NOKIA

GSM Air Interface & Network Planning

Training Document

Contents

1 Transmission

1.1 Introduction to radio and terrestrial transmission

In a mobile communications network, part of the transmission connection uses a **radio link** and another part uses **2 Mbit/s PCM links**. Radio transmission is used between the mobile station and the Base Transceiver Station, and the information must be adapted to be carried over 2 Mbit/s PCM transmission through the remainder of the network.

The radio link is the most vulnerable part of the connection and a great deal of work is needed to ensure its high quality and reliable operation. This will be discussed later in this chapter.

The **frequency ranges** of GSM 900 and GSM 1800 are indicated below:

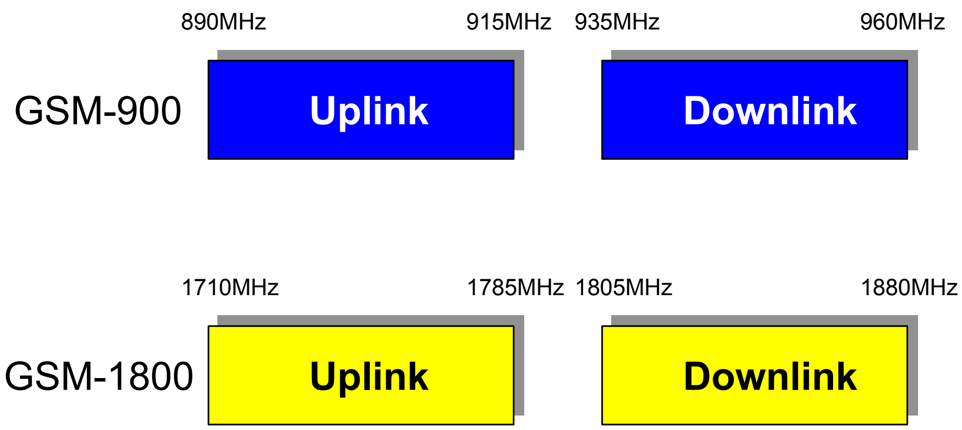


Figure 1. Frequency allocations for GSM

Note that the **uplink** refers to a signal flow **from the Mobile Station (MS) to the Base Transceiver Station (BTS)** and the **downlink** refers to a signal flow **from the Base Transceiver Station (BTS) to the Mobile Station (MS).** The simultaneous use of separate uplink and downlink frequencies enables communication in both the transmit (TX) and the receive (RX) directions. The radio **carrier frequencies** are arranged in pairs and the difference between these two frequencies (uplink-downlink) is called the **duplex frequency.**

The frequency ranges are divided into carrier frequencies spaced at **200kHz**. As an example, the following table shows the distribution of frequencies in GSM 900.

Table 1. GSM 900 frequencies

Channel	Uplink signal (MHz)	Downlink signal (MHz)
1	890.1 – 890.3 (890.2 -centre freq.)	935.1 – 935.3 (935.2 -centre freq.)
2	890.4 (centre freq.)	935.4 (centre freq.)
3	890.6 (centre freq.)	935.6 (centre freq.)
…	...	...
124	914.8 (centre freq.)	959.8 (centre freq.)

In GSM 900, the duplex frequency (the difference between uplink and downlink frequencies) is 45 MHz. In GSM 1800 it is 95 MHz. The lowest and highest channels are not used to avoid interference with services using neighbouring frequencies, both in GSM 900 and GSM 1800.

The total number of carriers in GSM 900 is 124, whereas in GSM 1800 the number of carriers is 374.

The devices in the Base Transceiver Station (BTS) that transmit and receive the radio signals in each of the GSM channels (uplink and downlink together) are known as **Transceivers (TRX).**

The radio transmission in GSM networks is based on **digital** technology. Digital transmission in GSM is implemented using two methods known as **Frequency Division Multiple Access (FDMA)** and **Time Division Multiple Access (TDMA).**

Frequency Division Multiple Access (FDMA) refers to the fact that each Base Transceiver Station is allocated different radio frequency channels. Mobile phones in adjacent cells (or in the same cell) can operate at the same time, but are separated according to frequency. The FDMA method is employed by using multiple carrier frequencies, 124 in GSM 900 and 374 in GSM 1800.

Time Division Multiple Access (TDMA), as the name suggests, is a method of sharing a resource (in this case a radio frequency) between multiple users, by allocating a specific time (known as a **time slot**) for each user. This is in contrast to the analogue mobile systems where one radio frequency is used by a single user for the duration of the conversation. In Time Division Multiple Access (TDMA) systems each user either receives or transmits bursts of information only in the allocated time slot. These time slots are allocated for speech only when a user has set up the call. Some timeslots are, however, used to provide signalling and location updates etc. between calls.

Figure 2 illustrates the TDMA principle.

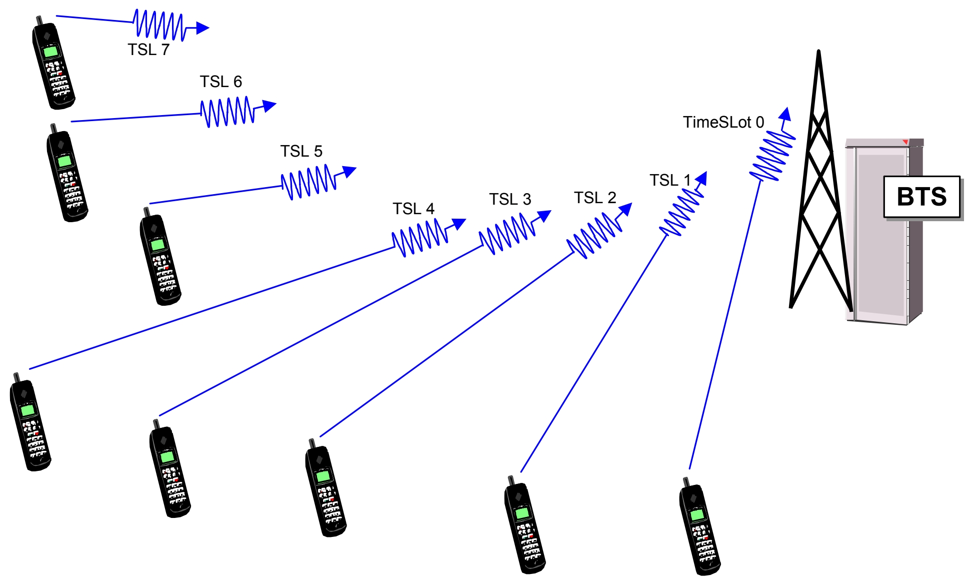


Figure 2. Time Division Multiple Access principle

GSM uses digital techniques where the speech and control information are represented by 0s and 1s. How is it possible to transmit digital information over an analogue radio interface?

The digital values 0 and 1 are used to change one of the characteristics of an analogue radio signal in a predetermined way. By altering the characteristic of a radio signal for every bit in the digital signal, we can "translate" an analogue signal into a bit stream in the frequency domain. This technique is called **modulation**. Analogue signals have three basic properties: amplitude, frequency and phase. Therefore, there are basically three types of modulation processes in common use:

- **amplitude modulation**
- **frequency modulation**
- **phase modulation.**

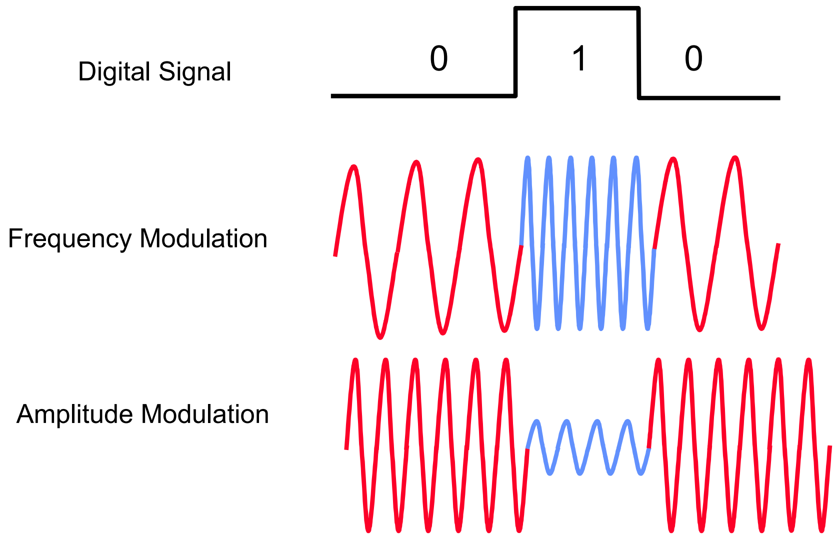


Figure 3. Examples of frequency and amplitude modulation

GSM uses a phase modulation technique over the air interface known as **Gaussian Minimum Shift Keying (GMSK)**. In order to understand how it works, let us take a simple example.

In the GSM air interface, the bit rate is approximately 270 Kbits/s (this will be explained later). At this bit rate, the duration of one bit is **3.69 µs**, that is, the value of the bit requires 3.69 µs of transmission time. GMSK changes the phase of the analogue radio signal depending on whether the bit to be transmitted is a 0 or a 1.

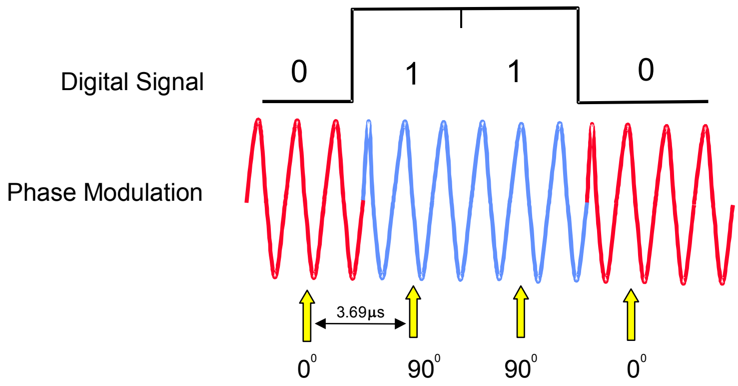


Figure 4. Example of phase modulation

The radio air interface has to cope with many problems, such as variable signal strength due to the presence of obstacles along the way, radio frequencies reflecting from buildings, mountains etc. with different relative time delays and interference from other radio sources.

With such levels of interference, complex equalisation techniques are required with GMSK.

1.2 Transmission through the air interface

To enable us to understand the principles of the air interface, let us imagine that an army has to be moved from one place to another, and a convoy of vehicles is set aside to do the job. The army consists of soldiers and officers.

