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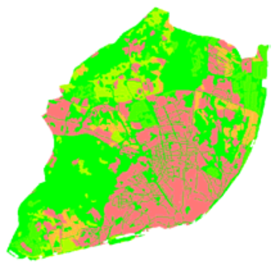

Analysis of Traffic Distributions Influence on UMTS-FDD Performance

Gonçalo Nuno Ramos Carvalho

(Licenciado)

Dissertation submitted for obtaining the degree of Master in Electrical and Computer Engineering

Supervisor: Doctor Luís Manuel de Jesus Sousa Correia

Jury:

President: Doctor Luís Manuel de Jesus Sousa Correia

Members: Doctor Rui Jorge Morais Tomaz Valadas

Doctor António José Castelo Branco Rodrigues

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Abstract

This work analyses the influence of traffic distributions on UMTS-FDD performance, taking into consideration the mobility profile of the users.

Nine different applications were considered and characterised for user traffic generation: Speech-Telephony, Video-Telephony, Streaming Multimedia, Web Browsing, Location Based, SMS, MMS, Email and File Download. Call generation and call duration processes have been implemented for each of these applications. Traffic data is drawn from the Busy Hour Call Attempt (BHCA) grids generated by the IST-MOMENTUM project.

Several mobility models were analysed and the one used in the simulator has a triangular velocity distribution and a pixel-oriented direction distribution with four possible directions. The mobility model does not take into consideration the city geometry in terms of streets and buildings.

The simulation scenario is the city of Lisbon and data is generated in three different locations: “Marquês de Pombal”, “Monsanto” and “Olivais”. Traffic, mobility and service information is based on the results by the IST-MOMENTUM project. Traffic distribution is non-uniform and generated based on the operational environment information. The performance indicators under analysis are: UL and DL load, BS TxP, handover UL and DL load, blocking probability and average bit rate. These are calculated for a seven-cell cluster.

As expected, the performance indicators are worse for the simulations in the area with the highest user density (“Marquês de Pombal”). For instance, the UL load goes over 70% when the threshold is 50%. In the area of “Monsanto”, load values are extremely low, since this is mainly a green area of the city (the average DL load is under 2%). On the other hand, the ratio of handover load relative to total load is higher due to the highway crossing this region (handover load represents around 50% of the total load in this area).

Keywords

UMTS, Traffic, Mobility, BHCA, Simulation.

Resumo

Este trabalho analisa a influência das distribuições de tráfego na performance do UMTS-FDD, tomando em consideração o perfil de mobilidade dos utilizadores.

Foram consideradas nove aplicações diferentes e caracterizadas para a geração de tráfego dos utilizadores: Chamada de Voz, Chamada de Vídeo, Streaming Multimedia, Web Browsing, Location Based, SMS, MMS, Email e File Download. Foram implementados processos de geração e duração de chamadas para cada uma destas aplicações. Os dados de tráfego foram retirados das tabelas de BHCA geradas pelo projecto IST-MOMENTUM.

Foram analisados vários modelos de mobilidade e o que foi utilizado na simulação tem uma distribuição triangular de velocidade e uma distribuição de direcção por pixel com quatro direcções possíveis. O modelo de mobilidade não toma em consideração a geometria da cidade em termos de ruas e de edifícios.

O cenário de simulação é a cidade de Lisboa e os dados são gerados em três localizações diferentes: Marquês de Pombal, Monsanto e Olivais. Os dados de tráfego, mobilidade e serviço são baseados nos resultados do projecto IST-MOMENTUM. A distribuição de tráfego é não-uniforme e é gerada com base na informação do *operational environment*. Os indicadores de performance em análise são: carga de UL e DL, BS TxP, carga de handover de UL e DL, probabilidade de bloqueio e débito binário médio. Estes são calculados para um agrupamento de sete células.

Como seria de esperar, os indicadores de performance degradam-se para as simulações na área de maior densidade de utilizadores (Marquês de Pombal). Por exemplo, a carga de UL vai acima dos 70% quando o limite máximo é de 50%. Na zona de Monsanto, os valores de carga são extremamente baixos visto que esta é maioritariamente uma zona verde (a carga média de DL é inferior a 2%). Por outro lado, a razão entre a carga de handover e a carga total é mais elevada devido à auto-estrada que atravessa esta zona (a carga de handover representa cerca de 50% da carga total desta área).

Palavras-chave

UMTS, Tráfego, Mobilidade, BHCA, Simulação.

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List of Abbreviations

2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
BHCA	Busy Hour Call Attempt
BoD	Bandwidth on Demand
BS	Base Station
CBD	Central Business District
CDMA	Code Division Multiple Access
CN	Core Network
CRT	Cell Residence Time
CS	Circuit Switch
DCA	Direct channel assignment
DECT	Digital enhanced cordless telephone
DL	Downlink
DPCCH	Dedicated physical control channel
DS-CDMA	Direct Sequence CDMA
DTX	Discontinuous transmission
EIRP	Equivalent Isotropic Radiated Power
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
GGSN	GPRS Gateway Support Node
GIS	Geographical Information System
GMSC	Gateway MSC
GPRS	Global Packet Radio System
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HLR	Home Location Register
HO	Handover
IMT-2000	International mobile telephony, 3rd generation networks are referred as IMT-2000 within ITU

IP	Internet Protocol
IS-95	cdmaOne, one of the 2nd generation systems, mainly in Americas and in Korea
ISDN	Integrated Services Digital Network
ITU	International Telecommunication Union
ME	Mobile Equipment
MMS	Multimedia Messaging Service
MSC/VLR	Mobile Services Switching Centre/Visitor Location Register
MT	Mobile Terminal
OVSF	Orthogonal variable spreading factor
PCS	Personal Communication Systems, 2nd generation cellular systems mainly in Americas, operating partly on IMT-2000 band
PDC	Personal Digital Cellular, 2nd generation system in Japan
PDF	Probability Density Function
PHS	Personal Handy phone System
PLMN	Public Land Mobile Network
PS	Packet Switch
PSTN	Public Switched Telephone Network
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RF	Radio Frequency
RNC	Radio Network Controller
RRM	Radio Resource Management
SGSN	Service GPRS Support Node
SMS	Short Messaging Service
SOHO	Small Office-Home Office
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
USIM	UMTS Subscriber Identity Module
UTRAN	UMTS Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access
WLL	Wireless Local Loop

List of Symbols

$\overline{\alpha}$	Average orthogonality factor of the cell
$\bar{i}$	Average value of the ratio between the other cells BS transmission power and the one considered, received by the user
ϕ	Angle between streets
σ_{φ}	Standard deviation of the direction distributions
η_{DL}	DL load
Δf	Bandwidth.
v_j	Activity factor of the user *j* in the physical layer
α_j	Channel orthogonality of user *j*
Δt	Iteration time step
η_{UL}	UL load
BS_TxP	BS transmission power
D	Down
d_I	Street length value between crossroads/direction of movement
E_b/N_0	Energy of one signal bit over the spectral noise density
EIRP	Equivalent Isotropic Radiated Power
f	Frequency
f(v)	Probability density function
F_N	Noise figure in the MT receiver
G_P	Processing gain
G_R	Receiver antenna gain
G_{SH}	Soft handover gain
G_T	Transmitter antenna gain
h_b	Building Height
h_{BS}	BS Height
h_m	MT height
i	Interference ratio
$\overline{L}_j$	Average loss between the BS and the MT
k_a	Walfisch-Ikegami model factor
k_d	Walfisch-Ikegami model factor
L	Left

L_{pen}	Path loss due to the penetration into a vehicle or house
$L_{R\ add}$	Additional attenuation at the receiver
$L_{T\ add}$	Additional attenuation at the transmitter
mc	Mean corridor stationary time
M_{ff}	Fast fading margin
M_I	Interference margin
mr	Mean office room stationary time
M_{sf}	Log-normal fading margin
N_C	Number of connections per cell
N_{RF}	Total effective noise
N_u	Number of users per cell
p	Probability
P_b	Blocking Probability
P_R	Receiver sensitivity
P_T	Transmitter output power
r	Ratio of MTs at office rooms
R	Right
R_{av}	Average bit rate
R_j	Binary throughput of user j
t_{rs}	Remaining residence time
t_s	Cell residence time
U	Up
v	Velocity
V_{av}	Average velocity
Δ	Velocity deviation
v_i	Average velocities
V_{max}	Maximum velocity
V_{min}	Minimum velocity
W	WCDMA chip throughput
w_{180^o}	Probability to turn 180º
w_{90^o}	Probability to turn 90º
w_{-90^o}	Probability to turn –90º
w_b	Block width
w_{mr}	Weight factor for the fraction of cars on major roads.
w_s	Street width

Chapter 1

Introduction

This chapter gives a brief overview of the work. Before establishing work targets and original contributions, the scope and motivations are brought up. The current State-of-the-Art in relation to the scope of the work is also presented. At the end of the chapter, the work structure is provided.

The new mobile communication systems that will become available in a near future, have the purpose to innovate the existing fixed and mobile systems in a revolutionary way, since they are based on principles of broad operation flexibility and available application variety. It is also intended to extend to the mobile network all the available services in the fixed network (in terms of variety and available bit rates), to which new services will be added.

Under the scope of the third generation (3G), there was the intention to globalise and standardise mobile communications around the world, in a way that one single system would be able to satisfy the needs of the variety and diversity of users, having as one of its points of attraction the mobility associated to services usually available only at fixed computer terminals. A high level of compatibility was required in order to guarantee the same services all around the world, using multimode terminals that would be able to work according to the European, Japanese and American standards. However, the obtained result was different than expected and the 3G differs in the American continent compared to Europe and Japan, due to the different frequency bands used for the communications.

The 3G European system is UMTS (Universal Mobile Telecommunication System), in order to respond to the emerging needs for new communications. A comparison of the several frequency bands used in various regions is shown in Figure 1.1. It can be seen that among Europe, Japan and Korea there is an almost total superposition of the spectrum to be used for UMTS communications, while in the United States that does not happen. This fact is explained by the bands already assigned to other services, becoming difficult to change those frequency bands, in order to standardise UMTS at global level. Besides these frequency aspects, there were also others that prevented the existence of a unique 3G standard, like backward compatibility to existing second generation (2G) systems.

The biggest attraction and novelty that UMTS presents compared to 2G systems, namely GSM (Global System for Mobile Communications), is the diversity of services and applications available to the user, each one of them being characterised by different throughputs and switching modes. This additional richness that UMTS presents, i.e. different throughputs, requires a different approach to the optimisation of network resources.

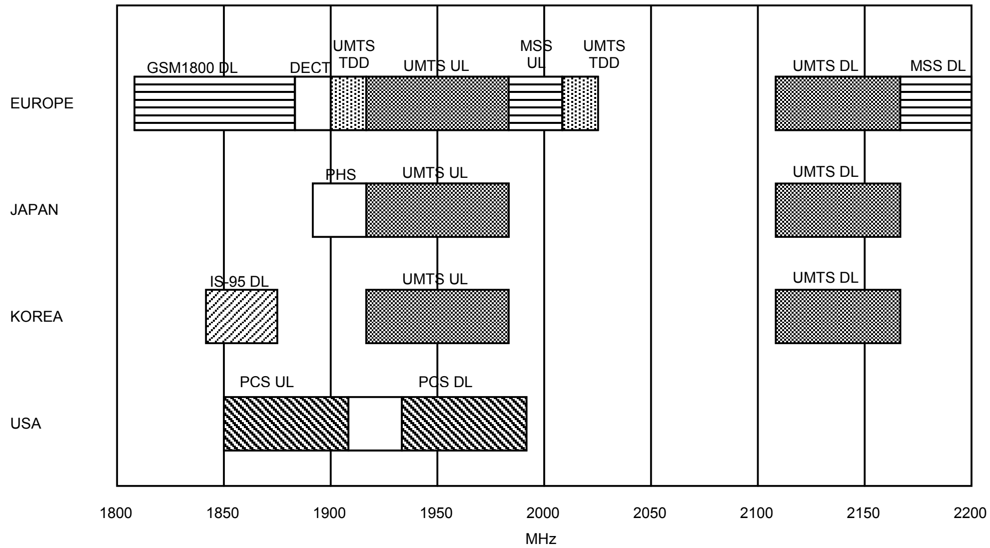


Figure 1.1. Allocation of Radio Spectrum in Europe, Japan, Korea and USA (adapted from [HoTo00]).

The following list includes some of the most significant services/applications that UMTS will bring:

- Speech-telephony: Traditional speech-telephony.
- Video-telephony: Communication for the transfer of voice and video between two locations.
- Streaming Multimedia/Information distribution: Service that allows the visualisation of multimedia documents on a streaming basis, e.g., video, music, or slide show.
- Multimedia Communication Service/Web Browsing: Interactive exchange of data between a user and a web server, allowing the access to web pages. This information may contain text, extensive graphics, video and audio sequences.
- Location Based Service: Interactive service that enables users to find location-based information, such as the location of the nearest gas stations, hotels, restaurants, and so on.
- Messaging/SMS: Messaging service that transfers small amounts of text (several hundred characters).
- Messaging/MMS: Messaging service that allows the transfer of text, image and video.
- Messaging/E-mail: Process of sending messages in electronic form, usually in text form; however, they can also include images and video clips.
- Unrestricted Data Retrieval Service/File Download: Download of a file from a database.

UMTS is based on UTRAN (UMTS Terrestrial Radio Access Network) for the access to the core network and other networks, and on interface WCDMA (Wideband-Code Division Multiple Access) as the multiple access technique which considers the existence of spread spectrum and distinct codes to be assigned to each user [HoTo00].

Like all systems, UMTS presents also some limitations, the most relevant being the ones related to interference, maximum Base Station (BS) transmission power, and, in some cases, issues regarding the maximum propagation attenuation.

Traffic estimation in the early days of 2G systems, was a simple task, since only voice was to be taken into account, and therefore it could be based on a simple estimation of population. More recently, with the introduction of GPRS, operators started to provide services and applications other than voice or simple messaging, i.e. based on data. In the case of UMTS, the foreseen variety of services and applications, the enormous set of possibilities of their use, and the lack of solid marketing information, makes the task of traffic estimation a very difficult and challenging one. Since the beginning, UMTS is intended to be a system providing a multiple choice of services and applications to users, enabling the mixed use of voice, video and data, partly at the will of the user, and partly depending on the availability of the network. This makes a huge difference from existing 2G systems and poses a problem to those involved in the design and dimensioning of UMTS networks, coming from the fact that there is no real data available that can be used for the estimation of the traffic offered to the system.

Several research groups and projects are (or have been recently), focused on UMTS traffic and mobility aspects, namely:

- The IST-MOMENTUM project. Deliverable 1.3 of this project [FCSC02] addresses the procedures to generate mobility and traffic scenarios, to be used in the deployment of UMTS radio networks. A traffic forecast of static users was built, based on an operational environment with users spread over it generating calls according to certain services usage patterns. Mobility is introduced in users by the definition of a mobility scenario, characterised by different mobility types and a mobility model that controls the movement of users on a motion grid. The impact of mobility in the traffic load is studied in detail.
- Allen Vasconcelos and Patrícia Carvalho on their final graduation work [VaCa02]. The objective of this work was to make cell dimensioning on UMTS, taking in

consideration traffic and propagation issues. A traffic model was established based on population characterisation and spatial characterisation of the city, in order to estimate active users and the respective services. The services offered to the users were analysed and also the way that its usage conditioned the performance of the cellular network.

- Leila Z. Ribeiro and Luiz A. DaSilva in the article "A framework for the dimensioning of broadband mobile networks supporting wireless internet services" [RiDa02]. This article discusses a framework for the dimensioning of wireless mobile networks by taking into account differentiated user and traffic profiles. Distinct QoS requirements from various applications result in different aggregate throughput per cell being achievable for the same loading factor and network layout depending on user mix. Therefore, appropriate characterization of user mixes and aggregation techniques that map these mixes into resource requirements are key in the design of 3G systems.

The motivation for this work consists in evaluating the influence of multi-service and user mobility on the performance of UMTS. User mobility influences the system load since during handover (soft and softer) the mobile terminal is connected to two BS. Since there is still no real data regarding the traffic to be generated, there is the need to estimate it, in order to be able to dimension the UMTS cellular network. The estimated traffic has a non-uniform distribution. When considering a generic traffic model that accounts for several relevant areas, it is necessary to define an approach that covers parameters such as population characterization and type of terrain occupation, related to the service region for which the cell dimensioning is being made. For that, it is necessary to do a study regarding the services that the population can and will use with a higher probability. Due to the fact that planning in GSM and UMTS is totally different, it becomes necessary to consider new limiting parameters and also to acquire a sensitivity to their relevance in the dimensioning. The objective of this thesis is to evaluate the influence of traffic distributions on UMTS performance, as well as of user mobility. The evaluation will be done in specific areas of the city of Lisbon, therefore using data from a real environment.

Network operators have been reducing cell size and introducing hierarchical micro/macro - cell systems due to the increase of mobile subscribers and the need to improve QoS. The reduction of cell size tends to decrease cell residence time, therefore to increase cross-over rates. This fact contributes to the growth of signalling traffic load.

When using micro/macro-cells, subscriber's speed is an important factor for making cell selection. Slow speed mobiles are covered by micro-cells, while the others are covered by macro-cells. Time spent by a MT in a call-initiated cell is one factor to consider in cell selection. For this reason, it is a major interest to find an appropriate model to estimate and analyse movements of MTs. The implementation of a cellular mobile communication network that provides full coverage requires the use of selective and up to date mobility models, which need to apply to both urban and suburban traffic scenarios.

Several sources have suggested their own mobility models, according to different criteria. In these sources, also the key parameters for model customisation have been pointed out. A brief summary of these various models is described in Chapter 3.

In order to evaluate the impact of user mobility, it was necessary to build a dynamic simulator. From the results given by the simulator it is possible to draw relevant conclusions regarding the network behaviour, even considering the approximations used, since real data was considered throughout the whole process as much as possible. Consequently, it will be possible to make decisions regarding implementation issues, in order to satisfy the largest number of users, in the most efficient way, minimising the costs resulting from a real UMTS implementation. It is possible to make the dimensioning for any city where the parameters regarding population, its profile and terrain characterisation are available. The simulator then outputs as performance parameters the cell load for both up- and down-links (UL and DL), the UL and DL handover load, the blocking probability, and average bit rate per service.

Chapter 2 gives a brief overview of UMTS in terms of network structure, multiple access scheme and available service classes. This chapter also shows a comparison between the two duplex schemes used in UMTS-TDD and FDD; the four available service classes are described and there is also a short overview of capacity and coverage planning. In Chapter 3, a description regarding radio network planning in UMTS is presented; it covers topics such as power balance and coverage efficiency, load factors and spectral efficiency and mobility models; it also addresses the calculation of UL and DL load and BS transmission power. Chapter 4 describes the implementation of the simulator; it gives a brief description of Geographical Information Systems (GIS) and describes the several inputs of the simulator; the main routines of the simulator are explained in detail together with the respective flow diagram; finally, all the simulator results are listed. Chapter 5 contains the analysis of results, starting with a description of the evaluated Lisbon scenarios, after which the different scenarios are compared in terms of the results given by the simulator (load, handover load, blocking probability and average bit rate); the last sections evaluate the impact of load threshold and soft handover in system's performance. Chapter 6 concludes this work, showing the final conclusions and considerations; it also makes a bridge to future work to be developed as the continuation of this study, and lists points that can improve the reliability of the obtained simulator data.

The main novelty of this thesis consists on the results obtained for the influence of mobility in network performance, considering real non-uniform traffic distributions and multi-service environments.

With the usage of the conceived simulator, it is possible to make considerations regarding the influence that the several system parameters have in the network for a real scenario; in the future, implementation decisions concerning cell planning should be based on results like the ones obtained in this thesis.

Chapter 2

General Aspects of UMTS

This chapter presents a brief description of UMTS in terms of network structure, multiple access scheme and available service classes, based on the description presented in [HoTo00]. It also gives an overview of the available spectrum for UMTS and a short description of the TDD and FDD modes.

2.1 Network Structure

UMTS uses the same known architecture that was used in the major 2G systems and even in some 1st generation ones. It consists of a certain number of logical network elements where each one has its specific function. In the specifications, the network elements are defined at a logical level, but this frequently results in a similar physical implementation, especially due to some open interfaces (for an interface to be considered open, it is necessary to be defined in such a way that the equipment at both ends can be of different manufacturers). The network elements can be grouped based on similar functions or based on the sub-network to which they belong to.

Functionally, the network elements are grouped in the RAN (Radio Access Network), which is in charge of the "radio" functionalities, and the CN (Core Network), which is responsible for switching and routing calls and data links to outside networks. In order to complete the system, the UE (User Equipment), which makes the interface between the user and the radio interface is defined. The high level architecture of the system is represented in Figure 2.1, and briefly explained in what follows.

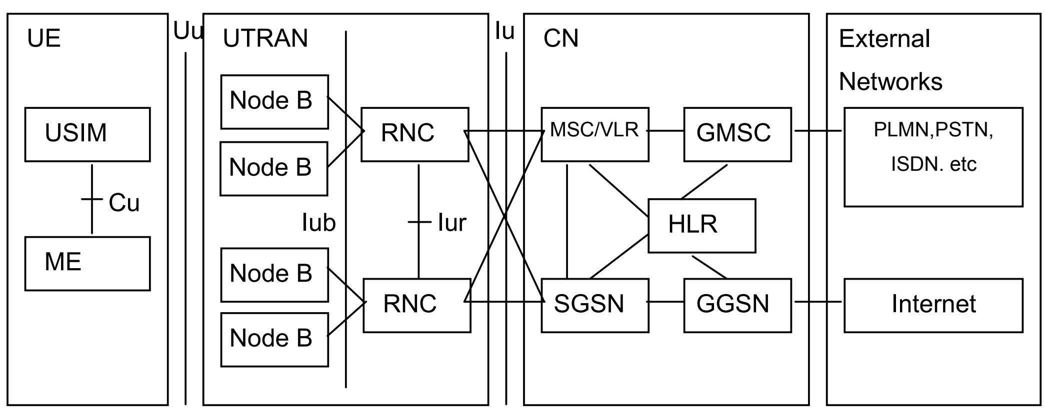


Figure 2.1. Network elements (adapted from [HoTo00]).

From the specification and standardisation points of view, both UE and UTRAN consist of completely new approaches, having their conception based on the needs of the new WCDMA radio technology; on the contrary, the CN definition is adopted from GSM. This gives the system with the new radio technology a global base of known and tested CN technology, which speeds up and eases its introduction and allows competitive advantages, such as global roaming.

A brief description of UTRAN elements is listed below.

The UE is divided in two parts:

- Mobile Equipment (ME) is the radio terminal used to communicate over the Uu interface.
- UMTS Subscriber Identity Module (USIM) is a smartcard that contains the subscriber identity, which executes authentication algorithms and saves authentication and encrypting keys and some subscriber information needed for the terminal.

The UTRAN is also composed of two separate elements:

- Node B converts the data flow between the interfaces Iub and Uu; it also participates in Radio Resource Management.
- The Radio Network Controller (RNC) owns and controls the radio resources in its domain (Node Bs connected to it); RNC is the access point to all the services that the UTRAN provides to the CN, e.g., connection management to the UE.

The most important elements of the CN are the following:

- HLR (Home Location Register) is a database located in the network that keeps the master copy of the users service profiles. The service profile consists of, for example, the information of the allowed services, forbidden roaming areas and information about supplementary services, such as call redirection state and redirection number. It is updated when a new user subscribes the system, and information remains while the subscription is active. In order to process transactions directed to the UE (e.g., calls or short messages), the HLR also stores the UE location in the level of the MSC/VLR and/or SGSN, i.e., at the server system level.
- MSC/VLR (Mobile Services Switching Centre/Visitor Location Register) are the switch (MSC) and the database (VLR) that serve the UE in its current location for circuit switch (CS) services. The purpose of the MSC is to switch the CS transactions and the purpose of the VLR is to keep a copy of the visiting user service profile, as well as more precise information about the UE location on the server system. The network part accessible through the MSC/VLR is usually referred to as CS domain.
- GMSC (Gateway MSC) is the switch at the point where the UMTS PLMN is connected to the external CS networks. All the CS connections go in and out through the GMSC.
- SGSN (Service GPRS Support Node), in functional terms, is similar to the MSC/VLR but is typically used to packet switched (PS) services. The network part that is accessed through the SGSN is usually called PS domain.

- GGSN (GPRS Gateway Support Node), in functional terms, is similar to the GMSC but related to PS services.

The external networks can be divided in two groups:

- CS networks, which provide connections in circuit switching, like the existing telephone service, ISDN and PSTN being examples of these networks.
- PS networks, which provide connections for packet switched services, the Internet being one example of such a network.

The UMTS standards are structured in such way that the internal functionality of network elements is not specifically detailed. Instead, the interfaces between logical elements are defined. The following open interfaces are specified:

- Interface Cu - this is the electrical interface between the USIM smartcard and the ME. The interface follows a standard format for smartcards.

- Interface Uu - this is the WCDMA radio interface. The Uu is the interface through which the UE accesses the system fixed part, and it is, for this reason, probably the most important open interface of UMTS. There are probably much more UE manufacturers than for fixed network elements.

- Interface Iu - this interface connects the UTRAN to the CN. Like the similar GSM interfaces, A (circuit switching) and Gb (packet switching), the open interface Iu supplies UMTS operators the possibility to buy UTRAN and CN equipment from different suppliers. Competition was one of GSM success factors, which is intended to be kept in UMTS.

- Interface Iur - the open interface Iur allows soft handover between RNCs of different suppliers and, this way, complementing the open Iu interface.

- Interface Iub - the Iub connects Node B with the RNC. UMTS is the first commercial mobile telephone system where the Base Station Controller is standardised as a completely open interface. Just like the other open interfaces, Iub should motivate even more the competition between suppliers in this area. It is most likely that new suppliers will enter the market, exclusively dedicated to Node Bs.

2.2 TDD/FDD Modes

The allocation of radio spectrum to 3G and UMTS in particular, in Europe, Japan, Korea and USA is illustrated in Figure 1.1. In Europe and in the major part of Asia, the IMT-2000 bands of 2×60 MHz (1920-1980 MHz and 2110-2170 MHz) will be available for UMTS FDD; the availability of TDD spectrum varies, being expected in Europe to have 25 MHz available for licenses in the bands 1900-1920 MHz and 2020-2025 MHz. FDD systems uses different frequency bands in UL and DL, separate by the duplex distance, while TDD uses the same frequency for both UL and DL.

In Japan and Korea, the IMT-2000 band for FDD is the same for the rest of Asia and Europe. Japan implemented PDC as a 2G system, while in Korea IS-95 is used for cellular operation and PCS. The PCS spectrum assignment in Korea is different from the one in the USA, leaving the IMT-2000 spectrum completely available in Korea. In Japan, part of the IMT-2000 spectrum is used by PHS, the cordless phone system.

In China, there are reserves to be used by PCS or WLL (Wireless Local Loop) in part of the IMT-2000 spectrum, however these have not been allocated to any operator. Depending on the decisions from the regulator, up to 2×60 MHz of the IMT-2000 spectrum will be available for the use of FDD in China. The TDD spectrum is also available in China.

In the USA, no new spectrum has been allocated to 3G systems, which will be implemented through the insertion in the existing PCS spectrum. This possibility will require the replacement of part of the existing 2G frequencies for 3G systems.

Figure 2.2 illustrates the operation of the FDD and TDD modes.

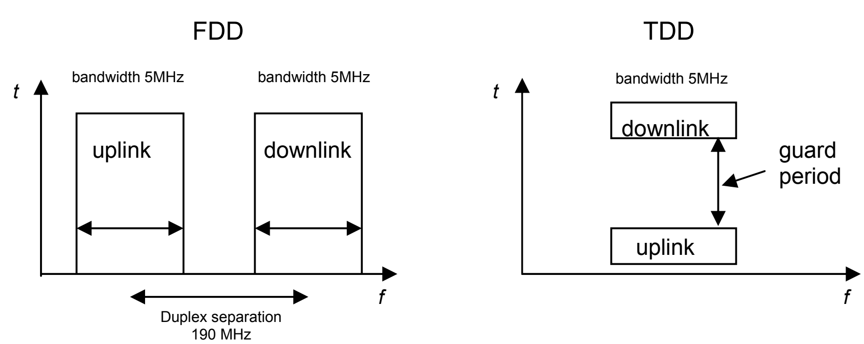


Figure 2.2. Operation in FDD and TDD.

Some particular characteristics of TDD and FDD systems are listed below.

- Usage of unpaired or paired bands

  TDD can be implemented in an unpaired band while FDD requires always a pair of bands. In the future it will be likely that more unpaired spectrum resources can be assigned to UMTS, since TDD is more adequate for many of new foreseen applications.
- Discontinuous Transmission

  Switching the transmission link in TDD requires time and the commuting transient has to be controlled. To avoid corrupted transmissions, the UL and DL transmissions require a common medium to agree upon the transmission link and the time lost to transmit. The corruption in the transmission is avoided through the assignment of a guard period that allows for the compensation of the propagation delay.
- Interference between UL and DL

  Since in TDD UL and DL share the same band, the signals from those two transmissions can interfere with each other, while in FDD this interference is completely avoided by the duplex separation of 190 MHz. In the TDD mode, the BSs are synchronised among them at the frame level to minimise this interference.
- Asymmetric assignment of UL/DL capacity

  In TDD, the ascending and descending channels are divided in the same time domain. This way, it is possible to change the duplex commuting point and to move the UL capacity to the DL, or vice versa, depending on the capacity required by the two transmission links. This makes this mode very efficient for asymmetric applications, which is not the case of FDD since it has same capacity in both links.
- Reciprocal Channel

  Fast fading depends on the frequency, therefore, in FDD systems fast fading is not correlated between the ascending and descending channels. Since the same frequency is used in TDD for UL and DL, the fading is the same for the two transmission links. Based on the received signal, the TDD transducer can estimate the fast fading, which will affect the transmission. The estimation for fast fading can then be used for power control and in adaptive antenna techniques in TDD.

The UMTS TDD mode uses a combined scheme of time division and code division multiple access that adds a CDMA component to a TDMA system (TD/CDMA). Hence, the different user signals are separated in both time and code domain. Table 2.1 presents a summary of the UTRA physical layer parameters. All the major RF parameters are harmonised inside the UTRA for the FDD and TDD modes.

	UTRA TDD	UTRA FDD
Multiple access method	TDMA, CDMA (FDMA inherent)	CDMA (FDMA inherent)
Duplex method	TDD	FDD
Channel spacing	5 MHz (nominal)	
Chip generation	3.84 Mcps	
Timeslot structure	15 slots/frame	
Frame length	10 ms	
Multirate concept	Multi-code, multislot and orthogonal variable spreading factor (OVSF)	Multi-code and OVSF
Error correction	Convolutional coding R=1/2 or 1/3, constraint length K=9, turbo coding (8 states PCCR R=1/3) or service specific coding	
Spacing	Spacing between frames (10, 20, 40 and 80 ms)	
Modulation	QPSK	
Burst Types	Three types: burst traffic, random access and synchronisation burst	Not applicable
Detection	Coherent, based on midamble	Coherent, based on pilot symbols
Channel power control	Uplink: open cycle; 100Hz or 200Hz Downlink: closed cycle; 800Hz	Fast closed cycle; 1500Hz
Intra-frequency handover	Hard handover	Soft handover
Inter-frequency handover	Hard handover	
Channel assignment	Supports slow and fast DCA	Does not require DCA
Interference cancelling	Supports joined detection	Supports advanced receivers at the BS
Spreading factor	1 … 16	4 … 512

Table 2.1. Comparison of the physical layer major parameters for the UTRA FDD and TDD.

WCDMA is the multiple access system used for the UMTS radio interface. WCDMA is a Multiple Access system through Code Division in Direct Sequence (DS-CDMA), i.e., the user information bits are spread over a large bandwidth through the multiplication of data by almost random bits (called chips) derived from the CDMA spreading codes. In order to hold with very high transfer speeds (up to 2 Mbps), the use of variable spreading code and multi-code connections is supported.

