Part 2:
Wireless Communication

- Section 1: Wireless Transmission

- Section 2: Digital modulation
- Section 3: Multiplexing/Medium Access Control (MAC)

Section 1
Wireless Transmission

Intro. to Wireless Transmission

- An appropriate antenna attached to an electrical circuit produces electromagnetic waves...
  – predicted by Maxwell (1865) and produced by H. Hertz (1887)

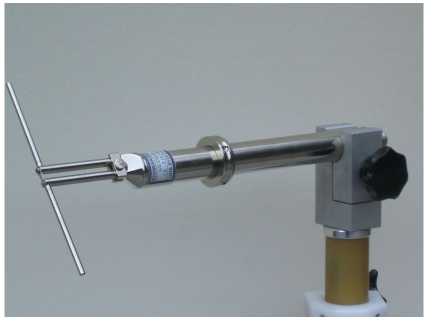
- The numbers of oscillations per second of a wave is called its **frequency**, f, and is measured in Hertz (Hz)
- The distance between 2 consecutive maxima is called the **wavelength**, and is designated by λ (lambda)
- Since waves travel at the light speed c, we have:

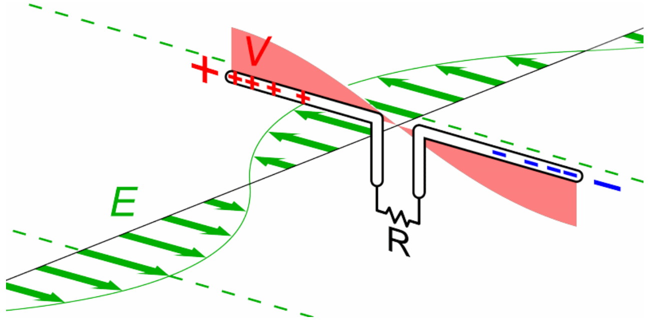
$$\lambda = c / f, \text{ where } c = 3.10^8 \text{ m/s}$$

- The frequency range [f1; f2] of a signal is called its **bandwidth** and is **measured in Hz**

About antennas

- **An antenna must have a size K.λ**
- Antennas are symmetric: reception (rx) / transmission (tx)
- Dipole antenna:
  - usually of size equal to half-wavelength
  - the electric signal arrives (tx) or leaves (rx) at the “feeding line”





- Monopole antenna
  - usually of size equal to ¼ of the wavelength

- monopole and dipole antennas work at a **given** frequency

About antennas (2)

- Parabolic antenna:
  - it's a **directive** antenna (unlike mono/dipole antennas)

  - ex.: the Arecibo radio-telescope (https://www.naic.edu/)
    - » operates at frequencies from 50 MHz (**6 m** wavelength) up to 10 GHz (**3 cm** wavelength)
    - » why is it so large (305 m diameter)?

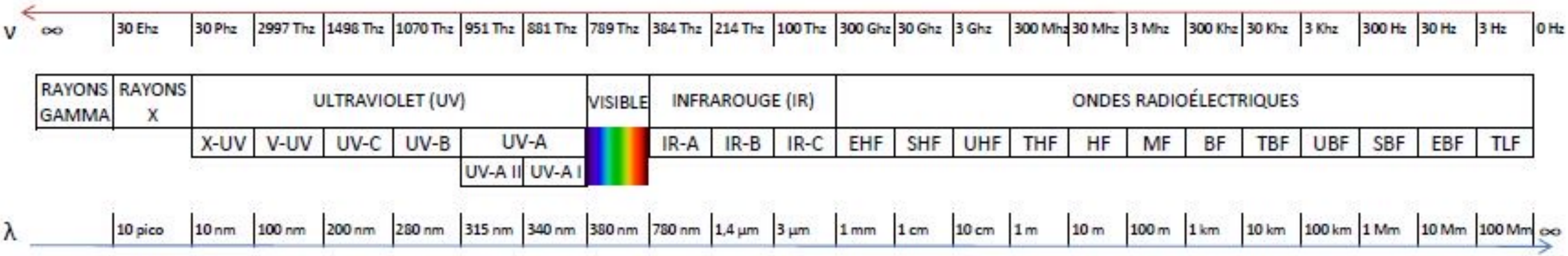
About antennas (3)

