Department of Electrical Engineering
IIT Hyderabad

EE 6340/3801
Wireless Communications

Channel

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Lecture 2 Outline

- Announcements
  - 1st HW will be posted tonight, due next Monday 12 pm.
  - Review of Last Lecture
- Wireless Channel
- TX and RX Signal Models
- Path Loss Models
  - Free-space and Simplified Path Loss Model
  - General Ray Tracing
  - 2-Ray Models
  - Empirical Models
  - mmWave Models

Transmit and Receive Signal Models

- Transmitted signal

$$s(t) = Re\{u(t)e^{j(2\pi f_c t+\emptyset 0)}\}$$
$$= Re\{u(t)\}\cos(2\pi f_c t + \emptyset 0) - Im\{u(t)\}\sin(2\pi f_c t + \emptyset 0)$$
$$= x(t)\cos(2\pi f_c t + \emptyset 0) - y(t)\sin(2\pi f_c t + \emptyset 0),$$

$u(t) = x(t) + jy(t)$ is a complex baseband signal

- Received Signal

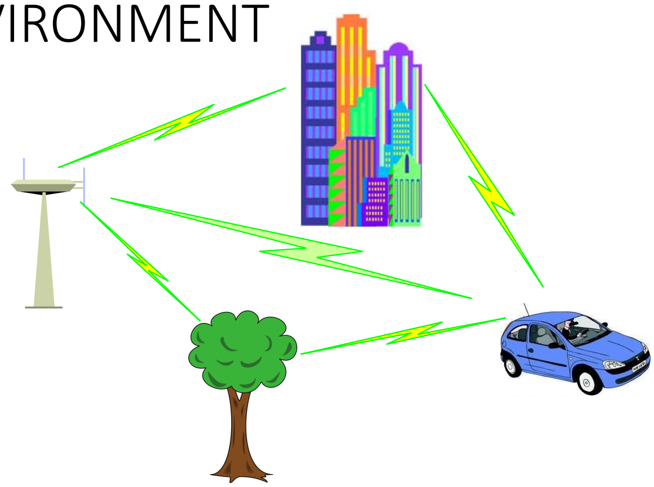
$$r(t) = Re\{v(t)e^{j(2\pi f_c t+\emptyset 0)}\}$$

- $v(t) = u(t) * h(t) + n(t)$

$h(t)$ is time-invariant channel

n(t) is additive white Gaussian noise

CHANNEL: PROPAGATION ENVIRONMENT



CHANNEL: PROPAGATION MODES

- **Free-space (line-of-sight)**
  - There is a clear transmission path between transmitter (Tx) and receiver (Rx).
  - E.g. satellite
- **Reflection**
  - The bouncing of electromagnetic waves from surrounding objects
  - Size of reflecting objects must be large compared to the wavelength of signal
  - Reflecting surface must be smooth compared to the wavelength of signal
  - E.g. ground, building, walls, windows, lakes

CHANNEL: PROPAGATION MODES (CONT'D)

- **Diffraction**
  - The bending of electromagnetic waves around objects (such as buildings), or through objects (such as trees).
  - Due to diffraction, signals can propagate
    - Around curved surface of Earth
    - Beyond LOS horizon
    - Behind obstructions
- **Scattering**
  - Electromagnetic waveforms incident upon rough or complex surfaces are scattered in many directions
    - Relfection: smooth surface, one direction
- **Refraction (not common in terrestrial wireless communication).**
  - Electromagnetic waves bend as they move from one medium to another.

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CHANNEL

Channel: a collection of propagation effects and other signal impairments caused by the environments

- **Wireless channel: propagation, noise and interference**
  - Propagation effects: line-of-sight, reflection, diffraction, scattering
    - Induced by the transmission of desired signals itself
    - Impairments: large scale fading (path loss, shadowing), small scale fading
    - Unique to wireless communication
  - Noise and interference: unwanted electrical signals interfering with desired signal.
    - Thermal noise (movements of electrons)
    - Automobile ignition, electrical machinery, etc.
    - Interferences from other users operating on the same frequency.

Present in all communication systems

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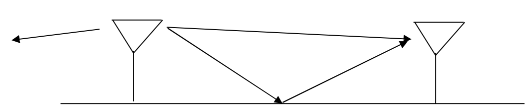
PATH LOSS

- **Path loss: the power loss during signal propagation from Tx to Rx**
  - Only a portion of the power from Tx will be captured by the receiver.



