

**UNIVERSIDADE TÉCNICA DE LISBOA**  
**INSTITUTO SUPERIOR TÉCNICO**

**Optimisation of Cell Radius in**  
**UMTS-FDD Networks**

**António João Nunes Serrador**

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**Supervisor:** Doctor Luís Manuel de Jesus Sousa Correia

**Chairman:** Doctor Luís Manuel de Jesus Sousa Correia

**Jury:** Doctor Francisco António Bucho Cercas  
Doctor António José Castelo Branco Rodrigues

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Under the supervision of:

**Doctor Luís Manuel de Jesus Sousa Correia**

Department of Electrical and Computer Engineering

Instituto Superior Técnico

Technical University of Lisbon



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# Abstract

This work focus on a key subject for Third Generation (3G) mobile operators, which is planning and optimising a UMTS-FDD multi-service mobile radio network, having a radio interface based on WCDMA.

Radio systems aspects defined for this new technology and related with this topic are presented: system operation modes, multiple access techniques, handover mechanisms, scenarios definition, services and applications characterisation, propagation models, traffic and capacity estimation, and interference.

Basic parameters, defining planning, are identified: radio planning procedures, traffic estimation algorithm, cellular location scenarios, and the number of required cells. Estimation is performed in order to guarantee the desired coverage and capacity.

After initial studies, the developed planning and optimisation tool is presented, which optimises (taking the STORMS project approach) the cell radius as a function of a given scenario, users services characterisation, general radio network aspects, and quality indicators. Using this tool, impacts and tendencies of several parameters over optimum cell radius are analysed, like urban characterisation parameters, population density, and general system configurations. For example, the population density impact on the cell radius, ranging from 2 500 to 20 000 persons/km<sup>2</sup> (only voice active), results in a cell radius from 700 to 400 m respectively.

## Key words

UMTS. Radio Network Planning. Optimisation. Simulation. Cell radius.

# Resumo

Este trabalho aborda o planeamento e a optimização de uma rede móvel UMTS-FDD de multi-serviços com uma interface rádio baseada em WCDMA.

São descritos alguns aspectos dos sistemas rádio, por exemplo: os modos de operação, acesso múltiplo, mecanismos de *handover*, definição de cenários, caracterização de aplicações e serviços, modelos de propagação, tráfego, estimação da capacidade e interferência do sistema.

São identificados parâmetros relativos a planeamento: procedimentos para planeamento rádio, cálculo ou estimação de tráfego, cenários de localização celular e estimativa do número de células necessárias. Estimativas são realizadas de forma a garantir a desejada cobertura e capacidade.

Após estes estudos, foi desenvolvida uma ferramenta (simulação ao nível de sistema) que optimiza o raio de uma célula em função de um determinado cenário: caracterização de utilização dos serviços pelos utilizadores, configurações gerais da rede e indicadores de qualidade. Com base nesta ferramenta, são verificadas as influências e tendências que os parâmetros ao nível urbano, populacional e configurações gerais do sistema têm no raio óptimo de uma célula. Por exemplo, o impacto da densidade populacional no raio celular, de 2 500 para 20 000 pessoas/km<sup>2</sup> (apenas para o serviço de voz activo), corresponde a um raio de 700 para 400 m respectivamente.

## Palavras chave

UMTS. Planeamento Rádio. Optimização. Simulação. Raio celular.

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# List of Acronyms

2G	2 <sup>nd</sup> Generation
3G	3 <sup>rd</sup> Generation
3GPP	3 <sup>rd</sup> Generation Partnership Project
AAA	Adaptive Antenna Arrays
AI	Air Interface
BCH	Broadcast Channel
BER	Bit Error Rate
BS	Base Station
CBD	Central Business District
CDMA	Code Division Multiple Access
CPCH	Common Packet Channel
CS	Circuit Switched
DCH	Dedicated Channel
DL	Downlink
DPCCH	Dedicated Physical Control Channel
DPDCH	Dedicated Physical Data Channel
DSCH	Downlink Shared Channel
EIRP	Equivalent Isotropic Radiated Power
EU	European Union
FACH	Forward Access Channel
FBI	Feedback Information
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
GoS	Grade of Service
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HCS	Hierarchical Cell Structure
HIMM	High Interactive Multimedia
HMM	High Multimedia
HTTP	Hyper Text Transfer Protocol

ITU	International Telecommunication Union
LAN	Local Access Network
LoS	Line of Sight
MCL	Minimum Coupling Loss
MM	Multimedia
MMM	Medium Multimedia
MS	Mobile Station
MUD	Multi-User Detection
NLoS	Non Line of Sight
OBQ	Offered Bit Quantity
PCH	Paging Channel
PCMCIA	Personal Computer Memory Card International Association
PD	Population Density
PS	Packet Switched
PSTN	Public Switching Telephone Network
QoS	Quality of Service
RACH	Random Access Channel
RF	Radio Frequency
RNC	Radio Network Controller
RRM	Radio Resource Management
S	Speech
SD	Switched Data
SF	Spreading Factor
SH	Soft Handover
SIR	Signal-to-Interference Ratio
SM	Simple Messaging
SMS	Short Message Service
TD-CDMA	Time Division - Code Division Multiple Access
TFCI	Transport-Format Combination Indicator
TPC	Transmit Power-Control
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System

UTRA     UMTS Terrestrial Radio Access  
WCDMA   Wideband Code Division Multiple Access  
WWW     World Wide Web

# List of Symbols

$A$	Offered traffic
$AT$	Average Connection Time
$b$	Building Separation
$B$	Blocking Probability
$B_i$	Information Bandwidth
$BL$	Building Loss
$BS_{NF}$	BS Receiver Noise
$B_t$	Transmitted Bandwidth
$C$	Number of Channels in the System
$C_{ch,SF,k}$	Channelisation codes
$C_m$	Correction Factor (Suburban/Urban areas)
$D$	Target Delay
$d$	Distance between Transmitter and Receiver
$D_{bb}$	BS antenna height measured from the average roof top level
$d_n$	Illusory Distance
$E_b/N_0$	Energy of Bit over Noise Density Ratio
$F$	Inter-cell Interference by the Total Interference Ratio
$f$	Frequency
$F_{FM}$	Fast Fading Margin
$F_M$	Fading Margins
$F_{SM}$	Slow Fading Margin
$GoS_{Current}$	Instantaneous or Current GoS
$GoS_{IM}$	GoS Interval Margin
$GoS_{Target}$	Maximum allowed GoS
$G_p$	Processing Gain
$G_r$	Maximum Receiver Antenna Gain
$G_{Rx}$	Receiver Antenna Gain
$G_{SH}$	Soft Handover Gain
$G_t$	Maximum Transmitter Antenna Gain
$G_{Tx}$	Transmitter Antenna Gain
$h_{Base}$	BS Height

$h_{Building}$	Building Height
$h_{Mobile}$	Mobile Height
$I$	Inter- to intra- cell interference Ratio.
$I_{Inter}$	Interference from other Cells
$I_{Intra}$	Interference generated by users connected to the same BS
$i_j$	Ratio $i$ , Received by User $j$
$j$	User $j$
$k$	Code number
$k_n$	Street Section $n$
$L_0$	Free Space Attenuation
$L_C$	Cable Loss
$L_j$	Load Factor of One Connection
$L_m$	Interference Margin
$L_{msd}$	Multi-screen Diffraction Loss
$L_{ori}$	Attenuation Caused by Street Orientation in Relation to Radio Path
$L_{Other}$	Others Attenuations, like car loss
$L_p$	Propagation Model Average Path Loss
$L_{p,macro}$	Path Loss for Macro Cells
$L_{p,micro}$	Path Loss for Micro Cells
$L_{Pmax}$	Maximum Propagation Loss
$L_{rts}$	Roof-to-street Diffraction and Scatter Loss
$L_{tx}$	Additional Attenuation on Transmission
$L_{UB}$	User Body Loss
$L_x$	Additional Attenuation in a Link
$N$	Total Effective Noise Plus Interference Power
$n$	Number of Straight Street Segments between BS and MS
$N_0$	Thermal Noise Density
$N_{sec}$	Number of Sectors per Cell
$N_U$	Number of Users Associated/Connected to a BS
$P_n(t)$	The $n^{th}$ Message Probability
$P_{Rx}$	Received Signal Power
$P_t$	Transmitter Power
$P_{Tx}$	Transmitted Signal Power
$R_c$	Chip Rate

$R_{cell}$	Cell Radius
$R_I$	Receiver Interference Power
$R_j$	User Bit Rate
$R_N$	Receiver Noise Power
$R_{NO}$	Receiver Noise Density
$R_{Smin}$	Receiver Sensitivity (Service Based)
$S$	Received Signal
$s_{n-1}$	Length of the Last Segment
$SP$	Service Penetration
$t$	Time Interval
$VB$	Voice Blocking
$v_j$	User Activity Factor
$VP$	Voice Penetration
$W$	Street Width
$x_{br}$	Break Point
$Y$	Year
$\alpha_j$	Orthogonality Factor in DL
$\beta$	Interference Reduction Factor
$\eta_{DL}$	Downlink Load Factor
$\eta_{UL}$	Uplink Load Factor
$\lambda$	Mean Arrival Rate
$\Psi$	Street Orientation Angle

# 1 Introduction

When the standardised digital era arrived to mobile communications (2G systems), an increasing number of users and technologies became unstoppable. At present days, the average penetration in the European Union (EU) (15 countries) is about 72 %, some countries like Portugal and Italy being already above 80 % [ICPo01]. This means that almost every one has/uses a mobile phone (basically speech). However, many mobile users desire Multimedia and Internet based services as in fixed networks. This potential market requires a new technology, capable of offering all these kind of services, the 3G. In order to accomplish this, a new standard was defined by the 3<sup>rd</sup> Generation Partnership Project (3GPP): the Universal Mobile Telecommunications System (UMTS).

Nowadays, it is clear that UMTS is the near future of mobile communications, pointed as the mobile technology for the next decade. UMTS is also the new mobile generation, with a new radio interface, capable of integrating the existing 2G networks, and adding modern wideband services and applications into the mobile world. These services are mainly characterised by their different bit rate, delay tolerance and switching type (packet or circuit).

UMTS is characterised as a multi service mobile radio platform. Different services mean different network demands, and services with asymmetric traffic (e.g. Internet) that may be supported and optimised; Time Division Duplex (TDD) is the operation mode allowing radio resources management to allocate resources in terms of traffic differences between Up- and Down- Links (UL and DL). Symmetric services (i.e. speech) are handled mostly by Frequency Division Duplex (FDD) operation mode, assuming an equilibrium of traffic load between UL and DL. In FDD, two carriers, 5 MHz each, are used at the same time, while in TDD both forward and reverse links use the same carrier, also with 5 MHz of bandwidth.

Some years ago (in 1998), the UMTS agenda was defined as shown in Table 1.1; at that time, the commercial launch was predicted for the first of January of 2002. Nowadays (2002) there is at least 1 year delay, assumed by all. All parties (governments, operators, manufacturers, companies, researchers, users) are hoping that UMTS will move mobile communications forward, from the current status, into the Information Society of 3G services, delivering speech, location based services, data, Internet, pictures, graphics, video communication, and other wideband information directly to people on the move. The new economy depends greatly on UMTS deployment and success. The fact that UMTS deployment and operation are delayed justifies the existence of this thesis, where optimal UMTS radio network is estimated, based on the optimal cell radius process.

Table 1.1 - UMTS Schedule for Europe (extracted from [UMTS98b]).

Task name	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
UMTS revised vision										
Co-operative research: ACTS										
UMTS Forum report no 1										
ERC spectrum decision										
EU UMTS decision										
National licence conditions										
National license decision										
ITU Framework standards										
Basic standards studies										
Detailed freezing UMTS standards										
UMTS System development										
Pre-operational trials										
UMTS Planning, deployment										
UMTS: Commercial operation										

Frequency allocation for UMTS worldwide is shown in Figure 1.1. The missing countries are expected to follow ITU recommendations [UMTS98a]. North America, Japan and Europe, have some problems to solve, mainly in the lower band.

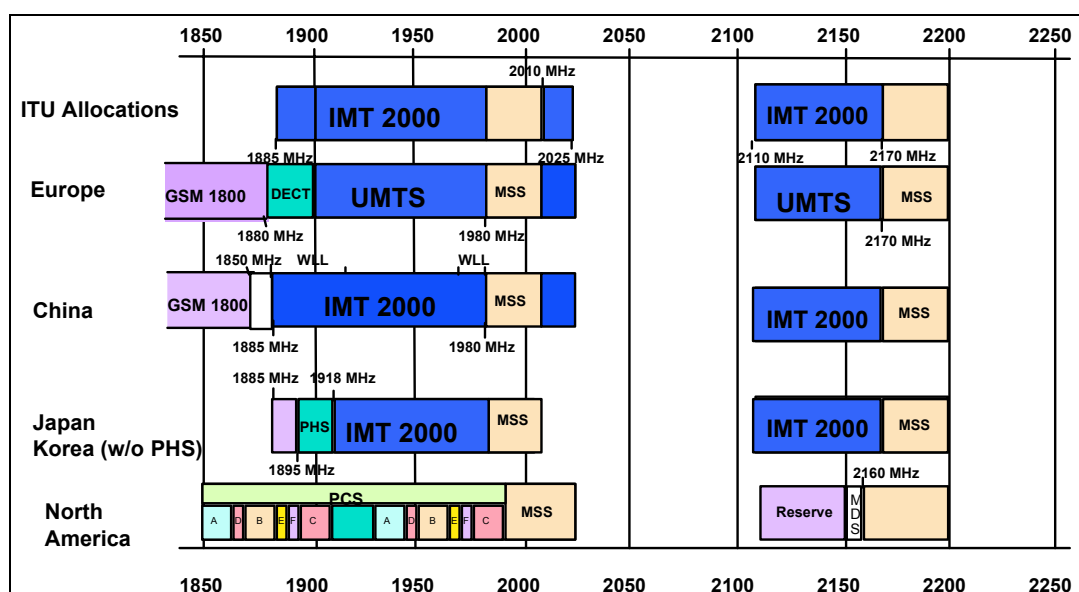


Figure 1.1 - Frequency bands for UMTS (extracted from [UMTS98a]).

Countries have their own strategy concerning UMTS licensing policy, some of them having adopted an auction scheme that in many cases achieved extremely high values, while others selected candidates based on the proposals quality (the so-called “beauty contest”), a minority having a hybrid scheme, which consisted in a minimum licensing cost for the “beauty contest”, Table 1.2.

Table 1.2 - European UMTS licence revenue [DaEr00], [JeMo01].

Country	Number of Licences	Type of sell	€ /pop
Finland	4	Beauty Contest	0
France	4	Hybrid	337
Germany	6	Auction	613
Italy	5	Auction	240
Netherlands	5	Auction	171
Portugal	4	Beauty Contest	40
Spain	4	Beauty Contest	15
Sweden	4	Beauty Contest	0
United Kingdom	5	Auction	648

As mentioned before, UMTS deployment has some delay, which is due to several aspects, like specifications delay, difficulties in some technological areas, and perhaps a non realistic time schedule. Today, the majority of European Countries has already licensed and selected which operators will explore this new market, therefore, there is a huge pressure from the operators to start network operation, and from the users to see fulfilled the expectations that were placed at a high level; applications and contents suppliers are also in standby. All parties, somehow, are waiting for something to happen. Nevertheless, the UMTS Forum (composed mostly by suppliers) [UMTS01] keeps expectations at a high level, predicting huge revenues in the future [2005, 2010], and a massive users number arriving to the system.

UMTS brings new features, which carry also many new problems, aiming to be comprehended and solved. Radio network planning in UMTS has a high degree of complexity compared to other cellular systems. The quality criterion in Global System for Mobile Communications (GSM) for example, has been defined for basically a single type of service, enabling radio resources planning to deal with only one carrier-to-interference ratio requirement (the service is only speech). The introduction of General Packet Radio Service (GPRS) does bring some changes, but the basic decisions remain untouched.

UMTS networks will support many types of bearer services, these services being characterised by their own intrinsic properties, like bit rate, Bit Error Rate (BER), blocking probability, maximum delay, etc. Naturally, these imply a more complex radio network planning. Therefore, the characterisation of main parameters (with more impact on coverage and capacity) in UMTS, is an important task.

From the cellular operator point of view, there is one vital issue, network planning and optimisation, which main goals are to minimise the financial cost (minimising the number of base stations), guaranteeing the desired quality and network capacity. There are not direct and simple methods or algorithms capable of accomplishing these goals; therefore, solving these complex and important problems is highly motivating. Work in these areas has already begun, for example the STORMS project [MePi99] optimises the cellular network coverage by minimising the use of network resources (i.e. base stations and their controllers). More recently the MOMENTUM project [MOME01] intends to perform a study on UMTS networks and produce a powerful simulator to estimate the capacity, coverage, and Base Station (BS) deployment, based on services definition and usage profiles and planning scenarios. In [KNLA01], it is also presented a new approach to UMTS radio planning; however, it is build on theoretical scenarios, becoming far from European cities reality.

As already mentioned, UMTS planning and optimisation has a huge interest and importance to the mobile world, and it is the main objective of this thesis. In order to accomplish this goal, some vital steps must be accomplished, like the study of UMTS network radio air interface, services and applications definition and characterisation, system simulation algorithm, optimisation algorithms, traffic prediction, traffic generation, and finally how to obtain some optimal results. One main parameter, which must be optimised, is the number of BSs in the network, or the average BS radius.

In order to accomplish these results, a software tool, capable of providing the optimum cell radius and antenna height for UMTS-FDD, based on major network parameters, traffic forecast and environment, was developed in this work.

This thesis is organised in 6 chapters, including this one. In Chapter 2, some basic radio systems aspects are described, oriented to radio networks planning, like air interface, propagation, link budget, capacity and traffic models. Chapter 3 gives an overview of 3G systems, and presents an approach to 3G planning strategies and cellular architectures. Chapter 4 describes the implementation of the models presented in Chapters 2 and 3, the developed planning and optimisation algorithm being detailed. Chapter 5 deals with simulation results, where the UMTS Forum scenario is used, and the network sensitivity to system and scenarios parameters variation

is tested. In Chapter 6, final conclusions are presented and future research work lines are also proposed.

This thesis introduces some new and innovated approaches to UMTS radio network analysis, based on system optimisation simulations results, several answers to operator's, frequently asked questions being given. For example: "Which is the optimum cell radius, when  $n$  users using multi services (circuits and packets) are connected, within a set of environmental and system parameters?". In order to achieve these kind of answers, three main planning issues were simulated and optimised: propagation, traffic generation and service usage characterisation. The planning and optimisation algorithm produces good results, using less computational effort and time compared with other heavier simulators build in European projects, like ASILUM [Héra02], STORMS [MePi99] and more recently the MOMENTUM project [MOME01].



## 2 Radio Systems Aspects

### 2.1 System Description

#### 2.1.1 Operation Modes and Multiple Access

UMTS may work in two different modes, the TDD and the FDD ones [3GPP00e] [3GPP00f], which means that channels in the UL and DL will be managed in two different ways:

- In the FDD mode, two pairs of frequency bands are used at the same time, one for UL and the other for DL. This mode uses Wideband Code Division Multiple Access (WCDMA), the carried services being characterised by their symmetric traffic, like voice. This mode will be the most used, being deployed in every kind of environment, particularly in macro- and micro-cells, which is the reason why this thesis addresses the FDD mode.
- In the TDD mode, both links (UL and DL) use the same frequency, through a scheme of Time Division - Code Division Multiple Access (TD-CDMA) in unpaired bands, which will be advantageous to handle services with asymmetric traffic, like Internet one. It will be used mainly in pico-cells (indoor) or in hot-spot areas.

The frequency bands that are allocated for the FDD mode are [3GPP00b]:

- 1920 – 1980 MHz : UL
- 2110 – 2170 MHz : DL

while for the TDD mode the following are allocated [3GPP00e]:

- 1900 - 1920 MHz : UL/DL
- 2010 - 2025 MHz : UL/DL

Each Radio Frequency (RF) channel in UMTS has a 5 MHz bandwidth, for both FDD and TDD modes, which leads to a total of 12 channels in FDD and 7 in TDD.

The key properties of WCDMA are [OjPr98]:

- Improved performance over 2G systems, including:
  - improved capacity;
  - improved coverage, enabling migration from a 2G deployment.
- A high degree of service flexibility, including:
  - support of a wide range of services, with a bit rate up to 2 Mbps, and the possibility for multiple parallel services in one connection;
  - a fast and efficient packet-access scheme.

- A high degree of operator flexibility, including:
  - support of asynchronous inter-base-station operation;
  - efficient support of different deployment scenarios, including Hierarchical Cell Structure (HCS) and hot-spot scenarios;
  - support of evolutionary technologies, such as adaptive antenna arrays (AAA), multi-user detection (MUD) and DL antenna diversity;
  - a TDD mode designed for efficient operation in uncoordinated environments.

The wide bandwidth of WCDMA gives an inherent performance gain over previous cellular systems, since it reduces the fading of the radio signal. In addition, WCDMA uses coherent demodulation in UL, a feature that was not previously implemented in cellular CDMA systems. Fast power control in DL will also increase network performance, especially in indoor and low-speed outdoor environments, which will increase cell capacity by at least a factor of two. Fast power control has a major impact on the performance of a WCDMA system in several ways:

- The fast fading channel may be counterbalanced by power control, changing the fading channel into a non fading one;
- The fading channel compensation by power control leads to peaks in Mobile Station (MS) transmission power, which affect the inter-cell interference in the network;
- Fast power control stabilises the MS power at the BS, avoiding the near-far effect in UL.

The power control algorithm is implemented based on the Signal-to-Interference Ratio (SIR). The objective of the algorithm is to keep SIR at a suitable level by adjusting the transmission power. The principle is very simple: the received SIR level is compared to an appropriate threshold; if it is higher than the threshold, the receiver sends to the transmitter a "power down" command, otherwise a "power up" command is sent.

The coverage demonstrated for WCDMA shows that it is possible to reuse GSM1800 cell sites when migrating from GSM to UMTS, supporting high-rate services. Assumptions for this comparison are that the average MS output power is equal in UMTS and GSM [OjPr98]. Some simulations show that speech over WCDMA will tolerate a few dB higher path loss than GSM. This means that WCDMA gives better speech coverage than GSM, reusing the same cell sites, when the latter is deployed in the nearby frequency band.

One of the most important characteristics of WCDMA is the fact that power is the common shared resource among users. In DL, the total transmitted power of an RF carrier is shared among users, while in UL, there is a maximum tolerable interference level at the BS receiver; this maximum interference power is shared among transmitting MSs in the cell, in the sense that each one contributes to the interference. Power being the common resource makes WCDMA very flexible in handling mixed services, as well as services with variable bit-rate

demands. Radio resource management is done by allocating power to each user (connection) to ensure that the maximum interference is not exceeded. Reallocation of codes or time slots is normally not needed as the bit rate demand changes, which means that the physical channel allocation remains unchanged even if the bit rate changes. Furthermore, WCDMA requires no frequency planning, since a cell reuse factor of one is applied.

### 2.1.2 WCDMA Air Interface

A unique code sequence, called "spreading code", is assigned to each user, which is used to encode the information-bearing signal. The receiver, knowing the code sequence of the user, decodes the received signal after reception, and recovers the original data; this is possible due to the low cross correlations between the code of the desired user and the codes of the other users. The bandwidth of the code signal is chosen to be much larger than the bandwidth of the information-bearing signal, hence, the encoding process spreads the spectrum of the signal. Therefore, a spread-spectrum technique must carry out two criteria:

1. The transmission bandwidth must be much larger than the information bandwidth;
2. The bandwidth must be statistically independent of the information signal.

The flexibility supported by WCDMA is achieved with the use of Orthogonal Variable Spreading Factor (OVSF) codes for channelisation of different users. OVSF codes have the characteristic of maintaining DL transmit orthogonality among users (or different services allocated to one user) in an ideal scenario, even if they operate at different bit rates. Therefore, one physical resource can carry multiple services with variable bit rates. As the bit rate demand changes, the power allocated to this physical resource is adjusted, so that Quality of Service (QoS) is guaranteed at any instant of the connection.

The ratio of the transmitted bandwidth,  $B_p$ , to information bandwidth,  $B_i$ , is called the processing gain,  $G_p$ :

$$G_p = \frac{B_p}{B_i} \quad (2.1)$$

Many times, the processing gain is also expressed in terms of the information bit rate,  $R_b$ , and the code chip rate  $R_c$ ,

$$G_p = \frac{R_c}{R_b} \quad (2.2)$$

Transport channels are the services offered by layer 1 to higher layers. Transport channels are always unidirectional, and are defined by how and with what characteristics data is transferred over the air interface. The classification of transport channels is the following [3GPP00g]:

- Dedicated channels (allocated to a specific user), using inherent addressing of User Equipment (UE). There is only one type of dedicated transport channel, the Dedicated Channel (DCH), which can be either DL or UL. The DCH is transmitted over the entire cell, or over only a part of it.
- Common channels (shared among several users), using explicit addressing of UE if addressing is needed. There are six types of common transport channels:
  - Broadcast Channel (BCH), which is a DL channel that is used to broadcast system and cell-specific control information;
  - Forward Access Channel (FACH), which is a DL transport channel used to carry control information and short user packets to a MS, when its location is known to the system;
  - Paging Channel (PCH), which is a DL channel used to carry control information to a MS, when its location is not known to the system;
  - Random Access Channel (RACH), which is a UL channel used to carry control information and short user packets;
  - Common Packet Channel (CPCH), which is a UL channel associated with a dedicated channel on the DL that provides power control and control commands;
  - Downlink Shared Channel (DSCH), which is a DL channel shared by several users, being associated to one or several DL DCHs.

Physical channels usually consist of a structured layer of radio frames and time slots, although this is not true for all physical channels. Depending on the channel bit rate of the physical channel, the configuration of the slot varies. A radio frame, 10 ms long is a processing unit that consists of 15 slots, its length corresponding to 38 400 chips: a slot is a unit that consists of fields containing bits, its length corresponding to 2 560 chips. The number of bits per slot may be different for different physical channels, and may, in some cases, vary in time.

The UL Dedicated Physical Control Channel (DPCCH) is used to carry control information generated at layer 1, which consists of known pilot bits that support channel estimation for coherent detection, Transmit Power-Control (TPC) commands, Feedback Information (FBI), and an optional Transport-Format Combination Indicator (TFCI). TFCI informs the receiver about the instantaneous transport format combination of the transport channels mapped on the simultaneously transmitted UL Dedicated Physical Data Channel (DPDCH) radio frame. There is one and only one UL DPCCH on each radio link. Figure 2.1 shows the frame structure of UL dedicated physical channels.

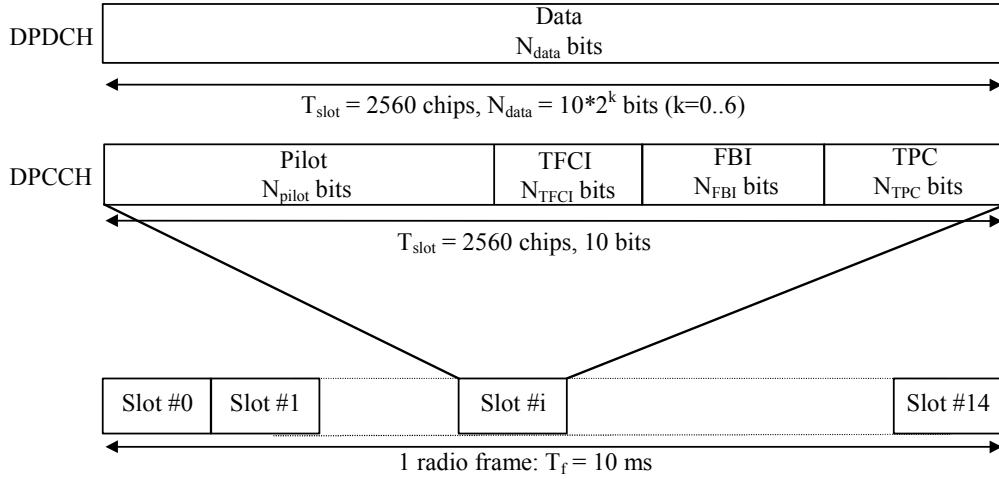


Figure 2.1 - Frame structure for UL DPDCH/DPCCH (extracted from [3GPP00c]).

In UL, a specific code is assigned to each MS for spreading purposes, which is called scrambling code. Different channels from the same MS are distinguished by a second spreading code, the channelisation code [3GPP00d]. The Spreading Factor (SF) and the total number of bits per DL Dedicated Physical Channel (DPCH) slot are determined by  $k = 0 \dots 7$ , where  $SF = 512/2^k$ ; thus, the SF may range from 4 to 512. There is only one type of DL DPCH, within each dedicated data generated at layer 2, and above it is transmitted in time-multiplex with control information generated at layer 1 (known pilot bits, TPC commands, and an optional TFCI). Hence, the DL DPCH can be seen as a time multiplex of a DL DPDCH and a DL DPCCH. Figure 2.2 shows the frame structure of the DL DPCH.

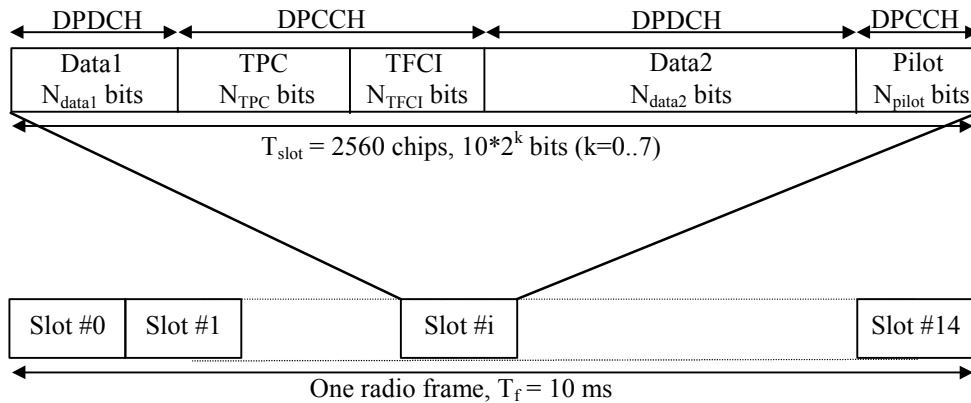


Figure 2.2 - Frame structure for DL DPCH (extracted from [3GPP00c]).

In UMTS the spreading operation of physical channels is carried out in two consecutive steps:

1. Data is multiplied by the channel code (direct sequence);

2. The complex signal obtained by adding several spread physical channels from I (in phase) and Q (in quadrature) branches is multiplied by a complex value, corresponding to a transmitter specific scrambling code.

### 2.1.3 Code Generation

DPDCHs and DPCCH are spread by a specific code, chosen from a node of the OVSF tree represented in Figure 2.3, which preserves the orthogonality between users in different physical channels. Channelisation codes are uniquely described as  $C_{ch,SF,k}$ , where SF is the code spreading factor and  $k$  is the code number,  $0 \leq k \leq SF-1$ , each level in the code tree defining channelisation codes of length SF.

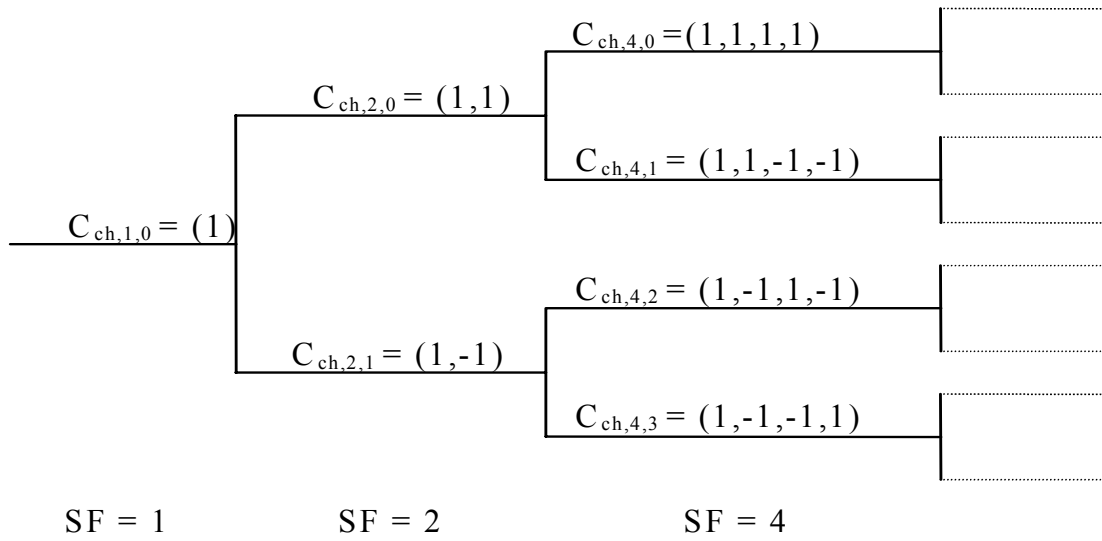


Figure 2.3 - Code-tree for generation of OVSF codes (extracted from [3GPP00d]).

Multipath is an expected phenomenon in mobile communications environments. The original transmitted signal diffracts and reflects from several obstacles, e.g. buildings, therefore, the receiver gets several copies of the signal with different delays; because of this, codes lose their orthogonality level. In order to compensate for this problem, the RAKE receiver is used. The RAKE receiver is based on several correlators, each receiving and processing a different multipath signal. The main function of these correlators (fingers) is despreading the different signals and combining them, thus, taking advantage from the multipath channel environment. The number of RAKE correlators is an important factor: the higher the number of fingers, the more optimised the reception capacity will be; however, the complexity of the receiver increases very fast when the number of fingers increases (Annex A).

### 2.1.4 Handover

Handover is one of the most important mechanisms in all wireless networks, since it provides the maintenance of seamless communication when the MS moves from one site to another.

In UMTS there are different types of handover mechanisms:

- Soft Handover (SH);
- Softer Handover;
- Hard Handover.

SH means that the MS is simultaneously connected to more than one Node B (BS), Figure 2.4. The main reason for SH is the reduction of the interference into other cells, another advantage being the performance improvement through macro diversity coming from the diversity gain provided by the reception of one or more additional signals. In DL, the MS can combine signals from more than one BS, since the MS sees each BS as just one more multipath component; with this type of technique, the receiver may see different BSs as one. In the UL, more than one BS can receive the same signal due to the reuse factor of one, combining being done at the Radio Network Controller (RNC). The SH state is reached by a MS when the signal strength of a neighbouring cell exceeds a certain level, but it is still below the current BS signal strength.

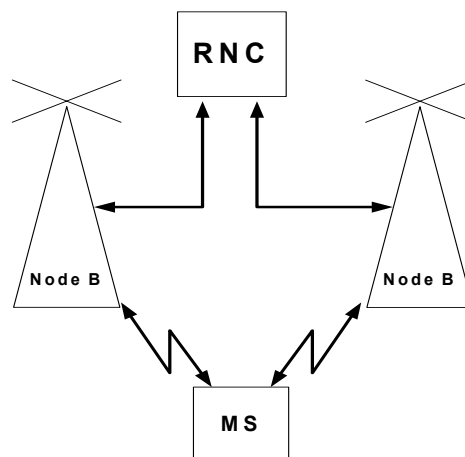


Figure 2.4 - Soft Handover example.

Softer Handover is the same as SH, but it works inside the same BS, which means, handover between different sectors in a BS.

The Hard Handover exists because the architecture of the UMTS network will consist of micro-cells overlaid by macro-cells, each having multiple frequency carriers, but micro- and macro-cells may also have different ones. Hot-spot cells can have a larger number of carriers than the surrounding ones, therefore, a different mechanism of handover is necessary between

different frequencies, which is Hard Handover. The support of seamless Hard Handover through a DL slotted mode is a key feature of WCDMA, not previously implemented in cellular CDMA. Hard Handover is necessary for the support of HCS: a cellular system can provide very high capacity through the micro-cell layer, offering at the same time full coverage and supporting high mobility via the macro-cell one, therefore Hard Handover being needed to perform handover between the different layers. A second scenario where Hard Handover is necessary is the hot-spot one, where a certain cell that serves a high traffic area uses carriers in addition to those used by the neighbouring cells. If the deployment of extra carriers is to be limited to the actual hot-spot area, the possibility of Hard Handover is essential.

The Hard Handover means also that a MS makes handover between 2G systems and UMTS, this type of handover implying a commutation between different systems, frequency bands and air interface. Therefore, the complexity of the terminal increases, due to terminal multi-mode and multi-band features.

## 2.2 Services, Applications and Scenarios

In GSM, basically one has only one major service, speech (circuit switching), from which a network cannot offer many services and applications to a demanding user. UMTS will be able to supply a wide range of services with different bit rates and flexible traffic asymmetry.

