Degree project

Mobile Network Planning and KPI Improvement

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Abstract

In this project, coverage planning in GSM networks as well as capacity and frequency planning has been studied. Various signal interruptions and the necessary steps to remove those interruptions in order to maintain signal quality in mobile communication have been studied. Precautions that should be taken for reducing the effects of interruptions have also been discussed. A drive test has been performed as a part of the improvement process. Guidelines for key performance indicators (KPI) pave the way for radio network quality, coverage and the smooth functioning of the GSM system.

Key words: KPI, GSM, SDCCH, TCH, call drop, drive test.
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1 Introduction

1.1 Thesis approach

The thesis encompasses radio network planning and key performance indicator improvement. A signal that is transmitted by the transmitting antenna (BTS/MS) and received by the receiving antenna (MS/BTS) is affected by a number of factors in the environment. Topics are coverage, capacity and the frequency planning process. Quality indicators such as call setup success and drop rates are considered. Lastly, a drive test has been performed to improve the radio network quality.

1.2 Objective

- Study of the radio network wave propagation effects, and how to remove the fading for GSM system.
- Coverage, capacity and frequency planning in GSM networks.
- Implementation of a drive test of the improvement for GSM system.

1.3 Thesis organization

Chapter 1 introduces the objectives of the thesis. Chapter 2 presents the evolution of cellular networks. Chapter 3 gives a short overview of the process for coverage planning in GSM networks. Chapter 4 relates to the basics of radio network optimisation. Chapter 5 addresses radio access network quality. Chapter 6 concludes and suggests future work that can be done in this field.
2 Evolution of cellular networks

2.1 Introduction to cellular networks

The history of mobile telephony dates back to the 1920s with the use of radio by the police departments in the United States. The first mobile telephony was introduced in 1940 but had a limited capacity and maneuverability. Mobile communications have developed continuously to become the industry that we have today.

2.1.1 1G cellular networks

The trail system of what is today known as the first generation (1G) of cellular networks was implemented in Chicago in 1978 and launched commercially launched in 1983. The technology used in the system was known as an advanced Mobile Phone Service (AMPS) and operated in the 800 MHz band. Japan launched a commercial AMPS system in 1979, and later in 1981, the Nordic Mobile Telephony (NMT) network, operating in the 450 MHz and 900 MHz bands, was launched in the Nordic countries. A modified version of AMPS called Total Access Communications Systems (TACS) was also deployed in the UK in the 900 MHz band. Many countries followed along and mobile communications spread out over the world. 1G systems used Frequency Division Multiplexing (FDM) technology to divide a predefined spectrum into portions named channels. Each channel was able to serve one user at a time. All these technologies formed 1G cellular networks which were offering only analog voice service [1].

The network’s geographical area is divided into small sectors, each called cell. Derived from this concept, the technology was named cellular and the phones were called cell phones. The first generations of cellular networks were incompatible with each other as each network had its own standard. Handsets were expensive and networks had limited capacity and mobility. Moreover, networks had difficulties with frequent use, security, roaming, power and so on. Such drawbacks resulted in a very low penetration of 1G cellular networks and mandated a significant effort to develop the second generation networks.

2.1.2 2G cellular networks

The second generation (2G) of cellular networks was based on digital communications and was first deployed in the early 1990s. The shift from analog to digital technology improved the quality, capacity, cost, power, speed, security and quantity of services. Like 1G cellular networks, several types of technologies were developed for the second generation. Depending
on the multiplexing technique, 2G cellular networks are divided into two main groups: Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA). Global Systems for Mobile communications (GSM) and Interim Standards 136 (IS-136) are key 2G systems based on TDMA and Interim Standards 95 (IS-95) is a famous 2G system based on CDMA. More information on 2G systems is provided in the following.

Global Systems for Mobile Communications:
Other 2G systems were developed in Europe. Despite the introduction of NMT in Europe, there were several incompatible variants of analog 1G systems deployed across Europe. The need for a Pan European digital cellular network was announced during the Conference on European Post and Telecommunications (CEPT) in 1982. CEPT established the GSM organization to harmonize all European systems. Several researches and tests were done by the GSM group before prior to the foundation of the European Telecommunications Standards Institute (ETSI) in the mid 1980s. ETSIs technical groups finalized the first set of specifications of GSM in 1989 and the first GSM network was launched in 1991. Introducing a digital technology, GSM offered new services like Short Message Service (SMS) and moderate Circuit Switch Data (CSD) in addition to a better voice service. GSM rapidly became popular in Europe and was deployed in many countries over the world.

GSM is based on TDMA and operates at 900 MHz and 1800 MHz (850 MHz and 1900 MHz in North America). For the 900 MHz, the uplink frequency band is 935-960 MHz and the downlink frequency band is 890-915 MHz. Thus, the bandwidth for both uplink and downlink is 25 MHz which allows 124 carriers with a channel spacing of 200 KHZ. In GSM, each Radio Frequency (RF) channel caters for 8 speech channels. Techniques like cell sizing and splitting, power control and frequency reuse are applied to increase GSM network capacity [1].