- **Path loss is defined as the ratio between the signal power at transmitter (P_T) and signal power at receiver (P_R).**

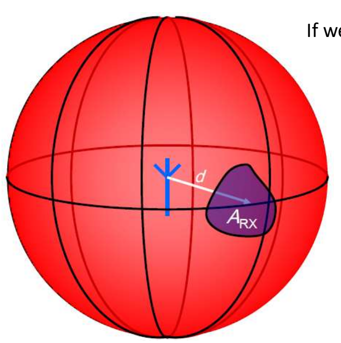
$$L_p = \frac{P_T}{P_R}$$

$$L_p(dB) = 10\log_{10}\frac{P_T}{P_R} = 10\log_{10} P_T - 10\log_{10} P_R$$

Path Loss Modeling

- Maxwell's equations
  - Complex and impractical
- Free space and 2-path models
  - **Too simple**
- Ray tracing models
  - Requires site-specific information
- Simplified power falloff models
  - Main characteristics: good for high-level analysis
- Empirical and Standards-based Models
  - Not accurate; used to assess different designs

Free Space Path Loss (LOS) Model



If we assume RX antenna to be isotropic

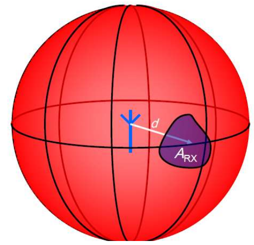
$$P_{RX} = \left(\frac{\lambda}{4\pi d}\right)^2 P_{TX}$$

Attenuation between two isotropic antennas in free space is (free-space loss):

$$L_{free}(d) = \left(\frac{4\pi d}{\lambda}\right)^2$$

Friis’ Formula

- Isotropic antenna radiates equally in all directions
- Radiation pattern is spherical



- If the TX antenna radiates isotropically, then the receive power density on the surface is

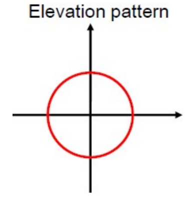
$$\frac{P_{TX}}{4\pi d^2}$$

- The received power is given by

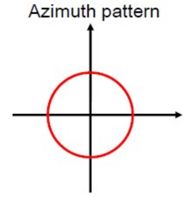
$$P_{RX}(d) = A_{RX}\frac{P_{TX}}{4\pi d^2}$$

where A_{RX} is the effective area of the receive antenna

Elevation pattern



Azimuth pattern



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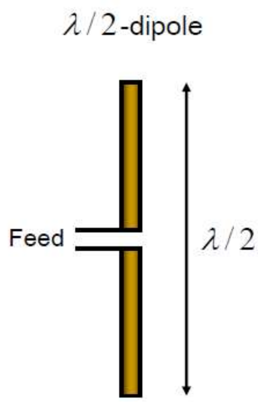
Friis’ Formula

Dipole Antenna and Antenna Gai

$G_{\lambda/2}$ is 2.15 dB or 1.64

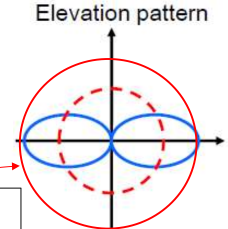


A dipole can be of any length, but the antenna patterns shown are only for the λ/2-dipole.

This antenna does not radiate straight up or down. Therefore, more energy is available in other directions.

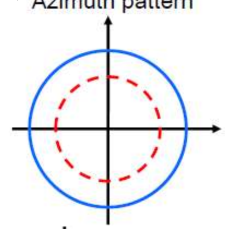
Isotropic with increased power

Elevation pattern



The amount of increase in I/P power to isotropic antenna, to get the same maximum radiation is called antenna gain, G

Azimuth pattern



-- Antenna pattern of isotropic antenna.

Friis' Formula

- The received power for a nonisotropic TX antenna is given by

$$P_{RX}(d) = G_{TX} A_{RX} \frac{P_{TX}}{4\pi d^2}$$

- The effective Area is related to G_{RX} as $A_{RX} = \frac{\lambda^2}{4\pi} G_{RX}$
- The Friis Formula is given by

$$\boxed{P_{RX}(d) = P_{TX} G_{TX} G_{RX} \left(\frac{\lambda}{4\pi d} \right)^2}$$

Limitations
- >30 MHz (VHF & higher)

- Far field of the antenna:

the far field requires

$d >> \lambda, La$

Where La is the largest dimension of the antenna

- Received Signal

- **For system with fixed P_T, G_T and G_R**
  - $d \uparrow \Rightarrow P_{RX} \downarrow$
  - $f \uparrow \Rightarrow \lambda \downarrow \Rightarrow P_{RX} \downarrow$

$$r(t) = Re\{v(t) e^{j(2f\pi \quad \emptyset 0)}\}$$
$$= Re\left\{\left[\frac{\lambda\sqrt{G} e^{-j2\pi d/\lambda}}{4\pi d} u(t) + n(t)\right] e^{j(2\pi f c t + \emptyset 0)}\right\}$$

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PATHLOSS: FREE-SPACE

- **Example**
  - In order to operate properly, a receiver must capture the signal power of at least -90dBm. Assuming a 100-miliwatt transmitter and free-space path loss. The antenna gain at Tx and Rx are 3dB. What is the service area radius of the Tx for a signal frequency of 800MHz?

Sol: $P_T = 100mW$

$$P_R(dBm) = 10\log_{10}\frac{P_R(mW)}{1(mW)} \Rightarrow P_R(mW) = 10^{P_R(dBm)/10} = 10^{-9}(mW)$$

$$G_T(dB) = G_R(dB) = 3dB \Rightarrow G_T = G_R = 10^{3/10} = 2$$

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi R}\right)^2 \Rightarrow R = \frac{\lambda}{4\pi}\sqrt{\frac{P_T G_T G_R}{P_R}}$$

$$R = \frac{c}{4\pi f}\sqrt{\frac{P_T G_T G_R}{P_R}} = 18.9km$$