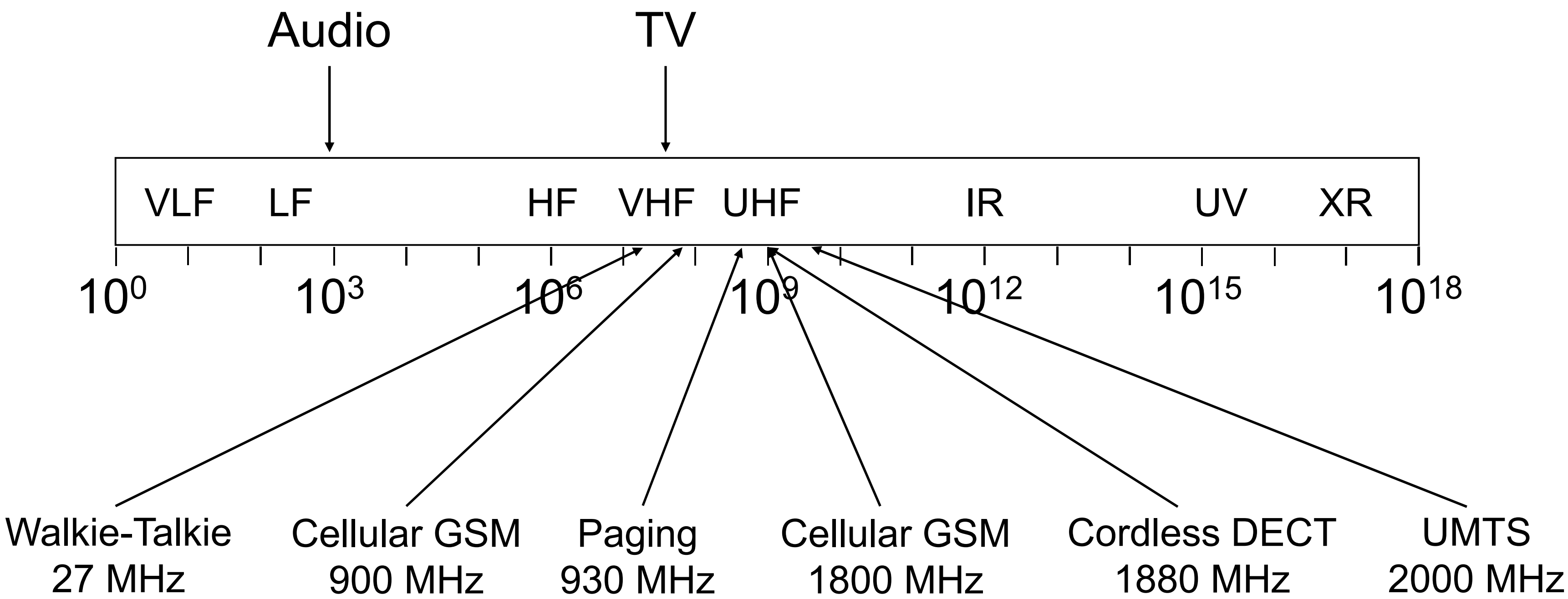
Mobile Communications Fundamentals

- Frequencies
- Modulation
- Antennas
- Mobility Management

Frequency Spectrum for Communication

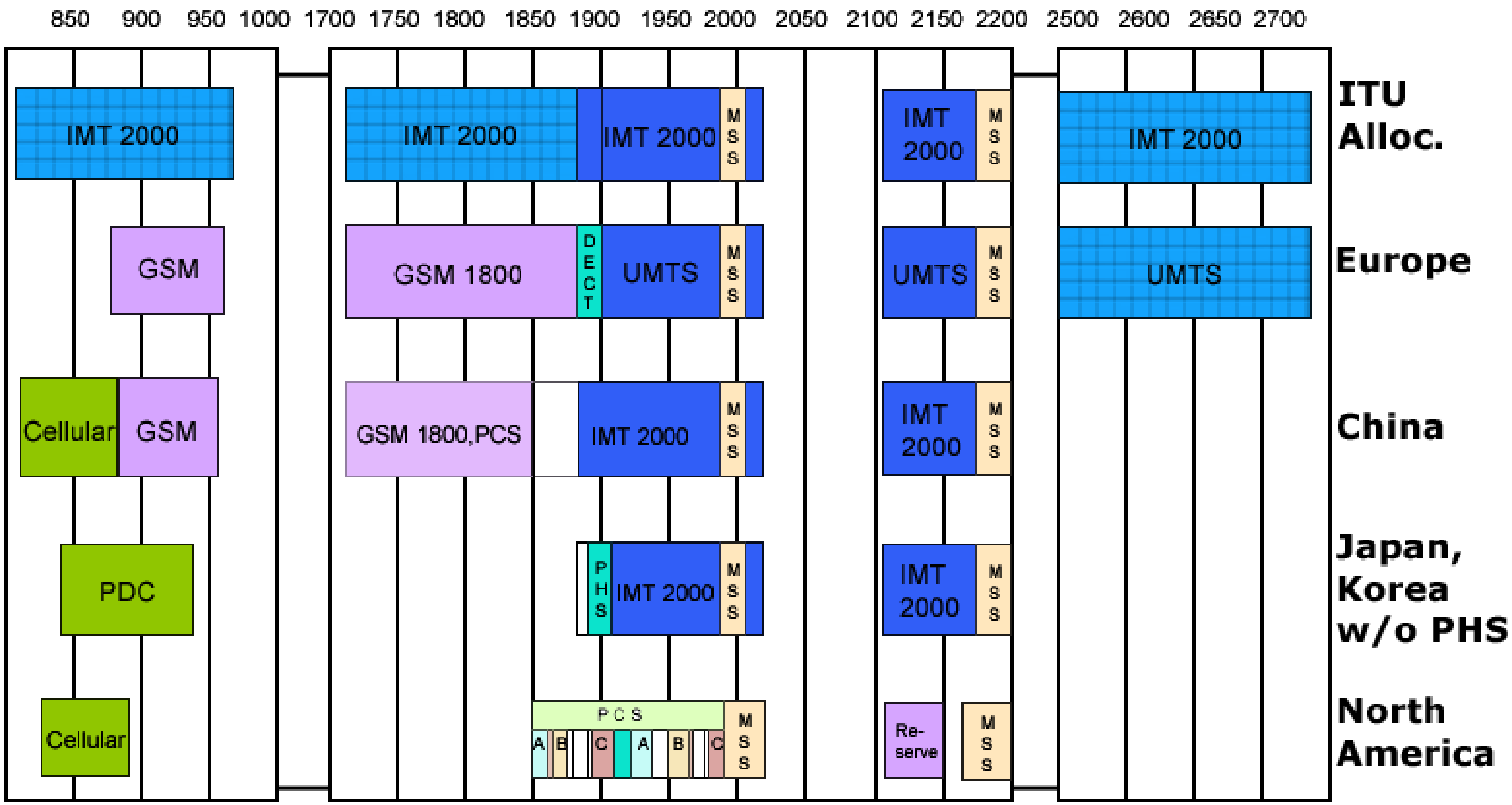
Frequencies, Examples:



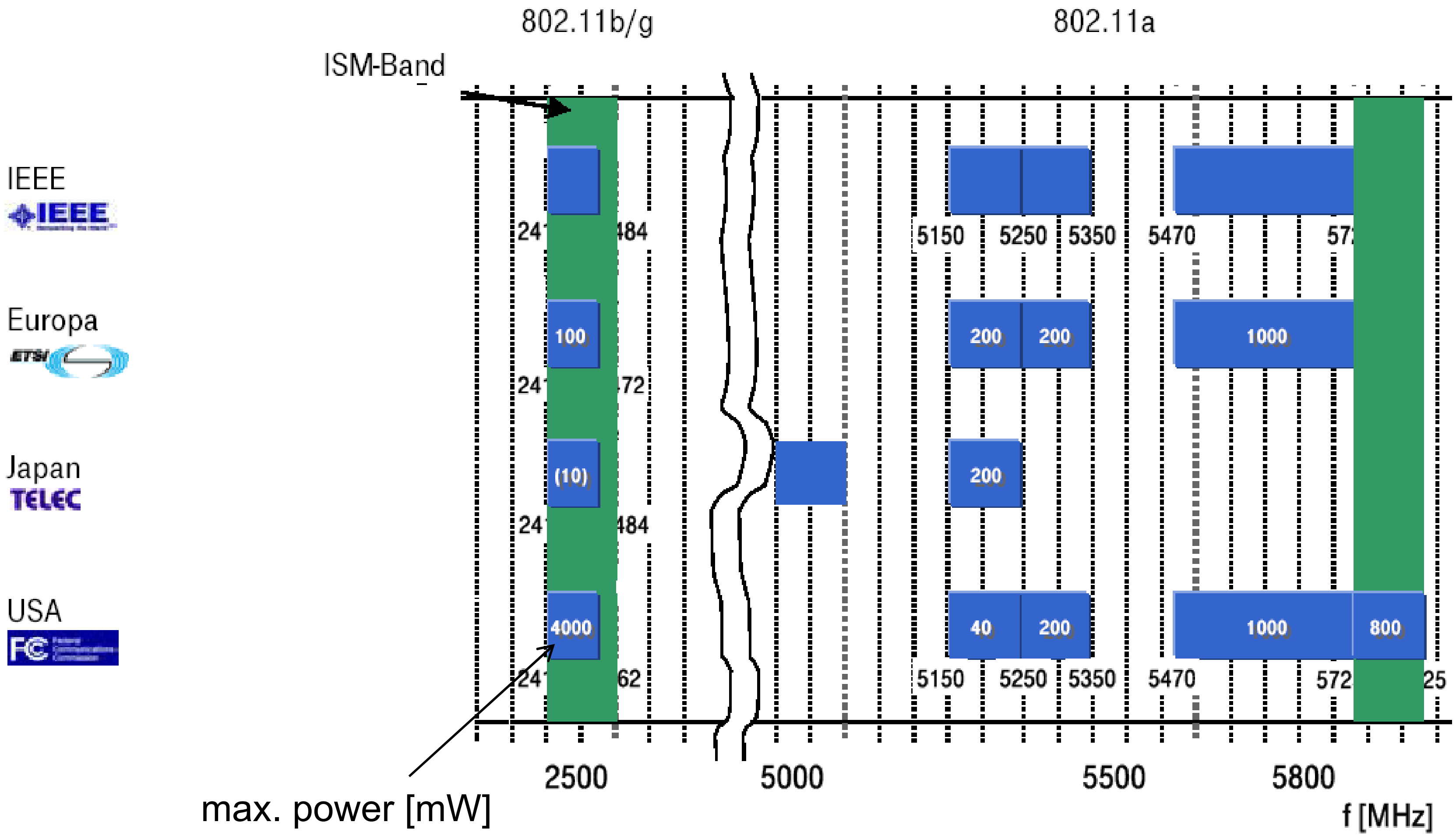
Frequency Spectrum for Communication

- Different applications use different frequency spectrum (carrier frequencies)
  - e.g. FM-Radio 88,5 MHz – 107,9 MHz
  - e.g. cordless telephone DECT 1880 MHz – 1990 MHz
- ITU-R regularly organizes conferences in order to coordinate the frequency spectrum worldwide
  - e.g. FM-Radio (UKW) is approximately the same in Germany and Croatia
- However, there is no exact harmonization of spectrum over the world, because spectrum is a national issue
  - e.g. GSM Europe 900 and 1800 MHz
  - e.g. GSM USA 1900 MHz

