Wave Propagation

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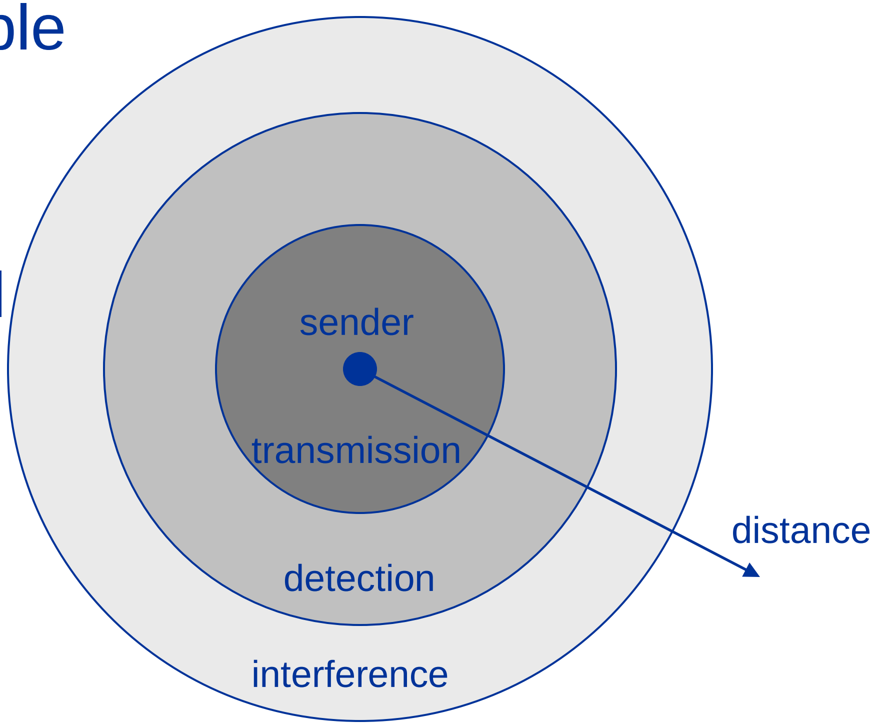
Signal Propagation Ranges

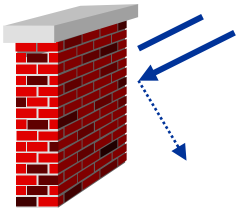
- Transmission range
  - communication possible
  - low error rate
- Detection range
  - detection of the signal possible
  - communication not possible
- Interference range
  - signals may not be detected
  - signals add to the background noise



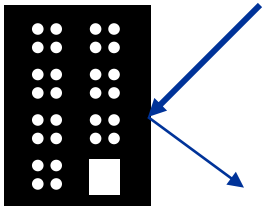
Note: These are **not** perfect spheres in real life!

Signal Propagation

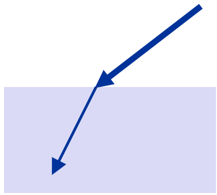
- Propagation in free space is always like light (straight line).
- Receiving power proportional to **1/d²** in vacuum – much more in real environments (**d** = distance between sender and receiver)
- Receiving power additionally influenced by
  - fading (frequency dependent)
  - Shadowing (blocking)
  - reflection at large obstacles
  - refraction depending on the density of a medium
  - scattering at small obstacles
  - diffraction at edges



