# Wireless Communication

## Lecture 4

## Antennas and Propagation

# Introduction

- An antenna is an electrical conductor or system of conductors
  - Transmission - radiates electromagnetic energy into space
  - Reception - collects electromagnetic energy from space
- In two-way communication, the same antenna can be used for transmission and reception

# Radiation Patterns

- Radiation pattern
  - Graphical representation of radiation properties of an antenna
  - Depicted as two-dimensional cross section
- Beam width (or half-power beam width)
  - Measure of directivity of antenna
- Reception pattern
  - Receiving antenna's equivalent to radiation pattern

# Types of Antennas

- Isotropic antenna (idealized)
  - Radiates power equally in all directions
- Dipole antennas
  - Half-wave dipole antenna (or Hertz antenna)
  - Quarter-wave vertical antenna (or Marconi antenna)
- Parabolic Reflective Antenna

# Antenna Gain

- ## Antenna gain

  - Power output, in a particular direction, compared to that produced in any direction by a perfect omnidirectional antenna (isotropic antenna)

- ## Effective area

  - Related to physical size and shape of antenna

# Antenna Gain
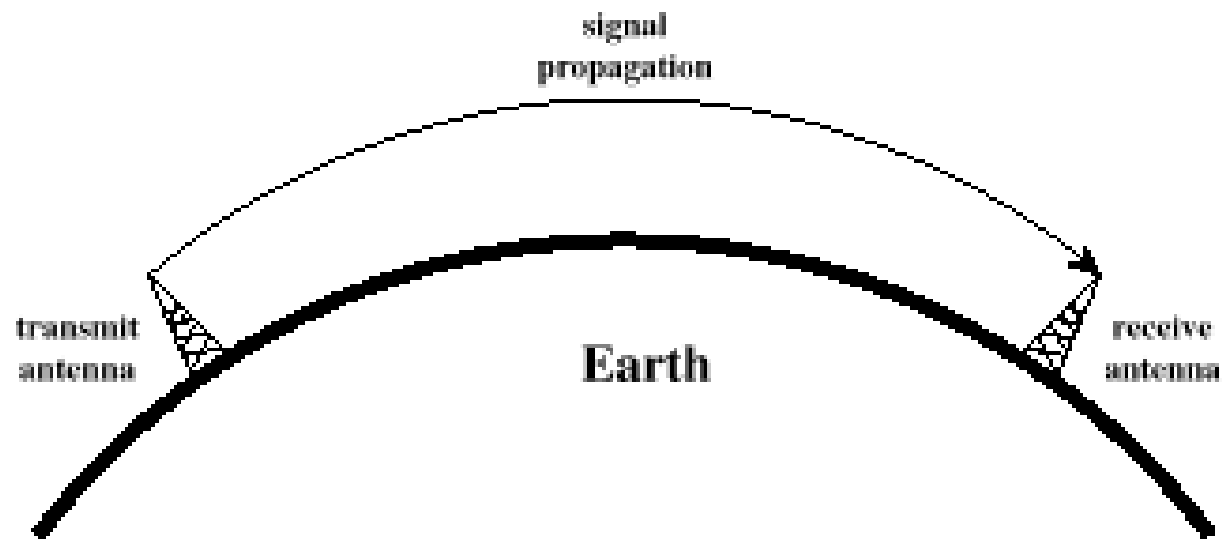
- Relationship between antenna gain and effective area

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

- $G$ = antenna gain
- $A_e$ = effective area
- $f$ = carrier frequency
- c = speed of light ($\approx 3 \times 10^8$ m/s)
- $\lambda$ = carrier wavelength

