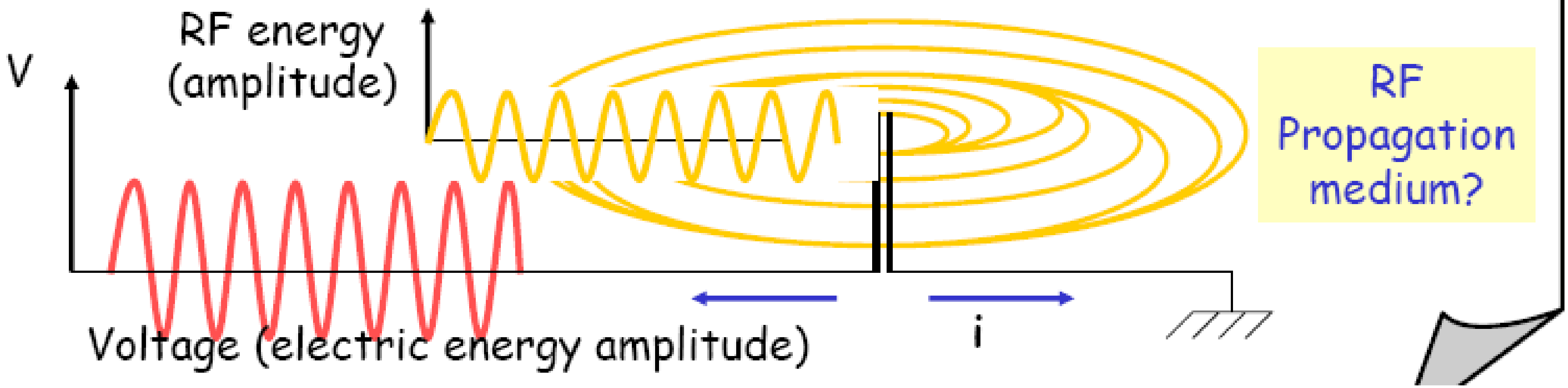
Wireless Networks for Mobile Applications

Prof. Claudio Palazzi
cpalazzi@math.unipd.it

Università degli Studi di Padova

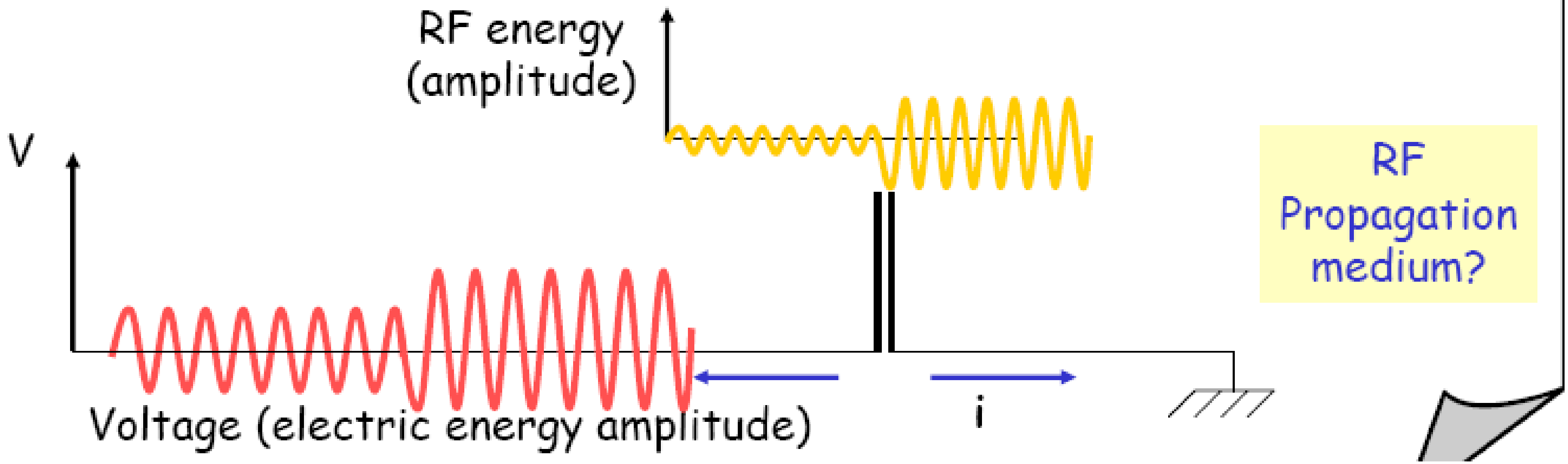
RF Properties

- **Understanding Radio Frequency**
  - Generation, coverage and propagation issues
  - Fundamental for wireless planning and management
- **Radio Frequency Signals**
  - Electromagnetic energy generated by high frequency alternate current (AC) in antennas
  - Antenna: converts the wired current to RF and viceversa



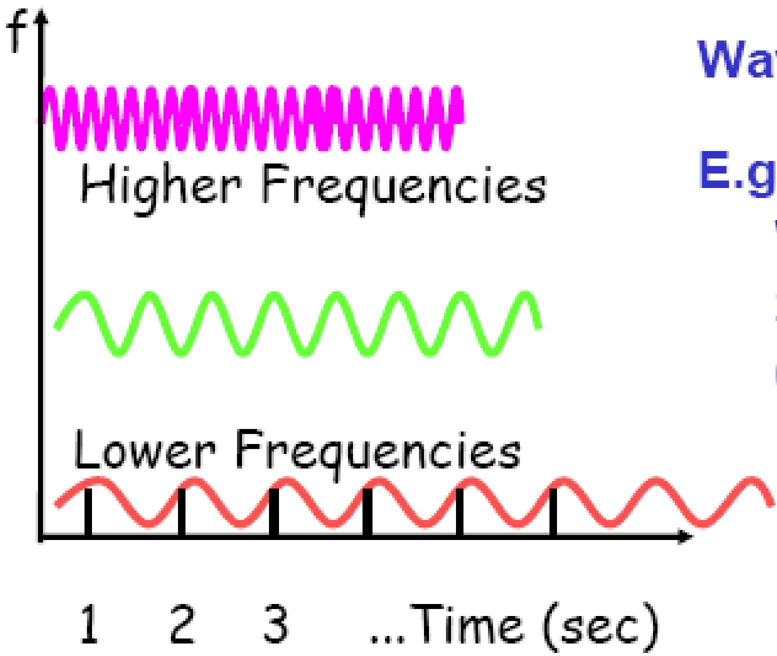
RF Properties

- **Amplitude**
  - Higher amplitude RF signals go farther
  - Transmission Power (Watts) = Energy / Time = Joule / Sec
    - More energy (voltage) moves more electrons (current)
    - Power = Voltage * Current



RF Properties

- **Frequency (and Wavelength)**
  - Wireless Spectrum (see next slides)
  - Portion of wireless spectrum regulated by regional authorities and assigned to wireless technologies



Wavelength = c / frequency

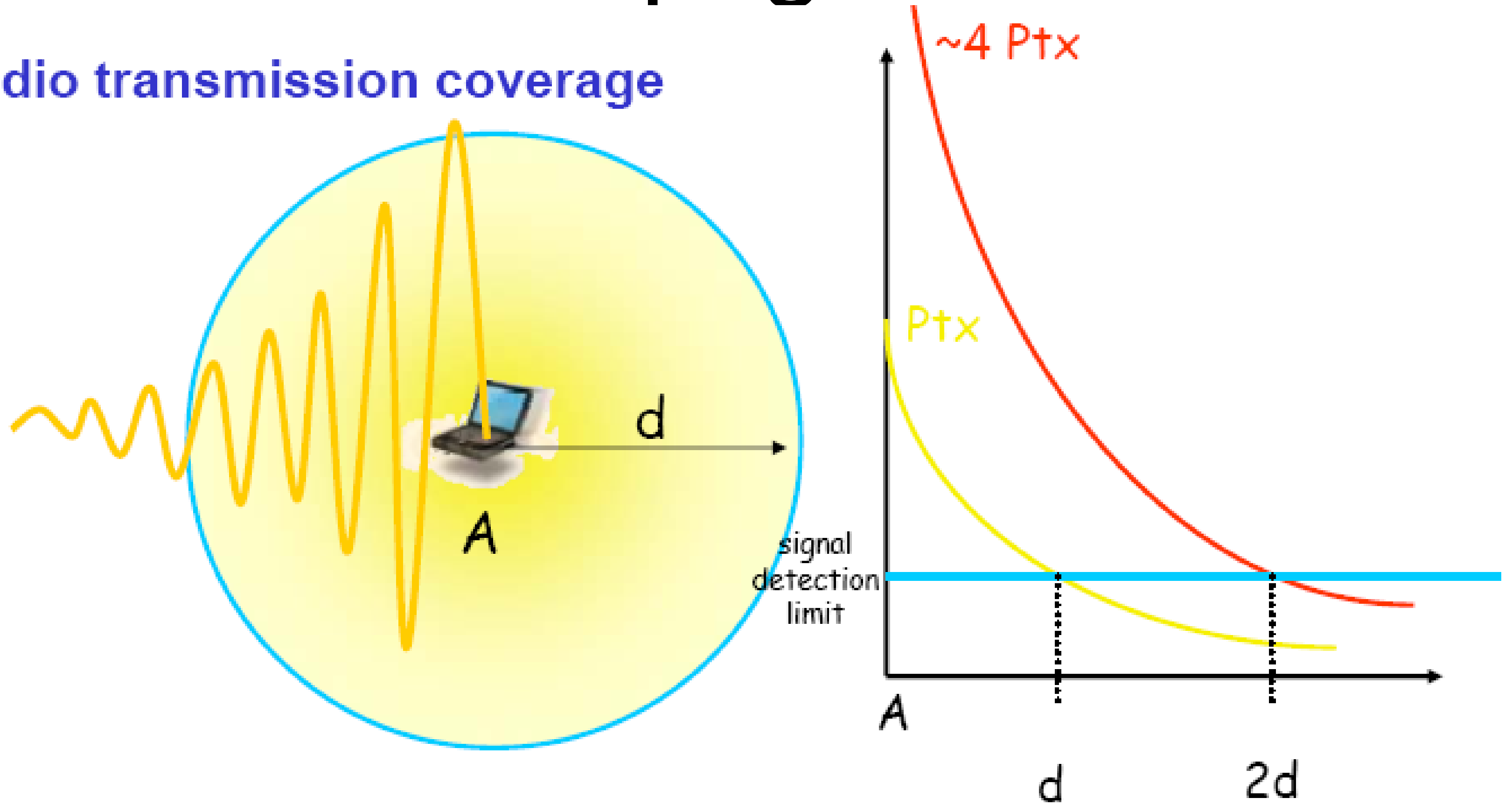
E.g. 2.4 GhZ (ISM band)

Wave Length =
300.000.000(m/s) / 2.400.000.000 Hz =
0.125 m = 12.5 cm

In practice:
Antennas work better
with size = 1, $\frac{1}{2}$, $\frac{1}{4}$ of wavelegth
(try to measure antenna size of your IEEE 802.11 device)

