2

Radio Network Planning and Optimisation

Since the early days of GSM development, GSM system network planning has undergone extensive modification so as to fulfill the ever-increasing demand from operators and mobile users with issues related to capacity and coverage. Radio network planning is perhaps the most important part of the whole design process owing to its proximity to mobile users. Before going into details of the process, we first look at some fundamental issues.

2.1 BASICS OF RADIO NETWORK PLANNING

2.1.1 The Scope of Radio Network Planning

The radio network is the part of the network that includes the base station (BTS) and the mobile station (MS) and the interface between them, as shown in Figure 2.1. As this is the part of the network that is directly connected to the mobile user, it assumes considerable importance. The base station has a radio connection with the mobile, and this base station should be capable of communicating with the mobile station within a certain coverage area, and of maintaining call quality standards. The radio network should be able to offer sufficient capacity and coverage.

2.1.2 Cell Shape

In mobile networks we talk in terms of 'cells'. One base station can have many cells. In general, a cell can be defined as the area covered by one sector, i.e. one antenna system. The hexagonal nature of the cell is an artificial shape (Figure 2.1). This is the shape that is closest to being circular, which represents the ideal coverage of the power transmitted

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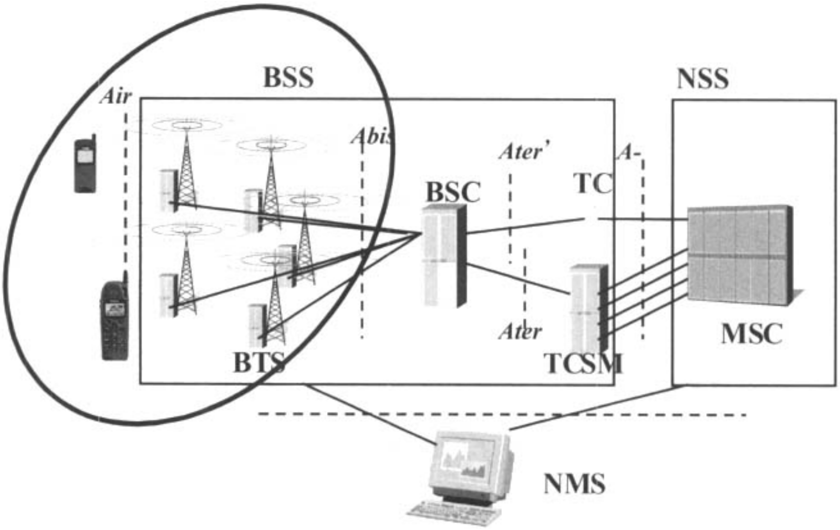

Figure 2.1 The scope of radio network planning

by the base station antenna. The circular shapes are themselves inconvenient as they have overlapping areas of coverage; but, in reality, their shapes look like the one shown in the 'practical' view in Figure 2.2. A practical network will have cells of nongeometric shapes, with some areas not having the required signal strength for various reasons.

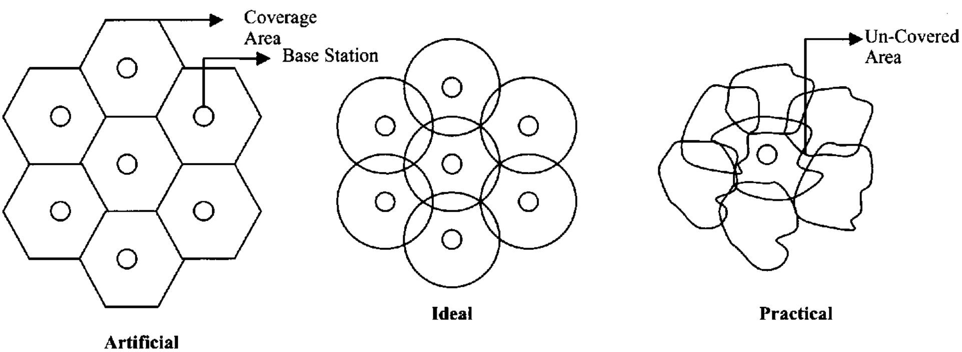

Figure 2.2 Cell shapes

2.1.3 Elements in a Radio Network

Mobile Station (MS)

The mobile station is made up of two parts, as shown in Figure 2.3: the handset and the subscriber identity module (SIM). The SIM is personalised and is unique to the subscriber. The handset or the terminal equipment should have qualities similar to those of fixed phones in terms of quality, apart from being user friendly. The equipment also has functionalities

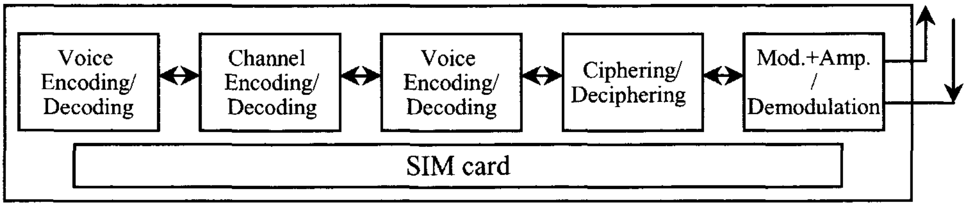

Figure 2.3 Block diagram of a GSM mobile station

like GMSK modulation and demodulation up to channel coding/decoding. It needs to be dual-tone multi-frequency generation and should have a long-lasting battery.

The SIM or SIM card is basically a microchip operating in conjunction with a memory card. The SIM card's major function is to store data for both the operator and subscriber. The SIM card fulfills the needs of the operator and the subscriber as the operator is able to maintain control over the subscription and the subscriber can protect his or her personal information. Thus, the most important SIM functions include authentication, radio transmission security, and storing of the subscriber data.

Base Transceiver Station (BTS)

From the perspective of the radio network-planning engineer the base station is perhaps the most important element in the network as it provides the physical connection to the mobile station through the air interface. And on the other side, it is connected to the BSC via an A_{bis} interface. A simplified block diagram of a base station is shown in Figure 2.4.

The transceiver (TRX) consists basically of a low-frequency unit and a high-frequency unit. The low-frequency unit is responsible for digital signal processing and the high frequency unit is responsible for GMSK modulation and demodulation.

2.1.4 Channel Configuration in GSM

There are two types of channels in the air interface: physical channels and logical channels. The physical channel is all the time slots (TS) of the BTS. There are again two types in this: half-rate (HR) and full-rate (FR). The FR channel is a 13 kbps coded speech or data channel with a raw data rate of 9.6, 4.8 or 2.6 kbps, while the HR supports 7, 4.8 or 2.4 kbps. 'Logical channel' refers to the specific type of information that is carried by the physical channel. Logical channels can also be divided into two types: traffic channels (TCH) and control

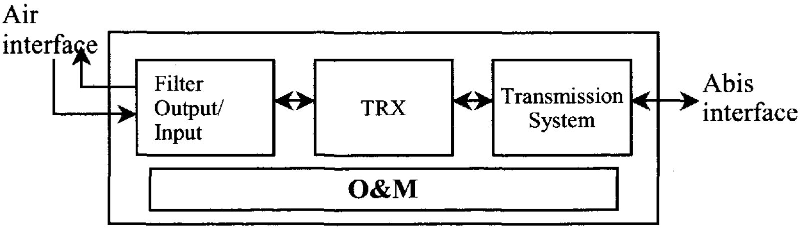

Figure 2.4 Block diagram of a base transceiver station

Table 2.1 Control channels

Channel	Abbreviation	Function/application
Access grant channel (DL)	AGCH	Resource allocation (subscriber access authorisation)
Broadcast common control channel (DL)	BCCH	Dissemination of general information
Cell broadcast channel (DL)	CBCH	Transmits the cell broadcast messages
Fast associated control channel (UL/DL)	FACCH	For user network signalling
Paging channel (DL)	PCH	Paging for a mobile terminal
Random access channel (UL)	RACH	Resource request made by mobile terminal
Slow associated control channel (UL/DL)	SACCH	Used for transport of radio layer parameters
Standalone dedicated control channel (UL/DL)	SDCCH	For user network signalling
Synchronisation channel (DL)	SCH	Synchronisation of mobile terminal

channels (CCH). Traffic channels are used to carry user data (speech/data) while the control channels carry the signalling and control information. The logical control channels are of two types: common and dedicated channels. Table 2.1 summarises the control channel types.

2.2 RADIO NETWORK PLANNING PROCESS

The main aim of radio network planning is to provide a cost-effective solution for the radio network in terms of coverage, capacity and quality. The network planning process and design criteria vary from region to region depending upon the dominating factor, which could be capacity or coverage. The radio network design process itself is not the only process in the whole network design, as it has to work in close coordination with the planning processes of the core and especially the transmission network. But for ease of explanation, a simplified process just for radio network planning is shown in Figure 2.5.

The process of radio network planning starts with collection of the input parameters such as the network requirements of capacity, coverage and quality. These inputs are then used

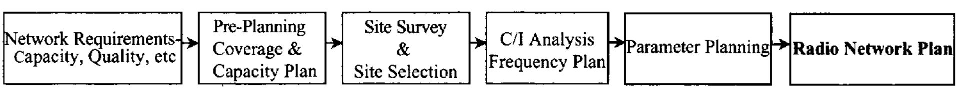

Figure 2.5 The radio network planning process

to make the theoretical coverage and capacity plans. Definition of coverage would include defining the coverage areas, service probability and related signal strength. Definition of capacity would include the subscriber and traffic profile in the region and whole area, availability of the frequency bands, frequency planning methods, and other information such as guard band and frequency band division. The radio planner also needs information on the radio access system and the antenna system performance associated with it.

The pre-planning process results in theoretical coverage and capacity plans. There are coverage-driven areas and capacity-driven areas in a given network region. The average cell capacity requirement per service area is estimated for each phase of network design, to identify the cut-over phase where network design will change from a coverage-driven to a capacity-driven process. While the objective of coverage planning in the coverage-driven areas is to find the minimum number of sites for producing the required coverage, radio planners often have to experiment with both coverage and capacity, as the capacity requirements may have to increase the number of sites, resulting in a more effective frequency usage and minimal interference.

Candidate sites are then searched for, and one of these is selected based on the inputs from the transmission planning and installation engineers. Civil engineers are also needed to do a feasibility study of constructing the base station at that site.

After site selection, assignment of the frequency channel for each cell is done in a manner that causes minimal interference and maintains the desired quality. Frequency allocation is based on the cell-to-cell channel to interference (C/I) ratio. The frequency plans need to be fine-tuned based on drive test results and network management statistics.