The services definitions are based on market forecasts by the UMTS Forum, Table 2.1. The Speech (S) service corresponds to a GSM speech CODEC. The channel coding gives rise to an overhead of 1.75 times the user net bit rate of the CODEC. Speech is a symmetric service with the same amount of information in the UL as in the DL, and an occupancy factor of 0.5 is assumed, which implies that the system should be able to handle the discontinuous transmission mode. The Simple Messaging (SM) service is the evolution of the GSM Short Message Service (SMS). The user net bit rate of the SM service is based on the assumption that the typical size of a message is 40 kbyte, and an acceptable delay for this service is assumed to be 30 s (user net bit rate 10.67 kbps). The final user net bit rate is deducted by dividing the obtained relation between the file size and the acceptable delay to get an equivalent continuous user net bit rate. Further on, an assumption is made of a packet efficiency factor of 0.75. The Switched Data (SD) is a 14.4 kbps CS service type similar to existing data services GSM. The same type of calculations is made in order to find the user net bit rate for the medium and high MultiMedia (MM) services; the services are similar to evolved World Wide Web (WWW) types of services. The typical amount of data that needs to be transmitted for the medium MM service is 0.5 Mbytes during 14 s (user net bit rate 286 kbps), while the same figures for the high MM service are 10 Mbytes and 53 s (user

net bit rate 1.51 Mbps). Further on, the MM services are assumed to be asymmetrical, and it is assumed that the interactive MM service is based on a 128 kbps symmetrical connection.

Table 2.1 - Types of Services (extracted from [Garcia00]).

Services	Applications
Speech (S) (symmetric)	<ul style="list-style-type: none"> <li>• Simple one to one and one to many voice (teleconferencing) services</li> <li>• Voicemail</li> </ul>
Simple Messaging (SM) (asymmetric)	<ul style="list-style-type: none"> <li>• SMS (short message delivery) and paging</li> <li>• Email delivery</li> <li>• Broadcast and public information messaging</li> <li>• Ordering/payment (for simple electronic commerce)</li> </ul>
Switched Data (SD) (symmetric)	<ul style="list-style-type: none"> <li>• Low speed dial-up LAN access</li> <li>• Internet/Intranet access</li> <li>• Fax</li> </ul> <p>Legacy services, mainly using radio modems such as PCMCIA cards, are not expected to be very significant by 2005.</p>
Medium Multimedia (MMM) (asymmetric)	<p>Asymmetric services which tend to be 'bursty' in nature, require moderate data rates, and are characterised by a typical file size of 0.5 Mbytes, with a tolerance to a range of delays. They are classed as PS services.</p> <ul style="list-style-type: none"> <li>• LAN and Intranet/Internet access</li> <li>• Application sharing (collaborative working)</li> <li>• Interactive games</li> <li>• Lottery and betting services</li> <li>• Sophisticated broadcast and public information messaging</li> <li>• Simple online shopping and banking (electronic commerce) services</li> </ul>
High Multimedia (HMM) (asymmetric)	<p>Asymmetric services, which also tend to be 'bursty' in nature, require high bit rates. These are characterised by a typical file size of 10 Mbytes, with a tolerance to a range of delays. They are classed as PS services.</p> <ul style="list-style-type: none"> <li>• Fast LAN and Intranet/Internet access</li> <li>• Video clips on demand</li> <li>• Audio clips on demand</li> <li>• Online shopping</li> </ul>
High Interactive Multimedia (HIMM) (symmetric)	<p>Symmetric services which require reasonably continuous and high-speed data rates with a minimum of delay.</p> <ul style="list-style-type: none"> <li>• Video telephony and video conferencing</li> <li>• Collaborative working and telepresence</li> </ul>

The signalling overhead, training sequence and for the radio interference for all types of service is 20 %. The above figures indicate representative delays that might be acceptable for PS

services. In reality, a range of delay constraints will be appropriate, depending on the nature of the application being supported over the radio interface. The delays represent a user net bit rate that is slightly lower than the nominal rate. However, the assumption made in the calculations is that the traffic carried for PS applications will include session control overheads (not to be confused with the air-interface signalling overheads), including set-up and clear-down control messages. These overheads will be invisible to the user, but will occupy the channel apparent delay time. In the absence of detailed applications information, it is assumed that the gross traffic bit rate offered to the air interface is equal to the nominal user bit-rate. Therefore, nominal bit rates are used in the spectrum calculations.

Table 2.2 - Service Characteristics (adapted from [UMTS98b]).

Services	User nominal bit rate [kbps]	Effective call duration [s]	User net bit rate [kbps]	Coding factor	Asymmetry factor	Switch Mode	Service bandwidth [kbps]
HIMM	128	144	128	2	1/1	CS	256/256
HMM	2000	53	1509	2	0.005/1	PS	15/3200
MMM	384	14	286	2	0.026/1	PS	15/572
SD	14	156	14.4	3	1/1	CS	43/43
SM	14	30	10.67	2	1/1	PS	22/22
S	16	60	16	1.75	1/1	CS	28/28

Table 2.2 shows UMTS service characteristics [UMTS98b], where one can find some major service parameters that make possible traffic and capacity estimations, and can be explain as follows [Garcia00]:

- User Nominal Bit Rate corresponds to the output bit rate from the source without error protection.
- Effective Call Duration of a service corresponds to how long, on average, the service is connected. It is based on the average call duration multiplied by the occupancy factor (see Table 2.3). The usage of the occupancy factor (the occupancy indicates if and how much, on average, the activity of the service will vary) implies that the system should be able to handle the discontinuous transmission mode.
- User Net Bit Rate is a measure of the bit rate taking into account the packet efficiency factor, which is based on considerations of practical packet networks and includes the effect of retransmission of unsuccessful packets.
- Coding Factor is a generalised measure of the degree of coding required to transport the service to the required quality.
- Asymmetry Factor is used to show that some services will have a different load (bit rate and bandwidth) in the UL and DL.

- Service Bandwidth is the product of user nominal bit rate, coding factor and asymmetry factor.
- Switch Mode defines if the service is CS or PS, since the call duration and the occupancy are not suitable to characterise PS services, an estimation of effective call duration is generated.

The various service classes have different characteristics. HIMM, e.g., video telephony, require isochronous transmission, as well as SD and S. Therefore, they are calculated as CS services. This means that the average call duration time corresponds to the actual connection set-up time, and that the effective call duration depends on the occupancy factor, which is 0.5 for speech and 0.8 for video telephony. For PS services, the call duration is calculated as the sum of time intervals, where data is actually transferred via the air interface; thus, the occupancy factor in this scenario is equal to one, Figure 2.5. The effective call duration per service according to occupancy and average call duration is given in Table 2.3.

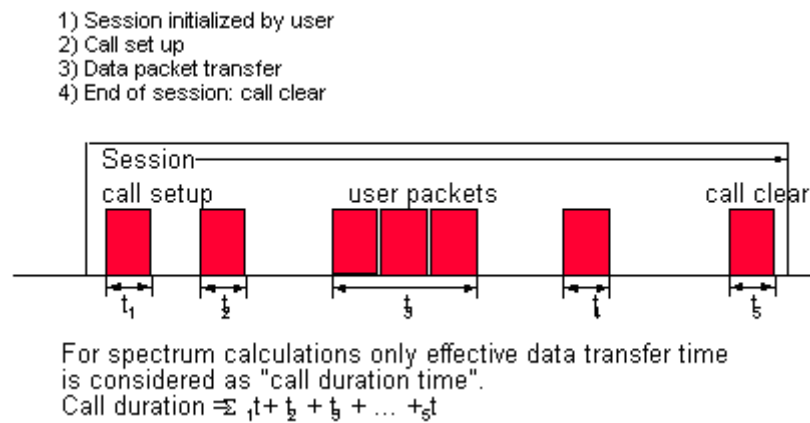


Figure 2.5 - Packet transmission over the UMTS Air Interface (extracted from [UMTS98a]).

Table 2.3 - Effective Call Duration (extracted from [UMTS98b]).

Services	Occupancy	Average call duration [s]	Effective call duration[s]
HIMM	0.8	180	144
HMM	1	53.3	53.3
MMM	1	13.9	13.9
SD	1	156	156
SM	1	30	30
S	0.5	120	60

The call duration and the occupancy are not suitable to characterise packet switched services. However, an estimation of effective call duration, and the equivalent offered bit quantity that packet services will generate, can be based on calculations that consider busy hour calls and an acceptable throughput and delay for packet services. The effective call duration for packet based services should be interpreted with an acceptable delay.

The 3GPP services classification is shown in Table 2.4, where one may find four main traffic or service classes: Conversational, Streaming, Interactive and Background. These classes may be described as follows [HoTo00]:

- Conversational: Real time applications (speech services, voice over IP, video telephony), strict low end-to-end delay.
- Streaming: Streaming data transferring applications (web broadcast, video streaming on demand), with high symmetric traffic.
- Interactive: Client-Server applications (web browsing, database access, games, tele-machines), low round trip delay is required.
- Background: Long delay applications (SMS, e-mail, downloading databases, etc).

Table 2.4 - 3GPP traffic classes classification.

		Traffic class			
		Conversational	Streaming	Interactive	Background
Fundamental characteristics	Connection delay (main attribute)	Minimum fixed	Minimum variable	Moderate variable	Big variable
	Buffering	No	Allowed	Allowed	Allowed
	Nature of traffic	Symmetric	Asymmetric	Asymmetric	Asymmetric
	Bandwidth	Guaranteed bit rate	Guaranteed bit rate	No guaranteed bit rate	No guaranteed bit rate

Traffic is a major parameter, because radio network planning is designed as a function of it, therefore, it is necessary to perform some traffic forecast based on users and services statistics. Table 2.5 shows statistical information that is fundamental for the network planning process, since most of traffic estimation is dependent on user density, therefore, the corresponding network capacity estimation for each operational environment may be obtained. Only three of the operational environments (marked in bold in Table 2.5) contribute to the maximum total amount of capacity required, because they coexist in the same geographical area, and, of course, present high user density values.

It should be noted that the conclusions made here are dependent upon market forecasts data for the years up to 2005 [UMTS98b]. For example, it is assumed that 90% of the total speech and low speed data traffic will be carried over existing 2G networks within this period. It is also considered that 60% of the indoor traffic will be carried over license-exempt networks, and that high (2 Mbps) and medium (384 kbps) multimedia services are PS, which are tolerant to

delay. It is important to note that although the majority of users will continue to use speech, most of the capacity is needed for multimedia services. The UMTS Forum (Spectrum Aspects Group) assumptions are that market is expected to continue to grow strongly after this date, and additional spectrum will be required in the future (up to year 2010).

Table 2.5 - Operational environment and cell types (extracted from [UMTS98b]).

Operational environments	Density of potential users/km <sup>2</sup>	Cell Type
CBD/Urban(in building)	<b>180 000</b>	Micro/pico
Suburban (in building or on street)	7 200	Macro
Home (in building)	380	Pico
Urban (pedestrian)	<b>108 000</b>	Macro/micro
Urban (vehicular)	<b>2 780</b>	Macro/micro
Rural in- & out-door	36	Macro

UMTS is primarily envisaged for multi-service in these environments, and inhomogeneous traffic distributions are expected to occur, where the asymmetric traffic will be the main reason for this.

## 2.3 Propagation

### 2.3.1 Propagation Models

In order to perform radio network planning, among other things, it is essential to estimate the propagation loss as a function of a given propagation environment (indoor, outdoor, urban, rural, etc). This key parameter makes the estimation of several other main network planning parameters possible, like average mobile received power, cell coverage, interference and load factor.

In this thesis, several propagation models were studied, but only the following are presented, due to their particular characteristics:

- 3GPP;
- COST 231 - Walfisch-Ikegami;
- COST 231 - Hata.

3GPP proposes a propagation model for macro- and micro-cells [3GPP00a], where two propagation environments are considered. For each environment, a different formulation is used to evaluate the path loss. An important parameter to be defined is the Minimum Coupling Loss (MCL), i.e., the minimum distance loss, including antenna gain, measured between antenna connectors; the following values are assumed for MCL: 70 dB for the macro-cellular

environment, and 53 dB for the micro-cellular one. The MCL is most important for the study of the near-far effect limitations.

The macro-cell model is applicable for scenarios in urban and suburban areas outside the high rise core, where buildings are of nearly uniform height [ETSI98]. Also the micro-cell model is adopted from [ETSI98]. This model is to be used for spectrum efficiency evaluations in urban environments, through a Manhattan-like structure, in order to properly evaluate the performance in micro-cell situations that will be common in European cities at the time of UMTS deployment. The proposed model is a recursive one, which calculates the path loss as a sum of Line of Sight (LoS) and Non Line of Sight (NLoS) segments. The shortest path along streets between the BS and the MS has to be found within the Manhattan environment (for more details see Annex B).

The well-know semi-empirical Walfisch and Bertoni [WaBe88] and Ikegami [IkYU84] propagation models, were adapted by COST 231 based on measurements performed in Europe [DaCo99], producing acceptable estimations for urban environments. Like any kind of propagation model, this one also has some constrains, e.g., on frequency band, BS height and distance. For example, the validity range of this model in frequency is [800, 2000] MHz, while UMTS works in [1900, 2170] MHz, hence, for the upper band of UMTS one will be using the model outside its range; nevertheless, this does not imply a large error, since the difference in frequency is not large. This model has also distance limitations between BS and MS, being applicable for NLoS in [0.2, 5] km, and in [0.02, 0.2] km for LoS. These ranges satisfy the major UMTS micro-cell radius, mainly in urban areas. Therefore, this model may be used for estimation of signal propagation loss in UMTS (more details in Annex B).

The Okumura-Hata Model empirical propagation model is based on approximations performed by Hata [Hata80] supported on Okumura et al. model [OOKF68]. It gives the average field intensity, which depends on frequency, distance, antennas height, type of environment where the MS moves, and characteristics between the BS and MS. This model is applicable to long distances between the MS and the BS. COST 231 has investigated this model, and created a new one, called the COST 231-Hata-Model [DaCo99], which corresponds to extending Hata's model to the frequency band [1500, 2000] MHz (more details in Annex B).

Combining the output of one of these models (Path Loss) with the link budget, it is possible to estimate the cell coverage as a function of a given service; therefore, it is possible to estimate the number of cells in a given area, which is one major goal of this work.

These models have some validity limitations, as for example frequency up to 2000 MHz; as explained before this, does not imply a large error. In order to choose a model to be implemented in this thesis, some differences among these models must be identified, like propagation environments or cell types (dimensions); the 3GPP model is more dedicated to

micro-cells in a city with a Manhattan like urban structure; the COST 231 – Hata is for macro-cells and urban and suburban environments; the COST 231-Walfisch-Ikegami model is dedicated to dense urban (European type) scenarios and for micro-cells. In this work, the main goal is to achieve optimal network values for this last scenario, therefore, the COST 231-Walfisch-Ikegami propagation model was selected and implemented in this thesis.

### 2.3.2 Link Budget

In order to perform radio network planning, one needs to establish the link budget for coverage, capacity and optimisation reasons. Reference [HaTo00] presents the link budget algorithm, which enables the estimation of the allowed maximum propagation loss  $L_{pmax}$ .

A common parameter between propagation models and link budget algorithms is the path loss,  $L_p$ ,

$$L_{pmax}[\text{dB}] = P_t[\text{dBm}] + G_t[\text{dBi}] + G_r[\text{dBi}] + G_{SH}[\text{dB}] - R_{Smin}[\text{dBm}] - \sum L_x[\text{dB}] - \sum F_M[\text{dB}] \quad (2.3)$$

where:

- $L_{pmax}$  is the maximum propagation loss allowed for a given service;
- $P_t$  is the transmitted power (delivered to the antenna);
- $P_{Tx}$  is the transmitter output power;
- $P_r$  is the antenna received power;
- $P_{Rx}$  is the receiver input power;
- $G_t$  is the maximum transmitter antenna gain;
- $G_r$  is the maximum receiver antenna gain;
- $G_{SH}$  is the soft handover gain;
- $R_{Smin}$  is the receiver sensitivity for a given service bearer;
- $L_x$  represents additional attenuations in a link, which may be user body loss  $L_{UB}$ , cable loss  $L_C$ , and others (car loss)  $L_{Other}$ ;
- $F_M$  represents fading margins, i.e., fast fading margin  $F_{FM}$ , and slow fading margin  $F_{SM}$ .

The Equivalent Isotropic Radiated Power (EIRP), depends on  $P_t$  and  $G_t$  as follows:

$$EIRP_{[\text{dBm}]} = P_t[\text{dBm}] + G_t[\text{dBi}] \quad (2.4)$$

where  $P_t$  is defined by:

$$P_t[\text{dBm}] = P_{Tx}[\text{dBm}] - L_C[\text{dB}] \quad (2.5)$$

and  $P_{Rx}$  is defined as follows:

$$P_{Rx}[\text{dBm}] = P_r[\text{dBm}] - L_C[\text{dB}] \quad (2.6)$$

A major parameter in radio network planning is  $R_{Smin}$ , because it depends on the service type (energy of bit over noise and bit rate), therefore, different  $L_{Pmax}$  and cell radius are expected for each service.  $R_{Smin}$  is defined as follows:

$$R_{Smin[dBm]} = \frac{E_b}{N_0 [dB]} - G_P[dB] + N[dBm] \quad (2.7)$$

where:

- $E_b/N_0$  is a relation between energy of bit and noise density which depends of the service, mobile speed, receiver algorithms and BS antenna structure;
- $G_P$  is the processing gain, which depends on the relation between chip rate and bit rate (2.2);
- $N$  is the total effective noise plus interference power.

$N$  can be written as:

$$N_{[dBm]} = 10 \log(10^{R_N[dBm]/10} + 10^{R_I[dBm]/10}) \quad (2.8)$$

where the receiver interference power  $R_I$ , is given by:

$$R_{I[dBm]} = 10 \log(10^{(R_N[dBm] + I_m[dB])/10} - 10^{R_N[dBm]/10}) \quad (2.9)$$

and the receiver noise power  $R_N$ , is given by:

$$R_{N[dBm]} = R_{NO[dBm/Hz]} + 10 \log[3.840 \cdot 10^6 [cps]] \quad (2.10)$$

where:

- $I_m$  is the interference margin;
- $R_{NO}$  is the receiver noise density;

The receiver noise density,  $R_{NO}$  depends on the thermal noise density  $N_o$  and on the noise factor,  $F_N$ .

$$R_{NO[dBm/Hz]} = N_o[dBm/Hz] + F_N[dB] \quad (2.11)$$

Using propagation models and link budgets algorithms, it is possible to estimate the interference load in a given area, therefore in a given cell (BS).

To estimate the amount of supported traffic (capacity) per BS, it is very important to calculate the interference, because cellular systems that use a frequency reuse factor of 1 are typically strongly interference-limited by the air interface. Therefore, the amount of interference and cell capacity must be estimated.

## 2.4 Capacity and Interference

Capacity evolution is a key issue in cellular systems, it being important to estimate the number of users per cell and per MHz. Capacity in UMTS depends mainly on: DL total power, available channel codes that depend on users behaviour (used services, bit rate,  $E_b/N_0$  targets), quality network targets (blocking and delay), urban environment (multipath spread), signalling, and soft handover channels.

As shown in [HaTo00], capacity depends more on the load in DL than UL. The reason is that in DL the maximum transmission power is the same, regardless of the number of users, and it is shared among users, while in UL each additional user has its own power amplifier. Therefore, even with low load in DL, coverage decreases as a function of the number of users. So one may conclude that coverage is limited by the UL, while capacity is DL limited.

The capacity formula for the network without MUD in the BS is defined for UL and DL. The maximum MS Tx power is 21 dBm (both for speech and data) and the MS power control range is 65 dB (the minimum Tx power is -44 dBm). Values for the UL  $E_b/N_0$  targets are presented in Table 2.6.

Table 2.6 - UL  $E_b/N_0$  target for different cells and type of services (adapted from [3GPP00a]).

Environment	$E_b/N_0$ [dB]	
	Speech	Data
Macro-cellular	6.1	3.1
Micro-cellular	3.3	2.4

Dividing the received signal by the interference and multiplying by the processing gain, the local-mean SIR is calculated. Signals from other users are summed together and seen as interference.  $SIR_{UL}$  will be as follows [3GPP00a]:

$$SIR_{UL} = \frac{G_p \cdot S}{(1 - \beta) \cdot I_{Intra} + I_{Inter} + N_0} \quad (2.12)$$

where:

- $G_p$  is the processing gain;
- $S$  is the received signal;
- $I_{Intra}$  is interference generated by those users that are connected to the same BS that the observed user;
- $I_{Inter}$  is interference from other cells;
- $N_0$  is thermal noise, which may be neglected when compared with interference levels;

- $\beta$  is an interference reduction factor due to the use of, for example, MUD in UL.

A rough estimation for  $I_{Intra}$  is to make it equal to  $SN_U$ , where  $N_U$  is the number of users that are associated or connected to a given BS. The fraction  $F$  of the intracell interference  $I_{Intra}$  generated by users connected to the same cell and by the total of interference ( $I_{Intra} + I_{Inter}$ ) is given by the following equation:

$$F = \frac{I_{Intra}}{I_{Intra} + I_{Inter}} \quad (2.13)$$

where  $F$ , simulated in [OjPr98] for macro-cells, is about 0.73. In the multi-operator case,  $I_{Inter}$  may include the interference coming from the adjacent operator.

A rough system capacity estimation [OjPr98] may be written as:

$$N_U = F \frac{G_p \left( \frac{E_b}{N_0} \right)^{-1} - (\beta - 1)}{1 + F\beta} \quad (2.14)$$

If MUD is not included in the simulations,  $\beta = 0$  must be considered, which represents the conventional RAKE receiver-based system.

Working assumption for DL traffic channel power control range in [3GPP00a] is 25 dB, and the maximum power for each DL traffic channel is (both for speech and data) shown in Table 2.7, where input values for simulation are presented, as well as target values for  $E_b/N_0$ .

Table 2.7 - Values for each DL traffic channel (adapted from [3GPP00a]).

Environment	Max. Tx Power [dBm]	$E_b/N_0$ [dB]		
		Speech	Data	Tx or Rx Diversity
Macro-cellular	30	7.9	4.5	2.5
Micro-cellular	20	6.1	1.9	1.9

SIR in DL can be expressed as follows [3GPP00a]:

$$SIR_{DL} = \frac{G_p \cdot S}{\alpha \cdot I_{Intra} + I_{Inter} + N_0} \quad (2.15)$$

Parameter  $I_{Intra}$  includes also interference caused by traffic channel and common channels. In the multi-operator case,  $I_{Inter}$  may include the interference coming from the adjacent operator.

The orthogonality factor  $\alpha$  takes into account the fact that the DL is not perfectly orthogonal due to multipath propagation; an orthogonality factor of 0 corresponds to perfectly

orthogonal intra-cell users, while for the value of 1 intra-cell interference has the same effect as inter-cell one.

Table 2.8 presents values assumed for the orthogonality factor  $\alpha$  and for maximum transmitting power in 3GPP simulations.

Table 2.8 - Simulation input values (adapted from [3GPP00a]).

Environment	Orthogonality factor $\alpha$	Total max. BS Tx Power [dBm]
Macrocellular	0.4	43
Microcellular	0.06	33

Compared to a micro-cellular environment, a signal in macro-cellular one follows a more complex path, which is translated into a more complex multipath; because of these higher distances (more reflection and refraction points), the  $\alpha$  factor in a macro-cellular environment is expected to be higher than in a micro-cellular one.

## 2.5 Traffic Models

In 2G cellular networks like GSM, where voice (in CS) is the only service being supported (or almost), traffic has some well-know characteristics, like symmetry in UL and DL, channel assignment, call arrival rate, call duration model and blocking behaviour. This type of traffic is very easy to simulate or predict by an analytical expression, the well-know Erlang B model [Rapp96]:

$$B = \frac{\frac{A^c}{C!}}{\sum_{i=0}^c \frac{A^i}{i!}} \quad (2.16)$$

where  $B$  is the blocking probability,  $A$  is the offered traffic in Erlang, and  $C$  is the number of channels. One should note that in UMTS the number of channels is not deterministic, so this model cannot be used, unless very crude estimations are intended.

PS in relation to CS has some additional complexity, namely traffic asymmetry between UL and DL, bursty traffic, and packet delay behaviour. A service like Internet is a very popular PS example, which shows how different it can be.

In order to simulate the mixed CS and PS services behaviour, a study on traffic models was performed, aiming to build a traffic generator, traffic properties were identified. Connections arrival rate can be characterised by a Poisson distribution [Yaco93]:

$$P_n(t) = \frac{(\lambda t)^n e^{-\lambda t}}{n!} \quad (2.17)$$

where  $P_n(t)$  is the  $n$  message probability, arrived in a time interval  $t$ , and  $\lambda$  is the mean arrival rate (calls per second).

The individual packet duration is assumed as constant, but for each different service (packet based) an average connection total time is considered. The model adopted for voice call duration is the exponential negative one [Yaco93] [ETSI98]:

$$f(t) = \frac{1}{\tau} e^{-\frac{t}{\tau}}, \quad t \geq 0 \quad (2.18)$$

where  $\tau$  is the average voice call duration, and  $\mu = 1/\tau$ , is the service rate.

As referenced before, in UMTS the number of available channels is not deterministic (due to CDMA features), therefore, known traffic models for packets do not fit. This fact forces the use of random traffic generators at system level simulator.

When users do not move, or when they do not leave the cell in which the call was originated, this means that there is only inside traffic (no handover traffic); in this case, a Poisson distribution describes the call arrivals process. However, when mobility is considered, there are calls in a cell arriving from handovers, the process depending on the users speeds and cell radius, generating traffic due to handover. Therefore, these models are valid only for a static scenario. In this thesis, only one BS is simulated, hence, handover traffic it is not considered explicitly. Nevertheless, the SH impact is introduced on the network, when a given number of channel codes (default 30 %) are reserved from the channel code tree used by the BS.

Note that the work developed in this thesis encloses simulation of mixed traffic aspects for UMTS. Presently there are no adequate models for an analytical approach, therefore, in order to simulate multi-service traffic, several source models were implemented. Thus, this thesis provides a new perspective in this field.

## 3 UMTS Planning

### 3.1 Cellular Structure

Typically, the cellular structure of GSM is deployed as a function of traffic, therefore, special areas where traffic demand is huge (shopping, business, entertainment centres, etc) need special indoor coverage provided by small cells, the pico-cells. For urban outdoor scenarios, where traffic is generated mainly by pedestrian and vehicle users, micro-cells are deployed. For suburban and rural areas, where traffic is expected to be low, macro-cells are enough to serve the area, but in urban areas, macro-cells are also used, for optimisation issues, like carrying fast users or traffic management.

Naturally, scenarios for UMTS are quite the same, but there are some important differences in the operation modes: for indoor environments (pico-cells) where the asymmetric and high bit rates services are expected to be more used, the TDD mode will support this services. For the majority of micro- and macro-cells, the mode of operation will be FDD.

There are several types of cells for different environments, Figure 3.1. In this work, the satellite cell is ignored, and in many cases the pico-cell is also ignored, because this type of cell is only used for the TDD mode.

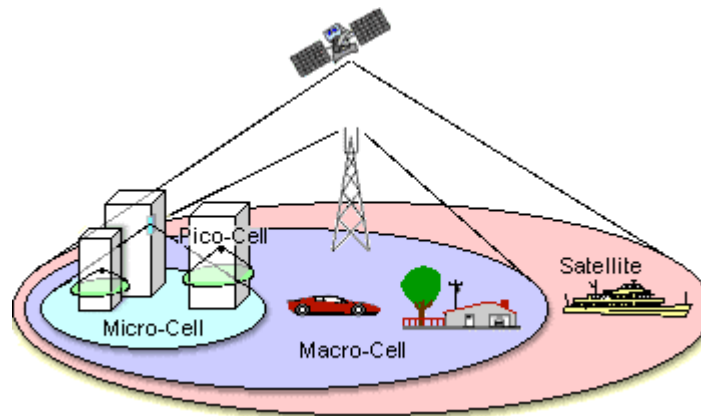


Figure 3.1 - General Hierarchical Cell Structure.

Based on [UMTS98a], the averaged cell radius for the Central Business District (CBD) is assumed to be 75 m, for both years 2005 and 2010. The average cell radius for the other two operational environments of significance (the urban, pedestrian and vehicular) is about 700 m for year 2005, and will decrease approximately to 600 m for year 2010. An average cell radius of 700 m describes an environment where the cell sizes varies from 400 m to 1 km. Similar to this, the average cell radius of 600 m corresponds to values between 300 to 900 m, Table 3.1.

Table 3.1 - Assumed BSs radius and cell areas.

Cell Type	Distance [km]	Cell area [km <sup>2</sup> ]
Macro	1	3.14
Micro	0.4	0.5
Pico	0.075	0.017

For macro- and micro-cells, the maximum available data rate is 384 kbps with full mobility, while for micro- and pico-cells with low mobility the data rate goes up to 2 Mbps.

In WCDMA, the common radio resource to be used by all users in the DL is power, since the frequency re-use of one is used for all bearer services. There is a need to plan for the number of BSs, according to the level of traffic that is expected, including the service mixture. This can be performed by using an automatic planning tool with the following inputs: expected services, radio propagation models, link budget parameters, mobile speeds, traffic loads, quality requirements, etc. However, since UMTS is not yet in operation, there is no such tool that has been assessed by experience.

For an optimal UMTS radio network, it is proposed that UMTS will be planned by using a hierarchical cell structure, composed of macro-, micro- and pico-cells, like in Figure 3.2. The choice on the UMTS mode, FDD or TDD, and on the superposition of the cells, needs to be done according to traffic demands. With a flexible deployment, it will be possible for an operator to re-deploy pico-cell channels in some indoor locations, and use these channels again in macro-cells in urban areas. Traffic is assigned to pico-cells in CBD scenarios that use the HMM service, because all urban-pedestrian HMM traffic is allocated to micro-cells (partly at a lower data rate), and all HMM urban-vehicular traffic is carried by macro-cells at a lower data rate.

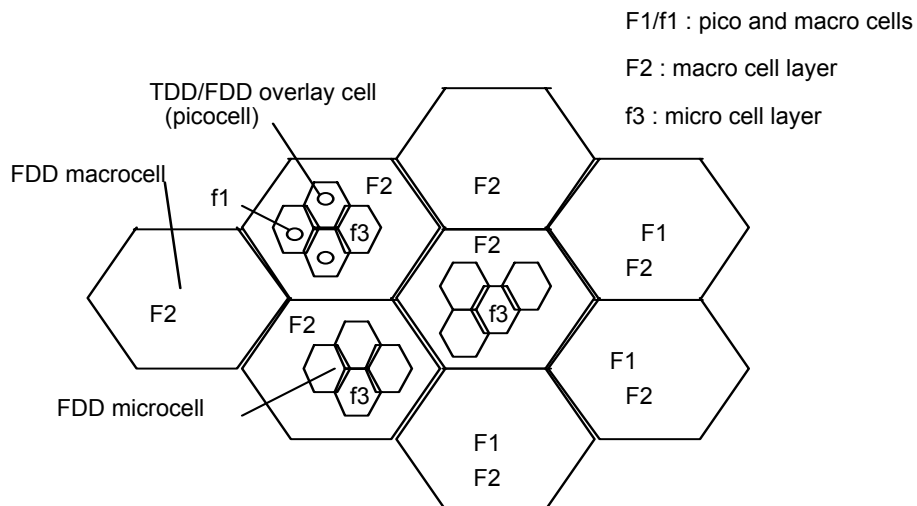


Figure 3.2 - UMTS Hierarchical Cell Structure (extracted from [UMTS98a]).

The FDD macro-cell provides wide area coverage, and is also used for high-speed mobiles. The micro-cells are used at street level for outdoor coverage, to provide extra capacity where macro-cells could not cope. A cluster of them is shown in Figure 3.2, although they can be deployed singly. The shape of these micro-cells will not be hexagonal, but rather canyon-like, which reflects the topography of the streets, with a distance between 200 and 400 m; note that this distance is specific of the city type. Pico-cells will be deployed mainly indoors, in areas where there is a demand for high data rate services, such as laptops networking or multimedia conferencing. The way in which these pico-cells can be deployed will depend on their maximum range in given environments (indoor and outdoor), which will be about 75 m. A limiting factor will be the range of mobile terminals when used for high data rate services, given the high demand this will place on batteries and in the BS power budget.

Table 3.2 shows dimensions for sectorised cells, cell radius and sectorised hexagon cell area. The sectorised hexagon cell area is calculated according to [UMTS98b]:

$$A_{\text{sec}} = \frac{3}{2} \sqrt{3} \frac{R_{\text{cell}}^2}{N_{\text{sec}}} \quad (3.1)$$

where  $R_{\text{cell}}$  is the cell radius, and  $N_{\text{sec}}$  is the number of sectors per cell. A simplified model for the hexagonal cell is used instead of a three-sector model. This is shown in Figure 3.3.

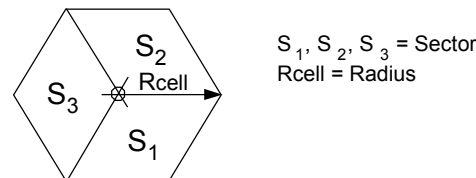


Figure 3.3 - Simplified Sector Cells (adapted from [UMTS98b]).

Table 3.2 - Cell Dimensions per Operating Environment (adapted from UMTS98b)).

Operational environments	Sectors per base	Cell radius [km]		Sectorised Hexagon Cell Area [km <sup>2</sup> ]	
		2005	2010	2005	2010
CBD/Urban (building)	3	0.075	0.075	0.005	0.005
Suburban (building / street)	3	3	2.0	7.79	3.46
Home (building)	1	0.02	0.02	0.001	0.001
Urban (pedestrian)	3	0.7	0.6	0.424	0.312
Urban (vehicular)	3	0.7	0.6	0.424	0.312
Rural in- & out-door	3	8	8	55.43	55.43

Table 3.2 shows the cell radius and sector area as a function of operational environments, based on traffic forecast for years 2005 and 2010. Note that, mainly in urban scenarios, the cell radius decreases by the year 2010 relatively to 2005.

## 3.2 Other systems

### 3.2.1 GSM

Network planning in GSM [Yaco93] has basically two main areas, capacity and interference, because GSM uses FDMA/TDMA as air interface access schemes. Capacity is limited by the number of available carriers in a cluster (group of cells using different frequencies) or in a cell, while interference (mainly co-channel interference) is limited by the cell reuse distance. Figure 3.4 represents a typical GSM cell structure, (several clusters of four cells), where the different colours represent different frequency groups.

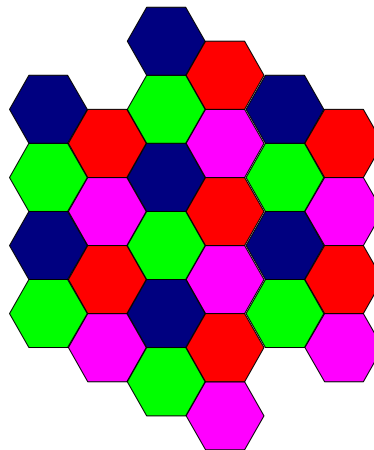


Figure 3.4 - GSM "classical" planning.

To increase capacity in GSM the reuse factor must be decreased, but since co-channel interference increases, a trade-off between the reuse factor and the ratio of carrier to co-channel interference must be achieved. Note that in GSM the thermal noise is usually neglected compared to interference.

UMTS has major differences compared to GSM mainly at the radio interface level. The carrier spacing in GSM is 200 kHz, while in UMTS-WCDMA is 5 MHz. The frequency reuse factor used in GSM typically is 3 or 4, while in UMTS the reuse factor is one, due to CDMA. Due to multipath propagation, signals suffers several delays, leading to a lack of absolute orthogonality among receiving signals, i.e., received signals have some correlation, which means interference; in order to minimise this critical element, WCDMA performs power control at 1500 Hz. GSM also has power control but only at 2 Hz. In the quality control field, UMTS is also different, since

radio resource management is essential (5 MHz gives multipath diversity), while in GSM the main issue is frequency planning (frequency hopping).

Packet switching is a key element, load-based in UMTS, and time-slot based in GSM. Finally, UMTS offers DL diversity, improving capacity.

### 3.2.2 CdmaOne

The IS-95/cdmaOne [OjPr98] air interface uses a carrier with 1.25 MHz of bandwidth. The network is synchronous within a few microseconds. This characteristic allows the use of long codes sequence, with different phase offsets as pilot sequences. However, to obtain synchronism a system like Global Positioning System (GPS) is required. Such characteristics are not applicable to UMTS.

The used chip rate in CdmaOne is 1.2288 Mcps. Table 3.3 shows the main parameters that characterise cdmaOne compared with UMTS.

Table 3.3 - cdmaOne Air Interface (extracted from [OjPr98]).

