INTEGRATED TECHNICAL EDUCATION CLUSTER
AT ALAMEERIA

E-716-A
Mobile Communications Systems

Lecture #2
Basic Concepts of Wireless Transmission (p1)

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Agenda

- Frequencies for Radio Transmission
- Signals for conveying Information
- Analog and Digital Data Transmission
- Signal Propagation

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FREQUENCIES FOR RADIO TRANSMISSION

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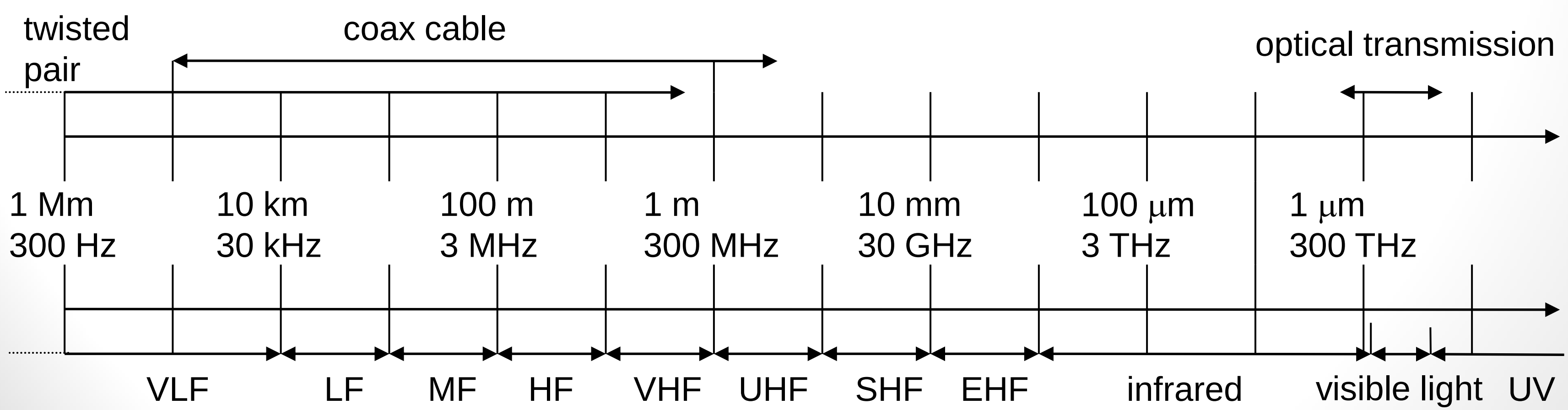
Frequencies for communication

- VLF = Very Low Frequency
- LF = Low Frequency
- MF = Medium Frequency
- HF = High Frequency
- VHF = Very High Frequency

UHF = Ultra High Frequency
SHF = Super High Frequency
EHF = Extra High Frequency
UV = Ultraviolet Light

- Frequency and wave length
  - $\lambda = c/f$
  - wave length λ, speed of light $c \cong 3 \times 10^8$ m/s, frequency f



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Example frequencies for mobile communication

- VHF-/UHF-ranges for mobile radio
  - simple, small antenna for cars
  - deterministic propagation characteristics, reliable connections
- SHF and higher for directed radio links, satellite communication
  - small antenna, beam forming
  - large bandwidth available
- Wireless LANs use frequencies in UHF to SHF range
  - some systems planned up to EHF
  - limitations due to absorption by water and oxygen molecules
    - weather dependent fading, signal loss caused by heavy rainfall etc.

Frequencies and regulations

- In general: ITU-R holds auctions for new frequencies, manages frequency bands worldwide

Examples	Europe	USA	Japan
Cellular networks	**GSM** 880-915, 925-960, 1710-1785, 1805-1880 **UMTS** 1920-1980, 2110-2170 **LTE** 791-821, 832-862, 2500-2690	**AMPS, TDMA, CDMA, GSM** 824-849, 869-894 **TDMA, CDMA, GSM, UMTS** 1850-1910, 1930-1990	**PDC, FOMA** 810-888, 893-958 **PDC** 1429-1453, 1477-1501 **FOMA** 1920-1980, 2110-2170
Cordless phones	**CT1+** 885-887, 930-932 **CT2** 864-868 **DECT** 1880-1900	**PACS** 1850-1910, 1930-1990 **PACS-UB** 1910-1930	**PHS** 1895-1918 **JCT** 245-380
Wireless LANs	**802.11b/g** 2412-2472	**802.11b/g** 2412-2462	**802.11b** 2412-2484 **802.11g** 2412-2472
Other RF systems	27, 128, 418, 433, 868	315, 915	426, 868

