7 Radio Theory

Objectives:

After this chapter the student will:

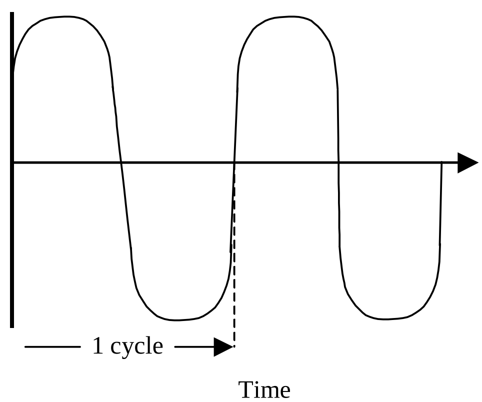
- be able to understand basic access methods and radio properties.

7.1 Multipath Propagation, Time Dispersion etc

The content of this chapter deals with some selected radio properties and their effects on a mobile system. In a mobile network the connection between the mobile phone and the network is done via the air interface with the help of radio waves. The area in witch the mobile and the network can stay in contact with some acceptable quality is called the coverage hgdffdsarea. This area is served by a transmitter/receiver that will transmit towards the mobile and receive from the mobile. The serving area is called a cell.

7.2 Radio Waves

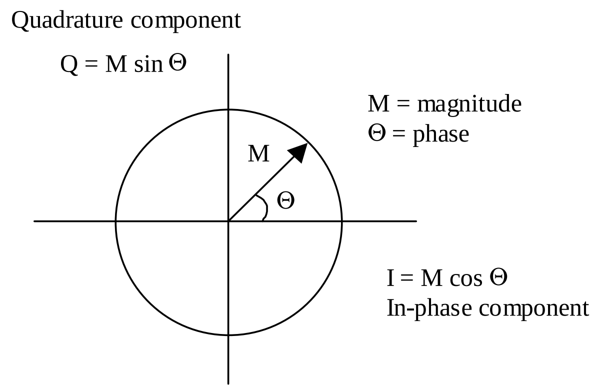
A radio wave is an electromagnetic wave of a frequency lower than 3000 GHz. The electromagnetic wave is produced by the interaction of time varying electric and magnetic fields. The number of cycles or events per time unit is the frequency, which is expressed in Hertz, Hz.



There are many different types of electromagnetic waves including radio waves, light, infrared rays and x-rays. Radio waves are one example of what we refer to as electromagnetic radiation. They are generally generated by oscillating charges on a transmitting antenna.

To be able to use the radio waves for transfer of information such as speech or data a modulation technique is used. Modulation is the process where a radio frequencies (or light wave) amplitude, frequency, or phase is changed.

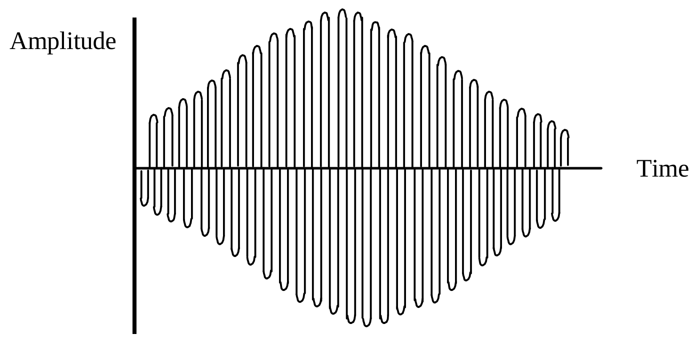
Modify carrier´s amplitude and/or phase (and frequency)



Digital Modulation Techniques

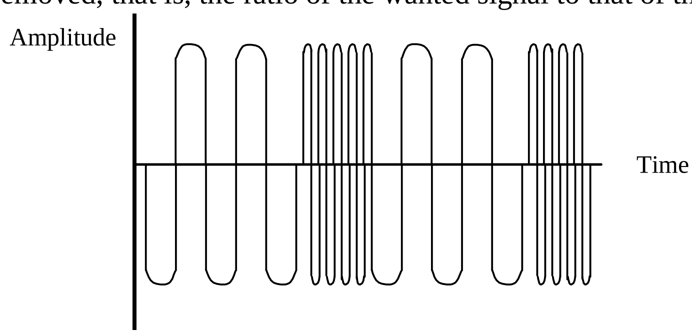
There are different ways to modulate a radio signal. We could change the amplitude, the frequency, the phase or use pulse modulation.

