Antennas and Propagation

Stallings "Wireless…", Chapter 5

Fundamental background for wireless transmission
- Antennas
- Propagation/transmission
- Fading

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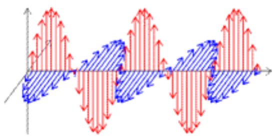
Introduction

- 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

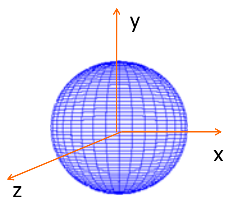
Electromagnetic propagation

- 1 - An alternating current generates an alternating magnetic field around itself.
- 2 – An alternating magnetic field generates an alternating electric field around itself.
- 3 - An alternating electric field generates an alternating magnetic field around itself and so on ...



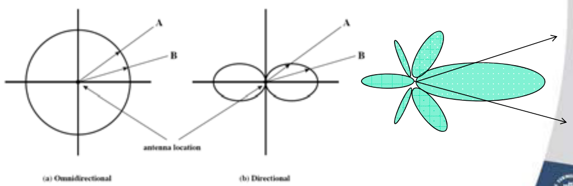
Types of Antennas

- Isotropic antenna (idealized)
  - Radiates power equally in all directions
  - Used as a reference antenna



Radiation Patterns

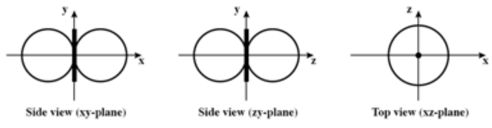
- **Radiation pattern**: Graphical representation of radiation properties, depicted as two-dimensional cross section
- **Beam width**: Measure of directivity of antenna
- **Reception pattern**: Receiving antenna's equivalent to radiation pattern



Types of Antennas

- Omni-directional antenna
  - Dipole antennas
    - Half-wave dipole antenna (or Hertz antenna)

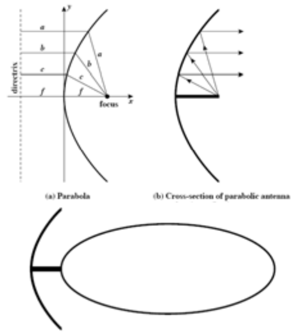
Radiation Pattern View



Side view (xy-plane) Side view (zy-plane) Top view (xz-plane)

(a) Simple dipole

Parabolic Antenna

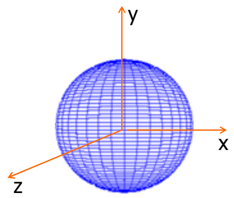


Types of Antennas

- Directional antenna
  - Yagi-Uda antenna
  - Parabolic Dish Antenna

Isotropic Antenna

- Virtual and Ideal
  - Equal radiation in all directions
  - Used as a reference antenna



Antenna Gain

- Antenna gain, G: Power output, in a particular direction, compared to that produced in any direction by a perfect isotropic antenna.

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

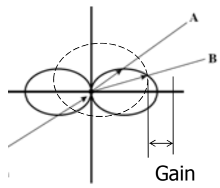
  - G = antenna gain, A_e = effective area, f = carrier frequency
  - c = speed of light (appro. 3 x 10^8 m/s), λ = carrier wavelength
- Antenna Gain is very often given in decibel

$$G_{dB} = 10 \cdot \log_{10}(G) \quad [\text{dBi}]$$

Effective Area (A_e)

- Difficult to calculate analytically.

Type of Antenna	Effective Area A_e (m^2)	Power Gain (relative to isotropic)
Isotropic	$\lambda^2/4\pi$	1
Infinitesimal dipole or loop	$1.5\ \lambda^2/4\pi$	1.5
Half-wave dipole	$1.64\ \lambda^2/4\pi$	1.64
Horn, mouth area A	0.81 A	10 A/λ^2
Parabolic, face area A	0.56 A	7 A/λ^2

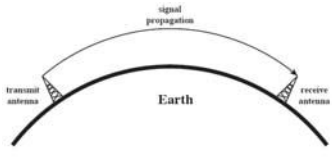


Propagation Characteristics

- Ground-wave propagation
- Sky-wave propagation
- Line-of-sight (LOS) propagation

Ground Wave Propagation

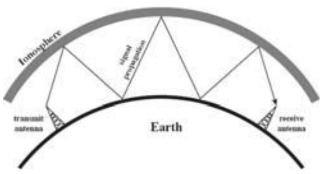
- Follows contour of the earth
- Can Propagate considerable distances
- Frequencies up to 2 MHz (λ ~ 1.5 km)
- Example: AM radio



(a) Ground-wave propagation (below 2 MHz)

Sky Wave Propagation

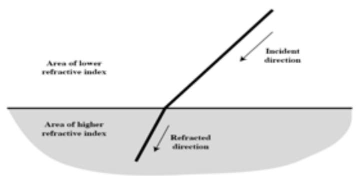
- Signal “reflected” from ionized layer of atmosphere
- Signal can travel a number of hops
- Reflection effect caused by refraction
- Frequencies: 2 MHz – 30 MHz (λ ~ 100 m)
- Examples
  - Amateur radio
  - Short-wave radio



(b) Sky-wave propagation (2 to 30 MHz)

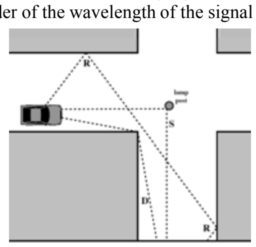
Refraction of an Electromagnetic Wave

- Refraction – bending of radio waves as they propagate from one medium to another.
- Under normal propagation, the refraction index of the atmosphere decreases with height so that radio waves travel more slowly near the ground than higher altitudes, which result bending towards the earth.



