NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

CELL PLANNING

Graduation Project
EE- 400

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ABSTRACT

Cell planning can be described briefly as all the activities involved in determining which sites will be used for the radio equipment, which equipment will be used, and how the equipment will be configured. In order to ensure coverage and to avoid interference, every cellular network needs planning.

The major activities involved in the cell planning process are; Traffic & coverage analysis, nominal cell plan, surveys, system design, implementation, system tuning.

Cellular network engineering encompasses all work required to design a cellular (radio base station) network. During the initial phase of a system design, the system requirements are collected and analyzed. These include cost, capacity, coverage, GoS, speech quality, and system growth capability. When the system requirements phase is complete, it is time to prepare a nominal cell plan. This plan covers the distribution (location) and configuration of radio base stations and is based on the system requirements. The nominal cell plan must later be verified so that it is as accurate as possible. Once the system design has been implemented, cell planning work continues using data from the existing network.

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". A more detailed survey is performed on the base station sites. This is called the "Site investigation" and is not discussed in this project.

INTRODUCTION

This project, Cell Planning, is intended to give the student an understanding of the Radio network engineering processes and what elements they contain.

The project is broken down into chapters that explain the different elements of the process.

The first chapter, system description. Upon completion of this chapter; explain the basic functionality of a GSM system, describe the network nodes of a GSM system and describe general terms used in the GSM system.

The second chapter, traffic. Objectives of this chapter is, define the terms "traffic" and "grade of service (GoS) and use Erlang's B- table to dimension the number of channels needed in the system.

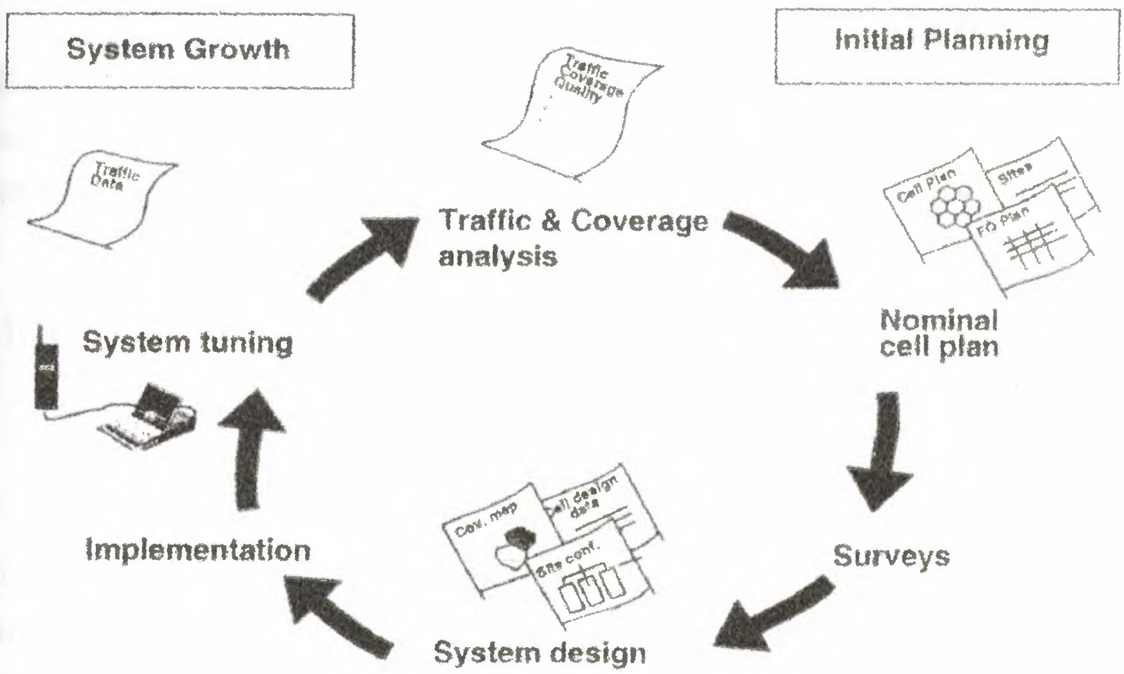
The third chapter, nominal cell plan. This chapter represent; describe the key terms when relating to cell structure, explain the TDMA concept, explain how the balance a cellular system, e.g. to be able to set the output power, describe the most common re-use patterns and their channel plans, explain briefly why interference occurs, discuss general properties of electromagnetical waves, describe radio wave propagation and attenuation.

Chapter four surveys. This chapter is overview of radio network survey of a cellular network as well as some radio measurements. Objectives of this chapter, explain briefly what a site survey is and what to consider during a survey and describe three different types of radio measurements.

Chapter five is system tuning. System tuning means analyzing the traffic data collected by the system to better adjust the system to the actual traffic demand distribution. This chapter explain the reasons for optimization of the radio network and briefly how parameter adjustment affects the network.

CHAPTER 1: SYSTEM DESCRIPTION

CELL PLANNING PROCESS



The cell planning process

1.1 GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS (GSM)

In 1982, the Nordic PTT sent a proposal to Conference Europeenne des Postes et Telecommunications (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, The Personal Communication Services (PCS) 1900 for the 1900 MHz frequency range was also established.

1.1.1 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.

Figure 1.1 Frequency bands for the different GSM-based networks

Network type	Frequency band UL / DL	Implementations
GSM 900	890-915 / 935-960 MHz	GSM 900
GSM1800	1710 – 1785 / 1805 -1880 MHz	GSM 1800
GSM1900	1850-1910 / 1930-1990 MHz	GSM1900

1.2 NETWORK HARDWARE

Every cellular system has hardware that is specific to it and each piece of hardware has a specific function.

The system solutions integrate 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.

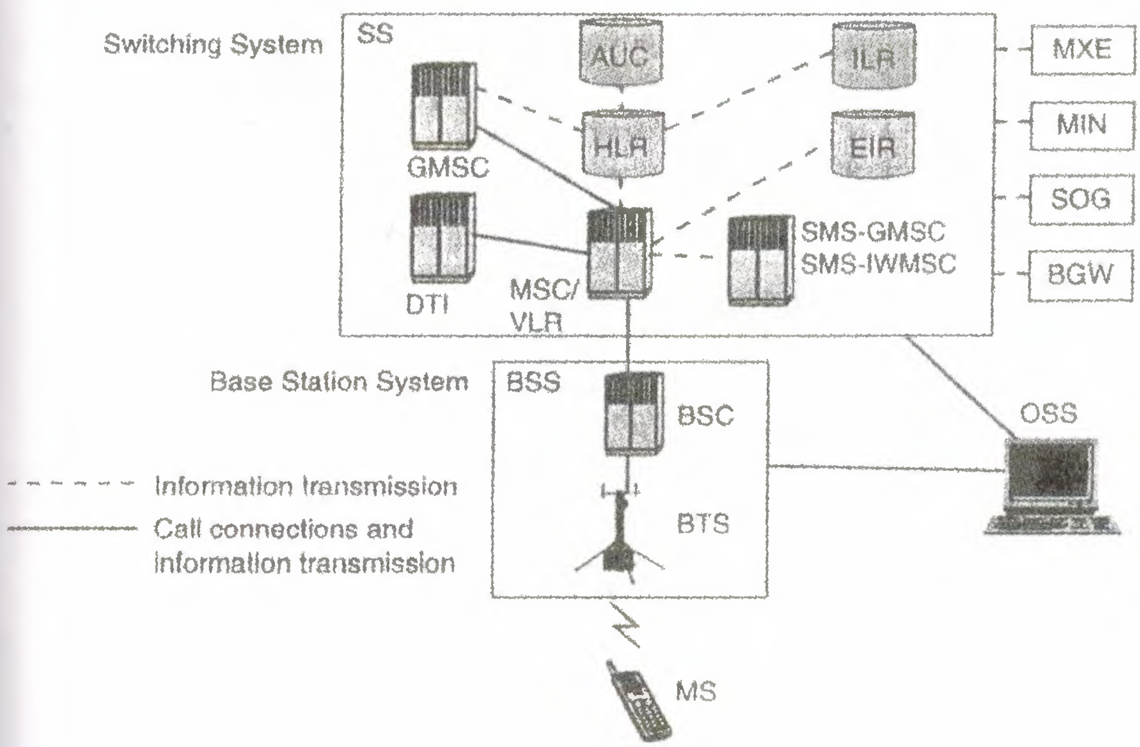


Figure 1.2 GSM-based system model

1.3 OPERATION AND SUPPORT SYSTEM (OSS)

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

- Cellular network administration
- Network operation support

1.4 SWITCHING SYSTEM (SS)

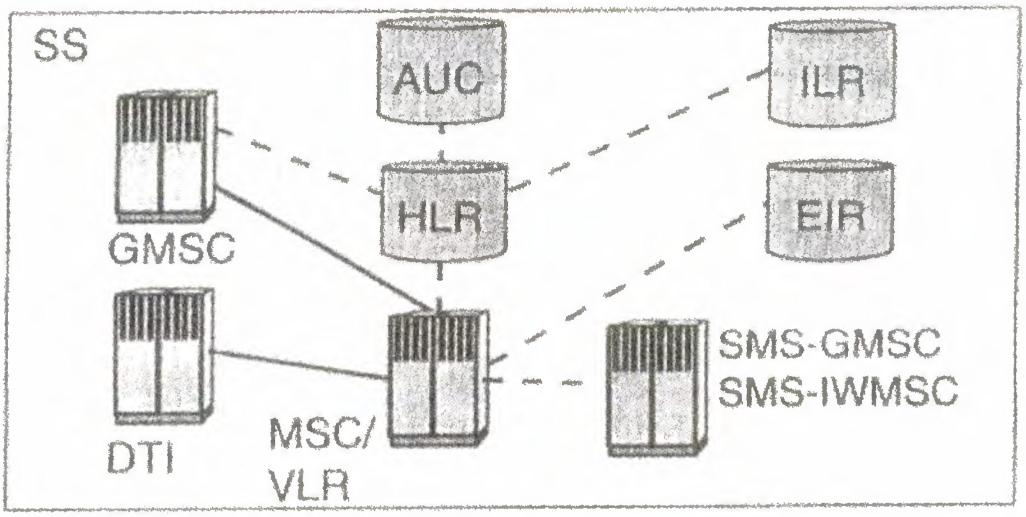


Figure 1.3 Switching System

- **Mobile services Switching Center (MSC)**

The MSC is responsible tor 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.

- **Home Location Register (HLR)**

In GSM, each operator has a database (the HLR) containing information about all subscribers belonging to that specific Public Land Mobile Network (PLMN). Logically there is only one HLR per PLMN but it can be implemented physically in one or more databases. Examples of information stored in the database arc the location (MSC/VLR service area) of the subscribers and the services attached to the subscription, The HLR is built on an AXE-10 platform.

- **Visitor Location Register (VLR)**

In the GSM based solution, the VLR is integrated with the MSC. This is referred lo as the MSC/VLR. The VLR contains non-permanent information about the mubile subscribers visiting Ihe MSC/VLK service area (e.g. which location area the MS is in currently and which services are activated).

- **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 node as an MSC/VLR.

- **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 for subscriber verification to ensure call confidentiality.

- **Equipment Identify 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. The SMS-GMSC functionality is normally integrated in an 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 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 rale adaptation. It was earlier implemented as the OSM InterWorking Unit (GIWU).

1.5 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)

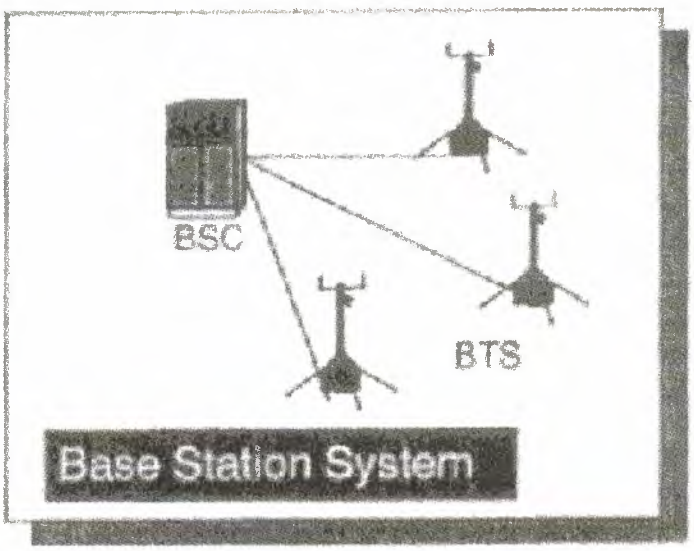


Figure 1.4 Base Station System

1.5.1 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

1.5.2 BTS

The Base Transceiver Station (BTS) includes all radio and transmission interface equipment needed in one cell. Name for the BTS is Radio Base Station (RBS). 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 of each pair is used to transmit signals to the mobile station and the other is used to receive signals from the mobile station. For this reason at least one transmitter and one receiver is needed.

1.5.3 RBS200

The RBS 200 Base Station family was the first base station developed in the early 1990's. It exists only in the GSM 900/1800 product line. The RBS 200/204 is the GSM 900 BTS, and the RBS 205 is the BTS supporting GSM 1800.

1.5.4 RBS 2000

The RBS 2000 Base Station family is the second generation of base stations 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.

1.6 AIR INTERFACE

1.6.1 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.

1.6.2 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 eight = 992 channels. These are called physical channels, The corresponding number of carrieis for GSM 1800 and GSM 1900 are 374 and 299, respectively.

1.6.3 LOGICAL CHANNELS

On every physical channel, a number of logical channels are mapped. 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.

TRAFFİC CHANNELS (TCH)

Two types of TCH are used:

- **Full rate channel, Bm**

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, Lm**

This channel can be used for half rate speech (6-5 kbit/s after speech coder} or data up to 4.8 kbit/s.

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 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 to 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 TCH or a SDCCH, up-and downlink. On this channel the measurement reports are sent on the uplink, and timing advance and power orders on the downlink.

- Fast Associated Control Channel (FACCH)

Control channel associated with a TCH, up- and downlink. FACCH works in 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 TSO (on one carrier per cell, the BCCH-carrier) the broadcast channels and the common control channels are multiplexed.

