Radio Network Test Configuration for Maximum Test Coverage

Model based load generation in system verification of a GSM Base Station Controller

Master Thesis in Communication Systems
Staffan Grundberg
LITH-ISY-EX--07/4037--SE
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Master Thesis in Communication Systems, Department of Electrical Engineering, Linköping University

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Abstract

GSM has been developed during more than a decade and has grown to a very complex system. Due to the wide range of functionality, the high capacity and the complexity of the BSC the testing of stability and performance is time consuming. A simulator is needed for these tests as live networks are not available at this stage in the development process. The performance and stability need to be verified for each new release of functionality.

This thesis describes a conceptual model of a GSM network. The conceptual model can be used to configure a simulated radio network and to communicate what is simulated on a conceptual level rather than a detailed level.

The model presented consists of several sub models. The subscriber model describes the actions and movement of subscribers; the cell model describes the radio conditions experienced by a subscriber moving within one cell; and the cell network model describes the geographical and structural properties of the network.

Together the models are used to compose scenarios with the aim to describe varying radio conditions, varying subscriber behavior and varying cell structures. The aim is that different features of the Ericsson base station controller shall be used in the different scenarios. The scenarios represent different parts of a radio network connected to the same base station controller.

Keywords

GSM, BSC, Verification, Radio Network, Radio Propagation
Abstract

GSM has been developed during more than a decade and has grown to a very complex system. Due to the wide range of functionality, the high capacity and the complexity of the BSC the testing of stability and performance is time consuming. A simulator is needed for these tests as live networks are not available at this stage in the development process. The performance and stability need to be verified for each new release of functionality.

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1. Introduction

1.1 Goal
The overall goal of the thesis is to describe a GSM radio network test configuration to be used in load test at BSC System Verification at Ericsson AB in Linköping. The thesis also includes defining requirements on the test configuration.

Describing a complete network configuration is a complex task. Therefore, this thesis is limited to presenting a conceptual model that can be used for describing such a network. The term test configuration is defined in the requirement specification chapter, which also gives a more detailed description of what aspects are focused upon in this thesis.

1.2 Intended reader
The reader of this thesis is assumed to have good knowledge of the GSM and GPRS system. This includes knowledge of telecommunication, cellular and radio concepts such as channel, TDMA, cell, handover and radio propagation.
2. Background

2.1 Context

Ericsson develops mobile communication systems. The most used mobile communication system in the world is GSM and new networks are still rolled out all over the world. GSM is still being enhanced and many operators are evolving their GSM systems towards 3G performance.

The BSC is the node in the GSM network that is responsible for the handling of radio resources and it is developed and tested mainly at Ericsson AB in Linköping, Sweden. New functionality is released for the BSC twice a year. The new functionality in each release is divided into features. The new features are developed and tested one by one in a modular fashion in BSC Design.

There is, however, a need to test the new features in a close-to-realistic network together with old features from previous projects. This is done in BSC System Verification (SV). In this part of the development process the focus is not the features per se but the coexistence with previous features and the impact on the overall system performance and stability.

This kind of testing is preferably done in real networks (i.e. all existing and possible customers of Ericsson) but this is not economically feasible. Therefore, during the many years the Ericsson BSC has been developed, a simulated test environment has been developed alongside. The simulator is developed by the Simulation Products and Solutions (SPS) department. It is used to simulate the surrounding world of the BSC in most parts of BSC SV (see Figure 2).

![Diagram](image)

Figure 1 A simplified view of the parts of the organization and development process which influences the test configuration.

There is one simulated network defined to be used in BSC SV. The overall characteristics and layout of this network is specified by the BSC System department. The specification is used as input for the ETE (Ericsson Test Environment) department when setting up System Test Plants (STPs). The STPs are constituted by a real BSC node, the simulated radio network and other simulated network nodes. The workflow with the involved organizational units at Ericsson is illustrated in Figure 1.
Figure 2 illustrates the test environment in schematic form. The system under test, the real BSC node, is in the center of the picture. The BSC is connected to one or several base transceiver stations (BTSs) via the Abis interface. The BTSs together form the cell network where mobile stations are moving around. The right side of the picture illustrates how the BSC is connected the core network and other telephone or data networks. Note that all other network nodes than the BSC is simulated.

2.2 The new simulator

During 2007 a new simulator was introduced in the load test environment. The new simulator is more sophisticated than the old one. The fundamental difference to the previous simulator is that it allows geographical simulation. That is, the subscribers (mobile terminals) are moving around (geographically) in a simulated world.

One of the problems when designing the network to be used in the simulator has been the lack of consistent models of how the environment affects the condition of the subscriber’s radio channel when moving through the network.

This has meant that all organizations involved in the design and testing of the BSC have been forced to have detailed knowledge of how the simulator works in order to understand under what conditions the BSC is tested. The lack of a common conceptual model of how the radio environment is simulated has led to that defining a radio network to be used in BSC SV is unnecessary difficult and time consuming.

There is also a desire to gain more from the new geographical aspects of the simulator. An example of this is that the testing of traffic regulating features can be made more realistic which would make it possible to give more realistic measures of BSC performance and stability. The features that are responsible of regulating traffic are mostly controlled by measurement reports from the BTSs and MSs in the radio network.
3. Method
The work with this thesis has been divided into several phases, which can be described as:

3.1 Phase 1 - Literature Studies
A literature study of general telecommunication and cellular technology was conducted. The relevant parts of the literature study are presented in chapter 4 “Theoretical background”.

3.2 Phase 2 - Requirements Specification
The next phase was to set requirements and define what aspects of the test configuration to study more in detail. The requirements are based on informal interviews with Ericsson employees and observations of the working methods at Ericsson. The interviews were conducted at Ericsson AB in Linköping and Kista.

3.3 Phase 3 – Model design
A strategy for creating a test configuration which will fulfill the requirements from phase 2 is presented. Here the different models are presented based on the literature studies and the requirement specification.

3.4 Phase 4 – Model implementation
The models presented in phase 3 are used to describe four different scenarios that together form a radio network connected to a single BSC.

3.5 Phase 5 - Analysis and conclusions
The suggested models are analyzed against the requirement specification and the main conclusions are presented.
4. Theoretical background
This chapter presents an overview of the theoretical background necessary to understand the problem area.

4.1 GSM/GPRS Architecture
The GSM system is constituted of a number of network elements or nodes with different responsibilities in the network.

Figure 3 GSM/GPRS architecture
Figure 3 describes an overview of the GSM/GPRS system architecture. The most important nodes are described further below.

- MSC – The Mobile Switching Center is the switching node in the PLMN. G-MSC is an MSC on the border of the PLMN which connects the network to other telephony networks.
- BSC – The Base Station Controller is the node in the network that is responsible for radio resource management, that is a number of BTSs and the MS within the coverage area of the BTS.
- BTS – The Base Transceiver Station is the fixed transmitter and receiver responsible for one cell.
- MS – The Mobile Station is the normally handheld device the subscriber uses to access the network.

4.1.1 Channel concept
The GSM system is based on a mix of frequency (FDMA) and time division multiplexing (TDMA). A physical channel is defined as one timeslot on one frequency carrier. There are 8 timeslots per carrier (see Figure 4).
Logical channels are mapped on top of the physical channels. The three most important logical channels are:

- **BCCH** – Broadcast control channel, transmits control information downlink in the cell
- **SDCCH** – Slow dedicated control channel, control signaling in both uplink and downlink
- **TCH** – Traffic channel, the actual traffic information is sent on this channel

### 4.1.2 Frequency bands

GSM has been developed over the years to operate in several different frequency bands. One network can utilize frequencies from more than one of these bands at the same time. The Ericsson GSM system supports the 800, 900, 1800 and 1900 MHz band. The multiband usage is described further in [12] and [13]. Table 1 lists the most common frequency bands used in GSM.

