# Basic Radio Physics

Developed by Sebastian Buettrich

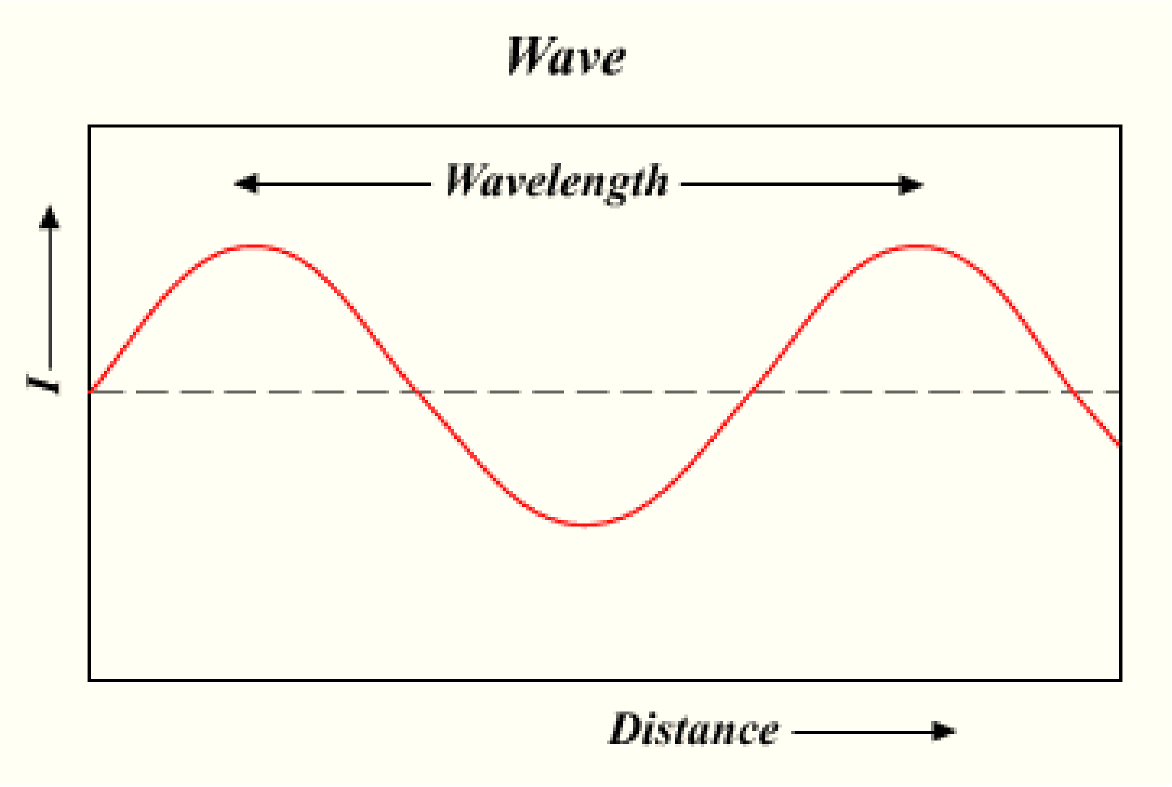
# Goals

- Understand radiation/waves used in wireless networking.
- Understand some basic principles of their behaviour.
- Apply this understanding to real life situations, specifications, installations.

# Electromagnetic waves

- Much like an air pressure wave can travel (that's sound!), an electromagnetic field can travel as an electromagnetic wave.
- Examples of electromagnetic waves are: light, X-rays, microwaves, radio waves.

# A wave




[image: from wikipedia.org]

