# 18-452/18-750
# Wireless Networks and Applications
## Lecture 4: Physical Layer - Channel Capacity and Antennas

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**http://www.cs.cmu.edu/~prs/wirelessF18/**



## Outline

- RF introduction
- Modulation and multiplexing
- Channel capacity
- Antennas and signal propagation
  - » How do antennas work
  - » Propagation properties of RF signals
  - » Modeling the channel
- Equalization and diversity
- Modulation and coding
- Spectrum access



## What is an Antenna?

- Conductor that carries an electrical signal and radiates an RF signal.
  - » The RF signal "is a copy of" the electrical signal in the conductor
- Also the inverse process: RF signals are "captured" by the antenna and create an electrical signal in the conductor.
  - » This signal can be interpreted (i.e. decoded)
- Efficiency of the antenna depends on its size, relative to the wavelength of the signal.
  - » E.g. quarter of a wavelength

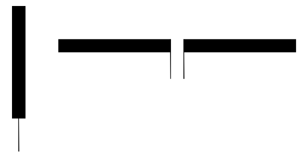


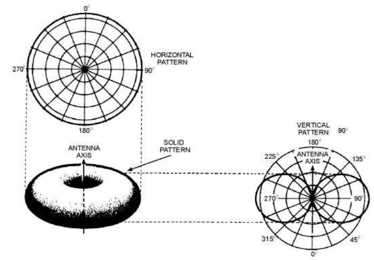
## Types of Antennas

- Abstract view: antenna is a point source that radiates with the same power level in all directions – omni-directional or isotropic.
  - » Not common – shape of the conductor tends to create a specific radiation pattern
  - » Note that isotropic antennas are not very efficient!!
    - – Unless you have a very large number of receivers
- Common shape is a straight conductor.
  - » Creates a "disk" pattern, e.g. dipole
- Shaped antennas can be used to direct the energy in a certain direction.
  - » Well-known case: a parabolic antenna
  - » Pringles boxes are cheaper

# Antenna Types: Dipoles

- Simplest: half-wave dipole and quarter wave vertical antennas
  - » Very simple and very common
  - » Elements are quarter wavelength of frequency that is transmitted most efficiently
  - » Donut shape
- May other designs

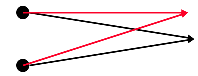


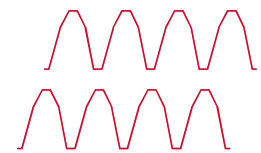





# Multi-element Antennas

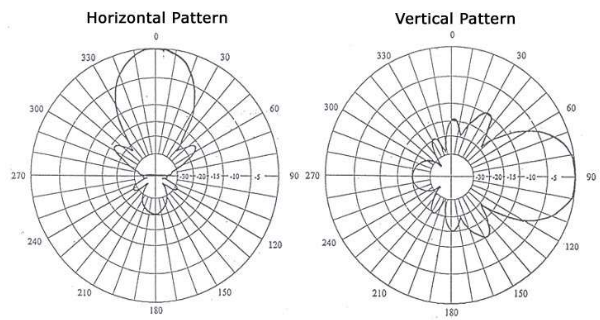
- Multi-element antennas have multiple, independently controlled conductors.
  - » Signal is the sum of the individual signals transmitted (or received) by each element
- Can electronically direct the RF signal by sending different versions of the signal to each element.
  - » For example, change the phase in two-element array.
- Covers a lot of different types of antennas.
  - » Number of elements, relative position of the elements, control over the signals, …







# Directional Antenna Properties




- dBi: antenna gain in dB relative to an isotropic antenna with the same power.
  - » Example: an 8 dBi Yagi antenna has a gain of a factor of 6.3 (8 db = 10 log 6.3)



# Examples 2.4 GHz

## Summary

- The maximum capacity of a channel depends on the SINR
  - » How close you get to this maximum depends on the sophistication of the radios
  - » Distortion of the signal also plays a role – next lecture
- Antennas are responsible for transmitting and receiving the EM signals
  - » The “ideal” isotropic antenna is a point source that radiates energy in a sphere
  - » Practical antennas are directional in nature, as a result of the antenna shape or the use of multi-element antennas
  - » The antenna gain is expressed in dBi



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- Modulation
- Diversity and coding
- OFDM

