Introduction to Wireless Networks: protocols and performance analysis

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Cumulative credits: some figures have been taken from slides found on the web, by the following authors (in alfabethical order):

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Testi consigliati:

William Stallings, *Wireless Communications & Networks*, Prentice Hall, 2001, ISBN 0130408646

Jochen H. Schiller, *Mobile Communications*, Addison Wesley, 2000, ISBN 0201398362

Yi B. Li, Imric Chlamtac, *Wireless and Mobile Network Architectures*, John Wiley & Sons, 2000, ISBN 0471394920

Theodore S. Rappaport, *Wireless Communications: principles and practice*, Prentice Hall, 2001, ISBN 0130422320

...altri testi e articoli saranno forniti in seguito.

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Wireless PHY level

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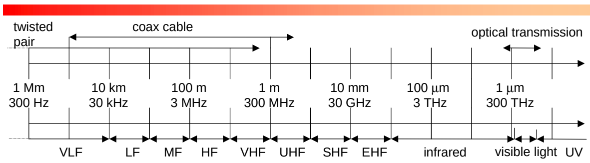
Frequencies for (wired and wireless) communicat.



- 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 $c \cong 3\times10^8$ m/s, frequency f

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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, large bandwidth available
- **Wireless LANs use frequencies in UHF to SHF spectrum**
  - 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...

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Frequencies and regulations

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

	Europe	USA	Japan
Cellular Phones	**GSM** 450-457, 479-486/460-467,489-496, 890-915/935-960, 1710-1785/1805-1880 **UMTS** (FDD) 1920-1980, 2110-2190 **UMTS** (TDD) 1900-1920, 2020-2025	**AMPS**, **TDMA**, **CDMA** 824-849, 869-894 **TDMA**, **CDMA**, **GSM** 1850-1910, 1930-1990	**PDC** 810-826, 940-956, 1429-1465, 1477-1513
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** 254-380
Wireless LANs	**IEEE 802.11** 2400-2483 **HIPERLAN 2** 5150-5350, 5470-5725	902-928 **IEEE 802.11** 2400-2483 5150-5350, 5725-5825	**IEEE 802.11** 2471-2497 5150-5250
Others	**RF-Control** 27, 128, 418, 433, 868	**RF-Control** 315, 915	**RF-Control** 426, 868

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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 φ
  - sine wave as special periodic signal for a carrier:

$$s(t) = A_t \sin(2 \pi f_t t + \varphi_t)$$

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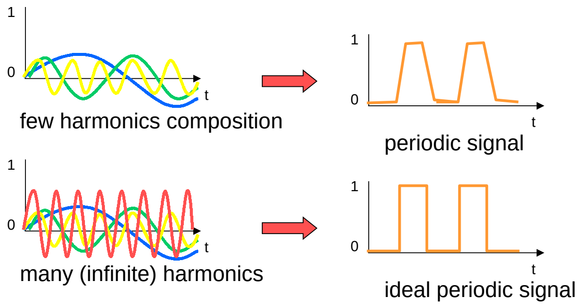
Fourier representation of periodic signals

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



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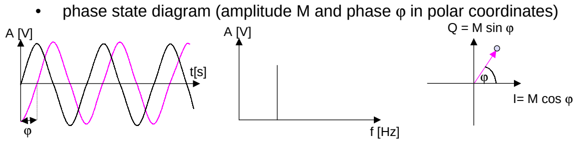
Signals II

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



- **Composed signals transferred into frequency domain using Fourier transformation**
- **Digital signals need**
  - infinite frequencies for perfect transmission
  - modulation with a carrier frequency for transmission (analog signal!)