Frequency spectrum for cellular mobile systems



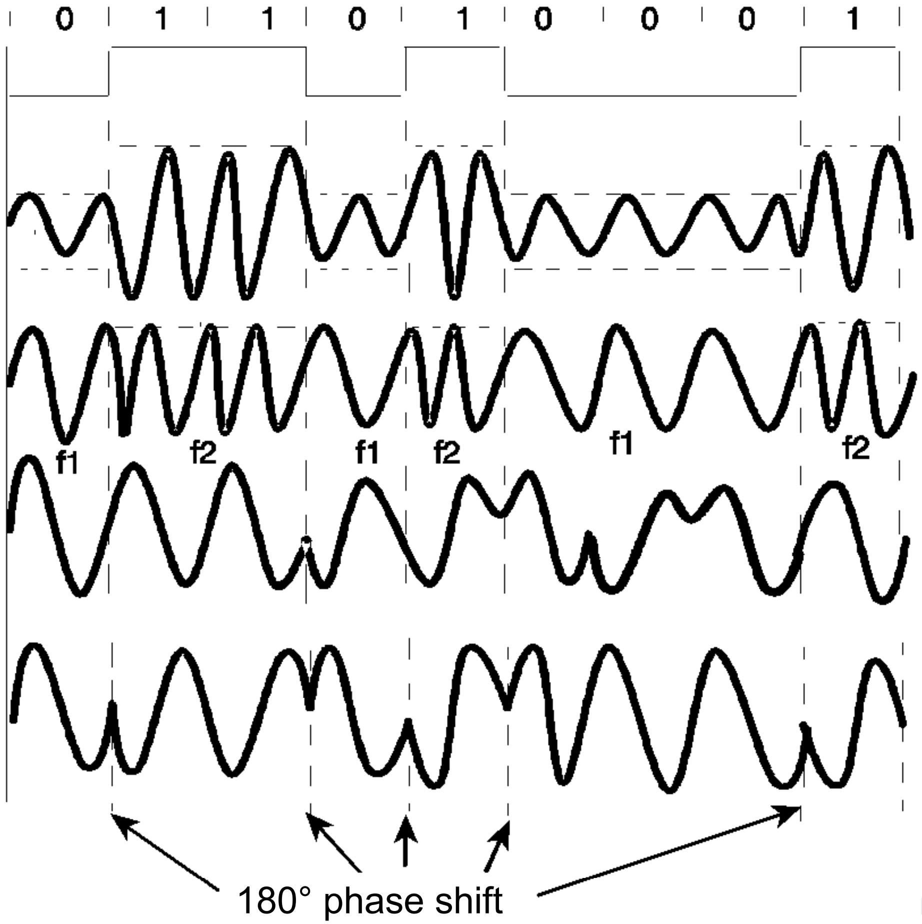
Frequency spectrum for wireless LAN (WLAN)



Modulation

Digital Information is modulated on a carrier frequency

e.g.



Amplitude modulation
ASK (Amplitude Shift Keying)

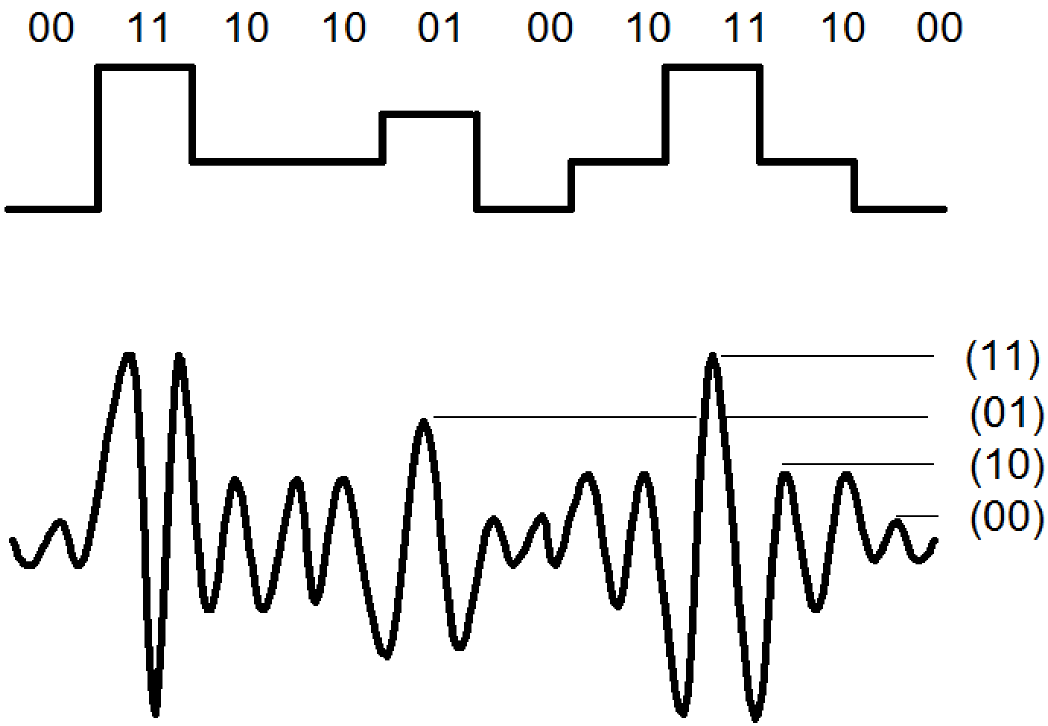
Frequency modulation
FSK (Frequency Shift Keying)

Phase modulation
Phasen shift at binery 0

Phasenmodulation
PSK (Phase Shift Keying)

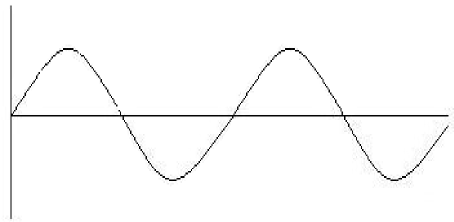
Modulation: several bits per signal state

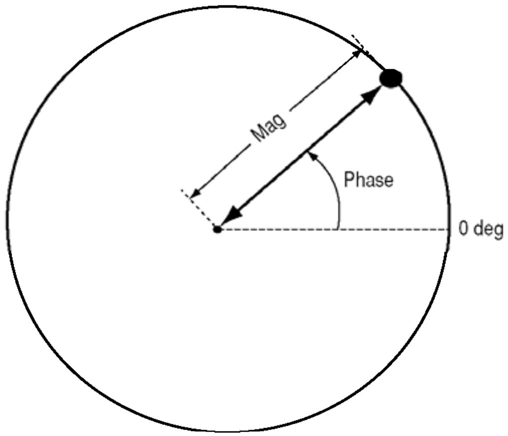
There are variants of the modulation techniques which can transmit serveral bits at one signal state change, e.g. amplitude with 4 levels

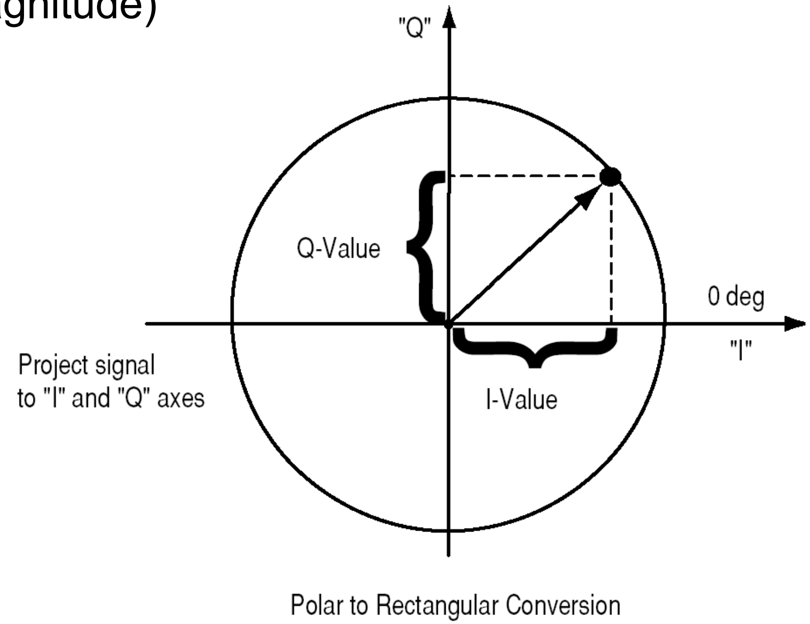


I/Q-Modulation diagram

Example: Oscillation with stable amplitude (Magnitude)



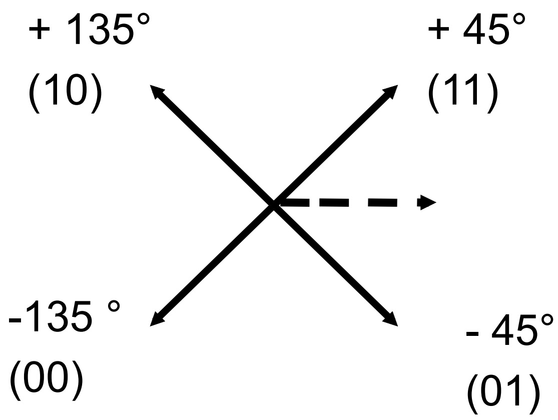




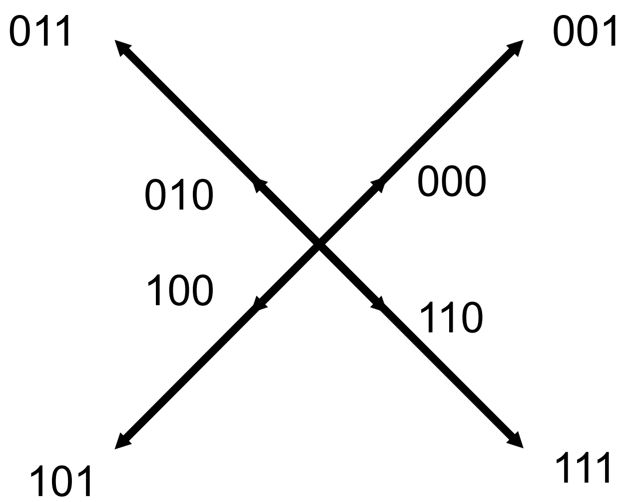
Polar diagram: Phase and Amplitude are spcified by a Q and I value