2.1.3 2.5G cellular networks
2G cellular networks were designed based on Circuit Switching (CS) and were capable to offer good voice services, but low CSD rates (up to 14.4 Kbps). By using multiple 14.4 Kbps tile slots, GSM successfully introduced High Speed Circuit Switch Data (HSCSD) which could provide a data rate of 57.6 Kbps. The problem with HSCSD was the reduction in scarce voice channels and this became a motivation to introduce Packet Switching (PS); a
technology for faster data services like Multi Media Service (MMS) and Internet communications. PS technology enhanced 2G cellular networks to 2.5G through adding a PS domain to the existing CS domain. Voice traffic in 2.5G systems uses circuit switching like 2G systems, but data traffic is based on packet switching. Packet switching allocates radio resources on demand, meaning that resources are utilized only when the user is actually sending or receiving data. This allows client use of scarce radio resources and rather than dedicating a radio channel to a mobile data user for a fixed period of time, the available radio resources can be concurrently shared between multiple users. PS technology is known as CDMA2000 one times Radio Transmission Technology (CDMA2000 1xRTT) in CDMA standards which can provide speeds of 144 Kbps. Similarly, in GSM standards, PS technology is known as General Packet Radio Service (GPRS), providing a speed of 171 Kbps. GPRS uses Gaussian Minimum Shift Keying (GMSK) as the modulation scheme [1].

As shown in Figure 1, the general architecture of a 2.5G cellular network is composed of a Radio Network and a Core Network. The Radio Network comprises a Mobile Subscriber (MS), a Base Station (BS) and a Base Station Controller (BSC). As mentioned earlier, the 2.5G core network is divided into CS and PS domains from a functional point of view in which the Mobile Switching Center (MSC) performs circuit switching functions in the CS domain, while the Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN) perform packet switching in the PS domain. MSC also connected to the Public Switch Telephony Network (PSTN) switch. GGSN connected to a gateway external data networks (e.g. Internet), respectively. The information about all subscribers, currently administrated by the associated MSC, is stored in the Visitor Location Register (VLR) which
is usually a built-in unit of MSC. Another key NE is the Home Location Register (HLR), acting as a database of subscriber profiles. HLR could perform an identity check for subscribers and mobile handsets if it is equipped with an Authentication Center (AUC) and an Equipment Identity Register (EIR), otherwise these functional formed by separate NEs. The Value Added Services (VAS) such as SMS and mail require integration of additional NEs into the network.

2.1.4 2.75G cellular networks
Enhanced Data Rate for GSM Evolution (EDGE) is an improvement over GPRS data rate by means of an efficient modulation scheme. EDGE uses 8-Phase Shift Keying (8PSK) as modulation scheme and coexists with GMSK that is used for GPRS. EDGE provides a speed of 384 Kbps which is three times more than that of GPRS, but the major advantage of EDGE is its low upgrade cost. The major change is in the software and only minor hardware changes in BS are required to upgrade a 2.5G network to 2.75G [1]. Despite the high data rate in 2.75G cellular networks, they lack higher capacities and global roaming.

2.1.5 3G cellular networks
3G finds application in wireless voice telephony, mobile internet access, fixed wireless internet access, video calls and mobile TV. 3G is required to meet IMT-2000 technical standards, including standards for reliability and speed (data transfer rates).

The following are the most important specifications of IMT-2000:
• Global standard and flexible with the next generation of wireless systems;
• Worldwide roaming;
• High speed packet data rate: 2 Mbps for fixed users, 384 Kbps for pedestrian traffic and 144 Kbps for vehicular traffic.
3 Radio network planning

3.1 Network planning project organization

The network planning project organisation is based on the network planning roll-out process steps. The final target of the network planning roll-out process is to deliver a new network for the operator according to the agreed requirements. The process steps, inputs and outputs will be discussed in more detail later, as well as network planning tasks and deliverables. Here the general frame of the roll-out process will be introduced.

![Network planning project organisation](image)

Figure 2(a) : Network planning project organisation.

The project organization is shown in Figure 2(a). The network planning team has the assistance of the field measurement team. The site proposals are an input for the site acquisition team, which is responsible for finding the actual site locations. Telecom implementation covers installation, commissioning and integration. Installation is the setting up of the base station equipment, antennas and feeders. Commissioning stands for functional testing of stand-alone network entities [2].