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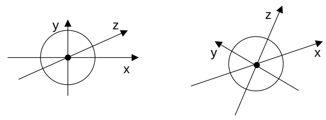
Antennas: isotropic radiator

- **How electromagnetic waves diffuse on space?**
- **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**



ideal isotropic radiator

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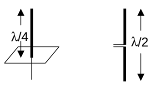
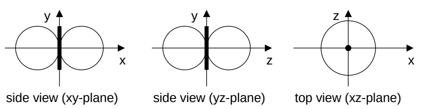
Antennas: simple dipoles

- **Real antennas are not isotropic radiators but, e.g., dipoles**
  ➔ shape of antenna proportional to wavelength



- **Example: Radiation pattern of a simple Hertzian dipole**



simple dipole

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

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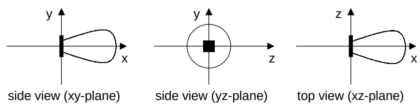
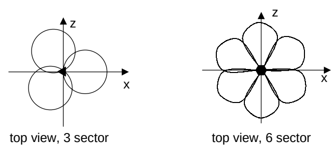
Antennas: directed and sectorized

- **Often used for microwave connections or base stations for mobile phones (e.g., radio coverage of a valley)**



directed antenna



sectorized antenna

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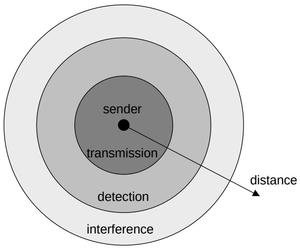
Signal propagation ranges

- **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



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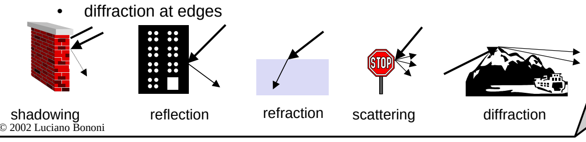
Signal propagation

- **Propagation in free space always like light (straight line)**
- **Receiving power proportional to $1/d^2$**
  (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



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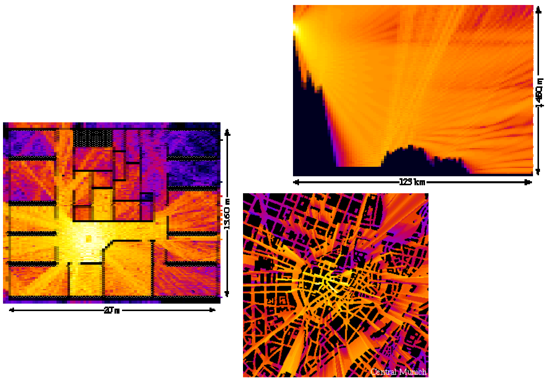
Real world example



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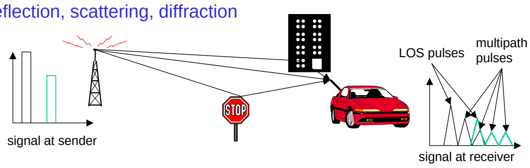
Multipath propagation

- 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

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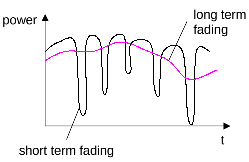
Effects of mobility

- **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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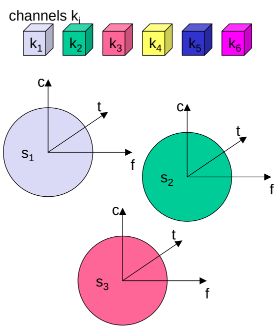
Multiplexing: multiple use of shared medium

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



- **Goal: multiple use of a shared medium**
- **Important: guard spaces needed!**

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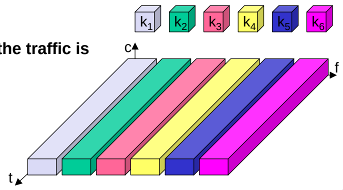
Frequency multiplex

- 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



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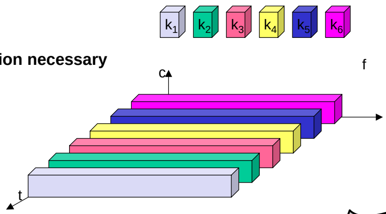
Time multiplex

