Mobilkommunikation - Mobile Communications

Lecture 2: Wireless Transmission

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Outline

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- Radio Propagation
  - Line-of-sight propagation
  - Non-line-of-sight and multipath propagation
  - Mobility
- Channel Capacity
- Encoding and Modulation
- Multiplexing
- Spread Spectrum

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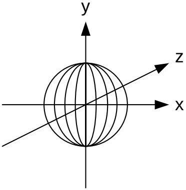
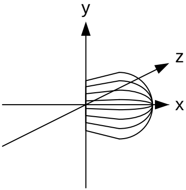
Antennas

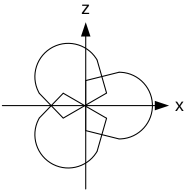
- **isotropic** antenna
  - theoretic concept of point antenna
  - omni-directional in x, y, and z
- **directed** antennas
  - directive effects in all real antennas
  - size of antennas is in the order of the wavelength
- **sectorized** antennas



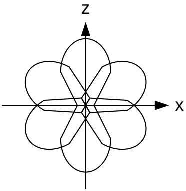
omni-directional



directional



top view, 3 sectors



top view, 6 sectors

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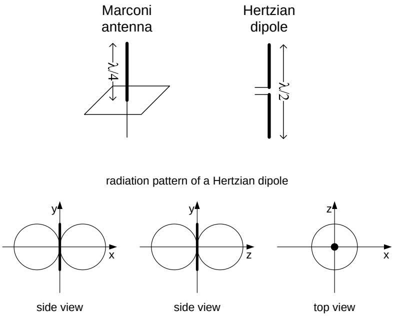
Simple antenna dipoles

- length in the order of the wavelength, e.g. $\lambda/4$ or $\lambda/2$

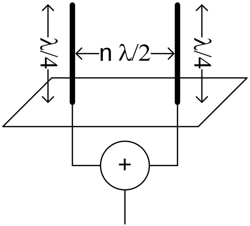


Real antennas are not isotropic

- antenna gain: power in the direction of the main lobe relating to the power of an isotropic radiator

Antenna diversity: use of 2 or more antennas, also called multi-element antenna arrays

- diversity at
  - sender
  - receiver
  - both
- switched or selection diversity
  - receiver selects the antenna with the largest output
- diversity combining
  - receiver combines the output power of all antennas to produce gain
  - cophasing is used to avoid cancellation of signals



Multiple-input multiple-output

Multiple-input multiple-output (MIMO) refers to multi antenna systems at sender and receiver.

Given two antennas at the sender and receiver each, the signals at the receiver y_j depend on the respective channel condition $h_{i,j}$ and the signals at the sender x_i

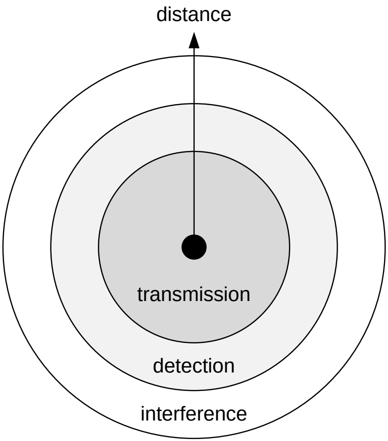
$$\begin{bmatrix} y_1(t) \\ y_2(t) \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix}$$

MIMO can be used in different ways

- transmit and receive diversity
- beamforming
- spatial multiplex

Signal propagation

- **transmission range**
  low error rate at the receiver
- **detection range**
  transmitted power differs from background noise
- **interference range**
  sender adds to background noise



Free-space path loss

Consider an isotropic antenna that emits an electromagnetical signal with power P_t. The signal propagates at the speed of light c. It forms a sphere with surface $4\pi d^2$ where d is the distance from the sender resulting in the **inverse square law** (Friis)

$$S = P_t \frac{1}{4\pi d^2}$$

where S is the power per unit of area, i.e., Watt/m^2. Higher exponents in the range of $2 \dots 5$ apply if the assumption of free space does not hold.