# Propagation Modes

- Ground-wave propagation
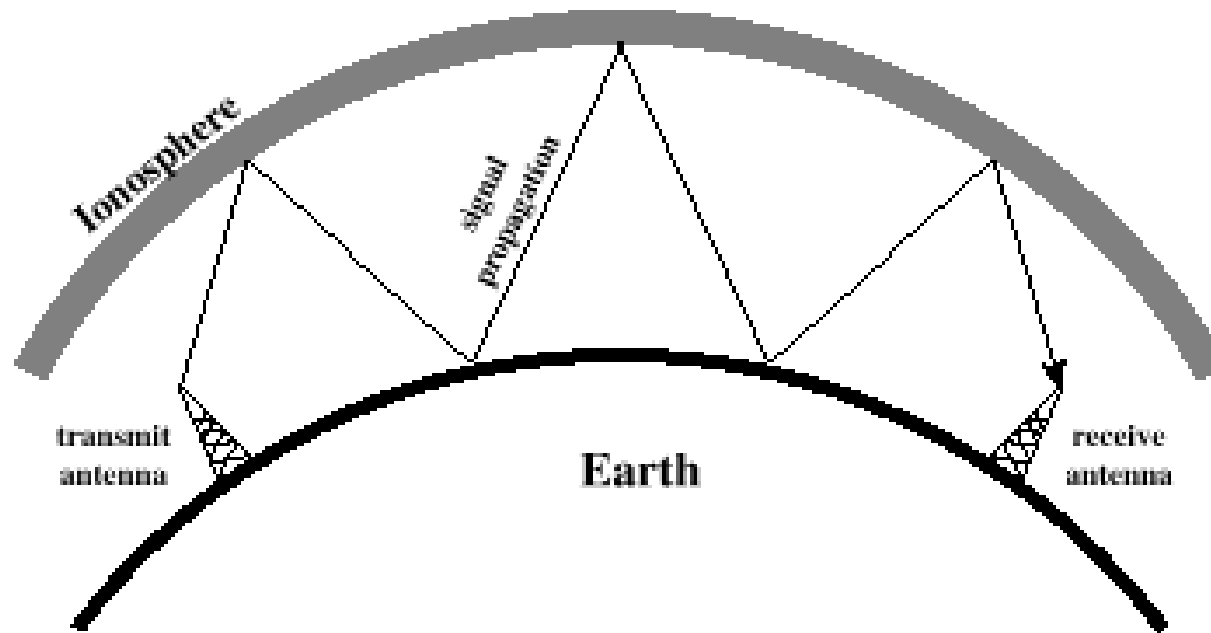- Sky-wave propagation
- Line-of-sight propagation

# Ground Wave Propagation

# Ground Wave Propagation

- Follows contour of the earth
- Can Propagate considerable distances
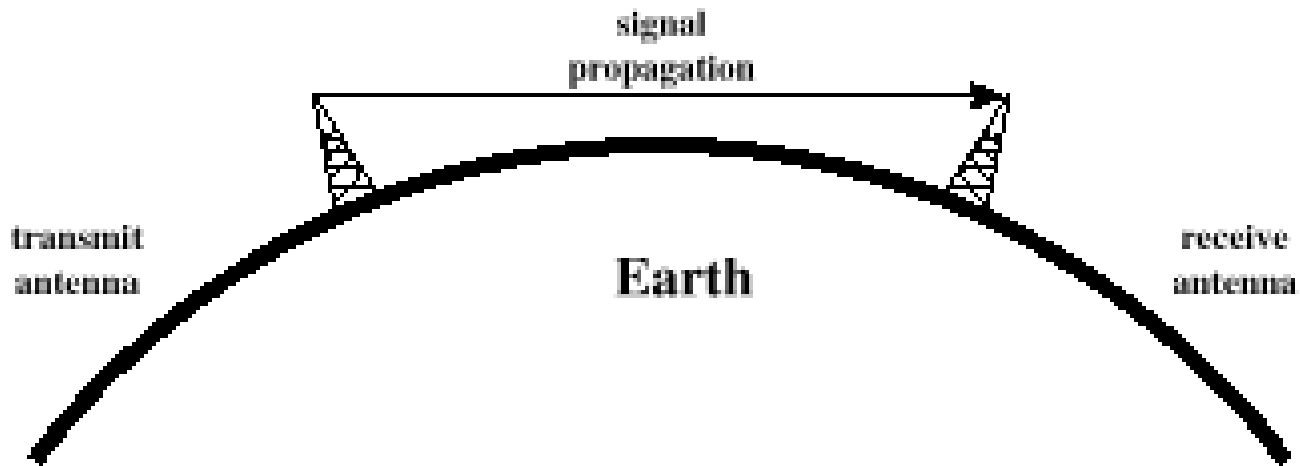- Frequencies up to 2 MHz
- Example
    - AM radio