Parameter plans are drawn up for each of the cell sites. There is a parameter set for each cell that is used for network launch and expansion. This set may include cell service area definitions, channel configurations, handover and power control, adjacency definitions, and network-specific parameters.

The final radio plan consists of the coverage plans, capacity estimations, interference plans, power budget calculations, parameter set plans, frequency plans, etc.

2.2.1 Radio Cell and Wave Propagation

Coverage in a cell is dependent upon the area covered by the signal. The distance travelled by the signal is dependent upon radio propagation characteristics in the given area. Radio propagation varies from region to region and should be studied carefully, before predictions for both coverage and capacity are made. The requirement from the radio planners is generally a network design that covers 100% of the area. Fulfilling this requirement is usually impossible, so efforts are made design a network that covers all the regions that may generate traffic and to have 'holes' only in no-traffic zones.

The whole land area is divided into three major classes – urban, suburban and rural – based on human-made structures and natural terrains. The cells (sites) that are constructed in these areas can be classified as outdoor and indoor cells. Outdoor cells can be further classified as macro-cellular, micro-cellular or pico-cellular (see Figure 2.6).

Macro-cells

When the base station antennas are placed above the average roof-top level, the cell is a known as a macro-cell. As the antenna height is above the average roof-top level, the area

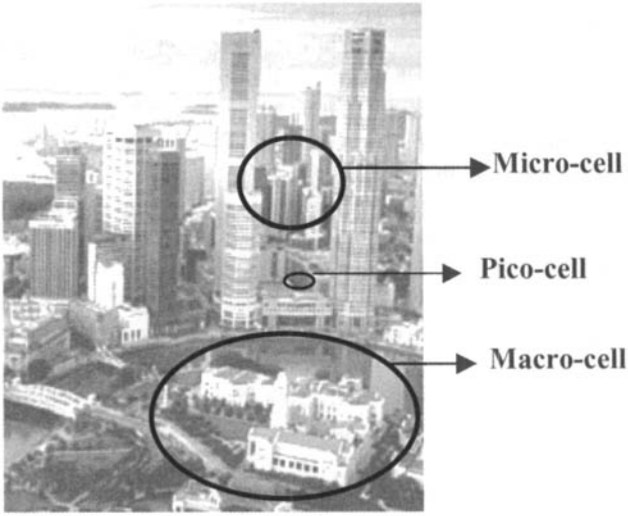

Figure 2.6 Macro-, micro- and pico-cells

that can be covered is wide. A macro-cell range may vary from a couple of kilometres to 35 km, the distance depending upon the type of terrain and the propagation conditions. Hence, this concept is generally used for suburban or rural environments.

Micro-cells

When the base station antennas are below the average roof-top level, then the cell is known as a micro-cell. The area that can be covered is small, so this concept is applied in urban and suburban areas. The range of micro-cells is from a few hundred metres to a couple of kilometres.

Pico-cells

Pico-cells are defined as the same layer as micro-cells and are usually used for indoor coverage.

2.2.2 Wave Propagation Effects and Parameters

The signal that is transmitted from the transmitting antenna (BTS/MS) and received by the receiving antenna (MS/BTS) travels a small and complex path. This signal is exposed to a variety of man-made structures, passes through different types of terrain, and is affected by the combination of propagation environments. All these factors contribute to variation in the signal level, so varying the signal coverage and quality in the network. Before we consider propagation of the radio signal in urban and rural environments, we shall look at some phenomenon associated with the radio wave propagation itself.

Free-space Loss

Any signal that is transmitted by an antenna will suffer attenuation during its journey in free space. The amount of power received at any given point in space will be inversely

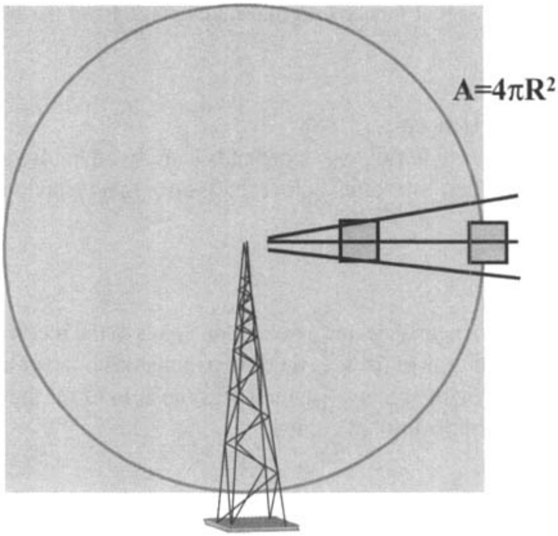

Figure 2.7 Isotropic antenna

proportional to the distance covered by the signal. This can be understood by using the concept of an isotropic antenna. An isotropic antenna is an imaginary antenna that radiates power equally in all directions. As the power is radiated uniformly, we can assume that a 'sphere' of power is formed, as shown in Figure 2.7.

The surface area of this power sphere is:

$$A = 4\pi R^2 \tag{2.1}$$

The power density S at any point at a distance R from the antenna can be expressed as:

$$S = P^*G/A \tag{2.2}$$

where P is the power transmitted by the antenna, and G is the antenna gain. Thus, the received power P_r at a distance R is:

$$P_r = P^*G_t^*G_r^*(\lambda/4\pi R)^2 \tag{2.3}$$

where G_t and G_r are the gain of the transmitting and receiving antennas respectively. On converting this to decibels we have:

$$P_r(\text{dB}) = P(\text{dB}) + G_t(\text{dB}) + G_r(\text{dB}) + 20\log(\lambda/4\pi) - 20\log d. \tag{2.4}$$

Last two terms in equation 2.4 are together called the path loss in free space, or the free-space loss. The first two terms (P and G_t) combined are called the effective isotropic radiated power, or EIRP. Thus:

$$\text{Free-space loss (dB)} = \text{EIRP} + G_r(\text{dB}) - P_r(\text{dB}). \tag{2.5}$$

The free-space loss can then be given as:

$$L_{\text{dB}} = 92.5 + 20\log f + 20\log d \tag{2.6}$$

where f is the frequency in GHz and d is the distance in km.

Equation 2.6 gives the signal power loss that takes place from the transmitting antenna to the receiver antenna.

Radio Wave Propagation Concepts

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

Reflections and Multipath

The transmitted radio wave nearly never travels in one path to the receiving antenna, which also means that the transmission of the signal between antennas is never line-of-sight (LOS). Thus, the signal received by the receiving antenna is the sum of all the components of the signal transmitted by the transmitting antenna.

Diffraction or Shadowing

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

Building and Vehicle Penetration

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

Vehicle penetration loss is similar, except that the object in this case is a vehicle rather than a building.

Propagation of a Signal Over Water

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

Propagation of a Signal Over Vegetation (Foliage Loss)

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

Fading of the Signal

As the signal travels from the transmitting antenna to the receiving antenna, it loses strength. This may be due to the phenomenon of path loss as explained above, or it may be due to the Rayleigh effect. Rayleigh (or Rician) fading is due to the fast variation of the signal level both in terms of amplitude and phase between the transmitting and receiving antennas when there is no line-of-sight. Rayleigh fading can be divided into two kinds: multipath fading and frequency-selective fading.

Arrival of the same signal from different paths at different times and its combination at the receiver causes the signal to fade. This phenomenon is multipath fading and is a direct result of multipath propagation. Multipath fading can cause fast fluctuations in the signal level. This kind of fading is independent of the downlink or uplink if the bandwidths used are different from each other in both directions.

Frequency-selective fading takes place owing to variation in atmospheric conditions. Atmospheric conditions may cause the signal of a particular frequency to fade. When the mobile station moves from one location to another, the phase relationship between the various components arriving at the mobile antenna changes, thus changing the resultant signal level. Doppler shift in frequency takes place owing to the movement of the mobile with respect to the receiving frequencies.

Interference

The signal at the receiving antenna can be weak by virtue of interference from other signals. These signals may be from the same network or may be due to man-made objects. However, the major cause of interference in a cellular network is the radio resources in the network. There are many radio channels in use in a network that use common shared bandwidth. The solution to the problem is accurate frequency planning, which is dealt with later in the chapter. The mobile station may experience a slow or rapid fluctuation in the signal level in a radio network. This may be due to one or more of the factors discussed above, and as shown in Figure 2.8. These factors form the basis of cell coverage criteria.

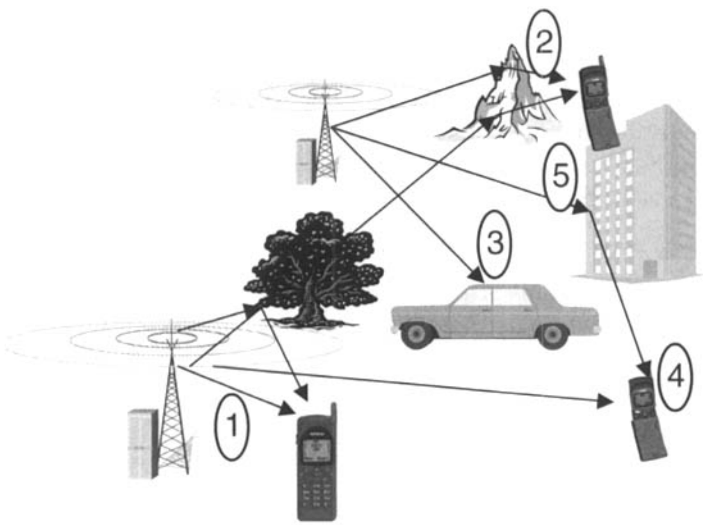

Figure 2.8 Factors affecting wave propagation: (1) direct signal; (2) diffraction; (3) vehicle penetration; (4) interference; (5) building penetration

2.2.3 Dimensioning

The dimensioning exercise is to identify the equipment and the network type (i.e. technology employed) required in order to cater for the coverage and quality requirements, apart from seeing that capacity needs are fulfilled for the next few years (generally 3–5 years). The more accurate the dimensioning is, the more efficient will be network rollout. In practice, network rollout very closely follows the output of network dimensioning/planning. For an efficient network rollout, the equipment has to be ordered well before the planning starts (i.e. after dimensioning), as the equipment orders are placed based on the dimensioning results. Planning engineers should try to do very realistic/accurate dimensioning for each cell site. The inputs that are required for the dimensioning excercise include:

- the geographical area to be covered
- the estimated traffic in each region
- minimum requirements of power in each region and blocking criteria
- path loss
- the frequency band to be used and frequency re-use.

With the above parameters, the radio planner can predict the number of base stations that will be required for coverage in the specified area to meet the individual quality targets, and to meet the expected increase in traffic in the next few years.

