DISCLAIMER

This book is a training document and contains simplifications. Therefore, it must not be considered as a specification of the system.

The contents of this document are subject to revision without notice due to ongoing progress in methodology, design and manufacturing.

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This document is not intended to replace the technical documentation that was shipped with your system. Always refer to that technical documentation during operation and maintenance.

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## REVISION RECORD

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# GSM Cell Planning Workshop

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This chapter is designed to provide the student with an overview of the GSM system.

OBJECTIVES:

Upon completion of this chapter, the student will be able to:

• Explain the basic function of a GSM system
• Describe the network nodes of a GSM system
• Describe general terms used in the GSM system
• Explain the differences between the three major systems of the GSM network
# 1 System Description

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<td>10</td>
</tr>
</tbody>
</table>
GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS (GSM)

In 1982, the Nordic PTT sent a proposal to Conférence Européenne des Postes et Télécommunications (CEPT) to specify a common European telecommunication service at 900 MHz. A Global System for Mobile Communications (GSM) standardization group was established to formulate the specifications for this pan-European mobile cellular radio system.

During 1982 through 1985, discussions centered around whether to build an analog or a digital system. Then in 1985, GSM decided to develop a digital system.

In 1986, companies participated in a field test in Paris to determine whether a narrowband or broadband solution would be employed. By May 1987, the narrowband Time Division Multiple Access (TDMA) solution was chosen.

Concurrently, operators in 13 countries (two operators in the United Kingdom) signed the Memorandum of Understanding (MoU) which committed them to fulfilling GSM specifications and delivering a GSM system by July 1, 1991. This opened a large new market.

The next step in the GSM evolution was the specification of Personal Communication Network (PCN) for the 1800 MHz frequency range. This was named the Digital Cellular System (DCS) 1800 (or Ericsson’s GSM 1800). The Personal Communication Services (PCS) 1900 (or Ericsson’s GSM 1900) for the 1900 MHz frequency range was also established.
THE DIFFERENT GSM-BASED NETWORKS

Different frequency bands are used for GSM 900/1800 and GSM 1900 (Figure 1-1). In some countries, an operator applies for the available frequencies. In other countries (e.g. United States), an operator purchases available frequency bands at auctions.

<table>
<thead>
<tr>
<th>Network type</th>
<th>Frequency band UL/DL</th>
<th>Ericsson’s implementations</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSM 900</td>
<td>890 - 915/935 - 960 MHz</td>
<td>GSM 900</td>
</tr>
<tr>
<td>GSM 1800</td>
<td>1710 - 1785/1805 -1880 MHz</td>
<td>GSM 1800</td>
</tr>
<tr>
<td>GSM 1900</td>
<td>1850 - 1910/1930 -1990 MHz</td>
<td>GSM 1900</td>
</tr>
</tbody>
</table>

*Figure 1-1 Frequency bands for the different GSM-based networks*
NETWORK HARDWARE

Every cellular system has hardware that is specific to it and each piece of hardware has a specific function. The Ericsson GSM-based systems comply to the GSM standard while varying from it for the purpose of overall system improvement.

The system solutions integrate existing Ericsson hardware and new technology to provide a "total" solution to the mobile telephony market. The major systems in the network are:

- Operation and Support System
- Switching System
- Base Station System

The system is normally configured as depicted in Figure 1-2.

![Figure 1-2 Ericsson GSM-based system model](image-url)
OPERATION AND SUPPORT SYSTEM (OSS)

For GSM system administration, the OSS supports the network operator by providing:

• Cellular network administration
• Network operation and support
SWITCHING SYSTEM (SS)

Figure 1-3 shows the main components of the switching system. The following is a brief description of each of these components.

- **Mobile services Switching Center (MSC)**
  
  The MSC is responsible for set-up, routing, and supervision of calls to and from mobile subscribers. Other functions are also implemented in the MSC, such as authentication. The MSC is built on an AXE-10 platform.

- **Visitor Location Register (VLR)**
  
  In the Ericsson GSM based solution, the VLR is integrated with the MSC. This is referred to as the MSC/VLR. The VLR contains non-permanent information about the mobile subscribers visiting the MSC/VLR service area, e.g. which location area the MS is in currently.

- **Gateway MSC (GMSC)**
  
  The GMSC supports the function for routing incoming calls to the MSC where the mobile subscriber is currently registered. It is normally integrated in the same nodes as MSC/VLR.
• **Home Location Register (HLR)**

In GSM, each operator has a database containing information about all subscribers belonging to the specific Public Land Mobile Network (PLMN). This database can be implemented in one or more HLRs. Two examples of information stored in the database are the location (MSC/VLR service area) of the subscribers and services requested. The HLR is built on an AXE-10 platform.

• **Authentication Center (AUC)**

For security reasons, speech, data, and signaling are ciphered, and the subscription is authenticated at access. The AUC provides authentication and encryption parameters required for subscriber verification and to ensure call confidentiality.

• **Equipment Identity Register (EIR)**

In GSM there is a distinction between subscription and mobile equipment. As mentioned above, the AUC checks the subscription at access. The EIR checks the mobile equipment to prevent a stolen or non-type-approved MS from being used.

• **Interworking Location Register (ILR)**

Around the world there are market demands for roaming capabilities with GSM. The ILR is the node that forwards roaming information between cellular networks using different operating standards. This currently exists only in the GSM 1900 network.

• **Short Message Service - Gateway MSC (SMS-GMSC)**

A Short Message Service Gateway MSC (SMS-GMSC) is capable of receiving a short message from a Service Center (SC), interrogating an HLR for routing information and message waiting data, and delivering the short message to the MSC of the recipient MS. In Ericsson’s GSM system, the SMS-GMSC functionality is normally integrated in the MSC/VLR node.

• **Short Message Service - InterWorking MSC (SMS-IWMSC)**

A Short Message Service InterWorking MSC (SMS-IWMSC) is capable of receiving a mobile originated short message from the MSC or an ALERT message from the HLR and submitting the message to the recipient Service Center (SC). The SMS-IWMSC functionality is normally integrated in the MSC/VLR node.
• **Data Transmission Interface (DTI)**

  DTI - consisting of both hardware and software - provides an interface to various networks for data communication. Through DTI, users can alternate between speech and data during the same call. Its main functions include a modem and fax adapter pool and the ability to perform rate adaptation. It was earlier implemented as the GSM InterWorking Unit (GIWU).
BASE STATION SYSTEM (BSS)

The Base Station System (BSS) is comprised of two major components. They are:

- Base Station Controller (BSC)
- Base Transceiver Station (BTS)

**BSC**

The Base Station Controller (BSC) is the central point of the BSS. The BSC can manage the entire radio network and performs the following functions:

- Handling of the mobile station connection and handover
- Radio network management
- Transcoding and rate adaptation
- Traffic concentration
- Transmission management of the BTSs
- Remote control of the BTSs

**BTS**

The Base Transceiver Station (BTS) includes all radio and transmission interface equipment needed in one cell. The Ericsson name for the BTS is Radio Base Station (RBS). The Ericsson RBS corresponds to the equipment needed on one site.
rather than one cell. Each BTS operates at one or several pairs of frequencies. One frequency is used to transmit signals to the mobile station and one to receive signals from the mobile station. For this reason at least one transmitter and one receiver is needed.

**RBS 200**

The RBS 200 family was the first Ericsson GSM base station developed in the early 1990’s. It exists only in the GSM 900/1800 product line. The RBS 200 is the BTS supporting GSM 900, and the RBS 205 is the BTS supporting GSM 1800.

In general, the RBS 200 family supports 4 transceiver modules (TRXs) per cabinet.

**RBS 2000**

The RBS 2000 Base Station family is the second generation of base stations from Ericsson and can be used for GSM 900/1800 and GSM 1900. There are six different models in the series:

- RBS 2101 with 2 Transceiver Units (TRUs)
- RBS 2102 and 2202 with 6 TRUs
- RBS 2103 (GSM 900 only) with 6 TRUs and smaller footprint
- RBS 2301 is the micro-base station
- RBS 2302 is the micro-base station supporting Maxite™
- RBS 2401 is the first dedicated indoor radio base station

All models are outdoor versions except RBS 2202 and RBS 2401.
AIR INTERFACE

FREQUENCY ALLOCATION

Figure 1-1 (shown earlier) lists the band allocations for each of the different GSM based networks.

In many countries, the whole frequency band will not be used from the outset.

CHANNEL CONCEPT

The carrier separation in GSM is 200 kHz. That yields 124 carriers in the GSM 900 band. Since every carrier can be shared by eight MSs, the number of channels is 124 times $8 = 992$ channels. These are called physical channels. The corresponding number of carriers for GSM 800 and GSM 900 are 374 and 299, respectively.

LOGICAL CHANNELS

A number of logical channels are mapped on each physical channel. Each logical channel is used for specific purposes, e.g. paging, call set-up signaling or speech.

There are eleven logical channels in the GSM system. Two of them are used for traffic and nine for control signaling. Traffic and Control channels are explained in the following sections.

Traffic Channels (TCH)

Two types of TCH are used:

- Full rate channel, $B_m$
  
  This channel can be used for full rate or enhanced full rate speech (13 kbit/s after speech coder) or data up to 9.6 kbit/s.

- Half rate channel, $L_m$
  
  This channel can be used for half rate speech (6.5 kbit/s after speech coder) or data up to 4.8 kbit/s.

Note that in Ericsson’s GSM system R7 multislot connections are available, implemented as HSCSD, High Speed Circuit Switched Data.
Control channels

Nine different types of control channels are used.

**Broadcast Channels (BCH)**

- **Frequency Correction Channel (FCCH)**
  Used for frequency correction of the MS, downlink only.

- **Synchronization Channel (SCH)**
  Carries information about TDMA frame number and the Base Station Identity Code (BSIC) of the BTS, downlink only.

- **Broadcast Control Channel (BCCH)**
  Broadcasts cell specific information to the MS, downlink only.

**Common Control Channels (CCCH)**

- **Paging Channel (PCH)**
  Used to page the MS, downlink only.

- **Random Access Channel (RACH)**
  Used by the MS to request allocation of a Stand alone Dedicated Control Channel (SDCCH), either as a page response or an access at MS call origination/registration, location updating, etc. uplink only.

- **Access Grant Channel (AGCH)**
  Used to allocate SDCCH to a MS, downlink only.

**Dedicated Control Channels (DCCH)**

- **Stand alone Dedicated Control Channel (SDCCH)**
  Used for signaling during the call set-up or registration, up- and downlink.

- **Slow Associated Control Channel (SACCH)**
  Control channel associated with a Traffic Channel (TCH) or a SDCCH, up- and downlink. On this channel the measurement reports are sent on uplink, and timing advance and power orders on downlink.
• Fast Associated Control CHannel (FACCH)

The control channel, FACCH, is associated with a TCH, up- and downlink. FACCH works in a bit-stealing mode, i.e. 20 ms of speech is replaced by a control message. It is used during handover when the SACCH signaling is not fast enough.

Several logical channels can share the same physical channel, or Time Slot (TS). On TS0 (on one carrier per cell, the BCCH-carrier) the broadcast channels and the common control channels are multiplexed.
<table>
<thead>
<tr>
<th>Frame</th>
<th>Downlink</th>
<th>Uplink</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frame</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 1-5** Mapping of logical channels on the BCCH-carrier.  
*F = FCCH, S = SCH, B = BCCH, C = CCCH, I = Idle, Dx = SDCCH, Ax = SACCH*
Eight SDCCHs can share the same physical channel, normally TS 2 on the same frequency as the BCCHs and the CCCHs. This is called a SDCCH/8. A SACCH will be associated with every SDCCH and they will share the same TS.

The SDCCH can be mapped together with the BCCH and CCCH on TS 0. This is called a SDCCH/4. TS 2 can then be used as a TCH. In this way we increase the capacity on the traffic channels, but the capacity will decrease on the SDCCH.

This mapping is useful in cells with only one carrier.

---

**Figure 1-6 Multiplexing of BCCH + CCCH + 4 SDCCH/4 on TS0**
Chapter 2

This chapter contains the Radio Frequency (RF) Guidelines that Ericsson recommends for planning a cellular network.

OBJECTIVES:

Upon completion of this chapter, the student will be able to:

• Perform a power balance
• Obtain design criteria
• Estimate cell coverage
# 2 Radio Frequency (RF) Guidelines

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RF GUIDELINES GSM 900/1800/1900

**INTRODUCTION**

The GSM 900 system is required to operate in the following frequency band, with a carrier spacing of 200 kHz:

| MS transmit, Base receive | (880) 890 - 915 MHz |
| Base transmit, MS receive | (925) 935 - 960 MHz |

*Table 2-1 Frequency band of GSM 900 (values within brackets refer to E-GSM)*

The GSM 1800/1900 systems are required to operate in the following frequency bands (Table 2-2 and Table 2-3), with a carrier spacing of 200 kHz:

| MS transmit, Base receive | 1710-1785 MHz |
| Base transmit, MS receive | 1805-1880 MHz |

*Table 2-2 Frequency band of GSM 1800*

| MS transmit, Base receive | 1850 - 1910 MHz |
| Base transmit, MS receive | 1930 - 1990 MHz |

*Table 2-3 Frequency band of GSM 1900*

**EQUIPMENT CHARACTERISTICS**

In this section the equipment characteristics are presented. All values presented represent guaranteed values from base station, which are intended to be used in link budgets for cell planning. They are valid for all channel types, frequencies and temperatures. The figures for sensitivity and output power may change.

In the GSM specifications reference sensitivity levels are mentioned. As well the BTSs and MSs must meet some predefined performance values in terms of FER, BER and RBER\(^1\) defined in the GSM specification. The actual sensitivity level is defined as the input level for which the performance is met and should be less than a specified limit, called the reference sensitivity level. This section contains reference values

\(^1\) FER=Frame Erasure Ratio; BER=Bit Error Ratio; RBER=Residual Bit Error ratio
for different types of BTS configurations and MS power classes. Here must be noted that these sensitivity figures can change e.g. at high temperature (exceeding 30°C) and for hilly terrain.

RBS 2000

RBS 2000 is the second generation of Ericsson BTSs for GSM. Four different types of RBSs are available: 2101 (2 TRU outdoor cabinet), 2102 (6 TRU outdoor cabinet), 2202 (6 TRU indoor cabinet) and RBS 2302 (2 TRU micro BTS).

For RBS 2101, 2102 and 2202, functional units as for example combiners are included in a Combining and Distribution Unit (CDU). There are three different CDU types, A, C+ and D, all with different characteristics. When selecting CDU type, three different alternatives exist:

- **Maximum Range** (CDU-A). It is designed to maximise the output power and can be used together with a Tower Mounted Amplifier (TMA), see Section 3.4.3. With this alternative up to 2 TRUs can be connected to one antenna in a cell but is configurable up to 6 TRUs.

- **Standard** (CDU-C+). It contains a hybrid combiner, which allows 4 TRUs to be connected to one antenna in a cell but is configurable for up to 12 TRUs. There are two versions, one for Standard GSM (900/1800/1900) and one for Extended GSM (900 only).

- **High Capacity** (CDU-D). It contains a filter combiner, which makes it possible to connect up to 12 TRUs to one antenna in a cell. Using CDU-D, it is not possible to perform synthesizer frequency hopping, only base band hopping.

There is another alternative, **Smart Range**, which allows a CDU-A and a CDU-C+ to be combined in the same cell. This solution combines high coverage with high capacity, up to 6 TRUs per cell can be connected.
Software Power Boost can be used to improve the downlink output power for RBS 2000 and thus achieve better coverage. A prerequisite is that CDU-A is used and that each cell is equipped with 2 TRUs per cell. TX-diversity is then used in order to obtain a downlink diversity gain of 3 dB, which should be added to the link budget.

<table>
<thead>
<tr>
<th>Software Power Boost gain</th>
<th>3 dB</th>
</tr>
</thead>
</table>

The micro base station RBS 2302 is not equipped with any CDU. 3 RBS 2302s can be connected in order to build up to 6 TRUs per cell (note: BTS 7.1 required). Software Power Boost can even be used together with RBS 2302.

The output power, sensitivity and minimum carrier separation of the RBS 2000 series are listed in Table 2-4, Table 2-5 and Table 2-6.

![Figure 2-1 RBS 200 and RBS 2000 TX and RX reference points](image)

<table>
<thead>
<tr>
<th>CDU/RBS</th>
<th>Output power [dBm]</th>
<th>Sensitivity [dBm]</th>
<th>Minimum carrier separation [kHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>44.5</td>
<td>-110(^1)</td>
<td>400(^3)</td>
</tr>
<tr>
<td>C(^2)</td>
<td>41</td>
<td>-110</td>
<td>400(^3)</td>
</tr>
<tr>
<td>C+</td>
<td>41</td>
<td>-110</td>
<td>400(^3)</td>
</tr>
<tr>
<td>C+(E-GSM)</td>
<td>40.5</td>
<td>-109.5</td>
<td>400(^3)</td>
</tr>
<tr>
<td>D (E-GSM)</td>
<td>42</td>
<td>-110</td>
<td>600</td>
</tr>
<tr>
<td>RBS 2302</td>
<td>33</td>
<td>-107</td>
<td>400(^3)</td>
</tr>
</tbody>
</table>

Table 2-4 Output power, sensitivity and minimum carrier separation of RBS 2000. (GSM 900)
### Table 2-5 Output power, sensitivity and minimum carrier separation of RBS 2000. (GSM 1800)

<table>
<thead>
<tr>
<th>CDU/RBS</th>
<th>Output power [dBm]</th>
<th>Sensitivity [dBm]</th>
<th>Minimum carrier separation [kHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>43.5</td>
<td>-110(^1)</td>
<td>400(^3)</td>
</tr>
<tr>
<td>C(^2)</td>
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<td>-110(^1)</td>
<td>400(^3)</td>
</tr>
<tr>
<td>C+</td>
<td>40</td>
<td>-110(^1)</td>
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<tr>
<td>D</td>
<td>41</td>
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</tr>
<tr>
<td>RBS 2302</td>
<td>33</td>
<td>-106</td>
<td>400(^3)</td>
</tr>
</tbody>
</table>

1With TMA the sensitivity is –111.5 dBm. This sensitivity figure applies for antenna feeders with up to 4 dB loss. If the loss between the TMA and the BTS exceeds 4 dB the sensitivity is decreased.

2CDU-C is today replaced by CDU-C+

3The CDU can from a radio performance perspective handle 200 kHz carrier separation, but bursts may then be lost due to low C/A. From a system point of view the consequences of going below 400 kHz are not fully investigated. Problems with for example standing wave alarms may occur. Thus it is recommended to keep 400 kHz carrier separation.

4These sensitivity figures apply for antenna feeders with up to 4 dB loss. If the loss between the TMA and the BTS exceeds 4 dB the sensitivity is decreased.

### RBS 200

RBS 200 belongs to the first generation of Ericsson base stations for GSM. Each cabinet can take 4 TRXs, and the cabinets must be placed indoors. The RBS 200 is designed for different types of combiners: filter combiners and hybrid combiners.

With filter combiners 1 to 8 transmitters can be connected to the same antenna. In order to use 9 to 16 transmitters in a cell, two
filter combiners and two transmitting antennas must be used. Using filter combiners it is not possible to perform synthesizer frequency hopping, only base band hopping.

With one hybrid combiner 2 transmitters can be connected to one antenna and using three combiners 4 transmitters can be connected to the same antenna. Hybrid combiners allow both base band hopping and synthesizer hopping.

Table 2-7 and Table 2-8 shows the output power, sensitivity and minimum carrier separation for the different configurations.

<table>
<thead>
<tr>
<th>Combiner type</th>
<th>Output power [dBm]</th>
<th>Sensitivity without TMA [dBm]</th>
<th>Minimum carrier separation [kHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filter (1-8 TX)</td>
<td>42.5</td>
<td>-107</td>
<td>600</td>
</tr>
<tr>
<td>Hybrid (2 TX)</td>
<td>41.5</td>
<td>-107</td>
<td>400(^1)</td>
</tr>
<tr>
<td>3 x Hybrid (3-4 TX)</td>
<td>38</td>
<td>-107</td>
<td>400(^1)</td>
</tr>
<tr>
<td>RBS 200 Maximum Range</td>
<td>45</td>
<td>-109 with TMA</td>
<td></td>
</tr>
</tbody>
</table>

*Table 2-7 Output power, sensitivity and minimum carrier separation of RBS 200.(GSM 900)*

<table>
<thead>
<tr>
<th>Combiner type</th>
<th>Output power [dBm]</th>
<th>Sensitivity without TMA [dBm]</th>
<th>Minimum carrier separation [kHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filter (1-8 TX)</td>
<td>40</td>
<td>-106</td>
<td>1200</td>
</tr>
<tr>
<td>Hybrid (2 TX)</td>
<td>49.5</td>
<td>-106</td>
<td>400(^1)</td>
</tr>
<tr>
<td>3 x Hybrid (3-4 TX)</td>
<td>36</td>
<td>-106</td>
<td>400(^1)</td>
</tr>
</tbody>
</table>

*Table 2-8 Output power, sensitivity and minimum carrier separation of RBS 205.(GSM 1800)*

\(^1\)The combiner can from a radio performance perspective handle 200 kHz carrier separation, but bursts may then be lost due to low C/A. From a system point of view the consequences of going below 400 kHz are not fully investigated. Problems with for example standing wave alarms may occur. Thus it is recommended to keep 400 kHz carrier separation.
Maxite™

To provide a possibility of extending the limited coverage area of RBS 2302, Maxite™ has been developed. Maxite™ consists of an RBS 2302 together with an Active Antenna Unit (AAU) and a Power Battery Cabinet (PBC). The AAU contains a set of distributed power amplifiers for the transmitted signals, a low noise amplifier for the received signals and an integrated patch antenna. Apart from extending the coverage of the RBS 2302 similar to a macrocell, it also provides the possibility to use thinner antenna feeders. (There is at present no data for Maxite™ for 900 MHz available.)

<table>
<thead>
<tr>
<th>Maxite™ Product</th>
<th>Antenna</th>
<th>Diversity gain</th>
<th>Slant loss</th>
<th>Output power</th>
<th>Sensitivity</th>
<th>Minimum carrier separation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxite 500 W</td>
<td>17.5 dBi</td>
<td>3.5 dB</td>
<td>1.5 dB</td>
<td>39.5 dBm</td>
<td>-110 dBm</td>
<td>400 kHz</td>
</tr>
</tbody>
</table>

Table 2-9 Equipment characteristics of Maxite™ (GSM 1800)

Figure 2-2 Maxite™ TX and RX reference points. Both TX and RX reference points are defined at the antenna inside the AAU.

<table>
<thead>
<tr>
<th>Maxite™ Product</th>
<th>Antenna</th>
<th>Diversity gain</th>
<th>Slant loss</th>
<th>Output power</th>
<th>Sensitivity</th>
<th>Minimum carrier separation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxite 500 W</td>
<td>18.5 dBi</td>
<td>3.5 dB</td>
<td>-</td>
<td>38.5 dBm</td>
<td>-110 dBm</td>
<td>400 kHz</td>
</tr>
<tr>
<td>Maxite 1250 W</td>
<td>21 dBi</td>
<td>3.5 dB</td>
<td>-</td>
<td>40 dBm</td>
<td>-110 dBm</td>
<td>400 kHz</td>
</tr>
</tbody>
</table>

Table 2-10 Equipment characteristics of Maxite™ (GSM 1900)
Mobile station

There are four MS power classes for GSM 900, two for GSM 1800 and one for GSM 1900 described in the GSM Specifications. Typical values of maximum output power and sensitivity are shown in Table 2-11, Table 2-12 and Table 2-13. The figures are specified at the MS antenna connector.

<table>
<thead>
<tr>
<th>MS power class</th>
<th>Output power [dBm]</th>
<th>Sensitivity [dBm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>39</td>
<td>-106</td>
</tr>
<tr>
<td>3</td>
<td>37</td>
<td>-106</td>
</tr>
<tr>
<td>4 (handheld)</td>
<td>33</td>
<td>-104</td>
</tr>
<tr>
<td>5 (handheld)</td>
<td>29</td>
<td>-104</td>
</tr>
</tbody>
</table>

*Table 2-11 MS power classes. (GSM 900)*

According to the GSM Specification, the sensitivity is –102 dBm for small (handheld) MSs. However experiences from leading mobile manufacturers show that the sensitivity is 2 – 4 dB better and therefore this value is set to -104 dBm.

No loss or antenna gain should be used for the MSs.

<table>
<thead>
<tr>
<th>MS antenna gain: 0 dBi</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>MS power class</th>
<th>Output power [dBm]</th>
<th>Sensitivity [dBm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>-104</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>-104</td>
</tr>
</tbody>
</table>

*Table 2-12 MS power classes. (GSM 1800)*

<table>
<thead>
<tr>
<th>MS power class</th>
<th>Output power [dBm]</th>
<th>Sensitivity [dBm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>-104</td>
</tr>
</tbody>
</table>

*Table 2-13 MS power classes. (GSM 1900)*
Antenna near part

Base station feeders and jumpers

When calculating the power budget, the feeder loss must be taken into account. The most commonly used feeder type is 7/8”. In Table 2-14, the losses for the most common macrocell feeder types are listed.

<table>
<thead>
<tr>
<th>Feeder type</th>
<th>900 [dB/100m]</th>
<th>1800/1900 [dB/100m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCF 1/2”</td>
<td>7.2</td>
<td>10.5</td>
</tr>
<tr>
<td>LCF 7/8”</td>
<td>4.0</td>
<td>6.5</td>
</tr>
<tr>
<td>LCF 1-1/4”</td>
<td>3.0</td>
<td>5.3</td>
</tr>
<tr>
<td>LCF 1-5/8”</td>
<td>2.5</td>
<td>4.2</td>
</tr>
</tbody>
</table>

Table 2-14 Attenuation in some feeder types at 900/1800/1900 MHz.

Apart from the feeder loss, additional loss will arise in jumpers and connectors. Typical values are 0.5 dB for every jumper and 0.1 dB for every connector.

External filters

Duplex filters make it possible to use the same antenna for transmission and reception. When an external duplex filter is used there will be an additional loss in both uplink and downlink.

Apart from external duplexers, some TMAs contain duplex filters. Duplex filters can be used with RBS 200/205; RBS 2000 contains internal filters.

<table>
<thead>
<tr>
<th>Devise</th>
<th>Typical loss [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>External duplex filter</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 2-15 Duplex attenuation values
Diplex filters make it possible to use the same feeders for GSM 900 as GSM 1800 in a dual band site. They are needed in order to differentiate the two frequency bands.

<table>
<thead>
<tr>
<th>Device</th>
<th>Typical loss [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>External diplex filter</td>
<td>0.3</td>
</tr>
</tbody>
</table>

*Table 2-16 Diplex attenuation values*

**Tower Mounted Amplifiers**

In order to improve the sensitivity on the uplink a Tower Mounted Amplifier (TMA) can be used. The purpose of the TMA is to amplify the received signal before it is further attenuated in the antenna feeder.

<table>
<thead>
<tr>
<th>TMA products</th>
<th># Duplexers</th>
<th>TMA downlink loss [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBS 2000 TMA 900 Simplex</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RBS 2000 TMA 900 Dual Duplex</td>
<td>2</td>
<td>0.3</td>
</tr>
</tbody>
</table>

*Table 2-17 TMA products for RBS 2000 (GSM 900).*

<table>
<thead>
<tr>
<th>TMA products</th>
<th># Duplexers</th>
<th>TMA downlink loss [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBS 2000 TMA 1800 Simplex</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RBS 2000 TMA 1800 Dual</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td>RBS 2000 TMA 1800 Dual Duplex</td>
<td>2</td>
<td>0.3</td>
</tr>
</tbody>
</table>

*Table 2-18 TMA products for RBS 2000 (GSM 1800).*
Table 2-19 TMA products for RBS 2000 (GSM 1900).

With a TMA the receiver sensitivity will not be affected by the loss in the feeder as long as it does not exceed 4 dB. When the loss exceeds 4 dB the sensitivity decreases according to Table 2-20. For example the sensitivity of CDU-A with a feeder loss of 8 dB between the RBS and the TMA would become $-111.5 + 1.5 = -110$ dBm at the TMA connector (GSM 900).

<table>
<thead>
<tr>
<th>TMA products</th>
<th># Duplexers</th>
<th>TMA downlink loss [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBS 2000 TMA 1900 Simplex</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RBS 2000 TMA 1900 Dual</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td>RBS 2000 TMA 1900 Dual Duplex</td>
<td>2</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table 2-20 Sensitivity deterioration when the loss between the TMA and the BTS exceeds 4 dB. These figures were measured with a TMA amplification of 12 dB. Some TMAs can amplify the signal more and in this case the deterioration decreases.

<table>
<thead>
<tr>
<th>Loss [dB]</th>
<th>Sensitivity deterioration [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 4</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0.5</td>
</tr>
<tr>
<td>8</td>
<td>1.5</td>
</tr>
<tr>
<td>10</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Diversity

One way of reducing the influence of multipath fading in the uplink is to use antenna diversity. In the Ericsson GSM system this means that the signals from two RX branches are decoded and the most probable bit values are chosen on a bit per bit basis. The result of the method is equivalent to maximum likelihood estimation. The antenna diversity gain will depend on the correlation between the fading of two antenna signals as well as the efficiency in power reception of the two separate antennas. There are two different types of antenna diversity: space diversity and polarization diversity.

Polarization diversity offers relief by allowing two space diversity antennas separated by several meters to be replaced by one dual polarized antenna. This antenna has normal size but contains two antenna arrays with different polarization.
It has been shown that due to different propagation characteristics the propagation loss for the horizontally polarized component is larger than for the vertical component. This consequence is that an extra “slant loss” margin of 1.5 dB must be added to the normal path loss when ±45° polarized antennas are used. However, a dual polarized antenna offers very low correlation in critical environments such as indoor and in-car. In these situations the diversity gain of polarization is about 1.5 dB better than space diversity. This is just enough to compensate for the slant loss. For simplicity the uplink slant loss is in this document included in the diversity gain. This means that for space as well as polarization diversity the uplink gain is 3.5 dB, and that no slant loss should be added to the uplink.

| Space and polarization diversity gain | 3.5 dB |

In order to compensate for the downlink slant loss, 1.5 dB must be added to the downlink propagation loss.

| Slant (±45°) polarization downlink loss | 1.5 dB |
CELL COVERAGE

Previous sections present the sensitivity levels for both the MS and the BTS. However, when planning a system it is not sufficient to use this sensitivity level as a planning criterion. Various margins have to be added in order to obtain the desired coverage. In this chapter these margins are discussed and the planning criteria used in different types of environments are presented. Furthermore, the principles of how to perform coverage acceptance tests are described.

Definitions

Required signal strength

Margins have to be added to the sensitivity level of an MS, to compensate for Rayleigh fading, interference, and body loss. The obtained signal strength is what is required to perform a phone call in a real-life situation and will be referred to as $SS_{req}$. $SS_{req}$ is independent of the environment.

$$SS_{req} = MS_{sens} + RF_{marg} + IF_{marg} + BL$$  \hspace{1cm} (1)

where

$MS_{sens}$ = MS sensitivity

$RF_{marg}$ = Rayleigh fading margin

$IF_{marg}$ = Interference margin

$BL$ = Body loss
Design level

Extra margins have to be added to $SS_{req}$ to handle the log-normal fading as well as different types of penetration losses. These margins depend on the environment and on the desired area coverage. The obtained signal strength is what should be used when planning the system, and it will be referred to as the design level ($SS_{design}$). This signal strength is the value that should be obtained on the cell border when planning with prediction tools such as EET/TEMS CellPlanner.

The design level can be calculated from:

$$SS_{design} = SS_{req} + LNF_{marg(o)} \quad MS \text{ outdoor} \quad (2)$$

$$SS_{design} = SS_{req} + LNF_{marg(o)} + CPL \quad MS \text{ in-car} \quad (3)$$

$$SS_{design} = SS_{req} + LNF_{marg(o+i)} + BPL_{mean} \quad MS \text{ indoor} \quad (4)$$

where

$$LNF_{marg(o)} = \text{Outdoor log-normal fading margin.}$$

$$LNF_{marg(o+i)} = \text{Outdoor + indoor log-normal fading margin,}$$

$$CPL = \text{Car penetration loss}$$

$$BPL_{mean} = \text{Mean building penetration loss}$$

Margins

Rayleigh fading

Rayleigh fading is due to multipath interference and it has a peak to peak distance of approximately $\lambda/2$.

The required sensitivity performance of GSM in terms of FER, BER, or RBER$^2$ is specified for each type of channel and at different fading models (called channel models). The channel models reflect different types of propagation environment and different MS speeds. The sensitivity is measured under simulated Rayleigh fading conditions for all the different channel models; the sensitivity is defined as the level where the required quality performance is achieved. In a noise limited environment, the sensitivity is the one listed previously. This

---

$^2$ FER = Frame Erasure Ratio; BER = Bit Error Ratio; RBER = Residual Bit Error Ratio
would mean that Rayleigh fading is already taken into consideration in the sensitivity definition.

However, the GSM standard allows less quality for slow MSs than for moving MSs. The sensitivity performance at fading conditions corresponding to an MS speed of 50 km/h (called TU50) is in accordance with good speech quality, while the sensitivity performance at 3 km/h (TU3) does not correspond to acceptable speech quality.

In order to obtain good speech quality even for slow mobiles, an extra margin \( RF_{\text{marg}} \) is recommended when planning. From experience, 3 dB margin seems adequate (see Table 2-21). In a frequency hopping system, the Rayleigh fading dips are leveled out, and there is no need for a Rayleigh fading margin. Also, antenna diversity reduces the effect of Rayleigh fading but in a different way than frequency hopping. Therefore, diversity gain is still relevant in frequency hopping systems.

Note: In cell coverage estimations, no actual frequency hopping gain is used, except for the omitted \( RF_{\text{marg}} \). For simplicity the diversity gain figure is considered independent of frequency hopping and MS speed distribution.