The receive power is $P_r = S \cdot A$ where A is the aperture area. For isotropic antennas $A = \lambda^2/(4\pi)$ where λ is the wave length, i.e.

$$P_r = S \frac{\lambda^2}{4\pi}.$$

Free-space path loss (2)

By insertion the received power for free space propagation is

$$P_r = P_t \frac{G_t G_r}{L_p}$$

- P_r = received power
- P_t = transmitted power
- G_r = gain of the receiving antenna
- G_t = gain of the transmitting antenna
- L_p = free space path loss

$$L_p = \left(\frac{4\pi d}{\lambda}\right)^2 \qquad \text{or} \qquad L_p = 20 \log \left(\frac{4\pi d}{\lambda}\right) \text{ [dB]}$$

- λ = wave length $= c/f$
- c = speed of light, in free space $c = 3 \cdot 10^8$ m/s
- f = carrier frequency

Free-space path loss (3)

Free space path loss after insertion of constants

$$L_p = 32.5 + 20 \log f + 20 \log d \text{ dB}$$

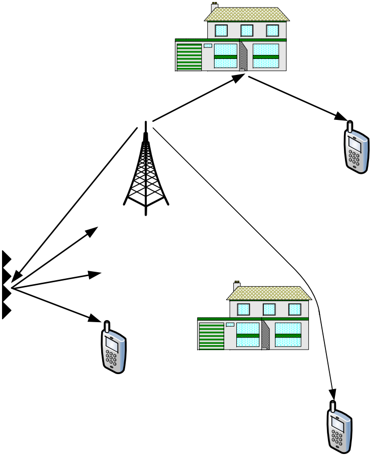
- f carrier frequency in MHz
- d distance in km where $d > 1$ km

Useful rules to remember

- doubling the length of a path increases free space attenuation by 6 dB
- doubling the frequency also increases free space attenuation by 6 dB

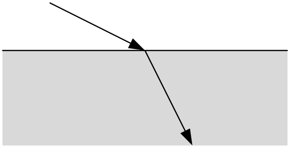
Attributes of radio wave propagation

- **reflection:**
  if a radio wave impinges upon the boundary of two materials with different electromagnetic properties; causes shadowing
- **diffraction:**
  radio waves bend in the neighborhood of obstacles
- **scattering:**
  if a radio wave hits a rough surface or an object having a size in the order of the wavelength



Attributes of radio wave propagation (2)

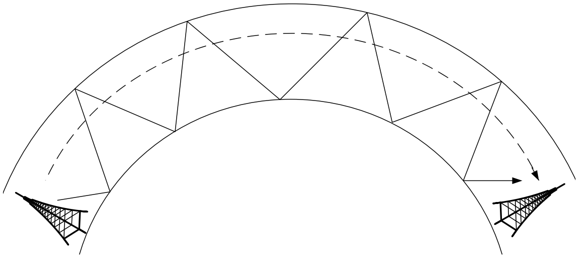
- **refraction:** the velocity of of electromagnetic waves depends on the density of the medium; at the boundary to a denser medium waves are bent towards the medium



This effect causes that radio waves are bent towards the earth, since the density of the atmosphere increases closer to the ground.

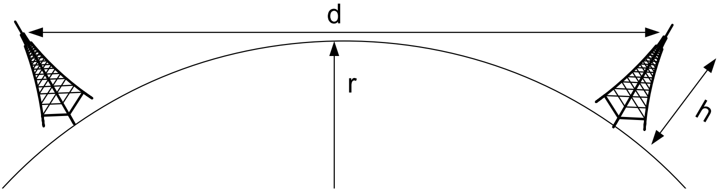
Propagation behavior at different frequencies

- **ground wave** < 2 Mhz: Low frequencies can follow the curvature of the earth over long distances
- **sky wave** 2-30 MHz: Short waves are reflected at the ionosphere and at the surface of the earth
- **line-of-sight** > 30 Mhz: Ultrashort waves and below closely follow a straight line of sight

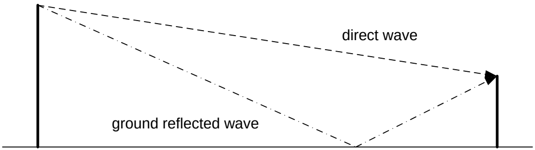


Line-of-sight (LOS) propagation

- without any obstructions due to obstacles etc.
- Pythagoras $(r+h)^2 = r^2 + (d/2)^2$
- earth radius $r = 6370$ km
- height of the antenna, e.g. $h = 30$ m
- distance to horizon $d/2 = \sqrt{2rh + h^2}$, e.g. $d/2 = 20$ km



Multipath propagation



Signals propagate along different paths due to reflection, diffraction, scattering, and refraction.