RF Propagation

- **Radio transmission coverage**

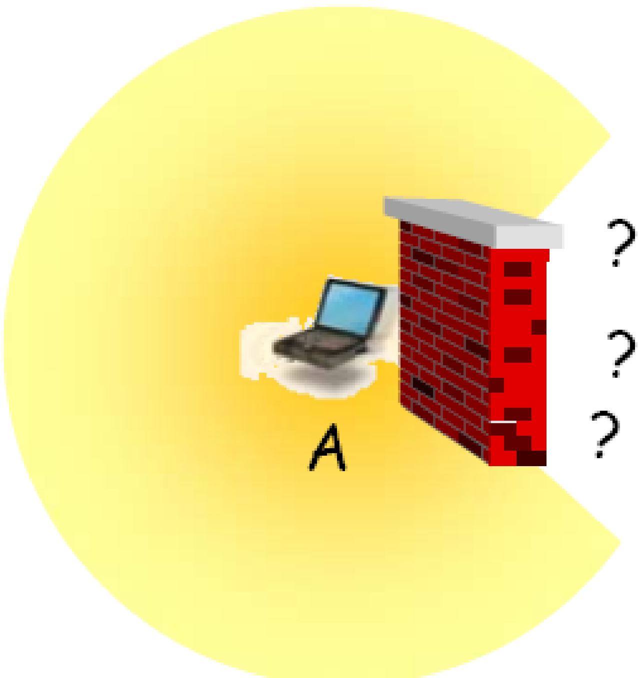


The range is a function of power transmission (Ptx)
Signal strength reduces with d^k →
(K>=2..3, no obstacles, isotropic radiator)

In 3D, sphere:
$V=(4 \pi r^3/3)$
$S=(4 \pi r^2)$

RF Propagation

- **Radio transmission coverage**



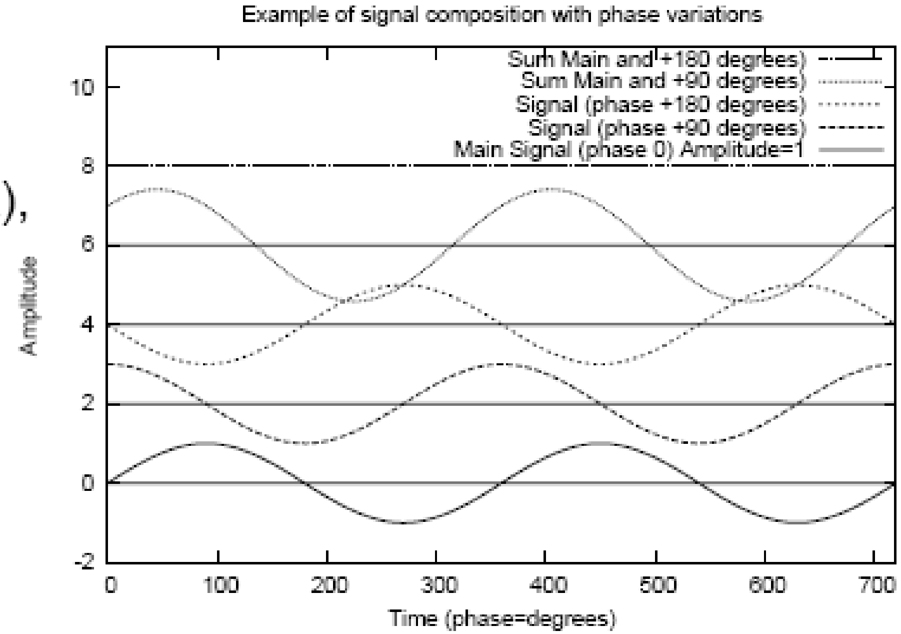
Rules of thumb:

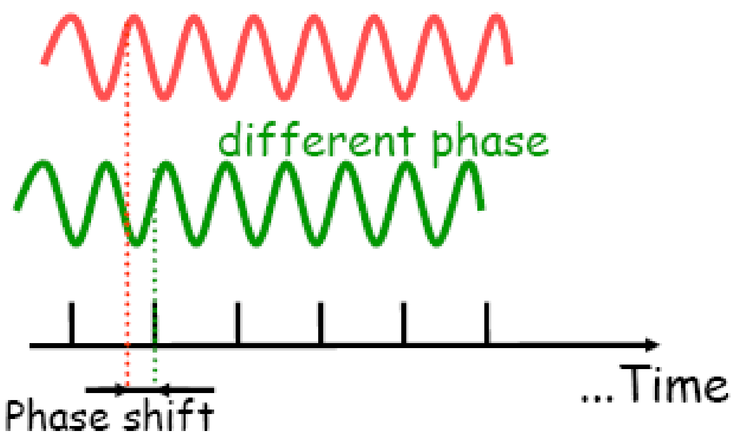
- high frequencies are good for short distances and are affected by obstacles
- low frequencies are good for long distances and are less affected by obstacles

obstacles can reflect or absorbe waves depending on materials and wave frequencies

RF Properties

- **Phase: shift of the wave (in degrees or radians)**
  - Positive phase (left-shift), early wavefront
  - Negative phase (right-shift), late wavefront





In practice:
RF echoes arriving at receivers with different phase may have positive or negative effects... Why?

RF Properties

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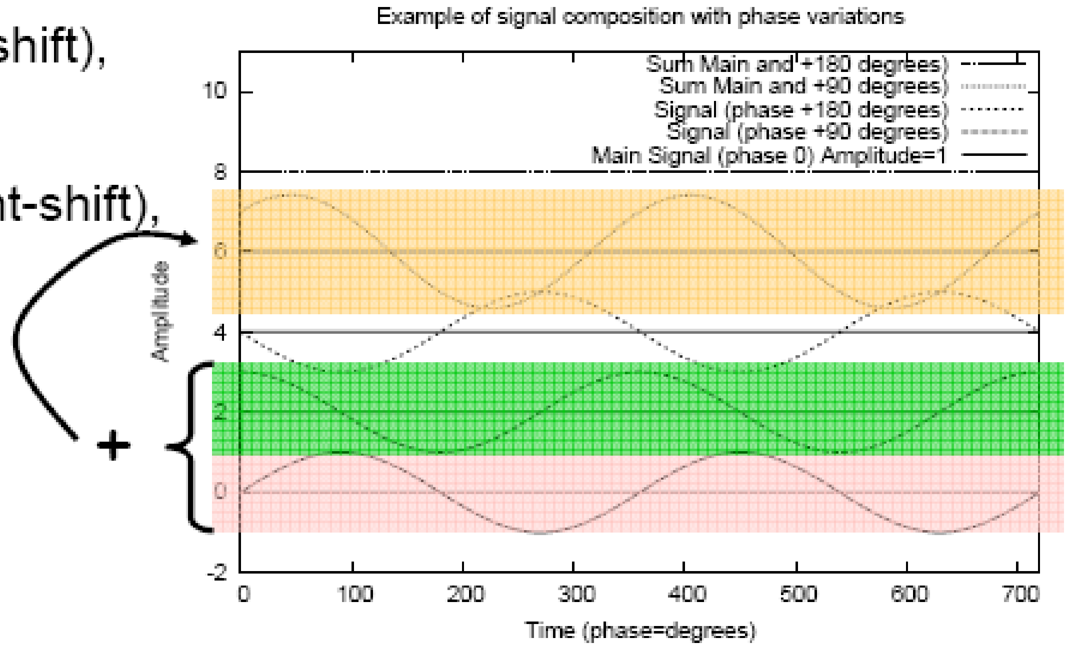

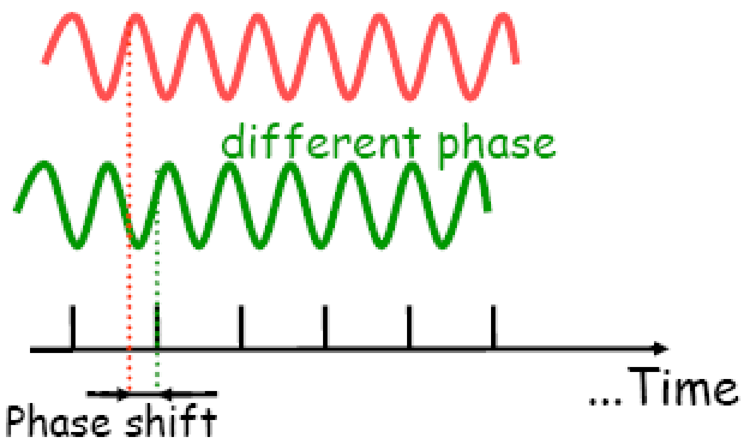

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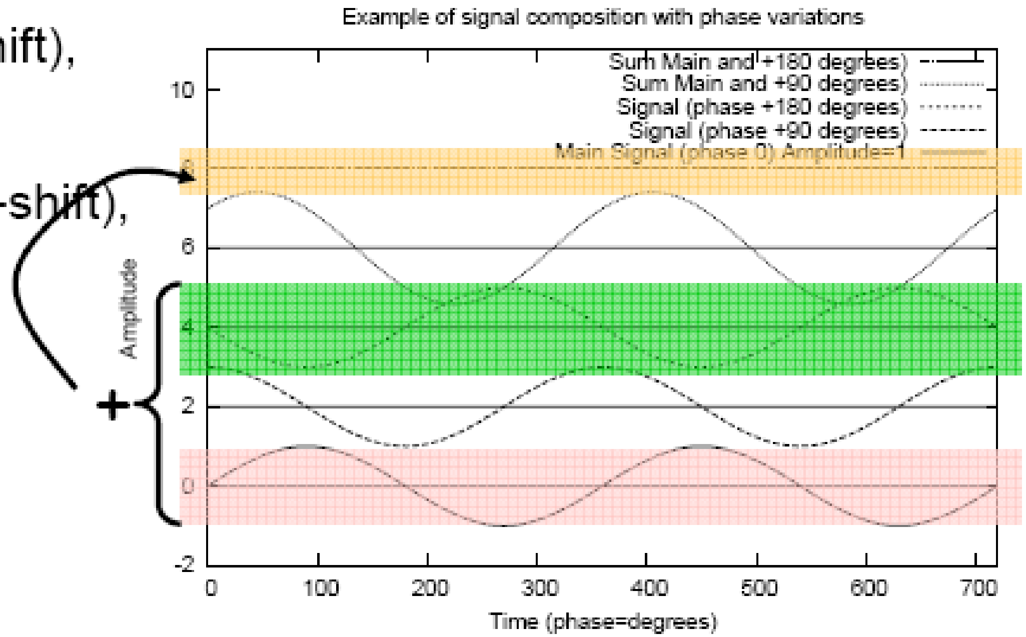

