Introduction and technological Fundamentals
Basic Transmission Techniques

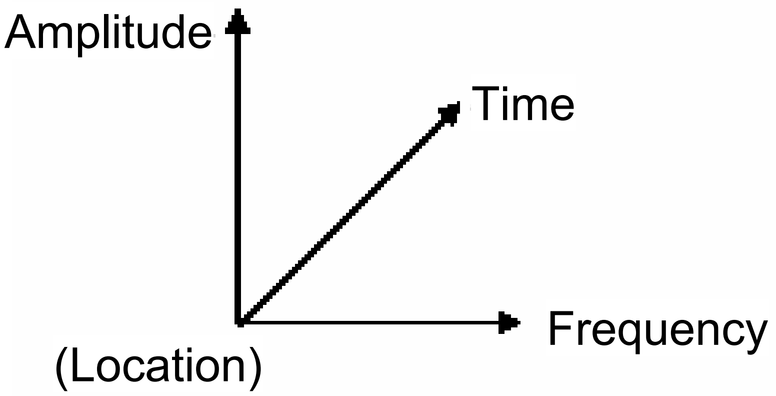
Contents - Fundamentals - Transmission Techniques

- Multiplexing Schemes
- Duplexing Schemes
- Modulation Schemes
- Source and Channel Coding
- Error Protection
- Multiple Access Schemes

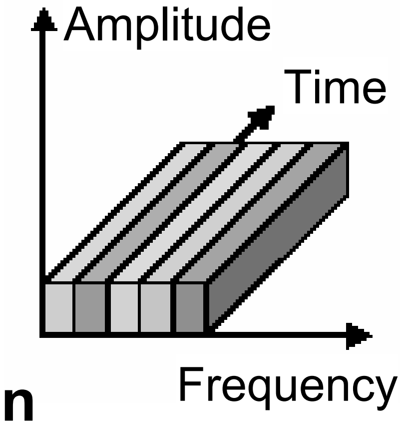
Multiplexing Schemes

Multiplexing Schemes - Overview

- **Targets:**
  - partitioning of the available finite mobile radio resources to several parallel users
  - separating the signals of different users
  - avoiding mutual interferences
- **Different subscribers might be separated by:**
  - location
  - time, e.g the instance of the access to the resource (timeslot)
  - frequency, e.g. radio channel
  - code
- **The signal space can be divided wrt. amplitude, frequency and time**

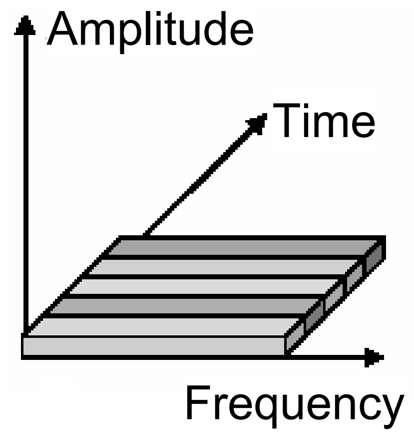


Frequency Division Multiplex (FDM)



- **Frequency Division Multiplex**
  - bandwidth is divided into individual channels
  - unlimited transmission-time per channel
  - simultaneous activity on channels
- **User signals are differentiated in the frequency domain**
- **Characteristics:**
  - simple and robust multiplexing scheme
  - low transmission rate, low bandwidth per user
  - few inter-symbol interference (ISI) → simple equalization
  - entire signal cancelation possible through Rayleigh-Fading
- **FDM is often applied in combination with TDM/CDM**
- **Examples:**
  - C-Netz (analog transmission, pure FDMA), 20kHz / voice channel
  - GSM (TDMA/FDMA)

Time Division Multiplex (TDM)



- **Time Division Multiplex**
  - time is divided into time slots
  - within one time slot the whole bandwidth can be used
- **User signals are differentiated in the time domain**
- **Characteristics:**
  - allows high transmission rate, high bandwidth per user
  - requires time synchronization and guard intervals
  - higher inter-symbol interference → efficient channel equalizer needed
  - low vulnerability wrt. frequency selective Rayleigh-Fading
- **Design of small mobile devices and base stations feasible**
- **Example:**
  - GSM (TDMA in combination with FDMA)
    - 200kHz channel bandwidth (= carrier spacing)
    - 8 time slots per channel (carrier), 0.577ms per time slot

Space Division Multiplex (SDM)

- **Space Division Multiplex**

  2 application scenarios:

  a) resources (frequency, code, …) are reused in spatially separated areas → applied e.g. in frequency allocation for whole or sectorized cells

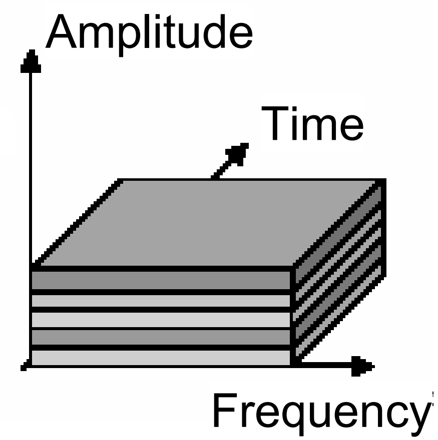
  b) dynamic multiple reuse of transmission channels within a cell

  Used for scenario b): Smart Antennas (with beamforming capability)

  - goal: focus the transmission in the direction of users (beamforming)
  - disadvantage: high implementation complexity
    - signal processing effort
    - hardware effort
    - beamforming control required (for beam tracking)

Code Division Multiplex (CDM)

- **Code Division Multiplex**
  - power is partitioned by use of (pseudo-)orthogonal codes
  - always the whole bandwidth can be used (spread spectrum technique)
  - users are active simultaneously and continuously



- **User signals are differentiated by specific codes**
- **Characteristics:**
  - very high transmission data rate possible
  - small influence through interfering signals
  - very low vulnerability wrt. frequency selective Rayleigh-Fading
- **CDM is often applied in case of large bandwidth: wideband CDMA**
- **Example:**
  - UMTS: 5MHz bandwidth, channel data rate 3.84Mchips/s

Code Division Multiplex (CDM) Variants

Time Hopping (TH) CDM(A):