Each vehicle has eight seats and, therefore, only eight people can be carried in each vehicle.

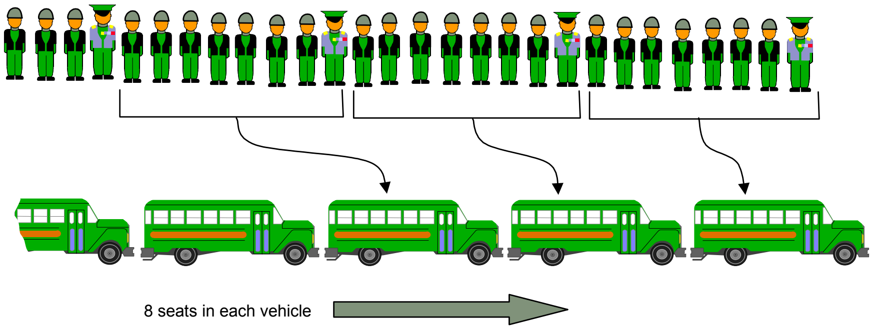


Figure 5. A small logistical problem

Obviously, the only solution is to divide the army into groups of eight people. One officer and seven soldiers are allocated to each vehicle. The officer sits in the front seat and seven soldiers sit in the others.

There are different types of people in the army, soldiers and officers. These could be referred to as **"logical"** differences, as they are all human beings, but their functions are different. In addition, there can be many different ranks of officers, each one with different responsibilities.

To move them from one place to another, a **"physical"** connection is employed, that is, the vehicles and the seats.

1.2.1 Physical and logical channels

Time Division Multiple Access (TDMA) divides one radio frequency channel into consecutive periods of time, each one called a **"TDMA frame".** The TDMA frame can be compared to the vehicle in our example.

Each TDMA frame contains eight shorter periods of time known as **"timeslots".** These timeslots can be compared to the seats in the vehicle. The TDMA timeslots are called **"physical channels",** as they are used to physically move information from one place to another.

The radio carrier signal between the mobile station and the BTS is divided into a continuous stream of timeslots, which in turn are transmitted in a continuous stream of TDMA frames - like a long line of vehicles with eight seats in each.

If the time slots of the TDMA frame represent the physical channels, what about the contents? The contents of the physical channels – that is, the soldiers and officers travelling in the eight seats of the vehicle, according to their roles, are called **"logical channels"**. In the example of the army, the soldiers are one type of logical channel and the officers are other types of logical channels, and they exercise some kind of control depending on their responsibilities.

In GSM, the logical channels can be divided into two types:

- **dedicated channels**
- **common channels.**

Let us look at things in a more practical way: a subscriber switches on his mobile phone and receives a call. This simple act of switching on the phone involves the following steps:

1. The mobile scans all the radio frequencies and measures them.
2. It selects the frequency with the best quality and tunes to it.
3. With the help of a synchronisation signal in a TDMA frame, the mobile synchronises itself to the network.

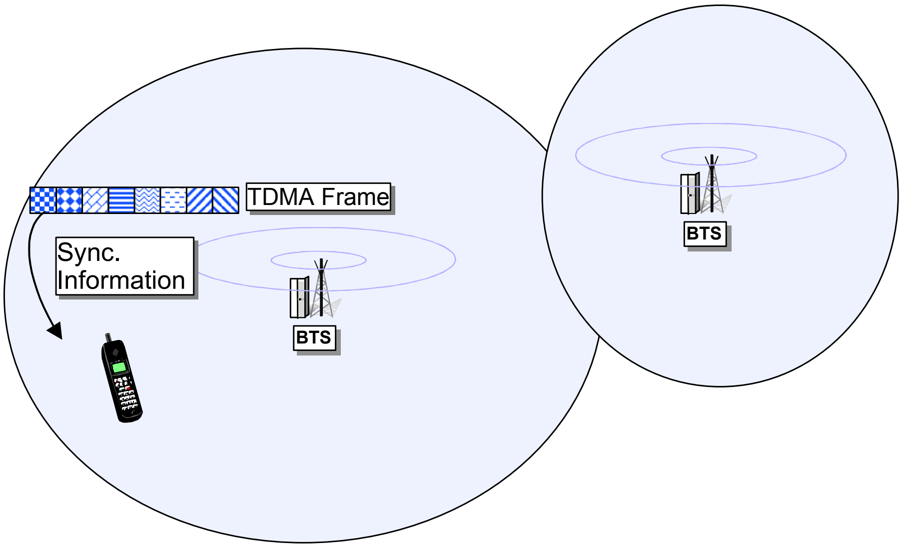


Figure 6. Tuning into the network

The synchronisation information required by this process is **broadcast by the network** and analysed by the mobile.

Registration and authentication are the next steps and they consist of the following operations:

1. A point to point connection must be set up. The mobile station makes a request for a channel to establish the connection.
2. The network acknowledges the request and allocates a channel. The mobile receives and reads this information.
3. The mobile then moves to the allocated (dedicated) channel for further transactions with the network. The next steps are registration and authentication.

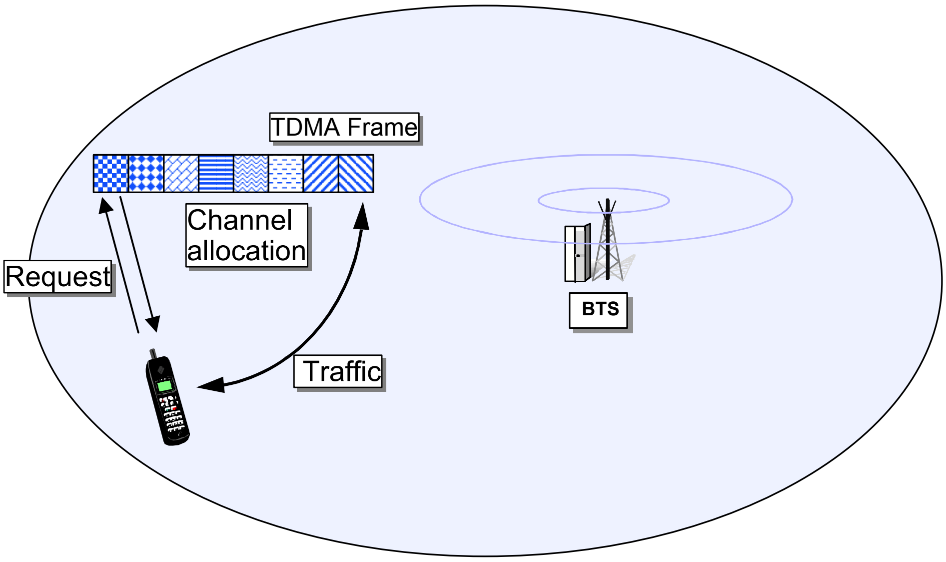


Figure 7. Initiation of a call

Once the subscriber is registered in the network and the authentication is successful, calls can be set up. In the case of a mobile terminated call, the subscriber has to be paged. This process is described below:

1. The network sends a paging message to all the Base Transceiver Stations (BTS) within the **Location Area (LA)** where the subscriber is registered.
2. The mobile station answers the paging message by sending a service/channel request.
3. The network acknowledges this request and again an authentication is needed. A dedicated signalling channel is assigned in order to transmit the data related to the call.
4. A traffic channel is assigned for the conversation.

During the conversation, the mobile measures the signal strength of adjacent carriers and sends measurement reports to the Base Station Controller (BSC). A channel must be dedicated also for this function.

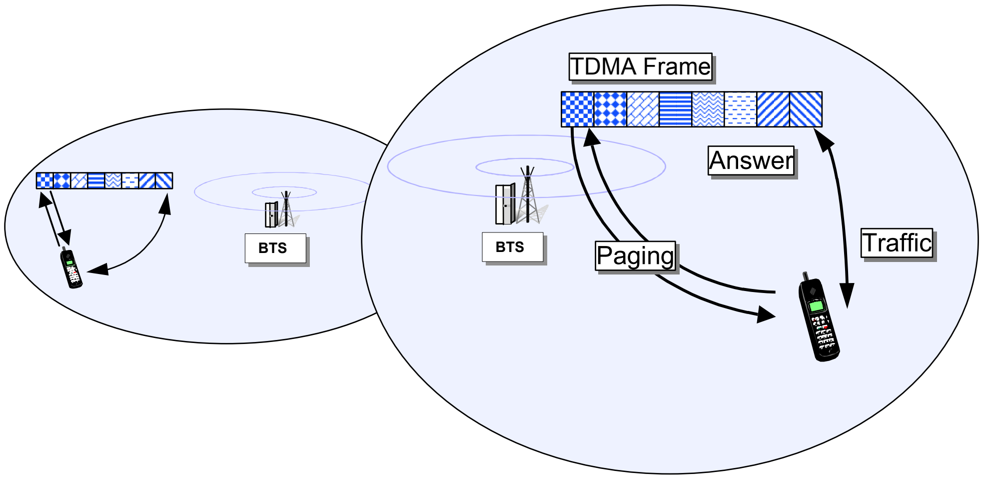


Figure 8. Call completion from the called side

This is a simplified description of the process, but it conveys the idea that there are many functions involved in the air interface to enable a mobile user to have conversation. Each one of these functions requires a separate "logical channel", as the data contents are different. Some of them are **uplink**, others are **downlink** and some are **bi-directional**.

1.2.2 Logical channels

There are twelve different types of logical channels, which are mapped into physical channels in the radio path. Logical channels comprise of **common channels** and **dedicated channels**. Common channels are those that are used for broadcasting different information to mobile stations and for setting up signalling channels between the MSC/VLR and the mobile station.

