

# Basic Radio Physics

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# Goals

- Understand electromagnetic waves used in wireless networking
- Understand the basic principles of their behaviour
- Apply this understanding to real life situations

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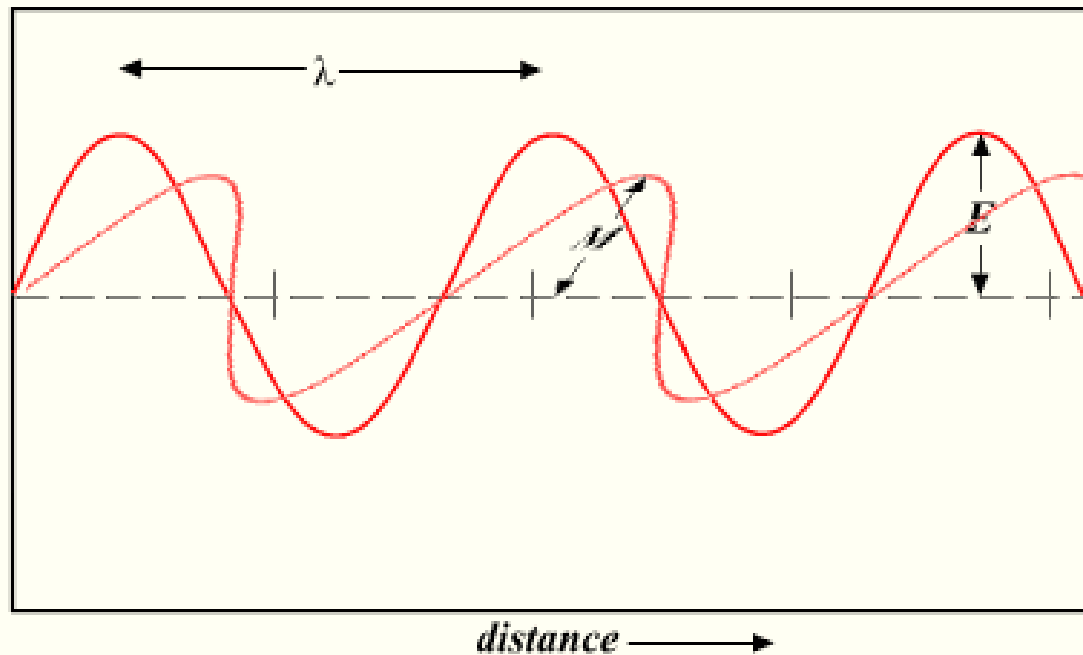
- Electromagnetic fields and waves
  - Characteristics
- The electromagnetic spectrum
- Electromagnetic effects
  - Absorption, reflection, diffraction, refraction, interference
- Propagation in free space
- Situations where physics really matters

# Electromagnetic Waves

- Also known as Electromagnetic radiation
- A propagating wave in space with electrical (E) and magnetic (H) components
- E and H oscillate **perpendicular to each other and to the direction of the propagation**
- Examples: light, X-rays and radio waves

# Electromagnetic Waves

## *Light Wave*

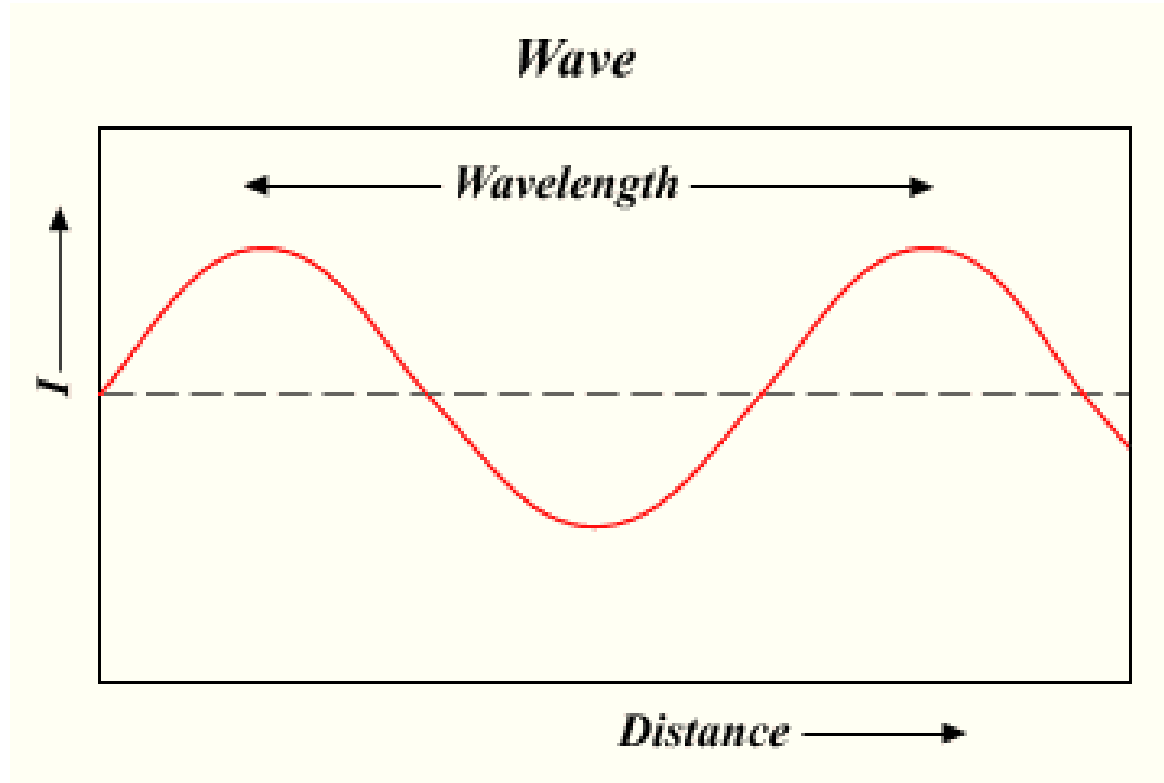


$\lambda$  = wavelength  
 $E$  = amplitude of electric field  
 $M$  = amplitude of magnetic field