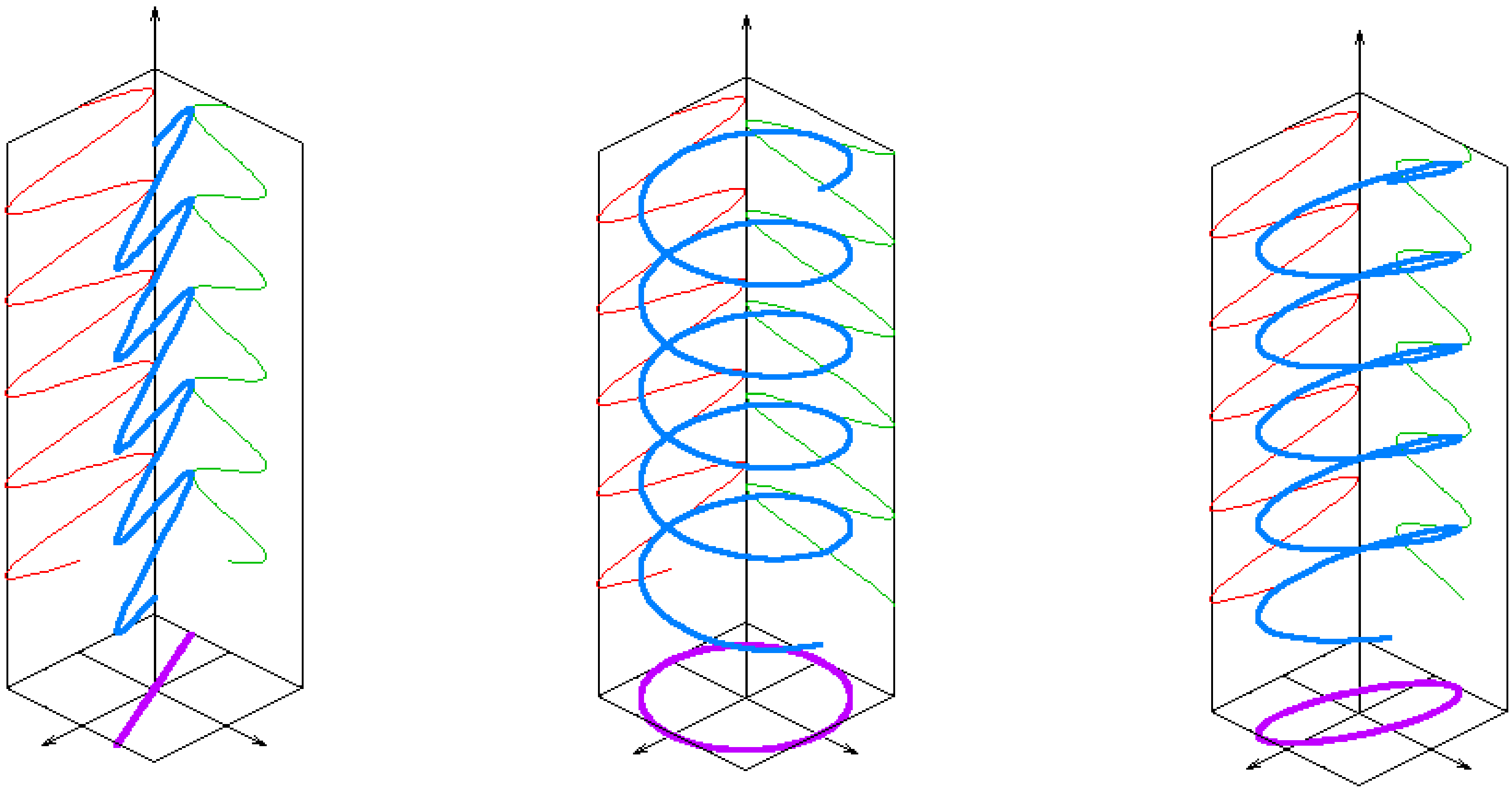
# Electromagnetic waves

- $c = \lambda * f$
- c is the speed of light ($3\times10^8$ m/s)
- $\lambda$ Lambda is the wavelength [in m]
- f is the frequency [1/s = Hz], also called $\nu$
- Light (or a radio signal) needs 1.3 seconds from the moon to earth, and 8 minutes from the sun, and 300 microseconds (0.3 milliseconds) for 100 km.

# Powers of ten

| | | | | |
|---|---|---|---|---|
| • Micro- | **$10^{-6}$** | **1/1000000** | **μ** | |
| • Milli- | $10^{-3}$ | 1/1000 | | 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 |