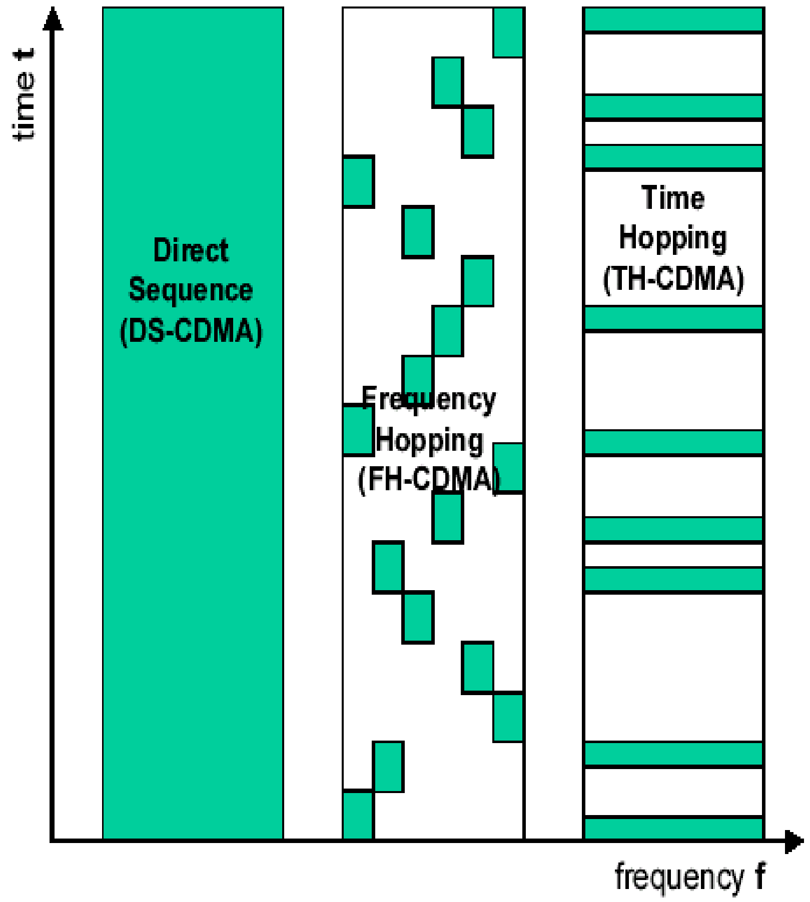
The signal is transmitted in bursts of defined lenght (no time continuous transmission); a user specific code defines the start time instances of the bursts

Frequency Hopping (FH) CDM(A):

The carrier frequency on which the signal is transmitted is changed after a certain time; a user specific code defines the sequence of the frequency hops

Direct Sequence (DS) CDM(A):

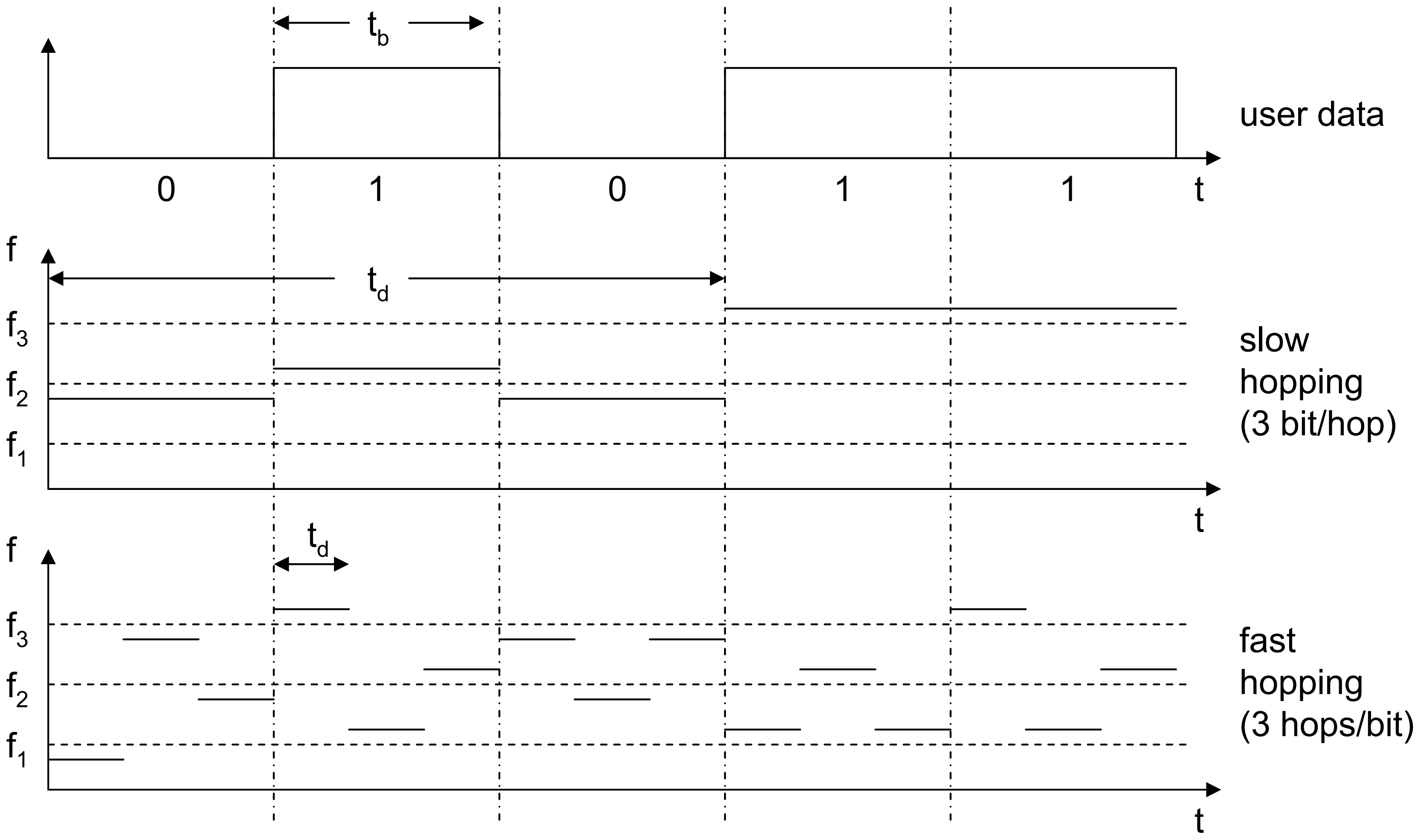
The signal is directly spread by multiplication with a broadband carrier signal; the carrier signal represents a user specific code sequence



FH-CDMA (1)