# Electromagnetic Characteristics

- E and H fields
- No need of carrier medium
- Wavelength and frequency

# A Wave



[image: from wikipedia.org]

# Wavelength and Frequency

$$c = \lambda * f$$

$c$  = the speed of light ( $3 \times 10^8$  m/s) [m/s]

$\lambda$  = wavelength [m]

$f^*$  = frequency [1/s]

(\*) the frequency is also called  $\nu$  (Nu)

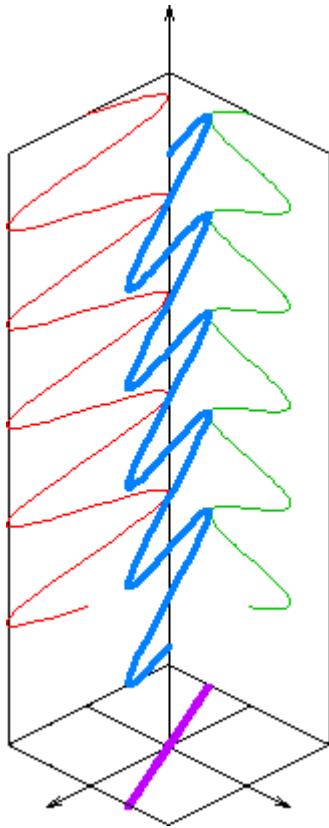
# Wavelength and Frequency

- An EM wave with a frequency of 2.4 GHz has a wavelength of 12,5 cm
- Light (or a radio signal) that travels with the speed of the light needs:
  - 1.3 seconds from the Moon to Earth
  - 8 minutes from the Sun
  - 300 microseconds for 100 km

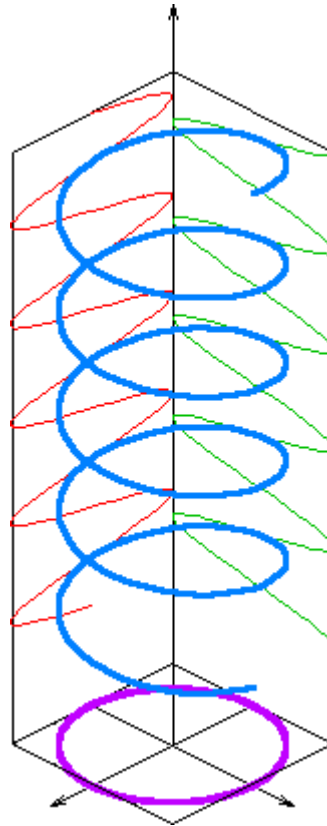
# Powers of Ten

<i>Prefix</i>	<i>Quantity</i>		<i>Symbol</i>
Nano	$10^{-9}$	1/ 1,000,000,000	n
Micro	$10^{-6}$	1/1,000,000	$\mu$
Milli	$10^{-3}$	1/1,000	m
Centi	$10^{-2}$	1/100	c
Kilo	$10^3$	1,000	k
Mega	$10^6$	1,000,000	M
Giga	$10^9$	1,000,000,000	G