The chip generation rate used of 3.84 Mcps creates a band of 5 MHz which makes of it a wideband DS-CDMA system; the systems with a bandwidth of approximately 1 MHz, like IS-95, are usually called narrow band ones. The inherent WCDMA broadband supports high throughputs and has also performance benefits, such as a higher multipath diversity. Subject to the operating license, the network operator can implement multiple 5 MHz carriers in order to increase the capacity, possibly through the form of hierarchical cell layers. The real spacing between carriers can be selected in intervals of 200 kHz between approximately 4.4 and 5 MHz, depending on the interference between carriers.

WCDMA supports a wide variety of throughputs, in other words, the concept of having Bandwidth on Demand (BoD) is well supported. A time window of 10 ms, frame, is assigned to each user, during which the throughput is kept constant. Nevertheless, the data transfer capacity between users can vary from frame to frame. This fast adaptivity of radio capacity will be typically controlled by the network to obtain the optimal throughput for packet data services.

WCDMA supports the operation of asynchronous BSs, in such a way that contrary to the synchronous IS-95 system, there is no need for a global time reference, like GPS. WCDMA uses coherent detection in UL and DL based on the use of pilot symbols or common pilot. While this is already used in the DL of IS-95, the use of coherent detection in the UL is new to public CDMA systems, and will result in a global increase of the UL coverage and capacity.

The air interface of WCDMA was conceived in a way that advanced concepts of CDMA reception, such as multi-user detection and intelligent adaptive antennas, can be implemented by the network operator as a system option in order to increase capacity and/or coverage. In most part of 2G systems, no provision was made for such receiver concepts, and as a result these either are not applicable or can only be applied under severe restrictions and limited performance increases.

UMTS is conceived to be implemented together with GSM. This way, handovers between GSM and UMTS are supported in order to be possible to level the GSM coverage with the introduction of 3G.

UMTS supports softer and soft handover types. During softer handover, a mobile station is in the overlapping cell coverage area of two adjacent sectors of a BS. The communications between mobile station and BS take place concurrently via two air interface channels, one for each sector separately. During soft handover, a mobile station is in the overlapping cell coverage area of two sectors belonging to different BSs. In addition to soft/softer handover, UMTS provides inter-frequency and inter-system hard handovers.

2.3 UMTS Service Classes

In general, applications and services can be divided in different groups, depending on the way they are considered and UMTS makes an effort to contemplate the QoS requests coming from the applications and the user. Four traffic classes were identified:

- Conversational
- Streaming
- Interactive
- Background

The main distinguishing factor among these classes is the sensitivity level to delay: the conversational class is destined to very delay sensitive traffic while the background class is more insensitive to delay. The UMTS QoS classes are summarised in Table 2.2.

Traffic Class	**Conversational**	**Streaming**	**Interactive**	**Background**
Fundamental Characteristics	Preserves the time relation (variation) between information entities. Conversational pattern.	Preserves the time relation (variation) between information entities.	Requests response pattern. Preserves the data integrity.	The receiver does not have a pre-determined time for the data reception. Preserves the data integrity.
Application Examples	Voice, videophone, video games	Multimedia	Internet browsing, network games	E-mail
Transfer delay	Minimum fixed	Minimum variable	Moderate variable	Big variable
Buffering	No	Allowed	Allowed	Allowed
Nature of traffic	Symmetric	Asymmetric	Asymmetric	Asymmetric
Burstiness	Non-bursty	Non-bursty	Bursty	Bursty
Bandwidth	Guaranteed bit rate	Guaranteed bit rate	No guaranteed bit rate	No guaranteed bit rate
Reliability	Generally low	Generally low	High	High

Table 2.2. UMTS QoS Classes.

During the initial phase of UMTS, the conversational and streaming classes will be transmitted as real time connections over the WCDMA interface, while the classes interactive and background will be transmitted as packet information, not in real time.

The list below presents a brief description of each of the referred classes.

- Conversational Class

  The most known application of this class is the voice service over CS. With Internet and multimedia, a group of new applications will require this type, for example voice over IP and video telephony. Conversation in real time is always established between "live" users (humans). This is the only one in the 4 classes where the required characteristics are imposed by human perception. The conversation in real time is characterised by the fact that the delay between extremes is low and the traffic is symmetric, or almost symmetric. The maximum delay between extremes is given by the human perception of a video or of an audio conversation: subjective evaluations have shown that peer to peer delay must be less than 200 ms.
- Streaming Class

  The streaming of multimedia is a data transfer technique where this can be processed with a stable and continuous flow. The streaming technologies are getting more important with the growth of Internet, since most part of the users do not have an access fast enough in order to make a fast download of large multimedia files. With streaming, the client's browser or plug-in can initiate the information visualisation before the complete file has been sent. For streaming to work, the user side that receives the information must be able to receive it and send it at a constant throughput to the application that is processing and converting it to sound or image. Streaming applications are very asymmetric, therefore, they typically tolerate a larger delay than the more symmetrical conversational services. This also means that they tolerate a larger jitter in the transmission. Jitter can be easily attenuated through buffering.
- Interactive Class

  When the final user, whether machine or human, is on-line requiring information from a remote equipment (e.g., a server), this scheme applies. Examples of human interaction with remote equipment are Internet browsing, access to databases or access to servers. Examples of interactions between machines and remote equipment are polling, to register measurements and automatic access to databases (tele-machines). Interactive traffic is another classic communication scheme that is broadly characterised by the pattern request-answer of the final user. In the message receiver there is an entity waiting for the message (response) within a certain time. The delay time of the answer is in this way one of the main attributes. Another characteristic is that the content must be transferred with transparency (with low error level).

- Background Class

  The traffic of application data, such as sending e-mails, SMS, database download and reception of measurement records, can be sent in background since these applications do not require immediate action. The delay can range from seconds to minutes. The background traffic is one of the classic data communication schemes that is broadly characterised by the fact that the receiver is not waiting for data in a defined period of time. This way it is more or less insensitive to the sending time. Another characteristic is that the content does not need to be transparently transferred. The information transmitted must be received without errors. The electronic postcard is one example of the new applications that are gradually becoming more and more common. It is easily predictable that as soon as terminals possess built-in cameras and big colour screens become enough smaller, the electronic postcard will dramatically increase in utilisation.

Chapter 3

Radio Network Planning and Users Mobility

This chapter describes specific issues regarding network planning in UMTS. It covers the link budget and coverage efficiency, and describes the calculation of load and BS transmission power. It also addresses, as well as the several performance parameters of the system, the several user mobility models that were evaluated.

3.1 Network planning

3.1.1 Capacity and coverage

The planning of the radio network in UMTS is a process in which the possible configurations and the quantity of network equipment are estimated based on the operator requisites in terms of:

- Coverage
- Coverage regions
- Information on the type of region
- Propagation conditions
- Capacity
- Available spectrum
- Forecasts on user growth
- Traffic volume forecast
- Quality of Service
- Coverage probability
- Blocking probability
- Access and transmission delays
- Average throughput

The tasks related to planning include the analysis of the radio link budget and coverage, the capacity estimation and finally the estimation of the equipment quantity for the sites and BSs, RNCs, interfaces and CN elements (i.e., core networks in the domains of circuit switching and packet switching). Basically, only the radio related aspects are dealt with in this thesis.

There are some specific parameters in the link budget of UMTS that are not used in a system with a radio access based on TDMA, such as GSM. The most important ones are the following [HoTo00]:

- Interference Margin
  The interference margin is necessary because the cell load (associated to the load factor) has implications on the coverage. The larger the load allowed in the system, the larger interference margin needed and the smaller the coverage area. For situations where coverage is a limiting factor, a smaller interference margin is recommended,

while in cases limited by capacity a larger interference margin should be used. In situations limited by coverage, the cell range is limited by the maximum allowed attenuation in the link budget, and the maximum capacity of the base station is not used. A typical value for the interference margin is 3 dB, corresponding to 50% of load.

- Fast fading margin

  It is necessary some margin in the transmission power of the MT in order to maintain a fast close cycle power control. This applies essentially to mobile pedestrians with slow movement where a rapid power control is able to effectively compensate fast fading. Typical values for the fast fading margin are around 2.0-5.0 dB to MTs at low speeds.

- Soft handover gain

  Handovers – soft or softer – supply gain against slow fading through the reduction of the corresponding fading margin. This is due to the fact that the fast fading is partially non-correlated among BSs, and through the handover the MT can select a better BS. Soft handover supplies an additional macro-diversity gain through the reduction of the necessary signal-to-noise ratio regarding a single radio link. A total gain due to soft handover is assumed between 2.0 and 3.0 dB.

The calculation of the link budget requires the evaluation of many parameters [Corr03]. First, one can calculate the EIRP of the transmitter according to

$$EIRP_{[dBm]} = P_{T[dBm]} + G_{T[dBi]} - L_{T\,add[dB]} \tag{3.1}$$

where

- $EIRP$ is the Equivalent Isotropic Radiated Power
- P_T is the transmitter output power
- G_T is the transmitter antenna gain
- $L_{T\,add}$ is the additional attenuation at the transmitter, coming either from the body loss at the MT, L_B, or the cable loss at the BS, L_C

Afterwards, the receiver sensitivity is calculated according to

$$P_{R[dBm]} = \left(E_b / N_0\right)_{[dB]} - G_{P[dB]} + N_{RF[dBm]} + M_{I[dBm]} \tag{3.2}$$

where

- P_R is the receiver sensitivity
- E_b/N_0 represents the energy of one signal bit over the spectral noise density
- G_P is the processing gain
- N_{RF} is the total effective noise
- M_I is the interference margin

The value of N_{RF} can be obtained from

$$\begin{aligned} N_{RF[dBm]} &= -174 + F_N + 10 \cdot \log(\Delta f) \\ N_d &= -174 + F_N \end{aligned} \tag{3.3}$$

where F_N is the noise figure in the mobile station receiver (with typical values around 5-9 dB) and Δf is the bandwidth.

Then, the calculation of the maximum path loss, is obtained by

$$L_{p[dB]} = EIRP_{[dBm]} - P_{R[dBm]} + G_{R[dBi]} - L_{R\,add[dB]} - M_{ff[dB]} - M_{sf[dB]} + G_{SH[dB]} - L_{pen[dB]} \tag{3.4}$$

where

- G_R is the receiver antenna gain
- $L_{R\,add}$ is the additional attenuation at the receiver, coming either from the body loss at the MT, L_B, or the cable loss at the BS, L_C
- M_{ff} is the fast fading margin
- M_{sf} is the log-normal fading margin
- G_{SH} is the soft handover gain
- L_{pen} is the path loss due to the penetration into a vehicle or house

The UL is considered for link budget calculations, since this is usually the most restrictive case.

Tables 3.1 and 3.2 list typical values of the parameters used in the equations above, both for the MT and the BS [HoTo00].

	Speech terminal	Data Terminal
Maximum Transmission Power	21 dBm	24 dBm
Antenna Gain	0 dBi	2 dBi
Body Loss	3 dB	0 dB

Table 3.1. Typical values for the mobile terminal.

Total effective noise	5.0 dB
Antenna gain	18 dBi (3-sector base station)
E_b/N_o: - Speech - 144 kbps real-time data - 384 kbps non-real-time data	5.0 dB 1.5 dB 1.0 dB
Cable loss	2.0 dB
Interference margin	3.0 dB
Fast fading margin	2.0-5.0 dB
Log-normal fading margin	6.0-10.0 dB
Soft handover gain	2.0-3.0 dB
Penetration path loss: - car - house	8.0 dB 15 dB

Table 3.2.Typical values for the base station.

3.1.2. Load

Since in WCDMA every user shares the same air interface resources, these cannot be analysed independently. Each user is influencing the others and causing the variation of their transmission power. These own variations cause variations in others and this way further. This way, all the prediction process must be done iteratively until the transmission power stabilises. In a similar way, the MT velocity, the multipath channel profiles, and the throughputs and services being used play a much more important role than in the 2G TDMA/FDMA systems. Additionally, in WCDMA, fast power control is considered both in UL and DL, and also soft/softer handover and orthogonal codes have impact in system performance. The main difference between WCDMA and TDMA/FDMA coverage prediction is that the interference estimation is already crucial at the WCDMA prediction coverage phase. In the actual coverage planning processes in GSM, the sensitivity of the receiver is assumed as constant and the coverage threshold is the same for each BS. In the case of WCDMA, the sensitivity of the BS depends on the number of users and their throughputs, therefore, it is specific per cell and per user profile. Note also that in 3G networks, the DL can be heavier loaded than the UL and vice-versa, depending on the applications being used, and their asymmetry ratio.

The second phase of dimensioning consists in estimating the traffic load supported by each BS. Since the frequency reutilization of the WCDMA system is equal to 1, the system is typically limited in the air interface by the interference level, which imposes the cell capacity.

The load in UL can be written as [HoTo00]

$$\eta_{UL} = (1+i)\cdot\sum_{j=1}^{N_u} L_j = (1+i)\cdot\sum_{j=1}^{N_u}\frac{1}{1+\dfrac{W}{(E_b/N_0)_j\cdot R_j\cdot\nu_j}} \qquad (3.5)$$

where

- N_u is the number of users per cell
- ν_j is the activity factor of the user j in the physical layer
- E_b/N_0 is the signal energy per bit divided by the spectral noise density necessary for a specific Quality of Service (e.g., binary error rate). Noise includes both thermal noise and interference
- W is the WCDMA chip throughput
- R_j is the binary throughput of user j
- i is the interference ratio between the other cells and this one as seen by the base station receiver

The load equation gives the noise rise value over the noise floor due to interference, which is equal to $10\cdot\log_{10}(1-\eta_{UL})$. The interference margin in the link budget must be equal to the maximum planned noise rise.

The necessary E_b/N_0 can be derived from link budget simulations and measurements. This includes the power control effect in closed loop and the soft handover. The effect of soft handover is measured as the combined gain of macro diversity regarding the result of E_b/N_0 of one single connection. The interference ratio between the other cells and one under consideration, i, is a function of the cell environment or the cell isolation (e.g., macro/micro, urban/suburban) and type of antenna (e.g., omni, 3 sectors, 6 sectors). Table 3.3 shows recommended values for these parameters [HoTo00].

The load equation is typically used to make semi-analytic forecast of the average capacity of a cell, without going into capacity simulations at system level. This load equation can be used with the purpose of predicting the capacity of one cell and to plan the noise rise in a dimensioning process.

For a classic network service of only voice, where all the N_u users have a low binary throughput R, one has

$$\frac{W}{E_b / N_0 \cdot R \cdot \nu} >> 1 \tag{3.6}$$

the load being approximated by

$$\eta_{UL} = \frac{E_b / N_0}{W / R} \cdot N_u \cdot \nu \cdot (1 + i) \tag{3.7}$$

Parameter	Recommended values
ν_j	0.67 for voice, assuming 50% of voice activity and the additional control during DTX 1.0 for data
E_b/N_0	Depending on the service, binary throughput rate, multipath fading channel, reception antenna diversity, mobile velocity, etc.
W	3.84 Mcps
R_j	Service dependent
i	Macro cell with omnidirectional antennas: 55%

Table 3.3. Parameters used in the calculation of the load in the UL channel.

The load in the DL channel, η_{DL}, can be defined based on a similar way of the UL channel, taking in consideration that the parameters are slightly different [HoTo00]

$$\eta_{DL} = \sum_{j=1}^{N_C} \nu_j \cdot \frac{(E_b / N_0)_j}{W / R_j} \cdot \left[\left(1 - \alpha_j\right) + i_j \right] \tag{3.8}$$

where

- N_C is the number of connections per cell = number of users per cell * (1 + soft handover overhead)
- ν_j is the activity factor of user *j* in the physical layer
- E_b/N_0 is the signal energy per bit divided by the spectral noise density necessary for a specific Quality of Service (e.g., binary error rate). Noise includes both thermal noise and interference
- *W* is the WCDMA chip throughput
- R_j is the binary throughput of user *j*
- α_j is the channel orthogonality of user *j*
- i_j is the ratio between the other cells base station power and itself, as received by user *j*

Again, the noise rise over the thermal noise due to multiple access interference is equal to $-10\cdot\log_{10}(1-\eta_{DL})$. Comparing with the load in the UL channel, the most important new parameter is α_j, which represents the orthogonality factor of the DL channel. WCDMA uses orthogonal codes in the DL channel for user separation, and without multi path propagation the orthogonality remains when the BS signal is received by the MT. Nevertheless, if there is enough spreading in the radio channel delay, the MT will see part of the BS signal as multiple access interference. Orthogonality equal to 1 corresponds to perfectly orthogonal users; typically, the orthogonality is between 0.4 and 0.9 in multi path channels.

In the DL channel, the ratio of other cells interference to the one considered, *i*, depends on the user location and is in this way different for each user *j*.

In the interference modelling for the DL channel, the transmission effect in soft handover can be modelled by having additional connections in the cell. The soft handover overhead is defined as the total number of connections divided by the total number of users minus one. At the same time the soft handover gain regarding the single connection E_b/N_0 is taken in consideration. This gain, called combined macro diversity gain, can be derived by simulation analysis at the connection/system level and is measured as the reduction in E_b/N_0 required for every user. The diversity effect in the transmission antenna shall be included in the required E_b/N_0.

The load in DL shows a very similar behaviour to the load for UL, in the sense that by approaching the unit, the system reaches its full capacity and the noise rise tends to infinite.

To design the DL channel link budget, it is important to estimate the value of the total transmission power required by the BS. This shall be based on the average transmission power per user and not in the maximum transmission power for the cell periphery calculated in the link budget.

Parameter	Recommended Values
ν_j	0.67 for voice, assuming 50% of voice activity and the additional DPCCH during DTX 1.0 for data
E_b/N_0	Depending on the service, binary throughput rate, multi path fading channel, reception antenna diversity, mobile velocity, etc.
W	3.84 Mcps
R_j	Service dependent
α_j	Depending on the multi path propagation 1: Completely orthogonal multi path single channel 0: without orthogonality
i_j	Every user sees a different i_j, depending on its location inside the cell and of the log-normal shadowing
$\overline{\alpha}$	Channel A vehicular ITU: ~60% Channel A pedestrian ITU: ~90%
$\overline{i}$	Macro cell with omnidirectional antennas: 55%

Table 3.4. Parameters used for the load calculation in the DL channel.

The minimum transmission power necessary per user is determined through the average loss between the BS and the MT, $\overline{L}_j$, and the sensitivity of the MT receiver, in the absence of multi-access interference (intra- or inter-cells). Then the noise rise effect due to interference is added to this minimum power and the total represents the required transmission power for a user in an 'average' location inside the cell. Mathematically, the total BS transmission power can be expressed by [HoTo00]

$$BS\_TxP = \frac{N_{rf} \cdot W \cdot \sum_{j=1}^{N} \nu_j \frac{(E_b / N_0)_j}{W / R_j} \overline{L}_j}{1 - \overline{\eta}_{DL}} \tag{3.9}$$

The load can be approximated by its average value when crossing the cell, calculated according to

$$\overline{\eta}_{DL} = \sum_{j=1}^{N} \nu_j \cdot \frac{(E_b / N_0)}{W / R_j} \cdot \left[(1 - \overline{\alpha}) + \overline{i} \right] \tag{3.10}$$

where

- $\overline{\alpha}$ is the average orthogonal factor of the cell
- $\bar{i}$ is the average value of the ratio between the other cells base station transmission power and the one considered, received by the user. The own cell interference is here broadband

3.1.3. Performance Parameters

The performance of an UMTS system is evaluated through several parameters. These parameters are listed below together with their definition and calculation method.

- *UL Load*
  The UL Load indicates the usage level of the UL channel for a certain cell and is typically used to make semi-analytic forecast of the average capacity without going into simulations at system level. UL Load is calculated using (3.5). The maximum allowed UL Load is 50%.
- *DL Load*
  The DL Load indicates the usage level of the DL channel for a certain cell and shows a very similar behaviour to the UL Load in the sense that by approaching the unit, the system reaches its full capacity. DL Load is calculated using (3.8). The maximum allowed DL Load is 70%.
- *Base Station Transmission Power*
  The Base Station Transmission Power is calculated by evaluating the minimum power necessary per user, determined through the average loss between the BS transmitter and the MT receiver, and the sensitivity of the MT receiver. This calculation is expressed by (3.9). The maximum allowed BS transmission power is 43 dBm.
- *UL Handover Load*
  The UL Handover Load shows the amount of MTs that are performing handover, i.e., connected to more than one BS. This is important to evaluate the impact of the mobile users mobility. It is calculated in a similar way to the cell UL Load, but selecting only the users that are inside the handover region instead of the whole cell.
- *DL Handover Load*
  Similar to UL Handover Load but for the downlink channel.

- *Blocking Probability*

  The Blocking Probability is the QoS indicator for CS services since it gives the probability of a user not getting access to the network when attempting to perform a CS call. This parameter is calculated using

$$P_b = \frac{\#\,blocked\ CS\ calls}{\#\,total\ attempted\ CS\ calls} \tag{3.11}$$

- *Average Bit Rate*

  The Average Bit Rate is the QoS indicator for PS services, since it indicates the "real" bit rate per service, which can then be compared to the reference bit rate to give an idea on how the network is performing. This parameter is calculated using

$$R_{av} = \frac{Total\ volume\ of\ PS\ call}{Total\ elapsed\ time\ of\ PS\ call} \tag{3.12}$$

3.2 Mobility Models

3.2.1 Random Walk Modelling

The model described in [JaZh98] considers a discrete two-dimensional random walk process. The MT is assumed to move in roughly a straight line (with occasional backtracking) for a significant period of time before changing direction. The new direction tends to be roughly perpendicular to the previous one in an orthogonal road system.

During each time period of the random walk simulation, the MT can move in four directions: right, left, up or down, according to a four-point probability distribution. This distribution is conditioned to the direction taken in the preceding time period, since the probability of moving in the same direction is relatively high. Therefore, there actually is an underlying discrete-time Markov chain that is generating the current direction of travel, where the four states of the Markov chain correspond to the four directions.

The model assumes orthogonal travel with constant speed, which seems reasonable when using a more-or-less orthogonal road system. The approach is designed with tractability in mind.

It considers a discrete-time Markov chain with four states:

$$P = \begin{array}{c} \\ R \\ L \\ U \\ D \end{array} \begin{array}{c} \begin{array}{cccc} R & L & U & D \end{array} \\ \left(\begin{array}{cccc} X & & & \\ & X & & \\ & & X & \\ & & & X \end{array} \right) \end{array} \begin{array}{l} \\ \text{MostlyRight} \\ \text{MostlyLeft} \\ \text{MostlyUp} \\ \text{MostlyDown} \end{array} \quad (3.13)$$

where X is fairly close to 1. For any given current state, the model assumes a one-dimensional random walk, e.g., if the current state is Right then with high probability p, the next step is one step to the right and with low probability q=1-p, the next step is one step to the left.

One interesting special case is where there is no backtracking; in this special case p=1 (q=0). Furthermore, only one horizontal direction (right or left) and one vertical direction (up or down) is used. Without loss of generality, it is assumed that these directions are right and up, resulting in a 2-state Markov chain probably with $p11=p22$ (or $p12=p21$) (another option is to ask for the probability of never changing direction across and the derive $p12$).

3.2.2 Mobility Model with Triangular Velocity Distribution

The model in [ChLu95] considers a triangular distribution where the density function is given by

$$f(v) = \begin{cases} \frac{1}{\Delta^2}.\left[v - (V_{av} - \Delta)\right] & , \quad V_{av} - \Delta \le v \le V_{av} \\ -\frac{1}{\Delta^2}.\left[v - (V_{av} + \Delta)\right] & , \quad V_{av} \le v \le V_{av} + \Delta \\ 0 \quad , \quad otherwise \end{cases} \quad (3.14)$$

Five different scenarios, Table 3.5, with average $V_{av} = (V_{max}+V_{min})/2$ and deviation $\Delta = (V_{max} - V_{min})/2$, are considered for the velocity, Figure 3.1.

Scenario	V_{av} **[m·s^{-1}]**	Δ **[m·s^{-1}]**
Static	0	0
Pedestrian	1	1
Urban	10	10
Main Roads	15	15
Highways	22.5	12.5

Table 3.5. Scenarios of Mobility Characteristics.

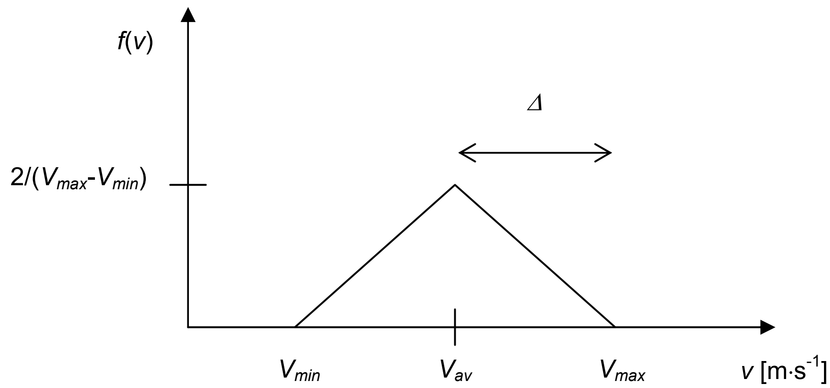


Figure 3.1. Velocity probability density function.

The scenarios are listed by increasing degree of mobility, shown by the increasing value in terms of average velocity. As the average velocity increases, so does the range of velocity variation, except for the highway scenario, where the deviation decreases.

3.2.3 Simulation of a Mobile Highway Traffic

The model described in [CvGa98] presents a simulation model for two directional highways, with multiple entrances and exits. The simulation is based on the deterministic fluid model. Vehicles moving along the highway, in one way, are treated as a continuous flow of fluid. Vehicles can be classified as calling and non-calling, depending on whether or not they have a call in progress.

Model parameters are:

- Traffic
- Vehicle speed
- Cell size
- Distance between entrance/exit points

The behaviour of the time non-homogeneous model for this case can be described by a system of three differential equations, the simulation of the deterministic fluid model being based on these equations. The respective numerical solution was achieved by an appropriate algorithm, based on the Runge-Kutta method. The simulation enables the calculation of the densities of the non-calling and calling vehicles, assuming some particular velocity pattern.

On a real highway, usually, a two way traffic occurs. Vehicles with mobile phones are moving in both ways, and can enter or leave the highway at certain points. Under this situation, three scenarios are possible:

- The normal traffic conditions (when the vehicles are moving at constant speed in both ways, and the slowing is noticed only near the entrance/exit points);
- Accidents that cause traffic jam in one way only;
- Accidents that cause traffic jam in both ways.

3.2.4 Mobility Models described in ETSI

[ETSI98] considers 4 different mobility scenarios:

- Indoor Office
- Outdoor to Indoor and Pedestrian
- Vehicular Environment
- Mixed-cell Pedestrian/Vehicular

These are described in detail in the following paragraphs.

Indoor Office Scenario

The Indoor Office environment consists of a large office building with an open floor plan layout; office cubicles are separated by conducting moveable partitions. In this scenario, users in elevators and stairwells are not considered, though realistically they would have to be accounted for. The specific assumptions about the indoor physical deployment environment are summarised in Table 3.6.

Area per floor [m^2]	5000
Number of floors	3
Room dimension [m^3]	10 × 10 × 3 (room) 100 × 5 × 3 (corridor)
Log-Normal Standard Deviation [dB]	12
Mobile Velocity [km/h]	3

Table 3.6. Assumptions for indoor physical deployment.

The indoor model is illustrated in Figure 3.2 together with a default deployment scheme, where BSs use omnidirectional antennas.

The mobility model is characterised as follows:

- there is no mobility between floors;
- MTs are either stationary or moving with constant speed from an office room to corridors or vice versa;
- if a MT is in an office room, it has higher probability to be stationary;
- if a MT is in the corridor, it has lower probability to be stationary.

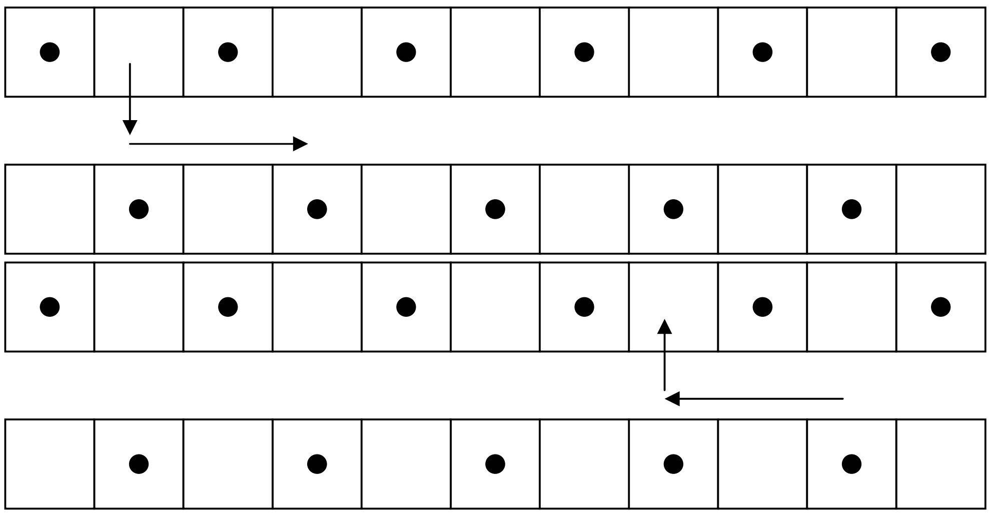


Figure 3.2. Indoor office and deployment scheme.

Each MT is either in the stationary or the moving state. The transition from the stationary state to the moving state is a random process. The time each MT spends in the stationary state is drawn from the geometric (discrete exponential) distribution with different mean values depending whether the MT is in an office room or in the corridor. The transition from the moving state to the stationary state takes place when the MT reaches its destination. Figure 3.3 illustrates the state transition.

When a MT is switched to the moving state while being in an office room, it moves to the corridor (see Figure 3.2) according to the following procedure:

- Select the destination co-ordinates in the corridor with uniform distribution (each place in the corridor has equal probability to become the destination point).
- The MT 'walks' from its current location to the destination location so that first the vertical co-ordinate is matched with the new co-ordinates and next the horizontal co-

ordinate is matched with the destination co-ordinate. The speed is constant during the 'walking'.

- When the MT reaches the destination point it is transferred into the stationary state.

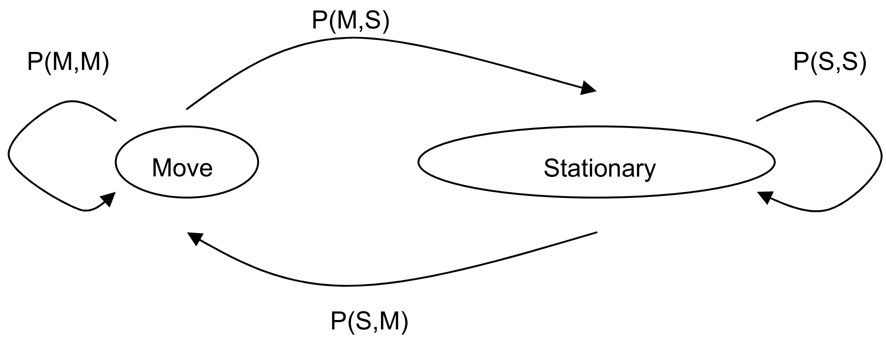


Figure 3.3. State automate presentation MT movement.

It is simply assumed that the door dividing each office room and corridor is as wide as the office room itself, since MTs simply walk straight out from the office room. When a MT is switched to the moving state, while being in the corridor, it moves to either any of the office rooms with equal probability.

In order to derive transition probabilities from the stationary state to the move state, the following parameters must be set:

- ratio of MTs at office rooms (*r*)
- mean office room stationary time (*mr*)
- iteration time step (Δt)

With these parameters, the transition probabilities per iteration time step (1-Δt/*mr*, 1-Δt/*mc*) and mean corridor stationary time (*mc*) can be derived, so that flow to the office rooms equals the flow from the office rooms.

$$r \cdot \frac{\Delta t}{mr} = (1 - r) \cdot \frac{\Delta t}{mc} \tag{3.15}$$

With the default parameters, listed in Table 3.7, the following values are obtained:

- P(M,M) in office room = 1-0.005/30=0.999833
- P(M,S) in office room = 0.005/30=0.0001667
- P(S,S) in office room = 1- 0.0009444=0.9990556
- P(S,M) in office room = 0.005*85/(30*15)=0.0009444

Average stationary time in the corridor becomes Δ*t*/P(S,M)=5.294 s. Table 3.7 presents the default parameters for the indoor mobility model.