In Amplitude Modulation the carrier frequency's amplitude changes in accordance with the modulated user signal, while the carrier's frequency is fixed



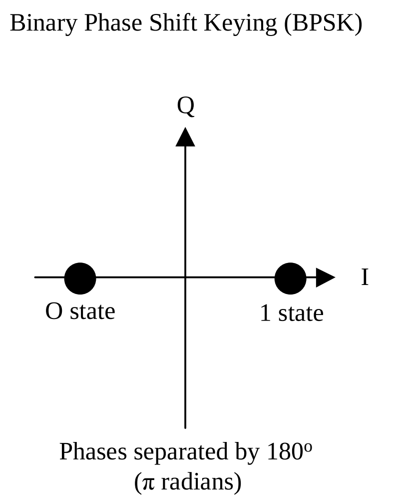
Amplitude Modulation

Frequency modulation occurs when a carrier's frequency is changed according to the input signal, while the amplitude is unchanged. FM modulation is more immune to noise than AM and improves the overall signal-to-noise ratio. The signal-to-noise ratio is the ratio between the signals maximum peak-to-peak signal and what remains when the signal is removed, that is, the ratio of the wanted signal to that of the noise.

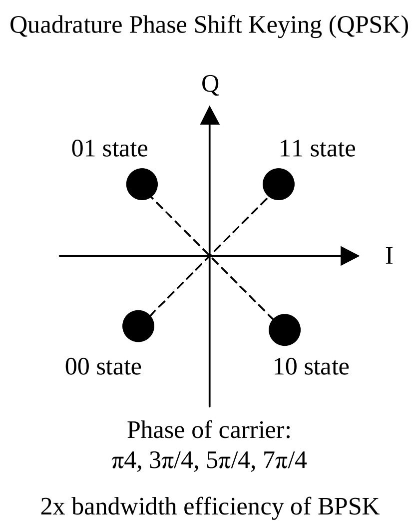


Frequency Modulation

Phase Modulation is similar to FM but instead of changing the frequency of the carrier wave, the phase of the carrier changes.



Binary Phase Shift Keying



Quadrature Phase Shift Keying

Pulse Modulation, is a sample of the waveform taken at regular intervals. There exist a variety of Pulse Modulation schemes not covered here.

To be able to use analogue signals for digital information they have to be processed by an intermediate stage before transmission. This is done by a modulator/demodulator in a process known as a modem.

7.3 Access methods

In a cellular network we have a mobile phone or terminal connected to the network via a basestation that transmits towards the mobile phone and receives signals from the mobile phone. This connection is wireless, that is it uses radio waves in the air interface to set up the connection. The way we utilises these radio waves in the air is called Access Methods and there exists a number of them with different properties

Commonly used access methods in radio networks are Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA) and a Code Division Multiple Access (CDMA).

FDMA is used for standard analogue mobile telephony. Each user is assigned a discrete part of the RF spectrum. FDMA permits only one user per channel since it allows the user to use the channel 100% of the time.

In TDMA the users are still assigned a discrete part of RF spectrum, but multiple users now share that RF carrier on a time slot basis. Each of the users alternates their use of the RF channel. Frequency division is still used, but these carriers are now further sub-divided into some number of time slots per carrier (3 for TDMA-AMPS, 8 for full rate GSM, 16 for half rate GSM).

In CDMA there is no time division, and all users use the entire carrier, all of the time. CDMA is a spread-spectrum communication system in which multiple users have access to the same frequency band. The allocated frequency segment for that one carrier is considerably larger than that used in FDMA or TDMA. To distinguish the different users occupying the same frequency band simultaneously, each user is assigned a binary code.

