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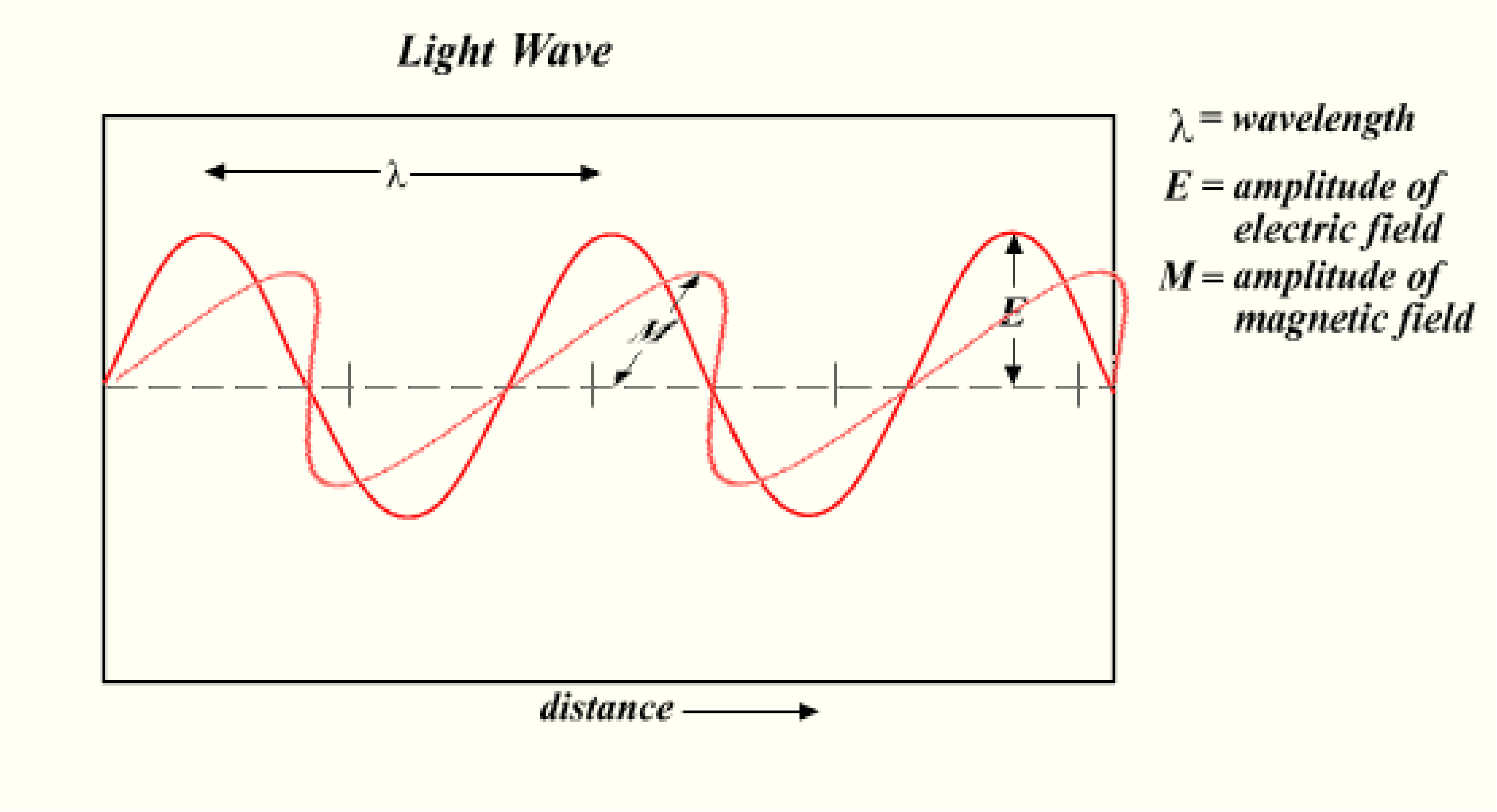
  - Characteristics
- The electromagnetic spectrum
- Electromagnetic effects
  - Absorption, reflection, diffraction, refraction, interference
- Propagation in free space
- Situations where physics really matters