*all values in MHz

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SIGNALS FOR CONVEYING INFORMATION

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Signals

- physical representation of data
- function of time
- signal parameters: parameters representing the value of data
- Classification:
  - continuous time/discrete time
  - continuous values/discrete values
  - analog signal = continuous time and continuous values
  - digital signal = discrete time and discrete values

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Time Domain Concepts

- Analog signal - signal intensity varies in a smooth fashion over time
  - No breaks or discontinuities in the signal
- Digital signal - signal intensity maintains a constant level for some period of time and then changes to another constant level
- Periodic signal - analog or digital signal pattern that repeats over time
  - $s(t+T) = s(t) \qquad -\infty < t < +\infty$
    - where T is the period of the signal
- Aperiodic signal - analog or digital signal pattern that doesn't repeat over time
- Peak amplitude (A) - maximum value or strength of the signal over time; typically measured in volts

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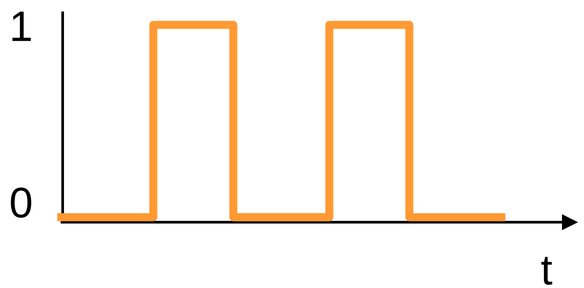
Time Domain Concepts..

- Frequency (*f*)
  - Rate, in cycles per second, or Hertz (Hz) at which the signal repeats
- Period (*T*) - amount of time it takes for one repetition of the signal
  - $T = 1/f$
- Phase (ϕ) - measure of the relative position in time within a single period of a signal
- Wavelength (λ) - distance occupied by a single cycle of the signal
  - Or, the distance between two points of corresponding phase of two consecutive cycles

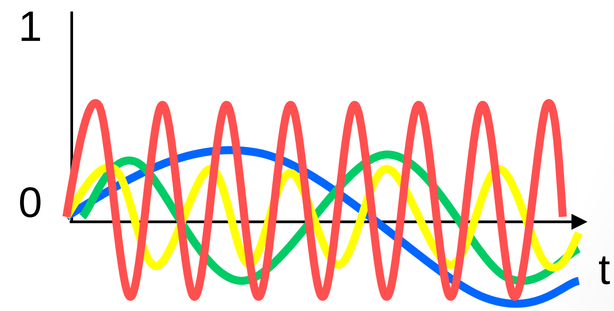
Fourier representation of periodic signals

- Signals can also be expressed as a function of frequency
  - Signal consists of components of different frequencies

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$



ideal periodic signal



real composition
(based on harmonics)

Frequency Domain Concepts

- Fundamental frequency - when all frequency components of a signal are integer multiples of one frequency, it's referred to as the fundamental frequency.
- Spectrum - range of frequencies that a signal contains.
- Absolute bandwidth - width of the spectrum of a signal.
- Effective bandwidth (or just bandwidth) - narrow band of frequencies that most of the signal's energy is contained in.
- Any electromagnetic signal can be shown to consist of a collection of periodic analog signals (sine waves) at different amplitudes, frequencies, and phases.
- The period of the total signal is equal to the period of the fundamental frequency.