2.3 RADIO NETWORK PRE-PLANNING

Although, in a real scenario, network dimensioning and pre-planning go hand in hand, they have been separated in this chapter for the ease of understanding. Pre-planning can be considered to be the next stage after dimensioning and it is at this stage that some concrete plans related to coverage, capacity and quality are made.

The major target of the radio planner is to increase the coverage area of a cell and decrease the amount of equipment needed in the network, so obtaining the maximum coverage at minimum cost. Maximum coverage means that the mobile is connected to a given cell at a maximum possible distance. This is possible if there is a minimum signal to noise ratio at both the BTS and MS. Another factor attributing to the path length between the two antennas (BTS and MS) is the propagation loss due to environmental conditions.

Example 1: Calculation of number of sites required in a region

A network is to be designed that should cover an area of 1000 km^2.
The base stations to be used are 3-sectored. Each sector (cell) covers a range of 3.0 km
Thus, area covered by each site $= k * R^2$
Where: $k = 1.95$
$\Rightarrow$ *Area covered by each site* $= 1.95 * 3^2 = 17.55$ *km*
Thus: total number of sites $= 1000/17.55 = 56.98 \approx 57$ *sites*

Capacity can be understood in simplest terms as the number of mobile subscribers a BTS can cater for at a given time. The greater the capacity, the more mobile subscribers can be connected to the BTS at a given time, thereby reducing the amount of base stations in a given network. This reduction would lead to an increase in the operation efficiency and thereby profits for the network operator. As the number of frequency channels in the GSM is constant (i.e. 125 for GSM 900 in either direction), the re-use of these frequencies determines the number of mobile subscribers who can be connected to a base station. So, efficient frequency planning which includes the assignment of given frequencies and their re-use plays an important part in increasing the capacity of the radio network.

The quality of the network is quite dependent upon the parameter settings. Most of these are implemented during the rollout of the network, just before the launch. In some cases these values are fixed, and in some other cases they are based on measurements done on existing networks. With the first GSM network to be launched in a given region/country, it is helpful for the radio planners to plan these values beforehand for the initial network launch before they have the first measurement results. These may include radio resource management (RRM), mobility management, signalling, handover, and power control parameters. Once there are some measurements available from the initial launch of the network, these parameters then can be fine-tuned. This process becomes a part of the optimisation of the radio network.

2.3.1 Site Survey and Site Selection

When the pre-planning phase is nearing completion, the site search process starts. Based on the coverage plans, the radio planner starts identifying specific areas for prospective sites. There are some points to remember during the process of site selection:

- The process of site selection, from identifying the site to site acquisition, is very long and slow, which may result in a delay of network launch.
- The sites are a long-term investment and usually cost a lot of money.

Therefore, radio planners in conjunction with the transmission planners, installation engineers and civil engineers should try to make this process faster by inspecting the site candidates according to their criteria and coming to a collective decision on whether the candidate site can be used as a cell site or not.

What is a good site for radio planners? A place that does not have high obstacles around it and has a clear view for the main beam can be considered a good radio site. Radio planners should avoid selecting sites at high locations as this may cause problems with uncontrolled interference, apart from giving handover failures.

2.3.2 Result of the Site Survey Process

There are two types of report that are generated in the site survey process. One is at the beginning of the search and the other at the end, which is a report on the site selected. Both reports are very important and should have the desired information clearly given. The site survey request report should stipulate the area where the site candidates should be searched for. The report may contain more specific information such as the primary candidate for search and secondary site candidates – thereby giving the site selection team more specific information on where to put their priorities. Also, this report should contain addresses, maps, and information in the local dialect if possible. The report made after site selection should have more detailed information. This may contain the height of the building/green-field, coordinates, antenna configuration (location, tilt, azimuth, etc.), maps, and a top view of the site with exact location of the base station and the antennas (both radio and transmission).

2.4 RADIO NETWORK DETAILED PLANNING

2.4.1 The Link (or Power) Budget

The detailed radio network plan can be sub-divided into three sub-plans:

(1) link budget calculation,

(2) coverage, capacity planning and spectrum efficiency,

(3) parameter planning.

Link budget calculations give the loss in the signal strength on the path between the mobile station antenna and base station antenna. These calculations help in defining the cell ranges along with the coverage thresholds. Coverage threshold is a downlink power budget that gives the signal strength at the cell edge (border of the cell) for a given location probability. As the link budget calculations basically include the power transmission between the base station (including the RF antenna) and the mobile station antenna, we shall look into the characteristics of these two pieces of equipment from the link budget perspective.

Link budget calculations are done for both the uplink and downlink. As the power transmitted by the mobile station antenna is less than the power transmitted by the base station antenna, the uplink power budget is more critical than the downlink power budget. Thus, the sensitivity of the base station in the uplink direction becomes one of the critical factors as it is related to reception of the power transmitted by the mobile station antenna. In the downlink direction, transmitted power and the gains of the antennas are important parameters. In terms of losses in the equipment, the combiner loss and the cable loss are to be considered. Combiner loss comes only in the downlink calculations while the cable loss has to be incorporated in both directions.

For the other equipment (i.e. the MS), the transmitted power in the uplink direction is very important. To receive the signal transmitted from the BTS antenna even in remote areas, the sensitivity of the MS comes into play. The transmitting and the receiving antenna gains and the cable loss parameters are to be considered on the BTS side.

Important Components of Link Budget Calculations

- MS sensitivity: This factor is dependent upon the receiver noise figure and minimum level of *Eb/No* (i.e. output signal to noise ratio) needed. This is calculated by using the GSM specifications (ETSI GSM recommendation 05.05). The value of MS sensitivity given in these specifications is according to the class of mobile being used. The recommended values of MS sensitivity in GSM 900 and 1800 are –102 dBm and –100 dBm respectively. However, when doing power budget calculations, values given by the manufacturer (or measured values) should be used.

- BTS sensitivity: The sensitivity of the base station is again specified by the ETSI's GSM recommendations 05.05 and is calculated in the same manner as the MS sensitivity. The recommended value of BTS sensitivity is –106 dBm. However, when doing power budget calculations, the value given by the manufacturer (or measured value) should be used.
- Fade margin: This is the difference between the received signal and receiver threshold. Usually a fast fade margin is of importance in power budget calculations. Different values are used for different types of regions, such as 2 dB for dense urban or 1 dB for urban.
- Connector and cable losses: As cables and connectors are used in power transmission, the losses incurred therein should be taken into account. Cable attenuation figures are usually quoted in loss (dB) per 100 m. In such cases, the actual length of the cable should be multiplied by this value to get the theoretical loss taking place in the cable. Sometimes, the theoretical loss may exceed the desired value, so preamplifiers (also known as mast-head amplifiers) may be used to counter the cable loss. Connector losses are usually much less – of the order of 0.1 dB.
- MS and BTS antenna gain: The antennas used for MS and BTS have significantly different gain levels. For obvious reasons, the MS antenna has a lower gain, of the order of 0 dBi, while the BTS antenna gain can vary from 8 dBi to 21 dBi depending upon the type of antenna (omnidirectional versus directional) being used. This gain can be increased by using various techniques, such as antenna diversity (both uplink and downlink).

Example 2: Power budget calculation

Consider a BTS and MS along with the parameters as shown in Figure 2.9.

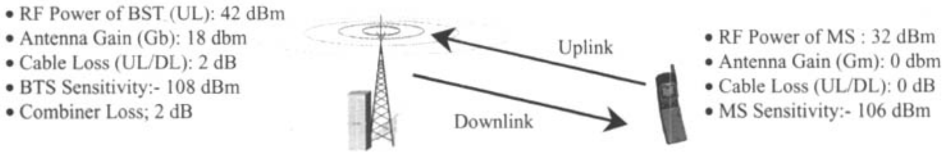

Figure 2.9 Example of a power budget

Uplink calculations

PLu (Path Loss in uplink) = EIRPm (Peak EIRP of Mobile) – Prb (Power Received by the base station)

$$
\begin{aligned}
EIRPm &= \text{Ptm (Power transmitted from the MS)} - \text{Losses} + \text{Gm} \\
Losses &= \text{Lcm (cable loss at mobile)} + \text{Lom (any other loss)} \\
Prb &= -\text{Gb (antenna gain)} - \text{Losses} + \text{Bs (BTS sensitivity)} \\
Losses &= \text{Lcb (cable loss at BTS)} + \text{Lob (any other loss)} \\
PLu &= \text{EIRPm} - \text{Prb} \\
&= [Ptm - Lcm - Lom + Gm] - [-Gb + Lcb + Lob + Bs] \\
&= [32 - 0 + 0 + 0] - [-18 + 2 + 0 + (-108)] \\
&= 32 + 124 = 156\,dB
\end{aligned}
$$

Downlink calculations

PLd (Path Loss in downlink) = EIRPb (peak EIRP of BTS) − Prm (Power received by the MS)

$$EIRPb = Ptb\ (Power\ transmitted\ by\ BTS) + Gtb\ (antenna\ gain) - Losses$$
$$Losses = Lcb\ (cable\ loss\ at\ BTS) + Lccb\ (combiner\ loss\ at\ BTS)$$
$$Prm = Ms\ (Mobile\ sensitivity) + Losses - Gm\ (mobile\ antenna\ Gain)$$
$$Losses = Lcm\ (cable\ loss) + Lom\ (any\ other\ loss)$$
$$\begin{aligned} PLd &= EIRPb - Prm \\ &= [Ptb + Gtb - Lcb - Lccb] - [Ms - Lcm - Lom - Gm] \\ &= [42 + 18 - 2 - 2] - [-106 - 0 - 0 - 0] \\ &= 56 + 106 = 162\,dB \end{aligned}$$

As can be seen, there is an obvious difference in the results of the uplink and downlink power budget calculations, where the downlink path loss exceeds the uplink power loss. This is an indication that the area covered by the base station antenna radiations is more than the area covered by the mobile station antenna, thereby giving more coverage in the downlink direction. Reducing the power in the downlink direction can reduce this difference but results in a loss of coverage. Another way is to introduce diversity at the BTS, or even to introduce low-noise amplifiers (LNA) at the BTS. Both measures will have a positive impact on the BTS receiver power level. Another power budget calculation for GSM 900 and 1800 system using different classes of mobiles (A and D) is shown in Example 3.

How can there be an improvement in the power budget results? As seen above, apart from varying the power transmitted from the BTS antenna, these results can be improved by using enhanced planning techniques such as frequency hopping and/or by using some enhancements such as receiver diversity, LNA for the uplink directions, and boosters or filters for the downlink directions.