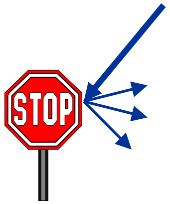
shadowing



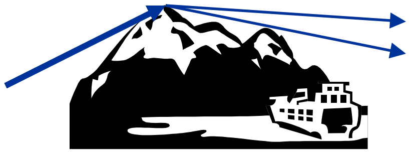
reflection



refraction



scattering

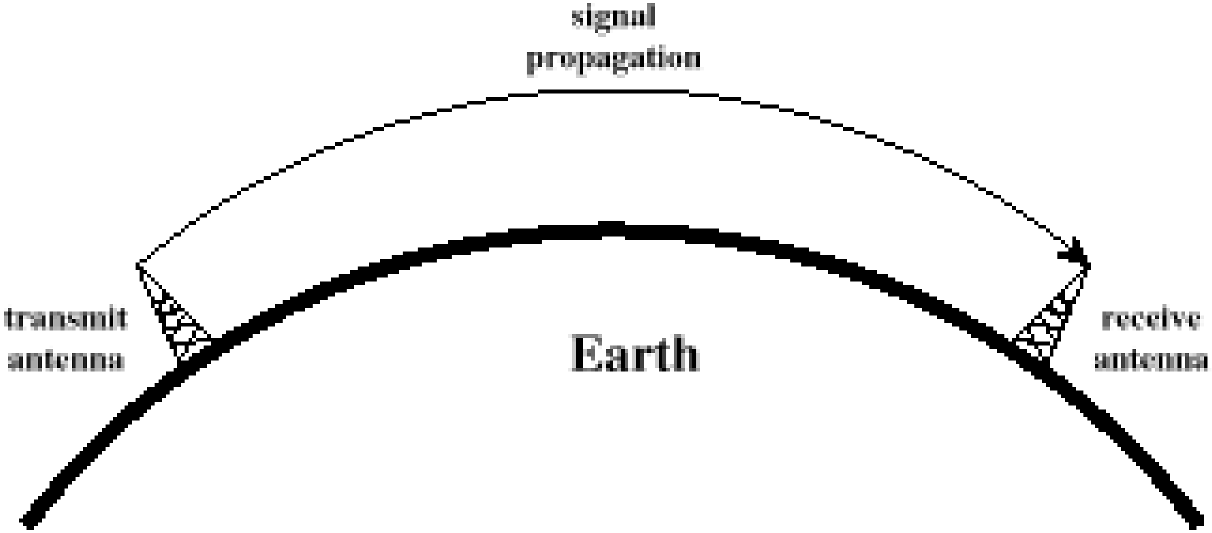


diffraction

Propagation Modes

- Ground-wave (< 2MHz) propagation
- Sky-wave (2 – 30 MHz) propagation
- Line-of-sight (> 30 MHz) propagation

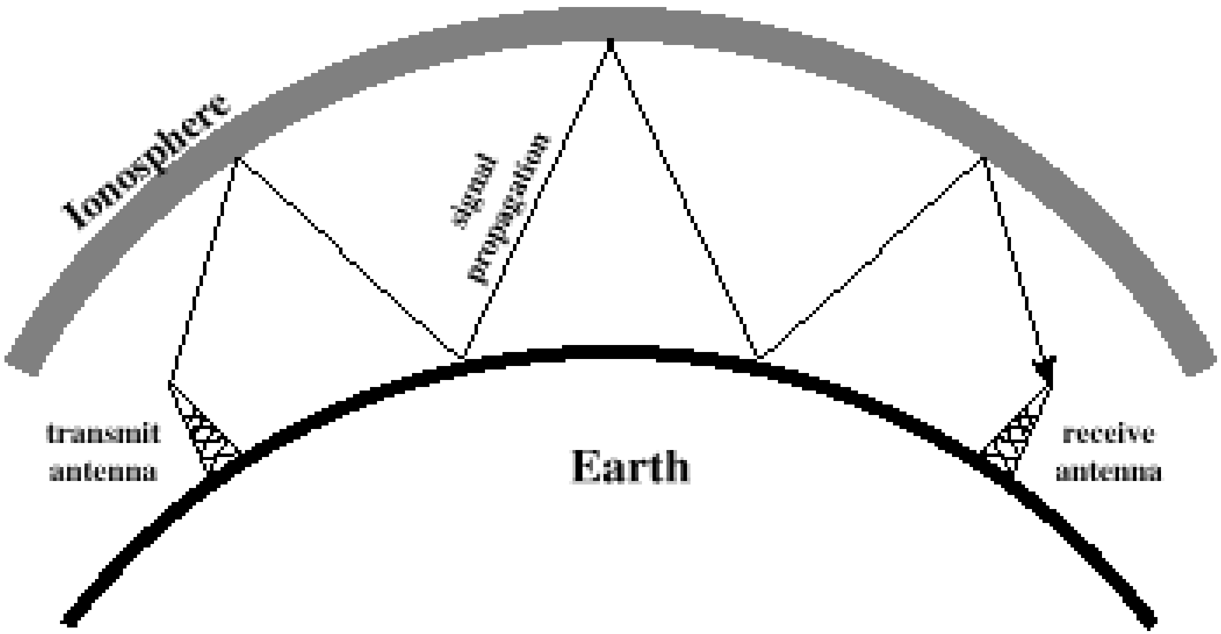
Ground Wave Propagation



Ground Wave Propagation

- Follows the contour of the earth
- Can propagate considerable distances
- Frequencies up to 2 MHz
- Example
  - AM radio
  - submarine communication (long waves)

Sky Wave Propagation



Sky Wave Propagation

- Signal reflected from ionized layer of atmosphere back down to earth
- Signal can travel a number of hops, back and forth between ionosphere and the earth surface
- Reflection effect caused by refraction
- Examples
  - amateur radio
  - International broadcasts

Skip distance

- The skip distance is the distance over the Earth's surface between the point where a radio signal is transmitted, and the point where it is received having travelled to the ionosphere, and been refracted back by the ionosphere.