- 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



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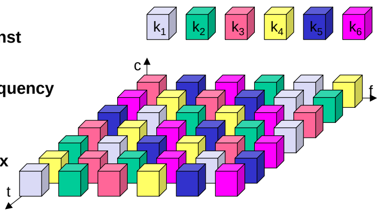
Time and frequency multiplex

- 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 mux
- but:
  - precise coordination required



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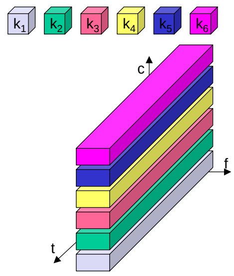
Code multiplex

- 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



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Modulation

- Digital modulation
  - digital data is translated into an analog signal (baseband)
  - ASK, FSK, PSK differences in spectral efficiency, power efficiency, robustness
- Analog modulation
  - shifts center frequency of baseband signal up to the radio carrier (i.e. FM)
- Motivation
  - smaller antennas (e.g., λ/4)
  - Frequency Division Multiplexing
  - medium characteristics
- Basic schemes
  - Amplitude Modulation (AM)
  - Frequency Modulation (FM)
  - Phase Modulation (PM)

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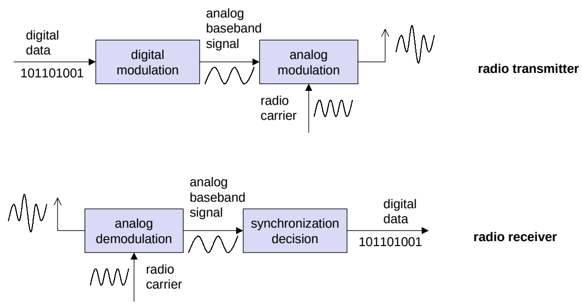
Modulation and demodulation



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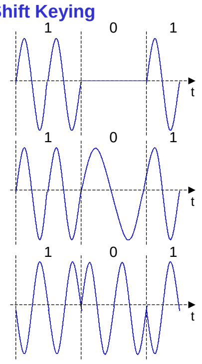
Digital modulation

- **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



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Advanced Frequency Shift Keying

- **bandwidth needed for FSK depends on the distance between the carrier frequencies (range of frequency variation).**
- **special pre-computation avoids sudden phase shifts ➔ MSK (Minimum Shift Keying)**
- **bit separated into even and odd bits, the duration of each bit is doubled**
- **depending on the bit values (even, odd) the higher or lower frequency, original or inverted is chosen**
- **the frequency of one carrier is twice the frequency of the other**
- **Equivalent to offset QPSK**
- **even higher bandwidth efficiency using a Gaussian low-pass filter ➔ GMSK (Gaussian MSK), used in GSM**

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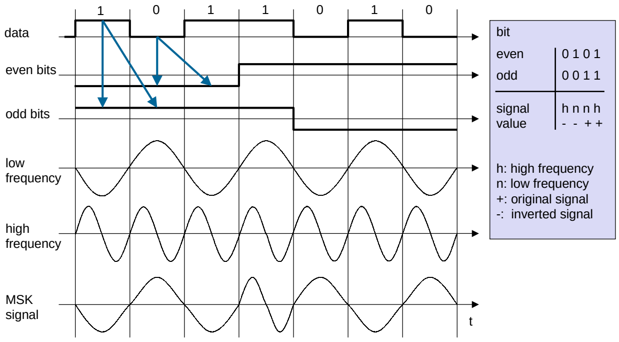
Example of MSK



No phase shifts!