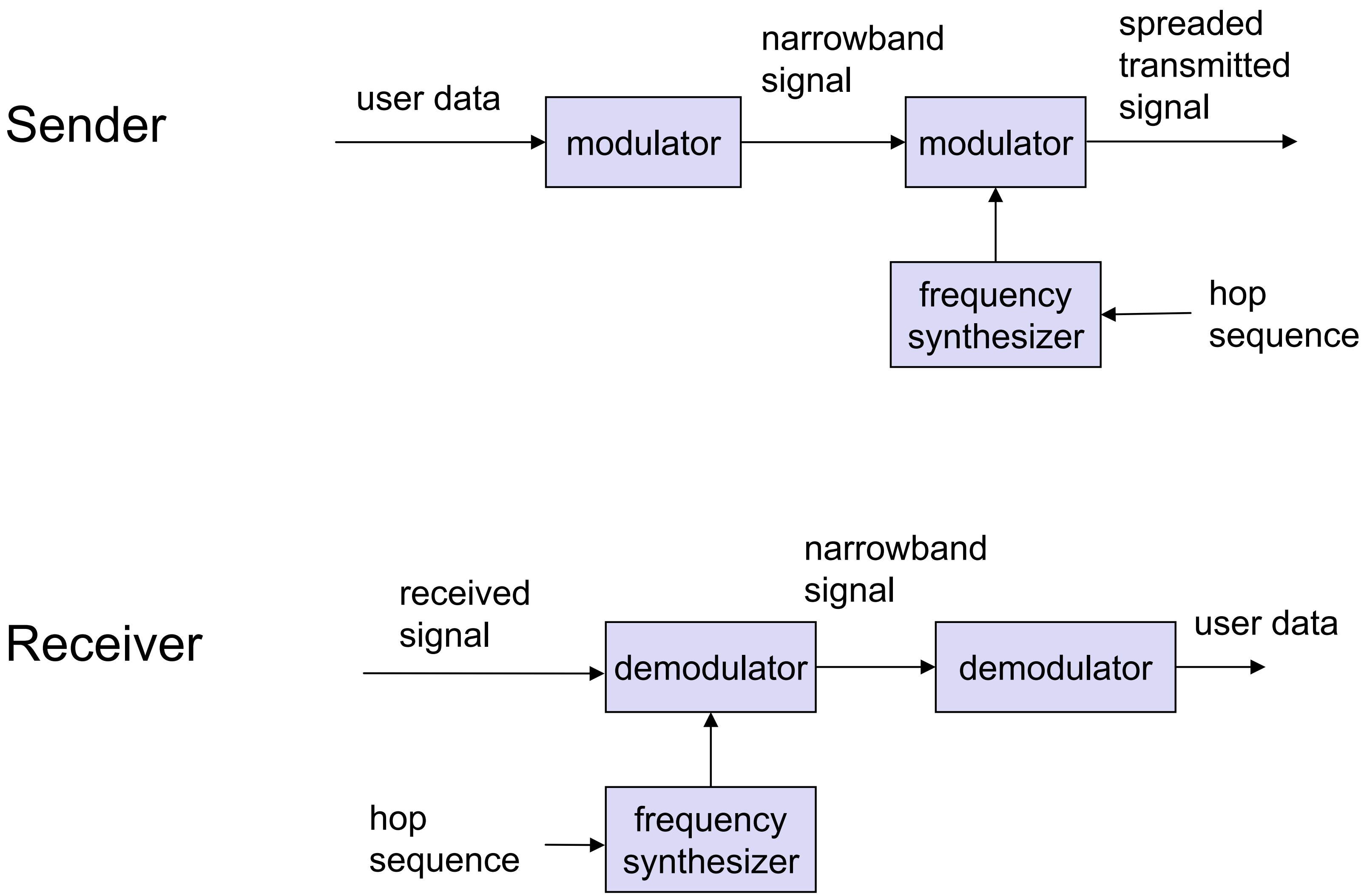
- Discrete change of the carrier frequency
  - the sequence of frequency hops is determined through pseudo random numbers
  - two versions:
    - fast hopping: multiple frequency hops per transmitted data bit
    - slow hopping: multiple transmitted data bits per frequency hop
- Advantages:
  - frequency selective fading and interferences are limited to small time periods
  - simple implementation
  - uses only a small part of the total spectrum at a certain point of time
- Disadvantages:
  - not as robust as DS-CDMA
  - easier to intercept

FH-CDMA (2)



t_b: bit period t_d: dwell time

FH-CDMA (3)

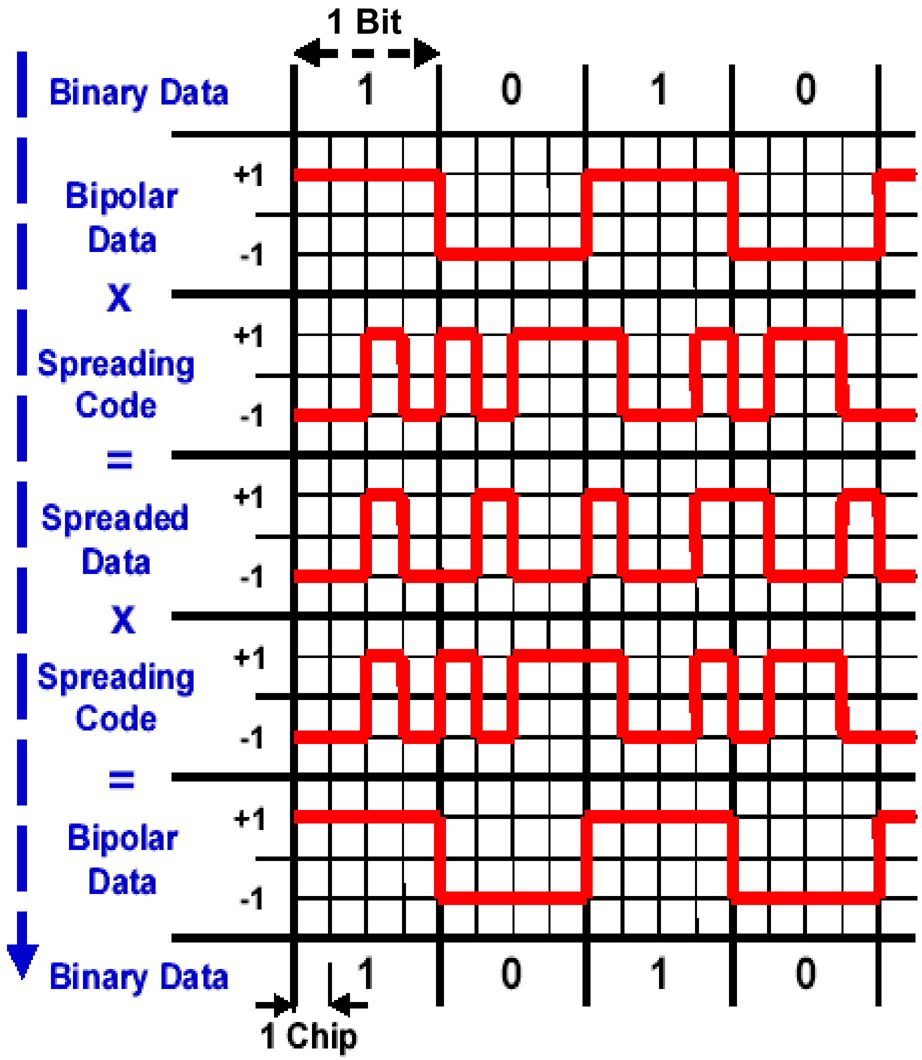

Sender
user data
modulator
narrowband signal
modulator
spreaded transmitted signal
frequency synthesizer
hop sequence
Receiver
received signal
demodulator
narrowband signal
demodulator
user data
hop sequence
frequency synthesizer

