

Basic Radio Physics

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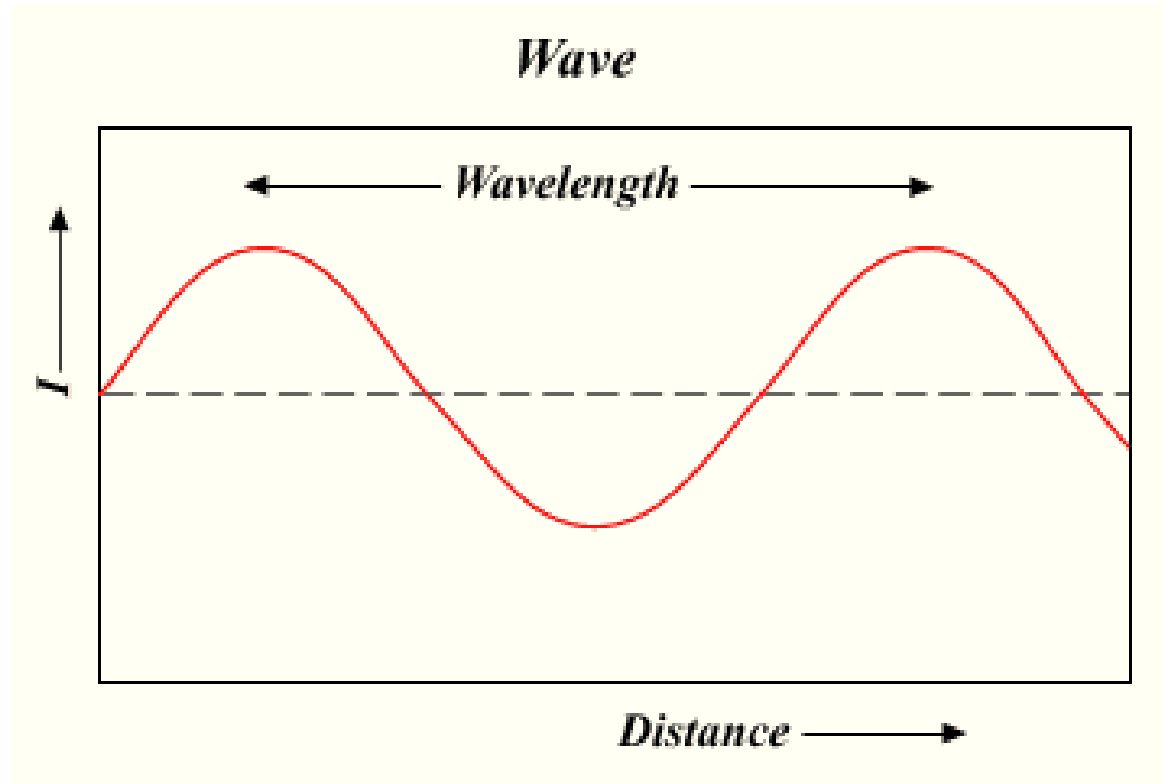
Goals

- 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]

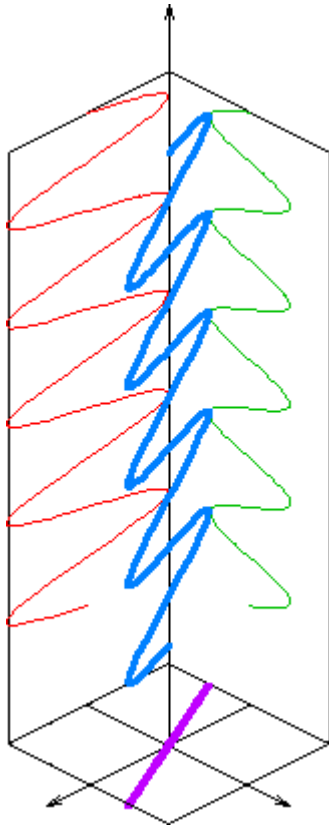
Electromagnetic waves

- $c = \lambda * f$
- c is the speed of light (3×10^8 m/s)
- λ Lambda is the wavelength [in m]
- f is the frequency [$1/s = \text{Hz}$], also called ν
- 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.