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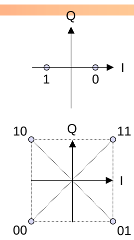
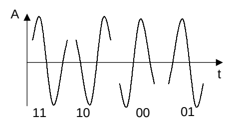
Advanced Phase Shift Keying

- **BPSK (Binary Phase Shift Keying):**
  - **bit value 0: sine wave**
  - **bit value 1: inverted sine wave**
  - **very simple PSK**
  - **low spectral efficiency**
  - **robust, used e.g. in satellite systems**
- **QPSK (Quadrature Phase Shift Keying):**
  - **2 bits coded as one symbol**
  - **symbol determines shift of sine wave**
  - **needs less bandwidth compared to BPSK**
  - **more complex**
- **Often also transmission of relative, not absolute phase shift: DQPSK - Differential QPSK (IS-136, PHS)**





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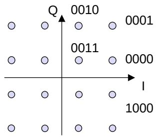
Quadrature Amplitude Modulation

- **Quadrature Amplitude Modulation (QAM): combines amplitude and phase modulation**
- **it is possible to code n bits using one symbol**
- **2^n discrete levels, n=2 identical to QPSK**
- **bit error rate increases with n, but less errors compared to comparable PSK schemes**

Example: 16-QAM (4 bits = 1 symbol)



- **Symbols 0011 and 0001 have the same phase, but different amplitude. 0000 and 1000 have different phase, but same amplitude.**
- **➔ used in standard 9600 bit/s modems**

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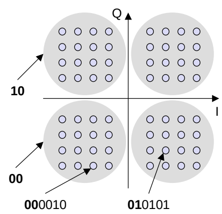
Hierarchical Modulation

- **modulates two separate data streams onto a single stream**
- **High Priority (HP) embedded within a Low Priority (LP) stream**
- **Multi carrier system, about 2000 or 8000 carriers**
- **QPSK, 16 QAM, 64QAM**
- **Example: 64QAM**
  - good reception: resolve the entire 64QAM constellation
  - poor reception, mobile reception: resolve only QPSK portion
  - 6 bit per QAM symbol, 2 most significant determine QPSK
  - HP service coded in QPSK (2 bit), LP uses remaining 4 bit



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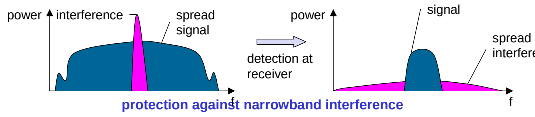
Spread spectrum technology

- **Problem of radio transmission: frequency dependent fading can wipe out narrow band signals for duration of the interference**
- **CDMA: spread narrowband signal into broadband signal using special code**
- **protection against narrow band interference**



protection against narrowband interference

- **Side effects:**
  - coexistence of several signals without dynamic coordination
  - tap-proof (cannot be detected without knowing the code)
- **Alternatives: Direct Sequence, Frequency Hopping**

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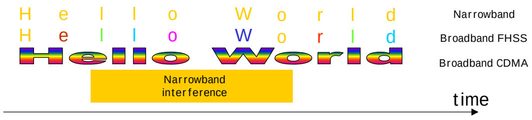
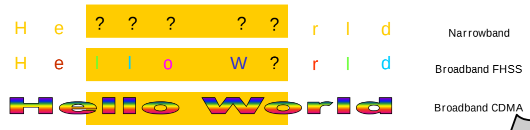
Spread spectrum technology

- **intuitive example: narrowband interference effect on transmission:**
  - transmit "Hello World" coded using narrowband "yellow" frequency and broadband "many colors" frequencies



  - a burst of yellow interference adds to the signal for a significant time: what is the result at the receiver?