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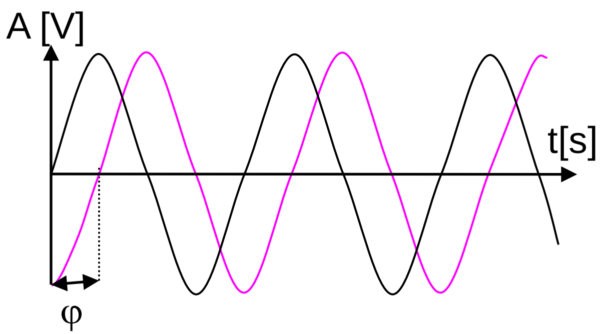
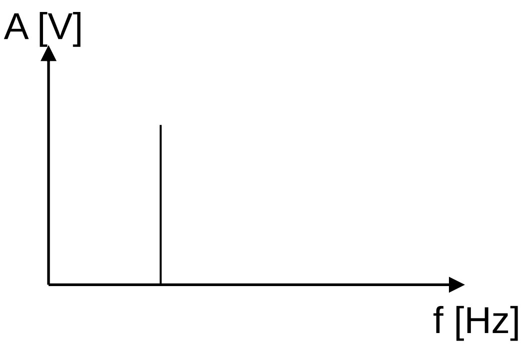
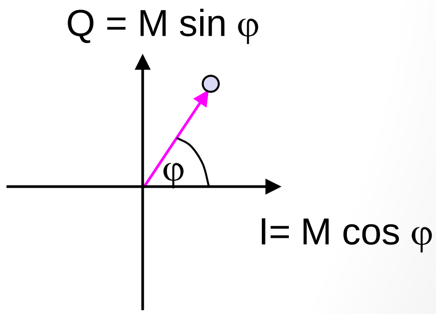
Signals representations

- Different representations of signals
  - amplitude (amplitude domain)
  - frequency spectrum (frequency domain)
  - phase state diagram (amplitude M and phase φ in polar coordinates)







ANALOG AND DIGITAL DATA TRANSMISSION

Data Communication Terms

- Data - entities that convey meaning, or information
- Signals - electric or electromagnetic representations of data
- Transmission - communication of data by the propagation and processing of signals
- Examples of Analog/Digital Data:
  - Analog
    - Video
    - Audio
  - Digital
    - Text
    - Integers

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Analog and Digital Signals again ☺