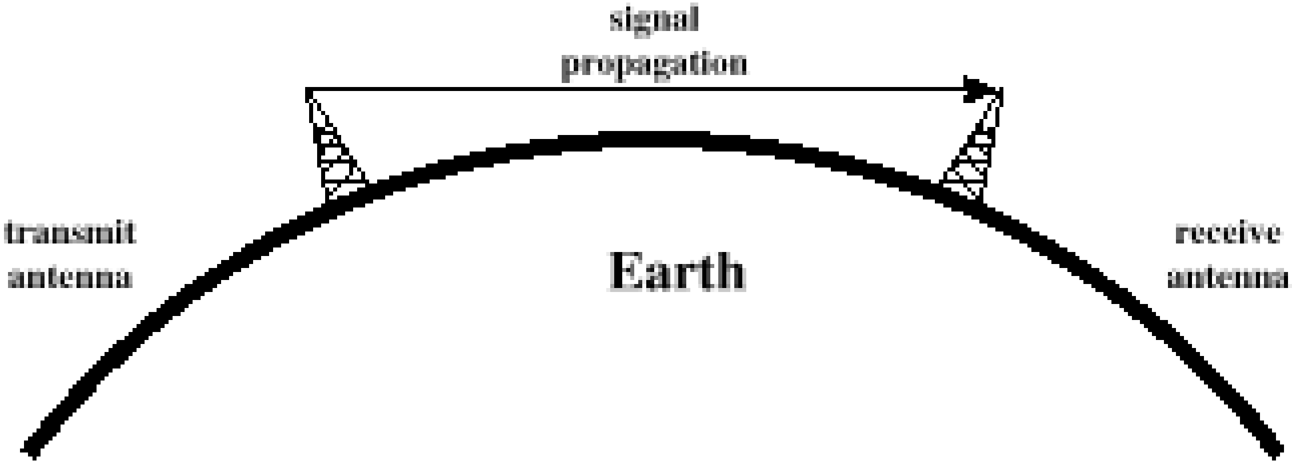
Critical Frequency

- The critical frequency is an important figure that gives an indication of the state of the ionosphere and the resulting HF propagation. It is obtained by sending a signal pulse directly upwards. This is reflected back and can be received by a receiver on the same site as the transmitter.

Maximum Usable Frequency, MUF

- When a signal is transmitted using HF propagation, over a given path there is a maximum frequency that can be used.
- The frequency at which radio communications just starts to fail is known as the Maximum Usable Frequency (MUF).
- $MUF = F_c / \cos\theta$

Line-of-Sight Propagation



Line-of-Sight Propagation

- Transmitting and receiving antennas must be within line of sight
  - Satellite communication – signal above 30 MHz not reflected by ionosphere
  - Ground communication – antennas within *effective* line of sight due to refraction
- Refraction – bending of microwaves by the atmosphere
  - Velocity of an electromagnetic wave is a function of the density of the medium
  - When wave changes medium, speed changes
  - Wave bends at the boundary between mediums
- Mobile phone systems, satellite systems, cordless phones, etc.

Line-of-Sight Equations

- Optical line of sight

$$d = 3.57\sqrt{h}$$

- Effective, or radio, line of sight

$$d = 3.57\sqrt{\mathrm{K}h}$$

  - *d* = distance between antenna and horizon (km)
  - *h* = antenna height (m) (altitude relative to a receiver at the sea level)
  - K = adjustment factor to account for refraction caused by atmospherics layers; rule of thumb K = 4/3

Line-of-Sight Equations

- Maximum distance between two antennas for LOS propagation:

$$3.57\left(\sqrt{\mathrm{K}h_1} + \sqrt{\mathrm{K}h_2}\right)$$

  - h_1 = height of antenna one
  - h_2 = height of antenna two

LOS Wireless Transmission Impairments

- Attenuation and attenuation distortion
- Free space loss
- Atmospheric absorption
- Multipath (diffraction, reflection, refraction…)
- Noise
- Thermal noise

Duct Propagation

- In the region of troposphere, the higher frequencies or microwave frequencies tend to refract back into the Earth’s atmosphere, instead of shooting into ionosphere, to reflect. These waves propagate around the curvature of the earth even up to a distance of 1000km.
- This refraction goes on continuing in this region of troposphere. This can be termed as **Super refraction** or **Duct propagation**.