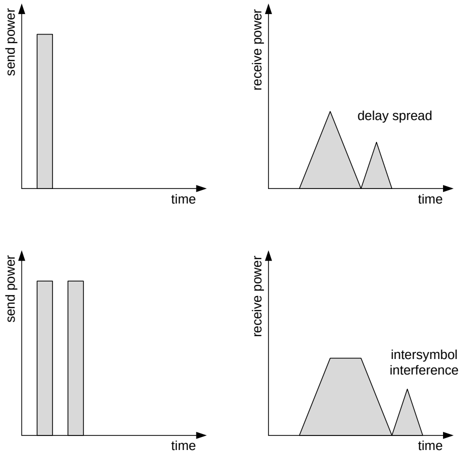
Since the speed of light is finite, different paths result in different receive times resulting in **delay spread** at the receiver

- the signal is smeared or separated into several weaker impulses
- originally separated signals interfere with each other

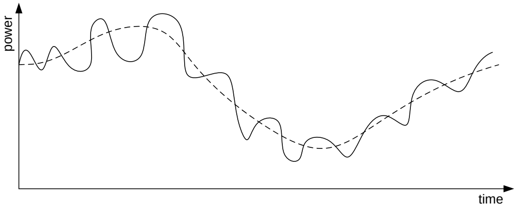
E.g. in case of 5 km path difference the delay spread is 16 μs.

The problem is addressed using **training sequences** to tune an equalizer at the receiver that seeks to compensate the distortion.

Delay spread and intersymbol interference



Fading



Due to multipath propagation receivers (even in close proximity) may see largely different signal strengths

- **fast fading:** usually over distances of about half a wavelength
- **slow fading:** average over five to forty wavelengths
- **shadowing:** due to buildings and other objects

Fading can be frequency-selective or not, referred to as flat fading.

Fading models

A number of statistical models are frequently used today to analyze fading:

- **Rician** distribution: fast fading, line-of-sight
- **Rayleigh** distribution: fast fading
- **Lognormal** distribution: slow fading

Moreover, a number of propagation path-loss models exist, such as the Okumura/Hata model that is based on a collection of experimental data collected in the Tokyo area.

Doppler shift

In case of relative motion between sender and receiver a Doppler shift f_D, i.e. change in frequency, occurs:

$$f_D = \frac{v}{c} f$$

where

- $c =$ speed of light
- $v =$ relative speed
- $f =$ carrier frequency

The Doppler shift is relevant in case of fast moving transceivers, e.g. in particular satellites.

Characteristics of the wireless medium

Startseite | Anmelden | Einloggen | Service | Übersicht | Hilfe

Kaufen | Suchen | Verkaufen | Mein eBay | Gemeinschaft

zurück zur Startseite   Kategorie: Computer > Netzwerk > Wireless LAN > Sonstige

100m langes W-Kabel (Wireless Lan Kabel)!   Artikelnummer: 3069976001

Bieter oder Verkäufer dieses Artikels? Einloggen zur Statusabfrage

Angebot ist beendet (comenden ist der Käufer).

Erfolgreiches Gebot:	**EUR 10,50**
Endet:	08.01.04 12:50:55 MEZ
Übersicht:	4 Gebote (EUR 1,00 Startpreis)
Käufer:	comenden (13)
Ort:	nähe Mannheim Deutschland /Rhein-Neckar

Angaben zum Verkäufer

vincent1500 (30)

Bewertungen: 30
Positive Bewertungen: 100%
Angemeldet seit 20.01.03 Land: Deutschland

Bewertungen ansehen
Frage an den Verkäufer
Andere Artikel des Verkäufers
Erst informieren, dann kaufen

Angaben zu Zahlung und Versand

Beschreibung (überarbeitet)   Der Verkäufer ist verantwortlich für das Angebot, insbesondere Titel und Beschreibung.

In dieser Auktion bieten sie auf ein nagelneues original verpacktes Wireless Lan Kabel.