Figure 1.5 Mapping of logical channels on the BCCH-carrier. F = FCCH. S = SCH, B = BCCH, C = CCCH, I = Idle, Dx = SDCCH #x, Ax = SACCH #x

Carrier C_0	Downling								Uplink							
	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7
Frame 0	F	T	D_0	T	T	T	T	T	R	T	A_5	T	T	T	T	T
	S	T	D_0						R	T	A_5					
	B	T	D_0						R	T	A_5					
	B	T	D_0						R	T	A_5					
	B	T	D_1						R	T	A_6					
	B	T	D_1						R	T	A_6					
	C	T	D_1						R	T	A_6					
	C	T	D_1						R	T	A_6					
	C	T	D_2						R	T	A_7					
	C	T	D_2						R	T	A_7					
	F	T	D_2						R	T	A_7					
	S	T	D_2						R	T	A_7					
12	C	A	D_3	I	A	I	A	I	R	A	I	I	A	I	A	I
	C	T	D_3						R	T	I					
	C	T	D_3						R	T	I					
	C	T	D_3						R	T	D_0					
	C	T	D_4						R	T	D_0					
	C	T	D_4						R	T	D_0					
	C	T	D_4						R	T	D_0					
	C	T	D_4						R	T	D_1					
	F	T	D_5						R	T	D_1					
	S	T	D_5						R	T	D_1					
	C	T	D_5						R	T	D_1					
	C	T	D_5						R	T	D_2					
	C	T	D_6						R	T	D_2					
25	C	I	D_6	A	I	A	I	A	R	I	D_2	A	I	A	I	A
	C	T	D_6						R	T	D_2					
	C	T	D_6						R	T	D_3					
	C	T	D_7						R	T	D_3					
	C	T	D_7						R	T	D_3					
	F	T	D_7						R	T	D_3					
	S	T	D_7						R	T	D_4					
	C	T	A_0						R	T	D_4					
	C	T	A_0						R	T	D_4					
	C	T	A_0						R	T	D_4					
	C	T	A_0						R	T	D_5					
	C	T	A_1						R	T	D_5					
38	C	T	A_1						R	T	D_5					
	C	A	A_1	I	A	I	A	I	R	A	D_5	I	A	I	A	I
	C	T	A_1						R	T	D_6					
	F	T	A_2						R	T	D_6					
	S	T	A_2						R	T	D_6					
	C	T	A_2						R	T	D_6					
	C	T	A_2						R	T	D_7					
	C	T	A_3						R	T	D_7					
	C	T	A_3						R	T	D_7					
	C	T	A_3						R	T	D_7					
	C	T	A_3						R	T	A_0					
	C	T	I						R	T	A_0					
	C	T	I						R	T	A_0					
50	I	T	I						R	T	A_0					

Eight SDCCHs can share the same physical channel, normally TS 2 on the same frequency us the BCCHs anil llie 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 1 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

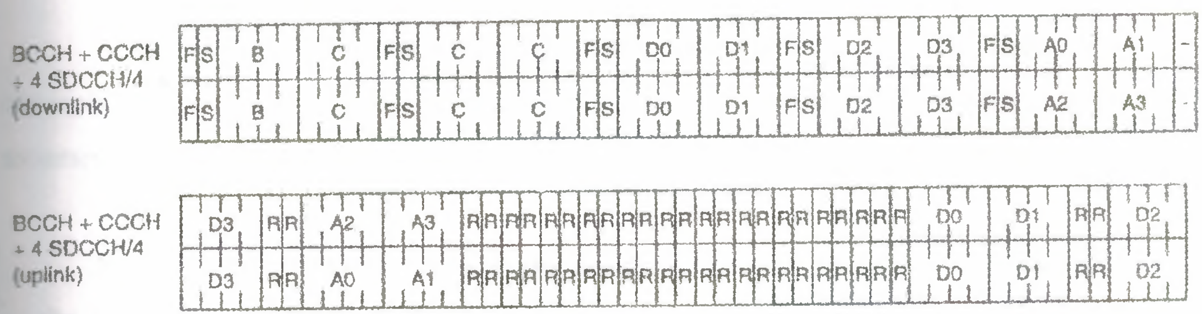


Figure 1.6 Multiplexing of BCCH + CCCH + 4 SDCCH/4 on TSO

CHAPTER 2:TRAFFIC

2.1 TRAFFIC AND CHANNEL DIMENSIONING

Cellular system capacity depends on a number of different factors. These include

- The number of channels available for voice and/or data
- The grade of service the subscribers are encountering in the system

Traffic theory attempts to obtain useful estimates of, e.g., the number of channels needed in a cell. These estimates depend on the selected system and the assumed or real behavior of the subscribers.

What is traffic? Traffic refers to the usage of channels and is usually thought of as the holding time per time unit (or the number of "call hours" per hour) for one or several circuits (trunks or channels). Traffic is measured in Erlangs (E). For example, if one subscriber spends all of his/her time on the telephone, he/she can generate one call hour per hour or 1 E of traffic.

How much traffic can one cell carry? That depends on the number of traffic channels available and the acceptable probabitily that the system is congested, the so-called Grade of Service (GoS). Different assumptions on subscriber behavior lead to different answers to this question. Eriang's (a Danish traffic theorist) B-table is based on the most common assumptions used. These assumptions are:

- No queues
- Number of subscribers much higher than number of traffic channels
- No dedicated (reserved) traffic channels
- Poisson distributed (random) traffic

- Blocked calls abandon the call attempt immediately

This is referred to as a "loss system". Erlang's B-table relates the number of traffic channels, the GoS, and the traffic offered. This relationship is tabulated in Figure 2.1. Assuming that one cell has two carriers, corresponding typically to 2x8-2=14 traffic channels and a GoS of 2% is acceptable, the traffic that can be offered is A=8.20 E (Figure 2.1).

This number is interesting if an estimate on the average traffic per subscriber can be obtained. Studies show that the average traffic per subscriber during the busy hour is typically 15-20 mE (this can correspond to, e.g., one call lasting 54-72 seconds per hour). Dividing the traffic that one cell can offer, Acell=8.20 E, by the traffic per subscriber, here chosen as Asub=0.025 E, the number of subscribers one cell can support is derived as 8.20/0.025 = 328 subscribers.

Figure 2.1 Part of Ertang's B-table, yielding the traffic (in Eriangs) as a function of the GoS (columns) and number of traffic channels (rows)

n	.007	.008	.009	.01	.02	.03	.05	.1	.2	.4	*n*
1	.00705	.00806	.00908	.01010	.02041	.03093	.05263	.11111	.25000	.66667	1
2	.12600	.13532	.14416	.15259	.22347	.28155	.38132	.59543	1.0000	2.0000	2
3	.39664	.41757	.43711	.45549	.60221	.71513	.89940	1.2708	1.9299	3.4798	3
4	.77729	.81029	.84085	.86942	1.0923	1.2589	1.5246	2.0454	2.9452	5.0210	4
5	1.2362	1.2810	1.3223	1.3608	1.6571	1.8752	2.2185	2.8811	4.0104	6.5955	5
6	1.7531	1.8093	1.8610	1.9090	2.2759	2.5431	2.9603	3.7584	5.1086	8.1907	6
7	2.3149	2.3820	2.4437	2.5009	2.9354	3.2497	3.7378	4.6662	6.2302	9.7998	7
8	2.9125	2.9902	3.0615	3.1276	3.6271	3.9865	4.5430	5.5971	7.3692	11.419	8
9	3.5395	3.6274	3.7080	3.7825	4.3447	4.7479	5.3702	6.5464	8.5217	13.045	9
10	4.1911	4.2889	4.3784	4.4612	5.0840	5.5294	6.2157	7.5106	9.6850	14.677	10
11	4.8637	4.9709	5.0691	5.1599	5.8415	6.3280	7.0764	8.4871	10.857	16.314	11
12	5.5543	5.6708	5.7774	5.8760	6.6147	7.1410	7.9501	9.4740	12.036	17.954	12
13	6.2607	6.3863	6.5011	6,6072	7.4015	7.9667	8.8349	10.470	13.222	19.598	13
14	6.9811	7.1154	7.2382	7.3517	8.2003	8.8035	9.7295	11.473	14.413	21.243	14
15	7.7139	7.8568	7.9874	8.1080	9.0096	9.6500	10.633	12.484	15.608	22.891	15
16	8.4579	8.6092	8.7474	8.8750	9.8284	10.505	11.544	13.500	16.807	24.541	16
17	9.2119	9.3714	9.6171	9.6516	10.656	11.368	12.461	14.522	18.010	26.192	17
18	9.9751	10.143	10.296	10.437	11.491	12.238	13.385	15.548	19.216	27.844	18
19	10.747	10.922	11.082	11.230	12.333	13.115	14.315	16.579	20.424	29.498	19
20	11.526	11.709	11.876	12.031	13.182	13.997	15.249	17.613	21.635	31.152	20
21	12.312	12.503	12.677	12.838	14.036	14.885	16.189	18.651	22.848	32.808	21
22	13.105	13.303	13.484	13.651	14.896	15.778	17.132	19.692	24.064	34.464	22
23	13.904	14.110	14.297	14.470	15.761	16.675	18.080	20.737	25.281	36.121	23
24	14.709	14.922	15.116	15.295	16,631	17.577	19.031	21.784	26.499	37.779	24
25	15.519	15.739	15.939	16.125	17.505	18.483	19.985	22.833	27.720	39.437	25
26	16.334	16.561	16.768	16.959	18.383	19.392	20.943	23.885	28.941	41.096	26
27	17.153	17.387	17.601	17.797	19.265	20.305	21.904	24.939	30.164	42.755	27
28	17.977	18.218	18.438	18.640	20.150	21.221	22.867	25.995	31.388	44.414	28
29	18.805	19.053	19.279	19.487	21.039	22.140	23.833	27.053	32.614	46.074	29
30	19.637	19.891	20.123	20.337	21.932	23.062	24.802	28.113	33.840	47.735	30
31	20.473	20.734	20.972	21.191	22.827	23.987	23.773	29.174	35.067	49.395	31
32	21.312	21.580	21.823	22.048	23.725	24.914	26.746	30.237	36.295	51.056	32

Dimensioning the network now implies using demographic data to determine the sizes of the cells. The preceding example is simplified, however, it provides an understanding of what is meant by traffic and traffic dimensioning.

The problem may be that given a number of subscribers in one particular area, e.g. an airport, how many carriers do we need to support the traffic if only one cell is to be used? Dimensioning a whole network while maintaining a fixed cell size means estimating the number of carriers needed in each cell, In addition, traffic is not constant. It varies between day and night, different days, and with a number of other factors. Mobile telephony implies mobility and hence subscribers may move from one area to another during the course of a day.

It is important that the number of signaling channels (SDCCHs) is dimensioned as well, taking into account the estimated system behavior in various parts of the network. For example, cells bordering a different location area may have lots of location updating, and cells on a highway probably have many handovers. In order to calculate the need for SDCCHs the number of attempts for every procedure that uses the SDCCH as well as the time that each procedure holds the SDCCH must be taken into account. The procedures are; location updating, periodic registration, IMSI attach/detach, call setup, SMS, facsimile and supplementary services. The number of false accesses must also be estimated. This is typically quite a high number, but still small compared to the traffic.

When the GoS that should be used to consult the traffic tables is chosen, the fact that calls go through two different devices must be kept in mind.

2.2 CHANNEL UTILIZATION

Assume the task is to find the necessary number of traffic channels for one cell to serve subscribers with a traffic of 33 E. The GoS during ttie busy hour is not to exceed 2%. By considering the above requirements and consulting Erlang's B-table, 43 channels are found to be needed (Figure 2.2).

n	.007	.008	.009	.01	.02	.03	.05	.1	.2	.4	n
43	30.734	31.069	31.374	31.656	33.758	35.253	37.565	42.011	49.851	69.342	43

Figure 2.2 Part of Erlang's B-table for 43 channels giving the offered traffic (E) as a function of the GoS (%)

Assume five cells are designed to cover the same area as the single cell. These five cells must handle the same amount of traffic as the cell above, 33 E. Acceptable GoS is still 2%. First, the total traffic is divided among the cells (Figure 2.3). Traffic distribution over several cells results in a need for more channels than if all trafflc had been concentrated in one cell.

This illustrates that it is more efficient to use many channels in a larger cell than vice versa. To calculate the channel utilization, the traffic offered is reduced hy the GoS of 2% (yielding the traffic served) and dividing that value by the number of channels (yielding the channel utilization).

With 43 channels (as in the previous single cell example) the channel utilization is 33.083 / 43 = 77%, i.e. each channel is used approximately 77% of the time. However, by splitting this cell into smaller cells. more traffic channels are required and hence the channel utlization decreases

Cell	Traffic (%)	Traffic (E)	No. of channels	Channel utilization (%)
A	40	13.20	21	62
B	25	8.25	15	54
C	15	4.95	10	49
D	10	3.30	8	40
E	10	3.30	8	40
Total	100	33.00	62	

Figure 2.3 What happens when a certain amount of traffic is distributed over several cells

As we will see in the following chapter, capacity and interference problems prevent us from always using the most effective channel utilization scheme and so solutions in real networks must compromise between efficiency (i.e.,cost) and quality.

CHAPTER 3: NOMINAL CELL PLAN

3.1 WAVES

There are many seemingly different types of electromagnetic waves. They include radio waves, infrared rays, light, x-rays, and gamma rays among others. Radio waves are one type of electromagnetic radiation. They are typically generated as disturbances sent out by oscillating charges on a transmitting antenna. Other types of electromagnetic radiation are caused by intense heat, atomic reactions, and stimulated emission (lasers). Regardless of its origin, an electromagnetic wave is comprised of oscillating electric and magnetic fields. For a simple, traveling, plane wave, the electric and magnetic fields are perpendicular to each other and also to the direction of propagation. Waves can be described by simple sinusoidat functions (Figure 3.2) and are conveniently characterized by their wavelength, λ (the length of one cycle of oscillation), or equivalently with its frequency, f The two are related via the speed of propagation, c, as

$$\lambda \times f = c$$

where:

λ = wavelength in meters per cycle

f = frequency in cycles per second (or hertz)

c = speed of light, a constant approximately equal to $3 \cdot 10^8$ meters/second for all electromagnetic waves.

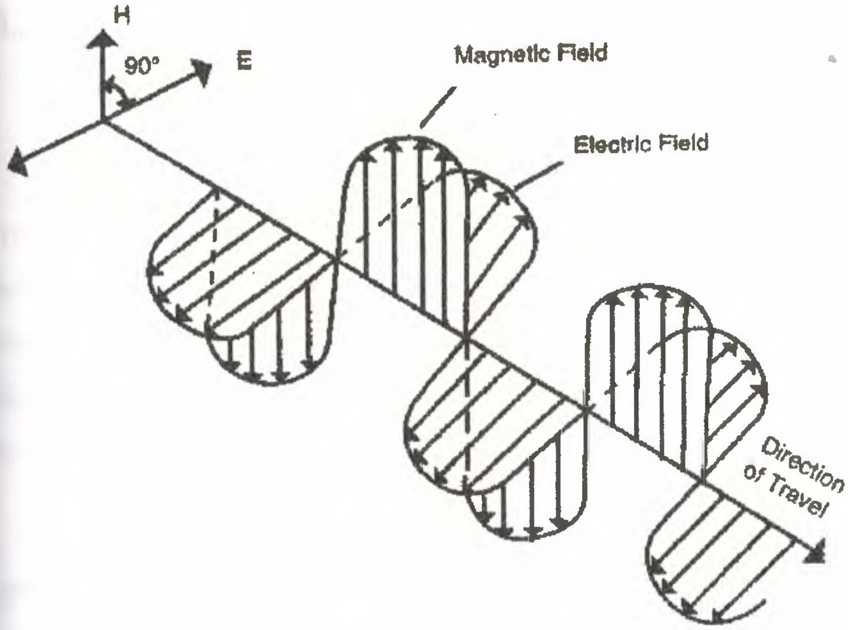


Figure 3.2 An electromagnetic plane wave "frozen" in time

Propagation properties are different across the frequency spectrum. Radio waves fall in the frequency spectrum between 3 Hz and 3000 GHz. This pan of the spectrum is divided into twelve bands (Figure 3.3). Only the Ultra High Frequency (UHF) band is considered from now on, since properties of UHF waves and frequency allocations liave made this the mobile telephony frequency band.

Figure 3.3 Frequency spectrum bands

FREQUENCY	CLASSIFICATION	DESIGNATION
3 - 30 Hz		
30 - 300 Hz	Extremely Low Frequency	ELF
300 - 3000 Hz	Voice Frequency	VF
3 - 30 kHz	Very-Low Frequency	VLF
30 - 300 kHz	Low Frequency	LF
300 - 3000 kHz	Medium Frequency	MF
3 - 30 MHz	High Frequency	HF
30 - 300 MHz	Very High Frequency	VHP
300 - 3000 MHz	Ultra High Frequency	UHF
3 - 30 GHz	Super High Frequency	SHF
30 - 300 GHz	Extremely High Frequency	EHF
300 - 3000 GHz		

3.2 GENERATION OF RADIO WAVES

High frequency radio waves are typically generated by oscillating charges on a transmitting antenna. In the case of a radio station, the antenna is often simply a long wire (a dipole) fed by an alternating voltage/current source; i.e., charges are placed on the antenna by the alternating voltage source. We can think of the electric field as being disturbances sent out by the dipole source and the frequency of the oscillating electric field (the electromagnetic wave) is the same as the frequency of the source.