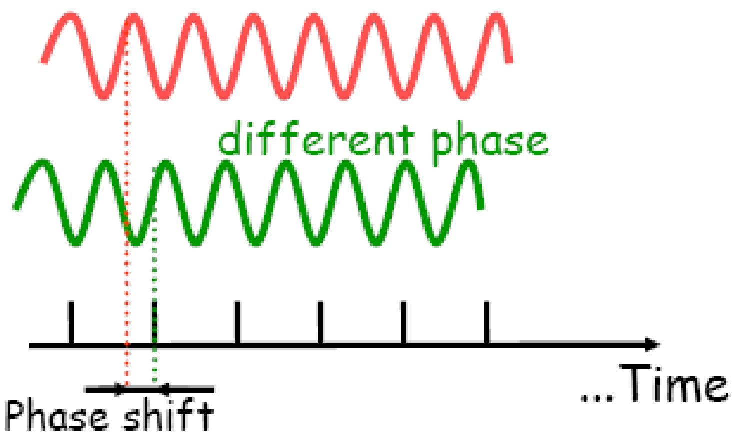

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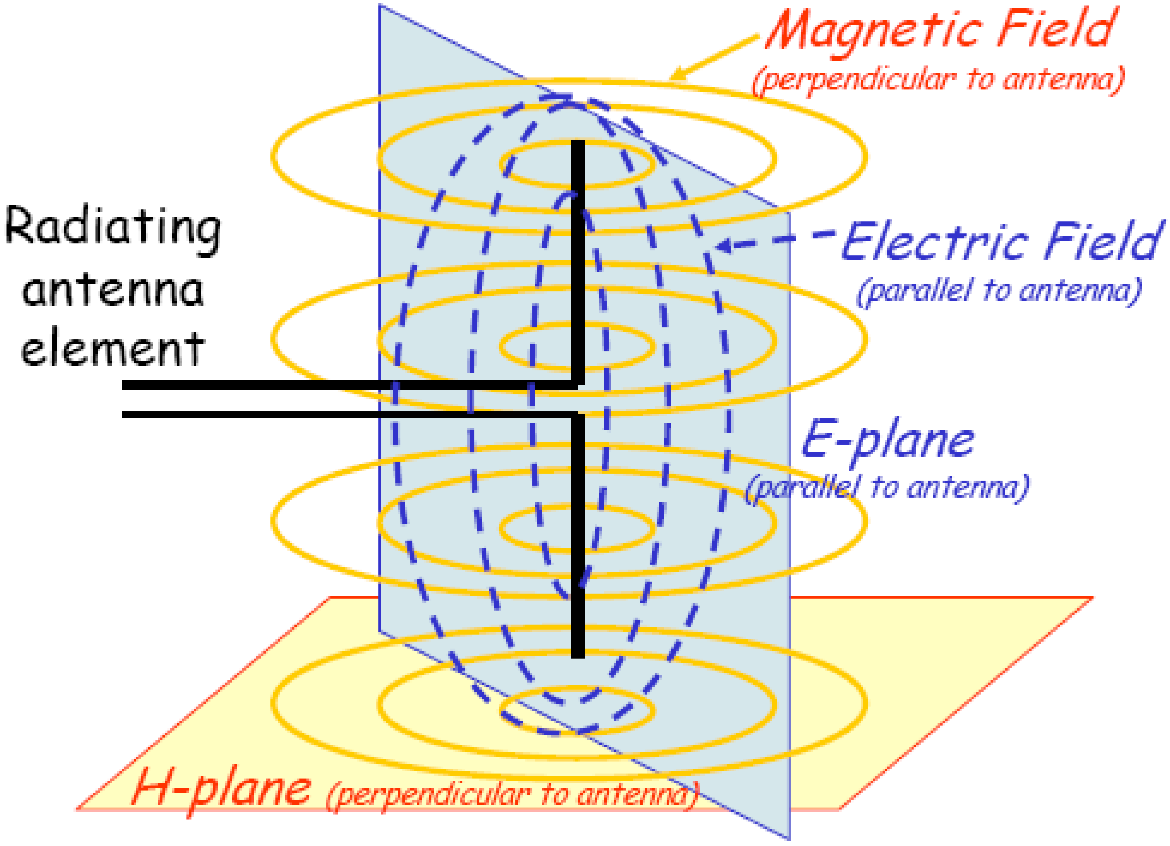
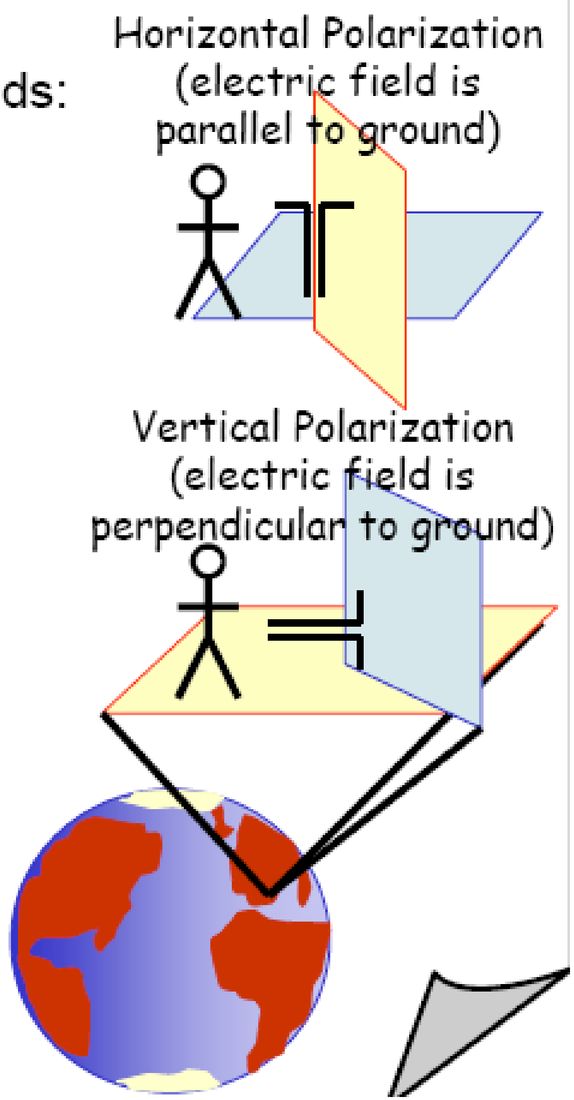
RF echoes arriving at receivers with different phase may have positive or negative effects... Why?

RF Properties

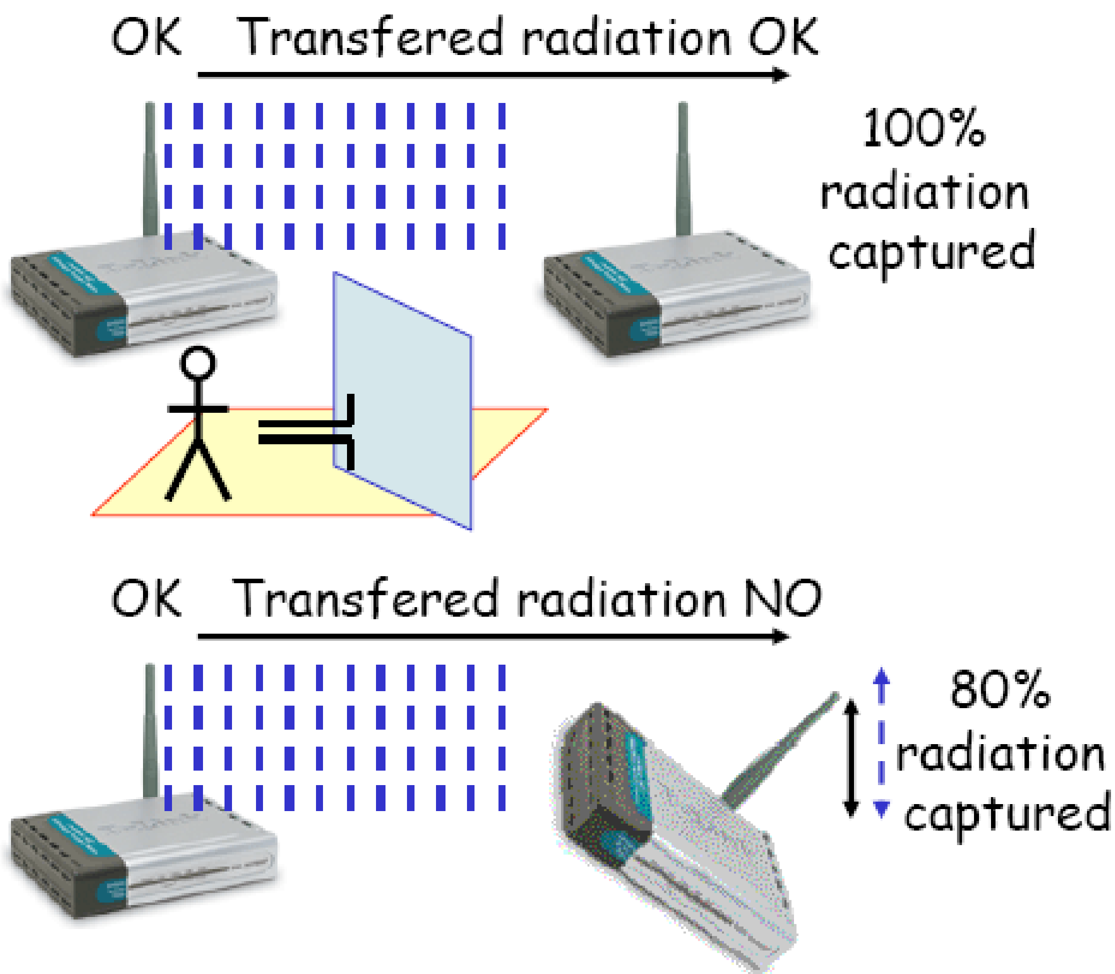
- **Polarization: (physical orientation of antenna)**
  - RF waves are made by two perpendicular fields:
    - Electric field and Magnetic field