Ratio of mobiles at office rooms [%]	85
Mean office room stationary time [s]	30
Simulation time step [s]	0.005
Number of office rooms	40
Mobile speed [km/h]	3

Table 3.7. Default parameters for the indoor mobility model.

Outdoor to Indoor and Pedestrian Scenario

This scenario considers a velocity of 3 km/h for both Indoor and Outdoor. The Outdoor to Indoor and Pedestrian environment considers also a Manhattan-like structure. Parameters for this structure are defined in Table 3.8 and illustrated on Figure 3.4. A default deployment scheme is also proposed with BSs using omnidirectional antennas.

Area [km^2]	Block Size [m]	Street Width [m]	BS-MT height difference [m]
6.5	200 × 200	30	10

Table 3.8. Manhattan-like structure parameters.

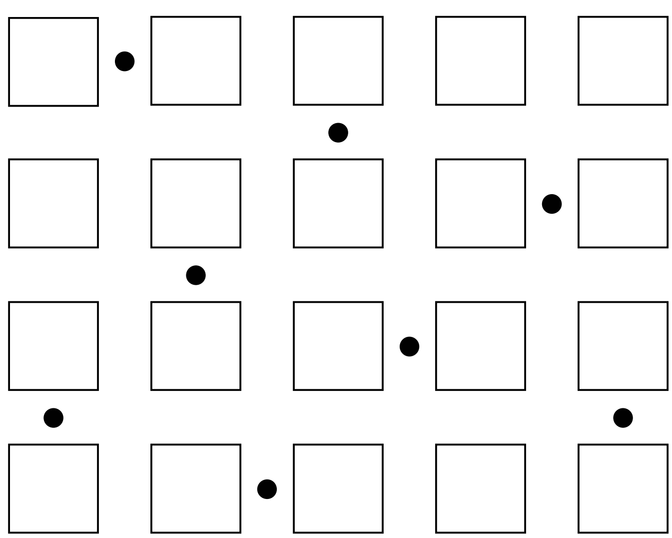


Figure 3.4. Manhattan-like urban model and deployment scheme.

The mobility model is dependent on the Manhattan-like structure defined in Figure 3.4. Mobile users move along streets, and at crossroads they may turn with a certain probability. The MT position is updated every 5 m, and velocity can be changed at any position update according to a certain probability. The parameters of the mobility model are shown in Table 3.9.

Mean speed [km/h]	3
Minimum speed [km/h]	0
Standard deviation for speed (normal distribution) [km/h]	0.3
Probability to change speed at position update	0.2
Probability to turn at cross street	0.5

Table 3.9. Mobility model parameters.

Turning probability at crossroads is illustrated in Figure 3.5.

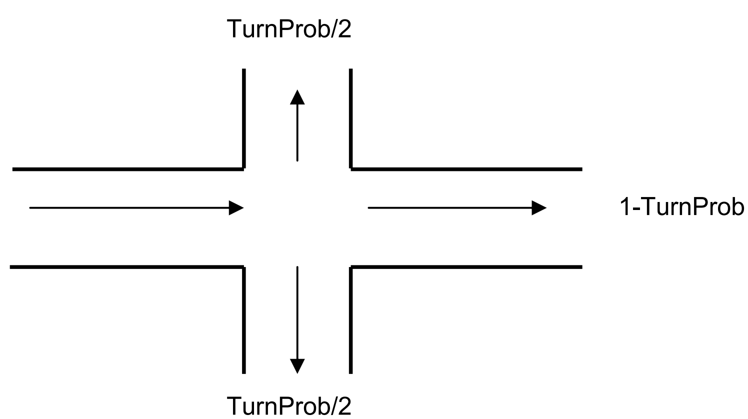


Figure 3.5. Turning probability.

MTs are uniformly distributed in the street. The respective direction is chosen at initialisation according to a random process.

Vehicular Scenario

The Vehicular environment considers a pseudo random mobility model with semi-directed trajectories. MT position is updated according to the decorrelation length, and direction can be changed at each position update according to a given probability. To simulate semi-directed trajectory, direction can be changed within a given sector.

MT speed is constant, and the mobility model is defined in Table 3.10.

Speed value [km/h]	120
Probability to change direction at position update	0.2
Maximal angle for direction update [º]	45
Decorrelation length [m]	20

Table 3.10. Mobility model parameters.

Mobile users are distributed uniformly on the map. During initialisation, the respective direction is randomly chosen.

Mixed-cell Pedestrian/Vehicular Scenario

This scenario can be used in the mixed environment. The physical environment consists in an urban area covered with micro-cells, and overlaid by macro-cells. It consists of a mixture of Outdoor to Indoor and Vehicular environments. The surrounding open area covered by macro-cells has to be large enough, so that umbrella macro-cells above the urban area are fully interfered by a full tier of co-channel interfering cells. An example is presented in Figure 3.6.

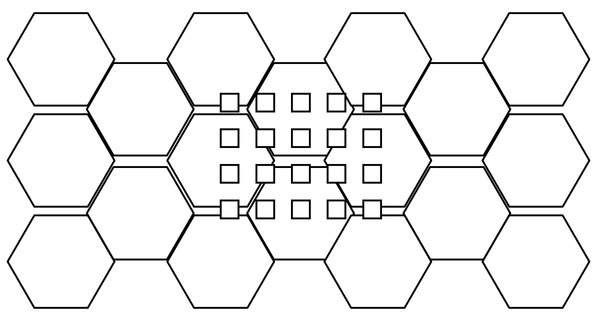


Figure 3.6. Mixed physical environment and proposed deployment model.

The specific assumptions about the outdoor and vehicular physical deployment environment are summarised in Table 3.11.

Path loss Type	MT Velocity [km/h]	Percentage of users [%]
Pedestrian (Outdoor)	3	60
Vehicular	80-120	40

Table 3.11. Mixed test deployment model physical environment.

Users move according to the Vehicular mobility model in the open area, and according to the Outdoor to Indoor and Pedestrian model in urban area.

3.2.5 Mobility Model described in COST 259

The mobility model described in COST 259 [Corr01] was proposed in [BrPB97]. This model assumes the heterogeneity of both the subscriber units and the traffic systems. MTs may move along crossroads and major roads. The following parameters are inputs to the model:

- road network pattern
- street length between crossroads
- street width
- traffic regulations
- subscriber behaviour

A mobile call can be initiated at any point within the cell along the path of the vehicle as shown in Figure 3.7. From these parameters, the Cell Residence Time (CRT) t_s or the remaining residence time t_{rs} are calculated according to the call initiating position of the MT. The path the MT follows during the call is modelled by the vectors d_I , which include the street length value between crossroads and the direction of movement. The average velocities v_i are related to the different sections of the traffic path. The direction of a MT is uniformly distributed between [-π,π[and then the PDF of the starting angle is 1/(2π) for the range [-π,π[.

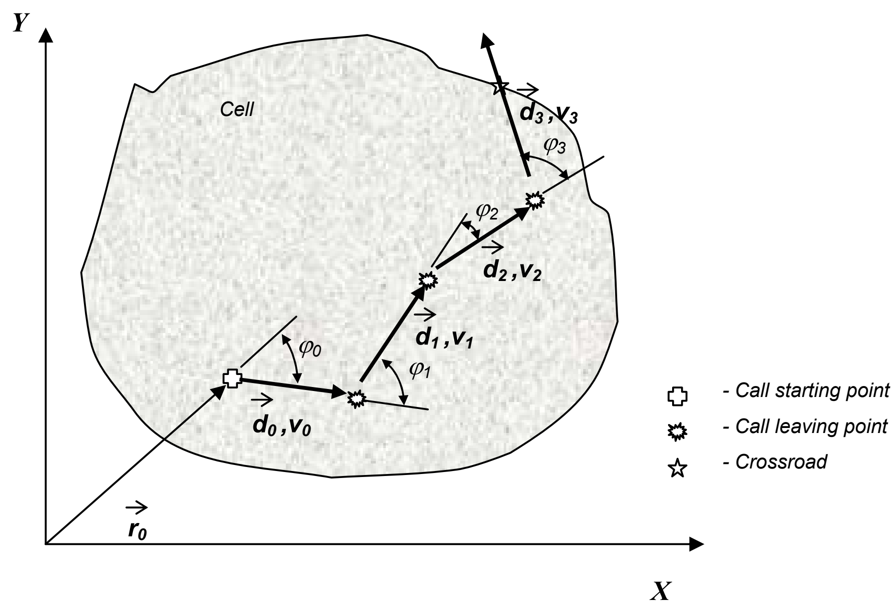


Figure 3.7. Tracing a MT within the cell (remaining residence time in the call initiated cell).

For the incoming call, the cell due to HO, the starting point corresponds to a point somewhere on their boundaries. The PDF of direction [XiGo93] is given by

$$p(\varphi_0) = \begin{cases} \frac{1}{2}\cos\varphi_0 & , \quad -\frac{\pi}{2} \le \varphi_0 < \frac{\pi}{2} \\ 0 & , \quad otherwise \end{cases} \tag{3.16}$$

Depending on street network pattern and traffic situation, relative direction changes at each crossroad, φ_i. The angle is expressed as the realisation of one of four normally distributed variables, with means estimated 90º apart. The PDF of φ_i is then given by

$$p(\varphi_i) = \frac{1}{1 + w_{90^\circ} + w_{-90^\circ} + w_{180^\circ}} \cdot \frac{1}{\sigma_\varphi \sqrt{2\pi}} \cdot \left(e^{-\frac{\varphi_i^2}{2\sigma_\varphi^2}} + w_{90^\circ} e^{-\frac{\left(\varphi_i - \frac{\pi}{2}\right)^2}{2\sigma_\varphi^2}} + w_{-90^\circ} e^{-\frac{\left(\varphi_i + \frac{\pi}{2}\right)^2}{2\sigma_\varphi^2}} + w_{180^\circ} e^{-\frac{(\varphi_i - \pi)^2}{2\sigma_\varphi^2}} \right) \tag{3.17}$$

In this equation, w_{90°, w_{-90° and w_{180° are the weight factors corresponding to probabilities, and σ_φ is the standard deviation of the direction distributions; standard deviation is assumed to be equal for the four variables.

The projections d_i,X and d_i,Y will be regarded as normally distributed random variables, since streets take a random course with respect to the axes of the co-ordinate system. In areas with an irregular street network pattern, the random variables d_i,X and d_i,Y can be characterised as statistically independent, with zero mean and showing the same variance. Therefore, the street-length between crossroads turns out to be a Rayleigh distribution:

$$p(d_i) = \begin{cases} \frac{d_i}{\sigma_d^2} e^{-\frac{d_i^2}{2\sigma_d^2}} & , \quad d_i > 0 \\ 0 & , \quad d_i \le 0 \end{cases} \tag{3.18}$$

$$where \quad \sigma_d = \overline{d}\sqrt{\frac{2}{\pi}}$$

When the majority of MTs use major roads only, the Rice distribution is proposed as an alternative, as stated in [BrPB97].

In this model, the velocity of the MT does not change while covering the distance d_i, allowing an equation with the average velocities v_i. The average velocity can then be expressed as a Rayleigh/Rice distributed random variable. According to measurements taken in Vienna and Helsinki, [VaNi94] suggests adding a second term to the distribution to consider the users in major roads, whose velocity is better described by a normally distributed random variable.

$$p(v_i) = \begin{cases} \dfrac{1}{1+w_{mr}} \cdot \left[\dfrac{v_i}{\sigma_v^2} e^{-\frac{v_i^2+\bar{v}^2}{2\sigma_v^2}} I_0\left(\dfrac{v_i \bar{v}}{\sigma_v^2}\right) + w_{mr} \dfrac{1}{\sigma_v \sqrt{2\pi}} e^{-\frac{\left(v_i^2-\overline{v_{mr}}\right)^2}{2\sigma_v^2}} \right], v_i > 0 \\ 0, \qquad v_i \le 0 \end{cases} \tag{3.19}$$

where w_{mr} is the weight factor for the fraction of cars on major roads.

3.2.6 Choice of the Mobility Models

In conclusion, one may say that there are several mobility models that can be applied to simulate the movement of mobile terminals. These models are designed for different mobility situations: pedestrian, urban and highway scenarios.

The described models receive as input some or all of the following variables (depending on the model): mobile velocity, mobile direction, direction change probability, road network pattern and subscriber's behaviour.

Considering the different referred models, one must choose the appropriate ones, taking into consideration the scenarios for which the system is being designed.

The chosen model to describe the MT velocity was the one with the Triangular Velocity Distribution. For the direction distribution, the chosen model was the one described in COST 259 but simplified in only four possible directions. Both models were chosen due to their simplicity and ease of usage.

Chapter 4

Implementation of the Simulator

This chapter focuses on how the simulation was implemented. After giving a brief introduction on GIS systems, it describes the several input parameters used in the simulation. Then the structure of the program is presented, together with an explanation of each main sub-routine. Finally, each output parameter is described and examples are given.

4.1 Initial considerations

The objective of this simulator is to implement a model to evaluate the influence of non-uniform traffic distributions and the impact of user mobility on UMTS performance. The need for developing this software came from the fact that a tool was needed to model traffic and user mobility in order to obtain relevant data in terms of system parameters. Some approximations were made which are identified in what follows.

In order to obtain realistic data for this evaluation, the simulator takes several inputs based on actual scenarios. Some of these inputs are given by a Geographic Information Systems (GIS) application.

GIS is a methodology to visualise, manipulate, analyse and display spatial data. GIS combines layers of information on a region, Figure 4.1, in order to give a better understanding of it, as smart maps linked to databases.

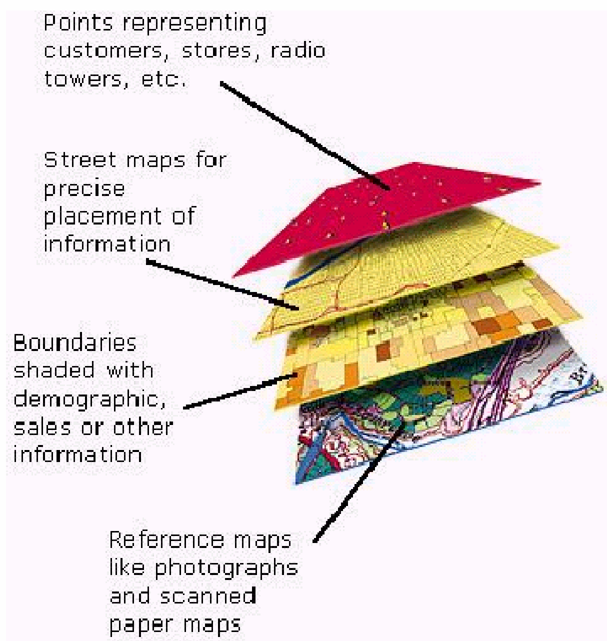


Figure 4.1. GIS layers of information.

Several tools are available in the market (ArcView [ARCV03], MapInfo [MAPI03], IDRISI [IDRI03]). MapInfo was chosen as the GIS tool to be used since it was the available one, and there was already data under its format. Nevertheless, it is compatible with all other GIS tools. The basic concepts of this tool are presented in this section. GIS, Figure 4.2, is used to visualise, manipulate and analyse spatial data, and create the scenarios and grids. The city of Lisbon was chosen due to the availability of data, and it is being considered hereafter.

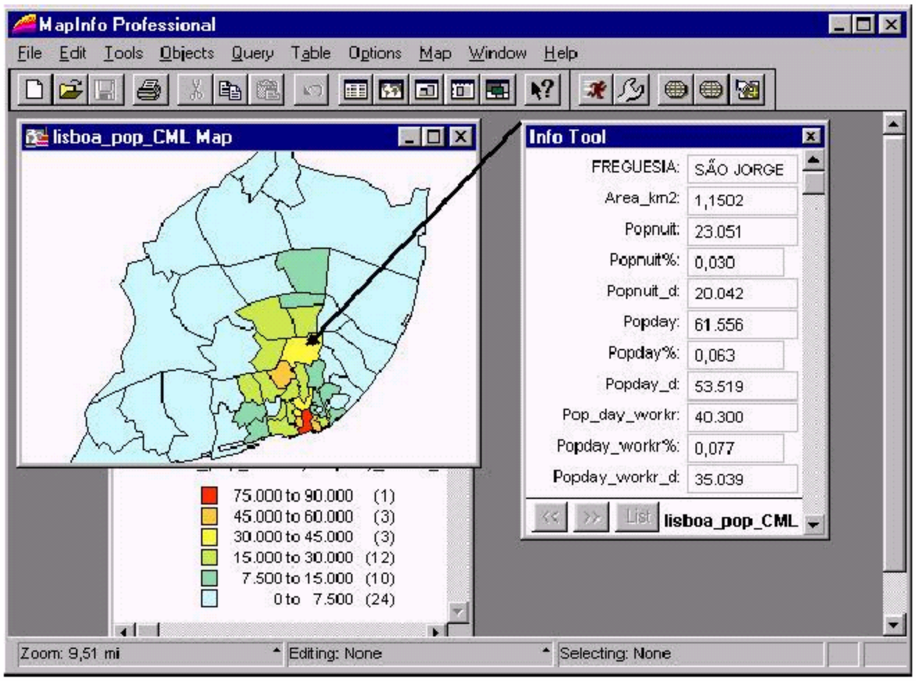


Figure 4.2. Geographic Information System tool.

GIS allows visualising smart maps, Figure 4.3, and databases, Figure 4.4, which can be linked together, Figure 4.5, allowing the creation of thematic maps, Figure 4.6.

Other important potentialities are:

- Import/export from/to many formats;
- Work with raster (pixel grid) and vector data;
- Queries;
- Select and combine data;
- Automatic reports;
- Programming language (MapBasic, in the case of MapInfo), which will be used to create the mobility and traffic scenarios.

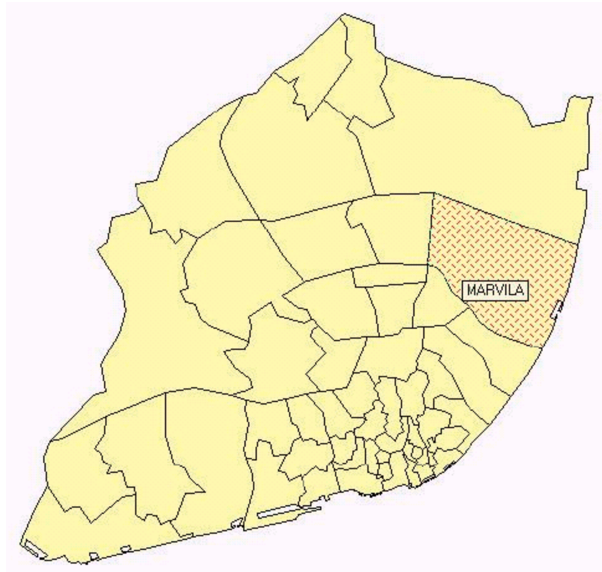


Figure 4.3. Map.

Lisboa_dados Browser

Freguesia	Area__km2_	Populaçã	dens_po	Rend_	Nenhum	_1_ciclo_%	_2_ciclo_%	_3_ciclo_%	Ens__Sec__%	En
AJUDA	2,92952	17.971	6.137	16.762	11,4	36,8	9,7	10,3	18,0	
ALCÂNTARA	4,39787	14.443	3.284	7.845	9,4	31,4	8,7	9,3	19,0	
ALTO DO PINA	0,824756	10.253	12.432	20.740	8,9	23,4	7,3	9,0	17,7	
ALVALADE	0,59159	9.620	16.261	21.282	6,1	18,8	6,2	8,0	19,4	
AMEIXOEIRA	1,59966	9.650	6.033	21.319	12,2	28,7	8,4	9,3	17,7	
ANJOS	0,489944	9.738	19.876	13.629	9,5	28,5	8,5	9,2	19,3	
BEATO	1,55886	14.241	9.136	8.560	10,7	33,7	9,8	9,8	19,3	
BENFICA	7,97973	51.368	6.437	15.571	7,0	21,1	6,3	7,6	15,0	
CAMPO GRANDE	2,45996	11.148	4.532	21.282	8,7	26,7	7,6	9,0	17,2	
CAMPOLIDE	2,74763	15.928	5.797	17.611	12,0	30,7	9,3	10,2	18,7	
CARNIDE	3,98295	21.097	5.297	21.722	13,7	27,2	8,7	8,7	14,2	
CASTELO	0,0541667	587	10.837	10.683	10,9	41,9	10,6	11,9	15,5	
CHARNECA	1,91792	10.509	5.479	21.319	17,9	36,1	12,9	12,6	17,2	
CORAÇÃO DE JESUS	0,557312	4.319	7.750	17.857	9,9	25,7	8,1	8,7	17,0	
ENCARNAÇÃO	0,182393	3.182	17.446	10.579	10,9	33,0	8,6	9,6	19,6	
GRAÇA	0,353406	6.960	19.694	10.683	10,4	32,6	9,8	11,2	18,1	
LAPA	0,741845	8.671	11.688	17.857	9,2	21,4	6,5	8,9	17,8	
LUMIAR	6,08861	35.585	5.845	21.319	9,7	17,6	6,6	7,4	15,8	
MADALENA	0,114019	380	3.333	10.579	7,6	25,8	6,1	11,3	28,4	
MARTIRES	0,0982405	341	3.471	10.579	8,5	27,3	8,5	6,5	17,3	
MARVILA	6,32381	38.766	6.130	24.647	15,3	34,5	11,4	11,7	19,4	
MERCES	0,272557	4.093	15.017	17.857	14,5	36,2	10,0	11,6	22,5	
NOSSA SENHORA DE FÁT	1,92769	15.291	7.932	21.282	8,2	20,3	6,8	7,7	17,2	
PENA	0,513767	6.068	11.811	10.579	13,2	31,2	9,4	9,0	17,9	
PENHA DE FRANCA	0,705468	13.722	19.451	10.683	10,3	30,2	8,9	9,8	19,7	
PRAZERES	1,55758	8.492	5.452	13.641	10,9	29,2	7,8	8,2	17,8	

Figure 4.4. Database.

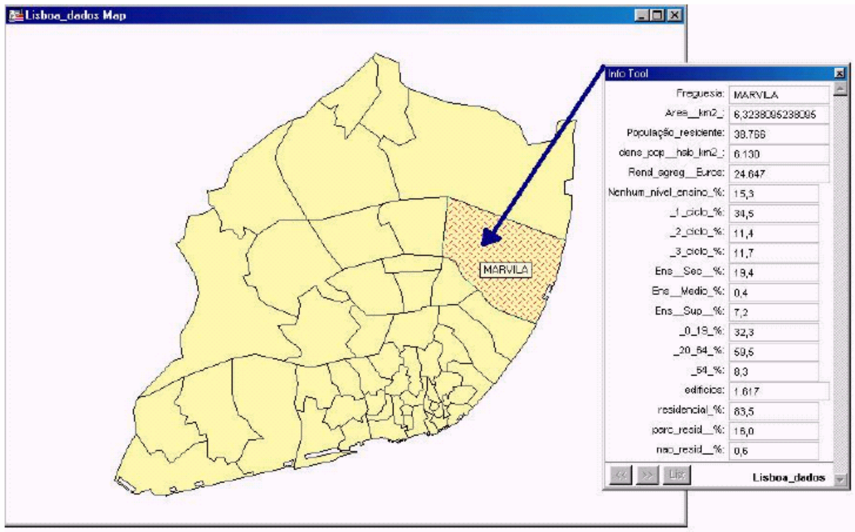


Figure 4.5: Database linked to map.

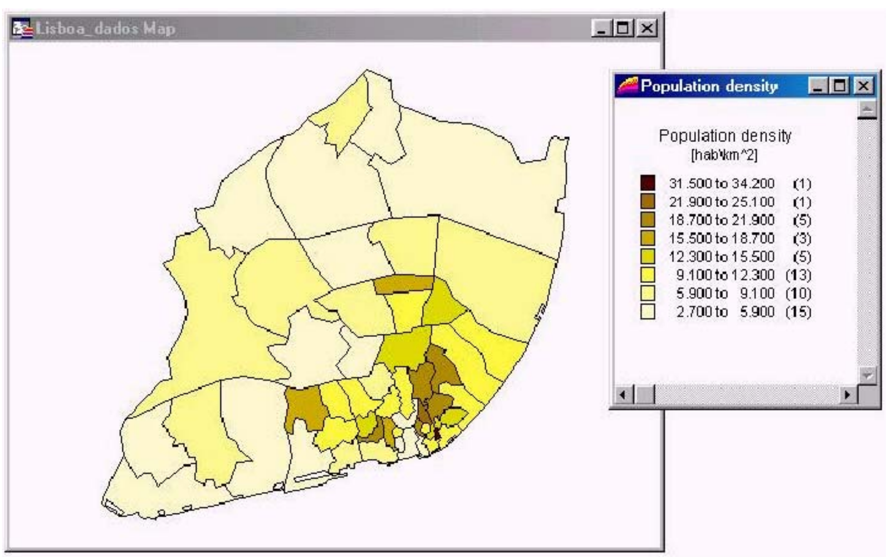


Figure 4.6. Thematic map.

4.2 Input Parameters

The simulator requires several inputs:

- Busy Hour Call Attempt (BHCA) grid
- Operational Environment
- Mobility profile
- User profile
- Call generation

- Call duration
- BS location and cell radius
- Maximum UL and DL loads per cell
- Maximum BS transmission power
- Number of simulation steps and step duration

All these inputs are described below in more detail.

BHCA grid

BHCA is the parameter chosen to characterise the usage of the system and it is defined as the average number of calls that a user attempts to perform in the busy hour. An approach for the creation of the BHCA grid was defined under the scope of the IST-MOMENTUM project and is described in detail in [FCSC02]. Underlying the generation process of the BHCA grids was the need to define a broad set of services and environments that would reflect the UMTS usage diversity. To better characterise the diversity of service usage patterns that UMTS can bear, three types of users are considered, as presented in Table 4.1. This customer segmentation is extracted from the ACTS-TERA project [CSYK99].

Customer segment (user type)	**Description**	**Characteristic**
Business/corporate	With intensive and almost entirely professional use, primarily during office hours.	Early adopters
Residential/Small Office-Home Office (SOHO)	With both professional and private use, during the day and in the evening.	Followers
Mass-market	With low use, staying within flat traffic levels.	Mass-market

Table 4.1. Customer segmentation.

Users of each customer segment are spread differently over the operational environment, according to their characteristics. Each customer segment has also a specific profile: having available the set of services identified further on in this chapter, each user generates new calls of each service according to a service set usage table, specific for each customer segment. In this way, the scenario can be dimensioned in order to have, for example in the Central Business District (CBD) a higher percentage of business users than mass-market users, and the opposite in a rural area. Business users largely using video-telephony and E-mail services, contrasting with mass-market users mainly making speech-telephony calls and sending SMS.

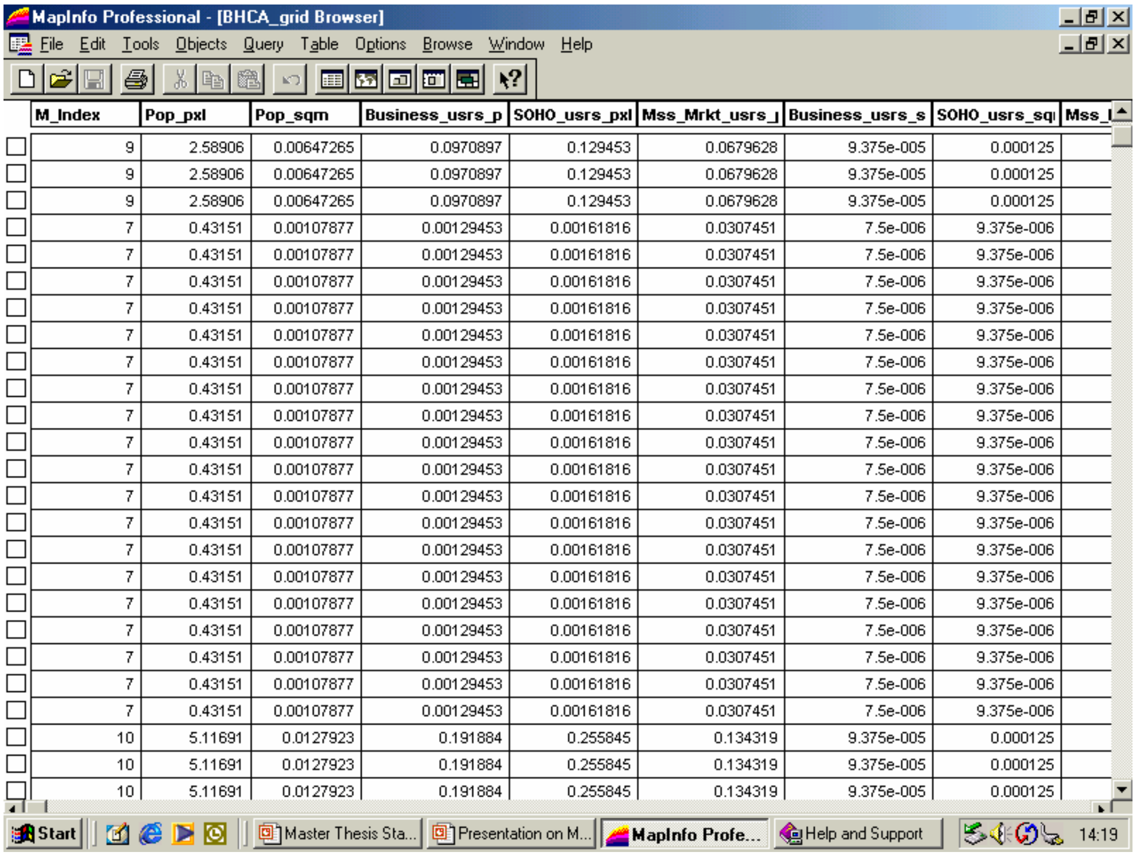
Enough "screws" are available to create a rich traffic forecast that can be adapted to a desired reality. The first element needed to build a traffic forecast is an operational environment. A set of operational environment classes is proposed in [FCSC02]. By identifying regions with similar characteristics in terms of land use (urban area, sea, highway, etc.), this characterisation, which is intended to be as realistic as possible, tries to cope with the main characteristics of the scenario. Based on land use and vector data given by operators for each city, a mapping is done into the IST-MOMENTUM classes, obtaining in this way a characterised operational environment of each city. The operational environment is closely related with the users spatial distribution as well as the different mobility patterns. The operation environment classification for the city of Lisbon was obtained from the mapping done by the network operators Vodafone-Telecel, E-Plus and KPN under the scope of the IST-MOMENTUM project and is described in detail in [FCSC02].

The differentiation of population into three customer segments will imply the need of three spatial distributions of UMTS subscribers (users), one per customer segment. A customer segment share table is defined per operational environment class; this gives a spatial distribution of customer segments share according to each class (e.g., in a CBD area, 80% of the population are business persons, 10% SOHO persons and 10% mass-market persons). Combining this with a spatial distribution of population during the day results in three spatial distributions of population, one per customer segment. Applying a UMTS penetration table per customer segment to these distributions results finally in the three desired spatial distributions of UMTS subscribers. The customer segment share table used in this thesis was the one defined in the IST-MOMENTUM project. The generation of the spatial distribution of population is described in [FCSC02].

On the other hand, three user profiles need to be characterised, one for each customer segment. Three service set usage tables are built, based on marketing data. The used parameter to characterise the usage is the BHCA, which indicates the average number of calls that a user attempts to perform in the busy hour. These are service set BHCA tables.

The combination of the spatial distributions of subscribers with the BHCA tables, results in traffic forecasts for the services usage, per customer segment. These are expressed in terms of

BHCA grids, where for each unit of area (pixel), the average number of calls in the busy hour is specified, per user type and per service. Figure 4.7 shows a snapshot from the MapInfo application showing part of the BHCA table.