Characteristics	CdmaOne	UMTS-FDD
Bandwidth [MHz]	1.25	5
Chip Rate [Mcps]	1.2288	3.84
Frequency band [MHz]	869 – 894 (800 band)	UL 1920 - 1980
Frequency band [MHz]	1930 – 1990 (1900 band)	DL 2110 - 2170
Soft Handover	Yes	Yes
Power Control	UL : Open loop + fast closed loop (800 Hz) DL : Slow quality loop	1500 Hz, both UL and DL

In IS-95/cdmaOne, like in GSM, coverage is limited by only one service, speech. Deployment of BSs is therefore an easy task, because with a reuse factor of one network planning "it is just planting base stations". Therefore, the radio network planning of IS-95/cdmaOne is just to follow a simple hexagonal structure (with a reuse factor of one) and to make a suitable distribution of codes by several BSs.

### 3.3 Parameters for Radio Network Planning

#### 3.3.1 Radio Network Planning Procedure

Network planning is a very complex task that needs to be constantly updated. UMTS network planning covers two major areas, radio network planning and transport network dimensioning:

- radio network planning deals with the calculation of link budget, capacities, and of course the required number of cells; in addition, it includes detailed coverage and parameter planning for individual sites;
- in transport network dimensioning, the capacities of the links between BS and RNC, the number of RNC, switches and other network elements are calculated.

A large number of different services associated to different bit rates makes the process of network planning for 3G systems much more complex, as compared to 2G ones. In order to produce a good radio network planning, it is necessary to have a complete knowledge about the radio environment. Some approximations can be made based on general radio channel characteristics, however, since the radio environment is highly variable, even within the area of one cell, detailed measurements and optimisation need to be performed for each individual cell.

The radio network planning progress can be divided into three phases:

- preparation;
- estimation of cell count;
- detailed network planning.

In the preparation phase, coverage and capacity objectives are established, the network planning strategy is defined, and initial design operating parameters determined. Coverage and capacity objectives are a trade-off between desired quality and overall network cost. A smaller signal outage probability means smaller cells, thus, higher overall network costs; smaller interference outage probability means smaller capacity, thus, also higher cost. A typical outage probability target is 5 to 10%, corresponding to 90 to 95% availability/coverage probability. The coverage probability can be different for different services as discussed below. Blocking probability and delay quality targets must also be defined.

The estimation of cell count depends on the number of users in a given area, which is obtained by multiplying the population in the area by penetration forecast values. The number of users and offered traffic per user determine the overall offered traffic. When cell capacity and area are known, a rough number of cells can be determined, as show in Figure 3.5. The user profile forecast is calculated in the following subsection.

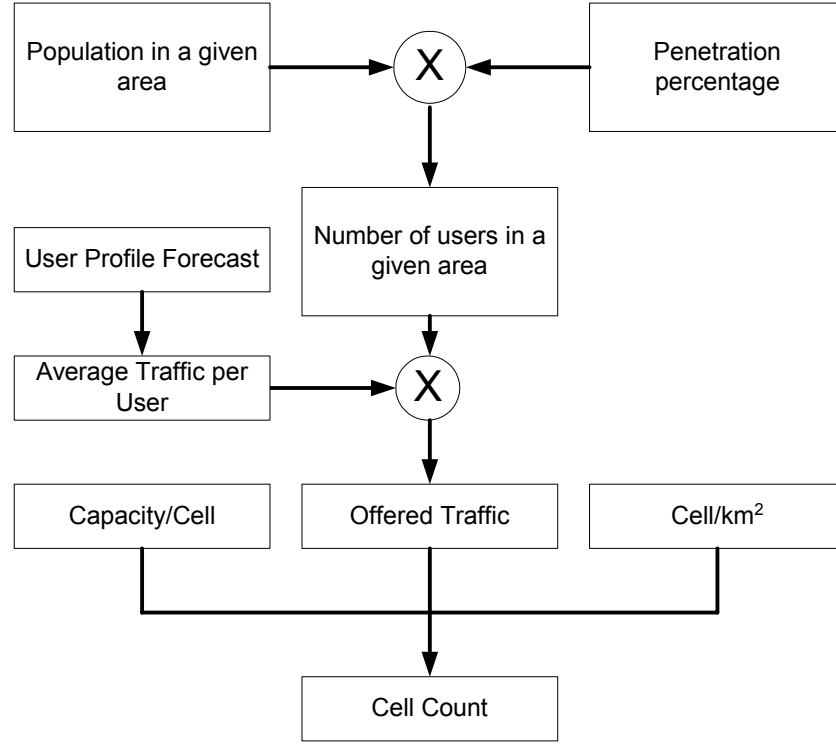


Figure 3.5 - Cell Count Forecast Algorithm.

In order to perform radio network planning, the network load factor is a vital parameter, because power is the shared resource in UMTS radio interface. The network load estimation is needed in order to perform the necessary changes on the network and develop an optimal network configuration. The load factor has some differences between the DL and the UL. For UL, the load factor is written as follows [HaTo00]:

$$\eta_{UL} = (1+i) \sum_{j=1}^N L_j = (1+i) \sum_{j=1}^N \frac{1}{1 + \frac{R_c}{\left(\frac{E_b}{N_0}\right)_j \cdot R_j \cdot v_j}} \quad (3.2)$$

where  $R_c$  is the chip rate,  $j$  is the "user",  $R_j$  is the user  $j$  bit rate,  $v_j$  is the user  $j$  activity factor,  $(E_b/N_0)_j$  is the ratio of bit energy over the noise spectral density for user  $j$ ,  $i$  is the ratio of other cells to own cell interference and  $L_j$  is the load factor of one connection. In DL, the load factor,  $\eta_{DL}$ , can be defined based on a principle similar as for the UL, although some parameters are slightly different:

$$\eta_{DL} = \sum_{j=1}^N v_j \cdot \frac{\left(\frac{E_b}{N_0}\right)_j}{\frac{R_c}{R_j}} [(1 - \alpha_j) + i_j] \quad (3.3)$$

where  $\alpha_j$  represents the orthogonality factor, and  $i_j$  is the ratio of other cells to own cell power, received by user  $j$ . Usually, the orthogonality factor in multipath channels is between 0.4 and 0.9. The optimal value for  $\alpha_j$  is 1, which means that there is a perfectly orthogonality among users in the area.

The network planning strategy includes issues like micro-cell deployment, provision for indoor and high bit rate coverage, and migration from 2G systems. Several factors need to be considered for the most feasible network planning approach. These include cost sites of fixed line transmission, how easily cell sites can be acquired, and at what cost cell sites can be acquired. Traffic distributions will of course have impact on deployment strategy.

One deployment strategy could be to use macro- and micro-cells for outdoor coverage, and pico-cells for indoor coverage in office buildings. In addition, macro-cells would be used to fill-in the gaps in indoor coverage. This is because extensive indoor coverage is most likely required in many cases. Therefore, it might be wiser to build additional capacity by increasing the number of indoor cells, rather than trying to provide indoor coverage from outdoor cells, thereby, being forced to introduce micro-cells earlier due to capacity restrictions. Nevertheless outdoor BSs provide indoor coverage, building penetration margin typically being about 10 to 20 dB, which needs to be taken into account in the link budget calculations.

Another approach is to use micro-cells extensively from the beginning, and to provide indoor coverage from them. This might be feasible in dense urban areas.

High bit rates can be provided either uniformly over the cell area, or the data rate at the cell border could be smaller than the one close to the BS to allow a larger cell range. This depends on the nature of the high bit rate services. For services that use available bit rates non-uniform coverage might be acceptable, but for applications that require maximum bit rate such as video transmission uniform coverage is required.

If an operator has a deployed 2G network, migration aspects need to be considered in the network planning strategy. These include reuse of existing cell sites, handover between the new and old systems, and co-existence requirements.

### 3.3.2 Offered Traffic

One starting point for network planning is the estimation of individual user traffic to obtain the total offered traffic in a given area. To quantify the traffic intensity, one could use

Erlang as a unit of measurement. Since 3G systems will have a large variety of services, a single traffic measure might not be suitable for all cases. For data services, traffic measured in kbit/h/km<sup>2</sup> will better characterise the traffic density.

The offered traffic is a quantity generated by users. All types of users must be considered (voice, multimedia, etc), all kind of services (service penetration, bit rate, average connection time, etc), and environments (urban, suburban, etc) must be computed. Figure 3.6 shows one estimation method to compute the user profile or the user offered traffic. In order to estimate the user profile one needs to multiply the service penetration by the bit rate and by the service average duration; this is done for each service and summed together, then a user offered traffic is achieved.

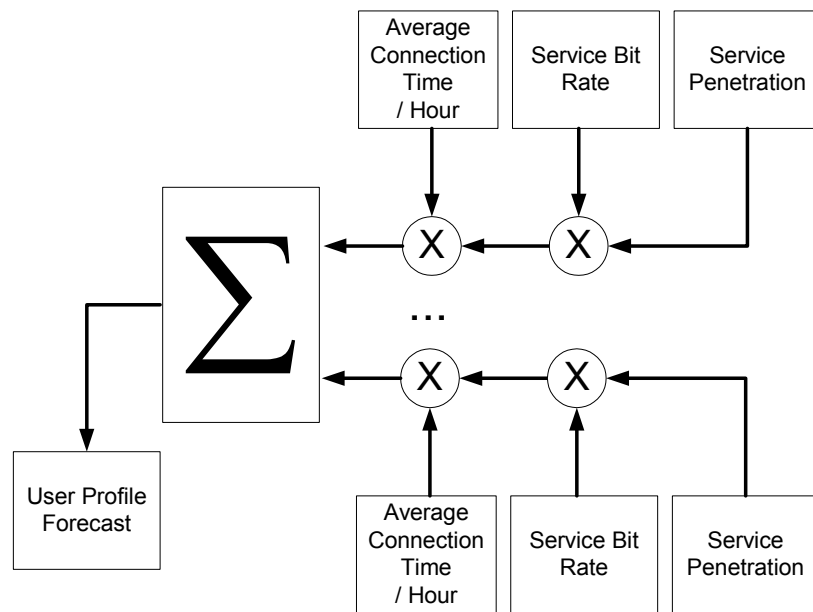


Figure 3.6 - User profile forecast based on service usage by user.

For example, typical values for the average connection time for speech service range from 120 to 180 s, with an activity factor of 50%; in Portugal [ICPo01] this value is about 92 s. For other services, the average connection time is more difficult to define, since there is no experience, therefore, these values are based on forecasts. Since the average connection time is an important factor on the generated network traffic, it is very important to be able to estimate it with reasonable accuracy. Table 2.2 shows some values that are used to characterise traffic as a function of several services. Note that the service bandwidth is a product of user nominal bit rate, coding factor and asymmetry factor.

The network capacity must be designed according to busy hour traffic. However, new user profiles and more service types might change this principle.

Figure 3.7 describes the calculation of Offered Bit Quantity (OBQ) which is based on the population density and penetration forecasts in the EU (15 countries). In the calculations of the number of users that need to be served, at least the following factors should be accounted for:

- population living in a given area;
- population working in a given area;
- vehicle traffic;
- special events, and use of recreational areas.

The population density is divided into three environments: urban, suburban and rural. The potential users per km<sup>2</sup> are estimated for each environment. Then, the penetration rate of users per service is multiplied with the potential number of users per km<sup>2</sup>, which gives the actual number of users per service per km<sup>2</sup>. Users will not use the service all time, therefore, one has to define busy hour call attempts. This means that one looks at the busiest hour of the day and estimates the average number of calls per user in that hour. Therefore, the busy hour call attempt is multiplied by the actual number of users per service per km<sup>2</sup>, which gives the equivalent number of active users during the busy hour for one km<sup>2</sup>. The active users multiply the throughput or service bandwidth in kbps during the busy hour and the effective call duration (the duration of the call), which gives the OBQ during the busy hour. This is also explained by the following equation:

$$OBQ = \text{BusyHourCallAttempts} \times \text{Penetration} \times (\text{Users}/\text{km}^2) \times \text{ServiceBandwidth} \times \text{EffectiveCallDuration} \quad (3.4)$$

Table 3.4 shows some forecast results in DL for the OBQ parameter.

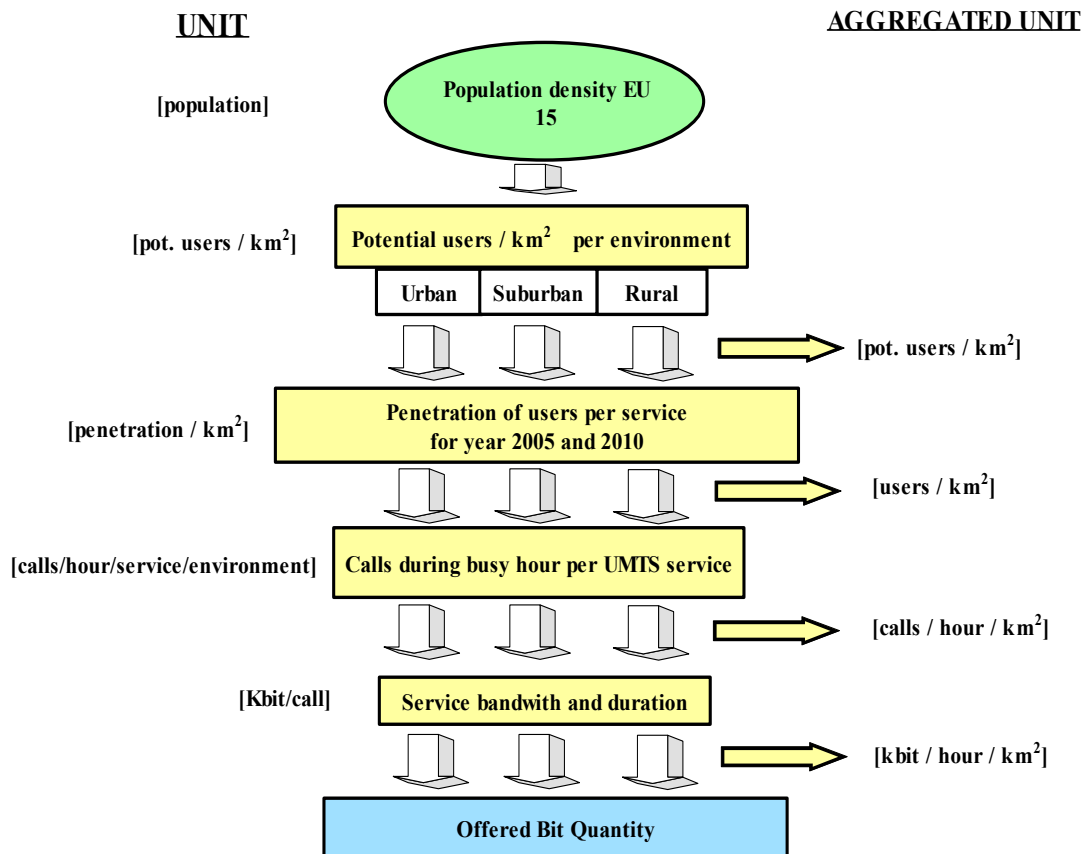


Figure 3.7 - The OBQ calculation steps (extracted from [UMTS98b]).

Table 3.4 - OBQ in DL for year 2005 (adapted from [UMTS98a]).

Service	OBQ [kbit/h/km <sup>2</sup> ]		
	CBD	Urban-pedestrian	Urban-vehicular
HIMM	9.56E+06	1.53E+06	2.62E+03
HMM	2.76E+08	7.86E+07	1.35E+05
MM	2.21E+07	6.42E+06	1.10E+04
SD	8.73E+06	2.62E+06	4.50E+03
SM	2.76E+06	8.29E+05	1.42E+03
S	2.18E+08	7.84E+07	2.02E+06

The penetration forecast values for 2005 and 2010 are presented in Table 3.5, for each service in each operating environment. This information is based on market research within Europe, and represents the fraction of the density of potential users given in Table 2.5.

Table 3.5 - Penetration Rate per Operating Environment and Service, years 2005 and 2010

(adapted from [UMTS98b]).

Services	CBD/Urban (building)		Suburban (building or on street)		Home (building)		Urban (pedestrian)		Urban (vehicular)		Rural in- & out-door	
	2005	2010	2005	2010	2005	2010	2005	2010	2005	2010	2005	2010
HIMM	0.010	0.050	0.005	0.053	0.005	0.053	0.005	0.053	0.005	0.053	0.005	0.053
HMM	0.050	0.180	0.047	0.180	0.047	0.180	0.047	0.180	0.047	0.180	0.047	0.180
MMM	0.080	0.180	0.047	0.180	0.047	0.180	0.077	0.180	0.077	0.180	0.047	0.180
SD	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
SM	0.250	0.400	0.250	0.400	0.250	0.400	0.250	0.400	0.250	0.400	0.250	0.400
S	0.600	0.750	0.600	0.750	0.600	0.750	0.600	0.750	0.600	0.750	0.600	0.750

After traffic generation, cell capacity estimation is required in order to proceed to the network optimisation process. In order to perform a cell capacity estimation, several main factors are identified: user data rate, traffic characteristics, quality of service (blocking, delay, BER), outage probability and cell link budget.

The number of users in a BS is essentially dependent on their current bit rate. With higher bit rate services, less users can be supported in a BS, because a larger number of users generates higher interference, therefore, more power must be transmitted, which implies power resource reduction.

### 3.3.3 Deployment Scenarios

To finally achieve the network planning, one has to consider different cellular deployment environments: macro-cellular, micro-cellular, and mixed (macro-to-micro). 3GPP [3GPP00a] proposes a hexagonal grid to deploy BSs in a macro-cellular environment, which are equipped with omnidirectional antennas placed in the middle of the cell.

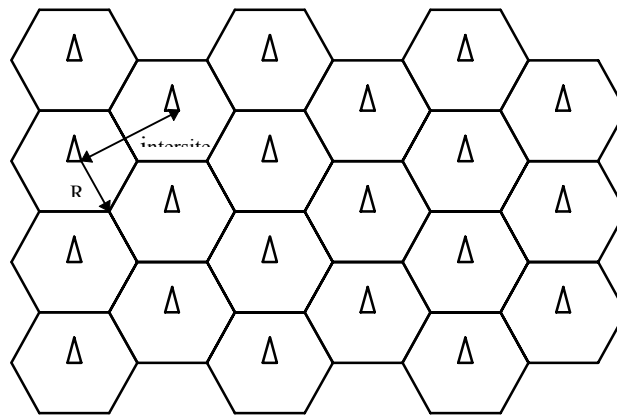


Figure 3.8 – Macro-cellular deployment (extracted from [3GPP00a]).

For the micro-cellular environment, 3GPP [3GPP00a] also proposes a deployment scenario to deploy micro BSs, called the Manhattan scenario; Figure 3.9 shows an example of this.

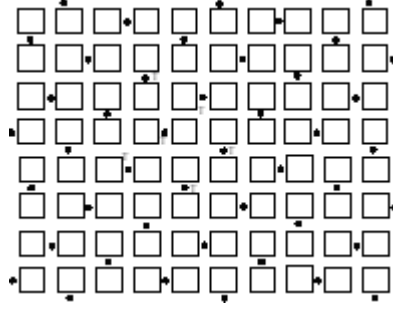


Figure 3.9 – Micro-cellular Deployment (adapted from [3GPP00a]).

To calculate the inter-cell interference between a macro- and micro-cells environments one must consider:

$$I = ACIR \cdot I_{micro} + \frac{1}{F} I_{macro} \quad (3.5)$$

where the value for  $F$  depends on the assumed propagation model (in [3GPP00a]  $F = 0.6$  is indicated as a typical value; while 0.73 is indicated in [OjPr98]),  $ACIR$  is the Adjacent Channel Interference Rejection ratio, and  $I_{macro}$  is the sum of interference from users connected to the BS.

Figure 3.10 shows two cellular layers, micro- and macro-cell deployment models, where it is possible to see how macro- and micro-cells coexist.

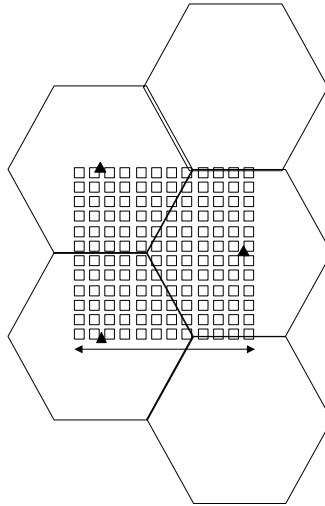


Figure 3.10 - Micro-to macro-cells Deployment (extracted from [3GPP00a]).

In the FDD mode, which is the main mode, the core bandwidth in UMTS for DL or UL is 60 MHz (UL 1920–1980 and DL 2110-2170 MHz), 5 MHz being the required bandwidth channel, therefore it is possible to have 60/5 operators (12). In this case, the quality of service provided by each operator would have serious limitations, so the reasonable solution for this is to

provide 3 channels to each operator. With this solution, UMTS will have 4 potential operators (the Portuguese case). For the TDD mode, in Portugal each operator has one single channel of 5 MHz.

### 3.4 Planning in STORMS

STORMS was a project in the ACTS programme partially funded by the European Commission. The first outcome of STORMS was the identification of a new planning process suited to the UMTS characteristic: multimedia services, new access schemes, and enhanced access network architecture were some of the major issues considered in STORMS [MePi99].

Three major blocks can be identified in STORMS network strategy, Figure 3.11: the initial dimensioning, the automatic radio coverage optimisation, and the refined dimensioning. Finally, network performance can be assessed through a powerful UMTS simulator incorporated in the STORMS platform. Note that the network optimisation process is based on a feedback process, where for a given dimensioning the simulator performs coverage and capacity calculations, after which an automatic and refined reconfiguration process begins, to be again evaluated in the new network dimensioning. Note that the all process is based on demographical and geographical information, due to traffic and propagation algorithm inputs.

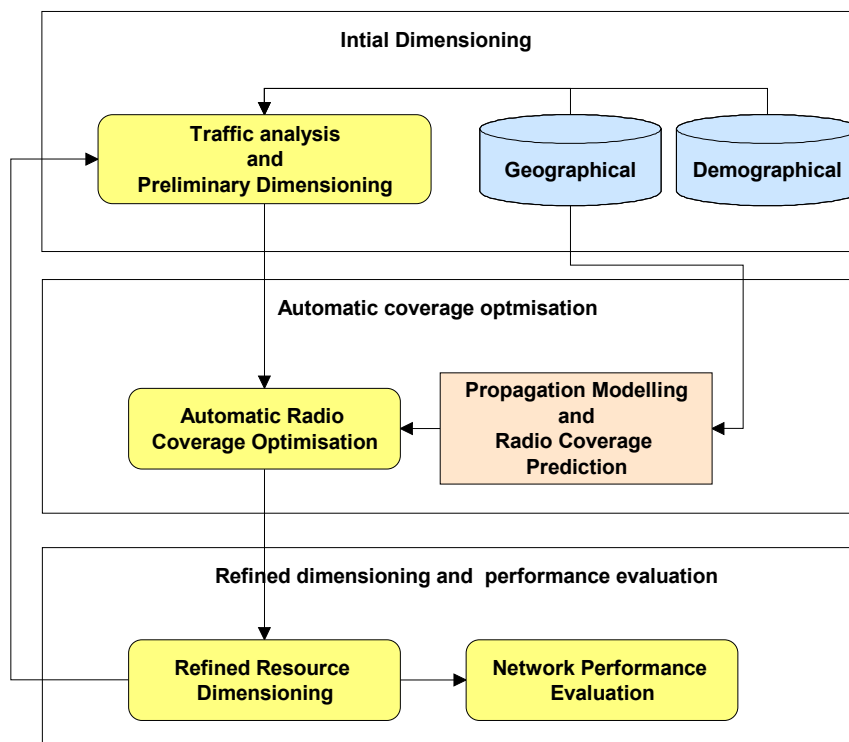


Figure 3.11 - Global network planning process (extracted from [MePi99]).

One of the major results of STORMS has been the development of a genetic optimisation algorithm for the selection of optimal BS configurations (in terms of coverage). Figure 3.12

shows the generic refined optimisation process for micro- and macro-cells, where, as inputs, it receives traffic and propagation estimation results. These parameters are separated into two groups, based on bit rate criteria, corresponding to low traffic macro-, and high traffic micro-cells. Afterwards, the simulator checks the cell capacity, and decides if this cell dimensioning is appropriated to traffic inputs; if it is not, it produces feedback to the optimisation process, until capacity is adequate.

STORMS major result was the integration of several software modules, which were integrated into a platform that can be used to study:

- Traffic density distributions on a per service and per layer (hierarchical structures) basis;
- Rough identification of cell sizes, essential to continue with a satisfactory radio planning;
- Automatic radio coverage optimisation and power planning;
- Dimensioning of a radio layer based on either FDD or TDD modes;
- Optimum allocation of RNCs and local exchanges, and identification of a cost effective interconnecting network;

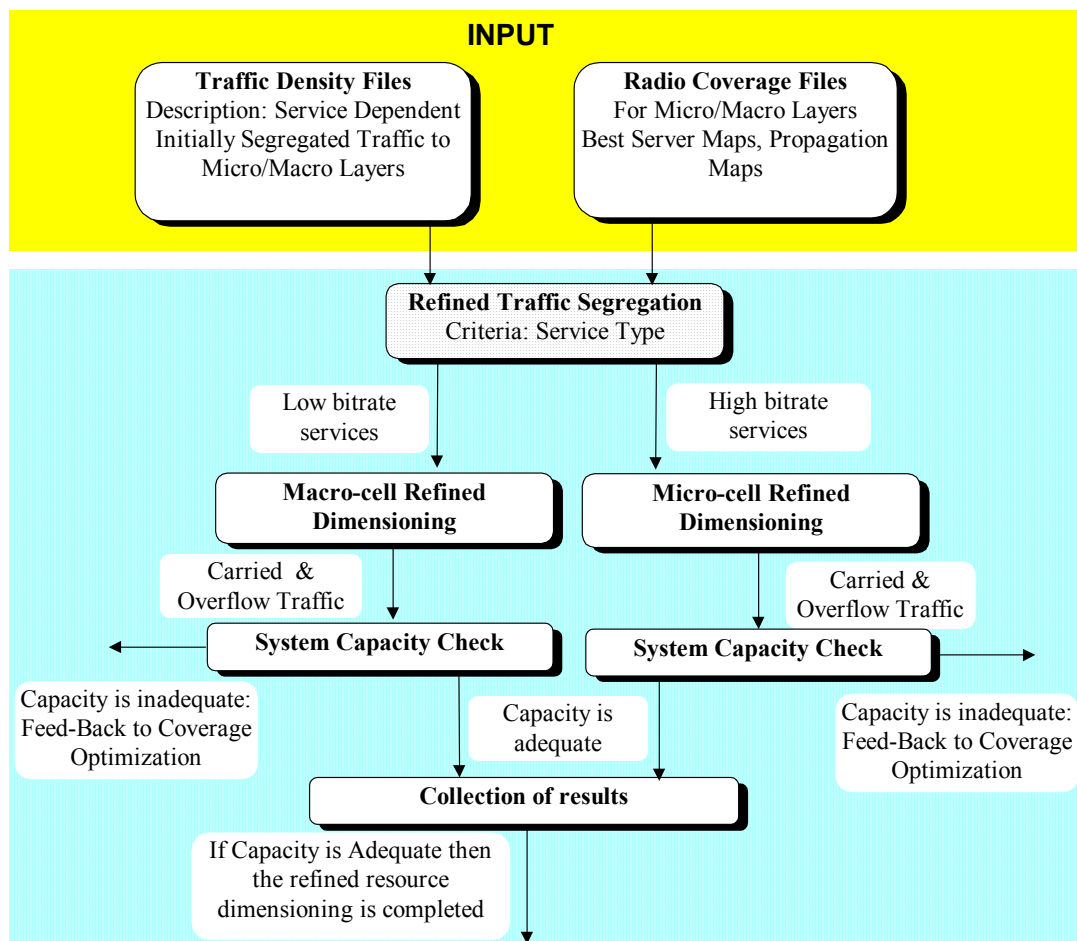


Figure 3.12 - The generic refined planning process (extracted from [MePi99]).

- Optimum dimensioning of location and paging areas, including also "intelligent" paging methods;
- Simulation of the final network configuration, in order to check the performance against the initial requirements.

The optimisation process in STORMS is based on a feedback algorithm that converges to an optimal network configuration in terms of radio coverage. This procedure inspired this thesis, in order to get the optimal BS configuration based on:

- Network simulation (traffic generation, propagation and BS simulation);
- Network capacity verification, where a quality indicators analysis is performed, followed by a decision for a new simulation or not;
- Network optimisation process, where new BS parameters are set, so that the network converge, to an optimal configuration.

Figure 3.13 shows the main idea collected from STORMS.

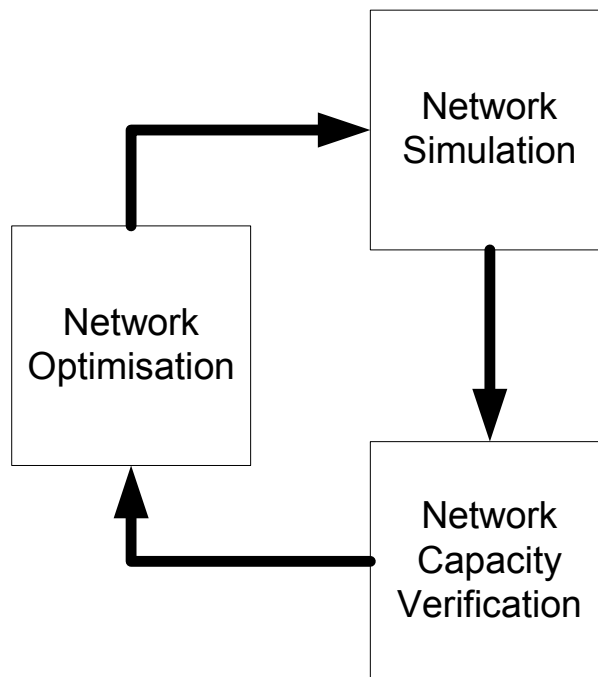


Figure 3.13 - Network optimisation feedback process.

Note that the STORMS project has ended before all UMTS standards were finalised, therefore, the real system characteristics were not considered by STORMS.

# 4 Planning and Optimisation Tool

## 4.1 Algorithm

As described in previous chapters, radio network planning is mainly based on three items: traffic, propagation and services. In order to build a tool, capable of performing radio planning and optimisation of a UMTS network [HaTo00], some major functional blocks are needed:

- Traffic generator based on traffic/service forecast tables;
- User behaviour and distribution for a given service area;
- Propagation model that fits the environment requirements;
- Description of services and radio interface characteristics.

After this, it is necessary to implement some computation algorithms to estimate or simulate the UMTS radio network. In order to achieve good results, a real time traffic and propagation simulator was developed.

A network planning and optimisation flow chart algorithm was designed, and all major parameters were identified as the starting point of the planning and optimisation tool. One main feature of this tool is that the optimisation process is automatic, which means that some network planning parameters are changed automatically by the tool, with the objective of achieving the optimum network design. In order to achieve this optimum configuration, sets of simulations are performed, some major network quality indicators being analysed for each set; in this way, it is possible to implement an algorithm that changes, from set to set, some parameters in the network that directly or indirectly influence system capacity. The optimisation algorithm stops when the required quality network goals are accomplished.

The major problems in GSM cellular planning tools are, in most cases, only related to propagation issues. This fact is mainly due to the relatively simple radio interface (FDMA/TDMA) of this type of networks: the number of channels allocated to each carrier is deterministic, which means that the number of available channels is well known; therefore, it is easy to establish a relation between traffic load, channels and blocking probability, usually via the Erlang-B model [Yaco93].

The estimation of the number of channels in UMTS is not as linear as in GSM, which is due to the quite different radio interface used (CDMA), as already described in previous chapters. The number of channels depends on several factors: service (bit rate, traffic asymmetry, average connection duration), power, multipath, interference, orthogonality level, distance between MT and BS, number of users in the area and their propagation conditions, environment (urban,

suburban or rural), number of channelisation codes in DL, network configuration (allowed load levels), soft handover, etc. Due to these aspects, it is quite difficult to find an analytical approach that computes and predicts some of these major features. Therefore, a real time system simulator is required, as realistic as possible, in order to estimate system capacity, and to obtain the network optimum parameters configuration.

Figure 4.1 shows the major functional blocks that are needed to accomplish a network planning and optimisation algorithm, described as follows:

- Geographical Data (streets, buildings and topographic information);
- Demographical Data (population density in a given area, or population distribution type);
- Forecast Tables (types of services used by potential users, bit rates, population penetration factor per service,  $E_b/N_0$  targets per service, average connection duration, etc);
- Users Profile Generation (MS settings, based on service penetration forecast and operator quotes);
- Mobile Users Random Distribution (users deployment in the simulation area);
- Propagation Model, Link Budget, Interference and Power Control (coverage, SIR and service estimation, and power control algorithm);
- Simulation Engine, Traffic Generation (CS and PS simulation, statistic system data base, major network parameters, parameters historical information, and interaction with other functional blocks);
- Network Performance Analysis (quality network measurements, blocking probability for CS and delay for PS);
- Optimisation Algorithms (based on Network Performance Analysis, decide which network parameter must be changed in order to achieve or converge to the quality goals);
- Node B Reconfiguration (resets the process, launches a new simulation with a new network configuration);
- UMTS Network Planning Complete Optimisation (the network quality key parameters were achieved and the optimisation process ends).

Note that the optimisation process is implemented on a feedback strategy, which makes the algorithm iterative. This feature enables the realisation of a fine optimisation tuning process.

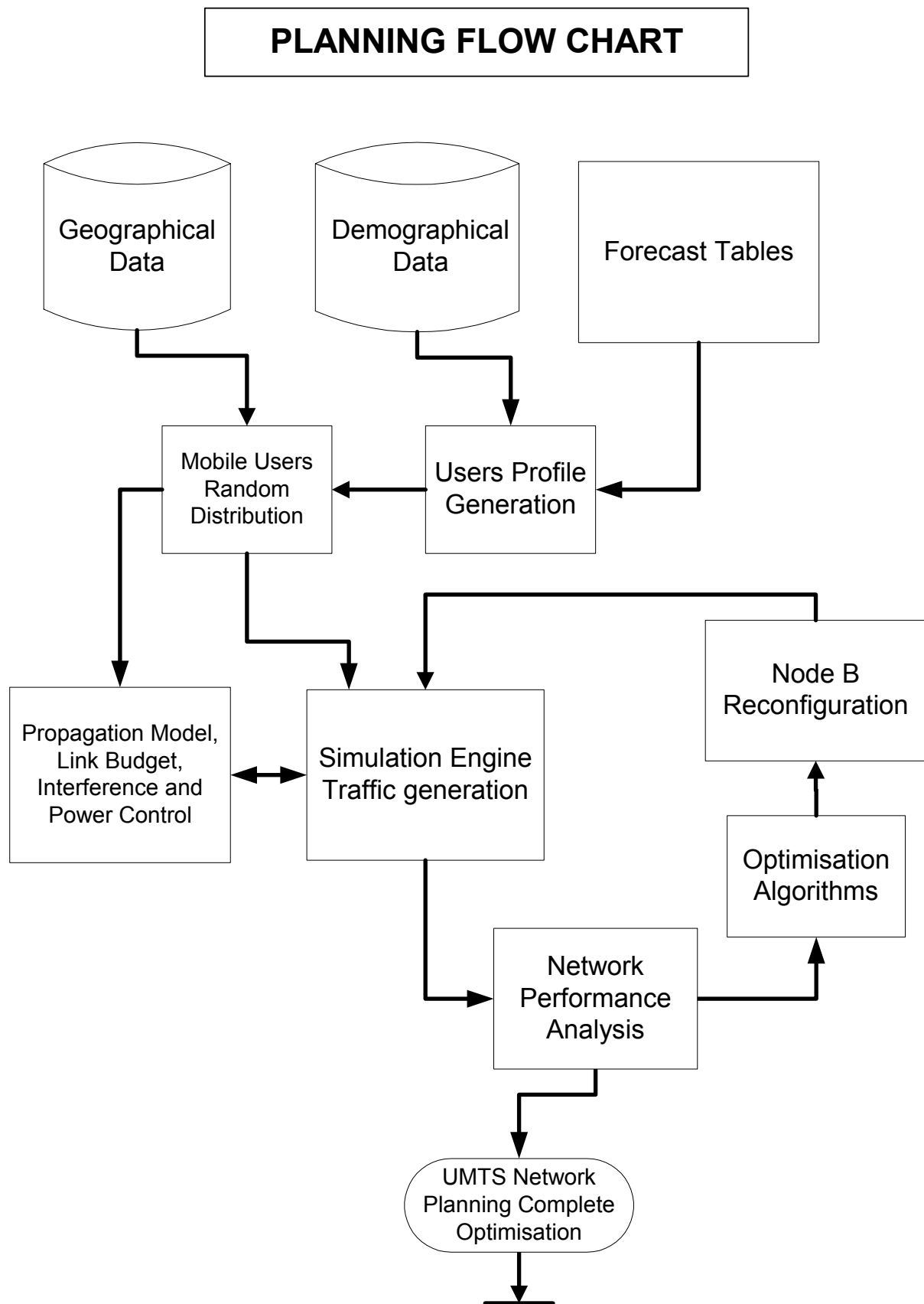


Figure 4.1 - UMTS planning and optimisation algorithm.