<table>
<thead>
<tr>
<th>Band</th>
<th>Sub band</th>
<th>Uplink (MHz)</th>
<th>Downlink (MHz)</th>
<th>ARFCN</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSM800</td>
<td></td>
<td>824-849</td>
<td>869-894</td>
<td>128-251</td>
</tr>
<tr>
<td>GSM900</td>
<td>P-GSM</td>
<td>891-915</td>
<td>935-960</td>
<td>1-124</td>
</tr>
<tr>
<td></td>
<td>G1-GSM</td>
<td>880-890</td>
<td>925-935</td>
<td>975-1023</td>
</tr>
<tr>
<td>GSM1800</td>
<td></td>
<td>1710-1785</td>
<td>1805-1880</td>
<td>512-885</td>
</tr>
<tr>
<td>GSM1900</td>
<td></td>
<td>1850-1910</td>
<td>1930-1990</td>
<td>512-810</td>
</tr>
</tbody>
</table>

### 4.2 Radio theory and concepts

#### 4.2.1 Link budget

A link budget expresses how the signal power is affected when traveling from a transmitter to a receiver. The link budget considers the transmitted and received power and all the losses and gains between them. Tabane describes a link budget (in dB) for a radio system in [16].

\[
P_r = P_t + G_t + G_r - L_p - M_f
\]

where
\( P_r \) is the received power
\( P_t \) is the transmitted power
\( G_t \) is the transmitting antenna gain
\( G_r \) is the receiving antenna gain
\( L_p \) is the propagation loss
\( M_f \) is the fading margin

Tabane gives a more detailed description of the losses and gains involved but for this thesis it is enough to state that the received power is dependant on the transmitted power, the gains and losses in the transmitter and the receiver; and the path loss between the transmitter and the receiver. Tabane also states that the propagation loss consists of three factors: the propagation path loss, the fast fade margin and the shadow margin where the fast fade margin compensates for rapid fluctuations in signal strength caused by Rayleigh fading and the shadow margin compensates for the “relatively” slow fluctuations caused by shadow fading.

### 4.2.2 Radio propagation

**Path loss**

The simplest form of path loss model is the traditional free space loss formula.

\[
L = \left( \frac{4\pi df}{c} \right)^2
\]

where

d is the distance in meters
f is the frequency in megahertz
c is the speed of electromagnetic waves

Or more commonly expressed in decibels, distance in kilometers and frequency in megahertz:

\[
L_{db} = 20\log(d) + 20\log(f) + 32.44
\]

where

d is the distance between transmitter and receiver in kilometers
f is the frequency in megahertz

The path loss formula hence describes the radio signal attenuation over distance as the frequency can be considered constant for a given system.

The free space loss formula is however a simplification, a model of an ideal world without obstacles. There are a number of other models partly based on the free space loss formula and adapted after given environmental conditions. Some examples are:

**CCIR Formula** [15]

\[
L_{db} = 40\log(d) - 20\log(h_t, h_r)
\]

where

d is the distance between transmitter and receiver in kilometers
h_t and h_r are the height of the transmitter and receiver

**British Urban Path Loss Formula** [15]

\[
L_{db} = 40\log(d) - 20\log(h_t, h_r) + \frac{f}{40} + 0.18L + 0.34H
\]
where

\( f \) is the frequency in megahertz

\( L \) is the land usage factor as percentage of land area covered by buildings

\( H \) is the terrain height difference between transmitter and receiver

Hata Model [1]

\[
L_{db} = 69.55 + 26.16 \log(f) - 13.82 \log(h_t) - a(h_t) + (44.9 - 6.55 \log(h_t)) \log(d)
\]

where

\( f \) is the frequency in megahertz

\( d \) is the distance between transmitter and receiver in kilometers

\( h_t \) and \( h_r \) are the height of the transmitter and receiver

The Hata model has also been expanded for the use in telecommunication systems. The major improvements are compensation for frequencies above 900 MHz (COST 231 Hata Model [1]) and for short distances urban environments (COST 231 Walfish Ikegami Model [1]).

To conclude, the path loss is often expressed as a function of distance. Various properties of the environment and the transmission system influence the path loss. In the above examples the major influencing properties are the frequency of the transmitted signal, the height of the transmitting and receiving antennas and some assumption of environmental properties (such as houses, obstacles and land elevation).

Slow/shadow fading

All the models above give a reasonable prediction of the mean path loss but the real world is more complex. Often there are obstacles (such as trees, houses or mountains) in the way between the transmitter and the receiver. The concept of shadow fading expresses the effects of this kind of “shadowing” on the signal. Edlund and Ljung give a good description and several mathematical models of the phenomenon in [4]. Their suggested model expresses the shadow fading as lognormal distributed with a given standard deviation. The model is dependant on the speed of the receiver and a so called correlation parameter which expresses how “fast” the shadowing is varying.

Fast/Rayleigh/Rician fading

The second type of fading, often referred to as fast, Rayleigh or Rician fading, is the consequence of multi path propagation. That is, several versions of the signal arrive at the receiver at different moments in time and with different phase. The effect on a moving receiver is a rapidly fluctuating signal, with occasionally very deep dips. [5]

Figure 5 illustrates the phenomena in the time domain for two mobiles using the 1800 band and moving at 6 km/h and 60 km/h.
Edlund and Ljung present models for simulation of this kind of fading in [4]. Their model is dependant on the speed of the mobile, the frequency and a factor known as Rice K-factor. The K-factor determines the power ratio between the direct radio path and the reflected paths.

4.2.3 Interference and noise

The propagation loss described above describes how the wanted signal is deteriorated by phenomena related to the signal itself and the environment. Another aspect of radio communication is the unwanted signals on the frequency used by the channel. These signals are generally referred to as interference if they originate from the same or a similar system or as noise if they originate from outside the system.

Co-channel interference

Co-channel interference is more strictly defined as the interference caused by another transmitter (in the same system) that operates on the same frequency (and possibly timeslot) as the reference transmitter.

Adjacent channel interference

Adjacent channel interference is the interference caused by neighboring frequency channels in the same system.

Noise

Noise is interfering signals that originate from outside of the observed system, for instance other communication systems, heat related electronic noise or electromagnetic phenomena from engines.

4.3 Cellular theory and concepts

4.3.1 Cell concept

Ericsson defines a cell as “the coverage area of one BCCH. In one cell there can be two subcells with the same or different coverage areas”. The cell is served by one BTS and is assigned a set of frequencies. A cell can be omni directional or a directed sector cell. Several BTS at the same location form a site and the cells are called co-sited cells. Figure 6 illustrates a simple cell network with 3 sites with 3 sector cells each.
A classification of cells based on cell size is made in the 3GPP technical report “Radio network planning aspects” [1]. An overview is presented here.

**Large cells**

“In large cells the base station antenna is installed above the maximum height of the surrounding roof tops; the path loss is determined mainly by diffraction and scattering at roof tops in the vicinity of the mobile i.e. the main rays propagate above the roof tops; the cell radius is minimally 1 km and normally exceeds 3 km.” [1]

**Small cells**

“For small cell coverage the antenna is sited above the median but below the maximum height of the surrounding roof tops ... However large and small cells differ in terms of maximum range and for small cells the maximum range is typically less than 1-3 km.” [1]

**Micro cells**

“COST 231 defines a micro cell as being a cell in which the base station antenna is mounted generally below roof top level. Wave propagation is determined by diffraction and scattering around buildings i.e. the main rays propagate in street canyons.” [1]

**4.3.2 Cell selection/Handover/Cell reselection**

When mobile terminals are moving through a cell network the general aim is to provide the best radio condition for the terminal. This is accomplished by the process of cell selection/reselection when the terminal is idle; and handover or cell reselection when the terminal is busy. The distinction between handover and cell reselection is that the handover is governed by the base station controller and the cell reselection by the terminal itself. In GSM the handover process is used for busy circuit switched traffic and the cell selection/reselection is used by idle terminals and busy terminals in packet switched mode (GPRS/EGPRS). [7] [10] [11]
These processes are controlled by the received signal strength. In practice this means that the terminal is always connected to the base station that offers the highest signal strength at the location of the terminal.

### 4.3.3 Overlaid and underlaid subcells

The overlaid/underlaid subcell feature of the BSS allows the definition of two separate coverage areas per cell. One underlaid which is usually larger and a smaller overlaid subcell. The underlaid subcell is limited in size by the normal cell border and other limiting factors of a normal cell. The overlaid subcell, however, is more strictly defined. It is limited either by an absolute measure of path loss from the BTS, an absolute distance (Timing Advance) or a distance to the normal cell border (DTCB). [14]

This subdivision of cells allows an operator to use two different frequency reuse patterns in the network. The overlaid frequency plan can utilize a much tighter reuse distance (relative the underlaid cells).

The subcell concept is illustrated in Figure 7. The figure shows two sites, one omnidirectional and one sectorized with subcell structures defined. Note the limited coverage area of the overlaid subcell.