Example 3: Simple power budget calculations

RADIO LINK POWER BUDGET — MS CLASS 1

GENERAL INFO				
Frequency (MHz):	1800		System:	GSM

RECEIVING END:		BS	MS	
RX RF-input sensitivity	dBm	-104.00	-100.00	A
Interference degrad. margin	dB	3.00	3.00	B
Cable loss + connector	dB	2.00	0.00	C
Rx antenna gain	dBi	18.00	0.00	D
Diversity gain	dB	5.00	0.00	E
Isotropic power	dBm	-122.00	-97.00	F=A+B+C-D-E
Field strength	dB V/m	7.24	32.24	G=F+Z*

* Z = 77.2 + 20*log(freq[MHz])

TRANSMITTING END:		MS	BS	
TX RF output peak power	W	1.00	15.85	
(mean power over RF cycle)	dBm	30.00	42.00	K
Isolator + combiner + filter	dB	0.00	3.00	L
RF-peak power, combiner output	dBm	30.00	33.00	M=K-L
Cable loss + connector	dB	0.00	2.00	N
TX-antenna gain	dBi	0.00	18.00	O
Peak EIRP	W	1.00	79.43	
(EIRP = ERP + 2dB)	dBm	30.00	49.00	P=M-N+O
Path loss due to ant./body loss	dBi	6.00	6.00	Q
Isotropic path loss	dB	146.00	146.00	R=P-F-Q

RADIO LINK POWER BUDGET — MS CLASS 4

GENERAL INFO				
Frequency (MHz):	900		System:	GSM

RECEIVING END:		BS	MS	
RX RF-input sensitivity	dBm	-104.00	-102.00	A
Interference degrad. margin	dB	3.00	3.00	B
Cable loss + connector	dB	4.00	0.00	C
Rx antenna gain	dBi	12.00	0.00	D
Isotropic power	dBm	-109.00	-99.00	E=A+B+C-D
Field strength	dB V/m	20.24	30.24	F=E+Z*

* Z = 77.2 + 20*log(freq[MHz])

TRANSMITTING END:		MS	BS	
TX RF output peak power	W	2.00	6.00	
(mean power over RF cycle)	dBm	33.00	38.00	K
Isolator + combiner + filter	dB	0.00	3.00	L
RF-peak power, combiner output	dBm	33.00	26.00	M=K-L
Cable loss + connector	dB	0.00	4.00	N
TX-antenna gain	dBi	0.00	12.00	O
Peak EIRP	W	2.00	20.00	
(EIRP = ERP + 2dB)	dBm	33.00	34.00	P=M-N+O
Path loss due to ant./body loss	dBi	9.00	9.00	Q
Isotropic path loss	dB	133.00	133.00	R=P-F-Q

Output and Effect of Link Budget Calculations

- Path loss and received power: This is the main output of the link budget calculations. The losses in signal strength that occur during transmission from the TX antenna to the RX antenna are given by the path loss, while the received power is the result of the path loss phenomenon. All the factors that contribute to increases (e.g. antenna gains) and decreases (e.g. losses due to propagation) are taken into account during the calculations. The better the input data accuracy, the more accurate the results.

- Cell range: If the path loss is lessened, the signal from the transmitter (BTS) antenna will cover more distance, so increasing the area covered by one BTS. Thus, the power budget calculations play a direct role in determining the covered area, and so deciding on the number of base stations that will be required in a network.
- Coverage threshold: The downlink signal strength at the cell border for a given location probability is known the coverage threshold. Although slow fade margin and MS isotropic power can be used to calculate this value, power budget calculations are used for this purpose. Propagation models are used for more accurate calculation of the cell range and coverage area (refer to Example 3).

2.4.2 Frequency Hopping

Frequency hopping (FH) is a technique that basically improves the channel to interference (C/I) ratio by utilising many frequency channels. Employment of the FH technique also improves the link budget due to its effects: frequency diversity and interference diversity.

The frequency diversity technique increases the decorrelation between the various frequency bursts reaching the moving MS. The effects of fading due to propagation conditions reduces, thereby improving the signal level. There are again two types of frequency diversity technique: random FH and sequential FH. Sequential FH is used more in practical network planning as it gives more improvement to the network quality.

If the number of frequency channels increases in the radio network, the number of frequencies used increases in the network, so reducing the interference effect at the mobile station. This leads to an increase in signal level, and an improvement in the power budget.

2.4.3 Equipment Enhancements

Receiver Diversity

Diversity is the most common way to improve the reception power of the receiving antenna. Major diversity techniques are space diversity, frequency diversity, and polarisation diversity. Frequency diversity is also known as frequency hopping.

Space diversity involves installing another antenna at the base station. This means that there are two antennas receiving the signal at the base station instead of one and are separated in *space* by some distance. There is no fixed distance of separation between the antennas, which depends upon the propagation environment. Depending on the environmental conditions, the distance between the main and the diversity antenna can vary from 1 to 15 wavelengths.

Polarisation diversity means that the signals are received using two polarisations that are orthogonal to each other. It can be either vertical–horizontal polarisation or it can be ±45-degree slated polarisation.

Low-noise Amplifiers (LNA)

Where the received power is limited by the use of long cables, low-noise amplifiers can be used to boost the link budget results. As the name suggest, a LNA has a low noise value and can amplify a signal. The LNA is placed at the receiving end. When space diversity is being used, the LNAs should be used on both the main and the diversity antennas, thereby improving the diversity reception. As stated above, this is used for improvement of the uplink power budget.

Power Boosters

Power in the downlink direction can be increased by the use of power amplifiers and power boosters. If the losses are reduced before the transmission by the use of amplifiers, which in turn increases the power, then the configuration is called a power amplifier. However, when the transmission power is increased, then it is done by using the booster. Power amplifiers are located near the transmission antennas while the boosters are located near the base station as shown in Figure 2.10.

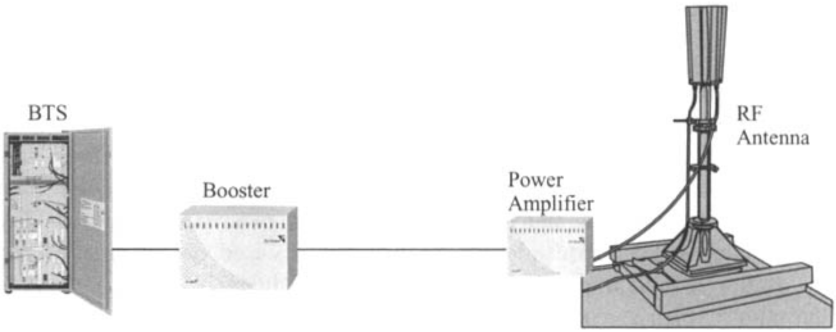

Figure 2.10 Power budget enhancement using a booster and power amplifier

2.4.4 Cell and Network Coverage

The cell and network coverage depend mainly on natural factors such as geographical aspect/propagation conditions, and on human factors such as the landscape (urban, suburban, rural), subscriber behaviour etc. The ultimate quality of the coverage in the mobile network is measured in terms of *location probability*. For that, the radio propagation conditions have to be predicted as accurately as possible for the region.

There are two ways in which radio planners can use propagation models. They can either create their own propagation models for different areas in a cellular network, or they can use the existing standard models, which are generic in nature and are used for a whole area. The advantage of using their own model is that it will be more accurate, but it will also be immensely time-consuming to construct. Usage of the standard models is economical from the time and money perspective, but these models have limited accuracy. Of course, there is a middle way out: the use of multiple generic models for urban, suburban and rural environments in terms of macro-cell or micro-cell structure.

A Macro-cell Propagation Model

The Okumara–Hata model is the most commonly used model for macro-cell coverage planning. It is used for the frequency ranges 150–1000 MHz and 1500–2000 MHz. The range of calculation is from 1 to 20 km. The loss between the transmitting and receiving stations is given as:

$$L = A + B\log f - 13.82\log h_{\mathrm{bts}} - a(h_{\mathrm{m}})(44.9 - 6.55\log h_{\mathrm{b}})\log d + L_{\mathrm{other}} \tag{2.7}$$

where f is the frequency (MHz), h is the BTS antenna height (m), $a(h)$ is a function of the MS antenna height, d is the distance between the BS and MS (km), L_{other} is the attenuation due to land usage classes, and $a(h_{\mathrm{m}})$ is given by:

$$a(h_{\mathrm{m}}) = (1.1\log f_{\mathrm{c}} - 0.7)h_{\mathrm{m}} - (1.56\log f_{\mathrm{c}} - 0.8).$$

For a small or medium-sized city:

$$a(h_{\mathrm{m}}) = 8.25(\log 1.54h_{\mathrm{m}})^2 - 1.1, \quad \text{for} \quad f_{\mathrm{c}} \leq 200\,\mathrm{MHz} \tag{2.8}$$

For a large city:

$$a(h_{\mathrm{m}}) = 3.2(\log 11.75h_{\mathrm{m}})^2 - 4.97, \quad \text{for} \quad f_{\mathrm{c}} \geq 400\,\mathrm{MHz} \tag{2.9}$$

The value of the constants A and B varies with frequencies as shown below:

$$A = 69.55 \quad \text{and} \quad B = 26.16 \text{ for } 150\text{–}1000\,\mathrm{MHz}$$
$$A = 46.3 \quad \text{and} \quad B = 33.9 \text{ for } 1000\text{–}2000\,\mathrm{MHz}.$$

The attenuation will vary with the type of terrain. This may include losses in an urban environment where small cells are predominant. Then there are foliage losses when forests are present in the landscape. Similarly, the effects of other natural aspects such as water bodies, hills, mountains, glaciers, etc., and the change in behaviour in different seasons have to be taken into account.

A Micro-cell Propagation Model

The most commonly used micro-cellular propagation model is the Walfish–Ikegami model. This is basically used for micro-cells in urban environments. It can be used for the frequency range 800–2000 MHz, for heights up to 50 m (i.e. the height of building + height of the BTS antenna) for a distance of up to 5 km. This model talks about two conditions: line-of-sight (LOS) and no-line-of-sight (NLOS). The path loss formula for the LOS condition is:

$$P = 42.6 + 26\log d + 20\log f. \tag{2.10}$$

For the NLOS condition, the path loss is given as:

$$P = 32.4 + 20\log f + 20\log d + L_{\mathrm{rds}} + L_{\mathrm{ms}}. \tag{2.11}$$

The parameters in the equations above for the model can be understood from Figure 2.11. The values of the rooftop-to-street diffraction loss are dependent upon the street orientation, street width and the frequency of operation. The multi-screen diffraction losses are dependent upon the distance and frequency.