- **the reflector is not the active "feed antenna"**
  - the parabolic reflector must be much larger than the wavelength
  - the feed antenna at the reflector's focus can be a dipole antenna
  - the same reflector can be used for **various frequencies**
    - » use different feed antennas, each optimized for a different frequency
  - the same reflector can be used to point **different areas**
    - » use different feed antennas at different locations
  - parabolic antenna gain is:

$$G = e\,(\pi * d \,/\, \lambda)^2$$

  - where:
    - » d is the parabolic reflector diameter
    - » e is the "aperture efficiency" parameter, typically in 0.55 to 0.7

The electromagnetic Spectrum



THÉORIE, DOMAINES DU SPECTRE ÉLECTROMAGNÉTIQUE

- The whole spectrum could be used for transmitting information with amplitude/frequency/phase modulation
- However waves above UV are hard to produce and modulate, do not propagate well, and are **dangerous**
- Primary choices for wireless transmissions:
  - **Infrared Red**
  - **Radio**
  - **Microwave**
  - **Visible light (LIFI)**

Infrared

- Light may be diffused (omnidirectional) or aimed
- Receiver detects power (i.e. **amplitude**)
  - and not frequency or phase
- **Advantages**
  - no licensing or regulations
  - cost is generally low
  - secure: signals can’t go through walls
- **Disadvantages**
  - short range
  - works only indoors (problem with sun light), has moderate throughput (~1 Mbps)
  - aimed light isn’t for mobile hosts

Radio and Microwaves

- From 30kHz (λ=10km) to 300 GHz (λ=1mm)
- **The frequency is the carrier frequency**
  - **WARNING: this is not the frequency band nor the source information frequency**
- Transmitter and receiver must be tuned to the carrier frequency
- Receiver detects frequency, amplitude or phase
  - depends on the modulation scheme used
- **Advantages:**
  - longer transmission ranges
  - works outdoors and through walls
  - throughput is only limited by available radio spectrum

Radio and Microwaves (2)

- **Disadvantages:**
  - tightly **regulated** and **licensed**
    - » to prevent chaos, there are national and international agreements
    - » FCC allocates spectrum in the US
    - » ARCEP allocates spectrum in France (http://www.arcep.fr/) (Autorité de Régulation des Communications Electroniques et des Postes)
    - » ITU-R allocates (or tries to) spectrum worldwide
      - very political...
  - cost ranges from medium to high (license)
  - many sources of noise, both natural and man-made
  - possible health concerns

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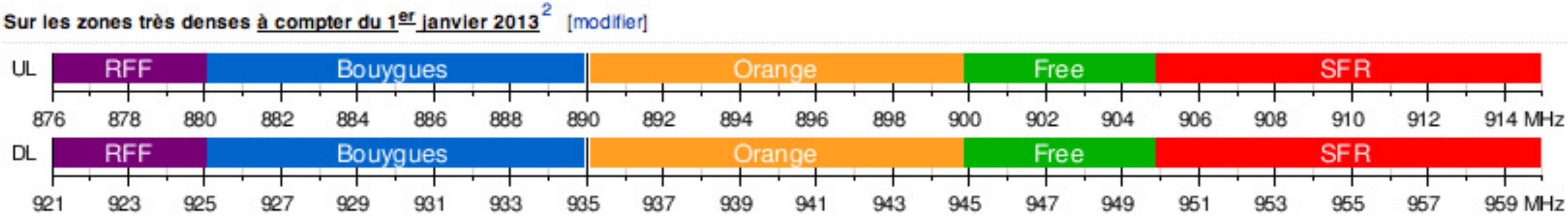
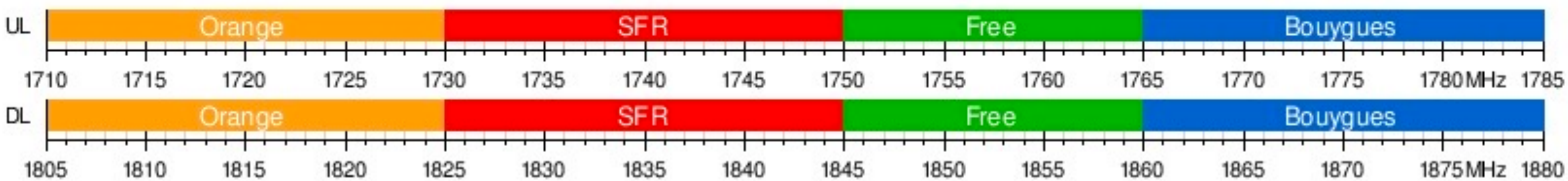
Radio and Microwaves (3)