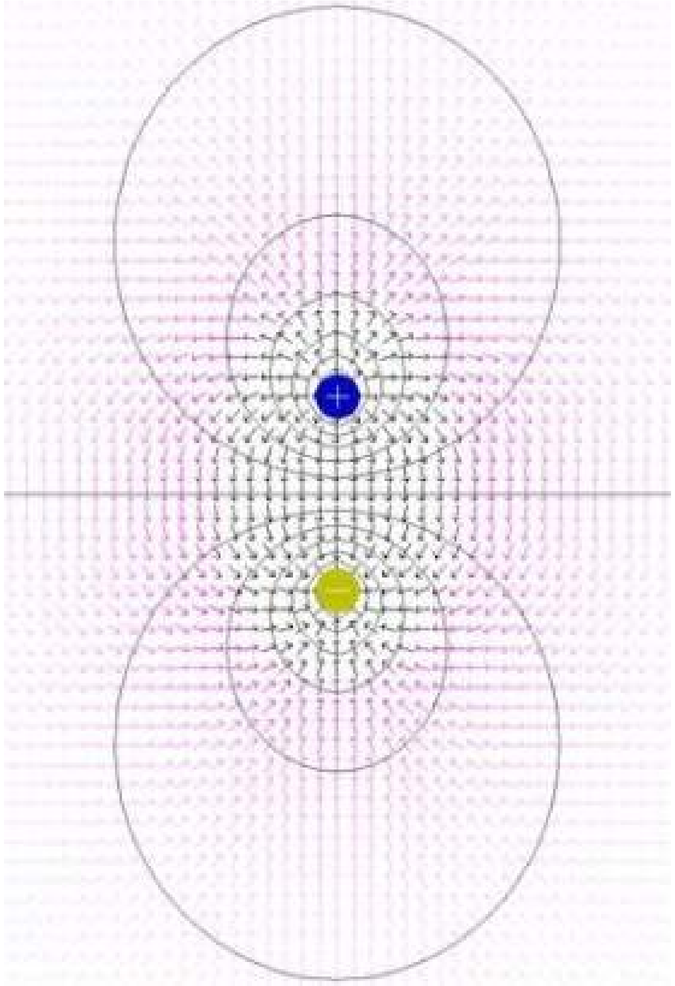
# Electromagnetic waves: polarization



linear circular elliptical polarization

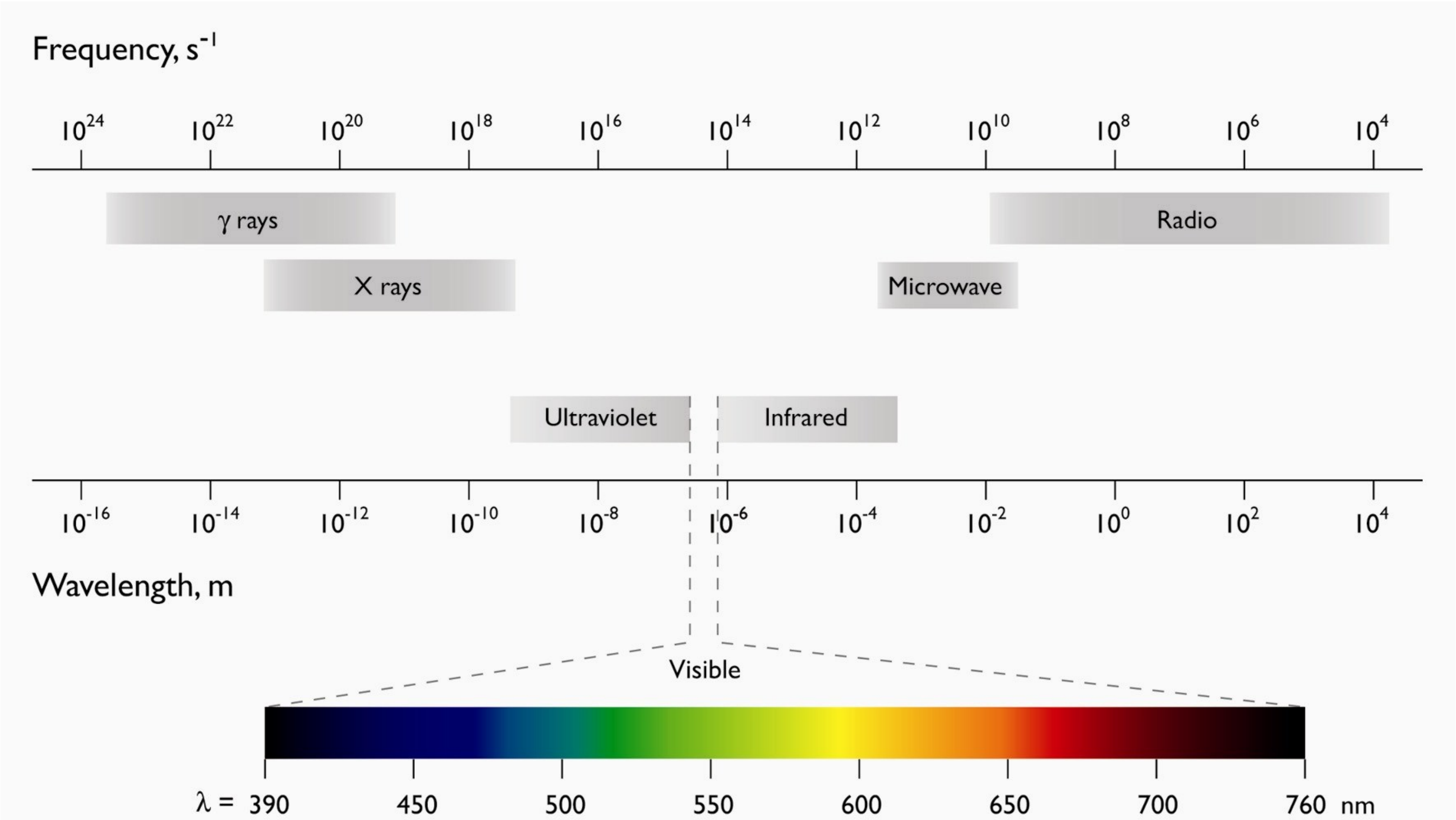
[image: from wikipedia.org]