# Sky Wave Propagation

# Sky Wave Propagation

- Signal reflected from ionized layer of atmosphere back down to earth
- Signal can travel a number of hops, back and forth between ionosphere and earth's surface
- Reflection effect caused by refraction
- Examples
  - Amateur radio
  - CB radio

# Line-of-Sight Propagation

# Line-of-Sight Propagation

- Transmitting and receiving antennas must be within line of sight
  - Satellite communication – signal above 30 MHz not reflected by ionosphere
  - Ground communication – antennas within *effective* line of site due to refraction
- Refraction – bending of microwaves by the atmosphere
  - Velocity of electromagnetic wave is a function of the density of the medium
  - When wave changes medium, speed changes
  - Wave bends at the boundary between mediums

# Line-of-Sight Equations

- Optical line of sight
$$d = 3.57\sqrt{h}$$

- Effective, or radio, line of sight
$$d = 3.57\sqrt{Kh}$$

  - $d$ = distance between antenna and horizon (km)
  - $h$ = antenna height (m)
  - K = adjustment factor to account for refraction, rule of thumb K = 4/3

# Line-of-Sight Equations

- **Maximum distance between two antennas for LOS propagation:**

$$3.57\left(\sqrt{Kh_1} + \sqrt{Kh_2}\right)$$

  - $h_1$ = height of antenna one
  - $h_2$ = height of antenna two

# LOS Wireless Transmission Impairments

- Attenuation and attenuation distortion
- Free space loss
- Noise
- Atmospheric absorption
- Multipath
- Refraction
- Thermal noise

# Attenuation

- Strength of signal falls off with distance over transmission medium
- Attenuation factors for unguided media:
  - Received signal must have sufficient strength so that circuitry in the receiver can interpret the signal
  - Signal must maintain a level sufficiently higher than noise to be received without error
  - Attenuation is greater at higher frequencies, causing distortion

# Free Space Loss

- Free space loss, ideal isotropic antenna

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

  - $P_t$ = signal power at transmitting antenna
  - $P_r$ = signal power at receiving antenna
  - $\lambda$ = carrier wavelength
  - $d$ = propagation distance between antennas
  - $c$ = speed of light ($\approx 3 \times 10\ 8$ m/s)

  where $d$ and $\lambda$ are in the same units (e.g., meters)

# Free Space Loss

- Free space loss equation can be recast:

$$L_{dB} = 10\log\frac{P_t}{P_r} = 20\log\left(\frac{4\pi d}{\lambda}\right)$$

$$= -20\log(\lambda) + 20\log(d) + 21.98\,\text{dB}$$

$$= 20\log\left(\frac{4\pi f d}{c}\right) = 20\log(f) + 20\log(d) - 147.56\,\text{dB}$$

# Free Space Loss

- Free space loss accounting for gain of other antennas

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

  - $G_t$ = gain of transmitting antenna
  - $G_r$ = gain of receiving antenna
  - $A_t$ = effective area of transmitting antenna
  - $A_r$ = effective area of receiving antenna

# Free Space Loss

- Free space loss accounting for gain of other antennas can be recast as

$$L_{dB} = 20\log(\lambda) + 20\log(d) - 10\log(A_t A_r)$$

$$= -20\log(f) + 20\log(d) - 10\log(A_t A_r) + 169.54\text{dB}$$

# Categories of Noise

- Thermal Noise
- Intermodulation noise
- Crosstalk
- Impulse Noise

# Thermal Noise

- Thermal noise due to agitation of electrons
- Present in all electronic devices and transmission media
- Cannot be eliminated
- Function of temperature
- Particularly significant for satellite communication