<table>
<thead>
<tr>
<th>Slow MSs, no FH</th>
<th>FH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rayleigh fading margin ( RF_{\text{marg}} )</td>
<td>3 dB</td>
</tr>
</tbody>
</table>

*Table 2-21*

**Log-normal fading**

The signal strength value computed by wave propagation algorithms can be considered as a mean value of the signal strength in a small area with a size determined by the resolution and accuracy of the model. Assume that fast fading is removed, the local mean value of the signal strength fluctuates in a way not considered in the prediction algorithm. This deviation of the local mean in dB compared to the predicted mean has an almost normal distribution. Therefore, this variation is called log-normal fading.

The received signal strength is a random process, and it is only possible to estimate the probability that the received signal strength exceeds a certain threshold. In the result from a prediction in (e.g. TEMS CellPlanner) 50% of the locations (for example, at the cell borders) can be considered to have a signal strength that exceeds the predicted value. In order to plan for
more than 50% probability of signal strength above the threshold, a log-normal fading margin \( LNF_{\text{marg}} \) is added to the threshold during the design process.

**Jakes’ formula**

A common way to calculate \( LNF_{\text{marg}} \) is to use Jakes’ formula. In Jakes’ formula a simple radial path loss dependence \( (1/r^n) \) is assumed in order to calculate the percentage of area within a cell with signal strength exceeding a certain threshold related to the percentage of locations at the cell border having a signal that exceeds the same threshold. The border coverage corresponding to a desired area coverage is given when the threshold referred to is the required signal strength in the MS. The margin in dB \( LNF_{\text{marg}} \) to go from the original 50% coverage at the cell border to the given border percentage is \( x \times \text{Standard deviation} \). \( x \) is the variable in the cumulative normal function \( F(x) \) when \( F(x) \) has the value of the border percentage given by Jakes’ formula. Curves of Jakes’ formula and \( F(x) \) are shown at the end of this chapter, figure 2-7 and figure 2-8 respectively.

**Simulation of log-normal fading margin in a multi-cell environment**

A disadvantage with Jakes’ formula is that it does not take the effect of many servers into account. The presence of many servers at the cell borders will reduce the required log-normal margin. This is because the fading pattern of different servers is fairly independent. If the signal from one server fades down below the sensitivity level, a neighbor cell can fill out the gap and rescue the connection.

In order to find the log-normal fading margins in a multi-cell environment, simulations have been performed.

The prerequisites for the simulations are:

- Omni\(^3\) cells with propagation loss proportional to \( 35 \log(d) \)
- Correlation of log-normal fading between neighbor cells is 0.5
- The time to perform a handover is neglected

Five different environments \( \sigma_{LNF} = 6, 8, 10, 12, 14 \) have been studied. For each of these cases, four different curves are

---

\(^3\) Simulations indicate that the difference between omni and sector cells is marginal.
presented representing the handover hystereses 0, 3, 5 and 100 dB between the cells. 100 dB corresponds to a single cell (Jakes’ case) and 3 dB is what is usual in a standard macrocell network. In order to find the required value of $LNF_{marg}$:

1. Pick the graph corresponding to the fading environment
2. Choose the curve corresponding to the hysteresis in question (usually 3 dB)
3. On the X axis, find the log-normal fading margin for the desired area coverage (Y-axis)

**Log-normal fading margins**

The size of the log-normal fading margin is given in Table 2-22 for different types of fading environments and area coverage. The values originate from the simulations described previously. A multi-cell environment with a handover hysteresis of 3 dB is assumed.

<table>
<thead>
<tr>
<th>Coverage [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$\sigma_{LNF}$ [dB]</strong></td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>14</td>
</tr>
</tbody>
</table>

*Table 2-22 Log-normal fading margins ($LNF_{marg}$) in dB for different environments*

**Interference**

The plain receiver sensitivity depends on the required carrier to noise ratio (C/N). When frequencies are reused, the received carrier power must be large enough to combat both noise and interference; that means $C/(N+I)$ must exceed the receiver threshold. In order to get an accurate coverage prediction in a busy system, an interference margin ($IF_{marg}$) is defined.
The interference margin depends on the frequency reuse, the traffic load, the desired percentage of area coverage, and whether the uplink or the downlink is considered. Frequency hopping, dynamic power control, and particularly DTX reduce the interference level. In a normal system, an interference margin of 2 dB is recommended.

\[
\text{Interference margin (IF_{marg})} = 2 \text{ dB}
\]

**Body loss**

The human body has several effects on the MS performance compared to a free standing mobile phone:

- The head absorbs energy
- The antenna efficiency of some MSs can be reduced
- Other effects may be a change of the lobe direction and the polarization. These effects can be neglected in the link budget since:
  - no mobile antenna gain is used
  - X-polarized antennas are standard equipment today

In this case, the polarization loss is included in the downlink link budget. In the uplink, both polarizations can be received. The body loss is less for higher frequencies than for lower. The body loss recommended by ETSI is 3 dB; however, this matter is not fully investigated. For 900 MHz, a need for another 2 dB has been indicated.

\[
\begin{array}{|c|c|}
\hline
\text{Body loss (BL)} & 5 \text{ dB} \\
\hline
\text{Body loss (BL)} & 3 \text{ dB} \\
\hline
\end{array}
\]

(900 MHz)  (1800/1900 MHz)
Car penetration loss

When the MS is situated in a car without an external antenna, an extra margin has to be added in order to cope with the penetration loss of the car. This extra margin is approximately 6 dB.

\[
\text{Car penetration loss (CPL)} = 6 \text{ dB}
\]

Design levels

In this section the design levels (\(SS_{\text{design}}\)) are calculated for outdoor, in-car, and indoor coverage for GSM 900 (the difference for GSM 1800/1900 is the body loss). This signal strength is calculated as the sum of the required signal strength (\(SS_{\text{req}}\)) and various margins (see equations 2, 3, and 4). In this section, the value of \(SS_{\text{req}}\) has been taken to be:

\[
SS_{\text{req}} = MS_{\text{term}} + RF_{\text{marg}} + IF_{\text{marg}} + BL = -104 + 3 + 2 + 5 = -94 \text{ dBm} \quad (5)
\]

Outdoor and in-car coverage

The design levels for outdoor and in-car coverage are calculated according to

\[
\begin{align*}
SS_{\text{design}} &= SS_{\text{req}} + LNF_{\text{marg(o)}} & \text{MS outdoor} \\
SS_{\text{design}} &= SS_{\text{req}} + LNF_{\text{marg(o)}} + CPL & \text{MS in-car}
\end{align*}
\]

where \(LNF_{\text{marg(o)}}\) is the log-normal fading margin that is needed to handle the outdoor log-normal fading. This fading will be represented by its standard deviation \(\sigma_{\text{LNF(o)}}\) and depends on the area type. Typical values of \(\sigma_{\text{LNF(o)}}\) are presented in Table 2-23.

<table>
<thead>
<tr>
<th>Area type</th>
<th>(\sigma_{\text{LNF(o)}}) [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense urban</td>
<td>10</td>
</tr>
<tr>
<td>Urban</td>
<td>8</td>
</tr>
<tr>
<td>Suburban</td>
<td>6</td>
</tr>
<tr>
<td>Rural</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 2-23 Typical values of the standard deviation of the outdoor log-normal fading for different area types.
In Table 2-24 the design levels $SS_{\text{design}}$, for different area types and coverage requirements are calculated. The value of $LNF_{\text{marg(o)}}$ is calculated according to simulations, which includes the multi-server gain. A hysteresis value of 3 dB between the cells has been used.

<table>
<thead>
<tr>
<th>Area type</th>
<th>Coverage [%]</th>
<th>$SS_{\text{req}}$ [dBm]</th>
<th>$LNF_{\text{marg(o)}}$ [dB]</th>
<th>$SS_{\text{design}}$ outdoor [dBm]</th>
<th>$SS_{\text{design}}$ in-car [dBm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense urban $\sigma_{LNF(o)} = 10$ dB</td>
<td>75</td>
<td>-94</td>
<td>-3</td>
<td>-97</td>
<td>-91</td>
</tr>
<tr>
<td></td>
<td>85</td>
<td>-94</td>
<td>0</td>
<td>-94</td>
<td>-88</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>-94</td>
<td>3</td>
<td>-91</td>
<td>-85</td>
</tr>
<tr>
<td></td>
<td>95</td>
<td>-94</td>
<td>6</td>
<td>-88</td>
<td>-82</td>
</tr>
<tr>
<td></td>
<td>99</td>
<td>-94</td>
<td>12</td>
<td>-82</td>
<td>-76</td>
</tr>
<tr>
<td>Urban $\sigma_{LNF(o)} = 8$ dB</td>
<td>75</td>
<td>-94</td>
<td>-3</td>
<td>-97</td>
<td>-91</td>
</tr>
<tr>
<td></td>
<td>85</td>
<td>-94</td>
<td>0</td>
<td>-94</td>
<td>-88</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>-94</td>
<td>2</td>
<td>-91</td>
<td>-86</td>
</tr>
<tr>
<td></td>
<td>95</td>
<td>-94</td>
<td>5</td>
<td>-89</td>
<td>-83</td>
</tr>
<tr>
<td></td>
<td>99</td>
<td>-94</td>
<td>10</td>
<td>-84</td>
<td>-78</td>
</tr>
<tr>
<td>Suburban + rural $\sigma_{LNF(o)} = 6$ dB</td>
<td>75</td>
<td>-94</td>
<td>-3</td>
<td>-97</td>
<td>-91</td>
</tr>
<tr>
<td></td>
<td>85</td>
<td>-94</td>
<td>-1</td>
<td>-95</td>
<td>-89</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>-94</td>
<td>1</td>
<td>-93</td>
<td>-87</td>
</tr>
<tr>
<td></td>
<td>95</td>
<td>-94</td>
<td>3</td>
<td>-91</td>
<td>-85</td>
</tr>
<tr>
<td></td>
<td>99</td>
<td>-94</td>
<td>7</td>
<td>-87</td>
<td>-81</td>
</tr>
</tbody>
</table>

Table 2-24 Design levels for various area types and coverage requirements. A car penetration loss (CPL) of 6 dB has been used.

**Indoor coverage**

**Definitions**

**Indoor coverage**

Indoor coverage is the percentage of the ground floors of all the buildings in the area where the signal strength is above the required signal level of the mobiles ($SS_{\text{req}}$).
Building penetration loss

Building penetration loss is defined as the difference between the average signal strength immediately outside the building and the average signal strength over the ground floor of the building. The building penetration loss for different buildings is log-normal distributed with a standard deviation ($\sigma_{\text{BPL}}$). Variations of the loss over the ground floor could be described by a stochastic variable which is log-normal distributed with a zero mean value and a standard deviation of $\sigma_{\text{floor}}$. In this chapter, $\sigma_{\text{BPL}}$ and $\sigma_{\text{floor}}$ are lumped together by adding the two as if they were standard deviations in two independent log-normal distributed processes. The resulting standard deviation ($\sigma_{\text{indoor}}$ or $\sigma_{\text{LNF(i)}}$) could be calculated as the square root of the sum of the squares.

General

Indoor coverage concerns calculation of a required margin to achieve a certain indoor coverage in a fairly large area (large compared to the average macrocell size). It is assumed that it is the macrocells in the area that provide the major part of the indoor coverage. Hotspot microcells in the area will improve on the indoor coverage, but that effect is not covered in this chapter.

The guidelines in this chapter regarding indoor coverage are not applicable to the case where the area of interest is covered by contiguous microcells and where macrocells are only used as umbrella cells.

It is common knowledge that the building penetration loss to floors higher up generally decreases. This effect is known as height gain. This is an effect of the building penetration loss definition and not of the building structure.

Indoor design level

The design level for indoor is calculated according to

$$SS_{\text{design}} = SS_{\text{req}} + LNF_{\text{marg(o+i)}} + BPL_{\text{mean}}$$

MS indoor

where the sum of $BPL_{\text{mean}}$ and $LNF_{\text{marg(o+o)}}$ can be seen as the indoor margin. $BPL_{\text{mean}}$ is the mean value of the building penetration loss, and $LNF_{\text{marg(o+o)}}$ is the margin that is required to handle the total log-normal fading -- which is composed of both the outdoor log-normal fading ($\sigma_{\text{LNF(o)}}$) and the indoor log-
normal fading ($\sigma_{\text{LNFI}}$). The total standard deviation of the log-normal fading is given by

$$\sigma_{\text{LNF(o+i)}} = \sqrt{\sigma_{\text{LNF(o)}}^2 + \sigma_{\text{LNFI}}^2} \quad (6)$$

In Table 2-25, some values of $\text{BPL}_{\text{mean}}$, $\sigma_{\text{LNFO}}$ and $\sigma_{\text{LNFI}}$ are presented. Note that the characteristics of different urban, suburban, and dense urban environments can differ quite a lot over the world. Thus the values in Table 2-25 must be treated with restraint. They should be considered as a reasonable approximation when no other information is obtainable. Rural areas are not considered in Table 2-25 as they are usually not designed for indoor coverage.

<table>
<thead>
<tr>
<th>Area Type</th>
<th>$\text{BPL}_{\text{mean}}$ [dB]</th>
<th>$\sigma_{\text{LNFO}}$ [dB]</th>
<th>$\sigma_{\text{LNFI}}$ [dB]</th>
<th>$\sigma_{\text{LNF(o+i)}}$ [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense urban</td>
<td>18</td>
<td>10</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>Urban</td>
<td>18</td>
<td>8</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Suburban</td>
<td>12</td>
<td>6</td>
<td>8</td>
<td>10</td>
</tr>
</tbody>
</table>

*Table 2-25 Some typical values of building penetration loss and log-normal fading for different area types*

In Table 2-26, the design levels required to obtain 75%, 85%, 90%, 95%, and 99% indoor coverage are given.

The parameters for the building penetration and the log-normal fading are taken to be those presented in Table 2-25.

The log-normal fading margins are given by the simulations in the end of this chapter. A multicell environment has been assumed with a hysteresis value of 3 dB.
Table 2-26 Indoor design level for various area types and coverage requirements.

### Coverage acceptance testing

#### General

The verification of a cell plan is done by performing measurements in the system. The aim is to measure the signal strengths and to estimate if the received level corresponds to the signal strength design level ($SS_{design}$), thus it is important to agree upon the value of $SS_{design}$ before signing any contracts. The recommended equipment to use in acceptance test is a TEMS mobile phone with roof-top antenna. This equipment shall be used in all acceptance cases below.

In order to be connected to the best server as much as possible during the acceptance test, a pure signal strength ranking (K-
ranking) shall be used in the locating algorithm. In addition, a small handover hysteresis, e.g. 3 dB shall be used. Power Control downlink shall also be switched off.

Compensation should be made for different objects affecting the measured values, i.e. feeder loss and antenna gain in the external antenna.

**Outdoor**

The acceptance level to verify is the signal strength design level \((SS_{design})\) for outdoor coverage minus the outdoor log-normal fading margin \((LNF_{marg}(0))\). Thus the acceptance level for outdoor equals the required signal strength \((SS_{req})\). This level should be measured at least in \(A\%\) of the samples, where \(A\) represents the required area coverage.

<table>
<thead>
<tr>
<th>Criteria for downlink signal strength</th>
<th>Rural, 95% outdoor coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptance level, ((SS_{req})) dBm or better in 95% of the samples</td>
<td>-94</td>
</tr>
</tbody>
</table>

*Example 1 95% outdoor coverage*

**In-car**

The acceptance level to verify is the signal strength design level \((SS_{design})\) for in-car coverage minus the log-normal fading margin \((LNF_{marg}(0))\). This equals \(SS_{req}\) plus the car penetration loss CPL. This level should be measured at least in \(A\%\) of the samples, where \(A\) represents the required area coverage.

<table>
<thead>
<tr>
<th>Criteria for downlink signal strength</th>
<th>Rural, 95% in-car coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptance level, ((SS_{req})) dBm or better in 95% of the samples</td>
<td>-88</td>
</tr>
</tbody>
</table>

*Example 2 95% in-car coverage*
Indoor

To verify indoor coverage, subtract the outdoor log-normal fading margin $LNF_{marg(o)}$ corresponding to the desired coverage (A%) from the $SS_{design}$ value. This level should be measured at least in A% of the samples.

<table>
<thead>
<tr>
<th>Criteria for downlink signal strength</th>
<th>Rural, 95% in-car coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>$SS_{design}$ [dBm]</td>
<td>-68</td>
</tr>
<tr>
<td>Acceptance level, $(SS_{design} - LNF_{marg(o)}$ dBm) or better in 95% of the samples</td>
<td>-73</td>
</tr>
</tbody>
</table>

Example 3 95% indoor coverage

CELL PLANNING

Wave propagation models for estimation

When roughly estimating the cell coverage (without respect to specific terrain features in the area) a fairly simple propagation algorithm can be used. That means the diffraction loss due to “knife edge” and “spherical earth” are ignored. The standard is to employ the original form of the Okumura-Hata algorithm. The equation below describes the propagation loss $Lp$:

$$Lp = A - 13.82 \log h_B + (44.9 - 6.55 \log h_B) \log d - a(h_M) \text{ [dB]}$$ (9)

where

$$A = \begin{cases} 
146.8 & \text{(900)} \\
153.8 & \text{(1800)} \\
154.3 & \text{(1900)} 
\end{cases} \text{ urban area}$$

$$A = \begin{cases} 
136.9 & \text{(900)} \\
146.2 & \text{(1800)} \\
146.9 & \text{(1900)} 
\end{cases} \text{ suburban and semi open areas}$$

$$A = \begin{cases} 
118.3 & \text{(900)} \\
124.3 & \text{(1800)} \\
124.8 & \text{(1900)} 
\end{cases} \text{ open areas}$$

$h_B$ = base station antenna height [m]

$d$ = distance from transmitter [km]

$h_M$ = mobile station antenna height [m]

$a(h_M) = 3.2(\log 11.75h_M)^2 - 4.97$
The cell range is the distance \( d \) corresponding to maximum allowed path loss \( L_{p_{\text{max}}} \). According to Okumura-Hata the range is

\[
d = 10^a \quad \text{where} \quad a = \frac{L_{p_{\text{max}}} - A + 13.82 \log h_b + a(h_m)}{44.9 - 6.55 \log h_b}
\]  

(10)

\[
\text{Area} = \frac{3}{2} \sqrt{3} R^2 \quad \text{d} = R = \text{cell range} \\
\text{Area} = \frac{3}{4} \sqrt{3} R^2 \quad \text{d} = 2R = \text{cell range}
\]

Figure 2-3 Relation between coverage area and cell range

**Power budget**

Path balance implies that the coverage of the downlink is equal to the coverage of the uplink. The power budget shows whether the uplink or the downlink is the weak link. When the downlink is stronger, the EiRP used in the prediction should be based on the balanced BTS output power. When the uplink is stronger, the maximum BTS output is used instead. Practice indicates that it is advantageous to have a somewhat higher base EiRP (2-3 dB) than the one strictly calculated from power balance considerations.

The antenna gain in the MS and the MS feeder loss are both zero and, therefore, omitted.

It is also assumed that the antenna gain and the feeder loss are the same for the transmitter and receiver side on the BTS.

The following abbreviations are used:

\[
\begin{align*}
P_{\text{in}}_{\text{MS}} & = \text{Received power in MS} \quad \text{[dBm]} \\
M_{\text{sens}} & = \text{Sensitivity MS} \quad \text{[dBm]} \\
P_{\text{in}}_{\text{BTS}} & = \text{Received power in BTS} \quad \text{[dBm]} \\
B_{\text{sens}} & = \text{Sensitivity BTS} \quad \text{[dBm]} \\
P_{\text{out}}_{\text{MS}} & = \text{Transmitted power from MS} \quad \text{[dBm]}
\end{align*}
\]
\[
P_{\text{out}}_{\text{BTS}} = \text{Transmitted power from BTS} \quad \text{[dBm]}
\]
\[
L_{f_{\text{BTS}}} = \text{Feeder and jumper loss at BTS} \quad \text{[dB]}
\]
\[
L_{\text{dupl}_{\text{BTS}}} = \text{Duplex loss at BTS} \quad \text{[dB]}
\]
\[
L_{\text{TMA}} = \text{Duplex loss at TMA} \quad \text{[dB]}
\]
\[
L_{\text{slant}_{\text{BTS}}} = \text{Slant polarization (±45°) downlink loss} \quad \text{[dB]}
\]
\[
L_{p} = \text{Path loss between MS and BTS} \quad \text{[dB]}
\]
\[
G_{a_{\text{BTS}}} = \text{Antenna gain in BTS} \quad \text{[dBi]}
\]
\[
G_{d_{\text{BTS}}} = \text{Diversity gain in BTS} \quad \text{[dB]}
\]
\[
D_{s} = \text{MS sens} - \text{BTS sens} \quad \text{[dB]}
\]

**Downlink budget:**

Downlink (DL) is the direction from the BTS to the MS. The downlink budget gives the power level received in the MS.

**Uplink budget:**

Uplink (UL) is the direction from the MS to the BTS. The uplink budget gives the power level received in the base station.

**Power balance**

**Power balance without TMA**

Please refer to figure 2-5.

![Figure 2-4 Loss and gain in the antenna system](image)
The formula for the received power in MS \((P_{in_{MS}})\) for the downlink (DL) is as follows:

\[
DL: \quad P_{in_{MS}} = P_{out_{BTS}} - (L_{dupl_{BTS}}) - L_{f_{BTS}} + G_{a_{BTS}} - (L_{slant_{BTS}}) - L_p \quad (11)
\]

The formula for \(P_{in_{BTS}}\) for uplink (UL) is as follows:

\[
UL: \quad P_{in_{BTS}} = P_{out_{MS}} - L_p + G_{a_{BTS}} + G_{d_{BTS}} - L_{f_{BTS}} - (L_{dupl_{BTS}}) \quad (12)
\]

\(P_{in_{BTS}}\) is referenced to RX ref. point and \(P_{out_{BTS}}\) is referenced to TX ref. point. The duplex loss within parentheses holds for RBS 200, and the slant loss holds for slant-polarized antennas.

Assuming that the path loss is reciprocal, i.e. \(L_{p_{uplink}} = L_{p_{downlink}}\).

Then (11) and (12) give

\[
P_{out_{BTS}} = P_{out_{MS}} + G_{d_{BTS}} + (L_{slant_{BTS}}) + P_{in_{MS}} - P_{in_{BTS}} \quad (13)
\]

To calculate the BTS output power that makes the system balanced for a certain MS power class the following formula is used:

\[
P_{out_{bal}} = P_{out_{MS}} + G_{d_{BTS}} + (L_{slant_{BTS}}) + D_S \quad (14)
\]

where the difference between the BTS and MS receiver sensitivity is referred to as \(D_S = MS_{sens} - BTS_{sens}\).

The corresponding \(EiRP\) is given by

\[
EiRP = P_{out_{bal}} - (L_{dupl_{BTS}}) - L_{f_{BTS}} + G_{a_{BTS}} - (L_{slant_{BTS}}) \quad (15)
\]

Example without TMA:

In Table 2-27 the balanced BTS output power for RBS 2000 equipped with CDU-A, and ±45° polarized antenna is calculated. The calculation is done according to equation (14). As can be seen the uplink is much weaker compared to the example with TMA.
<table>
<thead>
<tr>
<th></th>
<th>MS class 4</th>
<th>MS class 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{out_{MS}}$ [dBm]</td>
<td>33</td>
<td>29</td>
</tr>
<tr>
<td>$G_{d_{BTS}}$ [dBm]</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>$L_{slant_{BTS}}$ [dBm]</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>$D_s$ [dBm]</td>
<td>-104-(-110) = 6</td>
<td>-104-(-110) = 6</td>
</tr>
<tr>
<td>$P_{out_{tot}}$ [dBm]</td>
<td>44</td>
<td>40</td>
</tr>
</tbody>
</table>

*Table 2-27 Balanced BTS output power at TX reference point (GSM 900).*

**Power balance with TMA at the antenna**

Please refer to Figure 2-5.

![Figure 2-5 System with TMA at the antenna.](image)

The formula for $P_{in_{MS}}$ for downlink (DL) is as follows:

$$DL: \quad P_{in_{MS}} = P_{out_{BTS}} - L_{f_{BTS}} - (L_{dup_{BTS}}) + G_{a_{BTS}} - L_{TMA} - (L_{slant_{BTS}}) - L_{p}$$

(16)

The formula for $P_{in_{BTS}}$ for uplink (UL) is as follows:

$$UL: \quad P_{in_{BTS}} = P_{out_{MS}} - L_{p} + G_{a_{BTS}} + G_{d_{BTS}}$$

(17)

Assuming that the path loss is reciprocal i.e. $L_{p_{uplink}} = L_{p_{downlink}}$

then (16) and (17) give:

$$P_{out_{BTS}} = P_{out_{MS}} + G_{d_{BTS}} + L_{f_{BTS}} + L_{TMA} + (L_{dup_{BTS}}) + (L_{slant_{BTS}}) + P_{in_{MS}} - P_{in_{BTS}}$$

(18)
To calculate the BTS output power that makes the system balanced for a certain MS power class the following formula is used:

\[ P_{out_{bal}} = P_{out_{MS}} + G_d_{BTS} + L_{f_{BTS}} + (L_{dupl_{BTS}}) + (L_{slant_{BTS}}) + D_s \]  

(19)

where the difference between the BTS and MS receiver sensitivity is referred to as \( D_s = MS_{sens} - BTS_{sens} \).

The corresponding \( EiRP \) is given by

\[ EiRP = P_{out_{bal}} - L_{f_{BTS}} - (L_{dupl_{BTS}}) + G_{a_{BTS}} - (L_{slant_{BTS}}) \]  

(20)

**Example with TMA:**

In Table 2-28 Balanced BTS output power at TX reference point (GSM 900), the balanced BTS output power for RBS 2000 equipped with CDU-A, TMA, and ±45° polarized antenna is calculated. No software power boost is used. The calculation is done according to equation (18).

<table>
<thead>
<tr>
<th></th>
<th>MS class 4</th>
<th>MS class 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_{out_{MS}} ) [dBm]</td>
<td>33</td>
<td>29</td>
</tr>
<tr>
<td>( G_d_{BTS} ) [dBm]</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>( L_{f_{BTS}} ) [dBm]</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>( L_{dupl_{BTS}} ) [dBm]</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>( L_{TMA} ) [dBm]</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>( L_{slant_{BTS}} ) [dBm]</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>( D_s ) [dBm]</td>
<td>-104-(-111.5) = 7.5</td>
<td>-104-(-111.5) = 7.5</td>
</tr>
<tr>
<td>( P_{out_{bal}} ) [dBm]</td>
<td>48.8*</td>
<td>44.8*</td>
</tr>
</tbody>
</table>

*The maximum output power for RBS 2000 equipped with CDU-a is 44.5 dBm, thus this example the uplink will become stronger than the downlink.

**Table 2-28 Balanced BTS output power at TX reference point (GSM 900)**

Note that the system, in this example, cannot be balanced for MS class 1 since the highest output power of CDU type A is 43.5 dB. The downlink will not be strong enough.
Cell size

The maximum allowed path loss (\(L_p\)) can be calculated from the downlink power budget:

\[
L_p = E_{iRP} - SS_{design}
\]  

(21)

Once the maximum allowed path loss has been calculated, the corresponding cell size can be determined by using the wave propagation model in previous sections.

Table 30 and Table 31 show the calculated cell range, \(R\), for 95% area coverage and for the macrocell case. The allowed path loss, \(L_{path\text{max}}\), corresponds to outdoor path loss, for power balance according to the handheld class 4 MS in the Example with TMA, Section 5.3.1. \(R\) is calculated with equation (8).

<table>
<thead>
<tr>
<th>EIRP</th>
<th>56.7 dBm sector (17 dBi antenna, X polarized)</th>
<th>52.2 dBi omni (11 dBi antenna, Ver. polarized)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design level ((SS_{design}))</td>
<td>See Table</td>
<td></td>
</tr>
<tr>
<td>Height of MS ((HM))</td>
<td>1.5 m</td>
<td></td>
</tr>
<tr>
<td>Height of BTS antenna ((HB))</td>
<td>30 m</td>
<td></td>
</tr>
</tbody>
</table>

*Table 2-29 Assumptions for the cell sizes calculated in the tables below.*

<table>
<thead>
<tr>
<th>MS class</th>
<th>Area</th>
<th>Outdoor (L_p) [dB]</th>
<th>(R) [km]</th>
<th>In-car (L_p) [dB]</th>
<th>(R) [km]</th>
<th>Indoor (L_p) [dB]</th>
<th>(R) [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>33 dBm (2 W)</td>
<td>urban</td>
<td>145.7</td>
<td>3.5</td>
<td>139.7</td>
<td>2.4</td>
<td>127.7</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>suburban</td>
<td>145.7</td>
<td>7.7</td>
<td>141.7</td>
<td>5.2</td>
<td>132.7</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>open area</td>
<td>145.7</td>
<td>26.0</td>
<td>141.7</td>
<td>17.5</td>
<td>132.7</td>
<td>9.7</td>
</tr>
</tbody>
</table>

*Table 2-30 Cell sizes for sector cell, 95% area coverage (GSM 900).*
When determining the cell range for small cells in urban environments, the Walfish-Ikegami model is recommended. 95% coverage area is considered and the allowed path loss, $L_{\text{pathmax}}$, corresponds to outdoor path loss, for power balance according to the handheld class 4 MS in the example with TMA.

The following assumptions are made:

<table>
<thead>
<tr>
<th>EIRP</th>
<th>56.7 dBm sector (17 dBi antenna, X polarized)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design level ($S_{\text{design}}$)</td>
<td>-68 (see Table)</td>
</tr>
<tr>
<td>Height of MS (HM)</td>
<td>1.5 m</td>
</tr>
<tr>
<td>Height of BTS antenna (HB)</td>
<td>22 m</td>
</tr>
</tbody>
</table>

$\text{Cell size (R) = 700 metres}$

Table 2-32 Assumptions for the cell size for a small cell, 95% indoor coverage in an urban environment (GSM 900).
CURVES OF JAKES’ FORMULA

\[ \sigma = \text{standard deviation} \]
\[ \frac{1}{R^n} = \text{distance dependence} \]

![Figure 2-6 Curves of Jakes’ formula](image)

CUMULATIVE NORMAL FUNCTION

Log-normal fading margin = \[X \times \sigma - \text{HO gain}\]

![Figure 2-7 Log-normal fading margin = X \times \sigma - HO gain](image)
**SIMULATED LOG-NORMAL FADINGS MARGINS**

- **Hysteresis** = 0, 3, 5, 100 dB
- **Inter cell correlation** = 0.5
- **Propagation** = $35 \log(d)$

\[ \sigma = 6 \text{ dB} \]

![Figure 2-8 Log-normal fading margin $\sigma = 6$ dB](image1)

\[ \sigma = 8 \text{ dB} \]

![Figure 2-9 Log-normal fading margin $\sigma = 8$ dB](image2)
Figure 2-10 Log-normal fading margin $\sigma = 10$ dB

Figure 2-11 Log-normal fading margin $\sigma = 12$ dB

Figure 2-12 Log-normal fading margin $\sigma = 14$ dB
This chapter is designed to provide the student with information about antennas.

**OBJECTIVES:**

Upon completion of this chapter, the student will be able to:

- Describe the most important antenna parameters
- Describe space and polarization diversity
- Describe different antenna types
- Explain antenna tilt and null fill-in
# 3 Antennas

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ANTENNA PARAMETERS

GAIN

Since an antenna is passive, the only way to obtain gain in any direction is to increase the directivity by concentrating the radiation in the wanted direction. For a loss free antenna the directivity can be given with the same number as the gain if the latter is given with respect to an isotropic antenna. Hence, in this chapter the distinction between gain and directivity is not always strictly maintained.

The directivity can be increased by reflectors or by stacking dipoles on the same vertical line. The latter method can be used because a number of coherent radiation sources interfere constructively (in directions where they radiate in phase) and destructively (in directions where they are in “anti phase” and more or less cancel each other out). Each doubling of the number of dipole elements (corresponding to a doubling in length) increases the gain in the main direction by 3 dB. Figure 3-1 shows some different antenna arrays.

The gain is different in different directions. However, when the antenna gain is quoted it is usually given for the direction of maximum radiation.

Figure 3-1 Antenna arrays
Since the concentration of radiation is inversely proportional to the solid angle of the beam, the gain can be estimated if the beamwidths are known:

\[
G = 10 \times \log \frac{31000}{(V_3 \times H_3)}
\]

\( G \) = Antenna gain relative isotropic antenna (dBi)

\( V_3 \) = Vertical beamwidth relative -3 dB points (degree centigrades)

\( H_3 \) = Horizontal beamwidth relative -3 dB points (degree centigrades)

**BEAMWIDTH**

**Vertical Beamwidth**

Since the concentration of radiation is proportional to \( L/\lambda \), the vertical beamwidth decreases as the gain increases. The vertical beamwidth can be estimated if the length of the antenna is known:

\[
V_3 = \frac{15300}{f \times L}
\]

\( V_3 \) = Vertical beamwidth relative -3 dB points (degrees centigrades)

\( f \) = Frequency (MHz)

\( L \) = Antenna length (meter)
ANTENNA DOWN TILTING

The vertical beam of an antenna is normally directed towards the horizon, assuming the antenna is correctly mounted. Lowering the beam below the horizon is known as “down tilt” (Figure 3-2). Consequently, if the beam is directed above the horizon, “up tilt” is achieved. Below is a description of the methods used to achieve down tilt and a discussion on how down tilt can improve the performance of a system. Up tilt will not be discussed further.

![Figure 3-2 Antenna down tilt (basic geometry)](image)

ELECTRICAL TILT

Electrical down tilt requires an antenna with a number of vertically stacked dipoles. (Here, the word “dipole” represents other radiating elements as well.) The individual dipoles can be oriented vertically, which is the most common orientation in cellular systems. They can also be oriented horizontally or at a slant (±45°) position.

If all dipoles are fed with the same phase, the main beam of the vertical pattern will be perpendicular to the mechanical axis of the antenna (towards the horizon). A phase difference between the dipoles will result in a beam that deviates from the horizontal. Different tilt angles are available, depending on the antenna manufacturer. Typical values are 2° and 6°.