# Example: Dipole

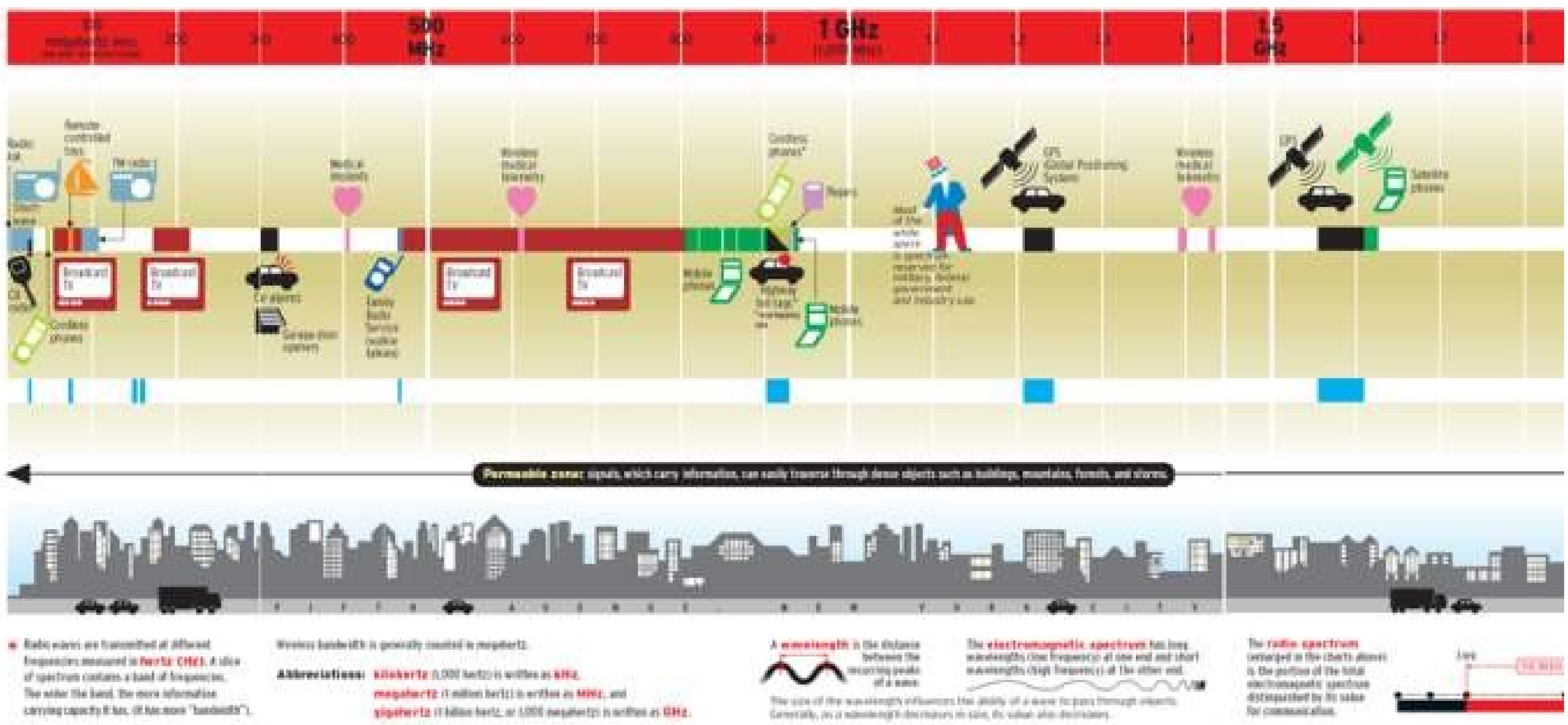


[image: from wikipedia.org]