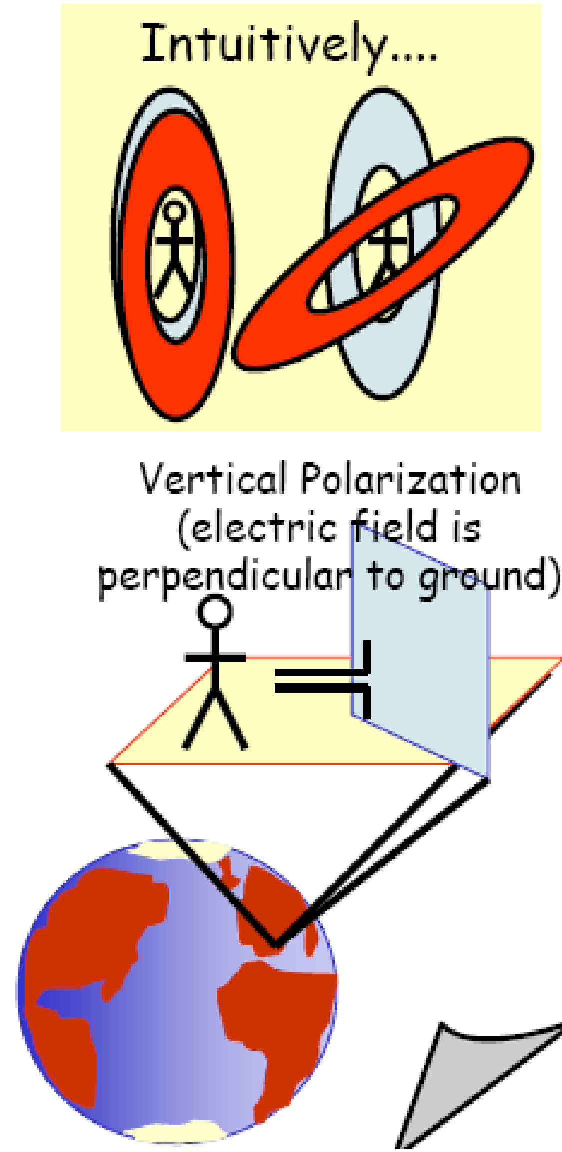




RF Properties

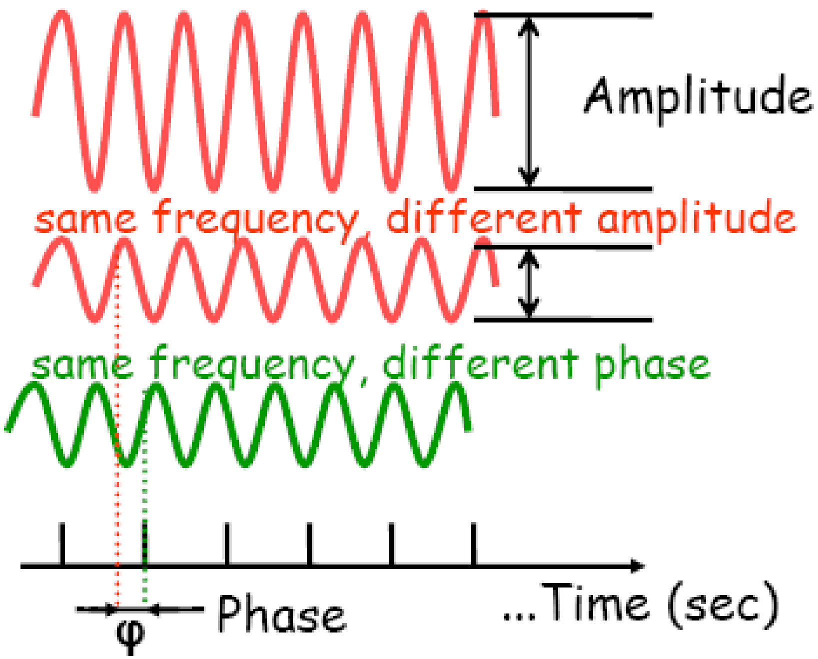
Vertical Polarization: typically used in WLANs

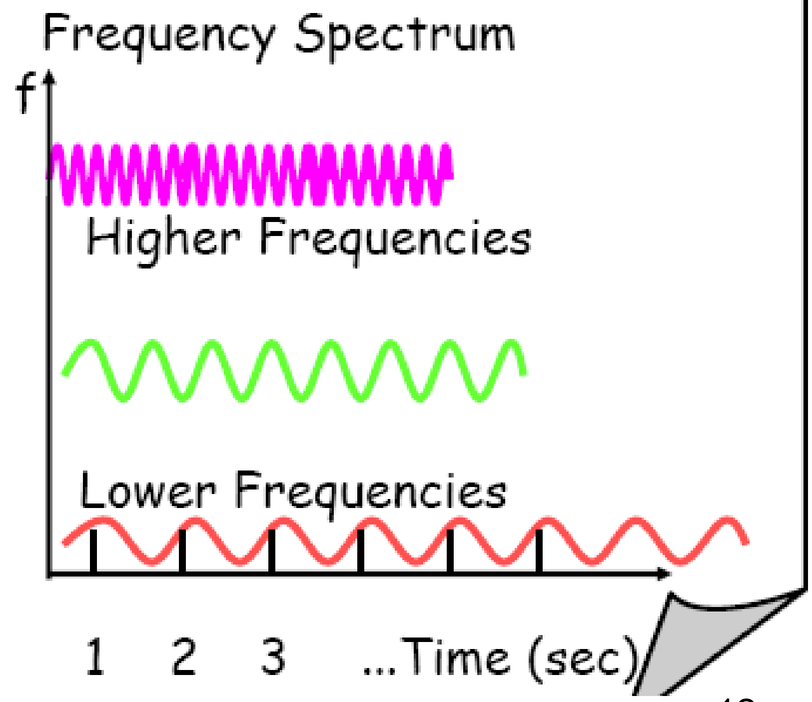




Wireless Transmission

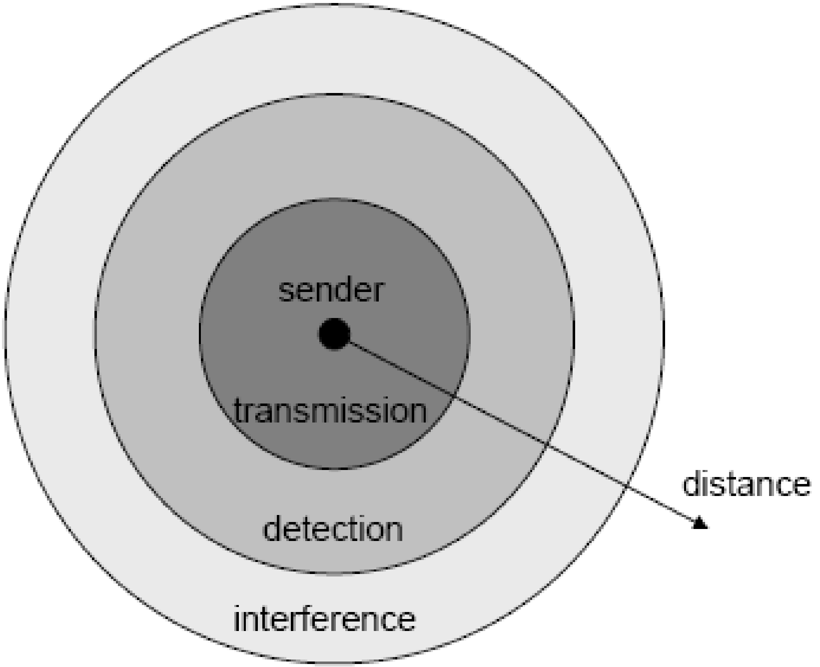
- **Different parameters of electromagnetic waves:**
  - amplitude **M** proportional to transmission energy (loudness)
  - frequency **f** (tone) measured in Hertz (Cycle/sec)
  - phase **φ** (peak shift with respect to reference signal) (rad)





Propagation Ranges

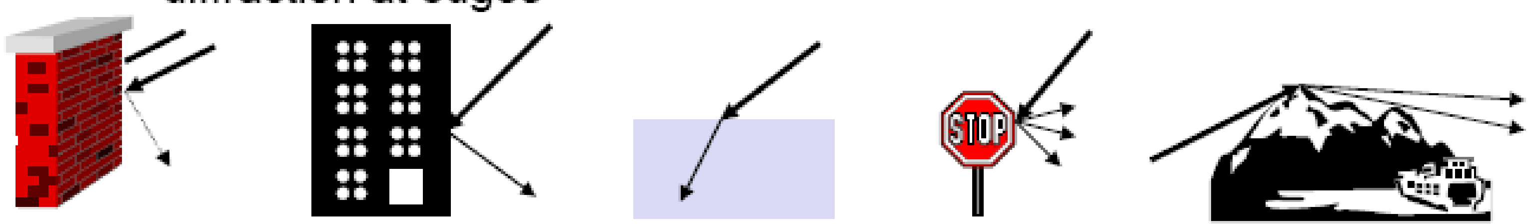
- **Transmission range**
  - communication possible
  - low error rate
- **Detection range**
  - detection of the signal possible
  - no communication possible
- **Interference range**
  - signal may not be detected
  - signal adds to the background noise



Ranges depend on receiver's sensitivity!

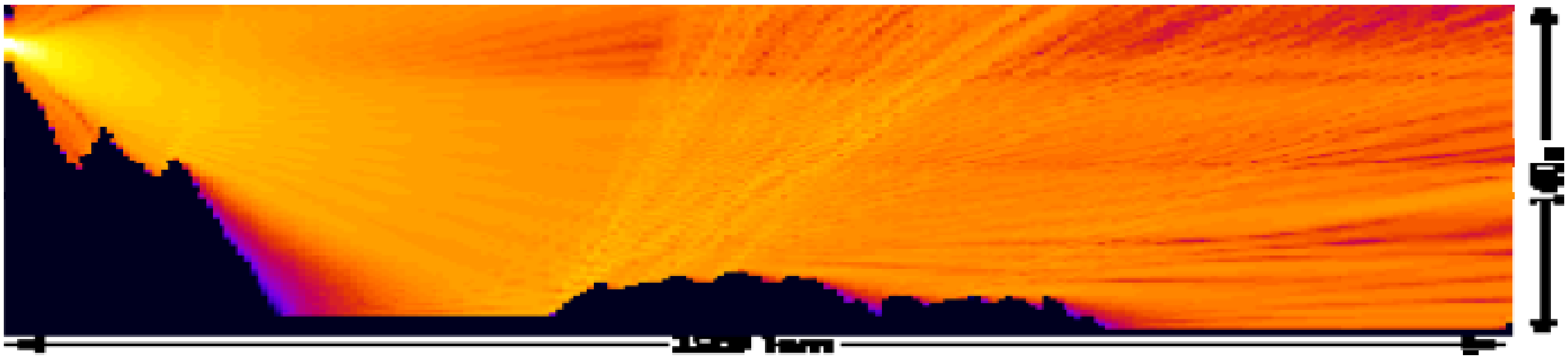
Propagation Effects

- **Propagation in free space always like light (straight line)**
- **Receiving power proportional to $1/d^2$**
  (d = distance between sender and receiver)
- **Receiving power additionally influenced by**
  - fading (frequency dependent)
  - shadowing
  - reflection at large obstacles
  - refraction depending on the density of a medium
  - scattering at small obstacles
  - diffraction at edges



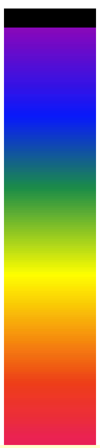
shadowing reflection refraction scattering diffraction