7.4 Some radio properties

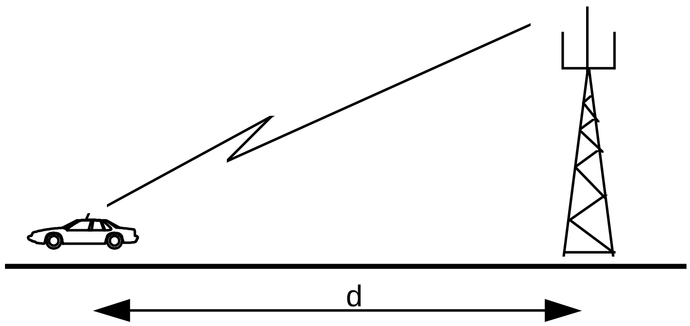
Needed vs. available capacity

One problem encountered with radio is that the available spectrum is limited. The less spectrum needed per subscriber the more subscribers that can be accommodated on the network. Since there is no way to create new frequencies we need good modulation techniques and efficient access methods to use the air interface properly.

Path loss

Path loss or attenuation of the signal causes the received signal at the receiver to get weaker the further away from the transmitter we are.

Path loss can be a problem, making it difficult to get sufficient signal strength levels, but it results also in a lower interference from non wanted transmitters far away from the receiver. If there would be no path loss the interference from all transmitters around us would be very high.



Path loss

For a given frequency, path loss depends on the distance between the receiver and the transmitter. One way to estimate this is to use the free space formula. According to this formula, the path loss varies proximally in the following way:

Pathloss $\approx$ distance ^{2} * frequency ^{2}

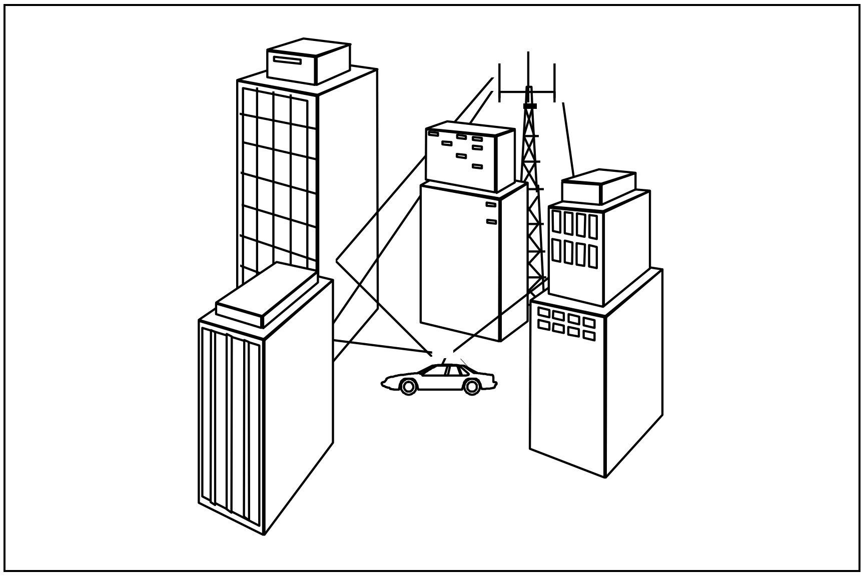
This formula assumes a line of sight condition between the transmitting and receiving antenna. It also assumes that there are no reflections interacting with the direct radio wave. Also, as indicated by the formula, the higher the frequency used, the higher the path loss. Since the pathloss will increase with an increasing frequency it is beneficial if the weakest part, according to transmitting power, is using the lowest frequency. By this it will gain some dB.

Shadowing

If the radio path does not have free line of sight between transmitter and receiver, the obstacles will cause shadowing. Shadowing is also called ” log normal fading” or ”long term fading”. Since the mobile phone normally is located in a low position, transmission will most likely be affected by shadowing objects, e.g. buildings, hills, the user or virtually anything in the radio path. When the mobile phone moves around, variations in signal strength, due to the character of the objects, can be measured in tens of meters.

Multi-path propagation

Another effect that might occur especially in an urban area with a lot of reflections objects near the transmitter and receiver is multi-path propagation. Since the transmitter normally not is transmitting directly towards the receiver but rather in a wide area towards him/here, there will be a lot of rays reflected by obstacles and the received by the receiver. Different reflections would then mean slightly different time delays for the rays and the reflections also will have different effects on the phase of the radio wave. Normally we would receive not one, but several reflected radio waves and the resulting wave could be stronger, or weaker, than the individual waves. If there is no phase difference between the waves, the resulting wave may have considerably better signal strength, but if the phase difference between the two signals is close to 180 degrees they may null each other out. This cancelling out effect may cause very deep fading dips. The phenomenon is called multi-path or Rayleigh fading. On the other hand a receiver could with the help of some addative procedure capture a number of different reflected rays and the take "the best" out of this information.