Bad News Good News Story



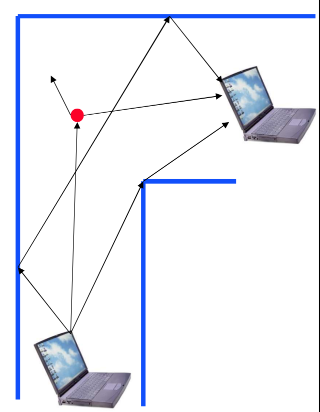
## Propagation Modes

- Line-of-sight (LOS) propagation.
  - » Most common form of propagation
  - » Happens above ~ 30 MHz
  - » Subject to many forms of degradation (next set of slides)
- Obstacles can redirect the signal and create multiple copies that all reach the receiver
  - » Creates multi-path effects
- Refraction changes direction of the signal due to changes in density
  - » E.g., changes in air temperature, humidity, …
  - » If the change in density is gradual, the signal bends!



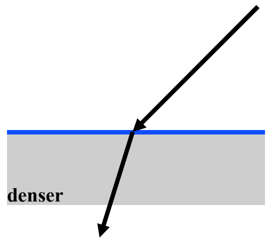
## Impact of Obstacles

- Besides line of sight, signal can reach receiver in three “indirect” ways.
- Reflection: signal is reflected from a large object.
- Diffraction: signal is scattered by the edge of a large object – “bends”.
- Scattering: signal is scattered by an object that is small relative to the wavelength.



## Refraction

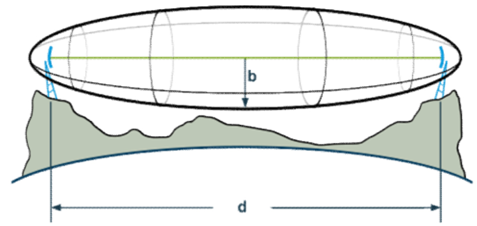
- Speed of EM signals depends on the density of the material
  - » Vacuum: $3 \times 10^8$ m/sec
  - » Denser: slower
- Density is captured by refractive index
- Explains "bending" of signals in some environments
  - » E.g. sky wave propagation: Signal "bounces" off the ionosphere back to earth – can go very long distances
  - » But also local, small scale differences in the air density, temperature, etc.






## Fresnel Zones

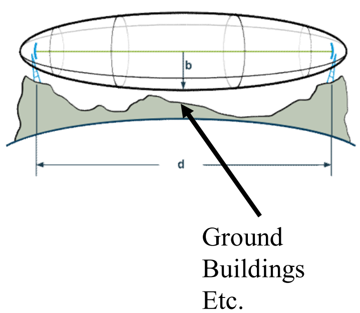
- Sequence of ellipsoids centered around the LOS path between a transmitter and receiver
- The zones identify areas in which obstacles will have different impact on the signal propagation
  - » Capture the constructive and destructive interference due to multipath caused by obstacles





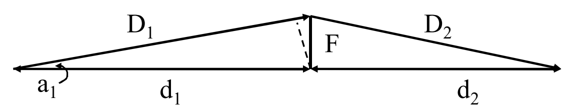

## Fresnel Zones

- Zones create different phase differences between paths
  - » First zone: 0-90
  - » Second zone: 90-270
  - » Third zone: 270-450
  - » Etc.
- Odd zones create constructive interference, even zones destructive
- Also want clear path in most of the first Fresnel zone, e.g. 60%
- The radius $F_n$ of the nth Fresnel zone depends on the distances $d_1$ and $d_2$ to the transmitter and receiver and the wavelength



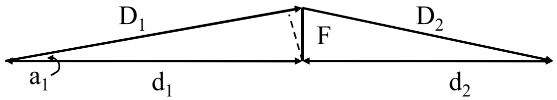



## Sketch of Calculation: Difference in Path Length




- Difference in path length ($a_1$ is small)
  - » $D_1 - d_1 \approx F * \sin a_1$
- But for small $a_1$ we also have
  - » $\sin a_1 = \tan a_1 = F / d_1$
- So $D_1 - d_1 = F^2 / d_1$

# Sketch of Calculation Fresnel Radios




- Given $D_1 - d_1 = F^2 / d_1$
- and $(D_1 + D_2) - (d_1 + d_1) = \lambda * n$
- $(D_1 - d_1) + (D_2 - d_2) = F^2 / d_1 + F^2 / d_2$
- or

$$F_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}$$