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

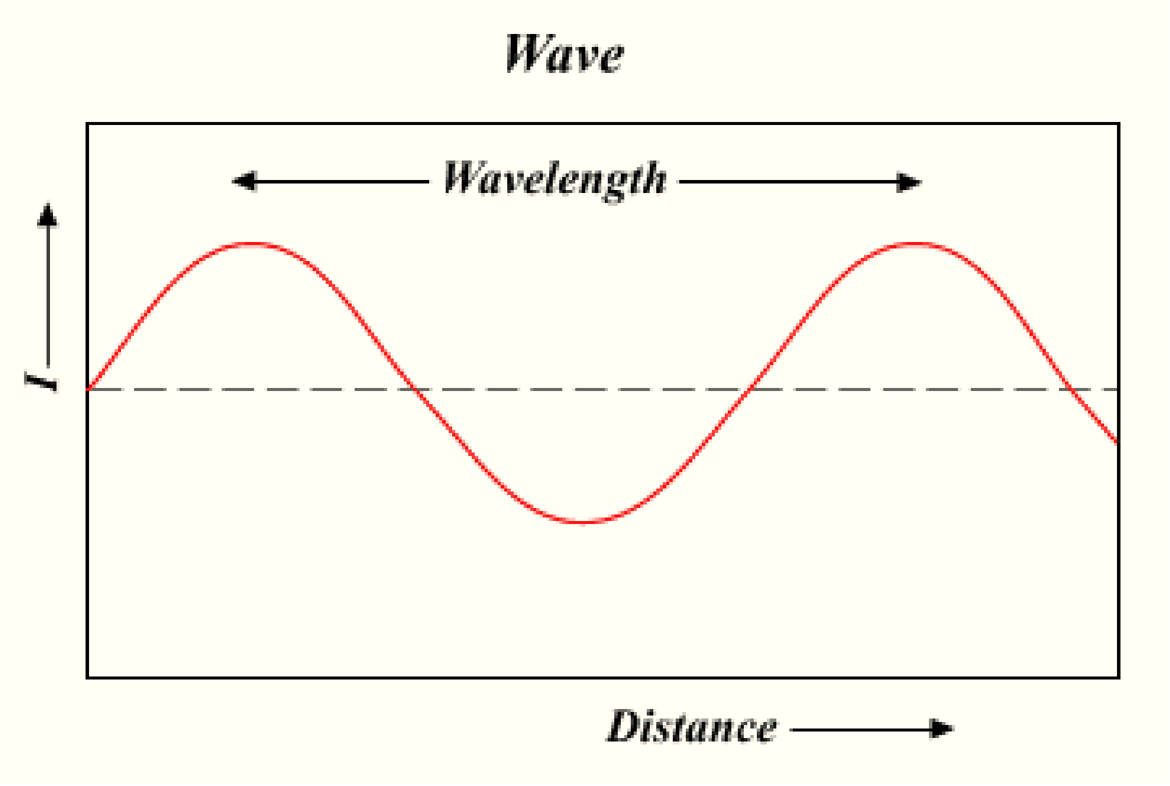
Electromagnetic Waves



Electromagnetic Characteristics

- E and H fields
- No need for carrier medium
- Characterized by: Wavelength, frequency, polarization

A Wave



[image: from wikipedia.org]

Wavelength and Frequency

- $c = \lambda * f$

- c = the speed of light ($3x10^8$ m/s) [m/s]
- λ = wavelength [m]
- f = frequency [1/s]

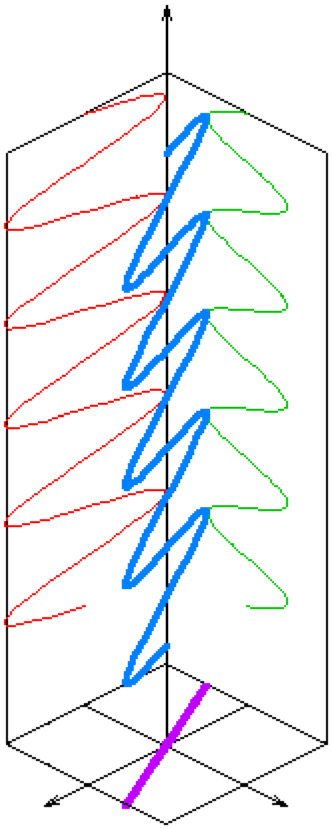
Wavelength and Frequency

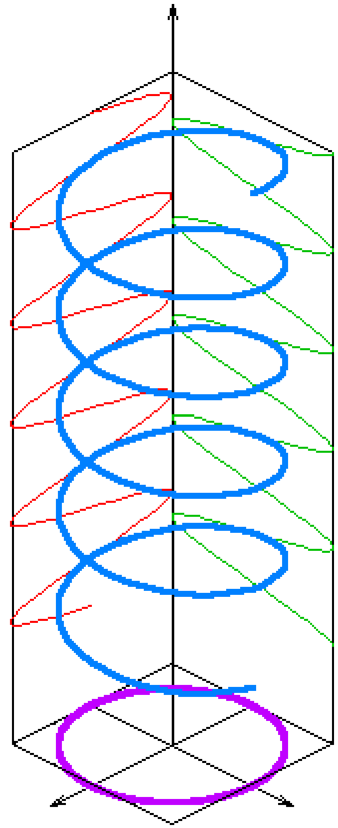
- A radio wave with a frequency of 2.4 GHz has a wavelength of 12,5 cm
- Light (or a radio signal) needs travel time:
  - 1.3 seconds from the Moon to Earth
  - 8 minutes from the Sun
  - 300 microseconds for 100 km

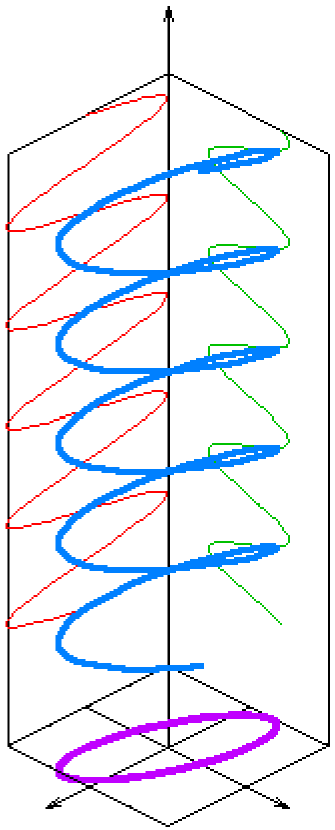
Powers of Ten

Prefix	*Quantity*		*Symbol*
Nano	10^{-9}	1/ 1,000,000,000	n
Micro	10^{-6}	1/1,000,000	μ
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