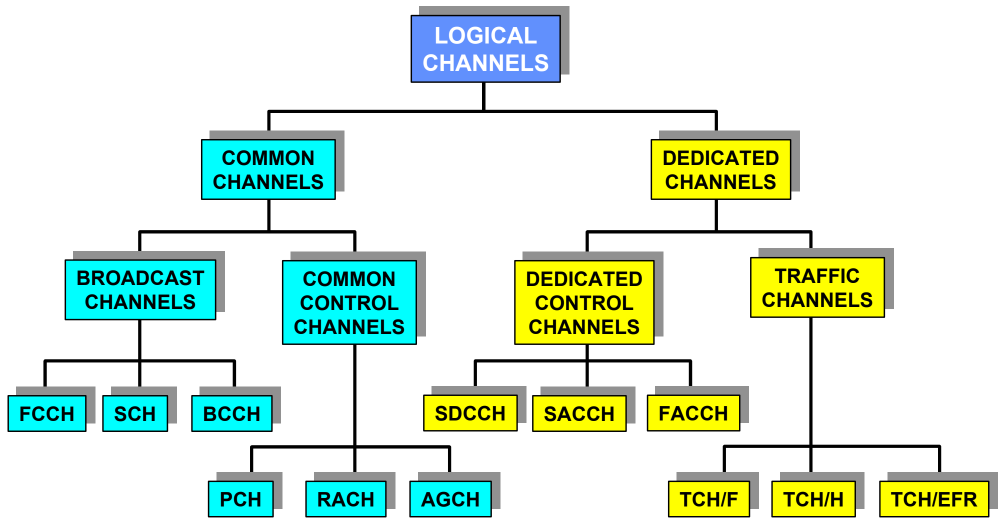


Figure 9. Logical channels

Over the radio path, different types of signalling channels are used to facilitate the discussions between the mobile station and the BTS, BSC and the MSC/VLR. All these signalling channels are called **dedicated control channels.**

Traffic channels are also dedicated channels, as each channel is dedicated to only one user to carry speech or data.

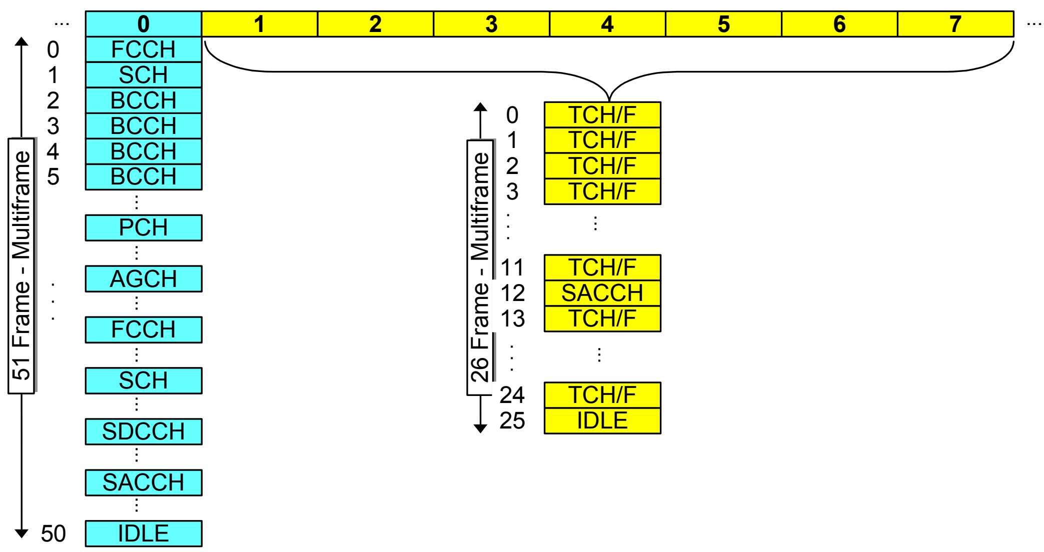


Figure 10. TDMA frames with common and dedicated channels

As seen in the figure above, different logical channels are placed in different timeslots depending on whether they are common channels used by several mobile stations (blue above) or if they are dedicated to a certain mobile station in connection with a call (yellow above).

The only dedicated channel among the blue ones above is the SDCCH. It is used for system signalling during idle periods and also for call set-up before a traffic channel has been allocated (in the example above located in one of the timeslots 1-7).

Furthermore, the common and dedicated channels are grouped in different **multiframes**. The common channels are grouped in a 51 TDMA frame order, and the dedicated channels are grouped in a 26 TDMA frame order. Why this organisation? The reason is that we need to be able to receive and decode common channels along with (but independently of) the dedicated channels used in busy mode.

By multiplying 51 with 26, we can conclude that any TDMA frame number will occur simultaneously in both multiframes every 1326 TDMA frames (which corresponds to 6.12 seconds). Such cycles are called **superframes.**

Let us now take a closer look at the different logical channels and their functions.

1.2.2.1 Broadcast channels

Base stations can use several TRXs, but there is always only one TRX that can carry common channels. Broadcast channels are downlink point-to-multipoint channels. They contain general information about the network and the broadcasting cell. There are three types of broadcast channels:

1. **Frequency Correction Channel (FCCH)**

   FCCH bursts consist of all "0"s that are transmitted as a pure sine wave. This acts like a flag for the mobile stations and enables them to find the TRX among several TRXs, which contains the broadcast transmission. The MS scans for this signal after it has been switched on, since it has no information as to which frequency to use.

2. **Synchronisation Channel (SCH)**

   The SCH contains the Base Station Identity Code (BSIC) and a reduced TDMA frame number. The BSIC is needed to identify that the frequency strength being measured by the mobile station is coming from a particular base station. In some cases, a distant base station broadcasting the same frequency can also be detected by the mobile station. The TDMA frame number is required for speech encryption.

3. Broadcast Control Channel (BCCH)

The BCCH contains detailed network and cell specific information such as:

- **Frequencies** used in the particular cell and neighbouring cells.
- **Frequency hopping sequence**. This is designed to reduce the negative effects of the air interface, which sometimes results in the loss of transmitted information; the mobile station may transmit information on different frequencies within one cell. The order in which the mobile station should change the frequencies is called the "frequency hopping sequence". *(However, implementing frequency hopping in a cell is optional.)*
- **Channel combination**. As we mentioned previously, there are a total of twelve logical channels. All the logical channels except traffic channels are mapped into timeslot 0 or timeslot 1 of the broadcasting TRX. The channel combination informs the mobile station about the mapping method used in the particular cell.
- **Paging groups**. Normally there is more than one paging channel in one cell (describer later). To prevent a mobile from listening to all the paging channels for a paging message, the paging channels are divided in such a way that only a group of mobile stations listens to a particular paging channel. These are referred to as paging groups.
- **Information on surrounding cells**. A mobile station has to know what the cells surrounding the present cell are and what frequencies are being broadcast on them. This is necessary if, for example, the user initiates a conversation in the current cell, and then decides to move on. The mobile station has to measure the signal strength and quality of the surrounding cells and report this information to the base station controller.

1.2.2.2 Common control channels

Common control channels comprise the second set of logical channels. They are used to set up a **point to point connection**. There are three types of common control channels:

1. Paging Channel (PCH)

The PCH is a downlink channel that is broadcast by all the BTSs of a location area in the case of a mobile terminated call.

2. Random Access Channel (RACH)

The RACH is the only uplink and the first point to point channel in the common control channels. It is used by the mobile station in order to **initiate** a transaction, or as a **response** to a PCH.

3. **Access Grant Channel (AGCH)**

   The AGCH is the answer to the RACH. It is used to assign a mobile a **Stand-alone Dedicated Control Channel (SDCCH)**. It is a downlink, point to point channel.

1.2.2.3 Dedicated control channels

Dedicated control channels compose the third group of channels. Once again, there are three dedicated channels. They are used for **call set-up, sending measurement reports and handover.** They are all bi-directional and point to point channels. There are three dedicated control channels:

1. **Stand Alone Dedicated Control Channel (SDCCH)**

   The SDCCH is used for system signalling: call set-up, authentication, location update, assignment of traffic channels and transmission of short messages.

2. **Slow Associated Control Channel (SACCH)**

   An SACCH is associated with each SDCCH and Traffic Channel (TCH). It transmits **measurement reports** and is also used for **power control**, **time alignment** and in some cases for transmitting short messages.

3. **Fast Associated Control Channel (FACCH)**

   The FACCH is used when a **handover** is required. It is mapped onto a TCH and it replaces 20 ms of speech and, therefore, it is said to work in "stealing" mode.

1.2.2.4 Traffic Channels (TCH)

Traffic channels are logical channels that transfer user speech or data, which can be either in the form of **half rate traffic** (5.6 Kbits/s) or **full rate traffic** (13 Kbits/s). Another form of traffic channel is the **Enhanced Full Rate (EFR)** traffic channel. The speech coding in EFR is still done at 13 Kbits/s, but the coding mechanism is different than that used for normal full rate traffic. EFR coding gives better speech quality at the same bit rate than normal full rate. Traffic channels can transmit both speech and data and are bi-directional channels.

1.2.3 Time slots and bursts

We have already seen that the technique used in the air interface is Time Division Multiple Access (TDMA) where one frequency is shared by, at the most, eight users. Consider the example of a 2 Mbit/s PCM signal that can carry 30 speech channels, with each channel occupying 64 Kbits/s. The speech signals from the mobile stations must be placed into a 2 Mbit/s signal that connects the BTS and the BSC.

It is very important that all the mobile stations in the same cell send the digital information at the correct time to enable the BTS to place this information into the correct position in the 2 Mbit/s signal.

How do we manage the timing between multiple mobile stations in one cell? The aim is that each mobile sends its information at a precise time, so that when the information arrives at the Base Transceiver Station, it fits into the allocated time slot in the 2 Mbit/s signal. Each mobile station must send a **burst** (a burst occupies one TDMA timeslot) of data at a different time to all the other mobile stations in the same cell. The mobile then falls silent for the next seven timeslots and then sends the next burst and so on.

It can be seen that the mobile station is sending information periodically. All the mobile stations send their information like this. If we go back to the analogy of the army, the road is the radio carrier frequency, the vehicle is the TDMA frame and the seats in each vehicle are the TDMA timeslots.

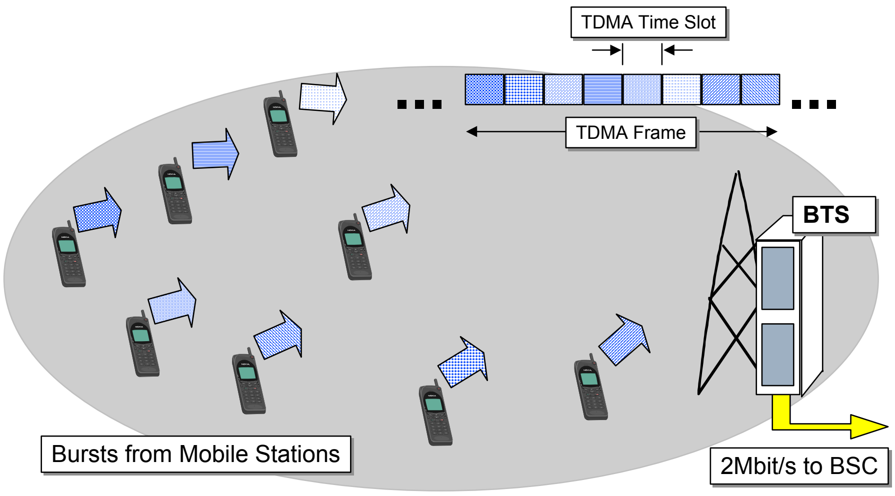


Figure 11. TDMA bursts and timeslots

In the air interface, a TDMA timeslot is a time interval of approximately 576.9 µs, which corresponds to the duration of 156.25 bit times. All bursts occupy this period of time, but the actual arrangement of bits in the burst depends on the burst type. Two examples are:

- **Normal burst**, which is used for the traffic channels, stand alone dedicated channels, broadcast control channel, paging channel, access grant channel, and slow and fast associated control channels.
- **Access burst,** which is used to send information on the Random Access Channel (RACH). This burst contains the lowest number of bits. The purpose of this "extra free space" is to measure the distance between the Mobile Station and the BTS at the beginning of a connection. This

process determines a parameter called **"timing advance"** which ensures that the bursts from different mobile stations arrive at the correct time, even if the distances between the various MSs and the BTS are different. This process is carried out in connection with the first access request and after a handover. A maximum theoretical distance of about 35 kilometres is allowed between the BTS and the MS.