Note: Walfish–Ikegami model can be used also for macro-cells. However, some radio planning engineers do use other models – such as ray tracing – for the micro-cellular environment.

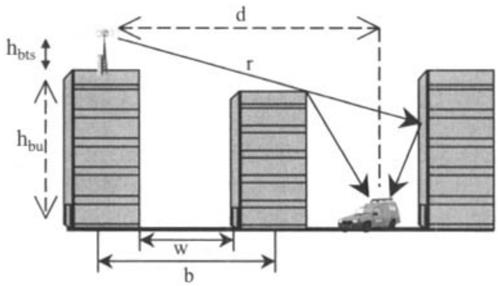

Figure 2.11 W–I model:
d: distance in km
f: frequency in MHz
L*rds*: rooftop-street diffraction and scatter loss
L*ms*: multi-screen diffraction loss
w: road width
b: distance between the centres of two buildings
H_{bu}: height of the building

Application of Propagation Models

The propagation models are usually not applied directly. The reason is that these models were developed taking particular cities into account, and every city has its own characteristics. Changes made to the propagation models are called correction factors and they are based on drive tests results. If there is no existing cellular network, the radio planning engineers install an omni-antenna at a location which would cover all or most of the types of region – dense urban, urban, rural, etc. A drive test is performed and correction factors for the propagation models are thereby determined. One such table of correction factors is shown in Figure 2.11(a).

Category	Offset(dB)	Code
No data	0.00	0
Water	-17.00	1
Open	-17.00	2
Evergreen	-17.00	3
Deciduous	-10.00	4
Low Density Residential	-15.00	5
High Density Residential	-10.00	6
Commercial/ Industrial	-15.00	7
Urban	-3.20	8

Figure 2.11(a) Correction factors

Planned Coverage Area

Based on propagation models, drive tests and correction factors, prediction of coverage areas is done. The sites are located according to the requirements of the network, and the coverage predictions are done as shown in Figure 2.11(b). Usually some radio network planning tools are used for such an exercise.

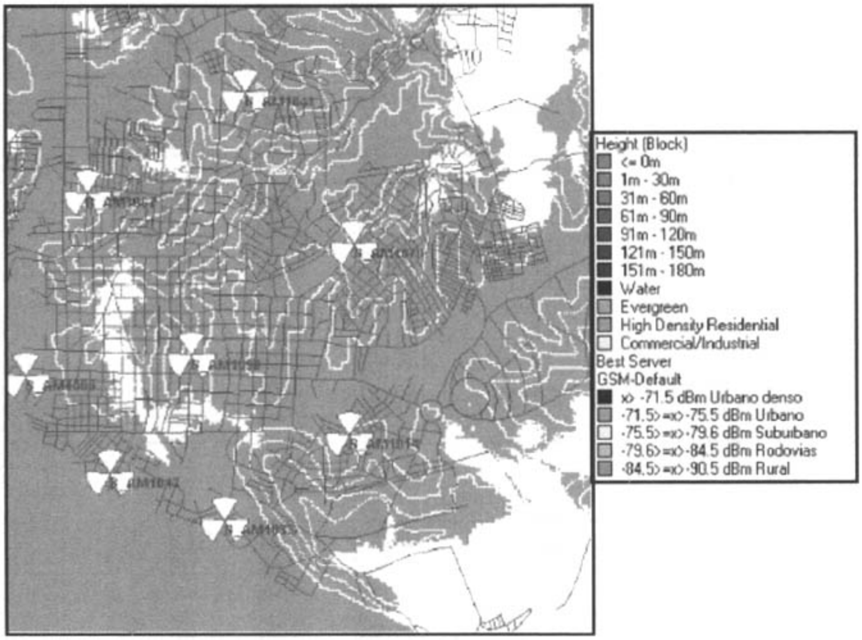

Figure 2.11(b) Planned coverage area

Location Probability

As mentioned above, the quality of coverage is defined in terms of location probability. Location probability can be defined as the probability of the field strength being above the sensitivity level in the target area. For practical purposes, it is considered that a location probability of 50% is equal to the sensitivity of the receiver in the given region. As the received power at the receiver should be higher than the sensitivity, the location probability should therefore be higher than 50%. Earlier we looked at the reasons behind fluctuations and fading of the signal strength. These fluctuations may be more or less than the sensitivity of the receiver. Hence, the design of the radio network incorporates a term known as the fade margin. Planning is done in such as way that the field strength of the signal is higher than the sensitivity by this margin. So, when the fading is taking place (slow fading or shadowing being the most prominent), then the signal level after fading is way above the sensitivity of the receiver.

A more accurate link budget calculation taking into account the propagation model effects is shown in Example 4.

Example 4: Detail Radio Link Power Budget

RADIO LINK POWER BUDGET					**MS CLASS:**		**2**
GENERAL INFO							
Frequency (MHz):		**900**			System:		**GSM**
RECEIVING END:				**BS**	**MS**		
RX RF-input sensitivity			dBm	**-106.00**	**-103.00**		A
Interference degrad. margin			dB	**2.00**	**2.00**		B
Cable loss + connector			dB	**2.50**	**10.00**		C
Rx antenna gain			dBi	**16.00**	**0.00**		D
Diversity gain			dB	**3.50**	**0.00**		E
Isotropic power			dBm	**-121.00**	**-91.00**		F=A+B+C-D-E
Field strength			dBμV/m	**8.24**	**38.24**		G=F+Z*
					** Z = 77.2 + 20*log(freq[MHz])*		
TRANSMITTING END:				**MS**	**BS**		
TX RF output peak power			W	**3.00**	**33.66**		
(mean power over RF cycle)			dBm	**34.77**	**45.27**		K
Isolator + combiner + filter			dB	**0.00**	**4.00**		L
RF-peak power, combiner output			dBm	**34.77**	**41.27**		M=K-L
Cable loss + connector			dB	**10.00**	**2.50**		N
TX-antenna gain			dBi	**0.00**	**16.00**		O
Peak EIRP			W	**0.30**	**300.00**		
(EIRP = ERP + 2dB)			dBm	**24.77**	**54.77**		P=M-N+O
Isotropic path loss			dB	**145.77**	**145.77**		Q=P-F
CELL SIZES							
COMMON INFO			**Region 1**	**Region 2**	**GENERAL**		
MS antenna height (m):			**1.5**	**1.5**	**1.5**		
BS antenna height (m):			**30.0**	**30.0**	**30.0**		
Standard Deviation (dB):			**7.0**	**7.0**	**7.0**		
BPL Average (dB):			**25.0**	**20.0**	**15.0**		
BPL Deviation (dB):			**7.0**	**7.0**	**7.0**		
OKUMURA-HATA (OH)			**Region 1**	**Region 2**	**GENERAL**		
Area Type Correction (dB)			**0.0**	**-4.0**	**-6.0**		
WALFISH-IKEGAMI (WI)			**Region 1**	**Region 2**	**GENERAL**		
Roads width (m):			**30.0**	**30.0**	**30.0**		
Road orientation angle (degrees):			**90.0**	**90.0**	**90.0**		
Building separation (m):			**40.0**	**40.0**	**40.0**		
Buildings average height (m):			**30.0**	**30.0**	**30.0**		
INDOOR COVERAGE			**Region 1**	**Region 2**	**GENERAL**		
Propagation Model			**OH**	**OH**	**OH**		
Slow Fading Margin + BPL (dB):			**32.4**	**27.4**	**22.4**		
Coverage Threshold (dBμV/m):			**70.6**	**65.6**	**60.6**		
Coverage Threshold (dBm):			**-58.6**	**-63.6**	**-68.6**		
Location Probability over Cell Area(L%):			**95.0%**	**95.0%**	**95.0%**		
	Cell Range (km):		**0.78**	**1.40**	**2.22**		
OUTDOOR COVERAGE					**GENERAL**		
Propagation Model					**OH**		
Slow Fading Margin (dB):					**7.4**		
Coverage Threshold (dBμV/m):					**45.6**		
Coverage Threshold (dBm):					[redacted]		
Location Probability over Cell Area(L%):					**95.0%**		
	Cell Range (km):				**5.92**		

2.4.5 Capacity Planning

Capacity planning is a very important process in the network rollout as it defines the number of base stations required and their respective capacities. Capacity plans are made in the pre-planning phase for initial estimations, as well as later in a detailed manner.

The number of base stations required in an area comes from the coverage planning, and the number of transceivers required is derived from capacity planning as it is directly associated with the frequency re-use factor. The frequency re-use factor is defined as the number of base stations that can be implemented before the frequency can be re-used. An example of frequency re-use is shown in Figure 2.12. The maximum number of frequencies in a GSM 900 system is 125 in both the uplink and downlink directions. Each of these frequencies is called a channel. This means that there are 125 channels available in both directions. The minimum frequency re-use factor calculation is based on the C/I ratio. As soon as the C/I ratio decreases, the signal strength starts deteriorating, thereby reducing the frequency re-use factor.

Another factor to keep in mind is the antenna height at the base station. If the antenna height is too high then the signal has to travel a greater distance, so the probability that the signal causes interference becomes greater. The average antenna height should be such that the number of base stations (fully utilised in terms of their individual capacities) is enough for the needed capacity of the network. Of course, as seen above, this depends heavily on the frequency re-use factor.

There are three essential parameters required for capacity planning: estimated traffic, average antenna height, and frequency usage.

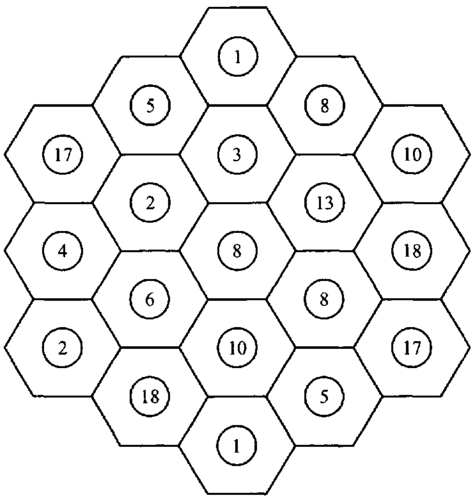

Figure 2.12 Example of frequency re-use

Traffic Estimates

Traffic estimation or modelling is based on theoretical estimates or assumptions, and on studies of existing networks (i.e. experience). Traffic in the network is dependent on the user communication rate and user movement in the network. The user communication rate means how much traffic is generated by the subscriber and for how long. The user movement is an estimate of the user's use of the network in static mode and dynamic mode.