Each antenna has a unique radiation pattern. This pattern can be represented graphically by plotting the received, time-averaged power, as a function of angle with respect to the direction of maximum power in a log-polar diagram. The pattern is representative of the antenna's performance in a test environment. However, it only applies to the free-space environment in which the test measurement takes place. Upon installation, the pattern becomes more complex due to factors affecting propagation in the reality. Thus, the real effectiveness of any antenna is measured in the field.

An isotropic antenna is a completely non-directional antenna that radiates equally in all directions. Since all practical antennas exhibit some degree of directivity, the isotropic antenna exists only as a mathematical concept. The isotropic antenna can be used as a reference to specify the gain of a practical antenna (see the appendix for a general discussion on gain/loss and logarithmic units). The gain of an antenna referenced isotropically is the ratio between the power required in the practical antenna and the power required in an isotropic antenna to achieve the same field strength in the desired direction of the measured practical antenna. Directive gain in relation to an isotropic antenna is expressed in units of "dBi".

A half-wave dipole antenna may also be used as a gain reference for practical antennas. The half-wave dipole is a straight conductor cut to one-half of the electrical wavelength with the radio frequency signal fed to the middle of the conductor. Figure 3.4 illustrates the radiation pattern of the half-wave dipole which normally is referred to as a dipole. Whereas the isotropic antenna's three dimensional radiation pattern is spherical, the dipole antenna's three dimensional pattern is shaped like a donut.

Directive gain in relation to a dipole is expressed in units of "dBd". For a dipole and an isotropic antenna with the same input power, the energy is more concentrated in certain directions by the dipole. The difference in directive gain between the dipole and the isotropic antenna is 2.15 dB. Figure 3.5 illustrates the differences in gain between the isotropic, dipole and practical antenna. The vertical pattern (Figure 3.5) for the practical antenna is that of a directional antenna.

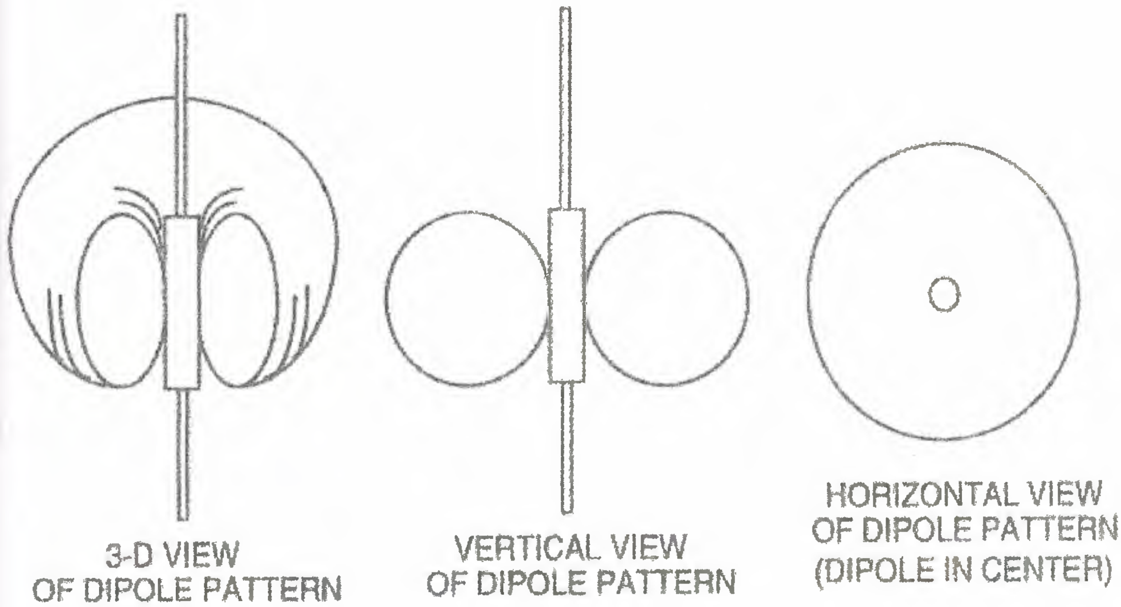


Figure 3.4 Dipole radiation pattern

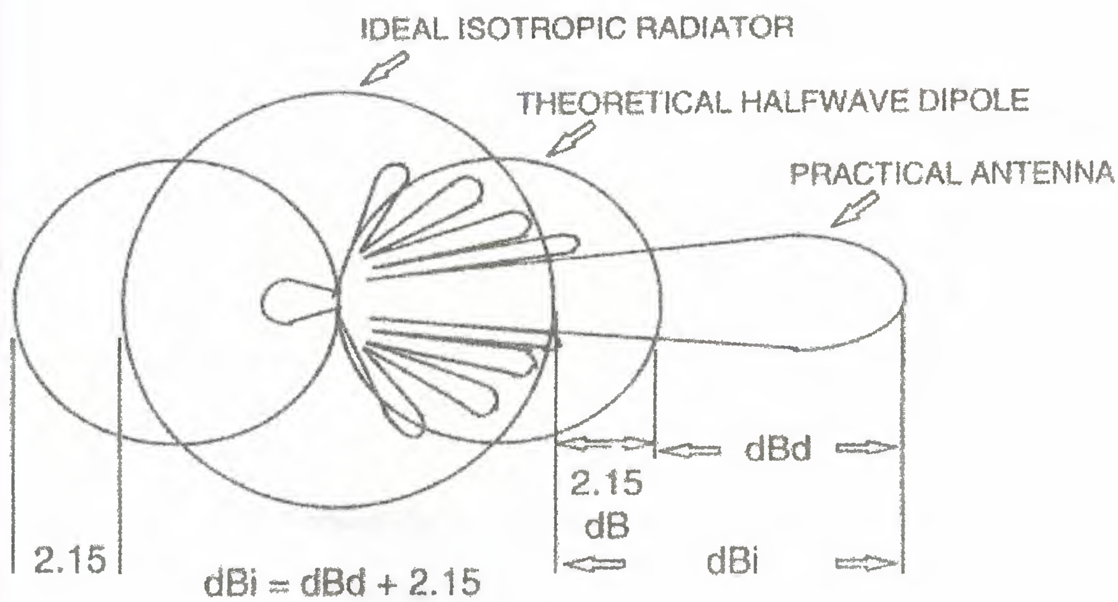


Figure 3.5 Gain comparison

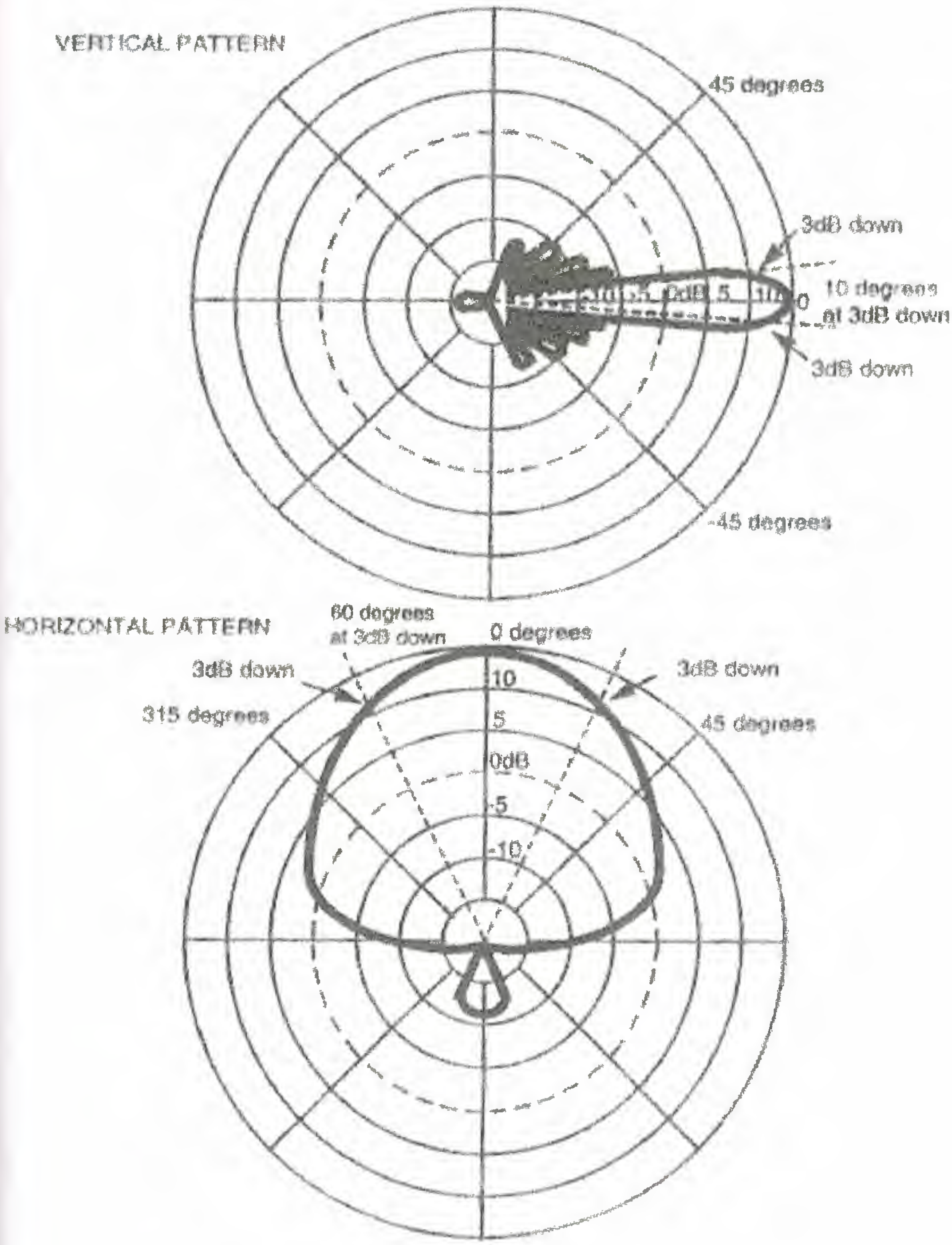


Figure 3.6 Vertical and horizontal antenna patterns for a "real" antenna

When choosing an antenna for a specific application, the manufacturer's data sheet must be consulted. The data sheet contains information including antenna gain, beamwidth (vertical and horizontal), and graphs showing the vertical and horizontal patterns. Examples of the graphs normally found in a data sheet are shown in Figure 3.6, The patterns displayed are those of a directional antenna. The antenna's gain is approximately 15 dBd.

The beamwidth, B, is defined as the opening angle between the points where the radiated power is 3 dB lower than in the main direction (Figure 3.7). Both the horizontal and vertical beamwidths are found using the 3 dB down points, alternatively referred to as half-power points.

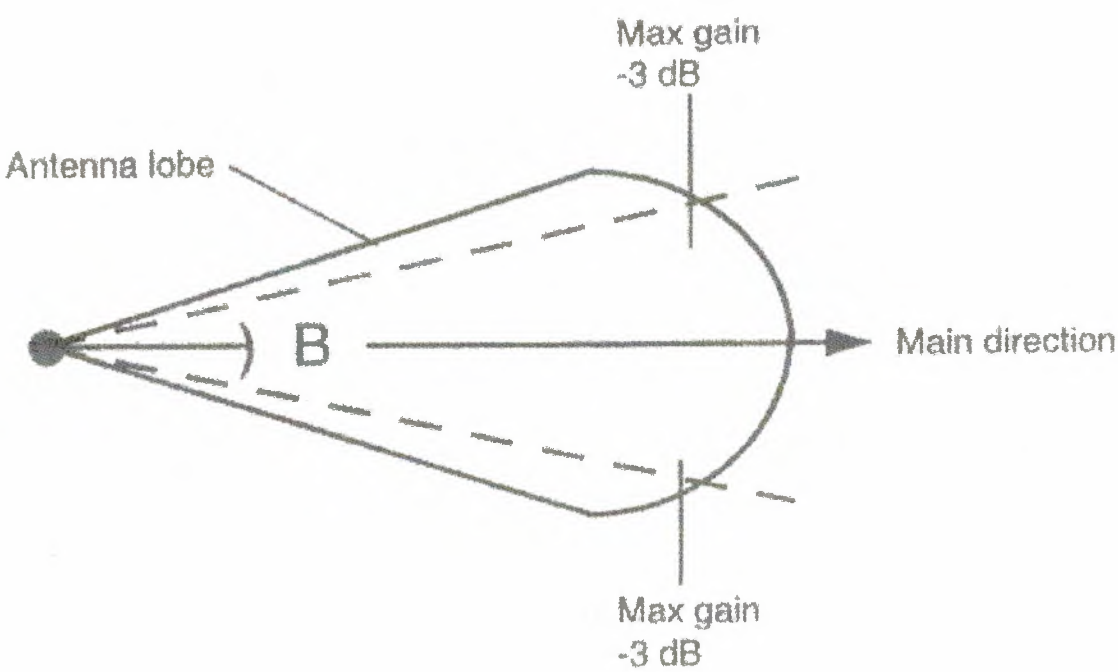


Figure 3.7 Definition of beamwidth

3.3 SUPERIMPOSING INFORMATION ON RADIO WAVES

Information is seldomly transmitted in the same frequency range as it was generated. The reason is that if, as an example, we want to broadcast a 2 kHz signal, the antenna would liave to be 75 km long (half a wavelength). However, by translating the signal to a much higher frequency band (e.g., the UHF band of cellular telephony) antenna sizes drop to a few decimeters. In addition, in order to have numerous "channels" simultaneously, a higher frequency is required.

Frequency translation is implemented by modulating the amplitude, frequency or phase of a so-called carrier wave in accordance with the wave form of the wanted signal. Several modulation schemes exist (e.g.amplitude modulation) common for analog radio signals and phase modulation. Any modulation scheme increases the carrier bandwidth and hence limits the capacity of the frequency band available. Since the bandwidth of the carrier increases if the bit rate increases, a high carrier frequency is necessary to obtain many different "channels". The cell planner cannot choose modulation techniques, but the consequences of the system choice are very important, since carrier bandwidth and carrier separation affects, e.g., interference properties. Wave propagation also behaves differently in different frequency bands.

The modulation technique used in GSM is called Gaussian Minimum Shift Keying (GMSK). This narrow-band digital modulation technique is based on phase shifting. That is, bits are represented by continuous positive or negative phase shifts. By changing the phase continuously, sharp discontinuities are avoided, thus narrowing the bandwidth of the modulated carrier. GMSK modulation also involves filtering the incotning bit stream with a Gaussian filter to obtain a more narrow bandwidth of the modulated carrier. In fact the full width at half maximum of the carrier becomes 162 kHz, corresponding nicely to the 200 kHz carrier separation.

Transmitting the information on the air interface in digitized form has an advantage over analog techniques, since channel coding protects bits, the signal is less sensitive to perturbations. In addition, it enables Time Division Multiple Access

(TDMA) which means that one carrier frequency can be used for several connections. Each connection uses only one particular time slot (out of the eight available in GSM). This has the advantage that the mobile is released from transmitting/receiving continuously and can perform, e.g., measurements on neighboring cells. One main advantage with TDMA is that it enables Mobile Assisted Hand Over (MAHO) which is essential for effective connection control.