DS-CDMA basic Principle: Encoding and Decoding

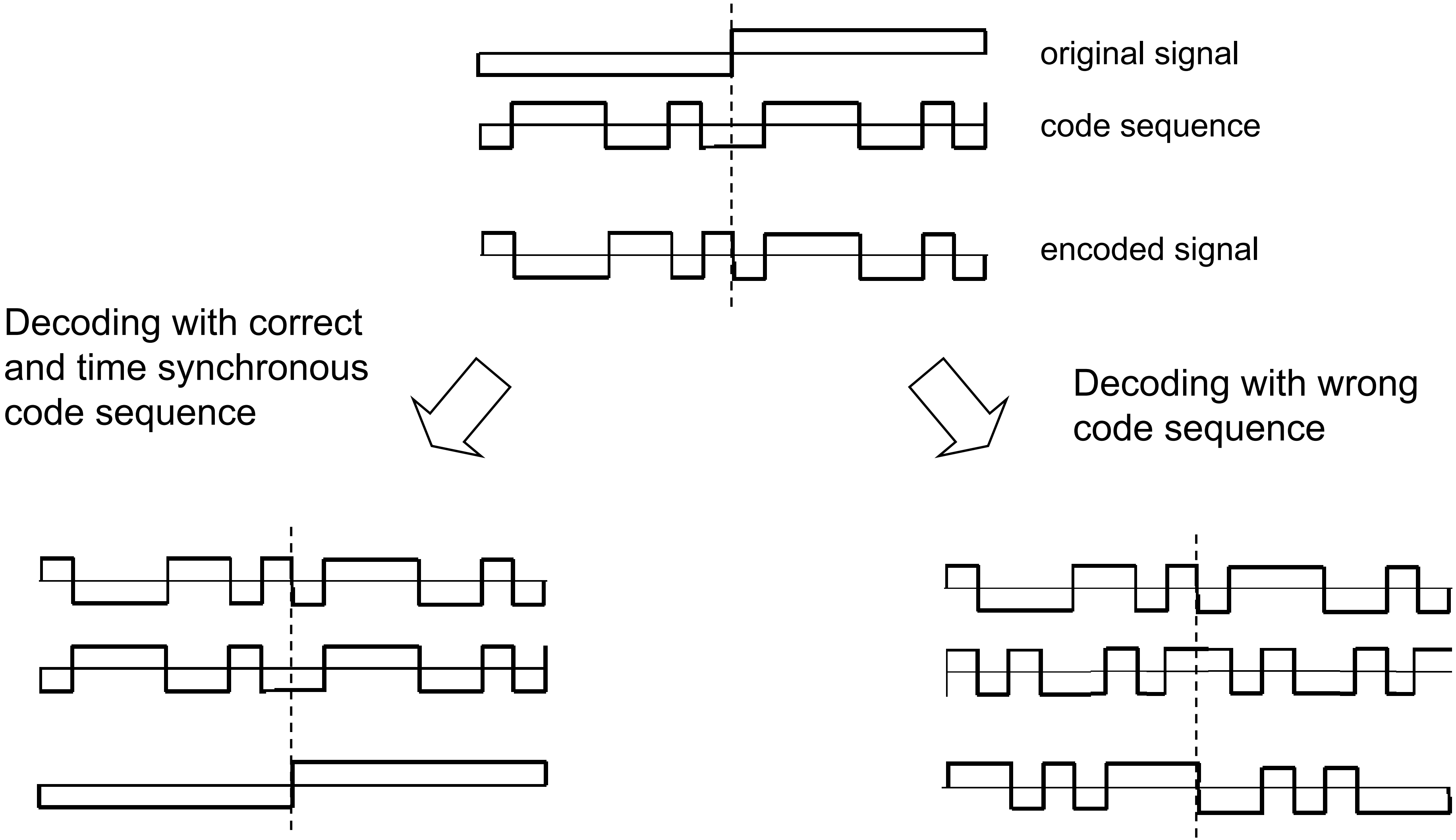
- **Assumption: narrow-band user signal (e.g. voice signal)**
- **At the sender:**
  - the user signal is spread over the whole available bandwidth
  - direct multiplication of user data and spreading sequence: Direct Sequence CDMA (DS-CDMA)
  - the chip rate of the spreading sequence is much higher than the bit rate of the user signal
- **At the receiver:**
  - despreading of the received signal
  - multiplication of the received signal with the same spreading sequence used for spreading at the sender (therefore the spreading sequence has to be known by the receiver → problem: security i.e. suitable encryption of the spreading code)
  - despreading causes a bandwidth reduction of the own signal, signals of other users remain broadband (appearing as broadband noise/interference)

DS-CDMA basic Principle: Encoding and Decoding

- The original (narrowband) signal is multiplied with the broadband code sequence (pseudo random sequence) spreading it to a multiple of its original bandwidth; every bit is mapped to a number of chips
- The original signal is recovered through the multiplication of the spreaded (broadband) signal with the same code sequence that has been used for spreading

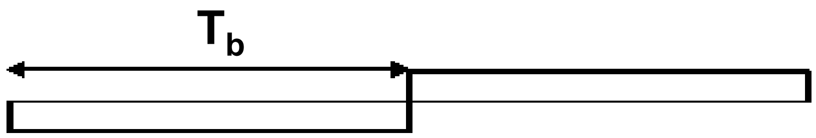


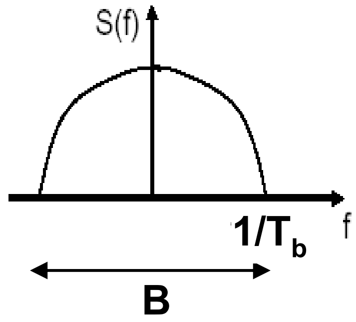
DS-CDMA basic Principle: Encoding and Decoding



