Mobile Communications
Chapter 2: Wireless Transmission

- Frequencies
- Signals
- Antenna
- Signal propagation
- Multiplexing
- Spread spectrum
- Modulation
- Cellular systems
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:

\[ \lambda = \frac{c}{f} \]

wave length \( \lambda \), speed of light \( c \approx 3 \times 10^8 \text{m/s} \), frequency \( f \)
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 (resonance frequencies)
    - weather dependent fading, signal loss caused by heavy rainfall etc.
Frequencies and regulations

ITU-R holds auctions for new frequencies, manages frequency bands worldwide (WRC, World Radio Conferences)

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Prof. Dr.-Ing. Jochen Schiller, http://www.jochenschiller.de/ MC SS05 2.4
Signals I

- physical representation of data
- function of time and location
- 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
- signal parameters of periodic signals:
  - period $T$, frequency $f=1/T$, amplitude $A$, phase shift $\varphi$
  - sine wave as special periodic signal for a carrier:

$$s(t) = A_t \sin(2 \pi f_t t + \varphi_t)$$
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
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
Real world example
Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction.

Multipath propagation

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)
Multiplexing

Multiplexing in 4 dimensions
- space ($s_i$)
- time ($t$)
- frequency ($f$)
- code ($c$)

Goal: multiple use of a shared medium

Important: guard spaces needed!
Frequency multiplex

Separation of the whole spectrum into smaller frequency bands

A channel gets a certain band of the spectrum for the whole time

Advantages:

- no dynamic coordination necessary
- works also for analog signals

Disadvantages:

- waste of bandwidth if the traffic is distributed unevenly
- inflexible
- guard spaces
Time multiplex

A channel gets the whole spectrum for a certain amount of time

Advantages:
- only one carrier in the medium at any time
- throughput high even for many users

Disadvantages:
- precise synchronization necessary
Time and frequency multiplex

Combination of both methods
A channel gets a certain frequency band for a certain amount of time
Example: GSM

Advantages:
- better protection against tapping
- protection against frequency selective interference
- higher data rates compared to code multiplex

but: precise coordination required
Code multiplex

Each channel has a unique code

All channels use the same spectrum at the same time

Advantages:
- bandwidth efficient
- no coordination and synchronization necessary
- good protection against interference and tapping

Disadvantages:
- lower user data rates
- more complex signal regeneration

Implemented using spread spectrum technology
Modulation

Digital modulation
- digital data is translated into an analog signal (baseband)
- ASK, FSK, PSK - main focus in this chapter
- differences in spectral efficiency, power efficiency, robustness

Analog modulation
- shifts center frequency of baseband signal up to the radio carrier

Motivation
- smaller antennas (e.g., $\lambda/4$)
- Frequency Division Multiplexing
- medium characteristics

Basic schemes
- Amplitude Modulation (AM)
- Frequency Modulation (FM)
- Phase Modulation (PM)
Modulation and demodulation

1. Digital data (101101001) enters the system.
2. Digital modulation process transforms the data into a digital signal.
3. Analog modulation converts the digital signal into an analog signal that can be transmitted over a radio carrier.
4. Radio transmitter sends the analog signal.
5. Radio receiver receives the analog signal.
6. Analog demodulation extracts the analog baseband signal.
7. Synchronization decision decodes the signal back into digital data (101101001).

Radio transmitter and receiver processes are illustrated in the diagram.
Digital modulation

Modulation of digital signals known as Shift Keying

- **Amplitude Shift Keying (ASK):**
  - very simple
  - low bandwidth requirements
  - very susceptible to interference

- **Frequency Shift Keying (FSK):**
  - needs larger bandwidth

- **Phase Shift Keying (PSK):**
  - more complex
  - robust against interference
Spread spectrum technology

Problem of radio transmission: frequency dependent fading can wipe out narrow band signals for duration of the interference

Solution: spread the narrow band signal into a broad band signal using a special code

- protection against narrow band interference

Side effects:
- coexistence of several signals without dynamic coordination
- tap-proof

Alternatives: Direct Sequence, Frequency Hopping
Effects of spreading and interference

i) $dP/df$

ii) $dP/df$

iii) $dP/df$

iv) $dP/df$

v) $dP/df$

sender

receiver

user signal
broadband interference
narrowband interference
Spreading and frequency selective fading

- Narrowband channels
- Spread spectrum channels
DSSS (Direct Sequence Spread Spectrum) I

XOR of the signal with pseudo-random number (chipping sequence)

- many chips per bit (e.g., 128) result in higher bandwidth of the signal

Advantages

- reduces frequency selective fading
- in cellular networks
  - base stations can use the same frequency range
  - several base stations can detect and recover the signal
  - soft handover

Disadvantages

- precise power control necessary

\[ t_b: \text{bit period} \]
\[ t_c: \text{chip period} \]
DSSS (Direct Sequence Spread Spectrum) II

**Transmitter**
- User data
- Chipping sequence
- Radio carrier
- Modulator
- Spread spectrum signal
- Transmit signal

**Receiver**
- Received signal
- Chipping sequence
- Radio carrier
- Demodulator
- Lowpass filtered signal
- Products
- Integrator
- Sampled sums
- Correlator
- Data
FHSS (Frequency Hopping Spread Spectrum) I

Discrete changes of carrier frequency

- sequence of frequency changes determined via pseudo random number sequence

Two versions

- Fast Hopping:
  - several frequencies per user bit
- Slow Hopping:
  - several user bits per frequency

Advantages

- frequency selective fading and interference limited to short period
- simple implementation
- uses only small portion of spectrum at any time

Disadvantages

- not as robust as DSSS
- simpler to detect
FHSS (Frequency Hopping Spread Spectrum) II

User data

slow hopping (3 bits/hop)

fast hopping (3 hops/bit)

$t_b$: bit period  
$t_d$: dwell time
FHSS (Frequency Hopping Spread Spectrum) III

transmitter

user data → modulator → modulator

narrowband signal

spread transmit signal

hopping sequence

frequency synthesizer

receiver

received signal → demodulator → demodulator

narrowband signal

data

hopping sequence

frequency synthesizer
Cell structure

Implements space division multiplex: base station covers a certain transmission area (cell)
Mobile stations communicate only via the base station

Advantages of cell structures:
- higher capacity, higher number of users
- less transmission power needed
- more robust, decentralized
- base station deals with interference, transmission area etc. locally

Problems:
- fixed network needed for the base stations
- handover (changing from one cell to another) necessary
- interference with other cells

Cell sizes from some 100 m in cities to, e.g., 35 km on the country side (GSM) - even less for higher frequencies
Frequency planning I

Frequency reuse only with a certain distance between the base stations

Standard model using 7 frequencies:

**Fixed frequency assignment:**
- certain frequencies are assigned to a certain cell
- problem: different traffic load in different cells

**Dynamic frequency assignment:**
- base station chooses frequencies depending on the frequencies already used in neighbor cells
- more capacity in cells with more traffic
- assignment can also be based on interference measurements
Frequency planning II

3 cell cluster

7 cell cluster

3 cell cluster with 3 sector antennas
Cell breathing

CDM systems: cell size depends on current load
Additional traffic appears as noise to other users
If the noise level is too high users drop out of cells