M_Index	Pop_pxl	Pop_sqm	Business_usrs_p	SOHO_usrs_pxl	Mss_Mrkt_usrs_	Business_usrs_s	SOHO_usrs_sq	Mss_
9	2.58906	0.00647265	0.0970897	0.129453	0.0679628	9.375e-005	0.000125	
9	2.58906	0.00647265	0.0970897	0.129453	0.0679628	9.375e-005	0.000125	
9	2.58906	0.00647265	0.0970897	0.129453	0.0679628	9.375e-005	0.000125	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
7	0.43151	0.00107877	0.00129453	0.00161816	0.0307451	7.5e-006	9.375e-006	
10	5.11691	0.0127923	0.191884	0.255845	0.134319	9.375e-005	0.000125	
10	5.11691	0.0127923	0.191884	0.255845	0.134319	9.375e-005	0.000125	
10	5.11691	0.0127923	0.191884	0.255845	0.134319	9.375e-005	0.000125	

Figure 4.7. Busy hour call attempt (BHCA) table.

Each table row characterises one pixel of the traffic grid. The first column represents the operational environment while columns 10 to 36 represent the BHCA value per service and per segment.

Figure 4.8 shows a graphical representation of the BHCA for Speech (business segment) for the city of Lisbon.

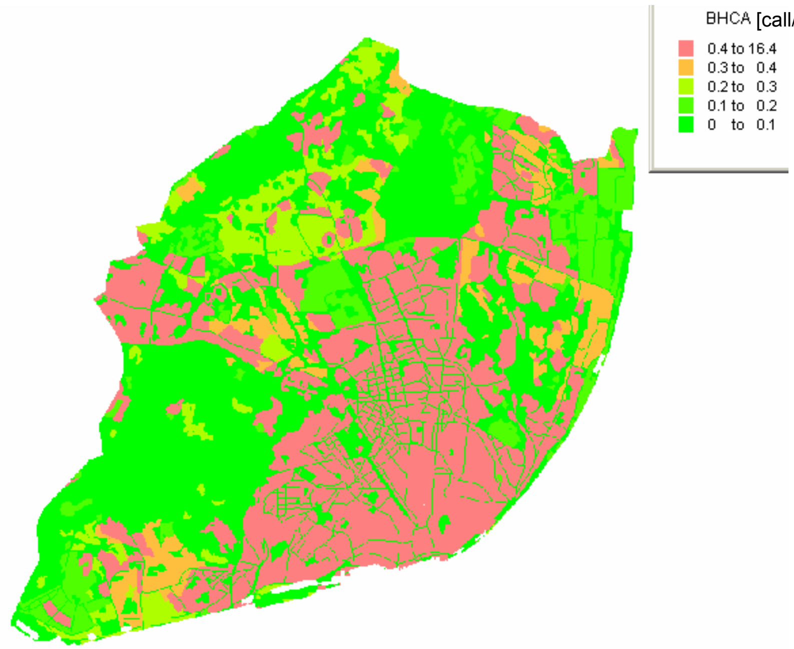


Figure 4.8. Graphical representation of the BHCA table.

Operational Environment

To build traffic or mobility scenarios for a certain city, the identification of the different existing operational environment classes is essential. This characterisation, which is intended to be as realistic as possible, has to translate the diversity of the scenario, identifying regions with similar characteristics in terms of land use (distinguishing, e.g., a highway from an urban area and the sea). A set of classes to characterise the operational environment is proposed by IST-MOMENTUM in Table 4.2.

E-Plus [Eplu02], KPN [KPN02] and Vodafone-Telecel [Tlcl02] IST-MOMENTUM operator partners have provided, for a group of cities under study, a large set of data for the construction of reference scenarios. For the specification of an operational environment, useful data is available:

- Raster land use data: a pixel grid (of a certain resolution, e.g., 20×20 m^2 for Lisbon) with information of the land use class (water, dense block buildings, open areas, etc.) of each pixel;
- Vector data: with information of streets (highways, main roads and streets), railways, and coastlines configurations.

Each operator has a specific classification of its raster and vector data, as presented in Deliverable D4.1 of the IST-MOMENTUM project [KCCL02]. A mapping is made of the specific raster and vector classes onto the operational environment classes. This allows the construction, for each city, of an operational environment grid.

Class	**Description**
Water	Sea, inland water (lakes, rivers).
Railway	Railway
Highway	Highway
Highway with traffic jam	Traffic jam in a highway, corresponding to a lot of cars stopped, or moving at a very low speed.
Main road	Main road of relatively high-speed users, typically inserted in suburban and rural areas.
Street	Street of low-speed users, typically inserted in an urban area.
Rural	Area with a low building density, and with a high vegetation density.
Sub-urban	Area with medium building and vegetation densities.
Open	Small pedestrian land area (square, open area, park, large pedestrian areas along streets) surrounded by mean urban, dense urban, or residential.
Urban	Area with high building density and with low vegetation density
Central Business District (CBD)	Area with very high building density, and very high buildings, with almost no vegetation.

Table 4.2. MOMENTUM operational environment classes.

By associating specific characteristics to each operational environment class, it is possible to create rich and realistic scenarios, such as:

- Segmented population scenario, with specific population segmentation associated to each operational environment class (e.g., in an urban area a higher percentage of business users than in a residential);
- Mobility scenario, with specific mobility types associated to each operational environment class (e.g., 100% fast vehicular users in a highway);
- Refined population density scenario: when spreading population over the scenario (considering that one has large areas – districts – with constant population density), weights are introduced to each operational environment in order to have population distributed in a more refined way (e.g., more people in a building area than in a park).

Figure 4.9 shows a graphical representation of the several operational environments defined for the city of Lisbon [FCSC02].

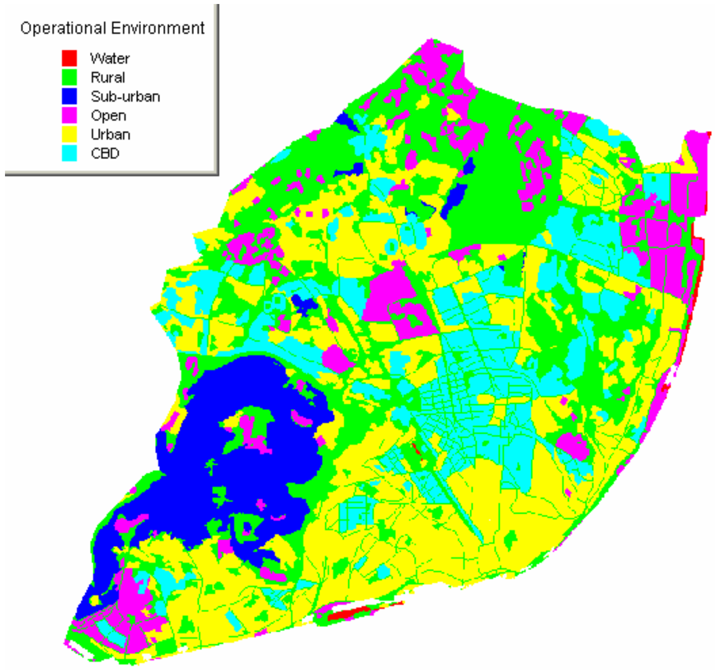


Figure 4.9. Graphical representation of the operational environments.

Mobility Profile

As mentioned in previous sections, user mobility is one of the aspects to be evaluated with this simulation. In Chapter 3, several types of mobility models were described; for the simulator, it was decided to use the triangular model [ChLu95] for the characterisation of user velocity. This model considers a triangular distribution for the velocity of a user, with a defined average and variance for each mobility scenario as can be seen in Figure 3.1.

To evaluate the impact of mobility on the system's performance, seven types of mobility profiles were defined, as already described in Chapter 3. The list below summarises these profiles:

- Static
- Pedestrian
- Street/Vehicular
- Main Road/Vehicular
- Highway/Vehicular
- Highway Traffic Jam/Vehicular

- Railway/Vehicular

Since user mobility is dependent on the environment, a table was created to relate user mobility with the operational environment. When the user is generated, mobility is assigned based on the operational environment at the current user location; the probability of each mobility type varies according to the operational environment. The correlation between these two factors is shown in Chapter 5. For each mobility type, a specific average speed and variance is assigned.

In terms of direction, the user is only allowed to move in 4 possible orthogonal directions [Corr01]: straight, left, right and backwards. An example of this approach is shown in Figure 4.10. The probability to change direction depends on the mobility type of the user, since a pedestrian is much more likely to change its direction than a vehicle on a highway.

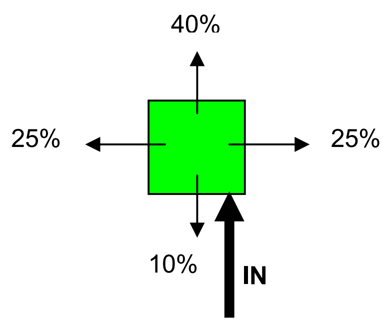


Figure 4.10. Graphical representation of the probability to change direction.

User profile

UMTS offers the technical possibility to provide a broad set of services and applications with different characteristics and target users. Each of these services will have a different impact on system's performance.

The service set considered for the simulation was the one defined for the IST-MOMENTUM project [FCSC02]. The following nine services/applications are proposed for simulation, classified according to the 3GPP service classes:

- Conversational class:
  - Speech-telephony: Traditional speech-telephony.
  - Video-telephony: Communication for the transfer of voice and video between two locations.

- Streaming class:
    - Streaming Multimedia/Information distribution: Service that allows the visualisation of multimedia documents on a streaming basis, e.g., video, music, or slide show.
- Interactive class:
    - Multimedia Communication Service/Web Browsing: Interactive exchange of data between a user and a web server. It allows the access to web pages. This information may contain text, extensive graphics, video and audio sequences.
    - Location Based Service: Interactive service that enables users to find location-based information, such as the location of the nearest gas stations, hotels, restaurants, and so on.
- Background class:
    - Messaging/SMS: Messaging service that transfers small amounts of text (several hundred characters).
    - Messaging/MMS: Messaging service that allows the transfer of text, image and video.
    - Messaging/E-mail: Process of sending messages in electronic form. These messages are usually in text form. However, they can also include images and video clips.
    - Unrestricted Data Retrieval Service/File Download: Download of a file from a database.

Several considerations have been taken into account for the choice of this set of services:

- These are among the most popular foreseen UMTS services;
- The four 3GPP service classes are represented by their most important services;
- These services have very different traffic patterns, being also very diverse in terms of traffic volume and average bit rate.

Call generation

The call generation uses a Poisson random process to define how many calls are created in each program iteration. This generation process takes the average number of generated calls as an input. This average comes from the BHCA grid.

Call duration

The call duration uses an Exponential random process to define the duration of each generated call. This process takes as input the average call duration. The call duration can be defined both in time (CS services) or volume (PS services). The average values come from [FCSC02].

BS location and cell radius

The simulator requires the location of the BS position (latitude and longitude) in order to plot the seven cells where it will perform calculations. To simplify the simulation, only seven cells are considered: one central hexagonal shaped cell and the six adjacent cells of the 1st ring. This approach, shown in Figure 4.11, was chosen since it allows analysing the data computed for the centre cell, with all the boundaries covered by the other six cells of the 1st ring.

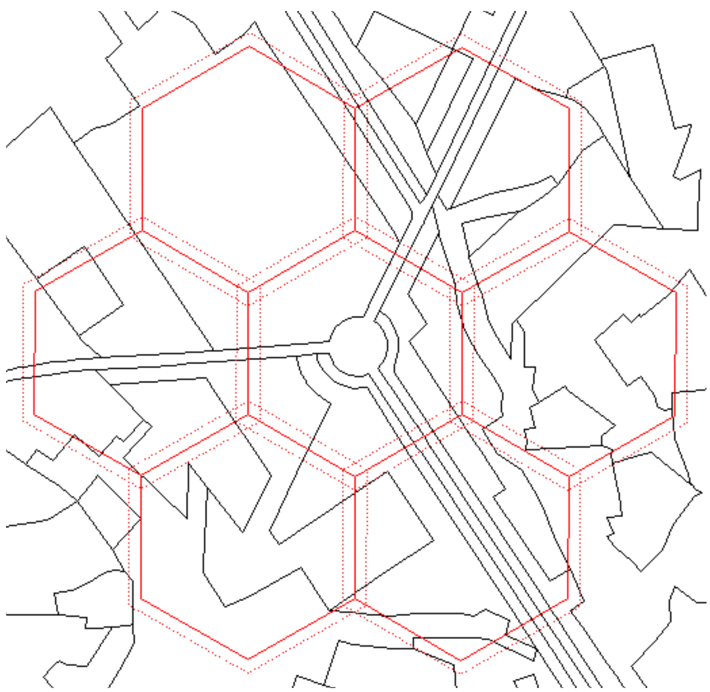


Figure 4.11. Graphical representation of the 7 cells in Lisbon ("Marquês de Pombal").

The corresponding cell radius is also an input to the program. All the cells are drawn with the same radius. The program also draws an additional hexagon (plotted with red dashed line) that represents the cell soft handover region. The relation between these two radiuses is also given as an input. All the calculations performed by the simulator assume the hexagon as the boundary to split the users per cell. In case the user is between two dashed lines, the program assumes that he is doing soft-handover, therefore, being connected to two BSs.

Maximum UL and DL loads and BS transmission power

The maximum cell load (UL and DL) and the BS transmission power are taken in consideration every time a new user is generated, to check if there is available capacity for the new call. The capacity is evaluated in terms of UL load, DL load and BS transmission power for each cell, and these values are compared to the limits defined. If the limits are reached, the simulator then takes appropriate action by blocking the call (CS) or lowering the service bit rate (PS).

The propagation model chosen in order to evaluate the path loss when calculating the BS transmission power was the model from COST 231 (Walfisch-Ikegami) [DaCo99], since it is appropriate for urban environments. The model parameters used are listed in Table 4.3.

Base Station Height (h_{BS}) [m]	30
Building Height (h_b) [m]	24
k_a (model factor)	54
k_d (model factor)	18
Frequency (f) [MHz]	2000
Block width (w_b) [m]	60
Angle between streets (ϕ) [º]	90
Mobile height (h_m) [m]	2
Street width (w_s) [m]	30

Table 4.3. Propagation model parameters.

Number of simulation steps and step duration

The simulation time step defines the time interval between each iteration of the simulator. The number of simulation steps defines the length of the simulation.

4.3 Description of the Simulator

4.3.1 General structure

In order to model an UMTS system using the available data for traffic and mobility described in the previous chapter, a program was built using MapBasic (Visual Basic adapted specifically to the MapInfo application). This language was chosen because it runs directly on top of the MapInfo application, making it easier to use the available data in MapInfo format (e.g., BHCA grid, Lisbon map) and also because it includes many built in graphical functions that simplify significantly the code of the simulator (e.g., cell plot, user query).

The program is divided in 5 main procedures, listed below:

- Create Tables
- Generate Users
- Update Users
- Calculate Parameters
- Load Control

A graphical representation of the program flow is shown in Figure 4.12.

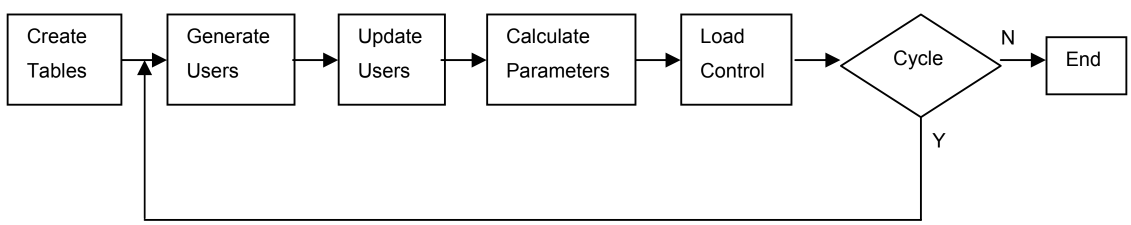


Figure 4.12. Graphical representation of the simulator flow.

4.3.2 Create Tables

The procedure Create Tables is responsible for creating and opening all the tables required to run the simulation. It is also responsible for all the actions that are made only once during the entire simulation (e.g., plotting the 7 cells). This happens since "Create Tables" is the only procedure out of the program main cycle; all the other procedures are repeated at every simulation step. Figure 4.13 represents the flow of the procedure Create Tables.

The tables that are opened are the ones that contain information that is not updated during the simulation. These tables are listed below.

- ZONAS_Lisboa: this table contains the graphical data necessary to plot a map of Lisbon representing the street structure and the city main areas. It is only opened by the program to provide the user of the application with a graphical background that helps to visualise the location of the 7 cell cluster that is being evaluated, Figure 4.14;

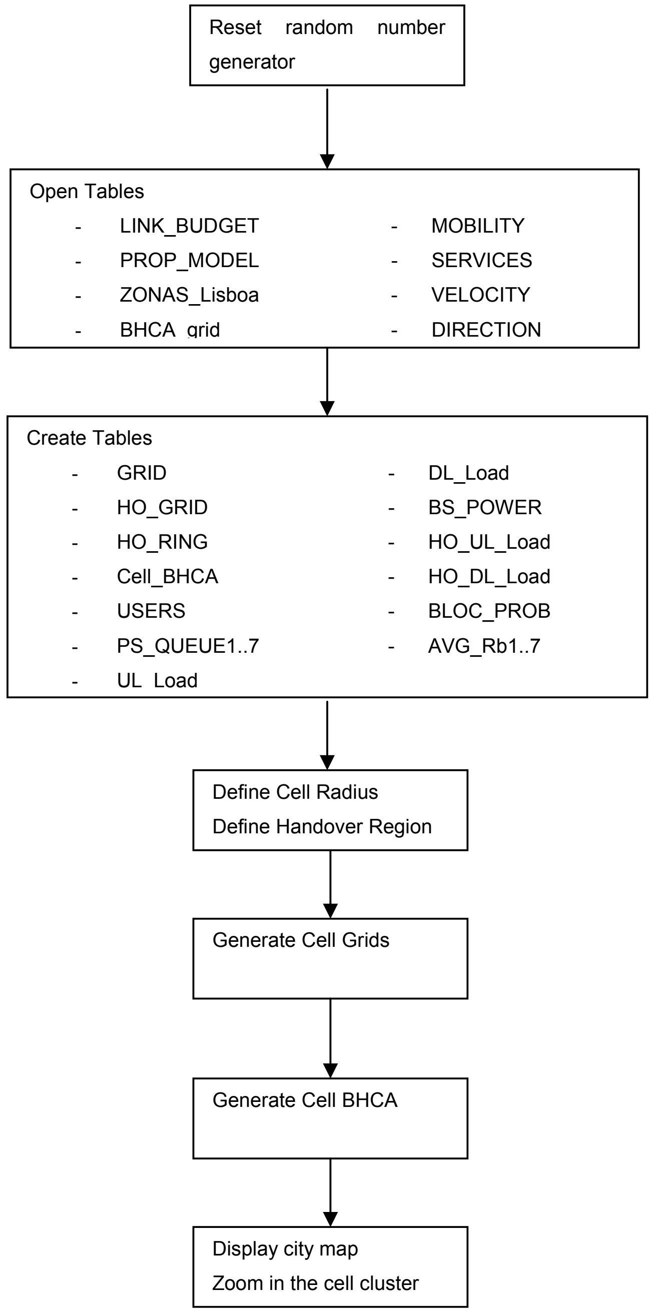


Figure 4.13. Flow of the procedure Create Tables.

- BHCA_grid: this table contains all Busy Hour Call Attempt values for every pixel in the city of Lisbon, which has a resolution of 20×20 m^2. Each row of the table represents one pixel; the several columns have all the BHCA information split per service and per segment (Business, SOHO and Residential). The table also characterises the pixel in terms of Operational Environment;

Figure 4.14. Table "ZONAS_Lisboa": Lisbon map.

- MOBILITY: this table relates operational environment with user mobility, giving specified probabilities for each mobility type depending on the operational environment of the pixel where the user is being generated;
- SERVICES: this table characterises the 9 services defined by IST-MOMENTUM in terms of UL and DL bit rates and in terms of E_bN_o. E_bN_o is defined for 3 types of mobility (indoor, pedestrian and vehicular);
- VELOCITY: this table assigns an average velocity and variance (plus and minus) for each type of user mobility (of the seven defined);
- DIRECTION: this table specifies for each type of mobility a defined probability for a user to move straight, to turn left or right or to move backwards.

The tables created are the ones that store information that is constantly updated during each simulation. These tables are listed below.

- GRID: used to store the map of the 7 cell cluster (one row for each cell);
- HO_GRID: used to store the map of the 7 cell cluster including the handover region (one row for each region);
- HO_RING: this table has one row for each of the 7 handover "rings" around each cell. It is used to determine the users from one specific cell that are currently under soft handover;

- Cell_BHCA: this table extracts from the table BHCA_grid only the information necessary for the simulation, i.e., stores only the pixels inside the 7 cell cluster (neglecting all the remaining pixels for the whole Lisbon area) and also combines the BHCA values for the 3 segments (business, SOHO and mass market) since the simulator does not take this factor into account;
- USERS: the most important table of the simulation, it contains all the information regarding the active users; it is a dynamic table, since every time a user is generated a new row is created in the table and a row is deleted when the user finishes its call. Each user is characterised in terms of position (longitude, latitude), service being used (CS or PS), respective duration (time or data volume), UL and DL bit rate;
- PS_QUEUE: table that stores information regarding the queue of users waiting to use a PS service within the system. Every time a PS user is generated and the system has no available resources, the user enters the respective cell queue waiting for its turn;
- UL_Load: stores for each simulation step the UL load values for each of the seven cells;
- DL_Load: stores for each simulation step the DL load values for each of the seven cells;
- BS_POWER: stores for each simulation step the BS transmission power for each of the seven cells;
- HO_UL_Load: stores for each simulation step the handover UL load values for each of the seven cells;
- HO_DL_Load: stores for each simulation step the handover DL load values for each of the seven cells;
- BLOC_PROB: stores for each simulation step the blocking probability percentage for each of the seven cells;
- AVG_Rb: one table is created for each cell; each of these tables stores, for each simulation step, the average bit rate values for each of the seven PS services.

Actions executed only once during each simulation include:

- Resetting the random number generator;
- Definition of propagation radius and cell radius (cell radius defines the cell boundaries, while propagation radius defines the cell soft handover region);
- Reset the blocked calls and generated CS calls counters;

- Grid generation (plots the 7 cell grid based on the defined radius and stores it in the table GRID);
- Handover grid generation (plots the handover boundaries for each cell and stores it in the table HO_GRID);
- Handover region generation (creates an handover ring around each cell to define the region where the users are doing handover and stores it in the table HO_RING);
- Extract relevant data from traffic grid (this routine extracts from the table BHCA_grid only the pixels traffic values that refer to the cell cluster being evaluated and combines the traffic values of the 3 segments, business, SOHO and mass market);
- Display Lisbon map, zooming on the area of the cell cluster.

The next four procedures are inside the program main cycle and are executed every simulation step. The maximum number of steps and the step duration are defined constants of the simulation.

4.3.3 Generate Users

The procedure Generate Users is responsible for creating new users based on a random Poisson process. This procedure takes in consideration the location of the cells and the average BHCA for the cell coverage area.

The routine starts by selecting the first cell of the grid, Figure 4.15. Then for each of the nine services defined in IST-MOMENTUM, the procedure runs a Poisson process to determine how many calls of that particular service will be generated during this simulation cycle (based on the average values contained in the table Cell_BHCA).

After the number of calls is determined, the routine runs a cycle to generate the calls. The calls are generated only if the conditions regarding the maximum UL and DL load and BS power are met. If this is the case, the program runs a random generator to determine the user coordinates inside the cell. Afterwards, user operational environmental is defined based on its position. User mobility is then assigned considering the operational environment.

In case of a CS call, a duration is generated using an exponential process applied to the average value defined in the table SERVICES and all the user data is inserted in the table USERS. The counter for generated CS calls is incremented. In case of a PS call, the respective UL and DL are determined based on the values defined in the table SERVICES.

The volume of DL data to be transferred is determined by running an exponential process over the average value found in the table SERVICES. All these properties are stored in the table USERS.

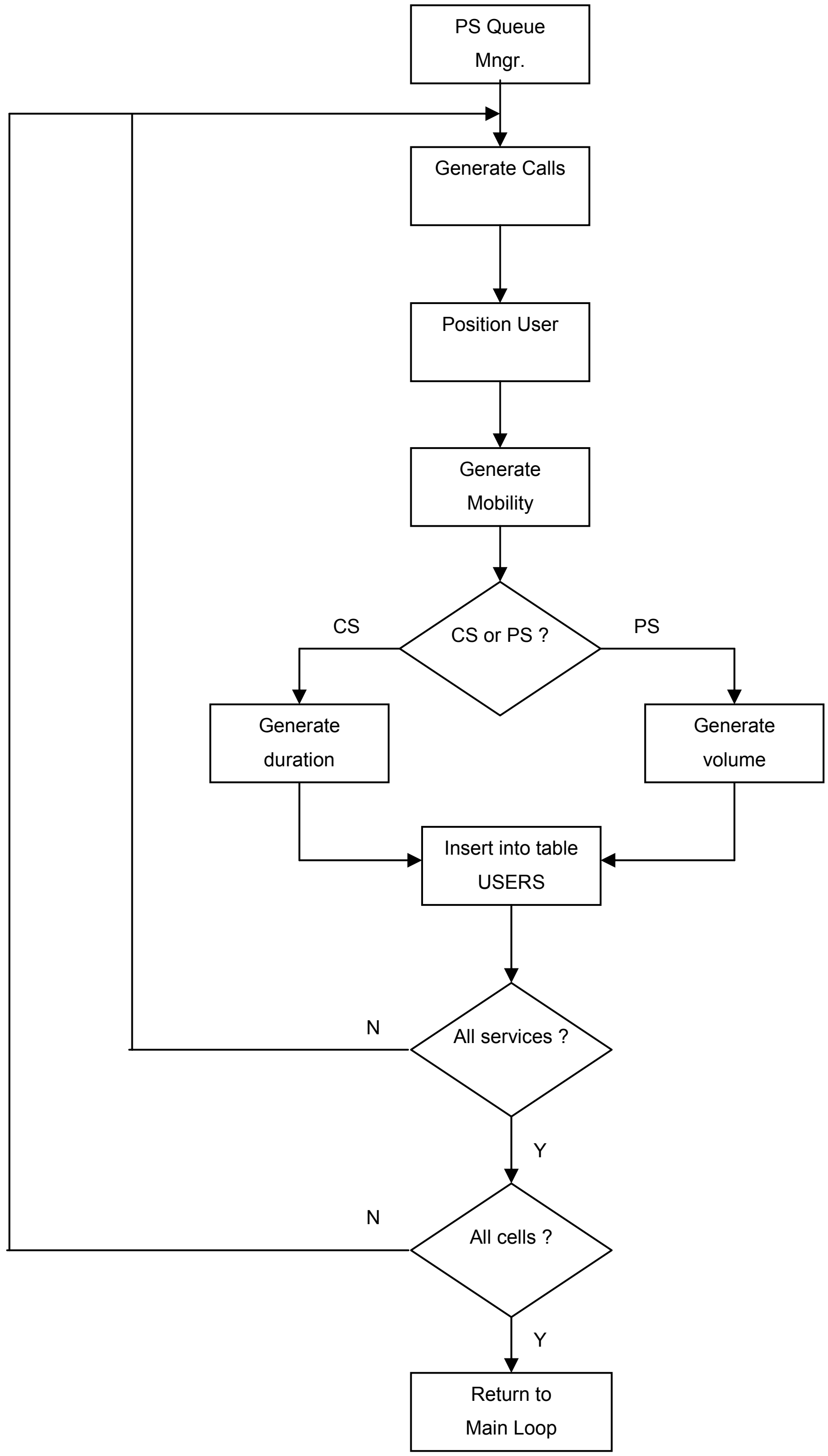


Figure 4.15. Generate Users – Program Flow.

If the call cannot be accepted the following two situations can occur:

- In case of a CS call, the blocked calls counter is incremented;
- In case of a PS call, the call is put in a queue and will wait for the cell load to decrease in order to become "live".

The cycle will run until all generated calls are processed, within the 9 possible services and through the whole cell cluster.

4.3.4 Update Users

The procedure Update_Users modifies at each simulation step, the parameters of the current "live" users in terms of position, direction and duration/transferred data.

The procedure starts with the first user of the table USERS (the oldest of the list of active users), as shown in Figure 4.16.

First, it updates the current position based on the last position and the current velocity and direction assigned. Then, the current direction is updated based on a uniform random generator and on the probabilities to change direction (different for every mobility type).

In case of a CS user, the respective call timer is decreased based on the defined time step. If the timer reaches zero the user is deleted from the table. If not, user information is updated in the table.

In case of a PS user, the respective counter for the transferred data is decreased based on the time step and current bit rate of the service being used. The counter for the number of steps elapsed for that user is increased in order to calculate the average bit rate. If the data transferred equals the total data for that call, the user is deleted from the table. If not, user information is updated.

These actions are performed for every user entry in the table.

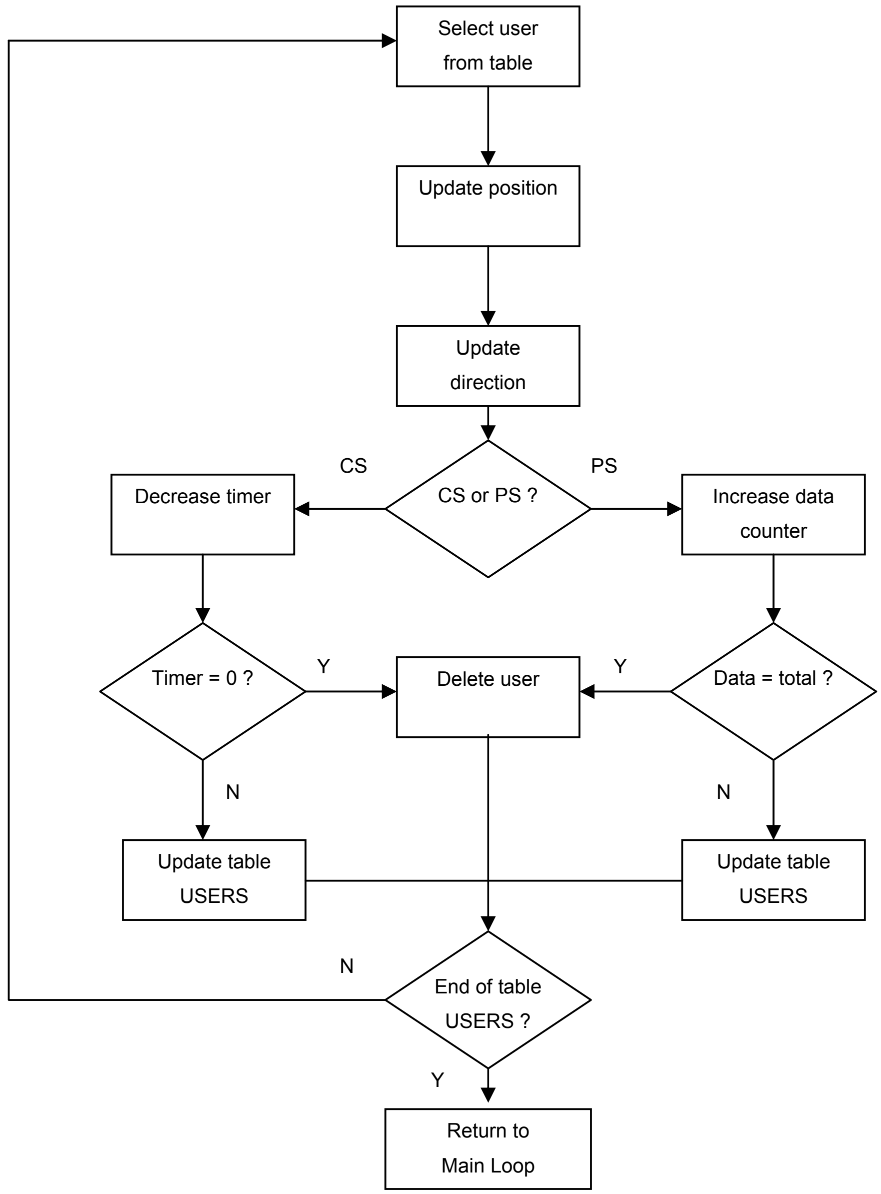


Figure 4.16. Update Users – Program Flow.