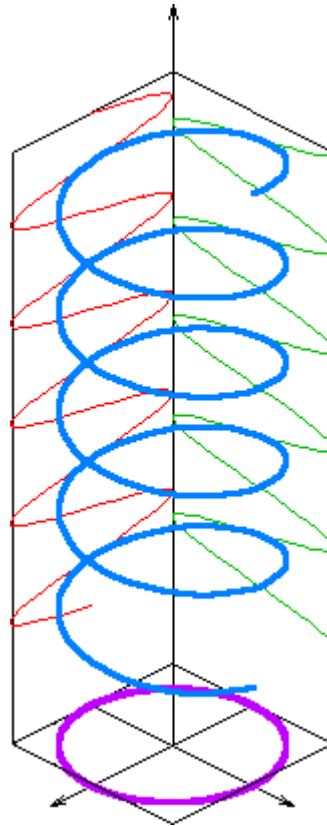
Powers of ten

• 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

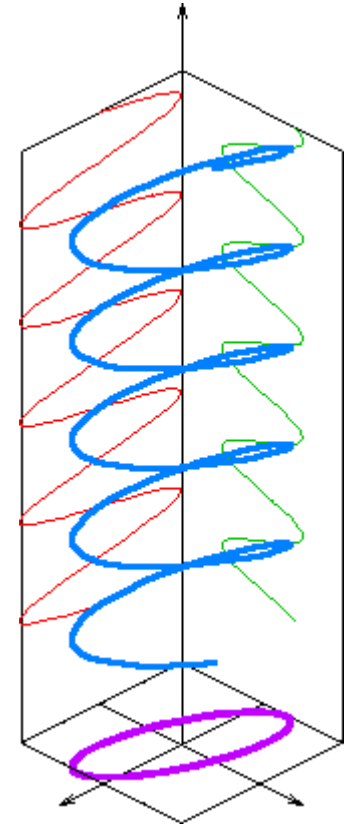
Electromagnetic waves: polarization



linear

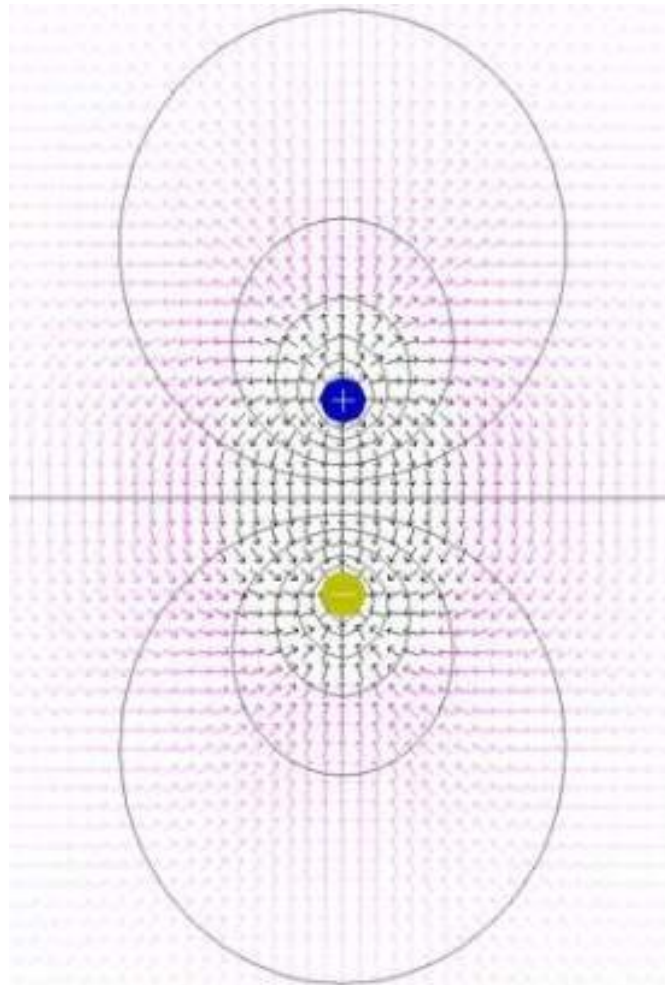


circular