Propagation Effects

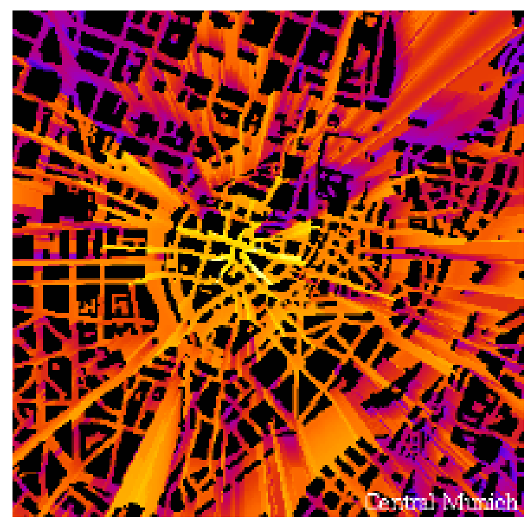


Raytracing examples

Low signal

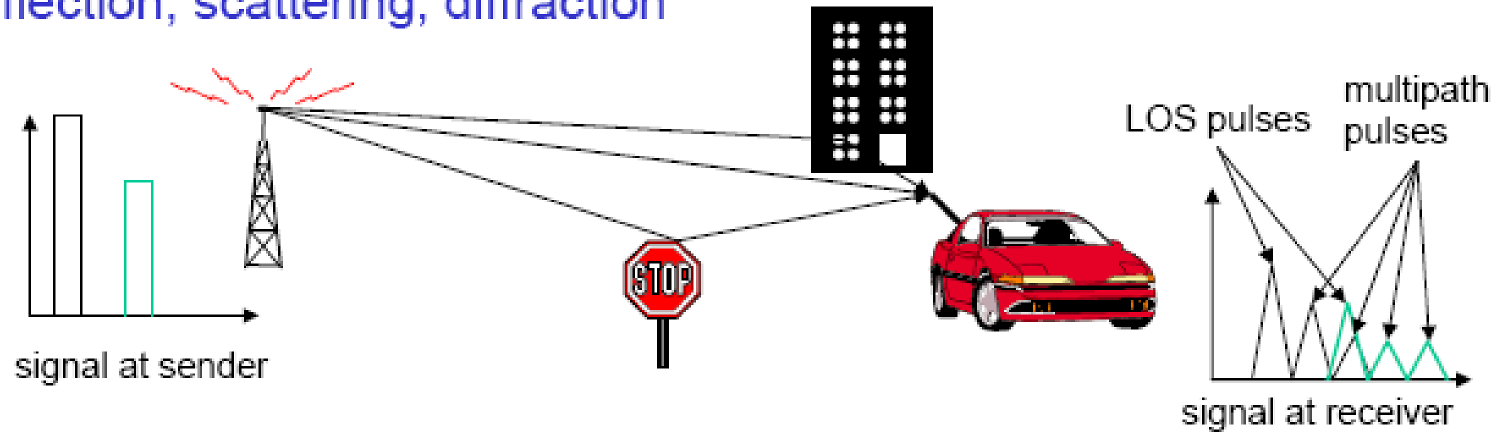


high signal



Multipath Propagation

- Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction



- Time dispersion: signal is dispersed over time
  ➔ interference with "neighbor" symbols, Inter Symbol Interference (ISI)

- The signal reaches a receiver directly and phase shifted
  ➔ distorted signal depending on the phases of the different parts

Power Measurement

- Decibel (dB): a power measurement unit designed to express power loss
  - It is more practical to use given the logarithmic decay of wireless signals
  - It allows to make easy calculations on "resulting power"
- Decibel (dB) measures the <u>logarithmic relative</u> strength between two signals (mW are a <u>linear absolute</u> measure a energy)
  - $Log_{10}(X) = Y \iff 10^Y = X$

Exponential growth

- $1 = 10^0$, $\log_{10}(1) = 0$
- $10 = 10^1$, $\log_{10}(10) = 1$
- $100 = 10^2$, $\log_{10}(100) = 2$
- $1000 = 10^3$, $\log_{10}(1000) = 3$

Linear growth "BEL" units (B)

  - How strong is a 10 dB signal? (it depends on the reference signal)

Power Measurement

- Decibel (dB): 1/10 of a Bel
- E.g. 1000 is one Bel greater than 100 => 1000 is 10 dB greater than 100

Linear signal difference (factor)

- 1 = 10^0, $\log_{10}(1) = 0$
- 10 = 10^1, $\log_{10}(10) = 1$
- 100 = 10^2, $\log_{10}(100) = 2$
- 1000 = 10^3, $\log_{10}(1000) = 3$

10 dB
10 dB
10 dB
20 dB
20 dB
30 dB

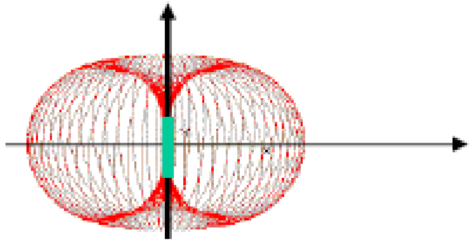
- How strong is a 10 dB signal? (it depends on the reference signal)
  - Positive dB value is power gain, negative dB value is power loss
  - e.g. given 7 mW power, a +10 dB signal gain is 70 mW
  - e.g. given 7 mW power, a -10 dB signal gain (loss) is 0.7 mW
- Power Difference (in dB) between Tx and Rx signal:
  - Power Difference (dB) = 10 * log(Power Tx(Watt) / Power Rx (Watt))
- Gain and Loss are relative power measurements: dB is the unit

Antennas

- Illustration of general issues
  - Convert electrical energy in RF waves (transmission), and RF waves in eletrical energy (reception)
  - Size of antenna is related to RF frequency of transmission and reception
  - Shape (structure) of the antenna is related to RF radiation pattern
- Radiation patterns of different antenna types
- Positioning antennas
  - Maximum coverage of workspace
- Real antenna types: omni-directional, semi-directional, highly-directional

Omnidirectional Antennas

- **Omni-directional antenna: radiates RF power equally in all directions around the vertical axis.**
- **Most common example: dipole antenna (see Access Points)**
  - See how to make it (disclaimer: do not try this at home):
    http://www.nodomainname.co.uk/Omnicolinear/2-4collinear.htm
    http://www.tux.org/~bball/antenna/
  - Info & fun: http://www.wlan.org.uk/antenna-page.html
  - More info: http://www.hdtvprimer.com/ANTENNAS/types.html

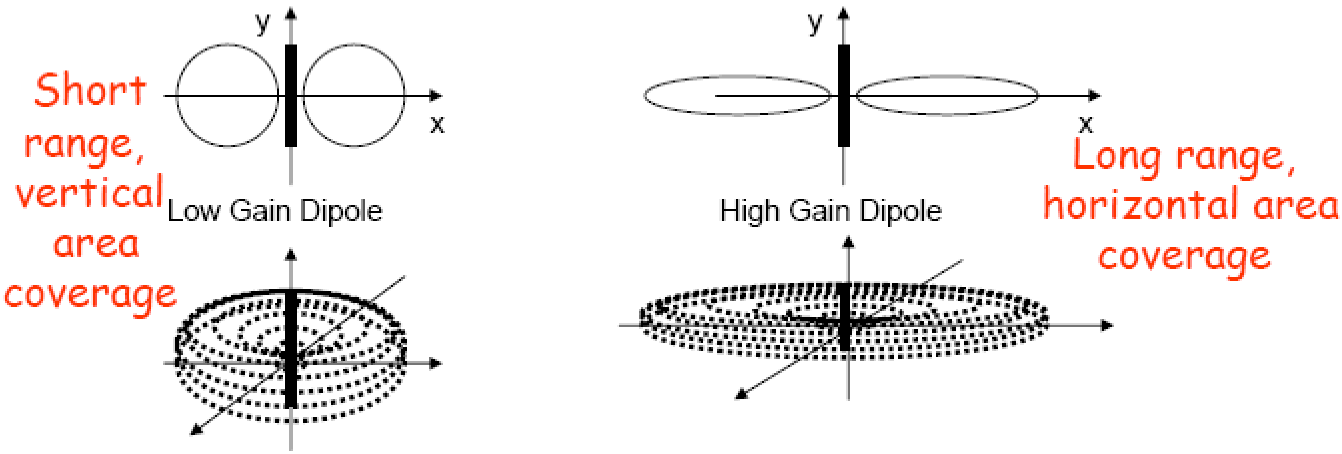


TV dipole

AP dipole

Omnidirectional Antennas

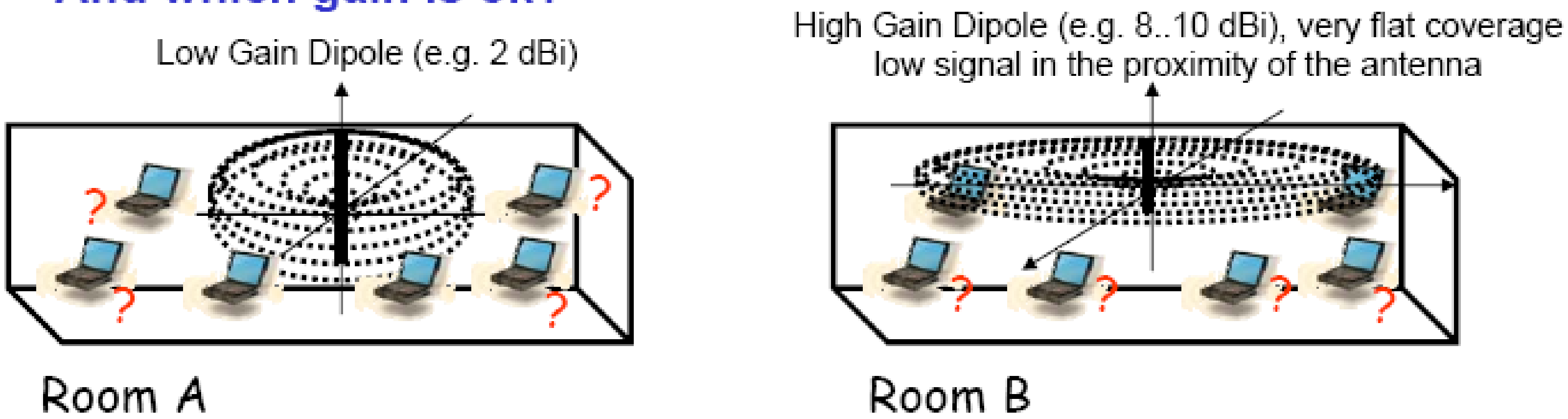
- Dipole: passive gain is due to concentration (shape) of radiation



- Dipole: active gain is obtained with power amplifiers (needs external source of energy)
- N.B. near (below) the dipole the signal is weak! And better radiation is obtained in sub-areas around the dipole!