# Thermal Noise

- Amount of thermal noise to be found in a bandwidth of 1Hz in any device or conductor is:

$$N_0 = \mathrm{k}T \left( \mathrm{W/Hz} \right)$$

- $N_0$ = noise power density in watts per 1 Hz of bandwidth
- k = Boltzmann's constant = $1.3803 \times 10^{-23}$ J/K
- $T$ = temperature, in kelvins (absolute temperature)

# Thermal Noise

- Noise is assumed to be independent of frequency

- Thermal noise present in a bandwidth of $B$ Hertz (in watts):

$$N = \mathrm{k}TB$$

or, in decibel-watts

$$N = 10\log \mathrm{k} + 10\log T + 10\log B$$

$$= -228.6\,\mathrm{dBW} + 10\log T + 10\log B$$

# Noise Terminology

- Intermodulation noise – occurs if signals with different frequencies share the same medium
  - Interference caused by a signal produced at a frequency that is the sum or difference of original frequencies
- Crosstalk – unwanted coupling between signal paths
- Impulse noise – irregular pulses or noise spikes
  - Short duration and of relatively high amplitude
  - Caused by external electromagnetic disturbances, or faults and flaws in the communications system

# Expression $E_b/N_0$

- Ratio of signal energy per bit to noise power density per Hertz

$$\frac{E_b}{N_0} = \frac{S/R}{N_0} = \frac{S}{\text{k}TR}$$

- The bit error rate for digital data is a function of $E_b/N_0$
  - Given a value for $E_b/N_0$ to achieve a desired error rate, parameters of this formula can be selected
  - As bit rate $R$ increases, transmitted signal power must increase to maintain required $E_b/N_0$

# Other Impairments

- Atmospheric absorption – water vapor and oxygen contribute to attenuation

- Multipath – obstacles reflect signals so that multiple copies with varying delays are received