3.4 AIR INTERFACE DATA

Below is a summary of some important air interface data for GSM 900, GSM 1800, and GSM 1900.

3.4.1 FREQUENCY SPECTRUM

Different frequency bands are used for GSM 900, GSM 1800, and GSM 1900 (refer to Figure 3.13). In some countries, operators apply for the available frequencies. In other countries e.g., the United Stales), operators purchase frequency bands at auctions.

In December of 1994, the Federal Communications Commission (FCC) auctioned "broadband" licenses to prospective operators offering personal communications services. Each operator owns the rights to the licenses for a period of ten years. The United States is divided into 51 regions or Major Trading Areas (MTA) and 493 Basic Trading Areas (BTA). The FCC issued two GSM 1900 licenses for each MTA and four for each BTA. One MTA can be geographically as large as a state, while one BTA can be compared in size to a large city. BTAs are designed for use in major metropolitan areas.

The FCC has specified the frequency range and output power. The frequency band is divided into six frequency blocks (Figure 3.8): three duplex blocks A, B, and C (90 MHz total spectrum bandwidth) and three other duplex blocks D, E, and F (30 MHz total spectrum bandwidth).

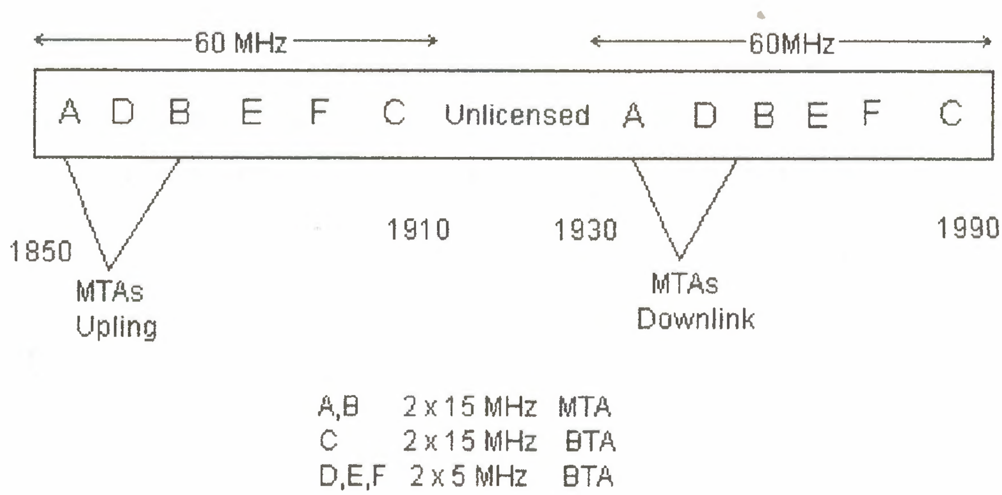


Figure 3.8 Spectrum allocation for GSM 1900 in United States. 140 MHz tor GSM 1900 (120 MHz licensed and 20 MHz unlicensed)

3.4.2 DUPLEX DISTANCE

The distance between the uplink and downlink frequencies is known as duplex distance. The duplex distance is different for the different frequency bands (Figure 3.9).

Standard	GSM 900	GSM1800	GSM1900
Duplex dist.	45MHz	95MHz	80MHz

Figure 3.9 Duplex differences for different frequency bands

3.4.3 CHANNEL SEPARATION

The distance between adjacent frequencies on the uplink or the downlink is called channel separation. The channel separation is 200 kHz, regardless of the standard chosen from the ones mentioned above. This separation is needed to reduce interference from one carrier to another neighboring frequency.

3.4.4 ACCESS METHOD AND TRANSMISSION RATE

GSM has chosen the TDMA concept for access. In GSM, there are eight TDMA time slots per frame (Figure 3.10). Each time slot is 0.577 ms long and has room for 156.25 bits (148 bits of information and a 8.25 bits long guard period) yielding a bit rate on the air interface of 270.8 kbits.

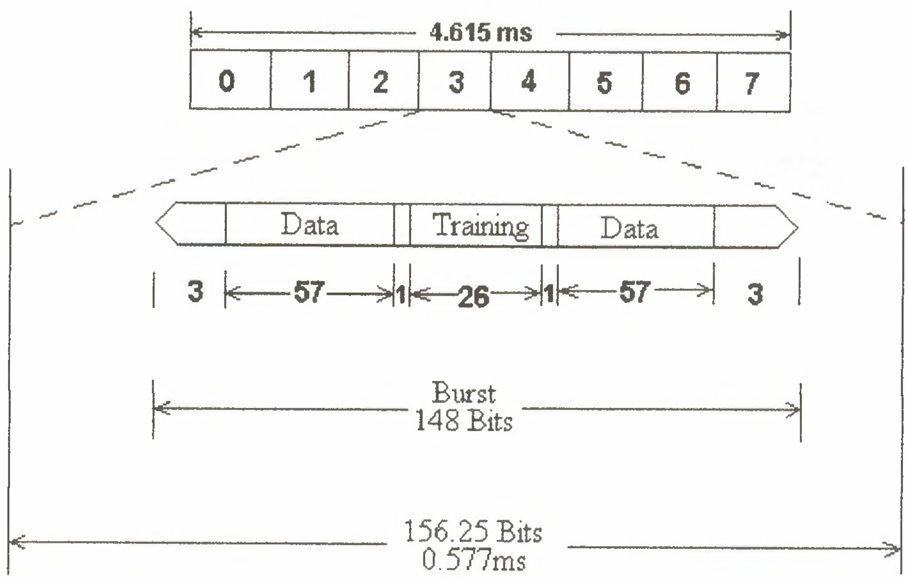


Figure 3.10Basic TDMA frame, timeslot, and burst structures

3.5 RADIO WAVE PROPAGATION

In this project we arc primarily interested in the transmission loss between two antennas: the transmitter/emitter and the receiver. Many factors including absorption, refraction, reflection, diffraction, and scattering affect the wave propagation. However, in free space an electromagnetic wave travels indefinitely if unimpeded. This does not mean that there are no transmission losses, as we will see in this first simple model where isotropic emission from the transmitter and line of sight between the two antennas separated by a distance, d, in free space are assumed (Figure 3.11).

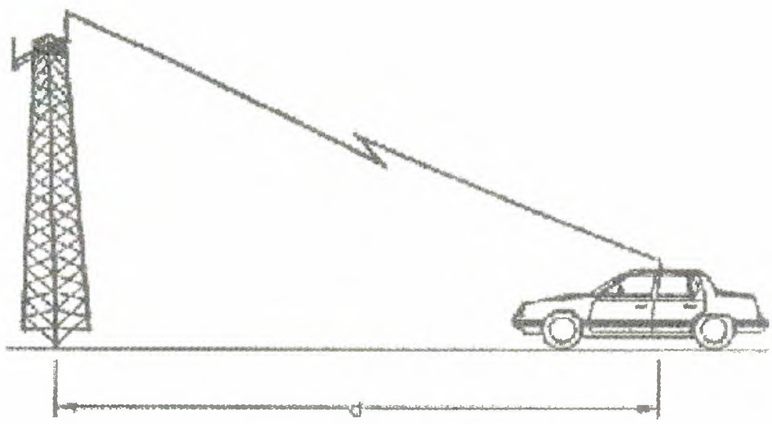


Figure 3.11 Radio wave propagation in free space

Since an isotropic antenna by definition distributes the emitted power, Pt, equally in all directions, the power density, Sr, (power per area unit) decreases as the irradiated area, 4 πd^2, at distance d, increases, i.e.:

$$S_r = \frac{P_t}{4\pi d^2}$$

If the transmitting antenna has a gain, G,, it means that it is concentrating the radiation towards the receiver. The power density at the receiving antenna increases with a factor proportional to G_t, i.e.

$$S_r = \frac{P_t G_t}{4\pi d^2}$$

The power received by the receiving antenna, Pr, is proportional to the effective area, Ar, of that antenna, i.e.

$$P_r = S_r \cdot A_r$$

It can be shown that the effective area of an antenna is proportional to the antenna gain. *Gr,* and the square of the wavelength, lamda, of the radio wave involved, i.e.

$$A_r = \frac{G_r \lambda^2}{4\pi}$$

and hence the received power becomes

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2}$$

The transmission loss can be calculated as the ratio between the transmitted power and received power, i.e.

$$loss = \frac{P_t}{P_r} = \frac{(4\pi d)^2}{G_t G_r \lambda^2}$$

Note that the wavelength dependency of the pathless does not correspond to losses in free space as such. It is a consequence of the finite effective receiver area.

This expression is fairly general. The only thing which changes when we improve our models is the expression for the pathloss. The antenna gain is normally given in dB(i), i.e., as 10 1og(G), where gain means a reduction of the total transmission loss, L, between a transmitting and receiving antenna.

This model helps us to understand the most important features of radio wave propagation. That is, the received power decreases when the distance between the antennas increases and the transmission loss increases when the wavelength decreases (or alternatively when the frequency increases).

For cell planning, it is very important to be able to estimate the signal strengths in all parts of the area to be covered, i.e. to predict the pathless. The model described in this section can be used as a first approximation. However, more complicated models exist. Improvements can be made by accounting for:

- The fact that radio waves are reflected towards the earth's surface (the conductivity of the earth is thus an important parameter)
- Transmission losses due to obstructions in the line of sight
- The finite radius of the curvature of the earth

The topographical variations in a real case as well as the different attenuation properties of different terrain types such as forests, urban areas, etc.

The best models used are semi-empirical, i.e., based on measurements of pathloss/attenuation in various terrains. The use of such models are motivated by the fact that radio propagation can not be measured everywhere. However, if measurements are taken in typical environments, the parameters of the model can be fine-tuned so that the model is as good as possible for that particular type of terrain.

3.6 SIGNAL VARIATIONS

The models described in the previous section can be used to estimate the average signal level (called the "global mean") at the receiving antenna. However, a radio signal envelope is composed of a fast fading signal super-imposed on a slow fading signal (Figure 3.9). These fading signals are The result of obstructions and reflections. They yield a signal which is the sum of a possibly weak, direct, line-of-sight signal and several indirect or reflected signals.

The fast fading signal (peak-to-peak distance = $\lambda/2$) is usually present during radio communication due to the fact that the mobile antenna is lower than the surrounding structures such as trees and buildings. These act as reflectors. The resulting signal consists of several waves with various amplitudes and phases. Sometimes these almost completely cancel out each other, This can lead to a signal level below the receiver sensitivity. In open fields where a direct wave is dominating, this type of fading is less noticeable.

Short-term fading is Rayleigh distributed with respect to the signal voltage. Therefore, it is often called Rayleigh fading. This type of fading affects the signal quality, and as a result some measures must be taken to counter it.

The first and most simple solution is to use more power at the transmitters(s), thus providing a fading margin. Another way to reduce the harm done by Rayleigh fading is to use space diversity, which reduces the number of deep fading dips. Diversity means that two signals are received which have slightly different "histories" and, therefore, the "best" can be used.

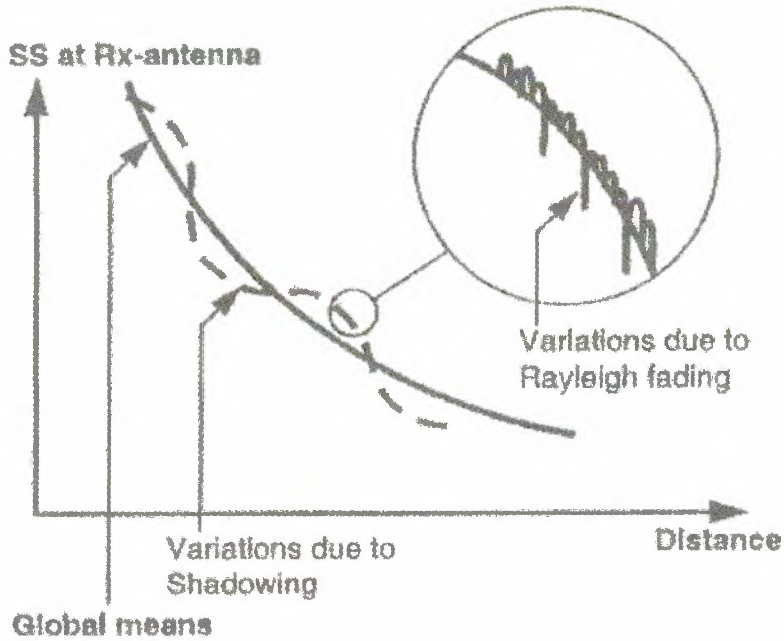


Figure 3.12 Short-term (fast) and long-term (slow) fading

The signal variation received if we smooth out the short-term fading is called the "local mean". Its power is often called the local average power, is expressed in a logarithmic scale, and is normally distributed. Therefore, this slow fading is called "log-normal fading". If we drive through a flat desert without any obstructions, the signal varies slowly with distance. However, in normal cases the signal path is obstructed.

Obstructions near the mobile (e.g., buildings, bridges, trees, etc,) cause a rapid change of the local mean (in the range of five to fifty meters), while topographical obstructions cause a slower signal variation. Because log-normal fading reduces the average strength received, the total coverage from the transmitter is reduced. To combat this, a fading margin must be used. Problems generated by multi-path reflections are made more severe by tog-normal fading since the direct beam is weakened by the obstructing object.

Phases between various reflected waves are different. This is due to the fact that they propagate over different distances or equivalently use different times to reach the receiver. This time dispersion can cause particular problems if the phase difference between the reflected waves is very large. For GSM 900, a large phase difference is on the order of several thousands of wavelengths (i.e. one kilometer or more). In this case, different waves added together in the receiver carry information about different symbols (bits). If the direct wave is weak, and consequently the reflected waves are relatively strong, it can be difficult to determine which symbol (bit) was transmitted.

3.7 SYSTEM BALANCING

An area is referred to as being covered if the signal strength received by an MS in that area is higher than some minimum value. A typical value in this case is around -90 dBm (1 pW). However, coverage in a two-way radio communication system is determined by the weakest transmission direction. Both uplink and downlink are taken into consideration here. That is, the signal received by the BTS from an MS in an area must be higher than some minimum value. It makes no sense to have different coverage on uplink and downlink because (his causes an excess amount of energy to be dissipated into the system adding extra interferences and costs. A system balance must be obtained before coverage calculation can start.

To achieve this balance it is necessary to make sure that the sensitivity limit, MS_{sens} of the MS (fur downlink transmission) is reached at the same point as the sensitivity limit, BTS_{sens}, of the BTS (for uplink transmission).