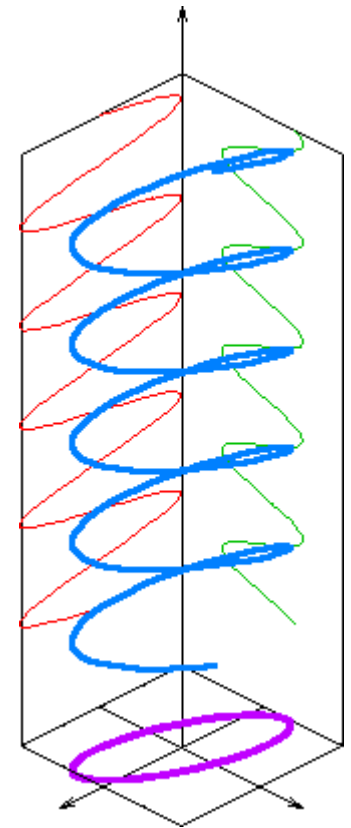
# Polarization



linear



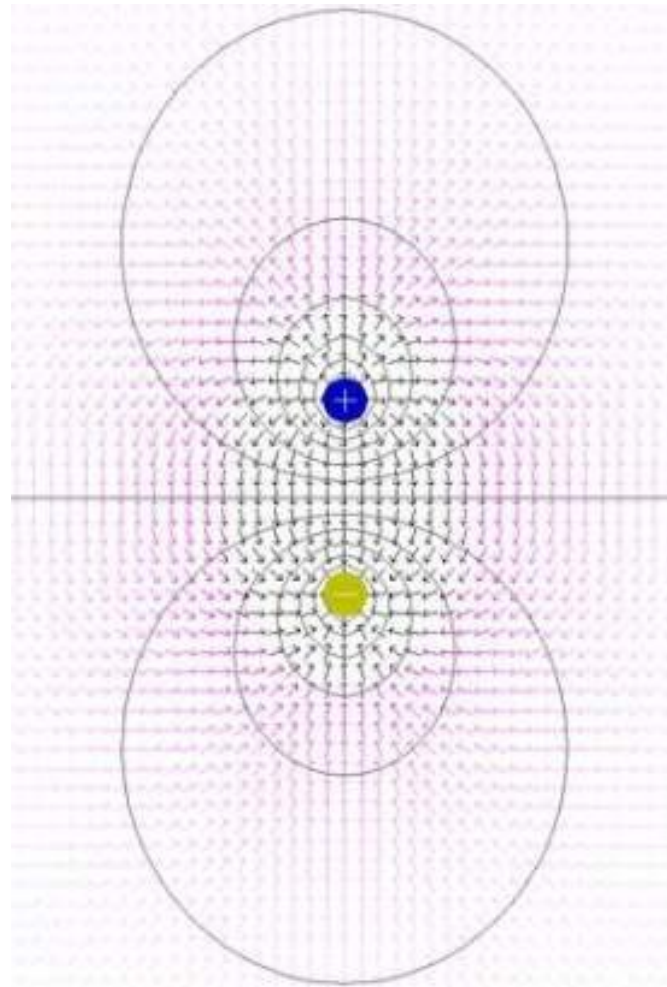
circular



elliptical

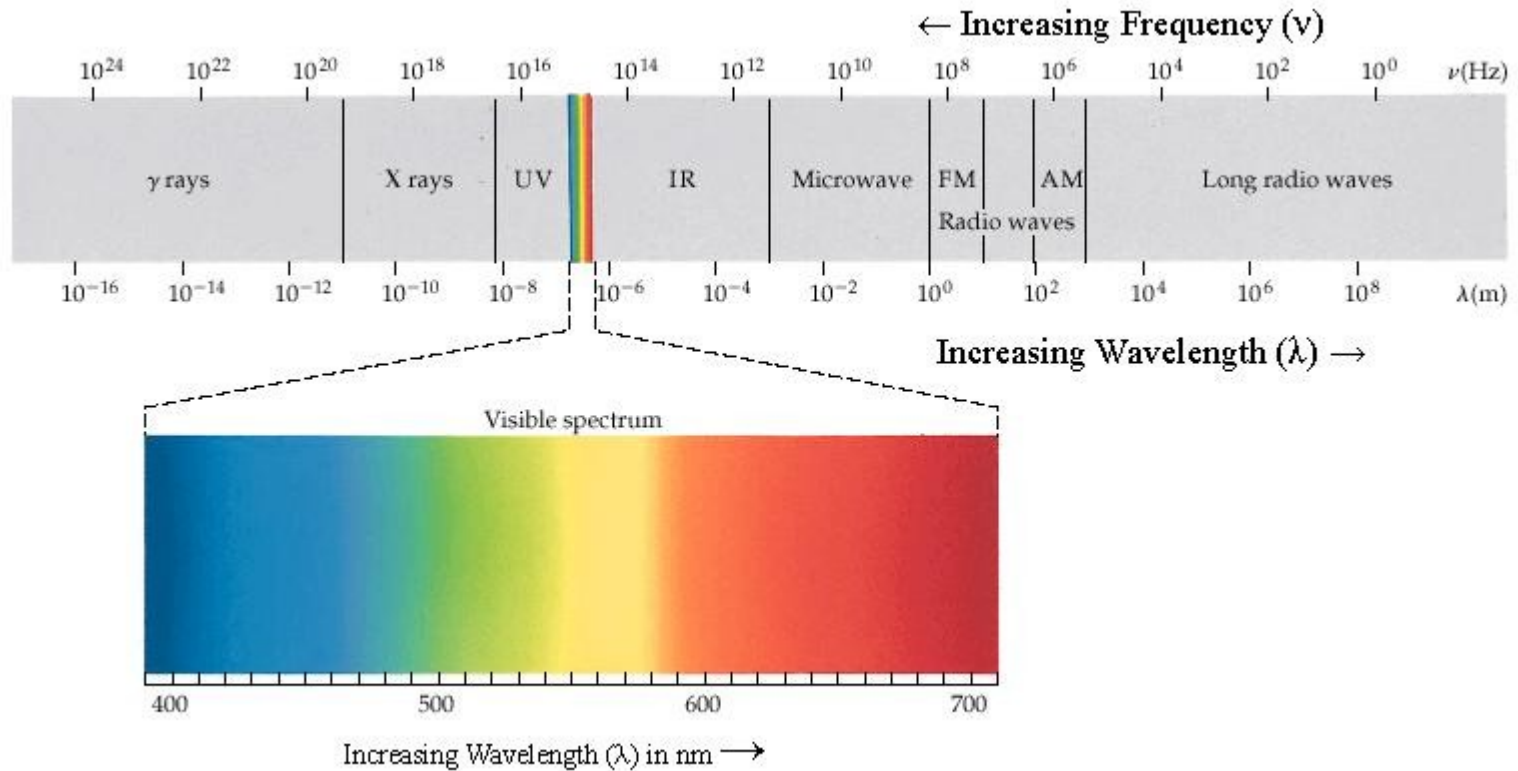
[Source: wikipedia.org]