Modulation: several bits per signal state

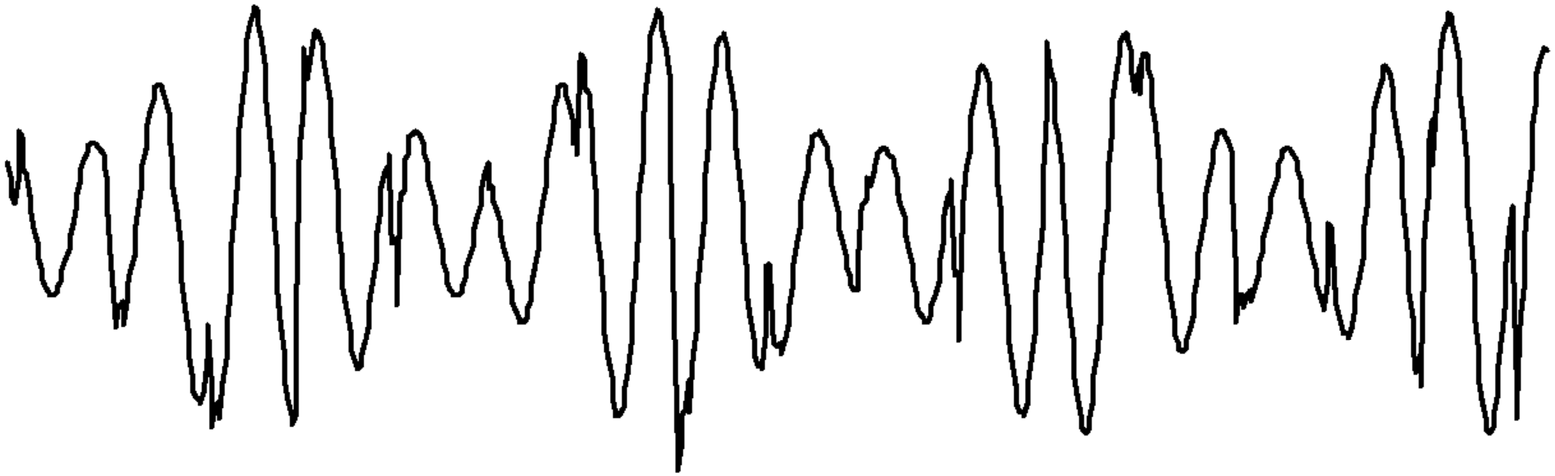
The signal changes for every pair of bits between 4 states



A combination of 4 phases and two amplitudes results in 8 different signal states, i.e. 3 bits can be transmitted in parallel



Amplitude and Phase modulation combined

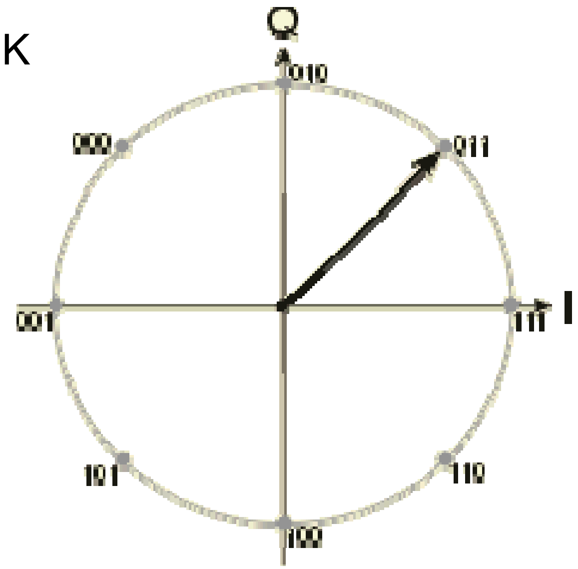


Modulation schemes for mobile communication

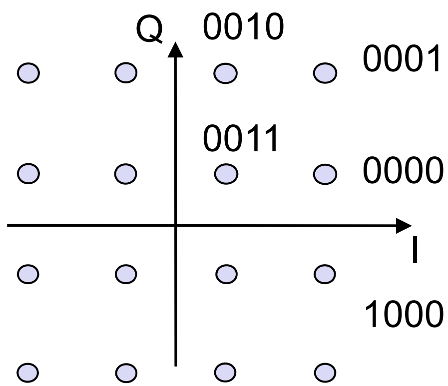
for the efficient use of spectrum frequency, amplitude and phase modulation are combined, e.g.

- 8-PSK (Phase Shift Keying), e.g. EDGE
- 16-QAM (Quadrature Amplitude Modulation), e.g. High Speed Downlink Packet Access (HSDPA), 10Mbps UMTS

8-PSK

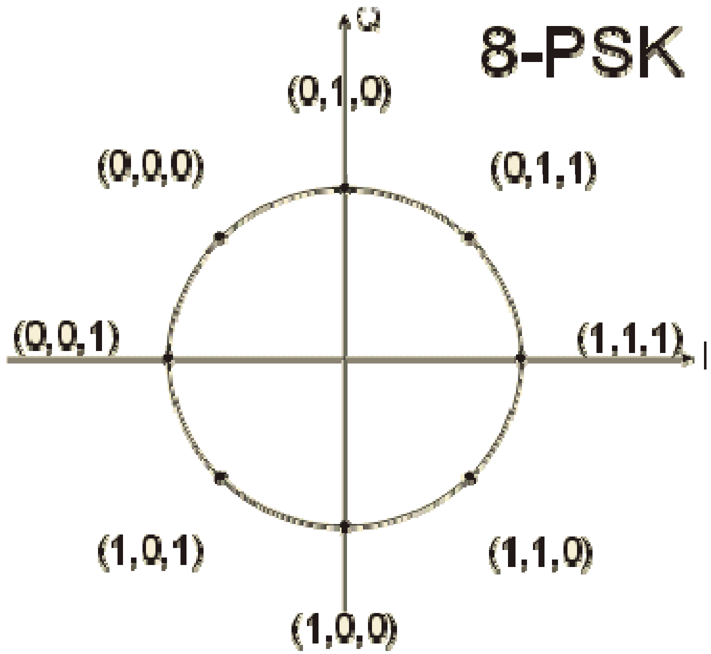


16-QAM



Modulation schemes for mobile communication

- 8-PSK combines 8 phases, at each phase change 3 bits can be transmitted
- Theoretically, there can be any number of signal states (phases)
- However, in reality it is difficult for the receiver to distinguish two states which are close to each other



Modulation schemes for mobile communication

Examples:

BPSK (= 2-PSK)	power line communication modem
QPSK (= 4-PSK)	UMTS/CDMA
8-PSK	GSM/EDGE
16-QAM	HSDPA
64-QAM	HSPA (cat15/16), LTE, 802.11a
GMSK	GSM
256QAM	Digital Video Broadcast
1024QAM	cabel modem

Modulation schemes for mobile communication

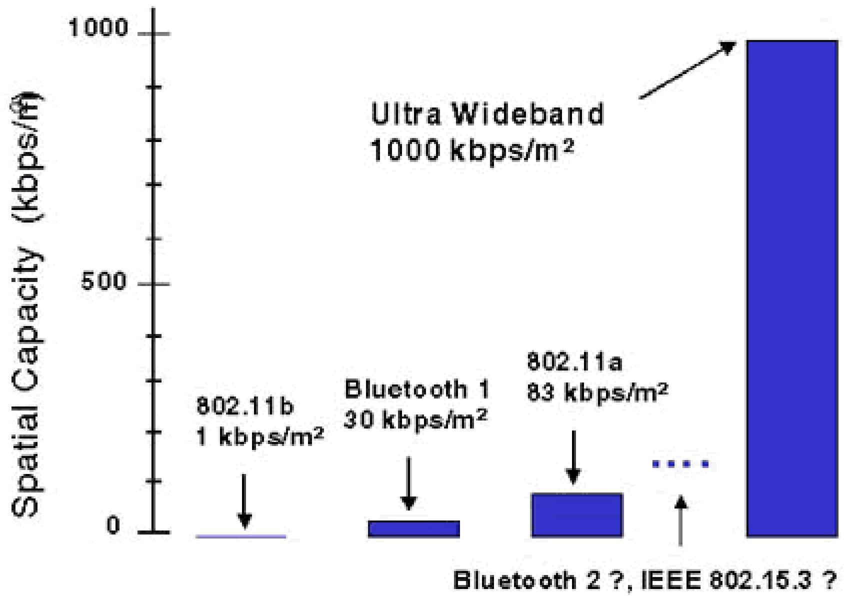
- GSM uses GMSK (Gaussian Minimum Shift Keying)
- GMSK is a frequency optimized FSK scheme
- GMSK is a modulation scheme that
  - is robust against radio disturbance
  - uses the spectrum in a very efficient way (bandwidth per transmission rate)
  - facilitates highly effective signal amplification so that mobile stations with battery have longer operation

More on modulation can be found here, for example:

http://www.educatorscorner.com/tools/lectures/appnotes/discipline/pdf/5965-7160E.pdf

Ultra Wide Band (UWB)

- Candidate for future high bit rate Wireless Personal Area Networks (WPANs). Ranges of <10m
- In order to increase wireless capacity, it is necessary to be able to transmit more kbps/m² (kilo bit per second per square meter)
- Example capacity of transmission systems:



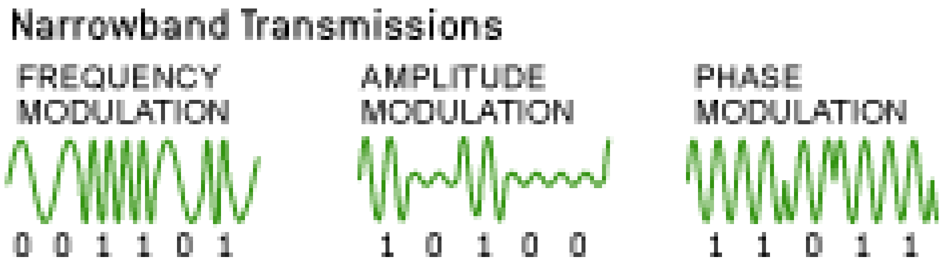
Ultra Wide Band (UWB)

- UWB doesn‘t need it‘s own frequency band, it co-exists as an overlay system with other services
- can be operated license free and uses unused or used spectrum
- can be operated very inexpensively and energy efficient
- transmits at very high transmission rate, multi channel and is robust against interference
- because of low PSD (Power Spectral Density), UWB cannot easily be detected by other systems

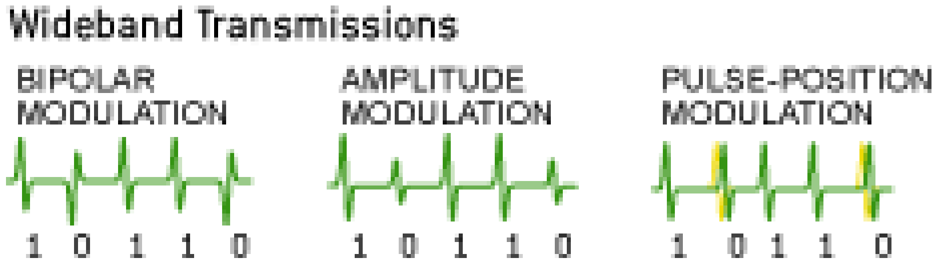
Ultra Wide Band (UWB)

How does it work?