Traffic estimation in the network is given in terms of 'erlangs'. One erlang (1 Erl) is defined as the amount of traffic generated by the user when he or she uses one traffic channel for one hour (this one hour is usually the busy hour of the network). Another term that is frequently used in network planning is 'blocking'. Blocking describes the situation when a user is trying to make a call and is not able to reach a dialled subscriber owing to lack of resources.

Generally, it is assumed that a user will generate about 25 mErl of traffic during the busy hour, and that the average speaking (network usage) will be about 120 seconds. These figures may vary from network to network; some networks use average figures of 35 mErl and 90 s.

Another factor is the user's behaviour in terms of mobility. In the initial years of the GSM, the ratio of static users to dynamic users was almost 0.7, but with rapid changes in technology this ratio may soon become 1.0! User mobility affects handover rates, which in turn affects network capacity planning.

The actual traffic flowing in the network can be calculated by using tables that use the maximum traffic at a base station and the blocking rate. Commonly used Erlang tables are Erlang B and Erlang C. Erlang B assumes that if calls cannot go through then they get dropped (i.e. no queuing possible). Erlang C considers that if a call does not get through then it will wait in a queue. These Erlang tables are good enough for circuit-switched traffic but not for packet switching. We look into the packet switching aspect in later chapters. Erlang B tables are given in Appendix E.

It is important for the radio planner to know the capacity that can be offered by the base station equipment, which means that the traffic handling capability of the transceivers takes precedence for capacity planning. Due to modulation, the modulated stream of bits is sent in *bursts* having a finite duration. These bursts are generally called *time slots* (TS) in GSM; they have a relatively fixed place in the stream and occur after 0.577 ms. The slots have a width of about 200 kHz. In the GSM system this is known as *one time slot.* Due to the modulation schemes (i.e. TDMA), there are eight TS at each frequency in each direction. All these eight time slots can be used for sending the traffic or the signalling information. Channel organization within the time slot should be done in such a way that every time a burst is transmitted, it is utilised completely. A typical time-slot composition is shown in Figure 2.13.

Signalling requires one time slot (e.g. TS0), and the remaining seven time slots can be used for traffic. In this configuration, the number of subscribers who can talk simultaneously is seven, on separate traffic channels (TCH). Now, when the number of transceivers increases in the cell, the traffic and signalling channel allocation also change. Generally,

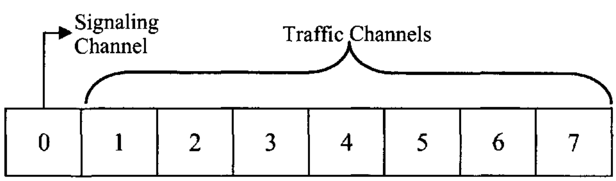

Figure 2.13 Time slot configuration for single TRX

two transceivers (TRX) would have 15 TCH and one SCH (signalling channel). Four TRX would have 30 TCH and two SCH, which means that the traffic channels increase by $7 + 8 + 7 + 8 \cdots$ for every single increase in the number of transceivers, while the signalling channels will have an increment at every alternate TRX addition (which means that a decrease in SCHs in the TRX increases the TCHs in it).

Average Antenna Height

The concept of the average antenna height is the basis of the frequency re-use pattern determining capacity calculations in a cellular network. The average antenna height is the basis of the cellular environment (i.e. whether it is macro-cellular or micro-cellular). If the average antenna height is low, then the covered area is small in an urban environment. This will lead to the creation of more cells, and hence increase the number of times the same frequency can be re-allocated. Exactly the opposite is the case in a macro-cellular environment. Here the coverage area would be more, so the same frequency can be re-allocated fewer times. All these calculations are based on the interference analysis of the system as well as the topography and propagation conditions.

Frequency Usage and Re-use

Frequency usage is an important concept related to both coverage and capacity usage. Frequency re-use basically means how often a frequency can be re-used in the network. If the average number of the transceivers and the total number of frequencies are known, the frequency re-use factor can be calculated.

Example 5: Frequency re-use factor

If there are 3 TRX that are used per base station and the total number of frequencies available is 27, then the total number of frequencies available for re-use is $27/3 = 9$.

2.4.6 Spectrum Efficiency and Frequency Planning

Spectrum efficiency is simply the maximum utilisation of the available frequencies in a network. In the radio planning process, this is known as frequency planning. Capacity and frequency planning do of course go hand-in-hand, but the concepts described so far in this chapter provide the inputs for frequency planning. A good frequency plan ensures that frequency channels are used in such a way that the capacity and coverage criteria are met without any interference. This is because the total capacity in a radio network in terms of the number of sites is dependent upon two factors: transmission power and interference. The re-use of the BCCH TRX (which contains the signalling time slots) should be greater than that of the TCHs, since it should be the most interference-free.

2.4.7 Power Control

The power that is transmitted both from the mobile equipment and from the base station has a far-reaching effect on efficient usage of the spectrum. Power control is an essential feature in mobile networks, in both the uplink and downlink directions. When a mobile transmits high power, there is enough fade margin in the critical uplink direction, but it can cause interference to other subscriber connections. The power should be kept to a level that the signal is received by the base station antenna above the required threshold without causing interference to other mobiles. Mobile stations thus have a feature such that their power of transmission can be controlled. This feature is generally controlled by the BSS. This control is based on an algorithm that computes the power received by the base station and, based on its assessment, it increases or decreases the power transmitted by the mobile station.

2.4.8 Handover

Handover is the automatic transfer of the subscriber from one cell to another during the call process, without causing any hindrance to the call. There are two main aspects to this: the necessity to find a dedicated mode in the next cell as the mobile is on call, and the switching process being fast enough so as not to drop that call.

So, how does the handover actually take place? There are many processes that can be used, but the one most used is based on power measurements. When a mobile is at the interface of two cells, the BSS measures the power that is received by the base stations of the two cells, and then the one that satisfies the criteria of enough power and least interference is selected. This kind of handover being directly related to power control, it provides an opportunity to improve the efficiency of use of the spectrum.

2.4.9 Discontinuous Transmission

Discontinuous transmission (DTX) is a feature that controls the power of the transmission when the mobile is in 'silent' mode. When the subscriber is not speaking on the mobile, a voice detector in the equipment detects this and sends a burst of transmission bits to BSS, indicating this inactivity. This function of the mobile is called voice-activity detection (VAD). On receiving this stream of bits indicating DTX, the BSS asks the mobile to reduce its power for that period of time, thereby reducing interference in the network and improving the efficiency of the network.

2.4.10 Frequency Hopping

Before we go into the concept and process of frequency hopping, let us understand the frequency assignment criteria in the GSM network. In GSM 900, the frequency bands used are 890–915 MHz in the uplink direction and 935–960 MHz in the downlink direction, which means a bandwidth of 25 MHz in each direction. The whole or some fraction of this band is available to the network operator. The central frequencies start at 200 kHz from the 'edge' of the band and are spread evenly in it. There are 125 frequency slots in this band. The major interference problem is between the adjacent bands because of frequency overlapping at the borders of the individual channels. For this simple reason, the adjacent (and same-frequency) channels) are not used on the cells belonging to the same site.

Frequency hopping is a technique by which the frequency of the signal is changed with every burst in such a way that there is minimum interference in the network, and at the same time allocated channels are used effectively. This process in GSM is also known as slow frequency hopping (SFH). By using SFH, improvement takes place by virtue of *frequency diversity* and *interference diversity*.

- Frequency diversity: Since every burst has a different frequency, it will fade in a different way and time. Thus the decorrelation between each burst increases, thereby increasing the efficiency of the coding signal. The assignment of the frequency can be done by two ways: sequentially or randomly. In the former, the system follows a strict pattern of frequency assignment to each burst; in the latter, it assigns frequencies randomly.
- Interference diversity: If each mobile has one constant frequency, some mobiles may be affected by interference more than others. With the use of frequency hopping, the interference spreads within the system because the interfering signal's effect gets reduced. As the interference becomes less, the frequency spectrum can be utilised better, and hence the capacity of the system increases.

Frequency hopping is of two types: base-band FH and RF FH. In base-band FH, the calls are *hopped* between different TRXs. The number of frequencies used for hopping is correlated to the number of TRXs and is thus constant. In RF FH, the call stays on one TRX but a frequency change takes place with every frame. These frequencies are not included in the hopping sequence, thus effectively creating two layers in each cell, one FH and one non-FH. As RF FH is not correlated to the number of TRXs, it is considered to be more robust and hence used in network deployment frequency planning.

2.4.11 Parameter Planning

The parameters used in a radio network are of two types: fixed and measured. These parameters include those related to signalling, radio resource management (RRM), power control, neighbour cells, etc.

Signalling

Any flow of data in a network requires some additional information that helps the data to reach the destination in the desired fashion. This additional information is known as signalling.

Signalling in GSM is required at all the interfaces, but radio network planners deal mostly with the signalling between the mobile station and base station (shown in Table 2.1). Signalling on all the interfaces except for the air-interface is done at 64 kbps. On the air-interface the signalling can be done either by using the slow associated control channels (SAACH), or by using the main channel itself wherein the signalling channel is sent instead of sending the data – this is known as fast associated control channel (FAACH) signalling. SAACH signalling is 'slow' and hence carries non-urgent messages, such as information containing handover measurement data. FAACH signalling carries information that is more urgent, such as decisions leading to handover of the mobile. Signalling is also required at the air-interface for sending information about the mobile itself even when it is not on a call. Thus, signalling can be in the dedicated phase (i.e. when TCHs have been allocated to the mobile) and in the non-dedicated or idle mode when the mobile is not on a call but is camped on the network.

When the mobile firsts tries to get connected to the network, it requires the help of two channels: the frequency correction channel (FCCH) and the synchronisation channel (SCH). These channels help the mobile to get synchronised and connected to the network. Each mobile, once connected, keeps on receiving information from the base station, and this is done through the broadcast channel (BCCH). Once a call is initiated, the paging channel (PCH) helps in transfer of information indicating that a dedicated channel will be allocated to the mobile. This allocation information comes via the allocation grant channel (AGH). If the mobile needs to send information to the base station, the request is made through the random access channel (RACH). All these channels except RACH are downlink channels.

The above-mentioned channels are logical channels. There are three kinds of physical channel also: the traffic channels for full-rate, half-rate and one-eighth rate (also known as TCH/F, TCH/H and TCH/8 respectively). TCH/F transmits the speech code at 13 kbps; TCH/H transmits speech code at 7 kbps. Although TCH/8 is a traffic channel, its rate is very low at almost one-eighth that of the TCH/F; thus its usage has been limited to signalling.