3.2 Network planning criteria and targets

Network planning is a complicated process consisting of several phases. The final target for the network planning process is to define the network design, which is then built as a cellular network. The network design can be an extension of the existing GSM network or a new network to be launched. Environmental factors also greatly affect network planning [2].
3.2.1 Network planning process steps

The radio network planning process is divided into five main steps, where four steps are prelaunch and the last one comes after the network has been launched. The flowchart for the network planning process is shown in Figure 2(b). The five main steps are: preplanning, planning, detailed planning, acceptance and optimisation.

3.2.1.1 Preplanning

The preplanning phase covers the assignments and preparation before the actual network planning is started. As in any other business it is an advantage to be aware of the current market situation and competitors. The network planning criteria are agreed with the customer.

Basic inputs for dimensioning are:

- Coverage requirements, the signal level for outdoor, in-car and indoor with the coverage probabilities;
- Quality requirements, drop call rate, call blocking;
- Frequency spectrum, number of channels, including information about possible needed guard bands;
- Subscriber information, number of users and growth figures;
- Traffic per user, busy hour value.

The dimensioning gives a preliminary network plan as an output, which is then supplemented in the coverage and parameter planning phases to create a more detailed plan. The preliminary plan includes the number of network elements that are needed to meet the service quality requirements set by the operator.
3.2.1.2 Planning
The planning phase takes input from the dimensioning, initial network configuration. This is the basis for nominal planning, which means radio network coverage and capacity planning with a planning tool. The nominal plan does not commit certain site locations but gives an initial idea about the locations and also distances between the sites. The nominal plan is a starting point for the site survey, finding the real site locations. The nominal plan is then supplemented when it has information about the selected site locations; as the process proceeds coverage planning becomes completed. The acquisition can also be other inputs, existing site locations or proposals from the operator. The final site locations are agreed together with the radio frequency (RF) team, transmission team and acquisition team. The target for the coverage planning phase is to find optimal locations for BSs to build continuous coverage according to the planning requirements.

The output of the planning phase is the final and detailed coverage and capacity plans. Coverage maps are made in the planned area for final site locations and configurations [2]-[3].

3.2.1.3 Detailed planning
After the planning phase has finished and the site location and configurations are known, detailed planning can be started. The detailed planning phase includes frequency, adjacency and parameter planning. Planning tools have frequency planning algorithms for automatic frequency planning. These require parameter setting and prioritization for the parameters as an input for the iteration. The planning tool can also be utilised in manual frequency planning. The tool uses interference calculation algorithms and the target is to minimise firstly the co-channel interference and also to find as low adjacent channel interference as possible. Frequency planning is a critical phase in network planning. The number of frequencies that can be used is always limited and therefore the task here is to find the best possible solution.

Neighbour planning is normally done with the coverage planning tool using the frequency plan information. The basic rule is to take the neighbouring cells from the first two tiers of the surrounding BTSs: all cells from the first circle and cells pointing to the target cell from the second circle. In the parameter planning phase, a recommended parameter setting is allocated for each network element. For radio planning the responsibility is to allocate parameters such as handover control and power control and define the location areas and set
the parameters accordingly. In case advanced system features and services are in use care
must be taken in parameter planning. The output of the detailed planning phase is the
frequency plan, adjacencies and the parameter plan [2]-[3].

3.2.1.4 Verification and acceptance
In addition to fine-tuning a search is made for possible mistakes that might have occurred
during the installation. Prelaunch optimisation is high level optimisation but does not go into
detail. Network optimisation continues after the launch at a more detailed level. At that point
the detailed level is easier to reach due to growing traffic.
The quality of service requirements for the cellular network, i.e. coverage, capacity and
quality requirements, are the basis for dimensioning. The targets are specified with key
performance indicators (KPIs), which show the target to meet before network acceptance.
Drive testing is used as the testing.

3.2.1.5 Optimisation
As we know that optimisation is a continuous process. All available information about the
network and its status is required as input for the optimisation. Some necessary components
like statistical figures, alarms and traffic have to be monitored carefully. Complaints from the
customers are also a source of input to the network optimisation team. For indicating
potential problems and analysing problem location both network level measurements and also
field test measurements are included in the optimisation process [2].

3.2.2 GSM network planning criteria
The definition of the radio network planning criteria is done at the beginning of the network
planning process.

<table>
<thead>
<tr>
<th>Area type</th>
<th>Coverage threshold</th>
</tr>
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<tbody>
<tr>
<td>Urban</td>
<td>&gt;-75 dBm</td>
</tr>
<tr>
<td>Suburban</td>
<td>&gt;-85 dBm</td>
</tr>
<tr>
<td>In Car</td>
<td>&gt;-90 dBm</td>
</tr>
<tr>
<td>Rural</td>
<td>&gt;-95 dBm</td>
</tr>
</tbody>
</table>

Table 1: Example coverage thresholds.
The coverage targets include the geographical coverage, coverage thresholds for different areas and coverage probability. Examples of coverage thresholds are presented in Table 1. The range for a typical coverage probability is 90–95%. The geographical coverage is case-specific and can be defined in steps according to network roll-out phases. The quality targets are those agreed in association with the customer during network planning. The main quality parameters are called success or drop call rate, handover success, congestion or call attempt success and customer observed downlink (DL) quality. The DL quality is measured according to BER as defined in GSM specifications and mapped to RXQUAL values. Normally downlink RXQUAL classes 0 to 5 are considered as a sufficient call quality for the end user. The target value for RXQUAL can be, for example, 95% of the time equal to or better than 5. Example values for network quality targets are shown in Table 2.