![Figure 7 Overlaid and underlaid subcells, one omni-directional cell and one three sector site.](image)

### 4.3.4 Hierarchical cell structures

In addition to subcell structures a hierarchical structure has also been implemented in the GSM standard. The general idea is that several different layers of cells can cover the same area. The higher layered, generally larger, cells are used to provide coverage and the lower layered, generally smaller cells, are used to provide capacity in areas with high density of subscribers. [9]

Figure 8 is an illustration of a three layered hierarchical cell structure.
The introduction of hierarchical cell structures (HCS) in a cellular network means that the normal “strongest server” principle is broken. This means that a lower layered cell can serve one terminal even though it provides lower signal strength than a higher layered cell.
5. Requirement specification

This chapter aims at describing the requirements on the model of the test configuration. This chapter is based on interviews with Ericsson employees and observations made by the author at Ericsson.

The interviews were conducted at Ericsson AB in Linköping and Kista. Employees of the departments BSC System, Ericsson Test Environment (ETE), Simulation Products and Solutions (SPS) and BSC System Verification (BSC SV) were interviewed.

The interviews with BSC System aimed at forming system level requirements on the models and to gain further knowledge of the Ericsson BSC and how it is used and configured in real networks.

The interviews with SPS employees aimed at understanding the existing simulation models and performance constraint of the simulator.

ETE and BSC SV interviewees gave practical information on the physical test environment. Together with the observation made by the author these interviews formed the base for the requirements described in the following sections.

5.1 Requirements

The term test configuration is hereby defined to mean:

- The model describing the subscriber behavior (Subscriber model)
- The model describing radio propagation and quality within one cell (Cell model)
- The geographical and structural model of the cell network (Cell network model)
- The configuration parameters of the BSC and each cell (BSC/Cell configuration)
- The hardware configuration

The focus of this thesis is the two bold bullets in the list above; the cell model and the cell network model. This means that the focus is put on traffic and radio network features of the Ericsson BSS. The introduction of geographical aspects in the simulator further narrows the scope of this thesis to features that are mainly controlled by the measurement reports sent to the BSC by the base transceiver stations and the mobile stations.

5.1.1 Coverage

One of the objectives of the test configuration is that it shall cover as much functionality in the BSC as possible. This was given in the original thesis description written by Ericsson [7]. It is however impossible to describe a test configuration that covers all functionality in the BSC. It is even more unrealistic to imagine testing all possible test configurations.

It is also worth noting that the objective of the tests performed in BSC load test is not to test the functionality of the features per se but to make performance and stability measurements in a test configuration where as much as possible of the BSC functionality is used. This should also be made in a close-to-realistic environment.

The model of the test configuration must also allow an analytic approach to determining what is tested. The goal is to have a deterministic but still varying overall system behavior in load test.
Since there are features that are incompatible with each other, irrelevant to use together or are only active under certain conditions it is however necessary to have different scenarios in the test configuration were different features of the BSC are used. For instance there are two versions of frequency hopping and several different Abis interface implementations which cannot or do not make sense to use together.

The requirements in Table 2 where identified.

### Table 2 Summary of coverage requirements

<table>
<thead>
<tr>
<th>COV1</th>
<th>The cell and cell network models shall make it possible to describe a radio network with different radio conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>COV2</td>
<td>The cell and cell network models shall make it possible to describe several different areas with different cell configurations</td>
</tr>
<tr>
<td>COV3</td>
<td>The cell and cell network models shall simplify the process of configuring the cell and BSC parameters as well as determining which and to what extent different features are tested in the test configuration</td>
</tr>
</tbody>
</table>

### 5.1.2 Realism

To obtain realistic figures of BSC performance and stability it is highly relevant to have a test configuration that resembles a real customer network. It is however neither relevant to base the test configuration on only one specific customer network, since this would not satisfy the coverage requirements, nor to base it on all operator networks, since this is not economically feasible.

It is also desirable to have a common cell simulation model that is independent of modulation and coding. This to enhance the realism of co-existence testing of several different systems, such as normal circuit switched traffic and packet switched traffic.

The cell model shall be good enough to use as the base when implementing the cell network model. The models shall also be realistic enough to allow the cell network to be dimensioned and planned according to standard methods.

Another goal is to minimize the required knowledge of how the simulator is working and gain from the fact that it behaves like a real radio network (which behavior can be considered to be known by employees of Ericsson).

The requirements in Table 3 where identified.

### Table 3 Summary of realism requirements

<table>
<thead>
<tr>
<th>REA1</th>
<th>The cell model shall be based on empiric data</th>
</tr>
</thead>
<tbody>
<tr>
<td>REA2</td>
<td>The cell model shall be independent of the modulation and coding technique used</td>
</tr>
<tr>
<td>REA3</td>
<td>It shall be possible to dimension and plan the cell network according to standard methods</td>
</tr>
</tbody>
</table>

### 5.1.3 Communication

As several different organizational units, with different focus and competence areas, at Ericsson are involved in the process of defining the requirements on, implementing and testing the BSC there is a need to easily communicate what aspects of and to what extent different features are used in the test configuration. This raises the requirement that the
models cannot be too complicated and that they shall be possible to use as means of communication among the organizational units.

The requirements in Table 4 were identified.

**Table 4 Summary of communication requirements**

<table>
<thead>
<tr>
<th>COM1</th>
<th>The cell model and cell network model shall be simple enough to function as means of communication between different organizational units within Ericsson</th>
</tr>
</thead>
<tbody>
<tr>
<td>COM2</td>
<td>The models shall be possible to illustrate as graphs and figures</td>
</tr>
</tbody>
</table>

5.1.4 Simulation constraints

One of the central parts of the test configuration is the simulator which implements the behavior of the radio network and the subscribers as well as the physical and logical connection to the BSC. The simulator is an in-house product of Ericsson.

The simulator puts constraints on how the models can be designed and on what can be tested in BSC load test. The different constraints of the simulator are:

- Performance constraints such as how many subscribers and cells that can be simulated and how good the resolution (in time and space) of the simulation can be. [17]
- Functional constraints such as which features and to what extent they are modeled and implemented in the simulator. [17]

The physical test environment also puts limits on what can be done:

- The models shall describe one radio network. That is, the radio network connected to a single BSC in one System Test Plant (STP). [18]

The requirements in Table 5 were identified.

**Table 5 Summary of simulation requirements**

<table>
<thead>
<tr>
<th>SIM1</th>
<th>The new models shall not make the calculation burden of the simulator grow considerably compared to the models of today</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIM2</td>
<td>The cell network model shall describe one radio network</td>
</tr>
</tbody>
</table>

5.1.5 Summary of the requirements

To conclude the requirements listed in Table 6 were set on the models of the test configuration. The requirements are on a conceptual level and hence difficult to verify but will be used as input when analyzing the suggested models.

**Table 6 Summary of all requirements**

<table>
<thead>
<tr>
<th>COV1</th>
<th>The cell and cell network models shall make it possible to describe a radio network with highly different radio conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>COV2</td>
<td>The cell and cell network models shall make it possible to describe several different areas with different cell configurations</td>
</tr>
<tr>
<td>COV3</td>
<td>The cell and cell network models shall simplify the process of configuring the cell and BSC parameters as well as determining which and to what extent different traffic features are used in the test configuration</td>
</tr>
<tr>
<td>REA1</td>
<td>The cell model shall be based on empiric data</td>
</tr>
<tr>
<td>REA2</td>
<td>The cell model shall be independent of the modulation and coding technique used</td>
</tr>
<tr>
<td>REA3</td>
<td>It shall be possible to dimension and plan the cell network according to standard methods</td>
</tr>
<tr>
<td>COM1</td>
<td>The cell model and cell network model shall be simple enough to function as means of communication between different organizational units within Ericsson.</td>
</tr>
<tr>
<td>COM2</td>
<td>The models shall be possible to illustrate as graphs and figures</td>
</tr>
<tr>
<td>SIM1</td>
<td>The new models shall not make the calculation burden of the simulator grow considerably compared to the models of today</td>
</tr>
<tr>
<td>SIM2</td>
<td>The cell network model shall describe one radio network</td>
</tr>
</tbody>
</table>
6. Proposed model

6.1 General Model

Figure 9 describes an overview of the test configuration where the models that will be described in this chapter are illustrated as input to the BSC and the behavior of the BSC (given the models) are the output and feedback to the models.

