EE 577: Wireless and Personal Communications

Antennas and Propagation

Antennas

- An Antenna is a passive device which converts RF power into electromagnetic fields, or intercepts electromagnetic fields and converts them into RF power.
- Antennas are generally characterized by:
  - Antenna gain
  - Radiation pattern
  - Antenna directivity

Basic Definitions

- **Combiners:** Allow multiple transceivers to share a single antenna

- **Duplexers:** Allow the TX and RX paths to share the same antenna

- **Isotropic RF Source:**
  - A point source that radiates RF energy uniformly in all directions (i.e.: in the shape of a sphere)
  - Theoretical only: does not physically exist

Antenna Gain

- **Antenna gain**:

  The ratio of the power density produced in a given direction to the power density that would be produced by a reference antenna in the same direction.

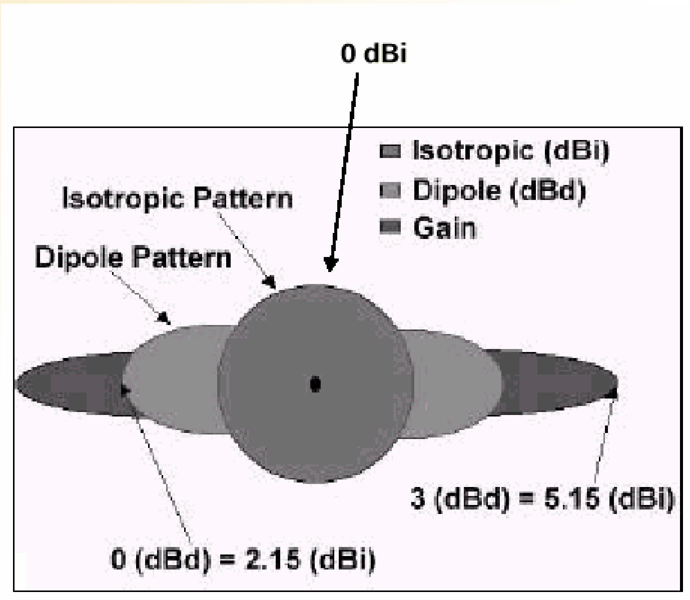
- The gain is measured relative to an ideal, isotropic, unity-gain antenna.

- The antenna gain is how most people rate the quality of the antenna.

Antenna Gain

- Two types of reference antennas:
  - **Isotropic antenna:** gain is given in dBi
  - **Half-wave dipole antenna:** gain is given in dBd
- Generally, the reference is dBd,
- dBi = dBd + 2.15 dB
- A_e: Effective Aperature

  (Related to the physical size of the antenna)



Universal Gain Equation

The universal gain equation is often used to compute the antenna gain in terms of:

- ❑Frequency, f, of the radiation ($\lambda f = c$)
- ❑Effective Aperture A_e:

(Related to the physical size of the antenna)

$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi A_e f^2}{c^2}$$

The **aperture efficiency** relates the effective aperture, A_e , to the physical aperture (area), A_p

$$\eta_{ap} = \frac{A_e}{A_p} = \frac{\text{effective aperture}}{\text{physical aperture}}$$