Attenuation

- Strength of signal falls off with distance over transmission medium
- Attenuation factors for unguided media:
  - Received signal must have sufficient strength so that circuitry in the receiver can interpret the signal
  - Signal must maintain a level sufficiently higher than noise to be received without error
  - Attenuation is greater at higher frequencies, causing distortion (attenuation distortion)

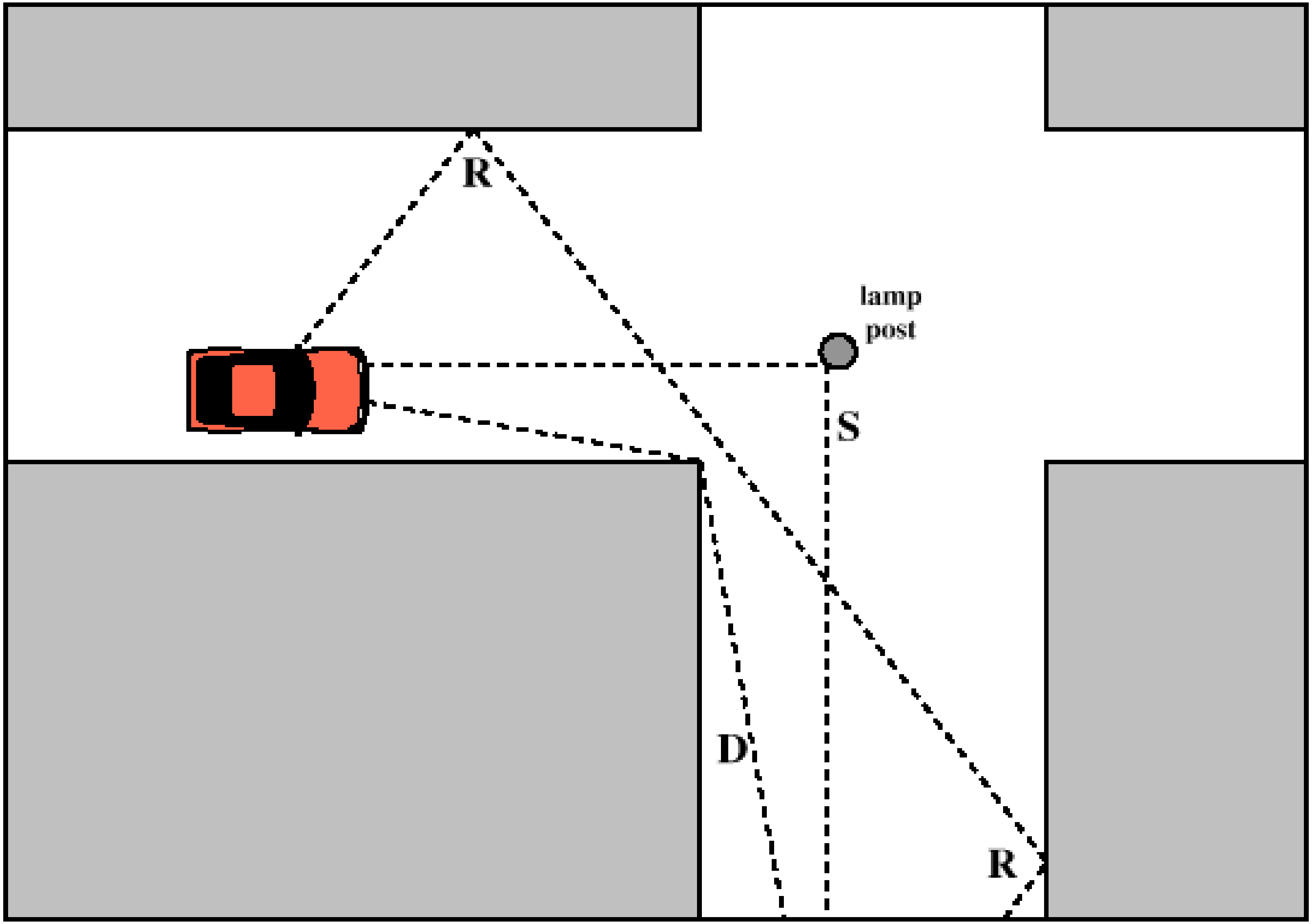
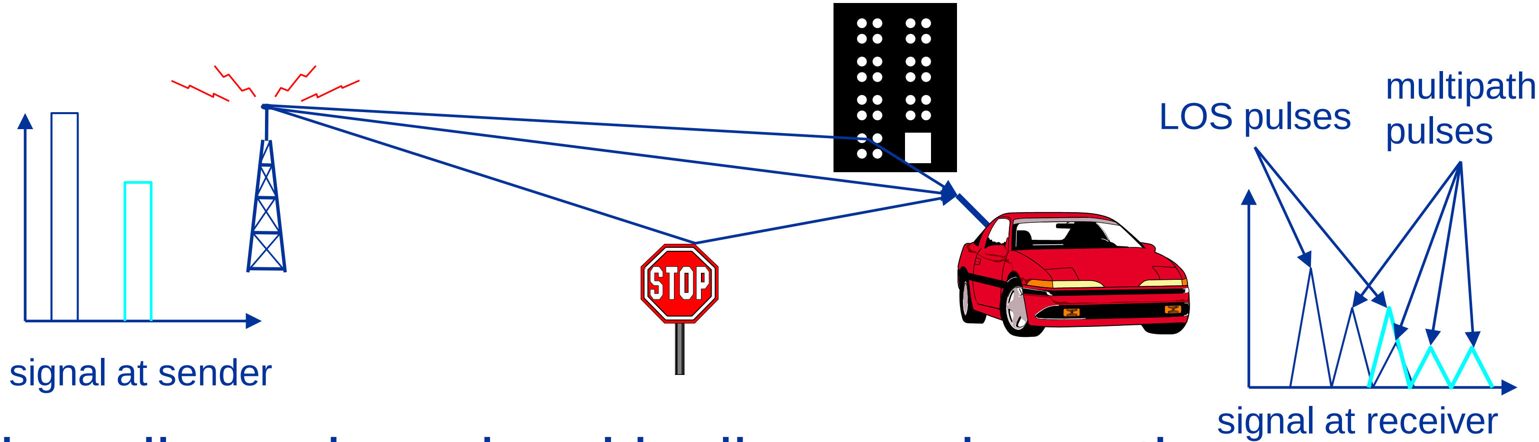