Figure 9 Overview of the test configuration

The general idea behind the models described below is that the subscriber model and the cell model shall serve as a base when describing the cell network model. That is, given a certain subscriber and cell model implementation the cell network model shall follow as a consequence. In addition the implementation of these three models shall serve as input and support to the actual parameter configuration of the cells and the BSC. The idea is illustrated in Figure 10.

Figure 10 Model dependencies

The focus of this thesis is put on the cell model and the cell network model. The subscriber and cell model represents the implementation in the simulator. The cell network model is theoretical plan of the cell network (including geographic coordinates, directions and cell structures) and the parameter configuration is the actual BSC/Cell parameter configuration that implements the cell network model.

6.2 Subscriber model

The subscriber model is not considered in this thesis. The assumption is that there exists a well designed model describing the movement and actions of mobile subscribers.

In this thesis the parameters listed in Table 7 will be used to describe the subscribers. The behavior is specified as circuit switched traffic (CS), packet switched traffic (PS), dual transfer mode traffic (DTM) and voice group call service traffic (VGCS).

Table 7 Summary of subscriber model parameters

| Geographical Distribution | Expressed as rectangular areas with evenly distributed users |
moving at constant speed in a fixed direction.

<table>
<thead>
<tr>
<th>Position</th>
<th>Coordinate (x, y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behavior</td>
<td>CS/PS/DTM/VGCS</td>
</tr>
<tr>
<td>Speed</td>
<td>FIXED (0 km/h)</td>
</tr>
<tr>
<td></td>
<td>WALKING (5 km/h)</td>
</tr>
<tr>
<td></td>
<td>CAR (50 km/h)</td>
</tr>
</tbody>
</table>

### 6.3 Cell model

This chapter presents a possible radio simulation model. The focus in this chapter is the radio channel between one fixed transmitter (BTS) and one mobile receiver (MS). Complete reciprocity of antennas and a symmetrical link budget is assumed so the model is valid also for the opposite link (MS to BTS).

#### 6.3.1 General

**Signal Strength**

The radio simulation model is based on a simple link budget. The link budget can be expressed (in decibels) according to the following expression:

\[
RxPwr_{dbm} = TxPwr_{dbm} + GL_{db} - PathLoss[d_{km}]_{db} + ShadowFading[t]_{db} + RayleighFading[t]_{db}
\]

where

- \( RxPwr_{dbm} \) is the received power in dBm.
- \( TxPwr_{dbm} \) is the transmitted power in dBm.
- \( GL_{db} \) is the power gain (compared to an isotropic antenna) and various losses (cable, connector etc.) of both transmitter and receiver expressed in decibels. In this thesis the gain is assumed to be 15 dB for all antennas.
- \( PathLoss_{db}(d_{km}) \) is the path loss prediction with distance \( d_{km} \) between the transmitter and receiver expressed in dB.
- \( ShadowFading_{db}[t] \) is the slow fading in dB caused by shadowing effects at time \( t \).
- \( RayleighFading_{db}[t] \) is the fast fading in dB caused by multi path propagation at time \( t \).

![Figure 11 Link budget illustration. Note the symmetry, i.e. reversing the link gives the same result.](image)

The reported quantity, RxLev, in measurement reports to the BSC is based on the \( RxPwr \) according to:
Quality

The quality simulation proposed for the cell model is based on the quality model described in [4]. Ljung et al defines the quality as the power ratio between the useful signal (using my notation, RxPwr) and the sum of the interference (I) and noise (N) power.

\[
SINR = \frac{RxPwr}{I + N} = \frac{1}{C/I + SNR} = \frac{1}{10^{C/I} + 10^{SNR}}
\]

where

SINR is the power ratio between the useful signal and the interference and noise.
RxPwr is the received signal strength in W.
I is the interference in W.
N is the noise in W.
C/I is the power ratio between the useful signal and the interference only.
SNR is the power ratio between the useful signal and the noise only.

In decibels this can be expressed as:

\[
SINR_{\text{db}} = RxPwr_{\text{dbm}} - (I + N)_{\text{dbm}} \approx \begin{cases} 
RxPwr_{\text{dbm}} - I_{\text{dbm}}, & \text{dominating I} \\
RxPwr_{\text{dbm}} - N_{\text{dbm}}, & \text{dominating N}
\end{cases}
\]

The reference point for the SINR measure (illustrated in Figure 12) is in line with the signal strength reference point.

![Figure 12 Link budget with reference point for SINR.](image)

6.3.2 Radio propagation

According to the link budget expression introduced in the previous section the calculation of radio propagation is divided into path loss as a function of distance and; shadow and rayleigh fading as functions of time.
Path loss

Path Loss is calculated according to standard path loss prediction methods based on empirical data described in [1]. The path loss model used is dependant on the cell size, frequency and the environment of the cell. The models proposed here follow the propagation prediction methods recommended in [1], but the classification of cells is simplified to LARGE (> 5 km) and SMALL (< 5 km) cells and the environment to RURAL and URBAN. The distance \( d \) in the path loss formulas below is expressed in kilometers.

- **LARGE RURAL 900 (Hata)**
  - Base station antenna height 100 m
  - Mobile height 1.5 m
  - \( PL_{dB} = 95.7 + 31.8 \log(d) \)

- **LARGE URBAN 900 (Hata)**
  - Base station antenna height 50 m
  - Mobile height 1.5 m
  - \( PL_{dB} = 123.3 + 33.7 \log(d) \)

- **SMALL URBAN 900 (COST 231-Walfish-Ikegami)**
  - Width of the road, \( w = 20 \) m
  - Height of building roof tops, \( H_{roof} = 15 \) m
  - Height of base station antenna, \( H_b = 17 \) m
  - Height of mobile station antenna, \( H_m = 1.5 \) m
  - Road orientation to direct radio path, \( \Phi = 90° \)
  - Building separation, \( b = 40 \) m
  - \( PL_{dB} = 132.8 + 38 \log(d) \)

- **SMALL URBAN 1800 (COST 231-Walfish-Ikegami)**
  - Width of the road, \( w = 20 \) m
  - Height of building roof tops, \( H_{roof} = 15 \) m
  - Height of base station antenna, \( H_b = 17 \) m
  - Height of mobile station antenna, \( H_m = 1.5 \) m
  - Road orientation to direct radio path, \( \Phi = 90° \)
  - Building separation, \( b = 40 \) m
  - \( PL_{dB} = 142.9 + 38 \log(d) \)

Hence the path loss expressed in decibels can be described as a line (with logarithmic distance scale) as illustrated in Figure 13 where \( A \) is the first kilometer loss and \( B \) is the loss increase per decade. The path loss models are illustrated in Appendix A – Path loss models.
Shadow fading and Rayleigh fading

The simulation of shadow fading and rayleigh fading is independent of the location of the mobile in the cell. The exact method for simulating the fading phenomena is described further in [4].

The shadow and rayleigh fading is dependant on the speed of the mobile (0, 5 or 50 km/h), the frequency (900 MHz or 1800 MHz) and the environment (URBAN or RURAL). The following values for parameters of the shadow and Rayleigh fading are assumed for RURAL and URBAN environments. The exact values of these parameters have been chosen based on existing models at Ericsson. The impact of these parameters are described in [4].

- RURAL
  - Shadow fading, standard deviation = 3 dB
  - Rayleigh fading, rice K-factor = 5 (Rician)
- URBAN
  - Shadow fading, standard deviation = 6 dB
  - Rayleigh fading, rice K-factor = 0 (Rayleigh)

Care has to be taken when adding the fading values to the path loss. The goal is that the planning of the network shall be made according to the path loss model. If the values from the fading simulation are not distributed around zero the mean value of the total loss over the air will shift. Hence the simulated fading values must have the mean value zero (see Figure 14).

It is beneficial if the fading is simulated in a way that the deviation can be calculated easily and be used as input to defining for example hysteresis thresholds and fading margins. Otherwise it is recommended that the simulation method used in [4] is used.
6.3.3 Quality

The quality measure proposed in this thesis is the same as the one used in [4]. The major assumptions made in [4] are:

- Interference and noise are modeled as white Gaussian noise
- The noise and interference is assumed additive i.e. the combined effect of n interferers and the noise equals nI + N.

\[
\text{SINR}_{\text{dB}} = \text{RxPwr}_{\text{dBm}} - (I + N)_{\text{dBm}} \approx \begin{cases} 
\text{RxPwr}_{\text{dBm}} - I_{\text{dBm}}, & \text{dominating I} \\
\text{RxPwr}_{\text{dBm}} - N_{\text{dBm}}, & \text{dominating N}
\end{cases}
\]

RxPwr is calculated according to previous chapters and the interference and noise levels are defined as constants in the whole cell. This can be illustrated according to Figure 15.