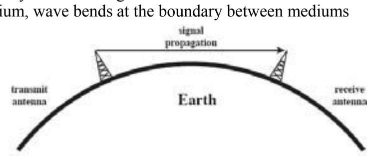
Propagation Effects

- ***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



Line-of-Sight Propagation

- Transmitting and receiving antennas within line of sight
  - Satellite communication – frequency above 30 MHz (λ<100m) is not reflected by ionosphere
  - Ground communication – antennas within *effective* line of sight
  - Refraction – bending of microwaves by the atmosphere
    - Velocity of electromagnetic wave is a function of the density of the medium, wave bends at the boundary between mediums



(c) Line-of-sight (LOS) propagation (above 30 MHz)

Line-of-Sight Equations

- **Optical** line of sight

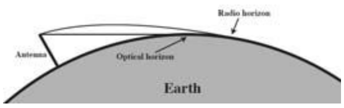
$$d = 3.57\sqrt{h}$$

(what is the line of sight for a 180 cm person?)

- Effective, or radio, line of sight

$$d = 3.57\sqrt{\mathrm{K}h}$$

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

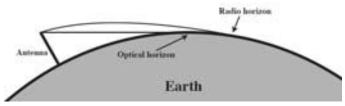


Line-of-Sight Equations

- Maximum distance between two antennas for LOS propagation:

$$3.57\left(\sqrt{\mathrm{K}h_1} + \sqrt{\mathrm{K}h_2}\right)$$

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



LOS Wireless Transmission Impairments

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

Attenuation

- Strength of signal falls off with distance over transmission medium
- Attenuation for unguided media more complex than number of dB per km
- Amplifiers and repeaters deals with signal level
- Attenuation is greater at higher frequencies, causing signal distortion

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 (transmitter, channel, repeaters, receiver)
- Particularly significant for satellite communication
- Amount:

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

  - N_0 = noise power density in watts per 1 Hz of bandwidth
  - k = Boltzmann's constant = $1.3803 \cdot 10^{-23}$ 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):

$$N = kTB$$

or, in decibel-watts

$$N = 10\log_{10} k + 10\log_{10} T + 10\log_{10} B$$
$$= -228.6 \text{ dBW} + 10\log_{10} T + 10\log_{10} B$$

Other Noise Than Thermal

- Intermodulation noise – occurs if medium has nonlinearities
  - Interference caused by signals produced at frequencies 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

The Expression E_b/N_0

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

$$\frac{E_b}{N_0} = \frac{S * T_b}{N_0} = \frac{S / R_b}{k * T} = \frac{S}{K * T * R_b}$$

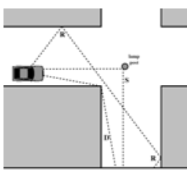
- The bit error rate (BER)for digital data is a function of E_b/N_0
- As bit rate R_b increases, transmitted signal power must increase to maintain required E_b/N_0

Other Impairments

- **Atmospheric absorption** – water vapor and oxygen contribute to attenuation, peaks at 22 and 60 GHz respectively
- **Multipath** – obstacles reflect signals so that multiple copies with varying delays are received
- **Refraction** – bending of radio waves as they propagate through the atmosphere

Multipath Propagation

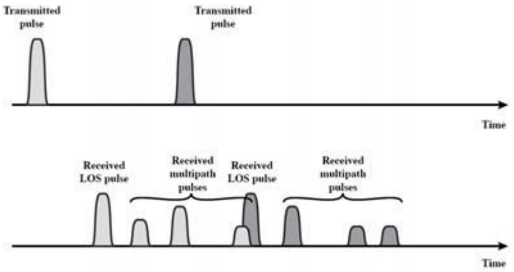
- **Reflection** - occurs when signal encounters a surface that is large relative to the wavelength of the signal
- **Diffraction** - occurs at the edge of an impenetrable body that is large compared to wavelength of radio wave
- **Scattering** – occurs when incoming signal hits an object whose size 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
  - If phases add constructively, the signal level is increased
- **Inter-symbol interference** (ISI)
  - One or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit
- Gives **fading** - time variations in the received signal power

The Effects of Multipath Propagation



Error Compensation Mechanisms

- Forward error correction, FEC
- Adaptive equalization
- Diversity techniques

Forward Error Correction

- Transmitter adds error-correcting code to data block
- Receiver checks incoming data bits, if error is detected the receiver corrects if possible
- Typical 2 to 3 times more data bits

Adaptive Equalization

- Can be applied to transmissions that carry analog or digital information
- Combats inter-symbol interference
- Involves gathering dispersed symbol energy back into its original time interval
- Performed by an adaptive FIR filter trying to make the inverse of the transmission channel
- Training sequences may be needed

Diversity Techniques

- Diversity is based on the assumption that individual channels experience independent fading events
- **Space diversity** (Antenna diversity)- techniques involving physical transmission.
- **Frequency diversity** – techniques where the signal is spread out over a larger frequency bandwidth or carried on multiple frequency carriers (e.g. CDMA system)
- **Time diversity** – techniques aimed at spreading the data out over time (e.g. TDMA system)

Questions and problems, WS chapter 5

- Recommended questions in ch. 5:
  - 1-12 (all)
- Recommended problems in ch 5:
  - (1), 2, (3), 5, 7, (9), 10, (11), (12), 13, 15
  - The problems without brackets are more recommended than the other