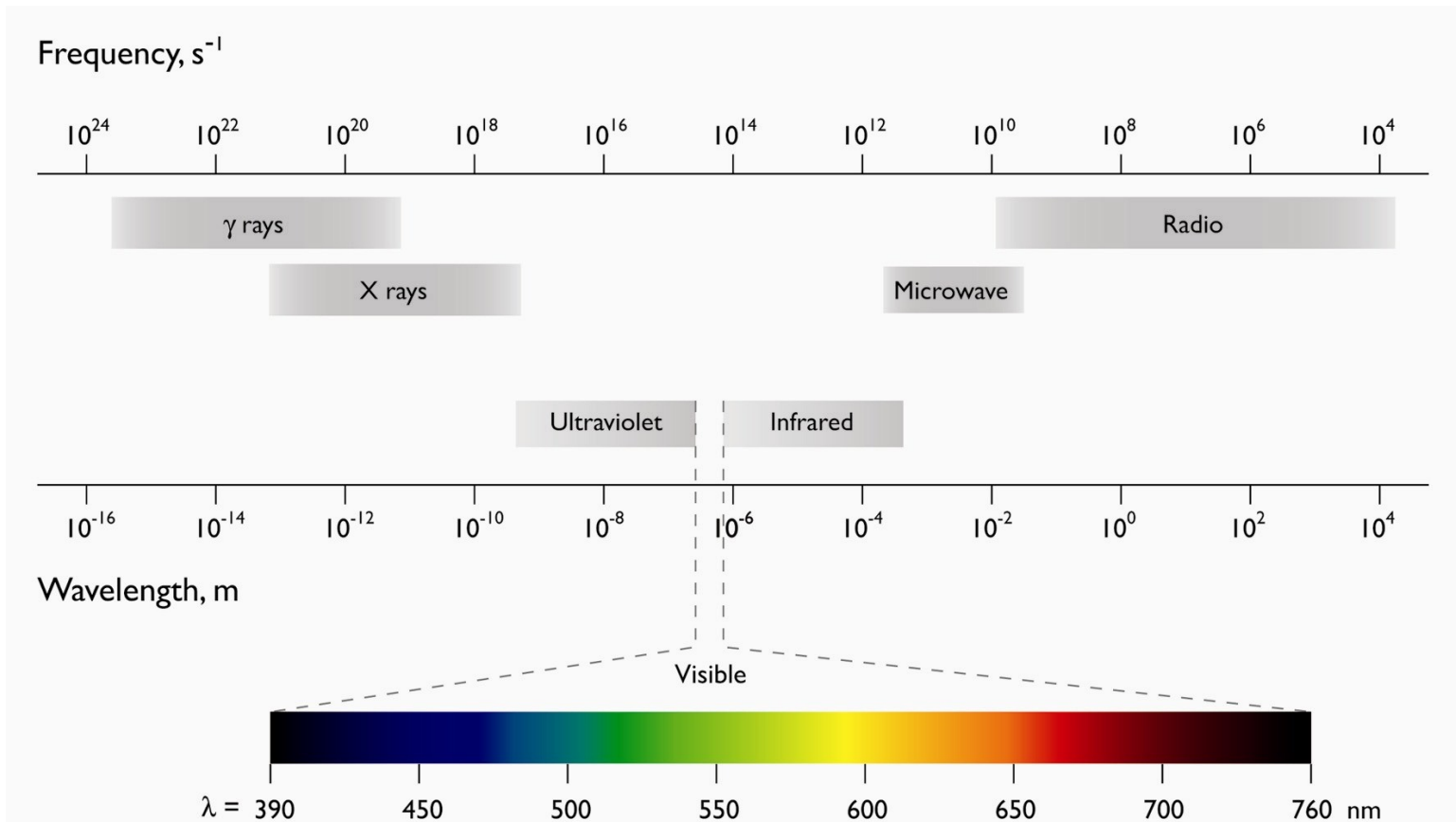


elliptical polarization

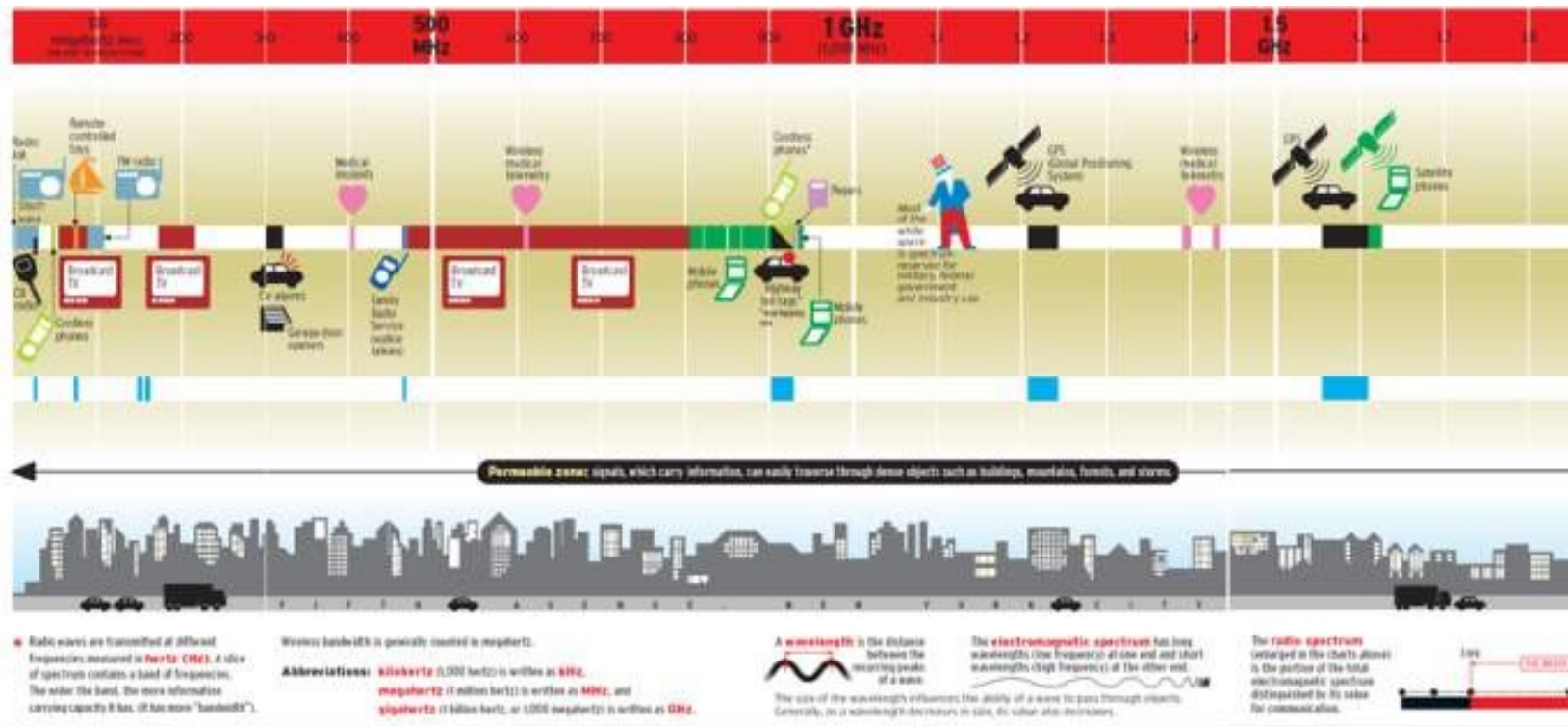
Example: Dipole