<table>
<thead>
<tr>
<th>Quality Parameter</th>
<th>Target value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Call drop rate</td>
<td>&lt;5%</td>
</tr>
<tr>
<td>Handover success rate</td>
<td>&gt;95%</td>
</tr>
<tr>
<td>Call attempt success rate</td>
<td>&gt;98%</td>
</tr>
<tr>
<td>DL quality</td>
<td>≥RXQUAL 5</td>
</tr>
</tbody>
</table>

Table 2: Typical network quality targets.

3.3 Wave propagation effects and parameters

This signal is exposed to a variety of man-made structures, passes through different types of terrain, and is affected by a combination of propagation environments. All these factors contribute to variation in the signal level and a varying signal coverage and quality in the network. Before we consider propagation of the radio signal in urban and rural environments, we shall look at some phenomena associated with the radio wave propagation itself.

3.3.1 Free-space loss

A signal that is transmitted by an antenna will suffer attenuation during its journey in free space. The amount of power received at any given point in space will be inversely proportional to the distance covered by the signal. This can be understood by using the concept of an isotropic antenna. An isotropic antenna is an imaginary antenna that radiates power equally in all directions. As the power is radiated uniformly, we can assume that a ‘sphere’ of power is formed, as shown in Figure 3 [4].
The surface area of this power sphere is:

\[ A = 4\pi R^2 \]  
(1)

The power density \( S \) at some point at a distance \( R \) from the antenna can be expressed as:

\[ S = \frac{P_t G_t}{A} \]  
(2)

Where \( P_t \), the power is transmitted by the antenna, and \( G_t \) is the antenna gain. Thus, the received power \( P_r \) is,

\[ P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2 \]  
(3)

Where \( G_t \) and \( G_r \) is the gain of the transmitting and receiving antenna, respectively. On converting this to decibels we have:

\[ P_r (dB) = P_t (dB) + G_t (dB) + G_r (dB) + 20 \log\left(\frac{\lambda}{4\pi R}\right) - 20 \log R \]  
(4)

The last two terms in equation (4) are together called the path loss in free space, or the free-space loss. The first two \( (P_t \) and \( G_t \) ) combined are called the effective isotropic radiated power, or EIRP. Thus:
\[ Free \ space \ loss(dB) = EIRP + G_r(dB) - P_r(dB) \]  \hspace{1cm} (5)

The free space loss can then be given as:

\[ L_{dB} = 92.5 + 20 \log f + 20 \log R \]  \hspace{1cm} (6)

Where \( f \) is the frequency in GHz.

Equation (6) gives the signal power loss that takes place from the transmitting antenna to the receiver antenna [4].

3.3.2 Radio wave propagation concepts

Propagation of the radio wave in free space depends heavily on the frequency of the signal and obstacles in its path. There are some major effects on signal behaviour described below.

3.3.2.1 Reflections and multipath

The transmitted radio wave rarely travels in one path to the receiving antenna, which also means that the transmission in a single path so the line-of-sight case (LOS) is an exception. Thus, the signal received by the receiving antenna is the sum of all the components of the signal transmitted by the transmitting antenna [3].

3.3.2.2 Diffraction or shadowing

Diffraction is a phenomenon that takes place when the radio wave strikes a surface and changes its direction of propagation owing to the inability of the surface to absorb it. The loss due to diffraction depends upon the kind of obstruction in the path. In practice, the mobile antenna is at a much lower height than the base station antenna, and there may be high buildings or hills in the area. Thus, the signal undergoes diffraction in reaching the mobile antenna. This phenomenon is also known as ‘shadowing’ because the mobile receiver is in the shadow of these structures.

3.3.2.3 Building and vehicle penetration

When the signal strikes the surface of a building, it may be diffracted or absorbed. If it is to some extent absorbed the signal strength is reduced. The amount of absorption is dependent on the type of building and its environment: the amount of solid structure and glass on the
outside surface, the propagation characteristics near the building, orientation of the building with respect to the antenna orientation, etc. This is an important consideration in the coverage planning of a radio network. Vehicle penetration loss is similar, except that the object in this case is a vehicle rather than a building.