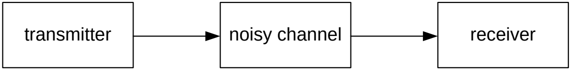
Das Kabel wurde bestens verarbeitet und besteht zum groeßten Teil aus Stickstoff(78%!). Die anderen 22% teilen sich in Sauerstoff und in Edelgase auf. Es soll noch erwähnt werden, dass der Anteil an Kohlenstoffdioxid nur 0,035% beträgt, sodass das Kabel schon etliche Umweltpreise eingeheimst hat !^

Das Kabel eignet sich ideal für das Verbinden von PC´s im Lan, da

- es eine unheimlich gute Formbarkeit hat
- es in wenigen Sekunden problemlos montiert werden kann

die Übertragungsrate ist sehr hoch , niedrige Latenzzeiten sind die Regel!

Noisy channel



Radio transmission over a wireless channel is subject to noise. Useful and frequently used is the is additive white Gaussian noise (AWGN) model

- linear addition of noise
- noise is white i.e.
  - it applies to all frequency bands
  - it has a constant spectral density independent of frequency
- noise samples have a Gaussian distribution

Gaussian noise has many natural causes such as thermal noise, radiation from the earth and sun, etc. It is, however, not a model for fading, interference, dispersion etc.

Shannon limit

Shannon's limit for AWGN channels states that

$$C = B \log_2 \left(1 + \frac{S}{N}\right)$$

where

- C = theoretical limit of the data rate [bit/s]
- B = channel bandwidth [Hz]
- S = signal power [W]
- N = noise power [W]
- S/N = signal-to-noise ratio

Shannon limit (2)

Given bits of duration $T = 1/C$ the energy per bit is $E_b = S/C$.

The noise can be expressed as $N = N_0 \cdot B$ where N_0 is the spectral noise power density [W/Hz] and B is the bandwidth [Hz].

By insertion

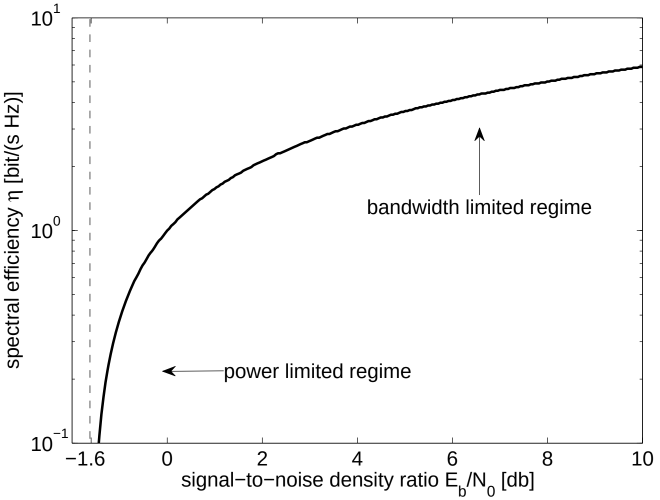
$$\frac{C}{B} = \log_2\left(1 + \frac{E_b}{N_0}\frac{C}{B}\right)$$

where

- $E_b/N_0 =$ signal-to-noise density ratio
- $C/B = \eta$ spectral efficiency [bit/(s·Hz)]

For $\eta \to 0$ it follows that $E_b/N_0 = \ln(2) \approx 0.7 \approx -1.6$ dB, i.e. information transfer is impossible if $E_b/N_0 < 0.7$ even if the bandwidth is arbitrarily large.

Shannon limit (3)



Impact of the signal power

Low SNR regime $\rightarrow$ small η

$$\eta = \log_2\left(1 + \frac{S}{N}\right) \approx \frac{S}{N} \cdot \text{const}$$

Doubling S doubles η.