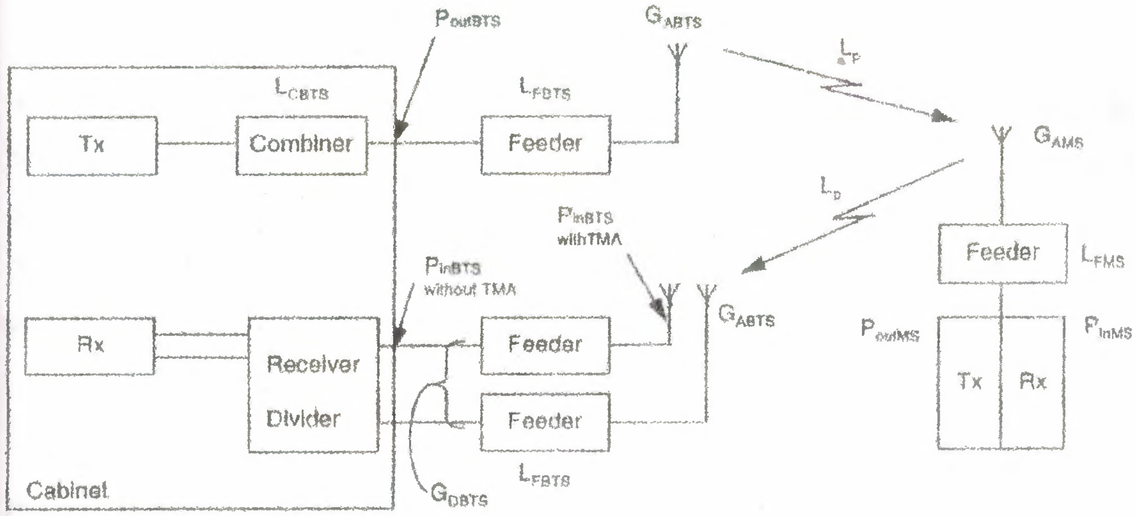


Figure 3.13 Schematic graph of the compionents included in a system balance. Abbreviations have the following translations:

G=Gain,*L=Loss,* A=Antenna, F=Feeder, C-=Combiner, MS=Mobile Station, BTS=Base Transceiver Station, D=Diversity, Pin=inpul power, Pout=output power, and Lp=path loss

The input power, Pin_{MS}, at the MS receiver equals the output power, $Pout_{BTS}$, of the BTS plus gains and losses.

$$Pin_{MS} = Pout_{BTS} - Lc_{BTS} - Lf_{BTS} + Ga_{BTS} - Lp + Ga_{MS} - Lf_{MS}$$

and

$$Pin_{BTS} = Pout_{MS} - Lf_{MS} + Ga_{MS} - Lp + Ga_{BTS} + Gd_{BTS} - Lf_{BTS}$$

For some configurations the duplex loss, $Ldupl_{BTS}$, can be important. If polarization diversity is used it may be necessary to introduce a slant polarization (±45°) downlink loss, $Lslant_{BTS}$. Assuming that the pathless, Lp, is identical on uplink and downlink (a good assumption since the difference in frequency is only on the order of 5%) and that the transmitting and receiving antennas of the BTS have the same gain, subtracting the second equation from the first

$$Pin_{MS} - Pin_{BTS} = Pout_{BTS} - Pout_{MS} - Lc_{BTS} - Gd_{BTS}$$

is obtained, and setting $Pin_{MS} - Pout_{BTS} = MS_{SENS} - BTS_{SENS}$

$$Pout_{BTS} = Pout + Lc_{BTS} + Gd_{BTS} + (MS_{SENS} - BTS_{SENS})$$

is obtained. The BTS output power, POUT BTS, measured at the RX output' must be higher than the output power of the MS, $Pout_{BTS}$, by a value corresponding to the sum of the diversity gain, Gd_{BTS}, the combiner loss, LC_{BTS}. and the difference in sensitivity $(MS_{SENS} - BTS_{SENS})$. Note that the reference points for the sensitivities may be different when balancing, e.g. a GSM 1800 system using an Antenna Low Noise Amplifier (ALNA).

For example, balancing the system for GSM 900 class 4 mobile stations, i.e. $Pout_{MS}$ =2 W or 33 dBm, using Gd_{BTS} = 3.5 dB, LC_{BTS} = 3 dB, and using values for the sensitivities as MS_{SENS} = -104 dBm and BTS_{SENS} = -110 dBm, an output power of the BTS

$Pout_{BTS}$ = 33 + 3+ 3.5 + (-104 + 110) = 45.5 dBm

is obtained. Hence, an 35 W BTS is needed. The output power of the BTS needs to be higher than the output power of the MS because not only is the BTS more sensitive (and hence can accept a smaller signal strength) it has also an extra loss when transmitting, LCBTS and an extra gain when receiving, Gd_{BTS}. Note that the balance is independent of the BTS antenna gain

However, the coverage can now be changed by changing the antenna gain, since it is symmetrical, i.e. increasing the coverage downlink by increasing ihe antenna gain is matched by a corresponding increase in coverage on the uplink.

The BTS output power should never be changed once the system is balanced for a particular configuration and mobile class. Note: If "smaller cells" are desired, the power can be decreased because it can be matched by a corresponding, forced, decrease in the output power of the MS.

3.8 CHANNEL LOADING PLAN

The simplest cell planning problem solution is to have one cell and use all available carriers in that cell (Figure 3.14). However, such a solulion has severe limitations. It is seldom that coverage can be maintained in the entire area desired. In addition, even though the channel utilization may be very high. limited capacity soon becomes a problem due to the limited number of carriers available to any operator.

A cellular system is based upon re-use of the same set of frequencies which is obtained by dividing the area needing coverage into smaller areas (cells) which togelher form clusters (Figure 3.15). A cluster is a group of cells in which all available carriers have been used once (and only once). Since the same carriers are used in cells in neighboring clusters, interference may become a problem. Indeed, the frequency re-use distance, i.e. the distance belween two sites using the same carrier, must be kept as large as possible from a interference point-of-view. At the same time they must be kept as small as possible from a capacity point of view.

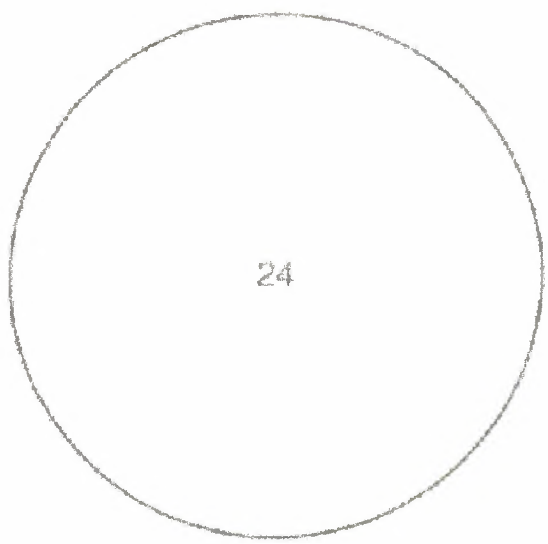


Figure 3.14 Example of an area served from one cell by 24 carriers

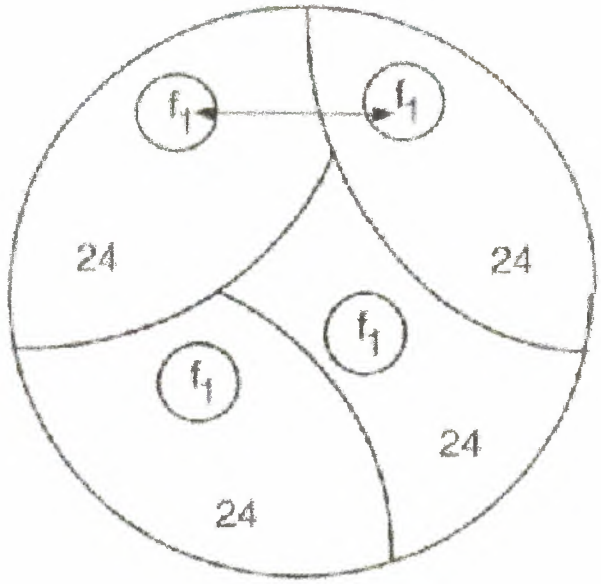


Figure 3.15 The same area as in Figure 3.3 but now schematically divided into four clusters, each cluster using all (here 24) carriers. The small circles indicate individual cells where the frequency f_1 is used and a distance between the corresponding sites, known as frequency re-use distance, is indicated by the double arrow.

3.8.1 INTERFERENCE

Cellular systems are often interference limited rather than signal strength limited.Therefore some elementary information about different problems associated with the re-use of carriers is provided in this section.

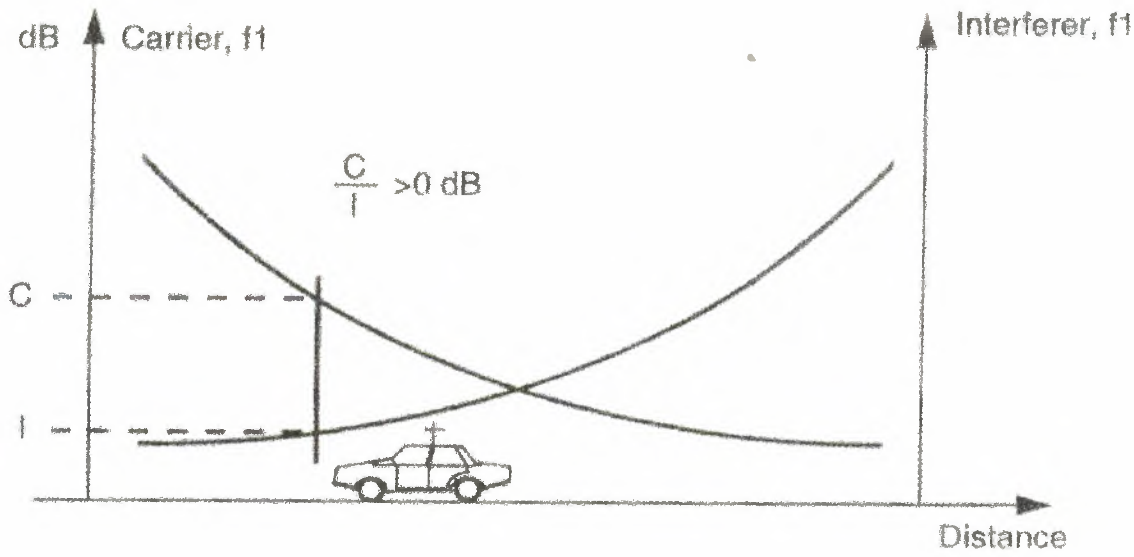


Figure 3.16 Co-channel interference

Co-channel interference is the term used for inlerference in a cell by carriers with the same frequency present in other cells. Figure 3.16 illustrates the situation. Since the same carrier frequency is used for the wanted carrier as for the unwanted carrier, quality problems can arise if the signal from the unwanted carrier is too strong.

The GSM specification states that the signal strength ratio, C/I, between the carrier, C, and the interferer, I, must he larger than 9 dB. If frequency hopping is implemented, it adds extra diversity to the system corresponding to a margin of approximately 3 dB, i.e.:

C/I > 12 dB (without frequency hopping)

C/I > 9 dB (with frequency hopping)

Adjacent carrier frequencies (i.e., frequencies shifted ±200 kHz) with respect to the carrier cannot be allowed to have too strong a signal strength either. Even though they are at different frequencies, part of the signal can interfere with the wanted carrier's signal and cause quality problems (Figure3.6). The GSM specification states that the signal strength ratio, C/A, between the carrier and the adjacent frequency interferer, A, must be larger than -9 dB. However, adjacent channel interference also degrades the sensitivity as well as the C/I performance. During cell planning the aim should be to have C/A higher than 3 dB, i.e.:

$C/A > 3$ dB

Adjacent frequencies must be avoided in the same cell and preferably in neighboring cells as well.

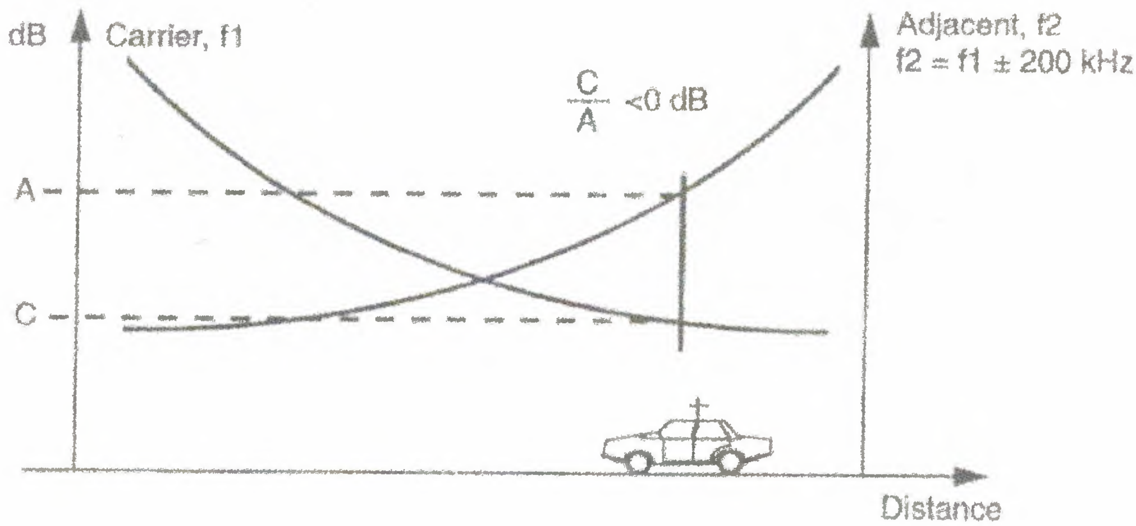


Figure 3.17 Adjacent channel interference

By re-using the carrier frequencies according to well-proven reuse patterns (Figure 3.7 and Figure 3.8). neither co-channel interference nor adjacent channel interference will cause problems, provided the cells have isolropic propagation properties for the radio waves. Unfortunately this is hardly ever the case. Cells vary in size depending on the amount of traffic they are expected to carry, and nominal cell plans must be verified by means of predictions or radio measurements to ensure that interference does not become a problem.

The re-use patterns recommended for GSM are 4/12- and 3/9-pattems. 4/12 means that each cluster has four three-sector sites Supporting twelve cells (Figure 3.18).

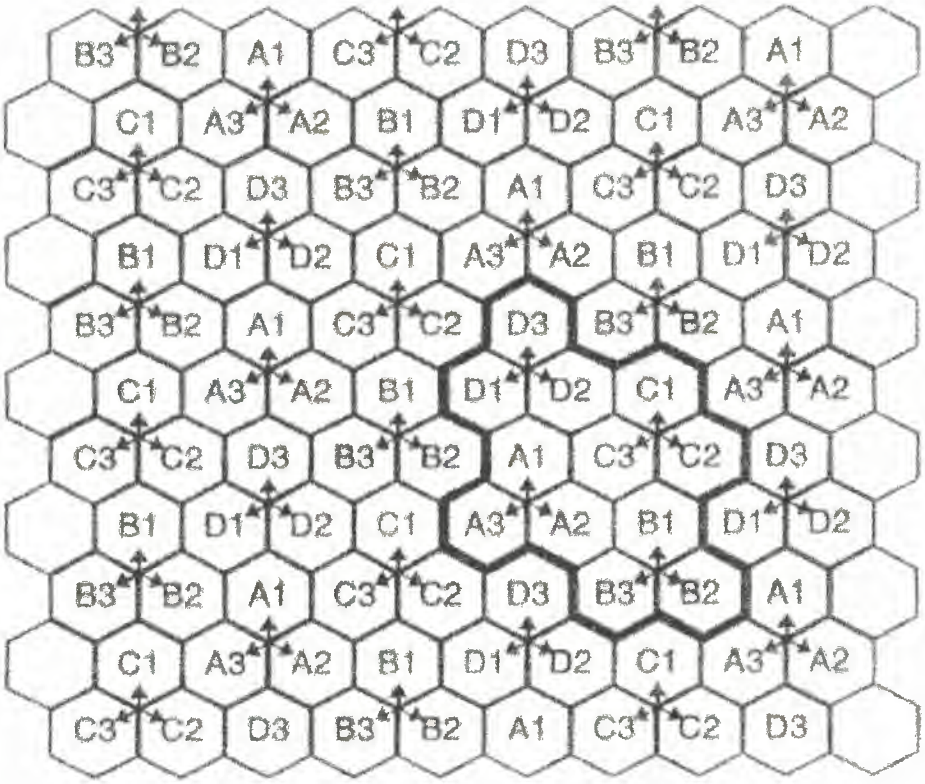


Figure 3.18 4/12 re-use pattern

The re-use pattern in Figure 3.18 is compatible with the condition C/I>12 dB. A shorter re-use distance, given a smaller C/I-ratio, is used in the 3/9-pattem (Figure 3.19).