The GSM System is engineered to cope with a C/(I+N) ratio of 9 dB [1]. The reference sensitivity level for a GSM 900 mobile is -104 dBm. This means that the system is engineered for noise levels of about -113 dBm [6]. This figure, -113, will be used as the noise level for all cell models.

The interference (I) and noise (N) are constants set per cell. The noise floor is about -113 dBm which can be considered to be the limiting factor of RURAL cells and the interference can vary heavily but can be assumed to be higher in URBAN cells making these cells interference limited rather than noise limited. The aim of the interference model is to allow modeling of scenarios with different interference levels.

In combination with the path loss and fading simulation this creates a quality measure SINR which varies according to Figure 16. The span of quality experienced by a terminal traveling...
in the cell is, hence, a consequence of the received signal strength and the overall interference and noise level in the cell. Expressed in decibels this equals:

$$\text{SINR}_{\text{dB}} = \text{RxPwr}_{\text{dBm}} - (I + N)_{\text{dBm}}$$

where $(I+N)_{\text{dBm}}$ is constant over both distance and time.

![Figure 16: Quality experienced by a receiver at distance d from the transmitter](image)

### 6.3.4 Modulation

The actual experienced quality of the user (the reported quality in measurement reports and the bit errors and block/frame errors) is assumed to be a consequence of SINR and the modulation methods used. In GSM and GPRS two different modulation techniques GMSK and 8-PSK are used. This means that the actual quality measures such as BEP and RxQual needs to be calculated differently depending on the modulation technique used. The main idea here, however, is that the different quality measures shall all be based on the simulated SINR. To conclude, there shall exist a function from SINR to the relevant quality measure.

Defining these functions is outside the scope of this thesis. The general idea of the functions can be illustrated by the following equations.

$$\text{BEP} = \text{BER} = f(\text{SINR}, \text{modulation})$$

$$\text{RxQual} = g(\text{BER})$$

$$\text{MEAN}_\text{BEP} = h(\text{BEP})$$

The functions from SINR to BEP for GMSK and 8-PSK are described in [4]. The mapping functions from BER to RxQual and from BEP to MEAN_BEP and CV_BEP are described in [2].

### 6.3.5 Summary - Model parameters

A cell is thus a combination of the environment and the size of the cell. The environment defined as either URBAN or RURAL and the size of the cell expressed as LARGE or SMALL.

The URBAN environment is characterized by:

- High path loss
- High shadow fading (std = 6 dB)
- High rayleigh fading (Rice K = 0)
- High interference (Interference limited, I > N)

The RURAL environment is characterized by:

- Low path loss (with LOS)
• Medium shadow fading (std = 3 dB)
• Low rayleigh fading (Rice K = 5)
• Low interference (Noise limited N > 1)

Adding the environment, the cell size and the frequencies described in this thesis we get a total of 4 different cell models which are summarized in Table 8.

Table 8 Cell models

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Environment</th>
<th>Noise/Interference</th>
<th>Cell size</th>
<th>Frequency band (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RURAL</td>
<td>Low</td>
<td>LARGE</td>
<td>900</td>
</tr>
<tr>
<td>2</td>
<td>URBAN</td>
<td>High</td>
<td>LARGE</td>
<td>900</td>
</tr>
<tr>
<td>3</td>
<td>URBAN</td>
<td>High</td>
<td>SMALL</td>
<td>900</td>
</tr>
<tr>
<td>4</td>
<td>URBAN</td>
<td>High</td>
<td>SMALL</td>
<td>1800</td>
</tr>
</tbody>
</table>

6.4 Cell network model

When defining the cell network the following aspects are considered: the cell models, the positions and directions of the cells, the subscriber model and certain features that highly influence the structure of the cell network namely HCS and Overlaid/Underlaid subcells.

6.4.1 Cell position and direction

The cell position is simply a coordinate (x, y) and a direction (0°-359°) in the simulated world.

6.4.2 Cell structure

The NORMAL cell structure is defined as cells laid out in the traditional pattern based on hexagons. Sites with three sectors are assumed and the cell plan is illustrated using hexagons to indicate sites (i.e. one hexagon illustrates three 120 degree sector cells). The cells are limited in size by a minimum signal power (the reference sensitivity, i.e. the lowest signal strength that guarantees a certain QoS) or the cell border to a neighbor (i.e. where rxPwr(s) = rxPwr(n)). The limit is illustrated with a hexagon or circle with radius R (see Figure 17).

Figure 17 Cell limit R for a NORMAL cell structure
The SUBCELL structure is equal to the normal cell structure except that each cell contains one overlaid (OL) and one underlaid (UL) subcell with potentially different cell models. The overlaid subcell is limited in size ($R_{OL}$) by one or several of the following thresholds:

- TAOL – an absolute distance measure expressed in TA periods
- LOL – a path loss ($TxPwr – RxPwr$) threshold in dBm
- DTCB – distance to the cell border expressed in dB

Note that the threshold limits are only enforced by the BSS for circuit switched traffic (at assignment and handover). Packet switched channels needs to be defined either in the OL or the UL subcell. The recommendation according to [9] is to place all GPRS/EGPRS channels in the same subcell as the BCCH or to make the coverage area of the two subcells identical.

![Figure 18 Overlaid cell limit $R_{OL}$ for a SUBCELL structure](image)

For cells supporting circuit switched traffic (and cells supporting packet switched traffic with a PBCCH defined) there are an additional cell structure defined.

The HIERARCHICAL cell structure (HCS) is defined as several layers of NORMAL or SUBCELL cell structures laid on-top of each other. The cells in the same layer are limited in size in the exact same manner as NORMAL cells. Cells in higher layers are prioritized higher than cells in lower layers as long as the absolute signal power is higher than a threshold value defined for that layer.

6.4.3 Summary - Model parameters

The cell network model is based on the subscriber model and the cell models in the sense that they are used when planning the cell network. The cell network model is then characterized by the cell positions, the cell directions and the cell structure (NORMAL, HCS, SUBCELL)
7. Model implementation

In this chapter the models described previously are used as building blocks to create four radio network configurations, called scenarios, with highly different characteristics. The scenarios describe different physical environment; radio environment; subscriber distribution and behavior; and hence different BSC/Cell configuration.

One scenario can be seen as a separate network and be configured and optimized separately without influencing the other scenarios. There is however some limitation to how different the scenarios can be. They are all connected to the same BSC and hence they share all configuration parameters on BSC level.

The scenarios presented here are based on the cell and the cell network model. The scenarios are described by general informal scenario descriptions. These descriptions are used to make the scenarios more “alive”. The next section describes the cell model(s) used in the scenario. The cell network model section specifies the conceptual network plan. Finally some important cell parameters (the actual BSC configuration) are presented. Cells using the same cell model in the same area shall be configured identically.

The last section in this chapter describes how the scenarios can be combined to form one logical network. In that section the scenarios are also illustrated with traditional geographical cell plans.

In appendixes B to E the scenario cell models and some parameters are illustrated as graphs. The graphs show the received signal strength and quality of a receiver located at distance, d, from a transmitter. Neighbors are illustrated in the graphs as worst case scenarios, i.e. the cell border is located at distance R from cell centers. The signal strength and quality that are plotted in the graphs are the mean values.

The cell plans are based on signal strength borders between neighbors. For circuit switched traffic this means that Ericsson3 shall be used as locating algorithm (or Ericsson1 configured to ignore the path loss criteria).

In all scenarios below the following assumptions is made:

- The noise floor in the receiver is -113 dBm.
- The sum of all losses and gains in the transmitter and the receiver, GL, is assumed to be 15 dB.
- The RxPwr and SINR values should be chosen (calculated from the link budget expression) to meet a certain QoS at the cell border. The values supplied in the scenarios below are examples that show how the signal strength and quality can vary between different cell models.
- The RxPwr and SINR values specified at the cell border are worst case scenarios when it comes to distance. The actual cell border will be located at most at distance R and at least at distance Q. Where

  \[ Q = \frac{\sqrt{3}}{2} R. \]

- The RxPwr and SINR values specified at the cell border are the mean values (i.e. the received power without any kind of fading).