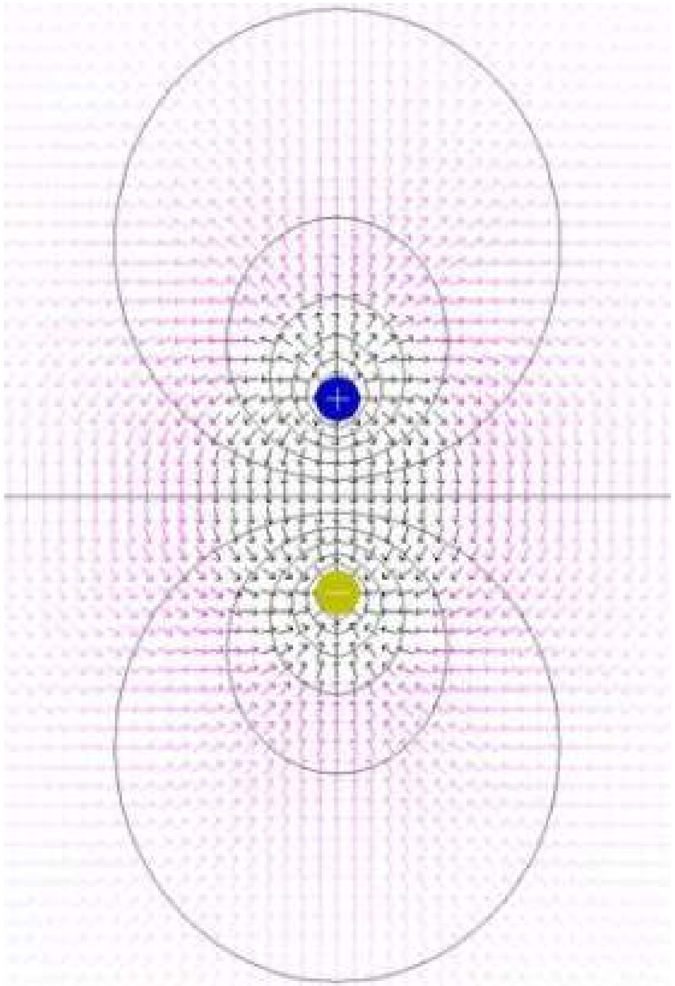
linear

elliptical

circular

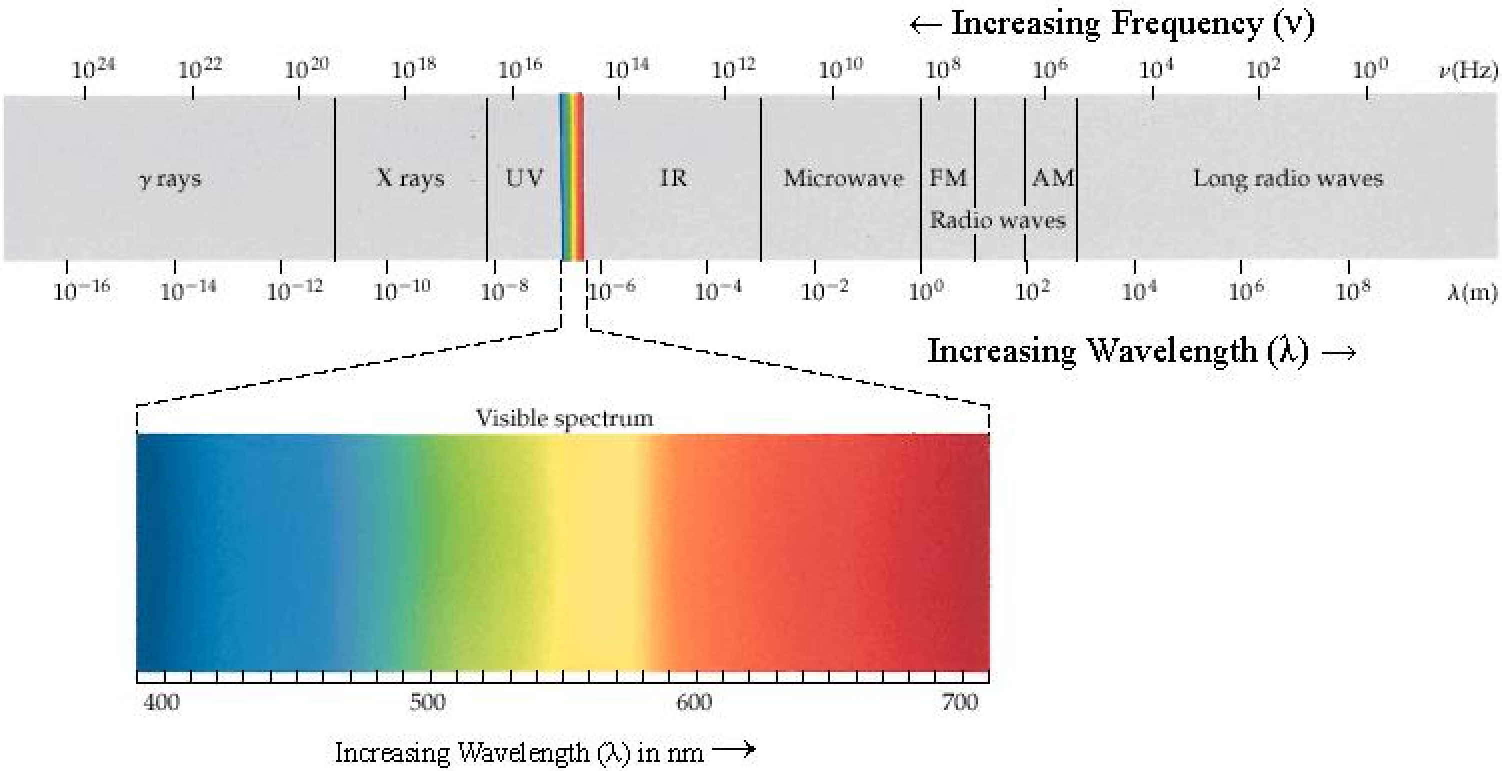
[Source: wikipedia.org]