- Traditional systems use carrier frequencies and modulate digital information on them



- UWB does not use a carrier. The 0s and 1s are coded by very short bursts, by use of one of the following methods:



Ultra Wide Band (UWB)

- Bipolar modulation: a 1 is represented by a positive (increasing) pulse, while a 0 is represented by the inverse (decreasing)

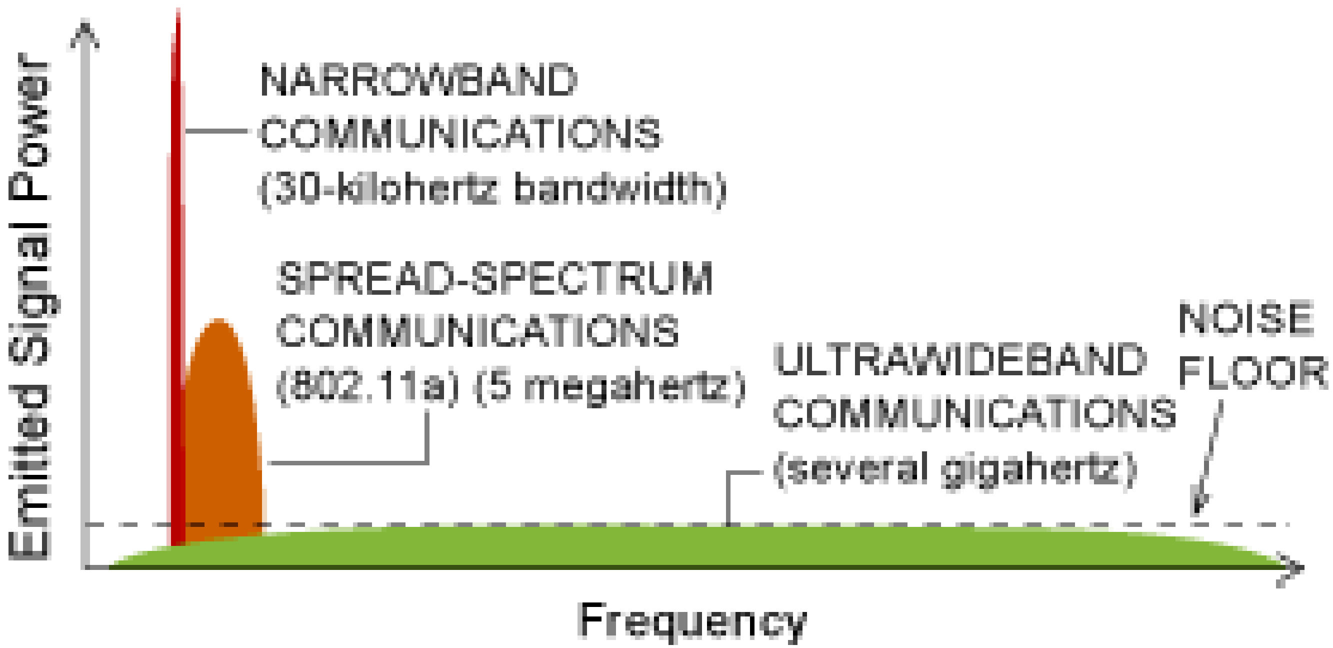
- Amplitude modulation: a 1 is represented by the full amplitude, while the 0 is represented by half of it

- Pulse position modulation: the time slot between two signals varies, a delayed pulse represents a 0

Ultra Wide Band (UWB)

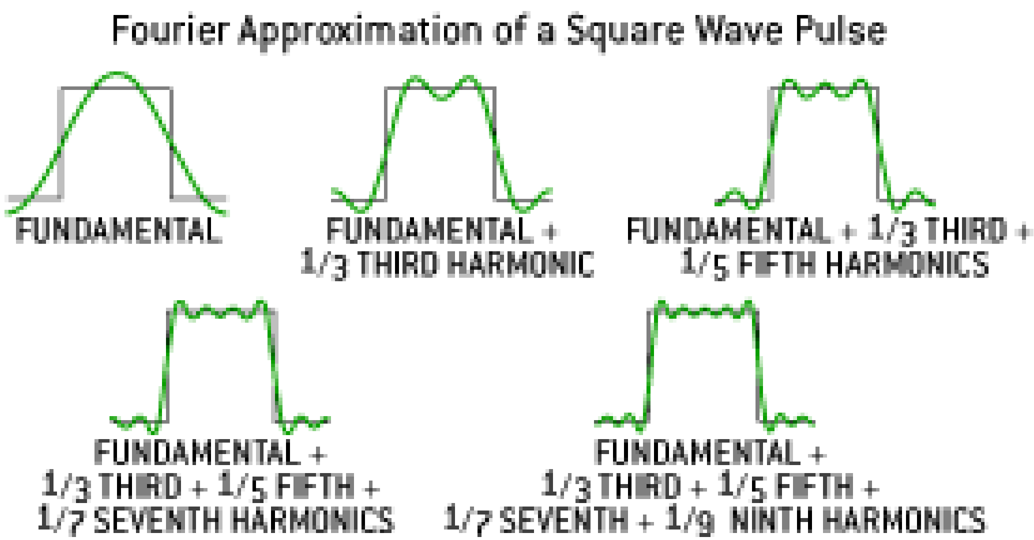
How does it work?

emitted transmission signal power vs. used spectrum



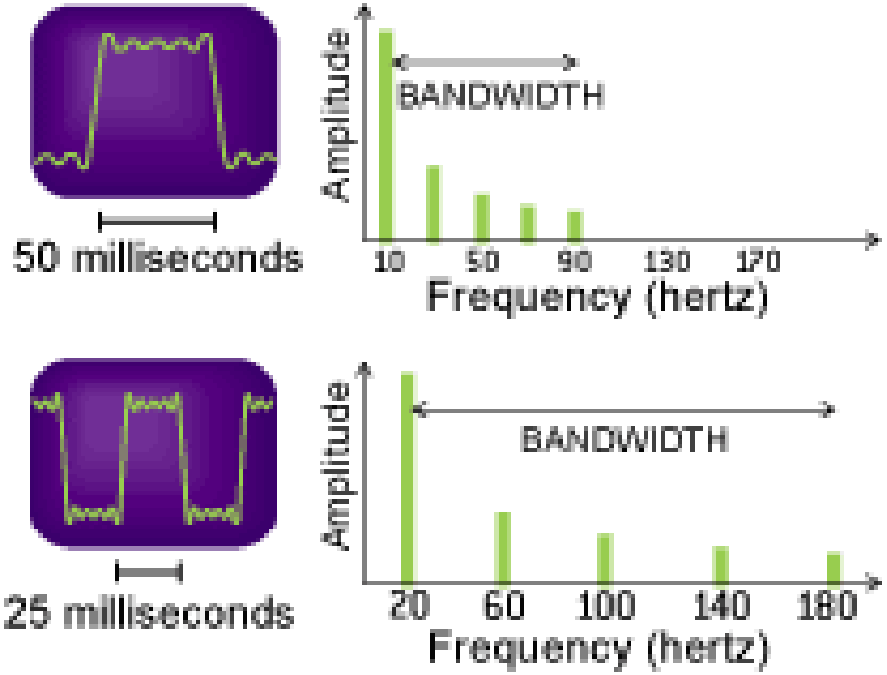
Ultra Wide Band (UWB)

- Why do the bursts occupy wide frequency band?
- Fourier transformation says that every pulse form can be approximated by the weighted sum of sine curves
- e.g., a rectangular pulse can be generated by the sum of a „Fundamental“ sine curve plus so called „Harmonics“



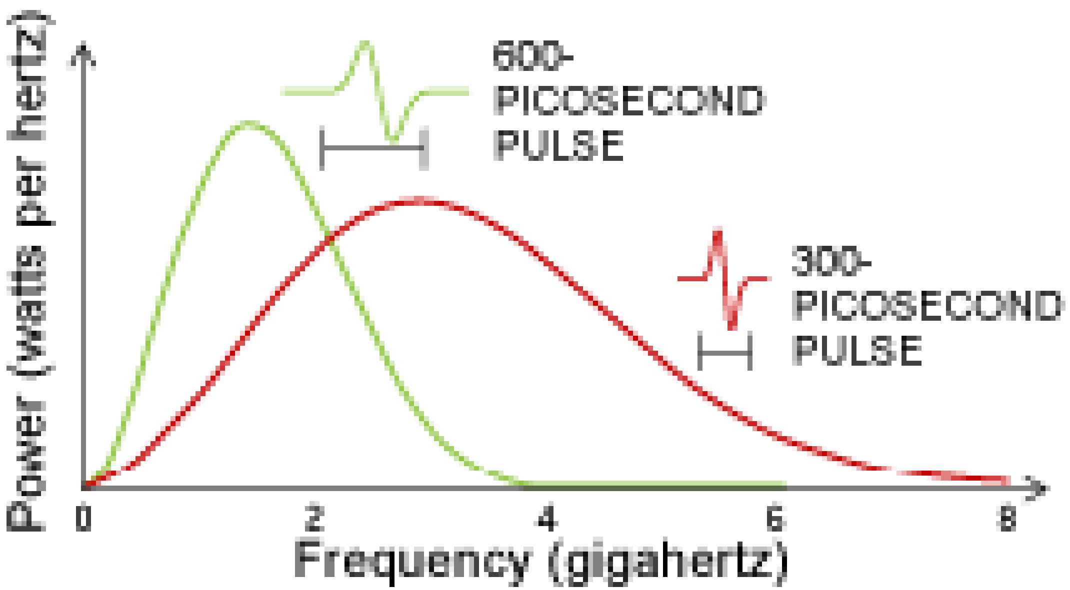
Ultra Wide Band (UWB)

- The shorter the pulse, the higher the frequency of the sine curve must be to reach approximation
- In the example below the 4 Harmonics occupy a higher bandwidth for a short pulse compared to a longer pulse



Ultra Wide Band (UWB)

- Comparison between the spectrum occupied by a 600 psec pulse compared by a that of a 300 psec pulse.