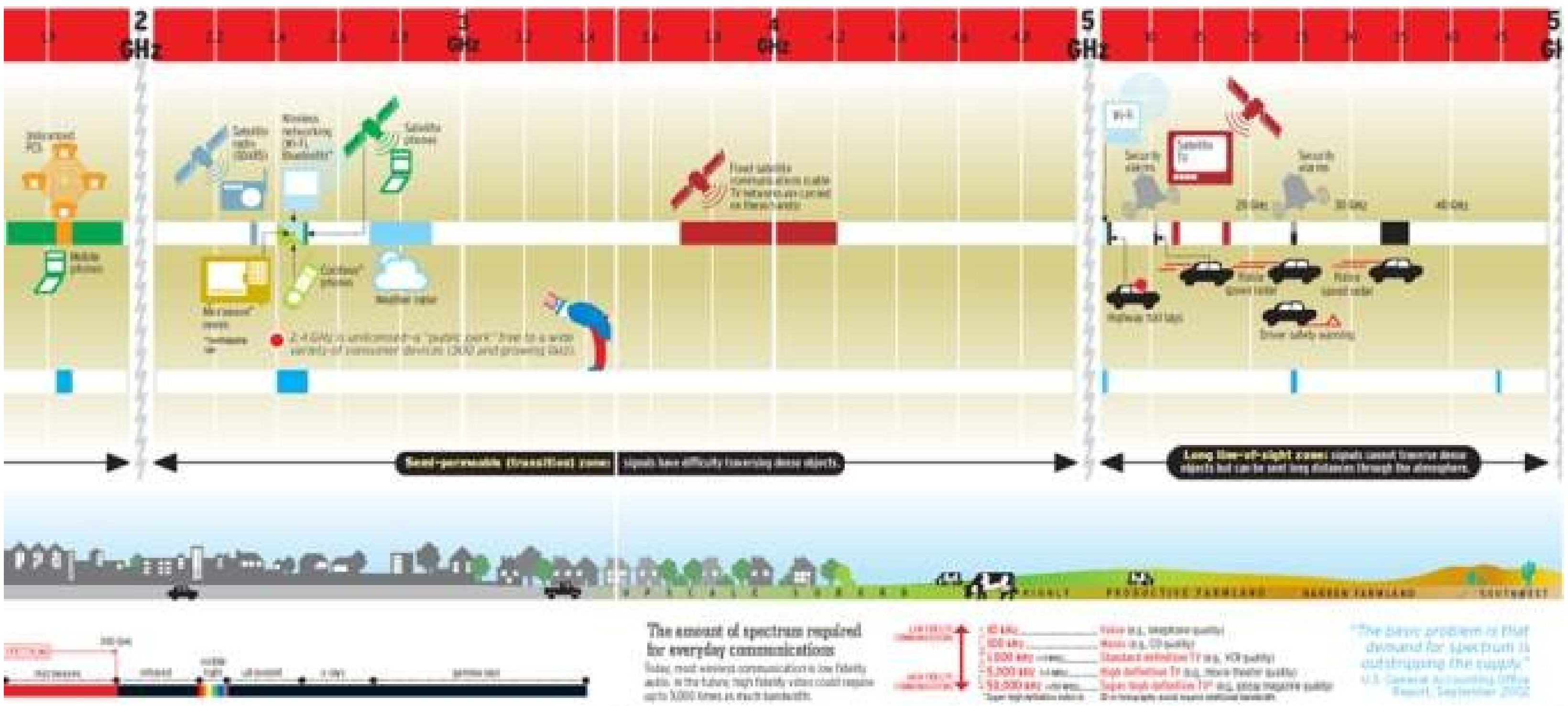
# Electromagnetic spectrum



# Use of electromagnetic spectrum



# Use of electromagnetic spectrum

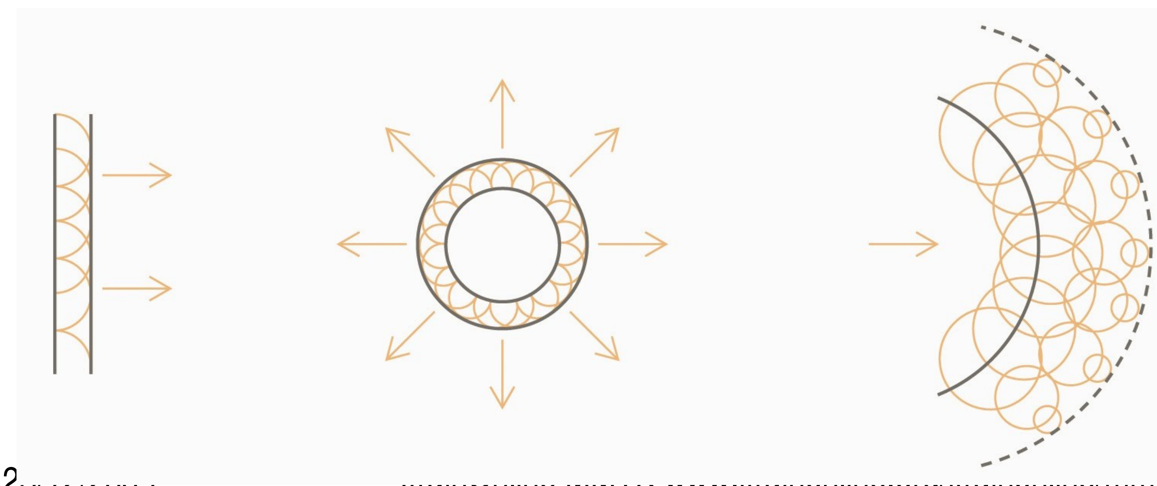


# Frequencies in wireless networking

- Focus on the ISM (Industry-Science-Medicine bands - license exempt) bands at
  2.4 Ghz 802.11b/g $\lambda$=12 cm
  5.x Ghz 802.11a $\lambda$=5...6 cm
- Other relevant frequency ranges:
  915 Mhz
  3.5 GHz
  ...

# Propagation of radio waves

- Wavefronts
- Huygens principle: at any point,
  spherical waves start
- Radio waves (just like light) are not strictly a straight line
- Radio waves need no medium



# Radio waves

- Absorption
- Reflection
- Diffraction
- Interference

# Radio waves: absorption

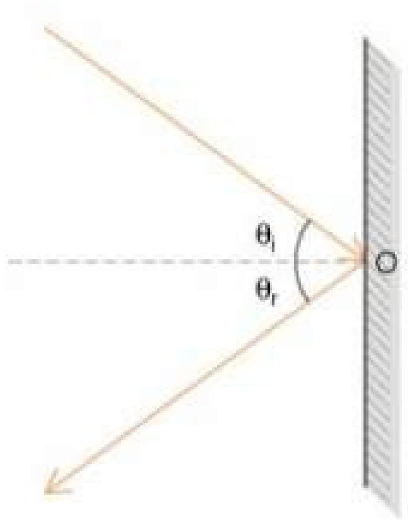
- Metal
- Water (rain, fog, water pipes, ...)