Figure 5.10 Sketch of Three Important Propagation Mechanisms: Reflection (R), Scattering (S), Diffraction (D) [ANDE95]

Multi-path Propagation

- Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction



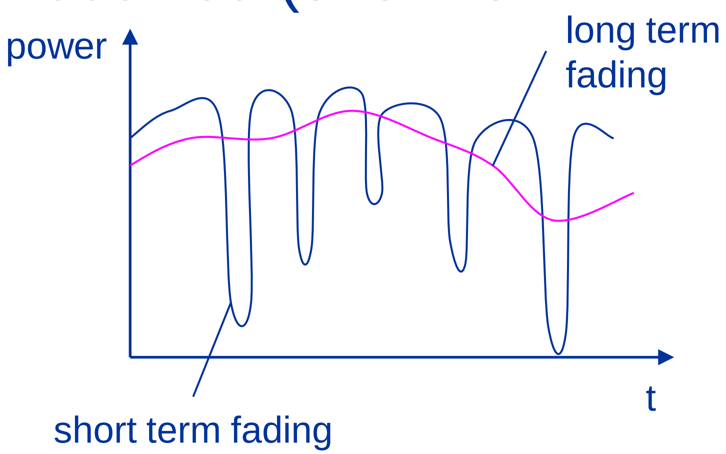
- Time dispersion: signal is dispersed over time
  - interference with “neighbor” symbols, Inter Symbol Interference (ISI)
- The signal reaches a receiver directly and phase shifted
  - distorted signal depending on the phases of the different parts

Atmospheric Absorption

- Water vapor and oxygen contribute most
- Water vapor: peak attenuation near 22GHz, low below 15Ghz
- Oxygen: absorption peak near 60GHz, lower below 30 GHz.
- Rain and fog may scatter (thus attenuate) radio waves.
- Low frequency band usage helps.

Effects of Mobility

- Channel characteristics change over time and location
  - signal paths change
  - different delay variations of different signal parts
  - different phases of signal parts
  - ➔ quick changes in the power received (short term fading)



- Additional changes in
  - distance to sender
  - obstacles further away
  - ➔ slow changes in the average power received (long term fading)

Fading Channels

- Fading: Time variation of received signal power
- Mobility makes the problem of modeling fading difficult
- Multipath propagation is a key reason
- Most challenging technical problem for mobile communications

References

- Mobile Communications, Jochen Schiller
- Antenna & Wave propagation, K D Prasad