Guide to Wireless Communications, Third Edition

Chapter 4

How Antennas Work

Objectives

- Define decibels, gain, and loss
- Explain the purpose of an antenna
- List the different antenna types, shapes and sizes as well as their applications
- Explain RF signal strength and direction
- Describe how antennas work

Gain and Loss

- Understanding RF signal transmission involves:
  - The strength or the power with which the transmitter is sending the signal
  - The amount of reduction in signal strength caused by cables, connectors, and other components
  - The transmission medium (atmosphere or free-space)
  - The minimum strength of the signal required by the receiver to be able to properly recover the data sent by the transmitter

Gain and Loss

- Amplifier boosts the power of a signal
  - The effect is called a gain
- Cables and connectors offer a resistance to the flow of electricity
  - They tend to decrease the power of a signal (loss)
- Signal power changes logarithmically
  - Not in a linear fashion
- Gain and loss are relative concepts
  - Need to know the power level of the signal at two different points

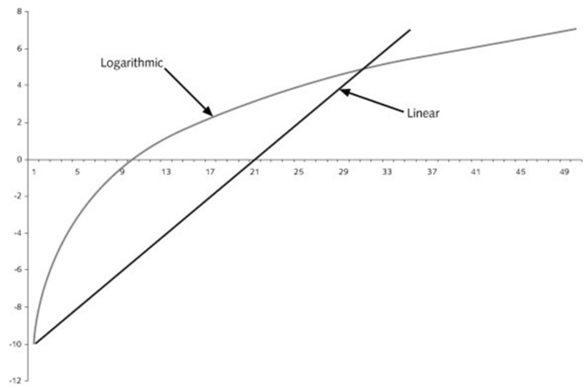


Figure 4-1 Linear vs. logarithmic

Decibel

- Decibel (dB)
  - Ratio between two signal levels
  - Makes it much simpler to express and calculate power gain or loss
- *Tens and threes of RF mathematics*
  - A gain of 3 dB (+3 dB) means the signal is two times bigger (twice the power)
  - A gain of 10 dB (+10 dB) means the signal is 10 times bigger (10 times the power)
  - The same applies for loss

Decibel

- dBm
  - Relative way to indicate an absolute power level in the linear Watt scale
  - 1 mW = 0 dBm
- Isotropic radiator
  - Theoretically perfect sphere that radiates energy equally in all directions
  - Provides a reference point for representing the gain of an antenna
    - Usually expressed in dB isotropic (dBi)

Decibel

- For microwave and higher frequency antennas
  - Gain is usually expressed in dB dipole (dBd)
- Dipole
  - The smallest, simplest, most practical type of antenna that can be made
    - But that also exhibits the least amount of gain
  - Has a fixed gain over that of an isotropic radiator of 2.15 dB

Nomenclature	Description	Refers To:
dBm	dB milliwatts	0 dB = 1 mW of power
dBd	dB dipole	The gain an antenna has over a dipole antenna at the same frequency
dBi	dB isotropic	The gain an antenna has over a theoretical isotropic (point source) radiator

Table 4-1 Decibel values and references

Antenna Characteristics

- Characteristics of antennas
  - Types, sizes, and shapes

Antenna Types

- Passive antennas
  - The most common type
  - Constructed of a piece of metal, wire, or similar conductive material
  - Does not amplify the signal in any way
  - Directional gain
    - Passive antennas radiate the RF energy supplied by the transmitter in one direction
    - Exhibits an effective gain that is similar to amplification of the signal

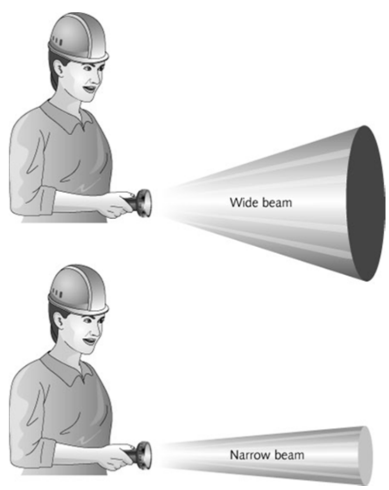


Figure 4-2 Directional gain

Antenna Types

- Active antennas
  - Passive antennas with an amplifier built-in
  - Amplifier is connected directly to the piece of metal that forms the antenna itself
  - Most active antennas have only one electrical connection
    - RF signal and the power for the amplifier are supplied on the same conductor