- Stones, bricks, concrete
- Wood, trees

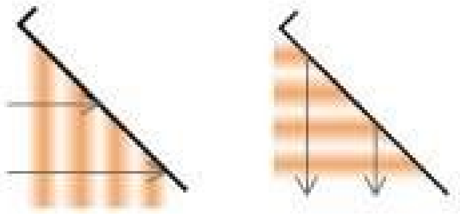
- People: see water :)
- Power decreases exponentially in medium: linear decrease in dB

# Radio waves: reflection

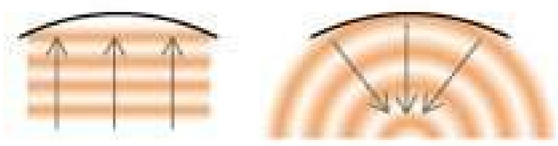
- Reflection of microwaves predominantly by metal surfaces, but also e.g. water surfaces
- angle in = angle out




e.g. plane reflector

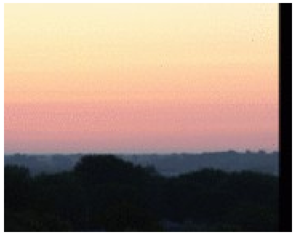


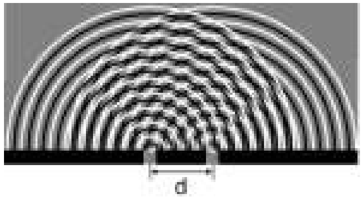
parabolic reflector

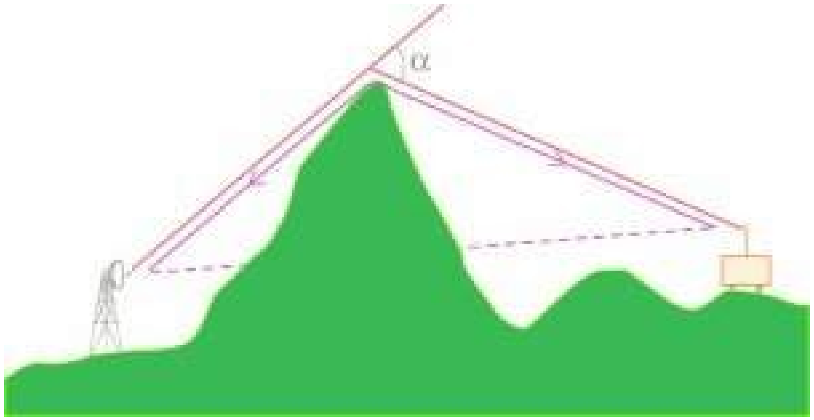


# Radio waves: diffraction

- Diffraction is the apparent bending and spreading of waves when they meet an obstruction. Scales roughly with wavelength.
- Reason: Huygens principle

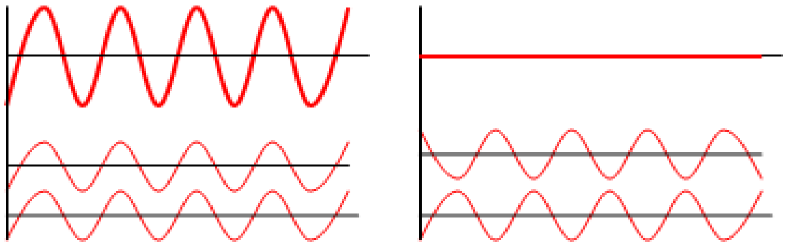




# Radio waves: interference

- Waves can annihilate each other, so that 1 + 1 = 0.



In wireless technology, the word *interference* is typically used in a wider sense, for disturbance through other RF sources, e.g. neighbouring channels.