Typical efficiencies are 45% - 65%

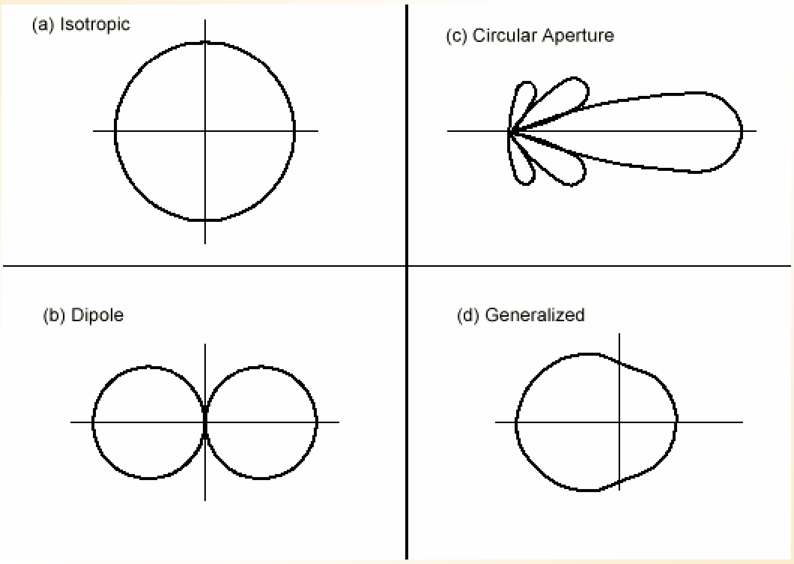
Antenna Area

- **<u>Effective area</u>** of the antenna measures **how well the antenna captures power**
- It is simply the ratio of the total power received by the antenna to the power density at the point where the antenna is located.
- Effective area of the antenna can be much larger than the antenna geometric area.

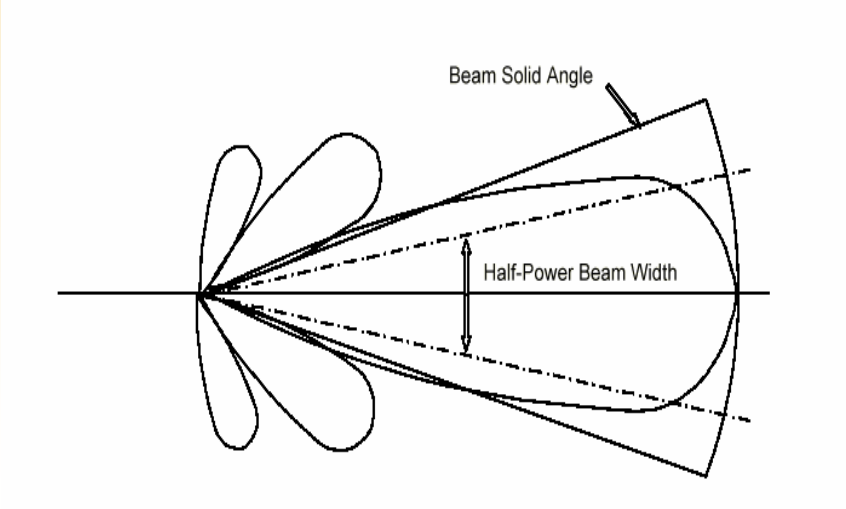
Antenna Directivity

- **Antenna pattern:** The shape of the power intensity radiated from an antenna
- **Antenna directivity:** A measure of how the antenna pattern is concentrated
- Antenna patterns are usually referenced to an ideal, unity-gain, spherically-symmetric isotropic antenna

Antenna Pattern



- Most antennas have a main lobe that defines the main radiation direction
- The **Half Power Beam Width** (HPBW) angle is the angle of coverage where the radiated energy is 3 dB down from the peak of the beam (half-power)
- The **Beam Solid Angle** measures the width of a main lobe that would radiate the same energy as the total energy radiated by the antenna

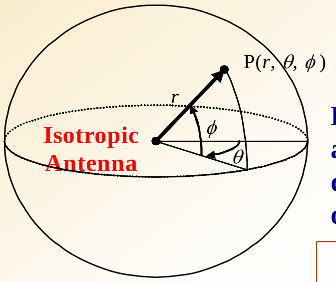


Side Lobes

The maximum relative size of the **side lobes** is also important in addition to the directivity or power pattern:

- ❑Determines the radiation spread outside of the direction of interest
- ❑Determines the spillover of the energy to or from the ground or other noise sources

Directivity



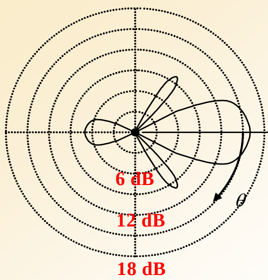
Power density at any point is dependent only on radius

For transmission antenna, the directivity of the antenna is the ratio of maximum power density to isotropic power density. This ratio is usually expressed in decibels:

$$D_{directivity} = \frac{w_{\max}(r)}{w_{ISO}(r)}$$

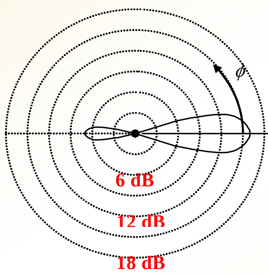
$$\text{decibels} \;:\; D = 10 \cdot \log\left(\frac{w_{\max}(r)}{w_{ISO}(r)}\right) dB$$

The power density is always dependent on the orientation of the receiver, which is measured in polar coordinates. The direction of maximum power density is assigned to $\theta = 0$, $\phi = 0$. This point is also called the foresight of the antenna.