An advantage of using electrical tilt is that the antenna is always mounted in a vertical position irrespective of tilt. A disadvantage is that the antennas must be ordered with a certain tilt angle. (Antennas with adjustable electrical tilt are available on the market to avoid the disadvantage of fixed tilt values. The antennas have a limited gain and are expensive.)
MECHANICAL TILT

Mechanical tilt is achieved by changing the mechanical alignment of the antenna. All antenna manufacturers have adjustable brackets designed for this purpose. It is possible to combine the electrical and mechanical methods.

CELL PLANNING ASPECTS ON DOWN TILT

Down tilt can be used to overcome coverage and/or interference problems. To be able to discuss down tilt from a general point of view, some special applications must be excluded, i.e. antennas on extreme hill tops, the “Manhattan syndrome”, etc. In these cases, tilt can always be motivated. As a general rule, to reduce co-channel interference, three criteria must be fulfilled:

1. Short site-to-site distances (small cells)
2. High mounted antennas
3. High gain antennas (narrow vertical beam)

Let us start with a case based on medium values (Figure 3-3). Site-to-site distance: 1 km; antenna height: 25 m; and an antenna with 14° vertical beamwidth (approximately at the -3 dB point). As a starting point, let us reduce the signals from the interfering site (Alpha) towards the interfered site (Bravo) by 7 dB. The diagram in Figure 3-4 shows that a tilt of 10° is needed to achieve a reduction of 7 dB towards the horizon. However, to reduce the signal by 7 dB at the cell border, a tilt of 11° is needed (10 + 1°) since the angle (α) towards the cell border is 1°. Note that the gain reduction at the cell border for no tilt is almost zero.
We started with site Alpha which is a potential interferer to site Bravo. As we down tilted Alpha by 11°, the interference situation in site Bravo is improved by 7 dB. But if the network is regular (in a reasonable sense) site Bravo is also an interfering site to site Cairo. Now we have to down tilt Bravo as well with the same values as Alpha and the result in a regular network is that almost all sites must be down tilted.

The next step is to see what happens in the own site area when the antenna is down tilted. The angle ($\beta$) between the horizontal and a mobile on street level on the cell border is 2° (Figure 3-3). It is obvious that the mean vertical beam is pointing somewhere inside the cell border. 11° corresponds to a distance of 129 m. From the same antenna diagram, it can be seen that the signals at the cell border are reduced by 5 dB, found in the diagram at $11 - 2° = 9°$. Note that the gain reduction at the cell border for no tilt is almost zero.

The net result regarding C/I increase is only 2 dB -- at the expense of 5 dB coverage loss!

![Figure 3-4 Typical gain reductions as a function of tilt angle for three different antennas (beamwidths are 7, 14, and 28 degrees)]
Note that the figures are not drawn to scale (i.e. that the horizontal scale is different from the vertical scale). It is common to make figures in this way but it can be misleading. It is obvious that the calculations so far are based on a network in open terrain as no obstacles can be seen between the base station and the mobile. A more realistic case with respect to co-channel interference problems is in urban or suburban areas with buildings in-between (Figure 3-5).

Figure 3-5 This figure illustrates the fact that there is seldom line-of-sight between two antennas in an urban environment

It is unlikely that the radio signals follow the direct line between the base station antenna and the mobile, passing all the buildings in-between. It is more realistic to see the signals coming from (by reflection and diffraction) the roof tops down to the street. The angle to the cell border can then be calculated from the base station antenna height above roof tops (e.g. 5 m). Assuming a site-to-site distance of 1 km, it is an angle of 0.4° to the cell border. The conclusion is: Signals from the interfering site and the interfered site arrive at the cell border with a very small difference in the vertical angle - regardless of how much down tilt is applied. However, down tilting means that less radiation is transmitted across the roof tops and the coverage might decrease.

Returning to the three requirements in this section:

1. Short site-to-site distances (small cells)
2. High mounted antennas
3. High gain antennas (narrow vertical beam)

It can be seen that the first requirement (small cells) gives the possibility to achieve a difference in the two vertical angles towards the roof tops on the cell border and towards the roof tops on the interfered site. The second requirement helps to increase that difference. Finally, with a narrow vertical beam, a C/I increase by 2-3 dB is possible if 1° angle difference can be
achieved (e.g. by mounting the antennas 20 m above the roof tops) and that not more than 5 dB coverage reduction is acceptable. For example, if a 7° antenna is tilted 5°, the gain reduction towards the roof tops for the interfered site is 3 dB (found at 5° - 2° = 3° in Figure 3-4); whereas for the interference, it is 5 dB (found at 5° - 1° = 4°) i.e. a 2 dB increase in C/I.

**CONCLUSION**

Although antenna tilting can be used to solve coverage or interference problems in special applications, it should be used with careful analysis.
NULL FILL-IN

As previously mentioned, antenna gain is different in different directions (Figure 3-6). This means that areas at a certain distance (depending on the antenna height) from the antenna will be radiated by the first null rather than the main direction. Hence, the signal level will not decrease monotonically as the distance between the transmitting antenna and the receivers increases, but more as it is illustrated in Figure 3-7 and Figure 3-8. For parallel-fed collinear arrays, it is possible to reduce the gain reduction in the direction of the first null by simply adjusting the power fed to the different antenna elements slightly. This gives a small reduction in gain in the main direction but this is compensated for by much more predictable signal strengths in areas closer to the transmitting antenna.

![Figure 3-6 Gain reduction as a function of (vertical) angle](image-url)
Figure 3-7 High-gain antenna at 25 m height

Figure 3-8 High-gain antenna at 75 m height
DIVERSITY

There is a need for receiver diversity in cellular systems to improve the uplink. Space diversity is the conventional method used where the two RX antennas are separated by a certain distance. Based on experience from measurements and simulations (and because of installation advantages) polarization diversity is used in standard configurations. The signals from the two RX antennas are later combined in the base station. The result is an increase in signal strength of three to six dB. (The exact value depends on the similarity between the signals received from the two antennas where the two receiving antennas are separated by 90 degrees in the polarization plane.)

SPACE DIVERSITY

Figure 3-9 shows a traditional configuration with space diversity. The horizontal space needed for the antennas is dependent on the required diversity separation.

Figure 3-9 Antenna configuration with space diversity
**POLARIZATION DIVERSITY**

A dual-polarized antenna is an antenna device with two arrays within the same physical unit. The two arrays can be designed and oriented in different ways as long as the two polarization planes have equal performance with respect to gain and radiation patterns.

![Diagram of Dual Polarized Antennas](image)

*Figure 3-10 Dual polarized antennas*

The two most common types are vertical/horizontal arrays and arrays in +/-45 degree slant orientation (Figure 3-10). The two arrays are connected to the respective RX branches in the BTS. The two arrays can be used as combined TX/RX antennas (Figure 3-11) and then the number of antenna units is reduced compared with space diversity. The use of a duplex filter reduces the number of antenna units to only one per cell depending on configuration.
The diversity gain obtained from polarization diversity is slightly less than the gain from space diversity. In the most critical environments (such as indoors and inside a car) the gain is, however, almost as good as if space diversity were used.

A dual polarized antenna offers very low correlation between the two received signals, but the power reception of each branch is slightly better with space diversity. This implies a small benefit for space diversity in noise-limited environments. For most applications, the difference is negligible. In interference limited environments on the other hand, the low correlation obtained by polarization diversity is advantageous.

Due to slightly different propagation characteristics for different kinds of polarization, the downlink from a +/-45 degree dual polarized antenna suffers from about 1.5 dB extra loss compared to a vertically polarized antenna. This loss only affects the downlink.

The isolation between the two polarization planes needs to be 30 dB. The size of the antenna must remain small, as the intention with polarization diversity is to reduce the outlook of the antenna installation.
INTERMODULATION (IM)

When two signals of a different frequency mix in a non-linear device, the result is InterModulation (IM). The non-linear devices can be, e.g. antennas, combiners, connectors, and duplex filters. IM can be a problem at any site that has two or more transmitters. The IM problems can be caused by a transmitter in the same system or by a transmitter in another system that is co-sited or has a site in the neighborhood.

Finding the intermodulation source can be time-consuming since the problem is often intermittent.

Second order products are given by the formula $f_1 \pm f_2$. Both these frequencies are outside the receiver passband. In fact, all the even-order products will be well outside the receiver passband. Third order products are given by the formulae $2 \times f_1 - f_2$ and $2 \times f_2 - f_1$. These frequencies fall inside the band. All odd-order products can cause problems (Figure 3-12). However, higher order products (usually 7th order and higher) decrease rapidly in power and therefore do not cause any problems.

The allocated frequency band and the duplex distance are what determines if the IM will cause problems (Table 3-1 and Table 3-2). IM3 products are strong enough to degrade the receiver sensitivity even though there is no combining; just backwards coupling from one antenna to the other. IM5 is a problem if the frequencies are combined before entering the duplex filter.
<table>
<thead>
<tr>
<th>System</th>
<th>Duplex distance D (MHz)</th>
<th>Max allocated band B, (MHz) to avoid IM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IM₃</td>
<td>IM₅</td>
</tr>
<tr>
<td>GSM 900</td>
<td>45</td>
<td>22.5</td>
</tr>
<tr>
<td>GSM 1800</td>
<td>95</td>
<td>47.5</td>
</tr>
<tr>
<td>GSM 1900</td>
<td>80</td>
<td>40.0</td>
</tr>
</tbody>
</table>

Table 3-1 The maximum band (B) to avoid intermodulation. Based on worst case scenario, which is IM from the lowest and the highest frequencies in the allocated band.

<table>
<thead>
<tr>
<th>IM of order</th>
<th>D/B</th>
</tr>
</thead>
<tbody>
<tr>
<td>IM₃</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>IM₅</td>
<td>&lt; 3</td>
</tr>
<tr>
<td>IM₇</td>
<td>&lt; 4</td>
</tr>
<tr>
<td>IM₉</td>
<td>&lt; 5</td>
</tr>
</tbody>
</table>

Table 3-2 Worst case relations for IM in the RX band. D = Duplex distance (MHz), B = allocated band (MHz)
BASIC ANTENNA TYPES

OMNI-DIRECTIONAL ANTENNAS

Omni-directional antennas have a uniform radiation pattern with respect to horizontal directions. However, looking at vertical directions, the radiation pattern is concentrated thus making gain possible.

Typical gain values are 6 to 9 dBd. The limiting factor is mainly the physical size. As an example, an omni antenna for 900 MHz with a gain of 9 dBd has a height of 3 meters.

(UNI-) DIRECTIONAL ANTENNAS

A uni-directional antenna has a non-uniform horizontal and vertical radiation pattern and is often used in sectored cells. The radiated power is concentrated, more or less, in one direction.

Directional antennas are used in cellular systems for two reasons: coverage extension and frequency reuse. The directional antenna has higher gain than an omni antenna because the radiation is compressed in one direction. This provides a better coverage range in comparison with an omni antenna.

Since the power is radiated in only one direction, it is easier to control the interference in the network. A uni-directional antenna mainly interferes with other antennas that are in the direction of the main lobe. This provides the ability to have tighter frequency reuse thus yielding higher capacity.

Typical gain values for unidirectional antennas are 9 to 16 dBd.

LEAKING CABLES

The leaking cable is a slotted coaxial feeder cable. The slots in the corrugated copper outer sheath allow a controlled portion of the transmitted signal to radiate along the entire length of the cable. Conversely, a signal transmitted near the cable will connect into these slots and be carried along the cable.

The leaking cable can be an alternative to antennas in some applications, e.g. they are useful in train tunnels and for indoor use.

Compared to distributed antennas, a leaking cable is generally a more expensive solution both in terms of equipment and
installation cost. An advantage with leaking cables is that the maximum radiation density tends to be much lower.

There are two losses associated with a leaking cable: longitudinal and coupling. Longitudinal loss is the analog of ordinary feeder loss. For a leaking cable, this loss is higher than for a normal coax due to the leaking (which of course is intentional). Coupling loss is the average difference between signal level in the cable and the power received by a dipole antenna at a certain distance, usually six meters from the cable. Some typical values of longitudinal and coupling loss are shown in Table 3-3.

<table>
<thead>
<tr>
<th>Cable type</th>
<th>Longitudinal loss (dB/100m)</th>
<th>Coupling loss at 6 m (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>900 MHz</td>
<td>1800/1900 MHz</td>
</tr>
<tr>
<td>3/8”</td>
<td>12 - 14</td>
<td>18 - 21</td>
</tr>
<tr>
<td>1/2”</td>
<td>9.5 - 11</td>
<td>13 - 18</td>
</tr>
<tr>
<td>7/8”</td>
<td>5.5 - 6</td>
<td>8 - 11</td>
</tr>
<tr>
<td>1 - 1/4”</td>
<td>4 - 4.5</td>
<td>5.5 - 7.5</td>
</tr>
</tbody>
</table>

*Table 3-3 Typical values of longitudinal and coupling loss*

Example:

Calculate the maximum range with a 1/2” leaking cable in a subway tunnel for an 1800 MHz system. See Figure 3-13.

*Figure 3-13 The 1800 MHz system in a subway tunnel*

Assumptions:

Feeder loss, $L_f$: 10 dB (100 m LCF 1/2”)

Splitter loss, $L_s$: 9 dB
Coupling loss, $L_C$: 73 dB
Wall/window loss, $L_W$: 5 dB
Output power BTS, $P_{out}$: 30 dBm
Required SS at MS, $P_{in}$: -90 dBm
Leaking cable loss, $L_{lc}$: 13 dB/100 m

Allowed loss, $L_{tot} = P_{out} - P_{in} = 30 - (-90) = 120$ dB

\[
L_{tot} = L_f + L_s + L_{lc} + L_c + L_w
\]

\[
L_{lc} = L_{tot} - L_f - L_s - L_c - L_w = 120 - 10 - 9 - 73 - 5 = 23$ dB
\]

The maximum distance, $d = 23 \times 100/13 = 170$ m

**INDOOR ANTENNAS**

An indoor antenna can be of one of the following types:

- (Uni-) directional, wall-mounted
- Bi-directional, wall-mounted
- Omni-directional, ceiling-mounted
- Leaking cable

The antenna position must be carefully investigated. Reasons for this are that obstacles can deteriorate the radiation pattern, aesthetic aspects, and safety regulations. The safety distances (according to European and American rules) are quite short (Table 3-4).

<table>
<thead>
<tr>
<th>RF exposure standard</th>
<th>Frequency range f (MHz)</th>
<th>Power density Power density (W/m²)</th>
<th>Average time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CENELEC (Europe)</td>
<td>f = 400 - 2000</td>
<td>f/200</td>
<td>6</td>
</tr>
<tr>
<td>IEEE (USA)</td>
<td>f = 300 - 3000</td>
<td>f/150</td>
<td>30</td>
</tr>
</tbody>
</table>

*Table 3-4 Safety distances in Europe and USA*
Example (900 MHz):

With an EiRP of 40 dBm, the effective power is 10 W. The allowed power density for 900 MHz is 4.5 W/m² (CENELEC). The minimum area is 10/4.5 m² = 2.2 m² = 4 x pi x d². The critical distance, d = 0.42 m.
Chapter 4

This chapter is designed to provide the student with information about antenna near products such as low noise amplifiers, repeaters, combiners, and duplexers.

OBJECTIVES:

Upon completion of this chapter, the student will be able to:

- Describe when a repeater should be used
- Describe how to implement and use a Tower Mounted Amplifier (TMA)
- Describe the use of duplexers and power splitters
- Describe combiners
- Describe the use of hybrid couplers
4 Antenna Near Products

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INTRODUCTION

Repeaters are used in cellular systems basically to improve coverage in "blind spots". Typical blind spots can be buildings, tunnels or isolated outdoor areas where the coverage is insufficient.

The choice between a repeater and traditional RBS equipment depends basically on two things:

1. How much traffic that can be expected. A RBS adds capacity as well as coverage, whereas a repeater only adds coverage. A repeater can be justified if the traffic demand is low, as costs for a repeater site are substantially lower compared with a traditional base station with transmission.

2. Acceptable implementation time. No transmission is needed for the repeater, which means that long delay waiting for permits is avoided. The rapid implementation time of a repeater can offer a quick solution to a coverage complaint, basically due to the simplicity of the concept.
BASIC REPEATER TYPES

REPEATER DESIGN

A repeater is, in a simplified view, a bi-directional amplifier with filters. There are three basic types with respect to the principle of transmission through the repeater. The types are called on-frequency repeaters, frequency shifting repeaters and fibre optic repeaters.

Repeaters can also be classified with respect to how the signals are processed. Two types of filtering can be seen, RF filtering (broadband repeaters) and IF filtering (band selective and channel selective repeaters).

![Repeater selectivity](image)

*Figure 4-1 Repeater selectivity*

All repeaters amplify noise as well as signals and broadband repeaters amplify plenty of signals beside the desired ones. This results in generally low repeater output power and increased noise in the system. Where channel selective repeaters can be used, this is always recommended instead of broadband or band selective units due to the better performance.

The IF filtering in a repeater introduces a delay, typically 5-6µs. Digital systems like GSM are not built with respect to long delays which means that when planning a repeater installation repeater delay time must be taken into account to avoid problems.

Broadband repeaters

When using a broadband repeater it is crucial to be aware of the noise introduced in the network by the unit. To keep the noise level low, the broadband repeater normally has very low gain.

The filters in a broadband repeater are designed to cover the whole actual RF band. The filtering and amplification are on the
RF band. The selection against systems close to the band is marginal. The broadband repeater is used in areas with low traffic and where the risk for interference with users directly outside the band is low. Broadband repeaters can be used for all existing 900 MHz systems and can be a good choice for certain multi operator applications.

Band selective repeaters

The band selective repeater is a compromise in order only to amplify one operator band, while not affecting the other operators. The band selective repeater handles a defined sub-band within the total cellular band.

For standards like TACS, PDC and AMPS/D-AMPS this is the most common repeater type. The incoming RF signals are down-converted to an intermediate frequency (IF) with filters that more effectively blocks signals directly outside the actual band. Band selective repeaters can be used for all existing 900 MHz systems.

GSM cells using synthesiser hopping sometimes use band selective repeaters, as an alternative to using channel selective repeaters.

Channel selective repeaters

A channel selective repeater is always the best choice when considering quality, but it is also the most expensive. A channel selective repeater is equipped with a number of narrow band channel units that effectively prevent unwanted signals to be amplified.

The number of channel units shall be equal to the number of carriers at the donor cell. The channel units can be remotely tuned to the required frequency. No site visit is needed in case of re-tuning of the donor cell, but it is important to know that channel selective repeaters often require two guard channels between the channels used in the same repeater. Channel selective repeaters are used in GSM systems and sometimes also offer the possibility of having traffic statistics measured by the unit.

If the cell is using frequency hopping on a limited number of frequencies, a channel selective repeater equipped with the same number of channels that there are frequencies in the hopping sequence.
**ON-FREQUENCY REPEATERS**

An On-frequency repeater can be broadband, band selective or channel selective. Other common names are Cell Enhancers, Boosters or RF repeaters.

![Figure 4-2 On-frequency repeater](image)

In the downlink direction, an antenna picks up signals from a donor cell. The pick-up antenna is connected to the input of the downlink amplifier. The signals are filtered, amplified and re-radiated into the service area via a service area antenna. The service area antenna can be anything from a single antenna to a system of antennas and leaking cables.

The uplink direction works in the same way. The service area antenna takes up signals from mobiles within the service area and re-radiates the amplified signals through the pick-up antenna to the donor cell.

On-frequency repeaters receive and transmit on the same frequency band, which sometimes create a problem since the antenna isolation effectively limits the gain. Choosing high gain antennas with low side/back lobes and performing a correct antenna installation is therefore very important. The resulting coverage from an on-frequency repeater can be said to be in direct relation to the antenna choice and installation skill.
**FREQUENCY SHIFTING REPEATERS**

A frequency shifting repeater should always be channel selective and consists of two units, a BTS unit and a Remote unit. The BTS unit can preferably have a physical connection to the BTS using directional couplers.

The low level input signal from the BTS is amplified and given a frequency offset in the BTS unit, and then sent out through the link antenna. The signal is picked up in the Remote unit link antenna and converted back to the original frequency.

By using a separate link channel the Remote unit avoids the antenna isolation problem, and can therefore provide up to 100 dB gain with a much lower antenna isolation. The high gain and low antenna isolation requirement makes this unit suitable for coverage extension in rural areas. However, the frequency shifting concept also introduces a cell planning problem since the link channels have to be accounted for in the cell plan.

The link channel is normally inverted, so that no mobiles will recognise the BCCH signal and lock on it. The link antennas shall be highly directional and sometimes it can be motivated to use panel antennas with high directivity and mount them horizontally to obtain a very narrow lobe with no other signals interfering at the remote unit.

![Figure 4-3 Frequency shifting repeater](image)

The frequency shifting repeater effectively solves the transmission problem in areas where rural coverage is the target, but the frequency shift normally requires four to five guard channels between RBS channel and link channel in order for the repeater to work. Successful operation also puts hard requirements on low adjacent channel signal levels in the area.

A normal problem with a frequency shifting repeater is the synchronisation. Even a very high quality local oscillator will
drift in frequency with time and needs to be manually re-tuned with an interval of less than two years. Some frequency shifting repeaters provide synchronisation via GPS or the mobile network to avoid the re-tuning.

**FIBRE OPTIC REPEATERS**

A fibre optic system is basically built up with two units: the optical master unit and the optical remote unit. A fibre optic repeater can be broadband, band selective or channel selective. This type of repeater can actually offer increased capacity in the service area, meaning that fibre optic repeaters are often used to distribute the capacity from a number of base stations.

The master unit, normally located nearby the base station, receives the downlink RF signals from the base station, converts them to optical signals and sends the signals on to the remote unit/s. On the uplink, the master unit receives the optical signals from the remote unit/s, converts them to RF and sends them on to the base station.

**Donor cell**

![Fibre optical repeater diagram](image)

*Figure 4-4 Fibre optical repeater*

The remote unit, located in the service area, is a bi-directional amplifier. The optical downlink signals coming from the master unit, are converted to RF, amplified and transmitted into the service area. Simultaneously, on the uplink path, the signals received from the mobile phones in the service area are picked up, amplified, converted to optical signals and sent on to the master unit.

A fibre optical system can be used to improve coverage in areas with a distance up to 10 km from a radio base station. It is recommended to use dedicated base stations connected to a system like this, but the optical master unit can also be
connected via a directional coupler to the feeder cable for the normal antenna system of the base station. The alternative to using optical fibre is sometimes a thick feeder. In many applications it is a compromise between cost and practical installation what to choose.

Fibre optical solutions give the possibility to build systems with very high trunking efficiency. This can be achieved by using radio base stations with many carriers and distribute the same carriers to a high number of remote units, giving coverage to, for example, large buildings with high demand for capacity. Multiple band or operator solutions are common for this application.
TOWER MOUNTED AMPLIFIERS

A Tower Mounted Amplifier (TMA) improves the sensitivity and noise figure of a base station. The TMA is mainly used in 1800 MHz and 1900 MHz systems. The noise figure is a component in determining the overall sensitivity of a base station.

ADVANTAGES OF TMA

The sensitivity improvement is the most significant advantage of a TMA. By improving the sensitivity of a base station, the range on the uplink can be extended.

The Receiver Sensitivity \( (RS) \), equation 1, is based on three parameters. The Noise Ratio \( (NR) \) is dependent on the devices added to the original system; the thermal noise power \( (Nc) \) is dependent on the atmospheric conditions; and the minimum signal-to-noise ratio \( (C/N) \) of the receiver is dependent on the initial receiver equipment. Nothing can be done about the thermal noise power, and maximizing \( C/N \) is not something that can be done in the receiver. The only way to improve the sensitivity of the system \( (RS) \) is to have the noise factor as small as possible.

\[
RS = NR + Nc + C/N \quad (1)
\]

The \( NR \) for any number of cascaded devices can be calculated with Friis’ formula. Equation 2 is Friis’ formula for a two-device system, which in this case consists of the TMA and the feeder.

\[
NR = 10 \log (NR1 + (NR2 - 1)/g1) \quad (2)
\]

\( NR1 \) is the noise ratio of the first device
\( NR2 \) is the noise ratio of the second device
\( g1 \) is the gain of the first device

The values of \( NR1, NR2 \) and \( g \), should be given in linear units.

In the following examples it is assumed that:

1. The feeder consists of 50 m 7/8” with 6 dB/100m loss
2. The gain of the TMA is 12 dB and the noise figure \( (NF) \) is 2 dB

Note that \( NR = 10^{(NF/10)} \) and \( g = 10^{(G/10)} \)
Tower Mounted LNA

In this example the first device is the LNA and the second device is the feeder.

\[ NF1 = 2 \text{ dB} \Rightarrow NR1 = 1.58 \]
\[ NF2 = 3 \text{ dB} \Rightarrow NR2 = 2.0 \]
\[ GI = 12 \text{ dB} \Rightarrow gl = 15.8 \]
\[ NR = 10 \log (1.58 + (2.0 - 1)/15.8) = 2.2 \text{ dB} \]

LNA Positioned at the Base Station

In this example the first device is the feeder and the second device is the LNA.

\[ NF1 = 3 \text{ dB} \Rightarrow NR1 = 2.0 \]
\[ NF2 = 2 \text{ dB} \Rightarrow NR2 = 1.58 \]
\[ GI = -3 \text{ dB} \Rightarrow gl = 0.50 \]
\[ NF = 10 \log (2.0 + (1.58 - 1)/0.5) = 5.0 \text{ dB} \]

Given the assumptions above, the placement of the LNA at the antenna would result in a lower (better) receiver sensitivity value. This is why the position at the antenna is preferred.
**DISADVANTAGES OF TMA**

The addition of a TMA does not come without some drawbacks. For instance, by adding equipment to a site, the overall Mean Time Between Failure (MTBF) is reduced. Also the maintenance and supervision cannot be carried out easily. There are, however, ways to provide TMA supervision, but the base station must be able to handle the task. There is a need to provide power to the TMA and possibly to relocate the duplex filter. Both needs are readily solved by using an RX feeder for the power supply. Because the TMA usually has a duplex filter, there is no need to relocate its base station position.

The performances that are somewhat hindered due to the TMA include a reduced receiver range and a reduced intermodulation performance.
**DUPLEXERS**

A duplexer is used to combine a transmitter and a receiver to one single antenna (Figure 4-7). The advantage is that only one antenna for RX and TX is needed. This makes it easier to find suitable sites.

The insertion loss for RBS 200 is less than 1 dB. For RBS 2000, the loss is already taken into account in the power and sensitivity figures. The loss varies with the level of mismatch between the devices which applies to all connection points between the RBS and the antenna. The typical TX to RX attenuation is more than 30 dB.

![Figure 4-7 A duplexer](image-url)
POWER SPLITTERS

A power splitter is used to divide a signal between one or several outputs. The power splitter consists of a quarter wavelength transformer. Such a transformer transforms the impedance for a load.

TWO-WAY POWER SPLITTER

A two-way power splitter splits one input signal to two branches (Figure 4-8). The loss is 3 dB due to the two-way split, and the insertion loss is less than 0.2 dB.

![Figure 4-8 A two-way power splitter](image-url)
**THREE-WAY POWER SPLITTER**

A three-way power splitter splits one input signal to three branches (Figure 4-9). The loss is 5 dB due to the three-way split. The insertion loss is less than 0.2 dB.

![Figure 4-9 A three-way power splitter](image)

**FOUR-WAY POWER SPLITTER**

A four-way power splitter splits one input signal to four branches (Figure 4-10). The loss is 6 dB due to the four-way split. The insertion loss is less than 0.2 dB.

![Figure 4-10 A four-way power splitter](image)
HYBRID COUPLERS

A hybrid coupler is used to combine two input signals so that they are equally divided between two outputs (Figure 4-11).

Figure 4-11 A hybrid coupler

This will give a 3 dB level drop from two inputs to one output. The insertion loss in the hybrid coupler is less than 0.3 dB. There will be a 90 degree phase shift between the two outputs. The isolation between the two inputs and two outputs is more than 20 dB for VSWR < 1.5 : 1.

The hybrid coupler can be used for combining two signals to one transmitting antenna (Figure 4-12). Several hybrid couplers can be cascaded so that more than two transmitters can be combined. As an example, three hybrid couplers (in two steps) will be needed for combining four transmitters.

Figure 4-12 Combining two transmitters
A hybrid coupler can also be used for dividing one signal to one or several outputs (Figure 4-13).

*Figure 4-13 Dividing signals to two antennas*
COMBINERS

Combiners are needed to enable more than one transmitter to be connected to one common transmitting antenna. Without a combiner the output from one transmitter would loop back into the output of another since both of them are physically connected to the same antenna.

In GSM, two different TX-combiners can be used: filter and hybrid.

FILTER COMBINER

The filter combiner (Figure 4-14) can combine the output of up to eight transmitters. In order to use nine to sixteen transmitters in a cell, two filter combiners and two antennas must be used. It is a narrow band combiner where the frequency of each of the connected transmitters (TRXs) must be tuned by adjusting a filter. This is done automatically by the system but nevertheless takes some time.

The total loss in a filter combiner is around 3-4 dB.

The combiner output is connected to the transmitting antenna on top of the cabinet via a Measuring Coupling Unit (MCU) and a bandpass filter TXBP.

The transmitter divider (TXD) distributes the loopback signal from the MCU to the different transmitters to enable automatic tuning of the filters in the combiner. It also enables Voltage-Standing-Wave Ratio measurements (VSWR).
Figure 4-14 TX combiner system, filter combiner, block diagram
HYBRID COMBINER

Hybrid combiners (Figure 4-15) can only combine two transmitter outputs to one common output. If the BTS has more than two TRXs, the combiners can be connected in a cascading fashion. The hybrid combiner is a broadband combiner and does not need tuning. The loss in the hybrid combiner is around 3 dB for each step in the cascade. This means a loss of 3 dB in a BTS with two TRXs and 6 dB in a BTS with four TRXs. A third step in the cascade results in total combiner loss of 9 dB. This loss is too high and gives a maximum of four TRXs combined to one output if hybrid combiners are used.

Figure 4-15 TX combiner system, hybrid combiner, block diagram
COMBINER AND DISTRIBUTING UNIT (CDU)

Currently, there are four different types of combiners that exist for RBS 2000:

- Combiner and Distributing Unit type A (CDU-A) has no hybrid combiner (Figure 4-16)
- Combiner and Distributing Unit type C (CDU-C) with hybrid combiner (Figure 4-17)
- Combiner and Distributing Unit type C+ (CDU-C+) is the new combiner which replaces CDU-C (Figure 4-18). This will be explained further.
- Combiner and Distributing Unit type D (CDU-D) which is a filter combiner (Figure 4-19)

Figure 4-16 CDU-A. TXs with diverse receiver antennas
Figure 4-17 Example of CDU-C. 4 TXs into two diverse receive antennas

Figure 4-18 CDU-C+ without TMA
The new combiner, CDU-C+, takes the place of the old CDU-C combiner in production. CDU-C+ is totally backwards compatible with CDU-C, i.e. it will mimic all the functions of CDU-C in all prior software revisions.

Some of the new features associated with CDU-C+ are as follows:

- An extra RX-chain - With the introduction of an extra RX (Receiver)-path, the most requested 2102 configuration (2,2,2) in one cabinet is possible. CDU-C+ requires only one CDU per sector instead of two per sector required by CDU-C. This allows customers wanting to deploy sites in a 2,2,2 configuration to do so with as few cabinets as possible, upgrading to two cabinets later when there is a need for higher capacity.

- Higher sensitivity – When using CDU-C+ with the required software release, a higher sensitivity is attained. Specifically, the improvement is 2 dB over CDU-C. This only applies when used without the TMA (Tower Mounted Amplifier). If the TMA is used, it is the sensitivity of the TMA that defines the system sensitivity.
• Built in duplexer – This is used to reduce the number of required antennas, but it is important to note that this feature can be bypassed if needed.

• Common antenna terminal – CDU-C+ can be used with a common antenna terminal for both RX and TX or with separate connections. The configuration using separate connections is designed mainly for use with a TMA system.

With CDU-C+, CDU-A is seen as the coverage solution, CDU-D as the large capacity solution, and CDU-C+ is considered as the “standard” configuration solution.
Study Case Phase 1

Chapter 5

This chapter is designed to provide the student with an application of the network process of using macrocells to provide coverage and capacity in a specific geographic region.

OBJECTIVES:

Upon completion of this chapter, the student will be able to:

• Design a network with macrocells
• Use EET/TEMS CellPlanner for predictions of coverage and interference capacity of the network
# 5 Study Case Phase 1

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GENERAL

This study case can be seen as a nominal cell plan. The sites in the site list are the ones proposed by the operator. These sites are not surveyed yet.

The task is to design a high capacity system (based on the GSM specification) for handheld mobiles with outdoor coverage.

As a first step, before starting the work with EET/TEMS CellPlanner and the site list, it is necessary to make some estimates. These estimates are made to find out the theoretical minimum number of sites for both capacity and coverage. Compare the site list with these estimates to find out if more or less sites than included in the list are needed.
BACKGROUND INFORMATION

The area which you will be planning a cellular network, for the operator Nordic Cell, is the city of Stockholm, Sweden and the surrounding areas. Along with Nordic Cell, there are two other GSM operators: Swedtel and Viking Cellular. Nordic Cell has been allocated only 5 + 5 MHz of bandwidth in the GSM band (5 MHz for uplink and 5 MHz for downlink). Stockholm is the largest city in Sweden and the second largest in all Nordic countries. Nordic countries have a mobile phone penetration of around 20 - 25%, which is the largest in the world. Swedtel and Viking Cellular have around 400,000 subscribers with 35-40% of them located in the Stockholm area.