3.3.2.4 Propagation of a signal over water

Propagation over water is a big concern for radio planners. The water acts as a mirror. The reason is that the radio signal might create interference with the frequencies of other cells. Moreover, as the water surface is a very good actor of radio waves, there is a possibility of the signal causing interference to the antenna radiation patterns of other cells.

3.3.2.5 Propagation of a signal over vegetation (Foliage loss)

Foliage loss is caused by propagation of the radio signal over vegetation, principally forests. The variation in signal strength depends upon many factors, such as the type of trees, trunks, leaves, branches, their densities, and their heights relative to the antenna heights. Foliage loss depends on the signal frequency and varies according to the season. This loss can be as high at 20 dB in GSM 800 systems.

3.3.2.6 Fading of the signal

As the signal travels from the transmitting antenna to the receiving antenna, it loses strength. This may be due to the phenomenon of path loss as explained above, or it may be due to interference. Rayleigh fading is caused by the rapid variation of the signal both in terms of amplitude and phase between the transmitting and receiving antennas when there is no line-of-sight. Rayleigh fading is always multipath since it is statistical. The arrival of the same signal from different paths at different times and its combination at the receiver causes the signal to fade. This phenomenon is multipath fading and is a direct result of multipath propagation.

3.3.2.7 Interference

The signal at the receiver antenna can be weak by virtue of interference from other signals. These signals may be from the same network or may be due to man-made objects. However, the major cause of interference in a cellular network is the radio resources in the network. There are many radio channels in use in a network that use common shared bandwidth. As shown in Figure 4
Figure 4: Factors affecting wave propagation: (1) direct signal; (2) diffraction; (3) vehicle penetration; (4) interference; (5) building penetration [4].

3.3.2.8 Co-channel interference

This interference originates from the frequency reuse scheme in the system (specific interference). This scheme permits the same frequency band to be used in different cell, in a planned way, with the objective of increasing the capacity of system [5].

Figure 5: Co-channel interference generated by frequency reuse.
3.4 Coverage planning

3.4.1 Coverage planning in GSM networks

Coverage planning deals with finding optimal locations for base stations that build continuous coverage according to the planning requirements. Especially in the case of coverage limited network the base transceiver station (BTS) location is critical. With a capacity limited network the capacity requirements also need to be considered. Coverage planning is performed with a planning tool including a digital map with topography and morphology information. The model selection is done according to the planning parameters. The coverage prediction is based on the map and the model and therefore the accuracy is dependent on those as well [2].

![Lower tail of the normal probability distribution for the location probability calculation.](image)

Figure 6: Lower tail of the normal probability distribution for the location probability calculation.

The theoretical maximum for the cell size is impossible to achieve in practice. Slow fading reduces the signal level due to obstacles in the signal propagation path. Therefore, the term location probability is introduced to describe the probability of the receiver being able to capture the signal; i.e. the signal level is higher than the receiver sensitivity. In reality there can never be 100% location probability because it is impractical with only a reasonable amount of resources. To determine the location probability a distribution for the received signal has to be defined. The distribution for slow fading is log-normal. This means that the normal distribution shown in Figure 6 is used for logarithmic entities.

Here, $\tilde{r}$ is logarithmic with the mean value $\tilde{r}_m$ and $\sigma$ is the standard deviation in dBs. The standard deviation $\sigma$ depends on the area type and is normally 5–10 dB. The value generally rises in dense areas. The slow fading is described by the normal random variable $\tilde{r}$. 


The location probability corresponds to the upper tail of probability in Figure 6. The probability \( p_{x_0} \) gives the location probability at a certain point when the random variable \( \bar{r} \) exceeds some threshold \( x_0 \):

\[
p_{x_0} = \int_{x_0}^{\infty} \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(\bar{r}-\bar{r}_m)}{(2\sigma^2)}} \, d\bar{r} = \frac{1}{2} \left[ 1 - \text{erf} \left( \frac{x_0-\bar{r}_m}{\sigma\sqrt{2}} \right) \right]
\]

(7)

As indicated in Equation (7) the probability would also be expressed as the lower tail. A practical example of the lower tail probability would be to calculate certain location probabilities at the cell edge; e.g. a 70 % location probability at the cell edge can be calculated by finding the \( x_0 \) value \( x_0 \) value below which the signal can be received with a 30 % probability. The planning target for the location probability is normally 90–95 % over the whole cell area [2].

