WIRELESS TRANSMISSION

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Outline

- Frequency Spectrum
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- Signals and Antennas
  - Propagation Characteristics
- Multiplexing
  - Space, Frequency, Time, Code
- Modulation
  - Amplitude, Frequency, Phase
- Spread Spectrum
  - Direct Sequence, Frequency Hopping
- Cellular Systems
  - Frequency Planning
FREQUENCY SPECTRUM

Usage and Licensing

“Carrier” Frequency

- **Frequency and wave length** \( (\lambda = c / f) \)
  - wave length \( \lambda \), speed of light \( c \approx 3 \times 10^8 \text{m/s} \), frequency \( f \)
Frequencies For Communication

VLF = Very Low Freq
LF = Low Freq
MF = Medium Freq
HF = High Freq
VHF = Very High Freq
UHF = Ultra High Freq
SHF = Super High Freq
EHF = Extra High Freq
UV = Ultraviolet Light

Submarines
AM, SW, FM
Radio

TV, Mobile, 3G
Directed Links
Wireless LANs
Directed Laser

Frequency Usage

- LF: used by submarines
  - Can penetrate water; can follow the earth’s surface
- MF-HF: hundreds of radio stations (AM, SW, FM)
  - Short waves are reflected at ionosphere (amateur radio)
- VHF-UHF: TV, DAB, mobile, cordless, 3G
  - Allow for small antennas; relatively reliable connections
- SHF: directed microwave links, fixed satellites
  - Small antenna; beam forming; high bandwidth
- Wireless LANs: UHF-SHF
  - Absorption by water/oxygen molecules (fading/loss in rain)
- Optical transmission:
  - Infra-red for directed links (laser links between buildings)

ITU regulates frequency usage world-wide
Signals

- Signals are physical representation of data
  - Parameters represent the data values
  - Are functions of time and location

- Analog vs. digital signals:
  - Analog signals: continuous time and continuous values
  - Digital signals: discrete time and discrete values

- Periodic signals characterized by parameters:
  - Amplitude $A$, period $T$, frequency $f = 1/T$, phase shift $\varphi$
  - Special case: sine wave: $s(t) = A \sin(2\pi ft + \varphi)$
  - General: $g(t) = \frac{1}{2} c + \sum_{n=1}^{\infty} a_n \sin(2\pi ft + \varphi) + \sum_{n=1}^{\infty} b_n \cos(2\pi ft)$
**Signal Representation**

- **Amplitude**
  - Time domain

- **Frequency spectrum**
  - Frequency domain
  - Fourier transformation
    - Transforms to time domain

- **Phase state diagram:**
  - amplitude $M$
  - phase shift $\phi$ in polar coordinates

**Antennas**

- **Role:**
  - Couple electromagnetic energy to/from space from/to a wire or other conductor

- **Physically:**
  - An arrangement of one or more conductors (elements)
  - Convert electromagnetic radiation into electric current (and vice versa)

- **Transmission:**
  - AC is created by applying voltage at terminals, which causes them to radiate electromagnetic field

- **Reception:**
  - External electromagnetic field induces an AC in elements, which induces voltage at the terminals
Theoretical Reference

- Theoretical reference antenna: isotropic radiator
  - Point in space radiating equal power in all directions (3D)

- Real antennas exhibit “directive effects”
  - Intensity not same in all directions

Antenna Types/Models

- Simple Hertzian Dipole
  - Two collinear conductors of equal length
    - Separated by small feeding gap
  - Length = $\frac{1}{2}$ wavelength to be transmitted

- Radiation pattern:

- Gain: max power in the direction of the main lobe
  - Compared to the power of isotropic radiator (with same average power)

* image source: wikipedia.org
Directed & Sectorized Antennas

- Fixed preferential transmission/reception directions
  - e.g., satellite dishes
  - Typically applied in cellular systems (radio coverage in a valley) and microwave connections

- Side view (yz-plane)
- Top view (xz-plane)

- Top view, 3 sector
- Top view, 6 sector

Signal Propagation Ranges (Ideal)

- Transmission range:
  - Communication possible
  - Low error rate

- Detection range:
  - Signal can be detected
  - No communication
    - Error rate too high

- Interference range:
  - Signal can’t be detected
  - But may disturb other signals
Path Loss of Radio Signals

- In free space, signals propagate like light (straight line)
  - Received power proportional to \(1/d^2\)
    - \(d\): sender-receiver distance
  - Received power also depends on atmosphere:
    - Rain absorbs much of radiated energy (microwave oven)

- Frequency-dependent propagation behavior:
  - Ground waves: low frequencies (< 2 MHz)
    - Follow the earth’s surface; can propagate long distances
    - Submarine communication, AM radio
  - Sky waves: 2 – 30 MHz
    - Reflected (refracted) at ionosphere; used for amateur radio
  - Line-of-sight (> 30 MHz)
    - Mobile phones, satellites, cordless phones, etc
    - Emitted waves follow straight line of sight

Additional Propagation Effects

- Receiving power additionally influenced by
  - Fading (frequency dependent)
  - Shadowing
  - Reflection at large obstacles
  - Refraction depending on the density of a medium
  - Scattering at small obstacles
  - Diffraction at edges
Multi-path Propagation

- Signal can travel different paths (scattering/reflection/diffraction)
  - Short impulse is smeared onto several weaker impulses
    - Signal distorted according to phases of different parts
  - Causes Inter-symbol Interference (ISI)
- Receiver can compensate if distortion is known
  - Sender first transmits a known “training sequence”
  - Receiver then programs an “equalizer” that compensates for distortion

Short-term and Long-term Fading

- Power of received signal varies over time if transmitter and/or receiver are mobile
  - Short-term fading – quick changes
  - Long-term fading – caused by varying distance