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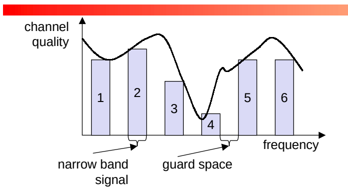
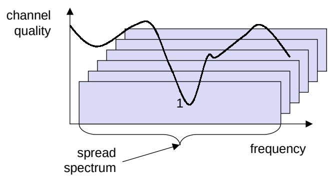
Spreading and frequency selective fading



narrowband channels



spread spectrum channels

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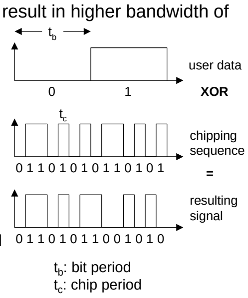
DSSS (Direct Sequence Spread Spectrum) I

- **XOR of the signal with pseudo-random number (chipping sequence)**
  - many chips per bit (e.g., 128) result in higher bandwidth of the signal (low throughput)
- **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



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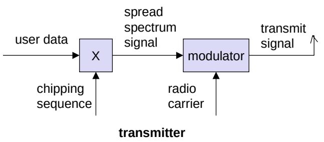
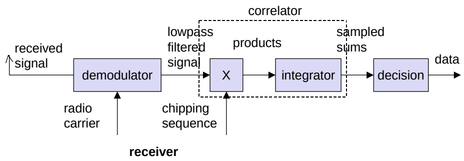
DSSS (Direct Sequence Spread Spectrum) II





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FHSS (Frequency Hopping Spread Spectrum) I

- **Discrete changes of carrier frequency**
  - sequence of frequency changes determined via pseudo random number sequence (e.g. seed = f(host identifier in Bluetooth))
- **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

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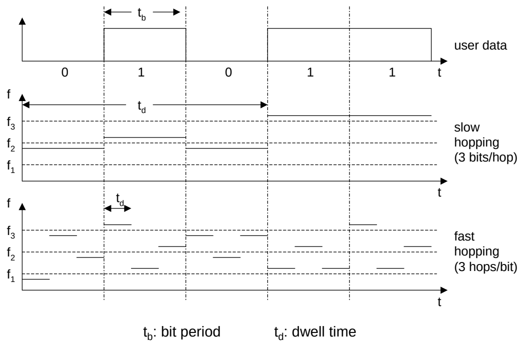
FHSS (Frequency Hopping Spread Spectrum) II



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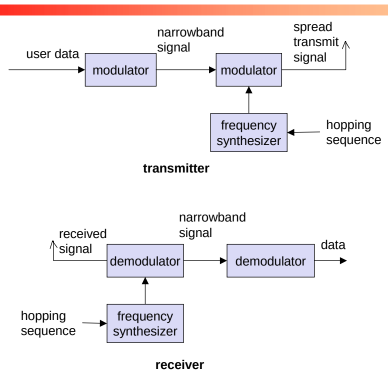
FHSS (Frequency Hopping Spread Spectrum) III



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Space division mux: cell structure

- **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 (infrastructure)
  - 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**

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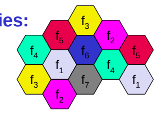
Frequency planning I

- **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

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PHY modelling issues

- **Usually the PHY layer is considered a Black box in the simulation model (e.g. when studying higher layers)**
- **Many PHY parameters can have a deep effect on higher layers' behavior (and are inherently "continuous"...)**
  - a modeler needs to know what is required to be modeled for obtaining significant results (e.g. mapping to "discrete"...)
  - simplifying assumptions can lead to wrong results
    - Warning: more analysis?
- **Usually the choice is to model only few parameters of the PHY layer, describing the aggregate effect of main parameters (see later) and their values' distributions.**
  - Trace driven simulation? Regression data from logged trace results?
  - e.g. channel states → Bit error rate → prob. of packet error?
  - e.g. network topology → interference → bit error rate?
  - e.g. coding and trasmission technique → data rate?

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PHY modelling issues

- **Homework: analitical analysis of a PHY system**
  - a given channel is DSSS with 8 chips/bit
  - maximum chipping rate = 2.000.000 chip/sec
  - can recover up to 2 chip errors/bit
  - probability of chip error = Pce
  - probability of a bit error?
  - frame length (constant) = 1500 Bytes
  - probability of frame error?

  will be used as the PHY (black box) reliability parameter...
  - timeout delay before packet retransmission attempt = 1 sec

  average delay before tagged frame's successful transmission?

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