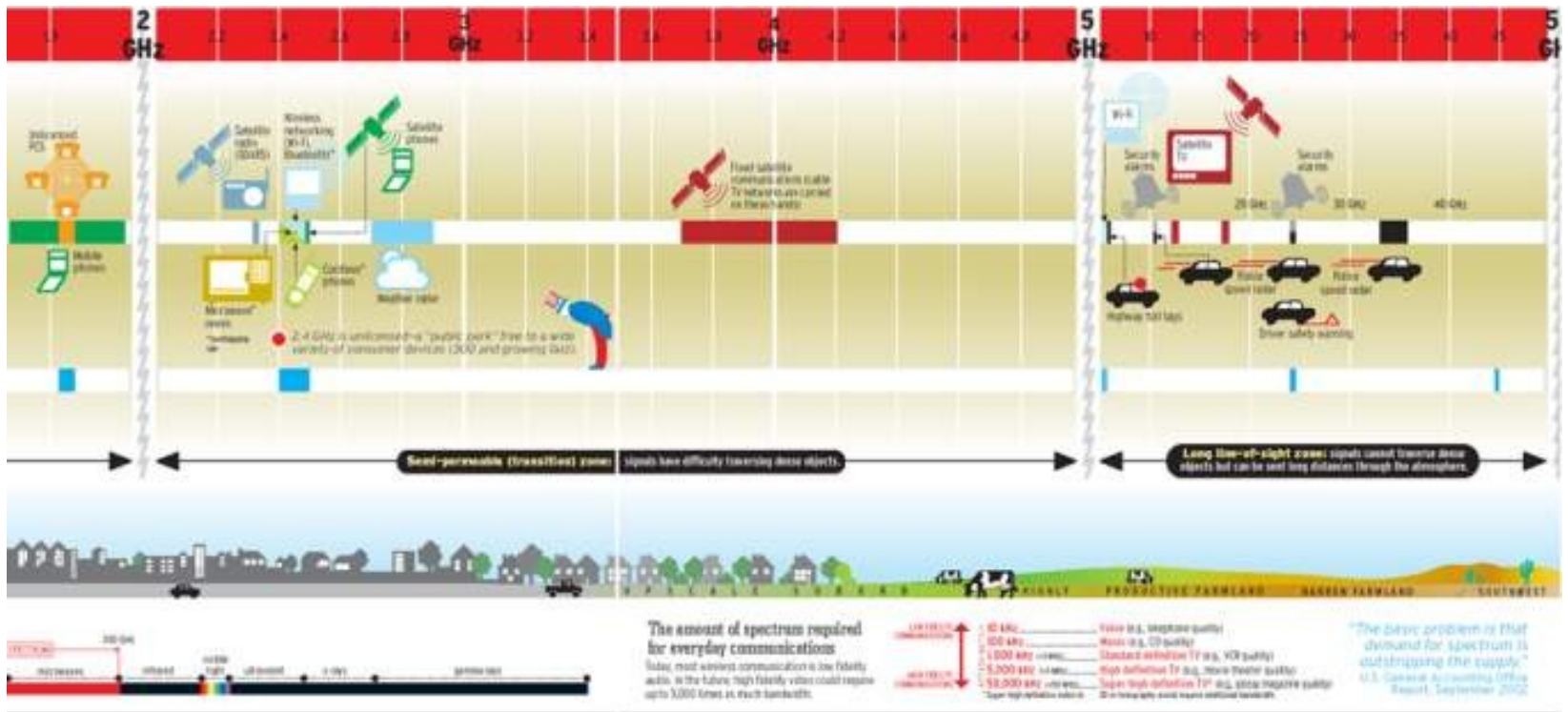
Electromagnetic spectrum



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:

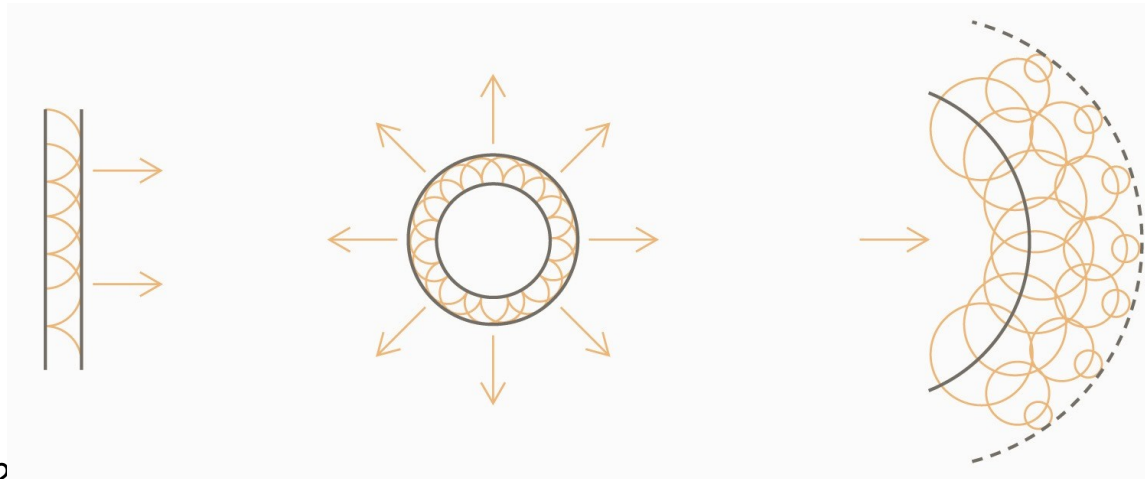
915 Mhz

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

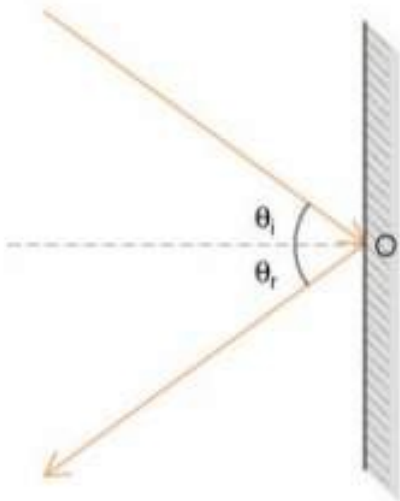
- Absorption
- Reflection
- Diffraction
- Interference

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

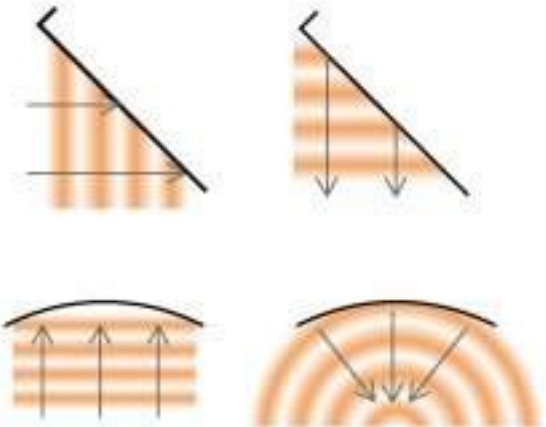
Radio waves: reflection

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



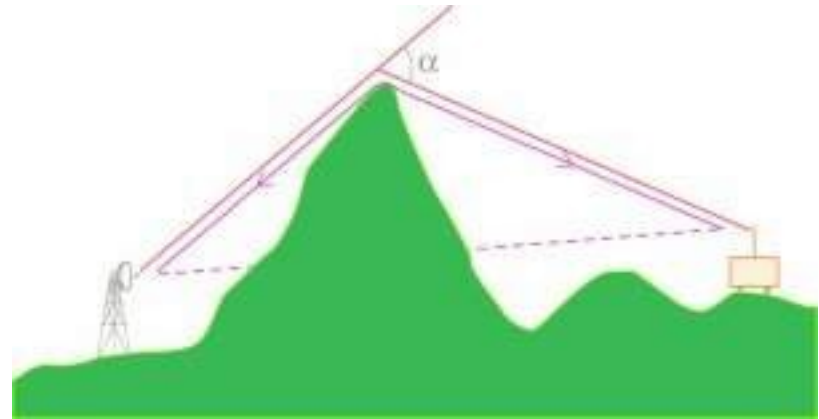
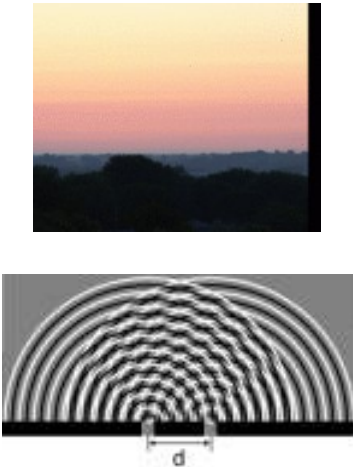
e.g. plane reflector