Also note that the functions from SINR to actual quality measures and packet/frame loss are not considered in this thesis hence the SINR level that is needed to achieve a certain QoS
must be specified more specifically than here. I.e. a suitable lowest QoS expressed in SINR, BEP, RxQual or any other quality measure should be specified for each scenario.
7.1 Urban scenario

7.1.1 General information
The URBAN scenario is assumed to be in a big city such as the central parts of New York or London. One set of frequencies in the 900 MHz band is available to the scenario. The scenario illustrates a technology-driven strategy with the latest technology in form of features such as EGPRS and AMR.

A high density of subscribers is assumed in all cells which motivates small cells and many traffic channels.

The radio environment in the scenario is modeled using the SMALL URBAN 900 MHz cell model with Rayleigh fading (Rice K factor = 0), shadowing with a standard deviation of 6 dB and a high interference level. The tightly planned cells and the high density of subscribers are also assumed to cause a heavy degree of interference, hence the interference (I) is set to a high value (-110 dBm).

The high interference will cause low SINR values at the cell border. A SINR of 8.64 dB at the cell border and shadowing with 6 dB standard deviation will cause quality problems.

7.1.2 Subscriber model
- High density of evenly distributed subscribers
- Subscribers with speed 0, 5 and 50 km/h

7.1.3 Cell model
- SMALL URBAN 900 MHz
  - Path loss = 132.8 + 38.0log(d)
  - High fast fading, Rice K factor = 0 (Rayleigh)
  - High slow fading, Standard deviation = 6 dB
  - GL = 15 dB (See chapter 6.3.1)
- High interference level
  - N = -113 dBm
  - I = -100 dBm

7.1.4 Cell network model
A graph of the signal strength and quality is presented in Appendix B – URBAN scenario.
- NORMAL cell structure
  - R = 0.5 km
  - TxPwr = 15 dBm
  - Mean RxPwr at cell border = -91.36 dBm
  - Mean SINR at cell border = 8.64 dB

7.1.5 Parameter configuration
- $BSPWRB = 15$ dBm (EIRP = 30 dBm)
7.2 Rural scenario

7.2.1 General information
The RURAL scenario is covering a huge rural area where noise is the limiting factor of the cell sizes. There is a low density of subscribers and the scenario is running a traditional one layered 900 MHz GSM network. The main focus of the scenario is to provide as much coverage as possible as the capacity is not a problem.

The rural environment is modeled using the large RURAL CELL model with low path loss. The low path loss is a consequence of a high BTS antenna and a higher degree of line of sight propagation than urban environments. The high antenna is also assumed to limit the effects of shadowing to a standard deviation of 3 dB.

7.2.2 Subscriber model
- Low density of evenly distributed subscribers
- Subscribers with speed 0, 5 and 50 km/h

7.2.3 Cell model
- LARGE RURAL 900 MHz
  - Path loss = 95.7 + 31.8\log(d)
  - Low fast fading, Rice K factor = 5 (Rician)
  - Low slow fading, Standard deviation = 3 dB
  - GL = 15 dB (See chapter 6.3.1)
- No interference and low noise level
  - N = -113 dBm

7.2.4 Cell network model
A graph of the signal strength and quality is presented in Appendix C – RURAL Scenario.
- NORMAL cell structure
  - R = 35 km
  - TxPwr = 39 dBm
  - Mean RxPwr at cell border = -92.80 dBm
  - Mean SINR at cell border = 20.20 dB

7.2.5 Parameter configuration
- BSPWRB = 39 dBm (EIRP = 54 dBm)
7.3 Urban HCS scenario

7.3.1 General information
The URBAN HCS scenario is a city scenario with frequencies in the 900 MHz band. The cell plan is based on a two layer hierarchical cell structure with three large layer 5 cells and 36 smaller layer 3 cells. One of the sites has three layer 5 cells co-sited with three layer 3 cells. The small layer 3 cells are loaded with traffic first and the large layer 5 cell is loaded when the smaller cells are congested, out of coverage or when a mobile is suffering from heavy fading close to a layer 3 cell border.

A medium density of subscribers is expected. The urban environment causes heavy path loss and complete Rayleigh fading is assumed. The high buildings in the urban environment cause shadowing with a standard deviation of 6 dB.

The scenario is very similar to the URBAN scenario. The major differences are the introduction of hierarchical cell structures and a slightly lower interference level.

7.3.2 Subscriber model
- Medium density of evenly distributed subscribers
- Subscribers with speed 0, 5 and 50 km/h

7.3.3 Cell model
- Small Urban 900 MHz
  - Path loss = 132.8 + 38.0log(d)
  - High fast fading, Rice K factor = 0 (Rayleigh)
  - High slow fading, Standard deviation = 6 dB
  - GL = 15 dB (See chapter 6.3.1)
- Large Urban 900 MHz
  - Path loss = 123.3 + 33.7log(d)
  - High fast fading, Rice K factor = 0 (Rayleigh)
  - High slow fading, Standard deviation = 6 dB
  - GL = 15 dB
- Low interference and noise level
  - N = -113 dBm
  - I = -110 dBm
7.3.4 Cell network model
A graph of the signal strength and quality is presented in Appendix D – URBAN HCS scenario.

- **HCS structure**
  - Layer 3: SMALL URBAN 900
    - $R_{\text{SMALL}} = 1$ km
    - $\text{TxPwr} = 19$ dBm
    - Mean $\text{RxPwr}$ at cell border = -98.80 dBm
    - Mean SINR at cell border = 11.20 dB
  - Layer 5: LARGE URBAN 900
    - $R_{\text{LARGE}} = 5$ km
    - $\text{TxPwr} = 39$ dBm
    - Mean $\text{RxPwr}$ at cell border = -92.86 dBm
    - Mean SINR at cell border = 17.14 dB

7.3.5 Parameter configuration

Layer 3
- $B_{\text{STXPWR}} = 19$ dBm (EIRP = 34 dBm)
- $L_{\text{AYERTHR}} = (-)100$ dBm

Layer 5
- $B_{\text{SPWRB}} = 39$ dBm (EIRP = 54 dBm)
7.4 **Small city scenario**

7.4.1 **General information**

The SMALL CITY scenario is operating in a growing small city where the increased capacity demand was solved by introducing a new frequency band. Hence the scenario is running a multi band network with a subcell structure. The original 900 band cell plan is kept as the underlaid cells and the 1800 band is used in the overlaid subcells. GPRS traffic channel are only configured in the underlaid subcells.

The sizes of the overlaid subcells are specified using the path loss and the DTCB criterions. The sizes of the overlaid subcells given the models is about 350 m (50 % of the underlaid cell area).

The path loss difference between the 900 and 1800 bands is according to the path loss models 10.1 dB.

The urban cell models are used for path loss and fading with similar parameter settings to the URBAN and the URBAN HCS scenarios.

7.4.2 **Subscriber model**
- Medium density of evenly distributed subscribers
- Subscribers with speed 0, 5 and 50 km/h

7.4.3 **Cell model**
- **SMALL URBAN 900**
  - Path loss = 132.8 + 38.0log(d) dB
  - High fast fading, Rice K factor = 0 (Rayleigh)
  - High slow fading, Standard deviation = 6 dB
  - GL = 15 dB (See chapter 6.3.1 )
- **SMALL URBAN 1800**
  - Path loss = 142.9 + 38.0log(d) dB
  - High fast fading, Rice K factor = 0 (Rayleigh)
  - High slow fading, Standard deviation = 6 dB
  - GL = 15 dB (See chapter 6.3.1 )
- High interference and noise level
  - N = -113 dBm
  - I = -100 dBm
7.4.4 Cell network model
A graph of the signal strength and quality is presented in Appendix E – SMALL CITY scenario.

- **SUBCELL structure**
  - BCCH in underlaid subcell (900 MHz)
  - Underlaid: SMALL URBAN 900
    - $R_{UL} = 0.5$ km
    - $\text{TxPwr} = 25$ dBm
    - Mean RxPwr at cell border = -81.36 dBm
    - Mean SINR at cell border = 18.64 dB
    - Mean RxPwr, OL border $\approx$ -75.47 dBm
    - Mean SINR, OL border $\approx$ 24.53 dB
  - Overlaid: SMALL URBAN 1800
    - $R_{OL} \approx 0.35$ km
    - $\text{TxPwr} = 25$ dBm
    - Mean RxPwr, OL border $\approx$ -85.57 dBm (-75.57 dBm incl. FBOFFSET)
    - Mean SINR, OL border $\approx$ 14.43 dB

7.4.5 Parameter configuration

- $BSPWRB_{UL} = 25$ dBm (EIRP = 40 dBm)
- $BSPWRB_{OL} = 25$ dBm (EIRP = 40 dBm)
- $DTCB = 6$ dB
- $NNCELS = 1$
- $LOL = 115$ dB
- $FBOFFSET = 10$ dB
7.5 Combined scenario

This scenario is a complete cell plan with different areas representing the scenarios described earlier. Each scenario needs to be constituted of at least three 3-sector sites (nine cells) but more is recommended. In the cell plan illustrated in Figure 20 twelve sites for each scenario is used. The logical connection between the system under test (the BSC node) and the different scenarios is shown in Figure 19.