SWEDEN

Location: Northern Europe
Total area: 449,964 sq km
Total land area: 410,928 sq km
Terrain type: mostly flat or gently rolling lowlands, mountains in west.
Land boundaries: Finland, Norway
Population: 8.9 million (est. 1996)
Capital: Stockholm

STOCKHOLM AREA

Location: eastern Sweden, along the Baltic Sea
Terrain type: mostly flat with large amounts of lakes
Land boundaries: none
Population: 1.1 million (est. 1996)

Key areas:

NORTH
1. International Airport, Arlanda
2. Kista, known as the “Silicon Valley” of Sweden, has a large amount of communication and computer business.
3. Bromma airport, much smaller than Arlanda
4. Lidingö, upper level customers
5. Djursholm, upper level customers
WEST
1. Drottningholm, the King and Queens home

EAST
1. Nacka, large amount of business
2. Boo, upper level customers
3. Skärgården, many beautiful islands for vacationers

SOUTH
1. The Globen, large sports arena, also for shows and concerts
2. Södertälje, a suburban area
TRAFFIC DATA

Average call duration: 110 seconds
Number of calls (busy) hour/ subscriber: 1
Grade of service: 2%
Erlang B formula

TRAFFIC DISTRIBUTION

The other operators are in the later phases of their networks. At Nordic Cell, the traffic estimation for our start up phase is 30,000 subscribers evenly distributed over the area. Assume that the traffic on the control channels is about 25% of the traffic on the traffic channels.

FREQUENCY BAND

Totally 5 + 5 MHz (uplink + downlink) frequency band has been allocated for you to use.

SIGNAL LEVEL CRITERIA

The design levels for urban and suburban level area types can be filled in below. Assume 90% coverage, and that no frequency hopping is used in the radio network.

URBAN

<table>
<thead>
<tr>
<th>Coverage Type</th>
<th>GSM 900</th>
<th>GSM 1800/1900</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In - Car</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-door</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SUBURBAN/RURAL

<table>
<thead>
<tr>
<th>Coverage Type</th>
<th>GSM 900</th>
<th>GSM 1800/1900</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In - Car</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-door</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CHANNEL LOADING PLAN

When deciding the number of TRUs per cell or site you should consider the different modularity in such a way that an economical optimization is done (see “Modularity” below).

MODULARITY

The number of channels per TRU is eight.

**RBS 2302**

- TRUs per cabinet: 2
- TRUs per cell: max. 2

**RBS 2202**

- TRUs per cabinet: 6
- TRUs per cell: max. 6
EQUIPMENT

<table>
<thead>
<tr>
<th>CDU/RBS</th>
<th>Output power [dBm]</th>
<th>Sensitivity [dBm]</th>
<th>Minimum carrier separation [kHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>44.5</td>
<td>-110¹</td>
<td>400³</td>
</tr>
<tr>
<td>C²</td>
<td>41</td>
<td>-110</td>
<td>400³</td>
</tr>
<tr>
<td>C+</td>
<td>41</td>
<td>-110</td>
<td>400³</td>
</tr>
<tr>
<td>C+(E-GSM)</td>
<td>40.5</td>
<td>-109.5</td>
<td>400³</td>
</tr>
<tr>
<td>D (E-GSM)</td>
<td>42</td>
<td>-110</td>
<td>600</td>
</tr>
<tr>
<td>RBS 2302</td>
<td>33</td>
<td>-107</td>
<td>400³</td>
</tr>
</tbody>
</table>

Table 5-1 Output power, sensitivity and minimum carrier separation of RBS 2000. (GSM 900)

<table>
<thead>
<tr>
<th>CDU/RBS</th>
<th>Output power [dBm]</th>
<th>Sensitivity [dBm]</th>
<th>Minimum carrier separation [kHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>43.5</td>
<td>-110¹</td>
<td>400³</td>
</tr>
<tr>
<td>C²</td>
<td>40</td>
<td>-110¹</td>
<td>400³</td>
</tr>
<tr>
<td>C+</td>
<td>40</td>
<td>-110¹</td>
<td>400³</td>
</tr>
<tr>
<td>D</td>
<td>41</td>
<td>-110¹</td>
<td>1000</td>
</tr>
<tr>
<td>RBS 2302</td>
<td>33</td>
<td>-106</td>
<td>400³</td>
</tr>
</tbody>
</table>

Table 5-2 Output power, sensitivity and minimum carrier separation of RBS 2000. (GSM 1800)
Table 5-3 Output power, sensitivity and minimum carrier separation of RBS 2000. (GSM 1900)

1With TMA the sensitivity is –111.5 dBm. This sensitivity figure applies for antenna feeders with up to 4 dB loss. If the loss between the TMA and the BTS exceeds 4 dB the sensitivity is decreased.

2CDU-C is today replaced by CDU-C+

3The CDU can from a radio performance perspective handle 200 kHz carrier separation, but bursts may then be lost due to low C/A. From a system point of view the consequences of going below 400 kHz are not fully investigated. Problems with for example standing wave alarms may occur. Thus it is recommended to keep 400 kHz carrier separation.

4These sensitivity figures apply for antenna feeders with up to 4 dB loss. If the loss between the TMA and the BTS exceeds 4 dB the sensitivity is decreased.

<table>
<thead>
<tr>
<th>CDU/RBS</th>
<th>Output power [dBm]</th>
<th>Sensitivity w/o TMA [dBm]</th>
<th>Minimum carrier separation [kHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>43.5</td>
<td>-111.5 / N/A</td>
<td>400³</td>
</tr>
<tr>
<td>C²</td>
<td>40</td>
<td>-111.5 / -110</td>
<td>400³</td>
</tr>
<tr>
<td>C+</td>
<td>40</td>
<td>-111.5 / -110</td>
<td>400³</td>
</tr>
<tr>
<td>RBS 2302</td>
<td>33</td>
<td>N/A / -106</td>
<td>400³</td>
</tr>
</tbody>
</table>

**FEEDERS**

Feeder type 7/8” is preferred. Other feeders are allowed to be used. The feeder length should be the sum of vertical length (equal to the antenna height) and horizontal length 30 m.

<table>
<thead>
<tr>
<th>Feeder Type</th>
<th>Attenuation 900 MHz</th>
<th>Attenuation 1800/1900 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCF 1/2”</td>
<td>7.2 dB/100 m</td>
<td>10.5 dB/100 m</td>
</tr>
<tr>
<td>LCF 7/8”</td>
<td>4.0 dB/100 m</td>
<td>6.5 dB/100 m</td>
</tr>
<tr>
<td>LCF 1 - 1/4”</td>
<td>3.0 dB/100 m</td>
<td>5.3 dB/100 m</td>
</tr>
<tr>
<td>LCF 1 - 5/8”</td>
<td>2.5 dB/100 m</td>
<td>4.2 dB/100 m</td>
</tr>
</tbody>
</table>
JUMPERS

The jumper loss is 0.5 dB per jumper. Two jumpers are used for each feeder cable, one at each end.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total jumper loss</td>
<td>1 dB</td>
</tr>
</tbody>
</table>

MOBILE STATION

There are four MS power classes for GSM 900, two for GSM 1800 and one for GSM 1900 described in the GSM Specifications. Typical values of maximum output power and sensitivity are shown in Table 5-4, Table 5-5 and Table 5-6. The figures are specified at the MS antenna connector.

<table>
<thead>
<tr>
<th>MS power class</th>
<th>Output power [dBm]</th>
<th>Sensitivity [dBm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>39</td>
<td>-106</td>
</tr>
<tr>
<td>3</td>
<td>37</td>
<td>-106</td>
</tr>
<tr>
<td>4 (handheld)</td>
<td>33</td>
<td>-104</td>
</tr>
<tr>
<td>5 (handheld)</td>
<td>29</td>
<td>-104</td>
</tr>
</tbody>
</table>

Table 5-4 MS power classes. (GSM 900)

According to the GSM Specification, the sensitivity is –102 dBm for small (handheld) MSs. However experiences from leading mobile manufacturers show that the sensitivity is 2 – 4 dB better and therefore this value is set to -104 dBm.

No loss or antenna gain should be used for the MSs.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MS antenna gain:</td>
<td>0 dBi</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MS power class</th>
<th>Output power [dBm]</th>
<th>Sensitivity [dBm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>-104</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>-104</td>
</tr>
</tbody>
</table>

Table 5-5 MS power classes. (GSM 1800)
### ANTENNAS

It is recommended to use polarization diversity to make the site acquisition process easier.

You have to check the EET/TEMS CellPlanner antenna database to see what antennas are available.

<table>
<thead>
<tr>
<th>MS power class</th>
<th>Output power [dBm]</th>
<th>Sensitivity [dBm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>-104</td>
</tr>
</tbody>
</table>

*Table 5-6 MS power classes. (GSM 1900)*
PRESENTATION OF PHASE 1

The result should be presented with the following contents:

- A verbal description of the proposal with explanation to site choice, site configuration (including $P_{\text{out}}$, EiRP and antenna gain), etc.
- Site/cell identification
- Number of SDCCHs/TCHs
- Used antennas
- Antenna height
- Traffic distribution in Erlang and number of subscribers (per cell and totally)
- Distribution of blocking (GoS)
- Frequency group per cell
- Coverage predictions (with percentages)
- C/I predictions (with percentages)
- C/A predictions (with percentages)
- Maximum capacity the system can provide
- Number of sites, cells, and TRXs
## SITELIST PHASE 1

<table>
<thead>
<tr>
<th>Site</th>
<th>Co-ordinates</th>
<th>Type of Structure</th>
<th>Height of Existing Structure Meters</th>
</tr>
</thead>
<tbody>
<tr>
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SITE CHOICE RESTRICTIONS

It is important that existing buildings and towers are used to the largest possible extent. The attached site list shows the position of the available sites and the height of existing structures provided by the operator. If no ground level has been indicated then it is only a piece of property. In this case the antenna height should either be equivalent to the tower height or lower. If new towers are needed, use the default value of 30 Meters Above Ground Level (MAGL), and be prepared to motivate the extra cost for these arrangements.
Figure 5-1 Part of Erlang’s B-table, yielding the traffic (in Erlang) as a function of the GoS (columns) and number of traffic channels (rows).
4/12 RE-USE PATTERN

Figure 5-2 4/12 re-use pattern.
Map Data Basics

Chapter 6

This chapter is designed to provide the student map data basics.

OBJECTIVES:

Upon completion of this chapter, the student will be able to:

- Describe the concepts geoid, ellipsoid, datum and map projection
- List what information is needed in digitized form for macro cell prediction using e.g. EET/TEMS CellPlanner
6 Map Digitizing

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MAP DATA BASICS

GEOID, ELLIPSOID AND DATUM

The earth was once believed to be round in form. Heights are referenced to the sea level and land defined at the point where water and land meets. This body, known as earth, is not round but very irregular and hard to define – it is also called the Geoid.

In order to create a representation of the Geoid on paper, a simplification of the Geoid is used. This simplification is called the Ellipsoid or Spheroid. The ellipsoid is oriented to match the geoid for a specific region or country and therefore many ellipsoids exist for the different regions.

An ellipsoid for Mexico could also be valid for Sweden if it is oriented in a different manner. These different relations between the ellipsoid and the geoid are called a Datum (or Map Datum or Geodetical Datum).

![Figure 6-1 Relation between the Geoid and one Ellipsoid with two orientations and two datums](image)

PROJECTIONS

All projections have an origin. Different types of projections are used to transfer the three dimensional image of the continents on earth to a two dimensional surface. These different methods have different characteristics and are good for specific areas on the earth. It is important to remember that no projection is perfect.
Figure 6-2 Cylinder-, Cone- and Flat projection

The result from the different types of projections is to be seen in Error! Reference source not found. Figure 6-3 in the different maps. As mentioned, no map projection is perfect. For instance, in the Stereographic North Polar Aspect the areas are nearly correct, but the angles are wrong. Distance cannot be measured.

Figure 6-3 Map projections

The different types of projections result in maps with different fields of accuracy. A map could have exact areas or exact directions or exact angles or a mixture of some of them, but never all three. Thus, a map can never be exactly accurate.
HEIGHT

It is important to know that the height measurement has two references. The height can be referred to either the ellipsoid or the geoid. The classical reference of ‘height above sea level’ is another expression of ‘height above the geoid’. GPS gives the height above the ellipsoid.

DISTANCE, CONVERSION FROM CO-ORDINATES TO METER

In different areas in the world, north to south, the longitude distances are not the same. The longitude lines come closer together towards the poles and meet at the north and south poles.

Looking Upon Seattle, WA from Space

Figure 6-4 An Orthographic Projection to show the distances difference between Latitudes further away from the equator, north or south.

When out on a site visit, one can roughly establish how far you are from the nominal point by making simple calculations. First of all you have to calculate the mean multiple number to use for the distance of the specific area. Between the latitudes, an average calculation can be made that corresponds to the real
distance between two points, using the co-ordinates read from the GPS. The reference point must of course be known.

![Map of the world](image)

*Figure 6-5 Geographic Co-ordinates*

The geographic co-ordinates are presented in a grid of equal sizes and perpendicular corners. But in such a presentation the areas are not correct.

In order to establish an approximate relationship between degrees (latitude, longitude) and meters you can measure on a reliable map that has co-ordinates, how many meters there are for a certain amount of degrees or minutes.

Please observe that you have to do separate calculations for latitude and for longitude due to the curvature of the earth. This kind of calculations would also just be valid for a limited area, when coming to another country or city You have to establish this relationship again.

**PAPER MAPS TO BE USED**

It is the responsibility of the cell planner to make sure the appropriate maps are available for cell planning and site finding purposes in the project. The customer has to supply the maps or the cell planner must find a supplier.

It is preferred if the datum on the paper maps used, is the same as the one used in when using the GPS. This datum should also correspond to the ellipsoid and projection settings in the cell-planning tool.

Referencing geodetic co-ordinates to the wrong datum can result in position errors of hundreds of meters. Different nations and agencies use different datums as the basis for co-ordinate systems used to identify positions in geographic information systems, precise positioning systems, and navigation systems.
LOOK FOR THE FOLLOWING IN A MAP FOR SURVEY

The north must be indicated and the scale must be clear and good for the application. The map should be in color on good paper quality. If possible it should be original printing. Do not use copied maps. Make sure that the whole map is represented.

The map must contain co-ordinates built on a defined projection. The type of projection of the map can be found in the geodetic information in the key or legend.

The Geodetic information and a co-ordinate system must be present on the map if the map is to be used for measurements and defining locations. The Geodetic information results from the projection, spheroid and geodetic datum. The projection and projection zone, ellipsoid/spheroid, datum and origin must be noted. The unit of measurement is also important.

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<td>Copyright © Sultanate of Oman</td>
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<td>Transliteration does not necessarily conform to PGNN or BGN Systems.</td>
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<td>False co-ordinates of origin 500,000mE 0mN</td>
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<td>Unit of measurement Metre</td>
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Figure 6-6 Grid data, geodetic information, etc. on a map from Oman
The legend should contain the colors and symbols used in the map with a good explanation.

Figure 6-7 An example of a good map with readable contours, Mexico

The map must contain height information, preferably in the form of contours. The contours must be clear and distinct and possible to follow. To the contour lines there must be height values in the form of figures. The best vertical interval is between 5-20 meters.

There often are several dates printed on the map. The important date is the year of making and not the year of printing. The year of making could be stated as ”made from air photography dated 1988-1990 and existing mapping dated 1981-1988” or ”field measurements 1987”. Maps should contain information as recent as possible.

The scale of the map is of great importance. The preferred scale depends on the purpose of use. If the map data is to be used for a countrywide OSS-system, a map in the scale of 1:200 000 - 1:500 000 is sufficient. If the purpose is cell planning for 450-900 MHz, the 1:50 000 is good, for 1800-1900 MHz systems is advisable to use 1:20 000. For micro cells and Urban-model even larger scales are needed, 1:5 000-1:10 000

Make sure that the whole area of interest is covered with maps. If the network will be expanded, the area of map coverage is important.
WHAT IS NEEDED FOR A DIGITAL MAP AND USAGE

Ericsson Digital Map Design is the main producer of geographic map data within Ericsson. Great care is taken to obtain the best input-data by a high standard of quality control.

To create digital maps for the cell-planning tool, good and accurate information is required. The source material can be paper maps, aerial photographs and satellite images.

The groups involved in Site Acquisition are not normally involved in obtaining this type of data. Turn any questions regarding map data and co-ordinate systems, and the quality of maps to be used, to Ericsson Digital Map Design.

The map database will include the following four data types:

- Height data (DEM, topography)
- Land usage data, (clutter, i.e. terrain classification)
- Vector data (roads, railways, rivers, etc.)
- Text data
This chapter is designed to provide the student with an overview of Ericsson’s algorithms for macrocell and microcell predictions.

OBJECTIVES:

Upon completion of this chapter, the student will be able to:

- Describe the main principles behind Ericsson macrocell algorithm and urban model.
- Provide the data needed as input for the prediction algorithms.
# 7 Ericsson Propagation Algorithms

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ERICSSON PROPAGATION ALGORITHM, 9999:

The algorithm 9999 calculates the expected path loss for electromagnetic waves between two coordinates, the transmitter’s coordinate and the receiver’s coordinate. The appearance of the terrain profile between the transmitter and the receiver can be seen from a topographical database. The algorithm takes elevation variations and land usage (e.g., forest, built-up areas, agricultural fields) along the terrain profile into account.

GENERAL

Algorithm 9999 calculates the expected path loss for electromagnetic waves between the transmitter antenna coordinate and the receiver antenna coordinate. The terrain profile, i.e., the cross-section of the earth along the straight line between transmitter and receiver, is taken into account. From a topographical database, the elevation variations and land usage (forest, cultivated land, houses and buildings etc) can be found. The land usage code is the index that specifies how the ground is used. This index is found in all the raster points in the topographic database. The path loss of radio waves also depends on the frequency and the antenna heights of the transmitter and receiver respectively.

Originally, the algorithm is based on Y Okumura’s measurements of wave propagation in Japan. M Hata developed a mathematical formula based on Okumura’s measurements, making the calculations easier. That model, which is now called the Okumura-Hata model, was developed further within Ericsson Radio Systems, by means of a large number of wave propagation measurements.

PURPOSE AND DELIMITATIONS

This section is a description of the wave propagation algorithm implemented in EET/TEMS CellPlanner.

It describes how to calculate the path loss along one single terrain profile, from transmitter to receiver. Therefore, the terrain profile establishment, where terrain profiles are drawn so they cover a larger area, is only partly and briefly described.

The algorithm is implemented so that path loss calculations can be made to a number of points along the same terrain profile.
Owing to the fact that some values can be re-used, since the same terrain profile path need not be scanned several times, the calculation time is minimised. Which values can be re-used, and how this re-use is implemented, is not described here.

PREREQUISITES

There are the following prerequisites for the algorithm in its present form:

- Prediction parameters etc. must be within the range where the algorithm is valid.
- The topography database must be available in raster format.
- The raster squares in the topography database must be quadratic and of the same size all over the prediction area.
- The topography database must have a resolution which is so high that no further interpolations are necessary in conjunction with the calculations.

VALIDITY

The algorithm applies in frequency ranges from 150 MHz up to approximately 2 Ghz if prediction parameters and land usage codes are adapted to the frequency range in question.

The distance from the transmitter within which the algorithm is valid is floating and depends on what the topography looks like. Prediction results are not reliable further away from the transmitter than 100 km. Prediction results at distance of less than 200 m from the transmitter are not reliable either.

The algorithm is valid when the antenna height of the transmitter is between 20 and 200 m. However, this is under the condition that the antenna is higher than the surrounding objects, for example buildings.

The antenna height of the receiver (the mobile) should be between 1-5 m in order for the calculation result to be valid.
INPUT/OUTPUT DATA

Input data to the algorithm: terrain profile, a number of parameters specific to each prediction, a number of constants, land usage code tables. Output data from the algorithm: calculated path loss, analysis values, if any. See Figure 7-1.

Parameters:
HM, HB, F
A0 - A4

Terrain profile:
d[q], h[q], mk[q], mobil[s]

ALGORITHM 9999

Path loss
Analysis values

Constants
Land usage code tables

Figure 7-1 Algorithm 9999’s communication with the environment around it.

Terrain profile

The terrain profile describes the topography along the straight line between transmitter and mobile. See Figure 2. The terrain profile is defined as a vector consisting of q topography points.

In each topography point, q, there is a value for:

<table>
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<th>units</th>
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<tr>
<td>ground elevation</td>
<td>h[q]  [m]</td>
</tr>
<tr>
<td>distance</td>
<td>d[q]  [m]</td>
</tr>
<tr>
<td>land usage code</td>
<td>mk[q]</td>
</tr>
</tbody>
</table>

where

q = 1, 2, 3 ...
The vector $h[q]$ contains the ground elevation above sea level at each point $q$. $h[q]$ may be a positive or negative integer.

The vector $mk[q]$ contains the land usage code, an integer which symbolises the different, existing types of ground appearance. e.g. mangrove swamp, rice fields, industrial estate, fir forest etc.

Path loss calculations should be performed to certain topography points, one or more, on the terrain profile. In this context, these points are called mobile points. The mobile points along a terrain profile can be regarded as a vector: $mobil[s]$. The value in $mobil[s]$ is the index of the topography point on the terrain profile to which the calculation is to be made. Therefore, in Figure 7-2, $mobil[1] = 4$, $mobil[2] = 8$ and $mobil[3] = 11$. In the following, only the path loss calculation to the first mobile point on the terrain profile is described.

Parameters

The parameters that control the calculations in the algorithm are chiefly specific to single predictions, they are site and system-related data:

The antenna height of the transmitter (HB) and the antenna height of the receiver (HM) should be specified in the unit [m]. Radio frequency (F) should be specified in the unit [MHz].

The prediction parameters $A0$, $A1$, $A2$, $A3$ and $A4$ are empirically adapted values, which control the distance- and frequency-dependent parts of the path loss equation.
Land usage code tables

A land usage code table is a list of all the existing land usage codes. The table contains a diffraction loss value, in the unit [dB], for each land usage code. This value should correspond to the additional loss, here called land usage code loss, which arises when the receiver is located within this particular land usage code. Since the land usage code loss is frequency-dependent, each land usage code table will apply only within a certain frequency band. In this way, each land usage code can be interconnected with more than one loss value. E.g., the land usage code loss for pine-forrest may be 43 dB at the frequency 900 MHz, but 53 dB for the frequency 1800 MHz.

The "exact" value for land usage code loss is hard to estimate. The loss also varies within one and the same area. There are variations not only in different locations within the land usage code, but also in time. E.g., the land usage code loss from vegetation is higher in summer when there are leaves on the trees.

Output data

Output data from the algorithm is predicted path loss for the electromagnetic wave between transmitter and receiver [dB].

OVERVIEW OF ALGORITHM BLOCKS

The path loss value obtained from algorithm 9999 consists of the following 4 parts, which, in a sophisticated way, are summed up as follows:

1) Okumura-Hata’s wave propagation equations with modifying prediction parameters A0 - A4.

2) Extra loss which arises when the wave propagation is disturbed by, e.g., mountain peaks. This is calculated with the so-called knife-edge algorithm.

3) When the distance between the transmitter and receiver becomes sufficiently large, earth’s curvature will disturb the wave propagation. The extra loss caused by this is calculated by using the spherical earth algorithm.

4) Land usage code loss.
Figure 7-3 The calculation blocks in 9999

Figure 7-3 is an overview where the algorithm is separated into 11 calculation blocks. The calculations follow the arrows.

DESCRIPTION OF ALGORITHM

Below is a description of the calculation blocks found in Figure 7-3.

Spherical earth

Earth is almost spherical, but in the map database, earth is described as if it were flat. This is a result of the ground elevation stored in each point being related to the level of the sea in that particular point. A new terrain profile must be created for the calculations. This terrain profile describes earth’s ground elevation variations, such as they appear, if an origin is put at the transmitter. (You could say that the transmitter is located “on the top of” the earth, and, therefore, earth slopes downwards in all directions from the transmitter, if you disregard local elevation variations).

The new corrected terrain profile describes the topography with the coordinate of the transmitter as origin. Furthermore, the bending of the electromagnetic waves around the earth due to the varying refraction index of the atmosphere is taken into account. The terrain profile is adjusted with the K-factor.
Knife-edge algorithm

This part of the algorithm calculates the diffraction loss which arises if, for example, there is a mountain peak between the transmitter and the receiver, and, therefore, the propagation of the radio waves is disturbed.

In this context, the word knife-edge refers to the local ground elevation maximum (= a peak) along the terrain profile, which, to the greatest extent, disturbs the wave propagation. This is not necessarily the peak that has the highest ground elevation. The criterion of which peak is considered to be the most disturbing for the receiver is instead: the peak that intrudes most into the first Fresnel zone. This depends on where the receiver is located.

The first Fresnel zone is the area around the travelled beam (= the straight line from transmitter to receiver), where the difference in distance of the reflected beam in relation to the direct beam is not more than \( \lambda/2 \). The direct path connection is considered undisturbed by diffraction loss if the first Fresnel zone is free from obstructions.

The knife-edge algorithm used here is sometimes called the “one-peak algorithm”.

Search knife-edge

The first step of the search for the peak of the terrain profile which disturbs the wave propagation to the greatest extent is to identify all local peaks on the terrain profile.

Straight line

To determine which one of the peaks that intrudes most into the Fresnel zone, the equation for the straight line between the transmitter antenna and the receiver antenna is needed. This line is drawn in Figure 7-4.

Choose knife-edge

The peak that gives the highest diffraction loss in the mobile point should now be identified.

Diffraction loss from a peak is calculated through the peak being approximated with a two-dimensional plane, a knife-edge. The diffraction loss depends on the diffraction parameter \( U \) according to a relationship. \( U \) is calculated as the quotient...
between Cs and rs. Cs is the height from the straight line to the peak of the knife-edge (see Figure 7-4) and rs is the radius of the Fresnel zone at the knife edge.

The knife-edge diffraction (KDFR) can be approximated to 0 when U < -0.49. When U is greater than -0.49, KDFR is strongly decreasing when U is increasing. In order to identify the local peak that gives the highest KDFR, we do not have to calculate U, but it is sufficient to calculate a value that is directly proportional to U. This value obtains the variable name temp.

![Figure 7-4 Calculating the straight line between transmitter and receiver](image)

**Knife-edge diffraction**

Finally, the knife-edge diffraction from maxtopp should be calculated. The diffraction parameter U is calculated, and then KDFR can be obtained from the relationships given by the diagram in Figure 7-5. The diagram may be described through equations which give KDFR as a function of U.
Figure 7-5
Effective antenna height

The concept effective antenna height refers to an antenna height which has been "corrected" by taking the topography along the terrain profile into account. One tries to calculate an antenna height which approximately corresponds to the height of the antenna in relation to the physical reality.

The calculation of the effective antenna height (HEB) is performed in two steps: First the effective antenna height is calculated mathematically, and second the calculated value is "empirically" adjusted (HEBK). ERA staff has performed numerous signal strength measurements in the field. The results of these have shown that the calculated effective antenna height should be adjusted when there is a high knife-edge between the transmitter and the receiver.

![Figure 7-6 Calculating HEB](image)

**Effective antenna height**

The antenna height of the transmitter in relation to a line which approximates the "mean elevation of the surroundings" is calculated.

The method means that a line, with one terminal point in the mobile point, is adapted according to the terrain profile in such a way that the area below the line but above the terrain profile, and the area above the line but below the terrain profile, become equally large. Figure 7-6 shows these areas.

The value Yb, which is calculated through the equation below, refers to the elevation of the end-point of the straight line at the transmitter.
Empirical correction

The mathematically calculated effective antenna height HEB is empirically corrected (HEBK). The performance of the correction depends on the magnitude of KDFR.

Spherical earth algorithm

Even if earth were completely free from ground elevation variations between transmitter and receiver, there is not full visibility between them if the distance is large enough. The spherical earth algorithm calculates the diffraction loss (JDFR) which arises at large distances from the transmitter owing to earth’s curvature.

Figure 7-7 illustrates this phenomenon. In conjunction with scant visibility (gracing), the diffraction loss is assumed to be 20 dB owing to earth’s curvature. JDFR has an effect only at large distances from the transmitter and if the terrain profile is relatively free from ground elevation variations. Otherwise, knife-edge diffraction will overshadow the effect of JDFR.

The calculation of JDFR is performed in several steps: the interesting thing is to calculate earth’s curvature such as it is between the transmitter and receiver antennas. Therefore, the straight line which corresponds best to the ground elevation variations between the transmitter and the receiver is identified. Then, the line is adapted according to the original terrain profile. The "effective antenna heights" for the transmitter (JHEB) and the receiver (JHEM) are calculated in relation to this straight line. Then, the diffraction loss (JDFR) is calculated on the basis of JHEB and JHEM.

Figure 7-7 Sperical earth
**Linear regression**

The equation for the straight line $h=p+t*d$ which corresponds best to the terrain profile is calculated with linear regression. The effective antenna heights in relation to this line are identified. But if one or both of these calculated effective antenna heights are less than the physical antenna heights, an adjustment to the physical antenna heights is performed. Neither JHEB nor JHEM, therefore, can be less than HB or HM respectively.

Just as in conjunction with the calculation of the effective antenna height, a straight line, which is here defined by $h=p+t*d$, is adapted to terrain profile. The difference from the effective antenna height calculation, in this case, that the line is adapted completely freely according to the terrain profile.

Using the method linear regression means that the distance between the terrain profile and the square of the straight line is minimised.

**Spherical earth loss**

The diffraction loss owing to spherical earth (JDFR) is now calculated on the basis of the effective antenna heights calculated above.
Hata open area

Okumura-Hata’s equation for wave propagation in Open area is calculated. The prediction parameters A0-A4 control the equations.

Calculate:

\[ \text{HOA} = A_0 + A_{11} + A_2 \cdot \log \text{HEBK} + A_3 \cdot \log \text{HEBK} \cdot \log D - 3.2 \cdot \left\{ \log(11.75 \cdot \text{HM}) \right\}^2 g(F) \]

where

\[
A_{11} = \begin{cases} 
A_1 \cdot \log D & \text{if } \text{KDFR} \leq 6\text{dB} \\
A_3 \cdot \log D + (A_1 - A_4) \cdot \log \text{DOB} & \text{if } \text{KDFR} \leq 6\text{dB}
\end{cases}
\]

\[ g(F) = 44.49 \cdot \log F - 4.78(\log F)^2 \]

D = d [mobil] and DOB = d [maxtopp]

It should be noted that since g(F) is a variable depending on the frequency only, it will be the same for all mobile points in a prediction area.

Path loss

The different diffraction losses from the knife-edge algorithm, the spherical earth algorithm, Okumura-Hata’s open area, and the land usage code diffraction should now be added up in order to finally obtain the predicted value of the path loss (PL).

The losses cannot be added up, but an adjustment of KDFR and JDFR must be performed.

A parameter \( \alpha \), which depends on Cs and rs, is assigned to control the adjustment.
Tilting function

The resulting signal strength is a function of the calculated path loss PL, the output power from the transmitter and also the antenna diagram. The vertical angle between the base and mobile antennas, i.e. the tilting angle, is required when determining the effects of the vertical antenna pattern on the calculated signal strength.

**TERMINOLOGY**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>α</td>
<td>Parameter which controls the adding up of the diffraction losses KDFR and JDFR.</td>
</tr>
<tr>
<td>Cs</td>
<td>The height from a straight line (transmitter-receiver) to the peak of the knife-edge.</td>
</tr>
<tr>
<td>d[q]</td>
<td>Vector containing the distances to the topography points.</td>
</tr>
<tr>
<td>h[q]</td>
<td>Vector containing ground elevations in the topography points.</td>
</tr>
<tr>
<td>HB</td>
<td>Antenna height of the transmitter (radio base station).</td>
</tr>
<tr>
<td>HEB</td>
<td>Effective antenna height.</td>
</tr>
<tr>
<td>HEBK</td>
<td>Empirically corrected effective antenna height.</td>
</tr>
<tr>
<td>HM</td>
<td>Antenna height of the receiver (mobile).</td>
</tr>
<tr>
<td>JDFR</td>
<td>Spherical earth diffraction.</td>
</tr>
<tr>
<td>JHEB</td>
<td>Effective height of the radio base station antenna, calculated for the spherical earth algorithm.</td>
</tr>
<tr>
<td>JHEM</td>
<td>Effective height of the mobile antenna, calculated for the spherical earth algorithm.</td>
</tr>
<tr>
<td>KDFR</td>
<td>Knife-edge diffraction.</td>
</tr>
<tr>
<td>λ</td>
<td>Wave length</td>
</tr>
</tbody>
</table>
maxtopp: The local peak that has been identified as the most disturbing knife-edge.

mk[q]: The vector that contains the land usage codes in the topography points.

mobil: The point on the terrain profile where path loss is calculated.

PL: Calculated path loss.

temp: A value which is directly proportional to U.

topography point: The points the terrain profile consists of.

U: Diffraction parameters pertaining to knife-edge.
THE URBAN MODEL

The Urban Model is especially designed for determining the wave propagation in an urban environment. Both heights and exact locations of single buildings are taken into account in the calculations. Two algorithms are used in the Urban Model, one for calculating the propagation above rooftops and one for calculating the propagation along streets. The resulting path loss from the Urban Model is then obtained by taking the minimum value of the two path loss values, calculated by the two algorithms. Inside a building, the path loss is calculated using the building penetration algorithm.

GENERAL

Figure 7-8 The Urban Model concept

In an urban environment, there are mainly two dominant paths for radio wave propagation, over the rooftops and along the streets. At far distance from the site, the first part dominates, but in a near environment of the site, the second one dominates. The Urban Model is a concept of two different wave propagation algorithms:

- The half-screen model
- The recursive microcell model

The resulting output value for the path loss is the minimum of the path loss values calculated by the two algorithms.

The half-screen model is used for calculating the propagation above the rooftops. Obstacles such as buildings and trees between the transmitter and the mobile are modelled with a number of screens with heights correlated to the heights of the obstacles. The path loss is then calculated by using a multiple knife-edge approach.

The recursive microcell model is used for calculating the propagation between buildings, e.g. along streets. For defining
the propagation paths, the exact locations of buildings, according to the building database, are used. The path loss is calculated by determining the so-called illusory distance between transmitter and mobile in a street system.