- French situation for GSM frequencies

  » 800 MHz band



  » 1800 MHz band



ISM Bands

- Industrial/Scientific/Medical bands allows unlicensed usage
- Allows cheaper and non-proprietary systems
- Bands (non exhaustive list)
  - 433,05 - 434,79 MHz (1.74 MHz wide)
  - 2400-2483.5 MHz (83.5 MHz wide)
    - » Available worldwide
    - » Medium use, but microwave ovens interfere
    - » used by IEEE802.11
  - 5725-5875 MHz (150 MHz wide)
    - » used by IEEE802.11
- systems in these bands must respect some rules:
  - emission power < 1 Watt
  - must use spread spectrum modulation

Terminology of Radio Bands

Band name	Frequency range	
VLF (voice)	300 - 3000 Hz	$(27.10^2 Hz)$
LF (Low)	3 - 30 kHz	$(27.10^3 Hz)$
MF (Medium)	300- 3000 kHz	$(27.10^4 Hz)$
HF (High)	3 - 30 MHz	$(27.10^5 Hz)$
VHF (Very High)	30 - 300 MHz	$(27.10^6 Hz)$
UHF (Ultra High)	300- 3000 MHz	$(27.10^7 Hz)$
SHF (Super High)	3- 30 GHz	$(27.10^8 Hz)$
EHF (Extremely High)	30- 300 GHz	$(27.10^9 Hz)$

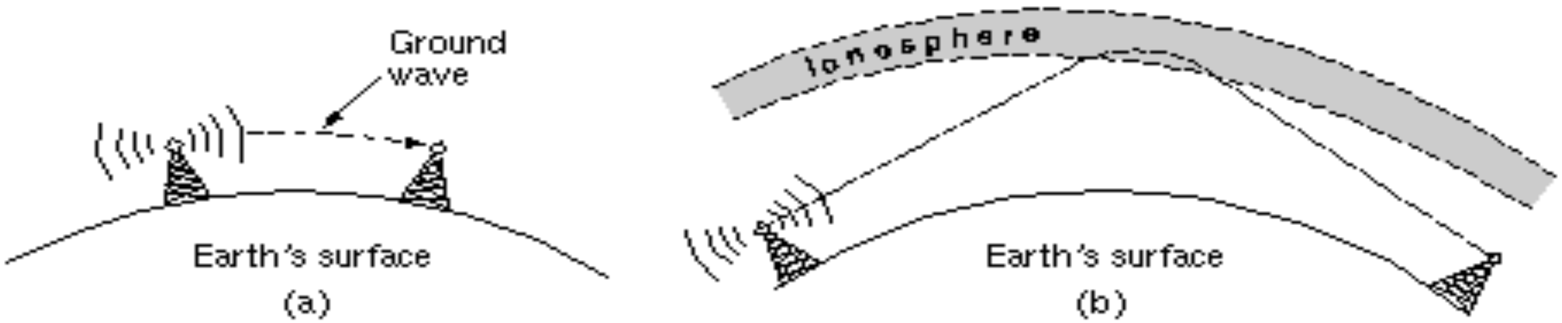
$\Rightarrow$ more frequencies are available in higher frequency bands...

Very Low and Low Frequency (VLF and LF) Bands

- 3-300 kHz
- initially used for radio telegraphy
- since wavelengths are in the kilometer range, enormous antennas have to be used
- As a result, this band is rarely used...

Medium and High Frequency (MF and HF) Bands

- MF: 300 kHz - 3 MHz / HF: 3 - 30 MHz
- commonly used for commercial AM broadcasting and amateur radio operations.
- Waves are reflected by *ionosphere*.
  - *Ionosphere* is a set of layers (altitude ranging from 90 to 400 km) of electrically charged particles at the top of earth's atmosphere. This layer is caused by the strong solar radiation entering the upper atmosphere.
  - Multiple reflections between this layer and the earth are possible, allowing great distances (even around the world). This is particularly true for the HF band.



Medium and High Frequency (MF and HF) Bands (2)

- The disadvantage is that it depends on the features of the ionosphere which varies widely especially during the day
  - Waves are reflected differently and take different paths over a period of time, causing the signal to vary in strength.

- MF waves (used by AM broadcasting)
  - little daytime reflections occur resulting in a radiation limited to 100kms with little fading. At night, more reflections occurs resulting in a transmission range of up to thousands of kms.

- HF waves
  - depend on ionospheric reflections all the time. With reasonable power, worldwide communications can be maintained in the HF band most of the time.