Ultra Wide Band (UWB)

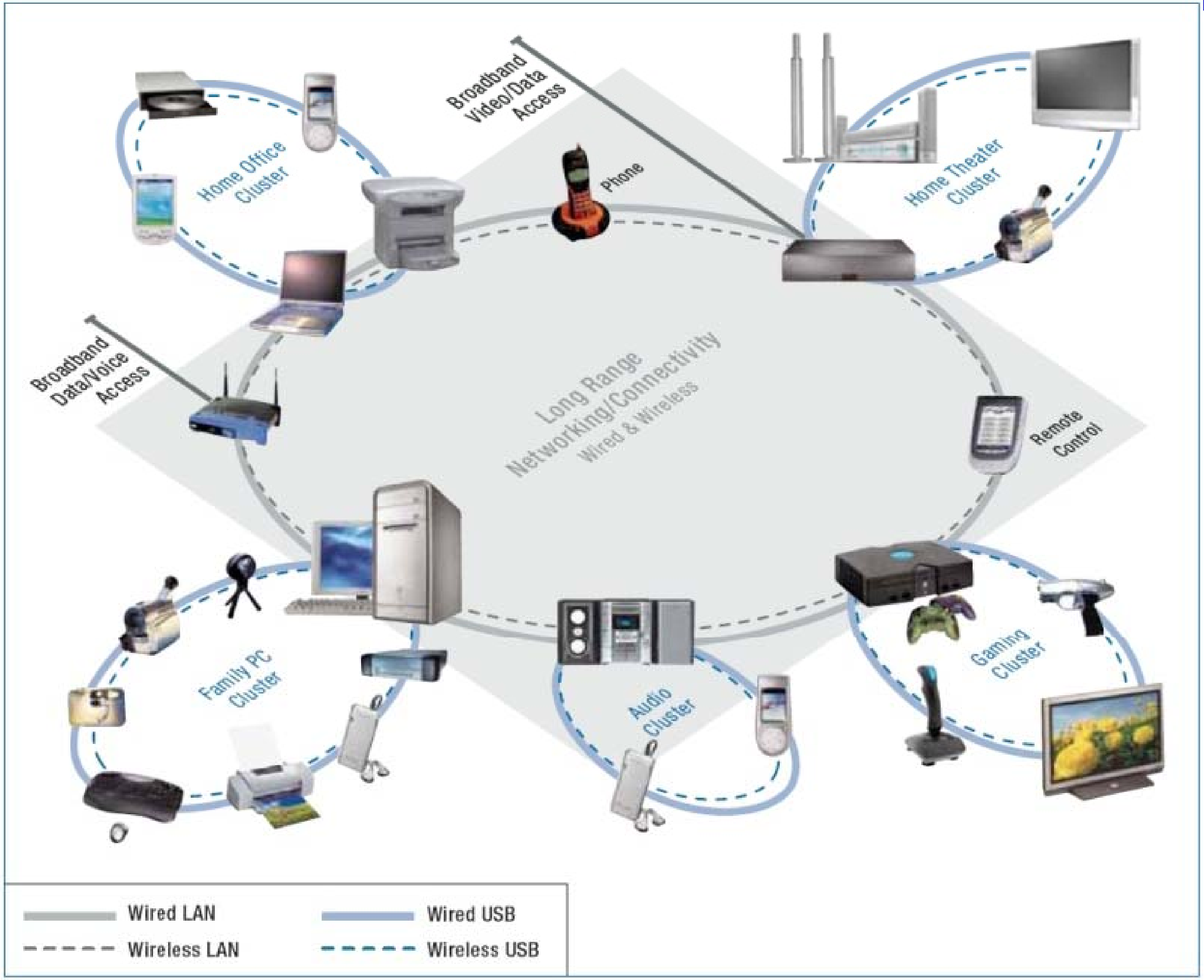
- Example of a wireless HDMI device with UWB
- "Wireless HDMI Extender„ of Gefen
- range is 10m line of sight

transmitter receiver

Ultra Wide Band (UWB)

- To date systems:
  - transmit 480 Mbit/s over 3m
  - transmit 110 Mbit/s over 10m

Example usage scenario for UWB



Ultra Wide Band (UWB)

Sources:

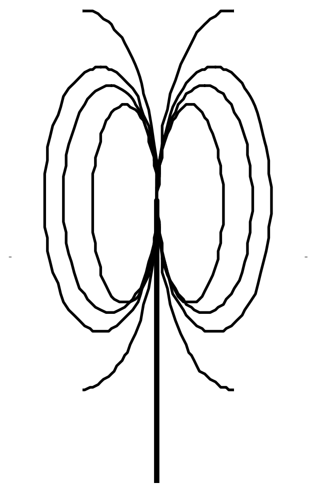
http://www.tecchannel.de/entwicklung/grundlagen/429761/

http://www.sciam.com/article.cfm?articleID=0002D51D-0A78-1CD4-B4A8809EC588EEDF&pageNumber=1&catID=2

http://www.sciam.com/article.cfm?articleID=000780A0-0CA3-1CD4-B4A8809EC588EEDF

Antennas: isotropic radiator

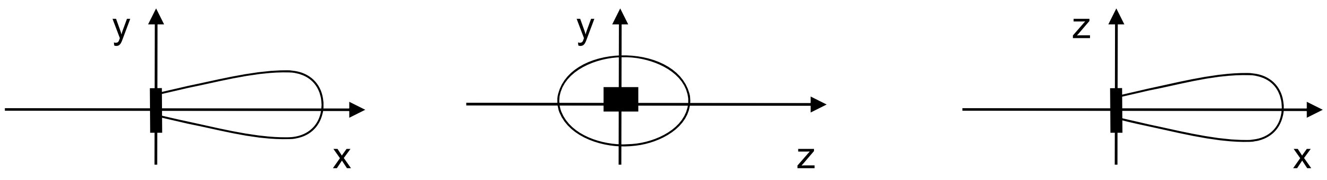
- Radiation and reception of electromagnetic waves
- Isotropic radiator: equal radiation in all directions (three dimensional) - only a theoretical reference antenna
- Real antennas always have directive effects (vertically and/or
- horizontally)
- Radiation pattern: measurement of radiation around an antenna



Gain: maximum power in the direction of the main lobe compared to the power of an isotropic radiator (with the same average power)

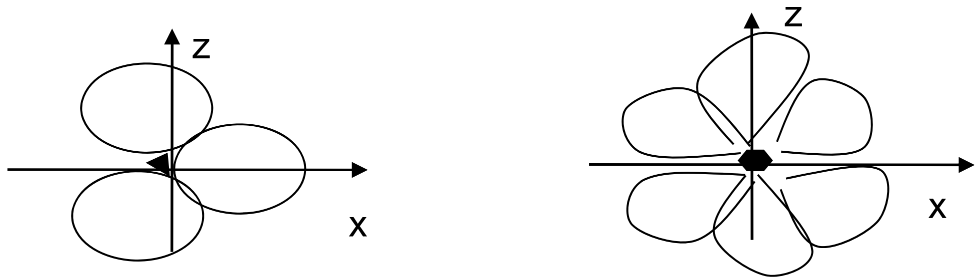
Antennas: directed and sectorized

- Antennas for mobile communication are often contructed in a way that they preferably transmit or receive in certain directions, e.g. transmission and reception along a rail track



side view (xy plane) | side view (yz plane) | top view (xz plane)

directed antenna



top view, 3 sectors | top view, 6 sectors

sectored antenna

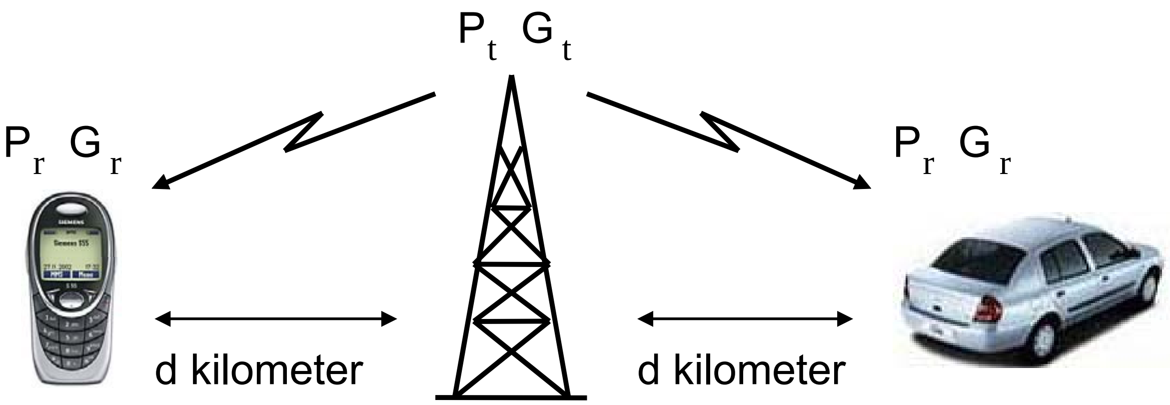
Antennas: samples

L-band satellite receiver station
(DFD, Oberpfaffenhofen)

L- and S-band receiver antenna

Antennas

- The received power P_r decreases with the distance between receiver and transmitter. It depends on the transmitted power P, the gain and the distance.



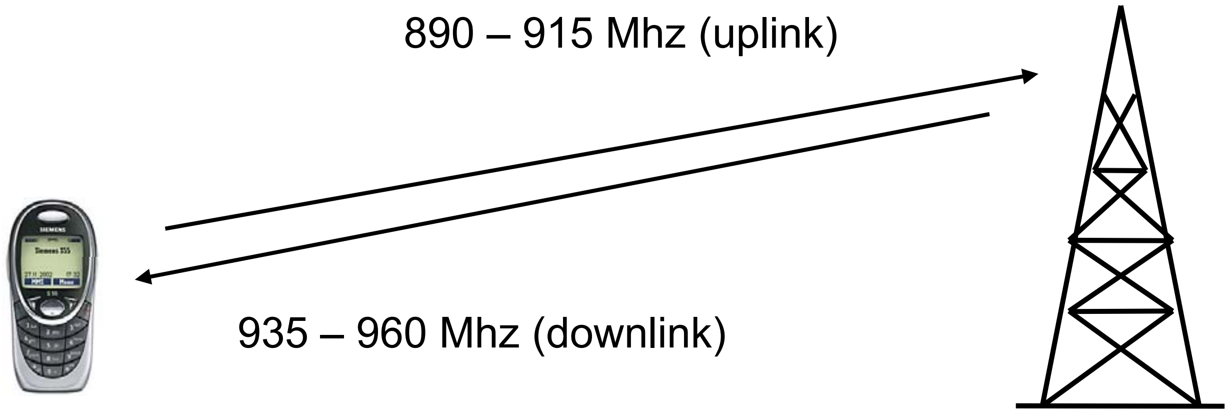
$$P_r = \left(\frac{P_t}{4\pi d^2} \right) G_t \times \left(\frac{\lambda^2}{4\pi} \right) G_r$$

P = energy (t/r = transmit/receive)
λ = wave length (c/frequency)
G = gain
c = speed of light