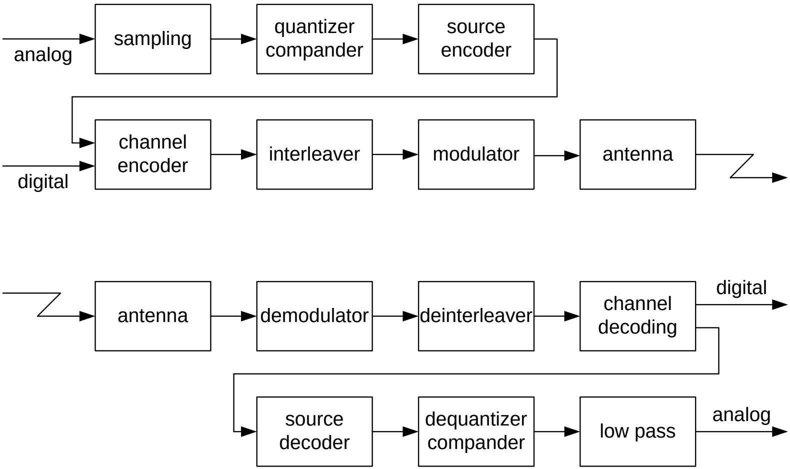
High SNR regime $\rightarrow$ large η

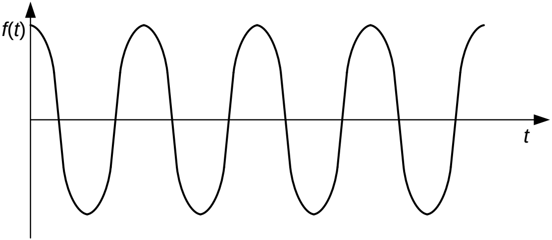
$$\eta \approx \log_2\left(\frac{S}{N}\right)$$

Doubling S increases η by 1 bit/(s Hz).

Generally, it follows that doubling S results in an increase of η approximately by $\min\{1, \eta\}$.

Digital communication



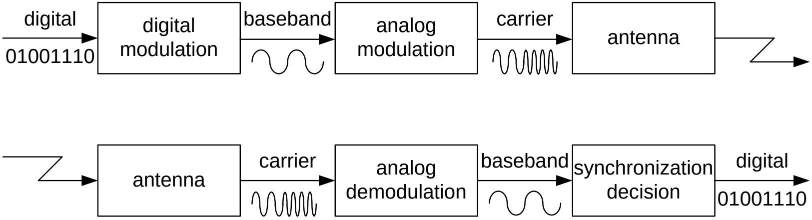


$$s(t) = a \cdot \cos(2\pi f t + \phi)$$

A basic cosine (sine) function has three parameters that can be modulated to encode data:

- a = amplitude,
- f = frequency,
- ϕ = phase.

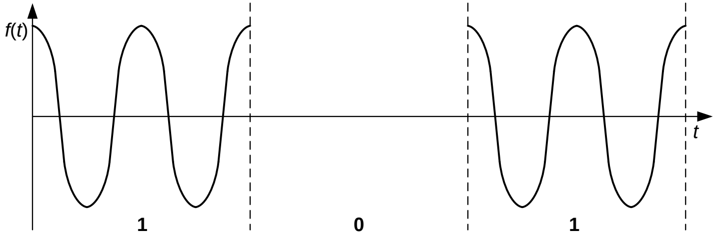
Send and receive path



Radio send and inverse receive path

- **digital modulation** modulates digital (binary) data onto a baseband signal
- **analog modulation** takes a baseband signal and modulates it onto the radio carrier, e.g. usually shifts the baseband signal into a different frequency band

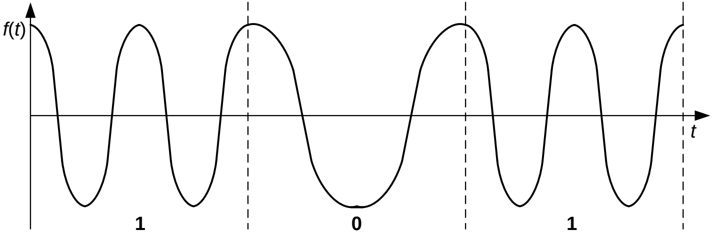
Amplitude shift keying



Amplitude shift keying (ASK)

- different amplitudes represent different symbols
- simple scheme with low bandwidth requirement
- susceptible to interference that influences the amplitude
- therefore usually not used for wireless transmission
- but used for optical transmission, i.e. light pulses

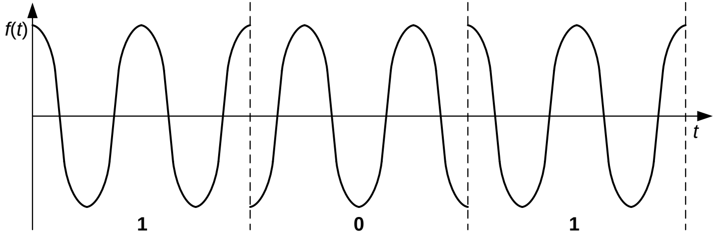
Frequency shift keying



Frequency shift keying (FSK)