# Dipole Radiation



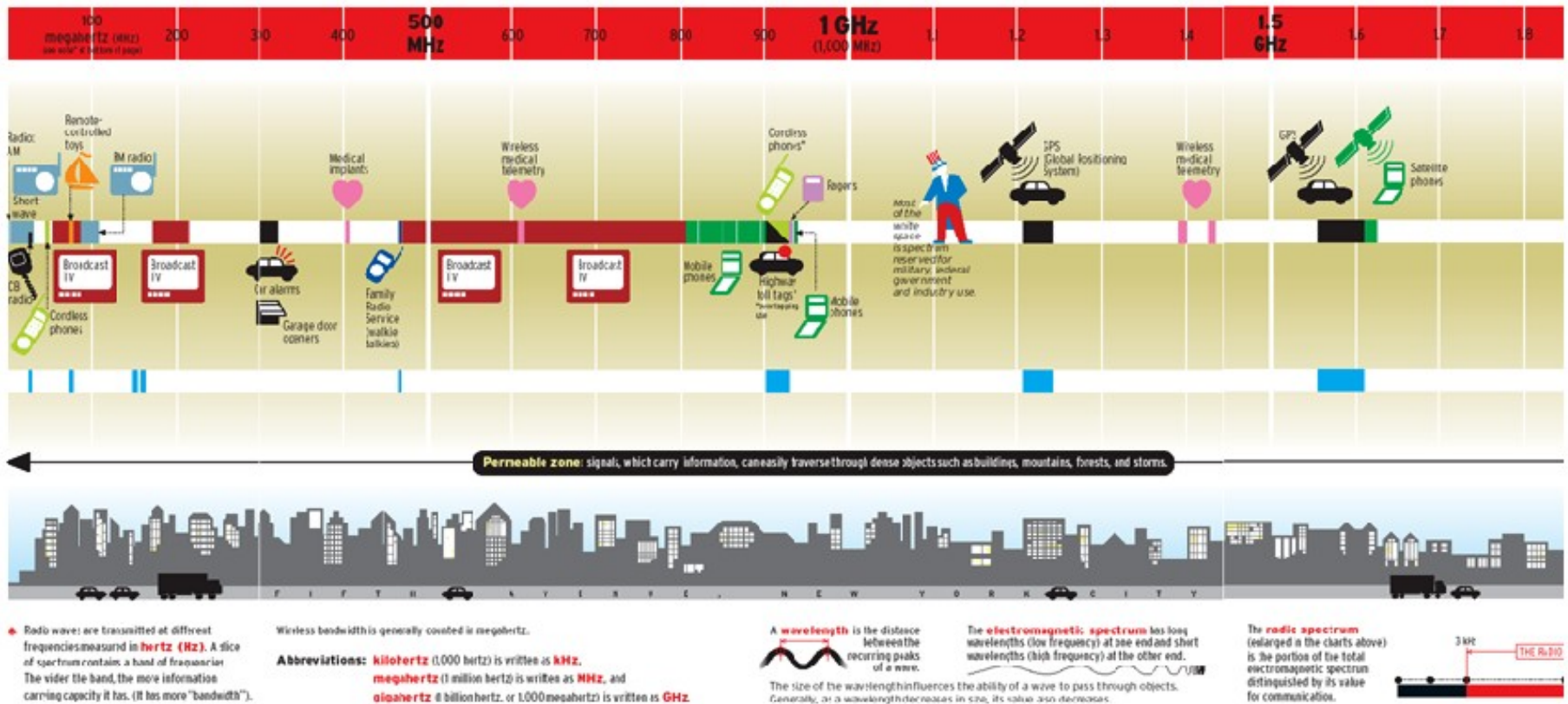
[Source: wikipedia.org]

# The Electromagnetic Spectrum



[Source: wikipedia.org]

# Use of Electromagnetic Spectrum



Radio waves are transmitted at different frequencies measured in **hertz (Hz)**. A slice of spectrum contains a band of frequencies. The wider the band, the more information carrying capacity it has. (It has more "bandwidth").

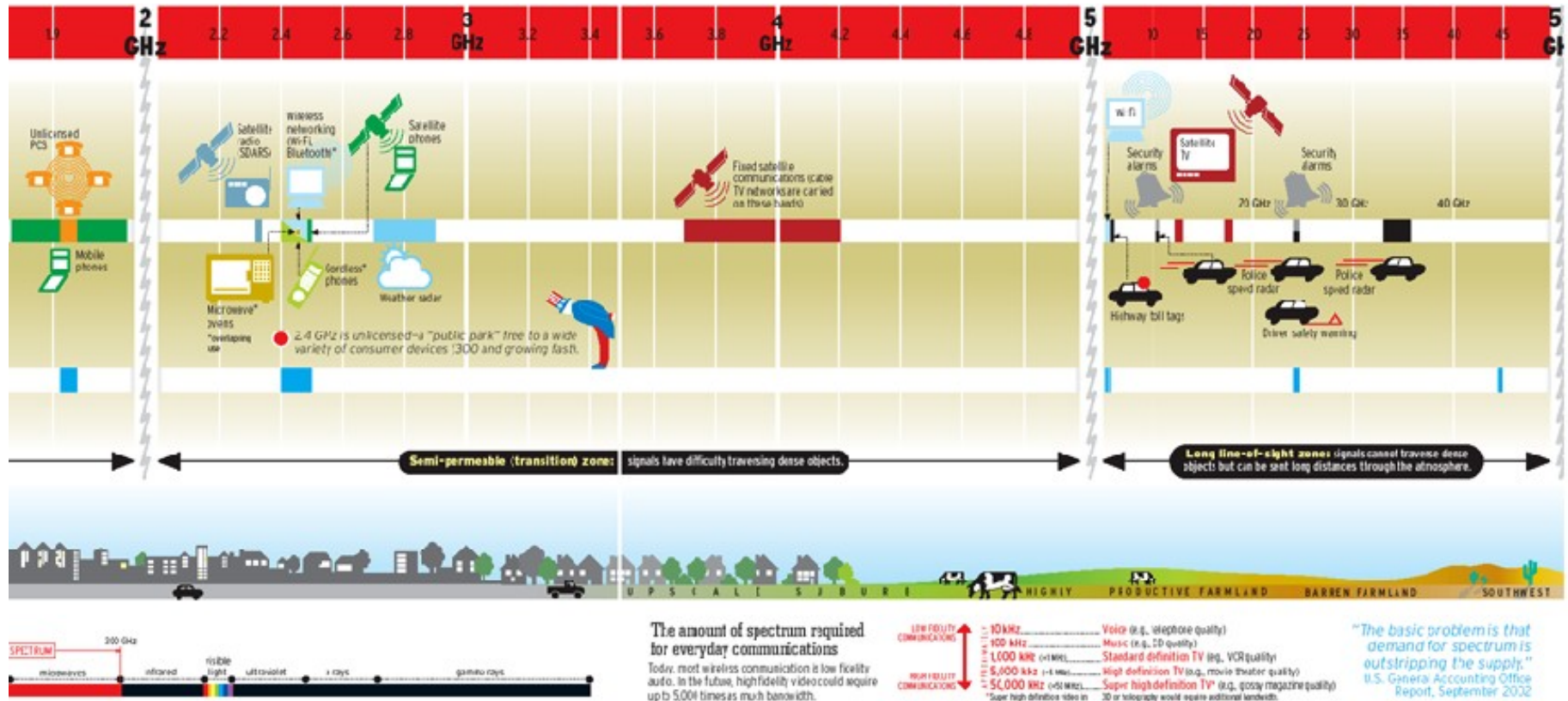
Wireless bandwidth is generally counted in megahertz.