Antennas

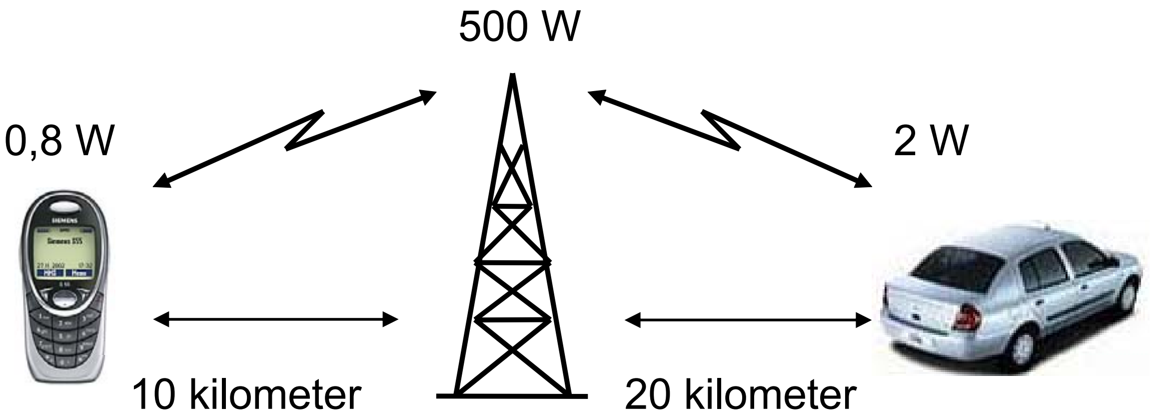
- because of the formula above the higher frequency is used for downlink and the lower frequency for uplink

Example GSM 900



Antennas

example



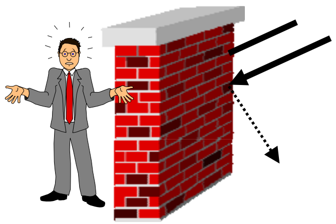
influenced by

- o curvature of the earth
- o relief features (mountains, etc.)
- o buildings, trees, etc.
- o atmosphere (in particular for high frequencies, e.g. 60 GHz)

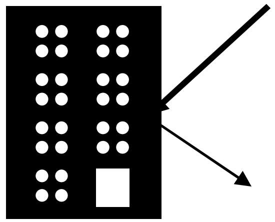
Signal propagation

Propagation in free space always like light (straight line)
Receiving power proportional to $1/d^2$ in vacuum – much more in real environments
(d = distance between sender and receiver)
Receiving power additionally influenced by

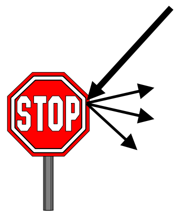
- fading (frequency dependent)
- shadowing
- reflection at large obstacles
- refraction depending on the density of a medium
- scattering at small obstacles
- diffraction at edges



shadowing



seflection

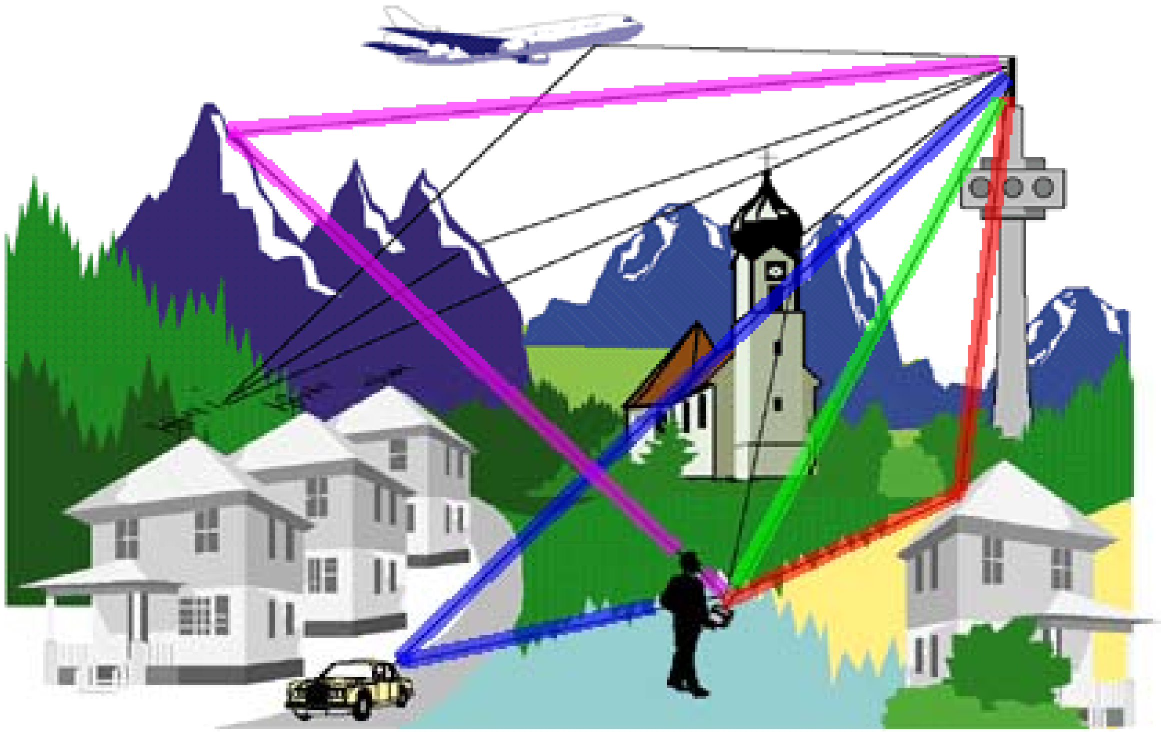


scattering

diffraction

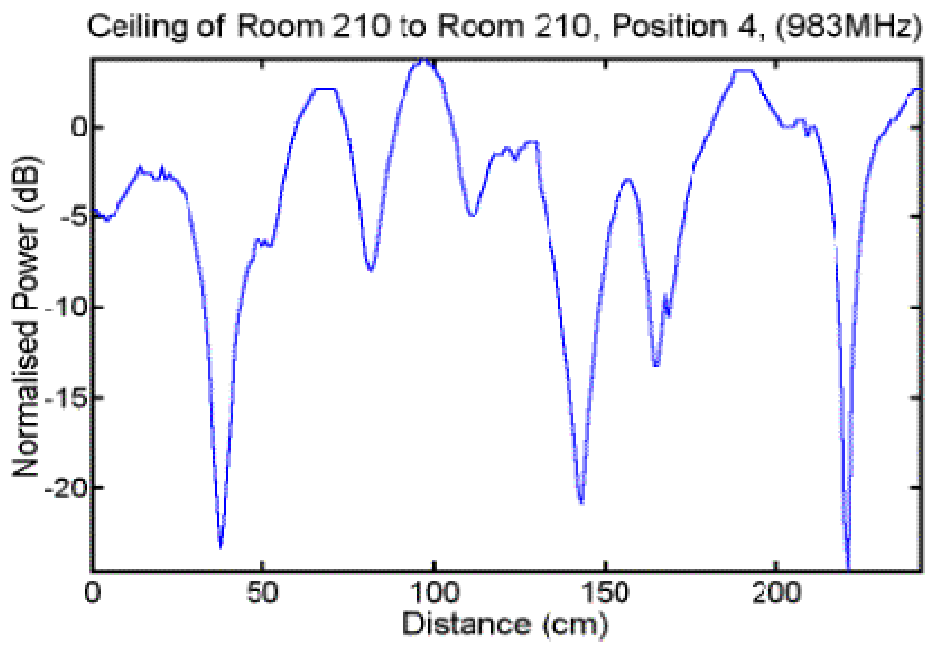
Multipath propagation

- Signals can take many different paths between sender and receiver due to reflection, scattering, diffraction?
- results in additional background noise
- Is a particular problem for modulation schemes with high bitrate, e.g. 64-QAM



Multipath propagation effects

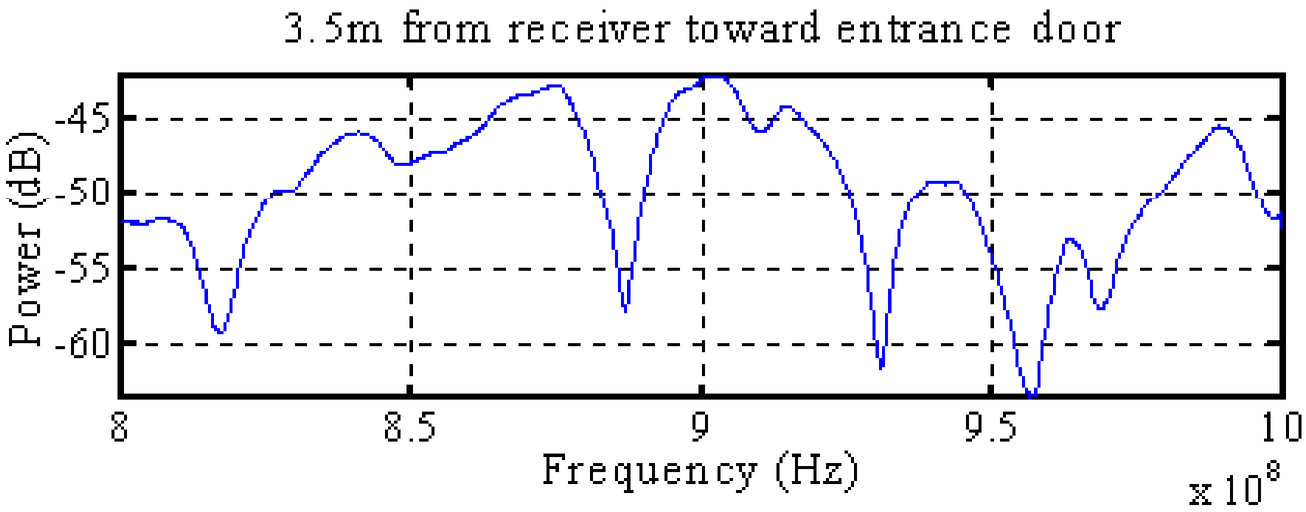
- The interference is location and frequency dependent
- example of a measurement of received signal strength vs. distance to the sender