Direction of maximum gain ($\theta = 0$, $\phi = 0$)
Foresight

Radiation diagram for horizontal plane ($\phi = 0°$)



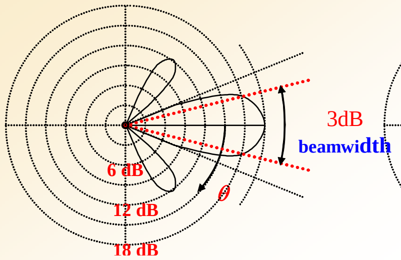
Direction of maximum gain ($\theta = 0°$, $\phi = 0°$)
Foresight

Radiation diagram for vertical plane ($\theta = 0°, 180°$)

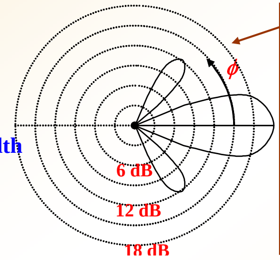
A radiation diagram describes the ratio of the antenna's power density at any orientation around the antenna to the isotropic power density

gain of the antenna in this direction.

Directional vs. Omnidirectional Antennas



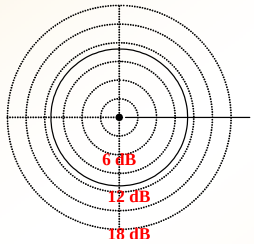
Horizontal plane ($\phi = 0°$)



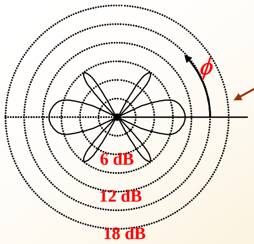
Vertical plane ($\theta = 0°$),

Directional antenna radiation pattern

3 dB beamwidth, the angle between point that are 3 dB below the maximum power output.



Horizontal plane ($\phi = 0°$)



Vertical plane ($\theta = 0°$),

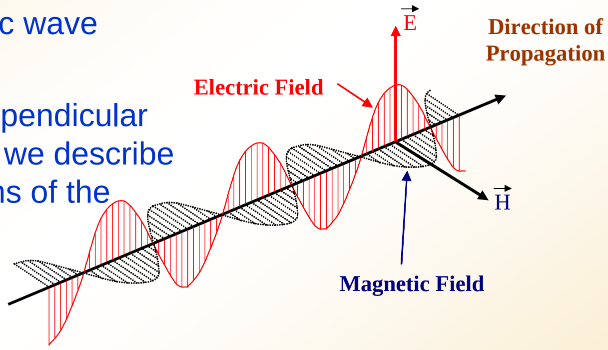
Omnidirectional antenna radiation pattern

Radiation Nulls

- Radiation nulls are the directions in which the gain of the antenna becomes very small
- In these directions, the power transmitted by the antenna becomes very small
- This results in dropping calls when the MS is in the direction of a radiation null

Polarization

- Polarization describes the direction of the electrical field of the electromagnetic wave
- There is also a perpendicular magnetic field, but we describe polarization in terms of the electric field.



- It is important that the polarization of the transmitting antenna matches the polarization of the receiving antenna.

Polarization

- In cellular systems, the MS changes its direction resulting in mismatch in polarization
- Also, scattering causes the signal to change its polarization due to non-uniform edges
- This makes cellular industry uses cross-polarization, i.e., combine vertical and horizontal polarization

Antennas and Diversity

- 1 antenna on a cell site:
  - Typically an omnidirectional cell
  - TX and RX duplexed onto the antenna.
  - Multiple transceivers could be combined
  - No space diversity.
- 2 antennas per sector:
  - Typically one antenna is a duplexed TX/RX
  - the other is a dedicated RX.
  - Receive diversity supported.