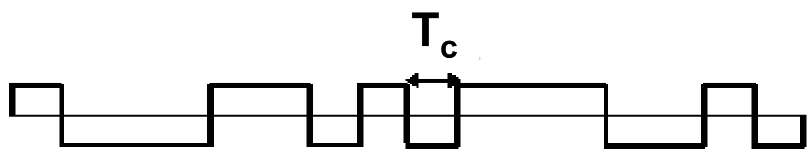
DS-CDMA - Spreading and Spread Factor

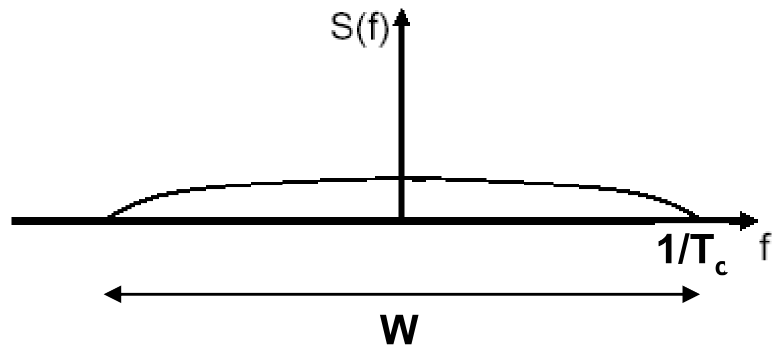
- **Original signal:**





- **Encoded signal:**



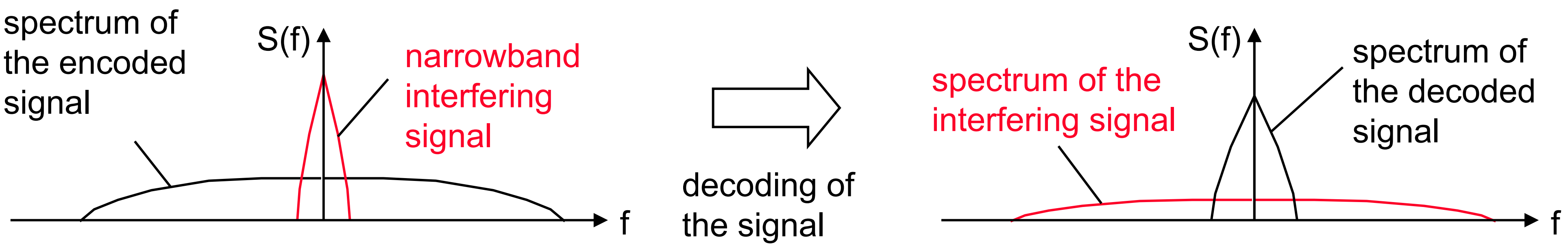


Spread Factor: $SF = \frac{T_b}{T_c} = \frac{W}{B}$

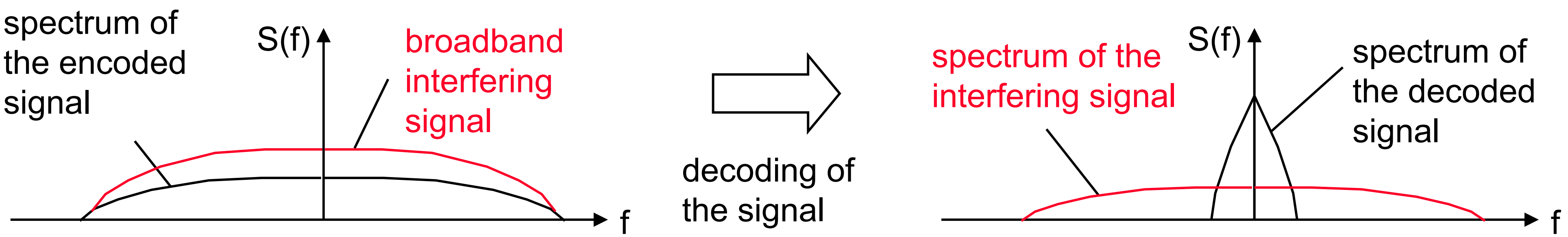
Spreading: W >> B

DS-CDMA - Robustness against interfering Signals

- **Narrowband interfering signal:**



- **Broadband interfering signal (white noise, other spreaded signals):**

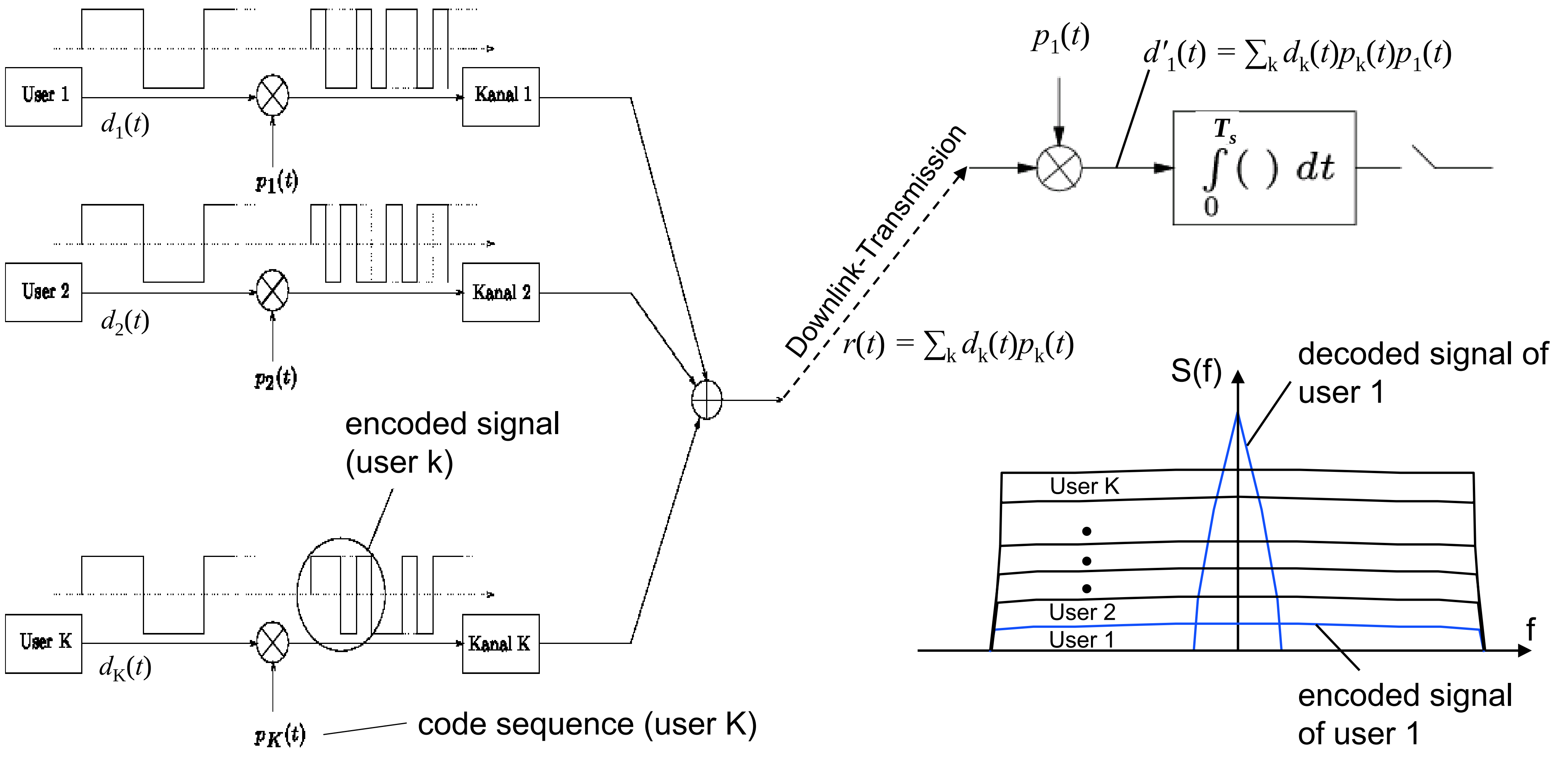


DS-CDMA - MUX/DEMUX of multiple Signals

Example: Downlink Transmission

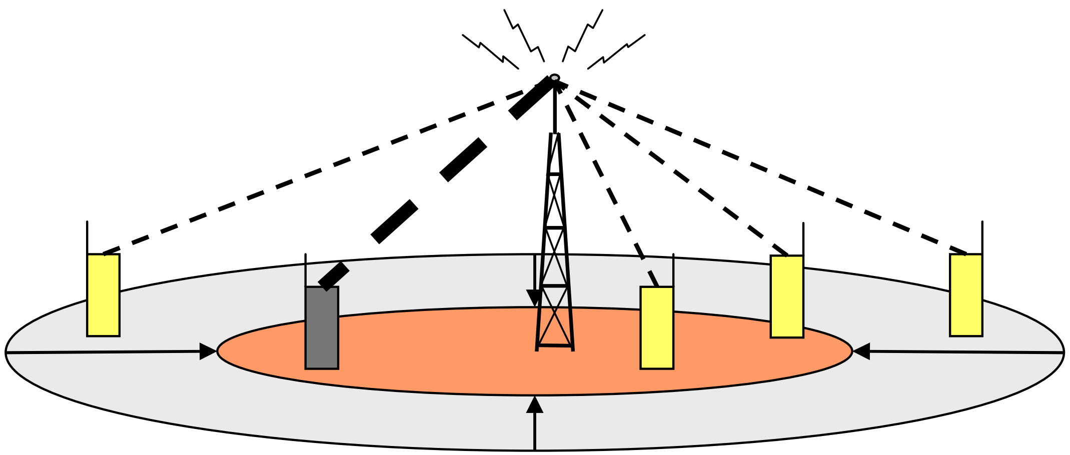
Sender (base station)

Receiver (User 1)



DS-CDMA - Near-Far-Problem and Cell Shrinking

- If mobile devices are transmitting with equal power but have different distances to the receiver (base station), the received power will be different (**Near-Far Problem**) ⇒ apply transmission power control to equalize the received power
- In case of high interference within a cell (e.g. caused by many users in the cell) the transmission power control of mobile devices close to the cell edge reaches its limit ⇒ the signals of these mobile devices cannot be received at the base station any more (**Cell Shrinking Effect**)



DS-CDMA - Advantages and Disadvantages

Advantages:

- continuous, broadband transmission with small spectral power density
- without the knowledge of the code sequence transmissions are hard to detect $\Rightarrow$ the signal could be “hidden” in the noise
- low vulnerability wrt. narrow- and broadband interfering signals
- low vulnerability wrt. multipath propagation
- no frequency planning needed - reuse of the same frequency in the neighboring cells possible
- exploitation of multipath transmission and soft handover
- “soft" capacity limits of cells

Disadvantages:

- need for power control
- cell shrinking effect

Multiplexing Schemes - Summary

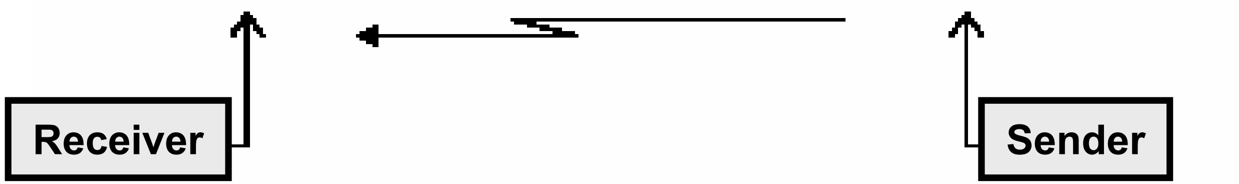
Scheme	SDM(A)	TDM(A)	FDM(A)	CDM(A)
Idea	partitioning the space into cells/sectors	partioning the transmission time into disjunct time slots	partitioning the frequency range into disjunct bands	spreading through individual codes
Ressouce Allocation to Users	each user is allocated a part of the space	each user is allocated an individual timeslot	each user is allocated an own frequency band	each user is allocated an individual code
Signal Separation	in space domain by cells, sectors and directional antennas	in time domain through synchronization	in frequency domain through filters	through code and by special receivers
Advantages	simple technology, easy planning and capacity enhancement	established technology, digital, versatile	established technology, easy, robust, easy planning	flexible, requires less frequency planning, soft handover
Dis-advantages	not flexible (except adaptive antennas with beamforming)	required: guard times due to multipath pro-, pagation, synchroniz.	low flexibility, inefficient use of scarce frequencies	complex receivers, precise control of transmission power
Comments	only reasonable in combination with TDMA, FDMA or CDMA	common practice in PSTN, in mobile nets often in combination with FDMA	usually in combination with TDMA or SDMA	high complexity, still some practical problems (e.g. cell shrinking effect)

Duplexing Schemes

Duplexing Schemes - Overview

- **Goal: separation of transmitted and received signal**
- **Simplex: transmission only in one direction possible**

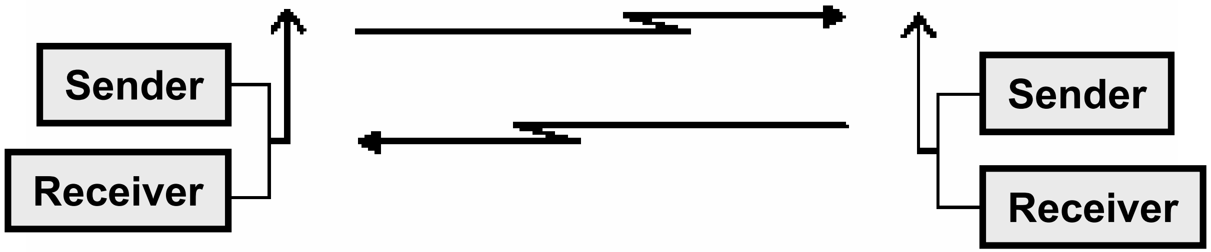
  Example: Paging



- **Half Duplex: alternate transmission and reception**

  Example: Push to Talk / Release to Listen

- **Full Duplex: simultaneous transmission and reception**

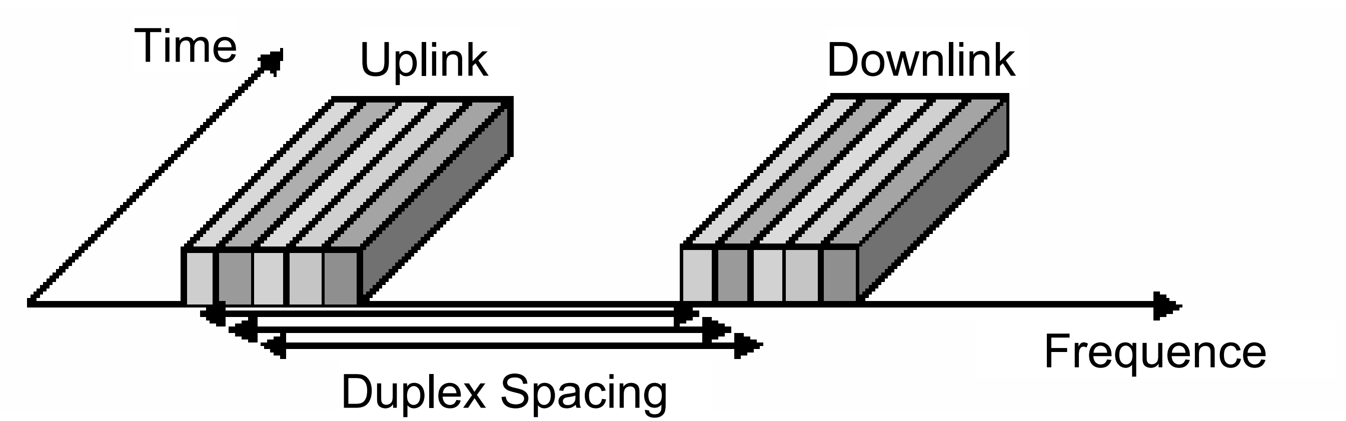


- **Definitions: base station → mobile station: Downlink (DL)**

  mobile station → base station: Uplink (UL)

Frequency Division Duplex (FDD)

- **Frequency Division Duplex**
  - two simplex channels (frequencies) are active at the same time
  - constant duplex spacing, independently of the channels in use
- **Particularly useful for symmetric traffic**
- **Paired frequency bands required**
  - same bandwidth for uplink and downlink channel

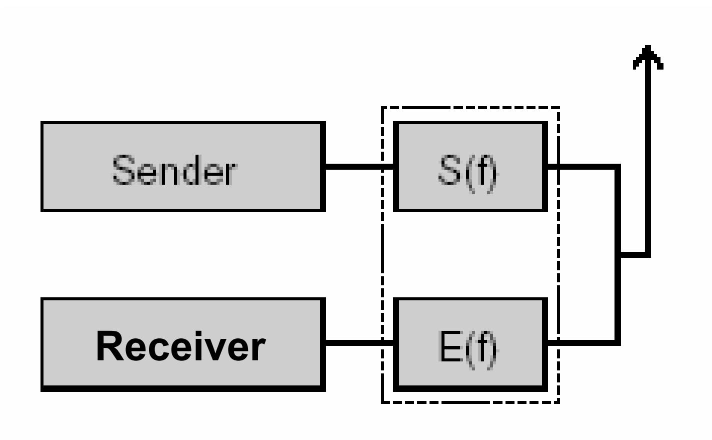


Example:

- separation of UL and DL through different frequency bands: FDD
- partitioning of UL/DL bands into separate channels: FDM(A)