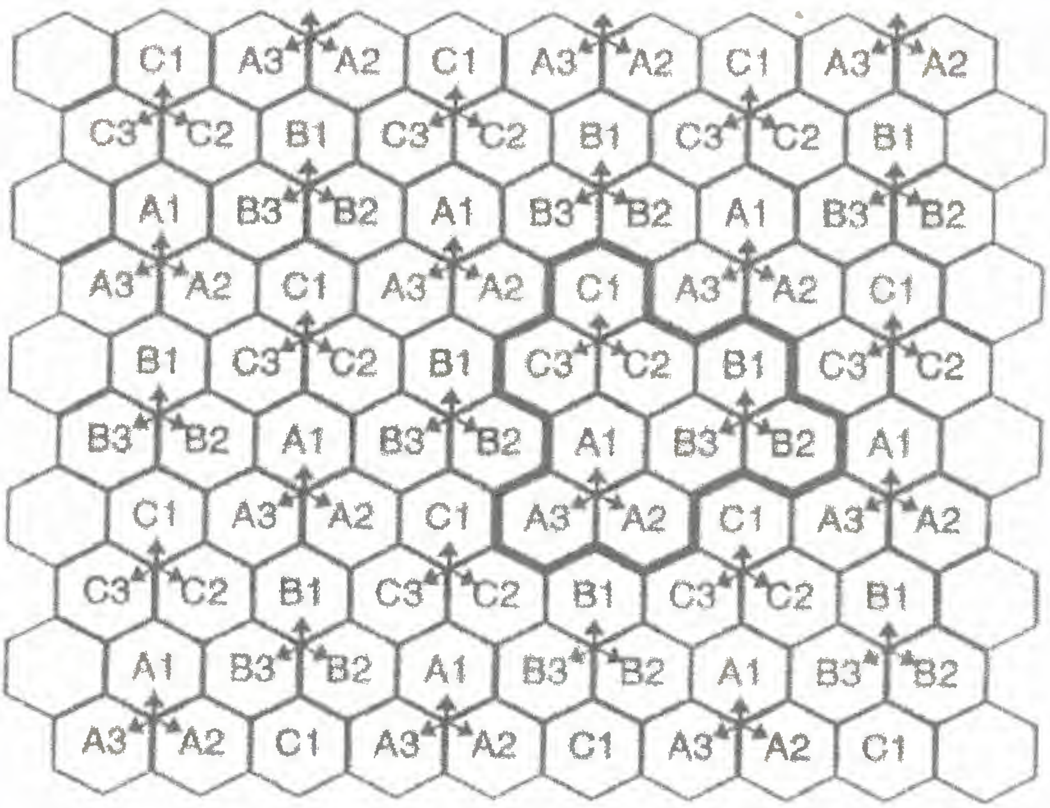


Figure 3.19 3/9 re-use pattern

This re-use pattern (Figure 3.19) is recommended only if frequency hopping is implemented. It has a higher channel utilization because the carriers are distributed among nine cells rather than 12. Other re-use patterns with much higher re-use distances (such as the 7/21) must be used for systems which are more sensitive to interference; e.g. analog mobile telephone systems.

3.8.2 INTERSYMBOL INTERFERENCE (ISI)

InterSymbol Interference (ISI) is caused by excessive time dispersion. It may be present in all cell re-use patterns. ISI can be thought of as co-channel interference. However in this case the interferer, R, is a time delayed reflection of the wanted carrier. According to GSM specifications, the signal strength ratio C/R must be larger than 9 dB (compared to the C/I-criterion). However, if the time delay is smaller than 15μs (i.e., 4 bits or approximately 4,4 km), the equalizer can solve the problem. ISI is not affected by the re-use pattern chosen, but is still an issue for the cell planner.

How can the cell planner avoid ISI in the cellular network? Normally, the reflected waves are much weaker than the direct wave. However, if the direct wave is obstructed (shadowed), or if the reflected wave has a very advantageous path of propagation, the C/R ratio may creep down lo dangerous values if the time delay is outside the equalizer window. Hence, time dispersion may cause problems in environments with, e.g., mountains, lakes with steep or densely built shores, hilly cities, and high metal-covered buildings. The location of the BTS can thus be crucial. Figure 3.20 and Figure 3.21 suggest some possible solutions.

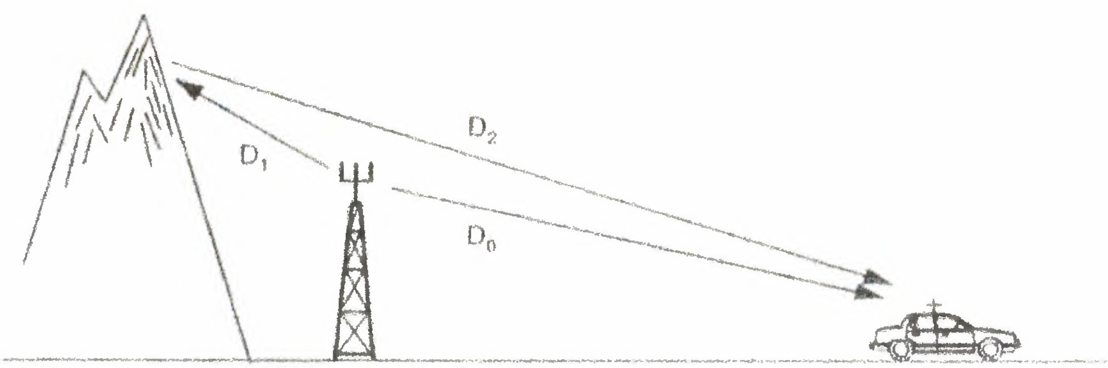


Figure 3.20 Locating the BTS dose to the reflecting object to combat ISI

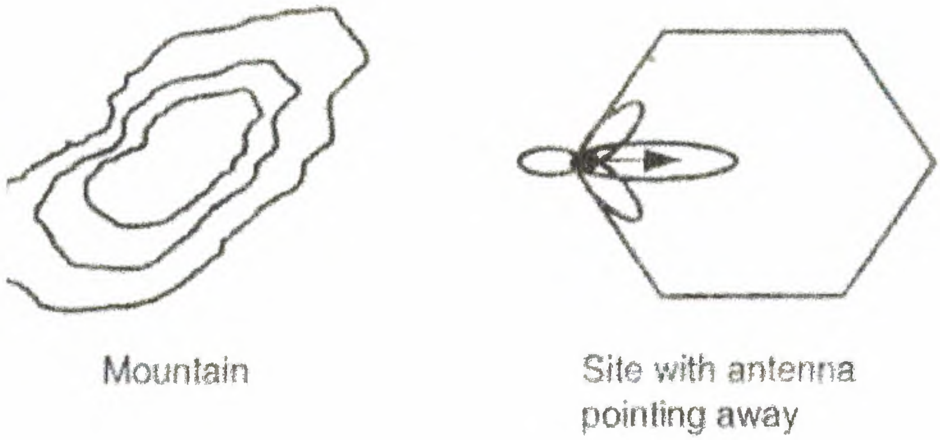


Figure 3.21 Pointing the antenna away from the reflecting object to combat ISI

CHAPTER 4: SURVEYS

4.1 RADIO NETWORK SURVEY

4.1.1 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

4.1.2 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.

4.1.3 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 maximum deviation 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 the predicted position, the operator must ensure that there is no risk force-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. These include coverage, isolation, diversity, and/or interference.

Note: Some of these considerations are discussed in the next section.

4.1.4 ANTENNA SEPARATIONS

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

- To achieve space diversity
- To achieve isolation

The horizontal separation distance to obtain sufficient space diversity between antennas is 12-18 λ or 4-6 meter for GSM 900 and 2-3 m for GSM 1800/1900. Typical values of separation distances between antennas to obtain sufficient isolation (normally 30 dB) are 0.4 m (horizontal) and 0.2 m (vertical) for GSM 900.

4.1.5 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. (NOTE: The fresnel zone is the area in open space that must be practically free of obstructions for a microwave radio path to function property; some degree of fresnel consideration is required in the immediate vicinity of the microwave radio RF envelope/field.)

It is not possible to follow this guideline because the path between the base and the mobile subscriber is normally not line-of-sight. In city areas, one cell planning criterion is to provide margins for these types 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.

4.1.6 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.

4.1.7 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.

4.1.8 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 project.

4.1.9 SERVICE AREA STUDY

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

4.1.10 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 is not discussed as a factor in this project.

4.2 RADIO MEASUREMENTS

4.2.1 PATH LOSS PARAMETERS

A radio survey involves installation of a transportable test transmitter somewhere in the area where the base station is to be installed. Using a specially equipped vehicle, signal strength can be measured. A locating unit, a measuring receiver with antenna, a control and processing unit, and a tape recorder are among the equipment contained in the unit. Signal level can be measured on a number of channel and, for each channel, samples are taken at an adjustable speed. Normally, samples are taken several times per wavelength traveled.

The data is pre-processed before it is stored on either the hard drive or a diskette and presented off-line after the survey. Results can be presented with respect to median value, standard deviation, and number of "measuring squares" along the test routes. The recorded files can be imported into EET and displayed on the map. The residual values (i.e., the difference between the prediction and the measurement) can also he displayed. If there is a difference, the path loss parameters in the prediction model can be adjusted according to the measurements.

4.2.2 TIME DISPERSION

Measurements must be performed to verify the time dispersion predictions. In addition, if there are quality problems, time dispersion measurements must be taken to verify that time dispersion is actually causing the poor quality.

The equipment used for time dispersion measurements consists of a transmitter and a receiver (Figure 4.1). The transmitter sends a short pulse, the signal is received, and the pulse response is evaluated in a controller(Fig. 4.2). In this way, the time delay and the carrier to reflection ratio can be found.

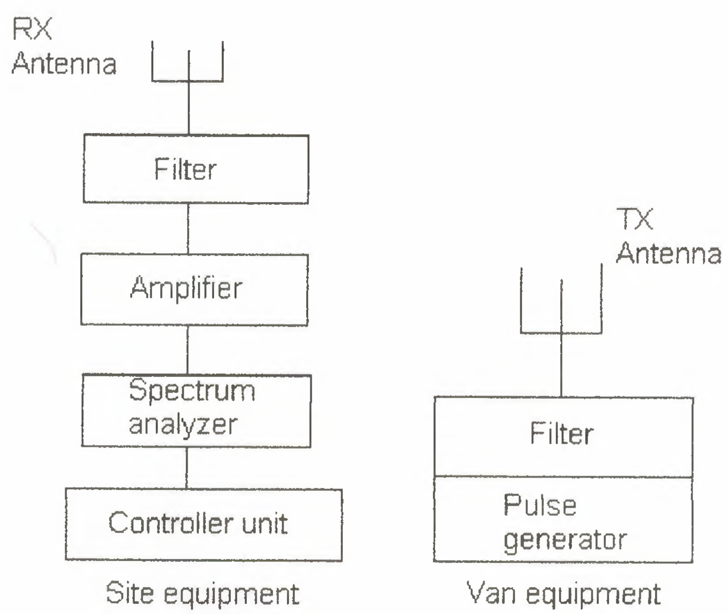


Figure 4.1 Time dispersion measurement equipment

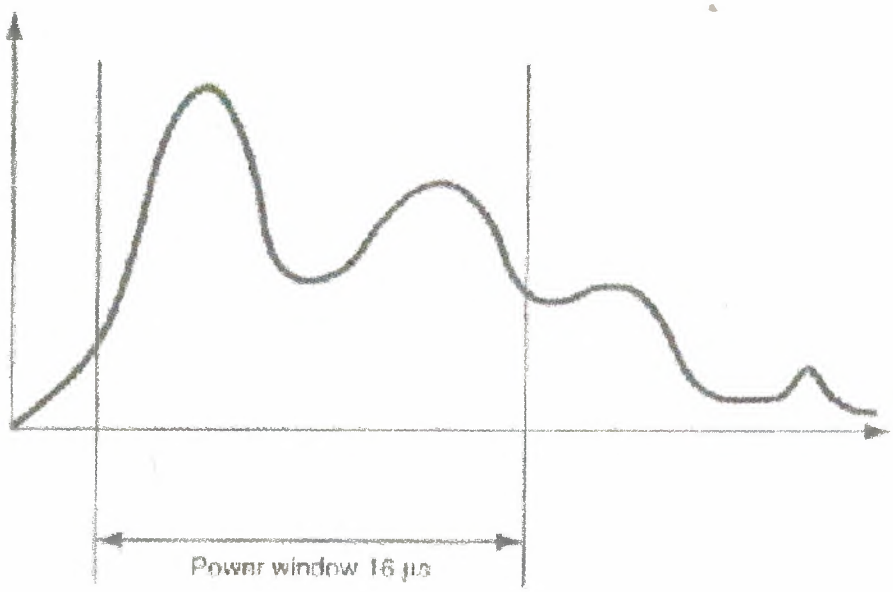


Figure 4.2 Impulse response

4.2.3 INTERFERING TRANSMITTERS

For sites where a number of other radio transmitters are co-located.These include a computer controlled spectrum analyzer and computer programs for calculating interference levels at different frequencies. The end result of a radio spectrum measurement is to accept the site from an interference point of view, to accept it with reservations, or to reject the site and find another one.

CHAPTER 5: SYSTEM TUNING,

5.1 SYSTEM DIAGNOSTICS

5.1.1 OSS

Operation and Support Syslem (OSS) can be used, e.g. to present system diagnostic information as statistics in graphs. The STS data is transfered to OSS where it is stored in a database. In OSS, the data can be displayed in different reports that illustrate network performance regarding, e.g., GoS in the cells.

OSS can also be used to present measurements collected by Mobile Traffic Recording (MTR), Cell Traffic Recording (CTR), and Channel Event Recording (CER). These are blocks located in the AXE exchange but accessible from OSS. In the graphical reports we can view, e.g. signal strength, quality, TA, and MS power (Figure 5.1).