**Abbreviations:** **kilohertz** (1,000 hertz) is written as **kHz**, **megahertz** (1 million hertz) is written as **MHz**, and **gigahertz** (1 billion hertz, or 1,000 megahertz) is written as **GHz**.

A **wavelength** is the distance between the recurring peaks of a wave. The size of the wavelength influences the ability of a wave to pass through objects. Generally, as a wavelength increases in size, its value also decreases.

The **radio spectrum** (enlarged in the charts above) is the portion of the total electromagnetic spectrum distinguished by its value for communication.

# Use of Electromagnetic Spectrum



# Frequencies in Wireless Networking

<i>Frequency</i>	<i>Standard</i>	<i>Wavelength</i>
2.4 GHz	802.11 b/g	12,5 cm
5.x GHz	802.11a	5-6 cm

# Propagation of Radio Waves

- Wavefronts
- Huygens principle
  - “At any point of a wave, spherical waves start”
- Radio waves are not strictly a straight line
- Electromagnetic waves are subject to a number of key effects

# Radio Wave Effects

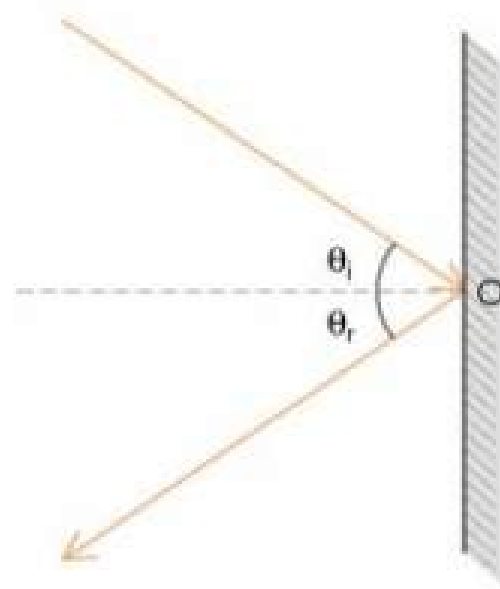
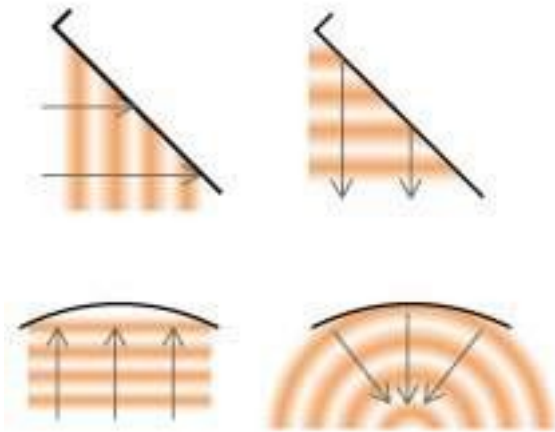
- Absorption
- Reflection
- Diffraction
- Refraction
- Interference

# Absorption

- Loss of energy to the medium that the wave is travelling through
- The power decreases exponentially
- An absorption coefficient [dB/m] is used to measure the loss
- Strong absorption
  - Metal and water (conducting materials)
  - Stones, bricks and concrete