Dipole Radiation



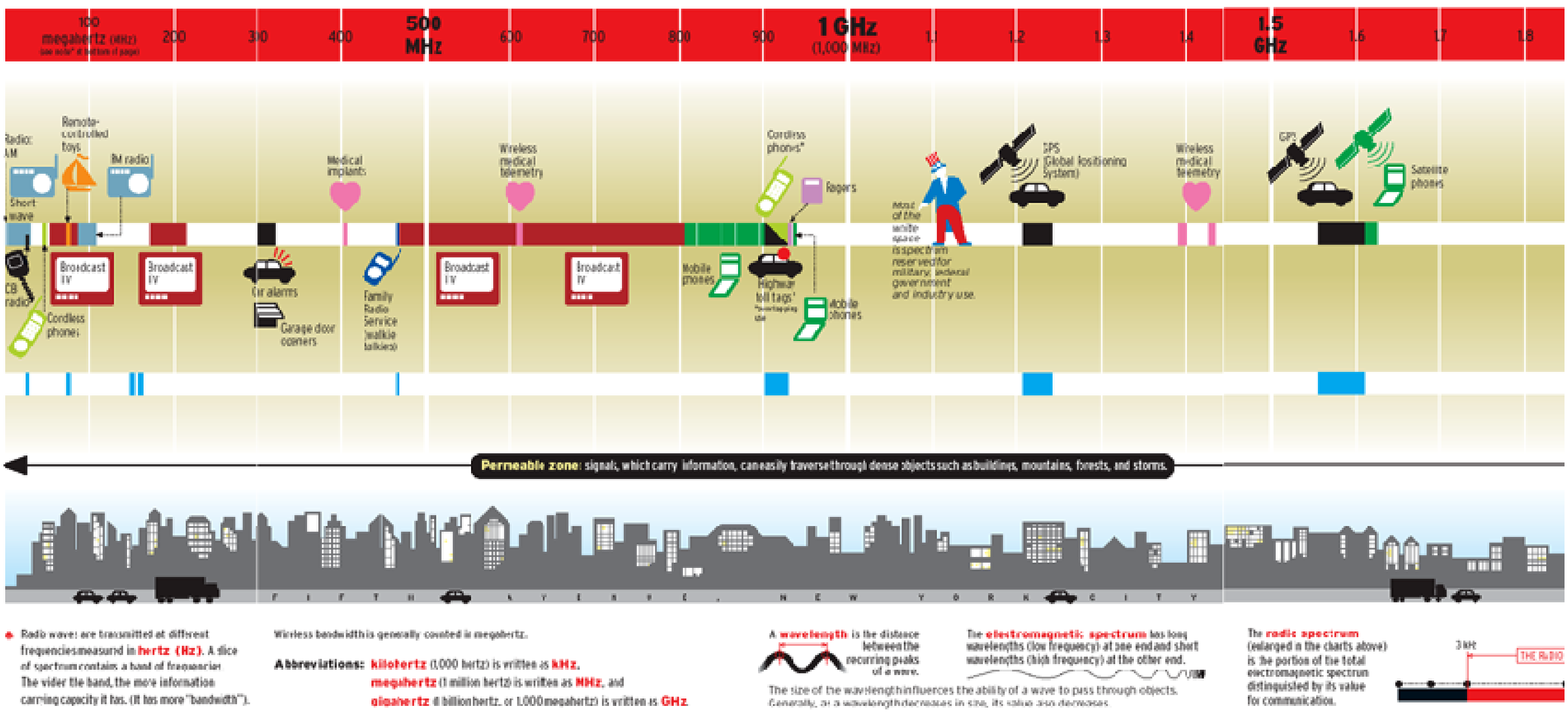
[Source: wikipedia.org]