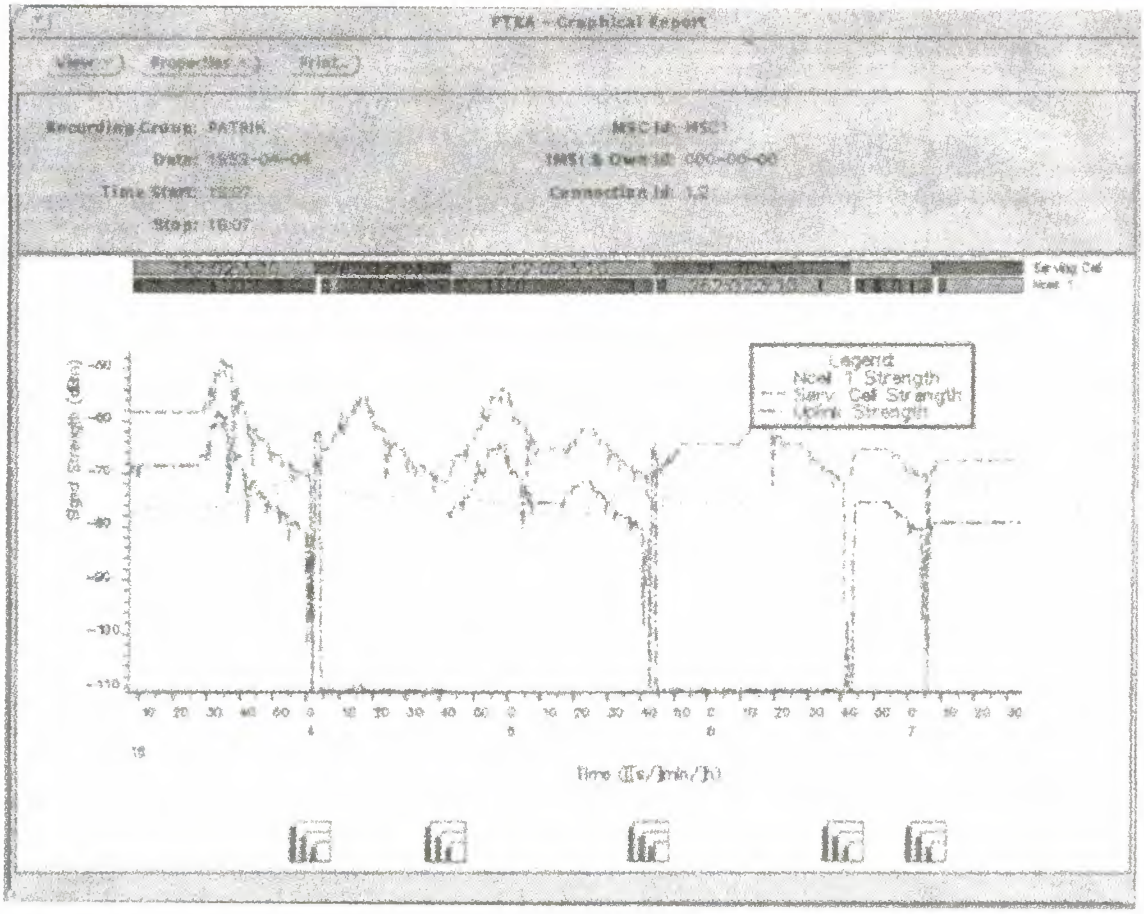


Figure 5.1 MTR

OSS also supports three RNO (Radio Network Optimization) applications:

FAS (Frequency Allocation Support)

FAS measures the uplink interference for possible interferers in order to find suitable frequencies to define in cells. FAS supplies the operator with suggestions about frequencies at expansions or reallocations.

NCS (Neighbouring Cell Support)

NSC is a tool meant as support for the operator when removing or adding neighbour cell relations. It is based on the measurement reports sent to the system by the mobile station during calls. The tool is useful when introducing micro cells and hierarchical cell structures.

MRR (Measurement Result Recording)

MRR collects information from the measurement reports sent by the BTSs to the BSC. Information such as RXLEV, RXQUAL etc. is included. The tool is used either for routine supervision or for checking specific cells.

5.1.2 TEMS

TEMS is **TE**st **M**obile **S**ystem for measuring the radio environment. TEMS consists of a mobile station with special software, a portable PC, a transmitter, and a receiver.

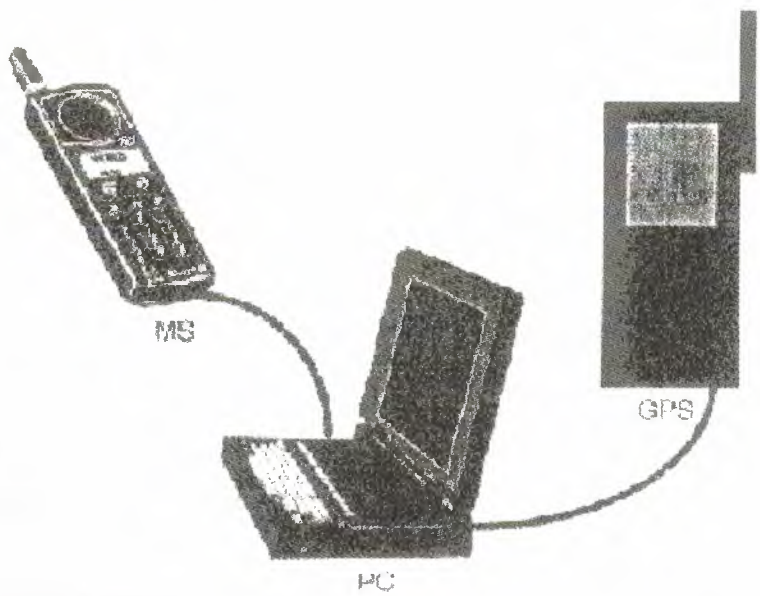


Figure 5.2 TEMS hardware

TEMS can be used, e.g., in a vehicle which drives around the network to analyze the air interface (Figure 5.3).

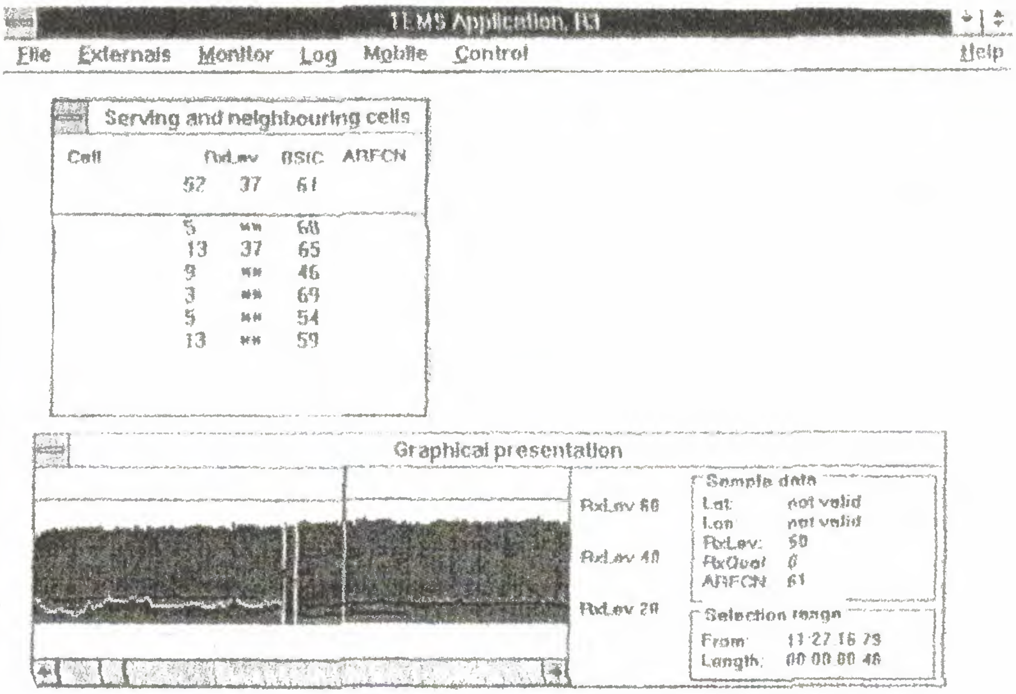


Figure 5.3 TEMS user interface

TEMS Transmitter

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 17 and 27 dBm. A complete editable BCCH is transmitted while the other 7 time slots contain an unmodulated carrier.

In absence of TEMS Transmitters, a **T**est **T**rans**M**itter (TTM) can also be used. This is a narrow band Continuous Wave (CW) transmitter with a maximum output power of 43 dBm.

TEMS Receiver

The recommended receiver is TEMS Light equipment. This is a TEMS mobile station connected to a small Fujitsu PC operated with a pen. The TEMS Light program is a reduced version of normal TEMS but with the possibility to log fixpoints by marking them with the pen on a scanned map. The information in the log files is displayed on the scanned map as color marks associated with a window containing more information about each mark.

If TEMS Light is not available, the standard TEMS equipment or a Test Measurement Receiver (TMR) can be used.

An even faster- coverage verification can be made by using TEMS Pocket. This is a test mobile station 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 **A**bsolute **R**adio **F**requency **C**hannel **N**umber (ARFCN) and **B**ase **S**tation **I**dentity **C**ode (BSIC) and reading the signal from the display. There is also an audible warning to indicate a low signal.

5.1.3 EET/TEMS CELLPLANNER

EET runs from a UNIX platform and interfaces with a graphical windows environment (Figure 5.4), whereas TEMS CellPlanner runs from a PC platform. Although they are not network diagnosing tools themselves, they are important tools used for optimizing network performance.

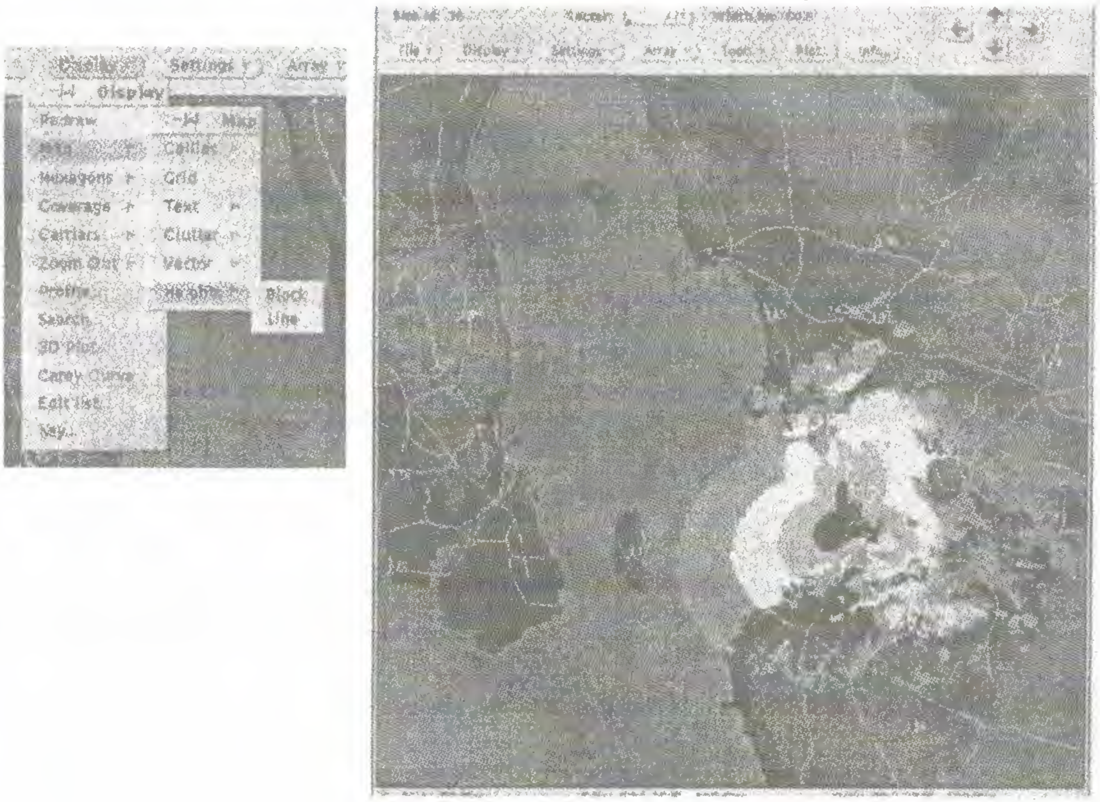


Figure 5.4 EET Graphical User Interface

The File Import Conversion System (FICS) is used to import log files from TEMS. By adding the diagnostic information generated by tools like TEMS, EET's/TEMS CellPlanner's theoretical predictions can be modified and improved with practical measurements from the field.

It is important when a system is new, i.e. in an initial tuning phase, to make sure that the mobiles behave as planned and that area coverage is what is expected.

The operator can useTEMS to monitor where handovers occur. If the predicted cell borders do not correspond to the data obtained by TEMS, the operator may need to make adjustments, e.g., changing cell parameters or reconstructing the entire network (or parts of it).

5.1.4 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 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 it the measurement reports for the mobiles in the surrounding cells.

5.1.5 CELLULAR NETWORK ANALYZER (CeNA)

The Cellular Network Analyzer (CeNA) is a cellular quality information system that enables optimization of a digital network's performance. The system consists of Mobile units (MTUs) that are mounted in vehicles and assigned subscriber numbers in the cellular network. A subscriber number in the public network is assigned to a fixed unit (FTU). In accordance with a measurement order, MTUs regularly call an FTU, execute measurements, and transfer the results to a database for storage and transition (DBMS). All measurement-order setups, result presentations, and report generations are executed from an operator terminal (PS, RG) as seen in Figure 5.5.

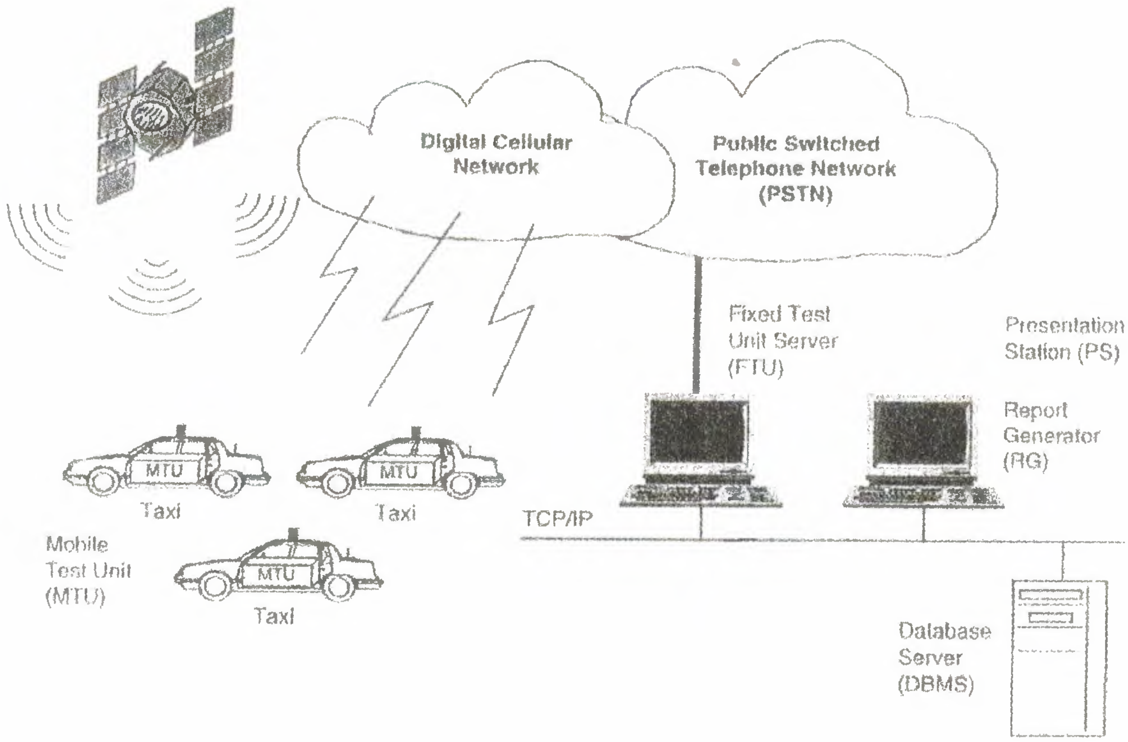


Figure 5.5 Cellular Network analyzer (CeNA)

The CeNA system can carry out a number of measurements. It is easy to generate rerorts and present measured result from a conversation or present statistics using CeNA.

5.2 CELL PARAMETER ADJUSTMENT

If measurement analysis shows an inconsistency in the parameter setting, hysteresis and offset parameters can be tuned to improve network quality.

OSS provides graphicaly user interface for changing paremeters. Using OSS also reduces the possibility of human errors by providing validation and consistency checks of the parameter settings. This means that checks can be run on parameter settings before updating the network. OSS also allows storage of a backup area which can be loaded if errors occur during the network update.

5.2.1 CELL PARAMETERS

Parameters are necessary so that the operator can adjust and tune the network to fit their specific requirements. All parameters have a specific permitted range and, in most cases, a default value.