# Reflection

- Metal and water surfaces
- Angle in = Angle out



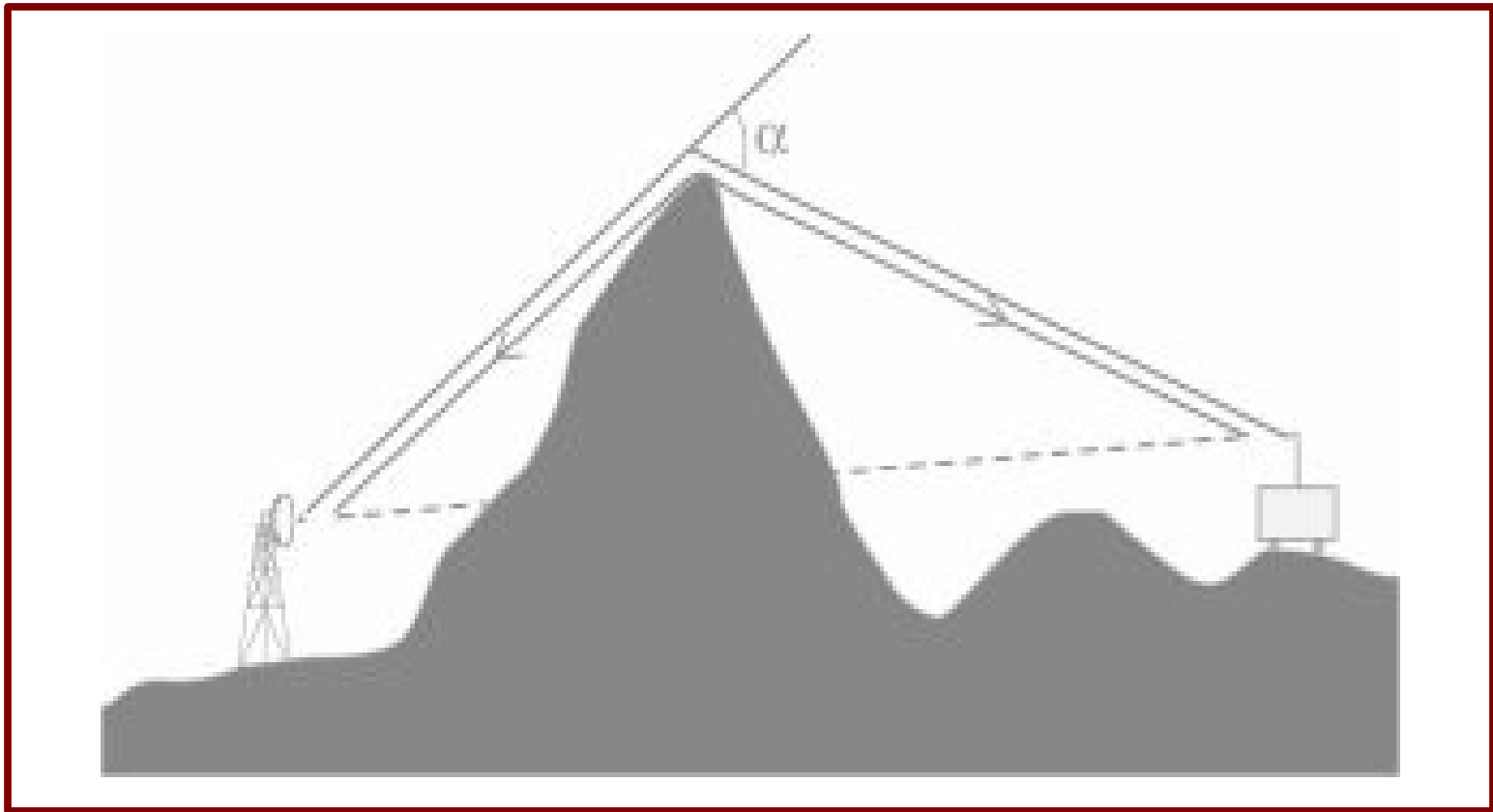
# Diffraction

- Waves do not propagate in a single direction
- Waves diverge into wider beams
- Implies that waves can be “bent” around corners
- Direct consequence of the Huygens principle
- Scales roughly with the wavelength

# Diffraction

- Waves bend easier the longer the wavelength
- AM Radio station operating at 100 kHz can easily be heard (  $\lambda = 3,000$  m)
- In wireless communication the wavelength is 12,5 cm