Antennas and Diversity

- 3 antennas per sector
  - Most common configuration.
  - One antenna is a TX while the other two are dedicated RX.
  - Receive diversity supported.
  - No duplexer loss.
- 4 antennas per sector
  - Rare; 4th antenna could be a spare or used as a second TX to eliminate combiner loss.
  - Could be using transmit diversity.

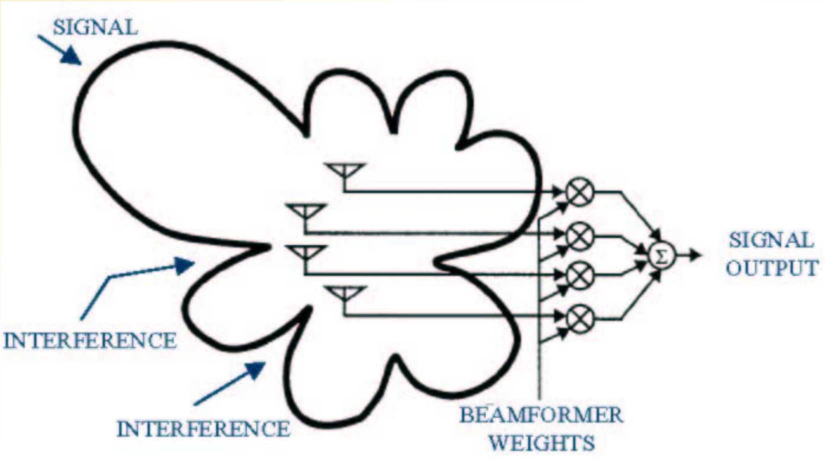
Smart Antennas

- Unlike TV and radio broadcasting, BSs in cellular systems transmit power to specific MSs (specific directions)

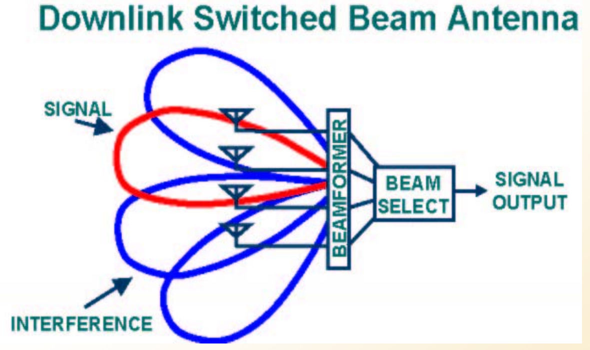
- Smart antennas concentrate transmitted power in the direction of the MS

- Smart antennas generally steer the beam to maximize *SIR* and minimize co-channel and adjacent-channel interference

Smart Antennas



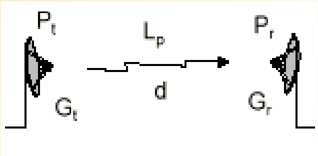
- **Multibeam:** Multiple fixed beams in a sector can be used to provide diversity or have the effect of shrinking the sector area
- **Adaptive Arrays:** Signals received by an array of antennas in a sector are weighted according to the individual SIR



Propagation - Basic Definitions

- Effective Radiated Power (ERP)
  - The radiated power from a half-wave dipole
- Effective Isotropic Radiated Power (EIRP)
  - The radiated power from an isotropic source
  - EIRP = ERP + 2.15 dB

Free Space Propagation



$$P_r = P_t \frac{G_t G_r \lambda^2}{(4\pi d)^2}$$

Propagation Loss

$$L_p = 10\log\left(\frac{4\pi d}{\lambda}\right)^2 \qquad L_p = 32.44 + 20\log(f) + 20\log(d)$$

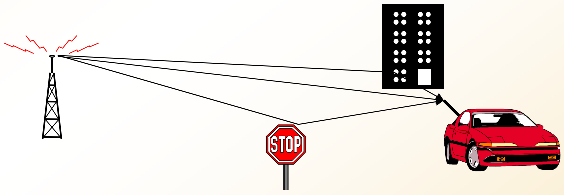
The square term is the propagation exponent (path loss exponent). It is greater than 2 when obstructions exist.