## 4.2 Geographical Information and Services Statistics

In this tool, geographical data concerns street and building location, and enables more accuracy to propagation calculations in the simulation. Figure 4.2 shows only a fragment of the geographic database used in this tool, where it is possible to see several buildings, streets and some green areas. This kind of information allows the implementation of a propagation algorithm, therefore, it is easy to implement LoS and NLoS calculations. This approach allows to introduce some additional attenuation due to building penetration when a MS is inside (over) a building. Thus, the simulation realism is increased, as well as the accuracy of the results.



Figure 4.2 - Geographic aspect (mainly buildings and streets).

The demographic density (people/km<sup>2</sup>) parameter must be entered into the tool, together with additional information, like the number of operators and the penetration factor for each service. After this, it is possible to estimate the number of potential users in a given area, Figure 4.3; note that potential users are uniformly distributed over the simulation area. In this example, each MS represented by a blue color means that it is out of coverage (there is no BS), while other mobile states are represented by different colors.

In order to estimate the traffic load, one will use the forecast tables related to the future UMTS users behaviour [UMTS98a], where one can find some parameters required for the traffic prediction process, like service penetration, average duration, connection and call rate, and service bit rate. This information is crucial as input to CS and PS generators, to allow the estimation of mixed traffic, hence, system load, blocking and delay.

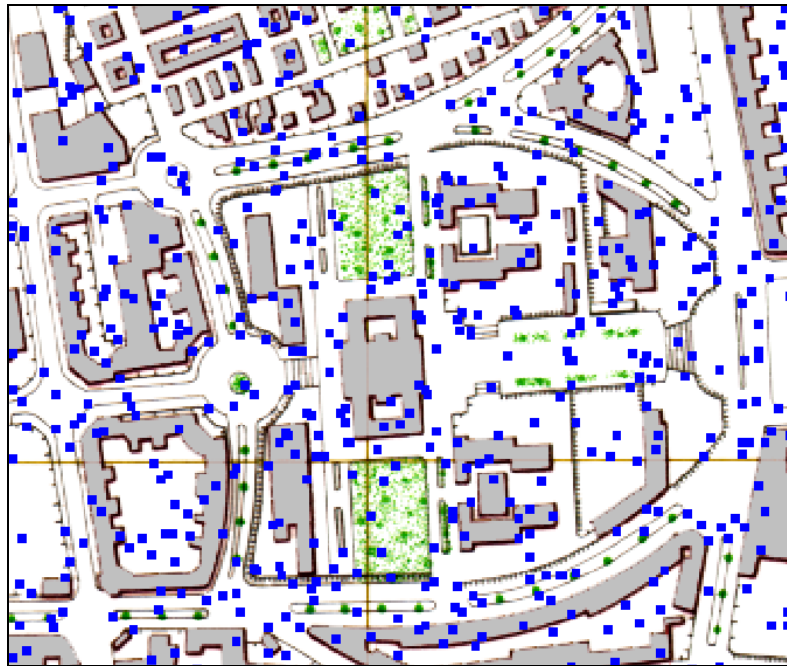


Figure 4.3 - User distribution example.

Figure 4.4 shows the window where one introduces some major traffic and service parameters, already described. Note that it is possible to activate or deactivate each service, for further individual/mixed service analysis. These parameters were described in Section 2.2, and their computation algorithm shown in Section 3.3.

	HMM	HMM	MMM
Type of Switching	<input type="radio"/> Circuit	<input type="radio"/> Packet	<input type="radio"/> Packet
	<input checked="" type="checkbox"/> Active?	<input type="checkbox"/> Active?	<input checked="" type="checkbox"/> Active?
Bit Rate [kbps]	128	2000	384
Eb/No UL [dB]	3.1	1.8	1.3
Eb/No DL [dB]	2.5	1.6	1.1
BHCA	0.06	0.06	0.06
Penetration [%]	0.005	0.047	0.077
Duration [s]	144	53	14

Figure 4.4 - Service and traffic forecast configuration (window partial view).

Users profile generation depends on the data of Figure 4.4, because one MS may use several services. To establish which service will be active in a given MS, it is necessary to use a statistically approach that configures MS services. Figure 4.5 shows the number of MSs for each service, based on penetration rate. Note that in this example the major service is speech and simple messaging, followed by the medium multimedia service. With this, it is possible to

calculate the ratio between the number of services and the number of users. This is possible because UMTS allows users to use several services in a simultaneous way. For example, if there is 100% of service penetration in all services the  $\#Services/\#Users$  parameter is 6.0, because all MSs use all 6 available services. In the particular example of Figure 4.5, on average a MS uses 1.330 services.

The 'Users Profiles' dialog box contains a table of active users per service and a calculated ratio.

Users per Service (active)					
HMM	HMM	MMM	SD	SM	S
29	274	411	54	1383	3375

# Services / # Users: 1.33028

Buttons: OK, Cancel

Figure 4.5 - Users profile verification window.

### 4.3 Propagation Model and Link Budget

In radio network planning, it is vital to use a propagation model that satisfies the environment and system parameters conditions. In order to fulfil these requirements the COST 231 Walfish-Ikegami [DaCo99] model was chosen, because it includes some major urban average parameters, like street and building dimensions (see Section 2.3). Another reason to elect this model is the cell type, since in this work only urban and micro-cell environments are considered.

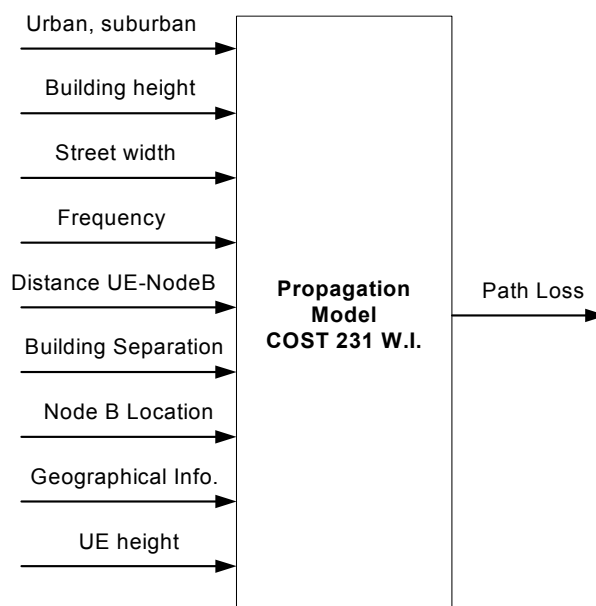


Figure 4.6 - COST 231 Walfish-Ikegami model parameters.

Figure 4.6 shows all parameters that the model needs to estimate the average path loss. All these parameters are introduced by the tool user, except of course the MS (UE-User Equipment according to the UMTS standard) location and distance between BS and the MS, which is a variable value.

Each BS may have different propagation model parameters, which may be considered more suitable for a given location area. The tool user may configure each BS through the window shown in Figure 4.7. Note that not all parameters are introduced in this dialog box, since some are introduced in the general simulation dialog or in BS configuration windows.

Figure 4.7 - Propagation parameters to each individual BS.

The link budget in UMTS introduces some additional concepts that must be considered in the power budget calculations. For example, the receiver sensitivity depends on energy of bit over noise, channel/system chip rate, user bit rate, and total estimated effective noise to allow the estimation of Signal over Noise Ratio. Figure 4.8 shows several input parameters required to perform the receiver power estimation algorithm already described in Section 2.3.2.

The link budget block performs a key role in the calculation of the power received by MSs in DL. To estimate the power received by the user, in general terms, it is necessary to know the following parameters: transmission power, antenna gain in a given direction, receiver antenna

gain, additional attenuations (cable, body and car loss), and of course the path loss (given by the propagation model) for each individual user.

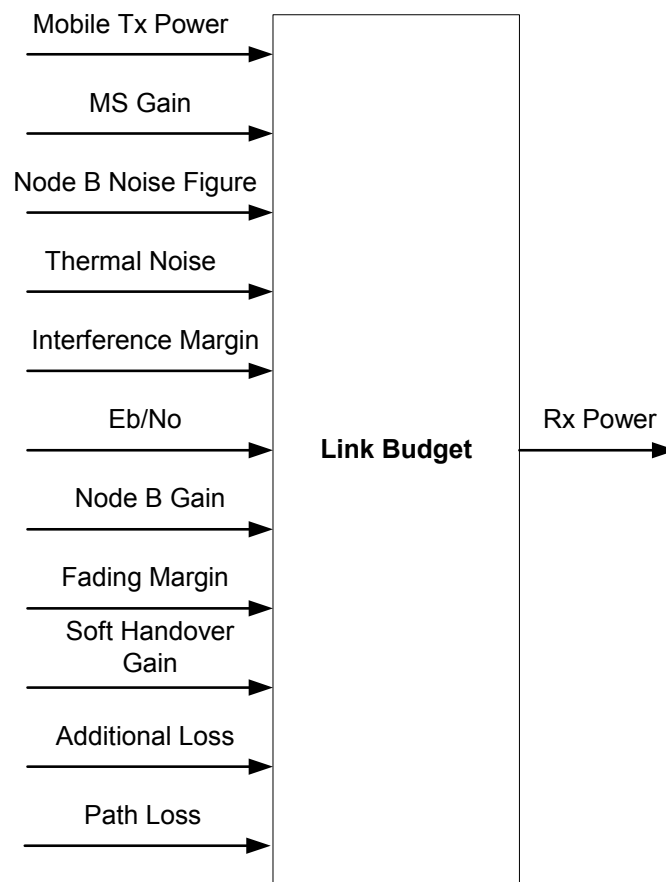


Figure 4.8 - Link Budget block parameters

The power received by an user must be estimated based on a link budget. Figure 4.9 allows the tool user to introduce the following link budget parameters:

- Thermal Noise Density, which models the typical natural density noise;
- Receiver Noise Figure, characteristic of the equipment, attenuators, internal noise etc;
- Receiver Noise Density, which is the sum of thermal noise density and receiver noise figure, the actual noise density at receiver input;
- Receiver Noise Power, the product of receiver noise density by the signal chip number;
- Interference Margin, the margin between noise and interference;
- Receiver Interference Power, estimated interference power based on interference margin and noise power at the receiver;
- Total Effective Noise + Interference, which is a sum of interference and noise power at the receiver;
- Max Mobile Tx Power, reserved for future work;

- Additional loss, the path loss increase, if a mobile is located inside a building, by user body loss or by the BS cable loss.

**Link Budget Parameters**

Thermal Noise Density [dB/Hz]	-174	
	+	
Receiver Noise Figure [dB]	5	
	=	
Receiver Noise Density [dBm/Hz]	-169	+ 10 log 3840000
	=	
Receiver Noise Power [dBm]	-103.157	
Interference Margin [dB]	3	
Receiver Interference Power [dBm]	-103.177	
Total effective Noise + Interference [dBm]	-100.157	
Max Mobile Tx Power [W]	0.125	

Additional Loss

Penetration Loss [dB]	10
In Body Loss [dB]	3
BS cable Loss [dB]	0

Figure 4.9 - Link Budget parameters window.

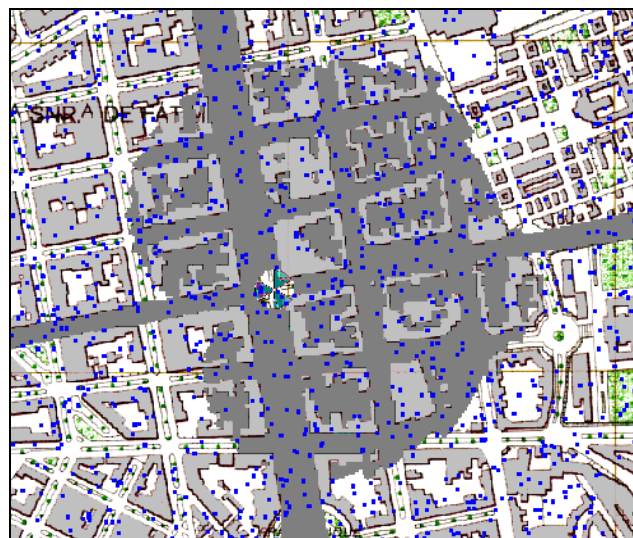


Figure 4.10 - Sector coverage example (partial view).

Figure 4.10 shows a coverage example with only one active sector, and only one active service on the BS. Coverage is limited by transmitter power, antenna pattern, receiver service sensitivity, and propagation parameters.

In UMTS, high bit rate services have a lower processing gain, therefore, the receiver sensitivity level is higher, leading to smaller service coverage distances. Figure 4.11 shows multi-services coverage, represented with different colour. As expected, coverage decreases when services bit rate increases, since lower bit rates correspond to higher processing gain.

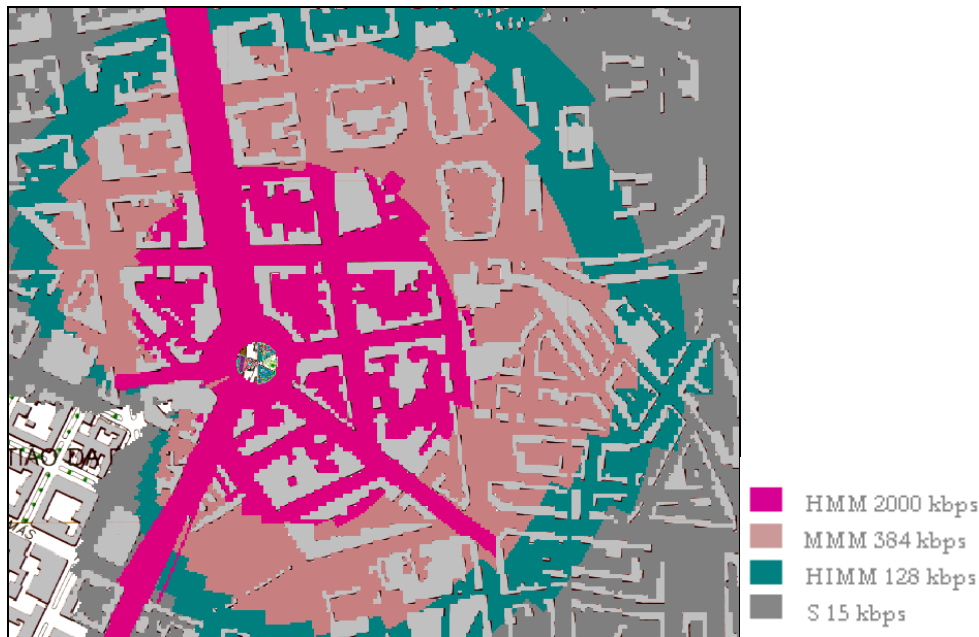


Figure 4.11 - Multi-service coverage in a single sector (partial view).

## 4.4 General Simulation Settings

Figure 4.12 shows the BS (Node B) major parameters that a user may configure. Each BS may have up to 3 active sectors, and each one may be configured independently, e.g., by loading different antenna radiation patterns.

Many other parameters are set here, like sector orientation (azimuth angle), expected or typical orthogonality factor, number of channel codes reserved to signalisation, percentage of channel codes reserved for soft handover, BS height (this parameter may automatically be changed by the simulator algorithm optimisation process), frequency (for propagation model reasons), manual BS repositioning, maximum transmitted power by the BS (to all users or to only one), percentage of inter-cell interference coming from other BSs as a function of local interference (aims to simulate the presence of other BSs, assuming a uniform load in the area), and maximum allowed load factor, over which blocking and delay start to occur in the cell. This latter parameter has a strong influence in network performance, because it is a threshold where

Radio Resource Management (RRM), starts to block or cause delay in connections. If the load factor is low (below 0.4), the BS does not support many users, but is stable; otherwise, if it is set at a high level, the BS allows many users, therefore, becoming very unstable, and starting to generate many drop events.

**Node B Setup**

**Sector Config**

☒ Sector#1    ☒ Sector#2    ☒ Sector#3

Orientation - North [°]    90    210    330

**Code Properties**

Orthogonality (alfa) [0...1]    0.5    # Sinali. Codes    128

Soft. Handover [%]    30

**Other Parameters**

Base Station Height [m]    22

Frequency [MHz]    1900

Node B Location X Y    510    337

**Power Levels**

Tx Power max [W]    10    Inter Interference [%]    30

Tx Power max/User [W]    5

Max Load Factor [0...1]    0.7    **Advanced Options**

**OK**    **Cancel**

Figure 4.12 - Individual Node B setup example.

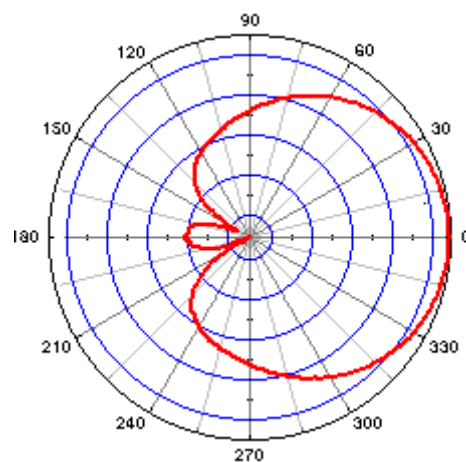


Figure 4.13 - Antenna radiation pattern visualisation (horizontal plane).

In Figure 4.13, it is possible to visualise information related to antenna pattern, supplied by antenna suppliers. By using this, one may define the best antenna solution for each sector.

Some BS parameters cannot be changed by the tool user, but may be monitored, being called “Node B properties”. The window shown in Figure 4.14 allows the tool user to view the site identification, load factor in DL (UL not implemented), number of services connected (not mobiles connected), current cell radius and current transmitted power.

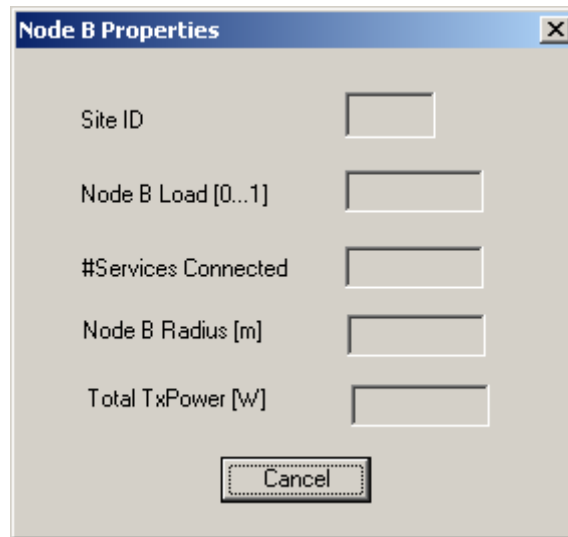


Figure 4.14 - Individual Node B proprieties visualisation.

As it was mentioned before, some major parameters are introduced in a general configuration window. Figure 4.15 shows a window where the tool user may configure several main parameters at two different levels, as follows:

- Scenario and Simulation environment level:
  - Number of operators (uniform distribution of population by operators is assumed), the default value being 4, which is the Portuguese case;
  - Output file directory to further analysis of results (where major internal parameters are written in files, in order to analyse network behaviour and simulation optimisation convergence steps, among others);
  - Number of scrambling codes/Carrier, also reserved for future work, since it may be possible to increase the number of scrambling codes for carrier (default value is 1);
  - Carriers per operator, also for future work; essentially it may be used for increasing the number of codes available, or for cell overlay analyses (default value is 1);
  - Max number of BSs (#Node B max), which is the number of BSs that may be defined for simulation memory management purposes;
  - Population density, which is not the users density, but the potential population density in the area (in the order of thousands/km<sup>2</sup>);

The dialog window is titled "General Configuration" and contains several sections for parameter setting:

- Country Parameters:** Number of Operators: 4
- Output Files:** Main Output Directory: c:\demo\
- Operator Parameters:**
  - Number of Scrambling Codes / Carrier: 1
  - Carriers per Operator: 1
- Node B Initial Parameters:**
  - # Node B Max: 15
  - Antenna Gain [dBi]: 5
  - Total Tx Power [W]: 10
  - Frequency [MHz]: 1900 M
  - Antenna Initial Height [m]: 22
  - Node B Initial Radius [m]: 900
- Mobile:**
  - Population Density [p/km2]: 10000
  - Antenna Gain [dBi]: 0
- Simulation Time Scale:**
  - Simulation Step [ms]: 200
  - Power Control [pc/s]: 500

At the bottom are "OK" and "Cancel" buttons.

Figure 4.15 - General system configuration dialog window.

- Simulation step, being the interrupt routine processing period (typically, this parameter depends on computer power processing capacity);
- Power Control, i.e., the number of times that power control is executed per second, (default value is the standard one – 1500).
- MS and BS level:
  - Antennas gain, for which, if no sector has been defined, a default value of 5 dBi for BSs and 0 dBi for MSs will be considered;
  - Node B initial radius, which may be automatically changed by the simulator optimisation algorithm process (an expected value is recommended for simulation time reduction proposes);
  - Frequency, 2000 MHz being the recommended value (this value must be within the propagation and UMTS boundaries);
  - Total Tx Power, the maximum power transmitted by each BS in a single carrier (this parameter, like others, may be changed in each BS individually);

- Antenna initial height, which may be automatically changed by the simulator optimisation algorithm process (an expected value is recommended for simulation time reduction proposes), default value is 22 m.

## 4.5 Optimisation Settings

As already mentioned in previous chapters, this simulation tool, besides network planning support, performs automatic network optimisation. In order that the tool user has control in this process, some system thresholds, margins, and targets must be specified.

The dialog window presented in Figure 4.16 allows the tool user to establish the optimisation and targets guidelines, as follows:

- Snapshot time means that after this simulation time some major network quality indicators (blocking and delay) are analysed by the optimisation algorithm, and a decision on a proper measure is taken in order that the simulation converges to the network quality targets, described in Figure 4.17;
- The Node B height step means that, if the current network quality parameters are “near” the network quality targets (based on a given criteria), the algorithm decides to change the BS antennas height by this order of magnitude;
- The Node B location step (reserved to future work - not implemented) means that the BS location may be optimised, therefore, site localisation may be changed by this order of magnitude;

Network Optimisation Parameters	
<b>Evaluation Parameters</b>	
Snapshot Time [s]	60
Node B Height Step [m]	1
Node B Location Step [m]	30
Node B Radius Step [m]	50
Power Control Step (Min) [%]	10
Power Control Step (Max) [%]	50
Minimum Number of Services ("Big Mobile")	4
<b>Evaluation Thresholds</b>	
GoS Interval Margin [%]	2
Time Interval to Write Values in Files [s]	10
Power Control Step Threshold [dB]	5
<b>Packet Delay Parameters</b>	
Delay Interval Margin [s]	2
Minimum Random Packet Delay [s]	3
Max Random Packet Delay [s]	10
<input type="button" value="OK"/> <input type="button" value="Cancel"/>	

Figure 4.16 - Network optimisation parameters configuration window.

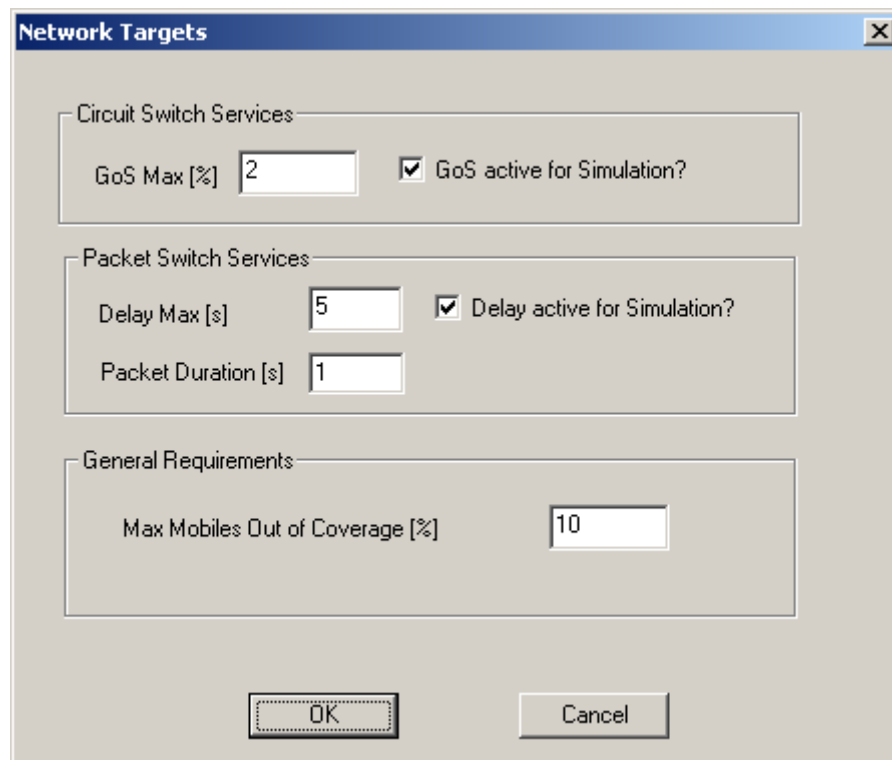
- Node B radius step means that, if current network quality parameters are “far” from the network quality targets (based on a given criteria), the algorithm decides to change the cell

radius by this order of magnitude (note that this assumption means that BS density increases or decreases in the simulation area);

- Power control step, minimum and maximum, means that the power control mechanism may work at two different speeds when increasing or decreasing power at each connection; this feature depends on how good or bad  $E_b/N_0$  is (based on a given criteria);
- Minimum number of services is a feature that configures the number of services established by a MS; the algorithm searches for a MS that matches this number, and outputs to a file the load caused by it (note that there is another concept associated to this one, which is the MS that introduces more load at the BS, the “Big Mobile”);
- GoS interval margin ( $GoS_{IM}$ ), which defines how “near” or “far” the  $GoS_{Target}$  value is; when the optimisation algorithm detects that  $|GoS_{Target} - GoS_{Current}| < GoS_{IM}$  is true or false (meaning “near” or “far”, respectively), it decides to change the BS antenna height (up or down using Node B height step value), for the former and to change the cell radius (increase or decrease using Node B radius step value) for the latter;
- Time Interval to Write in Files, defines a time period, within which the simulator engine saves a sample of the major dynamic parameters to the output files; this parameter is important to define the simulation output sample definition level to further network parameters analysis;
- Power Control Step Threshold is the power control decision margin; if the  $E_b/N_0$  target is inside this margin, the algorithm chooses the minimum step, otherwise it takes the maximum (this is useful to increase the power control convergence algorithm, process which is used in the UMTS standard);
- Delay Interval Margin, is the corresponding parameter to GoS Interval Margin;
- Minimum and Maximum Random Packet, which are defined in order to avoid the classical dead lock in connection establishment coming from a random delay (the random retry time algorithm is limited by these two parameters).

Figure 4.17 shows a dialog window where the tool user may configure network quality targets values (in this window, the tool user may also define a flag that enables or disables which parameter, one or both, that will guide the network optimisation process):

- GoS Max, is the CS blocking probability target for network optimisation;
- Delay Max, is the PS blocking delay target for network optimisation;
- Packet Duration, which defines the packet duration in all PS services;
- Max Mobiles out of Coverage, reserved for future work, where the tool user may define a percentage of MS without network coverage; it was not implement in this work because with a single BS in simulation it is not possible to cover all mobiles.



The image shows a 'Network Targets' configuration window. It has a title bar with a close button. The window is divided into three sections: 'Circuit Switch Services', 'Packet Switch Services', and 'General Requirements'. In the 'Circuit Switch Services' section, there is a 'GoS Max [%]' input field with the value '2' and a checked checkbox 'GoS active for Simulation?'. In the 'Packet Switch Services' section, there is a 'Delay Max [s]' input field with the value '5', a checked checkbox 'Delay active for Simulation?', and a 'Packet Duration [s]' input field with the value '1'. In the 'General Requirements' section, there is a 'Max Mobiles Out of Coverage [%]' input field with the value '10'. At the bottom of the window are 'OK' and 'Cancel' buttons.

Figure 4.17 - Network targets configuration window.

When quality indicator targets are reached after several snapshot simulations, the optimisation process stops, and shows an optimum configuration network solution.

Figure 4.18 shows a window where the tool user in run time may monitor major parameters, like traffic generation, MS state, delay, blocking and the optimisation process. The information from top to bottom is the following:

- Real time, time passed since the simulation started;
- Simulated time, is the current simulation time, which is reset when it reaches the snapshot time;
- Numbers of Node Bs and Users, quantity of equipment involved in simulation; note that the number of MSs is a consequence of the population density, number of operators, and services penetration;
- Circuit switching, total of circuit based services processed at current simulation time, number of blocked and dropped circuit connections, blocking due to BS high load (GoS Power), blocking due to lack of channel codes available (GoS Code), and the total blocking percentage (GoS Total);
- Packet switching, total of packet based services processed at current simulation time, number of blocked and dropped packet connections, delay due to BS high load (Power), delay due lack of channel codes available (Code), and the total average delay [s/packet] (Total Delay);

Time	
Real: 00:00:40	Simulated 00:02:21
Equipment	
# NodeBs 1	# Users 4160
Switching	
Circuit # Total 66 # Blocked 4 # Dropped 0 GoS(Power)[%] 0.00 GoS (Code)[%] 6.06 GoS (Tot.)[%] 6.06	Packet # Total 4549 # Delayed 2847 # Dropped 0 Power [%] 1.570 Code [%] 61.090 Delay (Tot.) [s/packet] 4.070
Mobile Status	
Circuits # Out of Cov. xxxx # Idle 3441 # Active 29	Packets # Out of Cov. xxxx # Idle 2059 # Active 14
Voice Service	
# Call/hour (estimation)	1709
Call Average Duration [s]	57.82
Traffic [Erl]	27.0360
Performance Parameters	
Coverage Area [km2]	2.270
NodeB's Radius [m]	850
NodeB's Height [m]	19
NodeB's Density [Node B/km2]	0.441
# Services 43	# Users 42
# Services / # Users	1.024
NodeB's Load Factor [0...1]	0.347
#Channel Codes Available	16

Figure 4.18 - Dynamic network monitoring window.

- The Mobile Status box, gives information about the number of active services or idle in circuit or packet connections;
- Voice Service, which is treated as a “special service” in this window, allowing to see the estimated number of calls per hour, current average call duration, and traffic [Erlang];
- Performance parameters box, where the tool user may monitor some optimisation evaluation/results: estimated coverage area, current cell radius, current BS height, number of BSs per square kilometre (important to estimate the network cost for a given area), number of

services connected to the BS, number of active users, relation between number of connected services and number of MSs (note that this is possible because one single MS may use different services simultaneously), BS load factor (which gives the relation between current transmitted power to users and the maximum allowed total power), and finally the number of DL channel codes available at the BS.

One should note that, when packet services are active, each MS may use higher layers in the code tree, therefore, consuming several codes in lower layers, causing a lack of codes for other incoming services.

## 4.6 Algorithms Validation

In order to validate some of the simulator main functionalities, namely propagation model, link budget, and circuit and packet traffic random generators, some validations were performed, which are presented in this section.

### 4.6.1 Propagation Model

A propagation model validation is essential, in order to achieve a reasonable accuracy in propagation simulation results. Figure 4.19 shows the propagation model output for LoS, for two frequencies (1900 and 2000 MHz), as a function of the distance between MS and BS. Note that the validity range for this particularly section of the model is 20 to 200 m.

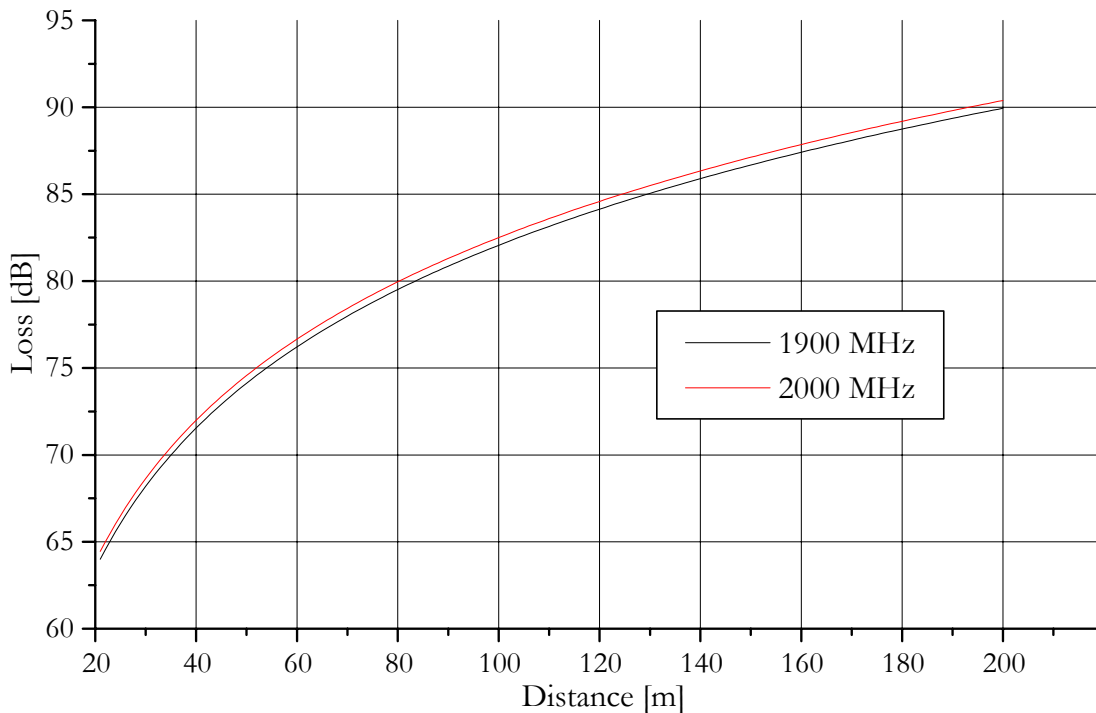


Figure 4.19 - Computation results for COST 231 W.I. model for LoS.

It is important to note in Figure 4.19 that different frequencies (within the UMTS band) do not have a major influence in signal attenuation. Therefore, one may assume that frequency has a minor role in the system sensitivity and stabilisation.

The COST 231 W.I. model for NLoS environments produces quite different attenuation results, Figure 4.20 presenting some of them. The black and red lines are almost 30 dB apart, the main reason for this being BS and building roof top heights: if BS antenna height increases, attenuation decreases for the same distance. Therefore, the BS antenna up and down movement will affect the MS received signal conditions, and consequently the BS load, number of served users, blocking and delay, etc.

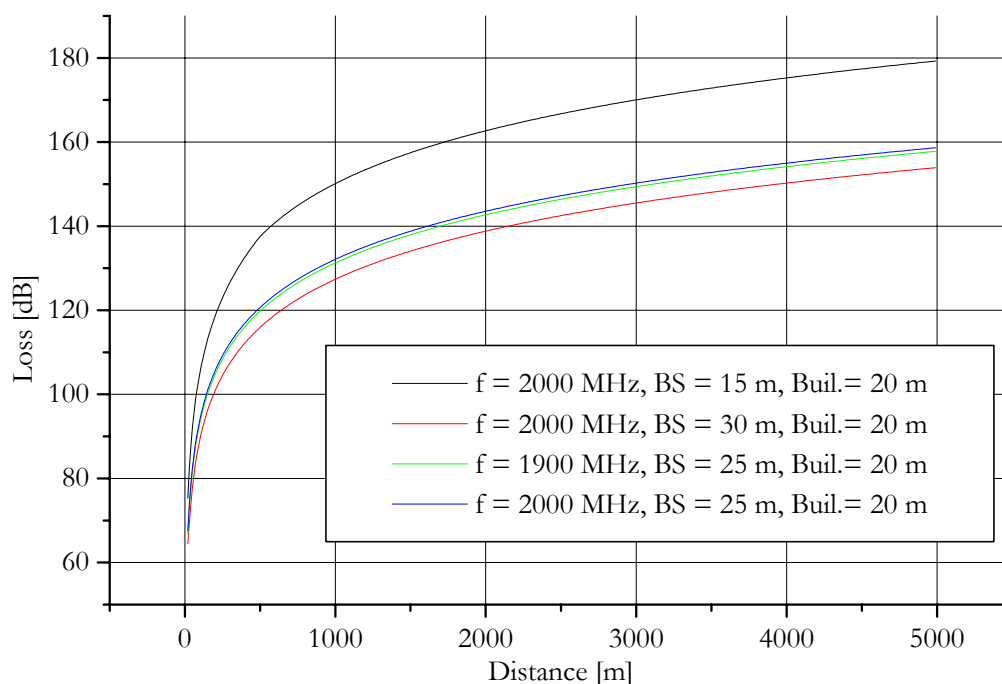


Figure 4.20 - Some computation results for COST 231 W.I. model in NLOS.

In the network optimisation process, it is important to identify several parameters that may have or not considerable influence on system behaviour. Having in mind to identify these parameters, several tests were performed. For example in Figure 4.21, attenuation was computed as a function of distance and street width. Analysing these results, one can see that street width variation does not have much influence in attenuation, therefore, one may conclude that from the network optimisation point of view, street width is not relevant.