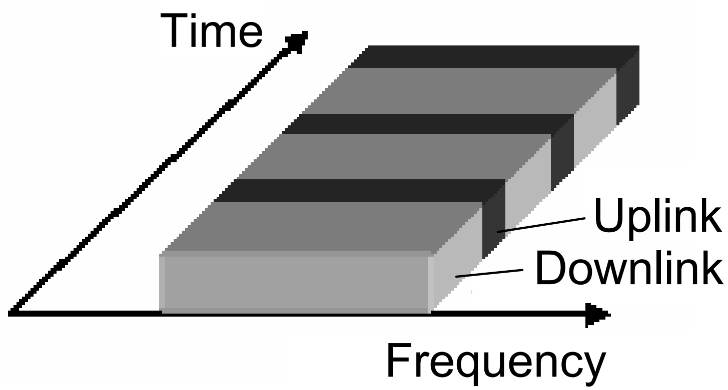
Frequency Division Duplex (FDD)

- **Standard scheme to separate the transmission directions**
- **Example GSM:** 45 MHz duplex spacing
  (UL: 890-915 MHz, DL: 935-960 MHz)
- **Duplexer: connects transmitter and receiver to the same antenna**
  - requires filter with a high edge steepness
  - compact/cheap implementation in mobile devices is complicated



Time Division Duplex (TDD)

- **Time Division Duplex:**
  - two simplex time slots (for UL and DL) are active on the same frequency
  - basically half duplex operation, but this is not noticeable for users due to the frequent switching between UL and DL time slots
- **Particularly useful for asymmetric traffic as the number of UL/DL time slots can be flexibly adjusted**
- **Only a single frequency band is needed**
- **No duplexer required in the mobile device**
- **Higher latency due to half duplex operation**
- **Complex synchronization → more suited for short distances**



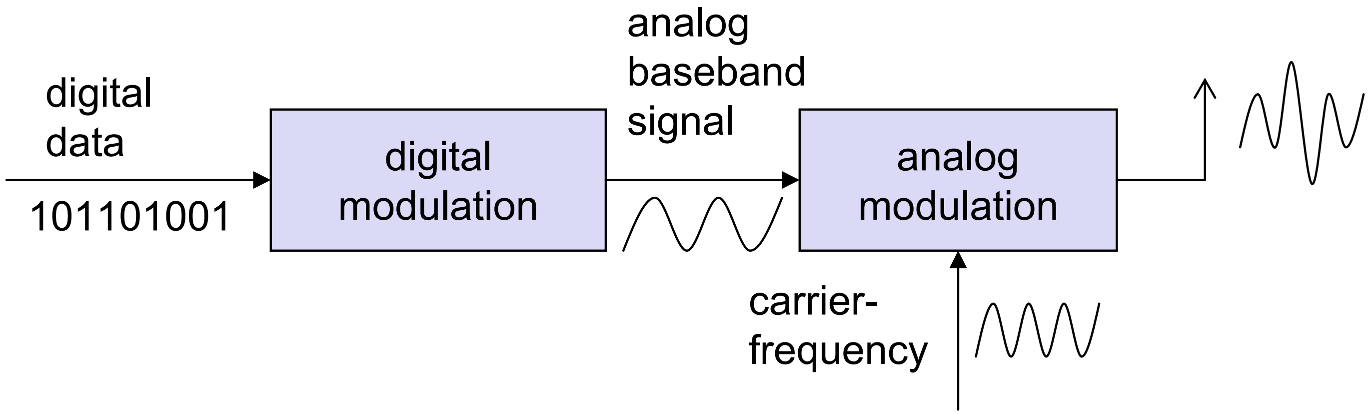
Modulation Schemes

Analog and digital Modulation

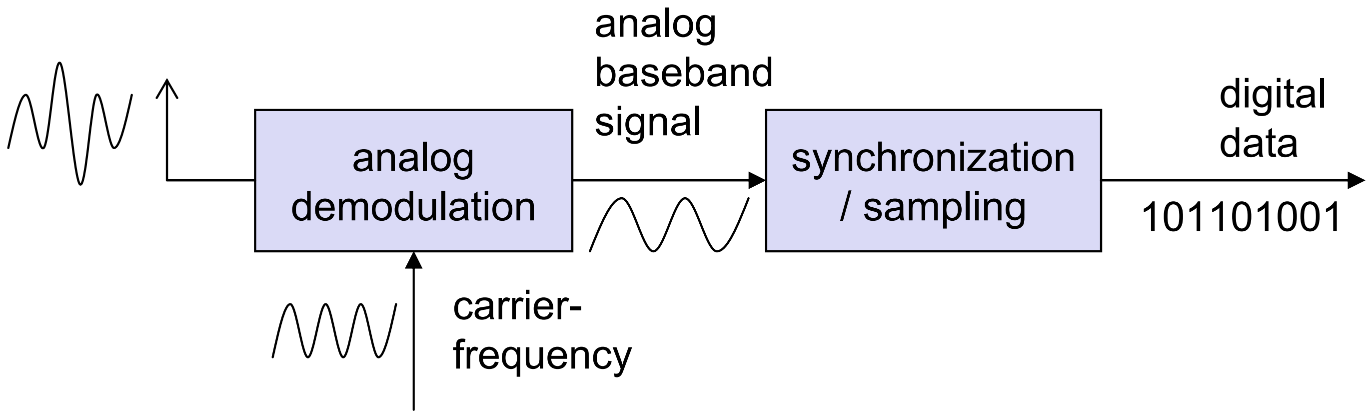
- **Digital Modulation**
  - digital data is converted into an analog (baseband) signal
  - variants:
    - ASK (Amplitude Shift Keying)
    - FSK (Frequency Shift Keying)
    - PSK (Phase Shift Keying)

    → some differences in efficiency and robustness
- **Analog Modulation**
  - shift the (analog) baseband signal on a high carrier frequency
  - motivation: smaller antennas (e.g. $\lambda/4$), frequency multiplex
  - variants:
    - Amplitude Modulation (AM)
    - Frequency Modulation (FM)
    - Phase Modulation (PM)