Very and Ultra High Frequency (VHF and UHF) Bands

- VHF: 30-300 MHz / UHF: 300- 3000MHz
- lower part of UHF is used for GSM (900 and 1800 MHz) and Cellular Phone systems.
- VHF and UHF are used for analog/digital television
- ionospheric reflection is very small. Communications are either **line-of sight or ground communications**
- The ground wave is the portion of the radiation that is directly affected by the ground and objects. The ground wave travels in contact with earth's surface by reflecting, diffracting, scattering off building, vegetation, hills...
  - affects all frequencies (from very low to micro-wave freq.)
  - The ground wave is the **most reliable propagation means**

Microwaves (SHF + EHF)

- Above 1 GHz
- Commonly used for radar and wideband communications (e.g. IEEE802.11).
- Advantages:
  - Radiation can be directed into very narrow beams. This makes these ranges very efficient in energy utilization as well as minimizing interference.
  - Wavelengths varies from 10 cms to few millimeters. Antennas can be very smalls.
- Disadvantages:
  - However small wavelengths can be a disadvantage. Transmissions are very **susceptible to weather effects**, particularly rain, because each rain drop can become a small antenna absorbing the energy...

Radio Wave Propagation and Transmission Interference

Waves are affected by several parameters:

1. Free space attenuation
2. Channel capacity
3. Basic propagation mechanisms
4. Shadowing
5. Multipath
6. Mobility

1. Free Space Propagation

- The *free space propagation model* is used to predict the received signal strength when the transmitter and receiver have a clear, unobstructed line-of-sight path:

$$\boxed{\mathbf{S(d) = S(0).Gt.Gr.\lambda^2 \,/\, ((4\pi)^2.d^2.L)}}$$

  - S(0) is the transmitted power,
  - S(d) the power at the receiver,
  - d the transmitter-receiver distance,
  - L a constant,
  - Gt and Gr the transmitter and receiver antenna gains.

AKA “Friis equation” (https://fr.wikipedia.org/wiki/%C3%89quation_des_t%C3%A9l%C3%A9communications)

- Lower frequencies travel longer distance…
- But in practice, this is not that simple
  - absorption depending on atmospheric conditions and frequency, etc.

2. Channel Capacity

- Consider a digital communication channel that transmits *S* watts of power in a bandwidth B_w
- We assume that the channel only adds white noise
- Claude Shannon showed that:

$$\boxed{C/B_w = \log_2[1 + S/(N_o.B_w)]} = \log_2[1 + E_b/N_o.(R/B_w)]$$

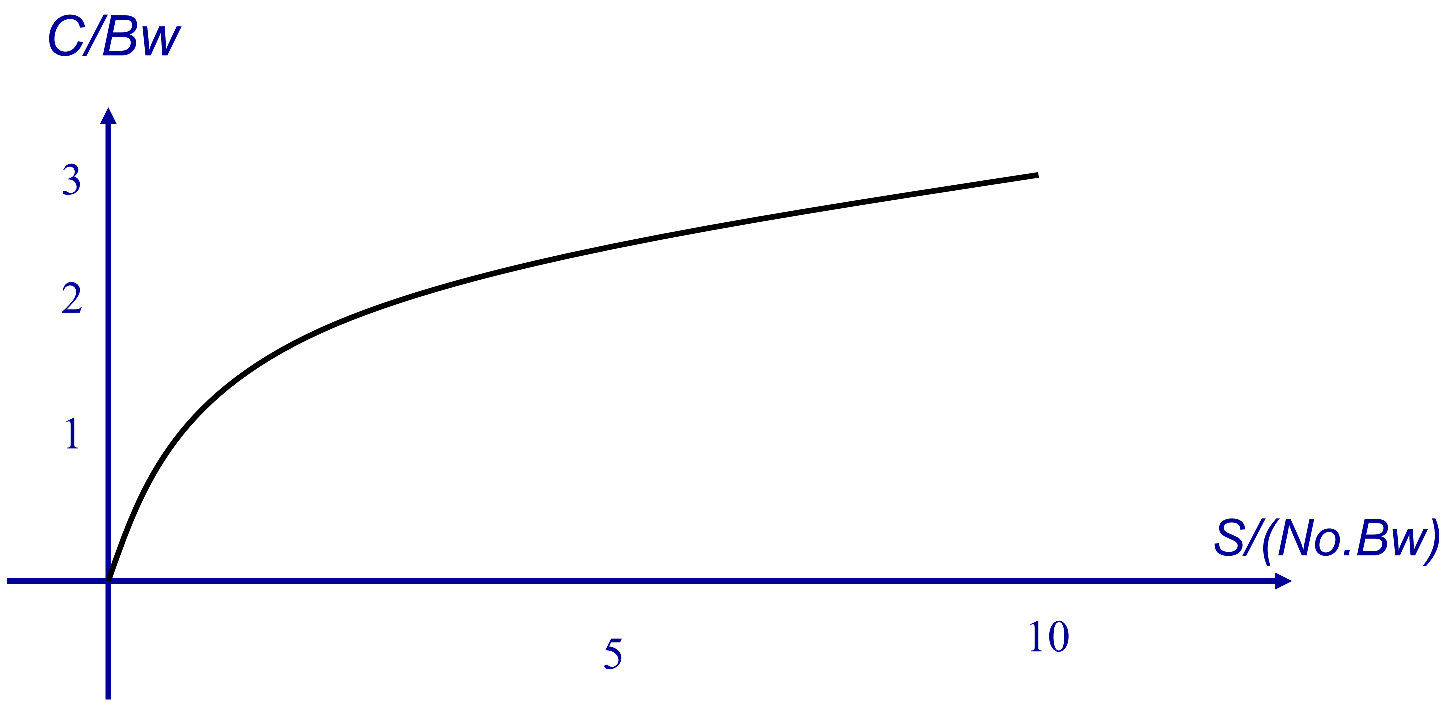
where:

- C = channel capacity (bits/s) = max useful reception rate
- B_w = one-way transmission bandwidth (Hz)
- Eb = energy per bit of the received signal (Joule)
- R = information rate (bits/s)
- S = Eb.R = emission signal power
- No = single-side noise power spectral density (W/Hz)

- Note: it defines an **upper bound!**

Channel Capacity (2)

- *$C/B_w = log_2[1 + S/(N_o.B_w)]$*
- For a fixed B_w, the bit rate increases as the emission power increases according to a $\log_2$ function

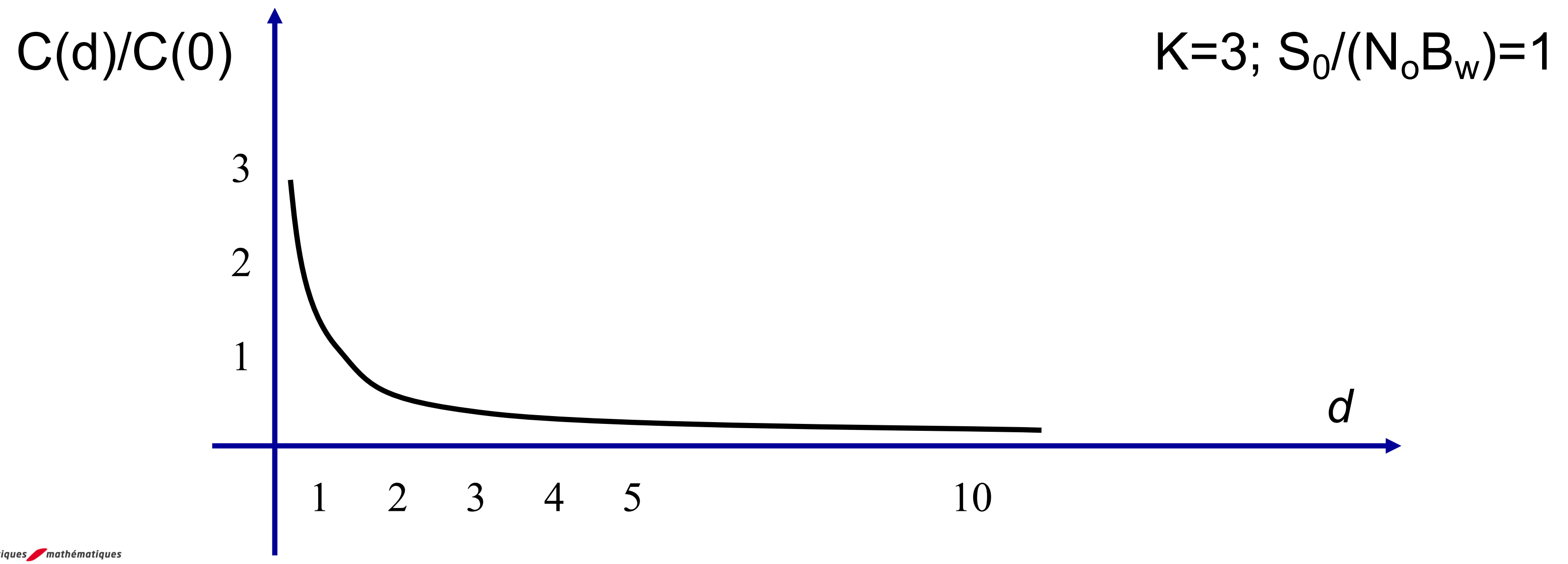


Channel Capacity (3)