**PURPOSE**

This section provides a description of the two wave propagation algorithms, which together create the conceptual Urban Model, implemented in EET/TEMS CellPlanner. Also the algorithm for calculating building penetration is described in this document.

It also describes the requirements of input data, including map data. Also there are some recommendations on map data resolution.

**PREREQUISITES**

There are some requirements on map data; a high-resolution map database is obligatory for running predictions with Urban Model. Depending on the city, a recommendation would be a resolution of 2 to 10 meters of square size. The database should contain the following information:

- Terrain data in raster format.
- Land usage data in raster format.
- Building database in raster format.
- Vector database containing information about the building outlines.

The vector database is optional; it is mainly used for increasing the resolution in areas e.g. containing walls and narrow passages that are not visible in the original raster data.

The half-screen model can be run without a building database, but in that case the accuracy of the predictions will decrease.

**VALIDITY**

The Urban Model is valid for frequencies from 450 MHz up to 2200 MHz.

The Urban Model has been shown to be valid for points at a close distance from the base antenna and has also been shown to be stable for distances up to at least 50 km from the base antenna.
The Urban Model has been validated for base antenna heights from 5 m to 60 m; and for antennas placed below as well as above rooftops.

The Urban Model is also valid for high mobile antenna heights, which means that it can be used for e.g. wireless local loop applications.

**INPUT/OUTPUT DATA**

**Input data for the half-screen model**

![Diagram](image)

*Figure 7-9 The half-screen model’s communication with the environment*

The following input data are required for the half-screen algorithm:

- **Base antenna height** HB
- **Mobile antenna height** HM
- **Frequency** F
- **Antenna diagram** A G (horizontal and vertical pattern)
- **Terrain data**
- **Land usage data**

The terrain profile is corrected due to the curvature of earth.

For increasing the accuracy of the predictions, a building database can be used. The algorithm uses the building database, the land usage information and the terrain database in order to generate the screen profile used in the calculations. However if there is no building data available, the screen profile is generated by the clutter database and the terrain database.
INPUT DATA FOR THE RECURSIVE MICROCELL MODEL

Figure 7-10 The microcell model's communication with the environment

The following input data are required for the microcell algorithm:

- Base antenna height HB
- Mobile antenna height HM
- Frequency F
- Antenna diagram A G (horizontal and vertical pattern)
- Building data
- Vector data containing information about the building outlines (optional)

For running the microcell model, a building database in raster format is compulsory.

OUTPUT DATA

The half-screen model will generate the path loss above L and the microcell model will generate the path loss below L. The resulting path loss arising from the Urban Model is then determined by,

\[ L_{\text{Urban}} = \min(L_{\text{below}}, L_{\text{above}}) \]

In the neighbourhood of the base station and in line-of-sight streets, the microcell model will dominate. In other cases, only the half-screen model will give contribution to the path loss.

This is however an approximation. In a real case, the radio waves will propagate both ways and the received signal strength is a sum of both contributions. But since in most situations, one of the propagation paths usually will dominate, the effect of this approximation will be small.
The resulting signal strength is a function of the calculated path loss, the output power from the transmitter and also the pattern of the base station antenna. When performing an area prediction, the signal strength values are stored in an array where every pixel is assigned a certain value. In presence of a building database, the signal strength values are removed from pixels defined as ‘building’. Signal strength values for these pixels are calculated with the building penetration algorithm, described in later.

**DESCRIPTION OF THE ALGORITHMS**

**The half-screen model**

The path loss $L_{\text{above}}$ in [dB] is given by,

$$L_{\text{above}} = 20 \cdot \log \left( \frac{4 \cdot \pi \cdot d}{\lambda \cdot u} \right)$$

where
- $d$: distance between transmitter and receiver [m]
- $\lambda$: wave length [m]
- $u$: normalised electric field along the path [-]

The electric field, $u$, is determined by using a multiple knife-edge approach; obstacles along the path from the transmitter to the receiver is modelled by using half-endless screens with different heights and separations.
Figure 7-11 Definition of the coordinate system for the multiple knife-edge case.

To start, the values of \( u \) are set to 1 above and on the screen and 0 below the screen, on a straight line that passes through the first screen. The following \( u \) values along the profile are then determined numerically by using the Forward-Difference method,

\[
u_{n,j+1} = \beta \cdot \left( u_{n+1,j} - 2 \cdot u_{n,j} + u_{n-1,j} \right) + u_{n,j}
\]

where

\[
\beta = \frac{\lambda}{2 \cdot \pi} \cdot \frac{r_{m} - r_{j}}{(\Delta s)^{2}}
\]

The arc distance, \( D \), is constant and here set to 5 m. The values of \( u \) are always between 0 and 1.

For calculating the electric field \( u \), the algorithm needs information regarding base antenna and mobile antenna heights, screen heights and screen locations. Important model parameters for determining \( u \) and thus for calculating the path loss are described in the figure below.

Figure 7-12 Definition of model parameters.

Two kinds of screens are used to describe the profile; permanent screens that are placed in a statistical way, and temporary screens, placed in a deterministic way. The permanent screens are used to define the environment along the calculation profile in a general way and the temporary screens will describe details of the environment more accurately, near the mobile antenna.

For example, when defining a path along an area with vegetation, the location of each screen does not have to coincide with the actual placements of trees etc; they are placed in a more
statistical way. The height of the screens should however coincide with the average height of the vegetation.

When using a building database, the values for heights and locations of the screens are taken from the database, i.e. they are set in a deterministic way.

The recursive microcell model

The path loss $L_{\text{below}}$ in [dB] is given by,

$$L_{\text{below}} = 20 \cdot \log\left(\frac{4 \cdot \pi \cdot d}{\lambda}\right)$$

where $d$ : illusory distance between transmitter and receiver [m]

$\lambda$ : wave length [m]

The illusory distance $d$ is determined with a recursive method, using input data from an arbitrary street system:

\[
\begin{align*}
\kappa_j &= \kappa_{j-1} + d_{j-1} \cdot q_{j-1} \\
\text{d}_j &= \kappa_j \cdot s_{j-1} + d_{j-1}
\end{align*}
\]
where \( q_j \): parameter describing the angle dependence of the path loss \\
\( s_j \): distance between the nodal points \( j \) and \( j+1 \) \\
\( d_j \): illusory distance, initial value \( d_0 = 0 \) \\
\( k_j \): help parameter, initial value \( k_1 = 1 \)

\[
q_j \left( \theta_j \right) = \left( \theta_j \cdot \frac{q_{90}}{q_0} \right)^\nu
\]

Here \( \theta_j \) is the corner angle in the nodal point \( j \), \( q_{90} \) and \( \nu \) are tuning parameters. These have been set to 0.5 and 1.5 respectively.

**The building penetration algorithm**

For calculating the path loss in [dB] between a base station antenna and a mobile placed inside a building, the following algorithm is used:

\[
L_{\text{inside}} = L_{\text{outside}} + W_e + s \cdot \alpha
\]

where \( W_e \): penetration loss through the external wall [dB] \\
\( s \): distance inside building [m] \\
\( \alpha \): building penetration slope [dB/m]
L_{outside} [dB] is the path loss in a point located just outside the external wall:

$$L_{outside} = \max (L_{Urban}, L_{fsp} (d) + W_{Ge})$$

$L_{Urban}$ is the path loss calculated with Urban Model, and $W_{Ge}$ is the increased wall loss [dB] at a small grazing angle. $L_{fsp} (d)$ is the free space propagation loss [dB] from the transmitting antenna to the external point:

$$L_{fsp} (d) = 32.4 + 20 \cdot \log d + 20 \cdot \log f$$

where:
- $d$: distance between transmitter and external point [km]
- $f$: frequency [MHz]

The building penetration loss is calculated in presence of a building database.

**TERMINOLOGY**

- $\alpha$: The slope used in the building penetration algorithm [dB/m].
- $\beta$: A parameter used in the numerical equation for determining the electric field $u$ in the half-screen model [-].
- $\Delta s$: The length of a sector in a circle that passes a screen along the calculation profile [m].
- $d$: The distance between transmitter and receiver [m] or [km].
- $D$: The distance between two screens in the calculation profile [m].
- $F$: The frequency [MHz].
- $G_A$: The base station antenna masking gain [dB].
- $H$: The screen height [m].
- $H_B$: The antenna height of the transmitter [m].
- $H_M$: The antenna height of the mobile [m].
- $\lambda$: The wave length [m].
L_{above} : The path loss calculated with the half-screen model [dB].

L_{below} : The path loss calculated with the recursive microcell model [dB].

L_{inside} : The path loss calculated with the building penetration algorithm [dB].

L_{outside} : The path loss in a point located just outside the external wall, used in the building penetration algorithm [dB].

L_{Urban} : The resulting output value for the path loss value from Urban Model [dB].

ν : A parameter that determines the shape of the q_j function [-].

q_j : A function that determines the angle dependence of the path loss in a street crossing when using the recursive microcell model [-].

q_{90} : A tuning parameter in the j q function [-].

r_j : The radius of a circle centred at the top of the base antenna that passes through a screen along the calculation profile [m].

s : The distance inside a building when calculating building penetration loss [m].

s_j : The distance between two nodal points when using the recursive microcell model [m].

θ_j : The corner angle in a nodal point at a street crossing [-].

u : The normalised electric field along a calculation profile [-].

W_e : The building penetration loss through an external wall [dB].

W_{Ge} : The increased wall loss at a small grazing angle [dB].
This chapter is designed to provide the student with an overview of the basic requirements involved in conducting a survey of the proposed radio sites of a cellular network. It will discuss the basic considerations that need to be addressed when accepting or denying a proposed site.

**OBJECTIVES:**

Upon completion of this chapter, the student will be able to:

- Discuss the basic considerations involved in a site survey
- Demonstrate an understanding of the requirements of each basic consideration
- Perform a site survey
# 8 Site Survey

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INTRODUCTION

The cell planning process results in a cell plan with nominal site positions. If the operator has access to existing locations, it is necessary to adapt the cell plan according to these locations. For this reason, it is important that the cell planner has a basic knowledge of the locations that can be used.

The on-site cell planning work that takes place is called the “Radio Network Survey”. This is described in the following section. A more detailed survey is performed on the base station sites. This is called the “Site investigation” and is not discussed in this course.
RADIO NETWORK SURVEY

BASIC CONSIDERATIONS

It is likely that the system operator has a number of alternative buildings which may be used in the cellular network planning phase. One reason for this is to reduce the initial cost.

The following aspects of site selection must be studied:

- Position relative to nominal grid
- Space for antennas
- Antenna separations
- Nearby obstacles
- Space for radio equipment
- Power supply/battery backup
- Transmission link
- Service area study
- Contract with the owner

POSITION RELATIVE TO NOMINAL GRID

The initial study for a cell system often results in a theoretical cell pattern with nominal positions for the site locations. The existing buildings must then be adapted in such a way that the real positions are established and replace the nominal positions. The visit to the site is to ensure the exact location (address/coordinates and ground level). It is also possible for more than one existing site to be used for a specific nominal position.

SPACE FOR ANTENNAS

The radio propagation predictions provide an indication on what type of antennas can be used on the base station and in what direction the antennas should be oriented.

The predicted antenna height should be used as a guideline when the on-site study starts. If space can be found within a deviation of a maximum of 15% from the predicted height, the original predictions can be used with sufficient accuracy.
If it is possible to install the antennas at a higher position than predicted, the operator must ensure that there is no risk for co-channel interference. If the antennas are to be installed at a lower position than predicted, new predictions must be carried out based on this position.

It is not necessary that all antennas in one particular cell have the same height or direction. That is, it is possible to have cells on the same base station with different antenna heights. This can be the case if space is limited in some directions. There are also cell planning reasons for placing antennas at different heights, e.g. coverage, isolation, diversity, and/or interference.

**ANTENNA SEPARATIONS**

There are two reasons for antennas to be separated from each other and from other antenna systems. They are:

- To achieve space diversity
- To achieve isolation

**Space diversity**

In a system with space diversity on the base receiver part, the two receiver antennas must be separated in space, horizontally or vertically. Horizontal separation is normally more efficient compared to vertical separation. The planning criterion specifies making a horizontal separation equal to or more than 10% of the effective antenna height. For mechanical reasons it is permitted to limit the separation to six meters. However, it is important to emphasize that higher separation gives better diversity. The minimum distance should not be below four meters (given values are for 900 MHz; the separation distance for 1800 - 1900 MHz is 2 - 3 meters as depicted in Figure 8-1).

Vertical separation requires approximately five times the horizontal value in order to get the same diversity gain.
Isolation

In order to avoid disturbance due to intermodulation, the transmit and receive parts of the base station must be isolated. The following isolation values should be fulfilled:

\[ \text{Tx - Rx: } 30 \text{ dB} \]

and

\[ \text{Tx - Tx: } 30 \text{ dB} \]

These values must be maintained both inside a dual polarized antenna as well as between two separated antennas (see Figure 8-2 for different mounting cases). In case of vertically separated antennas, 0.2 m spacing is sufficient. The Tx-Rx isolation of 40 dB mentioned in previous documents is still valid for analog systems to avoid disturbances due to intermodulation. However, a GSM 900-based system is less sensitive to intermodulation and can then use a lower isolation value.
**NEARBY OBSTACLES**

One very important part in the Radio Network Survey is to classify the close surroundings with respect to influence on radio propagation. In traditional point-to-point communication networks, a line-of-sight path is required. A planning criterion is to have the first fresnel zone free from obstacles.

It is not possible to follow this guideline because the path between the base and the mobile subscriber is normally not line-of-sight. It is especially important in city areas where one cell planning criterion is to provide margins for these type of obstacles.

If optimal coverage is required, it is necessary to have the antennas free for the nearest 50-100 m. The first fresnel zone is approximately five meters at this distance (for 900 MHz). This means the lower part of the antenna system has to be five meters above the surroundings.

**SPACE FOR RADIO EQUIPMENT**

Radio equipment should be placed as close as possible to the antennas in order to reduce the feeder loss and the cost for feeders. However, if these disadvantages can be accepted, other
locations for the equipment can be considered. In addition sufficient space should be allotted for future expansions.

The radio network survey includes a brief study with respect to this matter. A more detailed analysis takes place when the location is chosen to be included in the cellular network.

**POWER SUPPLY/BATTERY BACKUP**

The equipment power supply must be estimated and the possibility of obtaining this power must be checked. Space for battery back-up may be required.

**TRANSMISSION LINK**

The base station must be physically connected to the BSC. This can be carried out via radio link, fiber cable, or copper cable. Detailed transmission planning is not included in this course.

**SERVICE AREA STUDY**

During the network survey, it is important to study the intended service areas from the actual and alternate base station locations. Coverage predictions must be checked with respect to critical areas.

**CONTRACT WITH THE OWNER**

The necessary legal documentation must exist between the land owner and the proposed site user, e.g. a contract for site leasing. Even though cost is a major consideration in the site acquisition process, cost it is not discussed as a factor in this course.
SITE INVESTIGATION

The purpose of the site investigation is to investigate and record all factors that may have an influence on the project and to make a report that will be the basis for an agreement on the Confirmed System Design.

PREPARATIONS

The preparations start when the contract has been signed and include the following activities:

- Contact with the Network Design Department to obtain the proposed network design
- Obtain permission to visit the sites - Permits and other arrangements because of security regulations must be requested through the appropriate party.
- Collection of all necessary information about the project
- Collection of all required equipment and documents
- Practical arrangements for traveling to the sites
- Obtain a map to mark the sites on

Prepare a site visit binder with dividers for each site. Prepare and insert checklists for each site. Fill in the checklist with known data about the site.

Site visit

The purpose of the site visit is to collect and record (on the spot) all data that may have an influence on the installation engineering and the site preparation.

The following actions should be taken on site:

- Fill in the address/location in the checklist
- Locate the site on the map
- Check that the allocated space is sufficient
- Make a sketch of the premises/rooftop including existing structures, and take measurements
- Indicate the north direction on the sketch
- Select a location for the RBS equipment
• If the RBS is to be located indoors, make a floor plan sketch and indicate north on the sketch.
• Note heights of buildings
• Make a sketch of any existing tower
• Take measurements of tower legs, distances between legs, and height. Try to establish a suitable antenna location and note measurements of the tower at that location.
• Measure location of existing antennas
• Find cable paths and check cable ladders, ducts, and trays
• Measure the length of the cable way for antenna cables
• Find out from where the mains power can be supplied and if it has capacity for the increased load
• Investigate from where the transport network can be brought into the site
• Make a sketch of the layout of the earthing system and lightning protection system
• Take photographs to back up the notes

MEASURING HEIGHTS

To measure a height using the 45 degree method perform as follows:

Stretch out a measuring tape on the ground and walk along it until you reach the 45 degree angle (H=L). A height angle instrument usually shows “1” when you reach the 45 degree point. For other distances of L it will show the percentage of H/L.

If the tower is equipped with a ladder inside you can calculate the height while climbing by counting the number of steps and measuring the distance between them. It is very difficult to make written notes during climbing; it is recommended to use a small tape recorder instead.
Figure 8-3 The 45° method of measuring the height of a tower.

SITE INVESTIGATION REPORT

The Site Investigation Report consists of a binder or binder with dividers for each site. The report consists of two parts:

- Site documents
- Site preparations

The Site Investigation Report is handed over to the design review and will form the basis for a Confirmed System Design agreement.

Site documents

If no unusual conditions prevail, the Site documents consists of:

- Site data (Configuration data)
- A site layout drawing
- Antenna arrangement drawing
- Cabinet material list
Site preparations

The site preparation document is a document that describes the scope of the civil engineering work needed on each site and who is responsible for them. As an example, it will define the following responsibilities:

- Antenna tower
- Concrete foundation
- Roof reinforcements
- Earthing system
- AC mains power
- Transport network
- Necessary permits
This chapter is designed to provide the student with an application of network expansion, to increase coverage and capacity in an existing network.

**OBJECTIVES:**

Upon completion of this chapter, the student will be able to:

- Expand an existing network with new sites for improved coverage and capacity
- Make changes in the frequency plan when new sites are introduced
# 9 Study Case Phase 2

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GENERAL

This is an expansion of the network that has been designed in the previous phases of the study case. The sites from the previous phases shall, if possible, be used since this will reduce the cost of this phase.

The task is to increase the capacity by adding 14,000 subscribers to the central part of Stockholm, i.e. a circular area with a radius of 5 km (Phase 2). Inside the central Stockholm area, indoor coverage is required for 90% of the area outside Phase 2, but inside Phase 1 outdoor coverage is required. On the highway E4, which runs north and south, in-car coverage is required.
PRESENTATION OF STUDY CASE PHASE 2

The presentation should contain the following:

- A verbal description of the proposal with explanation to site choice, site configuration (including $P_{out_{BTS}}$, EiRP and antenna gain) etc.
- Site/cell identification
- Number of SDCCHs/TCHs
- Used antennas
- Antenna height
- Traffic distribution in Erlang and number of subscribers (per cell and totally)
- Distribution of blocking (GoS)
- Frequency group per cell
- Coverage predictions (with percentages)
- C/I predictions (with percentages)
- C/A predictions (with percentages)
- Maximum capacity the system can provide.
- Number of sites, cells and TRUs
## SITELIST STUDY CASE PHASE 2

<table>
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<th>Co-ordinates</th>
<th>Type of Structure</th>
<th>Height of Structure m</th>
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<tr>
<td>BERGHAMRA</td>
<td>1402020 6233970</td>
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Tools

Chapter 10

This chapter is designed to provide the student with an overview of cell planning tools such as GPS, the TEMS family, TMR, and TTM. It addresses the different features and capabilities of these tools.

OBJECTIVES:

Upon completion of this chapter, the student will be able to:

- Explain the use of GPS
- Explain the TEMS family and its applications
- Explain the use of TMR and TTM
# 10 Tools

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INTRODUCTION

The cell planner must use many types of tools throughout their work from the early stages of the nominal cell plan, through the field and site surveys, to the later stages of tuning and system growth. Some of these tools are discussed in this chapter.

- Global Positioning System (GPS)
- Field measurements with TEst Mobile Station (TEMS)
- Radio measurements with TMR and TTM
GLOBAL POSITIONING SYSTEM (GPS)

INTRODUCTION

Global Positioning System (GPS) is a system of about thirty satellites launched by the U.S. military and controlled by the U.S. Department of Defense (DoD). The satellites continually transmit information of their orbits and time that can be used by the GPS receiver to calculate the exact range to the satellites and its own position following some trigonometric calculations. If four satellites are tracked, a three-dimensional position can be calculated\(^1\); however, if only three satellites are tracked, only a two-dimensional position can be obtained. In such a case the altitude is usually left at the last known value.

The satellites are launched in six different twelve hour orbits in such a way that the probability for finding at least four satellites anywhere in the world at any time of the day is high. Common figures are 23 hours of two-dimensional coverage and 16-18 hours of three-dimensional coverage.

It is important to have line-of-sight to all satellites which are tracked. This is a problem in urban areas where satellite signals are received as reflections from buildings, thus introducing an error to the calculated distance.

All satellites transmit at the same frequency using a Code Division Multiple Access (CDMA) spread spectrum technique. This means that the signals from the satellites are separated by means of different codes and the GPS receiver must synchronize to the code for each one of the satellites that is to be listened to.

The synchronization to the code of a satellite can take up to two minutes. If the receiver knows what satellites to look for, it usually locks to them within two minutes. If it does not know where it is in the world when it is switched on (or does not have recently updated information about the satellite orbits), it must try each of the satellite codes to find out if the satellite is really there. This takes a much longer time. In the worst case, acquisition time for a typical GPS receiver is up to 30 minutes.

Some GPS receivers have several parallel receiver channels enabling searching and tracking of several satellites at the same time, thus cutting down on acquisition time. It also means that

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\(^1\) The receiver antenna is of omni type and hence no information is obtained of the direction of the radiation which was received.
the receivers can track some satellites for positioning while having other satellites synchronized, ready for use in case any of the first should be obstructed.

**ACCURACY**

The basic precision that can be obtained with the GPS system is one or a few centimeters if most of the error sources are taken care of. The atmospheric influence will degrade the accuracy, but can be overcome by using two frequencies for satellite transmission or by the use of differential GPS technique (see below). Since the system was launched by the U.S. military and they did not want others to be able to take advantage of this high precision system, DoD introduced a method called Selected Availability (SA).

Selected Availability (SA) decreases the precision by adding a time shift to the signals resulting in a slowly changing offset in the position (which can be up to about 150 meters). The time shift added is transmitted by the satellite in an encrypted form so the U.S. military can compensate for it. All others, however, have no way to compensate for this (unless differential GPS is used) except by averaging over several hours. This is only possible if the GPS receiver is stationary during that time.

Since the error is a slowly changing offset, it looks like the receiver is slowly moving around in a random way within an approximately circular area with 150 meter diameter even though it is stationary.

If the receiver must change the satellite configuration used for positioning, the new satellite configuration usually results in a different offset looking like a jump in the calculated position.

**DATUMS**

The datum is the reference system used for the coordinate data. There are many different datums used around the world. The one used internally by the GPS receiver is named WGS84 (and is a globally fitted ellipsoid); whereas, for example, the coordinate system used in Sweden (RT90) is based on a locally fitted ellipsoid named Bessel-1841. This means that the latitude and longitude coordinates given by GPS is different than the ones shown on Swedish maps unless an appropriate transformation is performed.
GPS receivers can perform transformations to most datums used in the world. However, not all of them are using the correct transformation parameters and certainly not all of them are using the full seven parameter transformation. Therefore, some care must be taken in order to check the uncertainty of the positions obtained after a datum transformation. Try to verify the position calculated by the receiver against a known position in the country you are working in.

**DIFFERENTIAL GPS**

By using reference GPS receivers in known positions the SA problem with the randomly changing offset can be removed and the uncertainty reduced to a few meters. In Sweden for example, twenty reference stations are available. By recording information from them transmitted by radio waves, the GPS receiver can compensate for the unknown offset. Unfortunately, the possibility to subscribe to this service is limited to only a few countries.

However, it is possible to generate an independent reference by using a reference GPS with a broadcast system (positioned in a local reference point) which must have known coordinates in the WGS84 system. Logging the data sequence in both the mobile and the reference station and post-processing the data can also give accurate positions without an established radio line.
TEST MOBILE SYSTEM (TEMS)

INTRODUCTION

The TEMS product family forms a complete system of air interface tools for all cellular networks conforming to the GSM standard. The Survey System enables operators to test and verify their cellular system on real-time, continuous basis for the purpose of development, cell planning, quality evaluation, network tuning, and operation and maintenance.

![Diagram showing TEMS Family]

Figure 10-1 Survey System by Erisoft

TEMS FAMILY

TEest Mobile System (TEMS)

TEMS or Test Mobile System is an easy-to-use versatile tool for testing of cellular mobile networks. The TEMS system is composed of a test mobile station (MS), a serial cable, and a personal computer (PC) software package. It can be completed with an additional MS and a position system (GPS). TEMS evaluates the network from the user's point-of-view as it monitors the air interface between the base station and the test mobile station. TEMS handles TEMS test mobile stations based on Ericsson mobiles using special test mobile software to enable the unique TEMS features. Based on the commonly used Microsoft window platform, the TEMS PC application is easy to use. All TEMS test features are accessible through Windows.
menu dialogue entries and a comprehensive on-line user manual is always available.

**Figure 10-2 TEMS system overview**

**TEMS LIGHT, Test Mobile System, Light Version**

A lighter version of the standard TEMS system (the TEMS Light) offers a combination of the basic functionality of TEMS with the advantage of a handheld portable system without the need of external positioning equipment. TEMS light consists of a test mobile station, a serial cable, PC software, and a palmtop computer. Using a bitmap presentation of the location as the application background, manually positioned measurements can be performed where GPS coverage is not available. So this test mobile can be used for indoor measurements in small city environments.
TEMS POCKET, Test Mobile station without PC

The smallest member of the TEMS family (the TEMS Pocket) offers a stand-alone test unit consisting of only a TEMS Pocket test mobile. The basic idea of TEMS Pocket is that every network engineer should have one. As the TEMS Pocket test functions are always present, an initial analysis can be made whenever an abnormal behavior of the network is observed. TEMS Pocket is based on the mobiles using special test mobile software to enable the unique TEMS pocket features.
TEMs Transmitter

For the generation of test signals, it is suitable (however not mandatory) to use one or several TEMS Transmitters. The TEMS Transmitter is a small unit that transmits in the GSM downlink band. The output power is adjustable between 17 and 27 dBm. A complete editable BCCH is transmitted while the other 7 time slots contain an unmodulated carrier.

In the absence of TEMS Transmitters, a Test TransMitter (TTM) can also be used. This is a narrow band Continuous Wave (CW) transmitter with a maximum output power of 43 dBm.

Additionally, the regular transmitter can be used for this function.

Geographical Information Mobile Surveys (GIMS)

GIMS is a Microsoft Windows and Mapinfo-based software for post-processing of TEMS data. TEMS log and scan data can be imported into GIMS where it can be viewed in a wide variety of methods. Radio coverage and radio quality can be presented geographically together with signaling events such as handovers and dropped calls by using background presentation. The user can also calculate statistics and make graphs of the TEMS information. Information can be easily interpreted, printed, and saved.
File & Information Converting System (FICS)

The FICS application is a post processing tool for conversion and analysis of TEMS data. Using one or more tools from the set offered, batch conversion can be performed overnight for a time saving function.

*Figure 10-5 FICS system*
TEMS Speech Quality Index

TEMS Speech Quality Index is an algorithm capable of producing a speech quality estimate. It is integrated into the TEMS mobile, requires no extra hardware, and works wherever TEMS is available. Because of this, it is a highly cost effective way of measuring speech quality on the mobile network.

The quality of speech on the network is affected by several factors including what type of mobile the subscriber is using, background noise, echo problems, and radio channel disturbances.
TEST MEASUREMENT RECEIVER (TMR) AND TEST TRANSMITTER (TTM)

INTRODUCTION

The purpose of a radio survey is to examine the propagation of radio signals over a particular area. These measurements can be performed to verify the nominal cell plan for signal strength, C/I, and C/A as well as to optimize the land usage parameters used by cell prediction tools. The radio survey can be performed for all cellular standards including GSM 900, GSM 1800, and GSM 1900. The equipment used for these measurements include TTM and TMR.

TEST TRANSMITTER (TTM)

The Test TransMitter (TTM) is intended for use with the test measurement receiver for GSM 900, GSM 1800, and GSM 1900 systems. The TTM transmits a signal for the TMR to read for the propagation measurements. TTM is designed for all types of environmental conditions that the cell planner may encounter during a field survey.

TEST MEASUREMENT RECEIVER (TMR)

The Test Measurements Receiver (TMR) is intended for signal level measurements during field surveys of the cellular system. The TMR consists of a main unit with a plug-in receiver for the system of interest and a notebook PC to store the measurements that are collected. The TMR can measure up to 27 frequencies simultaneously for signal strength levels as well as the interference of the network (C/I, C/A). TMR shall be connected to an antenna, an odometer sensor, and an optimal GPS receiver unit to allow for geographical coordinates to be included with the measured data.
Figure 10-6 TTM & TMR

- Mains AC
- Uses Mains or Battery
- Car Battery
- Transmitter
- Telescope Mast
- GPS Antenna
- Receiver Antenna
- PC
- Gyro for GPS
- Odometer
- 12V from vehicle
HOT SPOT FINDER

It is important to deploy microcells where the heaviest traffic is located (also known as “hot spots”). One way to find suitable locations for microcells is Ericsson’s Hot Spot Finder. The Hot Spot Finder is a GH388 mobile modified to transmit a BCCH/BSIC combination signal. Basically, it acts as a dummy cell. The mobiles in the surrounding cells will treat the Finder as a neighbor and include BCCH/BSIC combination signals in the measurement reports. Different locations and antenna types and positions can be tested prior to the implementation of the microcell. The potential traffic is estimated by looking at the measurement reports for the mobiles in the surrounding cells.
Chapter 11

This chapter is designed to provide the student with an overview of the parts of the Operations Support System that will assist them in the management of the radio network. It will specifically address the Cellular Network Administration (CNA) function, Performance Management Recordings (PMR) and Radio Network Optimisation (RNO) package.

OBJECTIVES:

Upon completion of this chapter, the student will be able to:

- List the benefits of using the OSS in managing the Radio Network
- Explain the usage of CNA in the OSS.
- Describe how radio network performance can be monitored and analysed using different OSS applications.
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INTRODUCTION

Every network needs a method to manage the overall operation of the system and the individual components that comprise the system. Ericsson’s solution to this need is the Operations Support System (OSS).

All of the benefits of this single, multi-tasking tool are too numerous to list; however, the major applications that apply to the radio network will be discussed.
CONFIGURATION MANAGEMENT IN OSS

INTRODUCTION TO CONFIGURATION MANAGEMENT

A cellular network consists of several nodes with certain functions in the network. To achieve and maintain high performance, the network has to be adapted all the time. New subscribers must be added, new cells must be introduced, the software of certain NEs must be updated, etc. Adaptation like this is achieved by configuration management.

OSS supports configuration management in a user-friendly way through its concept. OSS provides a network view, which means the user can see how changes in one NE have impacted on other NEs. So OSS is the best solution for configuration management in a network.

Configuration management in OSS can be divided into three areas:

- Configuration management for cells
- Configuration management for Base Transceiver Stations (BTSs)
- Configuration management for AXE-10 software

CONFIGURATION MANAGEMENT FOR CELLS

A cell is the area of radio coverage seen by the mobile station. The definition of this area is calculated by approximately 200 parameters. These parameters must be defined in the Mobile services Switching Centre (MSC) and the Base Station Controller (BSC), e.g. the insertion of a new cell is a very complicated task, because the new cell must be defined and the existing cell must be adapted. OSS offers two tools for user-friendly and consistent adaptation of cell and cell related parameters:

- Cellular Network Administration (CNA)
- Cellular Network Administration Interface (CNAI)

CNA uses a model of the physical network for the introduction of changes in the cellular network. The model consists of several Managed Objects (MOs), which are arranged in different layers. The MOs represent NEs and functions in the physical network. This model is stored in the Cellular Network Administration-
Data Base (CNA-DB). So changes to the cellular network are planned offline and the physical network is not affected. CNA provides areas for the handling of cell and cell related parameters. The following areas are available:

- **Valid Area**, is a copy of the physical network with all cell and cell related parameters. This area is used for information retrieval without interfering with the network. No cell or cell related parameters can be changed in the Valid Area.

- **Planned Area**, is used for the adaptation of cell and cell related parameters. In this area MOs, e.g. sites, cells, and channel groups, can be created, modified, and deleted. Planned Areas can be created from Valid Areas, existing Planned Areas, and the Fallback Areas. The parameter values stored in the source area are copied to the Planned Area during the creation of the Planned Area.

- **Fallback Area**, is used as a backup for security reasons. The parameter values stored in the source area are copied to the Fallback Area during the creation of the Fallback Area. The Fallback Area can be used to restore the data in the network to its original contents.

- **Profile Area**, is used to create predefined Internal Cells and Neighbor Relations which can be used as templates, e.g. the user can created different Internal Cells for urban and rural areas. The parameter values of these default cells can be used for future planning purposes in the Planned Area.

- **Log Area**, is created by the Performance Management-Traffic Recording (PMR) application during a measurement. In this area BSCs, Internal Cells and their Channel Groups are stored. The data can be used directly when the measurements in RNR are analyzed.
For all areas the same user interfaces are used. So the cell information is displayed in the same way, independent from the actual loaded area. This allows easy handling of the cell and cell related parameters. The areas are distinguished by name, which is shown in the user interface. The starting point for information retrieval is the CNA Base window. The base window provides several functions for easy navigation through the different MO layers, e.g. separate superior object selectors for MSC and BSC. The current selection and the related objects, if applicable, are shown in two lists in the base window. From here, the user can get detailed information about the selected object from a separate property window. This property window shows all parameters of the object, e.g. for a cell. The displayed parameters can be changed only when a Planned Area is loaded.