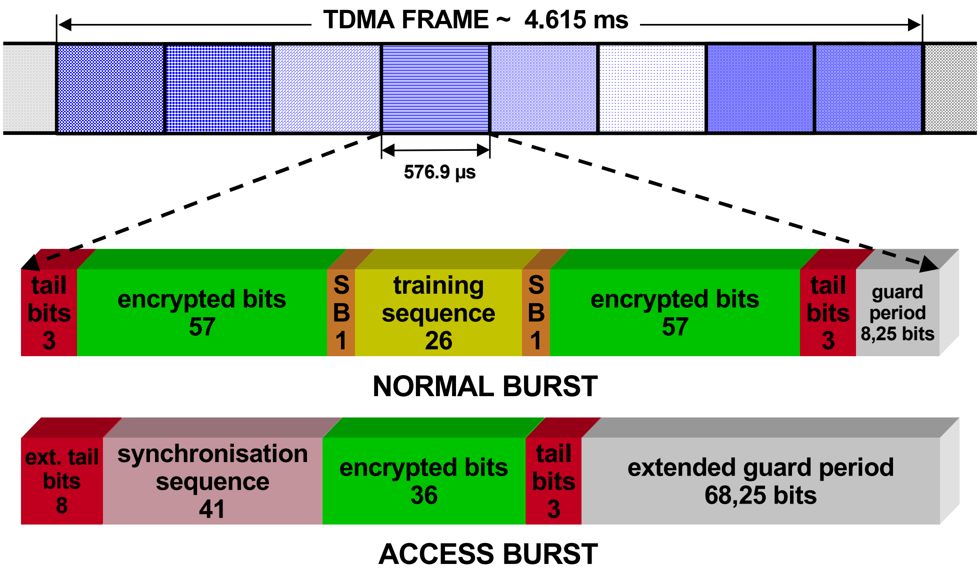


Figure 12. Normal bursts and access bursts

As you can see, the normal burst contains a training sequence and an SB (Stealing Bit). The training sequence is known, which makes it possible to correct bit errors by applying Viterbi Equalisation (see chapter 4.4.1). There are eight different sequence patterns, and the one to be used is determined at the time of call set-up. The stealing bits indicate if the burst contains FACCH (handover) information.

1.3 Problems and solutions of the air interface

It has already been pointed out that the radio air interface link is the most vulnerable part of the GSM connection. In this section we will briefly discuss some of the problems that occur in air interface and some solutions. There are three major sources of problems in the air interface, which can lead to loss of data. These are:

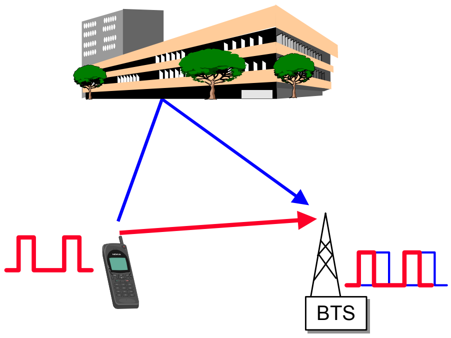
- **multipath propagation**
- **shadowing**
- **propagation delay.**

1.3.1 Multipath propagation

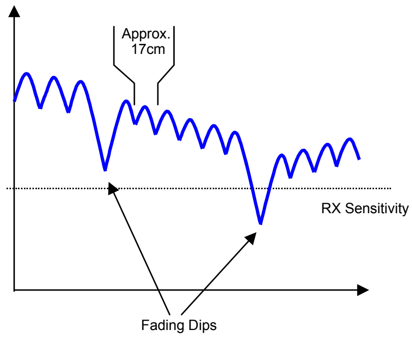
Whenever a mobile station is in contact with the GSM network, it is quite rare that there is a direct "line of sight" transmission between the mobile station and the base transceiver station. In the majority of cases, the signals arriving at the mobile station have been reflected from various surfaces. Thus a mobile station (and the base transceiver station) receives the same signal more than once. Depending on the distance that the reflected signals have travelled, they may affect the same information bit or corrupt successive bits. In the worst case an entire burst might get lost.

Depending on whether the reflected signal comes from near or far, the effect is slightly different. A reflected signal that has travelled some distance causes "inter symbol interference" whereas near reflections cause "frequency dips". There are a number of solutions that have been designed to overcome these problems:

- **Viterbi equalisation**
- **Channel coding**
- **Interleaving**
- **Frequency hopping**
- **Antenna diversity.**



Inter Symbol Interference



Fading dips caused by multipath propagation

Figure 13. The effects of multipath propagation

Viterbi equalisation

Viterbi equalisation is generally applicable for signals that have been reflected from far away objects. When either the base transceiver station or mobile station transmits user information, the information contained in the burst is not all user data. There are 26 bits that are designated for a **"training sequence"** included in each transmitted TDMA burst. Both the mobile station and base transceiver station know these bits and by analysing how the radio propagation affects these training bits, the air interface is mathematically modelled as a filter. Using this mathematical model, the transmitted bits are estimated based on the received bits. The mathematical algorithm used for this purpose is called "Viterbi equalisation".

Channel coding

Channel coding (and the following solutions) is normally used for overcoming the problem caused by fading dips. In channel coding, the user data is coded using standard algorithms. This coding is not for encryption, but for error detection and correction purposes and requires extra information to be added to the user data. In the case of speech, the amount of bits is increased from 260 per 20 ms to 456 bits per 20 ms. This gives the possibility to regenerate up to 12.5% of data loss.

Interleaving

Interleaving is the spreading of the coded speech into many bursts. By spreading the information onto many bursts, we will be able to recover the data even if one burst is lost. (Ciphering is also carried out for security reasons.)

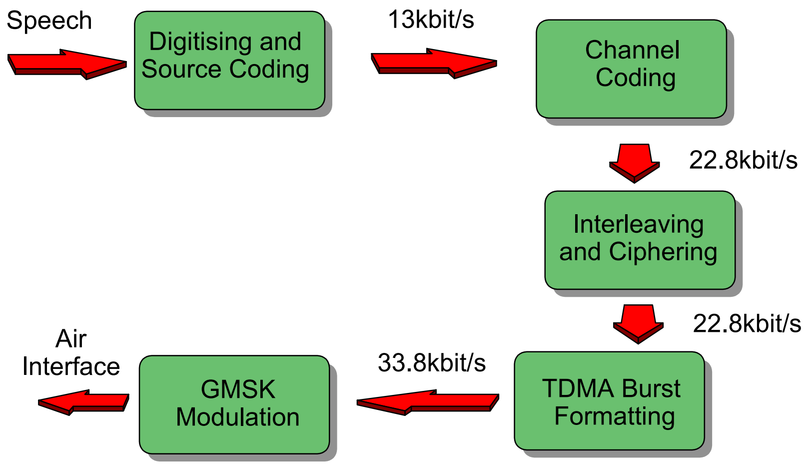


Figure 14. Speech processing in the mobile station

Frequency hopping

With frequency hopping, the frequency on which the information is transmitted is changed for every burst. Frequency hopping generally does not significantly improve the performance if there are less than four frequencies in the cell.

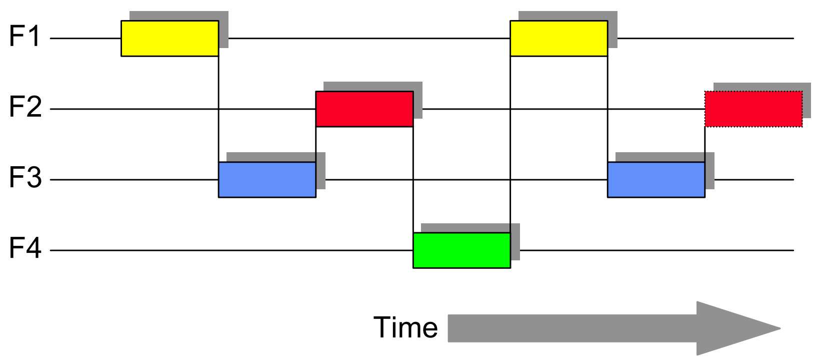


Figure 15. Example of frequency hopping

Antenna receiver diversity

In this case two physically separated antennas receive and process the same signal. This helps to eliminate fading dips. If a fading dip occurs at the position of one antenna, the other antenna will still be able to receive the signal. Since the distance between two antennas is a few metres, it can only be implemented at the Base Transceiver Station.

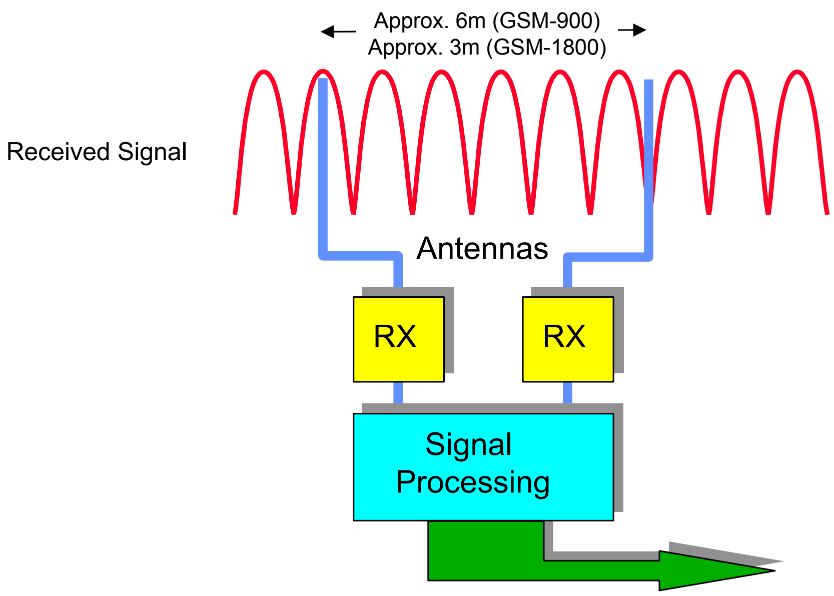


Figure 16. Antenna receiver diversity

1.3.2 Shadowing

Hills, buildings and other obstacles between antennas cause shadowing (also called log normal fading). Instead of reflecting the signal, these obstacles attenuate the signal.