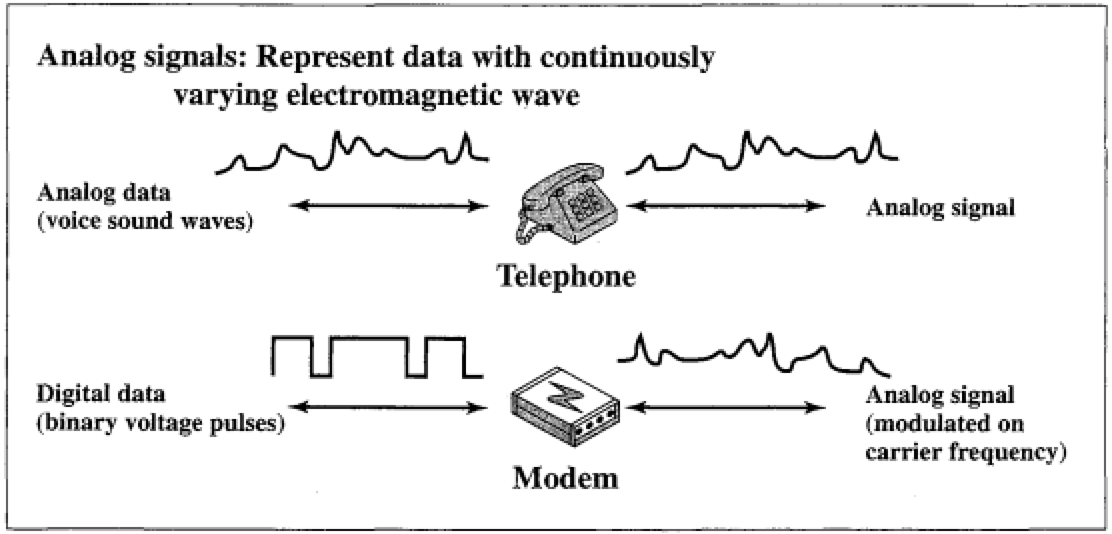
Analog

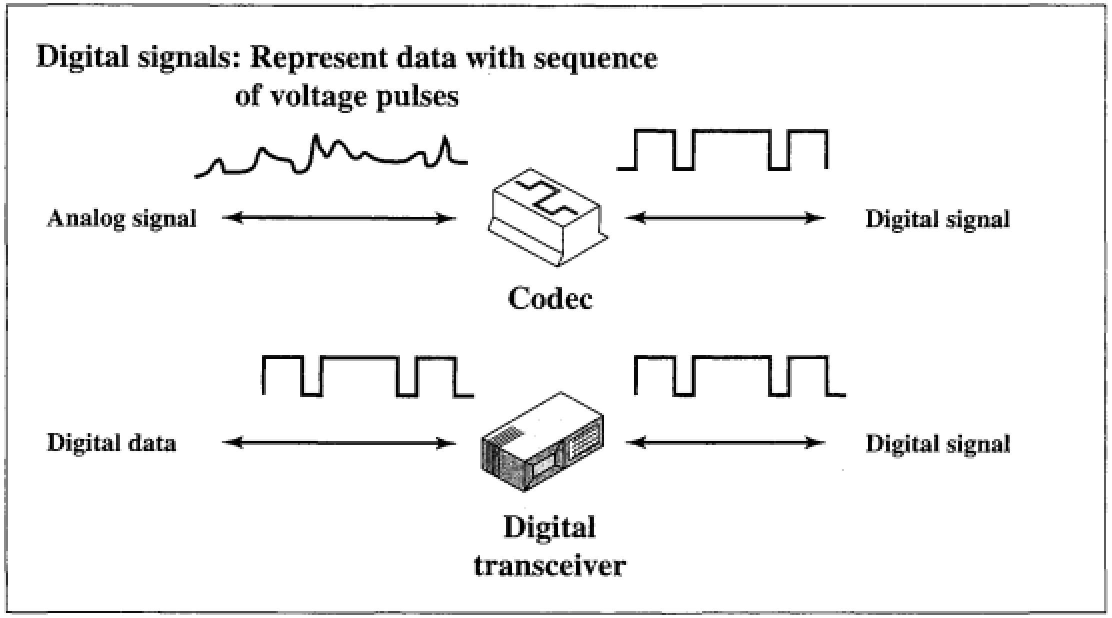
- A continuously varying electromagnetic wave that may be propagated over a variety of media, depending on frequency
- Examples of media:
  - Copper wire media (twisted pair and coaxial cable)
  - Fiber optic cable
  - Atmosphere or space propagation
- Analog signals can propagate analog and digital data

Digital

- A sequence of voltage pulses that may be transmitted over a copper wire medium
- Generally cheaper than analog signaling
- Less susceptible to noise interference
- Suffer more from attenuation
- Digital signals can propagate analog and digital data

Analog and Digital Signaling of Analog and Digital Data





Reasons for Choosing Data and Signal Combinations

- Digital data, digital signal
  - Equipment for encoding is less expensive than digital-to-analog equipment
- Analog data, digital signal
  - Conversion permits use of modern digital transmission and switching equipment
- Digital data, analog signal
  - Some transmission media will only propagate analog signals
  - Examples include optical fiber and satellite
- Analog data, analog signal
  - Analog data easily converted to analog signal

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Analog and Digital Transmission

Analog

- Transmitting analog signals without regard to their content.
- will suffer attenuation that limits the length of the transmission link.
- To achieve longer distances, include amplifiers that boost the energy in the signal.
- But, the amplifier also boosts the noise components.
- With amplifiers cascaded to achieve long distance, the signal becomes more and more distorted.
- For analog data, small distortion can be tolerated and the data remain intelligible.
- But, for digital data transmitted as analog signals, cascaded amplifiers will introduce errors.

Digital

- is concerned with the content of the signal.
- can be propagated only a limited distance before attenuation endangers the integrity of the data. Digital Signal
- To achieve greater distances, repeaters are used.
- A repeater receives the digital signal, recovers the pattern of ones and zeros, and retransmits a new signal.
- Thus, the attenuation is overcome.