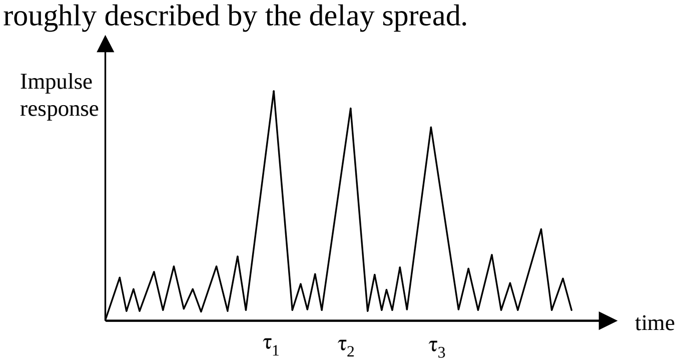


Multi-path propagation

In a GSM system multipath propagation can cause problems in the receiver, multpath fading, while in another system like UMTS with a RAKE receiver structure this leads to the possibility of diversity gain turning the multipath channel to its advantage.

Time Dispersion

One effect of multipath propagation is time dispersion due to varying propagation delays. The effect is that the impulse response of the propagation channel is spread out. The amount of time dispersion is roughly described by the delay spread.



Channel impulse response (power) / time delay

Diversity

One of the objectives in system optimisation is to reduce or benefit from the multipath and shadowing effects. Some are applicable to TDMA and FDMA as well as CDMA system. There are different combinations to diversity.

<u>Space diversity</u>
By using two receiving antennas, chances are that they do not experience the same multipath propagation at the same time. A certain distance between the antennas could be used (space diversity) or the antenna element could be polarised (polarisation diversity). The use of antenna diversity will improve the carrier to interference (C/I) properties of the system as the problem with fading dips is reduced.

<u>Frequency diversity</u>
Another effective way to fight negative effects of multi-path propagation is to change the frequency, thus changing the positions of the dips. When frequency hopping is applied as in GSM/DCS, each consecutive burst will be transmitted (and of course received) at a different frequency.

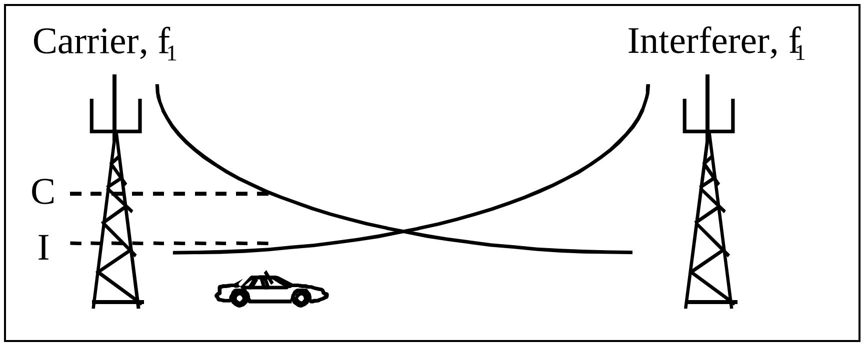
<u>Multi-path diversity</u>
Here versions of the signal arrive via separate paths and at different times and are then combined in the receiver.

<u>Macro diversity</u>
Simultaneous use of links between the mobile and two or more fixed transmitters. Can for example be used to provide a smooth transition as the mobile moves from transmitter to another (soft handover).

<u>Time diversity</u>
Obtained by using symbol interleaving and error correction coding to introduce time correlation into the signal (described later in this chapter).