Figure 4.22 shows an attenuation surface as a function of distance, and difference between building rooftop and BS height. Note that when BS antennas are below buildings rooftop, there is a strong increase of attenuation, the turning point being when building rooftop equals BS height. Therefore, one may conclude that the relation between BS and buildings rooftop is very important to coverage estimation and BS load impact, and relevant to the

optimisation process. BS antennas height is a good parameter for allowing a network tuning quality/capacity process.

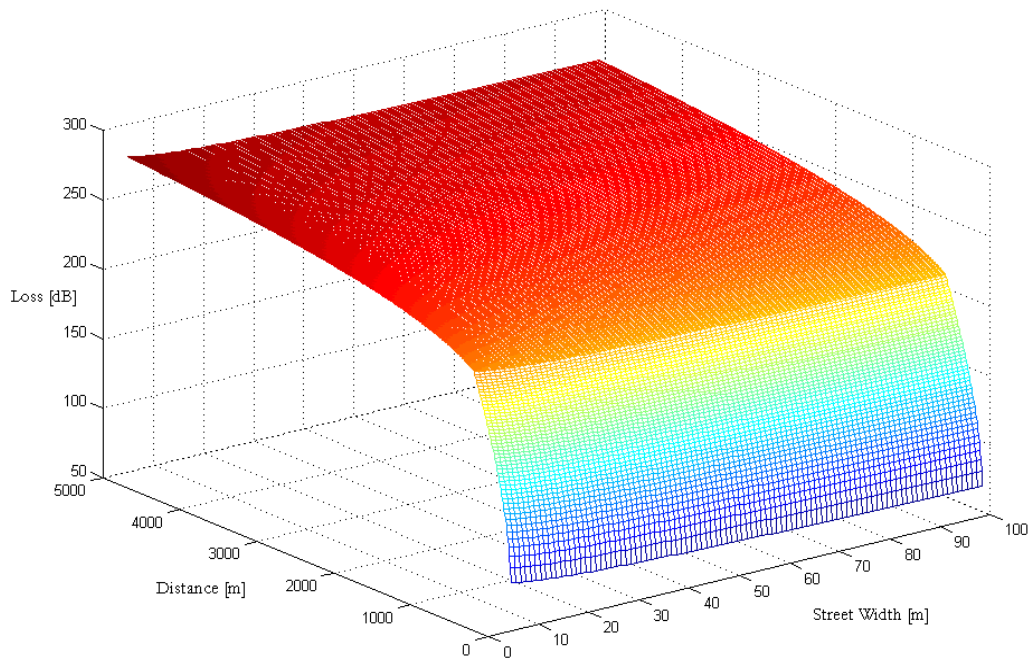


Figure 4.21 - Street width influence in NLoS attenuation.

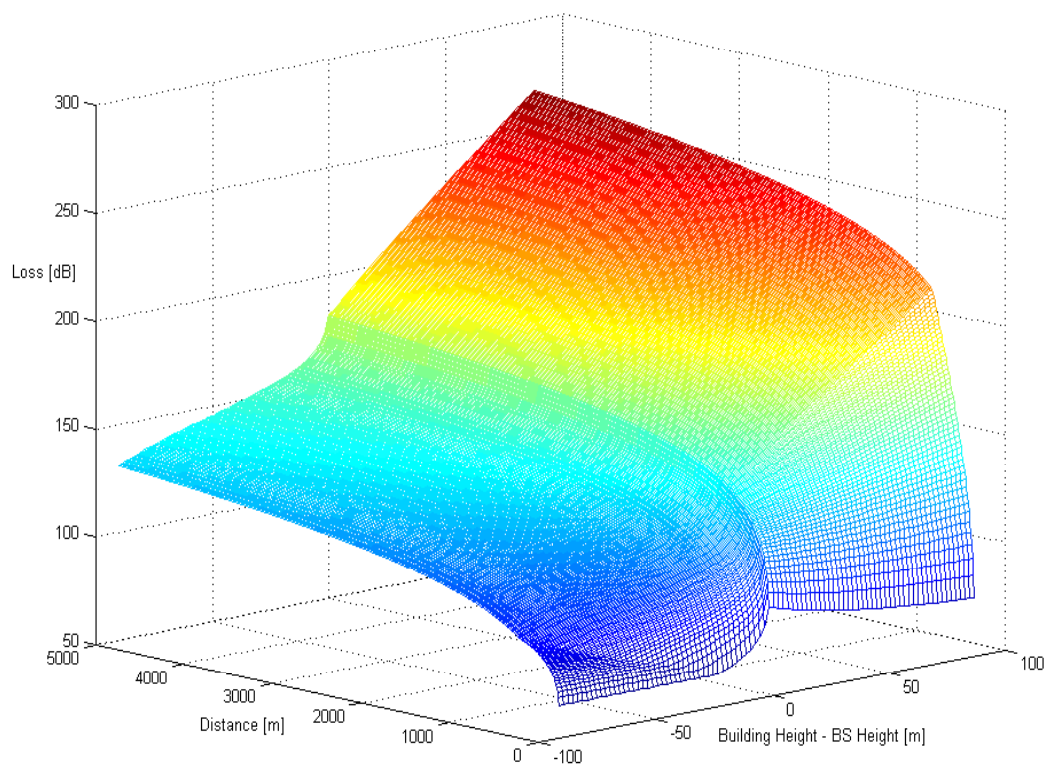


Figure 4.22 - (Building Height-BS Height) influence in NLoS attenuation.

If one takes a look to a particularly case of Figure 4.22 shown in Figure 4.23 (where distance is 750 m, orientation angle is  $45^\circ$  and the average buildings roof top is 25 m), it is possible to see the signal attenuation variation due to BS antenna height influence. Note that when BS antenna height equals the building rooftop at 25 m, attenuation decreases more rapidly, which is due to better propagation conditions over buildings roofs; therefore, the region around this turning point is very sensitive, and useful to guide optimisation algorithms.

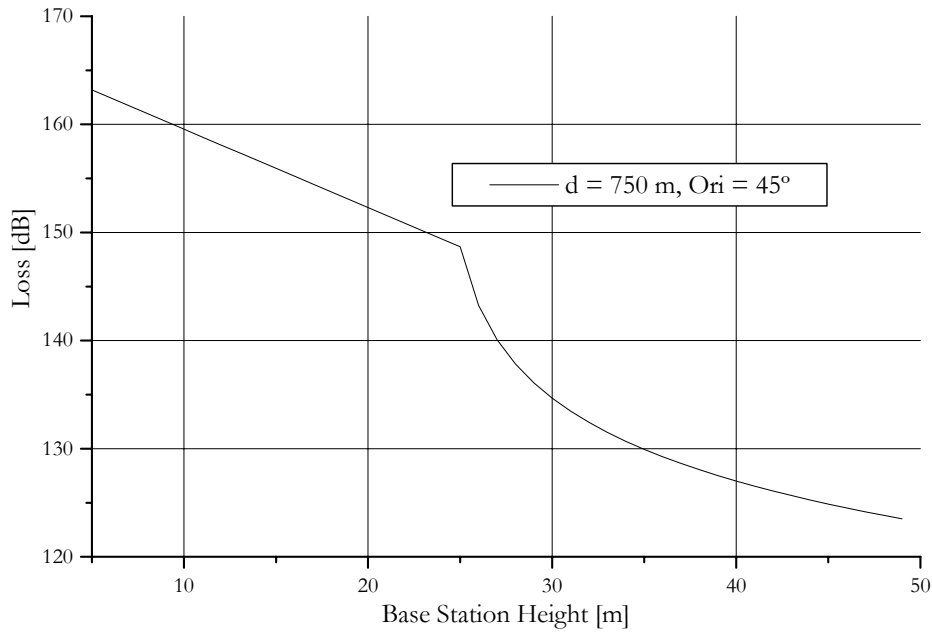


Figure 4.23 - BS Height influence in NLOS attenuation.

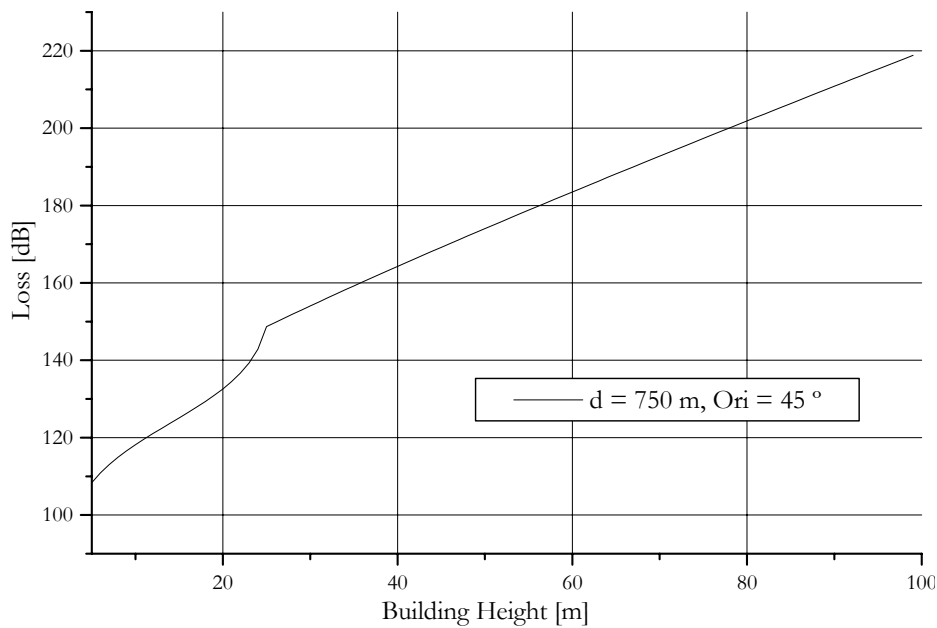


Figure 4.24 - Building Height influence in NLoS attenuation.

Like in the previous figure, Figure 4.24 shows building height influence on attenuation; as expected, when buildings average height reaches BS antennas height, one finds a turning point in

attenuation values. Therefore, one may conclude that if there is a need to decrease BS load factor (total power level used in DL over maximum power at BS) in a constant cell radius environment, one may increase a little bit the antennas height in order to decrease attenuation. On the other hand, if one has very low GoS or Delay levels (meaning good values), one may decrease the BS height, in order to reduce interference from and to other cells, decreasing load, and consequently the blocking and delay factors.

This propagation model has another characteristic parameter, which is street orientation angle. This is a correction parameter that weights the influence of street orientation relatively to the propagation direction. Influence of street orientation angle in the propagation loss is clearly shown in Figure 4.25, where two different curves for 200 and 400 m between MS and BS are presented. Note that COST 231 propagation model in NLoS conditions is very distance sensitive, therefore, cell radius or BS density in a given area is a major parameter that has to be optimised. In other words, it is possible to manipulate the cell radius, assuming that when increasing or decreasing cell radius a number of BSs per area modification is assumed, subsequently BS capacity (load) is changed, until target values be accomplish.

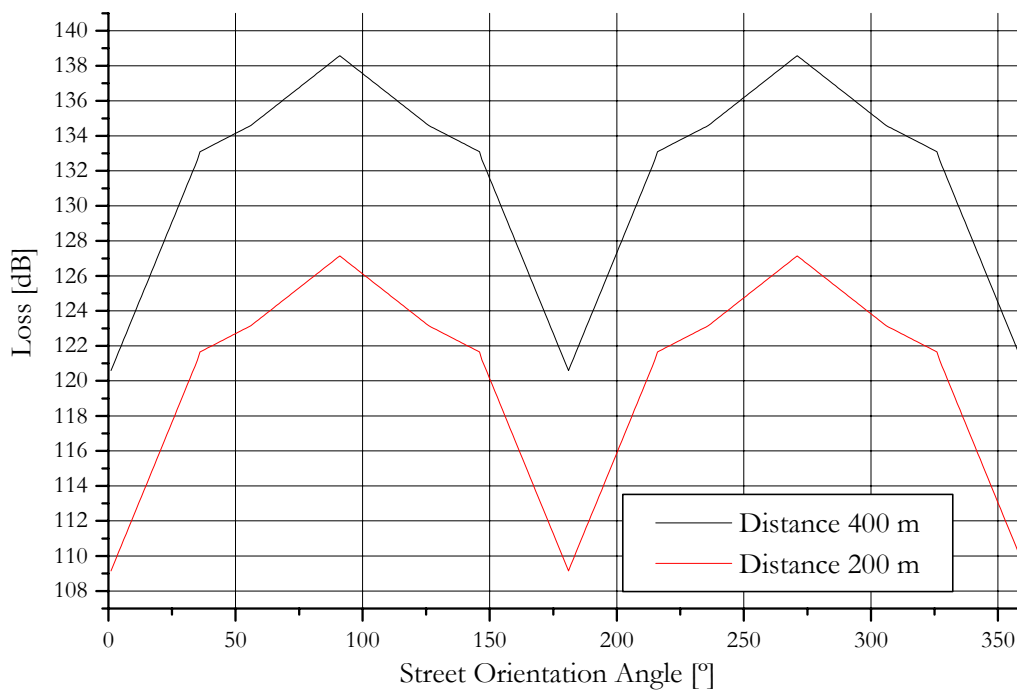


Figure 4.25 - Street orientation influence in NLoS attenuation.

#### 4.6.2 Link Budget

Link Budget has a major role in the simulator, because it is here that several receiver parameters are estimated, like MS received power, noise power, interference power, orthogonality level, service sensitivity, additional losses and processing gain.

Figure 4.26 shows a plot of MS receiver sensitivity as a function of bit energy per noise density, for several service bit rates. Note the differences between bit rates (services), like voice, data and multimedia; also note that different services with equal bit rate may need different  $E_b/N_0$  requirements, which of course implies in different sensitivity levels for each service. This effect is clearly shown in Figure 4.27, where different  $E_b/N_0$  levels are computed as a function of service bit rate. From the coverage point of view, services using the same bit rate, but with different  $E_b/N_0$  requirements, will have different sensitive levels, which imply in different cell coverage, per service.

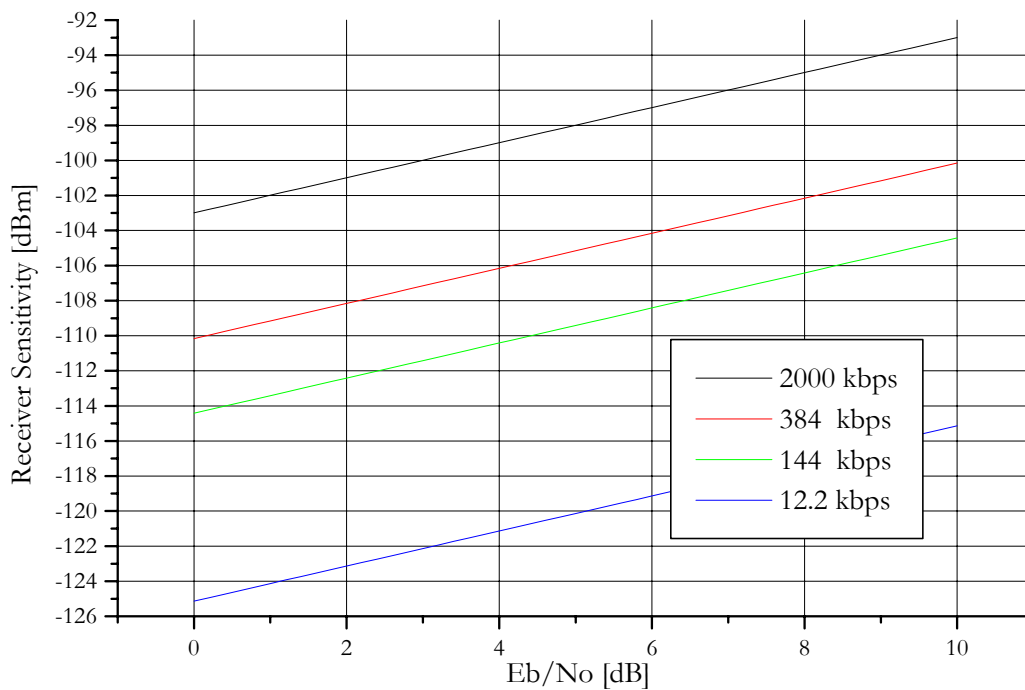


Figure 4.26 -  $E_b/N_0$  influence in receiver sensitivity for several services.

In Figure 4.26 and Figure 4.27, it is clear that for higher  $E_b/N_0$  levels there is a correspondent higher receiver sensitivity level, therefore, a need for a higher power level on the transmitter is required in order to guarantee the same coverage. Different  $E_b/N_0$  are specified in UMTS standards for each service and environment, therefore, at link budget level, in order to obtain a service sensitivity value, one just needs to consider standard values in the link budget expression; nevertheless, it is important to know these interdependencies for further scenarios analysis.

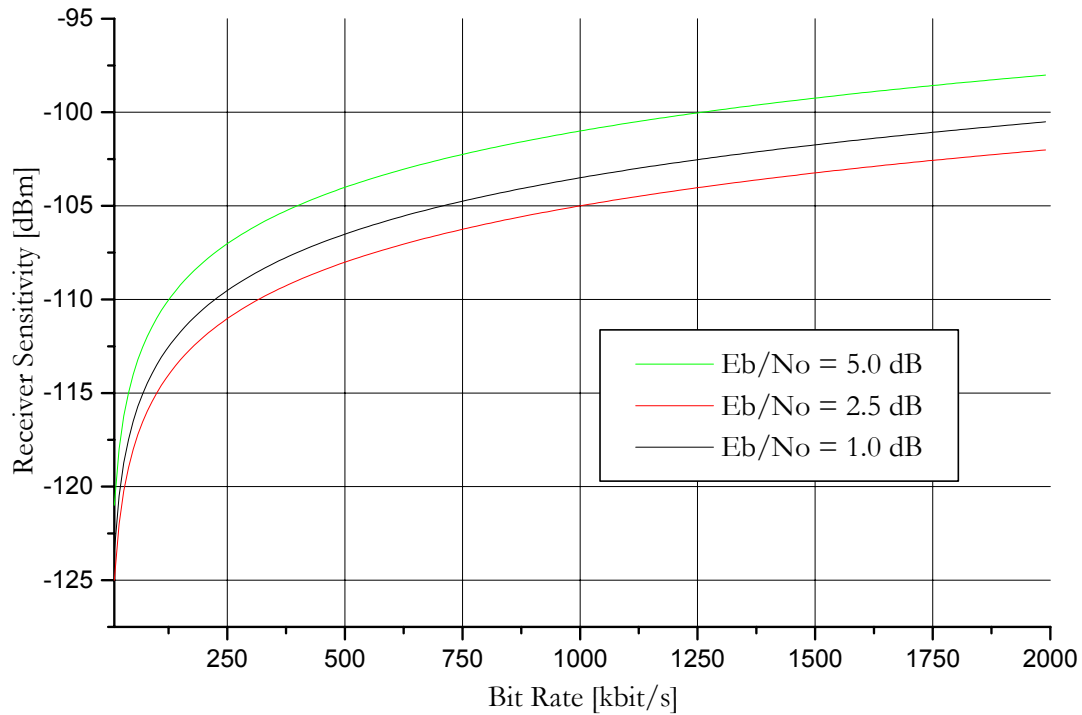


Figure 4.27 - Bit Rate influence on receiver sensitivity for  $E_b/N_0$  levels.

#### 4.6.3 Random Generator

In discrete simulation environments, random variables represent a crucial role. In this planning and optimisation UMTS tool, system traffic (CS and PS generation), users behaviour and users distribution are implemented with random generators. Users distribution in a given area is uniform distributed, as shown in Figure 4.3. Voice calls arrival rate follows a Poisson distribution process. Poisson distribution is also valid for PS behaviour, since applications like e-mail, file transfer or Internet browsing do not maintain long time connections.

Figure 4.28 compares a theoretical Poisson probability density function, represented by a single blue line, with Poisson discrete simulator generator, represented by blue bars. Observing this figure, one may conclude that the simulator generator is fair when compared to the theoretical line. Note that when simulation time is increased this error will decrease, which is due to an increase in the generator samples number.

Voice and videophone average call duration typically have a negative exponential distribution. In this tool, all packets have a constant duration, nevertheless the tool user may change it.

In conclusion one may say that the major and most sensitive random variables generators functional blocks were validated.

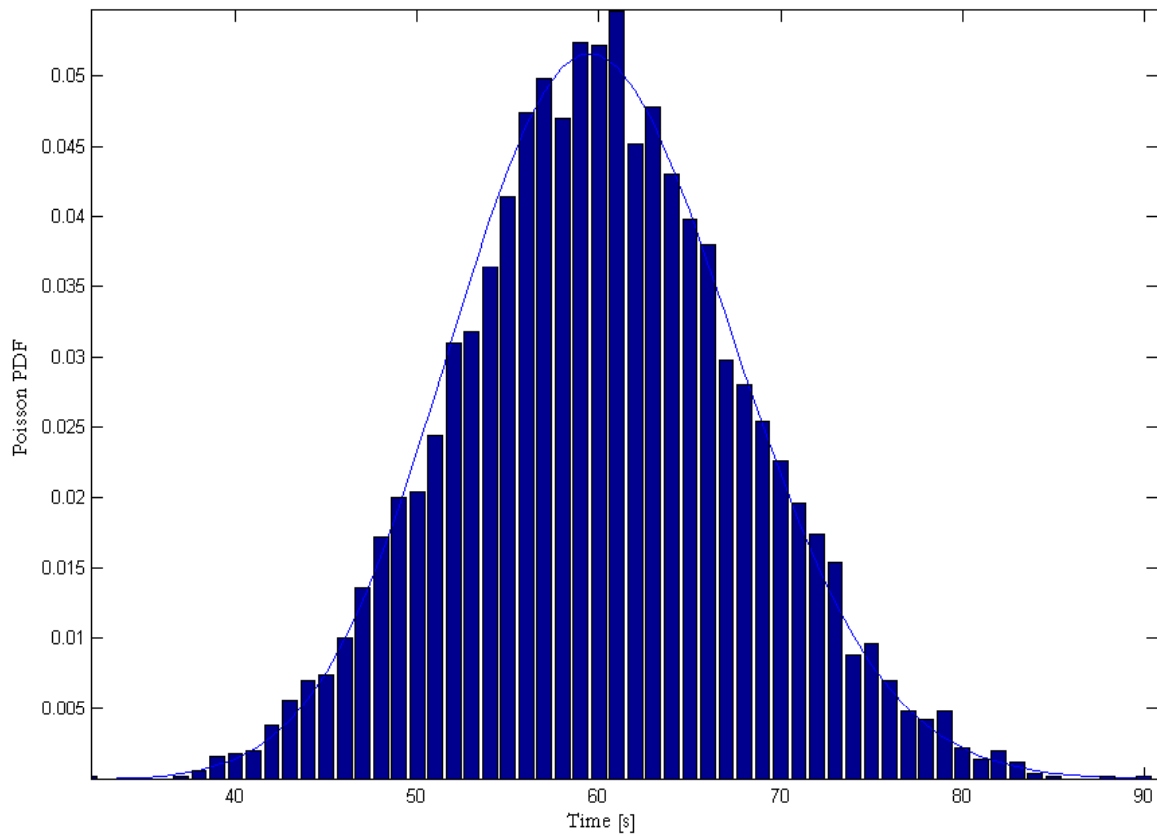


Figure 4.28 - Poisson probability density generated by simulation (Bars) and analytically (Line).

## 4.7 Output Examples

In order to analyse the simulator results, it was necessary to implement a mechanism that allows the analysis of main network parameters evaluation as a function of elapsed time. The following figures are just plots of examples of these parameters.

Figures 4.29 to 4.34 show some major network parameter evolution, like BS load, GoS, delay, cell radius, BS height and connections number. In these examples, the time resolution is 1 s, which means that 1 800 samples correspond to 0.5 hour of simulation snapshot. In this example, the simulator optimisation process time (snapshot) is set to 0.5 hour; after this time, a general reset is performed and a new snapshot is launched; this aspect is very clear when one observes the following figures, where the decision and snapshot reset points are made at 1 800, 3 600 and 5 400 s.

Figure 4.29 shows the total BS load in DL, where all active connection loads are sum. The BS load threshold in this example is 0.7, which means that equal or upper load values causes blocking or delay at the BS when new connections arrive; nevertheless, the BS allows upper values, due to power control in MSs that are already connected.

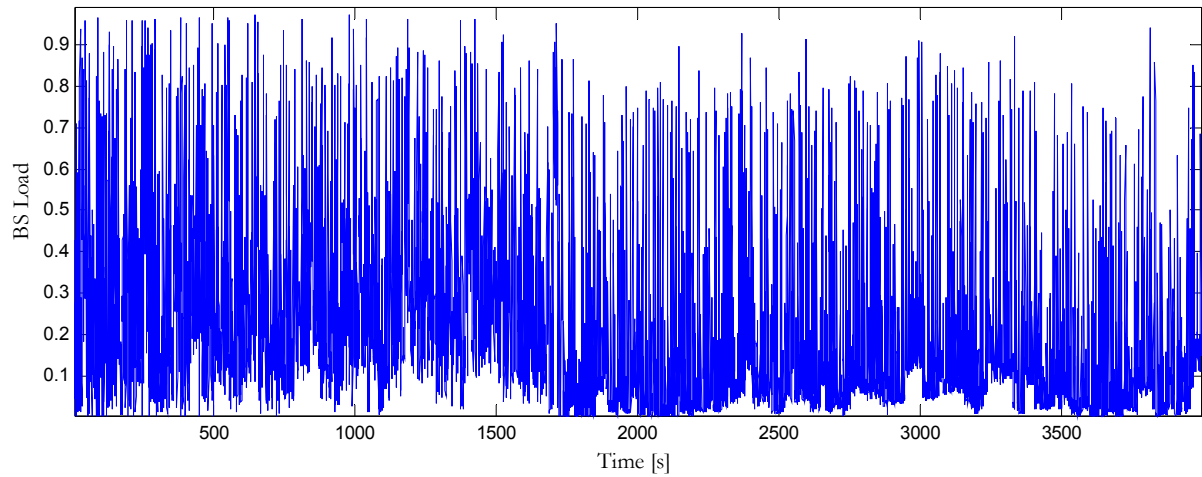


Figure 4.29 – Example of BS load through simulation time.

One major network quality indicator is the BS blocking probability, Figure 4.30, which is used by the simulator optimisation process to decide how the next snapshot configuration will be set, aiming to converge into a given target.

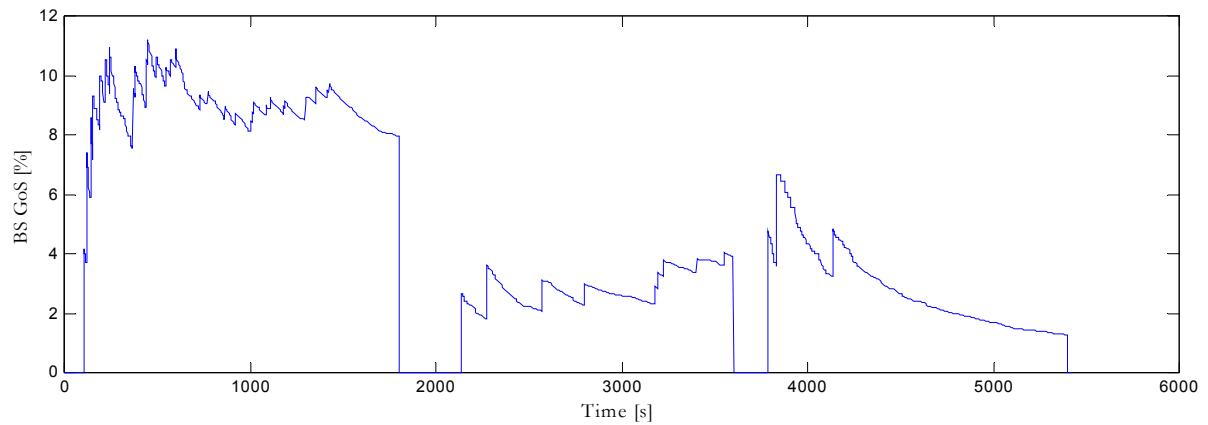


Figure 4.30 - Example of BS GoS converging to target (2%).

Other major network quality indicator is the BS delay, Figure 4.31. Again, the simulator optimisation process based on this parameter decides how the next snapshot configuration will be set.

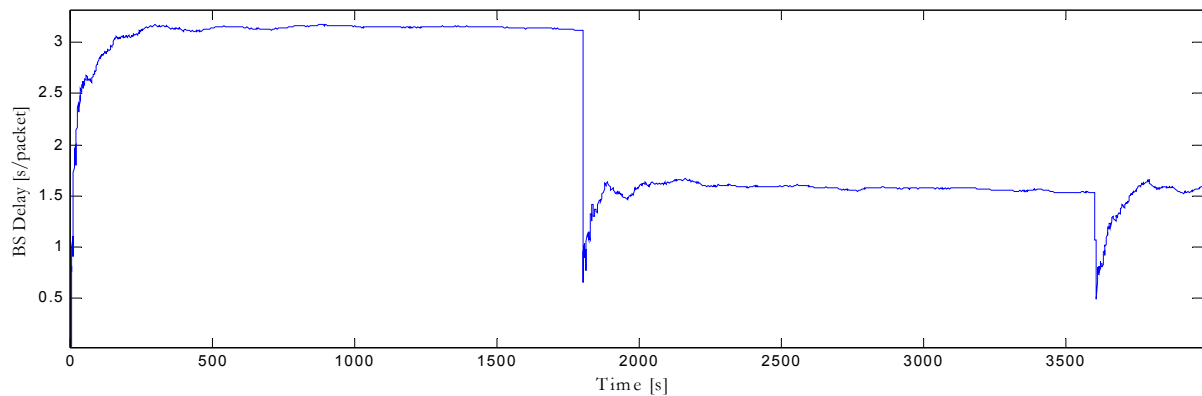


Figure 4.31 - Example of BS Delay converging to target (2 s/packet).

The convergence/optimisation in this example is very clear: in the second simulation (1 800 to 3 600 s), blocking and delay levels decrease relatively to the first one (0 to 1 800 s), which is due to cell radius decrease Figure 4.32. This reduction was decided by the optimisation process, based on first simulation results (which present values clearly above targets). Note that in Node B cell radius plot Figure 4.32, one may see some network convergence from 900 to 850 m, which implies a decrease on the average GoS and packet delay.

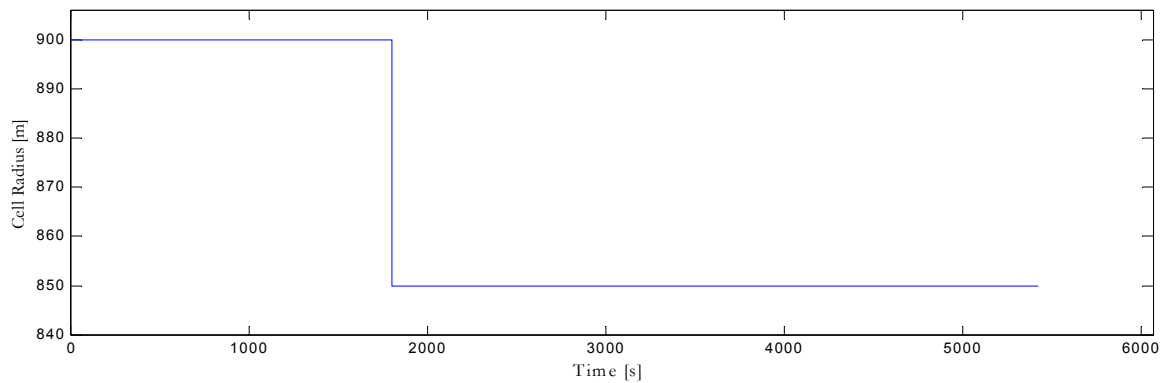


Figure 4.32 - Example of cell radius converging to optimum value.

Note that cell radius is an extremely important parameter, because, based on this, an operator may estimate the BS density, therefore, the cost, offered capacity and network quality.

In Figure 4.33, the BS height convergence is presented. This parameter also converges automatically to an optimum value. Based on this value, an operator may estimate the BS antenna height, in order to accomplish the quality targets.

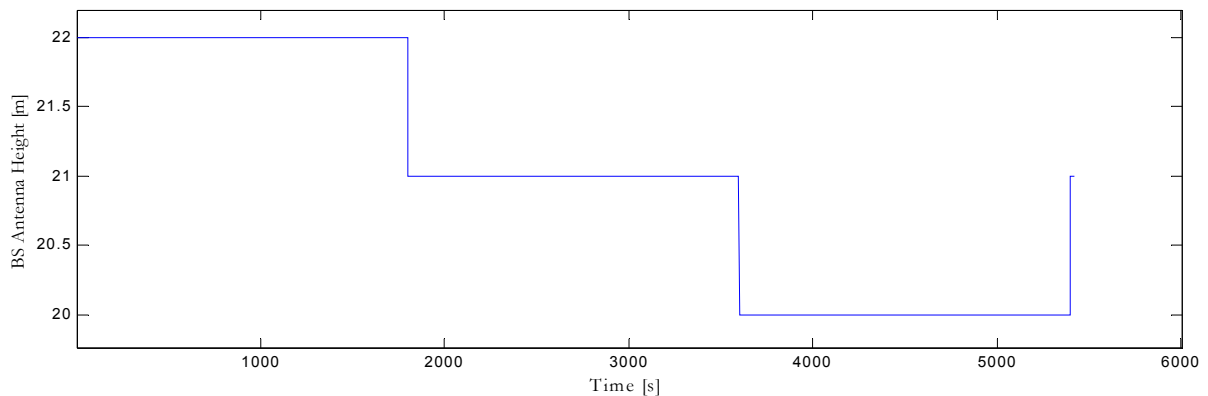


Figure 4.33 - Example of BS antenna height converging to the optimum value.

As already mentioned, a MS may use more than one service, therefore the number of active connections may be higher than the number of active MSs. This information is shown in Figure 4.34.

Figures 4.35 to 4.40 show all six individual UMTS Forum defined services, where each service load is plotted. It is possible to observe which services have more influence on the network (load). The HMM and S services present higher load, due to high bit rate service (2000 kbps) and to high penetration percentage, respectively. Also note that, on average, these

individual service loads decrease/increase depends on decisions performed by the optimisation process between snapshots.

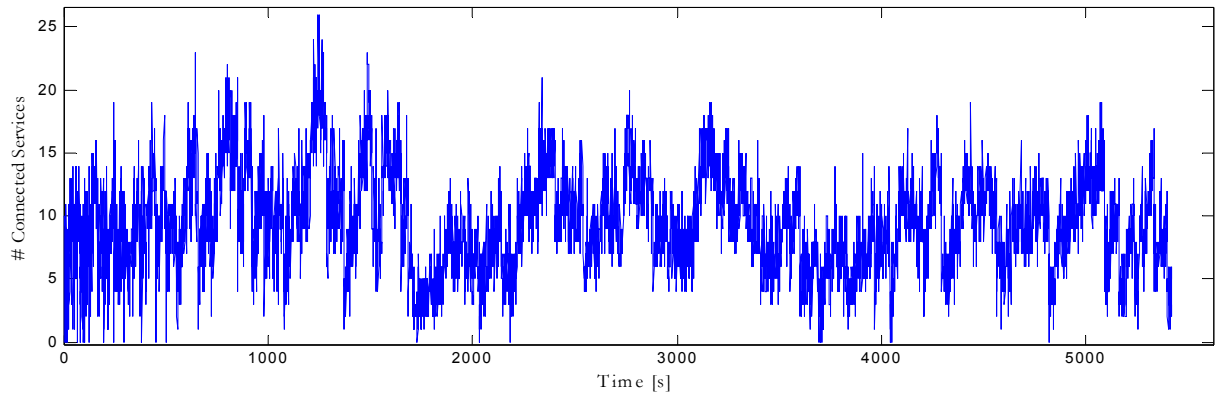


Figure 4.34 - Example of number of connected services.

Load depends greatly of service bit rate, service penetration and average connection time, therefore, some services offer more or less load. Figure 4.35 shows the speech load; although this service has a low bit rate, it is the most used by users, hence, it is an important service from the BS load point of view.

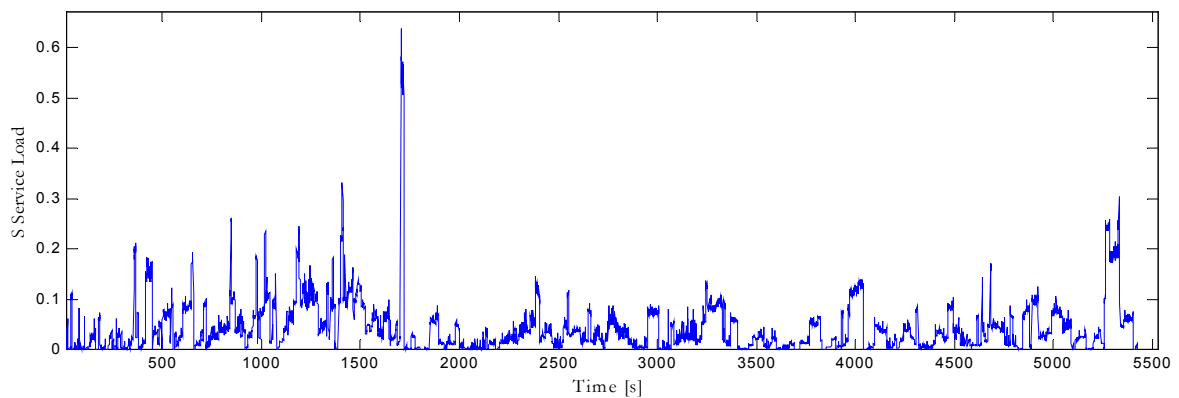


Figure 4.35 - Example of S service load.