![Logical view of the connection between the scenario networks and the BSC node.](image)

The different scenarios in the combined network aim to describe varying environment; varying radio conditions; varying subscriber behavior and distribution; and varying cell structures.

The idea is that one area shall describe one scenario and be entirely independent of the other areas. This implies some kind of separation between the areas. Three suggestions of how this can be accomplished are given here.

- The areas can be separated in space; so that the signals of transmitters in one area do not influence the other areas (i.e. a receiver in area A does not recognize any other transmitters than the transmitters in area A).
- The areas can also be separated by using different network codes for the BTSs in each area. The mobile terminals can then be configured to ignore all BTSs which do not have the correct network code.
- A third option is to satisfy with not configuring any cells in area A to be neighbors of any cell in any other areas than area A.
Figure 20 Cell plan with four different scenarios. The hexagons illustrate 3-sector sites and the dashed rectangles the subscriber mobility areas.
8. Analysis
This chapter gives an analysis of the suggested model of the test configuration that is suggested in the previous chapters. The analysis of the proposed solution is based on the requirements set in the Requirement specification.

The requirement were divided into the four groups

- Coverage
- Realism
- Communication
- Simulation

The following section dissects the requirements one by one.

8.1 Coverage

8.1.1 COV1
The cell and cell network models shall make it possible to describe radio networks with highly different radio conditions.

The described cell model allows the definition of highly varying radio conditions in terms of radio propagation (by varying the parameters of the path loss, shadow fading and rayleigh fading models). The foundation of the model described is also the cell model, in contrast to the mobile centered approach of the existing simulator. This new approach was chosen to allow the configuration of the radio related parameters (such as signal strength, path loss or quality thresholds) to be based on the simulated model.

8.1.2 COV2
The cell and cell network models shall make it possible to describe several different areas with different cell configurations.

This requirement further enhances the importance of moving the focus from the mobiles to the network plan (cell plan). This allows a more realistic configuration of the network. The different areas are used to describe different radio conditions, subscriber behavior, cell structures and different BSC/Cell configurations.

8.1.3 COV3
The cell and cell network models shall simplify the process of configuring the cell and BSC parameters as well as determining which and to what extent different features are used.

Within each of the areas mentioned in the previous requirement the intention is that the configuration of BSC and cell parameters shall be obvious given the subscriber, cell and cell network model used.

Given that the models are implemented in the simulator with a certain accuracy the planning of the test network can be made based on the models and the network can be configured in such a way that it requires certain features to meet certain performance or stability requirements.

The model is also consistent to a greater extent than earlier models. Earlier models differed from packet switched and circuit switched connections and were defined on either cell or
mobile basis. The suggested model is common for all types of access technology (circuit switched and packet switched) and is strictly defined on cell basis.

8.2 Realism
The model described in this thesis has one major drawback. The interference is simulated as constant power white gaussian noise. In a real network the interference level is of course dependent on the actual usage of the co-channels in neighboring cells and adjacent channels during the timeslot used for transmitting the information. Simulating the interference to this extent is however not possible given the amount of mobile terminals that shall be simulated and the complexity of calculating the effects of every single interferer on a given receiver.

This means that the effects of features aiming at reducing the interference level in the whole network cannot be tested. For instance the interference level is not affected by the usage of power control or frequency hopping. The logical functionality of these features can obviously be tested anyway.

8.2.1 REA1
The cell model shall be based on empiric data.

This requirement puts focus on describing a network that is realistic in terms of distance and time scales. This is the major reason why the empirically based Hata model was chosen as the base for the path loss simulation. The models include the phenomena shadow and Rayleigh fading. How accurate and realistic these models are, is however hard to say. They are however based on well known models. It should be noted that using these models assumes a flat fading radio channel.

8.2.2 REA2
The cell model shall be independent of the modulation and coding technique used.

The reason for this requirement was the need for a consistent radio simulation model. That is a simulation model that can be used to simulate both packet switched (read GPRS or EGPRS), and circuit switched traffic or any new modulation form for an evolving GSM system. The radio simulation model described is based entirely on the signal strength and its ratio towards the interference and noise level (SINR). This means that any given mobile will experience the same quality (SINR) irrespective of the access method (traditional circuit switched or packet switched). It however put higher demands on the simulator which are described further in the section Simulation constraints below.

8.2.3 REA3
It shall be possible to dimension and plan the cell network according to standard methods.

The cell model and the cell network model are based on models recommended by 3GPP for planning real cellular networks.

8.3 Communication

8.3.1 COM1
The cell model and cell network model shall be simple enough to function as means of communication between different organizational units within Ericsson.

The basic principles of the model can be expressed in two simple equations:
\[
\text{RxPwr}_{\text{dBm}} = \text{TxPwr}_{\text{dBm}} + \text{GL}_{\text{dB}} - \text{PathLoss}_{\text{dB}} + \text{ShadowFading}[t]_{\text{dB}} + \text{RayleighFading}[t]_{\text{dB}}
\]

\[
\text{SINR}_{\text{dB}} = \text{RxPwr}_{\text{dBm}} - (I + N)_{\text{dBm}}
\]

Hence the signal strength and quality of any mobile in the network is entirely determinable given the distance to the BTS and a certain uncertainty (the fading margin). Setting the \(\text{ShadowFading}[t]\) and \(\text{RayleighFading}[t]\) to identical zero gives a totally deterministic model.

### 8.3.2 COM2

*The models shall be possible to illustrate as graphs and figures.*

As the basic principles of the model are based on two mathematical formulas it is easy to represent as graphs. Together with a traditional “hexagonal” cell plan the graphs can communicate the complete radio environment of the cell network.

### 8.4 Simulation constraints

#### 8.4.1 SIM1

*The new models shall not make the calculation burden of the simulator grow considerably compared to the models of today.*

The models suggested in this thesis reuse the same principles that are already used in the simulator. The heaviest simulation burden (the shadow and Rayleigh fading) can be handled pre-runtme. The new propagation and quality model, however, requires that additional values (the fading values for every time \(t\)) are stored and transferred to the simulator for usage during run-time. This implies that the simulator will have to convert the SINR value to the relevant quality measure and an equivalent probability of packet/frame loss during run-time.

Choosing an intelligent implementation for this process is essential to the performance of the simulator. A table driven approach is suggested.

#### 8.4.2 SIM2

*The cell network model shall describe one radio network.*

The model allows the creation of different scenarios within one logical radio network. However, the model does not explicitly specify how they are separated. The different scenarios can be separated as described in the combined scenario or they can be specified as separate data transcripts in separate simulators. The different scenarios can be run alone or together connected to the same BSC.
9. Conclusions

This thesis presents a mathematical and conceptual model of a GSM radio network. The goal of the model is to allow Ericsson to describe a radio network configuration on a conceptual level. An example of a radio network with four different scenarios is also presented.

The base of the model is the cell model which is used as a building block to create a cell network. The cell model describes how the radio environment of a mobile terminal is affected by the geographical location in the cell and the surrounding environment.

The cell model can be used as a base for forming requirements on a simulator used for testing and as an analytic tool for planning the test network. The model is also simple enough to be used as a mean of communication among different organizational units within Ericsson.

The simplicity of the model and its ease of communication allow Ericsson to create a test configuration with a higher degree of feature coverage in a structured way.

9.1 Further studies

The obvious continuation of the work presented in this thesis is of course implementing the cell model as a real radio network simulator and start using the cell and cell network model as an analytic tool. It is of great importance that the models are common and well known among all the involved organizational units mentioned in the background chapter. Simply implementing it in a simulator will be contra productive if the system engineers designing the test network or the test engineers using the simulator does not have knowledge of the limitations and properties of the model. Note that implementing these models as they are described in this thesis is a task that will require restructuring and redesigning parts of the simulator and it might influence other users of the simulator.