Antenna Sizes and Shapes

- Size and shape of an antenna depend on:
  - Frequency on which the antenna will transmit and receive
  - Direction of the radiated electromagnetic wave
  - Power with which the antenna must transmit
- The size of an antenna is:
  - Directly proportional to the wavelength of the carrier
  - Inversely proportional to the frequency of the carrier

Antenna Sizes and Shapes

- Omnidirectional antennas
  - Used to transmit and receive signals from all directions with relatively equal intensity
  - Longer omnidirectional antennas usually have a higher gain
- Directional antennas
  - Transmit a signal in one direction only
  - Yagi antenna emits a wider, less focused RF beam
  - Parabolic dish antenna emits a narrow, more concentrated beam of RF energy

Figure 4-4 High-gain omnidirectional antenna

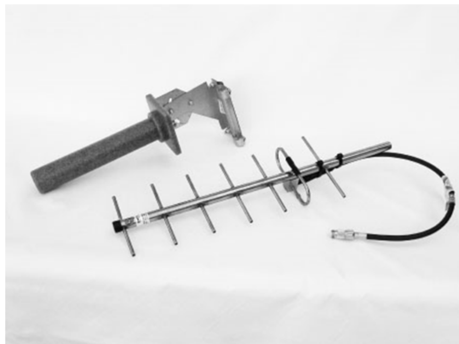


Figure 4-5 Yagi antennas

Antenna Sizes and Shapes

- Patch antennas
  - Emit an RF energy beam that is horizontally wide but vertically taller than that of a yagi antenna
  - Considered a semi-directional antenna
  - Often used to send RF energy down a long corridor
  - Some are designed for installation on building walls
    - To send an RF signal in one direction away from the structure
  - One common application for patch antennas is in cellular telephony

Figure 4-7 Cellular antenna with cutout to show internal construction

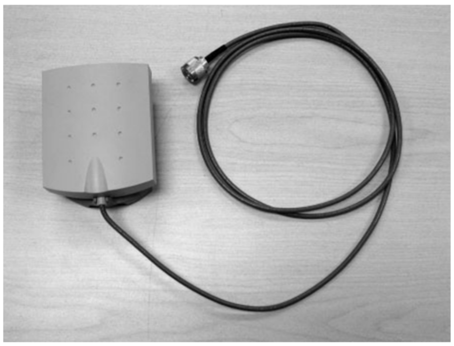


Figure 4-8 Indoor patch antenna

Signal Strength and Direction

- Distance between the transmitter and receiver
  - Determines the strength of the signal
- Transmitters produce a finite amount of RF energy
  - For most applications, active antennas can be extremely expensive
- Omnidirectional antenna divides strength of signal in a 360-degree circle around the antenna
- Free space loss
  - RF waves tend to spread away from the source of the signal (the antenna)
  - Free space loss calculator tools can be found on Internet

How Antennas Work

- Understanding antennas requires in-depth knowledge of physics, mathematics, and electronics
- General coverage of basic antenna functionality is covered in this text

Wavelength

- Wavelength: length of a single RF sine wave
  - Determines the size of an antenna
- Full-wave antenna
  - Antenna transmits and receives a signal most efficiently at a specific frequency
    - When it is as long as the full length of the wave
  - In most cases, this is not practical
- For practical reasons, antennas are more commonly:
  - Half-wave antennas, quarter-wave antennas, or eighth-wave antennas

Antenna Performance

- Antenna performance
  - A measure of how efficiently an antenna can radiate an RF signal
- Design, installation, size, and type of antenna can affect its performance

Radiation Patterns

- Antenna pattern
  - Graphic developed by measuring the signal radiating from the antenna
  - Indicates the direction, width, and shape of the RF signal beam coming from the antenna
- Antennas emit signals in two dimensions
  - Horizontally and vertically
- Antenna specifications almost always include the vertical beam angle that a particular antenna emits