The Electromagnetic Spectrum

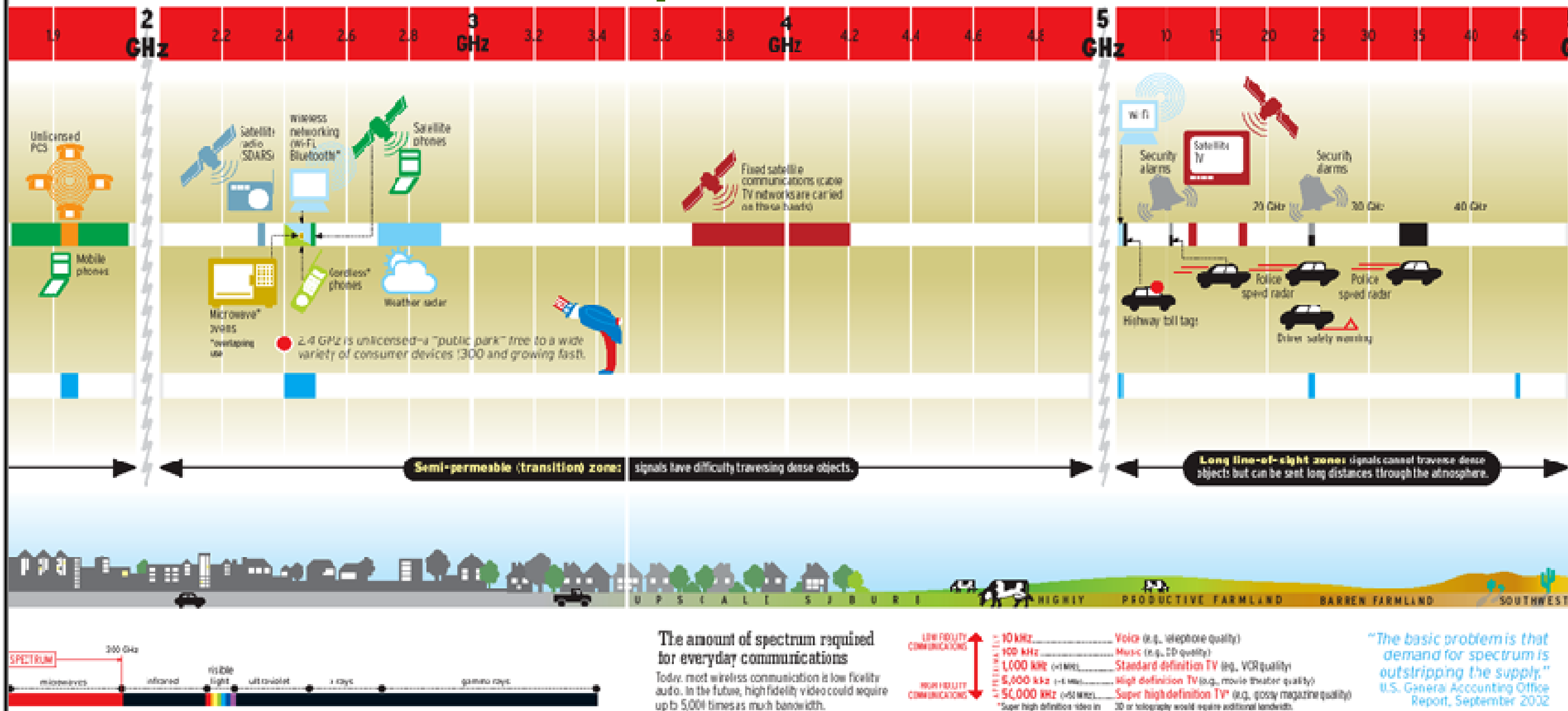


[Source: wikipedia.org]

Use of Electromagnetic Spectrum



Use of Electromagnetic Spectrum



Frequencies in Wireless Networking

Frequency	***Standard***	***Wavelength***
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

Radio Wave Effects

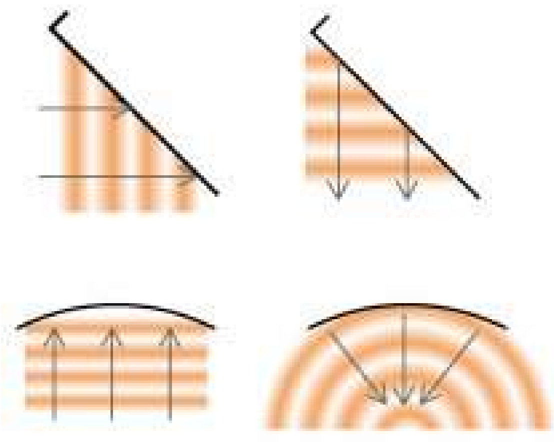
- Absorption
- Reflection
- Diffraction
- Refraction
- Interference