The location probability, slow fading margin, maximum path loss and cell range are all connected. If the location probability is, for example, 80 % on the cell edge with a certain slow fading margin; to get a higher 95 % location probability the slow fading margin has to be increased, which also has an effect on the maximum allowed path loss. The cell range is dependent on the maximum allowed path loss and therefore improvement in the location probability causes a decrease in the cell range. The cell range leads to the calculation of the coverage threshold, which is the minimum allowed downlink signal strength at the cell edge with a certain location probability. As shown in the equations above, the point location probability is normally calculated for the cell edge. From this an equation can be derived from the area location probability, which can be used for calculation of the cell coverage area probability. The parameter \( F_u \) defines the part of the useful service area when \( R \) is the radius of the whole area with at least a certain threshold \( x_0 \) is logarithmic. The parameter \( \bar{r} \) is again the received signal and \( p_{x_0} \) the probability that the received signal exceeds the threshold \( x_0 \) inside area \( dA \). The equation for the useful service area is

\[
F_u = \frac{1}{\pi R^2} \int p_{x_0} \, dA
\]

(8)

The mean value of the received signal strength \( r \) can be expressed as
\[ r = P_0 - 10 \gamma \log \frac{d}{R} \]  

(9)

for distances \(d\) and \(R\) shown in Figure 7. The average received carrier-to-interference ratio (CIR) is

\[ \bar{r}_m = \alpha - 10 \gamma \log \frac{d}{R} \]  

(10)

Where \(\alpha\) represents the average received CIR. The equation for the cell area location probability is

\[ F_u = \frac{1}{2} \left[ 1 + \text{erf}(a) + e^{(2ab+1)/b^2} \left( 1 - \frac{\text{erf}(ab)}{b} \right) \right] \]  

(11)

![Figure 7: Coverage at the cell edge.](image)

Where

\[ a = \frac{x_0 - \alpha}{\sigma \sqrt{2}} \]  

(12)

\[ b = \frac{10 \gamma \log e}{\sigma \sqrt{2}} \]  

(13)

For the normal case of urban propagation with a standard deviation of 7 dB and a distance exponential of 3.5, a 90 % area coverage corresponds to about a 75 % location probability at the cell edge [2]. The actual network coverage planning is done with a network planning tool using a digital map and a propagation model verified using model tuning measurements. Some of the vendors have their own coverage planning tools, but planning tools are also provided by some specialised tools vendors.
The coverage estimates given in the dimensioning phase produced only very rough figures, because they were based on the hexagonal model. In practice the cells of a GSM network are completely different from theoretical hexagons, the shape and size being dependent on the surrounding area and also the BTS parameters. Example hexagons are shown in Figure 8 and the terms macro, micro and pico cells are explained. In more dense areas smaller cells are used, because the capacity need limits the cell sizes.

3.5 Capacity planning

In the capacity planning phase a detailed capacity per cell level is estimated. The priority task was to select the base station locations and calculate the coverage area using an actual BTS parameter. The capacity allocation is based on these coverage maps and traffic estimates, which can be a separate layer on the map of the planning tool. The coverage dominance map provides the information for the cell borders. As mentioned, the maximum simultaneous usage is the main planning target for the network capacity. The capacity peaks are momentary and therefore define a blocking probability, which is the accepted level for unsuccessful call attempts due to lack of resources. This parameter has already been defined by the customer at the beginning of the planning process. The amount of traffic is expressed in Erlangs, which is the magnitude of telecommunications traffic. An Erlang describes the amount of traffic in one hour [2]:

\[
\text{Erlang} = \frac{\text{number of calls in hour}}{3600 \text{ s}} \cdot \text{average call length} \tag{14}
\]
3.6 Frequency planning

The dilemma of frequency planning is provide the needed capacity/coverage within a limited frequency band. The frequency channels therefore need to be re-used, but it is wise not to increase the interference level. Interference is caused when two network cells use the same channel too close to each other; more precisely this is a co-channel interference situation. When the interfering channels are consecutive there is some neighbour channel interference, but this is less serious. The interference level cannot be high when building a functional network. The interference level increases with high transmission power in a close location [2]. The frequency re-use rate is simplest to explain using a hexagonal model. A set of $N$ different frequencies $\{f_1, \ldots, f_n\}$ are used for each cluster of $N$ adjacent cells. Define coordinate axes, $u$ & $v$, at $30^\circ$ angles. Where $i$ steps in the $u$ direction and $j$ steps in the $v$ direction as shown in figure 9(a).

$$N = i^2 + ij + j^2$$  \hspace{1cm} (15)

The cell shapes are different and cells do not have equal sizes. Therefore the frequency re-use rate is not a constant throughout the network, but varies from one place to another and can also vary between BCCH and TCH layers. The closest distance between the centre’s of two cells using the same frequency (in different clusters) is determined by the choice of the cluster size $N$ and the lay-out of the cell cluster. This distance is called the frequency re-use distance [5]. It can be shown that the reuse distance, normalised to the size of each hexagon, is

$$D = \sqrt{3N}R$$  \hspace{1cm} (16)

To enable maximum capacity, the parameter $N$ should be minimized when the system is operational and fulfilling the planning requirements.
Figure 9(b): Co-channel interference with hexagonal cells.