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Channel Capacity

- Impairments, such as noise, limit data rate that can be achieved
- For digital data, to what extent do impairments limit data rate?
- Channel Capacity – the maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions
- Data rate - rate at which data can be communicated (bps)
- Bandwidth - the bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium (Hertz)
- Noise - average level of noise over the communications path
- Error rate - rate at which errors occur
  - Error = transmit 1 and receive 0; transmit 0 and receive 1

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Relationship between Data Rate and Bandwidth

- There is a direct relationship between the information-carrying capacity of a signal and its bandwidth
- The greater the bandwidth, the higher the information-carrying capacity
- Conclusions
  - Any digital waveform will have infinite bandwidth
  - BUT the transmission system will limit the bandwidth that can be transmitted
  - AND, for any given medium, the greater the bandwidth transmitted, the greater the cost
  - HOWEVER, limiting the bandwidth creates distortions

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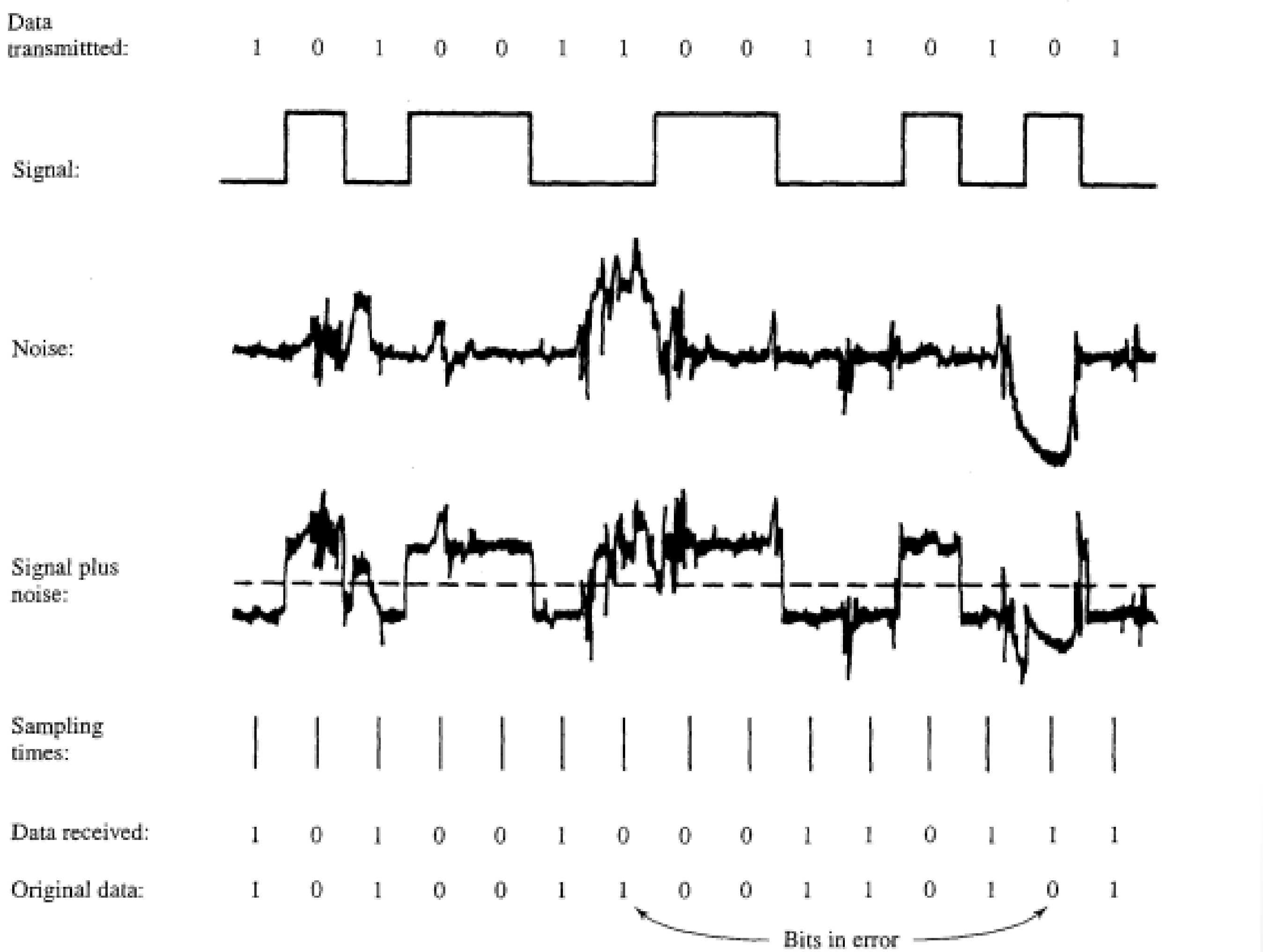
Signal-to-Noise Ratio