Another possibility to view object parameters is through a table. The CNA Table is a type of spreadsheet, which allows the presentation of parameter values of one or several MOs at the same time. The CNA Table is started from the main window, and all objects selected in the current selection list are displayed in the table. The MO must be of the same object type, e.g. Internal Cells. After a table has been opened, further MOs can be added or removed from the table. The user can customize the
table view and save the customized table view for future reuse. The following functions for customization are available:

- Change the relative order of the displayed rows and columns.
- Sort the displayed rows.
- Hide and unhide parameter columns.
- Freeze and unfreeze any row or column. Freezing means that the applicable row or column always remain visible, regardless of scrolling.

The big advantage of the CNA Table is that parameter values for different MOs can be changed simultaneously, e.g. Location Area Code (LAC) for the Internal Cells after a BSC split. This is a very powerful function, which can produce some problems. For security reasons there is a Reset and Restore function available. The Reset function returns the value to the last applied value. The Restore function sets the value equal to the parameter value in the Valid Area. The CNA Table is used in one of the following modes:

- View Mode, which is entered if the current area is not a Planned Area locked by the user
- Edit Mode, which is entered if the current area is a Planned Area locked by the user
- Freeze Mode, which is entered if the area in the CNA Table is not the same area as the current area in the CNA Base window

To help the user discover inconsistencies in the cellular network and to navigate easier, the Graphical Cell Configuration (GCC) was developed. GCC is an application which presents Sites and Cells graphically. For the depiction, the Geographical and Logical Network Information Presentation (GNIP) is used by GCC. GNIP is a common geographical and logical presentation tool, which can be used by several applications. Applications which use GNIP are called GNIP applications (GNAPs). GCC is one of the available GNAPs.

Before sites and cells are displayed, GCC must be connected to CNA. This is done in the CNA Base window. GCC must also be connected to GNIP. This is done in the GNIP Session Control window. After that, sites and cells are displayed on a predefined map. The map can consist of several layers with different geographical information. In GCC, the sites and cells can be selected. This is depicted by a special indication. The selected
MO automatically becomes the current selection in the CNA Base window, provided that the current CNA has been connected to GCC. The properties, e.g. the Internal Cell parameters, are directly accessible after the selection.

For the presentation of cells, two different cell shapes are available:

- Hexagon cell shape
- Approximate cell shape

For the cells, several parameter values are displayed by different colors, e.g. Location Area Code (LAC), Base Station Color Code (BCC), and Broadcast Control Channel Number (BCCHNO). In addition to the cell parameter, Neighbor Relations between cells can also be displayed. Several functions are available for the customization of a map, e.g. zoom and find. The user can save specific settings as private views.

The Cellular Network Administration Interface (CNAI) is a command line interface for import and export of data to and from the Cellular Network Administration (CNA) application. CNAI can be used to export cell data from the CNA-DB to the normal Unix file system. From here the cell data can be transferred by File Transfer Protocol (FTP) to another location, e.g. another Operation and Maintenance Centre (OMC). In the other OMC the cell data can be imported to the Cellular Network Administration-Data Base (CNA-DB) and used in the CNA. The file, with the exported cell data, can also be used for cell planning. For this purpose, TEst Mobile Station (TEMS) CellPlanner was developed. The cell data from the CNA can be loaded and processed by TEMS CellPlanner. Additional cells can be inserted and the network can be optimized. The processed cell data of TEMS CellPlanner can then be imported to the CNA-DB again.
**PROCESS OF CELL CONFIGURATION**

To create a new cell, to modify an existing cell or to delete an existing cell several steps must be performed by the user. Firstly, CNA must be started, then the Valid Area is automatically loaded in the CNA Base window. Before the user can start to plan cellular changes, a picture of the actual situation in the physical network is needed. The Valid Area is only a snapshot of the situation in the physical network. In the meantime, another user could have changed cell parameters from a local terminal connected to a NE. To get the actual configuration of the physical network, an Adjust must be performed. During an Adjust the parameters stored in the CNA-DB are compared against the cellular parameters in the network.

The user can decide to get a list with all differences found or to refresh the data for the Valid Area in the CNA-DB. For planning purposes the data for the Valid Area in the CNA-DB must be refreshed.
An Adjustment can be performed on:

- Network level
- MSC level
- BSC level
- Cell level

After the Adjustment, a new Planned Area based on the Valid Area must be created by the user. The new Planned Area includes all cell and cell related parameters of the Valid Area. The new Planned Area is automatically locked for the user. This is done so only the user, who has created the Planned Area, can change parameters in the Planned Area. Now the user can change cell parameters, create new cells or delete existing cells. Every action performed on the parameter is marked by a flag. The user can use the property window or the CNA Table to change parameters.

Several steps are necessary to insert a new cell. The steps must be performed according to the MO model, which is used in CNA, e.g. to insert a new Internal Cell, the cell must be created and the parameters given. For the new cell a related site and Transceiver Group (TG) must be created. The TG and the Internal Cell have to be connected through the Channel Group. After that the Neighbor Relations to the surrounding cells have to be specified. The corresponding Inner Cell on the MSC level is created automatically. If the new Internal Cell is located at a BSC or MSC border, the cell must be defined as External Cell or Outer Cell for the corresponding BSC or MSC area.

When a parameter is entered or changed, the value is Validation Checked. This means CNA checks if the value is within a defined range. If the value is outside the range an error message is issued.

It is necessary to check that the parameters in the network are set in a reasonable way, i.e. they are not allowed to be in conflict with rules that are defined for these parameters. The MSC and BSC do some checking of the network parameters of their own area, but they are unable to compare these values to values in other MSCs and BSCs. The Consistency Check, provided by CNA, handles the parameter settings from a network point of view and is not limited to the view of one NE at a time. The Consistency Check uses several rules to check the parameter and the relation to other parameters. At the end of the Consistency Check the user gets a list with all rule violations and all
undefined parameters. A Consistency Check can be performed at any time during the planning process, but should be performed at the end of a planning process.

Consistency Checking

OSS

Planned Area Valid Area

Update = Changes are made from the Planned Area to the Physical Network.

Adjust = Changes are made from the Physical Network to the Valid Area.

Figure 11-3 The CNA workflow

When all changes are done and the Consistency Check has been performed, the physical network can be updated with the changes in the Planned Area. For this an Update job is started. During the Update the Planned Area is compared to the Valid Area and all differences found are translated into Man Machine Language (MML) commands. The MML commands are sent one by one to the NEs and at the same time the Valid area is updated with the new parameters. The user can specify several parameters for the Update job e.g.:

- What happens if an error occurs during the Update
- If a Fallback Area should be created

A report is generated with the results of the Update Job.
PERFORMANCE MANAGEMENT

The network operator needs detailed information about the network performance to run the network, otherwise it is not possible to plan and dimension the network. The information can also be used to find areas of insufficient service and performance. So the operator is able to correct a problem before a fault occurs. The information, delivered by performance management systems, can be used to:

- Identity traffic patterns and traffic distributions
- Determine the amount of traffic in the exchange and the network
- Monitor the grade of service
- Find areas of insufficient service
- Fault finding

The AXE-10 includes a comprehensive set of measurement functions for all types of objects, which are of interest for the operator. The operator must distinguish between long-term statistics and short-term recordings.

- Long-term statistics are used for dimensioning, planning, and management of the network
- Short-term recordings are used for fault finding and trouble shooting

LONG-TERM STATISTICS

As previously mentioned, long-term statistics are used to dimension, plan, and manage a network. Long-term statistics mean that measurements are performed over a duration of several months or longer. The measurement functions are active all the time and supervise the AXE-10 continuously. The AXE-10 includes two subsystems which provide measurement functions for long-term statistics:

- Operation and Maintenance Subsystem (OMS)
- Statistical and Traffic Measurement Subsystem (STS)
The OMS provides recording functions for:

- Traffic measurement on routes
- Traffic type measurements
- Traffic dispersion
- Data recording per call
- Processor and input load-measurements

STS provides measurement functions for many different objects, e.g. STS includes the same measurement functions as OMS, but the recordings are more detailed. In addition, the STS includes measurement functions for:

- Supervision of the Link Access Protocol for the D-Channel (LAPD)
- Supervision of the C7 signaling
- Supervision of the paging in a Base Station Controller (BSC)
- Other objects e.g. number of handovers

**INITIATION OF LONG-TERM STATISTICS**

OSS provides an application for the initiation, supervision, and collection of long-term statistics, called Performance Measurement (PM) Data Collection. The user can perform OMS and STS measurements with PM Data Collection. PM Data Collection supports the following OMS measurements:

- Traffic measurement on routes
- Traffic measurement on traffic types
- Traffic measurement on traffic dispersion

All kinds of STS measurements are supported by PM Data Collection.

The user can easily handle OMS and STS measurements by means of a graphical user interface. No further knowledge about OMS and STS is required. All defined measurement functions of the different NEs are presented in a list. The list is a snapshot of the actual definitions of an NE. If new STS measurement functions were defined by another user, the list must be updated. The system administrator can do this with the Audit function of PM Data Collection. The results of the recording are transferred from the NE to TMOS and stored in the PM Application-Data
The user or other applications can access the PMA-DB over an open Standard Query Language (SQL) interface.

Figure 11-4 The process of data collection

To initiate a recording the user must specify the type of recording, this means OMS or STS measurement. After that the NE must be selected. The user gets a list of all available measurement functions of this NE and can easily select the desired one. It is possible to select one or several measurement functions for one measurement job. The user must specify the recording period and the daily recording interval. Then, the recording can be initiated. After that, a new measurement job is created and the job status is displayed in the main window.

All other settings are automatically handled by PM Data Collection. The parameters, given by the user, are translated by PM Data Collection. Command and Response scripts are used for communication with the NE. The recording is defined and started at the NE. The recording results are stored in files on the Input Output Group (IOG). The files are transferred periodically from the IOG to TMOS. PM Data Collection supervises the file transfer and after a successful file transfer, the files are deleted on the IOG. The files from STS recordings are stored directly in the PMA-DB. The files from OMS recordings are normalized first and then stored in the PMA-DB. The normalization
function performs a type of post processing, which formats the OMS files to the STS standard file format. The data stored in the PMA-DB is available over an open SQL interface.

PM Data Collection also provides functions to include existing STS and OMS PM files in the PMA-DB later on.

**PROCESSING OF LONG-TERM STATISTICS**

The recording results are stored as raw data in the PMA-DB. This data can be processed by other applications. An SQL interface is available for the access of the data. OSS includes an application for the processing of the raw data, called PM Data Processing. This application allows the user to post process raw data stored in the PMA-DB by several functions. These functions are controlled by graphical user interfaces, which allows easy and comfortable handling. PM Data Processing provides the following data processing functions:

- Summarization over a day, week, or month
- Maximum or minimum value per day
- Predefined functions

The user can create their own data processing functions and run this function through a graphical user interface provided by PM Data Processing. This is called predefined function.

![Data processing functions: Summarizations over day, week, or month, Maximum or minimum value per data, Pre-defined Function](image)

*Figure 11-5 The data processing process*

PM Data Processing accesses the PMA-DB and fetches the raw data according to the specifications given by the user. The raw data is processed and then stored in the Performance Measurement Application Result-Data Base (PMARES-DB).
The processed data is available over an open SQL interface for other applications. Following is an example for a data processing function.

When the summarization over a day function is selected, a Create Time Sum Day Job is created. The raw data of the specified table is processed and stored on a per day base. Gauge counters are summarized so that the mean value within the day interval is saved. Cumulative counters are summarized so that the accumulated sum within the day interval is calculated and saved. The processed data is stored in the PMARES-DB.

**PRESENTATION OF LONG-TERM STATISTICS USING STATISTICAL REPORT PACKAGE (SRP)**

The recording results, stored in the PMA-DB, are available over an open SQL interface. The network operator can use third party products to fetch and process the data out of the database. Ericsson provides a tool, which allows presentation of the data stored in the PMA-DB. The name of the application is Statistical Reports Package (SRP) and is part of the OSS. SRP presents STS and OMS measurement data in several reports. Additionally, data of the Cellular Network Administration-Data Base (CNA-DB) is used. The CNA-DB contains the current radio network configuration, which is used for the creation of reports. In addition to the data stored in the CNA-DB and the PMA-DB, printouts from the NEs are collected and processed for the reports. Printouts for the subscriber distribution are fetched from the responsible NE. Also restart messages are collected from the NE by SRP. The data which is presented in the different reports is stored in the Statistical Report Package-Data Base (SRP-DB). For the graphical presentation of the reports in spreadsheets and diagrams a third party product called Applix Ware is used.
SRP provides a number of reports that will support the user in analyzing the behavior of the radio network and the switching system. Three report types for different user groups are available. Each report package consists of several subreports. The reports can be scheduled or generated immediately and presented on screen or saved in a file. To schedule reports the Cellular Network Activity Manager (CNAM) is used. The reports can be generated once, hourly, daily, weekly, or monthly. CNAM supervise the generation process and allows the user to view, delete, and abort SRP jobs.

For some reports thresholds are used. The thresholds help the user to find cells and routes with exceptional characteristics in the network. The threshold definition is made in the report setup. Targets are also used to make it easier to compare a current value against a defined value. The user can define groups of Managed Objects which are used in the report. Managed Objects in this content are routes and cells.
The reports in SRP are grouped and structured into three types:

- Management
- Planning and Engineering
- Operation.

Management Reports

The Management Summary Report is customized to provide comprehensive information about the cellular network in both tabular and graphical form. The Management Summary Report contains information from both MSCs and BSCs, i.e. the whole network. This enables the management to increase the control of network size and behavior.

Planning and Engineering Reports

The Planning and Engineering Reports are specifically intended for planning and engineering personnel and are designed for identifying in which areas future expansion of the network is needed. The reports give overviews and detailed statistics for the network planning and engineering. The Planning Summary Report contains information about the whole network but is more detailed than the Management Summary Report. The information in all reports, except the Planning Summary Report, is sorted according to names and identities. The reports selected to be viewed on the screen will be shown in the spreadsheet format. This makes it possible to sort the information in the reports according to any performance criteria.

Operations Reports

The Operation Reports are used as “Management by Exception Reports” and include thresholds to be defined for the performance indicators in the reports. The reports present detailed statistics on the radio network, switch, and route performance. The reports are used in order to rapidly detect cells and routes with unacceptable performance, enabling the operator to take immediate action in order to preserve the quality of the network. The information in the Operation Reports, as in the Planning and Engineering Reports, is sorted according to names or identities. The reports selected to be viewed on the screen will be shown in the spreadsheet format. This makes it possible to sort the information in the reports according to any performance criteria.


**SHORT-TERM RECORDINGS**

As previously mentioned short-term recordings are used for fault finding and trouble shooting. Short-term recordings are also used to improve the network performance. Start point for short-term recordings are error messages received from an NE or customer complaints, e.g. several customer complaints about dropped calls within a cell. The BSC provides several measurement functions for short-term recordings. These measurement functions are all intended to find and solve problems within the cellular network. The user can initiate the measurement functions locally by Man Machine Language (MML) commands or remotely by different OSS applications. The measurement functions for short-term recordings are:

- Mobile Traffic Recording (MTR) function
- Cell Traffic Recording (CTR) function
- Channel Event Recording (CER) function
- Radio Interference Recording (RIR) function
- Active BCCH Allocation List Recording (ABAL) function
- Measurement Result Recording (MRR) function

OSS also includes several applications for the handling of the BSC measurement functions.

**PERFORMANCE MANAGEMENT-TRAFFIC RECORDING (PMR)**

The Performance Management-Traffic Recording (PMR) application is a tool to analyze network behavior. It is intended to be used for detailed performance analysis when determining the reason for identified problems. Such problems can be an increased rate of dropped calls, which are identified by using statistics or customer complaints. PMR provides functions to observe the radio network performance in detail. The observed performance is related to traffic behavior, such as:

- Setup of connections
- Handovers
- Release of connections

PMR supports the definition, initiation, supervision and collection of MTRs, CTRs, and CERs.
The MTR function is used for mobile related recordings. During a measurement a mobile is traced and all events are recorded, e.g. call setup, handovers, and call termination. The International Mobile Subscriber Identity (IMSI) number, which is stored on the Subscriber Identity Module (SIM) card, is used for the identification of the mobile. So a test mobile can be used to determine problems in the cellular network. The recording is initiated in the MSC because the subscriber data is fetched from the Home Location Register (HLR)/Visitor Location Register (VLR) through the MSC. The actual recording is performed in the BSC.
The CTR function is used for cell related recordings. During a measurement, a cell is supervised and all events in the cell are recorded, e.g. cell access, handover, and channel release. The Cell Global Identity (CGI) is used to identify the cell. The recording is initiated and performed in the BSC.

The CER function is used for channel related recordings for one or several cells. During a measurement the SDCCHs and the TCHs in the cell are supervised and measurements on the channels are performed, e.g. interference level measurement. The recording is initiated and performed in the BSC.

The user defines and initiates the different types of recordings through a graphical user interface. In addition to the measurement specific parameters, only some general parameters
must be given, e.g. job name and time interval. After that, a new measurement job is created and the job status is displayed in the main window. The measurement job is supervised by the CNAM application. The recording is initiated in the NE and the measurement function records all events. When the recording is finished, the recording results are stored in one or several files on the IOG. The files are transferred from the NE to TMOS and stored in the Performance Management-Traffic Recording-Data Base (PMR-DB).

PMR includes several reports to present the results of the recordings. Different reports are available for the different types of recordings. A general report, which presents general information of the recording, is available for all recordings. Some of the important reports are described below.

Reports for MTRs and CTRs:

- Events Statistics report displays a statistic of all events, e.g. Assignment Command and Inter Cell Handover Command
- Measurement Data and Event List report displays a chronological list of the events and the connected measurements, e.g. RX level uplink

Reports for CERs:

- Interference Band Statistics report displays the interference level for the SDCCHs and TCHs
- Channel Event Statistics report presents statistics with events for the different channels, e.g. released connections and dropped connections

Traffic Recordings, initiated outside of PMR, can be included in the PMR-DB by an Import Function.

**FREQUENCY ALLOCATION SUPPORT (FAS)**

The speech quality and the amount of dropped calls are directly affected by the interference level in the radio network. In order to use the frequency spectrum in an efficient way and to increase the capacity of the network, the interference level must be kept as low as possible.

OSS provides a tool that supports the network operator by frequency planning, called Frequency Allocation Support (FAS). FAS performs recordings of the uplink interference on up to 150
frequencies in at least 2000 cells handled by OSS. FAS can be used for:

- Network Optimization, i.e. to improve the frequency allocation in a cell
- Network Planning, i.e. to find suitable frequencies for a new cell
- Network Supervision, i.e. to monitor the interference levels on frequencies in use

FAS uses the Radio Interference Recording (RIR) function, which is located in the BSC, to perform the measurements.

**HANDLING OF FAS**

FAS is handled by means of the Radio Network Optimization (RNO) application. From here the user can initiate new FAS recordings, check the state of active FAS recordings, and generate FAS reports for finished FAS recordings.

The RNO main window is divided into two tabs:

- Recording Activities, for the handling of recordings. The user can schedule, stop, terminate, and delete recordings.
- Recording Results, for the handling of recording results. A list with all recording results and the current status of recording results is displayed. The user can start one of the available reports for the recordings in the list.

The user starts a new FAS recording from the Radio Network Optimization (RNO) main window. The user must specify several parameters for the FAS recording, e.g.:

- Interference Level Percentile for the measurement.
- Cells, which should be used for the measurement.
- Frequencies, which should be used for the measurement.
- Time interval for the measurement. The recording can be scheduled. The handling and supervision of scheduled recordings is done by the CNAM.

When all parameters are given, the recording can be started. The recording is initiated in one or several BSCs which are related to the selected cells. All actions and events during the recording are logged in a Recording Log. The user can view the information stored in the log. The recording results are stored in
files on the IOG. The user can decide if the files are transferred after each recording period or when the recording is finished from the BSCs to TMOS. The files are stored in the database and the recording results can be accessed from RNO user interface.

Figure 11-9 The FAS data flow

FAS provides several reports for the presentation of the recording results. All reports may be opened in an Applix Ware Spreadsheet, where the user can work with the result data and store it in the desired file format.

The two overview reports, FAS Overview Report and FAS Overview Comparison Report, are started from the RNO Recording Result tab. All other reports, e.g. the FAS Cell Report, are started from the overview report window. The FAS Overview Report and the FAS Cell Report are described in detail in the following paragraph.

In the FAS Overview Report the cells to be investigated are identified. The user can see if there are frequencies with a high interference level. Also if there are non-configured frequencies which are better than the configured frequencies currently used. To get more detailed information, the user can select one of the displayed cells and start a FAS Cell Report. The interference
level of the configured frequencies and of the non-configured frequencies is displayed in the FAS Cell Report. So the user can easily compare the values and decide which frequencies should be used for the cell.

FAS can interact with the SRP, the Geographical and Logical GNIP, and the CNA application.

Additional statistics can be obtained from SRP on the cells included in a FAS Overview Report. The Radio Exceptions Report or the Detailed Radio Statistics Report is started in SRP and the report is presented in an Applix Ware Spreadsheet.

The user can exchange a bad configured frequency with a better non-configured frequency in the FAS Cell Report. For this, the two frequencies must be selected and added to a FAS Change Order. The FAS Change Order is used to update the network. This can be done either by transmitting the data in the FAS Change Order to a Planned Area in CNA or by storing the data in a file. This file can be loaded into CNA through the Cellular Network Administration Interface (CNAI).

The recording results can be displayed in GNIP. The cells are colored and the result value is shown beside the cell. GNIP can also be used to define Cell Sets and Frequency Sets for FAS.

**NEIGHBORING CELL SUPPORT (NCS)**

The handover decision in a radio network is based on measurements from the mobile station, on the downlink, and from the base station, on the uplink. The accuracy of the measurements is of great importance to make a reliable handover decisions.

If the number of neighboring cell relations is too high, the measurement accuracy will decrease. It is however important to include all the relations that can be good handover candidates in the Active BCCH Allocation (BA) List. The Active BA List is sent to the mobile station and includes all BCCH frequencies, which should be measured by the mobile station for a handover.

Neighboring Cell Support (NCS) is a tool that helps the user to specify adequate neighboring relations for each cell in the radio network. Thus, the handover decisions will be more reliable and accurate, which leads to increased speech quality and fewer dropped calls. NCS performs recordings of the downlink quality on up to 150 BCCH frequencies in at least 2000 cells handled by OSS. NCS can be used for:
• Network Optimization, i.e. to find missing neighboring cell relations in the Active BA List
• Network Supervision, i.e. to evaluate the neighboring cell relations

NCS uses the Active BA List Recording (ABAL) function, which is located in the BSC, to perform the measurements.

**HANDLING NCS**

NCS is handled by means of the Radio Network Optimization (RNO) application. From here the user can initiate new NCS recordings, check the state of active NCS recordings and generate NCS reports for finished NCS recordings.

The RNO main window is divided into two tabs:

• Recording Activities, for the handling of recordings. The user can schedule, stop, terminate, and delete recordings.

• Recording Results, for the handling of recording results. A list with all recording results and the current status of recording results is displayed. The user can start one of the available reports for the recordings in the list.

The user starts a new NCS recording from the RNO main window. The user must specify several parameters for the NCS recording, e.g.:

• Change Interval for the measurement.
• Cells, which should be used for the measurement.
• Frequencies, which should be used for the measurement.
• Time interval for the measurement. The recording can be scheduled. The handling and supervision of scheduled recordings is done by the CNAM.

For the measurements, the default values for Relative signal Strength, Absolute Signal Strength, and Number of Test Frequencies should be used. The user should change these values only in a special situation.

When all parameters are given, the recording can be started. The recording is initiated in one or several BSCs which are related to the selected cells. All actions and events during the recording are logged in a Recording Log. The user can view the information stored in the log. The recording results are stored in files on the IOG. When the recording is finished, the files are
transferred from the BSCs to TMOS. The files are stored in the data base and the recording results can be accessed from RNO user interface.

Figure 11-10 The NCS data flow

NCS provides several reports for the presentation of the recording results. All reports may be opened in an Applix Ware Spreadsheet, where the user can work with the result data and store it in the desired file format.

The NCS Overview Report is started from the RNO Recording Result Tab. All other reports, i.e. the NCS Cell Report, the NCS Cell Report Chart, and the NCS Detailed Cell Report, are started from the NCS Overview Report window. The NCS Overview Report and the NCS Cell Report are described in detail in the following paragraph.

The NCS Overview Report presents the result data in a table, where the occurrence of frequencies is summarized for each cell. This helps the user to find a cell where the neighboring cell relations can be improved. If the best test frequency was reported more times than the worst configured frequency, the configured frequency should be exchanged. Detailed reports can be started on a per cell base to find the frequencies that should be exchanged. The NCS Cell Report presents the BA List
frequencies and the test frequencies in separate tabs. These tabs are sorted, so that the user can easily see which frequencies should be exchanged by test frequencies.

NCS can interact with the GNIP and the CNA application.

The recording results can be displayed in GNIP. The cells are colored and the result value is shown beside the cell. GNIP can also be used to define Cell Sets and Frequency Sets for NCS.

The user adds one or several test frequencies to the Active BA List. For this, the test frequencies must be selected and added to a NCS Change Order. The NCS Change Order is used to update the network. This can be done either by transmitting the data in the NCS Change Order to a Planned Area in CNA or by storing the data in a file. This file can be loaded into CNA through the CNAI. To delete frequencies from the Active BA List the user must use CNA. The deletion is done in a Planned Area and the changes in the configuration are transferred to the network through an Update job.

**MEASUREMENT RESULT RECORDING (MRR)**

The mobile station performs measurements in both idle mode (the mobile station is switched on and moves around) and during a call. The mobile station measures the downlink signal strength of the serving cell and of the 6 neighbor cells. Although the downlink signal quality of the serving cell is measured by the mobile station. These measurements are sent as measurement results to the BSC, which processes the information. Based on the measurement results a handover is initiated.

The measurement results can be used for the supervision and improvement of the radio network. For this, a new BSC recording function was introduced called Measurement Result Recording (MRR). MRR creates reports and histograms based on the uplink and downlink signal strength, the uplink and downlink signal quality, timing advance, and other parameters.

OSS provides an application which allows the user to initiate, supervise, and collect MRR recordings in the BSC, called Measurement Result Recording (MRR). MRR can be used for:

- Supervision of the network performance
- Trouble shooting in the network
- Comparison of the network performance before and after a change in the network
HANDLING MRR

MRR is handled by means of the Radio Network Optimization (RNO) application. From here the user can initiate new MRR recordings, check the state of active MRR recordings and generate MRR reports for finished MRR recordings.

The RNO main window is divided into two tabs:

- Recording Activities, for the handling of recordings. The user can schedule, stop, terminate, and delete recordings
- Recording Results, for the handling of recording results. A list with all recording results and the current status of recording results is displayed. The user can start one of the available reports for the recordings in the list.

The user starts a new MRR recording from the RNO main window. The user has to specify several parameters for the MRR recording, e.g.:

- Recording threshold for the measurement.
- Cells, which should be used for the measurement.
- Percentage value for the measurement.
- Time interval for the measurement. The recording can be scheduled. The handling and supervision of scheduled recordings is done by the CNAM.

When all parameters are given, the recording can be started. The recording is initiated in one or several BSCs which are related to the selected cells. The recording results are stored in files on the IOG. The user can decide, if the files are transferred after each recording period, or when the recording is finished from the BSCs to TMOS. The files are stored in the data base and the recording results can be accessed from RNO user interface.

MRR provides several reports for the presentation of the recording results. All reports can be stored as Unix files. The textual reports can be stored as Applix Spreadsheet.

The following reports are available in MRR:

- MRR Overview Report
- MRR Overview Chart
- MRR Cell Histogram
- MRR Comparison Report
• MRR Comparison Chart
• MRR Cell Comparison Histogram
• MRR Trend Report

Some of the reports, like the MRR Overview Report and the MRR Comparison Report, are started from the RNO Recording Result table. Other reports, like the MRR Cell Histogram, can be started from the open report window. The MRR Overview Report is described in detail in the following paragraph.

The MRR Overview Report presents the recording results on a per cell base. For each cell, common data e.g. cell name and cell type is displayed. The following recording results are presented:

• The number of received measurement reports
• STS statistics for traffic level
• Different radio statistics

Additionally summary information is given about the total number of measurement reports, the total STS statistics for traffic level and the total number of radio statistics. To get detailed information about the measurement results, the user can open the MRR Overview Chart from the Overview Report window. In the MRR Overview Chart one radio statistic is shown, e.g. the signal strength.

MRR can interact with the SRP and the GNIP.

The user can add more details to a report. Certain SRP reports, e.g. the Radio Exception Report, must be ordered from the MRR user interface. MRR provides SRP with cell names and time periods.

The recording results can be displayed in GNIP. The cells are colored and the result value is shown beside the cell. GNIP can also be used to view defined Cell Sets.
This chapter is designed to provide the student with an overview of the theory behind expanding the network by means of cell splitting. It will address basic methods and show how decreasing the size of the cells in a network actually adds capacity. This chapter will also discuss the frequency planning considerations involved with cell splitting.

**OBJECTIVES:**

Upon completion of this chapter, the student will be able to:

- Apply the cell splitting technique in order to increase the capacity of an existing network
- Tell the difference between macro, mini, micro, and indoor cells
- Understand the hardware requirements for micro and indoor cells
- Understand how frequency planning in a high capacity network can be carried out by using multiple re-use patterns
# 12 Network Expansion

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SYSTEM GROWTH

INTRODUCTION

If the number of subscribers in a system continues to increase, at some point it becomes necessary to increase the capacity of the system. There are several ways to do this:

- Increase the frequency band (e.g. a GSM 900 operator might buy GSM 1800 licenses)
- Implement half-rate
- Make frequency re-use tighter (e.g. going from a 4/12 re-use pattern to a 3/9 re-use pattern by implementing frequency hopping)
- Make the cells smaller and smaller

After a description of the regular procedure for adding new sites (cell split), tightening of the re-use pattern by means of Multiple Re-use Pattern (MRP) or fractional load is briefly discussed.

CELL SPLIT

It is clear that a smaller cell size increases the traffic capacity. However, a smaller cell size means more sites and a higher cost for the infrastructure. Obviously, it is preferable not to work with an unnecessarily small cell size.

What is needed is a method that matches cell sizes to the capacity requirements. The system is started using a large cell size; however, when the system capacity needs to be expanded, the cell size is decreased in order to meet the new requirements.

This normally also calls for using different cell sizes in different areas. This method is called cell split, and is illustrated in Figure 12-1 through Figure 12-4.

Example:

Initially, the largest possible cell size is used, considering coverage range (Figure 12-1). Next step is to introduce three cells per site (Figure 12-2), using the original sites and feeding the cells from the corners. This represents a cell split of 1 to 3, (Figure 12-3). Now the number of sites is still the same, but the number of cells are three times as many as before. The following step is to do a cell split of, e.g. 1 to 4 (Figure 12-4). As seen
from the figure, the old sites are still used in the new cell plan, but additional sites are now required.

Figure 12-1 Cell split (phase 0)

Figure 12-2 Cell split (phase 1)
Figure 12-3 Cell split 1:3 (phase 2)

Cell split 1 to 3 (Figure 12-3) requires three times as many cells. After the split, the capacity is three times higher per area unit, and the cell area is three times smaller. The antenna directions on the site that existed before the split must be changed by 30 degrees.

Figure 12-4 Cell split 1:4 (phase 2)
Cell split 1 to 4 (Figure 12-4) requires four times as many sites. After the split, the capacity is four times higher per area unit, and the cell area is four times smaller. There is no need to change the antenna directions in a 1:4 cell split.

Final traffic capacity

Having gone through the different steps in cellular system design, it is time to calculate the capacity of a typical cellular configuration.

Assume that a cell radius of 14 km is used initially, in an eight cell cluster of omni cells (step 0) and then introduce sectorization (step 1a). Since a 24 re-use is not common for digital cellular system, we immediately introduce a tighter (12) re-use pattern (step 1b). This is followed by two successive one to four (1:4) cell splits (2 and 3). Assume that 24 carriers are available. Estimating the traffic capacity per cell and km², and assuming a GoS of 2% and 20 mE per subscriber Table 12-1 is obtained.

<table>
<thead>
<tr>
<th>Step</th>
<th>Cell radius</th>
<th>N</th>
<th>Channels per cell</th>
<th>Cell area</th>
<th>Subscr./cell</th>
<th>D:o/km²</th>
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<tr>
<td>0</td>
<td>14 km</td>
<td>8</td>
<td>22</td>
<td>510 km²</td>
<td>745</td>
<td>1.5</td>
</tr>
<tr>
<td>1a</td>
<td>8 km</td>
<td>24</td>
<td>7</td>
<td>166 km²</td>
<td>145</td>
<td>0.9</td>
</tr>
<tr>
<td>1b</td>
<td>8 km</td>
<td>12</td>
<td>14</td>
<td>166 km²</td>
<td>410</td>
<td>2.5</td>
</tr>
<tr>
<td>2</td>
<td>4.6 km</td>
<td>12</td>
<td>14</td>
<td>55 km²</td>
<td>410</td>
<td>7.5</td>
</tr>
<tr>
<td>3</td>
<td>2 km</td>
<td>12</td>
<td>14</td>
<td>14 km²</td>
<td>410</td>
<td>29</td>
</tr>
</tbody>
</table>

Table 12-1

As the table shows, capacity is decreased after sectorization. This is due to lower trunking efficiency when we have less channels per cell. This is a necessary step to be able to proceed with the subsequent stages of cell splits. In the following 1:4 cell-splits, the capacity per km² increases four times per cell-split.
Implementation

Starting with a theoretical cell plan, site locations are now adjusted to conform to what is physically possible and convenient to realize using, e.g. existing buildings or towers. In this context, it is also wise to check the surroundings of the location for potentially intermodulating transmitters belonging to other radio networks. In practice it is not uncommon that two or even more alternative site locations exist at this stage. It is essential that both C/A and C/I are predicted for each cell, using selected sites and taking the previous mentioned factors into account.
DUAL BAND

INTRODUCTION

An operator with license to operate in the GSM 900 and the GSM 1800 frequency bands can choose to have these two networks combined into the same network. It will then work as a multiband network able to handle multiband mobiles. Each cell in a multiband network has frequencies from only one frequency band. The feature Multiband operation allows cell reselection, assignment and handover between the GSM 900 cells and the GSM cells. The coverage of the GSM 900 in a multiband network is independent of the coverage of the GSM network, and visa versa.