The parameter \( q \) is the co-channel interference reduction factor, where a high value of \( q \) corresponds to a small co-channel interference (see Figure 9(b)):

\[
q = \frac{D}{R}
\]

The co-channel interference can be calculated as the ratio of the carrier (\( C \)) to the sum of the interferers (\( I_n \)):

\[
\frac{C}{I} = \frac{C}{\sum_{n=1}^{N} I_n}
\]

where \( N \) is the number of interferers and the received carrier is

\[
C = \alpha d^{-\gamma}
\]

where \( d \) describes the distance between the transmitter and the receiver, \( \alpha \) is a constant and \( \gamma \) is the propagation path loss slope. Interference for the first tier is

\[
\frac{C}{I} = \frac{R^{-\gamma}}{\sum_{n=1}^{N} D_n^{-\gamma}} = \frac{1}{\sum_{n=1}^{N} q^{-\gamma}}
\]

and since all the interferers in the same tier are equally strong one has:

\[
\frac{C}{I_{\text{first tier}}} = \frac{1}{6q^{-\gamma}}
\]

Interference for the second tier is

\[
\frac{C}{I_{\text{second tier}}} \approx \frac{1}{6(2q)^{-\gamma}}
\]

The C/I relation can be improved by reducing transmission power and fine tuning antenna azimuth and down-tilting. All the methods have an impact on the cell coverage area and therefore they need to be used carefully, keeping in mind the coverage targets.
4 Basics of radio network optimisation

As we have seen, radio network planners first focus on three main areas: coverage, capacity and frequency planning. Then follows site selection, parameter planning, etc. In the optimisation process the same issues are addressed, with the difference that sites are already selected and antenna locations are fixed, but subscribers are as mobile as ever, with continuous growth taking place. Optimisation tasks become more and more difficult as time passes. Once a radio network is designed and operational, its performance is monitored. The performance is compared against chosen key performance indicators (KPIs). After fine-tuning, the results (parameters) are then applied to the network to get the desired performance. Optimisation can be considered to be a separate process or as a part of the network planning process (see Figure 10). The main focus of radio network optimisation is on areas such as power control, quality, handovers, subscriber traffic, and resource availability (and access) measurements [4].

![Network planning process](image)

Figure 10: Network planning process.

4.1 Key Performance Indicators (KPI)

For radio network optimisation (or for that matter any other network optimisation), it is necessary to have decided on key performance indicators. These KPIs are parameters that are to be observed closely when the network monitoring process is going on. Mainly, the term KPI is used for parameters related to voice and data channels, but network performance can be broadly characterised into coverage, capacity and quality criteria also that cover the speech and data aspects [4].
4.2 Network performance monitoring

The whole process of network performance monitoring consists of two steps: monitoring the performance of the key parameters, and assessment of the performance of these parameters with respect to capacity and coverage.

As a first step, radio planners assimilate the information/parameters that they need to monitor. The KPIs are collected along with field measurements such as drive tests. For the field measurements, tools are used that can analyze the traffic, capacity, and quality of the calls, and the network as a whole. For drive testing, a test mobile is used. This test mobile keeps on making calls in a moving vehicle that goes around in the various parts of the network. Based on the DCR, CSR, HO, etc., parameters, the quality of the network can then be analysed [4].

4.3 Parameter tuning

The tuning of parameter values is the most sensitive operation for optimisation engineers. It includes extracting parameters, analysing them, finding the appropriate new values and implementing them. As many parameters are interdependent, the tuning cycle never ends. After implementation of new values, monitoring takes place through the observation of statistics and drive tests. According to results, further analysis and tuning is made [2].
5 Radio Access Network Quality Improvement and Guidelines

5.1 Accessibility

Service accessibility is: “The ability of a service to be obtained [6], requested by the user.”

In other words:

\[
\text{Accessibility} = \frac{\text{Total No of Successful Calls Setup}}{\text{Total Calls Accesses to Network}}
\]  \hspace{1cm} (23)

Listed below are the KPIs connected to accessibility.

5.1.1 Paging success rate

The paging success rate measures the percentage of how many paging attempts that have been answered, either as a result of the first or the second repeated page [11].

\[
\text{PSR} = \frac{\text{PSR Time of Paging Responses}}{\text{Time of Paging}}
\]  \hspace{1cm} (24)

Possible reasons for poor Paging Performance could be:

- Paging congestion in MSC, BSC and MSC
- Poor paging strategy
- Poor parameter setting
- Poor coverage and high interference.
5.1.2 SDCCH access success rate.

SDCCH access success rate is a percentage of all SDCCH accesses received in the BSC. Possible reasons for poor SDCCH access performance could be [8]-[9]:

- Too high timing advance (MHT)
- Access burst from another co-channel, co-BSIC Cell
- Congestion
- False accesses due to high noise floor
- Unknown access cause code.