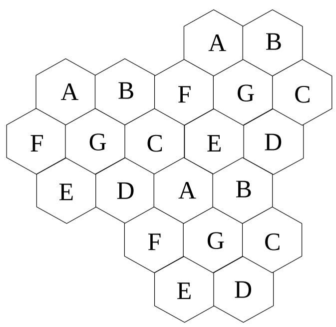
Interference, C/I

Interference is the term for a non-wanted signal that the receiver experiences. In e.g. GSM where we reuse the number of frequencies available this might mean that there is a transmitter using the same frequency as the wanted signal. Reusing an identical carrier frequency in different cells is limited by co-channel interference or C/I. Co-channel interference is the relation between the desired signal C and the undesired re-used signal I, both using the same carrier frequency.



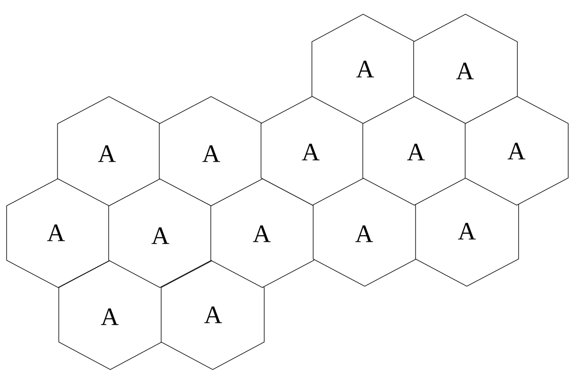
Interference

Radio communication systems often separate users either by frequency channels, time slots, or both. This is e.g. true for GSM. Since the number of available frequencies both are limited by physics and by regulation the frequencies then must be reused. This might cause an interference problem that will be handled by keeping the reuse frequencies (same frequencies) as far away from each other as possible. Satisfactory performance in these systems depends critically on control of the mutual interference arising from this reuse pattern.



Reusing frequencies in GSM

Another approach to this is used in CDMA. Instead of partitioning either spectrum or time into disjoint "slots" each user is assigned a different instance of the noise carrier. While those waveforms are not rigorously orthogonal (they do not interfere with each other), they are nearly so.



In CDMA all cells have the same frequency

The major benefit of noise-like carriers is that the system sensitivity to interference is fundamentally altered. Traditional time or frequency slotted systems must be designed with a reuse ratio that satisfies the worst-case interference scenario. Use of noise-like carriers, with all users occupying the same spectrum, makes the effective noise the sum of all other-user signals. The receiver correlates its input with the desired noise carrier, enhancing the signal to noise ratio at the detector. The enhancement overcomes the summed noise enough to provide an adequate Signal to Noise Ratio, SNR at the detector. Because the interference is summed, the system is no longer sensitive to worst-case interference, but rather to average interference. The reuse pattern is now the same for each.

Error Correction

In the first and second generation mobile system like NMT and GSM the main intention and use of the system have been for speech communication. The 3rd generation system, like UMTS, will need to handle more and more of data transmission and multimedia. This, in contrast to pure speech system, adds high demands on the quality. Typical data services require very low error rates. Over a radio channel that experiences a lot of problems we need something to detect errors and correct them. This could be done with the help of retransmission of information that was faulty and/or by adding redundant information to the data. Channel coding is a way to add information to the data so that errors could be detected and corrected. Interleaving is a technique to help the channel coding procedure.

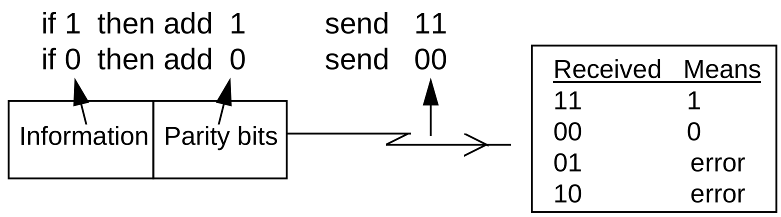
Channel coding

In an analogue network the loss of some information will only decrease the quality somewhat. The ear is able to correct the analogue signals that are slightly incorrect. In a digital network, however, the importance of each bit of information is crucial. The symbol "1" interpreted as a "0" gives a totally different piece of information. The quality of the received signal is often measured in Bit Error Rate (BER). The BER represents what percentage of the bits that are not correctly detected.
Two different methods of channel coding are block coding and convolutional coding. The philosophy of both of them is basically the same; the bits are protected by adding a number of redundant bits to help detect or correct the errors.