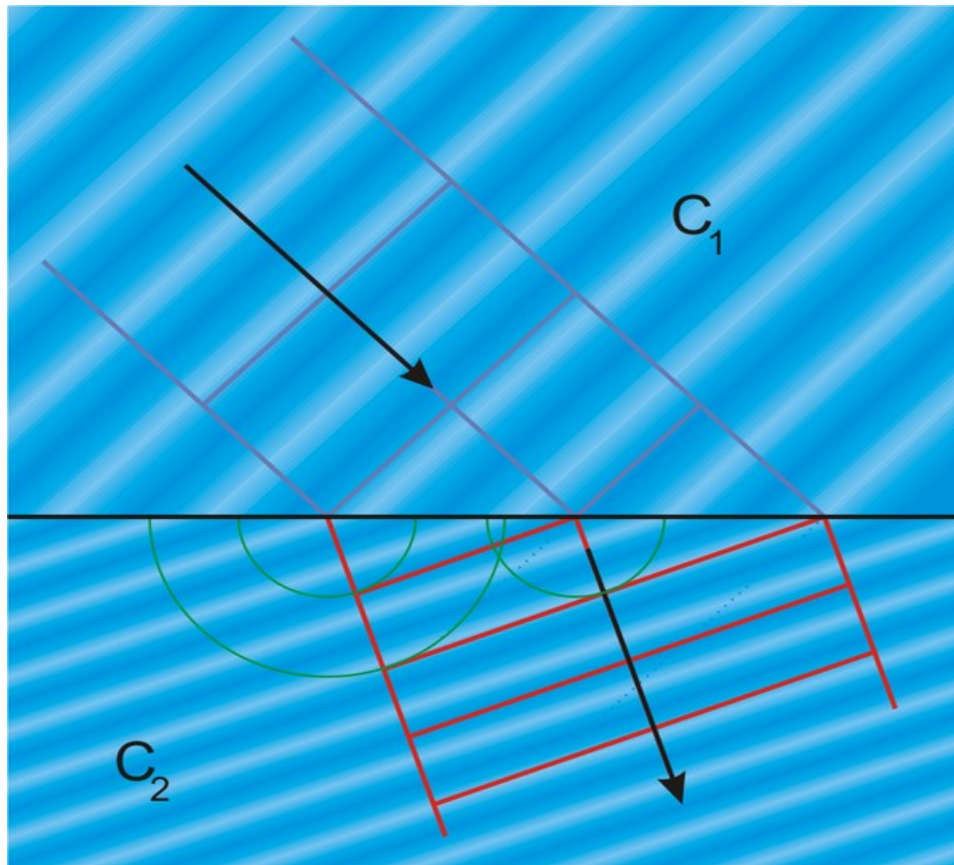
# Diffraction



# Refraction

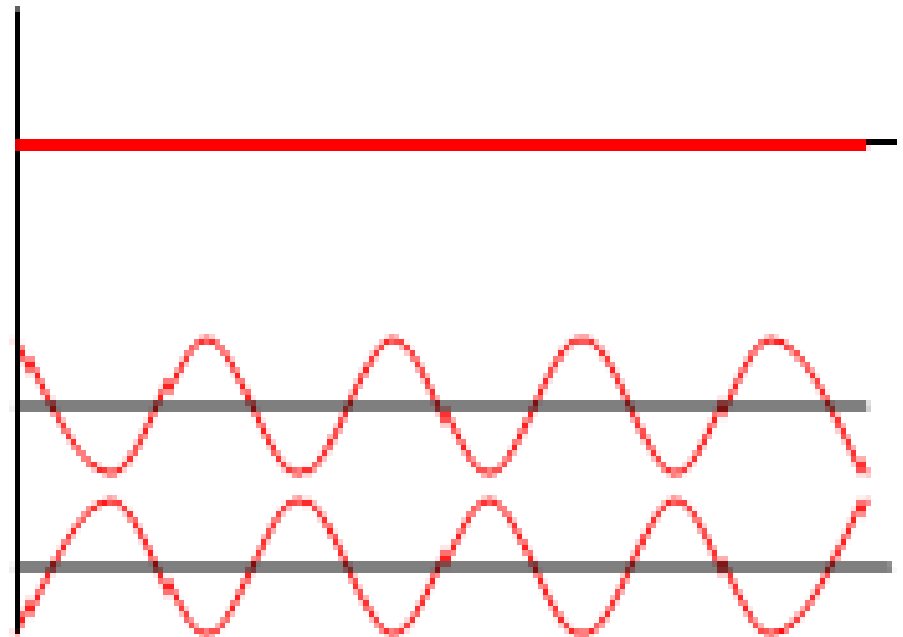
- The apparent “bending” of waves when they meet an obstacle with a different density
- A wave that moves from one medium to another of a different density, changes speed and direction when entering the new medium

# Refraction



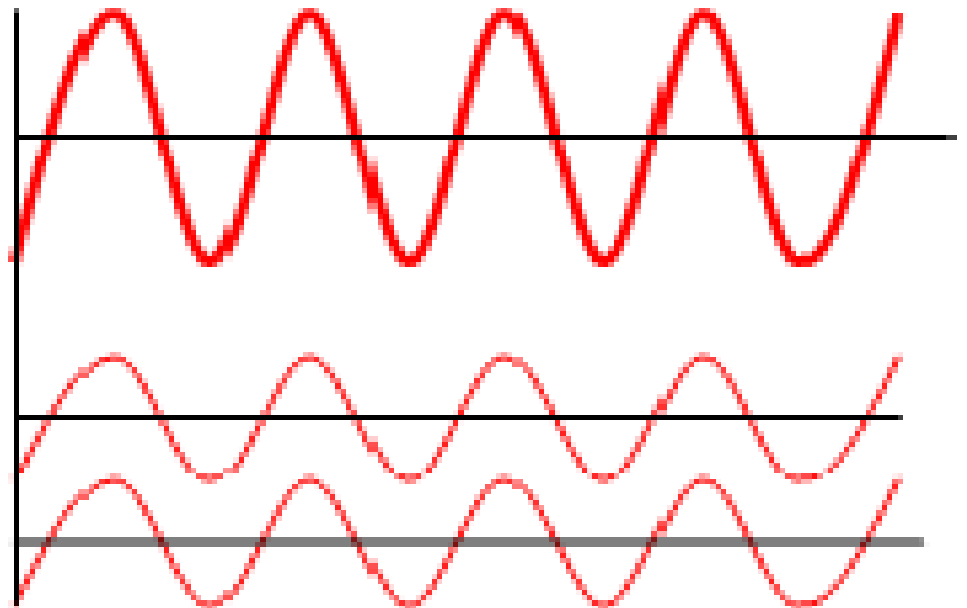
# Interference: Complete Annihilation

- Same frequency
- Fixed phase relation
- Same amplitude



# Interference: Maximum Amplification

- Same frequency
- Fixed phase relation



# Frequency Dependence Behaviour

- The lower frequency, the further it goes
- The lower frequency, the better it goes through and around things
- The higher frequency, the more data it can transport

# Radio Propagation in Free Space

- Free Space Loss (FSL)
- Fresnel Zones
- Line of Sight
- Multipath Effects

# Free Space Loss (FSL)

- Power loss is proportional to the square of the distance and proportional to the square of the frequency

$$\text{FSL(dB)} = 20\log_{10}(d) + 20\log_{10}(f) + K$$

d = distance

f = frequency

K = constant depending on the units used for d and f

# Free Space Loss (FSL)

**\*| F\***

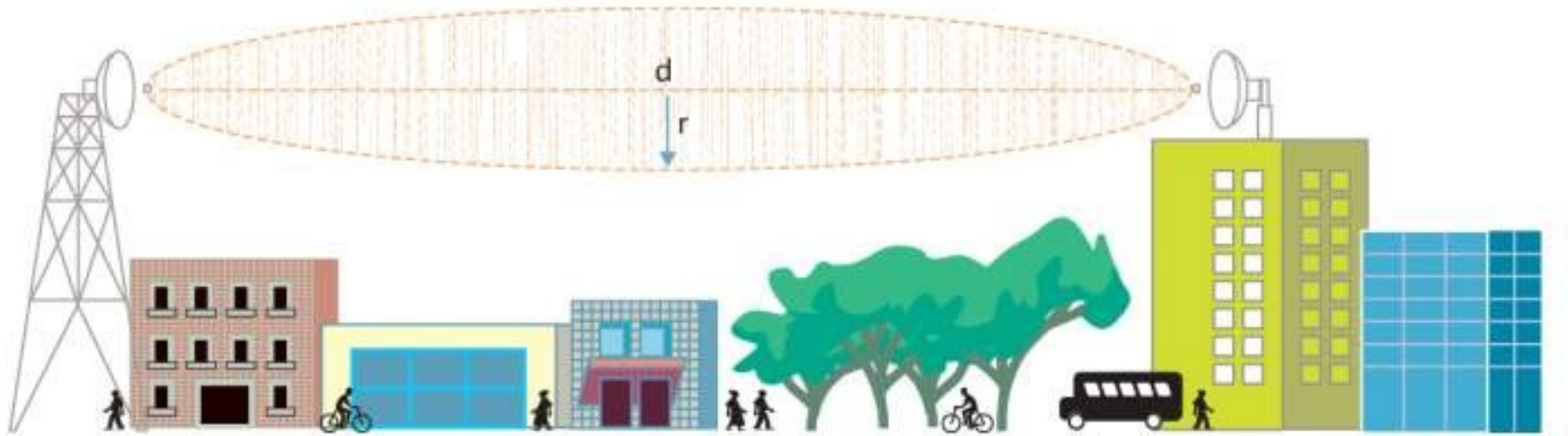
- d is measured in meters
- f is measured in Hz
- the link uses isotropic antennas