- different frequencies represent different symbols
- usually sudden changes in the phase are avoided, so-called continuous phase modulation
- demodulation can simply be performed using different bandpass filters and a comparator
- frequently used for wireless transmission

Phase shift keying



Phase shift keying (PSK)

- shifts in the phase of the signal represent different symbols
- to decode the signal the receiver has to synchronize in frequency and phase using a so-called phase lock loop
- more resistent to interference than FSK but also more complex transmitter and receiver

Advanced frequency shift keying

Minimum shift keying (MSK) is a widely used binary FSK scheme

- continuous phase modulation
- frequency changes occur at the carrier zero crossings
- binary scheme with two frequencies
- difference between low and high frequency is half the data rate
- minimum frequency spacing for continuous phase

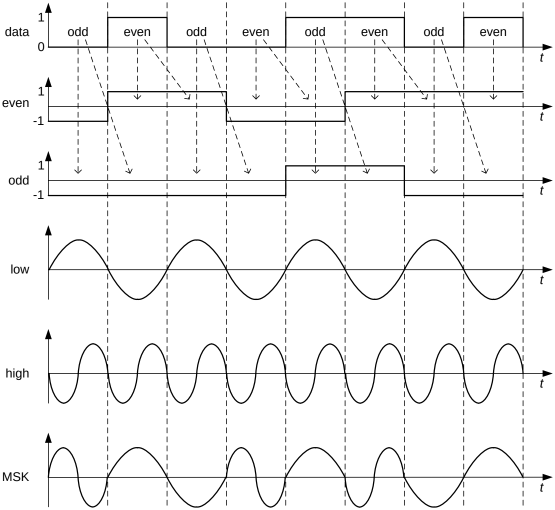
Gaussian MSK (GMSK) basically adds a Gaussian lowpass filter to reduce spectral side lobes. It is used e.g. for GSM and DECT.

Minimum shift keying

MSK modulation procedure

- bits are separated in odd and even positions
- each bit is doubled in time
- depending on the pair (even,odd) the frequency is chosen
  - (-1, 1): low frequency
  - (1, 1): high frequency
  - (1,-1): low frequency inverted phase
  - (-1,-1): high frequency inverted phase
- that is
  - low frequency if even $\cdot$ odd $= -1$ and high otherwise
  - phase inversion if odd $= -1$ and no inversion otherwise

Minimum shift keying (2)



- T = bit duration
- $R = 1/T$ data rate
- $f_H = 1/T$ high freq. by choice
- $f_L = f_H - R/2 = 1/(2T)$ low freq.

Advanced phase shift keying

Phase shift keying (PSK) is used in many ways

- Binary PSK (BPSK) only uses two phases with 180° shift to encode one bit
- Quadrature PSK (QPSK) uses four phases to encode two bit into one shift

The receiver uses a reference to detect phase shifts

- reference signal at the receiver, requires synchronization
- differential encoding, i.e. phase shifts relative to the previous phase, e.g. DQPSK

Combination of PSK with ASK

- Qudrature amplitude modulation (QAM) superposes two signals: in-phase (cos) plus quadrature (sin) each with
  - 4 different amplitudes $\Rightarrow$ 16 different symbols (16-QAM)
  - 8 different amplitudes $\Rightarrow$ 64 different symbols (64-QAM)

Multi-carrier modulation

High bit-rate transmission is vulnerable to inter-symbol interference (ISI). To this end, Multi-carrier modulation (MCM) performs a parallel transmission using several subcarriers.

- a data stream with rate R has bit duration $1/R$
- splitting the stream into N substreams the bit duration increases to N/R thus reducing ISI
- the bandwidth of the radio carrier f is split into N adjacent subcarriers of f/N width
- each of the substreams is assigned to one subchannel

An additional benefit is that frequency selective fading only influences certain subcarriers.

Orthogonal frequency division multiplexing (OFDM) is an efficient implementation of MCM that is used e.g. in IEEE 802.11a.

