Mobile Communications Fundamentals

- Frequencies
- Modulation
- Antennas
- Mobility Management
Frequency Spectrum for Communication

Frequencies, Examples:

- **Audio**: TV, Walkie-Talkie 27 MHz
- **TV**: Cellular GSM 900 MHz, Paging 930 MHz, Cellular GSM 1800 MHz
- **VHF**: Cordless DECT 1880 MHz
- **UHF**: UMTS 2000 MHz

**Frequencies**:
- VLF: 10^0 MHz
- LF: 10^3 MHz
- HF: 10^6 MHz
- VHF: 10^9 MHz
- UHF: 10^12 MHz
- IR: 10^15 MHz
- UV: 10^18 MHz

**Examples**:
- TV: VLF, LF, HF, VHF, UHF, IR, UV, XR
- Audio: TV, Walkie-Talkie 27 MHz
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

850 900 950 1000 1700 1750 1800 1850 1900 1950 2000 2050 2100 2150 2200 2500 2600 2650 2700

IMT 2000
GSM
Cellular
GSM
PDC

GSM 1800
DECT
UMTS

GSM 1800,PCS
IMT 2000

PHS
IMT 2000

A B C A B C MSS

ITU Alloc.
Europe
China
Japan, Korea w/o PHS
North America

Mobile Communication Fundamentals
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 binary 0

PSK (Phase Shift Keying)

180° phase shift
Modulation: several bits per signal state

There are variants of the modulation techniques which can transmit several 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 specified by a Q and I value

Polar to Rectangular Conversion

Project signal to "I" and "Q" axes
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
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:

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<th>Application</th>
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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:

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 its 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 to 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
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 constructed in a way that they preferably transmit or receive in certain directions, e.g. transmission and reception along a rail track.

![Directed Antenna Diagrams](image)

- Director antenna side view (xy plane)
- Director antenna side view (yz plane)
- Director antenna top view (xz plane)

![Sectorized Antenna Diagrams](image)

- Sectored antenna top view, 3 sectors
- Sectored antenna top view, 6 sectors
Antennas: samples

L-band satellite receiver station
(DFD, Oberpfaffenhofen)

L- and S-band receiver antenna
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.

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

- $P = \text{energy (t/r = transmit/receive)}$
- $\lambda = \text{wave length (c/frequency)}$
- $G = \text{gain}$
- $c = \text{speed of light}$
Antennas

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

Example GSM 900

- 890 – 915 Mhz (uplink)
- 935 – 960 Mhz (downlink)
Antennas

example

influenced by
- curvature of the earth
- relief features (mountains, etc.)
- buildings, trees, etc.
- 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
reflection
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. frequency (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

OFDM (Orthogonal Frequency Division Multiplexing)

- Separation of a high speed bit stream into several low speed ones
- Overlap of frequency bands

![Diagram of OFDM and FDM](image-url)
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 and 64 QAM
- OFDM is used in HSDPA, 802.11a and 802.11n
- adaptive wrt signal quality

![Graph showing Signal quality (SNR) over time with BPSK, QPSK, and 16QAM]

Signal quality
SNR (Signal/Noise Ratio)

**BPSK**
**QPSK**
**16QAM**
OFDM (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

![Diagram of OFDM and FDM frequency allocation]
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

Home (sub-)network

Foreign (sub-)network

"... I am here ..."
Mobility Management: Connection establishment

1. Home (sub-)network
2. Foreign (sub-)network
3. Home database
4. Mobile Communication Fundamentals 45
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?