$$\text{FSL(dB)} = 20\log_{10}(d) + 20\log_{10}(f) - 147.5$$

# Free Space Loss (FSL)

- Rules of the thumb for 2.4 Ghz wireless networks:
  - 100 dB are lost in the first kilometre
  - 6 dB is reduced every time that the distance doubles
  - a 2 km link has a loss of 106 dB
  - a 4 km link has a loss of 112 dB

# Fresnel Zones



$$r = 17,32 * \sqrt{(d/4f)}$$

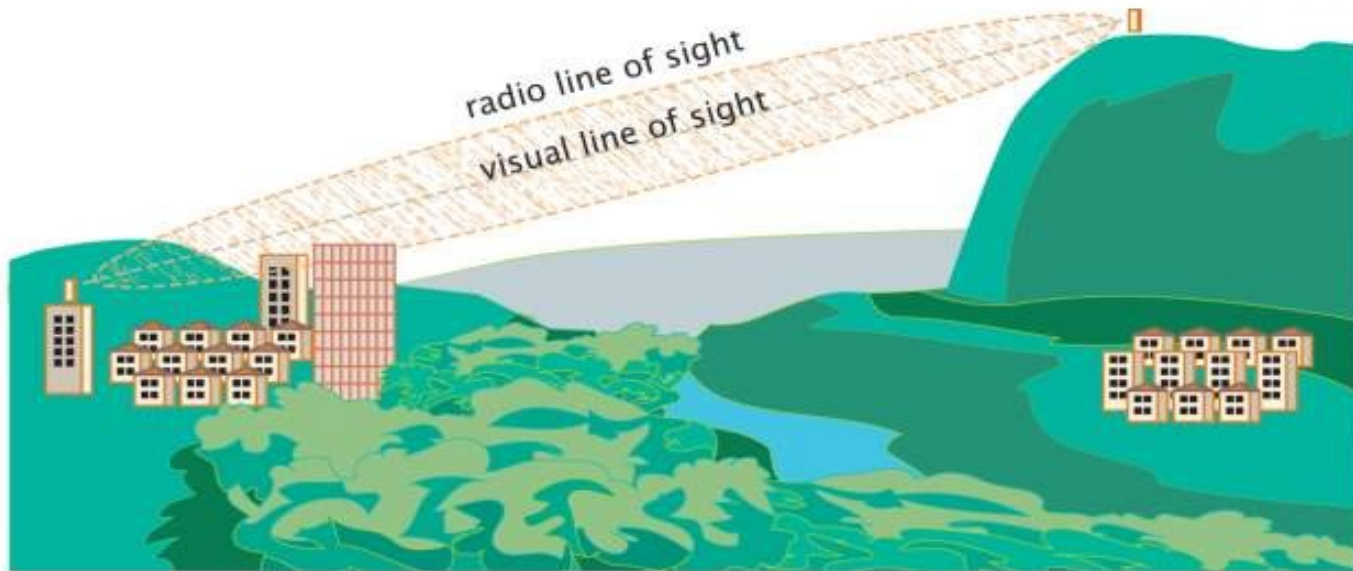
d = distance [km]

f= frequency [Ghz]

r= radius [m]

# Line of Sight (LOS)

In general, you need to have a free line of sight (LOS) for a radio link ... and bit of space around it.



# Multipath Effects

- A signal can reach a receiver via many paths
- Delays, partial modification and interference of signals can cause problems
- By taking advantage of multipaths, you can overcome the limits of line of sight
- MIMO is using multipath effects

# Where physics matters

1. When an access point is placed under a desk
2. When winter turns to spring
3. When it is rush hour in the city
4. When implementing very long distance links
5. When you need to tell marketing talk from the truth

# Example 1: Office network

- Typically had massively multipath conditions
- Problems with objects
  - People (water-filled moving objects)
  - Metal infrastructure (PCs, radiators, desks, CDs)
- The choice of locations and antennas is essential

## Example 2 : Winter turns to spring

- Regardless of your climate zone, factors like vegetation, humidity, rain will change
- Dry trees might be transparent but green trees are not

# Example 3: Rush hour in the city

- In urban environments, conditions can change dramatically with the hour
  - People (70% water), vans, cars, electromagnetic interference
- You should always verify on a monday what you measure on a sunday

# Example 4: Long Distance Links

- The travel time of the signal might lead to timeout and performance losses
- Depending on the hardware, this may become relevant already at 1-2 km
- A typical indicator of timeout problems is high packet loss in spite of a good radio signal

# Example 5: Marketing Talk

- An antenna or a radio device never has a reach or distance. Reliable parameters are:
  - Gain of the antenna
  - TX power of the radio card
- Even with WiMAX promising NLOS, microwaves still do not go through absorbing materials
  - Robust modulation techniques can let you “go round corners

# Conclusion

- We identified the carrier in wireless networking as electromagnetic waves in the GHz range.
- We understand the basics of wave propagation, absorption, reflection, diffraction, refraction and interference, and their implications.
- We can apply this knowledge to real life cases as well as to marketing lies.