- Ratio of the power in a signal to the power contained in the noise that's present at a particular point in the transmission
- Typically measured at a receiver
- Signal-to-noise ratio (SNR, or S/N)

$$(SNR)_{\mathrm{dB}} = 10\log_{10}\frac{\text{signal power}}{\text{noise power}}$$

- A high SNR means a high-quality signal, low number of required intermediate repeaters
- SNR sets upper bound on achievable data rate

Effect of Noise on a Digital Signal



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Nyquist Bandwidth

- if the rate of signal transmission is 2B, then a signal with frequencies no greater than B is sufficient to carry the signal rate.
- Given a bandwidth of B, the highest signal rate that can be carried is 2B.
- This limitation is due to the effect of intersymbol interference, such as is produced by delay distortion.
  - For binary signals (two voltage levels)
    - $C = 2B$
  - With multilevel signaling
    - $C = 2B \log_2 M$
      - M = number of discrete signal or voltage levels

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Shannon Capacity Formula

- Nyquist's formula indicates that, all other things being equal, doubling the band- width doubles the data rate.
- Now consider the relationship among data rate, noise, and error rate.
- Shannon Equation: $$C = B\log_2\left(1 + \mathrm{SNR}\right)$$
- Represents theoretical maximum that can be achieved
- In practice, only much lower rates achieved
  - Formula assumes white noise (thermal noise)
  - Impulse noise is not accounted for
  - Attenuation distortion or delay distortion not accounted for

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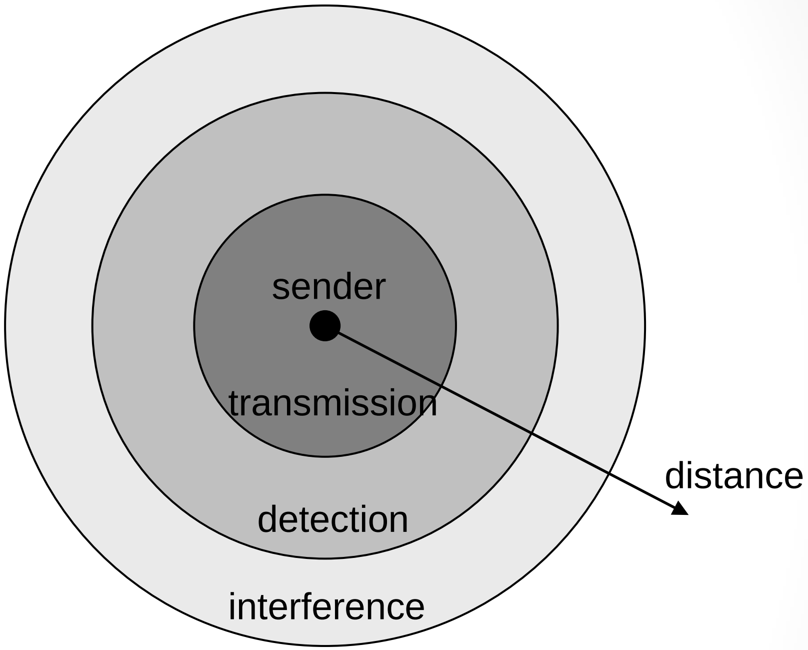
SIGNAL PROPAGATION

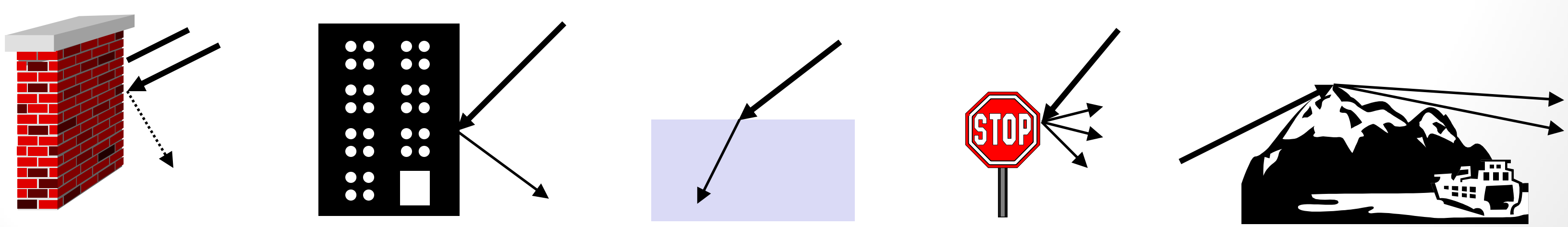
Signal Propagation Ranges

- Transmission range
  - communication possible
  - low error rate
- Detection range
  - detection of the signal possible
  - no communication possible
- Interference range
  - signal may not be detected
  - signal adds to the background noise
- Warning: figure misleading – bizarre shaped, time-varying ranges in reality!