source: http://www.skydsp.com/publications/phd_sem/index.htm

Multipath propagation effects

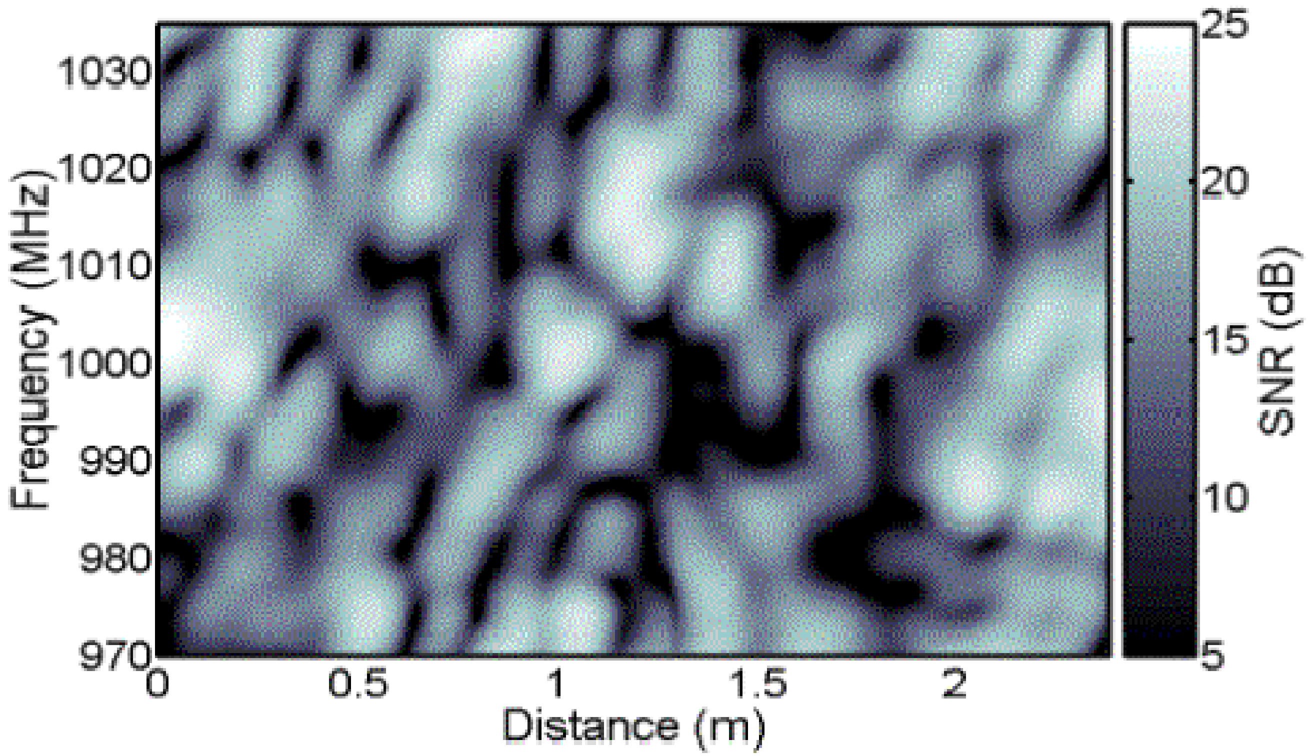
- example of a measurement of received signal strength vs. Frequencs (location is fixed)



source: http://www.skydsp.com/publications/phd_sem/index.htm

Multipath propagation effects

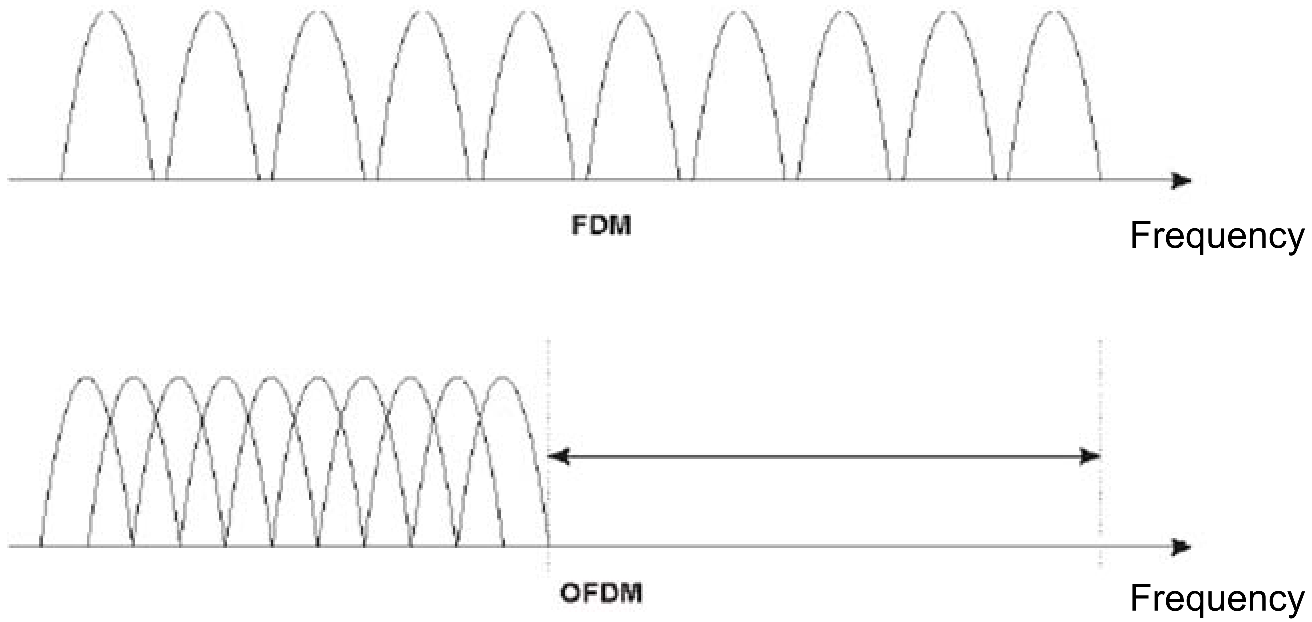
- example of a measurement of received signal strength by frequency and distance



SNR (Signal to Noise Ratio) is a measure of signal strength
source: http://www.skydsp.com/publications/phd_sem/index.htm

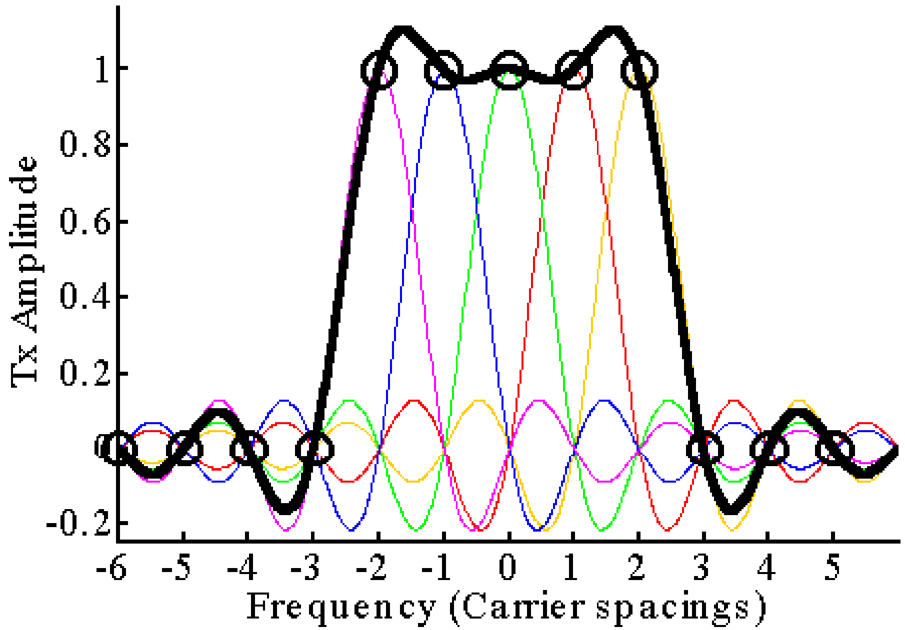
OFDM (Orthogonal Frequency Division Multiplexing)

- Separation of a high speed bit tream into several low speed ones
- overlap of frequency bands



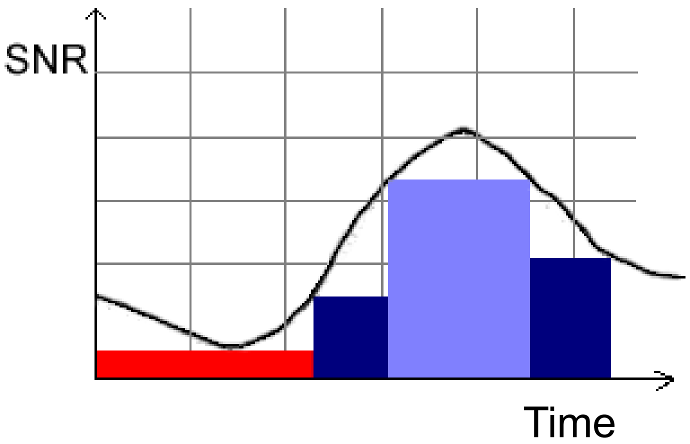
OFDM (Orthogonal Frequency Division Multiplexing)

- Elimination of overlap interference by orthogonal frequencies
- sub channel frequencies are chosen in a way such that the maximum on an oscillation at one frequency coincides with the zero location of the neighbouring frequencies



OFDM (Orthogonal Frequency Division Multiplexing)

- Each sub carrier can use its own modulation scheme
- common schemes: BPSK, QPSK, 16 QAM und 64 QAM
- OFDM is used in HSDPA, 802.11a and 802.11n
- adaptive wrt signal quality

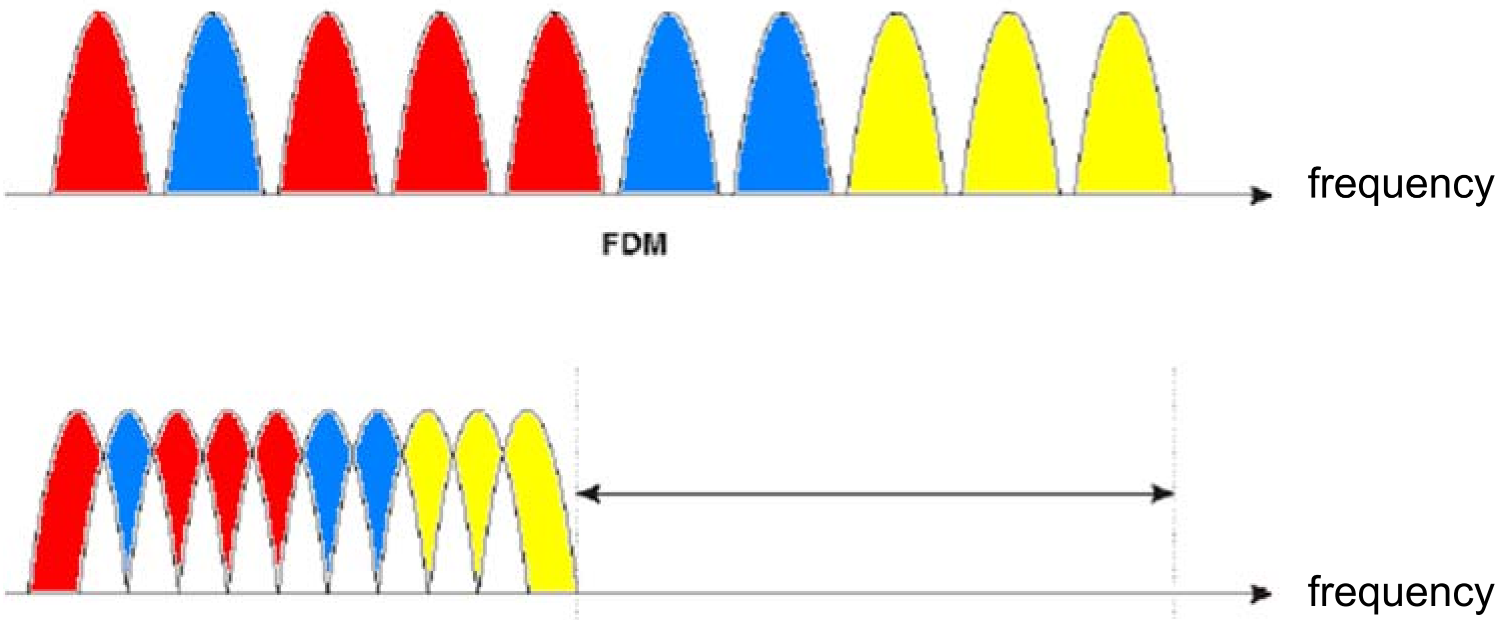


Signal quality
SNR (Signal/Noise Ratio)