Radio Resource and Mobility Management

The management of radio resources, functions related to mobile location update, communication management issues such as handover and roaming procedure handling, come under radio resource management (RRM). For these management functions to happen, information flow (traffic and signalling) takes place via three protocols, known as *link protocols* (see Figure 2.14). LAPDm is present over the MS–BTS connection and LAPD over the BTS–BSC connection. MTP (message transfer protocol) is used for signalling transport over the SS7 network.

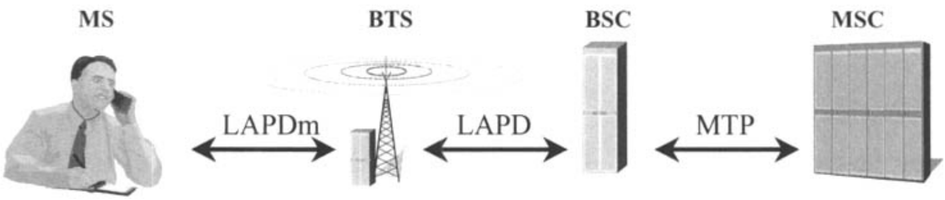

Figure 2.14 Link protocol in a GSM network

RRM procedures basically relate to the processes taking place during transitions between different states of the mobile station, such as the idle state, the dedicated state, during mobility, during handover, when calls are being re-established, etc.

In GSM, there are two states that are defined for a mobile: idle and dedicated. Thus, from an idle state, the mobile station enters a BTS access mode wherein 'access' is granted to the mobile based on whether or not the mobile station is allowed to 'use' the base station. Then the mobile station enters the dedicated mode and starts using the resources until it enters the release mode, i.e. the call ends.

Once a mobile is logged into the network, the transition procedure request always comes from the mobile, and this is done through the random access channel (RACH). As the timing of requests coming from mobiles cannot be predetermined, this may cause problems such as 'collision of call request'. Then factors such as congestion, the call-repetition process, traffic increase, etc., come into the picture. The radio planner should keep the throughput under control by means of parameters such as the number of times the request for a channel can be sent, and the timing of re-requests (which is usually kept 'random').

Paging is another function whereby, when a request from the mobile reaches the MSC, then the MSC 'pages' the requested subscriber information to all the BSCs within a location area. The BSC in turn sends this information to the BTS to find the subscriber through the paging and access grant channel (PAGCH). The tasks assigned to the BSC and BTS may vary from network to network.

The subscriber should be able to connect to the network irrespective of his or her location. The subscriber movement can be intra-region or inter-region (including inter-country). For this kind of flexibility, the subscription has to be associated with the concept of a 'public land mobile network' (PLMN). Any operational network can be said to be a PLMN. There can be one or more than one PLMN in one country. To give users the immense flexibility to be connected even when changing between PLMNs (in the same or a different country) means that communication has to take place between these PLMNs. The mobile, when entering a different PLMN, searches for its own home/serving cells. When no service is detected, then it can search in automatic mode or the desired PLMN can be selected manually.

Neighbour Cells

While in operation, a mobile is required to make evaluations regarding the quality and level of the neighbour cells. It has to decide which cells are better in terms of coverage and capacity. This is done by taking advantage of the TDMA scheme, whereby the measurements are made during the uplink transmissions and downlink reception bursts. The evaluation is done with the help of algorithms resident in the BSS. These algorithms make a decision and convey it to the mobile station.

One important thing to remember here is that every cell has its own identity code, known as the base station identity code (BSIC). Neighbour cells can have the same BSIC, so in those cases the mobile identifies the neighbour cell by a 'colour code'. Recall that SCH and FCCH play an important role in logging the mobile to the network, and these channels transmit their information on a frequency known as the *beacon* frequency. Neighbour cells may have the same beacon frequency. In such cases, the BSIC helps in distinguishing the channels of the same frequency.

2.5 RADIO NETWORK OPTIMISATION

2.5.1 Basics of radio network optimisation

Optimisation involves monitoring, verifying and improving the performance of the radio network. It starts somewhere near the last phase of radio network planning, i.e. during parameter planning. A cellular network covers a large area and provides capacity to many people, so there are lots of parameters involved that are variable and have to be continuously monitored and corrected. Apart from this, the network is always growing through increasing subscriber numbers and increases in traffic. This means that the optimisation process should be on-going, to increase the efficiency of the network leading to revenue generation from the network.

As we have seen, radio network planners first focus on three main areas: coverage, capacity and frequency planning. Then follows site selection, parameter planning, etc. In the optimisation process the same issues are addressed, with the difference that sites are already selected and antenna locations are fixed, but subscribers are as mobile as ever, with continuous growth taking place. Optimisation tasks become more and more difficult as time passes.

Once a radio network is designed and operational, its performance is monitored. The performance is compared against chosen key performance indicators (KPIs). After fine-tuning, the results (parameters) are then applied to the network to get the desired performance. Optimisation can be considered to be a separate process or as a part of the network planning process (see Figure 2.15).

The main focus of radio network optimisation is on areas such as power control, quality, handovers, subscriber traffic, and resource availability (and access) measurements.

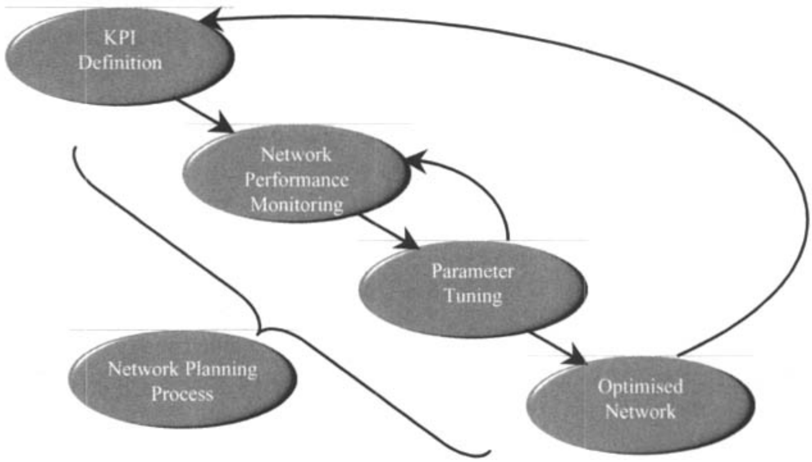

Figure 2.15 Radio network optimisation

2.5.2 Key Performance Indicators

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

Key Indicators–Voice Quality

The performance of the radio network is measured in terms of KPIs related to voice quality, based on statistics generated from the radio network. Drive tests and network management systems (described later) are the best methods for generating these performance statistics.

The most important of these from the operator's perspective are the BER (bit error rate), the FER (frame error rate) and the DCR (dropped call rate).

The BER is based on measurement of the received signal bits before decoding takes place, while the FER is an indicator after the incoming signal has been decoded. Correlation between the BER and the FER is dependent on various factors such as the channel coding schemes or the frequency hopping techniques used. As speech quality variation with the FER is quite uniform, FER is generally used as the quality performance indicator for speech. The FER can be measured by using statistics obtained by performing a drive test. Drive testing can generate both the uplink and the downlink FER.

The dropped call rate, as the name suggests, is a measure of the calls dropped in the network. A dropped call can be defined as one that gets terminated on its own after being established. As the DCR gives a quick overview of network quality and revenues lost, this easily makes it one of the most important parameters in network optimisation. Both the drive test results and the NMS statistics are used to evaluate this parameter. At the frame level, the DCR is measured against the SACCH frame. If the SACCH frame is not received, then it is considered to be dropped call. There is some relation between the number of dropped calls and voice quality. If the voice quality were not a limiting factor, perhaps the dropped call rate would be very low in the network. Calls can drop in the network due to quality degradation, which may be due to many factors such as capacity limitations, interference, unfavourable propagation conditions, blocking, etc. The DCR is related to the call success rate (CSR) and the handover success rate. The CSR indicates the proportion of calls that were completed after being generated, while the handover rate indicates the quality of the mobility management/RRM in the radio network.

KPIs can be subdivided according to the areas of functioning, such as area level, cell level (including the adjacent level), and TRX level. Area-level KPIs can include SDCCH requests, the dropped SDCCH total, dropped SDCCH A_{bis} failures, outgoing MSC control handover (HO) attempts, outgoing BSC control HO attempts, intra-cell HO attempts, etc. Cell-level KPIs may include SDCCH traffic BH (av.), SDCCH blocking BH (av.), dropped SDCCH total and distribution per cause, UL quality/level distribution, DL quality/level distribution etc. The TRX level includes the likes of UL and DL quality distribution.

2.5.3 Network Performance Monitoring

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

As a first step, radio planners assimilate the information/parameters that they need to monitor. The KPIs are collected along with field measurements such as drive tests. For the field measurements, the tools used are ones that can analyse the traffic, capacity, and quality of the calls, and the network as a whole. For drive testing, a test mobile is used. This test mobile keeps on making calls in a moving vehicle that goes around in the various parts of the network. Based on the DCR, CSR, HO, etc., parameters, the quality of the network can then be analysed. Apart from drive testing, the measurements can also be generated by the network management system. And finally, when 'faulty' parameters have been identified and correct values are determined, the radio planner puts them in his network planning tool to analyse the change before these parameters are actually changed/implemented in the field.

Drive Testing

The quality of the network is ultimately determined by the satisfaction of the users of the network, the subscribers. Drive tests give the 'feel' of the designed network as it is experienced in the field. The testing process starts with selection of the 'live' region of the network where the tests need to be performed, and the drive testing path. Before starting the tests the engineer should have the appropriate kits that include mobile equipment (usually three mobiles), drive testing software (on a laptop), and a GPS (global positioning system) unit.

When the drive testing starts, two mobiles are used to generate calls with a gap of few seconds (usually 15–20 s). The third mobile is usually used for testing the coverage. It makes one continuous call, and if this call drops it will attempt another call. The purpose of this testing to collect enough samples at a reasonable speed and in a reasonable time. If there are lots of dropped calls, the problem is analysed to find a solution for it and to propose changes.

An example of a drive test plan is shown in Figure 2.16. Some typical drive tests results giving the received power levels from own cell and neighbour cells, FER, BER, MS power control, etc., are shown in Figure 2.17.