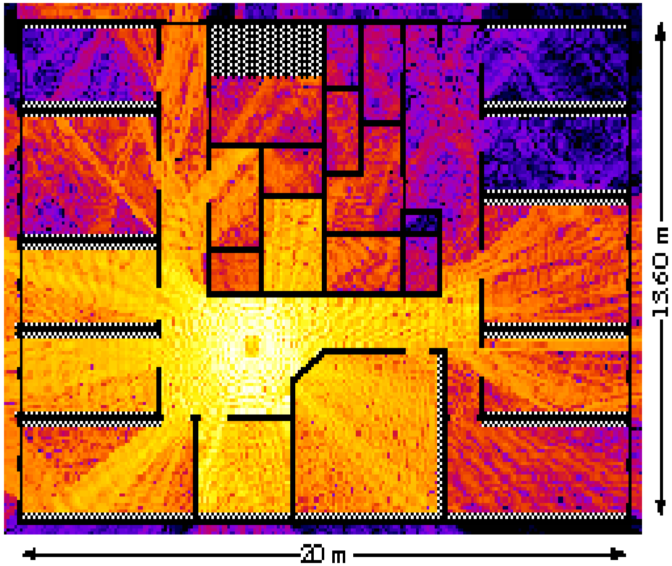
Signal Propagation

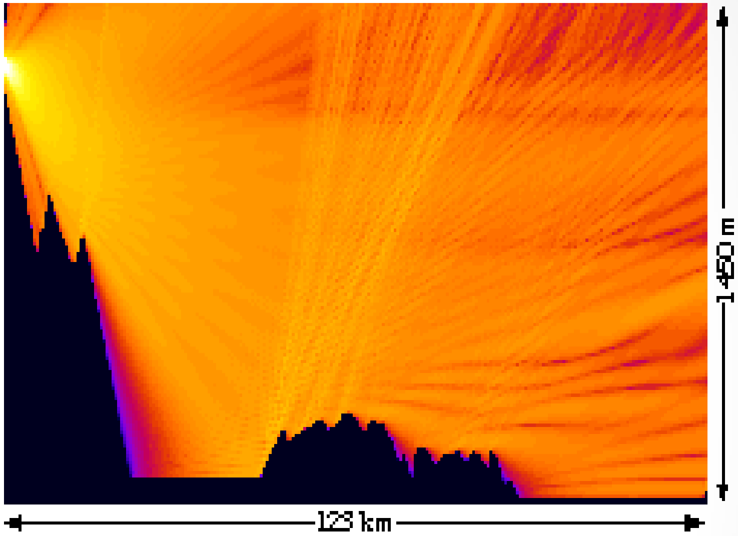
- Propagation in free space always like light (straight line)
- Receiving power proportional to $1/d^2$ in vacuum – much more in real environments, e.g., $d^{3.5}$…d^4
  (d = distance between sender and receiver)
- Receiving power additionally influenced by
  - fading (frequency dependent)
  - shadowing
  - reflection at large obstacles
  - refraction depending on the density of a medium
  - scattering at small obstacles
  - diffraction at edges