# Radio waves: frequency dependence of behaviour

- *Rules of thumb:*

  the longer the wavelength, the further it goes

  the longer the wavelength, the better it goes through and around things

  the shorter the wavelength, the more data it can transport

# Radio propagation in free space

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

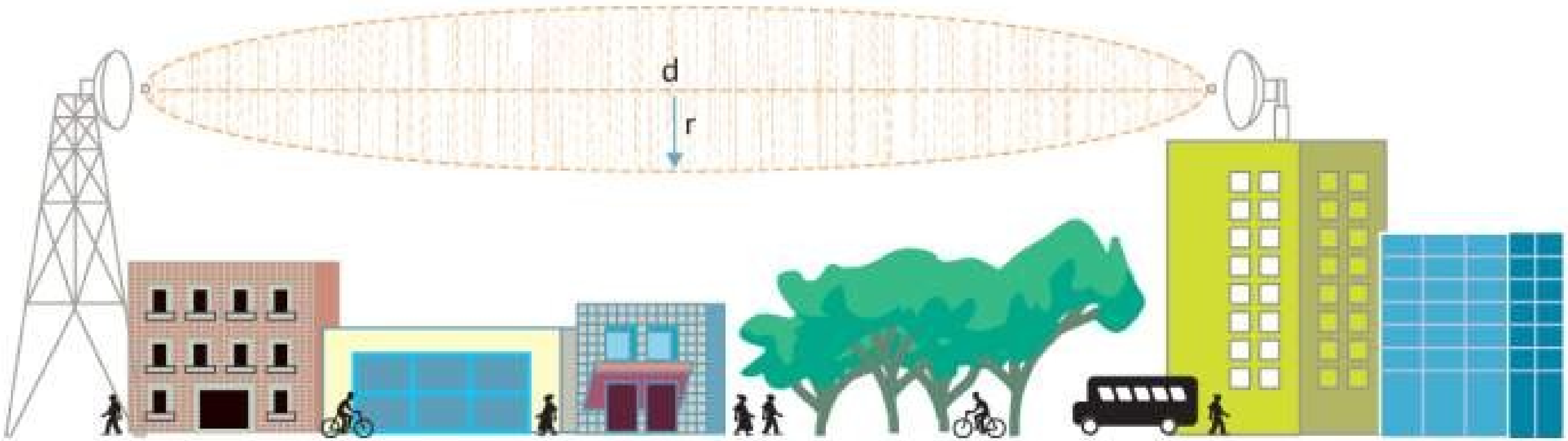
# Free space loss

- Power loss s proportional to the square of the distance and also proportional to the square of the radio frequency – in dB:

***FSL [dB]****= C + 20 * Log(D) + 20 * Log(F)*

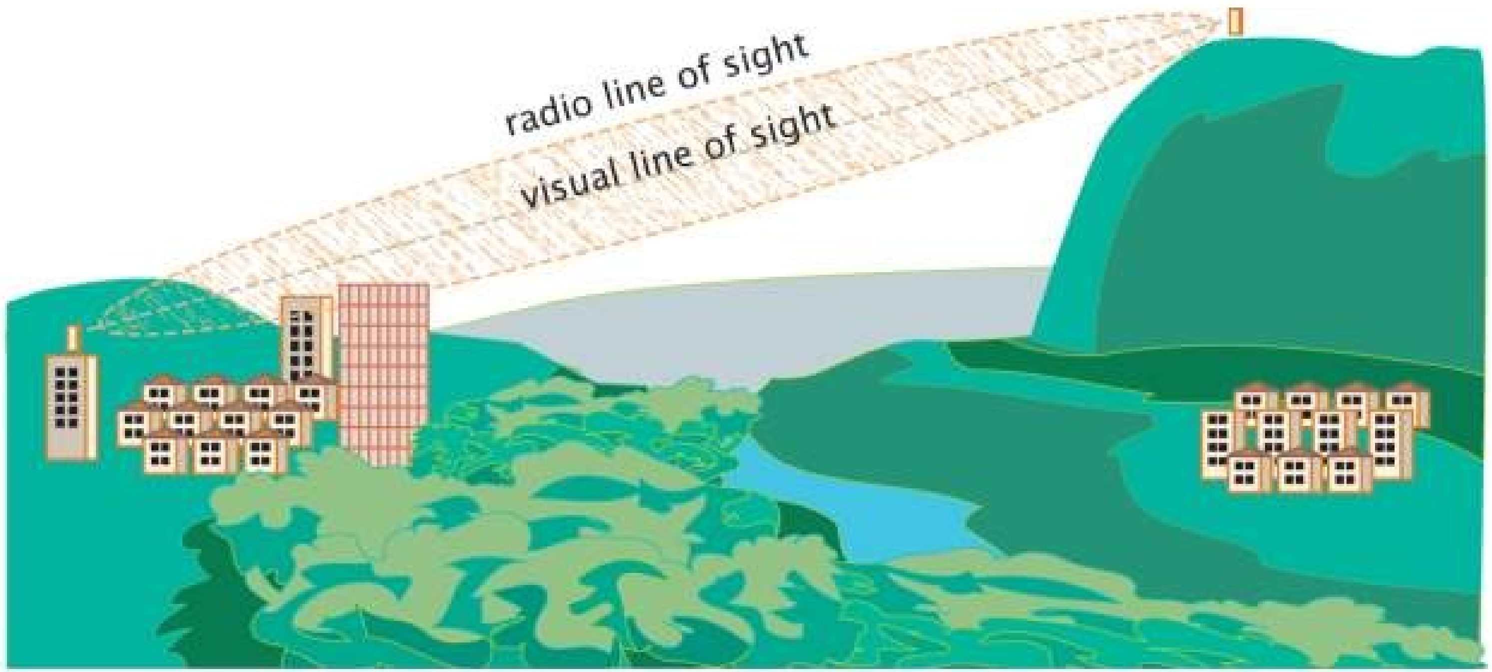
*D distance, and F frequency [MHz].*
*The constant C is 36.6 if D is in miles, and 32.5 if D is in kilometers.*