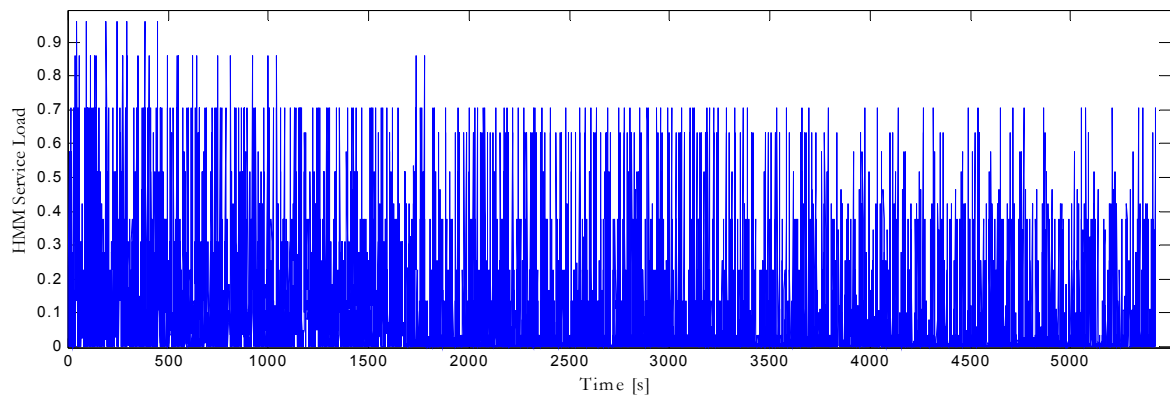


Figure 4.36 - Example of HMM service load.

As expected, HMM service has a huge impact on the BS load, mainly due to high bit rate. Figure 4.36 clearly shows this aspect, where this service is responsible for leading the BS to its power and channel code limits.

Based on the UMTS Forum, the HMM penetration forecast value is expected to be very low, therefore, the impact on the BS load is expected to be low as well, as Figure 4.37 shows.

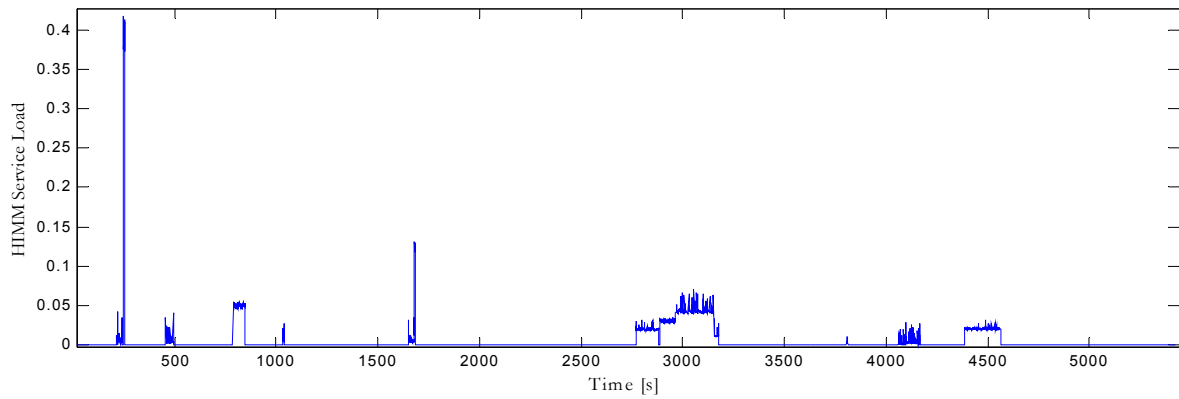


Figure 4.37 - Example of HMM service load.

The SD, Figure 4.38, and SM, Figure 4.39, have the same bit rate, but different penetration values. Due to this, SD and SM put quite different loads into the BS; besides this, it is important to remember that SD is CS while SM is PS.

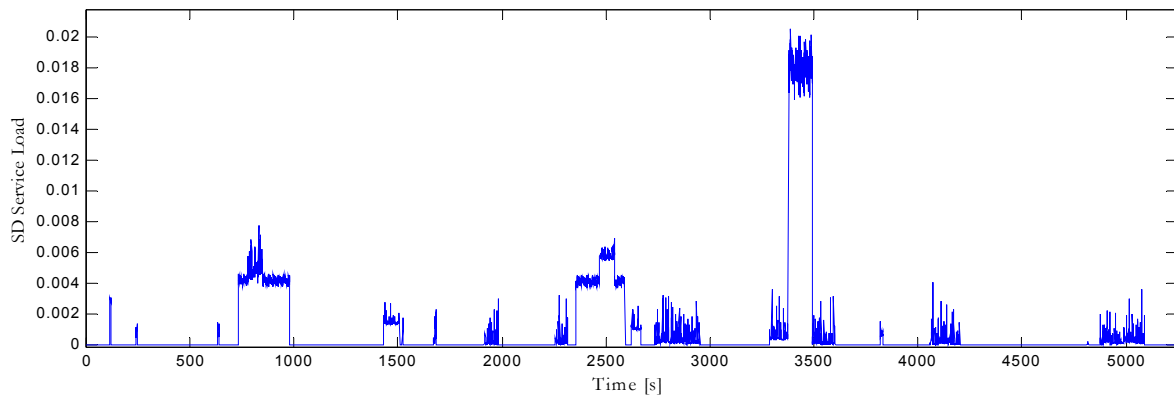


Figure 4.38 - Example of SD service load.

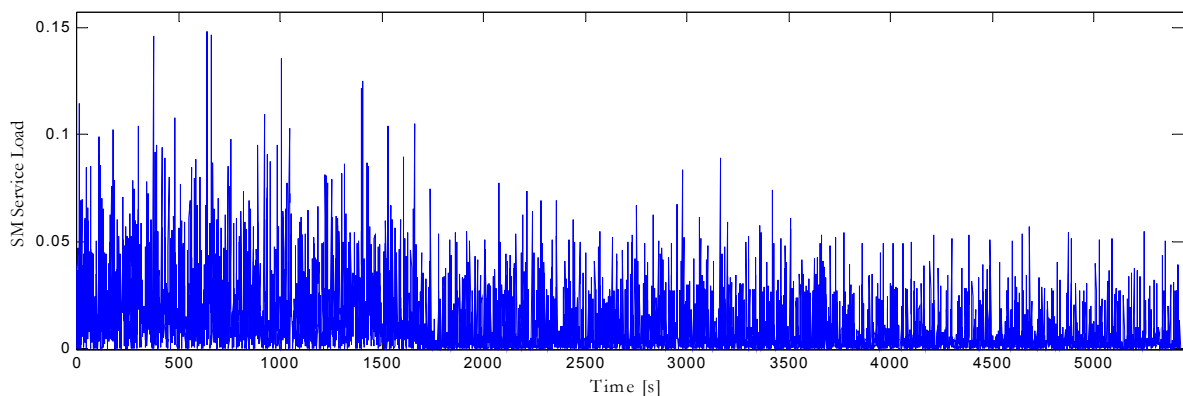


Figure 4.39 - Example of SM service load.

Figure 4.38 shows clearly the SD CS nature, where connections are maintained for a long period of time, compared to SM, Figure 4.39, which is a PS based service.

MMM is characterised mainly by a high bit rate and its PS nature. Due to these features, the fast power control mechanism leads this service to high load levels, like shown in Figure 4.40.

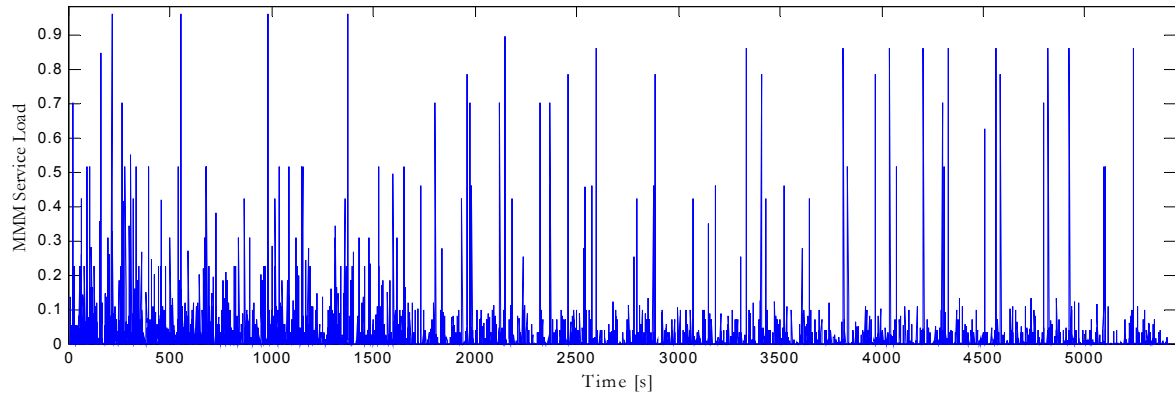


Figure 4.40 - Example of MMM service load.

At the BS 512 channel codes are available, which corresponds to one code tree [3GPP00c]. Each different bit rate service uses different SF levels; for example, a basic 15 kbps link uses a SF of 512 (1 channel code), while a 1960 kbps link uses a SF of 4 (128 channel code). Therefore, the number of available channel codes gives the BS load from the channels point of view. In simulations, it is assumed that 128 channel codes are used for signalling purposes and that 30 % (153 channels) are reserved for soft handover, therefore, a maximum of 230 channel codes are available for traffic. In Figure 4.41, a zoom of this parameter is shown, where it is easy to observed the arrival of high bit rate connections, mostly PS based services.

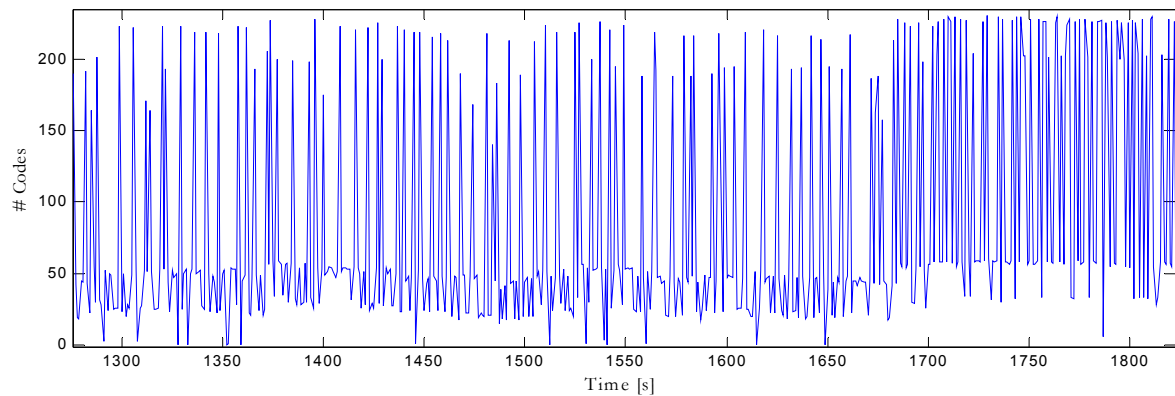


Figure 4.41 - Example of number of available channel codes.

As explained before, blocking is also due to the lack of channel codes. Figure 4.42 shows an example of blocking probability, due only to channel codes unavailability (mainly high bit rate service dependent).

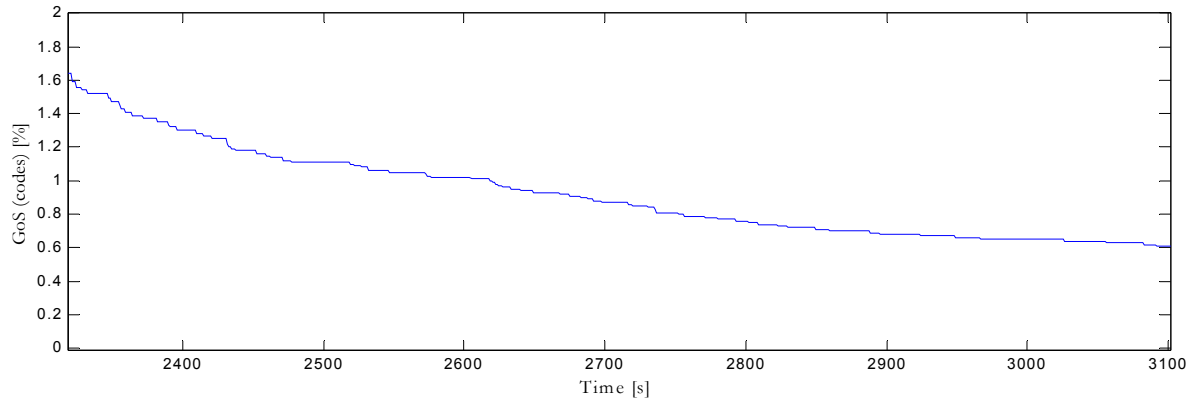


Figure 4.42 - Example of blocking due to lack of channel codes.

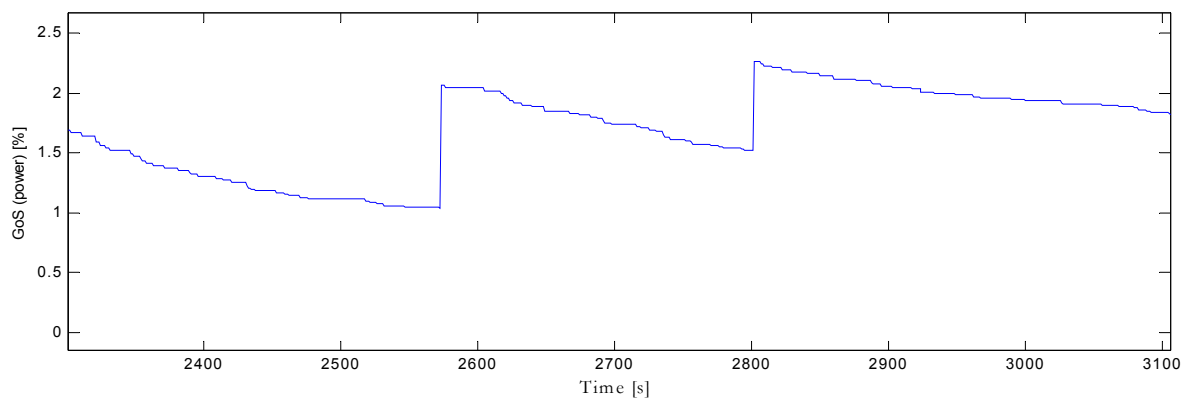


Figure 4.43 - Example of blocking only due to lack of power.

Like in the previous example, Figure 4.43 shows the blocking probability example, caused by the power load threshold, meaning that when the BS load reaches a given mark (i.e. 70 %) new connections originated by CS services will be blocked. Note that the total blocking probability is the sum of these two contributions.

PS based services will suffer delay on the network. In order to understand how delay depends on BS resources, the simulator distinguishes the total delay from two sources, power and codes. In Figure 4.44, an output example is shown where it is possible to observe the impact that power has on delay; in this particular example, it is also possible to see simulation convergence between the simulation reset points. As in the previous parameter, it is possible to observe the same points in Figure 4.45. Comparing Figure 4.44 and Figure 4.45, it is clear that delay is more sensitive to channel codes resource rather than power, because most of PS services (high bit rates) use the low levels on the code tree, which prevents the use of many channel codes.

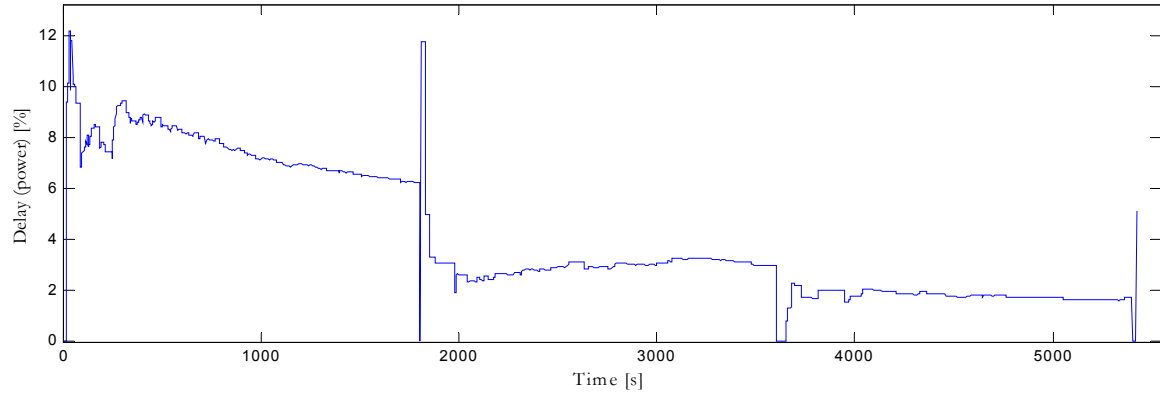


Figure 4.44 - Example of BS delay percentage due to lack of power.

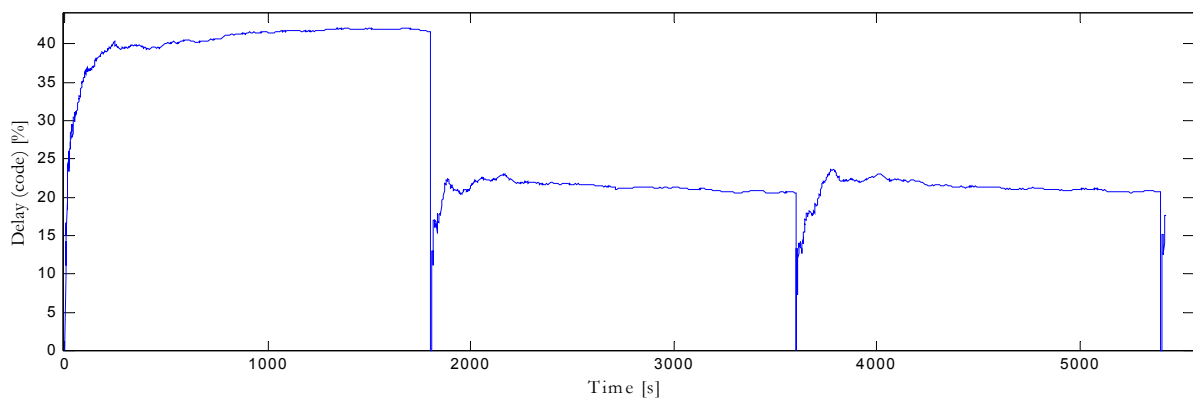


Figure 4.45 - Example of BS delay due to lack of channel codes.

In order to verify the power control algorithm, an internal simulator parameter was created that is sensitive to a “special MS”, and reveals the signal level received by this MS. This “special MS” is selected based on the following criteria: among all MSs, the one that is currently using more power resources at the BS is selected. An example of this output parameter is shown in Figure 4.46. Note that this parameter considers several MSs, through simulation time.

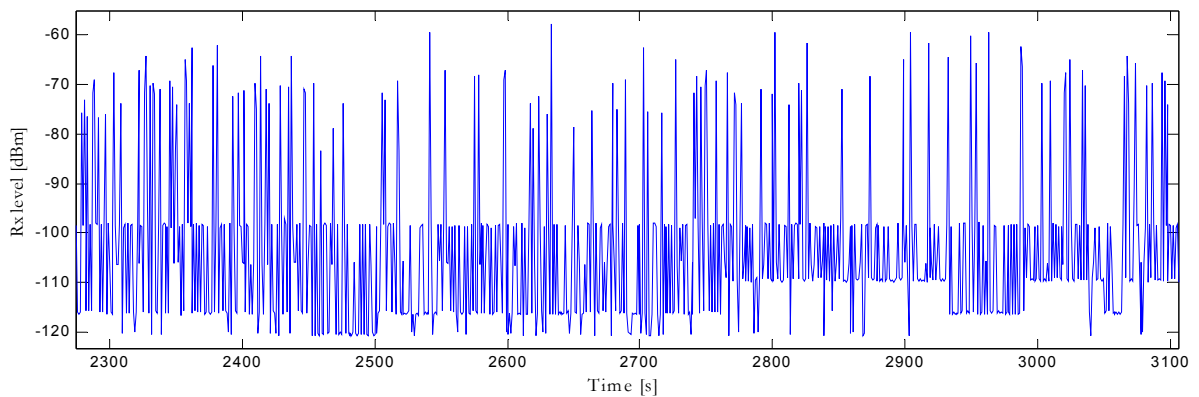


Figure 4.46 - Example of power control on special mobile receiver.

Using this tool, it is possible to monitor the optimisation process and all the main parameters (i.e. quality indicators, network configuration parameters), enabling the visualisation

of instantaneous network configurations and also average results, providing a detailed analysis on network parameters impact and sensitivity (users/services/network). Besides UMTS radio interface, this tool also produces an optimum cell radius. The optimisation process used in this tool is a very interesting feature that allows the user to focus his work onto scenario definition, entrusting into the automatic process the planning work, however, it is possible to control this process and all other parameters.

Compared to other simulation tools, this one presents good and interesting results using low computational resources, mainly due to the simplified algorithm approach (only one BS, expanded in future work).

Multi service generation was performed using source models, for voice, a classical voice model was implemented (Poisson arrival process and exponential call duration), to simulate packets an ON-OFF model was implemented. For data, a packet approach is taken, with fixed length ones.

The main algorithms used in this tool were validated, for example: propagation models, link budget, user generation, users profile generation, source models and output results.

This tool intends to give trends for major parameters, based on a simple approach, and with a low computation load.



# 5 Analysis of Scenarios

## 5.1 Scenarios, Definition

Cellular planning is quite scenario dependent, therefore, a scenario that represents an acceptable or typical service area is required, aiming to accomplish good results. In cellular networks, there are three well-known scenarios: rural, suburban and urban. The most important is the urban one, followed by the suburban, and finally the rural; this order is due to traffic load (population density), propagation issues, and scenario network dependency.

A differentiated urban scenario must be analysed in order to include several urban aspects. After searching this kind of scenario in the Lisbon area, a specific area was selected, Figure 5.1, which has large avenues, squares, rectangular urban architecture, and a relative constant building height. This area represents a typical urban environment that mixes several major propagation and services aspects. From the propagation modelling point of view, this environment has also another advantage: it fits the propagation model parameters' specifications. In order to easily distinguish streets from buildings borders, since the simulator can process this information (as already shown in Chapter 4), a simplification of the digital image was performed.



Figure 5.1 - Partial simulated scenario (adapted from [CMLi01]).

Any major city is characterised by different population densities in its different areas, which is due to several urban aspects, like industry location, airports, huge commercial centres,

large business areas, residential areas, historical and tourist areas, sport zones, etc. Cellular networks, like GSM, adapt their BS location as a function of these densities, in order to provide capacity and coverage to users. Figure 5.2 shows Lisbon population density map, where one can see that the larger population densities are located in business and historical areas downtown (during day time).

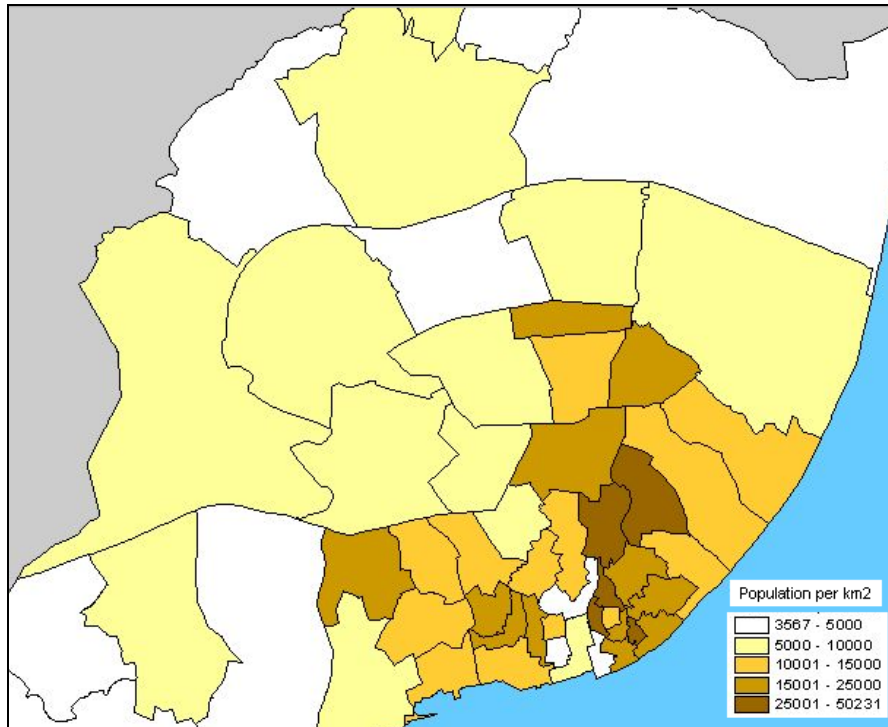


Figure 5.2 - Population density in Lisbon (adapted from [CMLi01]).

In GSM planning (voice service), it is possible to predict the traffic density load in Erlang per km<sup>2</sup>, generated by users, and then establish a relation between users offered traffic and network traffic capacity, leading directly to the BS density. In UMTS planning, this concept is not valid, as already discussed in previous chapters, therefore, a system simulator is required, in order to estimate some major UMTS network parameters, like cell range, among many others.

Simulations depend greatly on all parameters, but if there is a change on two or more parameters in the simulation set, certainly becomes impossible to distinguish the influence in the system sensitivity analysis from one particular parameter to another. In order to understand the impact that each parameter has on network behaviour, it is indispensable to perform an individual study, assuming that all others are constant. So, it is necessary to define a reference scenario from which it is possible to study the network dependency on system and scenario parameters. For all services identified by the previously mentioned UMTS-Forum scenario, Table 5.1 presents some major parameters and their respective values [UMTS98a]. Note that  $E_b/N_0$  target values were extracted from ETSI [ETSI00]. Tables 5.1 and 5.2 show all simulation default

parameters and values (UMTS Forum scenario), a description of these being found in Chapter 4. Exceptions to these assumptions are mentioned in explicit form.

Table 5.1 - Default individual service settings for urban pedestrian and vehicular (year 2005).

Service	HMM	MMM	HIMM	SM	SD	S
Bit rate [kbps]	2000	384	128	14	14	12
Av. Connec.. Time [s]	53	14	144	30	156	60
Penetration [%]	4.7	7.7	0.5	25	10	60
$E_b/N_0$ DL [dB]	1.6	1.1	2.5	1.2	1.2	6.1
Switching	PS	PS	CS	PS	CS	CS

Table 5.2 - Default general parameters settings.

Simulator Parameters	Value	Simulator Parameters	Value
Initial BS Height [m]	22	3 Sectors	90°, 210° 330°
Buildings Height [m]	20	Snapshot Time [s]	900
Buildings Separation [m]	60	BS Height Step [m]	1
Streets Width [m]	30	Cell radius Step [m]	25
MS Height [m]	1.5	Power Control Freq. [Hz]	500
Urban Type	Metro. Centre	Power Control Step Min. [%]	10
Frequency [MHz]	2000	Power Control Step Max. [%]	50
Orthogonality Factor	0.5	Power Control Step Marg. [dB]	5
Signalisation channel codes	128	Blocking Margin [%]	2
Soft Handover [%]	30	Delay Margin [s]	2
BS Max. Tx Power [W]	10	Blocking Target [%]	2
Inter Interference Load [%]	30	Delay Target [s]	2
BS Max. Load Factor	0.7	Retry Time Min. [s]	3
Packet Duration [s]	1	Retry Time Max. [s]	10
Thermal Noise Density [dB/Hz]	-174	Receiver Noise Figure [dB]	5
Receiver Noise Density [dB/Hz]	-169	Receiver Noise Power [dBm]	-103
Interference Margin [dB]	3	Building Penetration Lost [dB]	10
# Operators	4	Population Density [pop/km <sup>2</sup> ]	10 000

As already described in Chapter 4, the tool developed in this work gives the cell radius and antenna height as a function of pre-defined network quality targets and traffic generation. Knowing that virtually any network parameter has some influence over the overall network performance, results analysis are performed in this chapter, in order to predict some network parameters tendencies.

## 5.2 UMTS Forum Scenario

In the beginning, voice will be the most used service, and the one that will have the largest penetration value, therefore, it makes sense that voice has a special analysis in this work. In Figure 5.3, only the voice service is active (all the other five services are off), with 2% blocking, and a 60% service penetration was set in an universe of 4 operators (Portuguese case), the number of users assumed for each operator having a uniform distribution.

Several simulations were performed for different population densities: in Figure 5.3 it is possible to see the cell radius optimisation as a function of the population density. Note that when only the voice service is active, blocking is only due to the lack of power and not to lack of channel codes, because voice uses the most deep codes in the code tree. In other words, the voice service uses a high SF, which means that power breaks before code channels availability.

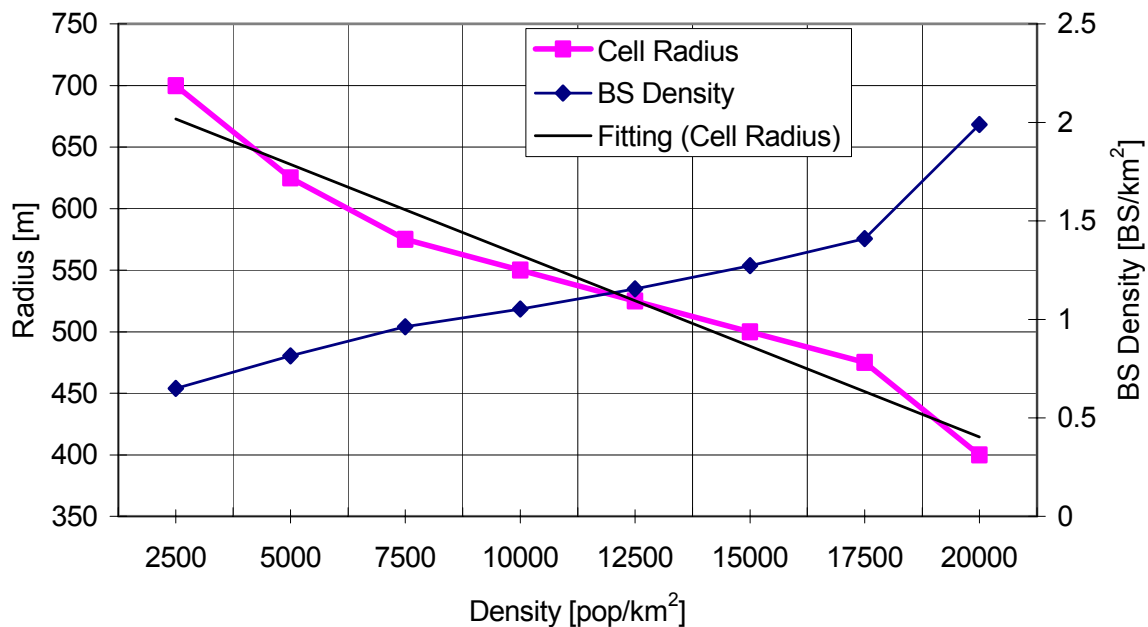


Figure 5.3 - Cell radius as function of population density (only 60% voice).

As expected, cell radius decreases when population density increases, therefore, one has a growing BS density, which may be seen by an operator as associated to population density. For these network conditions, it is possible to extract an approximation curve for cell radius,  $R_{cell}$ , dependent on population density, PD.

$$R_{cell[m]} = 710 - 0.0148 \times PD_{[pop/km^2]} \quad (5.1)$$

From the operator's point of view, this is a very important result, because it enables to provide an optimum coverage and capacity, knowing how many BSs are required for a given area or scenario.

Service penetration is another very important parameter, with a huge influence on UMTS behaviour. Figure 5.4 shows the cell radius variation as a function of voice service penetration (only voice service is active in the simulation). Once again, as already expected, cell radius decreases when voice service penetration increases.

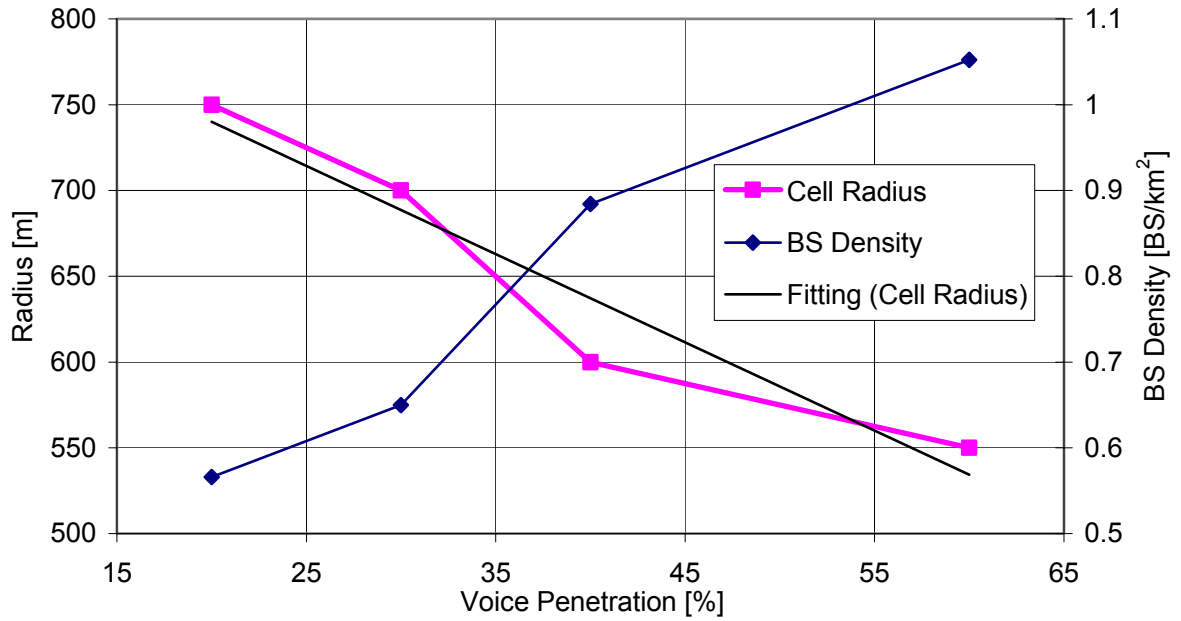


Figure 5.4 - Impact of voice penetration in cell radius.

This type of analysis is also very important for an operator, because knowing how the network behaves, offers the network planning process the knowledge to predict how and when the network must be prepared to handle future traffic growing. As in population density, it is possible to extract the cell radius dependency on voice penetration,  $VP$ .

$$R_{cell[m]} = 842.9 - 5.14 \times VP_{[%]} \quad (5.2)$$

In order to analyse the impact that multimedia CS and PS services have on the network, a study where all services defined by UMTS-Forum (year 2005) are active was performed. Based on parameters described in Table 5.1 and Table 5.2, several simulations with different population densities were performed, results being presented in Figure 5.5.

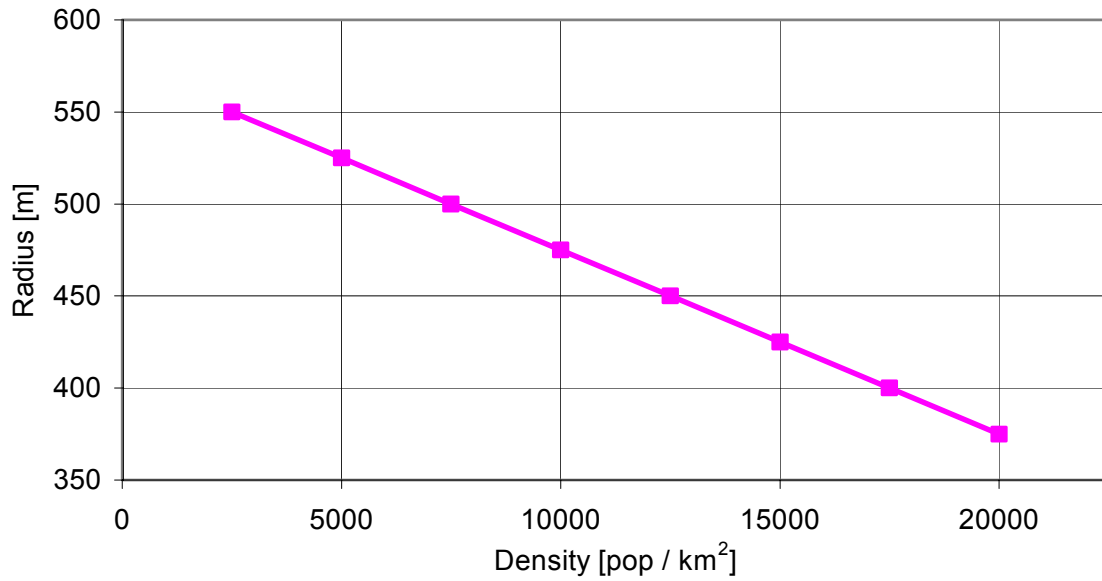


Figure 5.5 - Population density impact on cell radius.