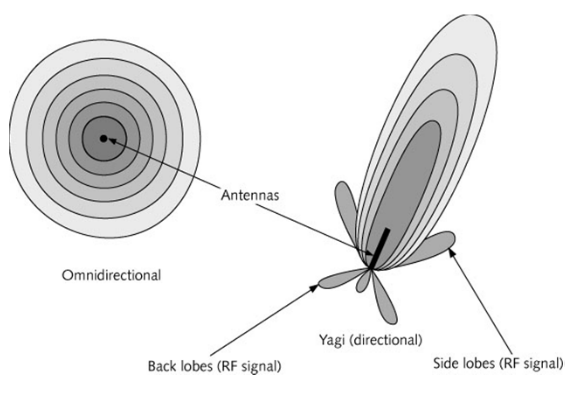


Figure 4-9 Antenna patterns viewed from above

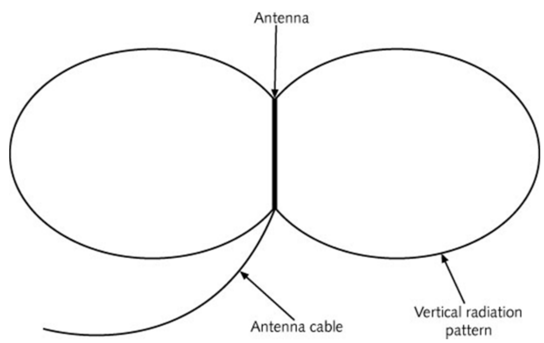


Figure 4-10 Vertical antenna pattern (side view of omnidirectional antenna pattern)

Antenna Polarization

- Antenna polarization: orientation of the wave leaving the antenna
- Vertical polarization
  - Sine waves travel up and down when leaving antenna
- Horizontal polarization
  - Sine waves travel from side to side on a horizontal plane
- Most efficient signal transmission and reception is experienced when both antennas are equally polarized

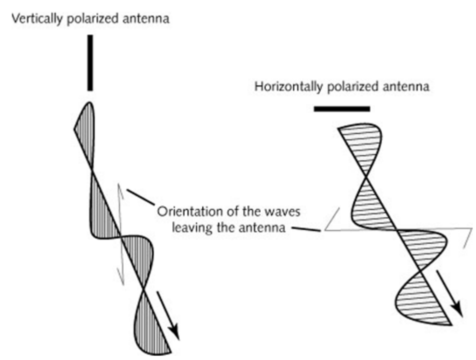


Figure 4-11 Antenna polarization

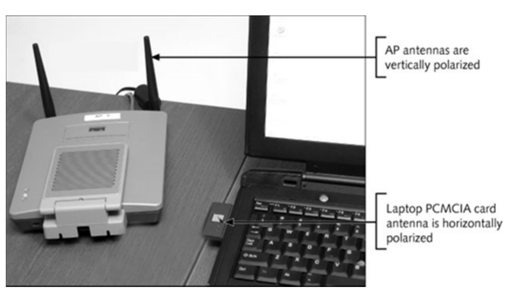


Figure 4-12 Mixed vertical and horizontal antenna polarizations

Antenna Dimensions

- One-dimensional antennas
  - Basically a length of wire or metal
  - Monopole antenna
    - Straight piece of wire or metal, usually a quarter of the wavelength, with no reflecting or ground element
  - Dipoles are commonly built as two monopoles
    - Mounted together at the base
  - A monopole antenna is less efficient than a dipole
  - Ground-plane
    - Large metal base
    - Simulates the signal-reflecting effect of the ground

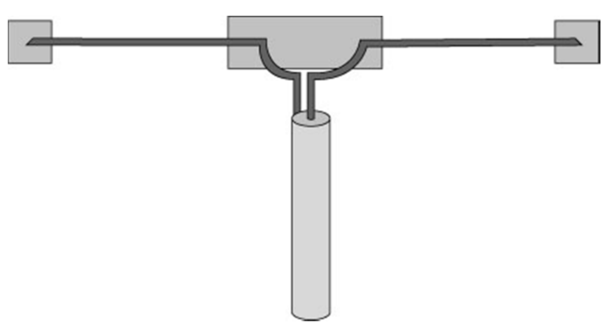


Figure 4-13 Common dipole antenna

Antenna Dimensions

- Two-dimensional antennas
  - Antennas organized in a two-dimensional pattern
  - Examples: patch and satellite dish antennas
  - Horn antenna
    - Another type of two-dimensional directional antenna
    - Resembles a large horn with wide end bent to one side
    - Common in telephone networks
    - Used to transmit microwave signals between two distant towers

Figure 4-14 Telephone transmission tower showing two horn antennas

Smart Antennas

- Used primarily in mobile or cellular telephony
- “Learn” where the mobile receiver is
  - Can track and focus RF energy in specific direction
- Classes of smart antennas
  - A switched beam antenna
    - Uses several narrow beam antennas pointing in different directions
  - Adaptive or phased array antennas
    - Divided into a matrix of radiating elements
    - Has the effect of sending the energy beam in a particular direction (generally called “beam forming”)