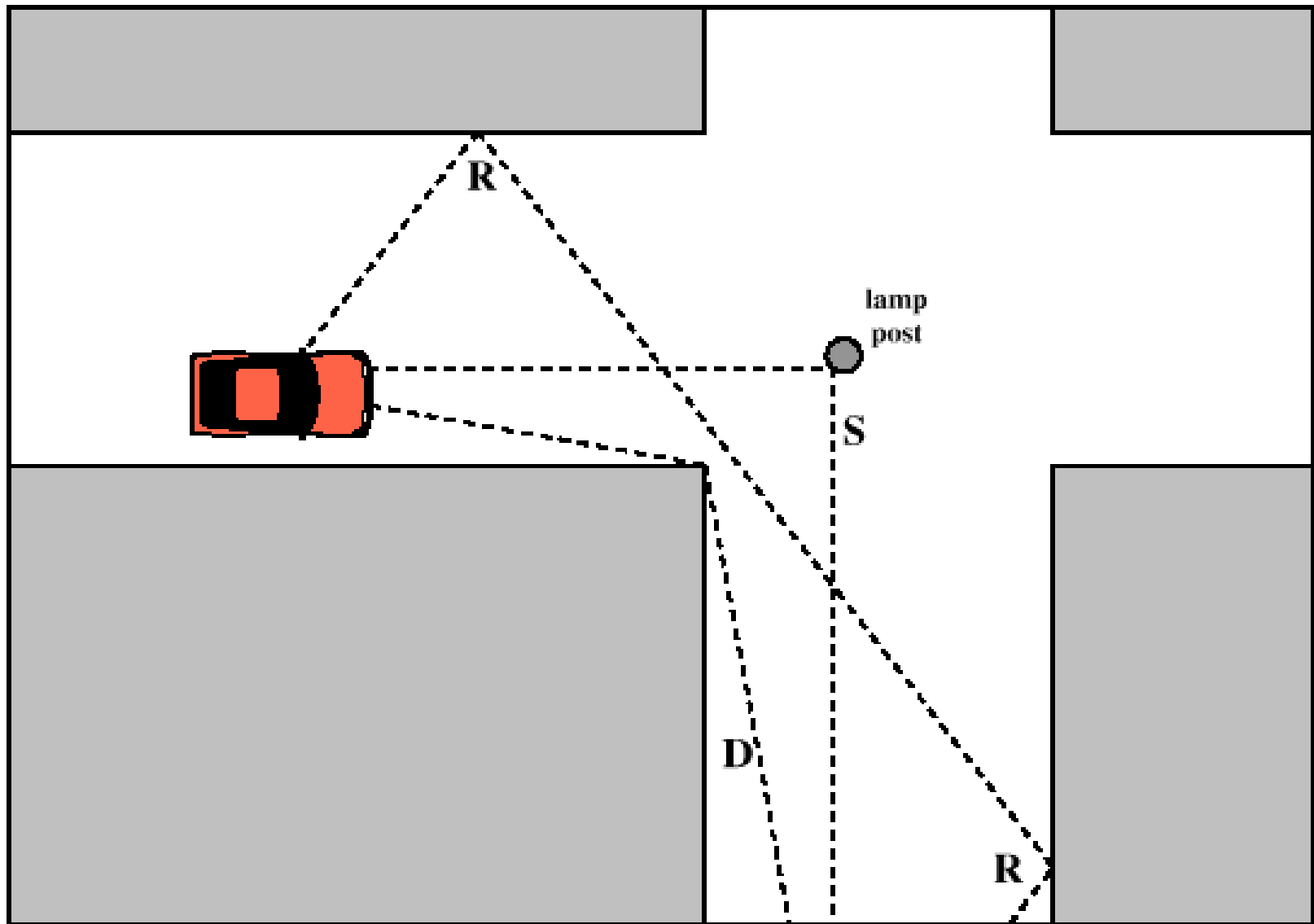- Refraction – bending of radio waves as they propagate through the atmosphere

**Figure 5.10 Sketch of Three Important Propagation Mechanisms: Reflection (R), Scattering (S), Diffraction (D) [ANDE95]**

# Multipath Propagation

- Reflection - occurs when signal encounters a surface that is large relative to the wavelength of the signal

- Diffraction - occurs at the edge of an impenetrable body that is large compared to wavelength of radio wave

- Scattering – occurs when incoming signal hits an object whose size in the order of the wavelength of the signal or less

# The Effects of Multipath Propagation

- Multiple copies of a signal may arrive at different phases
  - If phases add destructively, the signal level relative to noise declines, making detection more difficult
- Intersymbol interference (ISI)
  - One or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit

# Types of Fading

- Fast fading
- Slow fading
- Flat fading
- Selective fading
- Rayleigh fading
- Rician fading

# Error Compensation Mechanisms

- Forward error correction
- Adaptive equalization
- Diversity techniques

# Forward Error Correction

- Transmitter adds error-correcting code to data block
    - Code is a function of the data bits
- Receiver calculates error-correcting code from incoming data bits
    - If calculated code matches incoming code, no error occurred
    - If error-correcting codes don't match, receiver attempts to determine bits in error and correct

# Adaptive Equalization

- Can be applied to transmissions that carry analog or digital information
  - Analog voice or video
  - Digital data, digitized voice or video
- Used to combat intersymbol interference
- Involves gathering dispersed symbol energy back into its original time interval
- Techniques
  - Lumped analog circuits
  - Sophisticated digital signal processing algorithms

# Diversity Techniques

- Diversity is based on the fact that individual channels experience independent fading events

- Space diversity – techniques involving physical transmission path

- Frequency diversity – techniques where the signal is spread out over a larger frequency bandwidth or carried on multiple frequency carriers

- Time diversity – techniques aimed at spreading the data out over time