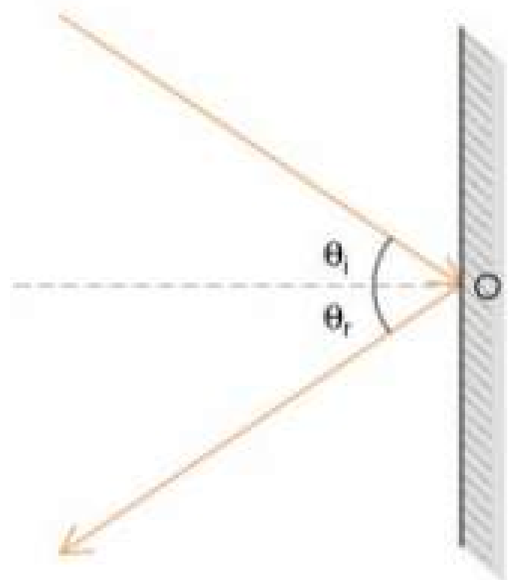
Absorption

- 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 surfac
- 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

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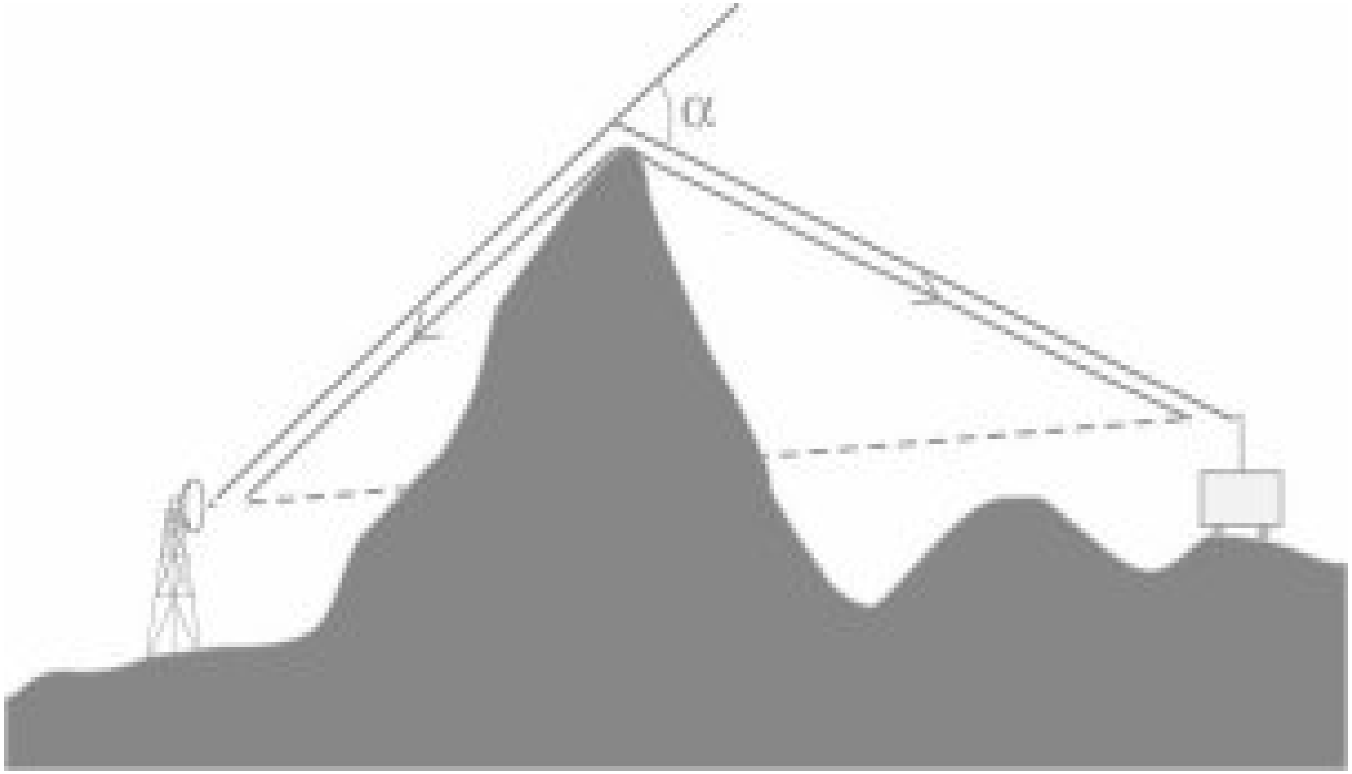