4.3.5 Calculate Parameters

Calculate_Parameters evaluates cell parameters such as UL and DL load, blocking probability and average bit rate.

The procedure starts by selecting the first cell being evaluated, Figure 4.17.

The first parameter to be calculated is the UL load. This load is computed by selecting all the users inside the cell (including handover region). Then the contribution to the load from every user is taken into account based on type of service (CS or PS), E_bN_o (function of service and mobility) and the corresponding bit rate. The load is then calculated using (3.5).

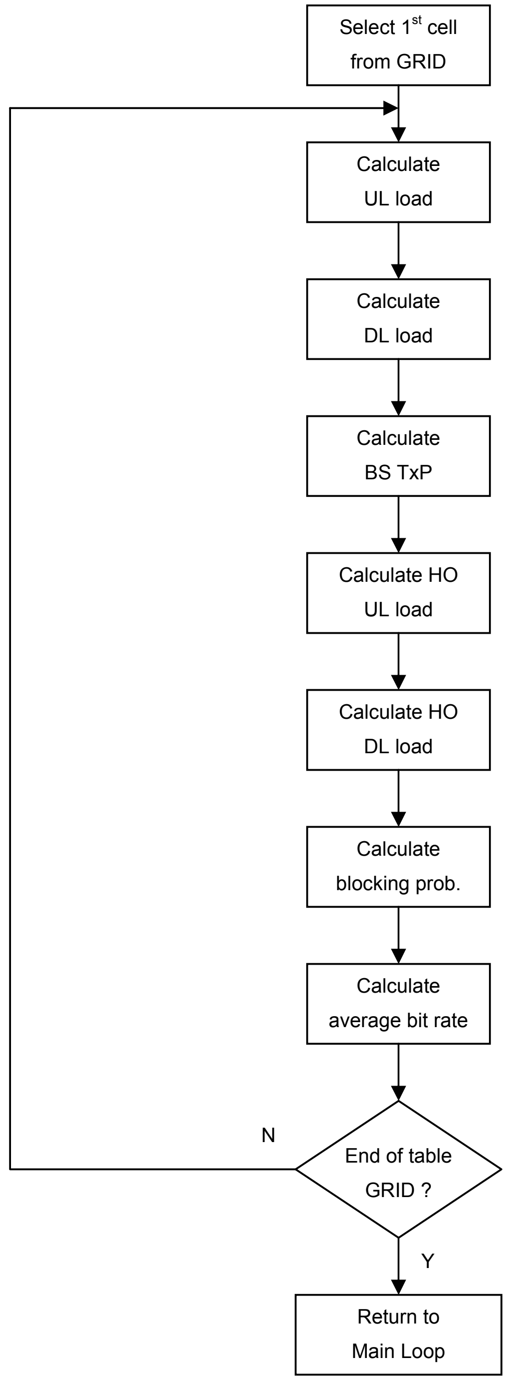


Figure 4.17. Calculate Parameters – Program Flow.

The same is accomplished for computing the DL load and BS transmission power, but now using (3.8) and (3.9) respectively. The handover load is computed using the same method but by only selecting the users inside the handover regions that were defined in the procedure Create Tables (stored in the table HO_RING).

The blocking probability is calculated by dividing the blocked calls counter by the generated CS calls counter.

To calculate the average bit rate per service the following steps are followed:

- The users of the cell are grouped by service and the total transferred data and simulation steps per service is calculated;
- The routine then divides the total transferred data by the total number of simulation steps taken;
- Average bit rate is then finally computed by dividing the previous result by the time step of the simulation.

The procedure then changes to the next cell in the cluster till all the seven cells are evaluated.

4.3.6 Load Control

Finally, the procedure Load_Control takes care of checking current cell load and lowering user bit rates if the load limits are exceeded.

It starts by first selecting the first cell of the cluster, Figure 4.18. For this cell, the routine checks if the maximum allowed load has been reached (UL or DL, depending of which has been defined as a limit for the simulation). If it has, the most recent active PS user is selected and the respective UL and DL bit rate are decreased one step (available bit rates are 384, 144, 64, 32, 16 and 8 kbps). After this step is taken, the load is recalculated and it iterates until the load is within the defined limits.

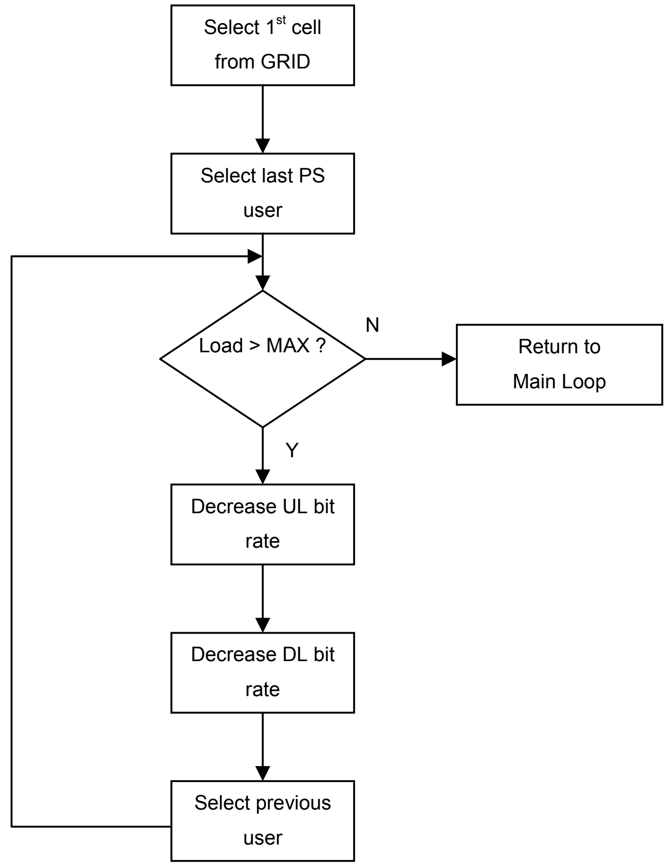


Figure 4.18. Load Control – Program Flow.

4.4 Results

In terms of outputs, the simulator calculates the following:

- UL load per cell
- DL load per cell
- BS transmission power per cell
- Handover UL load per cell
- Handover DL load per cell
- Blocking probability per cell
- Average bit rate per service for the central cell

UL load, DL load and BS transmission power are calculated in order to evaluate the system performance in terms of capacity. The handover loads (both UL and DL) are computed to check the impact of user mobility in the cell load (due to soft handover). The calculation of the Blocking Probability and Average Bit Rate serve as QoS indices for CS and PS services, respectively.

Each of these values is recorded in every step of the simulation and for the seven cells (except average bit rate, which is only calculated for the central cell).

The UL load is calculated using (3.5). Figure 4.19 shows an example of the UL load variation during a simulation, for the seven cell cluster. The duration of the simulation is 1 hour and the time step is 5 seconds.

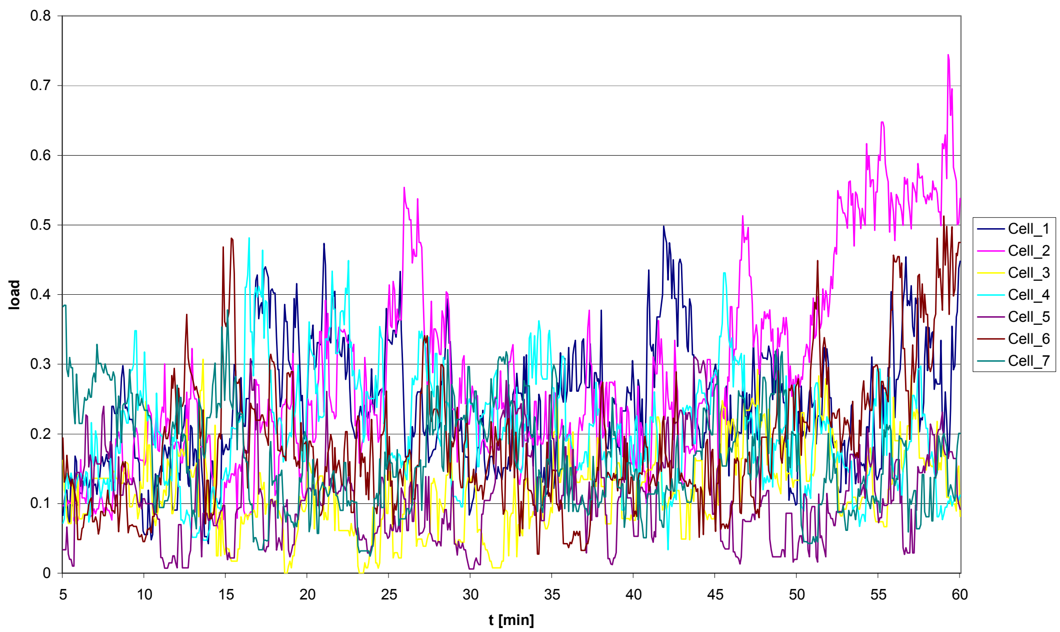


Figure 4.19. UL load variation.

The DL load is calculated using a similar approach to the UL, but with different parameters, using (3.8). Figure 4.20 shows an example of the DL load variation during a simulation, for the seven cell cluster. The duration of the simulation is 1 hour and the time step is 5 seconds.

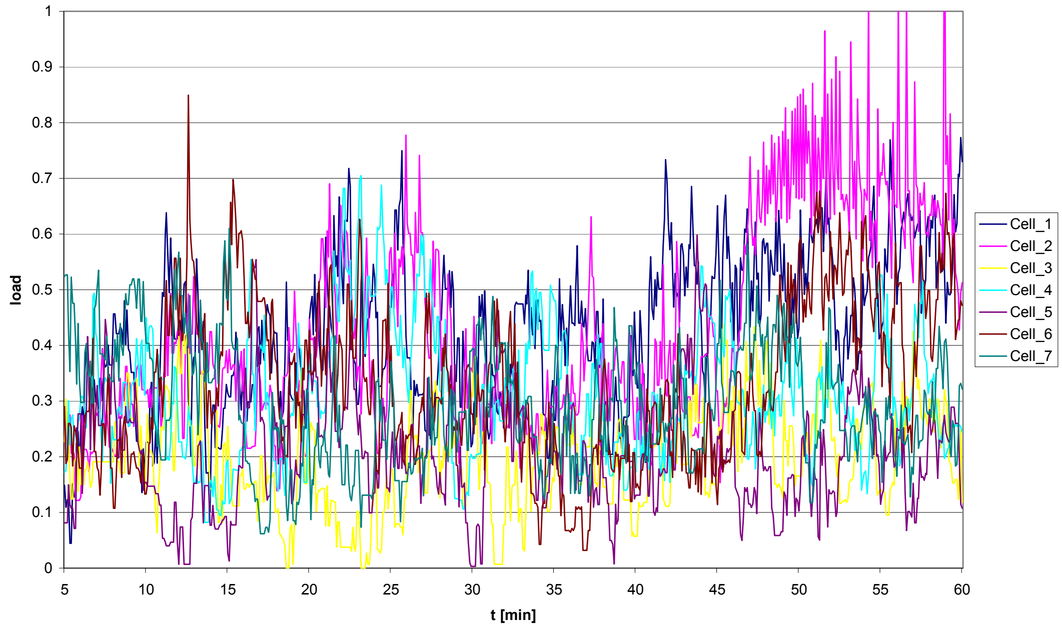


Figure 4.20. DL load variation.

BS transmission power is calculated using (3.9). In order to compute it, the program needs to calculate the propagation loss between the BS and the MT for every user in the cell.

Figure 4.21 shows an example of the BS transmission power variation during a simulation, for the seven cell cluster.

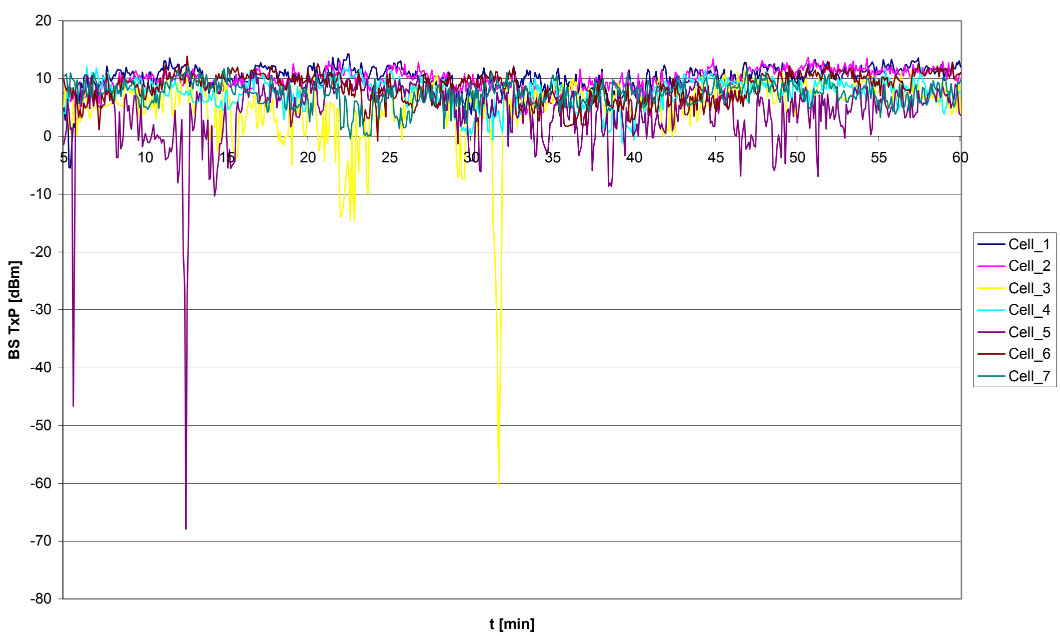


Figure 4.21. BS transmission power variation.

The handover UL load, Figure 4.22, is calculated using the same equation as the UL load, but with the difference that it only considers the users contained inside the handover region around each cell.

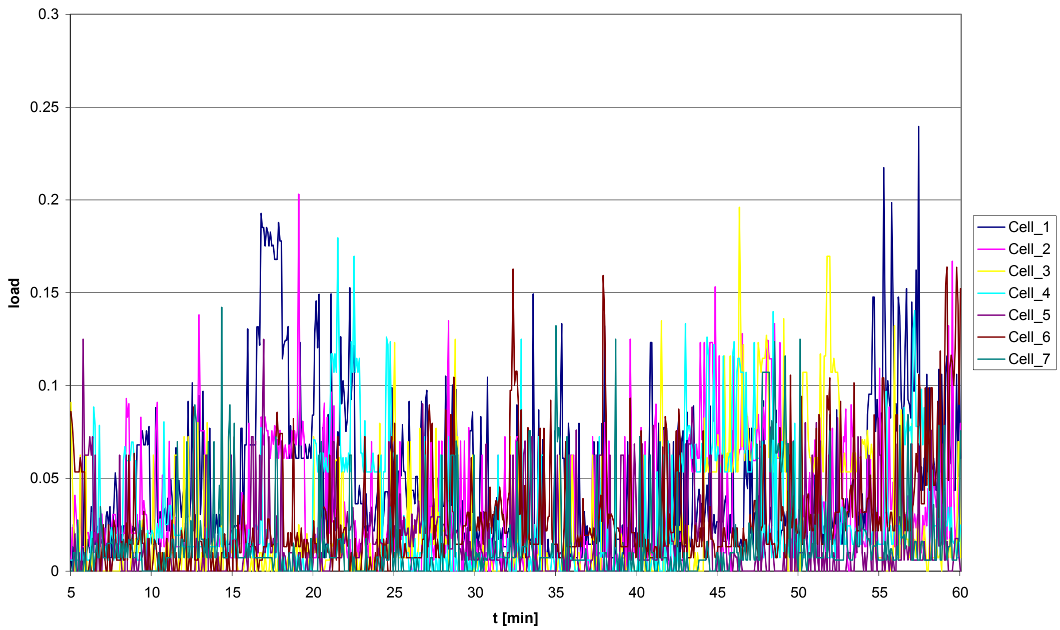


Figure 4.22. Handover UL load variation.

The handover DL load, Figure 4.23, is calculated using the same equation as the DL load, but with the difference that it only considers the users contained inside the handover region around each cell.

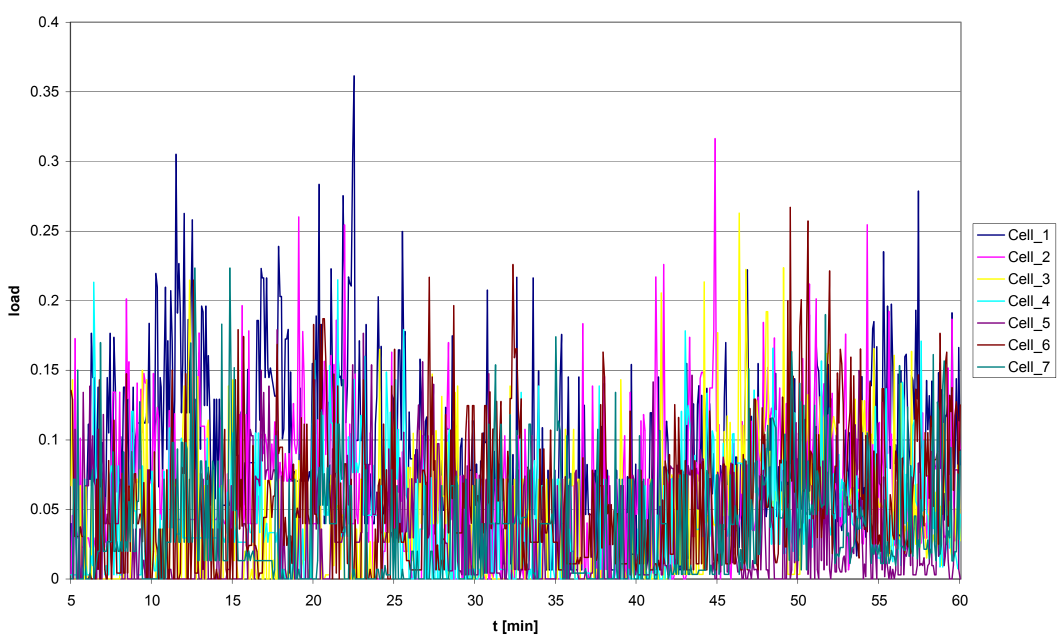


Figure 4.23. Handover DL load variation.

The blocking probability, Figure 4.24, is calculated using two counters: the number of rejected CS calls, and the number of generated CS calls. These counters are updated for each cell and at every time step. The ratio of these two gives the blocking probability as illustrated in (3.11).

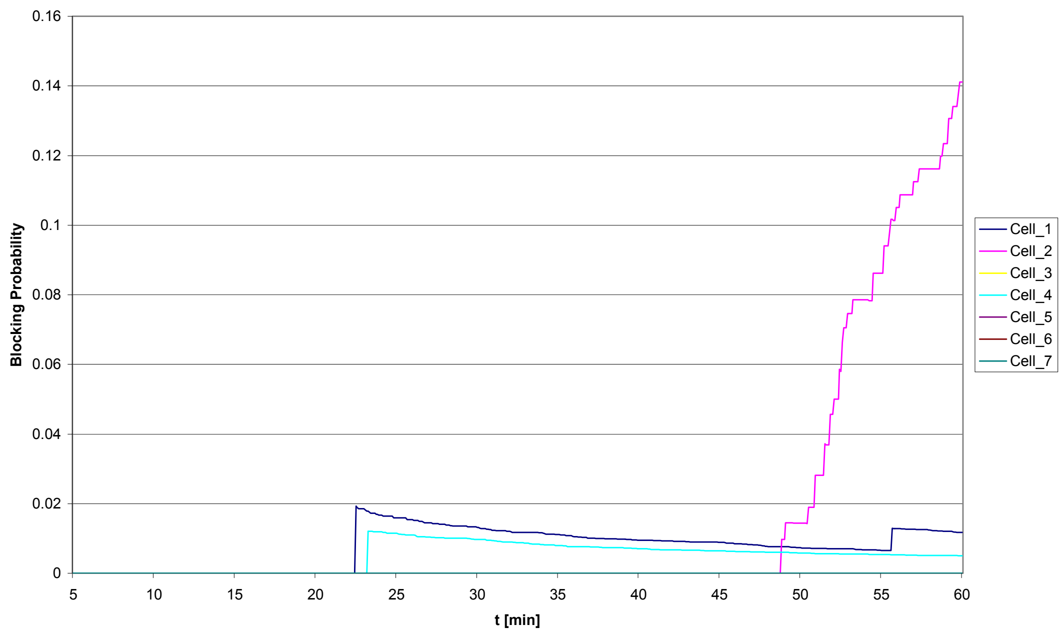


Figure 4.24. Blocking probability variation.

The average bit rate is only calculated for the central cell. This parameter is calculated for all the seven PS services and the respective values are updated at every time step. To calculate it the following sequence is followed:

- The users of the cell are grouped by service and the total transferred data and simulation steps per service is calculated
- The routine then divides the total transferred data by the total number of simulation steps taken
- Average bit rate is then finally computed by dividing the previous result by the time step of the simulation

This calculation is described by (3.12).

Figure 4.25 shows an example of the Average Bit Rate variation during a simulation, for the central cell.

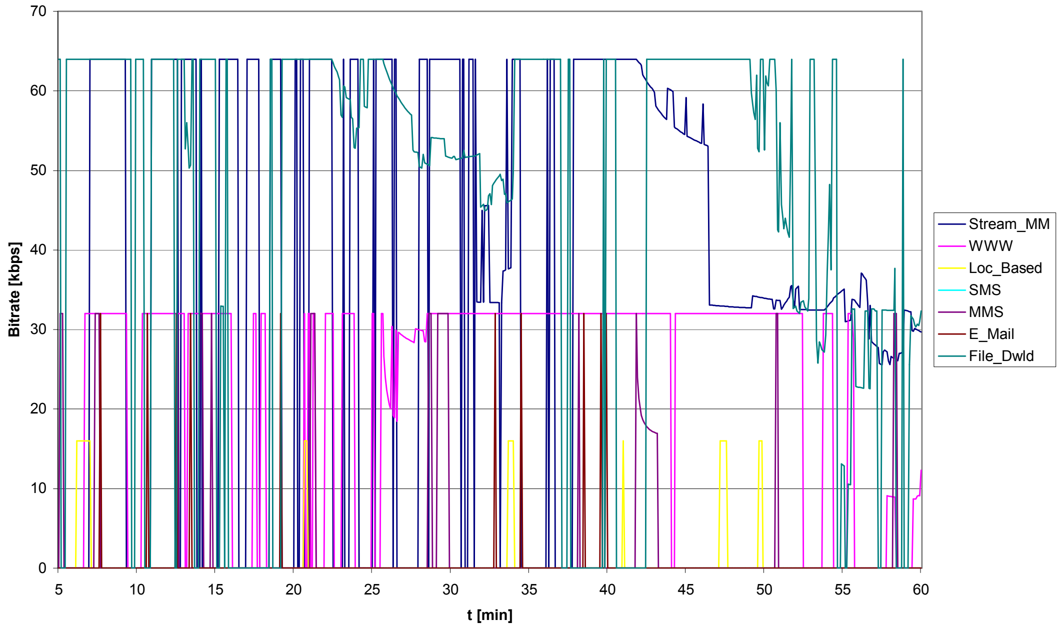


Figure 4.25. Average bit rate variation.

The simulations were made using a 233 MHz PC with 96 MB of RAM. Each simulation had duration of 1 hour (consisting of 720 simulation steps, with 5 seconds time step) and took approximately 1 hour to compute all the results (simulation time depends on the amount of users generated).

Chapter 5

Analysis of Results

This chapter focus on analysing the results obtained with the simulator. It starts by describing the scenarios considered for the simulations. Then, the three scenarios are compared in terms of the calculated parameters (e.g., load, power, bit rates). The next section analyses the influence of the threshold that avoids cell load to go beyond the defined limits. Finally, the impact of soft-handover is discussed based in comparing simulations with different sizes of handover regions.

5.1 Scenarios

The city chosen for performing the simulations was the city of Lisbon. Figure 5.1 shows a graphical representation of the BHCA distribution for this city. Figure 5.2 displays the distribution of the operational environment in the city area. These parameters are responsible for the call generation rates and mobility pattern of the users, respectively.

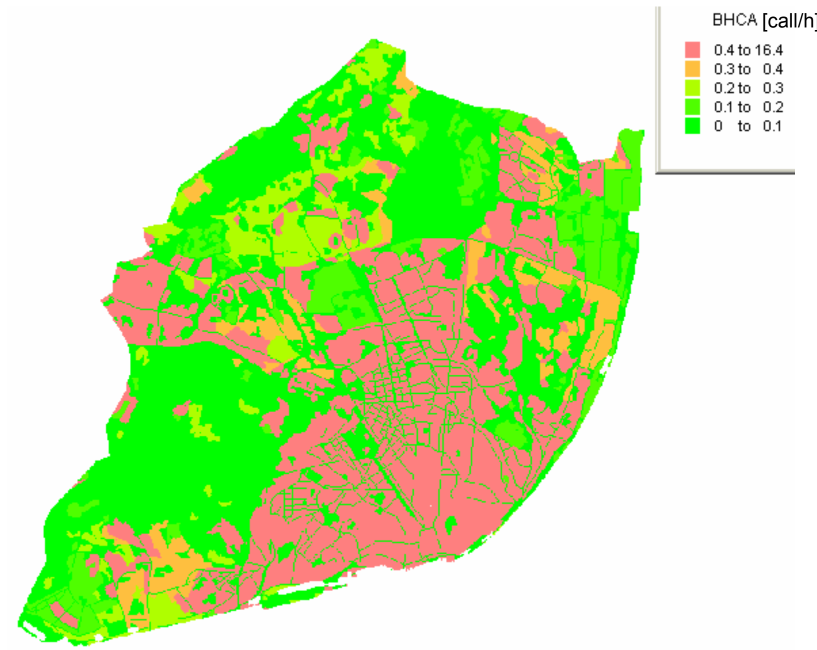


Figure 5.1. Graphical representation of the BHCA distribution.

Since the simulation is only performed in a seven cell cluster, three areas were chosen inside the city in order to cover different types of users (and the respective mobility and service profiles). The areas chosen were:

- “Marquês de Pombal” (business area)
- “Monsanto” (open space area)
- “Olivais” (residential area)

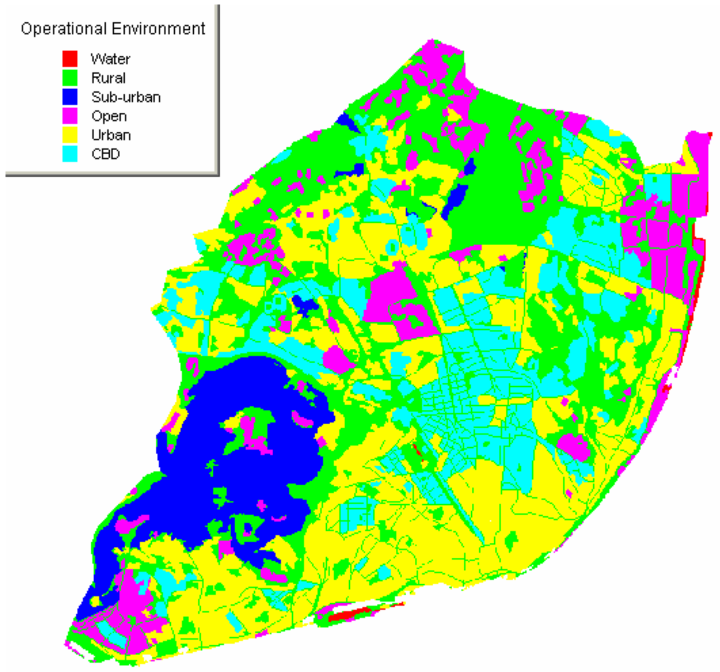


Figure 5.2. Graphical representation of the operational environment.

"Marquês de Pombal"

"Marquês de Pombal" is one of the major squares in the city of Lisbon, Figure 5.3. It is located at the centre of the city, and for that reason it was chosen by many companies to install their offices. It is also an area of intense traffic, both for people and vehicles.

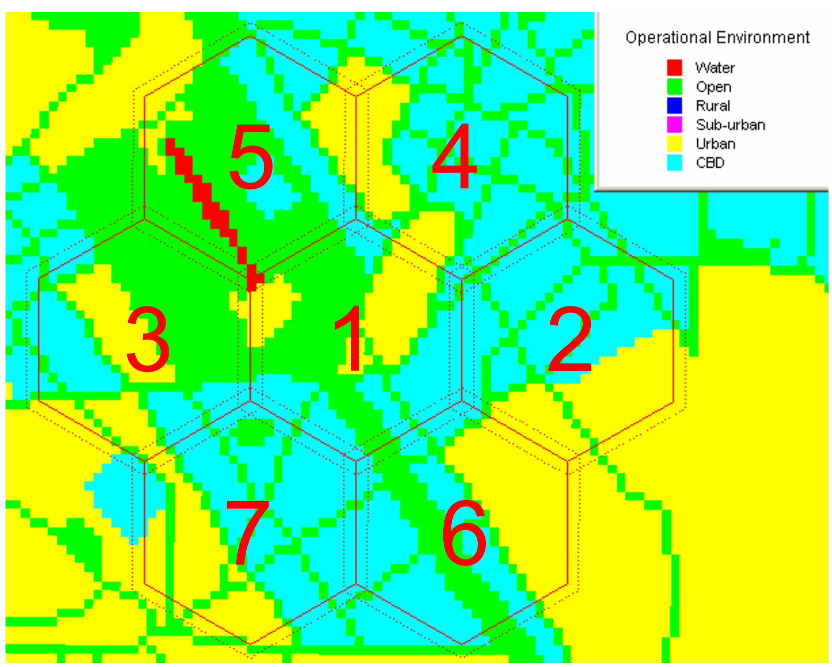


Figure 5.3. "Marquês de Pombal" operational environments.

The area inside the seven cell cluster is composed of mostly business buildings, however some residential houses are also covered by the cells. Some cells also cover part of a large green area called "Parque Eduardo VII" where the density of users and vehicles is much smaller than in the remaining area. The BS of the central cell of the cluster was placed at the centre of the square, Figure 5.4.

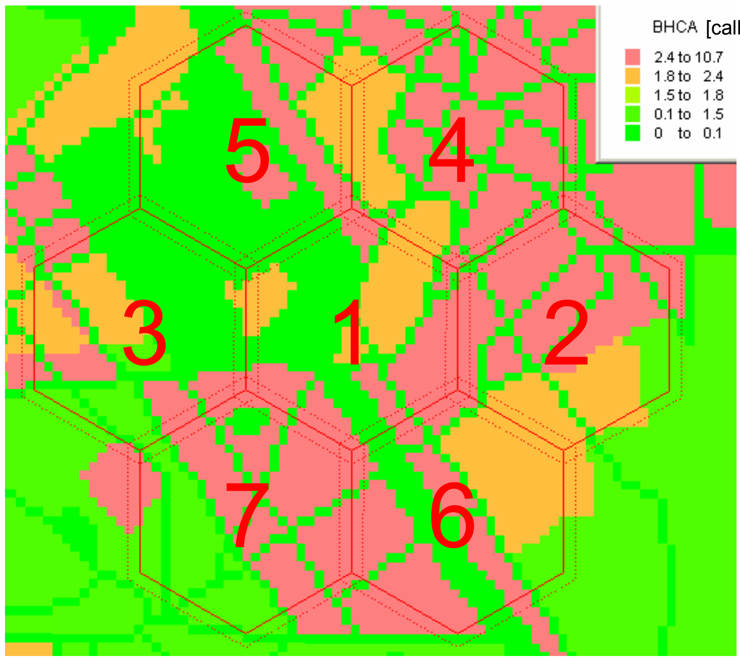


Figure 5.4. "Marquês de Pombal" traffic density (BHCA for speech).