parabolic reflector



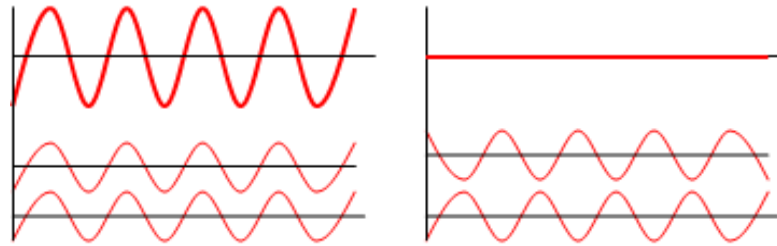
Radio waves: diffraction

- 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

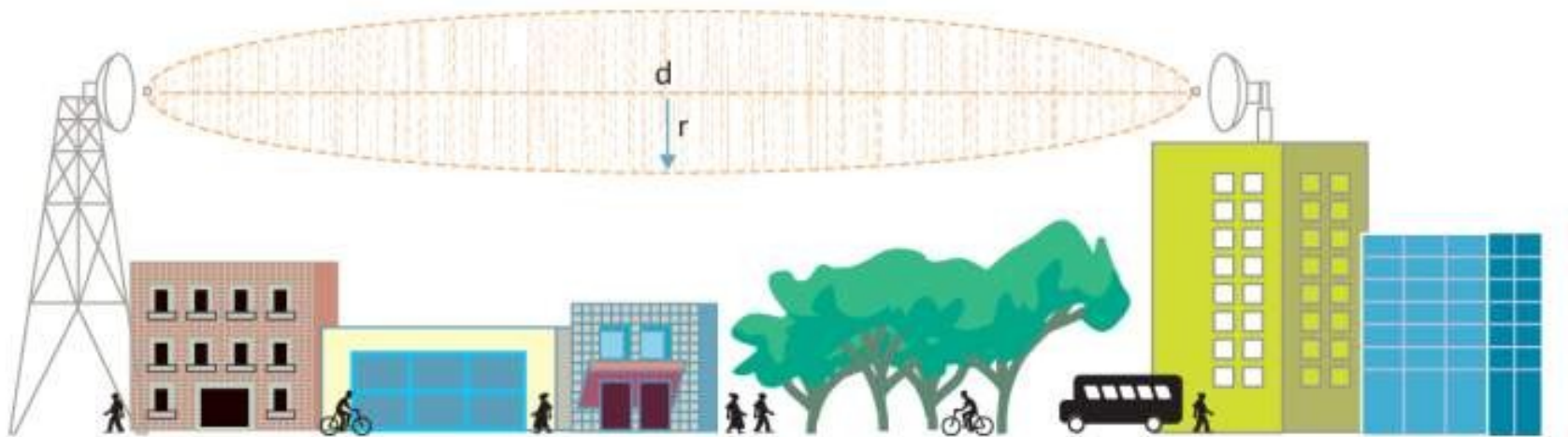
- Power loss is proportional to the square of the distance and also proportional to the square of the radio frequency – in dB:

$$FSL [dB] = C + 20 * \text{Log}(D) + 20 * \text{Log}(F)$$

D distance, and *F* frequency [MHz].

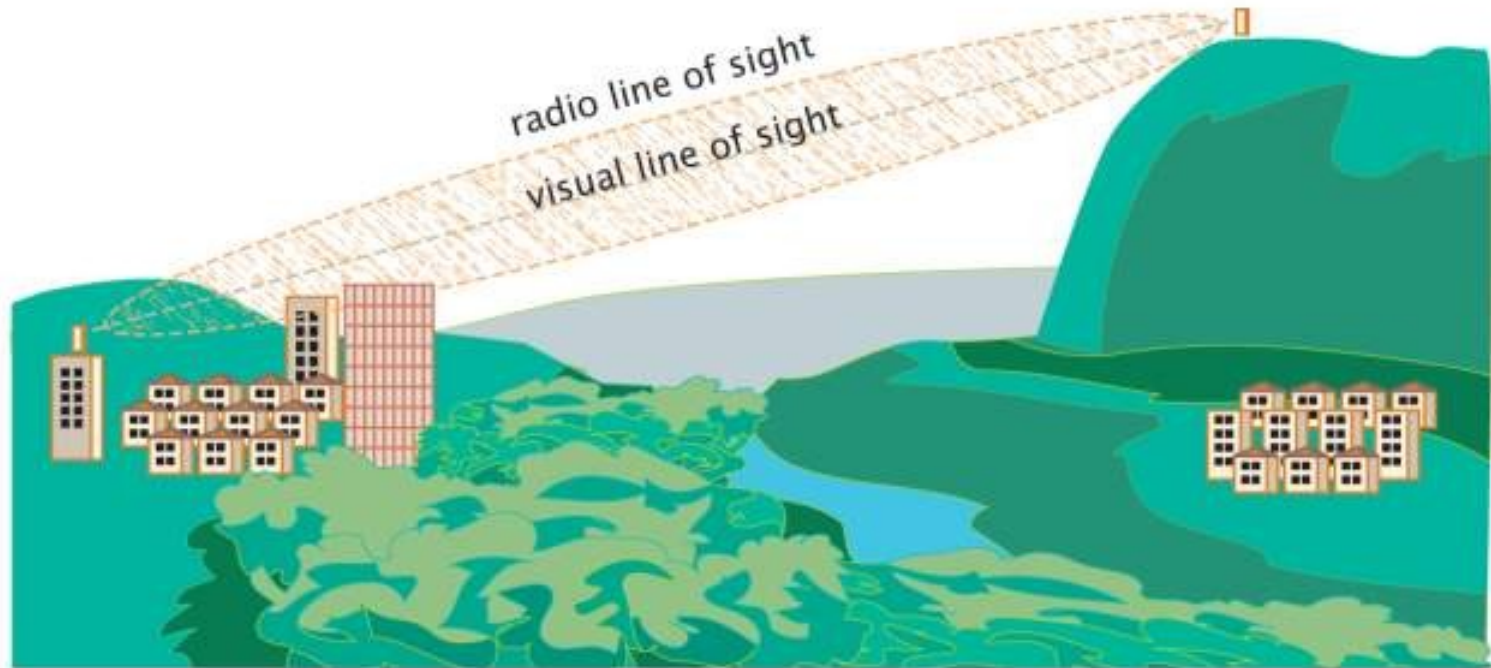
The constant C is 36.6 if D is in miles, and 32.5 if D is in kilometers.