Omnidirectional Antennas

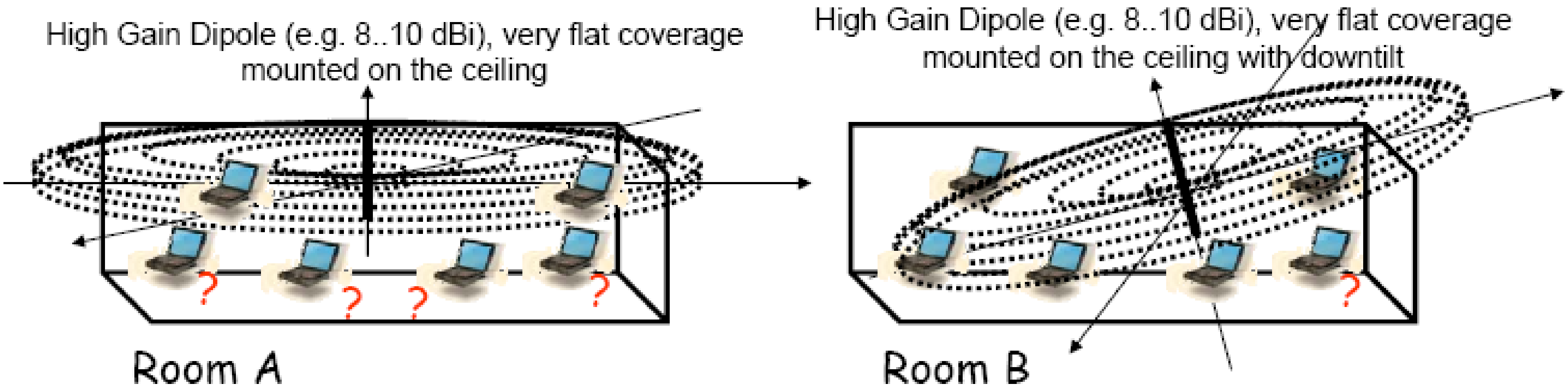
- **Problem: how and when to mount omidirectional antennas? And which gain is ok?**



- **How: Ceiling? Wall? Client positions? Area? Many factors influence the planning...**
- **When:**
  - **need for uniform radio coverage around a central point**
  - **Outdoor: point-to-multipoint connection (star topology)**

Omnidirectional Antennas

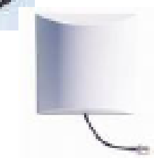
- **Antenna Tilt: degree of inclination of antenna with respect to perpendicular axis**

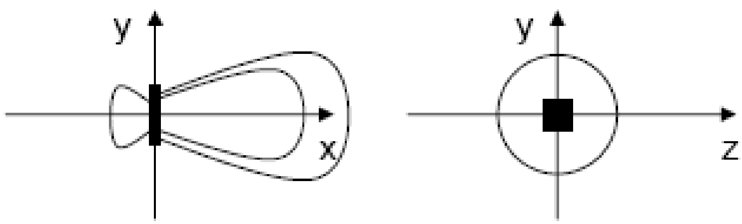


- **Some antennas allow a variable degrees downtilt.**
- **Half signal disperded "in the sky", 2nd half better exploited.**

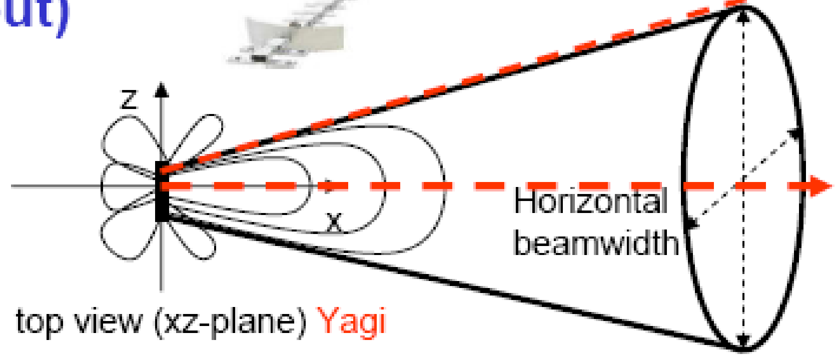
Semi-directional Antennas

- Patch (flat antennas mounted on walls)
- Panel (flat antennas mounted on walls)
- Yagi (rod with tines sticking out)



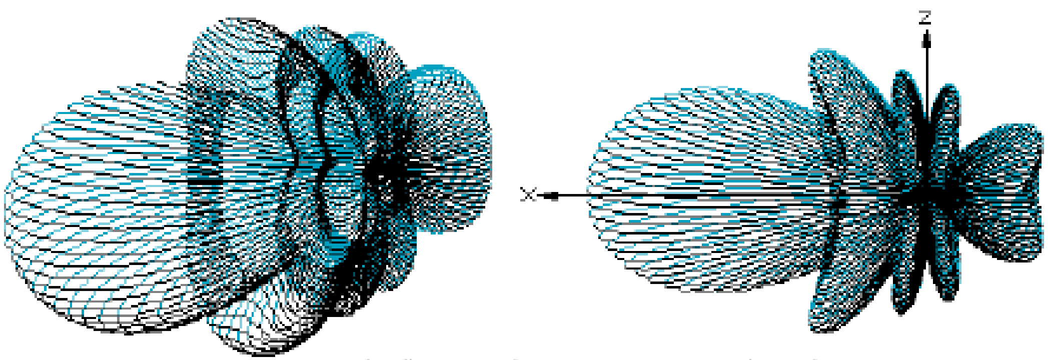


side view (xy-plane) Patch side view (yz-plane)



Vertical beamwidth

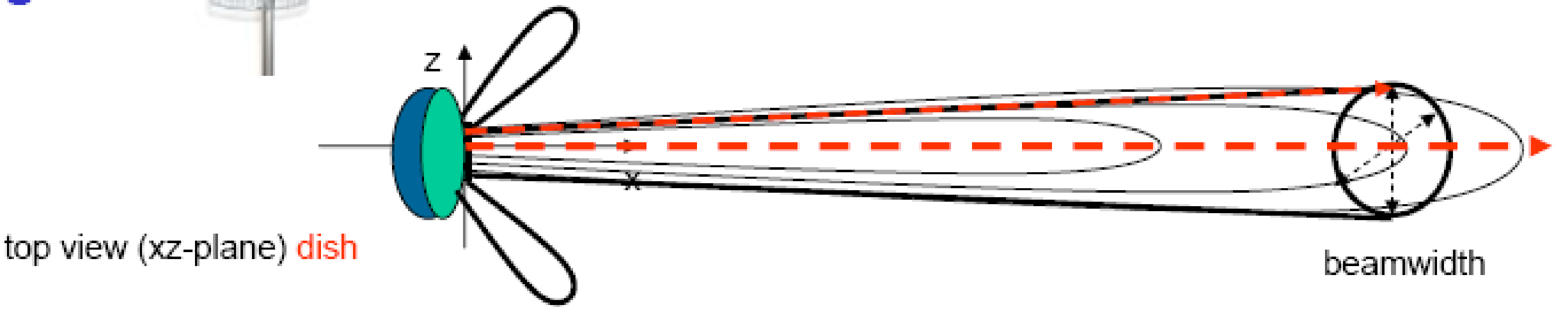
Semi-directional antenna



Credits: http://www.hdtvprimer.com/ANTENNAS/types.html

Highly-directional Antennas

- Parabolic Dish 
- grid 



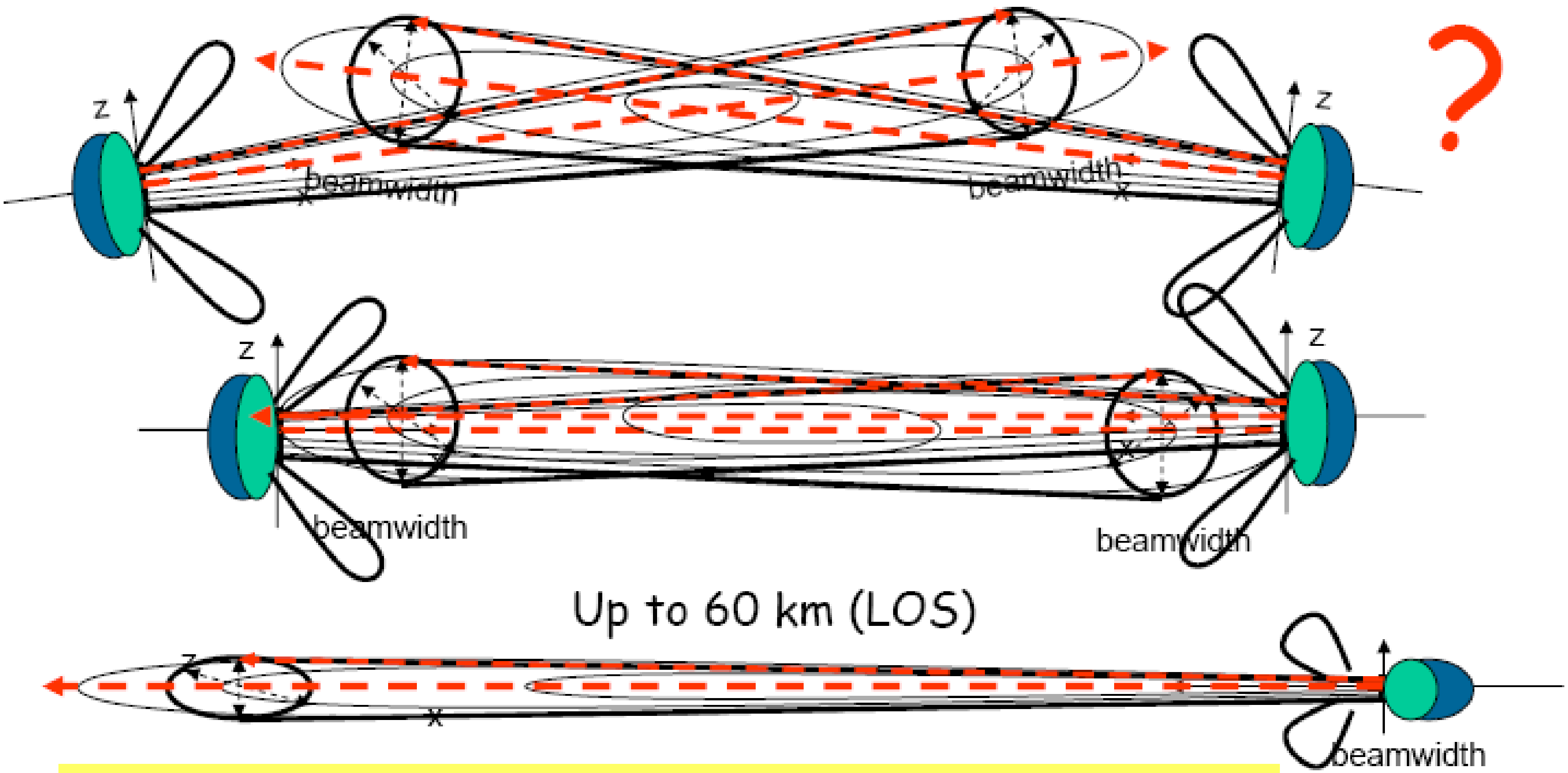
Antenna type	H beamwidth	V beamwidth
Omni-dir.	360°	7°.. 80°
Patch/panel	30° .. 180°	6° .. 90°
Yagi	30° .. 78°	14° .. 64°
Parabolic dish	4° .. 25°	4° .. 21°