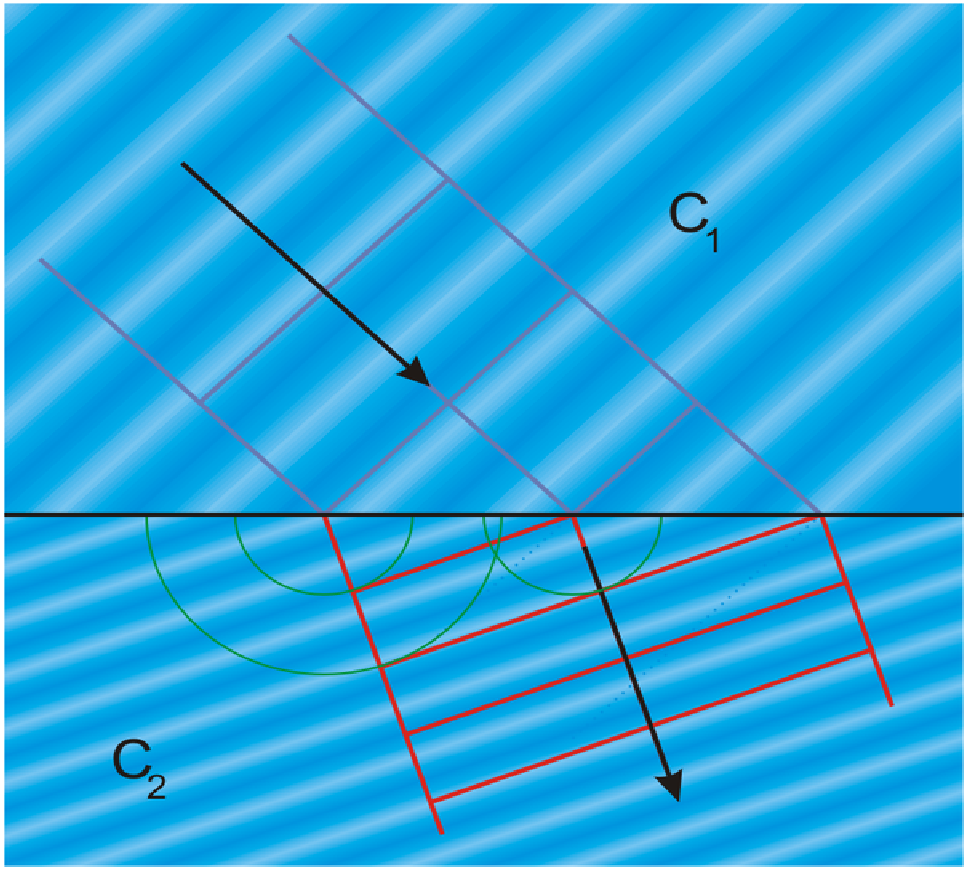
Diffraction

- Waves bend easier the longer the wavelength
- AM Radio station operating at 100 kHz can easily be received far away ($\lambda = 3{,}000$ m)
- In wireless communication at 2.4 GHz the wavelength is 12,5 cm

Refraction

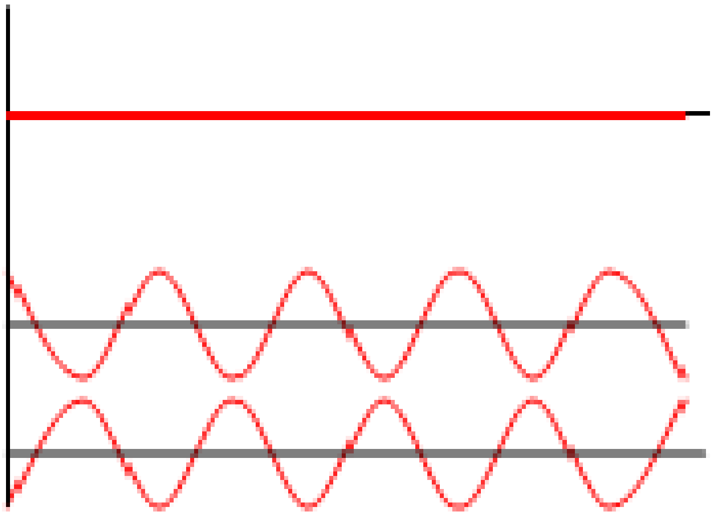
- The apparent “bending” of waves when they meet an obstacle with a different density
- A wave that moves from one medium to another of a different density, changes speed and direction when entering the new medium

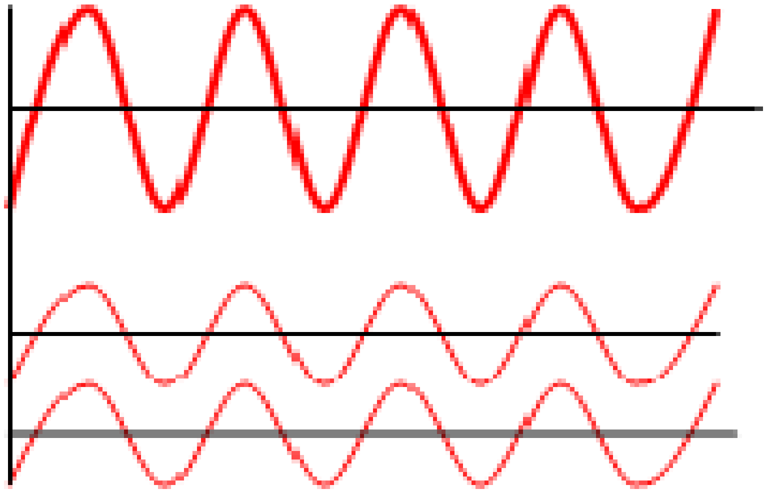
Refraction



Interference

- Same frequency
- Fixed phase relation





Frequency Dependence: Rules of thumb

- 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
- $FSL(dB) = 20\log_{10}(d) + 20\log_{10}(f) + K$
- d = distance
- f = frequency
- K = constant depending on the units used for d and f