Outline

Multiplexing

The goal is to divide radio resources and to assign space, time, frequency, and code to individual pairs of senders and receivers. To this end, multiplexing can use any combination of

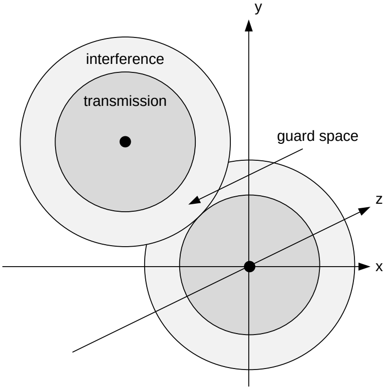
- space division multiplexing (SDM)
- time division multiplexing (TDM)
- frequency division multiplexing (FDM)
- code division multiplexing (CDM)

At the same time the target is to

- minimize interference
- maximize utilization

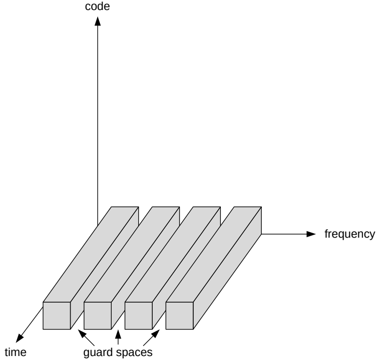
Space division multiplexing

- threedimensional space
- e.g. omnidirectional propagation
  - transmission range
  - interference range
- guard spaces
- spatial reuse



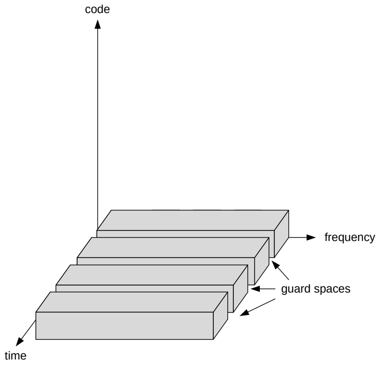
Frequency division multiplexing

- non-overlapping frequency bands
  - adjacent channel interference
  - guard spaces
- simple scheme without need for complex coordination
  - the receiver basically tunes to the frequency of the sender
- the static frequency allocation is, however, inflexible



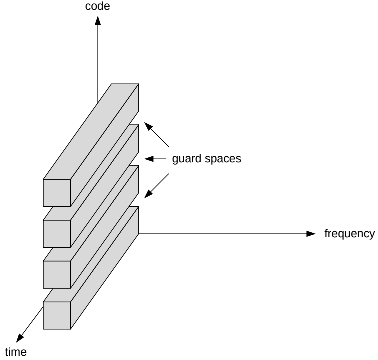
Time division multiplexing

- all senders use the same frequency but at different times
  - receivers have to listen exactly at the right time
  - synchronization of different senders is needed
  - exact clocks or synchronization signals
  - co-channel interference
  - guard spaces
- flexible since timeslots can be reassigned to heavily loaded senders
- frequently combined with FDM, e.g. in GSM



Code division multiplexing

- each channel uses a specific, individual code
  - codes have to be sufficiently orthogonal to realize guard spaces
- secret codes achieve security
- good protection against interference
- high complexity of the receiver
  - need precise synchronization
  - need sophisticated power control, other codes appear as background noise



Outline

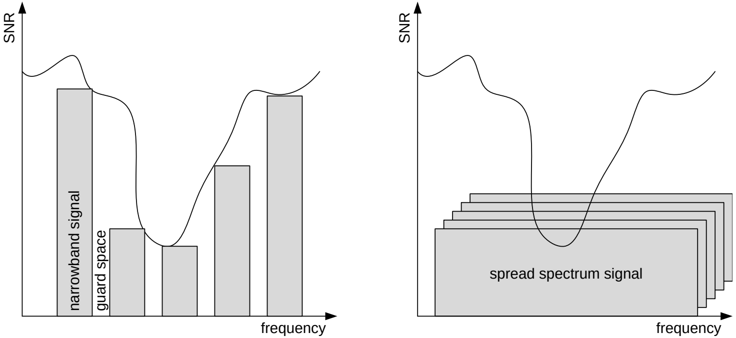
Spread spectrum

Spread spectrum techniques spread the frequency band that is used

- narrowband signals are converted into broadband signals
- achieves robustness against narrowband interference
- interference is frequency selective and can vary quickly in time
- assuming the same energy, the power of the spread signal can be much lower
- signals can look like background noise and may be hard to detect

E.g. a narrowband FDM system separates frequency bands while a spread spectrum system combines these bands and uses CDM.