"Monsanto"

"Monsanto" is a large green area located in the west part of Lisbon and is known as the "lungs of the city", Figure 5.5. This location was chosen in order to evaluate the system in a situation of low-density traffic and high mobility of users (since the area is crossed by a highway with intense traffic that serves as one of the major entrances to the city).

Monsanto is an area with dense vegetation (mostly trees) and with high elevations. The central cell BS is located at one of the highest spots in the area where several antennas already exist for television broadcast and military communications.

Please note that the BHCA figures, Figure 5.6, have different scales since differences in traffic load are very significant.

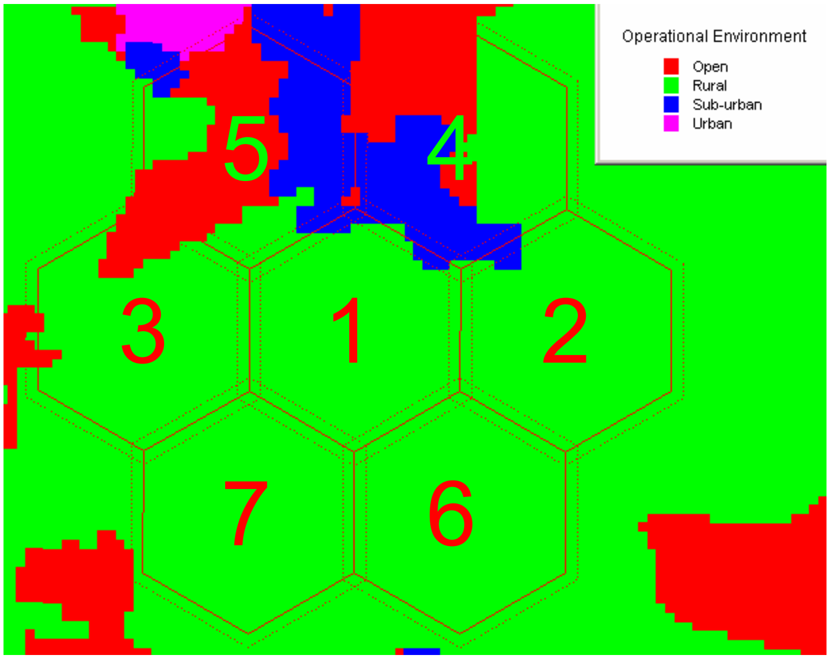


Figure 5.5. "Monsanto" Operational Environments.

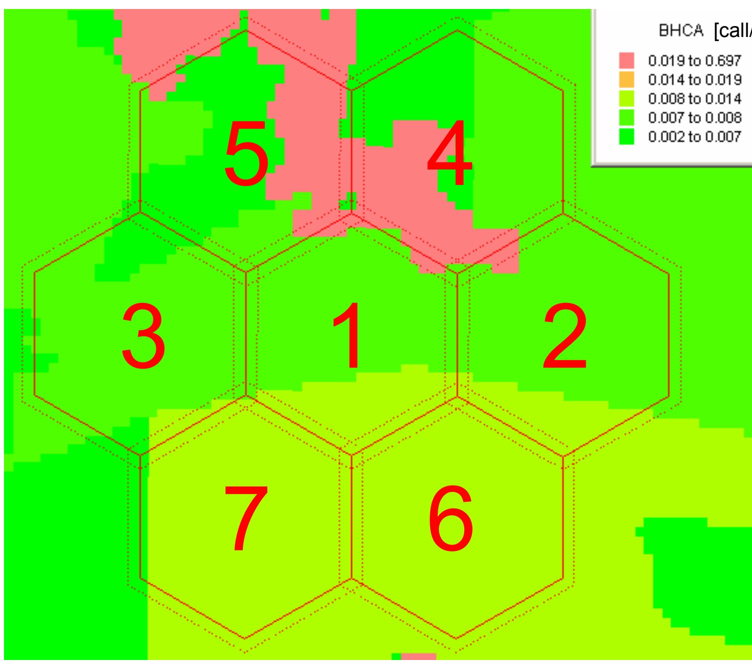


Figure 5.6. "Monsanto" Traffic Density (BHCA for Speech).

"Olivais"

"Olivais" is a large residential area located in the north part of the city, Figure 5.7. It is composed mostly with buildings with 4 or 5 floors. This location was chosen to evaluate system behaviour when mostly mass-market users are loading the communications network, Figure 5.8.

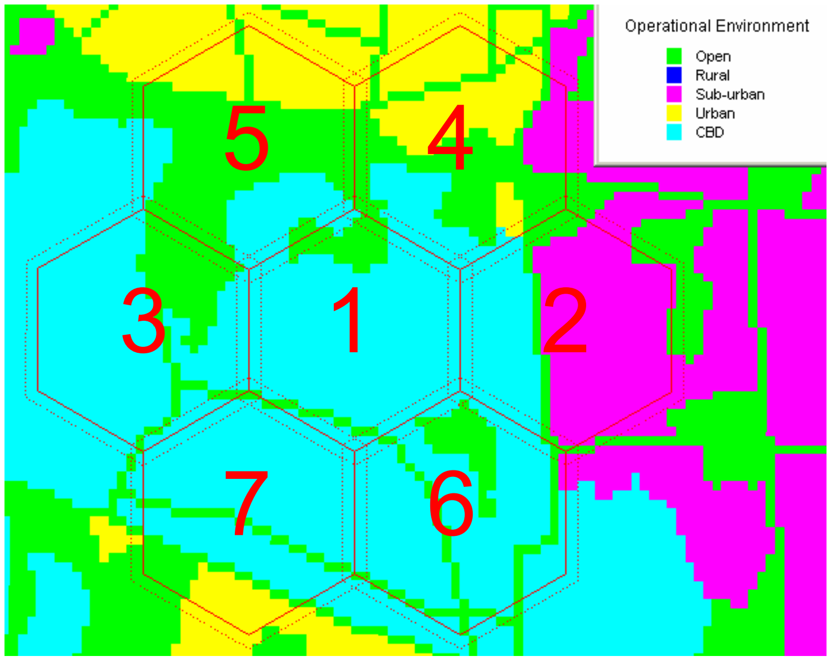


Figure 5.7. "Olivais" Operational Environments.

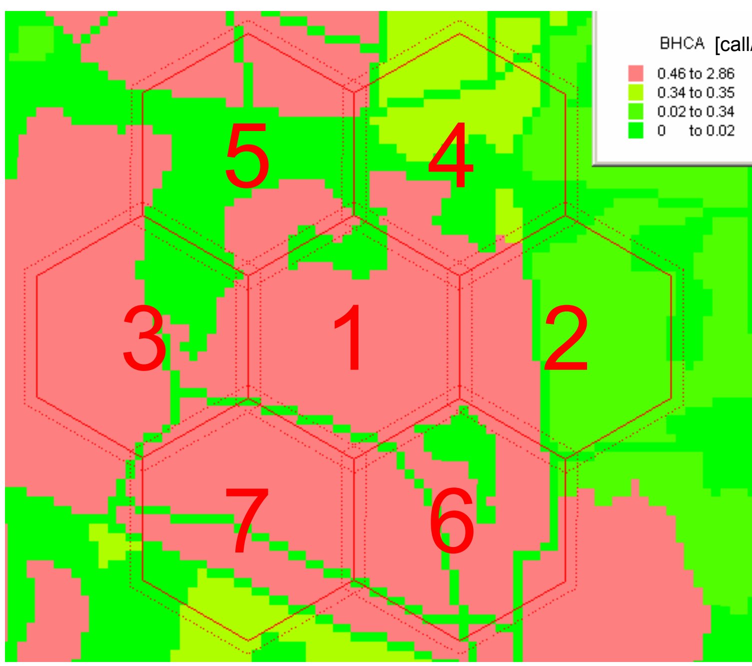


Figure 5.8. "Olivais" Traffic Density (BHCA for speech).

The traffic is smaller than in the business area and the services used have lower bit rates. Users are mostly static and pedestrian, however this cluster comprises the main city entrance from the north. The location of the central cell BS is at the core of the "Olivais" quarter.

5.2 Input Parameters

As explained in Chapter 4, the user mobility is dependent on the operational environment of the area the user is in when the call is generated. The probability of each mobility profile per operational environment is shown in Table 5.1.

Operational Environment	**Distribution of Users [%]**						
	Static	**Pedestrian**	**Street/ vehicular**	**Main road/ vehicular**	**Highway/ vehicular**	**Highway Traffic Jam/ vehicular**	**Railway/ vehicular**
Water							
Railway							100
Highway traffic jam						100	
Highway					100		
Main road		5		95			
Street	5	5	90				
Open	10	20	50	20			
Rural		5	10	30	50	5	
Sub-urban	10	10	30	40	10		
Urban	30	30	20	20			
CBD	40	30	30				

Table 5.1. Mobility types per operational environment.

The average speed per mobility type and the respective variance are listed in Table 5.2.

Mobility Type	V_{av} **[m/s]**	ΔV **[m/s]**
Static	0	0
Pedestrian	1	1
Street/vehicular	10	10
Main road/vehicular	15	15
Highway/vehicular	22.5	12.5
Highway with jam/vehicular	1	1
Railway/vehicular	22.5	22.5

Table 5.2. Average speed and variance per mobility type.

The probability for the user to change direction at each simulation step, Table 5.3, depends on the mobility profile.

Mobility Type	**Movement Probability [%]**		
	Straight	Turn left/right	Backwards
Pedestrian	40	25	10
Street/vehicular	50	25	0
Main road/vehicular	70	15	0
Highway/vehicular	80	10	0
Highway with jam/vehicular	80	10	0
Railway/vehicular	80	10	0

Table 5.3. Probability to change direction per mobility type.

As previously referred, there are 9 possible services available for the user. The characteristics for each of these services (e.g., bit rate, average duration, average volume) are listed in Table 5.4.

Service	**CS/PS**	**Symmetric/ Asymmetric**	**UL bit rate [kbps]**	**DL bit rate [kbps]**	**Avg. Duration [s]**	**Avg. DL Volume [kB]**
Speech-Telephony	CS	S	12.2	12.2	120	-
Video-telephony	CS	S	128	128	120	-
Streaming Multimedia	PS	A	8	64	-	2250
Web Browsing	PS	A	8	32	-	1125
Location Based	PS	A	8	16	-	22.5
SMS	PS	S	16	16	-	0.16
MMS	PS	S	32	32	-	60
E-Mail	PS	S	32	32	-	10
File Download	PS	A	8	64	-	1000

Table 5.4. Characterisation of the services defined.

For simulation purposes, there was the need to split the SMS, MMS and E-Mail services in two due to the fact that instantaneously these services are not symmetric, they are only symmetric considering a long period of time where the number of received messages equals the number of the messages sent. However for the simulation, there was the need to create one service for sending messages and another for receiving messages, as can be seen on the example below:

- Receive SMS: UL – 0 kbps; DL – 16 kbps

- Send SMS: UL – 16 kbps; DL – 0 kbps

Some properties are common to all the simulations that were performed. These properties are listed below together with the respective value:

- Cell radius: 300 m
- Simulation time step: 5 s
- Simulation total time: 1 h
- Maximum UL load: 50%
- Maximum DL load: 70%
- Maximum BS transmission power: 43dBm
- Traffic reduction factor: 4.5%
- Cell interference factor: 55%

A cell radius of 300 m was chosen, since this is a typical value for cells located inside urban areas. The time step (5s) and the duration (1h) were chosen in order to give enough resolution to the values and a significant amount of points to evaluate the trend in the calculated parameters, without sacrificing too much in terms of computation power and time. The graphs that represent the values given by the several simulations presented here do not show the 5 initial minutes, since this is the time it takes for the system to stabilise. Maximum UL load, maximum DL load, maximum BS transmission power and cell interference factor were values taken from [HoTo00]. A factor of 4.5% was used in order to reduce all the BHCA values since these forecasted values for traffic were too high.

5.3 Comparison of Scenarios

The first scenario under analysis is “Marquês de Pombal”, with a handover radius of 10% of total cell radius, using DL as the criteria on load threshold.

Figure 5.9 represents the variation in time of the UL load for the whole cluster during one simulation. As it can be seen, cell 2 reaches the highest values since it covers an area with higher BHCA values (as it can be seen in Figure 5.4). This is due to a high density of business buildings in this area (classified as CBD). Since the system was not limited in terms of UL load, the maximum value of 0.5 was exceeded 2 times in cell 2 during the simulation.

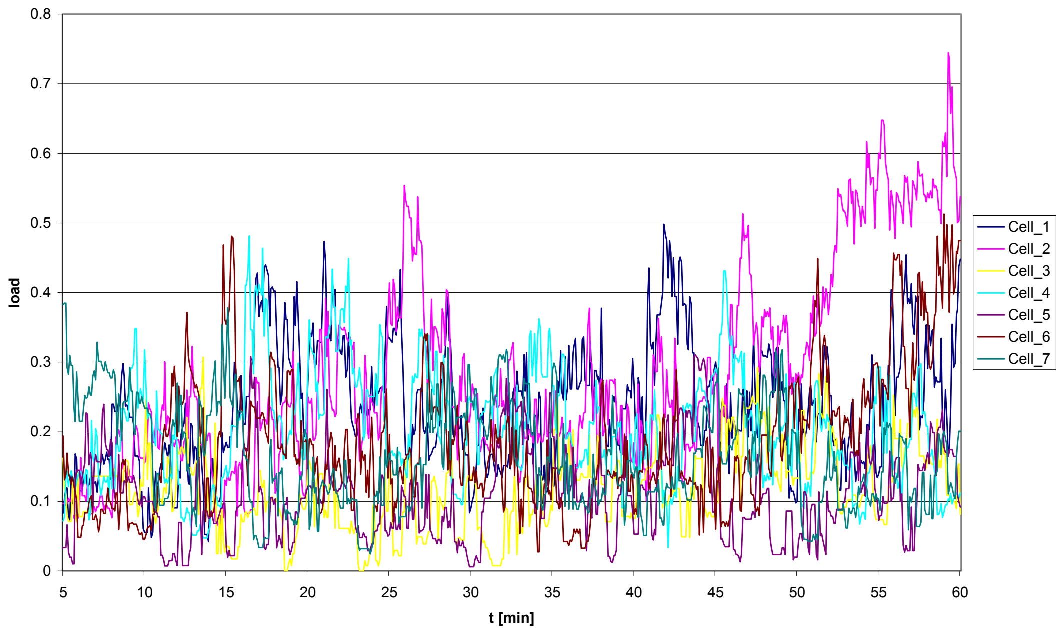


Figure 5.9 UL load for Marquês de Pombal (1 simulation).

Another aspect to be observed is the significant difference in terms of load level between the several cells in the cluster. This is due to the asymmetry in terms of operational environments covered by the seven cells, as can be seen in Figure 5.3, since these are linked to the differences observed in terms of BHCA, Figure 5.4.

The lower loads are observed in cell 3 since this cell has a big portion over the park "Eduardo VII", a large green area with low traffic density.

Figure 5.10 represents the average UL load as a result of performing 10 simulations with the same parameters. With this graph one can see a more clear separation between the load levels of the seven cells. When the average load is computed, the maximum value of 0.5 for the UL load is never exceeded.

Also, it becomes clear the unbalance in terms of traffic levels among the 7 cells: cell 2 has the highest traffic, cells 1, 4, 6 and 7 are in the range of 20% load and cells 3 and 5 have the lowest load (around 10%). This asymmetry is due to the difference in terms of covered operational environments.

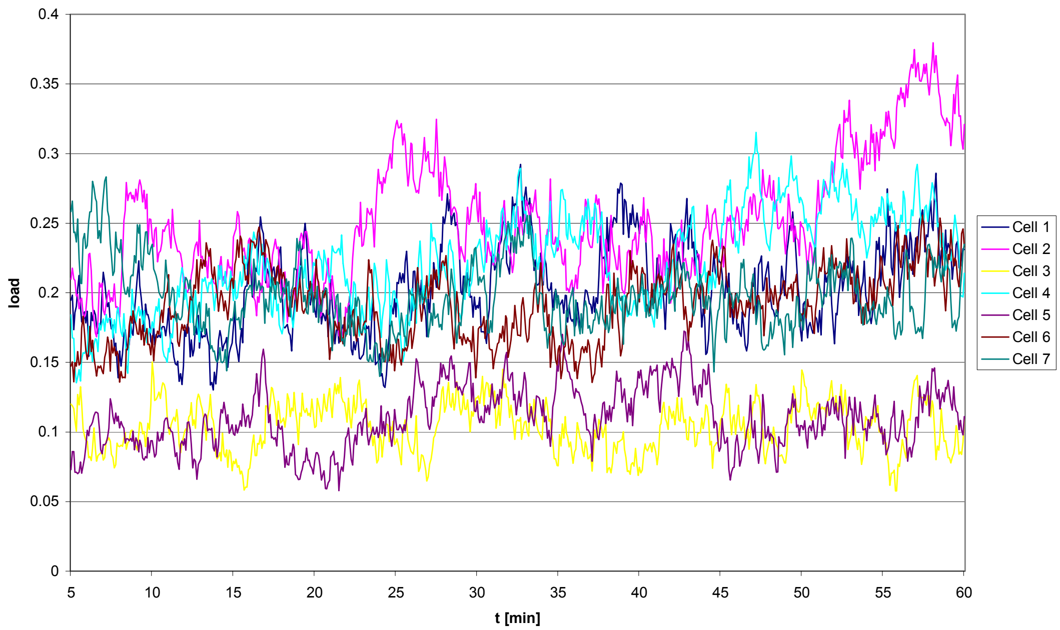


Figure 5.10 UL load for Marquês de Pombal (10 simulations).

Figure 5.11 represents the standard deviation between the values obtained in the 10 simulations. From the analysis of this graph, it can be observed that the standard deviation is usually in the range of 5 to 10% load for the 7 cells. These values of deviation show that the data is reliable, since there are no major differences from simulation to simulation. The deviation becomes higher at the end of the 60 minutes simulation in cells 2 and 4.

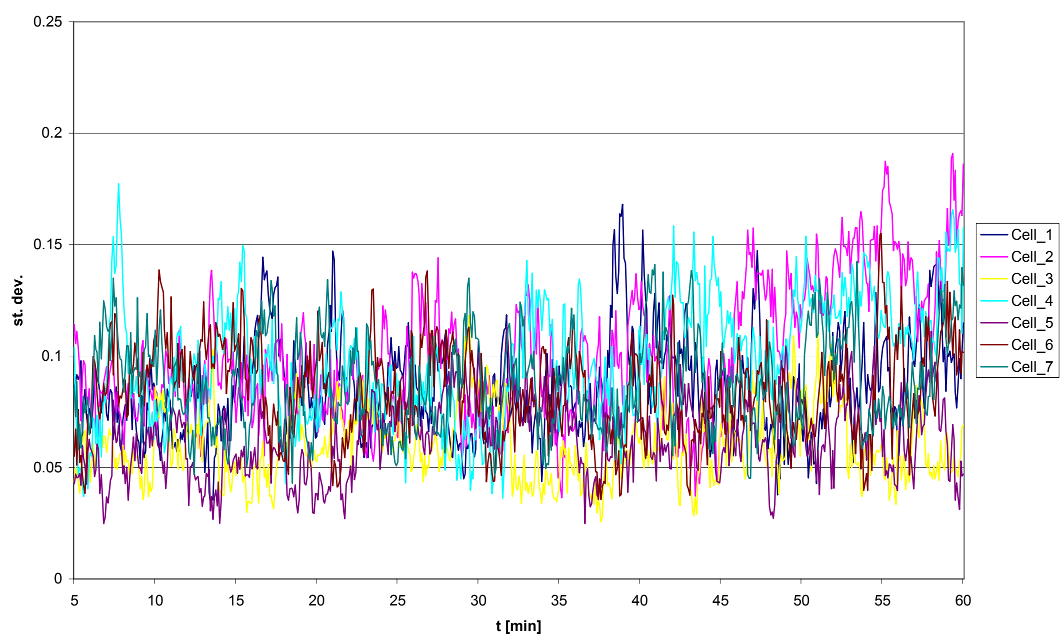


Figure 5.11. UL load standard deviation for “Marquês de Pombal”.

The graph represented in Figure 5.12 displays the variation of the DL load during one simulation. As stated above, the simulation is being limited by DL in terms of load control, which means that if the cell load goes above 70%, the program starts decreasing the bit rates for the PS users. This effect can be observed for cell 2 during the last 15 minutes of the simulation. The load goes above 70% and the load control procedure starts to decrease the bit rates to bring the load value below the limit. The next simulation step, since the load allows, the program generates more users for that cell and the load goes above the limit again. That is why that oscillating effect is observed in the load variation.

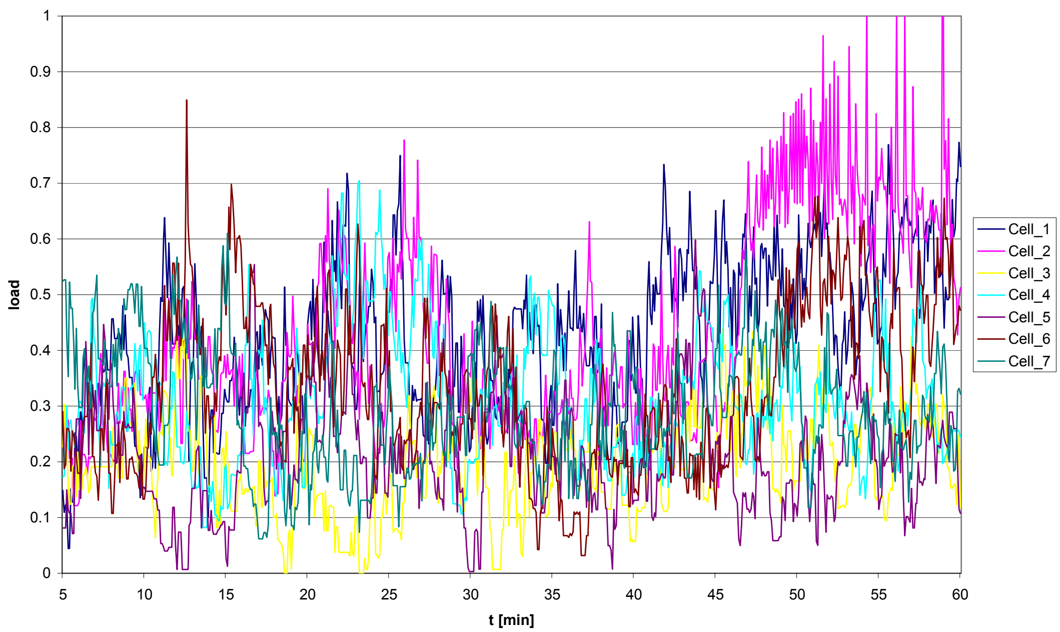


Figure 5.12. DL load (1 simulation).

Now looking at the average computed values for 10 simulations, Figure 5.13, the difference in cell load can be clearly observed, just like for UL. The split in terms of load is the same as for the UL, cells 3 and 5 being the ones with the lowest loads, and cell 2 having the highest load (however in average it does not reach the 70% limit in terms of DL load).

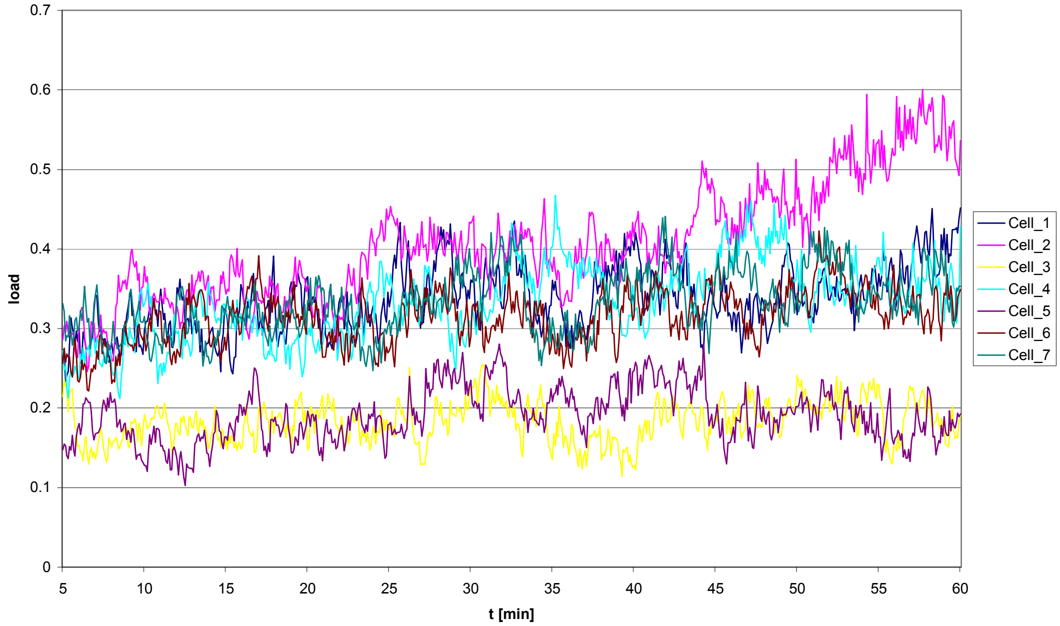


Figure 5.13. DL load (10 simulations average).

In terms of DL load standard deviation, Figure 5.14, the graph shows that it stays stable during the first ¾ of the simulation (around 10% load). After this period it starts increasing for the cells with higher loads. Comparing with the UL load standard deviation, Figure 5.11, one can see that in average the deviation is higher for the DL. Table 5.6 shows a comparison of load values for both UL and DL.

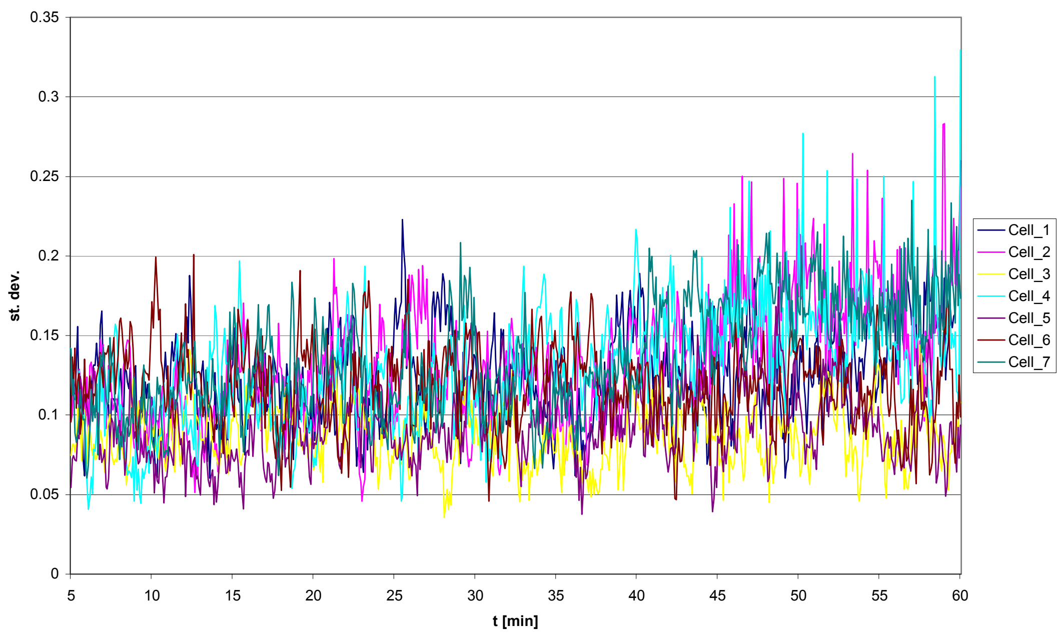


Figure 5.14. DL load standard deviation.

Load		Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
Average	UL	0.20	0.24	0.10	0.21	0.11	0.19	0.19
	DL	0.33	0.39	0.18	0.32	0.18	0.30	0.32
St. Dev.	UL	0.02	0.03	0.02	0.03	0.02	0.02	0.02
	DL	0.03	0.04	0.02	0.04	0.02	0.03	0.04

Table 5.6. Average load and st. dev. values for both UL and DL.

One can see from Table 5.6 that the DL load values are significantly higher than the UL (due to the services asymmetry). The standard deviation is similar for both transmission ways and differs slightly from cell to cell.

The evolution of the required BS transmission power is represented in Figure 5.15. This graph represents the values obtained for one simulation and clearly shows that the maximum values never reach the maximum limit of 43 dBm throughout the simulation time. The power remains approximately constant during the period around the 10 dBm reference. It is also clear that cells 3 and 5 have the smallest transmission power (due to the fact that less users are inside the respective cell coverage area).

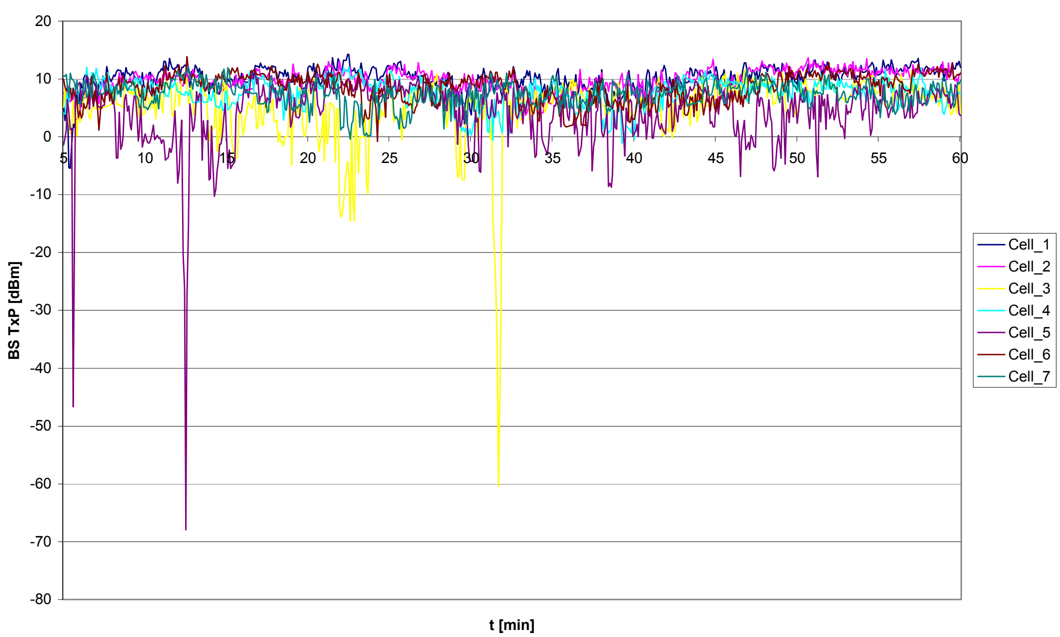


Figure 5.15. BS transmission power (1 simulation).

Looking now at the respective average values, Figure 5.16, a clear separation can be observed in terms of power level between the 7 cells. This separation is in line with what was observed in terms of load, the differences in terms of load levels between cells being clearly reflected here in terms of BS transmission power.