Fresnel zones



Line of sight

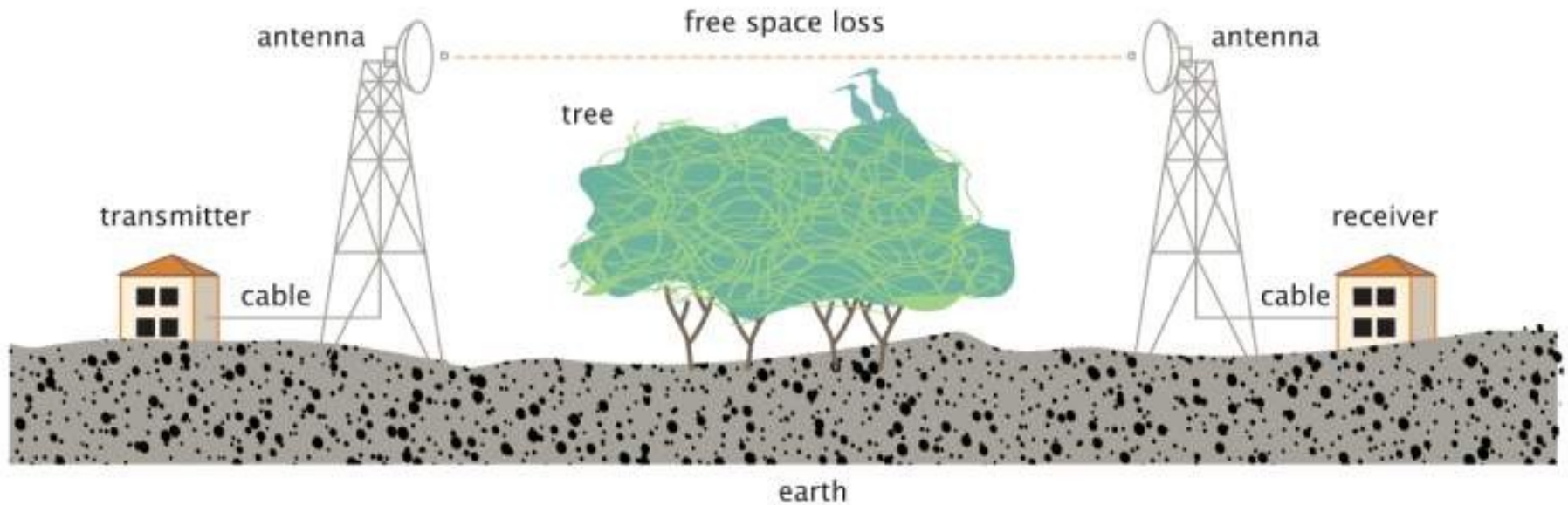
- *In general, you need to have a free line of sight (LOS) for a radio link ... and bit of space around it.*



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: $10 * \text{Log} (P_1 / P_0)$
- Important to remember:
 - 3 dB = double power
 - 10 dB = order of magnitude = x 10
- Relative dBs:
 - dBm = relative to 1 mW
 - dB_i = 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.