Comparing to the “only voice” scenario (Figure 5.3), these results show a clear reduction in the cell radius, which is due to multimedia impact on cell load. Again, a relation between cell radius and population density was extracted.

$$R_{cell[m]} = 575 - 0.01 \times PD_{[pop/km^2]} \quad (5.3)$$

In order to estimate the different weight that population density and mixed services has on cell radius ‘or network cost’, one may compare (5.1) and (5.3), and conclude that the population density influence is quite similar (in terms of slope), but that there is about 140 m offset, which is due to mixed services impact on network capacity.

Table 5.3 - Service penetration forecast values based on UMTS Forum, for various years.

Service	Penetration [%]			
	2003	2005	2007	2010
HIMM	0.1	0.5	2.9	5.3
HMM	2.0	4.7	11.4	18.0
MMM	2.6	7.7	12.9	18.0
SD	10.0	10.0	10.0	10.0
SM	17.5	25.0	32.5	40.0
S	52.5	60.0	67.5	75.0
Total	84.6	107.9	137.1	166.3
Average [Ser./user]	1.28	1.39	1.61	1.73

System sensitivity to different service penetration values is an important result, because it is possible to predict the future network behaviour. In order to do so, forecast penetration values for each service based on the UMTS Forum predictions were established for the years 2005 and 2010, Table 5.3. Note that values for years 2003 and 2007 were extra/interpolated, based on 2005 and 2010 service penetration ones [UMTS98a]. Note also that one user has the possibility to activate more than one service simultaneously, therefore, the average number of services per user was calculated; as expected, this parameter raises along the years. Furthermore, the total penetration (bottom row) represents the sum of all services penetration (if all users would have all services, the total would be 600% and the average 6.0).

Figure 5.6 shows some simulation results, using values presented in Table 5.3. As expected, the optimum cell radius decreases along the years, due to capacity needs (i.e., expected growing number of users).

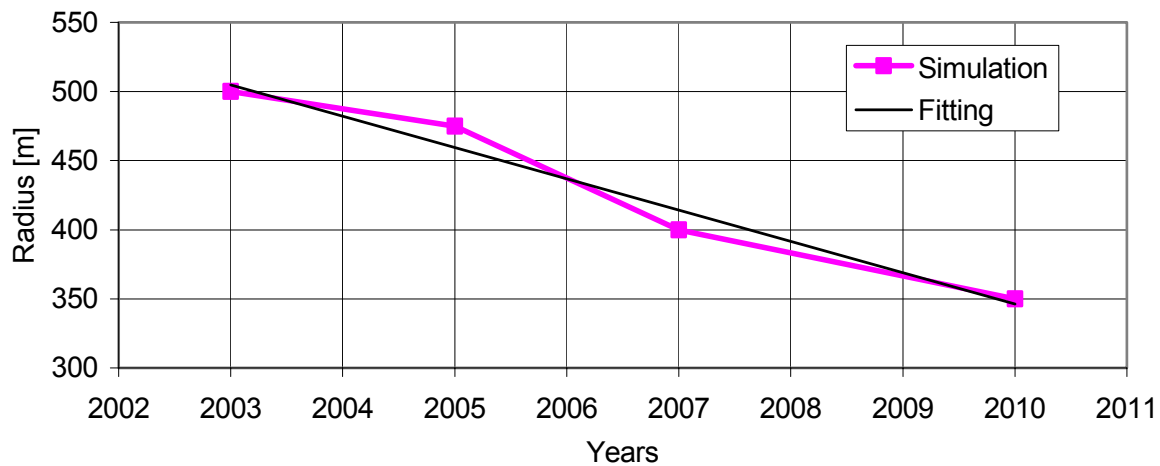


Figure 5.6 - Services penetration growing impact on the network.

Equation (5.4), extracted from Figure 5.6, suggests how the network behaves as a function of service penetration in the future, where  $Y$  represents the year.

$$R_{cell[m]} = 505 - 22.6 \times (Y - 2003) \quad (5.4)$$

In order to analyse the impact that individual high bit rate PS services (384 kbps and 2 Mbps) have on the network, some system simulations were performed, adding one of these two services to voice, in independent simulations; the voice service penetration was fixed to 60 %. Results are shown in Figure 5.7 and Figure 5.8, where it is possible to observe a strong cell radius reduction due to high bit rate impact (0 % to 20% service penetration). For lower penetration values, a more linear radius decrease curve is observed, always optimised by BS antenna height corrections, aiming to optimise system performance. Comparing Figure 5.4 with Figure 5.7, one may say that the voice service scenario has about less 200 m radius, when mixed with the 384 kbps service.

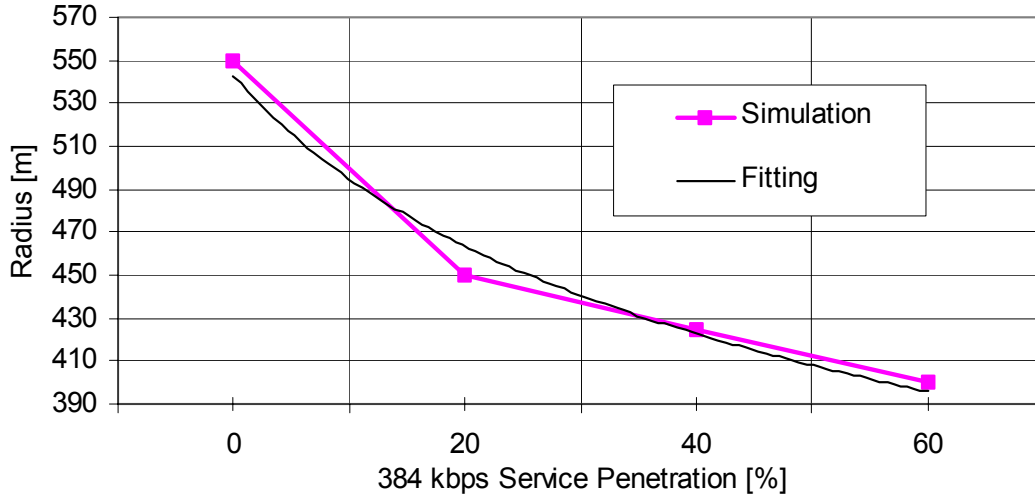


Figure 5.7 - Impact on cell radius, due to 384 kbps penetration variation over voice.

Again, using these results, it is possible to establish an analytical relation between 384 kbps service penetration,  $SP$  and cell radius:

$$R_{cell}[\text{m}] = 546 - 5.2 \times SP_{384}[\%] - 0.05 \times SP_{384}^2[\%] \quad (5.5)$$

As expected, higher service penetration values introduce additional load into the BS at the power level, and a strong reduction on channel codes availability. When high bit rates are active, higher power levels are required, and many codes are used, causing delay and blocking at the BS, therefore, a cell radius reduction is required (through a user reduction scheme), in order to maintain system quality targets in a given range (Table 5.1).

Figure 5.8 presents the HMM service (2000 kbps) penetration impact on BS load, which is huge as expected. It leads the cell radius to 150 m when HMM reaches 60% penetration, which means that the system reaches indoor environment characteristics, as already anticipated by other studies (mentioned in previous chapters).

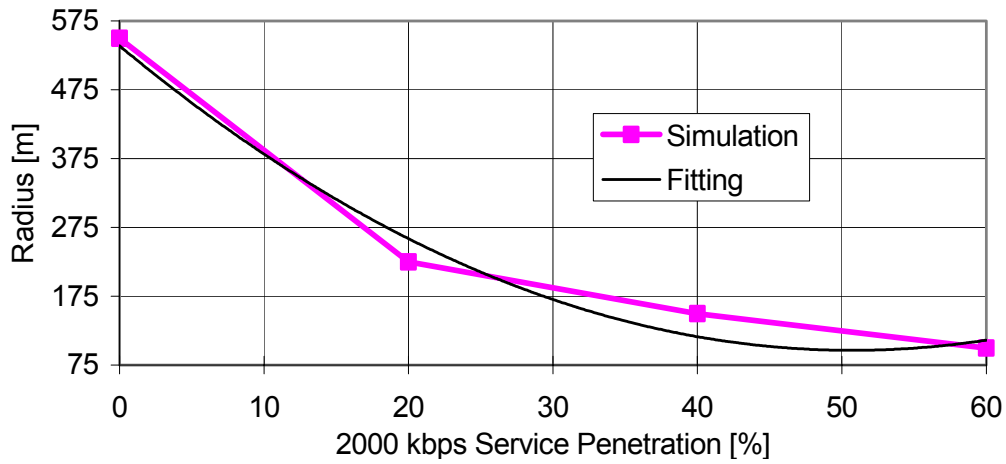


Figure 5.8 - Impact on cell radius, due to 2000 kbps penetration variation over voice.

The fitting curve shown in Figure 5.8 has higher coefficients than the ones for the 384 kbps service; this fact (strongest cell radius reduction) is related to different service needs, concerning power and channel codes.

$$R_{cell}[\text{m}] = 538.75 - 17.44 \times SP_{2000}[\%] + 0.17 \times SP_{2000}^2[\%] \quad (5.6)$$

Figure 5.9 compares both services, from the network density point of view. One may conclude that higher bit rates require a huge number of BSs per square kilometre in order to create a continuous service network. Under a realistic perspective, this type of service coverage may only be found in special zones, like indoor hot spot areas.

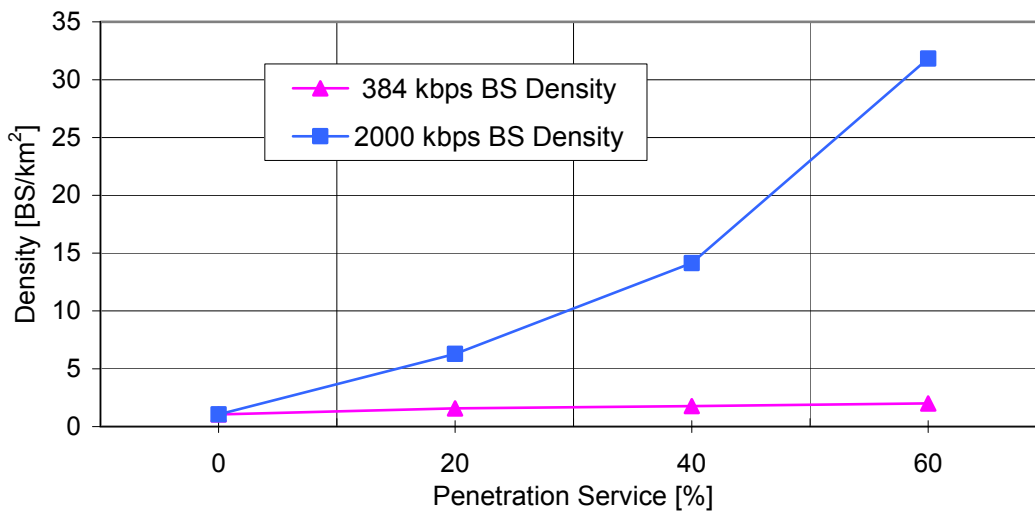


Figure 5.9 - BS density evolution with high bit rate packet services plus voice.

When a UMTS operator carries out the planning process, it may choose different levels of quality/service/coverage; in other words, an operator has to make an important decision:

- to implement a high bit rate coverage (384 kbps), but with a massive financial effort;
- to implement a relatively low bit rate coverage (64 kbps), hence, requiring a low cost.

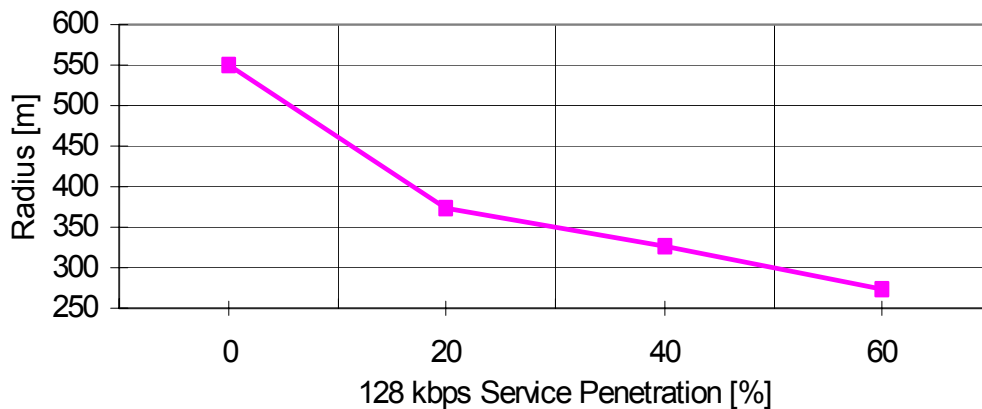


Figure 5.10 - Impact on cell radius, due to 128 kbps penetration variation over voice.

In general, CS services (low bit rate) have less impact on cell radius, nevertheless 128 kbps services have a considerable impact, because it is expected they will have a long average connection time, an intrinsic characteristic to all services that are directly human dependent. Figure 5.10 shows the strong impact of this service.

As a final note, one should be aware that equations extracted from these graphs should only be seen as trends of influence of parameters on network behaviour.

### 5.3 Impact from Environments-Characteristics

In order to analyse the influence that buildings have on network planning, a sequence of tests was done. As an example, the weight that different average building roof top has on BS planning is shown in Figure 5.11, where it is possible to see a strong radius decrease when buildings become higher than the initial BS height (22 m). This (expected) effect is mainly due to additional propagation loss over buildings, roof top (note that this propagation model only considers vertical propagation). The BS load increases, because additional losses imply higher transmission power levels managed by the power control system.

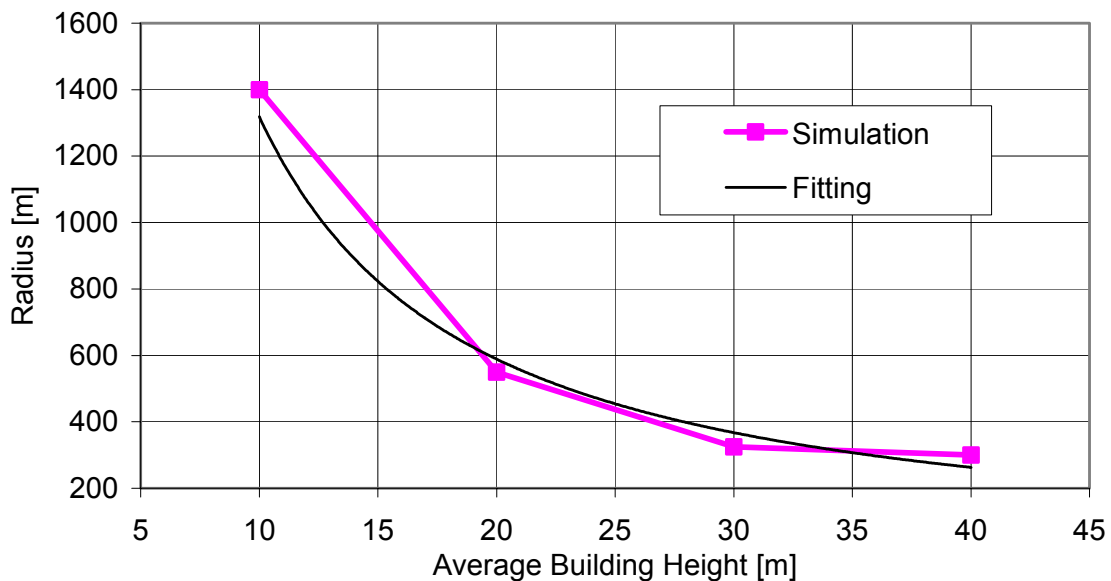


Figure 5.11 - Building height impact on cell radius (only voice is active).

Again, it is possible to extract an analytical relation between cell radius and the average building height,  $h_{building}$ .

$$R_{cell}[m] = 19198 \times h_{building}[m]^{-1.1631} \quad (5.7)$$

A similar study was performed using the UMTS Forum scenario. As one may see in this case, Figure 5.12, the cell radius converges to a lower value; nevertheless, the same type of curve appears when buildings become higher.

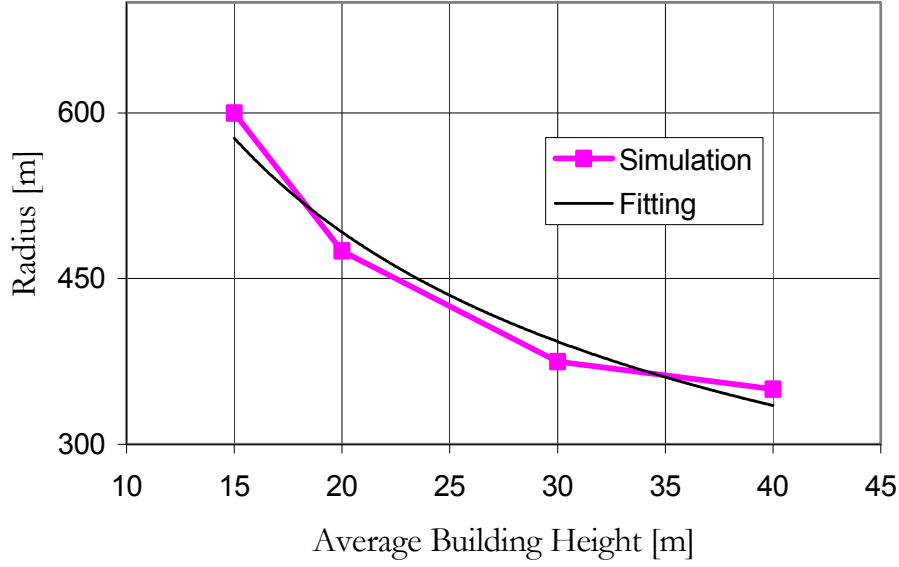


Figure 5.12 - Building height impact on cell radius (UMTS Forum scenario).

As in previous simulation results, a relation between cell radius and average building height,  $h_{building}$  is estimated.

$$R_{cell}[\text{m}] = 2590 \times h_{building}^{-0.55}[\text{m}] \quad (5.8)$$

Note that when roof top height becomes higher than BS height, the BS load increases due to high power demands, leading the cell radius to pico-cell coverage, which is a typical urban dense environment. This is due mainly to buildings influence by increasing propagation attenuation.

In order to analyse the impact that building penetration loss has on the cell radius, several simulations were performed using different penetration values ranging from 0 to 30 dB; each MS deployed inside a building adds this value into the link budget algorithm. Figure 5.13 shows the achieved results; again for this parameter a fitting equation was driven. As expected, when buildings offer higher attenuation values, the cell load increases, implying or requiring high network densification levels,

$$R_{cell}[\text{m}] = 578.8 - 0.88 \times BL_{[\text{dB}]} - 0.31 \times BL_{[\text{dB}]}^2 \quad (5.9)$$

Note that the number of MSs inside buildings depends on the MS deployment criteria and building density.

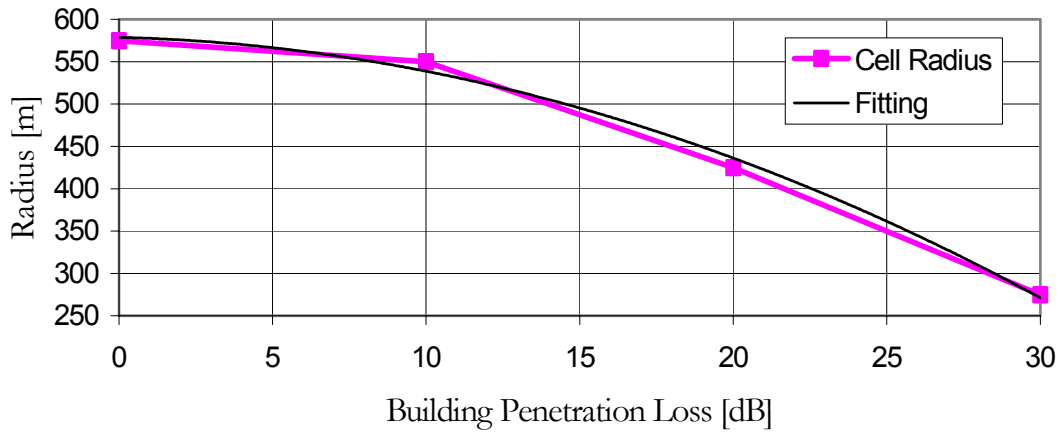


Figure 5.13 - Building penetration loss impact on cell radius.

## 5.4 Impact from Systems and Scenarios Characteristics

The impact that major configuration parameters have on the network behaviour is presented in this section: for each parameter, some simulations were executed, assuming parameters in Tables 5.2 and 5.3 as constants (UMTS Forum scenario).

One may start by analysing the impact that Soft Handover (SH) reservation channels codes has on cell performance. To do this, several simulations with different SH channel codes reservation percentage, ranging from 10 to 40 %, were carried out, Figure 5.14.

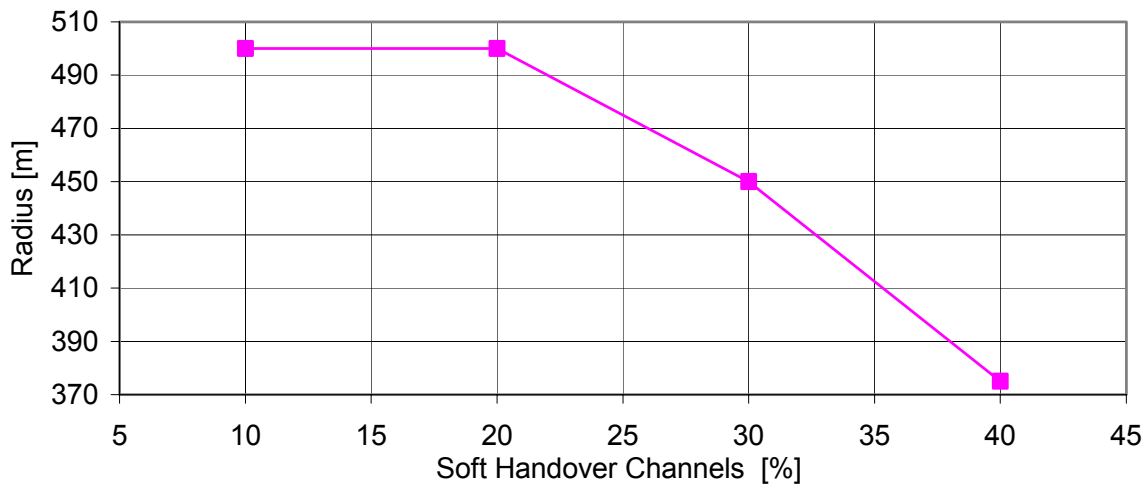


Figure 5.14 - Impact of SH percentage on cell radius.

A trade off must be achieved, so that a BS can support handover and new connections with reasonable success. Based on Figure 5.14, a reasonable value seems to be in the range from 20 to 30 %.

Another major network parameter is  $E_b/N_0$ . In UMTS, each service has a minimum  $E_b/N_0$  defined value, which means that the power control process aims to maintain this value at the receiver when it interacts with the transmitter. One may say that for a high  $E_b/N_0$ , (better

signal quality) in UL and DL, transmitted power levels will be higher, increasing the BS load and interference levels, therefore, the impact on cell radius regarding this effect must be analysed. Figure 5.15 shows  $E_b/N_0$  plotted for “only voice service”; like in all others simulations, this result depends on all other parameters, nevertheless, it is possible to observe  $E_b/N_0$  variation values, and consequently the impact on the cell radius. As expected, for higher  $E_b/N_0$  targets the cell radius decreases, in order to sustain its maximum allowed load.

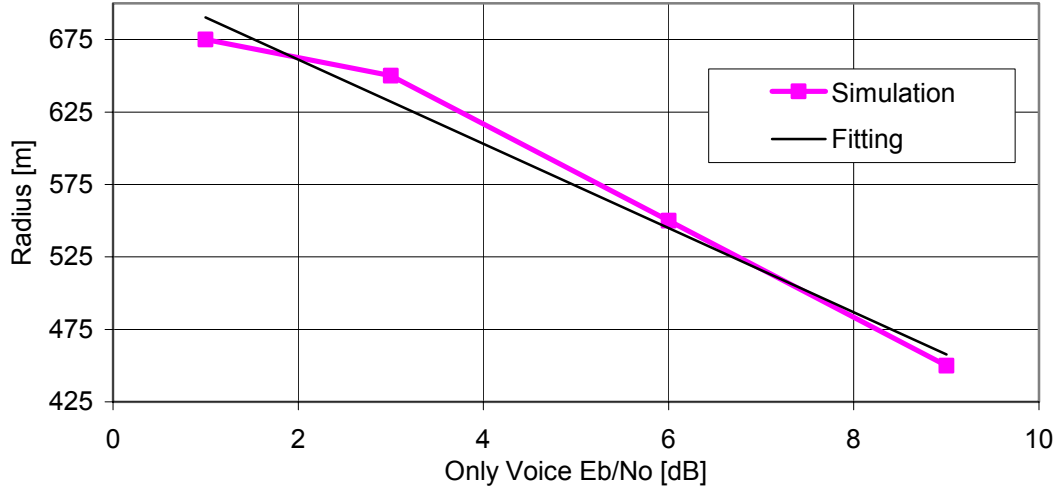


Figure 5.15 - Cell radius influence by  $E_b/N_0$  variation (only voice active).

It is possible to extract an analytical relation between  $E_b/N_0$  and the optimum cell radius. In this example, one may conclude that for each  $E_b/N_0$  dB unit the cell radius decreases about 29 m.

$$R_{cell}[\text{m}] = 719.39 - 29.08 \times \frac{E_b}{N_0} [\text{dB}] \quad (5.10)$$

All operators perform statistics concerning users behaviour, the service average connection time being one among others that is computed. In order to understand the influence on BS load due to this parameter, some simulations were carry out, Figure 5.16, with 60, 120 and 180 s of average connection time for the 128 kbps CS service, assuming voice with 60 s of average call duration.

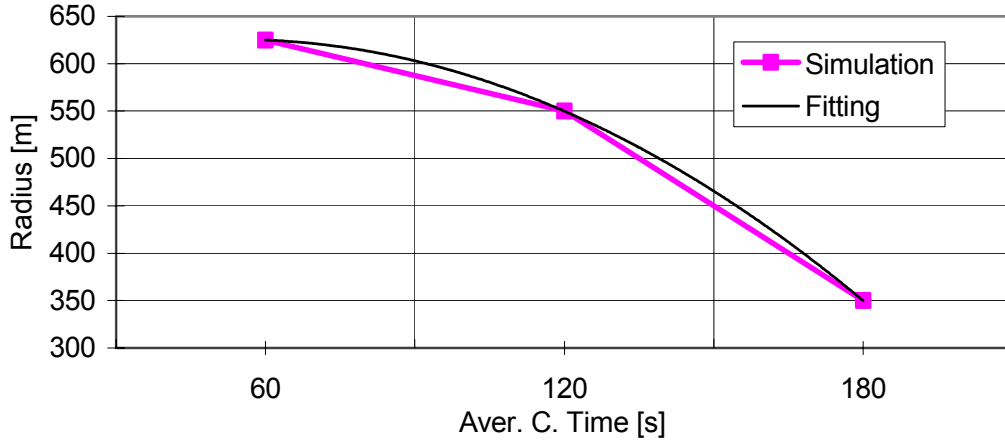


Figure 5.16 - 128 kbps average connection duration influence in cell load/radius, plus voice.

Equation (5.11) is the analytical approximation that fits the curve and produces the lowest error,

$$R_{cell}[\text{m}] = 575 + 112.5AT_{128[\text{s}]} - 62.5AT_{128[\text{s}]}^2 \quad (5.11)$$

where  $AT$  is the average connection time. Note that all other system parameters follow the UMTS Forum scenario.

The blocking probability target has a major role on system performance in any kind of CS based network, since when traffic increases in a given network, blocking probability increases. In order to study the impact that the blocking threshold has on cell radius, several simulations were performed (using only voice service) with different targets, ranging from 2 to 8 %.

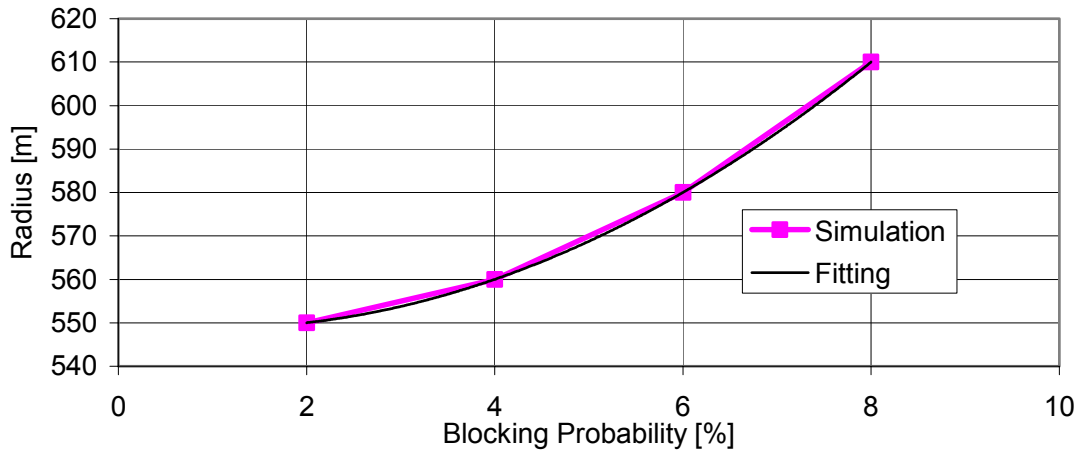


Figure 5.17 - Network influence as function of blocking percentage variation (only voice).

Figure 5.17 shows the optimum cell radius dependency on the blocking target. Like in all previous results, an equation was derived:

$$R_{cell}[\text{m}] = 550 - 2.5VB_{[\%]} + 1.2VB_{[\%]}^2 \quad (5.12)$$

where  $VB$  is the voice blocking optimisation target.

When resources are not available for PS communications, services get delayed. Some services are more tolerant to delay than others, but if a maximum average delay for PS is imposed, the cell radius will also converge to an optimum value. Like blocking probability, high values for average delay will increase the cell radius. Figure 5.18 shows the simulations results, where average simulation delay target were set from 2 to 8 s per packet.

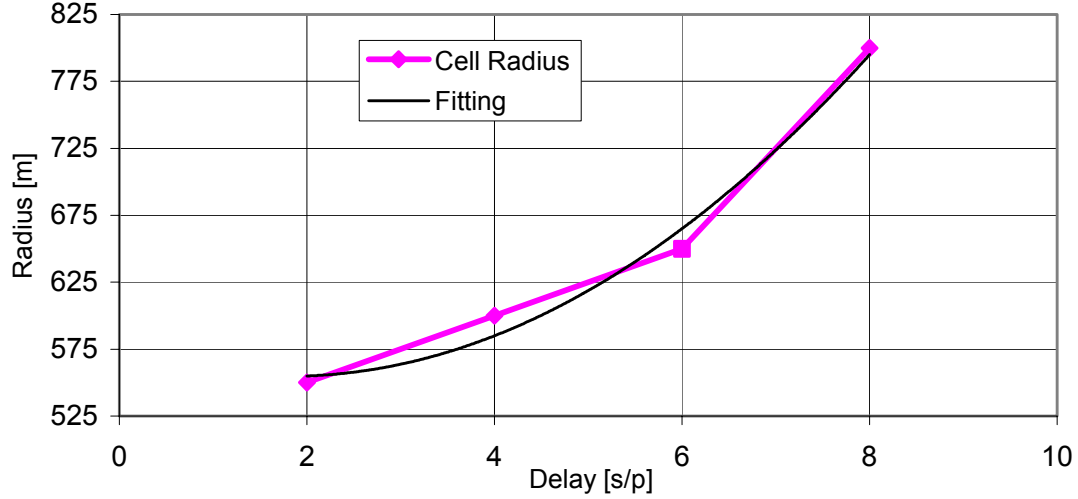


Figure 5.18 - Network influence as function of average delay variation.

Again, an analytical approach was obtained, for the target delay,  $D$ .

$$R_{cell}[\text{m}] = 575 - 22 \times D_{[s/p]} + 6.25D_{[s/p]}^2 \quad (5.13)$$

Call admission control may lead to a very complex world, but essentially it is an algorithm that decides if a connection in the air interface is accepted or not. There are two indicators where the simulation decides if a BS allows new connections or not. In order to perform a connection the following conditions must be respected:

- Current DL load indicator must be below the threshold defined at the BS (default value is 70%);
- Channels codes must be available for the requesting service.

If one of these two indicators is not respected, blocking or delay will occur. Note that the number of channel codes is constant, but DL load threshold is optional. In order to understand how this influences the BS load, several simulations were performed for different DL load thresholds. Figure 5.19 shows the results, where one can see that optimum threshold values are achieved between 55 and 70 % of load, and also that values above 70 % lead the system to an unstable power management, where increasing drop connections force a cell radius reduction.

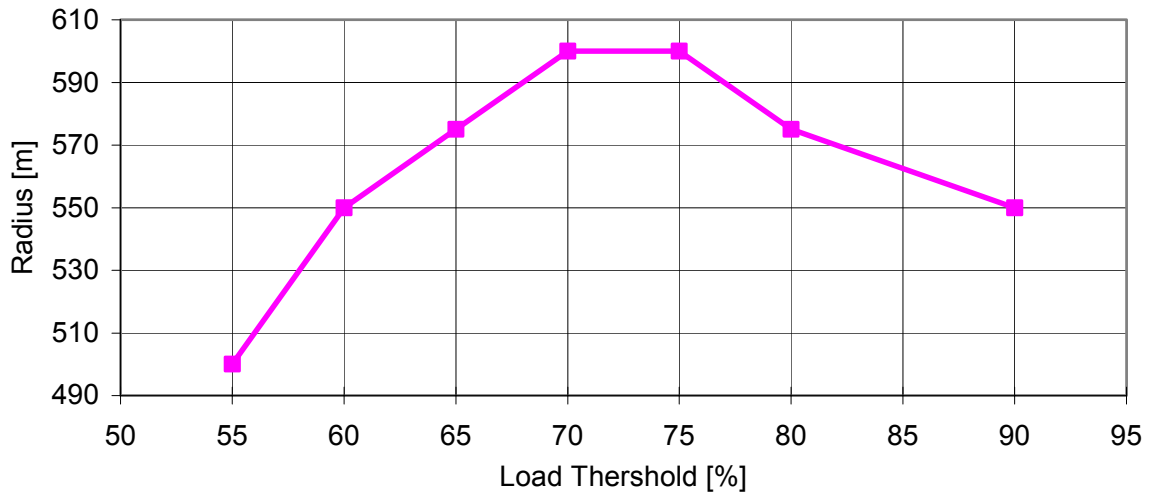


Figure 5.19 - Network impact as function of load thresholds variation.

In order to understand how PS and CS services are related from the BS load point of view, several scenarios were assumed and simulated, Table 5.4. For each switching type, different values are distributed for each service.

Table 5.4 - Penetration distribution scenarios.

Penetration Distribution [%]	PS			CS		
	HMM	MMM	SM	HIMM	SD	S
PS_45/CS_55	10	10	25	5	10	40
PS_40/CS_60	5	10	25	5	5	50
PS_35/CS_65	5	5	25	5	10	50

It is clear that results presented in Figure 5.20 directly depend on how individual service penetration values are distributed: if high bit rate services have a huge penetration value, the cell load will be quite different, so the cell radius is expected to decrease a bit.

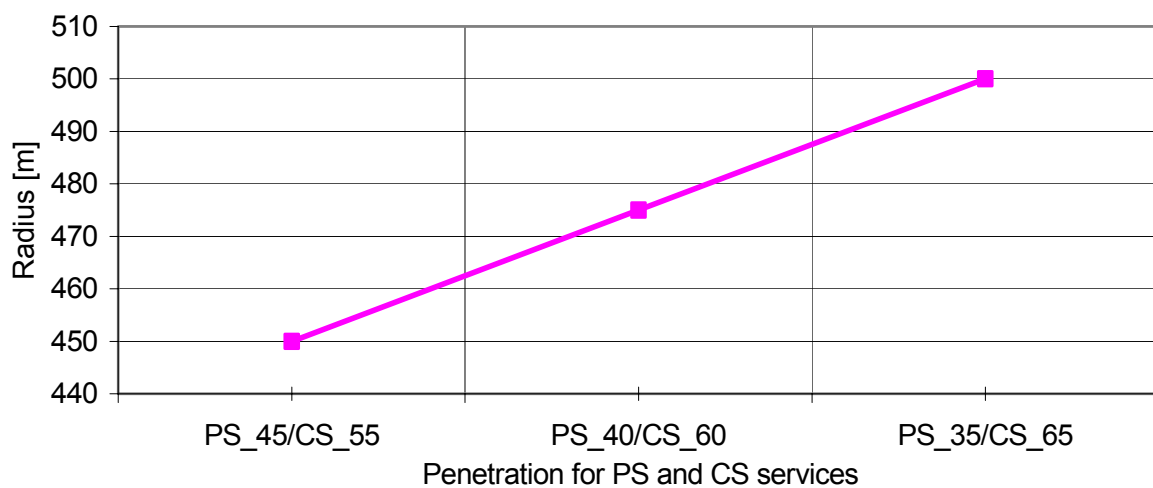


Figure 5.20 - Penetration distribution impact on BS.