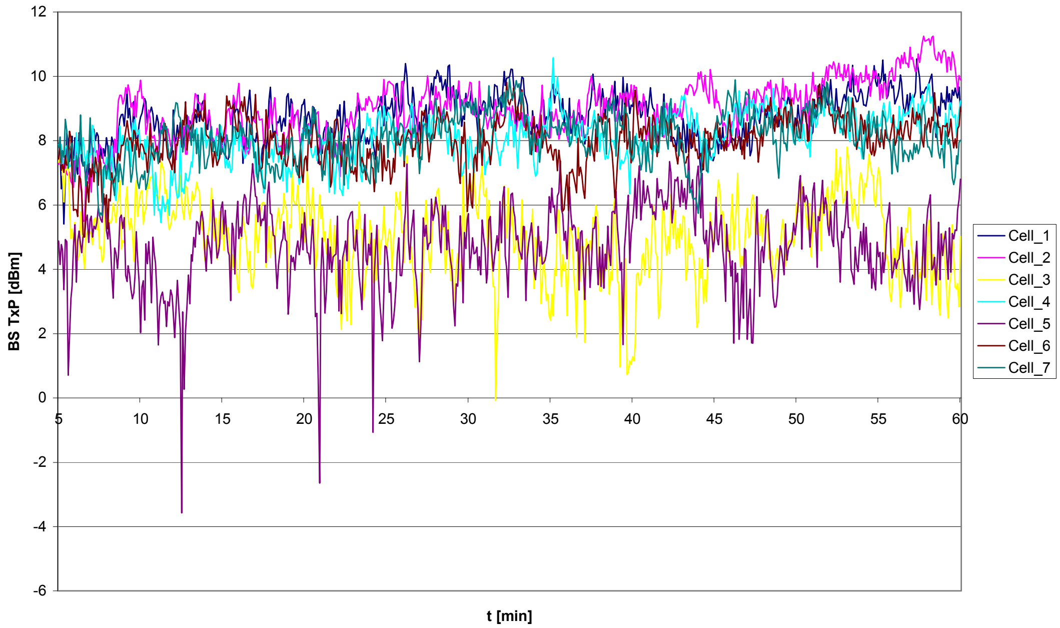


Figure 5.16. BS transmission power (10 simulations).

Figure 5.17 displays the evolution of the standard deviation for the BS transmission power (for a 10 simulation sample). The graph shows that the highest deviations appear in the cells with the lower transmission power (cells 3 and 5).

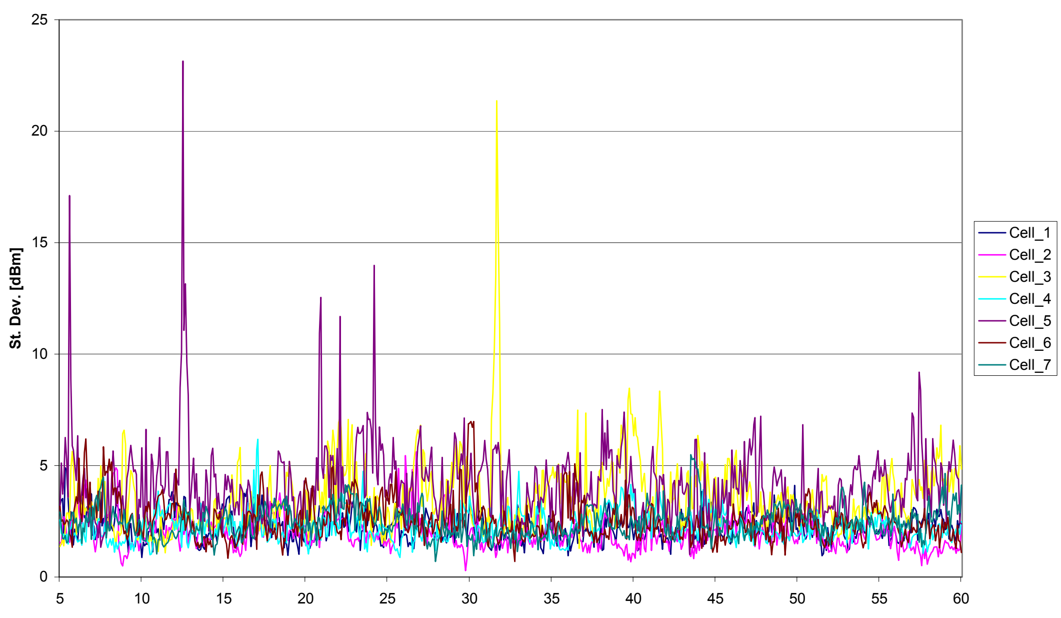


Figure 5.17. BS transmission power standard deviation.

Looking now at the UL load deriving from users in handover, Figure 5.18, one can see that it oscillates significantly, but rarely exceeds the 15% mark.

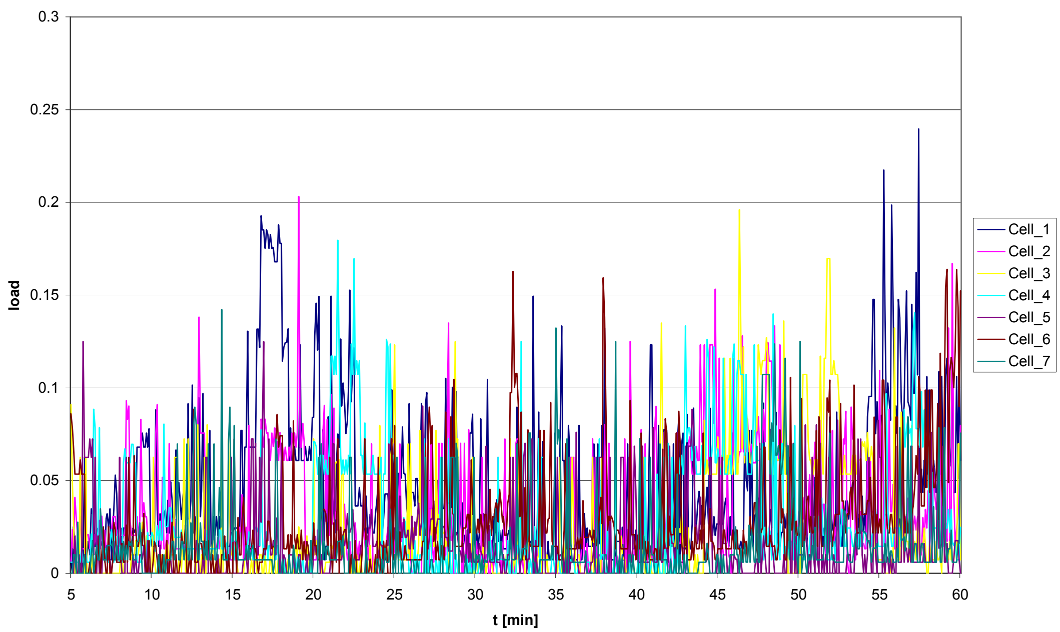


Figure 5.18. Handover UL load (1 simulation).

The ten simulations average, Figure 5.19, is more conclusive, since it is clearer to perceive the trend. The UL load is represented here as a percentage of the total load. From this graph it is possible to conclude that in average the UL load derived from handover is in the range of 10 to 20% of the total load. Here the preponderance of the 2nd cell is not so clear, since the mobility factor is extremely relevant.

One can see from Table 5.7 that the cell with the highest handover load is the central cell. This lies in the fact that cell 1 takes users from all the six surrounding cells while the others only suffer a main influence from three surrounding cells (since users are only generated inside the seven cell cluster).

The deviation between the values obtained in the 10 simulations is similar to the 7 cells and it averages around 5% load. Figure 5.20 displays the standard deviation for the handover UL load.

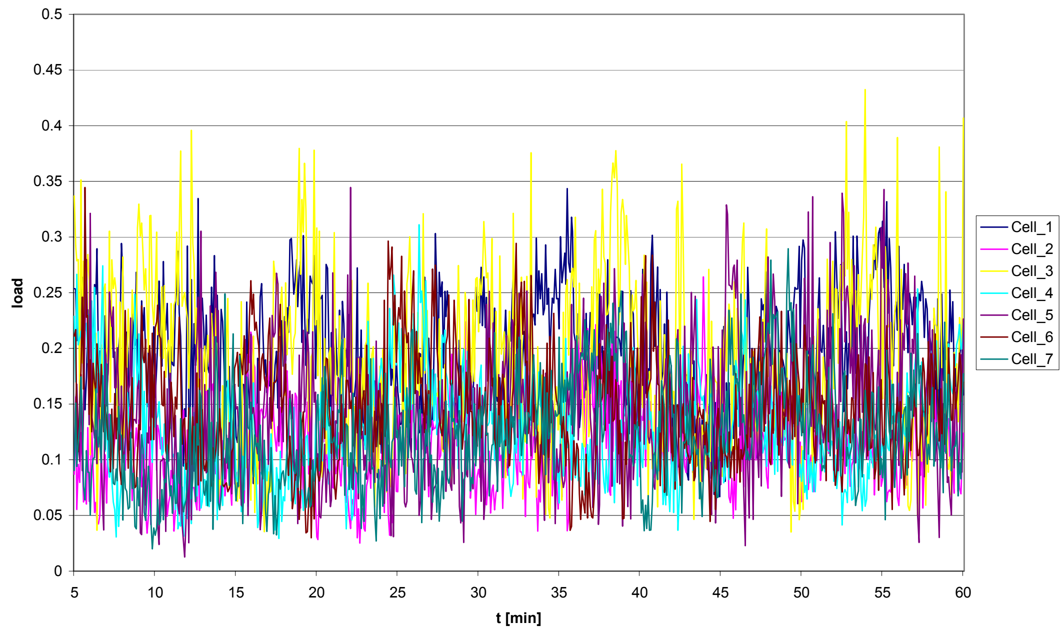


Figure 5.19. Handover UL load (average).

Load	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
Average	0.20	0.11	0.19	0.13	0.14	0.15	0.12
St. Dev.	0.05	0.04	0.08	0.05	0.06	0.05	0.05

Table 5.7. Handover UL load as a percentage of total UL load (average and st. dev.).

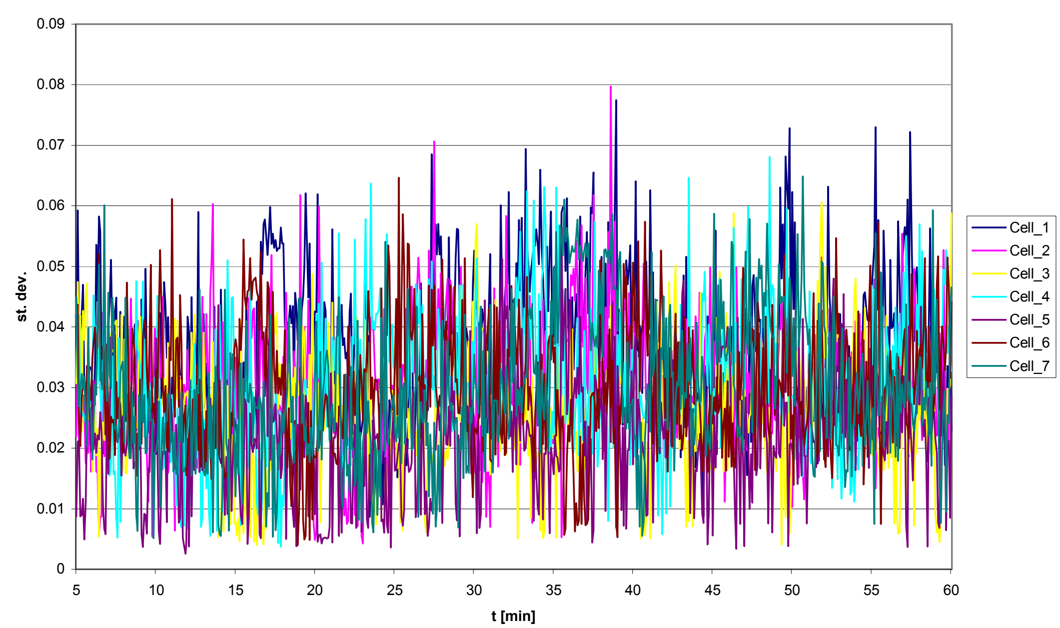


Figure 5.20. Handover UL load (standard deviation).

The handover load for the DL channel, Figure 5.21, is, as expected, higher than in the UL, due to the asymmetry of PS services. In this simulation, it is difficult to clarify which cell is preponderant since the values oscillate intensively.

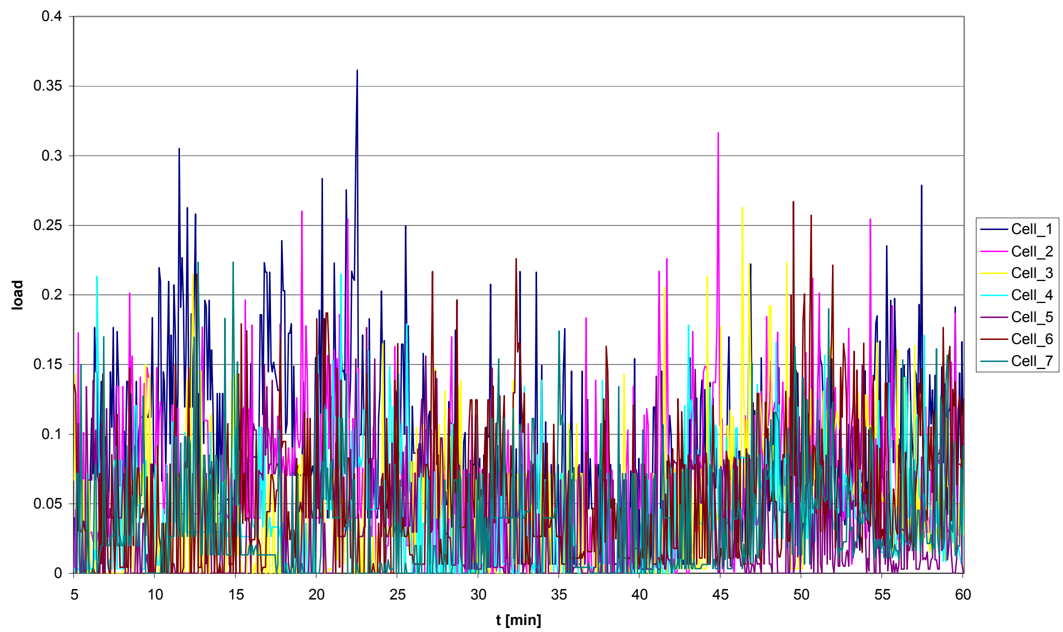


Figure 5.21. Handover DL load (1 simulation).

Figure 5.22 represents the variation of the handover DL load as a percentage of the total DL load. It can be seen that these values fluctuate around 10 to 25% of the total DL load.

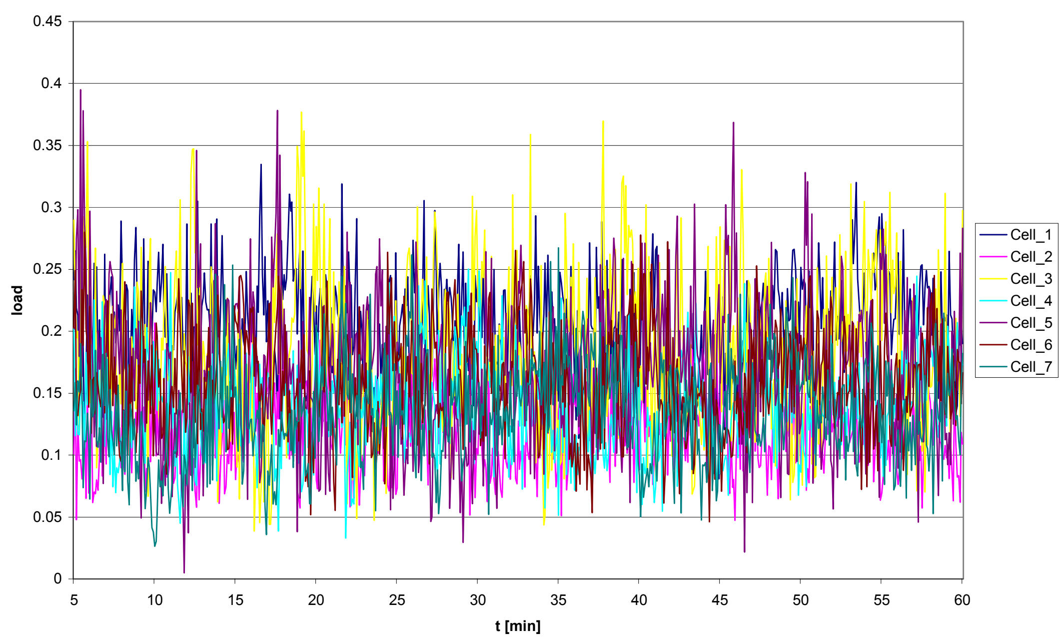


Figure 5.22. Handover DL load (average).

By looking at Table 5.8, it can be seen that cell 1 has the highest handover load for the same reasons has explained for the UL.

Load	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6	Cell 7
Average	0.20	0.12	0.18	0.14	0.17	0.16	0.13
St. Dev.	0.04	0.03	0.06	0.04	0.06	0.04	0.04

Table 5.8. Handover DL load as a percentage of total DL load (average and st. dev.).

Figure 5.23 represents the standard deviation between the 10 simulations effected for calculating the evolution of the handover DL load. The average deviation is around 4% load for the 7 cells, but with rapid fluctuations.

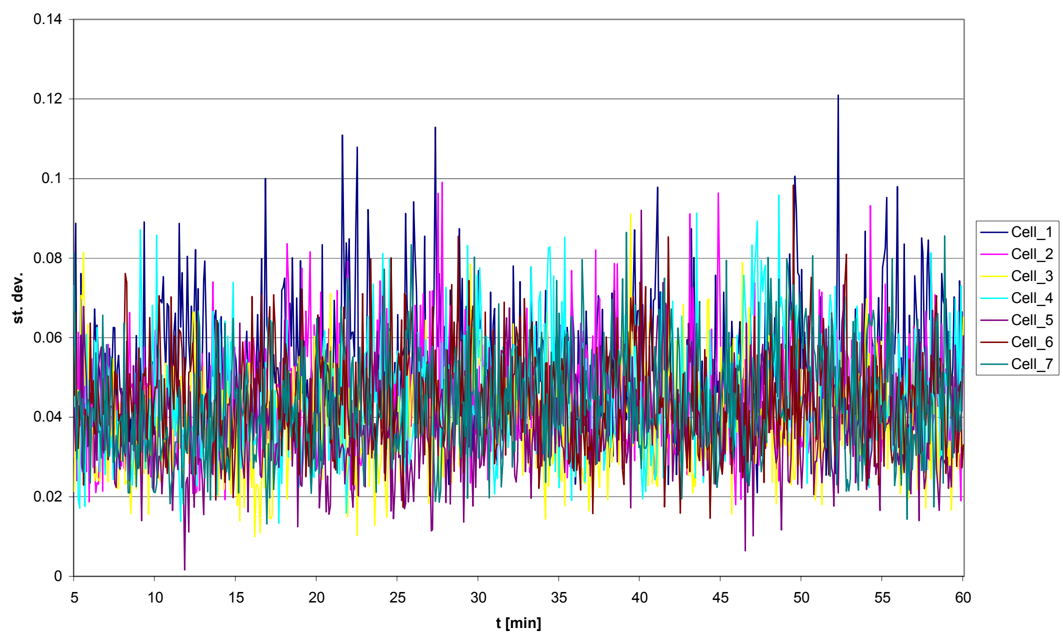


Figure 5.23. Handover DL load (standard deviation).

The graph displaying the Blocking Probability during the 1st simulation, Figure 5.24, clearly shows that only cells 1, 2 and 4 had blocked CS calls. The moment where these blocked calls appear can be related to the DL load graph, since blocked calls happen when the load on these cells goes above the 70% limit imposed by the system. While cells 1 and 4 recovered from the blocked call, cell 2 does not. It starts increasing the probability in the 48th minute of the simulation and it never stops increasing till the end of the simulation. This effect clearly indicates that the cell reached its saturation point and was not able to recover from it before the end of the simulation (60 minutes). This fact can be easily verified by looking at the DL load of cell 2: during the last 10 minutes of the simulation the load is always above the limit.

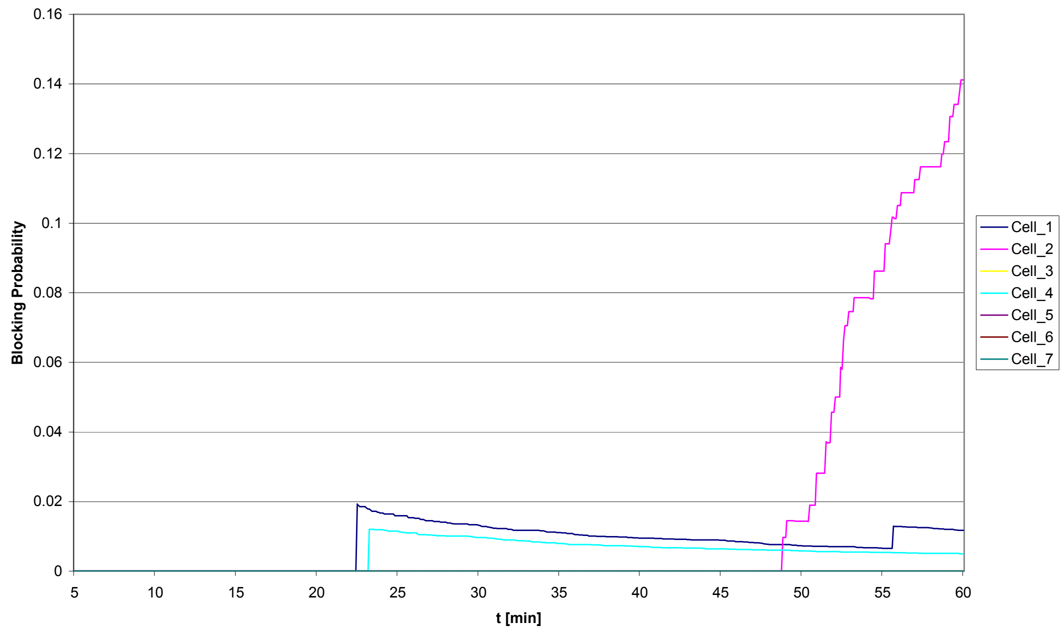


Figure 5.24. Blocking Probability (1 simulation).

Now looking at the average values for the Blocking Probability, obtained from a 10 simulation sample, it can be observed in Figure 5.25 that five of the seven cells had blocked CS calls during the simulations. The probability becomes higher at the end of the simulation, since cell load increases during the simulation time and when its maximum is reached, CS calls start to be blocked. Cell 2 has the highest blocking probability, since it is the cell with the highest loads.

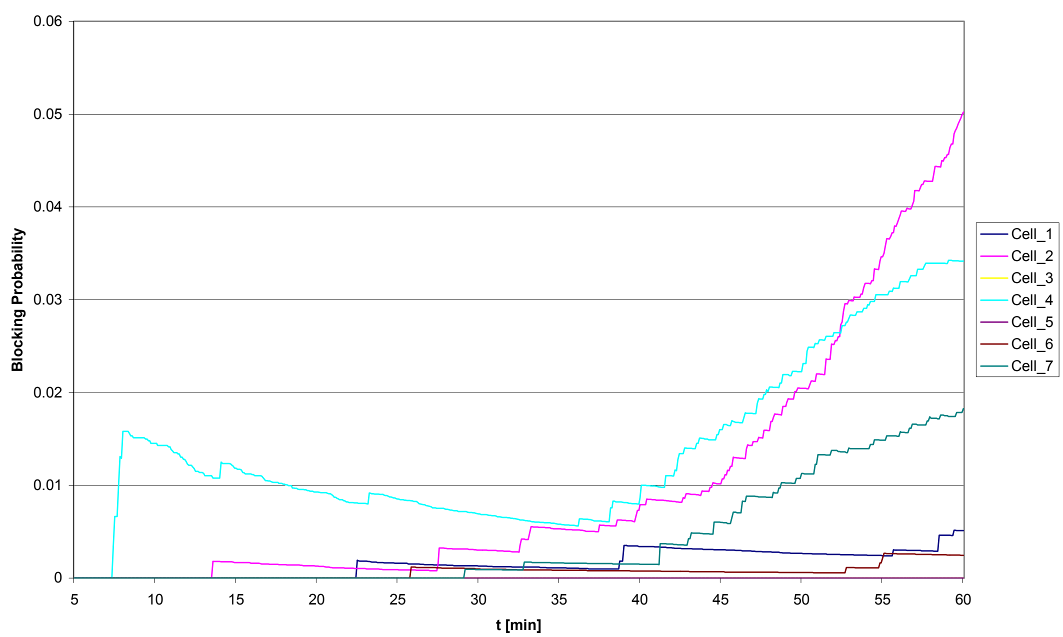


Figure 5.25. Blocking Probability (average).

Figure 5.26 (Blocking Probability standard deviation) follows a very similar trend to Figure 5.25. This fact demonstrates that the figures obtained for the Blocking Probability are very different from simulation to simulation.

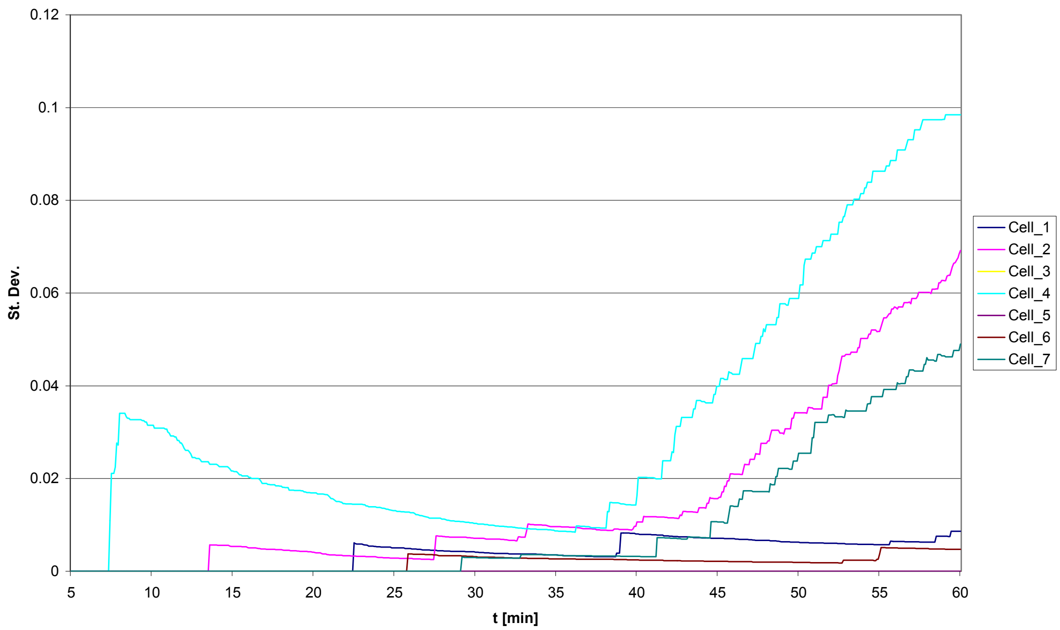


Figure 5.26. Blocking Probability (standard deviation).

The average bit rate per service is calculated only for the central cell. Figure 5.27 represents the evolution of the bit rates for one simulation. It becomes clear from the graph that the bit rates for a specific service start with the reference value and decrease for some periods due to the fact that when the maximum cell load is reached, the program starts decreasing the user's bit rate for a determined PS service. It is also possible to identify that at the end of the simulation, the system is no longer able to stay stable, since bit rates continue to decrease further and further in order to maintain the cell load within reasonable values.

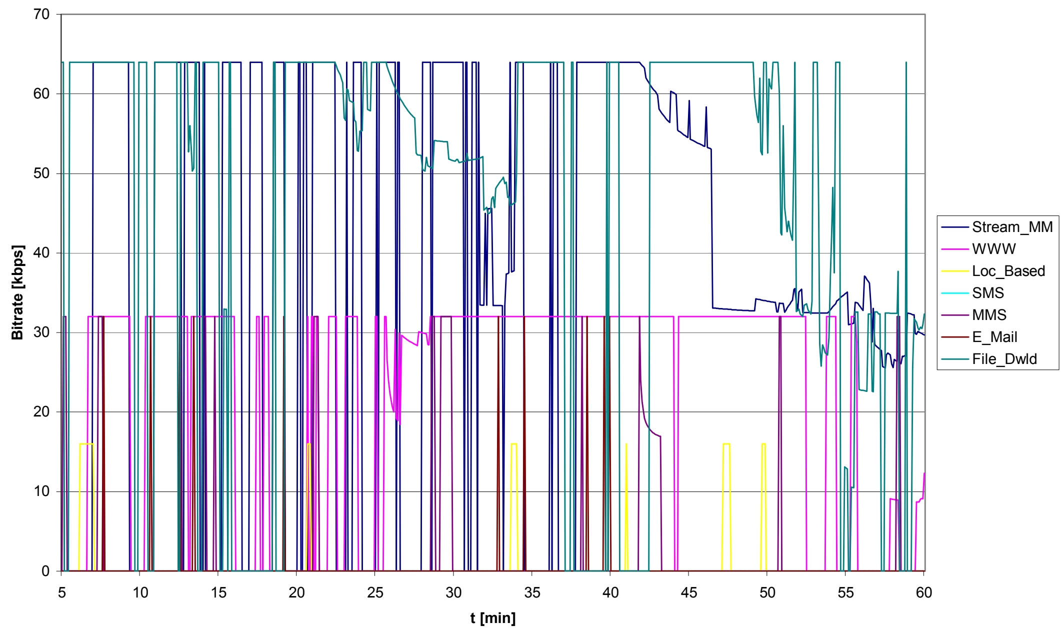


Figure 5.27. Average bit rate per Service (1 simulation).

In the average calculation of the bit rates, Figure 5.28, it is clearer to understand the separation between the several services in terms of bit rate. Also here, it is easy to observe that the average bit rates tend to decline near the end of the simulation due to the increase in terms of cell load.

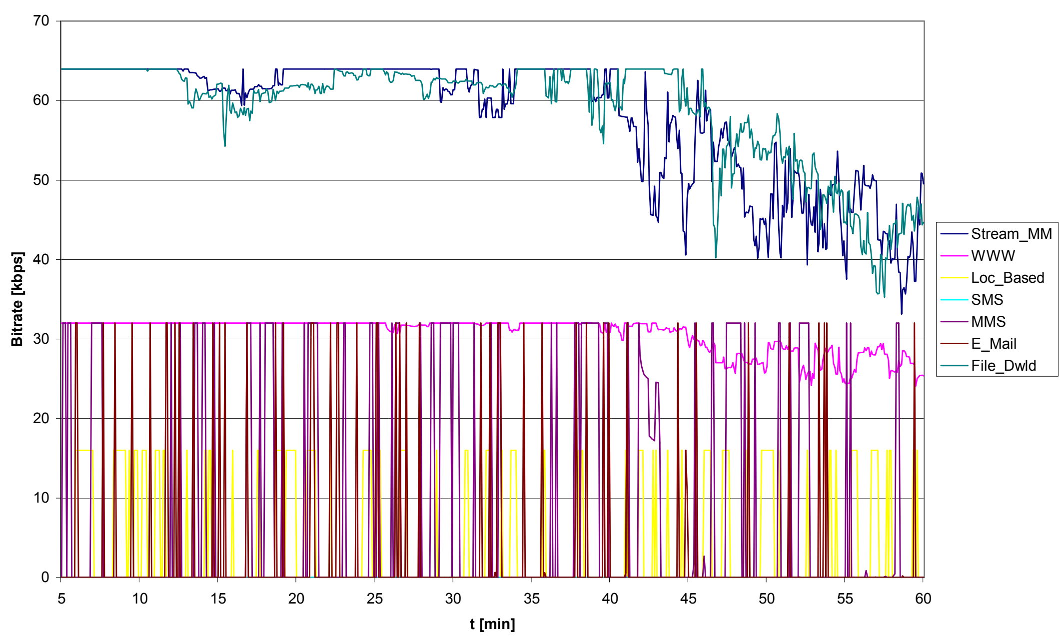


Figure 5.28. Average bit rate per service (10 simulations average).

Table 5.9 shows the DL bit rates for the PS services considered in the simulation, as well as the average bit rates and standard deviation obtained in the simulation. Relating these values with Figures 5.27 and 5.28, it can be seen that the services keep their target bit rate values unless the load goes above the limit and the system has to decrease bit rates. The most affected services are Streaming Multimedia and File Download since they are the ones with the highest bit rates and, therefore, with the highest contribution to the global cell load.

Service	Streaming Multimedia	Web Browsing	Location Based	SMS	MMS	E-mail	File Download
DL bit rate [kbps]	64	32	16	16	32	32	64
Average [kbps]	58.1	30.7	16	-	29.7	26.7	58.9
St. Dev. [kbps]	7.8	2.1	0	-	6.9	11.6	6.7

Table 5.9. DL bit rate for PS services.