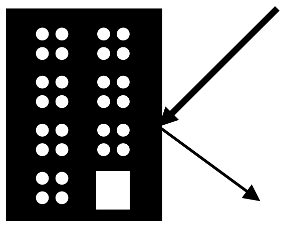
- $C/B_w = \log_2[1 + S/(N_o.B_w)]$
- According to the free space model:
  - $S(d) = K.S(0)/d^2$

    where S(d) is the power at distance d from source and K a constant
- $C(d)/B_w = \log_2[1 + S(d)/(N_o.B_w)] = \log_2[1 + KS_o/(N_o.B_{w.}\, d^2)]$
- and:

$$C(d)/C(0) = \log_2[1 + K.S_o/(N_o.B_w\, d^2)] / \log_2[1 + S_o/(N_o.B_w)]$$

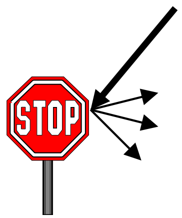


3. The 3 Basic Propagation Mechanisms



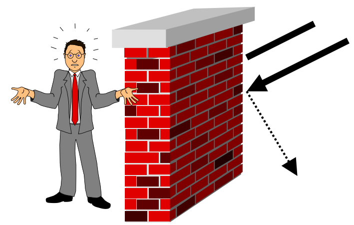
- Reflection occurs when a propagating wave impinges upon an object which has very large dimensions. Part of the original wave is transmitted, part is reflected.

- Diffraction occurs when the radio path between the Transmitter and Receiver is obstructed by a large obstacle with sharp edges. The resulting waves are present throughout the space, even if no line of sight exists.



- Scattering occurs when the medium through which the wave travels consists of objects with dimensions inferior to λ (e.g. foliage, lamp, street signs).

4. Shadowing



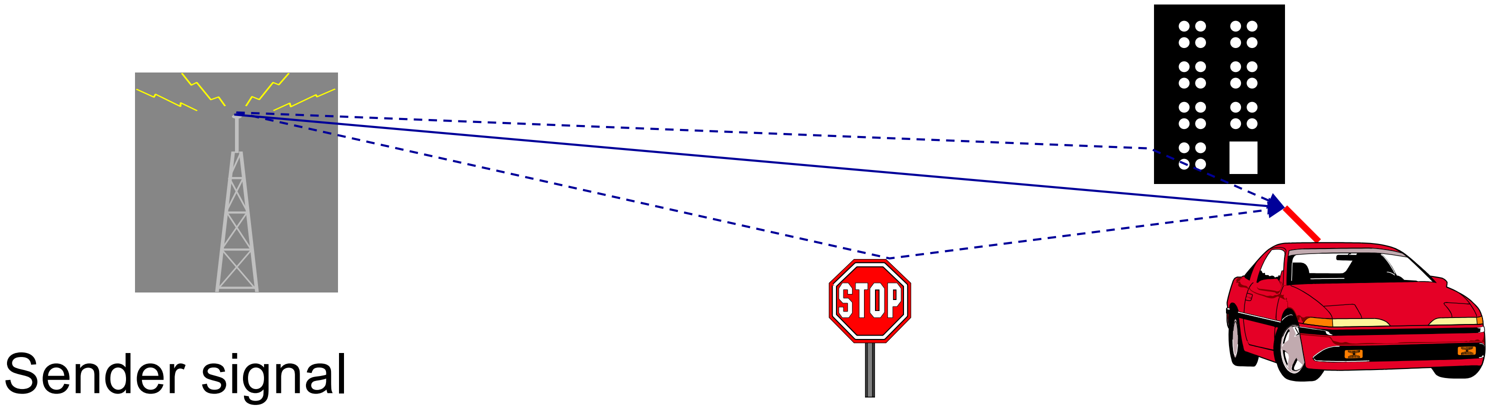
Attenuation or blockage

- Radio waves may be blocked (absorbed) by various objects
  - building
  - rain or atmospheric moisture
- Degree of attenuation depends on frequency:
  - lower frequencies penetrate objects much better
  - the higher the frequency, the greater the attenuation
- The problem in urban areas is the shadow from buildings
- The problem indoors is the need to pass through walls