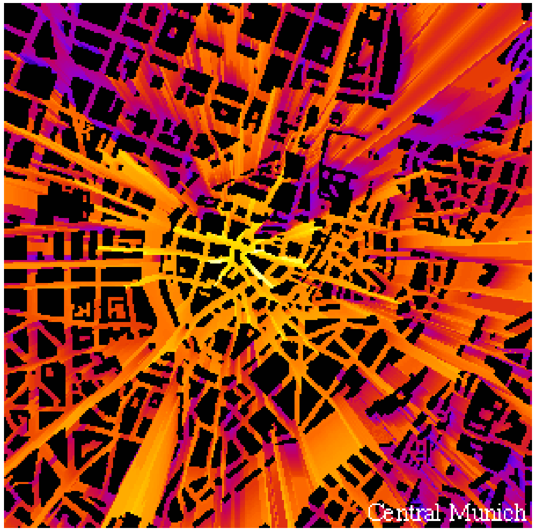


shadowing reflection refraction scattering diffraction

Real World Examples







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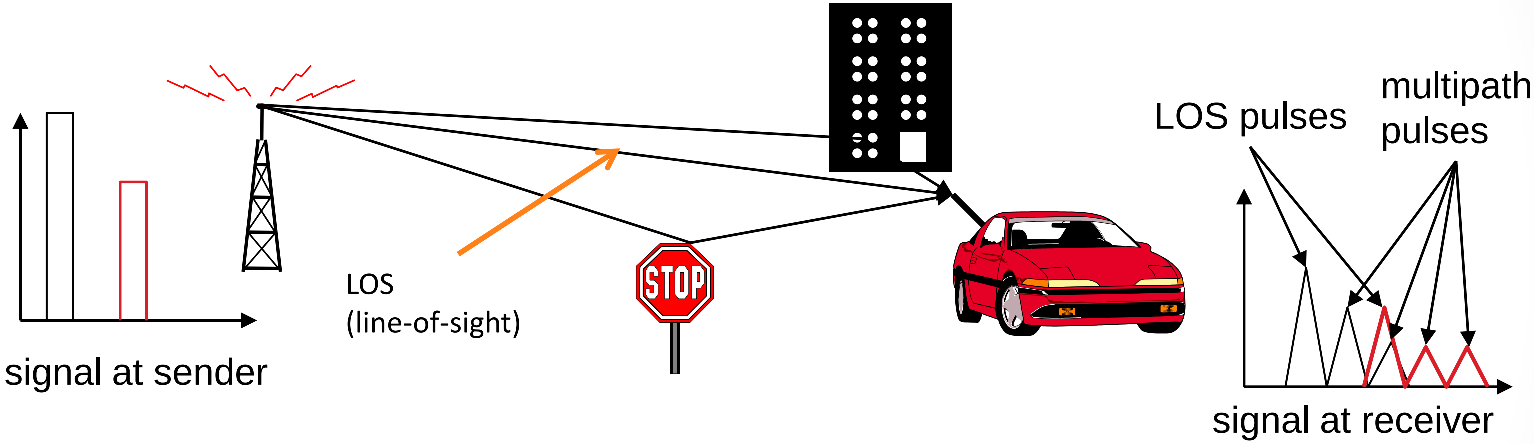
Multipath Propagation

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

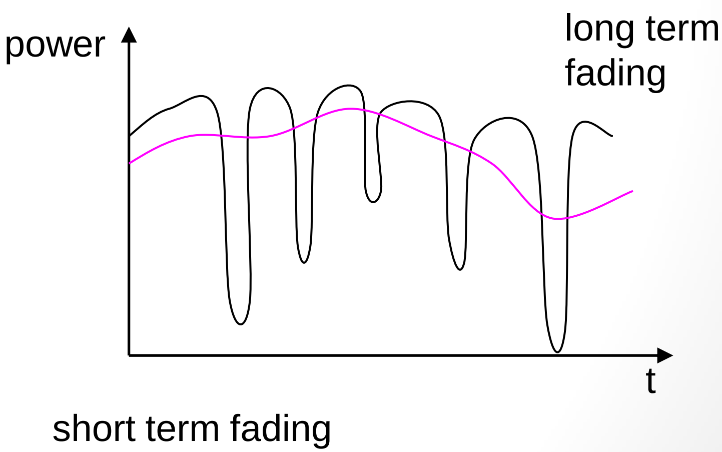


- Time dispersion: signal is dispersed over time
  - interference with "neighbor" symbols, Inter Symbol Interference (ISI)
- The signal reaches a receiver directly and phase shifted
  - distorted signal depending on the phases of the different parts

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)



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- For more details, refer to:
  - Chapter 2, J. Chiller, Mobile Communications, 2003.
  - Chapter 2, W. Stallings, Wireless Communications and Networks, 2005.
- The lecture is available onlin e at:
  - https://speakerdeck.com/ahmad_elbanna
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