Impact of narrowband noise

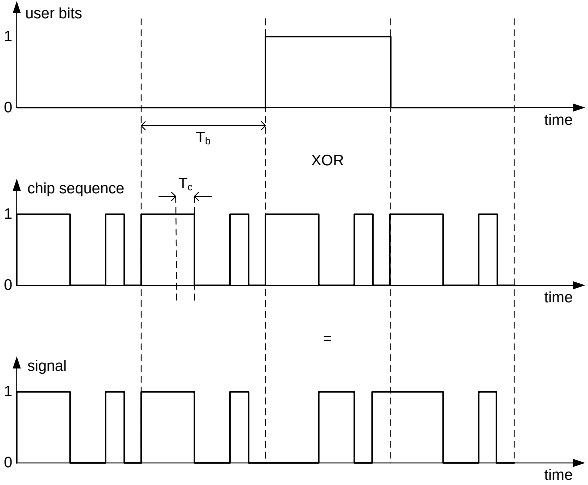


In spread spectrum systems narrowband noise affects all signals, but to a much lesser extend as opposed to narrowband signals.

Direct sequence spread spectrum

- signals are spread before modulation
- bits are XORed with a so-called chipping sequence
- bits have a duration T_b
- chips are small pulses of duration T_c
- the spreading factor is $s = T_b / T_c$
- given the bandwidth of the original signal is w the bandwidth of the spread signal is $s \cdot w$
- chipping sequences use specific codes that appear as random noise, also called pseudo-noise
  - e.g. Barker codes
  - spreading factors typically range from 10 up to 10000 if secret codes are needed

Direct sequence spread spectrum (2)



Direct sequence spread spectrum (3)

Decoding spread spectrum signals is much more complex

- basically another XOR with exactly the same chipping sequence at the receiver
- requires, however, exact synchronization at bit and chip level
- signals may be distorted at the receiver, i.e. chips are tilted
  - consequently the result after XOR (ideally a single bit) may alternate between zero and one
  - the receiver uses an integrator that generates a sort of "majority" decision

Multi-path propagation and different delays per path are a challenge for spread spectrum. So-called rake receivers use several decoders that are synchronized to different delays resp. paths.

Frequency hopping spread spectrum

Spread spectrum can be implemented using frequency hopping

- several frequency bands are used according to a fixed hopping sequence, i.e. combination of FDM and TDM
- frequency hopping is implemented as a part of analog modulation, i.e. after digital modulation

In case of several transmitters the hopping sequences have to be coordinated to avoid that transmitters use the same frequency at the same time

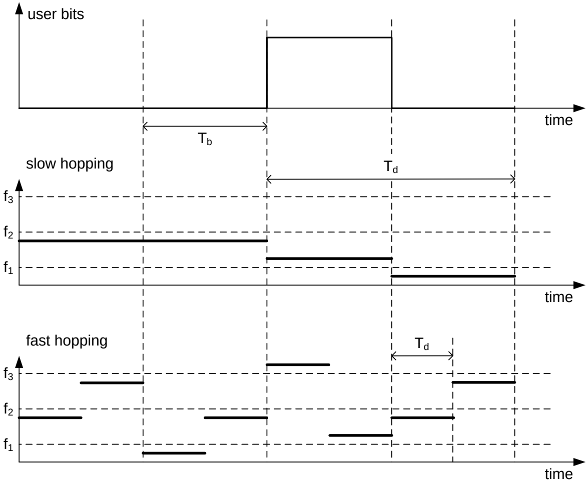
- coordination of all transmitters or
- pseudo-random hopping with different hopping sequences that are sufficiently orthogonal

Frequency hopping spread spectrum (2)

The time spent on a channel is called the dwell time T_d.

- slow hopping
  - speed of hopping is slower than the bit duration $T_d > T_b$, i.e. several bits are transmitted before a hop is performed
  - used e.g. in GSM and Bluetooth
- fast hopping
  - speed of hopping is faster than the bit duration $T_d < T_b$, i.e. several hops are performed while a single bit is transmitted
  - better robustness against narrowband interference and frequency selective fading
  - more complex due to high synchronization requirements

Frequency hopping spread spectrum (3)



Literature

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- Vijay Garg, Wireless Communications & Networking, Morgan Kaufmann, 2007.