5. Multipath

Radio waves reflects off different objects

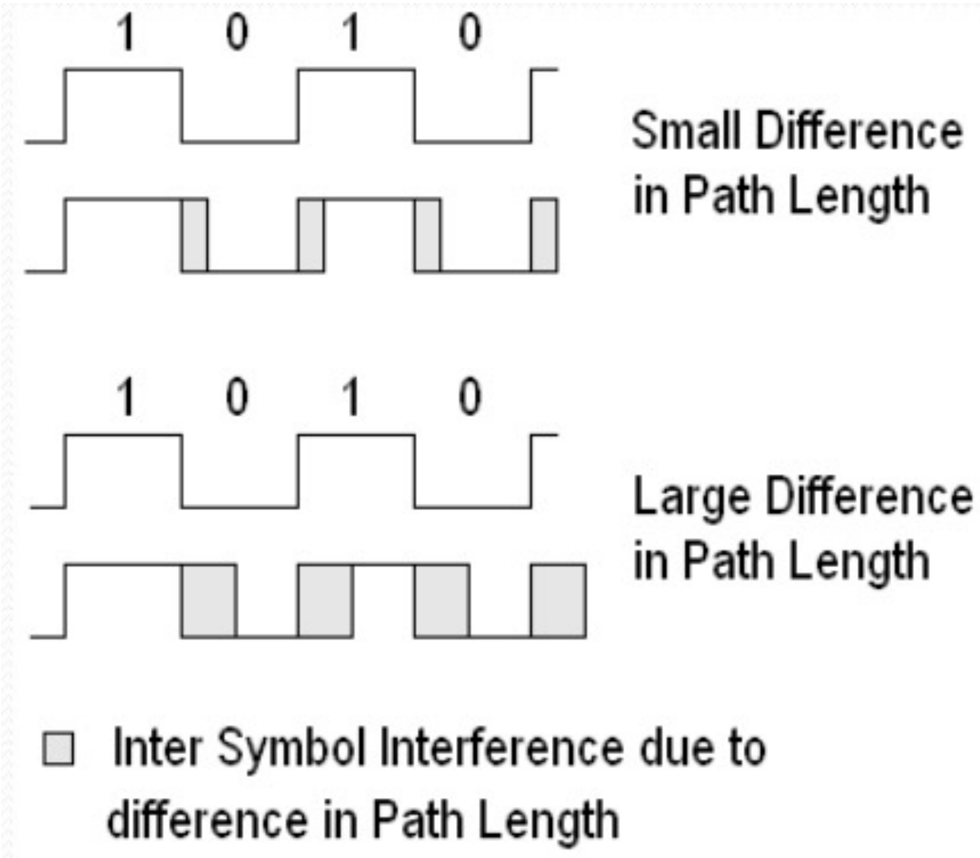
- this allows radio waves to reach receiver behind something
- but also creates some fundamentals problems for wireless transmissions...



Multipath Problems

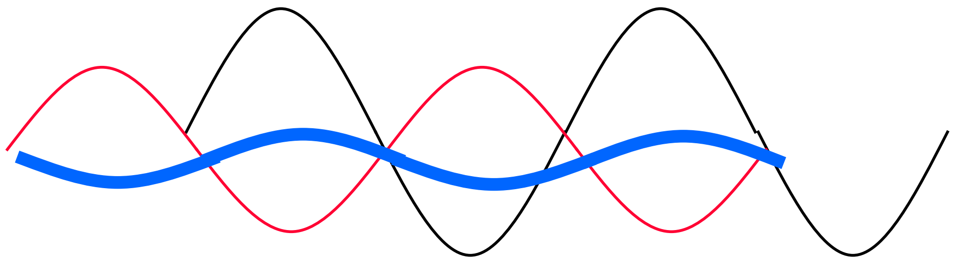
- Delay Spread
  - Signal along different paths arrive at different times
  - One "symbol" (e.g. bit) may overlap with another
  - the higher the bit rates, the worse the effect