BPSK
QPSK
16QAM

OFDMA (OFDM Access)

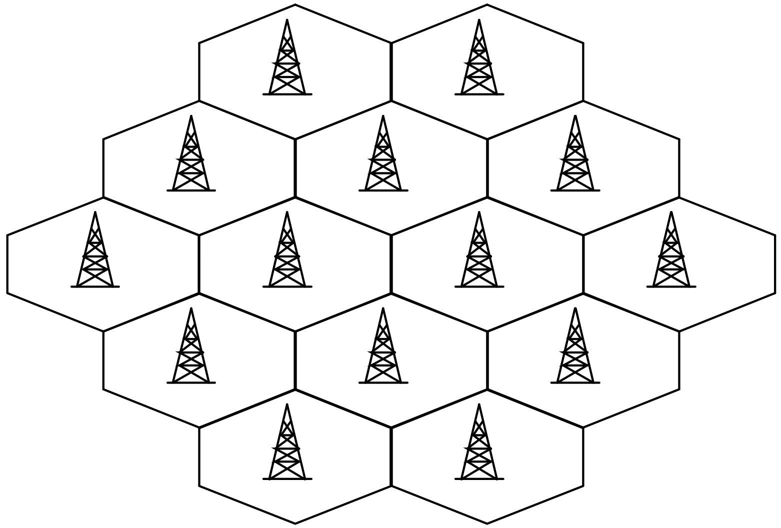
- Each sub carrier can be assigned to a different user for multiplexing purposes
- OFDM tutorial e.g.: http://www.wireless.per.nl:202/telelearn/ofdm



Cellular networks

- the further transmitter and receiver are apart from each other, the higher the energy necessary to transmit at the same data rate (assuming the environmental influences remain stable)
- because of limited battery capacity energy consumption of mobile devices should be kept limited
- therefore the range is limited
- How can we build a wide area mobile network?

→ cellular network



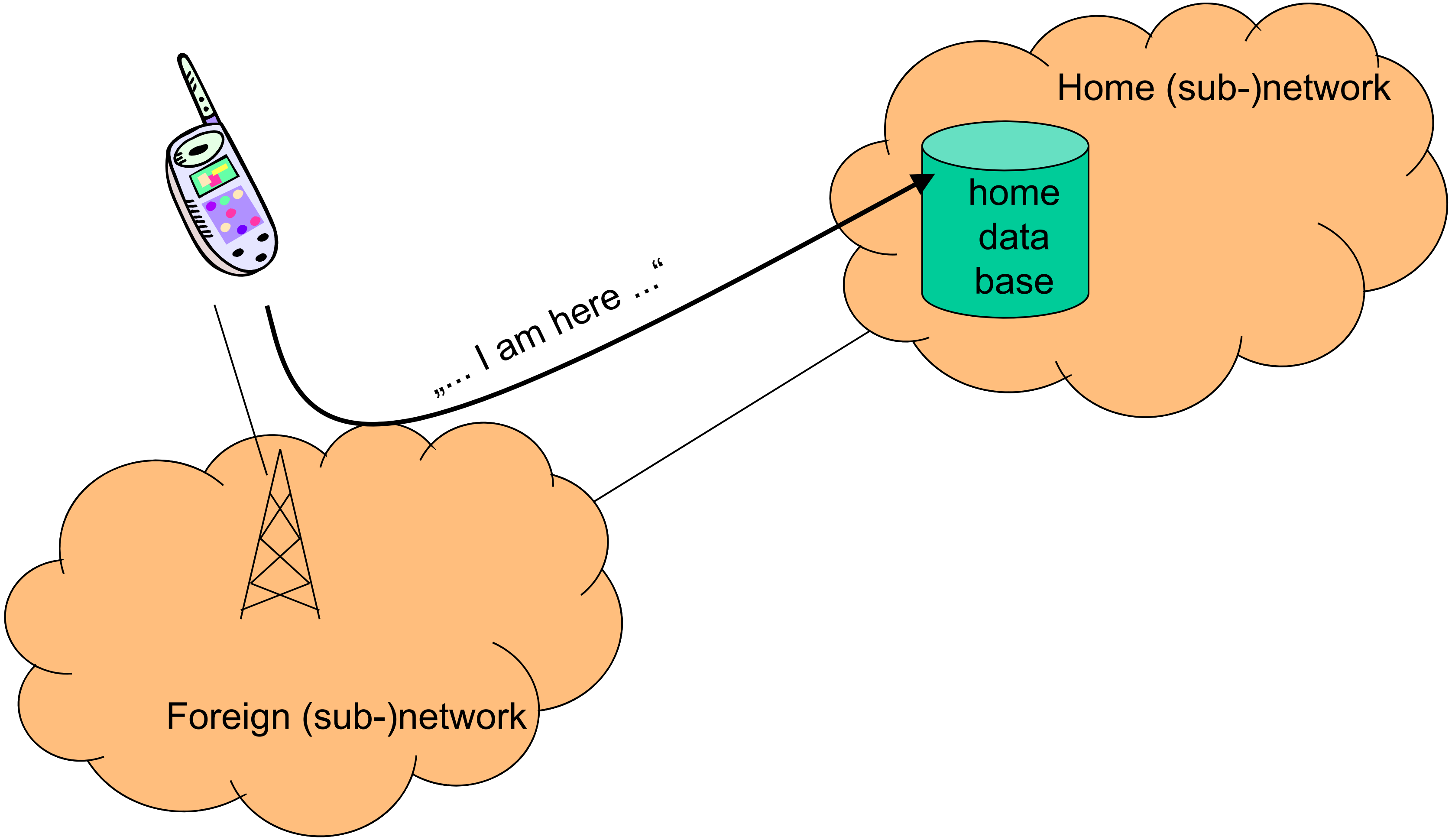
Mobility Management

Questions:

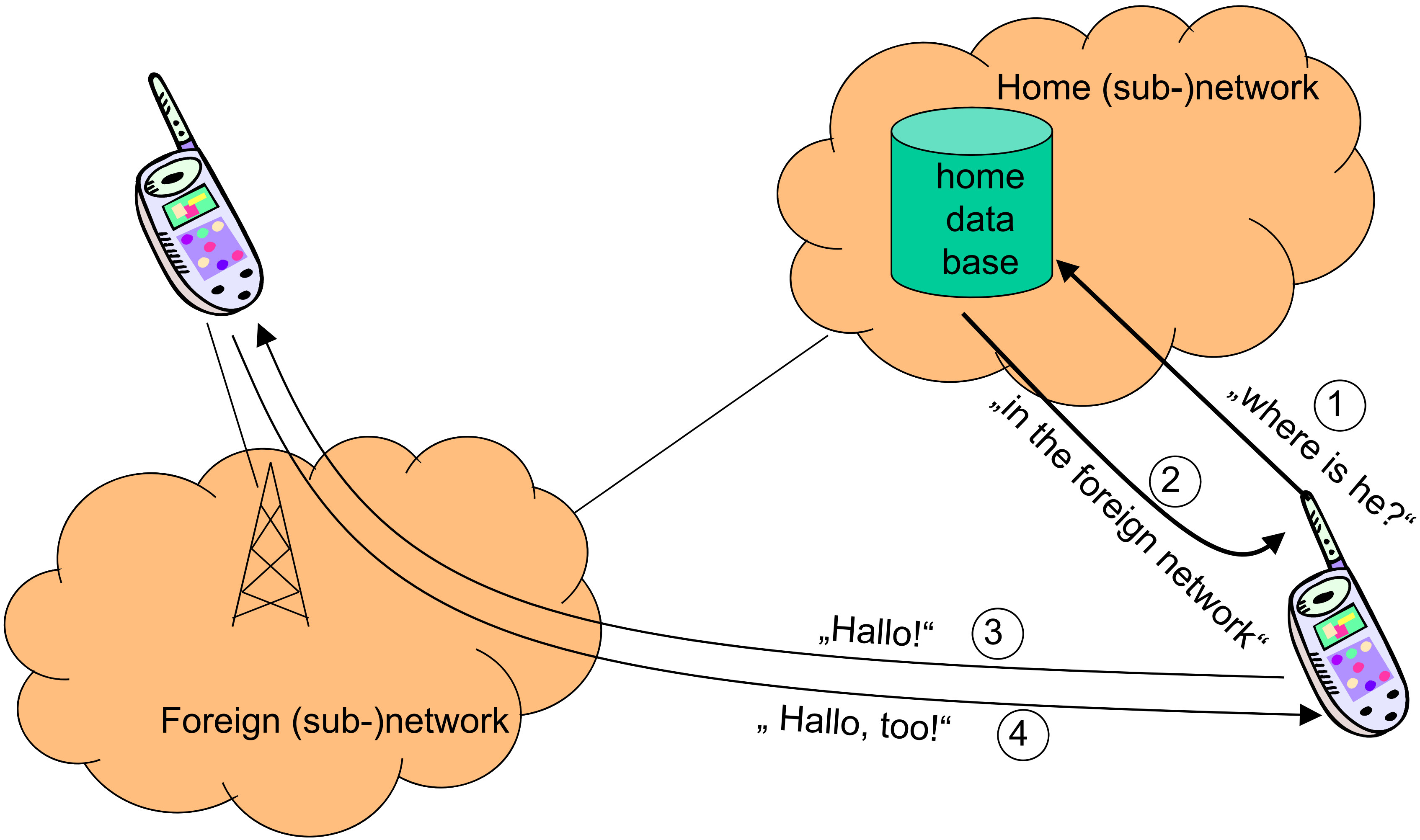
- Who is where?
- How can I reach him/her?
- May I access a foreign network? How?
- How can I be handed over from one access point to the next one
- ...

→ the fundamentals of mobility management are very similar over different network types

Mobility Management: Registration



Mobility Management: Connection establishment



Mobility Management

Fundamentals of mobility management are very similar over different network types . The home data base has different names, and it can be several data bases:

- Home Location Register (HLR) in GSM/UMTS
- Home Subscriber Server (HSS) in 3GPP-IMS
- Home Agent (HA) bei MobileIP
- SIP-Proxy in Voice over IP (VoIP) services
- AAA-Server (Authentication, Authorization and Accounting)
- etc.

The „home data base“ can be on one‘s own server (PC) at home, such as in Mobile IP, or it can be a data base at a mobile network operator with whom one has a contract, such as in GSM.

Mobility Management: Challenges

The challenges and the complexity of Mobility Management in real systems result, among other things, from the following:

- may the user access a foreign network?
- the user is mobile, i.e. he/she moves and therefore has to change access point once in a while (handover), how can, at the same time the connections be retained seamlessly?
- how does the accounting take place, when users move to foreign networks?
- how can it be insured that privacy is preserved, while the user is moving?
- on which routes, over which gateways, with which technology and resources operates the communication?