A dual band network may work in two different ways

- Single Band Network
- Dual Band Network

In a single band network (seen in Figure 12-5) both the GSM 1800 network and the GSM 900 networks operate with separate BSCs and MSCs. In a Dual Band Network (seen in Figure 12-6) both the GSM 900 cells and the GSM 1800 cells use the same BSC and MSC. To make site acquisition easier, you may co-locate your 1800 cells with your GSM 900 cells.

![Figure 12-5 Single Band Network](image)
INCREASE CAPACITY WITH MULTIBAND

An operator that has licenses in both GSM 1800 and GSM 900 networks may off load the traffic from the GSM 900 network to the GSM 1800 network with multiband. GSM 900 has 25 MHz with a channel separation of 200 kHz giving us 124 channels for the GSM 900 Band. An operator may only get 5 MHz of the GSM 900 spectrum. With GSM 1800 the spectrum is 75 MHz giving a total of 374 channels with a capacity increase of 302% as seen in Table 12-2.

<table>
<thead>
<tr>
<th>System</th>
<th>Bandwidth</th>
<th>Channel</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSM 900</td>
<td>2 * 25 MHz</td>
<td>124</td>
<td>100%</td>
</tr>
<tr>
<td>GSM 1800</td>
<td>2 * 75 MHz</td>
<td>374</td>
<td>302%</td>
</tr>
</tbody>
</table>

Table 12-2

An example of how much traffic maybe off loaded from the GSM 900 network to the GSM 1800 network:

Consider a cell with the following assumptions:

- 40% of the traffic originate from dual band mobiles
- 80% of the cell has coverage from at least one GSM 1800 cell

In this case, an average of 32% (0.8 * 0.4) of the traffic will be served by the GSM 1800 system. The GSM 900 cells are offloaded by 32% which means a potential traffic increase of 47% (1/ (1 - 0.32))
MACRO, MINI, MICRO AND INDOOR CELLS

The cells in a network can be divided into different categories: macrocells, minicells, microcells and indoor cells, see Figure 12-7. The type of cell is defined by the antenna position. The difference between the four cell types is explained below.

MACRO CELL

A macro cell is a traditional cell with the antenna above the average obstacle (building) height. This gives a good outdoor coverage, and pretty good indoor coverage. The macrocells can be one layer in the Hierarchical Cell Structure (HCS).

MINI CELL

The mini cell is a low macrocell or a roof micro cell. The antennas are mounted just below the rooftop level. The buildings shadow the line-of-sight waves, making the cell area more contained. The minicells are most effective in areas where the buildings have approximately the same height. They can also be one layer in the HCS.

MICRO CELL

A microcell uses low antenna height (typically 4 to 10 m). The antenna is mounted outdoors. The waves propagate between the buildings and not over the roof tops. Objects that may obstruct the propagation are trees, vehicles, advertising signs and sky walks. In squares, some parks and in areas with water there is free space propagation. The diversity gain in a microcell is large due to all reflections. Polarization diversity gives a better result than space diversity. However diversity is not always needed because the micro cell coverage is limited by the downlink.

The cell size is typically 150 to 500 meters. Microcells can be one layer in the HCS.
**INDOOR CELL**

The indoor cell (or pico cell) has the antennas inside a building. This indoor cell covers a building or a part of a building. This is the best solution when high capacity and very good indoor coverage is required. Indoor cells can be one layer in the HCS.

*Figure 12-7 Macro, mini, micro and indoor cells.*
APPLICATIONS FOR MINI, MICRO AND INDOOR CELLS

Both in the case where there is a need for an increase in capacity and where there is a need to increase the coverage the mini, micro and indoor cells can be used (Figure 12-4).

![Diagram of cell coverage and capacity improvement]

*Figure 12-8 Increasing coverage and capacity.*

**FILL IN COVERAGE**

Micro and indoor cells can be used in areas where coverage holes exist from the normal macro cell layer. In this case when coverage gaps are filled, it will be hard to reduce the load of the macro cells. The new coverage of the microcell will generate new traffic.

However, microcells and indoor cells do not have a good coverage characteristics. Therefore, macrocells are still the best choice when possible.

**HOT SPOT CAPACITY**

If there are areas with high traffic concentration such as busy streets or shopping areas, micro or indoor cells can handle this demand in a cost and spectrum efficient way.
HARDWARE REQUIREMENTS FOR MICRO AND INDOOR CELLS

RADIO BASE STATION

Micro and indoor cells are usually served by a very small (physical size) radio base station located close to the antennas. These cells can however be implemented with a larger RBS and by different means of distributing the RF to the antenna. The small radio base stations that are intended to be used for micro and indoor cells can also be used for ordinary macro cells if the output power is sufficient, as this will make it easier to find an appropriate site.

ANTENNAS

The antenna used for a micro or an indoor cell is usually an antenna with low gain. Since the antennas are mounted at a low height, there are higher requirements on the aesthetics than usual.

Power splitters are sometimes used in indoor cells when the loss in walls and floors/ceilings are so high that there is a need for several antennas to obtain coverage.

BSC

The micro and indoor cell networks demand a high capacity from the BSC. It is most cost efficient to have a centrally located BSC in the middle of the microcell network. A high capacity BSC implies fewer nodes leading to easier network handling; for example, no or less transfer of BTSs between BSCs will be required as the network evolves.

A high capacity BSC covering many cells absorbs the load from a larger area leading to a reduction in the load on the MSC resulting from a lower number of inter BSC handovers. The handover algorithm to be used is not limited by the standardized A interface as long as the handovers are within the same BSC. This allows us to use powerful handover algorithms for the microcell network.
HIGH CAPACITY NETWORK

The first step when more capacity is needed is to perform a tuning of the network. If quality problems do exist, these problems must be solved before building out the radio network. Things to check in the tuning are for example frequency plan, radio network parameters, transmission, and BTSs.

The following steps can be taken to increase the capacity:

- Small macrocells
- Tighter TCH frequency reuse
- Even tighter frequency reuse in the macro network and a micro cell hot spot network
- Even tighter frequency reuse in macrocell network and a contiguous microcell network.

SMALL MACRO CELLS

A 4/12 reuse pattern with a separate band for the BCCH frequencies must be used. A separate BCCH band is recommended since it enables the operator to control the level of interference on the BCCH carriers. A carrier by carrier cell planning is not recommended since the following steps can not be taken if that method is used.

TIGHTER REUSE ON TCH FREQUENCIES

Once a separate BCCH allocation is achieved the remaining spectrum can be used for the TCH carriers. These carriers can be planned for an average reuse of 8 - 9, by applying frequency hopping and dynamic power control. It is recommended to use random frequency hopping with the BCCH carrier included in the hopping sequence. Baseband hopping gives enough C/I improvement, so filter combiners can be used.

EVEN TIGHTER TCH REUSE & HOT SPOT MICRO CELLS

Apply an even tighter TCH reuse in the macrocell network to make micro cell carriers available. In this step random frequency hopping, quality based power control and DTX (both uplink and downlink) are prerequisites. The Multiple Reuse Pattern (MRP) is used. In MRP the frequency band used for the TCH carriers is divided into groups (Figure 12-5). The first group may keep the 8-9 frequency reuse and the last group is a 3-6 frequency reuse.
Table 12-3 gives an example with 31 carriers for the macro cells. These carriers are divided into four groups of unique carriers. Group A contains 12 carriers for BCCH only, group B contains 8 carriers for TCH only, group C contains 7 carriers for TCH only, group D contains 4 carriers for TCH only. The equivalent reuse is \((12 + 8 + 7 + 4)/4 = 7.75\). The TCH reuse is \((8 + 7 + 4)/4 = 6.3\).

\[\begin{array}{c|c|c|c}
\text{TRX/cell} & \text{MRP (A/B/C/D)} & \text{TCH reuse} & \text{Equivalent reuse} \\
1 & 12 & - & 12 \\
2 & 12/8 & 8 & 10 \\
3 & 12/8/7 & 7.5 & 9 \\
4 & 12/8/7/4 & 6.3 & 7.75 \\
\end{array}\]

*Table 12-3 Example of Multiple Reuse Pattern, MRP.*

The BCCH reuse is conservative. Keep the old frequency plan for BCCH if it is optimized.

The TCH frequency planning is aggressive. The TCH is more robust, so power control and DTX are used. A TCH reuse down to 6 or even lower is possible with 3 or more carriers per cell.
It should be possible to double the capacity using this method compared with the original macrocell network using a 12 frequency reuse. The reuse is tighter and tighter for every TRX that is added. The last TRX is not only giving more interference, but also gives us a new carrier to hop on. There will be an interference diversity gain associated with the extra TRX. This will compensate for the increased interference.

A contiguous microcell network is not needed at once. A hot spot micro cell network is more feasible in the early phases. Carriers can be borrowed from the macrocell network and reused in the microcell network, but a separate band of 2 - 3 carriers is the recommended solution.

**EVEN TIGHTER TCH REUSE & CONTIGUOUS MICRO CELLS**

An allocation of 5 to 8 carriers is normally sufficient as a micro cell BCCH allocation for a contiguous network. This microcell network can use 2 TRXs/cell since the TCH carrier can use synthesized frequency hopping with a large number of frequencies in the hopping sequence, avoiding only the strongest BCCH neighbors.
FREQUENCY PLANNING

Frequency planning is a function of bandwidth, current site-to-site distance, frequency reuse, and wanted capacity.

There are two different methods for frequency planning for micro- and indoor cells. You can either use separate parts of the frequency band or you can borrow frequencies.

SEPARATE FREQUENCY BAND

This method will give trunking losses, but can be used for big networks with many micro cells. If the operator has a very high number of frequencies (10 MHz) available for the system, this is a good method. In this solution it is recommended to use hierarchical cell structures with one layer for macro cells and another layer for microcells. Fast moving traffic can be handled by the macrocell layer. Since the two cell layers use different frequency bands, interference between macro and micro cells is not a problem.

FREQUENCY BORROWING

If the operator has a small frequency band (less than 6 MHz) frequency borrowing is recommended. This method can be used if there are not too many micro cells. The result depends on the locations and sizes of the microcells. The macrocells will provide the coverage and the micro or indoor cells will provide the hot spot capacity. Great care must be taken when allocating the frequencies to the micro cells. Co-channel interference must be predicted and verified. When it becomes impossible to borrow frequencies there is a need for a change to using the first method, a separate frequency band.

FREQUENCY HOPPING

Since the number of TRXs in a microcell will generally be low, baseband hopping will not be efficient. Synthesizer hopping must be used to gain from the frequency diversity.
FRACTIONAL LOAD

A network with 1/3 or 1/1 frequency reuse is characterised by that random synthesizer hopping is used in combination with fractional loading. This means that the number of transceivers per cell is smaller than the number of hopping frequencies. A lot of hopping frequencies per cell is possible if a tight frequency reuse is applied, for example 1/3\(^1\). In addition, the interference variation becomes larger since the interfering cells are closer now. These two effects increase the gain from frequency hopping. The network can cope with this very tight reuse since each frequency is only used a fraction of the time. Severe interference hits occur sufficiently seldom due to the hopping and the channel coding and interleaving schemes can thereby limit the bit errors in the received frames. It is vital to limit the traffic load and just fractionally load the frequencies, i.e. keep the number of TRXs smaller than the number of hopping frequencies otherwise the network quality will degrade. For this reason, a frequency load measure is used in order to measure the interference level of 1/3 networks. The frequency load is defined as the average traffic load per cell divided by the number of hopping traffic channels per cell (i.e. the number of hopping frequencies multiplied with the number of time slots). This measure can be written as:

\[
FRQLoad = \frac{\text{Erlang}_{\text{cell}}}{8 \cdot (# FRQ_{\text{cell}})}
\]

The frequency load reflects how much time a frequency is being transmitted. Sometimes, the frequency load is referred to as the fractional load.

Another commonly used measure is the hardware load defined as the average number of TRXs per cell divided by the number of hopping frequencies per cell. This measure is similar to the frequency load and the hardware load can be expressed as:

\[
HWLoad = \frac{\text{TRX}_{\text{cell}}}{# FRQ_{\text{cell}}}
\]

\(^1\) Note that 1/3 and 1/1 can only applied on the TCH frequencies. The BCCH frequencies must still use a sparse reuse for satisfactory control channel performance.
However, the hardware load does not take the trunking efficiency into account. The same hardware load results in different served traffic loads depending on the number of frequencies and thereby different frequency loads.

1/3 frequency reuse can be compared to MRP networks, which usually use baseband-hopping resulting in that the number of transceivers is equal to the number of hopping frequencies per cell. Thus, increased frequency hopping gain (interference and frequency diversity) due to the large number of frequencies in the hopping sequence is a potential advantage with 1/3. However, this might be compensated by the sparser reuse of the TCH frequencies (e.g. 8/6/4) with MRP. For an example of a 1/3 reuse see Figure 12-10 and for a comparison between FLP and MRP see below.

*Figure 12-10 1/3 Reuse*
MRP OR FRACTIONAL LOAD?

- MRP, Multiple Reuse Patterns
  - Works with Filter Combiners (narrow band combiners), Base band hopping
  - Usually best for older networks
  - Good for wide band networks
  - Well proven technique !!!

- Fractionally Loaded Channel Plans
  - Requires Hybrid Combiners (wide band combiners) or Combinerless Basestations
  - New networks with CDU-A or CDU-C
  - Good for narrow band networks (<6 MHz)
Indoor Cell Planning

Chapter 13

This chapter is designed to provide the student with examples of design for indoor coverage.

OBJECTIVES:

Upon completion of this chapter, the student will be able to:

• Make a simple design of an in-building installation.
# 13 Indoor Cell Planning

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INTRODUCTION

An indoor system can be built for different reasons. If the coverage is poor from cells outside the building, leading to bad quality, a solution can be to build an indoor system. Buildings generating a high traffic load, like conference centres and airports, may need indoor systems to take care of the traffic. A different application is the business indoor system with the aim to complement or replace the fixed telephony network.

The aim with indoor cell planning is, as for “traditional” cell planning, to plan for good coverage and capacity and at the same time interfere as little as possible. How this can be achieved is briefly described here. The focus is on antenna and RBS-systems, RF design and antenna configuration but also frequency planning, capacity issues and traffic control are described.

The tools for indoor cell planning, TEMS Prediction, TEMS Light and TEMS Transmitter, are also described with focus on how to use them in the planning process.

Figure 13-1 shows the workflow of indoor cellplanning.
Coverage and capacity demands

Capacity dimensioning

Choice of antenna and RBS system

RF design

Nominal antenna configuration

Final antenna configuration

Installation

Frequency planning

Traffic control

Tuning

Figure 13-1 The workflow of indoor cell planning
CAPACITY DIMENSIONING

When dimensioning the capacity of an indoor cell, one must take its application into account. Two different categories of indoor cells can be identified:

1. Public indoor cells. Indoor cells which cover public buildings such as shopping centres and airport terminals.

2. Business indoor cells. Indoor cells covering areas such as offices. In some applications the coverage, capacity and quality demands in business indoor cells may be considerably higher than in public indoor cells, and the GoS must probably be very low.

DIVIDING ONE CELL INTO SEVERAL CELLS

A way of increasing the capacity is to split the “one cell building” into more cells. This should only be considered when the building is large and the traffic demand is high. The splitting should be done into at least three cells to allow frequency re-use in the building, and the split should preferable be performed vertically. Horizontal splitting should be avoided, at least concerning frequency re-use, but may be necessary in low and long buildings.

The cell size, for the separating cell, makes the re-use distance. The recommended separating distance is around four floors, depending on the leakage between the co-channel cells.

Figure 13-2 Recommended cell plan (four floors for each cell). Building is seen from the side.
ANTENNA AND RBS SYSTEMS - OVERVIEW

When designing an indoor system, the ambition is (note! this is not a requirement) to get the antenna network as symmetric as possible in order to provide each single antenna within the system with the same output power. It is desirable to place the RBS somewhere in the middle of the building in order to minimise feeder distance to the antennas.

Preparation for any future extension of the indoor system, both from a coverage point of view and from a capacity point of view, shall always be considered before the installation. The RF-link budget shall be calculated so that there is a possibility to add power splitters, hybrid couplers, etc. to the antenna system in case of further extension of the antenna network.

Although if the intention is, when planning an indoor system, to be operating on a GSM frequency single-band, it is better to prepare the antenna network for multi-band. The cost of investing in multi-band equipment is marginal compared to what it would cost in the future to replace the single-band equipment with multi-band equipment.

In an indoor cell, the downlink is usually the most critical link in the air-interface. This means that there is no need for using uplink diversity in an indoor system or to use amplifiers for improving the uplink signal.

![Figure 13-3 Reception of the uplink signal via several antennas.](image)

However, multi-antenna indoor systems are using a sort of uplink diversity which will improve the uplink signal since it is received by several antennas, as depicted in Figure 13-3.
ANTENNA SYSTEMS

Antennas

The antenna configurations for indoor applications can be divided into four categories:

- Integrated antennas, i.e. antennas integrated in the base station (possible only for RBS 2302).
- Distributed antennas using a coax feeder network.
- Leaking cable.
- Distributed antennas using a fibre-optical feeder network.

*Please notice that a single antenna is here considered to be a special case of distributed antennas.*

There are several types of antennas that are suitable for indoor applications. The two most commonly used antenna types are the directional antenna (Figure 13-4) and the omni-directional antenna.

![Directional antennas](image)

*Figure 13-4 Directional antennas.*

Two commonly used types of omni-directional antennas are the so called “Mexican hat” antenna and the so called “rod” or “tubular mast” antenna, see Figure 13-5. Both types of antennas are attached to the ceiling where they are hard to spot among other equipment like smoke detectors. Comparing these two types of antennas, the “Mexican hat” is to prefer since it has a more stable construction than the “tubular mast”.

![Omni-directional antennas](image)
The “Mexican hat” is usually mounted without a jumper cable. The feeder is bent down into a drilled hole through the ceiling and connected to the antenna. When the antenna has been connected to the feeder, it is attached to the ceiling.

Integrated antennas

An indoor area that could be covered from one location, e.g. open premises, and where it is possible to have the RBS mounted on a wall is a suitable application for RBS 2302 using the integrated antennas. Examples of applications are for instance sports arenas and railway stations.

Antennas distributed via a coax feeder network

Antennas distributed via a coax feeder network is the configuration having the widest range of applications. This could be explained by the attractive features of the configuration:

- Low cost.
- Flexibility in the design when shaping the coverage area:
  - Power distribution can be controlled by using unequally distributed power splitters.
  - Additional antennas are inexpensive and easy to add on.
- Robust and well proven technique:
  - No active devices in the antenna system requiring local powersupply or supervision.
Coaxial cable

The most suitable dimensions of coaxial feeder for indoor systems are listed (including typical feeder loss values) in Table 13-1. The N - connector is suitable for all the listed coaxial cables except for the 7/8” coaxial cable. The 7/8” coaxial cable, which is hard to install due to its inflexibility, should be used together with 7/16 connectors.

<table>
<thead>
<tr>
<th>Feeder type</th>
<th>Feeder loss, dB/100 m</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>800-900 MHz</td>
<td>1800-1900 MHz</td>
</tr>
<tr>
<td>CF 1/4”</td>
<td>13.5</td>
<td>20.5</td>
</tr>
<tr>
<td>LCF 3/8”</td>
<td>10</td>
<td>14.5</td>
</tr>
<tr>
<td>1/2” Superflex</td>
<td>11</td>
<td>16.5</td>
</tr>
<tr>
<td>LCF 1/2”</td>
<td>7</td>
<td>10.5</td>
</tr>
<tr>
<td>LCF 7/8”</td>
<td>4</td>
<td>6.2</td>
</tr>
</tbody>
</table>

Table 13-1 Typical feeder loss values.

Power splitters

Power splitters are used for splitting up the antenna feeder network. There are two types of power splitters:

- Equally distributed
  The equally distributed power splitters divide the power equally over the output ports which means that a two-way power splitter has an attenuation of 3 dB, a three-way power splitter 5 dB and so forth. This is shown in Figure 13-6.

- Unequally distributed
  The unequally distributed power splitters distribute the power unequally over the output ports as shown in Figure 13-6. This type of power splitter is suitable in e.g. high buildings with small floor areas or tunnels.
Leaking cable

Leaking cable could be an alternative to distributed antennas in some applications such as car or train tunnels. Leaking cable is also conceivable in indoor applications. Compared to distributed antennas (coaxial) leaking cable is generally a more expensive alternative both in terms of equipment and installation cost.

There are two types of losses associated with leaking cable:

- **Longitudinal loss**
  
The longitudinal loss is the analogue of ordinary feeder loss. For a leaking cable it is somewhat higher than for a normal coaxial cable due to the intentional leakage.
• Coupling loss

The coupling loss is the average difference between signal level in the cable and the power received by a dipole antenna at a certain distance, usually 6 m, from the cable. Some typical values of longitudinal and coupling loss are given in Table 13-2.

<table>
<thead>
<tr>
<th>Cable type</th>
<th>Longitudinal loss, dB/100m</th>
<th>Coupling loss, dB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>800-900 MHz</td>
<td>1800-1900 MHz</td>
</tr>
<tr>
<td>1/4&quot;</td>
<td>23 - 32</td>
<td>32 - 52</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>12 - 14</td>
<td>18 - 21</td>
</tr>
<tr>
<td>1/2&quot;</td>
<td>9.5 - 11</td>
<td>13 - 18</td>
</tr>
<tr>
<td>7/8&quot;</td>
<td>5.5 - 6</td>
<td>8 - 11</td>
</tr>
</tbody>
</table>

*Table 13-2 Typical longitudinal and coupling loss values for leaking cables.*

Antennas distributed via a fibre-optical network

There are different solutions based on fibre-optics that can be used for indoor systems. The main purpose is to overcome losses in long coaxial feeder cable. One disadvantage of using a fibre-optical network is that each antenna terminal need local power supply and alarm handling.

*Figure 13-8 Antennas distributed via a fibre-optical network.*

Note that as the configuration is depicted in Figure 13-8, an additional fibre-optical antenna entails installation of two additional transmitter/receiver-fibres all the way from the optical interface unit to the location of the antenna. Ordinary antennas could however be connected to the external antenna terminal on the fibre-optical antenna.
Summary

The main features of the antenna systems are summarised in Table 13-3.

<table>
<thead>
<tr>
<th>Antenna system</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated antennas</td>
<td>+ Easy and quick installation</td>
</tr>
<tr>
<td></td>
<td>+ Low cost</td>
</tr>
<tr>
<td></td>
<td>- Limited coverage</td>
</tr>
<tr>
<td>Distributed antennas (coax)</td>
<td>+ Low cost</td>
</tr>
<tr>
<td></td>
<td>+ Flexible design</td>
</tr>
<tr>
<td></td>
<td>+ Robust and well proven technique</td>
</tr>
<tr>
<td>Leaking cable</td>
<td>+ Flexible design</td>
</tr>
<tr>
<td></td>
<td>- Expensive¹</td>
</tr>
<tr>
<td>Distributed antennas (fibre)</td>
<td>+ Low attenuation</td>
</tr>
<tr>
<td></td>
<td>+ Easy installation</td>
</tr>
<tr>
<td></td>
<td>- Expensive¹</td>
</tr>
<tr>
<td></td>
<td>- Limited design flexibility</td>
</tr>
<tr>
<td></td>
<td>- Power supply of antenna units</td>
</tr>
</tbody>
</table>

Table 13-3 Antenna system summary.

RBS SYSTEMS

The antenna system can be connected to a base station in one of the following ways:

- RF-repeater
- Single RBS
- Multiple RBSs configuration

¹ Please note that cost calculations should be made for each individual application in order to determine the cost.
RF-repeater

An RF-repeater offers a low cost and easy-to-install alternative to provide coverage in a building. The macro cell surrounding the building, termed donor cell, must however have spare capacity. When the capacity demand in the building increases and becomes higher than what the donor cell can offer, the RF-repeater may be replaced by an ordinary RBS (plus transmission). The indoor antenna system, originally designed for the RF-repeater, should in large parts be possible to keep. The RF-repeater can thus partly be viewed as a temporary solution for instance when there is doubt if the potential traffic in a building will motivate an ordinary indoor system.

Figure 13-9 RF-repeater.

Single and multiple RBS

A single RBS is the most straightforward way to configure the RBS system in an indoor application. It is more trunking efficient than using multiple RBSs. However, in large buildings where large areas are to be covered, high feeder loss values limit the applicability of a single RBS. In this case multiple RBSs, i.e. RBSs distributed over the building, is a better choice. The obvious reason for this is that in a multiple RBS system the RBSs may be placed closer to the antennas as compared to a single RBS system, and thereby the feeder losses are reduced.
Figure 13-10 RBS configurations

Besides the above depicted combinations some special combinations are conceivable, for instance the combination shown in Figure 13-11. It takes advantage of the low attenuation of the fibre for long distance communication and the flexibility and low cost of the ordinary coax distributed antennas for the actual antenna system.

Figure 13-11 Configuration providing coverage at several different locations at large distances.
**MULTICASTING MATRIX BOXES (MCM)**

With one Multicasting Matrix box up to 4 RBS RX/TX ports can be connected to the same in-building antenna system. The box has 4 antenna ports, and a low combining loss (<0.5 dB). The box is small and easy to install.

![Diagram of Multicasting Matrix Box](image)

*Figure 13-12 MCM in-building applications.*

![Multicasting Matrix Box](image)

*Figure 13-13 Multicasting Matrix Box.*
COMBINING BOX

The Combining box combine a multi-operator system and/or a multi-system to a single indoor antenna system. Up to 4 800/900 MHz systems can be combined with up to 4 1800/1900 MHz systems. The box has 4 antenna ports and a low combining loss (< 1 dB).

Figure 13-14 Combining Box.

RBS PRODUCTS

RBS OVERVIEW

Ericsson has three base stations suitable for in-building applications, the micro base station RBS 2302, the macro base station RBS 2202 and the office base station RBS 2401. Each base station is given a short description in this section.

Figure 13-15 RBS 2302, RBS 2202 and RBS 2401.

All RBSs are prepared for data services 14.4 kBit/s, GPRS, HSCSD and Support of Localised Service Area (SoLSA).

All RBSs can be operated from the common operation and maintenance system OSS.

The two charts in Figure 13-16 and Figure 13-17 show the output power and the level of traffic for different types of radio units in a 900 MHz system and an 1800 MHz system.
If the estimated traffic of the in-building system exceeds the maximum traffic a fully equipped RBS 2202 can handle, there are two alternatives of expanding the in-building system. One alternative is to use an extension cabinet to the RBS 2202, which can be equipped with an additional six transceiver units (giving 12 in total) configured as a single cell. The benefit with this alternative is the extra capacity due to the truncing effects. Another alternative is to add one or several RBS 2302 or RBS 2401 in areas where extra capacity is needed. The benefits with this solution are flexibility and the low cost. The transmission is a significantly part of the running cost, therefore co-siting should always be considered when possible.

In some installations in Asia, buildings are covered using an RBS 2102 installed on the rooftop of the building. The RBS 2102 is an outdoor radio basestation. This solution was choosen, since no room in the building was available for the RBS.
The table below shows the RBS characteristics for RBS 2401, RBS 2302 and RBS 2202.

<table>
<thead>
<tr>
<th>RBS</th>
<th>2401</th>
<th>2302</th>
<th>2202</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of TRXs</td>
<td>2</td>
<td>2-6 (2 per cabinet)</td>
<td>1-12 (max 6 per cabinet)</td>
</tr>
<tr>
<td>Output power [dBm]</td>
<td>900 MHz: 19 1800 MHz: 22 1900 MHz: 22</td>
<td>33 Per cabinet</td>
<td>900 MHz: 41.0 1800 MHz: 40.0 1900 MHz: 40.0 with CDU-C+</td>
</tr>
<tr>
<td>RX sensitivity Cell planning [dBm]</td>
<td>-100</td>
<td>900 MHz: -106 1800 MHz: -107 1900 MHz: -107</td>
<td>-111.5</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>+5°C to +35°C</td>
<td>-33°C to +45°C</td>
<td>+5°C to +40°C</td>
</tr>
<tr>
<td>Dimensions H x W x D [mm]</td>
<td>387x510x126</td>
<td>535x408x222</td>
<td>1775x600x400</td>
</tr>
<tr>
<td>Weight [kg]</td>
<td>&lt;19</td>
<td>&lt;29</td>
<td>~210</td>
</tr>
<tr>
<td>Power system</td>
<td>230/110 V AC Nom 65 VA</td>
<td>230/110 V AC Nom 150 VA</td>
<td>230 V AC +24 V DC –48 V DC Type: 1.0-1.2 kVA</td>
</tr>
</tbody>
</table>

Table 13-4 RBS characteristics.

**RBS 2401**

The RBS 2401 is a high quality small radio base station, designed for indoor mounting and applications. RBS 2401 is in itself a complete RBS, including transmission interface and integrated power supply. The product is designed for maximum efficiency in all situations, like office in-building solutions and public hot spot in-building applications.

RBS 2401 is a two TRX unit and is available for GSM 900 and GSM 1800. RBS 2401 will be available for GSM 1900 in the beginning of year 2000. G.703 transmission with long haul and multi drop functionality is supported, optional HDSL modem will be available.
No acoustic noise is generated since no active cooling components are used. For power back up an UPS could be installed.

The RBS 2401 can only be used with external antenna systems. The cabinet will have two external feeder interfaces. Both antenna ports contain the same signals since the RBS has a built in multicasting box (hybrid combiner).

The RSB 2401 supports a flexible antenna system configuration. One or two antenna branches is possible to connect to the RF connectors. Each antenna can be used to give extra coverage, no overlapping coverage is necessary.

This easy-to-install, high-quality unit for indoor coverage also supports Ethernet connection to the corporate Local Area Network (LAN) via an external interface unit.

**RBS 2302**

RBS 2302 is a complete BTS site, including transmission interface, integrated power supply, and optionally integrated antennas. The product is designed for maximum efficiency in range different situations, like micro cells and in-building applications. This together with flexible transmission solutions and antenna configurations, with integrated or external antennas, give efficient medium to high capacity solutions.

RBS 2302 is available for GSM 900, GSM 1800 and GSM 1900 MHz.
The RBS is a two TRX unit with expansion possibilities. Each cell can have up to 6 TRXs, and this is achieved by using three cabinets.

G.703 transmission with long haul and multi drop functionality is supported, and integrated HDSL is optional.

No acoustic noise is generated since no active cooling components are used.

A built-in battery back up is designed to last for three minutes under high load, typical battery back up time will be longer. The RBS 2302 can be supplied with an optional external battery back up, a Power and Battery Cabinet (PBC). One PBC can supply up to 2 hours and 45 minutes battery back up.

The RBS 2302 has two RF antenna connectors. The two TRXs are transmitting on one of the antenna connectors each. The RX signals from both of the connectors are split to the two TRXs for a possible use of RX diversity.

A multi casting box that contains a hybrid combiner is available as option. The use of the multicasting box allows for one or two antenna branch systems. RX diversity is not supported when the multicasting box is used.

**RBS 2202**

The RBS 2202 is a high quality, high capacity radio base station, designed for indoor mounting. In in-building applications the main usage is in large multicasting systems.

RBS 2202 is available for GSM 900, GSM 1800 and GSM 1900 MHz.

RBS 2202 can be equipped with 6 TRUs in one cabinet, two cabinets can form a 12 TRU cell.

For RBS 2202 battery backup is available in an external cabinet, with the same size as the RBS 2202 cabinet, providing 1 - 8 hours of backup.

The RBS 2202 is used with external antenna systems.
RF DESIGN

LINK BUDGET

The link budget for an indoor cell can be determined in a way similar to the link budget for macro cells.

**Required signal strength**

To be able to perform a call in a real-life situation some margins have to be added to the MS sensitivity level to compensate for Rayleigh fading, interference and body loss. This obtained signal strength will be referred to as SSreq and can be expressed as:

\[ SS_{req} = MS_{sens} + RF_{marg} + IF_{marg} + BL \]

where

- \( MS_{sens} \) = MS sensitivity (-104 dBm)
- \( RF_{marg} \) = Rayleigh fading margin (3 dB no frequency hopping\(^2\), 0 dB frequency hopping)
- \( IF_{marg} \) = Interference margin (Depends on the environment, see Table 13-4).
- \( BL \) = Body loss (5 dB 900 MHz, 3 dB 1800/1900 MHz)

**Design level**

In the design phase, an extra margin must be added to SSreq to handle the log-normal fading. The obtained signal strength is what should be used when planning the system according to the Keenan-Motley model and will be referred to as the design level, \( SS_{des} \):

\[ SS_{des} = SS_{req} + LNF_{marg} \]

where

- \( LNF_{marg} \) = The indoor log normal fading (5 dB can be used as an estimate).

\(^2\) This margin is used for outdoor environment. The margin should be increased for indoor, but no figure has been determined yet.
BTS output power

The required BTS output power can be calculated by adding the losses in the antenna network to the design level. That is:

\[ P_{\text{outBTS}} = SS_{\text{des}} + L_p - G_a + L_f + L_{ps} + L_c \]

where

- \( P_{\text{outBTS}} \) = BTS output power at antenna connector.
- \( L_p \) = Path loss from antenna to MS at the cell border.
- \( G_a \) = BTS antenna gain, MS antenna gain assumed to be 0 dB.
- \( L_f \) = Feeder loss
- \( L_{ps} \) = Loss in power splitters.
- \( L_c \) = Loss in external combiners, duplexers, diplexers etc. Note that the loss in the CDUs is not part of \( L_c \), since the reference point for BTS output power is at the antenna connector.

DESIGN LEVELS

In areas with a high level of interference the required interference margin has to be higher, and in areas with low interference it has to be lower. The question is only how high and how low.