  ⇒use **GI (Guard Intervals)** between symbols to avoid this issue



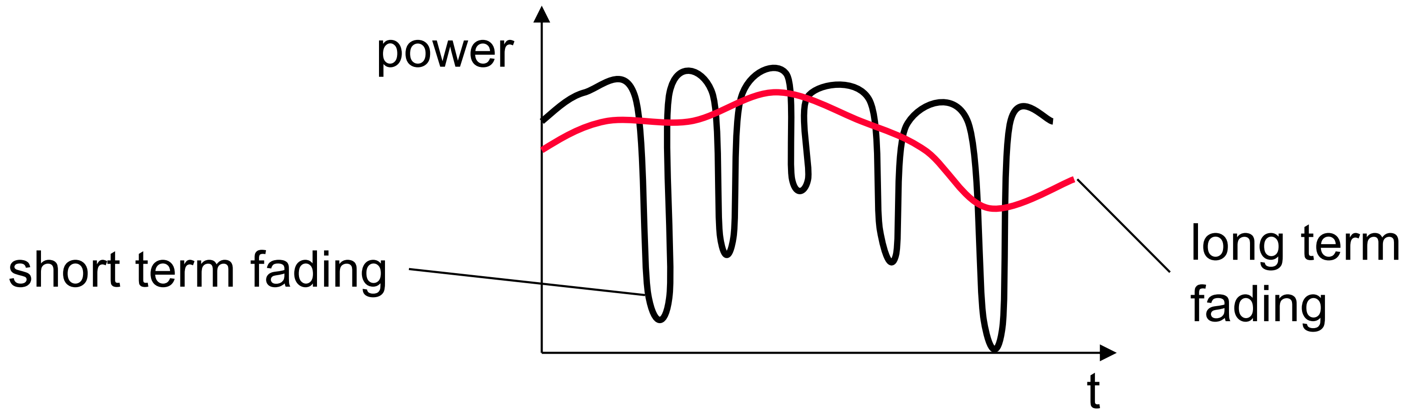
Multipath Problems

- Rayleigh Fading
  - Each reflected signal may have a different phase
  - Signal arrivals out of phase may cancel each other



6. Mobility Effects

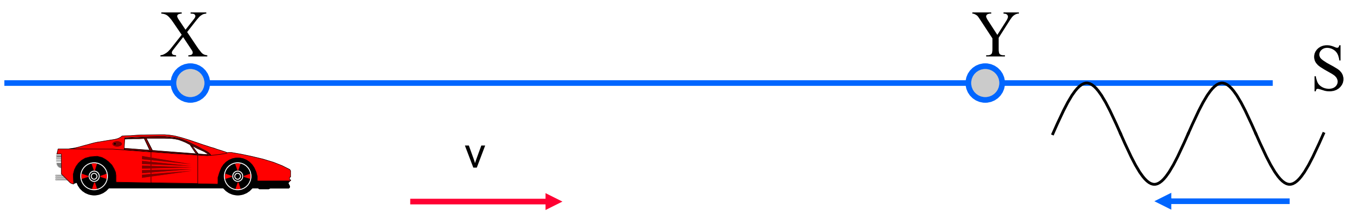
- Short and long term fading:
  - As the user or the objects move, channel characteristics change over time and location
    - » different delay variations of different signal parts
    - » different phases of different signal parts
  - The rapid fluctuations caused by local multipath are known as *fast fading or short term fading.*
  - The long-term variation are called *slow or long term fading.* The slow fading is caused by movement over distances large enough to produce gross variations



Mobility Effects (2)

Doppler Shift:

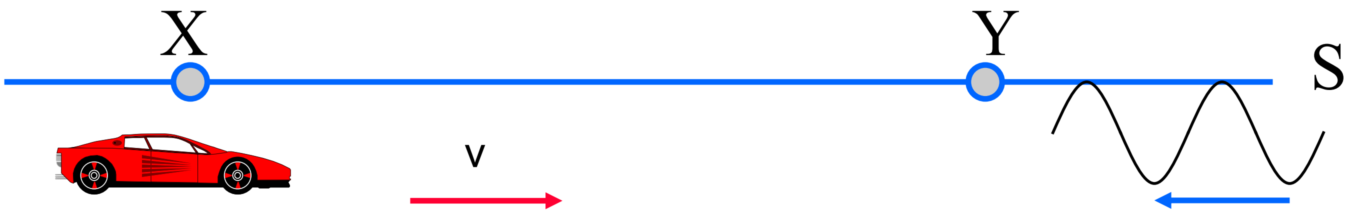
- mobility cause shift in frequency and random frequency modulation
- Consider that a mobile at location X receives a signal from source S of wavelength λ
  - » the frequency of the signal seen by the mobile is:
  - » f = c/λ where c is the speed of the light
- consider a mobile moving at speed v from X to Y while it receives a signal from S, of frequency fc



Mobility Effects (3)

Doppler Shift…

- This is not negligible…
  - » $f_c' = (c + v)/\lambda = f_c + v/\lambda = f_c + \mathbf{vf_c/c}$
  - » $f_c' - f_c = vf_c/c$
  - » if v=100km/h, f_c=500MHz, then $f'_c - f_c$ = 46.29Hz



A difficult problem in practice!

- S/N simulation in an office...