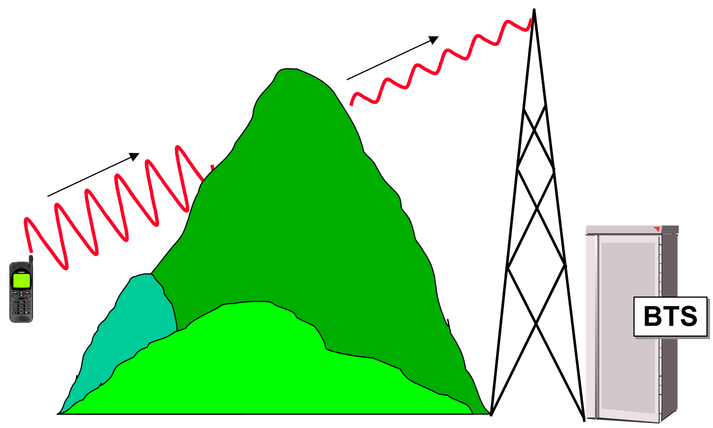


Figure 17. Shadowing effect

Shadowing is generally a problem in the uplink direction, because a Base Transceiver Station transmits information at a much higher power compared to that from the mobile station. The solution adopted to overcome this problem is known as **adaptive power control**. Based on quality and strength of the received signal, the base station informs the mobile station to increase or decrease the power as required. This information is sent in the **Slow Associated Control Channel (SACCH).**

1.3.3 Propagation delay

As you remember, information is sent in bursts from the mobile station to the Base Transceiver Station (BTS). These bursts have to arrive at the Base Transceiver Station so that they can map exactly into their allocated time slots. However, the further away the mobile station is from the BTS, the longer it will take for the radio signal to travel over the air interface. This means that if the mobile station or base station transmits a burst only when the time slot appears, then when the burst arrives at the other end, it will cross onto the time domain of the next timeslot, thereby corrupting data from both sources.

The solution used to overcome this problem is called **"adaptive frame alignment"**. The Base Transceiver Station measures the time delay from the received signal compared to the delay that would come from a mobile station that was transmitting at zero distance from the Base Transceiver Station. Based on this delay value, the Base Transceiver Station informs the mobile station to either advance or retard the time alignment by sending the burst slightly before the actual time slot. The base station also adopts this time alignment in the downlink direction.

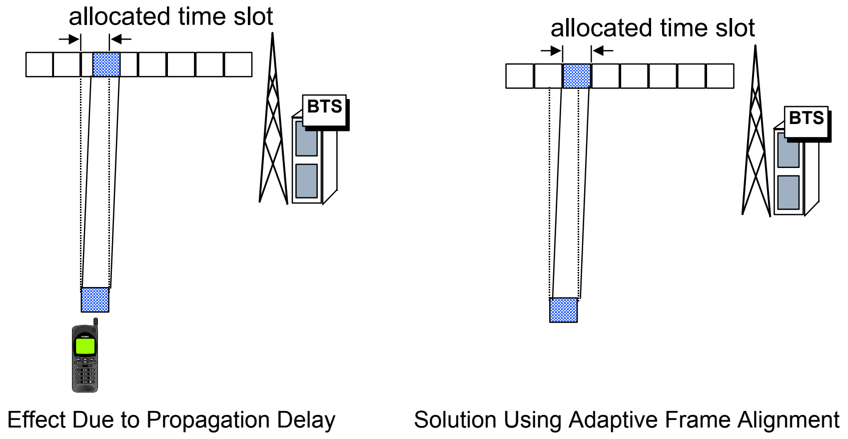


Figure 18. Propagation delay problem and solution

1.4 Terrestrial transmission

So far, we have concentrated solely on the radio link between the Base Transceiver Station (BTS) and the mobile station. Now we are going to follow the signal to the next phase and take a look at the transmission between the other network elements, in particular from the Base Transceiver Station to the Base Station Controller (BSC) and up to the Mobile services Switching Centre (MSC).

1.4.1 Base Transceiver Station

A base transceiver station is a physical site from where the radio transmission in both the downlink and uplink direction takes place. The radio resources are the frequencies allocated to the Base Station. The particular hardware element inside the Base Transceiver Station (BTS) responsible for transmitting and receiving these radio frequencies is appropriately named **"transceiver (TRX)".** A Base Station site might have any number of TRXs from one to twelve. These TRXs are then configured into one, two or three cells. If a BTS is configured as one cell it is called an **"omnidirectional BTS"** and if it is configured as either two or three cells it is called a **"sectorised BTS".**

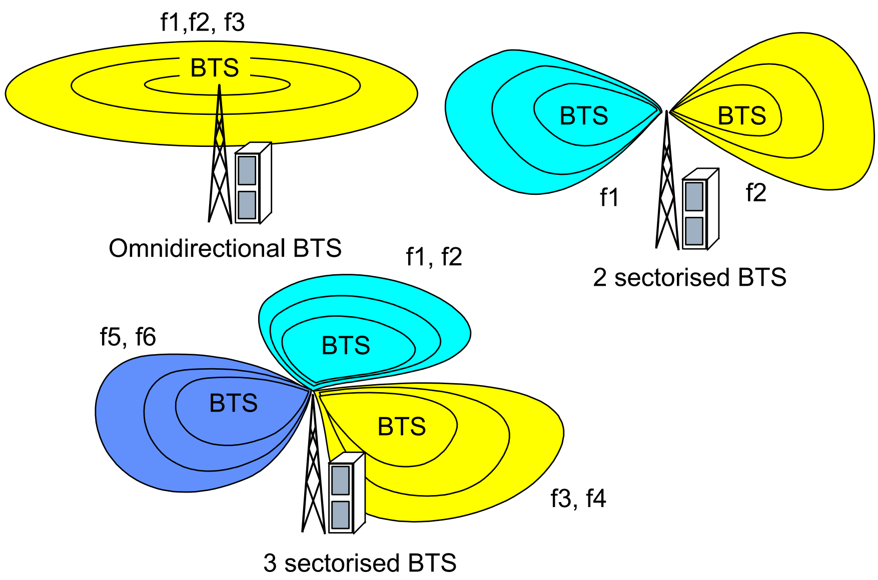


Figure 19. Examples of BTS configurations

1.4.2 Transmission between BSC and BTS

There are three alternative methods to provide the connections between a BSC and several BTSs. The method used will depend on a number of factors, such as the distance between the Base Station Controller (BSC) and the Base Transceiver Station (BTS), the number of TRXs used at a particular BTS site, the signalling channel rate between the Base Station Controller (BSC) and the Base Transceiver Station (BTS). There are three options available: point-to-point connection, multidrop chain and multidrop loop.

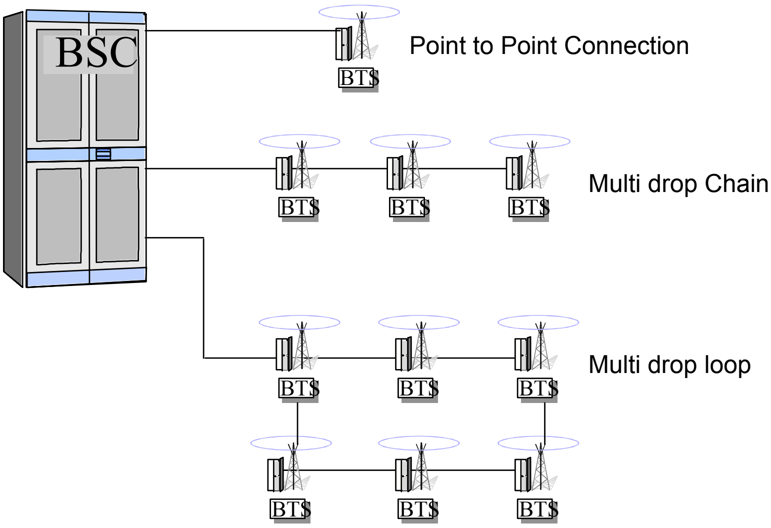


Figure 20. BTS - BSC connections

Point-to-point connection indicates that the Base Station Controller (BSC) is connected directly to every BTS with a 2 Mbit/s PCM line. This is a simple and effective method, particularly in cases when the distance between the BSC and the BTS is short. However, if the BSC - BTS distance is a few kilometres, whereas the distance between a group of BTSs is much shorter, it does not make sense to draw a point-to-point connection to every BTS. One PCM line has ample capacity to transfer data to several BTRs simultaneously. Therefore, it is possible to draw just one BSC - BTS connection and link the BTSs as a chain. This technique is called **"multidrop chain"**. The BSC sends all the data in one 2 Mbit/s PCM line and each BTS in turn analyses the signal, collects the data from the correct timeslots assigned for itself and passes on the signal to the next BTS.

There is, however, one problem with a multidrop chain. Consider what would happen if there is a malfunction somewhere along the line and the chain breaks. More BTSs are isolated and, if the BSC is not informed, it will continue to send data. The solution to this problem is called **"multidrop loop"** and instead of a chain we connect the BTSs in the form of a loop. Previously a dynamic node was needed to split the signal into the two directions around the loop, but later versions of BTS are capable of carrying out this function. The flow of the signal is similar to the signal flow in a multidrop chain, except that a BTS will change the “listening” direction if the signal from one side fails. This ensures that the BTSs always receive information from the BSC even if the connection is cut off at some point in the loop.

1.4.3 The concept of multiplexing

According to GSM 900 and GSM 1800 specifications, the bit rate in the air interface is 13 Kbits/s (full rate, enhanced full rate) and the bit rate in the Mobile services Switching Centre (MSC) and PSTN interface is 64 Kbits/s. This means that the bit rate has to be converted at some point after the signal has been received by the BTS and before it is sent to other networks. But the specifications do not put a constraint as to where exactly the conversion should take place. This brings up some interesting scenarios.