In order to avoid the complex matter of measuring the level of interference and from these data calculate \( SS_{\text{des}} \), a simplified design procedure is proposed. The idea is that by studying the surrounding radio environment it should be possible to classify the level of interference in the cell as low, medium or high and from this classification say what the required signal strength should be. In Table 13-4, proposed values of \( SS_{\text{des}} \) are given for each of the mentioned interference levels. Note that these values must be regarded as rules of thumb.
<table>
<thead>
<tr>
<th>Level of interference</th>
<th>Design level (SS$_{\text{des}}$)</th>
<th>Required level (SS$_{\text{req}}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>-85 dBm</td>
<td>-90 dBm</td>
</tr>
<tr>
<td>Medium</td>
<td>-75 dBm</td>
<td>-80 dBm</td>
</tr>
<tr>
<td>High</td>
<td>-65 dBm</td>
<td>-70 dBm</td>
</tr>
</tbody>
</table>

Table 13-5 Design levels and required signal strengths in areas of different interference. NOTE: The proposed values must be regarded as rules of thumb.

The cell should be designed so that SS$_{\text{des}}$ is obtained at the cell border when designing the cells according to the Keenan-Motley model. In the verification measurements it is of course not necessary to measure SS$_{\text{des}}$. Then SS$_{\text{req}}$ is enough since the log-normal fading dips are included in the measurements.
ANTENNA CONFIGURATION

When the requirements on received signal strength and coverage are defined, an antenna configuration must be chosen. Coverage measurements take a lot of time and should be used primarily to decide if a nominal configuration gives the anticipated coverage.

It becomes more and more important to plan for reduced interference towards surrounding cells. The requirement on low interference towards other cells implies that:

- Several antennas should be used. This lowers the necessary output power at each antenna. It is furthermore not expensive to add antennas to a distributed antenna system.
- Do not place antennas close to windows.

WORK FLOW

The purpose of this process is to create an antenna plan which works “on paper”. An antenna plan includes antenna locations and types as well as design of the feeder network.

Some antenna locations may be unsuitable from an implementation point of view and may have to be adjusted. If major changes are needed a creation of a new nominal antenna plan is required.

Since predictions inside buildings contain uncertainties such as wall losses it is necessary to control the actual coverage from the nominal antenna.

When the nominal antenna plan has been decided, the system is implemented.

*Figure 13-19 Antenna configuration work flow.*
**NOMINAL ANTENNA PLAN**

A nominal cell plan is made in two steps:

1. Studies of different indoor configurations with desired performance regarding public or business, interference situation and building types. The purpose of this is to gain a feeling for indoor antenna configurations.

2. Path loss estimations. This can be done with paper and pen or by using a prediction tool such as TEMS Prediction.

**Antenna configuration, examples**

**Single antenna in an office building**

In Figure 13-20 a single antenna solution used in an office building is shown.

![Antenna configuration with one antenna.](image)

**Requirements**: The required signal strength is -65 dBm to obtain a sufficient C/I. The requirement on the signal strength comes from the fact that the building is tall compared with the surrounding buildings and that the frequencies are very tightly re-used in the area, giving high interference into the building.

**Solution**: An omni-directional antenna was placed in the middle of the area intended to be covered. The antenna was fed with 30
dBm, the maximum power with the coax net and base station used.

**Result:** Floors 6 and 7 were fully covered, but floor 5 was not covered in the shadowed areas marked in Figure 13-20. The cell borders were not possible to control. The cell extended several floors outside the intended area. The signal strength was also varying significantly in the cell, and was very high in the vicinity of the antenna (approximately -25 dBm).

**Conclusions:**

1. The equipment and installation cost is slightly lower than with a distributed antenna system.
2. There may be difficulties in obtaining coverage.
3. The higher interference towards other cells may prevent tight re-use.
4. The cell borders may be hard to control.

**Distributed antenna system in an office building**

Another solution for providing coverage on the three floors is to use several antennas. This is shown in Figure 13-21.

![Figure 13-21 Antenna configuration with 11 antennas.](image-url)
**Requirements:** The same as in the preceding example.

**Solution:** A distributed antenna system consisting of 11 antennas, both directional and omni-directional antennas. The power fed into the antennas was 6 dBm. No antennas are mounted in rooms next to the outer wall.

**Result:** Full coverage. Evenly distributed signal strength and a low amount of radiated power to the surroundings.

**Conclusions:** A distributed antenna system can be used to control the cell borders, giving high coverage and lower interference than with a single antenna. This is especially desired in business applications where buildings tend to be high and excellent quality is required. It is especially important to use many antennas and low EIRP high up in a building with line-of-sight to other cells. This decreases the risk of interfering other cells.

**Coverage predictions**

In the same way that the Okumura-Hata model has been developed semi-empirically for macrocell coverage predictions, the Keenan-Motley model has been developed for indoor wave propagation predictions. This model has been accepted by COST 231, and contains a 3D term which is not possible to see in Figure 13-22. The tool calculates the wall type dependent loss for each wall in a straight line between the antenna and the prediction point, and adds the free space path loss. The following are rough estimates of wall loss parameters that can be used:

- 2 dB for plaster board walls in office buildings, etc.
- 5 dB for reinforced concrete walls in stairwells and car parks

Antennas and/or BTS + feeder network are distributed by the user and the program quickly calculates the signal strength. A prediction can look like in Figure 13-22:
Figure 13-22 Example of signal strength prediction made by TEMS Prediction. Omni antennas with 10 dBm EIRP are used.

The model underestimates the signal strength in certain locations. This may be seen in rooms in the end of corridors, far from an antenna. The underestimation of the signal strength is due to that the model assumes that the signal passes through several walls, while in reality it will be reflected and diffracted along the corridor. This will lead to higher signal strength than expected in these locations.

The floor plan used in TEMS predictions is drawn by hand on a scanned background image or is imported from a vectorizing program. The manual procedure is not too time consuming in case a good map without too much text can be found.
Estimate path loss manually

In a simplified form the Keenan-Motley model can be written in the following way for 900 MHz.

\[ L = 31.5 + 20 \log(d) + N_w \cdot W \]

where

- \( L \) is the path loss between isotropic antennas (dB).
- \( d \) is the transmitter-receiver separation (m).
- \( N_w \) is the number of walls passed by the direct ray.
- \( W \) is the wall attenuation factor (dB).

The free space path loss increases with 6 dB for 1800 MHz in the equation above, a figure that can be used for 1900 MHz as well. The free space path loss is shown in Figure 13-23 for different distances.

![Figure 13-23 Free space path loss as a function of transmitter - receiver distance.](image)

\(^3\) The estimations are assumed to be made on the same floor as the antennas, so the floor dependent parts are excluded.
The total wall loss is given by counting the number of walls between the antenna and estimated location and multiplying by the wall attenuation factor.

### INDOOR PROPAGATION

**Modified Keenan-Motley Model**

\[
L(\text{dB}) = 32.5 + 20 \log f + 20 \log d + k \cdot F(k) + p \cdot W(k) + D(d - d_b)
\]

**Free-space formula**

- \(L\): path loss (dB)
- \(f\): frequency (MHz)
- \(d\): transmitter to receiver separation (km)
- \(k\): number of floors traversed by the direct wave
- \(F\): floor attenuation factor (dB)
- \(p\): number of walls traversed by the direct wave
- \(W\): wall attenuation factor (dB)
- \(D\): linear attenuation factor (dB/m) (note 1)
- \(d_b\): indoor breakpoint (m) (note 1)

**Note 1:** For distances above the breakpoint, add typically 0.2 dB/m. Typical breakpoint = 66 m.

**Figure 13-24 Loss in free space plus loss in walls.**

A more elaborate model takes also floor loss as well as an additional distance dependent loss, due to diffraction, scattering, obstructive objects and destructive interference, which is added after a breakpoint distance, into account (Figure 13-24).
Figure 13-25 Diagrams showing approximate indoor propagation loss at 900MHz for a wall attenuation of 0.2 & 0.5 dB/m. At 1800MHz the loss is 6dB higher, thus change the 50 to 56 in the formula.
In the previous diagram (Figure 13-25), the total wall loss (for the estimated distance) is divided by the estimated distance to get a wall loss per meter.

A simplified way of estimating the loss between floors is shown in the diagram in Figure 13-26.

![Diagram: INDOOR PROPAGATION](image)

**Figure 13-26 Loss between floors.**
Distributed antenna configuration for indoor cells

If a building with low traffic concentration is to be planned as a single cell, antennas are positioned to get as even distribution of the signal strength as possible in the cell, see Figure 13-27.

![Antenna Configuration Diagram](image)

**Figure 13-27 Recommended antenna positioning for each consecutive floor for a building with one or several indoor cells.**

When “several-cell” configuration is used for a building, there should be enough distance separating co-channel cells. This distance is around four floors. The antennas can with this re-use distance still be placed in a zigzag manner to get as even distribution of the signal strength as possible. However, placing antennas on top of each other as Figure 13-28 shows might make planning and installation easier.

Buildings divided into several cells with very tight re-use (one or two floors separation) are recommended to have the same antenna positions on co-channel cells to get as good C/I as possible. Such tight re-use is however not recommended for business indoor systems.
Figure 13-28 Recommended antenna positioning for each consecutive floor, for a building with several indoor cells with very tight re-use.

Horizontal re-use of cells within buildings is not recommended.

**RF electromagnetic exposure**

Measurements and calculations of the RF exposure levels from omnidirectional and directional indoor picocell antennas have been performed at Ericsson, both at 900 and 1800 MHz. The tests were performed at maximum possible output power (according to the recommendations by Ericsson) and at a distance of 5 cm from the surface of the antenna unit, in the direction of maximum emission. This corresponds to worst case exposure conditions. The results have shown that the exposure levels are below the general public and occupational RF safety standards, for example those published by WHO, IRPA/ICNIRP, CENELEC, IEEE/ANSI and FCC.

Therefore, there is no need of any special RF exposure safety instructions for these antennas. Installation and maintenance people can work close to the antennas in operation without any risk of RF exposure exceeding the safety limits. It is however always advisable to place the antennas in such a way that people can not easily touch them or stay close to them, which could affect the performance. A discretely placed antenna will also reduce the risk of unnecessary public concern about the RF exposure.
**SURVEY**

The nominal configuration may not be suitable for the building. Reasons for this can be that the suggested locations are too close to where people sit, that there are obstacles deteriorating the radiation pattern or that there are problems mounting the antennas at these locations.

Note that the landlord often has an opinion about the antenna locations. Ensure that these locations are accepted before final installation. This will save unnecessary work. It is also necessary to consider the effect of non-optimal antenna locations.

See to that the antennas are not placed in positions that make the cable running difficult, for example with a concrete wall between the antenna location and the cable ladder.

Note that the omni-directional antennas are ceiling mounted and the directional antennas are wall mounted in general.

**COVERAGE MEASUREMENTS**

Coverage measurements are performed to verify the antenna configuration so that it provides a sufficient coverage. The antenna locations that are determined are then tested one or several at a time. A test transmitter is connected to the antenna and the signal strength is measured with a mobile receiver. In Figure 13-29 the measurement configuration is shown.

![Measurement configuration](image)

*Figure 13-29 Measurement configuration.*
Transmitter equipment

For the generation of test signals it is suitable to use one or several TEMS Transmitters. The TEMS Transmitter is a small unit that transmits in the GSM downlink band. The output power is adjustable between 20 and 27dBm (GSM 900/1900) or 22 and 27 dBm (GSM 1800). Using two optional attenuators the output power can be varied between 2 and 27 dBm (GSM 900/1900) or 4 and 27 dBm (GSM 1800). A complete editable BCCH is transmitted while the other 7 time slots contain an unmodulated carrier.

Receiver equipment

The recommended receiver is a TEMS Light equipment. This is a TEMS mobile connected to a small pen-operated PC. The TEMS light program is a reduced version of the standard TEMS PC software but with the possibility to log fixpoints by marking with the pen on a scanned map. The information in the log files is displayed on the scanned map as colour marks, associated to a window with more information concerning each mark. These measurements can be exported to TEMS prediction to calibrate prediction models used for that particular building.

If TEMS Light is not available the standard TEMS equipment or a TMR can be used.

A faster coverage verification can be made by using TEMS Pocket. This is a test mobile with some TEMS functions available on the mobile display. TEMS Pocket can not be operated from a computer. Areas where the signal may be weak are checked by locking TEMS Pocket to the used ARFCN and BSIC and read the signal from the display. There is also an audible warning for low signal.
FREQUENCY PLANNING

GENERAL

Here it is assumed that the public indoor cells use the same frequency band as the outdoor cells (macro cells and micro cells), if not stated otherwise. It is also possible that indoor cells have a dedicated frequency band. This makes the frequency planning much easier.

The business indoor cells should be planned in the same way as public indoor cells in the beginning. Separate band is recommended later on for quality and capacity reasons, easy frequency planning and O&M handling. Especially if a tight MRP is applied for the macro cells.

If only one cell is used within a building, no frequency plan is needed for that cell other than consideration taken for outdoor cells. When a building is divided into more than one cell, co-channels should be planned as far apart as possible.

PLANNING RULES WITH RE-USE OF OUTDOOR FREQUENCIES

The frequency planning is performed manually, selecting suitable frequencies by studying the operators frequency plan.

- Exclude frequencies in nearby cells, likely to interfere significantly with the indoor system, and adjacent frequencies to those.
- From the remaining frequencies, choose the ones most likely not to cause interference. The BCCH frequencies should be the least disturbed of them. Hop on several frequencies to smooth out the interference.

The following need to be considered if too few acceptable frequencies exist:

- Increase signal strength for indoor cell.
- Allocate dedicated frequencies for indoor cells. Start with frequencies for BCCH.
- Redesign the frequency plan.
PLANNING RULES WITH DEDICATED FREQUENCIES

Dedicated frequencies for public indoor is useful when there are several of indoor systems at rather low height in the buildings, i.e. mostly shopping malls, gallerias and subway stations. It is then recommended to use a group of 4-6 frequencies and re-use them in all buildings. The importance is that at least one best server outdoor cell must separate the public indoor cells geographically (figure 13-25).

![Diagram of outdoor cell separating indoor cells.](image)

Dedicated frequencies for business indoor should be considered when several of high buildings in a close area will be planned. The need for dedicated indoor cells when one cell is needed is rather low and the general method of re-using outdoor frequencies should be applied.

HIGH BUILDINGS AND SKYSCRAPERS

The business indoor cells will in several cases be located in high buildings. One way to plan is by using the standard method described above for the lower part of the building and use dedicated frequencies for higher parts of the building. The quality could then be good even for high buildings. There need to be several high buildings with indoor systems if the dedicated frequencies for indoor approach should be spectrum efficient.
TRAFFIC CONTROL

In many situations it is necessary to control the traffic flow in the indoor cell. For example it is often desired to direct the traffic from the nearby macro cells to the indoor cell, and make it stay there, in order to off-load the macro cell. Another requirement may be that only certain subscribers should be allowed to access the cell. This can be achieved with appropriate use of the radio network features: Hierarchical cell structures, Idle mode offsets and Differential channel allocation.
STUDY CASE

A building (e.g. the training center in Kista, Sweden) consists of four floors, each approximately 70 meters long and 18 meters wide (see section “Floor Plans”). All indoor areas in this building have poor coverage from the serving cell outside the building.

Indoor walls have a loss of 5 dB per wall. Floors/ceilings between two floors attenuate 25 dB. Outer walls have an attenuation of 18 dB.

DESIGN CRITERIA

COVERAGE

Good coverage, SS_{design} > -85 dBm.

CAPACITY

The capacity demand is 200 subscribers, with a traffic of 30 mE/subscriber in the busy hour.

The grade of service is 2%.

SYSTEM BALANCE

Balance towards the most common class of MS.

HARDWARE

BTS, antennas, cables, etc. in accordance with data given previously in this chapter.

TASK

Make the design based on the information provided previously. Present block diagram, signal level diagram, material list and floor plans with material positions marked.
FLOOR PLANS

Floors one through four must have coverage according to the previous specifications above.

Figure 13-31 Floor 1
Figure 13-32 Floor 2
Figure 13-33 Floor 3
Figure 13-34 Floor 4
This chapter is designed to provide the student with an application of network expansion, to increase coverage and capacity in an existing network.

OBJECTIVES:

Upon completion of this chapter, the student will be able to:

- Expand an existing network with new sites for improved coverage and capacity
- Understand the concept of the feature Hierarchical Cell Structure.
- Use the urban model for predictions of coverage.
14 Final Study Case Phase 3 (urban model)

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**GENERAL**

This is an expansion of the network that has been designed in the previous phases of the study case. To speed up the planning use only one of the macro cells in the center of Stockholm.

The task is to increase the capacity by adding 3,500 subscribers to the central part of Stockholm, i.e. in the area where there is a map resolution of 5 m. The capacity increase should be implemented by using micro cells in a hierarchical structure.

The prediction model Urban is to be used.

**TRAFFIC DATA**

The same subscriber data and subscriber behaviour as previous phase can be assumed.

**TRAFFIC DISTRIBUTION**

Assume an even distribution of traffic.

**FREQUENCY BAND**

The same frequency band as in previous phase should be used, but you are allowed to expand the frequency band with at maximum four new frequencies.

**SIGNAL LEVEL CRITERIA**

The frequency planning in the precious phase is probably as tight as it can be. Use the four new frequencies as BCCH-carriers for the micro cells. The design level should be indoor level on the busiest roads and squares.

**SPECIAL REQUIREMENTS**

Micro base stations should be used. Equipment information regarding the micro base station 2302 is found in the RF-guideline or in Study Case phase 2.

A micro cell is a cell with its antenna mounted below the rooftops. Generally the micro cell antenna should be considered to be mounted 3-5m above street level.
The internal antennas in the micro base stations can be considered to be either a sector antenna with a typical gain of 6 dBi, horizontal beamwidth 80 degrees or an omni antenna with a typical gain of 0 dBi.

**QUALITY REQUIREMENT**

C/I > 12 dB for non-hopping channels.

C/I > 9 dB for hopping channels.

C/A > 3 dB for all channels.

**PREDICTION MODEL**

The prediction model urban shall be used for at least the micro cells.

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**PRESENTATION OF FINAL STUDY CASE**

The presentation should contain the following:

- A verbal description of the proposal with explanation to site choice, site configuration (including $P_{\text{outBTS}}$, EiRP and antenna gain) etc.
- Site/cell identification
- Number of SDCCHs/TCHs
- Used antennas
- Antenna Height
- Traffic distribution in Erlang and number of subscribers (per cell and totally)
- Distribution of blocking (GoS)
- Frequency per cell
- Coverage predictions (with percentages)
- C/I predictions (with percentages)
- C/A predictions (with percentages)
- Maximum capacity the system can provide
- Number of sites, cells and TRXs
Figure 14-1 The central part of Stockholm
**HIERARCHICAL CELL STRUCTURE (HCS)**

In areas such as shopping centers and airports, a lot of traffic is generated. To handle this extra traffic load, it is common to build micro cells which will relieve the nearby macro cells so that they do not become congested.

However the nominal service area of micro cells is small compared to the one of macro cells; thus action needs to be taken to insure that the traffic is directed to the smaller cells. The Hierarchical Cell Structure (HCS) feature was designed for this purpose.

HCS provides an easy way for the operator to introduce two or three level cell structures with built-in priority handling between the layers. HCS is a very efficient traffic steering tool and is an important tool in a high capacity network.

HCS offers the following:

- A possibility to increase the traffic in micro cells so that a greater off-load of the macro cells can be accomplished.
- A simplified handling of traffic in multi-layered cell structures.

As mentioned before, HCS makes it possible to define three priority levels for a cell, where the smaller cells should have the higher priority. In addition to this priority level, a certain threshold is defined. Whenever the signal strength from a high priority cell is above the threshold, the mobile station will be directed to the cell, even though there may be stronger macro cells nearby. The procedure puts aside the usual signal strength ranking in favor of the small cells.

In field tests, the application of HCS has proven to be very successful. An increase in the serving area by 30% has been possible even in situations where frequencies from the macro layer have been re-used in the micro cells. If a dedicated frequency band for the micro cells is used, the increase can be even more substantial.

In order to simplify the traffic handling in multi-layered cell structures, neighbor cells belonging to different layers are treated somewhat different from ordinary neighbors (cells in the same layer). In the radio network logic, their function as “redundant coverage” is pronounced, making it very easy and
straight-forward to control the multi-layered cell structure to prevent fast mobiles from connecting to micro cells, something which may be undesired. HCS provides possibilities to use time-controlled penalties for the lower layer cells.
This chapter is designed to provide the student with information about the cell parameters.

**OBJECTIVES:**

Upon completion of this chapter, the student will be able to:

- Explain the use of the cell parameters
- Set the neighboring relations between two cells
- Allocate CGI and BSIC to the cells in a network
# 15 Parameters

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GENERAL

When a cell is added, or changed, in a cellular system, the cell planner has to produce a document for the cell containing data (the parameters). This document is called the cell design data (CDD). The data from all such documents is then converted into a data transcript tape and loaded in the BSC.

In this chapter some of the parameters are described. For a description of all parameters, with maximum, minimum and default settings, please refer to the Cell Design Data document, CDD. The parameters are divided here into site data, cell data, neighboring cell relation data and hardware characteristics data.
SITE DATA

The common site data is the same for all cells in a site.

MSC NAME

The parameter MSC NAME identifies the MSC, to which the cell belongs. MSC NAME is only information, and is not stored in the MSC or the BSC.

BSC

The parameter BSC identifies the BSC to which the cell is connected. This parameter is only present as information and is not stored in the BSC.

RSITE

The parameter RSITE stands for Radio site. Identity of the radio site where the transceiver group is located.

SITE NAME

The parameter SITE NAME is the name of the site. SITE NAME is stored neither in MSC nor in BSC, but is useful information that can help you geographically identify the site. Use a name that gives an easy explanation of the geographic location of the site, so that everyone familiar with the area knows where the site is.
CELL DATA

CELL

The parameter CELL stands for Cell name. It is recommended to use the name of the site plus one more character to identify the cell within the site. Usually numbers (1, 2, 3..) or letters (A, B, C..) are used to identify the cell within the site. Use a reference direction for the network, e.g. zero degrees true north. The cell whose antenna direction is closest to this reference should be assigned the letter A (or number 1).

CGI

The parameter CGI stands for Cell Global Identification. CGI is the global identity of the cell in the whole system. It is composed of four different parameters:

- MNC, Mobile Network Code. Identifies the PLMN, i.e. the operator.
- LAC, Location Area Code. Identifies the location area.
- CI, The Cell Identity within the location area.

The CGI is sent to the MS as part of the system information message.

BSIC

The parameter BSIC stands for Base Station Identity Code. BSIC is composed of two entities:

- NCC, Network Color Code.
- BCC, BTS Color Code.

NCC is used to discriminate cells in two different PLMNs that use the same frequency, see Figure 15-1. These PLMNs with the same frequencies are of course in different countries, since the PLMNs in one country use different parts of the frequency band. The NCC assignment must be decided by agreements between operators and countries. The operators may use more than one NCC value, as long as they only use their agreed value in the border areas.
BCC is used for protection against co-channel interference within the PLMN. The MS reports the BCC value so that the BSC can distinguish among different cells transmitting on the same frequency. If frequency reuse clusters are used it is recommended that all BTSs in a cluster use the same BCC, and that an adjacent cluster should use another BCC, see Figure 15-2. If clusters are not used, great care must be taken when planning BCC.
BSIC is defined per cell and is sent on SCH (on the BCCH carrier).

**MBCHNO**

The parameter MBCHNO is the Absolute RF channel number for measurements on BCCH.

The number is the absolute RF channel number for the BCCH for cells to be measured on by a mobile station in the cell.

MBCHNO is the BCCH allocation (i.e. it indicates to the MS the frequencies that must be monitored and measured in idle, active, or both modes). This number is sent to MSs in the system information message, on the BCCH channel in idle mode and on the SACCH in busy mode.

Up to 32 BCCH carriers can be defined by specifying their ARFCN.

The measurement reports from the MS are sent to the BSC on the SACCH, indicating the signal strength and quality of the serving link and the signal strength, frequency, and BSIC from the six BTSs with strongest signal strength.

Only measurements from neighboring cells that fulfill the requirement that their BCCH has a frequency as indicated by MBCHNO and an NCC as indicated by NCCPERM are valid. To be allowed to perform a handover to any of the measured cells, it is also necessary that the measured cell is defined as a neighbor to the serving cell. Up to 64 different cells can be defined as neighbors.

**LISTTYPE**

The parameter LISTTYPE identifies which type of list the chosen frequencies will be on. When the MS is in IDLE or ACTIVE mode, it will measure on the frequencies on the corresponding list.

If LISTTYPE is not specified, both lists are affected.
**CHGR**

The CHGR parameter stands for Channel Group Number. A cell is divided into one or more channel groups which contain all physical channels on an arbitrary number of frequencies. Channel groups are connected to a transceiver group (TG). Channel groups can be used for controlling the properties of the assigned frequencies (e.g. to set frequency hopping on and off).

Cells with a sub cell structure must have at least one channel group defined in each sub cell. A cell without a sub cell structure is given CHGR = 0 by default. However, a cell planned with a sub cell structure as overlaid underlaid sub cell is given CHGR = 0 by default for the underlaid sub cell.
NEIGHBORING CELL RELATION DATA

All neighbor relations should be defined. It is possible to define up to 64 neighbors for each cell.

CELLR

The CELLR parameter is the Related cell designation. The identity of the neighboring cell for which the set of parameters should be applied is set by means of CELLR. The name of the neighboring cell, as defined by the parameter CELL in its corresponding CDD, must be specified here.

All cell relations are mutual unless explicitly specified. Offset parameters have antisymmetric relations, and hysteresis parameters have symmetric relations.

CTYPE

The CTYPE parameter is the External Cell. If the neighboring cell belongs to another BSC then this must be specified explicitly by means of CTYPE.

- EXT The neighboring cell is external.
- omitted The neighboring cell is internal.

RELATION

The parameter RELATION is only specified when the relation is one way. This means that offset and hysteresis parameters are only defined in one direction. RELATION is always set to single for external cells, i.e. neighboring cells that belong to another BSC.

CGI

Cell Global Identification (CGI) for the neighboring cell.

BSIC

Basic Station Identity Code (BSIC) for the neighboring cell.
**LEVEL**

The parameter LEVEL is the Cell level. The priority levels in the hierarchical cell structure (HCS) are:

1. Layer 1 (high priority) cell
2. Layer 2 (medium priority) cell
3. Layer 3 (low priority) cell

The higher layers can be used for large cells and the lower for small cells.

**LEVTHR**

The parameter LEVTHR is the signal strength threshold used as a criterion when handing over to the cell from a higher layer (lower priority) cell.

**LEVHYST**

The parameter LEVHYST is the signal strength hysteresis used when handing over to the cell from a higher layer (lower priority) cell.

**PSSTEMP**

The parameter PSSTEMP is the signal strength penalty used when handing over to the cell from a higher layer (lower priority) cell. When a fast moving MS connected to a higher layer (lower priority) cell passes through a lower layer (higher priority) cell’s coverage area it is undesirable that the MS performs a handover to the lower layer cell. Therefore a penalty (PSSTEMP) can be temporarily assigned to the lower layer cell.

**PTIMTEMP**

The parameter PTIMTEMP is the penalty time used when handing over to the cell from a higher layer (lower priority) cell.

**BSPWR**

BSPWR is the BTS output power on the BCCH carrier. BSPWR is defined at the reference point used in the locating algorithm. This reference point is needed, because the locating algorithm has to be able to compare the output power from different cells. The output power from the transmitter, BSPWRT, can not be
used when comparing the power from different cells, since for example the combiner loss may differ in different cells. The reference point can be specified anywhere, but two points are common: at the top of the antenna or after the combiner.

If the top of the antenna is used as a reference point, BSPWR will be the same as the ERP. All differences in the Tx path between different cells will be considered by the locating algorithm.

If the reference point is immediately after the combiner, differences in the combiner loss between different cells will be considered by the locating algorithm. Differences in feeder loss and antenna gain will not be considered. These differences can be seen as a part of the path loss. The advantage with this reference point is that the operator does not have to keep track of the feeder losses and antenna gains at all of the sites.

**BSTXPWR**

BSTXPWR is the BTS output power on all carriers other than the BCCH carrier. BSTXPWR is defined at the reference point in the locating algorithm, see BSPWR above.

**BSRXMIN**

The parameter BSRXMIN is the minimum required signal strength received at the BTS (at the reference point) to consider the cell as a possible candidate for handover.

**BSRXSUFF**

The parameter BSRXSUFF is the sufficient signal strength received at the BTS (at the reference point) to consider the cell selectable for further ranking according to the magnitude of the path loss.

**MSTXPWR**

The parameter MSTXPWR is the maximum transmit power for MS on connection.
**MSRXMIN**

The parameter MSRXMIN is the minimum required signal strength received at the MS in a given cell to consider the cell as a possible candidate for handover.

**MSRXSUFF**

The parameter MXRXSUFF is the sufficient signal strength received at the MS to consider the cell selectable for further ranking according to the magnitude of the path loss.

**BCCHNO**

The parameter BCCHNO is the absolute RF channel number for BCCH. The frequency carrying the BCCH in a cell is defined by the Absolute Radio Frequency Channel Number, ARFCN, with the parameter BCCHNO.

**CS**

The parameter CS is the Co-site, which indicates if a cell shares the same site as its neighbor. Handover to an OL sub cell is only allowed when the neighbor is co-sited with the serving cell.

**TRHYST**

The parameter TRHYST is the signal strength hysteresis when transition between K- and L-cells.

**KHYST**

The parameter KHYST is the signal strength hysteresis when evaluating K-cells.

**LHYST**

The parameter LHYST is the path loss hysteresis when evaluating L-cells.

**TROFFSET**

The parameter TROFFSET is the signal strength offset when transition between K- and L-cells.
**KOOFFSET**

The parameter KOOFFSET is the signal strength offset when evaluating K-cells.

**LOOFFSET**

The parameter LOOFFSET is the path loss offset when evaluating L-cells.

**AW**

The parameter AW identifies if assignment to worse cell is allowed. This feature allows allocation of a TCH in a cell with worse radio conditions than the serving cell. This is used if there is congestion in the serving cell.

**CAND**

The parameter CAND is the candidate type. Indicates in which case the related cell shall be treated as a possible handover candidate.

- AWN  Neighbor at assignment to worse cell
- NHN  Neighbor at normal handover
- BOTH Both of the above

**AWOFFSET**

The parameter AWOFFSET is the signal strength region where assignment to worse cells are allowed.

**BQOFFSET**

The parameter BQOFFSET is the signal strength region for bad quality urgency handovers.

**EXTPEN**

The parameter EXTPEN is the handover penalty support. The parameter EXTPEN shall be used for external neighboring cells, and defines whether the penalty can be received by that cell (i.e. the BSC controlling that cell). It tells whether the target BSC supports the penalty handling or not.
- **OFF** Same inter-BSC handling as in CME 20 R4.
- **ON** Handover cause values are sent to the target BSC.

The target BSC carries out the punishment of the cell in the old BSC that was abandoned. However, it uses the penalty parameter value and penalty time of the new cell. This action can only be performed if the receiving BSC is of CME 20 R5CMS 40 R1 or later.

**MISSNM**

The parameter MISSNM is the maximum number of consecutive measurements for a serving cell or neighboring cell permitted before all old measurements are considered invalid.

If a measurement report from a BTS is missing, the preceding measurement report from that BTS is copied. When a new measurement report is received, the missing values are linearly interpolated if the number of missing measurements is smaller than MISSNM. If the number of missing measurements exceeds MISSNM all former measurements from that BTS are discarded and the evaluation of that BTS starts again when a new value arrives.

**SCHO**

SCHO is used to identify if handovers on SDCCH are allowed in the cell. The handover procedure is the same as for handover on the TCH. To be able to perform a handover on SDCCH between two cells, both cells must have SCHO = ON.
HARDWARE CHARACTERISTICS

TG

The parameter TG is the transceiver group identity. A TG includes all radio equipment connected to one transmission antenna, and serves one cell or a part of a cell. Each TG must be given a unique value of TG within a BSC. It is recommended to start with TG = 0 and then increase TG one step at a time.

A TG is connected to a cell via one or more channel groups. A TG can support maximum 16 channel groups.

If the BTS is an RBS 200 multicell, or an RBS 2000, a TG can support channel groups in more than one cell, i.e. one TG can serve all cells (maximum 3) at the site:

TG 0: CellA1, CellA2, CellA3

Each TG can contain up to:

- RBS 200 MC: 7 TRXs
- RBS 2101: 2 TRUs
- RBS 2102: 12 TRUs
- RBS 2202: 12 TRUs
- RBS 2103: 12 TRUs
- RBS 2301: 2 TRUs
- RBS 2302: 2 TRUs

It is recommended to define one TG per site if not more TRXs/TRUs than those specified above are required.

If the BTS is an RBS 200, or an RBS 205 a TG can only support channel groups belonging to the same cell, i.e. each cell must be served by a TG of its own:

TG 0: CellA1
TG 1: CellA2
TG 2: CellA3
Each TG can contain up to:

RBS 200: 16 TRXs
RBS 205: 16 TRXs

It is recommended to define one TG per site if not more TRXs/TRUs than those specified above are required.
ERICSSON3 ALGORITHM

OFFSET

The offset value is given by the parameter OFFSET.

HYSTSEP

The parameter HYSTSEP specifies when the signal strength for the serving cell is high or low. When the signal strength is high, a larger hysteresis value can be allowed than when it is low in order to reduce the number of handovers.

LOHYST

The HYST is set to the value of the parameter LOHYST if downlink rxlev is less than HYSTSEP.

HIHYST

The HYST is set to the value of the parameter HIHYST if downlink rxlev is greater than HYSTSEP.

NOTE: The two values LOHYST and HIHYST are symmetrical cell-to-cell parameters. HYSTSEP is a cell parameter. OFFSET is an asymmetrical cell-to-cell parameter.
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