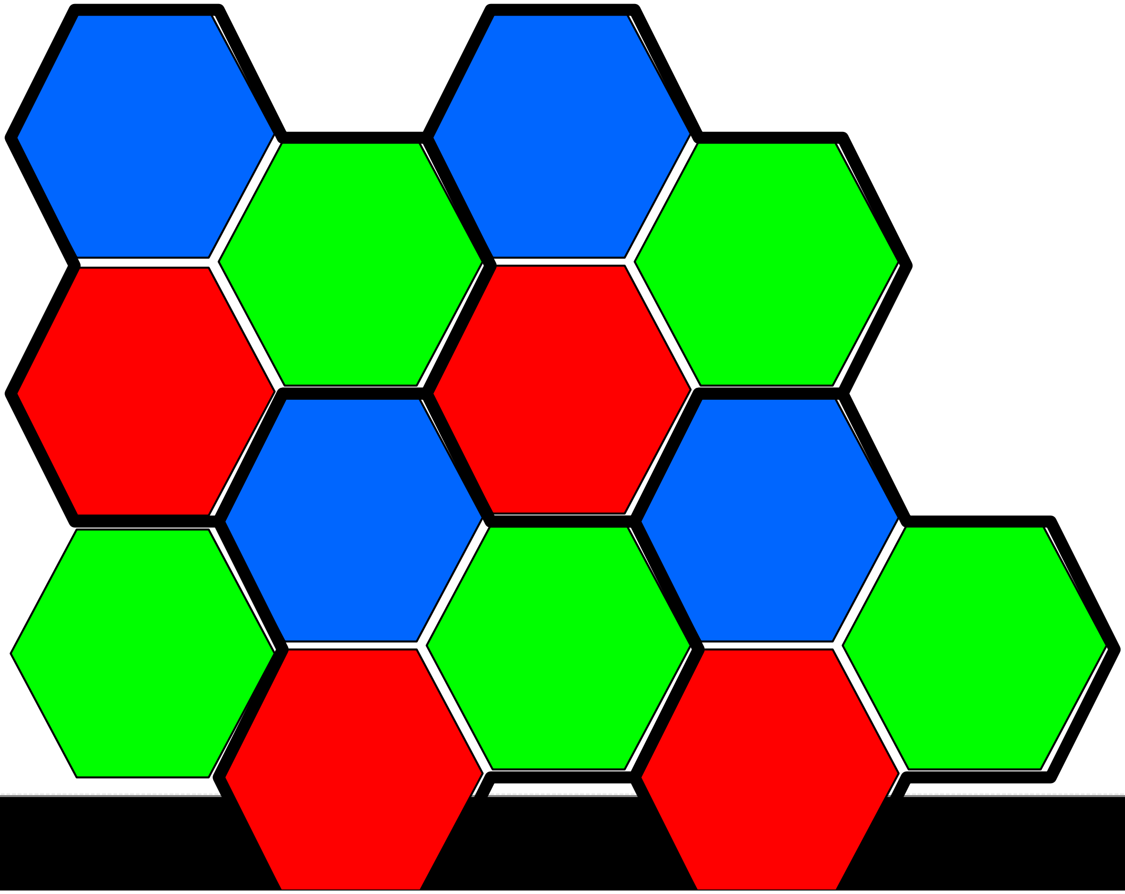
- **Diversity**, sending different copies of same information through different channels
- Diversity categories : space, time, frequency, polarization
- **Antenna diversity:**
  - **Space (or antenna):** antenna branches spaced at about wavelength to gather samples
  - **Smart antennas:** try to adapt to channel conditions
  - **Switched antenna lobe:** antenna array, return antenna element value with best performance
- **Coding:** parity, CRC, hamming code, convolutional

Improving Wireless Performance

- **Equalization:**
  - Used to combat ISI
  - **Basic strategy:** predict ISI, modify transmitted signal accordingly
- **Power Control:**
  - Try to minimize interference, conserve mobile node energy by varying transmission power
  - So, high noise, increase power
  - Low noise, decrease power

Cellular concepts

- **Frequency reuse:** divide spectrum into sub-channels
- 1 sub-channel freq. Per cell
- **Research:** how to color cells for maximal reuse?



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