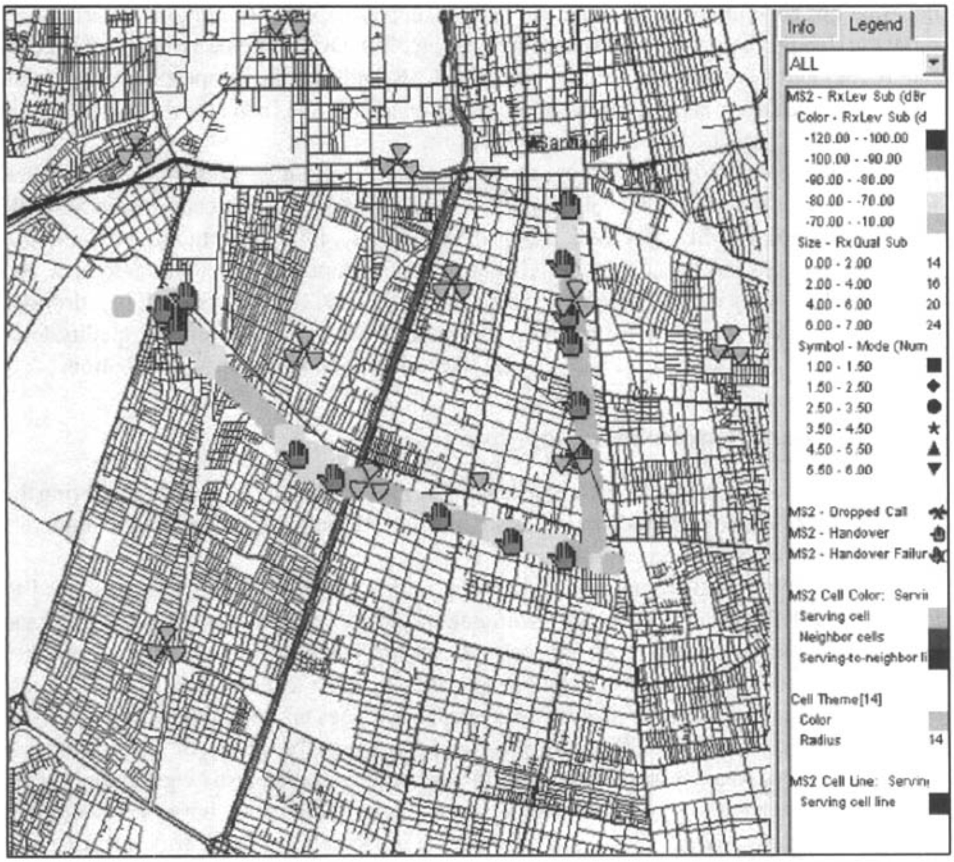

Figure 2.16 Drive test result analysis showing handovers (HO) on the path

Cellname	
CGI (MCC, MNC, LAC, CI)	730 02 12001 12095
Cell GPRS Support	
Band	1900
BCCH ARFCN	597
TCH ARFCN	697
BSIC	2-5
Mode	Dedicated
Time slot	4
Channel type	TCH/F + FACCH/F and SACCH/F
Channel mode	Speech full rate or half rate version 1
Speech Codec	FR
Ciphering Algorithm	
Sub channel number	
Hopping channel	NO
Hopping frequencies	
Mobile Allocation Index Offset (MAIO)	
Hopping sequence number (HSN)	

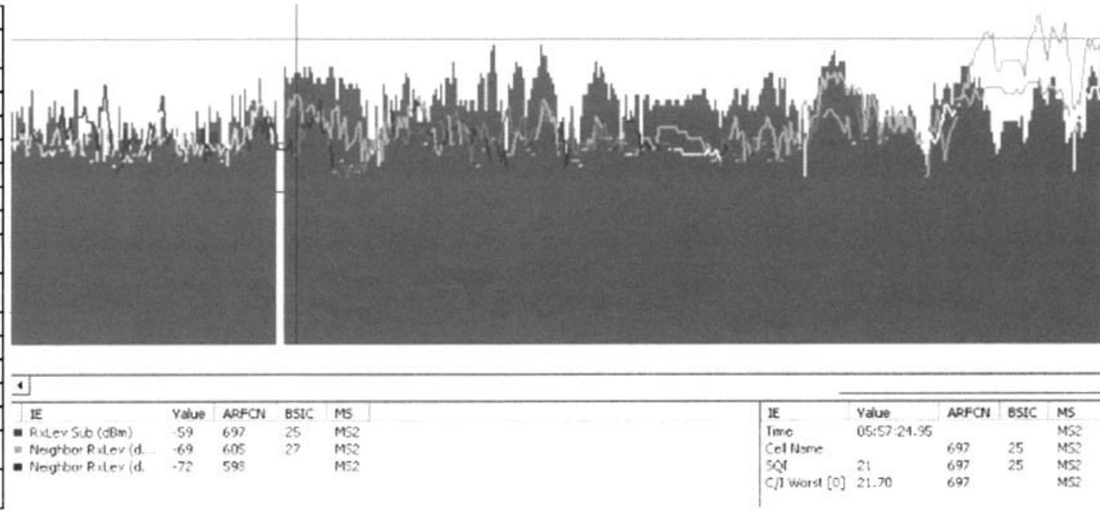

Figure 2.17 Some drive test results

Network Management System Statistics

After the launch of the network, drive tests are performed periodically. In contrast, the statistics are monitored on the NMS daily with the help of counters. The NMS usually measures the functionalities such as call setup failures, dropped calls, and handovers (successes and failures). It also gives data related to traffic and blocking in the radio network, apart from giving data related to quality issues such as frequency hopping, FER and BER, field strength, etc. An example of area-level KPI statistics is shown in Figure 2.18.

SDCCH

SDCCH availability ..../ava_4 81.30 %
Dynamic SDCCH allocation (TCH reconfigured to SDCCH):
. Attempts ..../c1154 0
SDCCH requests ..../c1000 6617
. HO in../c1006 0 (0.00 %)
. blocked ..../blck_15 (blck_5a) 33 (0.50 %)
. To FACCH call setup ..../c1099 0 (0.00 %)
. LU ..../c3019 4102 (61.99 %)
. MTC (incl. SMS) ..../c3012 145 (2.19 %)
. MOC (incl. SMS,SS) ..../c3013 343 (5.18 %)
. supplementary service request (S9) ..../c3044 4 (0.06 %)
. IMSI detach (S7) ..../c3033 114 (1.72 %)
. call re-establishment......................../c3020 0 (0.00 %)
. emergency call ..../c3021 255 (3.85 %)
. other (fails, ghosts) ..../sd_1a 1625 (24.56 %)
SDCCH usage ..../trf_7b 0.02 %
Average SDCCH seizure length ..../trf_4 2.05 sec

SDCCH failures

SDCCH seizures ..../trf_54 6584
SDCCH drop ratio ..../sdr_1a 27.70 %
. SDCCH_RADIO_FAIL............................./c1003 166 (2.52 %)
. SDCCH_A_IF_FAIL_CALL........................./c1078 0 (0.00 %)
. SDCCH_ABIS_FAIL_CALL........................./c1075 1658 (25.18 %)
. SDCCH_USER_ACT.............................../c1037 0 (0.00 %)
. SDCCH_BCSU_RESET............................./c1038 0 (0.00 %)
. SDCCH_NETW_ACT.............................../c1039 0 (0.00 %)
. SDCCH_BTS_FAIL.............................../c1036 0 (0.00 %)
. SDCCH_LAPD_FAIL............................../c1035 0 (0.00 %)
. SDCCH_RF_OLD_HO.........(HO drop)............./c1004 0 (0.00 %)
. SDCCH_ABIS_FAIL_OLD....(HO drop)............./c1076 0 (0.00 %)
. SDCCH_A_IF_FAIL_OLD....(HO drop)............./c1079 0 (0.00 %)

Figure 2.18 Example of area-level KPI statistics from the NMS

2.5.4 Network Performance Assessment

The performance indicators are listed below:

- amount of traffic and blocking
- resource availability and access
- handovers (same cell/adjacent cell, success and failure)
- receiver level and quality
- power control.

Coverage

Drive test results will give the penetration level of signals in different regions of the network. These results can then be compared with the plans made before the network launch. In urban areas, coverage is generally found to be less at the farthest parts of the network, in the areas behind high buildings and inside buildings. These issues become serious when important areas and buildings are not having the desired level of signal even when care has been taken during the network planning phase. This leads to an immediate scrutiny of the antenna locations, heights and tilt. The problems are usually sorted out by moving the antenna locations and altering the tilting of the antennas. If optimisation is being done after a long time, new sites can also be added.

Coverage also becomes critical in rural areas, where the capacity of the cell sites is already low. Populated areas and highways usually constitute the regions that should have the desired level of coverage. A factor that may lower the signal level could be propagation conditions, so study of link budget calculations along with the terrain profile becomes a critical part of the rural optimisation. For highway coverage, additions of new sites may be one of the solutions.

Capacity

Data collected from the network management system is usually used to assess the capacity of the network. As coverage and capacity are interrelated, data collected from drive tests is also used for capacity assessment. The two aspects of this assessment are dropped calls and congestion. Generally, capacity-related problems arise when the network optimisation is taking place after a long period of time. Radio network optimisation also includes providing new capacity to new hot-spots, or enhancing indoor coverage. Once the regional/area coverage is planned and executed in the normal planning phase, optimisation should take into consideration the provision of as much coverage as possible to the places that would expect high traffic, such as inside office buildings, inside shopping malls, tunnels, etc.

Quality

The quality of the radio network is dependent on its coverage, capacity and frequency allocation. Most of the severe problems in a radio network can be attributed to signal interference. For uplink quality, BER statistics are used, and for downlink FER statistics are used. When interference exists in the network; the source needs to be found. The entire frequency plan is checked again to determine whether the source is internal or external. The problems may be caused by flaws in the frequency plan, in the configuration plans (e.g. antenna tilts), inaccurate correction factors used in propagation models, etc.

Parameter Tuning

The ending of the assessment process sees the beginning of the complex process of fine-tuning of parameters. The main parameters that are fine-tuned are signalling parameters, radio resource parameters, handover parameters and power control parameters. The concepts that are discussed in the radio planning process and the KPI values should be achieved after the process is complete.

The major complexity of this process is the inhomogeneity of the radio network. Network planning will have used standard propagation models and correction factors based on some trial and error methods that may be valid for some parts of the network and invalid for other parts. Then, during network deployment, some more measurements are made and the parameters are fine-tuned again. Once the network goes 'live', the drive test and NMS statistics help in further fine-tuning of the parameters, and it is at this point that a set of default parameters is created for the whole network. However, as the network is inhomogeneous, these default parameters may not be sufficiently accurate in all regions, thereby bringing down the overall network quality – and leading to a reduction in revenue for the network operator.

Radio network optimization must be a continuous process that begins during the pre-launch phase and continues throughout the existence of the network.