Semi-directional antenna

Highly-directional Antennas

- **Common use: Point-to-point link**

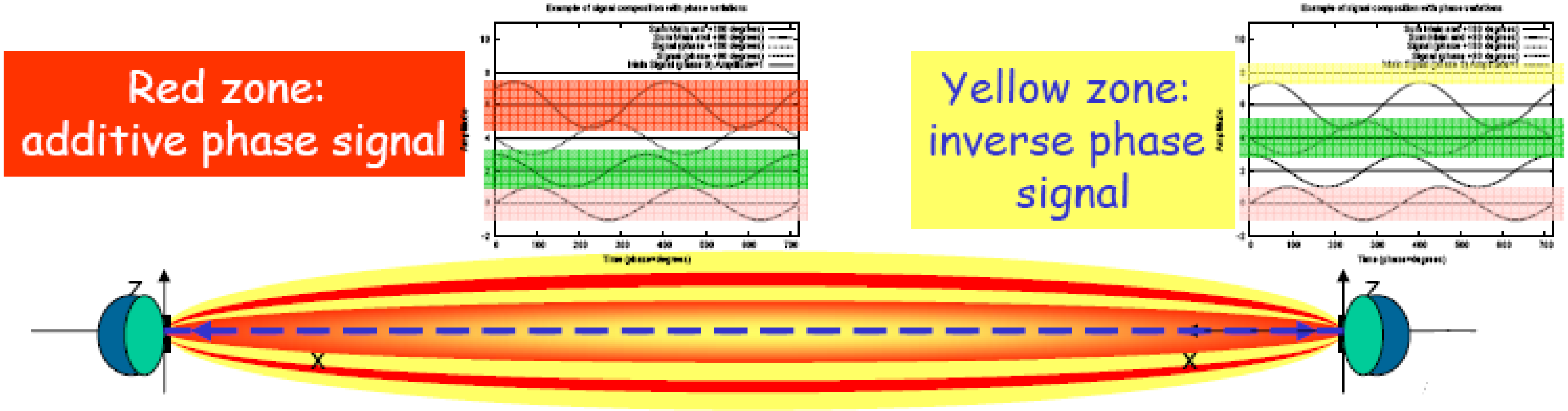
Out of beam alignment



Wind effect: better to have lower gain and wider beam

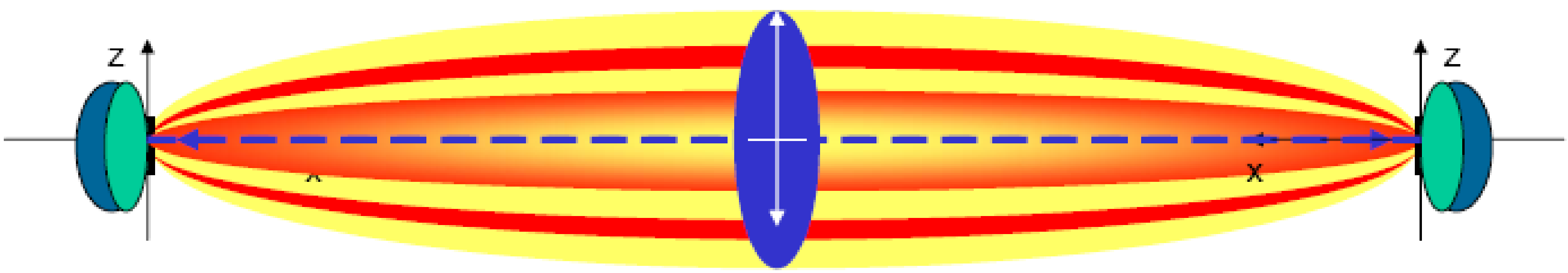
Highly-directional Antennas

- **Line of sight (LOS):**
  - Straigth line between transmitter and receiver
  - No obstructions (outdoor long range reduces reflections)
    - Polarization is more important than in indoor scenarios
- **Fresnel Zone: RF is not laser light, RF signals diffuse energy in space**
  - Ellipse shaped area centered on the LOS axis
  - Most additive RF signal is concentrated in the Fresnel Zone
  - It is important that Fresnel Zone is free from obstacles



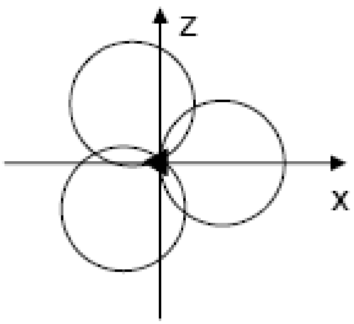
Highly-directional Antennas

- **Fresnel Zone (FZ)**
  - N.B. the FZ radius depends only on the distance d between antennas, and frequency f of RF signal!
  - Type of antenna, beam width (degree), and gain (dBi) have no effects!
    - E.g. +13 dBi Yagi (30 degree beam) vs. +24 dBi Dish (5 degrees) have the same FZ!!!!
  - In practice: if FZ is partially obstructed, it is not useful to use higher gain antennas (with small degree beam) !!!