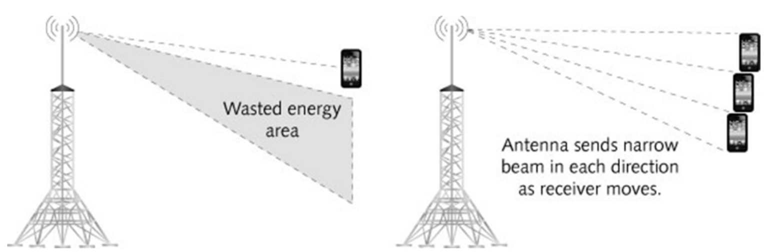
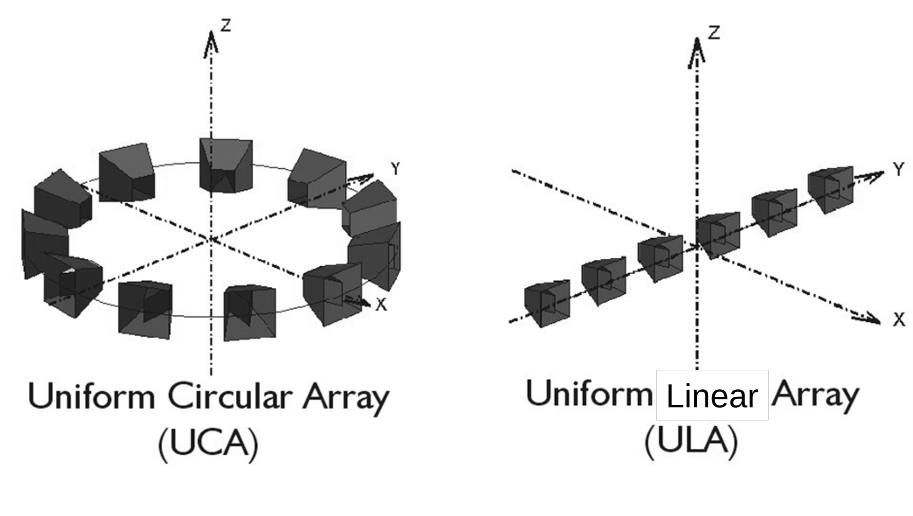
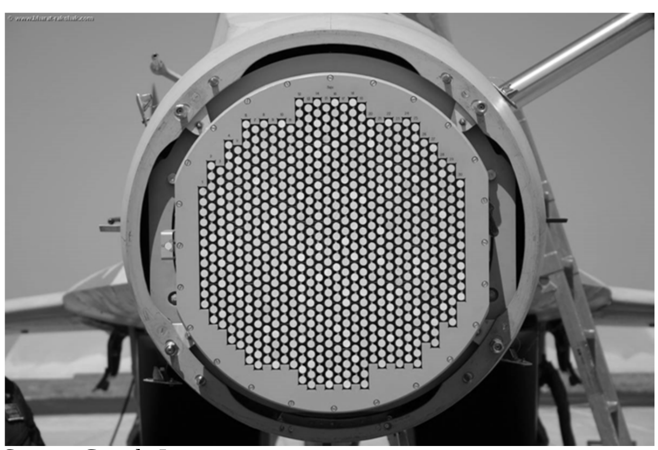


Figure 4-15 Directional antenna vs. smart antenna



Smart Array Antennas

MIG-35 Nose Radar (PA)



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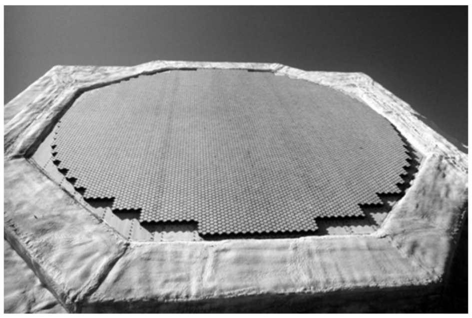
Large Phased-Array Radar Antenna



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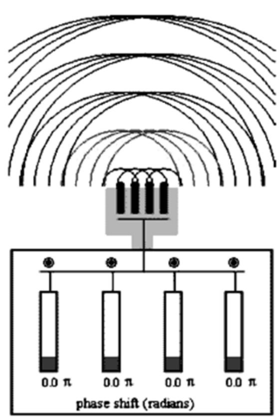
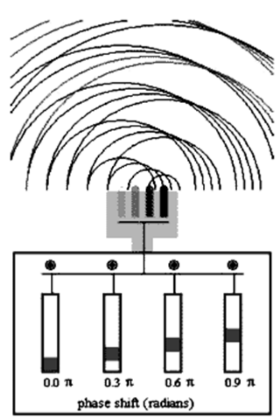
Phased-Array Antennas