The actual hardware that does the conversion from 13 Kbits/s to 64 Kbits/s and vice versa is called a **transcoder**. In theory, this piece of equipment belongs to the Base Transceiver Station. However, by putting the transcoder at a different place we can take some advantages in reducing the transmission costs.

If the transcoder is placed at the BTS site (in the BSC interface), the user data rate from the BTS to the Base Station Controller (BSC) would be 64 Kbits/s. The transmission for this would be similar to standard PCM line transmission with 30 channels per PCM cable. The same would also apply between the BSC and the MSC.

If we put the transcoder somewhere else, say just after the MSC, we can not get a significant advantage either. This is because, although after transcoding the bit rate reduces to 13 kbit/s, we still have to use the PCM structure to send the traffic channels, with 8 bits per time slot. However, since after transcoding we have a bit rate of 13 Kbits/s and an additional 3 Kbits/s (making 16 Kbits/s) only two bits per time slot will be used. The other 6 bits are effectively wasted. **Error! Reference source not found.** shows these two types of connections.

The additional 3 Kbits/s are used between the transcoder and the BTS for carrying the 260-bit vocoder block (equivalent with 20 ms of speech) and for inband signalling (information about speech coding algorithm, type of call, etc) when a call is connected.

Independent from its actual position, the transcoder belongs to the BSS even if it is placed next to the MSC. (A TC that is placed away from the BTS is called a remote TC according to the GSM recommendations).

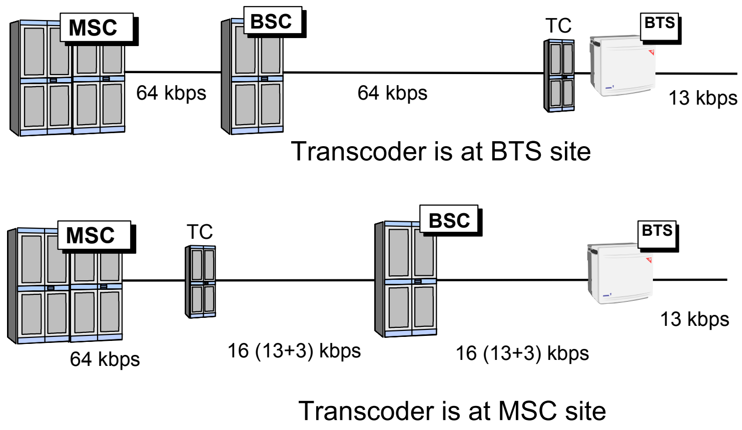


Figure 21. Implementations of the transcoder at different sites

The real advantage, however, comes if we use the second configuration shown in the figure with another piece of hardware called **submultiplexer**. We saw that from the MSC, data comes out at a 64 Kbits/s rate and from the Transcoder it comes out at 16 Kbits/s. Each PCM channel (timeslot) has 2 bits of information. It appears that we are able to put in data from three more PCM lines by multiplexing. Consequently, we are able to multiplex up to four PCM lines and send up to 120 traffic channels in one PCM line from the MSC (transcoder) towards the BSC. (Common Channel Signalling information, OMC data and some other network information are, however, not transcoded) The BSC is able to switch 2 bits per time slot (or 1 bit) to the correct direction. The next figure shows a configuration where 90 traffic channels are multiplexed in one PCM line towards the BSC.

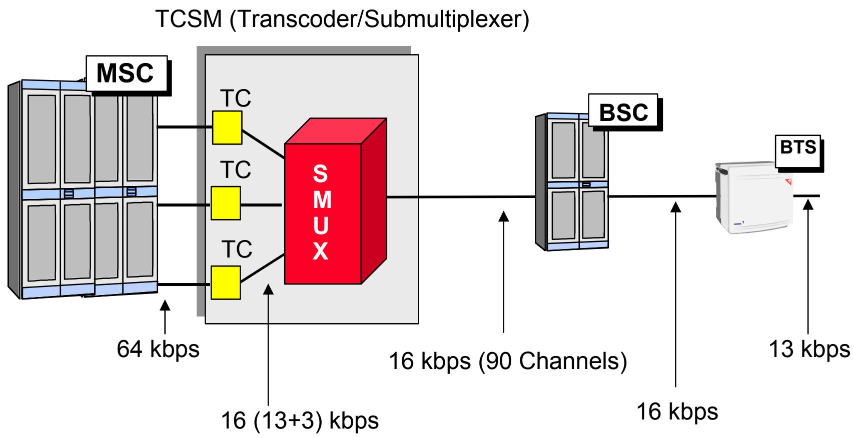


Figure 22. Transcoder and submultiplexer

1.5 Summary of the learning points

- GSM networks use Time Division Multiple Access (TDMA) technology in the air interface. By this method, one frequency resource can be shared by a maximum of eight mobile users.
- There are eight physical channels per frequency in the air interface.
- Logical channels are classified according to the type of information contained within each channel.
- There are eleven logical channels. Two of them are half and full rate traffic channels. The remaining nine are various control channels used to transfer information related to call set-up.
- Information is sent from the mobile station to the Base Transceiver Station (BTS) in intermittent bursts.
- There are four primary types of bursts. normal burst, access burst, synchronisation burst and frequency correction burst.
- There are primarily three sources of problems in the air interface. There is multipath propagation, shadowing and propagation delay. The methods adopted to overcome these problems are viterbi equalisation, channel coding, frequency hopping, interleaving, antenna receiver diversity, adaptive power control and adaptive frame alignment.
- A Base Transceiver Station (BTS) site can be configured as an omni-directional BTS or a sectorised BTS.
- There are three different methods of connecting a Base Transceiver Station (BTS) to the Base Station Controller (BSC): point to point, multidrop chain and multidrop loop.
- The transcoder is placed at the Mobile services Switching Centre (MSC). A transcoder used in conjunction with a submultiplexer makes it possible to multiplex traffic channels from three PCM lines, thereby reducing transmission costs.

2 Network planning and optimisation

2.1 Introduction

The geographical distribution of the subscribers poses a difficult problem for GSM networks. Without wire-connected telephones the subscribers can be virtually everywhere, but still the network must be able to provide a connection in spite of their movements. A good geographical **coverage** is the basis for providing network services. Careful **network planning** is thus a primary aspect of implementing GSM networks. One common misperception is that GSM network planning is the task of selecting and placing out base stations, but this is only one part. Network planning is an ongoing process, which requires inputs from a lot competence areas, such as transmission, access systems, data communications, mobile switching, Intelligent Network, site acquisition, etc.

Several requirements must be taken into consideration already in the early stages of the planning process:

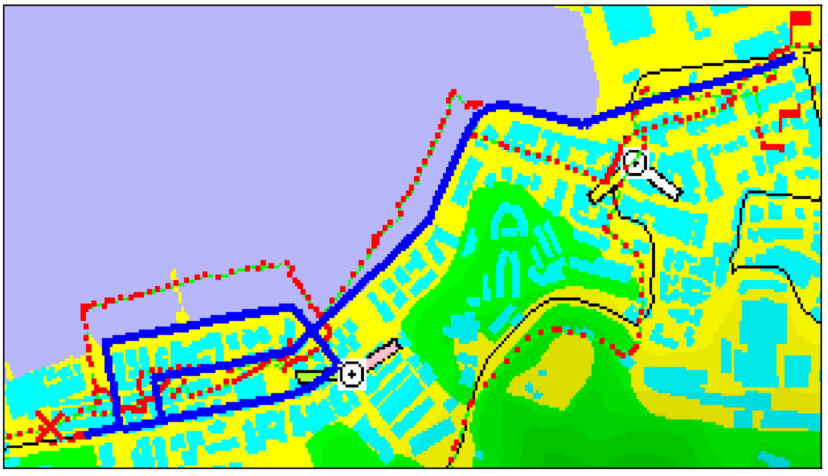


Figure 23. Network planning map

- **Costs** of building the network
- **Capacity** of the network
- **Coverage** and **location** of network elements
- **Maximum congestion** allowed (grade of service)
- **Quality** of calls
- Further **development** of the network.

Various factors that affect the demand for network services must also be considered. These are mostly related to the inhabitants of the area, such as distribution of the population and vehicles, income of the population and statistics on telephone usage.

The main steps of a network planning process are as follows:

1. Collection of all relevant information, for instance:
   - Regulations and laws.
   - Key information concerning, for instance, demography, income level, penetration forecast, geographical extension forecast, services to be supported, market segmentation, etc.
   - Availability of leased lines, microwave frequency availability, required connections with other systems, etc.
   - Numbering, addressing and routing principles.
   - Topographical maps.
   - Existing infrastructure, for example transmission network and transmission media.

   Already in this first planning step, site acquisition management must be involved, as it is necessary to identify the potential sites at an early stage.
2. Network dimensioning based on coverage and capacity requirements. The main objective here is to optimise the network in a cost-efficient way. In order to succeed, detailed information about the network is needed, such as growth estimates, protection, available and needed infrastructure, plus goals for quality and performance. The outcome is an integrated network architecture design that shows how the different services will be implemented and what equipment will be needed. Also, a preliminary rollout plan should be included.
3. Selection of MSC, BSC and Base Station sites (in this order).
4. Survey of intended MSC, BSC and Base Station sites, in other words to evaluate the intended location of each MSC, BSC and BTS. It is important to analyse if the locations fulfil the requirements. Factors to consider when, for instance, making a BTS site survey are the surroundings, possible structural and geographical obstacles and existing radio equipment.
5. Detailed network planning. Computer aided design systems and tools are used for coverage prediction, interference analysis, frequency planning, microwave link planning, documentation etc. In the Nokia implementation, the TOTEM Suite contains tools for managing most of the detailed network planning.

By co-ordinating different information and different competencies, it is possible to prepare a network plan that includes the coverage predictions and the dimensioning of the network.

In the following, we shall take a closer look at three different areas of network planning, namely Switching Network planning, Cellular Transmission Network planning and Radio Network planning. The main purpose is to illustrate the complexity of the planning process. Note also that areas like Fixed Transmission planning, Network Access planning, DCN (Data Communications Network) planning, Intelligent Network planning, 3G and IP Network planning etc., are not covered in this book, but that they also have to be included in the planning process.

2.2 Switching network planning

Switching network planning plays an important role in the process. During the network dimensioning process, there are several important tasks to consider. The switches need to be dimensioned in accordance with the estimated needed capacity, for instance, average conversation time, the need for signalling, such as number of handovers, location updates, short message distribution, etc. In the following, some important issues are presented.