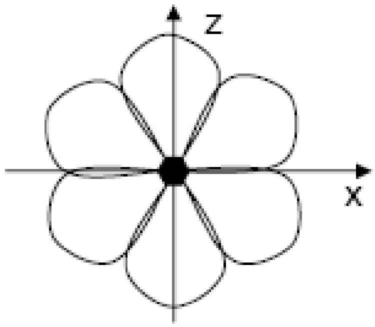


Sectorized-directional Antennas

- **Arrays of sectorized directional antennas**



top view, 3 sector

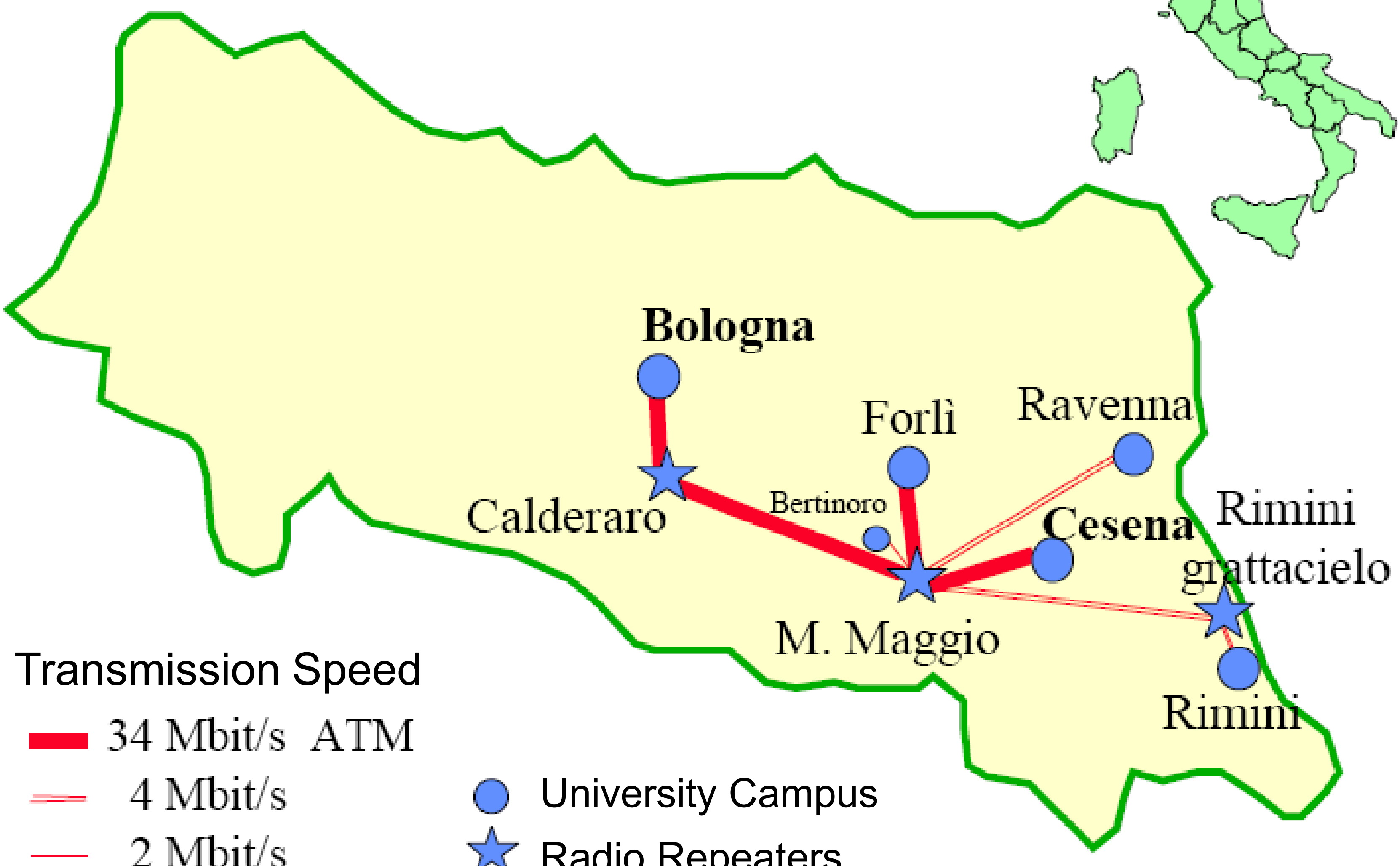


top view, 6 sector

sectorized antenna

- **Space multiplexing (channel reuse)**

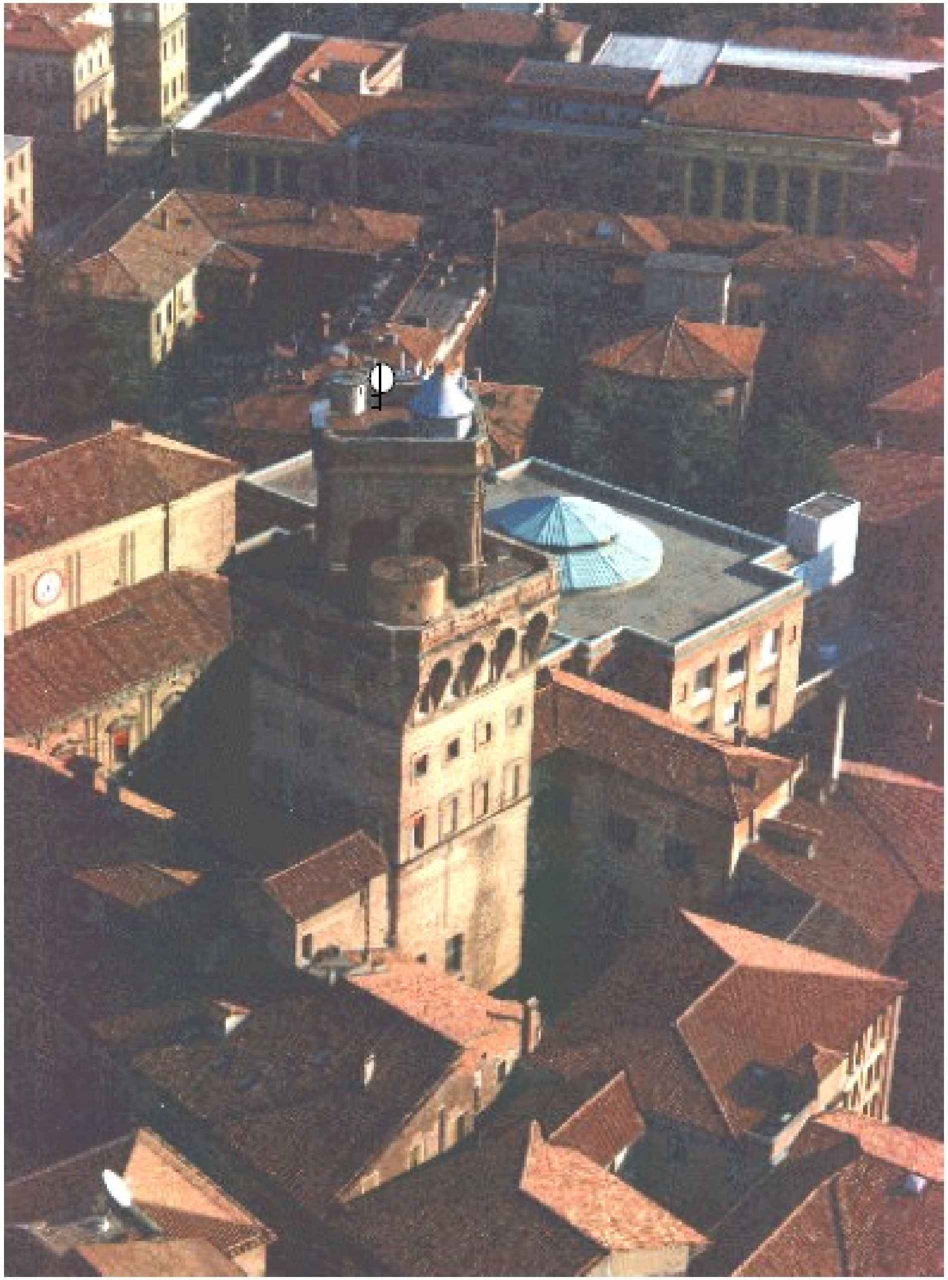
Radio Network of University of Bologna (deployed in 2000)



Orographic Study

Arrival point of radio transmissions in Bologna

Specola Tower



RAI TV Pylon in Monte Maggio (Bertinoro)

North view

East view

3m diameter Dish Antenna installed in Monte Maggio

View from below

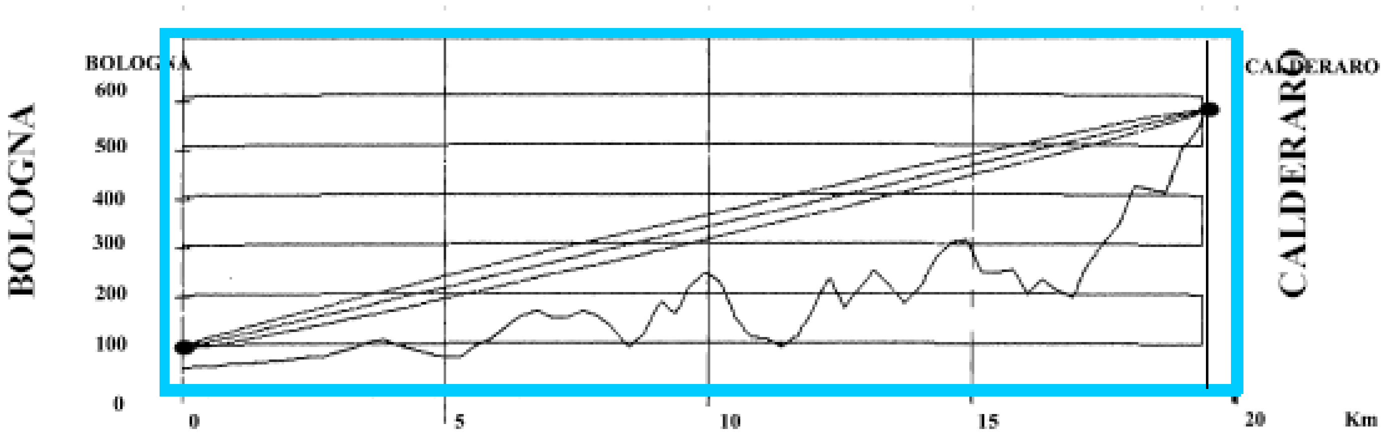
Side view

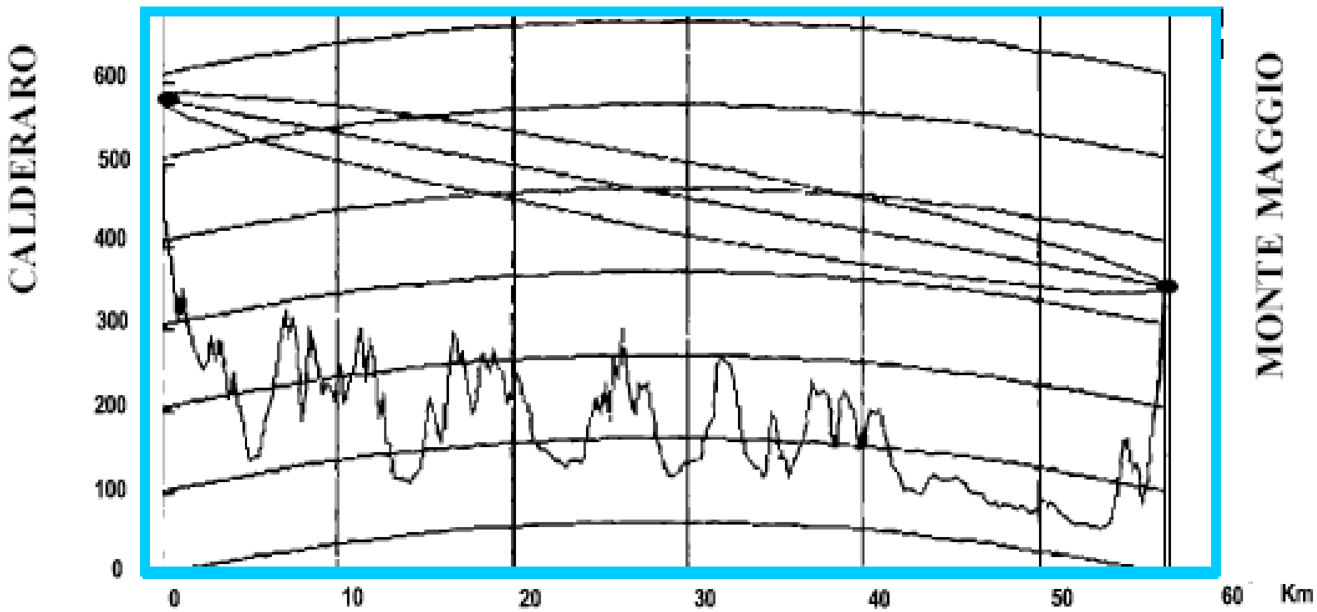
University Apparatus Room in Monte Maggio

General power supply and radio apparatus for communication towards Cesena and Forlì

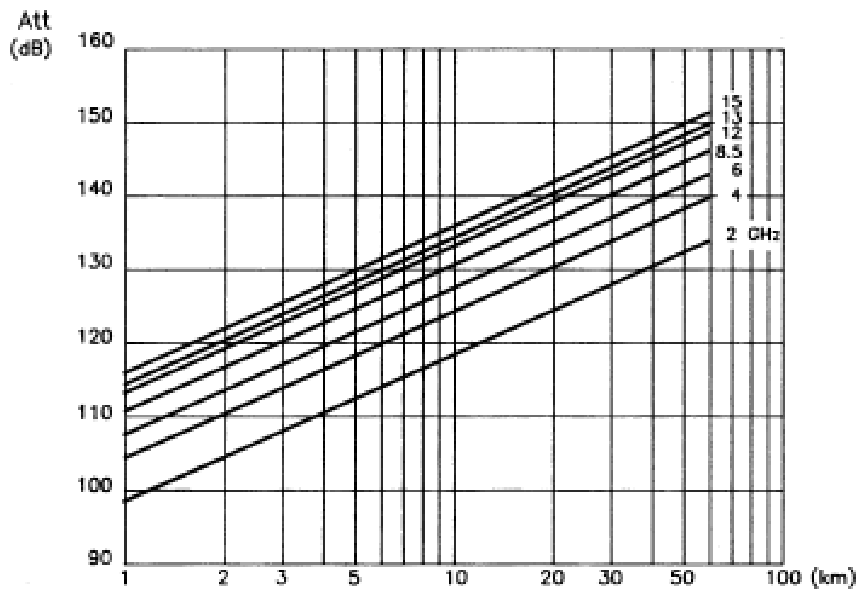
Routing apparatus

Orographic Profiles and Fresnel Zone

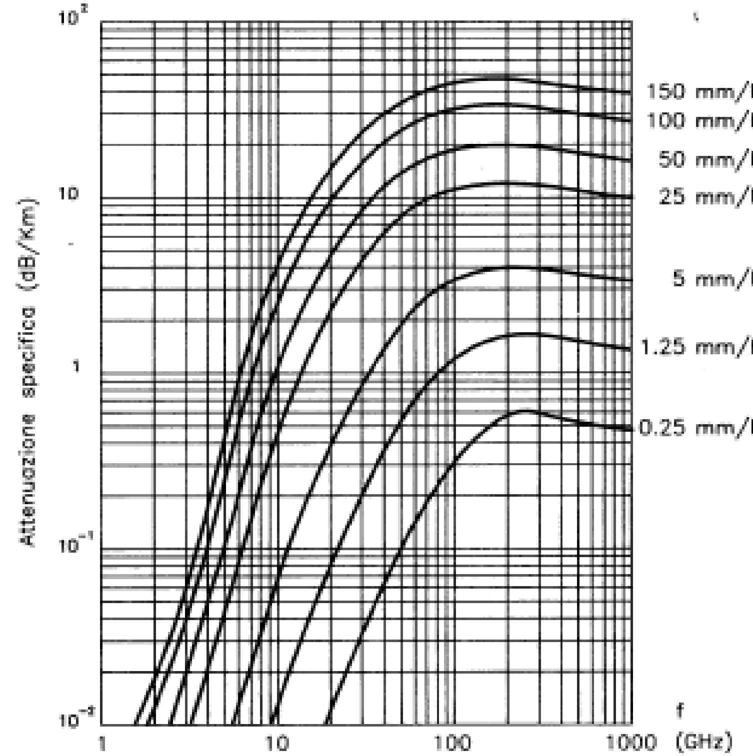




Parameters Computation



Signal attenuation in free space, when varying the transmission frequency



Signal attenuation caused by rain, when varying the rain intensity and the transmission frequency