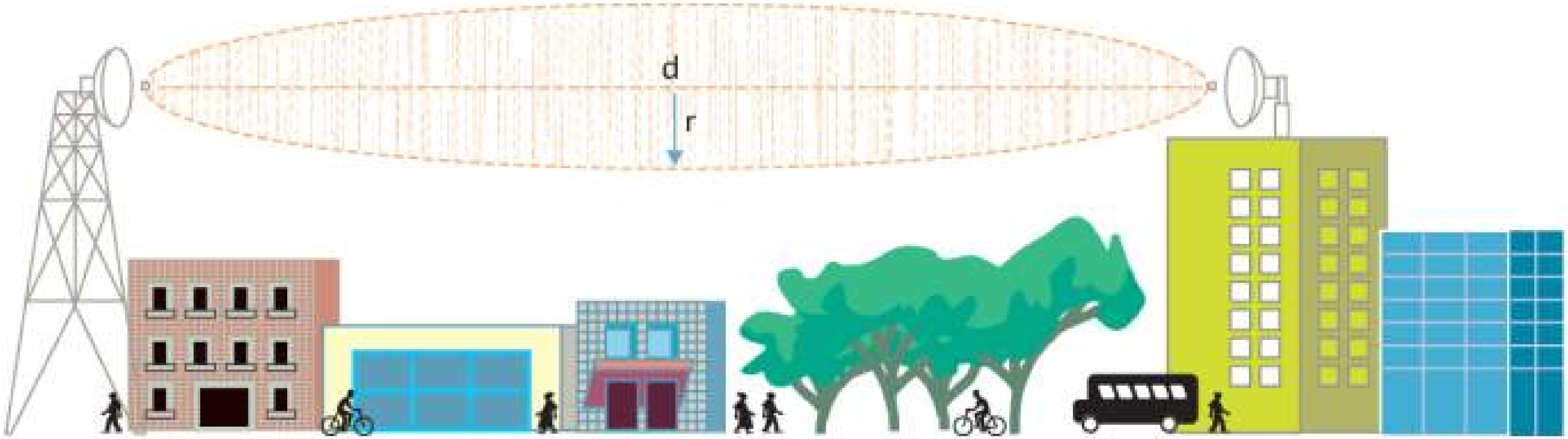
Free Space Loss (FSL)

- d is measured in meters
- f is measured in Hz
- $FSL(dB) = 20\log_{10}(d) + 20\log_{10}(f) - 147.5$

Free Space Loss (FSL)

- Rules of the thumb for 2.4 Ghz wireless networks:
  - 100 dB are lost in the first kilometre
  - 6 dB every time that the distance doubles
  - 2 km: loss of 106 dB
  - 4 km: loss of 112 dB
  - 10 km: loss of 120 dB
  - 100 km: loss of 140 dB

Fresnel Zones

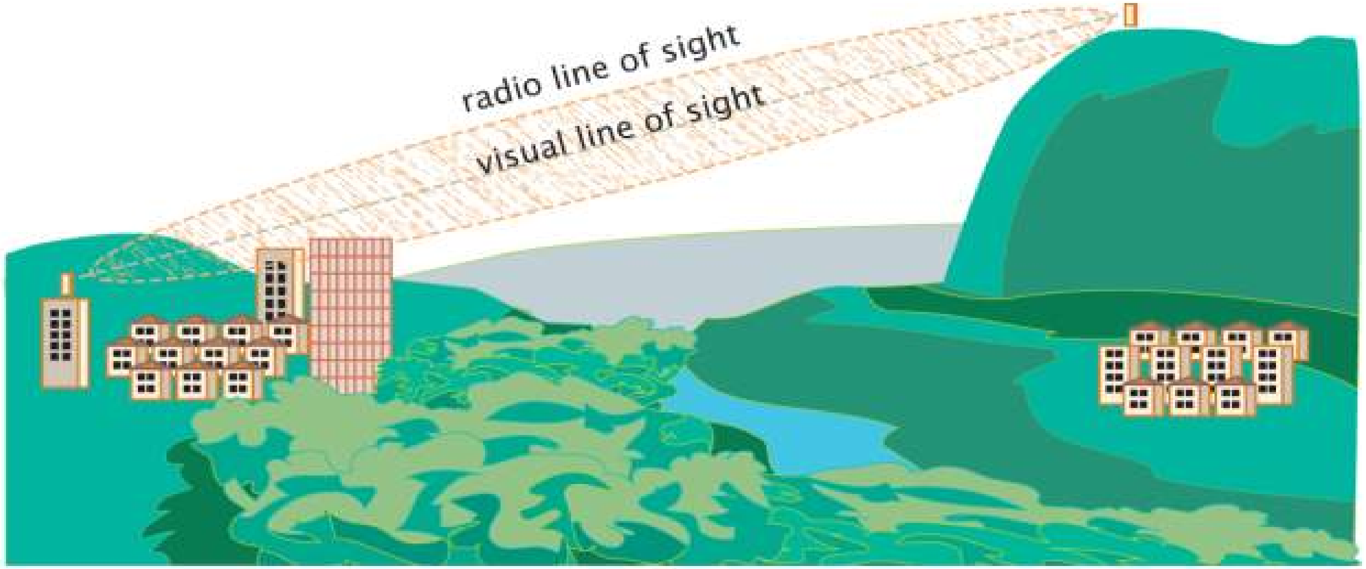


$$r = 17{,}32 * \sqrt{(d/4f)}$$

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 (802.11n) 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 have 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, reflaction and interference, and their implications.
- We can apply this knowledge to real life cases as well as to marketing lies.