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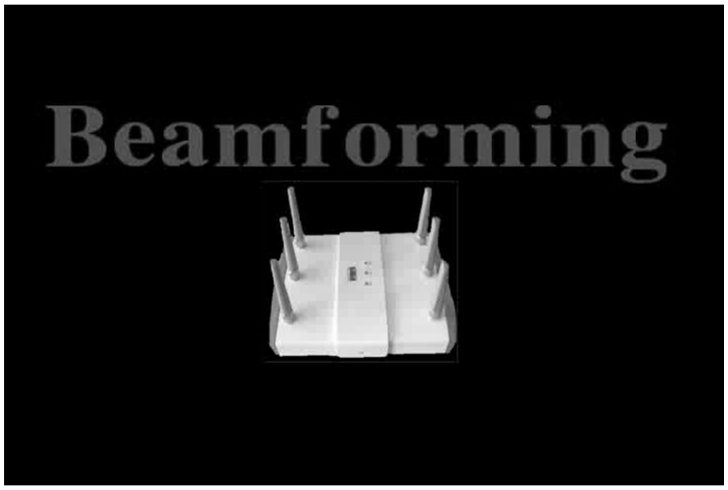
MIMO Beam Forming



Antenna System Implementation

- Proper installation of antennas requires knowing the user's requirements
- Challenges
  - – Physical obstacles
  - – Municipal building codes
  - – Other regulatory restrictions

Antenna Cables

- Most antennas are connected to the transmitter or receiver using coaxial cable
- Impedance
  - Opposition to the flow of alternating current in a circuit
  - Represented by the letter "Z" and measured in ohms
  - Combination of resistance, inductance, and capacitance of the circuit
  - Cable's impedance must match that of the transmitter circuit as well as that of the antenna
- You must consider the signal loss caused by the connector and by the cable itself

Antenna Cables

- Cable loss is measured in relation to the length of the cable
- You can use special low-loss antenna cables to minimize signal loss

Part Number	Diameter	Loss at 2.4 GHz (per 100 ft.)
LMR-100	$^{1}/_{10}$"	−38.9 dB
LMR-240	$^{3}/_{16}$"	−12.7 dB
LMR-400	$^{3}/_{8}$"	−6.6 dB
LMR-600	$^{1}/_{2}$"	−4.4 dB

Table 4-2 Low-loss LMR cables

RF Propagation

- The way that radio waves propagate depends on the frequency of the signal
- RF waves are classified in three groups:
  – Ground waves follow the curvature of the earth
  – Sky waves bounce between the ionosphere and the surface of the earth
  – Line-of-sight used by RF waves transmitted in frequencies between 30 MHz and 300 GHz
    - Require a line-of-sight path between the transmitter and the receiver antennas

Group	Frequency Range
Ground waves	3 KHz to 2 MHz
Sky waves	2 MHz to 30 MHz
Line-of-sight waves	30 MHz to 300 GHz

Table 4-3 RF wave propagation groups

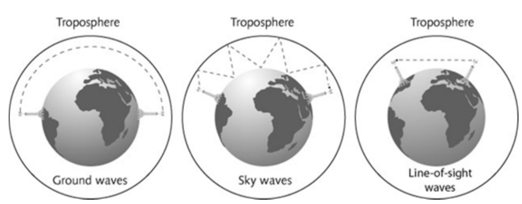


Figure 4-18 How radio waves propagate

Point-to-Multipoint Links

- Point-to-multipoint wireless link
  - One transmitter communicates with several mobile clients
- Maximize the signal distance by using an omnidirectional antenna at the central location
  - Use directional, higher-gain antennas at the remote locations

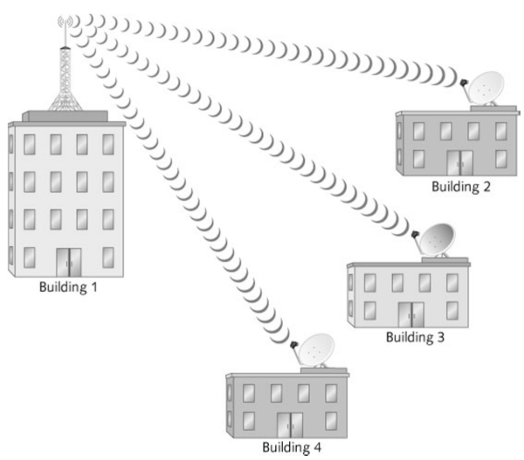


Figure 4-19 Point-to-multipoint links using a combination of omnidirectional and directional antennas