Default values are a good starting point in a new system. Later, when the system is operational and measurements have been collected, the parameters can be fine-tuned. Parameters should be changed one at a time because, if more then one parameter is changed, it is difficult to determine how each parameter affects the system.

Off set

An offset is used to make a cell appear better (worse) than it really is by increasing (decreasing) measured signal strengths.

Hysteresis

A hysteresis is used to prevent the ping-pong effect i.e., several consecutive handovers between two cells. The ping-pong effect can be caused by fading, the MS moving in a zig-zag pattern between the cells, or by non-linearities in the receiver.

Control of Radio Network Features

Other parameters are used to control radio network features such as Discontinuous Transmission (DTX), frequency hopping, and power control.

Tirmers and Filters

There are some timers and filters which can be set using parameters. Depending on the time settings or length of filters the system responds faster or slower- to changes, A fast system is less stable than a slow system. A fast system is necessary if micro cells are used because, in this case, handovers are frequent.

Identification

Parameters used to identify, e.g. a cell or a location area in the network.

Penalties

Penalties are used in the locating algorithm to punish a cell. The cell then appears worse then it really is. This is to avoid handback in case of an urgency handover and to avoid several repeated handover attemipts in case of signaling failure.

Thresholds

Thresholds for cell ranking, call release, and access can be set .

5.3 SYSTEM GROWTH

5.3.1 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

- 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 stuifier

Although the last solution often implies introducing micro-cells under a hierarchical cell structure, only the regular procedure for adding new sites (cell split) is discussed here.

5.3.2 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 in fact a method that matches cell sizes to the capacity requirements. The system is started using a large cell size and 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. The method is called cell split. This is illustrated in Figure 5.6 though Figure 5.9.

Example:

Initially, the largest possible cell size is used, considering coverage range (Figure 5.6). The next step is to introduce three cells per site, using the original sites and feeding the cells from the corners (Figure 5.7).This represents a cell split of one to three (1:3). 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. one to four (Figure 5.9). As seen from the figures, the old sites are still used in the new cell plan, but additional sites are now required.

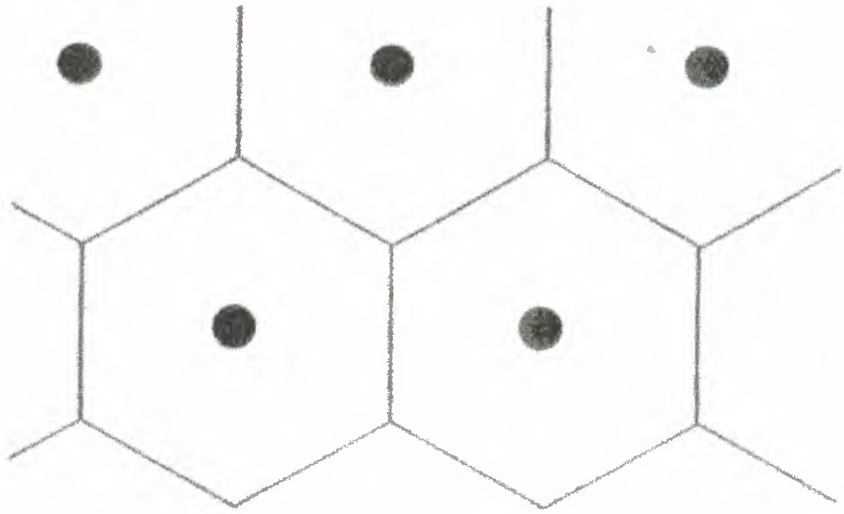


Figure 5.6 Cell split phase 0

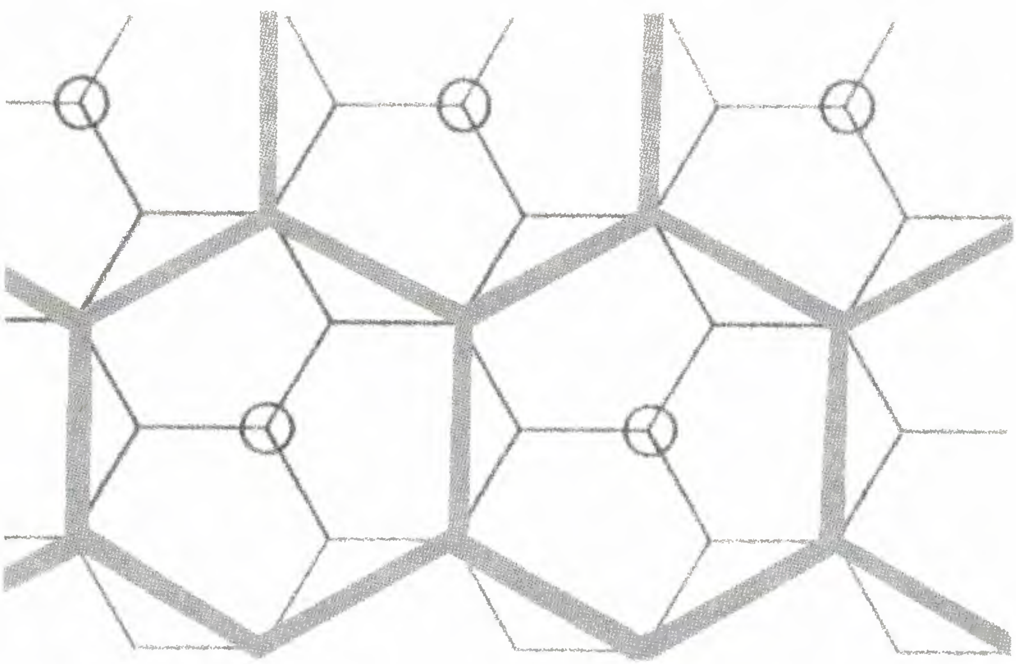


Figure 5.7 Cell split phase 1

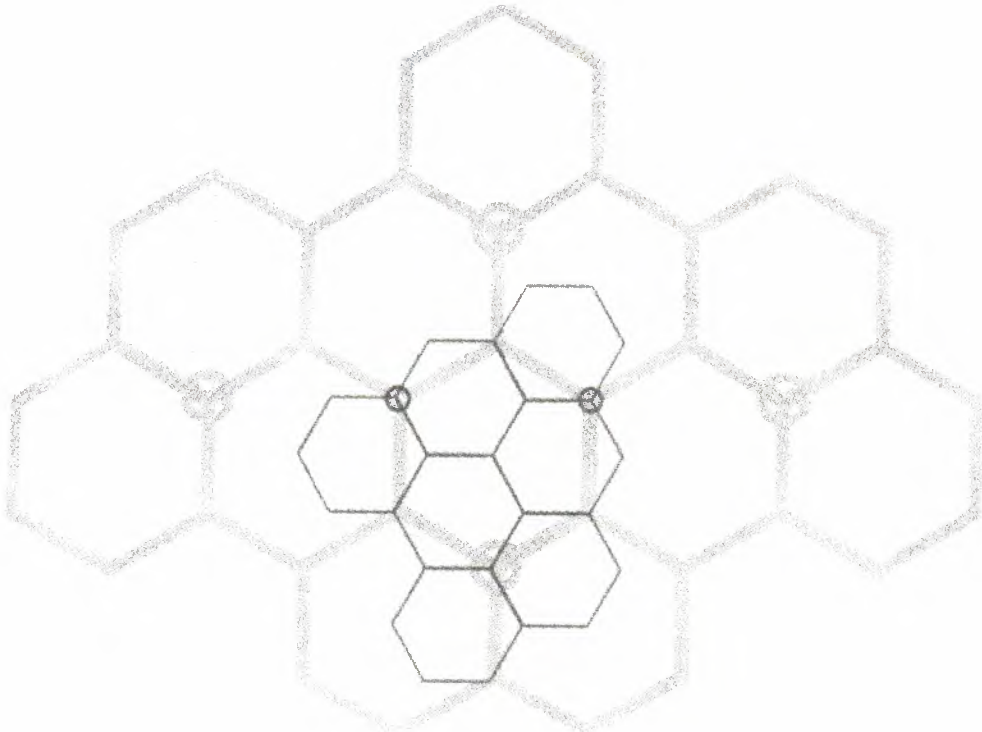


Figure 5.8 Cell split 1:3 (phase 2)

Cell split 1:3 (Figure 5.8) 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 30 degrees.

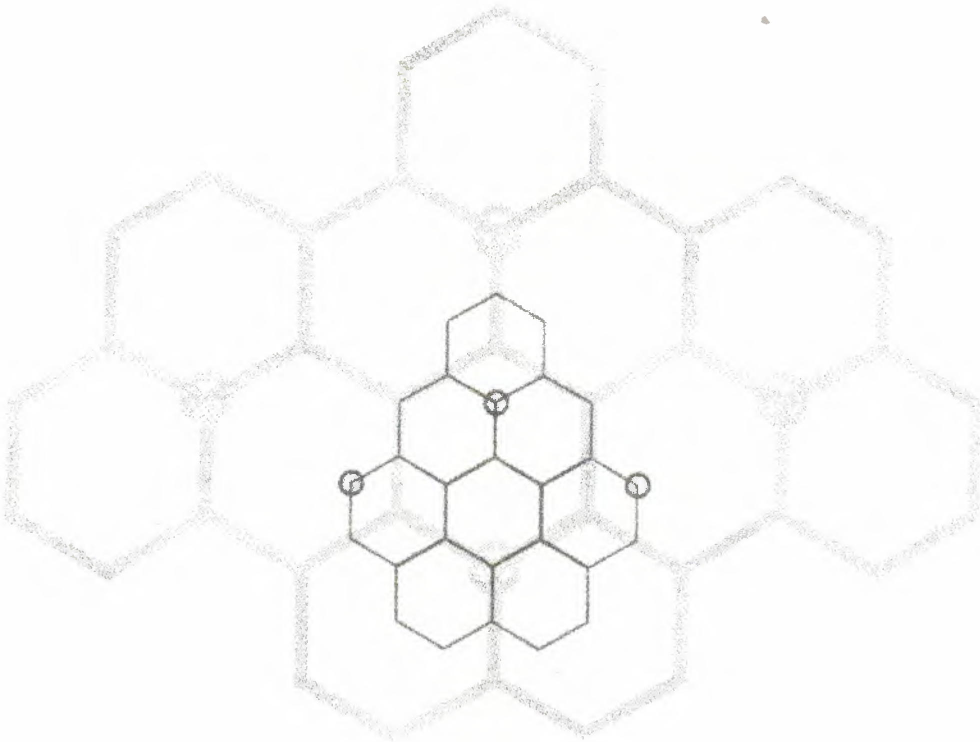


Figure 5.9 Cell split 1:4 (phase 2)

Cell split 1:4 (Figure 5.9) requires four times as many sites. After the split the capacitiy 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.

CONCLUSION

The cell planning process starts with traffic and coverage analysis. The analysis should produce information about the geographical area and the expected need of capacity. The types of data collected are: Cost, capacity, coverage, grade of service, available frequencies, speech quality index and system growth capability.

Nominal cell plans are the first cell plans and form the basis for further planning. Quite often a nominal cell plan, together with one or two examples of coverage predictions, is included in tenders. Coverage and interference predictions are usually started. Such planning needs computer-aided analysis tools for radio propagation studies.

Radio measurements are performed in order to verify the coverage and interference predictions. The sites where the radio equipment will be placed are visited. This is a critical step because it is necessary to assess the real environment to determine whether it is a suitable site location when planning a cellular network.

Once we have optimized and can trust the predictions generated by the planning tool, the dimensioning of the RBS equipment, BSC, and MSC is performed. The final cell plan is then produced. As the name implies, this plan is later used during system installation. In addition, a document called Cell Design Data (CDD) is filled out containing all cell parameters for each cell.

The system needs constant retuning because the traffic and number of subscribers increases continuously. Eventually, the system reaches a point where it must be expanded so that it can manage the increasing load and new traffic. At this point, a traffic and coverage analysis is performed and the cell planning process cycle begins again.

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APPENDIX

DECIBEL LOSS & GAIN

In many areas, if is convenient to use logarithmic units since the order of magnitude of the figures involved is reduced substantially. It also sometimes simplifies calculations. In this appendix, logarithmic units are discussed in connection with gain and loss.

On its way from one subscriber to another, speech may pass many different devices (such as the subscriber's telephone set, the lines, the switch, etc.). Some of those devices result in "loss" or "attenuation", others in "gain" or "amplification". To express the value of loss or gain in a device, the relation between the input and output signals can be used. However, it is more convenient to use the logarithm of the input/output signal ratio.

Definition:

Loss $L = 10 \log (Pin/Pout)$ (dB) $Pin > Pout$ (1)

Gain $G = 10 \log (Pout/Pin)$ (dB) $Pin < Pout$ (2)

Note that in the definition above, it is the ratio between input and output power that is used. To find the corresponding relationship between voltages, the following is used.

$P = U^2 / R$

This yields:

$Pout = (Uout)^2 / Rout$

$Pin = (Uin)^2 / Rin$

inserting this in (1) yields:

$L = 10 \log (Uin/Uout)^2$ (dB)

or

$L = 20 \log (Uin/Uout)$ (dB)

Note that for the above to be true, Rout must be equal to Rin

Example 1:

An amplifier delivers 2 W when 10 mW is fed to the input.Calculate the gain of the amplifier.

$G = 10 \log (2000/10) = 23$ dB

Example 2 :

An amplifier with equal input and output impedance is connected to a voltage source thus obtaining 500 mv ,at the input. The voltage at the output is measured at I V. Calculate the gain of the amplifier.

$G = 20 \log (1000/500) = 6$ dB

OVERALL LOSS

The overall loss (or gain) of a system (e.g, a telephone system) is obtained by adding the individual loss/gain figures for the components of the system (e.g. telephone lines, switch, etc.).

Example 3:

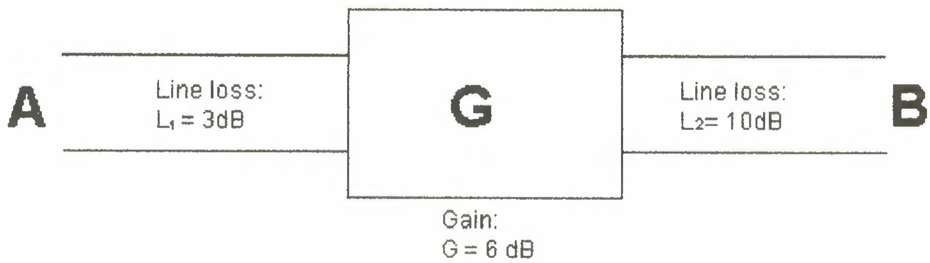

Figure A .1 Overall loss

Calculate the total loss from A to B above

Ltot =L1+L2 - G=3+10-6=7dB

POWER LEVEL, VOLTAGE LEVEL

It has been shown previously that dB is a convenient way to express the ratio between two signals with, respect to power voltage. The definition can, however, be used to express absolute power or voltage levels if a fixed reference is used.

Power level: $L_p = 10 \log (P/P_{ref})$ (5)

Voltage level : $L_u = 20 \log (U / U_{ref})$ (6)

Different reference levels can be used:

Power:	Pref = 1 W	Lp = 10 log (P/1) dBW
	Pref = 1mW	Lp = 10 log $(P/10^{-3})$ dBm
Voltage :	Uref = 775 mV	Lu = 20 log (U/0.775) dBU
	Uref = 1 μ V	Lu = 20 log $(U/10^{-6})$ dB μ V

The reason why a voltage level of 775 mV is used as a reference is that when fed to a resistance of 600 Ω, it causes a power dissipation of I mW. This means that the power level in dBm equals the voltage levels in dBU measured across a 600 Ω resistance.