<u>Block coding:</u>
When block coding is used, one or several check bits are added to the information block. The check bits only depend on the bits in that very block.

A simple form of block coding is using a parity bit. The parity bit could be set to zero if the 1´s in the block equal an even number. Otherwise the parity bit is set to one, so that the number of 1´s in the total block are always even.

Block coding is mainly used for detecting errors. In the computer world block coding is often used together with a retransmission command, demanding the transmitting part to resend. This is not so useful when dealing with a real time application such as speech.

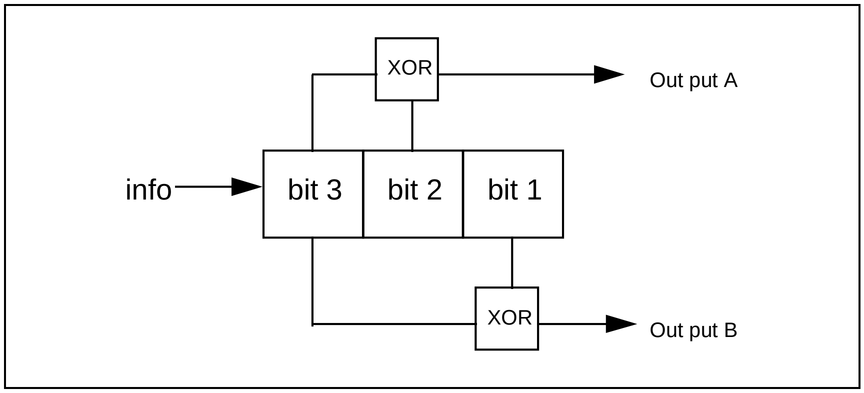


The principle of Block coding

Convolutional coding:

The convolutional coder consists of a shift register into which the information bits are shifted one by one. The coded information bits are produced by doing logical operations on the positions of the bits in the register. This will make several coded bits dependent on one of the information symbols shifted into the coder. When all the information bits are shifted through the register we have produced the coded bits that will be sent.

Convolutional coding is not only good for detecting errors, but also for correcting them. The condition for being able to correct errors is that only few errors appear at a time, with a certain number of correct bits in between the incorrect ones.

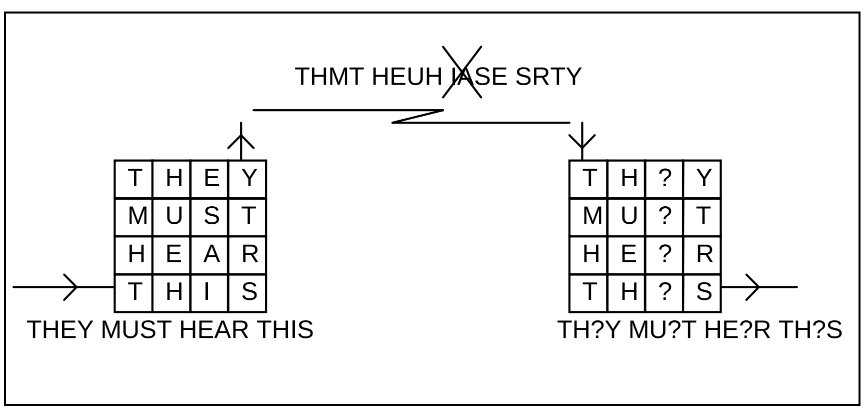


The principle of Convolutional coding

Interleaving

The error detection and correction methods mentioned, work best when the bits lost are spread out at a certain distance.

Interleaving is a method of spreading the potential losses, so that they can be taken care of by ”Channel Coding” thus minimising the harm longer sequences lost. An analogy of this is, if the last 20 pages are torn out of an Agatha Christie novel, it will be more difficult to reconstruct the plot than if every 10th page, totalling 20 pages are lost. As an example, let us assume that each message block contains four symbols. Assume also that it is likely that we loose not only one, but four consecutive symbols in a block. If we re-arrange them so that all number one symbols are put together in one block, all the number two symbols in another, etc., we will loose symbols from several blocks, BUT not one complete block. If only parts of a block are lost, the chance of reconstructing the information improves dramatically.



If the information is regrouped or interleaved, the loss of symbols from a lost burst will be "shared" by several blocks.