Point-to-Point Links

- Point-to-point wireless link
  - Connects two computer networks in different buildings
- Directional antennas provide the most reliable method of transmitting RF waves
  - Narrow beams and high gain ensure that most of the energy of the RF wave will be used
- Telephone companies make extensive use of point-to-point microwave links (instead of cables)
  - For long-distance voice and data communications
  - Cost of maintaining a wireless link is lower than installing and maintaining cables

Figure 4-20 Point-to-point link using directional antennas

Fresnel Zone

- RF waves have a tendency to spread out
  - Space between two antennas would be more accurately represented by an ellipse
    - Called the **Fresnel zone**
- When planning a wireless link
  - At least 60% of the Fresnel zone must be kept clear of obstructions
  - May affect the height of the antenna tower

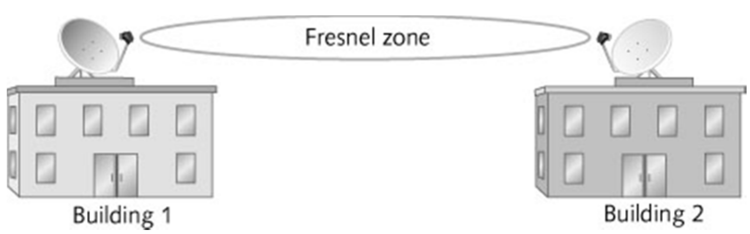


Figure 4-21 Fresnel zone

Link Budgets

- Link budgets
  - Calculate whether you will have enough signal strength to meet the receiver's minimum requirements
- Many link budgeting tools available on the Internet
- Information needed to calculate link budget includes:
  - Gain of the antennas
  - Cable and connector losses for receiver and transmitter
  - Receiver sensitivity
  - Free space loss figure

Antenna Alignment

- One of the challenges of implementing a point-to-point link:
  - Positioning the antennas at the same height and point them toward one another
- Some basic tools for antenna alignment:
  - A compass to position the antenna in the correct direction
  - A spotting scope or binoculars
  - A means of communication, such as a walkie-talkie or a cellular phone
  - If the distance is reasonably short, a light source, such as a flashlight or laser pointer

Antenna Alignment

- Spectrum analyzer
  - Used for long distance and accurate antenna alignment
  - Displays the signal amplitude and frequency
  - Can also detect interference in a particular frequency or channel

Figure 4-22 Spectrum analyzer

Other Challenges of Outdoor Links

- Radio waves can reflect, diffract, or be absorbed by some materials
- Weather phenomena can affect the performance and reliability of wireless links
  - Examples: heavy fog, rain, dust, or snowstorms
- Air disturbances and changes in temperature can also affect wireless links
- Seasonal changes can impact a wireless link
  - An antenna that was setup in winter (when there were no leaves on trees) may not work as well in the spring (when leaves can block a percentage of the Fresnel zone)

Other Challenges of Outdoor Links

- While planning an outdoor link:
  - Always consider environmental conditions
    - Check the history of the region's weather
  - Check for short- and long-term plans that may interfere with your intended link
  - Consider the possibility of another link that may interfere with your link

Summary

- Gain occurs when a signal is amplified or when most of the signal's energy is focused in one direction
- Loss occurs when the energy of a signal decreases
- Decibel (dB) is a relative measurement
  - Simplifies the calculations of gain and loss, and indicates the strength of a signal
- An isotropic radiator is a theoretical perfect sphere that radiates power equally, in all directions
- Most common type of antenna is a passive antenna

Summary

- Size of an antenna depends primarily on the frequency that it is designed to transmit or receive
- Types of antennas: omnidirectional and directional
- Free space loss is caused by the natural tendency of RF waves to spread out
- Antennas have a horizontal and a vertical radiation pattern
- Basic types of one-dimensional antennas
  - Monopole
  - Dipole

Summary

- Smart antennas can track a mobile user
  - And send a narrower, more efficient beam
- Special LMR antenna cables are used to reduce the signal loss
- RF waves propagate differently depending on the frequency of the signal
- Types of links: point-to-multipoint and point-to-point
- Challenges of outdoor links
  - Weather phenomena
  - Seasonal changes