# Fresnel zones



# Line of sight

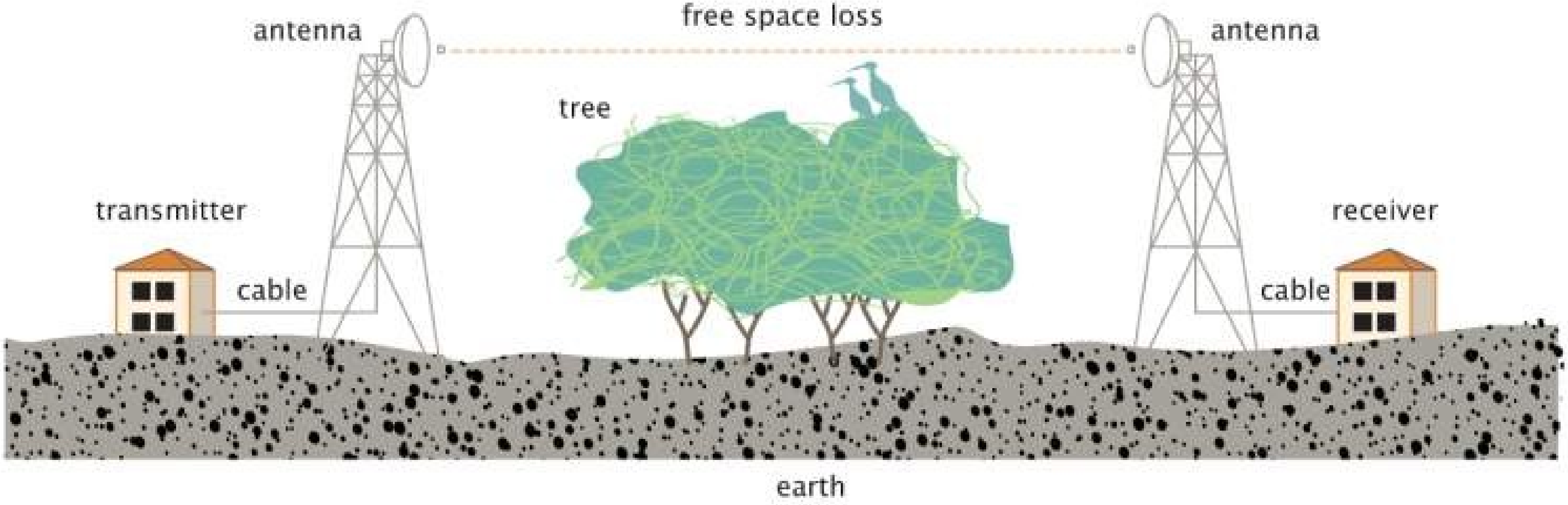
- *In general, you need to have a free line of sight (LOS) for a radio link ... and  bit of space around it.*



# Multipath effects

- Source: the same signal can reach the receiving side on many different paths – via reflection etc.
- Delays, partial modification and interference of signals can cause problems
- Taking advantage of multipath in order to overcome the limits of line of sight: Non Line of Sight (NLOS) links

# Example: a full transmission path



# The dB

- Definition: 10 * Log ($P_1$ / $P_0$)
- Important to remember:
  3 dB = double power
  10 dB = order of magnitude = x 10
- Relative dBs:
  dBm = relative to 1 mW
  dBi = relative to ideal isotropic antenna
- Calculation in dBs is standard in the planning of wireless systems, e.g making link budgets

# The dB: examples

- 1 mW = 0 dBm
- 100 mW = 20 dBm
- 1 W = 30 dBm

- “An omni antenna with 6 dBi gain”
- “A cable (RG213) with 0.5 dB/m loss”

# Transmit (Tx) power

- The output power of a radio card
- Example from a 802.11a/b card datasheet:

Output Power:
802.11b: 18 dBm (65 mW) peak power
802.11a: 20 dBm (100 mW) peak power

# Receive sensitivity

- Received power needed by a radio card to function properly
- Example from a 802.11b card datasheet

  Receive Sensitivity:

  1 Mbps: -95 dBm

  2 Mbps: -93 dBm

  5.5 Mbps: -91 dBm

  11 Mbps: -89 dBm

# Where physics matters

- Always!
  ... and especially ...

- when an access point is placed under a desk
- when winter turns to springtime ...
- when it is rush hour in the city ...
- when doing very long distance links (speed of light!)
- when you need to tell marketing talk from truth

# Examples: office network

- Offices typically have massively multipath conditions
- Problem objects: people :), metal infrastructure (computers, radiators, desks, even CDs!)
- Choice of locations and antennas essential

# Examples: when winter turns to spring ...

- Regardless of your climate zone, factors like vegetation, humidity, rain etc change with the seasons!
- Dry trees might be transparent, green trees are not!

# Examples: when it's rush hour in the city

- In urban environments, conditions change with the hour ... people, vans, cars, electromagnetic interference...
- You should verify on a monday what you measure on a sunday :)

# Examples: when speed of light comes into play

- Standard implementations of 802.11_ standards set time-out windows: PCF, DIFS, SIFS ...
- For long distance links, the travel time of the signal might lead to timeout and performance losses
- Depending on hardware, this may become relevant already at 1-2 kilometers, and for 100 kms, you will sure have to consider it.
- Typical indicator of time out problems:
  high packet loss in spite of a good radio signal

# Examples: looking through marketing talk, e.g. .....

- One antenna or radio device NEVER has a *reach* or *distance ... that is one hand clapping!*
- Even with WIMAX promising *NLOS* (Non line of sight), microwaves still do not go through absorbing materials.

# Further reading: URLs

- The best starting point is the articles at http://www.wikipedia.org and the links you find there!

# Conclusion

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