Signal Propagation

- In free space, the received power is proportional to $1/d^2$ (d = distance between transmitter and receiver)
- Receiving power is influenced by:
  - Multipath fading
  - Reflection at large obstacles
  - Diffraction around edges
  - Scattering at small obstacles
  - Shadowing

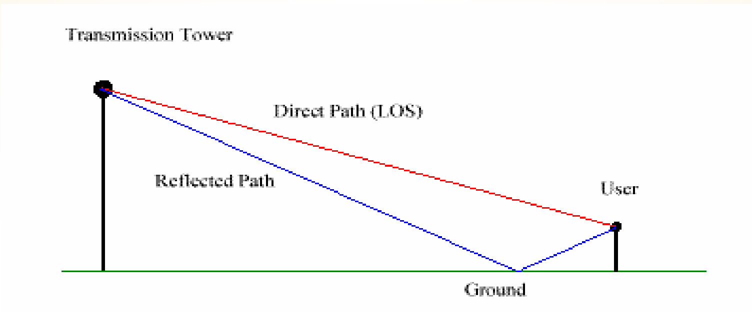
Multipath Propagation

The Signal can take many different paths between transmitter and receiver due to reflection, scattering and diffraction



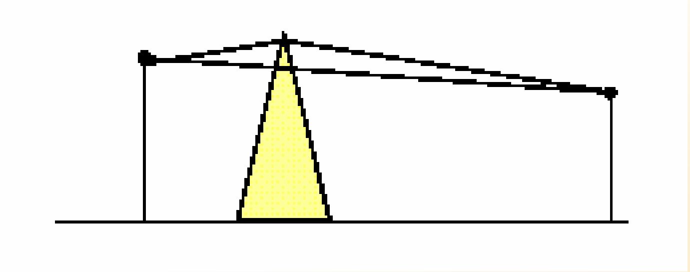
Reflection Effects

- Reflection occurs when a wave impinges upon a smooth surface
- Dimensions of the surface are large relative to λ (wavelength)

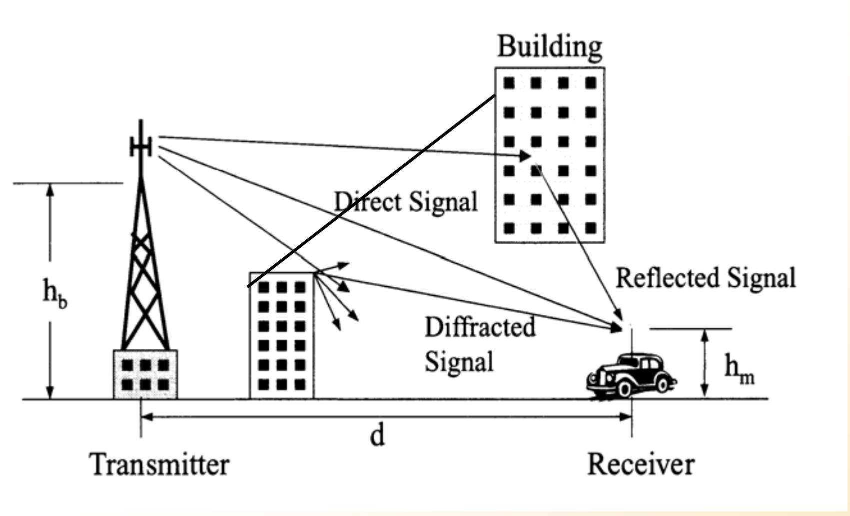


Diffraction Effects

Diffraction occurs when the path is blocked by an object with large dimensions relative to λ and sharp irregularities (edges)