It is necessary to define the network performance level, for instance the intended capacity of the switching network. The implementation of the switching and signalling network must also be considered. Moreover, there is a need to create rules for routing, protection, synchronisation and switch management. Voice and signalling traffic matrixes must be defined, as well as the equipment to be used.

After the network has been dimensioned, a detailed plan is made with a number of inputs, for instance Data Communications Network (DCN) settings towards the NMS, network diagrams, the synchronisation plan, a detailed routing plan, digit analysis, detailed signalling, numbering and charging plans, etc.

In addition to this, the planners must also consider the future expansion plans in order to have a roadmap to the future.

2.3 Cellular transmission network planning

Cellular transmission network refers to the usage of microwave links in the GSM network, for instance between the Base Transceiver Stations and the Base Station Controllers. Usually, the main alternative is to use leased lines, that is, to utilise the already existing fixed infrastructure.

In the network dimensioning phase, a lot of different information has to be collected and co-ordinated. The general transmission network diagram for base stations access and core networks must be drawn, in order to get a clear general picture of the network connections. It is also necessary to define the capacity requirements. Furthermore, rules for the general management of the network are to be defined. Gateway and switching network connections need to be identified, as well as the synchronisation principles for the network. Last, but not least, the future expansion plans must be taken into consideration.

In the detailed planning, a network layout diagram and a management network diagram must be drawn in order to identify how the network is to be implemented. Connections between sites as well as capacities, timeslot allocation of each link, routing diagrams, etc. must be defined. A more exact synchronisation plan with sources and hierarchy is needed.

An essential part of the planning of microwave links is to make sure that it is possible to get free line of sight between different elements (for instance between BTS and BSC sites).

2.4 Radio network planning

The type and location of the BTS depends on the characteristics of the surroundings. In city areas, cells are usually smaller than in the countryside. A larger traffic volume also affects the number of channel frequencies in a certain cell (TRXs).

The maximum theoretical distance from a BTS to the edge of the cell is 35 kilometres. The timing advance is adapted for these distances (that is the ability of the mobile station to send the bursts in advance so that they arrive in the BTS in the right timeslot). One factor that limits the cell size is the wavelength of the frequency. The rule is that the higher the frequency, the smaller the size of the cell. It means that the potential cell coverage in GSM 900 is larger than for 1800 and 1900 networks. Another factor that affects the cell size is the geographical condition. As an example, open water *attenuates* the signal less than for instance forest or city environment. It means that the signal can travel longer distances on open water.

As you can see from the picture below, there are three different types of BTS configurations, omnidirectional, 2 sectorised and 3 sectorised BTSs. The **omnidirectional BTS** has an antenna that transmits and receives 360 degrees. The sectorised (2 sectorised and 3 sectorised) BTSs have (sectorised) antennas, which receive and transmit in certain directions. The 2 sectorised BTS is suitable for, for instance, providing coverage for a highway.

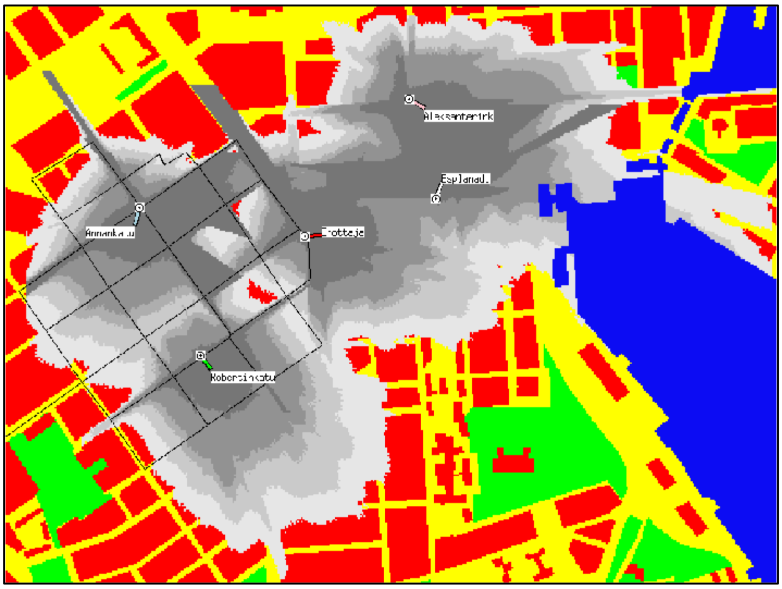


Figure 24. Simulated cellular radio network planning

The omnidirectional BTS is not as popular as the sectorised alternatives. There are mainly two reasons for this. Firstly, the degree of interference is higher than for sectorised BTSs, which in turn restrict the frequency reuse possibilities. Secondly, the gain value is lower than for omnidirectional BTSs. In other words, by using a sectorised antenna the covered distance increases.

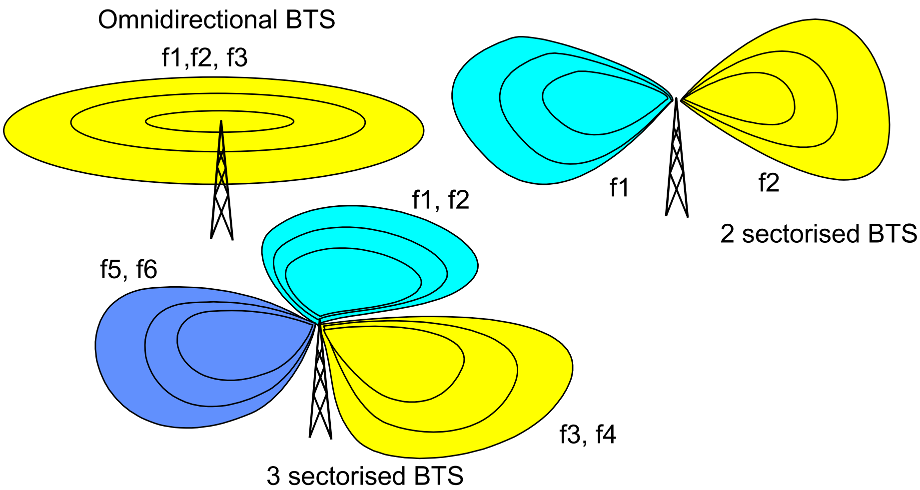


Figure 25. BTS configurations

After all the installation sites have been surveyed, a detailed network plan can be made. This includes the design of a **transmission network** (see for instance chapter 5.4). One important task is to choose between leased lines and microwave links.

After the installation work has been completed, the radio environment has to be **measured and tested** to ensure its proper operation and coverage before putting it into use. This is carried out in the surroundings of each individual site using portable test transmitters.

2.4.1 Dimensioning cells

A **cell** is the basic ‘construction block’ of a GSM network. One cell is the geographical area covered by one BTS. The actual size of a cell depends on several factors: the environment, number of users, etc. Cells are grouped under **Base Station Controllers (BSC).**

Dimensioning a cell means finding answers to two fundamental questions: How many **traffic channels (TCH)** does the cell need to handle and how many traffic channels are necessary? To solve these problems, that is, to determine the traffic capacity, we have to calculate the number of **Erlangs**. Erlang is the measuring unit of network traffic. One Erlang equals the continuous use of a mobile device for one hour. The traffic is calculated using a simple formula:

$$x \text{ Erlangs} = \frac{(\textit{calls per hour}) \times (\textit{average conversation time})}{3600 \text{ Seconds}}$$

The amount of traffic is independent of the observation duration. For example, it is possible to make the observation for only 15 minutes and then, in the formula above, calls per 15 minutes is taken and it is divided by 900 seconds.

The more traffic on available resources, the more chance that there will be congestion on these resources. Network planners carefully analyse the traffic volume on installed traffic channel capacity and, according to quality limits in the network, decide if there is need to install more capacity.

Let us take an example: if there are 540 calls per hour and the average conversation time is 100 seconds, the traffic capacity is 15 Erlangs. After obtaining this value, we must take a look at the **Erlang table**.

Table 2. Erlang B table

Chs	1%	2%	3%	5%
1	0.01	0.02	0.03	0.05
2	0.15	0.22	0.28	0.38
3	0.46	0.60	0.72	0.90
4	0.87	1.09	1.26	1.52
5	1.36	1.66	1.88	2.22
6	1.91	2.28	2.54	2.96
7	2.50	2.94	3.25	3.75
8	3.13	3.63	3.99	4.54
9	3.78	4.34	4.75	5.37
10	4.46	5.08	5.53	6.22
11	5.16	5.84	6.33	7.08
12	5.88	6.61	7.14	7.95
13	6.61	7.40	7.97	8.83
14	7.35	8.20	8.80	9.73
15	8.11	9.01	9.65	10.60
16	8.88	9.83	10.50	11.50
17	9.65	10.70	11.40	12.50
18	10.40	11.50	12.20	13.40
19	11.20	12.30	13.10	14.30
20	12.00	13.20	14.00	15.20

Chs	1%	2%	3%	5%
21	12.80	14.00	14.90	16.20
22	13.70	14.90	15.80	17.10
23	14.50	15.80	16.70	18.10
24	15.30	16.60	17.60	19.00
25	16.10	17.50	18.50	20.00
26	17.00	18.40	19.40	20.90
27	17.80	19.30	20.30	21.90
28	18.60	20.20	21.20	22.90
29	19.50	21.00	22.10	23.80
30	20.30	21.90	23.10	24.80
31	21.20	22.80	24.00	25.80
32	22.00	23.70	24.90	26.70
33	22.90	24.60	25.80	27.70
34	23.80	25.50	26.80	28.70
35	24.60	26.40	27.70	29.70
36	25.50	27.30	28.60	30.70
37	26.40	28.30	29.60	31.60
38	27.30	29.20	30.50	32.60
39	28.10	30.10	31.50	33.60
40	29.00	31.00	32.40	34.60

As you can see, the table also contains the **grade of service (GOS)** figure, which is the maximum congestion allowed. Supposing that GOS is 5 % - which means that during a certain observation period (usually 1 hour) 5 out of 100 calls fail due to lack of resources - the required number of channels is 20. Since each carrier supports eight channels, we can make a rough estimation that this cell must be equipped with three carriers, that is, three **transceivers or TRXs**.

2.4.2 Frequency reuse

Now we have to resolve another problem. There is a limited number of frequencies available to each Base Station Subsystem. These frequencies must be distributed between the cells, so that the capacity requirements are met in different parts of the BSS. Let us make a simplified exercise to illustrate the situation.

You are the network planner and the number of frequencies assigned to this project is 9. Your task is to distribute the frequencies in the network that is shown in the following figure with one frequency per cell.