5.1.3 SDCCH drop rate

The SDCCH drop rate statistic compares the total number of RF losses (while using an SDCCH), as a percentage of the total number of call attempts for SDCCH channels [11].

\[
SDCCH \ Drop \ Rate = \frac{SDCCH \ Drops}{SDCCH \ Successes} \tag{25}
\]

Possible reasons for SDCCH RF Loss Rate could be [9]:

- Low signal strength on down or uplink
- Poor quality on down or uplink
- Too high timing advance
- Congestion on TCH.

5.1.4 Call setup success rate

The call setup success rate measures successful TCH assignments of total number of TCH assignment attempts [11].

\[
CSSR = 1 - (SDCCH \ CR)(TCH \ ASR) \tag{26}
\]

\[
CSSR = \left(1 - \frac{SDCCH \ Overflows}{SDCCH \ Call \ Attempts}\right)(1 - TCH \ CR)(1 - TCH \ ASR)100 \tag{27}
\]

* CR is congestion rate.

* ASR is assignment success rate.

Reasons for low call setup success rate could be [7]-[8]:

- TCH congestion
- Interference and poor coverage
5.1.5  Call setup TCH congestion rate

The call Setup TCH congestion rate statistic provides the percentage of attempts to allocate a TCH call setup that was blocked in a cell [11].

\[
Call \ Setup \ TCH \ Congestion \ Rate = \frac{\text{No of TCH Blocks (Excluding HO)}}{\text{No of TCH Attempts}} \tag{28}
\]

Possible reasons for call setup block could be [10]:

- Increasing traffic demand
- Bad dimensioning
- High antenna position
- High mean holding Time (MHT)
- Low handover activity
- Congestion in surrounding cell.

5.2  Retainability

The service retains ability is “The ability of a service, once obtained, to continue to be provided under given conditions for a requested duration.” In other words:

\[
Retainability = \frac{\text{Total Calls Completed}}{\text{Total Successful Call Setup}} \tag{29}
\]

Listed below are the KPIs connected to retain the ability.

5.2.1  Call drop rate

This KPI gives the rate of drop call. percent of TCH dropped after TCH assignment complete

\[
CDR = \frac{\text{Total TCH Drops}}{\text{TCH Normal AS + Incoming DR + Incoming HO Successes HO Successes Outgoing HO Successes}} \tag{30}
\]

*DR is directed retry [11].

*AS is assignment success

Possible reasons for TCH Drop Call Rate could be [9]-[10]:

- Low signal strength on down or uplink
- Lack of best server
- Congestion in neighboring cells
• Battery flaw
• Poor quality on down or uplink
• Too high timing advance
• Antenna problems
• Low BTS output power
• Missing neighboring cell definitions
• Unsuccessful outgoing handover
• Unsuccessful incoming handover.

5.2.2 Handover success rate
The handover success rate shows the percentage of successful handovers of all handover attempts. A handover attempt is when a handover command is sent to the mobile [11].

HOSR
Possible reasons for the poor handover success rate could be [8]-[9]:

• Congestion
• Link connection
• Bad antenna installation
• The MS measures signal strength of another co-or adjacent cell than presumed
• Incorrect handover relations
• Incorrect locating parameter setting
• Bad radio coverage
• High interference, co-channel or adjacent.
5.3 Practical example solution

Figure 12: Before: Costal Office 3/6 overshooting.
At this site previous tilt was 0/0/0 and after rectification present tilt is 0/0/2. This reduces ping-pong handover which improves voice quality.

Figure 13: After: Costal office.
Before Activity: KUET to Doulotpur Exchange handover relation needs to check which leads to interference and abnormal call drop.

Figure 14: After creating handover between KUET and Doulatpur Exch it reduces call drop and interference.

Figure 15: After activity: handover relation created between KUET and Doulatpur Exch.
Probability the Jessore office Encircle area was sector swap.

Figure 17: After activity: Jessore office 2/5.
Figure 18: Before activity Jessore Office 3 (Probability of sector swap).

Need to check jumper cable connectivity, if swap then there is a need to rearrange the Encircle area served by Jessore 3/6. After rearranging the jumper connection, the encircled area is served by Jessore office 1/4. On that side all the jumper cables were connected 120 degrees apart, instead of the standard azimuth.

Figure 19: After activity: Jessore office 2/5.
6 Conclusion

The success of GSM network depends on its three factors: coverage, capacity and quality. Capacity is based on an assessment of dropped calls and congestion that has been removed by proper optimisation. Quality has been improved by eliminating interference from both external and internal sources.

A drive test was performed to assess capacity and coverage. The quality of the radio network depends on its coverage, capacity and frequency allocation. Most severe problems in a radio network can be attributed to signal interference, dropped calls and the amount of congestion that optimization has removed. The criteria that were discussed in the radio planning procedure were met and the needed KPI values were attained on completion of the process. As a result, dropped calls, handover, interference and RX levels were all improved.
References