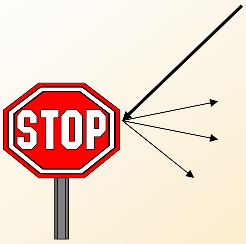


Reflection and Diffraction



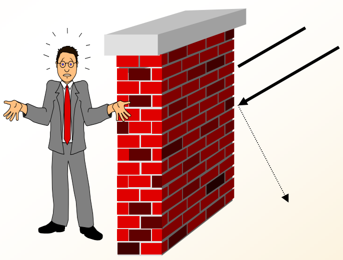
Scattering

- Scattering occurs when a wave impinges upon an object with dimensions on the order of λ or less
- Scattering causes the reflected energy to spread out or scatter in many directions
- Small objects such as street lights, signs, & leaves cause scattering
- Results in **small-scale fading**



Shadowing Effects

- Buildings, trees, etc. will all shadow the signal from the transmitter to the receiver
- Results in **large-scale fading**



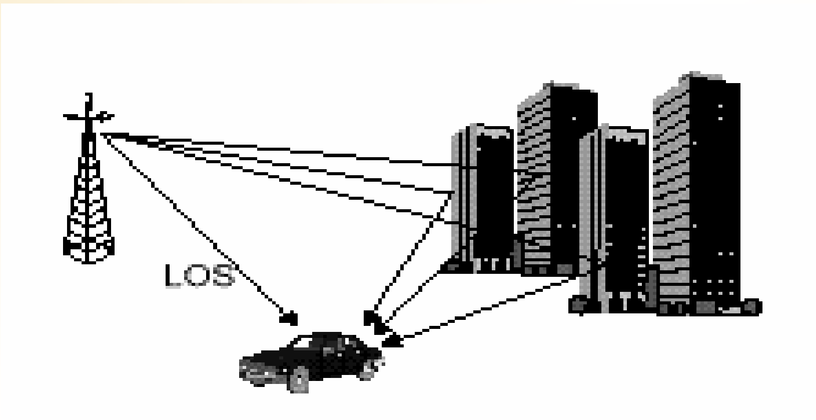
Multipath Effects

- Rapid changes in signal strength over a short distance or time

- Random frequency modulation due to Doppler Shifts on different multipath signals

- Time dispersion caused by multipath delays

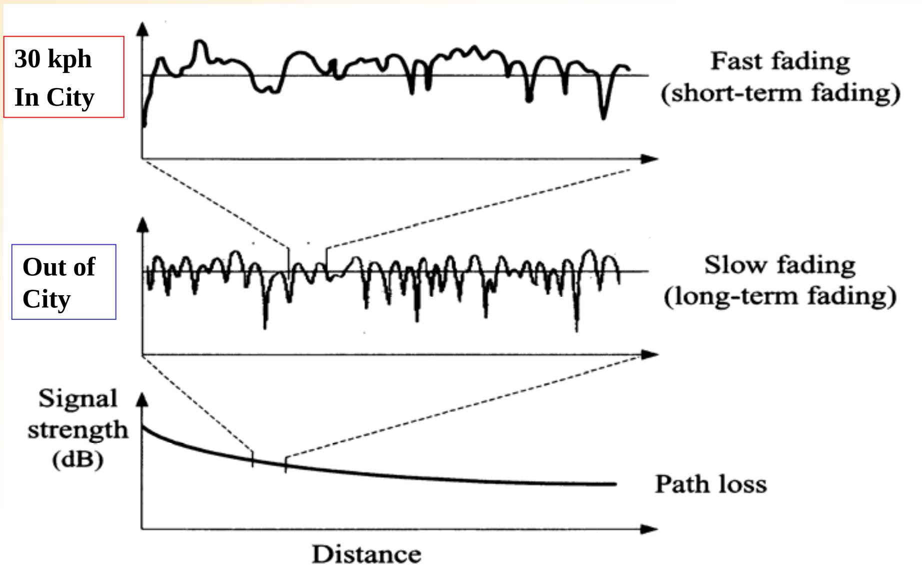
Multipath propagation results in small-scale fading



Classification of Propagation Models

- Large-Scale Propagation Models
- Small-Scale Propagation (Fading)

Propagation Loss and Fading



Large-Scale Propagation

- Slow changes in the average received power (long term fading)
- This is the loss that propagation models try to account for
- Mostly dependant on the distance from the transmitter to the receiver