When a MS is active, power control is executed at 1500 Hz (slot level), which is the defined standard value, nevertheless, it seems important to know the influence that this process

has on network performance. In order to analyse this, simulations with quite different power control frequency were performed. Figure 5.21 shows that higher power control frequencies result in a higher optimisation level in the WCDMA interface, therefore, power (the shared resource) will be managed more efficiently among to users, generating more capacity. This result (capacity improvement due to power control) is already estimated in [OjPr98]. Fast power control avoids the near-far effect, compensating a fading channel and reducing interference inside and outside the cell.

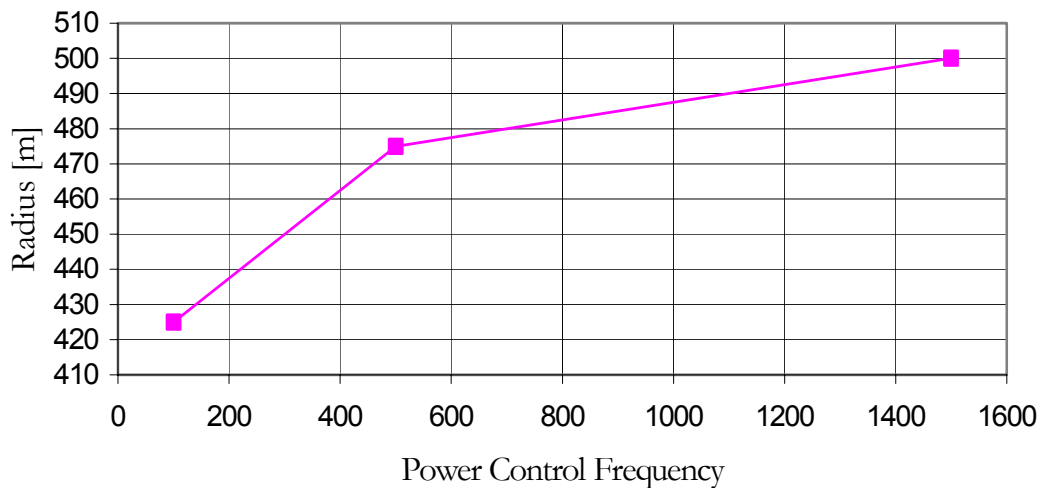


Figure 5.21 - Impact of power control frequency on cell radius.

## 5.5 Futuristic Scenario

It is hard to predict what the future will be from the service penetration point of view, nevertheless, it is expect that some interactive services will have more users. Therefore, a new scenario was set (futuristic scenario), where different service penetration values, compared to the UMTS-Forum forecast, were simulated. This new scenario assumes PS services at 10 %, and CS services at 20 and 60 % (the latter for voice). Basically, it assumes a strong growth in penetration percentages, Table 5.5, related to UMTS-Forum scenario.

Table 5.5 - Penetration settings for each service (new scenario).

HIMM	HMM	MMM	SD	SM	S
20%	10%	10%	20%	10%	60%

Simulation results are shown in Figure 5.22: cell radius and antenna height are shown as a function of population density. Note that BS antenna height also presents some variation, which is due to small modifications by the automatic optimisation process, because (as already explain in previous chapters) cell radius convergence steps approximations where not enough to achieve the network quality targets with precision. Note that for 12 500 pop/km<sup>2</sup> case, the cell radius seems

to increase; again, this is due to the optimisation algorithm, which in this particular case, increases the BS height. This means that network configuration process converges to a local optimum point.

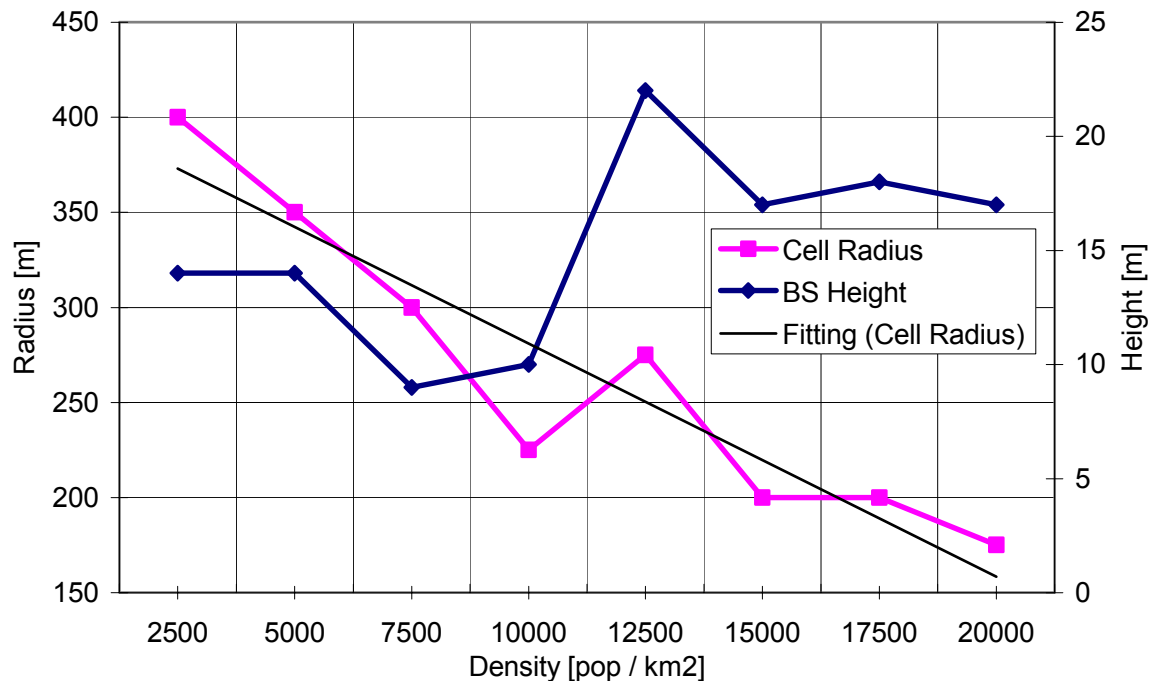


Figure 5.22 - Population density impact on cell radius with mixed services.

Comparing Figure 5.5 and Figure 5.22, the impact that higher penetration values has on cell radius is clear, since cell radius gets smaller (small cells for all different populations densities). One may conclude that, on average, cell radius decreases about 1.2 m for each extra 100 persons per square kilometre inside the cell, assuming 4 operators and the network conditions mentioned above.

The influence of one particular parameter on the cell radius may be estimated by running several simulations using different values of this parameter; using these results, it is possible to build an equation, which describes the impact on cell radius. This equation may be used as a heuristic in analytical simulations, to evaluate the weight that an individual parameter has on the optimum cell radius, and to estimate future scenarios.

Analysing all the previous parameters variation, one concludes that all of them have some impact on the cell radius, therefore, on network capacity. This impact may be huge in some cases, like high bit rate services, these services having a remarkable influence on the network capacity, due to high power and channel codes consumption, increasing the number of BS per km<sup>2</sup>. When the 2Mbps (HMM) service is used by an increasing number of users, the optimum cell radius easily converges to around 100 m and below. Therefore, in order to maintain the network health, some services usage (average connection time) may be “controlled” by the billing system. However, there are some other parameters, which cannot be manipulated by the operator (i.e.

building height, building walls penetration, etc); these parameters must be considered on the simulation scenario as a way to consider their impact on the overall results.

For some particular parameters, the network performance is very sensitive; for example, for the  $E_b/N_0$  voice target, the cell radius must be reduced about 30 m for each extra dB. Note that this value was achieved with only voice active, and the  $E_b/N_0$  target for services with higher bit rates will have more influence.

In this Chapter a reference scenario was simulated with the following characteristics: city map and population density from Lisbon, services forecast from the UMTS-Forum,  $E_b/N_0$  targets from ETSI, and all other system parameters from literature. Besides performing an analysis on parameters sensitivity, a futuristic scenario is proposed where data services usage is increased, leading the BS density (network cost) to expected higher values. From the operator point of view, one of the most interesting outputs of this analysis is the possibility to predict the UMTS network financial cost based on main parameters (quality targets, coverage, services, users, environment, UMTS, parameters, propagation, etc) specifications.



## 6 Conclusions

This thesis deals with radio planning and optimisation in UMTS networks. In order to achieve this, one has to investigate four main areas: propagation, traffic, services and optimisation techniques. UMTS planning puts many questions that have to be answered. Cell radius is a fundamental network parameter, that responds to many of these questions, therefore, finding the optimum cell radius is an important goal. Afterwards, coverage, cellular density, network cost and many radio network configurations (as a function of a given scenario) are easily achieved.

Several cellular propagation models were examined. The COST 231 Walfish-Ikegami model was selected, because it fits many UMTS constraints, being dedicated to micro-cellular environments (urban scenario) and European cities. From the propagation point of view, urban environmental aspects have a huge impact on network impact. For example, if the BS antenna height is below buildings roof tops, or the MS is placed between high buildings, signals suffer higher attenuation levels, which increase the radio link level for each user connection. This leads the BS power level to its limits, causing power capacity problems, which can be solved only by network densification (cell radius reduction); nevertheless, this is not a negative point, because areas with high buildings usually have a high users density, needing high network densification. Therefore, also the BS antenna height is optimised, aiming to enhance results accuracy (particularly when it is tangential to building roof top), which, from the operator side, is very easy to adjust.

Traffic generation in the simulation is a key element in planning, because it is mainly based on this that all other parameters are achieved. Traffic depends on user's profile, which is generated as a function of services usage, defined by penetration, bit rate, time constraints, average connection time, location, etc. Based on this, traffic source models are used to simulate user's traffic in the air interface: Poisson distribution to characterise connection arrival process, ON-OFF model for PS and data transfer based on CS, and exponential distribution to model the typical voice call duration.

When propagation, traffic and services are being simulated, a feedback process, based on quality network indicators, performs adequate changes on cell radius or BS antenna height. This process is repeated until quality targets are accomplished, producing an optimum cell radius, for a given scenario. The UMTS Forum scenario is used as reference.

High codes consumption is made mainly by high bit rate services with low spreading factors. Furthermore, extra codes are needed for MS in soft handover. The use of a single code per user implies orthogonality among the different services provided by the cell, which exists only

in theory; in reality, the multipath environment disrupts the orthogonality among them, causing interference. In this work, only one cell is simulated, inter-cell interference being extrapolated from intra-cell one. Therefore, results about inter-cell interference present some error, nevertheless, intra-cell one is expected to be the most problematic, due to short distance reasons.

Coverage in UMTS is quite a complex issue, because each connection (service) may use different bit rates, which means different spreading factor and processing gain. High bit rates will certainly have some gaps in coverage, mostly probably outside hot-spot areas, where the network density is lower. In order to guaranty high capacity and coverage, the network cost will be necessarily increased, because the number of BSs density has to be higher.

Indoors coverage in this work has a simplistic approach: any user located in a building, suffers additional loss (average building penetration value) in the link budget calculations. A higher penetration loss produces higher loads into the BS, due to power control. Therefore, accurate information about building penetration values will increase the simulation precision.

In order to maintain coverage, capacity, services within network quality indicators, in a growing population density scenario, the cellular network density (resources per area) must be increased to sustain an inherent growing traffic. Hence, the generated traffic is a very important issue, i.e., if users use only the voice service the BSs density will be lower than in a network where users use high data rate services (multimedia ones). One may conclude that network planning is very sensitive to user's generated traffic, which implies a very careful radio network planning, aiming to achieve the optimum network configuration.

The simulation tool developed in this thesis has an "MS and BS oriented design", meaning that each MS and BS has its own state machine, each state being responsible to initiate independent services connections, based on traffic source models and services forecasts. This approach is good to simulate reality and takes advantage from the intrinsic object oriented programming language used (C++). When information concerning user/services (traffic), propagation, environment (map/buildings), equipment (i.e. antennas) and simulation parameters (i.e. quality targets) are introduced, the simulation engine may start. The propagation model and the link budget algorithm estimate power and interference received by MSs, in parallel the BS runs simple RRM algorithms. If traffic generated by services does not match the network capacity, some changes are perform in the network, aiming to a get an optimal configuration.

One simulation is composed of many parameters defining the system and the scenario, all of them having influence on results. In order to analyse the planning sensitivity to each particularly parameter, a set of simulations was carried out, varying only one parameter in each simulation. Parameters like population density (number of users), service penetration, average service connection time, bit rate,  $E_b/N_0$  target for each service, urban environment, connection

rate, BS load threshold, antenna pattern, additional attenuations, fading and interference margins, soft handover, orthogonality level, blocking probability and delay targets, were accounted for; the weight that each parameter has is measured as a function of the optimum cell radius result. In many cases, the cell radius tendency is naturally expected, nevertheless, an important knowledge is learned: the order of magnitude or impact that a parameter has on the cellular structure.

One may conclude, for example, that an operator with only voice service active, may reduce on average about 50 m on the cell radius, for each 800 customers per km<sup>2</sup> (linear decrease). In the case of all active services, the UMTS Forum scenario has about the same relationship, but with an initial offset on radius, around 150 m less than the previous case, which translates the multimedia impact. Based on the forecast from the UMTS Forum, one may conclude that for each year, the cell radius should decreased about 23 m, this seems to be a neglectable value, considering that operators are constantly performing network upgrade, and optimising it in function of growing traffic.

Main services were also individually analysed, 384 kbps with a growing penetration added to voice presenting an exponential curve in the optimum cell radius. Also the 2000 kbps service presents the same tendency. This effect is mainly due to the high bit rate service impact on the network (low service penetration), since for a growing that when penetration the cell radius becomes smaller, nearly to the indoor case, for 2000 kbps.

The BS load threshold is a quite sensitive parameter. If it is set to high values, the BS allows new connections, even with a high load, and the BS, reaches the limit very fast due to power control, therefore, also very fast, many connections will be dropped, essentially due to power restrictions. This effect was detected in simulations, when this parameter was set above 70%, and to prevent this effect, values between 50% and 60% are recommended.

For each service, a different  $E_b/N_0$  minimum quality value is defined and imposed, which has a huge impact on cell radius: higher values introduces higher power needs in the radio links, hence the optimum cell radius must be decreased to avoid the BS power limit and the network collapse. Therefore, a trade-off between quality parameters and network cost must be found, in order to minimise the impact that these parameters have on the network.

In UMTS system simulation level, it is virtually impossible to create a highly accurate simulator, due to the huge number of environments and system aspects that need to be modelled and simulated. It is obvious that this thesis cannot addresses in a realistic way all the issues that have impact on radio network planning, optimisation, and simulation, thus, many topics are left for further work which include several environmental and system mechanisms that lead to a more realistic simulation.

Adding terrain information to the simulation, like digital terrain height and classification databases makes it possible to implement accurate radio propagation models. Also building information, like construction type and height, is very important in urban environments.

User distribution density and mobility modelling has also a huge importance in mobile communications. GSM existing knowledge may be a good starting point. Mobility modelling introduces also a higher level of realism in simulations, because it enables to address many problems, e.g., traffic jams, highways traffic, handover statistics, and drop connections (pedestrian and vehicular networks analysis). These characteristics make possible the implementation of a better network optimisation process concerning other issues besides radio planning, i.e., handover algorithms.

Soft, softer and hard handover implementation is also suggested. Hierarchical Cell Structure is also very importance in network planning, because a UMTS operator may use overlaid macro-, micro- and pico-cells in order to increase network capacity or to provide special services coverage. Other system aspects, like radio resource management (RNCs simulation) optimisation algorithms, may be integrated into simulation, where many network configuration options may be optimised.

UMTS may be seen as a “mobile multi-service platform”, which brings many new traffic concepts that need to be investigated. For example, traffic source models, related to multimedia services in a CDMA radio interface, must be included in simulations. Therefore traffic source models that produce accurate multi service simulation, like voice, WWW based services (HTTP, e-mail, FTP, UDP, VoIP, etc), data (PS and CS), video, etc., have to be implemented, in order to introduce more realism to system simulation and consequently planning accuracy.

Initially UMTS deployment will be based on GSM location sites, due to economical and already tested propagation reasons; nevertheless, new sites will be required, in order to offer capacity to incoming users, therefore, it is also suggested for future work to investigate an algorithm that optimises BS deployment location and configuration.

# Annex A - UMTS Characteristics

Figure A.1 (MS UL transmitter) shows the general spreading scheme in the case where several UL DPDCHs are used.

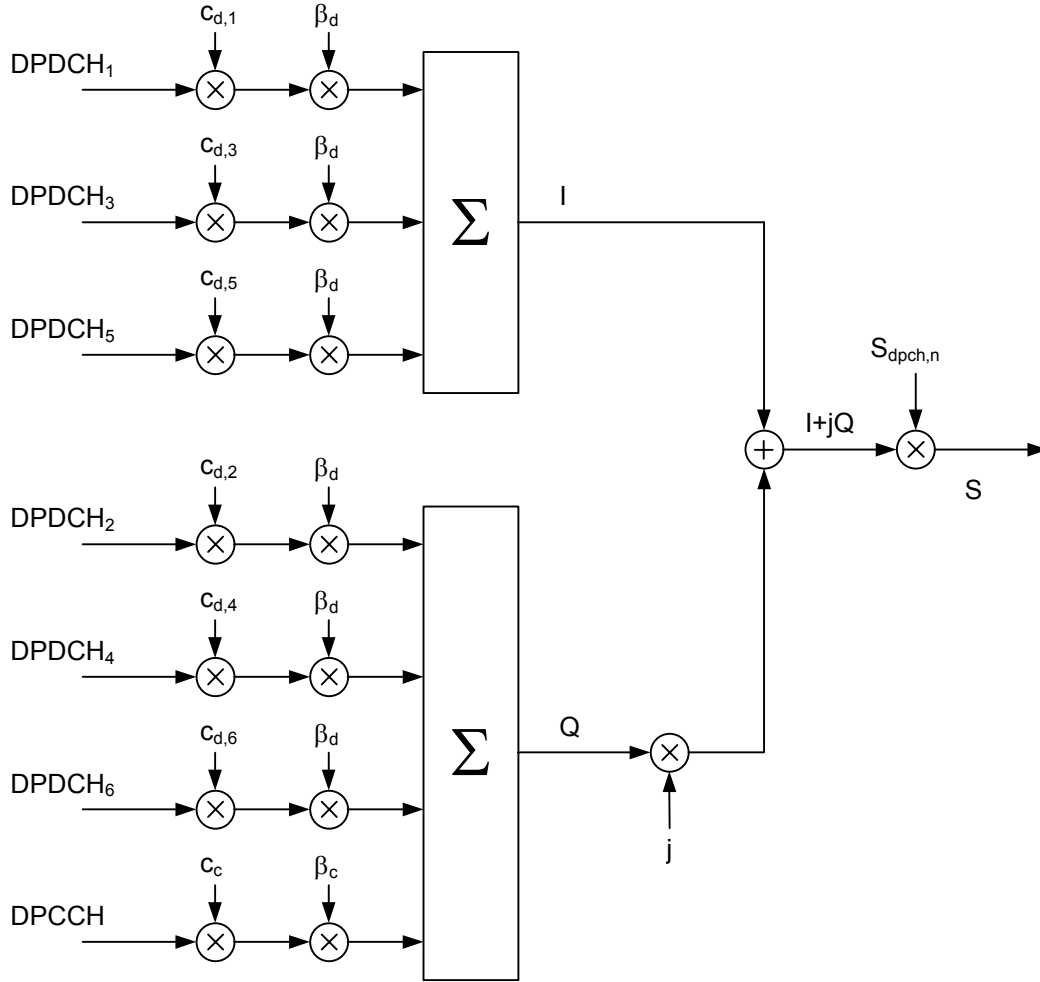


Figure A.1 - Spreading for uplink DPCCH and DPDCHs (extracted from [3GPP00d]).

Each different DPDCH<sub>n</sub> carry different types of services multiplexed by different channelisation codes ( $C_{d,n}$ ). Each channel has their own independent power level, which are controlled by different power regulators ( $\beta_d$ ).

The generation method for the channelisation code is defined [3GPP00d] as follows:

$$C_{ch,1,0} = 1,$$

$$\begin{bmatrix} C_{ch,2,0} \\ C_{ch,2,1} \end{bmatrix} = \begin{bmatrix} C_{ch,1,0} & C_{ch,1,0} \\ C_{ch,1,0} & -C_{ch,1,0} \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

$$\begin{bmatrix} C_{ch,2^{(n+1)},0} \\ C_{ch,2^{(n+1)},1} \\ C_{ch,2^{(n+1)},2} \\ C_{ch,2^{(n+1)},3} \\ \vdots \\ C_{ch,2^{(n+1)},2^{(n+1)}-2} \\ C_{ch,2^{(n+1)},2^{(n+1)}-1} \end{bmatrix} = \begin{bmatrix} C_{ch,2^n,0} & C_{ch,2^n,0} \\ C_{ch,2^n,0} & -C_{ch,2^n,0} \\ C_{ch,2^n,1} & C_{ch,2^n,1} \\ C_{ch,2^n,1} & -C_{ch,2^n,1} \\ \vdots & \vdots \\ C_{ch,2^n,2^n-1} & C_{ch,2^n,2^n-1} \\ C_{ch,2^n,2^n-1} & -C_{ch,2^n,2^n-1} \end{bmatrix}$$

The leftmost value in each channelisation code word corresponds to the chip transmitted first in time. In [3GPP00d] the scrambling codes are specified.

Figure A.2 and Figure A.3 illustrates the principle of RAKE receiver. After transmission, the signal passes through a multipath channel, which is modelled by several delayed blocks  $\tau_1$ ,  $\tau_2$  and  $\tau_3$ , and afterwards attenuated by  $a_1$ ,  $a_2$  and  $a_3$  lines (signals which are reflected are delayed and attenuated in a multipath channel), corresponding to each relevant propagation path. Because the MSs is in "permanent" movement the delay and attenuation factors are also dynamic, so the RAKE receiver requires a constant measurement on the tapped delay line profile and to reallocate RAKE fingers.

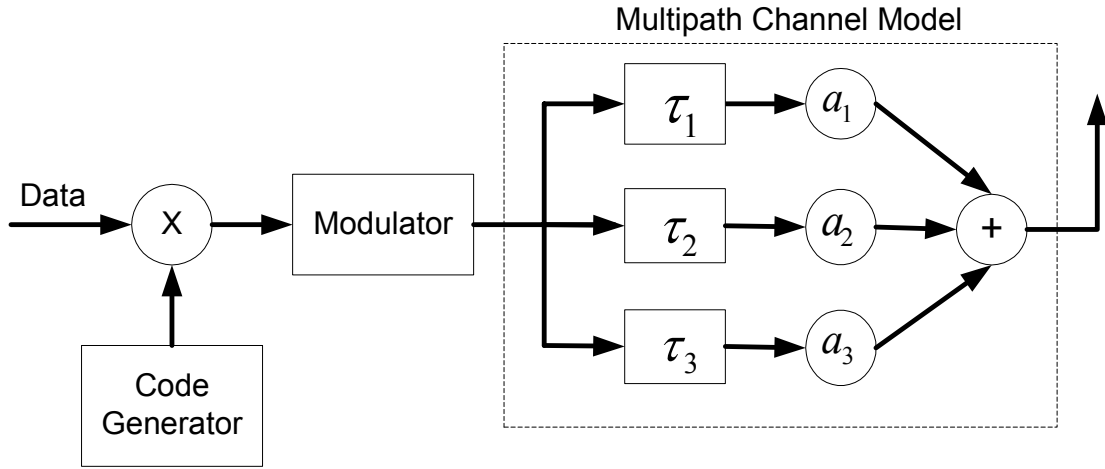


Figure A.2 - The transmitter and the Multipath Channel Model (adapted from [OjPr98]).

Note that the number of “fingers” in the RAKE receiver will be typically 3 or 4, because higher numbers will increase the receiver complexity, and do not bring too much gain (higher signal components are 3 or 4).

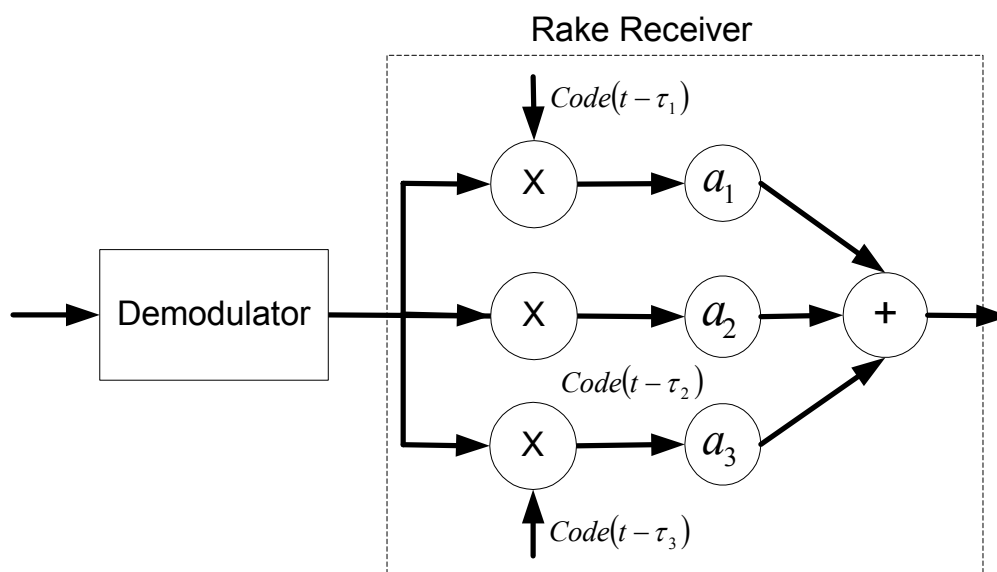


Figure A.3 - RAKE receiver architecture model (adapted from [OjPr98]).



# Annex B - Propagation Models

## COST 231 Walfish-Ikegami Model

For a good estimation of the received average power, one may use the Walfisch-Ikegami propagation model adapted by COST 231 for microcell environment [DaCo99]. This model has the following input parameters:

- $h_{Base}$  : BS height [m];
- $h_{Building}$  : Building height [m];
- $h_{Mobile}$  : MS height [m];
- $w$  : Street width [m];
- $f$  : Frequency [MHz];
- $d$  : Distance between Transmitter and Receiver [km];
- $b$  : Building separation [m];
- $\Psi$  : Street orientation angle [°].

The following default values are recommended:

- $b$  : 20...50 m
- $w$  :  $b/2$
- $h_{Building}$  :  $3 \text{ m} \times [\text{number of floors}] + \text{roof}$
- $\Psi$  :  $90^\circ$

The path loss when in LoS is given by:

$$L_p = 42.6 + 26 \cdot \log d + 20 \cdot \log f \quad (\text{B.1})$$

The path loss in the case of NLoS of sight is given by (all path loss values are expressed in dB):

$$L_p = \begin{cases} L_0 + L_{rts} + L_{msd} & \text{for } L_{rts} + L_{msd} > 0 \\ L_0 & \text{for } L_{rts} + L_{msd} \leq 0 \end{cases} \quad (\text{B.2})$$

where:

$$L_0 = 32.4 + 20 \cdot \log d + 20 \cdot \log f \quad (\text{B.3})$$

$$L_{rts} = -16.9 - 10 \cdot \log w + 10 \cdot \log f + 20 \cdot \log \Delta h_{Mobile} + L_{ori} \quad (\text{B.4})$$

$$L_{ori} = \begin{cases} -10 + 0.34 \cdot \Psi & \text{for } 0^\circ \leq \Psi < 35^\circ \\ 2.5 + 0.075 \cdot (\Psi - 35) & \text{for } 35^\circ \leq \Psi < 55^\circ \\ 4.0 + 0.114 \cdot (\Psi - 55) & \text{for } 55^\circ \leq \Psi \leq 90^\circ \end{cases} \quad (\text{B.5})$$

$$L_{msd} = L_{bsh} + K_a + K_d \cdot \log d + K_f \cdot \log f - 9 \cdot \log b \quad (\text{B.6})$$

where:

$$L_{bsh} = \begin{cases} -18 \cdot \log(1 + \Delta h_{Base}) & \text{for } h_{Base} > h_{Building} \\ 0 & \text{for } h_{Base} \leq h_{Building} \end{cases} \quad (\text{B.7})$$

$$\Delta h_{Base} = h_{Base} - h_{Building} \quad (\text{B.8})$$

$$K_a = \begin{cases} 54 & \text{for } h_{Base} > h_{Building} \\ 54 - 0.8 \cdot \Delta h_{Base} & \text{for } d \geq 0.5 \text{ km e } h_{Base} \leq h_{Building} \\ 54 - 0.8 \cdot \Delta h_{Base} \cdot d/0.5 & \text{for } d < 0.5 \text{ km e } h_{Base} \leq h_{Building} \end{cases} \quad (\text{B.9})$$

$$K_d = \begin{cases} 18 & \text{for } h_{Base} > h_{Building} \\ 18 - 15 \cdot \Delta h_{Base} / h_{Building} & \text{for } h_{Base} \leq h_{Building} \end{cases} \quad (\text{B.10})$$

$$K_f = \begin{cases} -4 + 0.7 \cdot (f/925 - 1) & \text{for medium size cities and suburban} \\ & \text{centres with moderate tree density} \\ & \text{densidade de  rvores} \\ -4 + 1.5 \cdot (f/925 - 1) & \text{for metropolitan centres} \end{cases} \quad (\text{B.11})$$

$L_0$  is the free space attenuation,  $L_{rs}$  is "roof-to-street diffraction and scatter loss",  $L_{ori}$  is the attenuation caused by main street orientation with respect to the direct radio path and  $L_{msd}$  is the "multi-screen diffraction loss". The output parameter of the model is  $L_p$  in dB.

Some parameters have a validity range, Table B.1.

Table B.1 - Valid parameters range.

Frequency	800...2000 MHz
Distance NLoS	0.02...5 km
Distance LoS	0.02...0.2 km
BS antenna height	4...50 m
MS antenna height	1...3 m

### 3GPP Propagation Models

For each environment, a different formulation is used to evaluate the path loss. An important parameter to be defined is the Minimum Coupling Loss (MCL), i.e., the minimum distance loss including antenna gain measured between antenna connectors; in [3GPP00a] the MCL of 70 dB is assumed for the macro-cellular environment and 53 dB for the micro-cellular one.

With the above definition, the received power in DL or UL can be expressed for the macro-cellular environment as:

$$P_{Rx} = P_{Tx} - \max(L_{p,macro} - G_{Tx} - G_{Rx}, MCL) \quad (B.12)$$

and for the micro-cellular as:

$$P_{Rx} = P_{Tx} - \max(L_{p,micro} - G_{Tx} - G_{Rx}, MCL) \quad (B.13)$$

where  $P_{Rx}$  is the received signal power,  $P_{Tx}$  is the transmitted signal power,  $G_{Tx}$  is the transmitter antenna gain,  $G_{Rx}$  is the receiver antenna gain.  $L_{p,macro}$  and  $L_{p,micro}$  are the output of the propagation model. It is assumed an antenna gain of 11 dBi (including cable losses) in the BS and 0 dBi in the MS.

The macro-cell propagation model proposed by the 3GPP is applicable for test scenarios in urban and suburban areas outside the urban core, where the buildings are of nearly uniform height. The micro-cell model also adopted one proposed in [ETSI98]. This model is to be used for spectrum efficiency evaluations in urban environments, through a Manhattan-like structure, in order to properly evaluate the performance in micro-cell situations that will be common in European cities at the time of UMTS deployment. The proposed model is a recursive one, which calculates path loss as a sum of LoS and NLoS segments. The shortest path along streets between the BS and the MS has to be found within the Manhattan environment.

The macro-cell model is:

$$L_{p,macro}^{50\%} = 40 \cdot (1 - 4 \cdot 10^{-3} \cdot D_{hb}) \cdot \log_{10}(d) - 18 \cdot \log_{10}(D_{hb}) + 21 \cdot \log_{10}(f) + 80 \quad (B.14)$$

where:

- $d$  is the distance between BS and MS [km];
- $f$  is the carrier frequency [MHz] (default 2000);
- $D_{bb}$  is the BS antenna height, measured from the average rooftop level, [m] (default, 15 m);
- $L_{p,macro}^{50\%}$  is the average path loss [dB].

After  $L_{p,macro}^{50\%}$  is calculated, log-normally distributed shadowing,  $LogF$ , with standard deviation of 10 dB should be added, so that the resulting path loss is the following:

$$L_{p,macro} = L_{p,macro}^{50\%} + LogF \quad (B.15)$$

The following constrains: applies:

1.  $L_{p,macro}^{50\%}$  shall in no circumstances be less than free space loss. This model is valid for NLoS case only and describes the worse case propagation.
2. The model is valid for a range of  $D_{bb}$  from 0 to 50 m.
3. This model is designed mainly for distances from few hundred meters to kilometres, and it is not very accurate for short distances.

The micro-cell model has the path loss given by:

$$L_{p,micro}^{50\%} = 20 \cdot \log_{10} \frac{4\pi d_n}{\lambda} \quad (B.16)$$

where:

- $d_n$  is the "illusory" distance;
- $\lambda$  is the wavelength;
- $n$  is the number of straight street segments between BS and MS (along the shortest path).

The illusory distance is the sum of these street segments, and can be obtained by recursively using expressions  $k_n = k_{n-1} + d_{n-1}c$  and  $d_n = k_n s_{n-1} + d_{n-1}$ , where  $c$  is a function of the angle of the street crossing. For a 90° street crossing,  $c$  should be set to 0.5. Further,  $s_{n-1}$  is the length in meters of the last segment. The initial values are set 1 for  $k_0$  and 0 for  $d_0$ . The illusory distance is obtained as the final  $d_n$  when the last segment has been added.

The model is extended to cover the micro-cell dual slope behaviour, by modifying the expression to:

$$L_{p,micro}^{50\%} = 20 \cdot \log_{10} \left( \frac{4\pi d_n}{\lambda} \cdot D \left( \sum_{j=1}^n s_{j-1} \right) \right) \quad (B.17)$$

where:

$$D(d) = \begin{cases} d / x_{br}, & d > x_{br} \\ 1, & d \leq x_{br} \end{cases} \quad (\text{B.18})$$

being  $d$  the distance from the transmitter to the receiver.

Before the break point  $x_{br}$ , the slope is 2, after the break point it increases to 4; the break point  $x_{br}$  is set to 300 m. To take effects of propagation going above rooftops into account, it is also needed to calculate the path loss according to the shortest geographical distance. This is done by using the commonly known COST Walfish-Ikegami Model, and with antennas below rooftops:

$$L_{p,micro}^{50\%} = 24 + 45 \cdot \log(d + 20) \quad (\text{B.19})$$

where  $d$  is the shortest physical geographical distance from the transmitter to the receiver in [m].

The final path loss value is the minimum between the path loss value from the propagation through streets and the path loss based on the shortest geographical distance, plus the log-normally distributed shadowing,  $\text{Log}F$ , (with standard deviation of 10 dB).

$$L_{p,micro} = \min(L_{p,micro}^{50\%}, L_{p,macro}) + \text{Log}F \quad (\text{B.20})$$

### COST 231-Hata-Model

COST 231 has extended Hata's model to the frequency band [1500, 2000] MHz by analysing Okumura's propagation curves in the upper frequency band. This combination is called "COST-Hata-Model" described in [DaCo99].

$$L_b = 46.3 + 33.9 \cdot \log(f) - 13.82 \cdot \log(h_{Base}) - a(h_{Mobile}) + (44.9 - 6.55 \cdot \log(h_{Base})) \cdot \log(d) + C_m \quad (\text{B.21})$$

where

$$a(h_{Mobile}) = (1.1 \cdot \log(f) - 0.7) \cdot h_{Mobile} - (1.56 \cdot \log(f) - 0.8) \quad (\text{B.22})$$

$C_m$  being 0 dB for medium sized city and suburban centres with medium tree density, and 3 dB for metropolitan centres.

The COST-Hata-Model is restricted to the following range of parameters:

- $f$ : 1500 ... 2000 MHz
- $h_{Base}$ : 30 ... 200 m
- $h_{Mobile}$ : 1 ... 10 m
- $d$ : 1 ... 20 km

The application of the COST-Hata-Model is restricted to large and small macro-cells, i. e., BS antenna heights above roof-top levels adjacent to it. Hata's formula and its modification must not be used for micro-cells.



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