Modulation and Demodulation



Sender

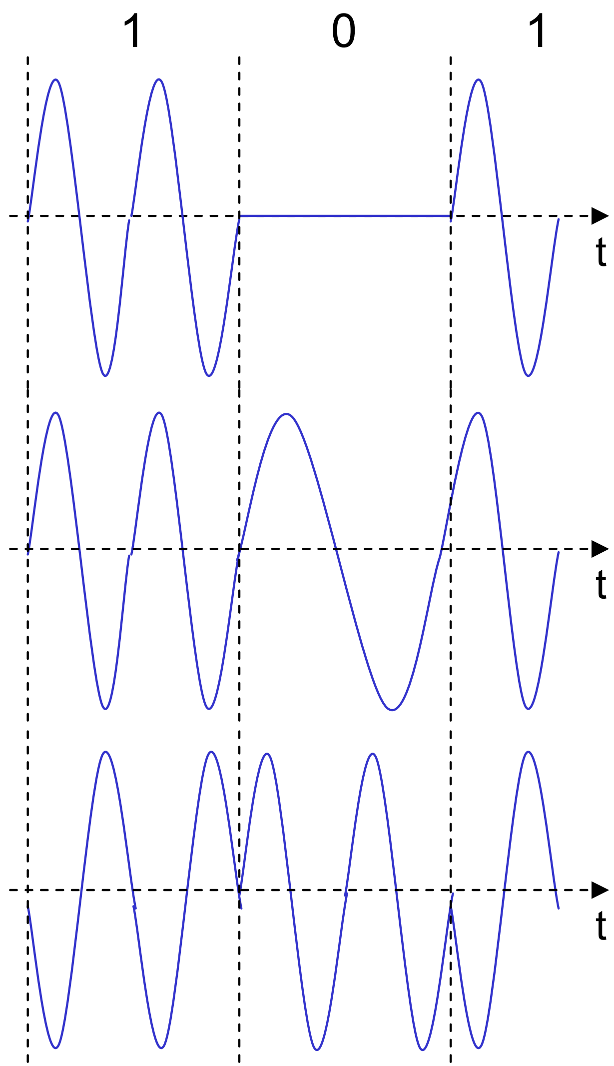


Receiver

Digital Modulation Schemes

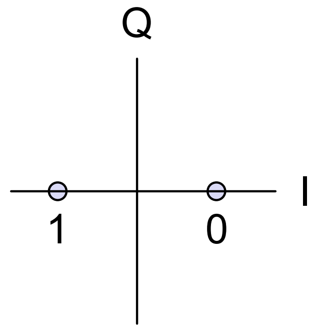
The modulation of digital signals is also named Shift Keying (SK)

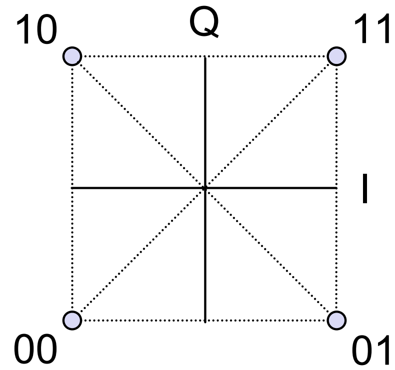
- Amplitude Shift Keying (ASK):
  - simple
  - requires low bandwidth
  - error-prone
- Frequency Shift Keying (FSK):
  - requires higher bandwidth
  - well suited for voice transmission
- Phase Shift Keying (PSK):
  - complex demodulation
  - robust

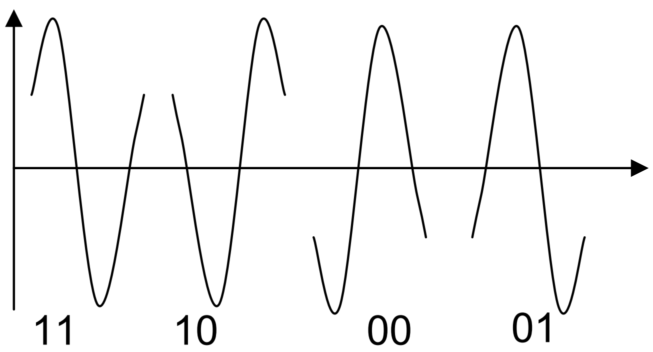


Advanced PSK Schemes

- Binary Phase Shift Keying (BPSK):
  - bit value 0: sinus-shaped signal
  - bit value 1: negative sinusoidal signal
  - simplest phase shift keying scheme
  - low spectral efficiency (Bit/(s·Hz))
  - robust (e.g. used in satellite systems)
- Quaternary Phase Shift Keying (QPSK):
  - 2 bits are encoded into one symbol
  - a symbol is represented by a phase-shifted sinusoidal signal
  - less bandwidth needed compared to BPSK (as one symbol represents 2 bits)
  - higher complexity

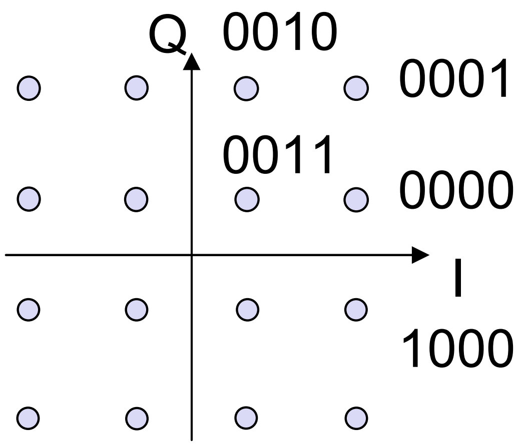






Quadrature Amplitude Modulation (QAM)

- QAM: combined amplitude and phase shift keying scheme
- Division of single bits or groups of bits onto two channels
- Separate ASK modulation of these two channels with 90° phase shifted carriers and subsequent addition of the two channels
- Encoding of n bits into one symbol possible
- 2^n discrete steps, n=2 equals QPSK
- The bit error rate increases with n, however less overall bit errors compared to PSK

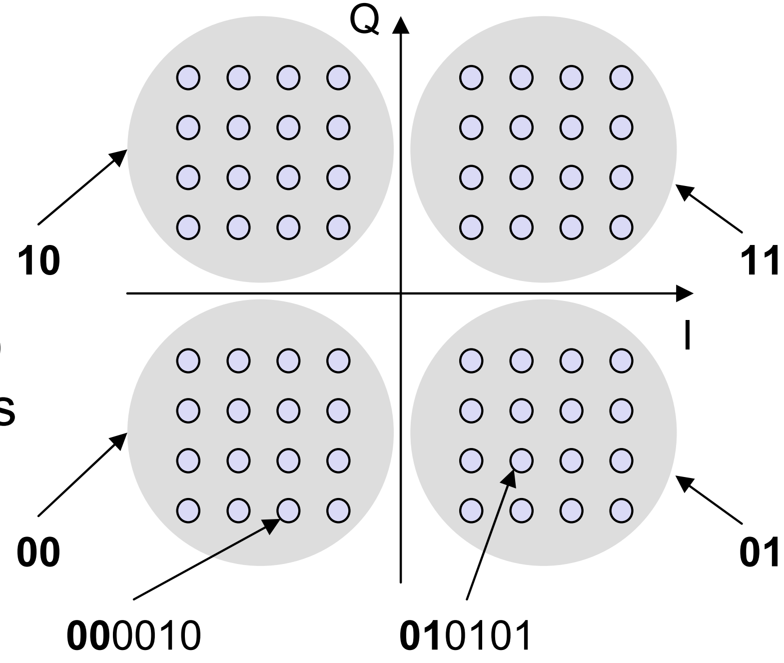


Example: 16-QAM
(4 bits correspond to one symbol)

The symbols 0011 und 0001 have the same phase and different amplitudes, the symbols 0000 und 1000 have a different phase and the same amplitude.

Hierarchical Modulation

- Application example: DVB-T
- DVB-T modulates two separate data streams into one single DVB-T stream; the high priority (HP) data stream is embedded into a data stream with low priority (LP)
- Example: QPSK/64QAM
  - in case if good reception quality: use of the total 64QAM stream
  - in case of bad reception quality: use of the QPSK component only
  - 6 bits per QAM-symbol, the 2 most significant bits represent the QPSK
  - the HP data stream is coded in QPSK (2 bit) the LP data stream uses the remaining 4 bits



Modulation Schemes - Application Examples

- BPSK (= 2-PSK) $\longrightarrow$ Cable Modem
- QPSK (= 4-PSK) $\longrightarrow$ UMTS/CDMA
- 8-PSK $\longrightarrow$ GSM/EDGE
- 16-QAM $\longrightarrow$ HSDPA
- 64-QAM $\longrightarrow$ HIPERLAN/2, 802.11a
- GMSK $\longrightarrow$ GSM