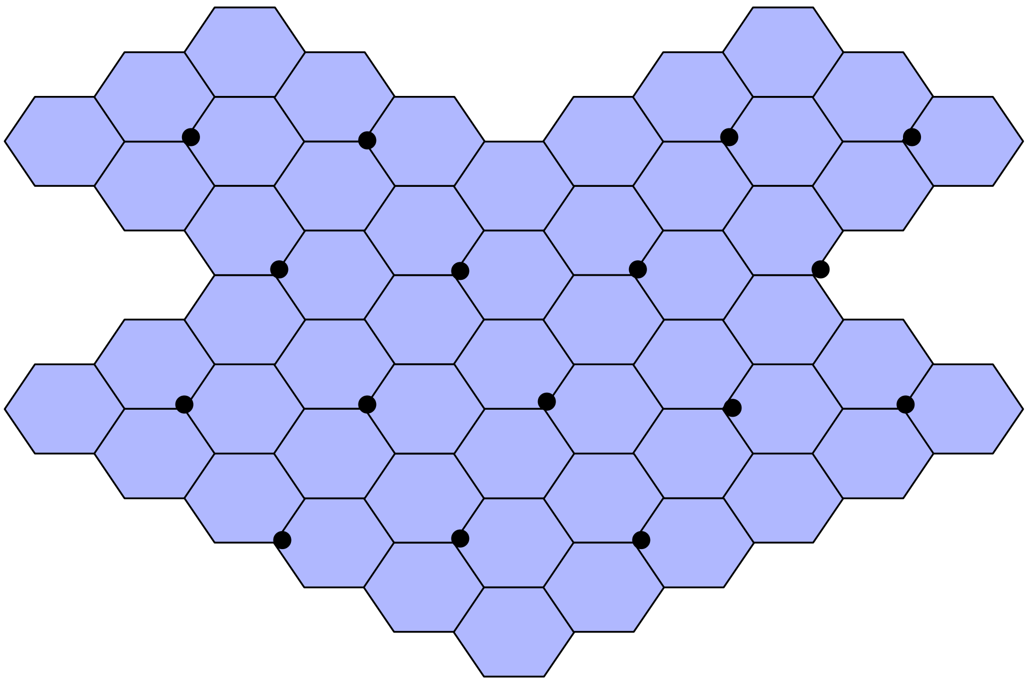


Figure 26. Frequency planning exercise

As you can see, the frequencies have to be **reused**. If you do not distribute the frequencies properly throughout the network, the result will be a high level of **interference** caused by overlapping frequencies. To avoid this, the GSM network includes a specification of the **Frequency reuse patterns.** In the figure below, one of these is presented. Note, however, that cell planning is normally made with the help of a computer based design program.

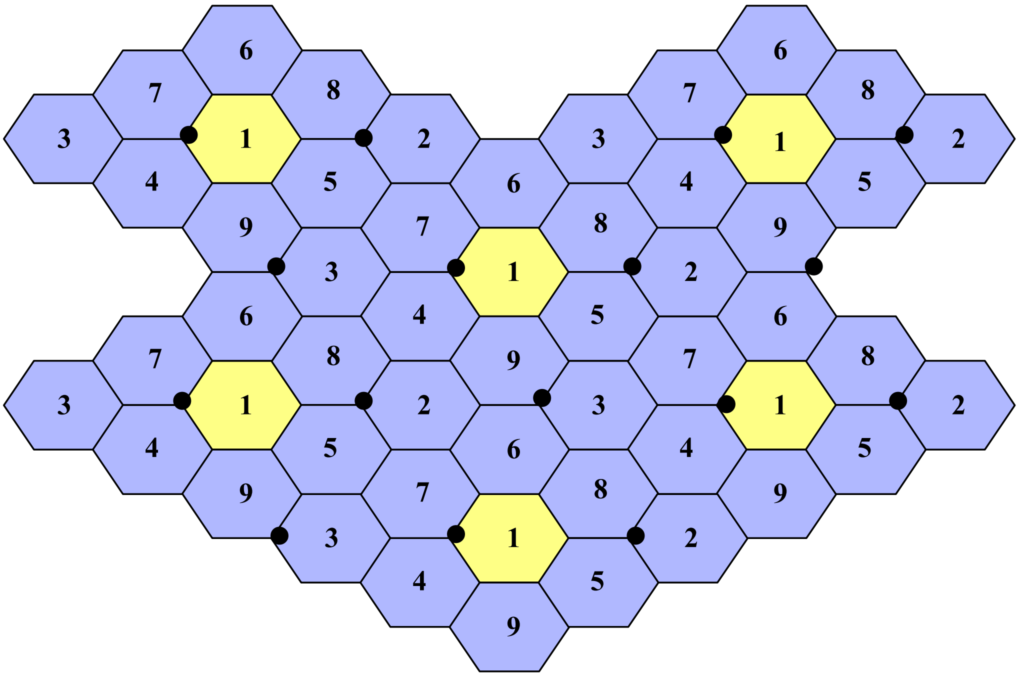


Figure 27. Frequency reuse pattern example

The next step involves the dimensioning of the location areas. This is carried out according to the traffic characteristics of each area. The final phase is the dimensioning of the **fixed network** on the basis of the traffic requirements and dimensioning of the entire radio network.

2.5 Optimising and developing the network

The network planning described so far is only the first part of a continuous process of improving the network performance. In the following, we will discuss the importance of network optimisation and development. Furthermore, different ways of obtaining information about the network are presented.

2.5.1 Why is it important?

The mobile network needs to be monitored continuously, and there are several reasons for this.

Firstly, the increase in the number of subscribers requires network expansion at the right times and places. A favourable cost structure is of major importance for any operator in a competitive marketplace. Therefore, excess network capacity should be avoided. At the same time, it is necessary to offer sufficient **grade of service** (see chapter 5.5.1) to the subscribers. It is certainly a paradox that the network should be large enough (sufficient coverage and quality) and small enough (cost efficient) at the same time.

Secondly, the **quality of service** experienced by the subscribers has to be high. Therefore, it is important to, for instance, reduce the number of dropped calls and the degree of interference in the air interface (in a cost efficient way).

Thirdly, **present and future demand** for basic and supplementary services must be satisfied. Today, large investments are directed towards facilitating higher bit rates for data transmission (High Speed Circuit Switched Data (HSCSD), General Packet Radio Service (GPRS) and Enhanced Data Rates for Global Evolution (EDGE). The reason is that huge growth is anticipated in the demand for wireless data transmission services for the next years to come.

2.5.2 Sources of information

It is obvious that there are several factors to take into consideration when performing network optimisation and development. When we monitor the performance of the network, we can utilise different sources of information. We can obtain a lot of useful information from the Network Management System, and also other performance management tools can be used, for instance Nokia's Traffica monitoring tool. Furthermore, we can perform field-testing in order to identify the performance from the user's point of view. Last, but not least, the subscribers can give us valuable information concerning the experienced quality of service.

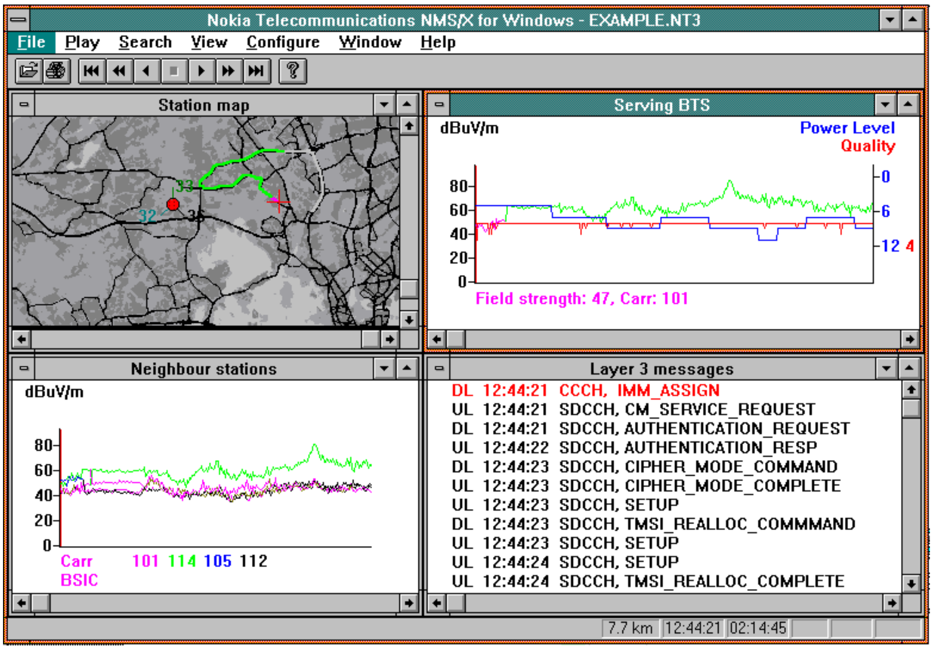


Figure 28. Toolkit Drive survey

There are of course advantages and disadvantages with each of these information sources.

NMS and performance management tools give us valuable information about the different parts of the network, and at least for larger operators, they are relatively inexpensive alternatives. It is also possible to tailor what kind of information to gather, and what kind of reports to produce (for operation and maintenance purposes, for executive reports, etc.). One of the problems with these tools is that they can not fully reflect the quality the way the subscribers experience it.

Field-testing is an excellent way of receiving information in different geographical areas. The findings also reflect the actual quality as perceived by the subscribers. Furthermore, it is possible to monitor the competitors' networks and compare them with the own network. One of the major drawbacks with field tests is that it they are costly processes.

Customers can give valuable information about the network, as their feedback reflects the experienced quality. The subscribers may also discover problems that would not otherwise be identified. It can seem to be an inexpensive way of gathering information, but do consider that large resources are engaged when customer calls are followed up (problem identification and location). In addition to this, low customer satisfaction decreases the success of the operator. Therefore, customer feedback should be regarded as a complementary information source besides NMS/performance management tools and field-testing.

2.6 Summary of the learning points

- Two of the most important factors in planning a GSM network are the **coverage** and **capacity** of the network.
- The demographic data of the intended coverage area plays a major role in network planning.
- Frequencies have to be reused in GSM network according to certain predefined methods.
- Omnidirectional cells are less popular than sectorised due to smaller coverage (lower gain value) and higher degree of interference.
- The required number of traffic channels in a cell is estimated with the help of Erlang's formula of loss and waiting times.
- The network needs continuous monitoring and optimisation, as there are constant changes in both the number of users and technologies. Reliable information sources are NMS/performance management tools and field testing. Additional information can be obtained with the help of subscribers' feedback.