Further work also includes completing the parameter configuration of the cells in each scenario, for instance configuring different features in relevant scenarios. Only a limited set of features and cell parameters have been specified in this thesis. The informal description of each scenario also needs further work. The idea is that the informal description shall motivate the usage of different kinds of features (i.e. answer the question: why are these features active in this scenario) and make the scenarios more “alive”.

Another practical issue is fitting the different scenarios in to different simulator nodes. There is a need to test how the new models influence performance of the simulator.

The model can also be used for comparing our simulated environment to a customer network. For example modeling a customer network and comparing for instance signal strength and quality experienced in real life with the theoretical model.

Future work can also include adapting the model for use with other access network technologies such as WCDMA or LTE. An interesting field of study is to investigate if it is possible to use a common radio simulation model for several different access technologies and then experiment with inter-system handovers and load balancing between the systems.
### 10. Acronyms and abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-PSK</td>
<td>8 Phase Shift Keying</td>
</tr>
<tr>
<td>BEP</td>
<td>Bit Error Probability</td>
</tr>
<tr>
<td>BER</td>
<td>Bit Error Ratio</td>
</tr>
<tr>
<td>BCCH</td>
<td>Broadcast Control Channel</td>
</tr>
<tr>
<td>BSC</td>
<td>Base Station Controller</td>
</tr>
<tr>
<td>BSS</td>
<td>Base Station (Sub)System</td>
</tr>
<tr>
<td>BTS</td>
<td>Base Transceiver Station</td>
</tr>
<tr>
<td>CDMA</td>
<td>Code Division Multiple Access</td>
</tr>
<tr>
<td>CPI</td>
<td>Customer Product Information</td>
</tr>
<tr>
<td>CS</td>
<td>Circuit Switched</td>
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<tr>
<td>CS</td>
<td>Coding Scheme</td>
</tr>
<tr>
<td>CSD</td>
<td>Circuit Switched Domain</td>
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<tr>
<td>DL</td>
<td>Downlink</td>
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<tr>
<td>DTCB</td>
<td>Distance To Cell Border</td>
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<tr>
<td>DTM</td>
<td>Dual Transfer Mode</td>
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<tr>
<td>E-PDCH</td>
<td>EGPRS Packet Data Channel</td>
</tr>
<tr>
<td>E-TCH</td>
<td>EGPRS Traffic Channel</td>
</tr>
<tr>
<td>EDGE</td>
<td>Enhanced Data rates for GSM/Global Evolution</td>
</tr>
<tr>
<td>EGPRS</td>
<td>Enhanced GPRS</td>
</tr>
<tr>
<td>EIRP</td>
<td>Effective Isotropic Radiated Power</td>
</tr>
<tr>
<td>ETE</td>
<td>Ericsson Test Environment</td>
</tr>
<tr>
<td>FDMA</td>
<td>Frequency Division Multiple Access</td>
</tr>
<tr>
<td>FER</td>
<td>Frame Erasure Rate</td>
</tr>
<tr>
<td>FR</td>
<td>Full Rate</td>
</tr>
<tr>
<td>G-PDCH</td>
<td>GPRS Packet Data Channel</td>
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<tr>
<td>G-TCH</td>
<td>GPRS Traffic Channel</td>
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<td>GGSN</td>
<td>Gateway GPRS Support Node</td>
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<td>GMSK</td>
<td>Gaussian Minimum Shift Keying</td>
</tr>
<tr>
<td>GPRS</td>
<td>General Packet Radio Service</td>
</tr>
<tr>
<td>GSM</td>
<td>Global System for Mobile communications</td>
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<tr>
<td>HCS</td>
<td>Hierarchical Cell Structures</td>
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<td>HR</td>
<td>Half Rate</td>
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<tr>
<td>IP</td>
<td>Internet Protocol</td>
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<tr>
<td>Abbreviation</td>
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<tr>
<td>kbps</td>
<td>Kilo bits per second</td>
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<tr>
<td>LA</td>
<td>Location Area</td>
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<td>LTE</td>
<td>Long Term Evolution</td>
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<td>MCS</td>
<td>Modulation and Coding Scheme</td>
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<td>MPDCH</td>
<td>Master PDCH</td>
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<tr>
<td>MS</td>
<td>Mobile Station</td>
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<tr>
<td>MSC</td>
<td>Mobile services Switching Center</td>
</tr>
<tr>
<td>OL</td>
<td>Overlaid (subcell)</td>
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<tr>
<td>PCM</td>
<td>Pulse Code Modulation</td>
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<tr>
<td>PCU</td>
<td>Packet Control Unit</td>
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<td>PDN</td>
<td>Packet Data Network</td>
</tr>
<tr>
<td>PDCH</td>
<td>Packet Data Channel</td>
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<tr>
<td>PLMN</td>
<td>Public Land Mobile Network</td>
</tr>
<tr>
<td>PS</td>
<td>Packet Switched</td>
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<td>PSD</td>
<td>Packet Switched Domain</td>
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<tr>
<td>PSTN</td>
<td>Public Switched Telephony Network</td>
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<tr>
<td>QoS</td>
<td>Quality of Service</td>
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<tr>
<td>RA</td>
<td>Routing Area</td>
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<tr>
<td>SDCCH</td>
<td>Stand alone Dedicated Control Channel</td>
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<tr>
<td>SGSN</td>
<td>Serving GPRS Support Node</td>
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<tr>
<td>SMS</td>
<td>Short Message Service</td>
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<tr>
<td>STP</td>
<td>System Test Plant</td>
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<td>TA</td>
<td>Timing Advance</td>
</tr>
<tr>
<td>TCH</td>
<td>Traffic Channel</td>
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<tr>
<td>TDMA</td>
<td>Time Division Multiple Access</td>
</tr>
<tr>
<td>TG</td>
<td>Transceiver Group</td>
</tr>
<tr>
<td>UL</td>
<td>Underlaid (subcell)</td>
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<td>UL</td>
<td>Uplink</td>
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<tr>
<td>WCDMA</td>
<td>Wideband CDMA</td>
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</table>
11. References


11.1 Interviews

[17] Holmstrand, Anders; Ljung, Fredrik; 2007-10-01 SPS, Ericsson AB

Figure 21 Path loss models for LARGE URBAN and LARGE RURAL cell.

Figure 22 Path loss model for SMALL URBAN cells using the 900 and 1800 bands.
Appendix B – URBAN scenario

Figure 23 Mean received signal strength at distance d from a transmitter of URBAN scenario with SMALL cells. $I = 100$ dBm, $\text{TxPwr} = 15$ dBm, $\text{GL} = 15$ dB and $R = 500$ m. The dashed line illustrates a neighbour and the dotted the interference level.

Figure 24 Mean downlink quality (SINR) at distance d from the transmitter of an URBAN scenario with SMALL cells. $I = -100$ dBm, $\text{TxPwr} = 15$ dBm, $\text{GL} = 15$ dB and $R = 500$. 
Appendix C – RURAL Scenario

Mean Received Downlink Signal Strength

Figure 25 Mean received signal strength at distance d from a transmitter of RURAL scenario with large cells. $N = -113$ dBm, $TxPwr = 39$ dBm, $GL = 15$ dB and $R = 35$ km. The dashed lined illustrates a neighbor.

Mean Downlink Quality

Figure 26 Mean downlink quality at distance d from the transmitter of a RURAL scenario with LARGE cells. $I = -113$ dBm, $TxPwr = 39$ dBm, $GL = 15$ dB and $R = 35$ km.
Appendix D – URBAN HCS scenario

Figure 27 Mean received signal strength at distance d from a transmitter of URBAN HCS scenario with LARGE and SMALL cells. The dashed lined illustrates neighbors, the line at -110 dBm the interference and the line at -100 dBm is the layer threshold.

Figure 28 Mean quality at distance d from the transmitter of a URBAN HCS scenario with LARGE and SMALL cells.
Appendix E – SMALL CITY scenario

Figure 29 Mean received signal strength at distance d from a transmitter of SMALL CITY scenario. The line marked 900 illustrates the propagation of the 900 MHz underlaid subcell and the line marked 1800, the 1800 MHz overlaid subcell. The OL border is specified using DTCB and LOL, the TAOL threshold is virtually useless.

Figure 30 Mean quality at distance d from a SMALL CITY Scenario. The upper curve is the 900 band and the lower the 1800 band.