High standard deviations like the ones shown in Figure 5.29 are common to this type of evaluation, since the bit rates vary dramatically throughout the simulation. This is due to the fact that the bit rates are extremely dependant on the cell load. And when the cell load increases, bit rates have to be decreased in order to maintain cell load within limits.

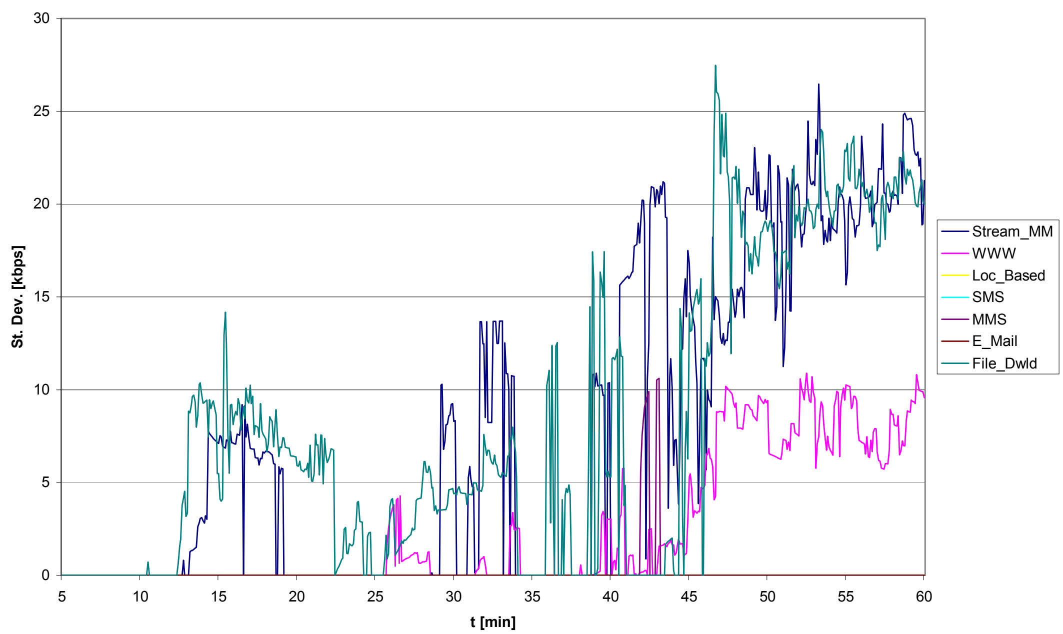


Figure 5.29. Average bit rate per service (standard deviation).

The second scenario under analysis is “Monsanto”, with a handover radius of 10% of total cell radius, using DL as the criterion for load threshold.

As it can be seen in Figure 5.30, the load in the “Monsanto” area is very low (DL load in the case of this Figure). This is due to the fact that most of the area covered by these seven cells, is classified as rural environment, Figures 5.5 and 5.6, therefore, low traffic values are associated to this region. Looking at the load evolution, one can see that cell DL load rarely exceeds 1% during the simulation period, therefore, extremely far from the 70% load limit.

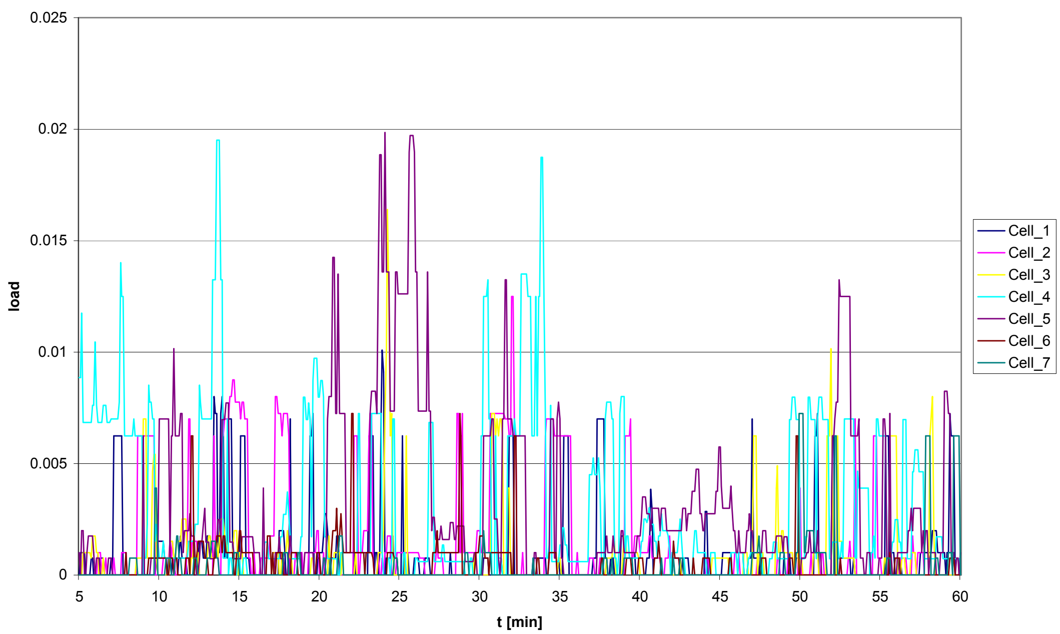


Figure 5.30. DL load (average from 10 simulations).

Comparing now these values with the values obtained for “Marquês de Pombal”, Figure 5.13, where the average load values where around 30 to 40% for the DL channel, it is quite obvious that traffic conditions are completely different. This is due to the fact that the cell radius (300 m) was kept constant for the two areas, but the traffic values (BHCA) emerging directly from the cell covered environments are completely distinct.

Regarding the handover DL load, Figure 5.31, a similar effect can be observed. Load values are only a fraction of the values registered for “Marquês de Pombal”, Figure 5.22. On the other hand, when comparing the handover load with the total load, it can be observed that the portion of load due to handover is much higher at this location (around 50% of load due to handover).

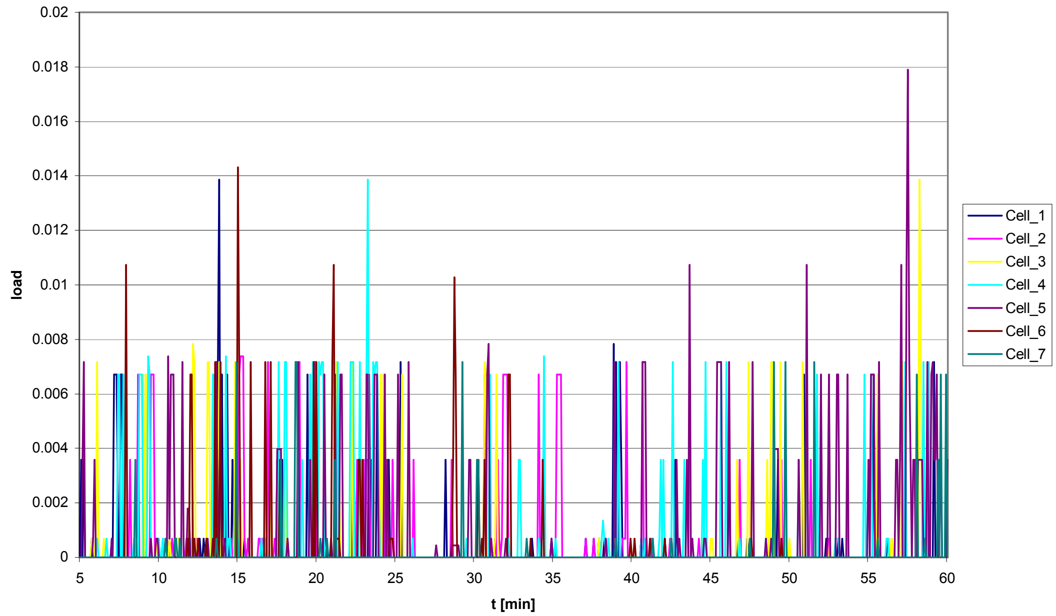


Figure 5.31 Handover DL load (average of 10 simulations).

There were no blocked calls throughout this simulation. This is relatively easy to understand since the DL load never reaches the maximum value; therefore no CS calls are blocked.

Looking now at the average bit rate per service for the central cell, Figure 5.32, it can be observed that during this simulation only two services were used: web browsing and file download.

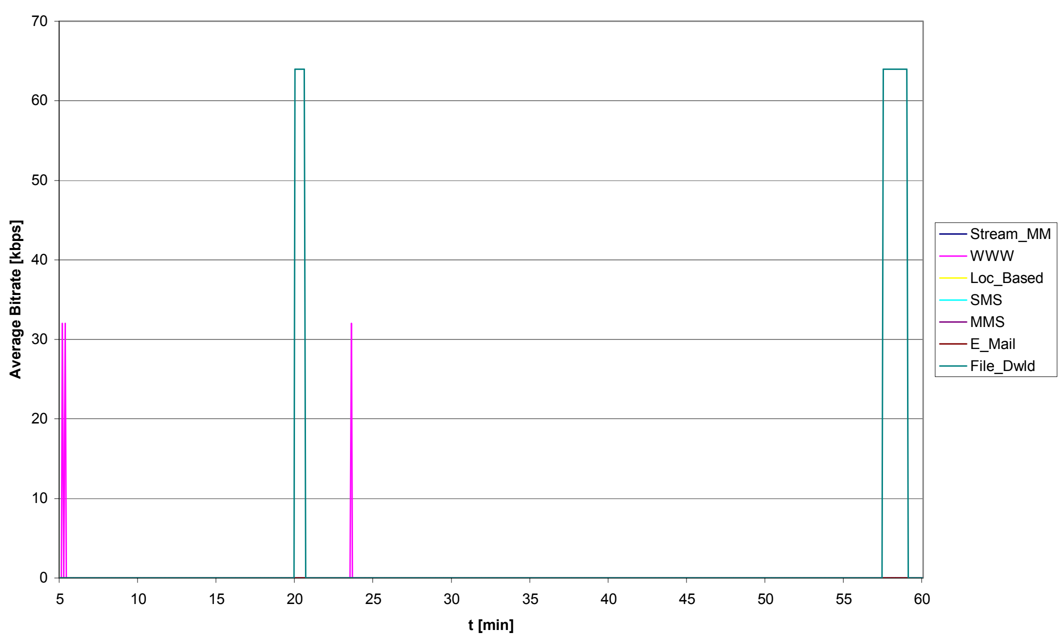


Figure 5.32. Average bit rate per service for the central cell (1 simulation).

It can be seen from the graph that the bit rates at which those services were performed are the ones specified. This means that the bit rate was never decreased for load reasons since the DL load is far below the load threshold.

The third scenario under analysis is "Olivais", with a handover radius of 10% of total cell radius, using DL as the criterion for load threshold.

Figure 5.33 displays the DL load of the "Olivais" area. As can be observed through the load levels, "Olivais" is between "Marquês de Pombal" and "Monsanto" in terms of traffic. This is due to the fact that "Olivais" is a residential area as can be seen in Figures 5.7 and 5.8. Looking at the graph in more detail, one can see that the average DL load is usually around 2 to 12%, without being possible to distinguish a clear separation of load levels between cells. In fact is extremely difficult by simply observing the graph, to choose the cell with the higher average load. This is a consequence of a good balance among the seven cells regarding traffic generation. In the same way as it happened for "Monsanto", the load in "Olivais" never reaches the threshold during the simulation period.

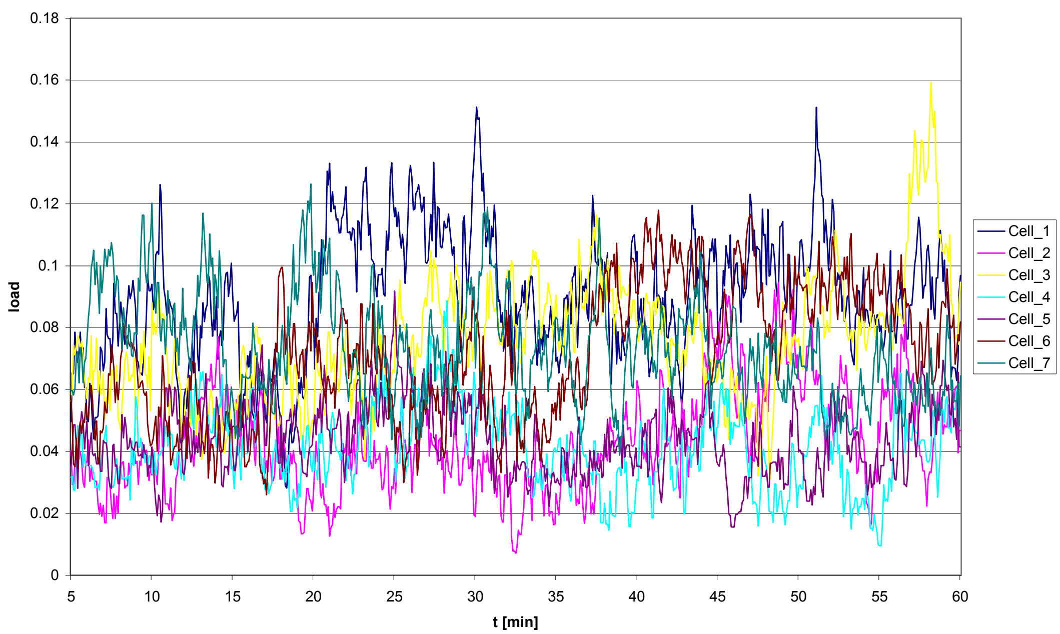


Figure 5.33. DL load (average of 10 simulations).

The handover DL load, Figure 5.34, is around the 1% to 2% value for the seven cells. It is not possible to distinguish which cell is preponderant in terms of load since the absolute value per cell is always oscillating. In terms of percentage of total load, one can say that it is above the percentage obtained for "Marquês de Pombal" but below the values obtained for "Monsanto".

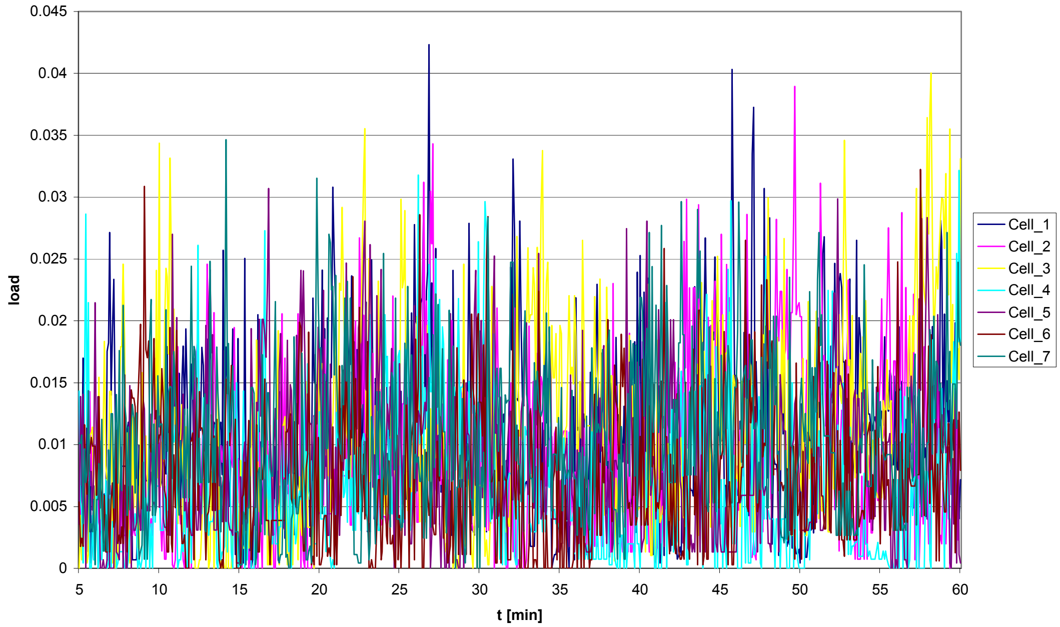


Figure 5.34. Handover DL load (average of 10 simulations).

The evolution of the average bit rate is represented in Figure 5.35. Just like in "Monsanto", load values never reach the threshold, therefore, the average bit rates correspond to the services nominal values, since the system does not need do decrease bit rates in order to keep the load below the threshold. The "on/off" fluctuations seen for some of the services correspond to periods in time when that particular service is not active in any cell.

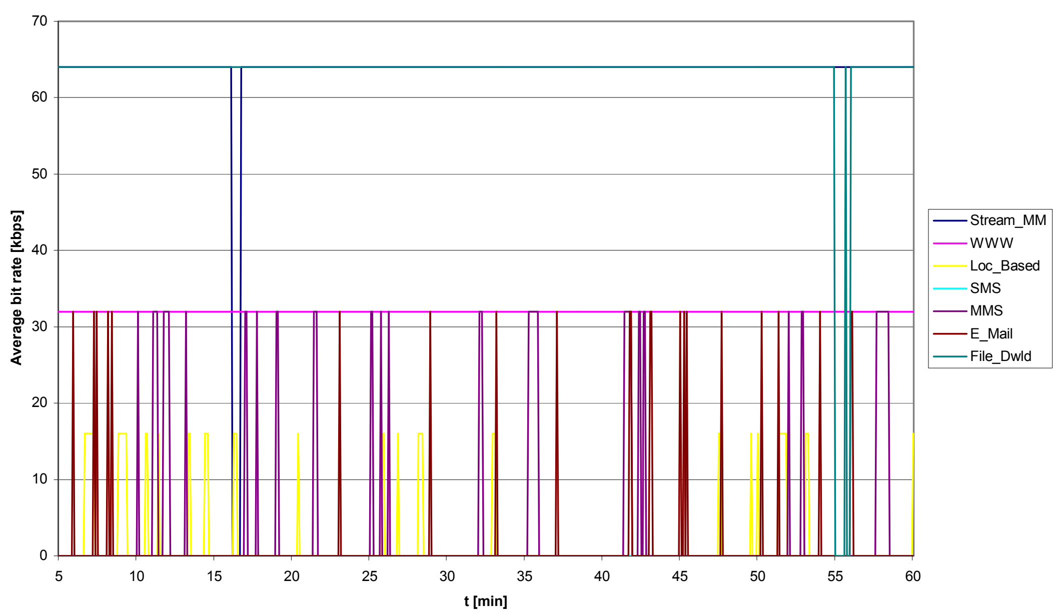


Figure 5.35. Average bit rate per service for the central cell (10 simulations).

The Blocking Probability is zero for all cells during the simulation time since the cell DL load never reaches the threshold.

As can be seen from the data presented for the three areas evaluated, these are very distinct in terms of traffic load. This asymmetry in terms of network load clearly impacts performance parameters such as the blocking probability and the average bit rate, being “Marquês de Pombal” the area where the higher loads have a clear negative impact on system performance.

5.4 Impact of load threshold

The simulations shown before were limited in terms of DL load, i.e., when the DL load reached 70% the simulator started blocking CS calls and decreasing the bit rate for PS services. In order to evaluate the performance of the system, a simulation was performed with exactly the same conditions as the one for “Marquês de Pombal”, but limiting the load in terms of UL (50% maximum load).

Figure 5.36 shows the UL load variation average for a total of 10 simulations. It is possible to identify that in average the load never goes above the threshold of 0.5.

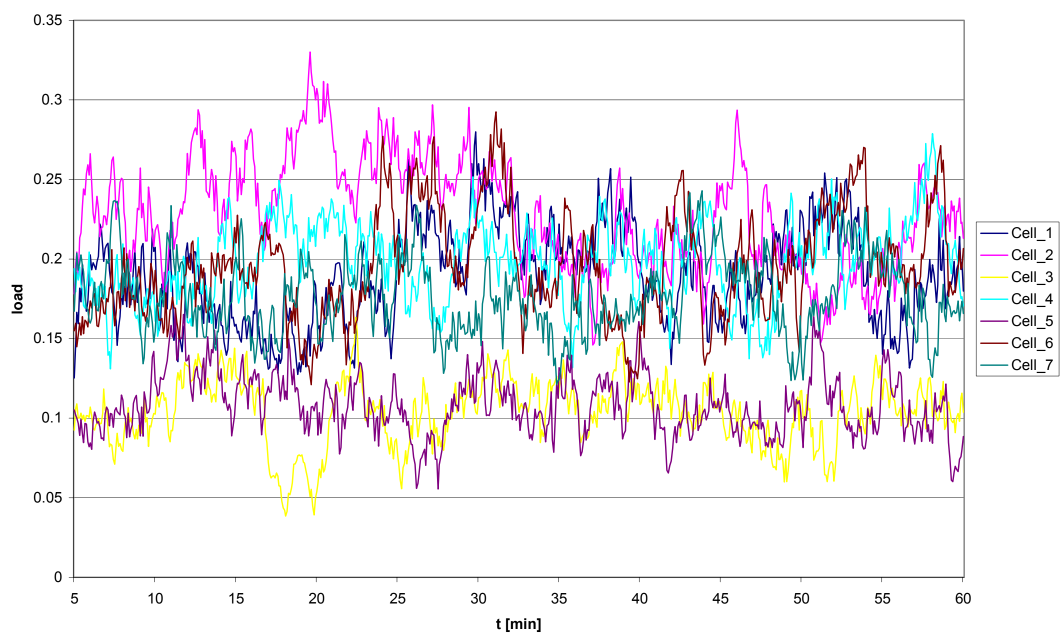


Figure 5.36. UL load (average of 10 simulations w/ UL threshold).

Figure 5.37 displays the same variation for the DL. Here it is possible to spot that the load in cell 2 goes above the 70% limit for DL load. This is perfectly possible since the system in this situation is not looking at the DL to balance the load. The load is only controlled in the UL.

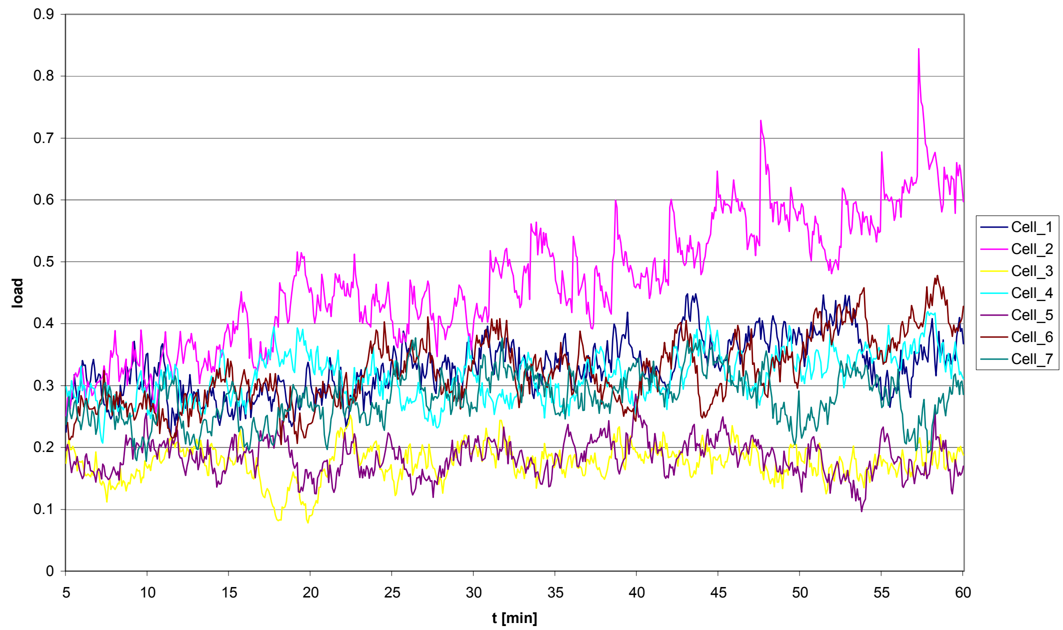


Figure 5.37. DL load (average of 10 simulations w/ UL threshold).

The Blocking Probability gives an idea on how the system is handling the CS requests. Figure 5.38 clearly shows that cell 2 has the highest problems in terms of blocked CS calls, showing an increasing probability since the beginning of the simulation. It may seem strange that the system is having blocked calls in spite of the UL load being always less than the 50% threshold. However what is shown in Figure 5.36 is the 10 simulation average, for sure in individual simulations the UL load goes above the limit (since blocked calls can only happen when the UL load goes above its top).

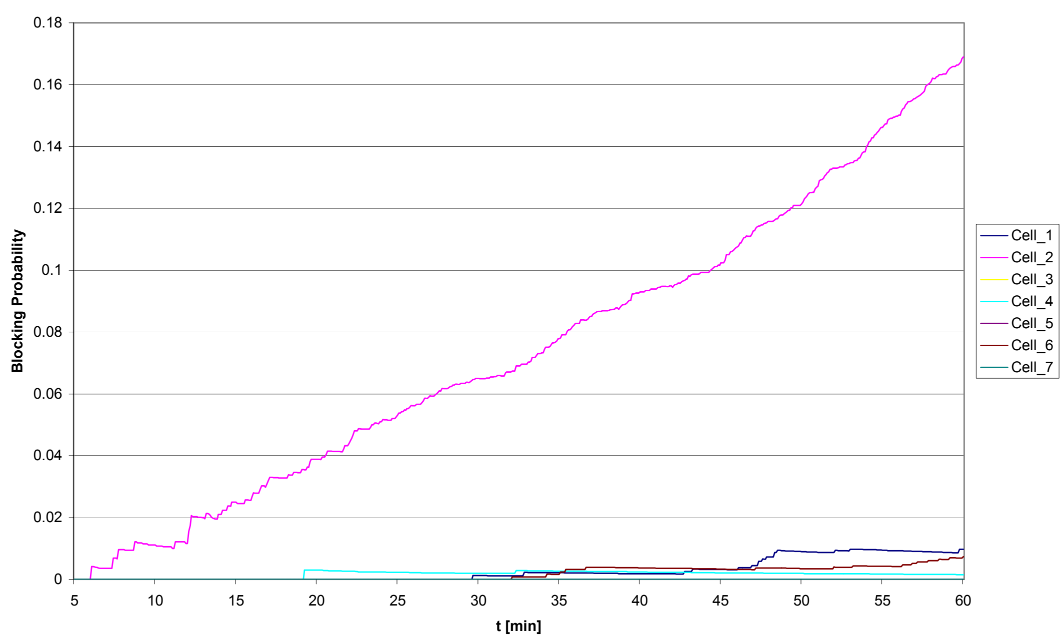


Figure 5.38. Blocking Probability (average of 10 simulations w/ UL threshold).

Figure 5.39 shows the average bit rate for the central cell, calculated for each PS service. When compared to the values obtained for the DL threshold scenario, Figure 5.28, one can clear identify that the impact on the system performance is much stronger if the load limit is on the DL side. The services with high bit rates decrease much deeper their average bit rate by the end of the simulation in the DL limit situation. It can also be identified that services like E-mail decrease their bit rate on the DL situation but are not affected when the limit is on the UL.

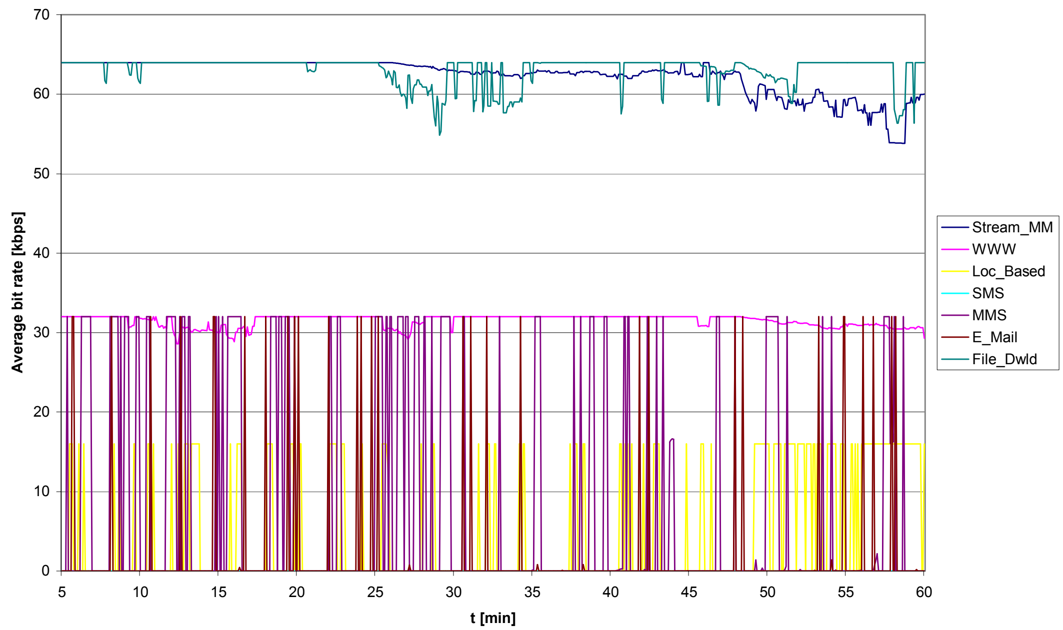


Figure 5.39. Average bit rate for the central cell (10 simulations w/ UL threshold).

5.5 Impact of Soft-handover

The final evaluation consisted in running the simulator with different cell handover radius in order to check the impact of user mobility in the system performance. Two additional simulations were performed: one with 20% and the other with 30% handover radius. The location is "Marquês de Pombal" for which we have already results with 10% handover radius. The total cell radius is the same for the three cases.

Figure 5.40 display the evolution of the handover DL load for the situation with 20% handover radius. When comparing this with Figure 5.22 (10% handover radius) it clearly points out that the respective handover load is much higher for the 20% situation.

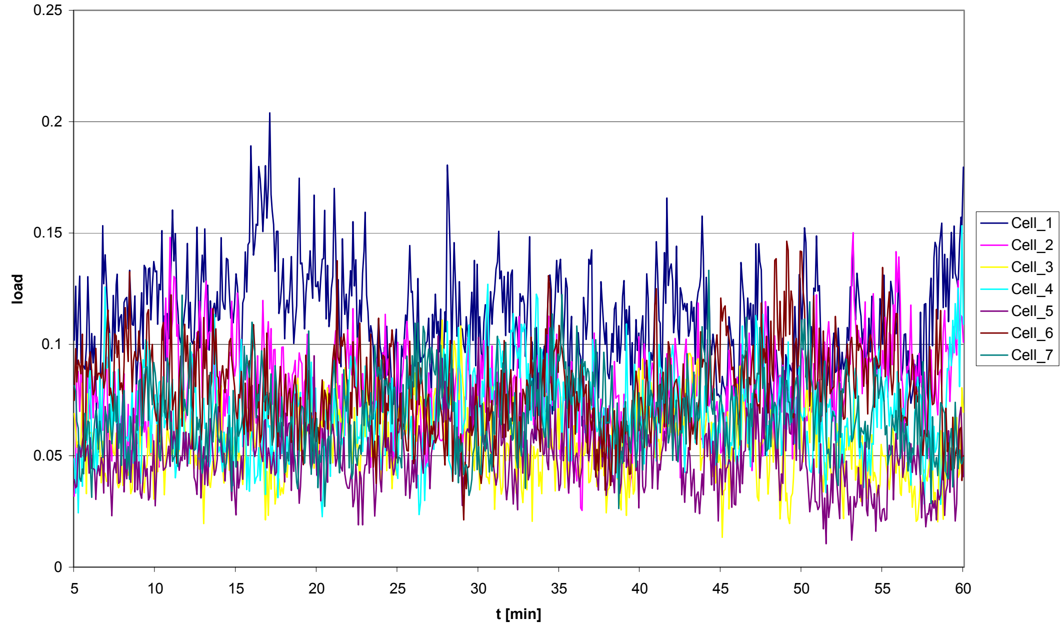


Figure 5.40. Handover DL load w/ 20% handover radius (average of 10 simulations).

While in Figure 5.22 it rarely goes above the 0.1 mark, in the 20% radius situation it sometimes goes up till 0.2 in load. It is also clear in Figure 5.40 that cell 1 has the highest handover loads due to the fact that it is the cell that suffers most influence from neighbouring cells (makes border with 6 user generating cells).

Figure 5.41 shows the same situation but now with 30% handover radius. Here the preponderance of the central cell in terms of load is even more evident (due to the reasons explained in the paragraph before). The load goes frequently above the 20% mark for cell 1.

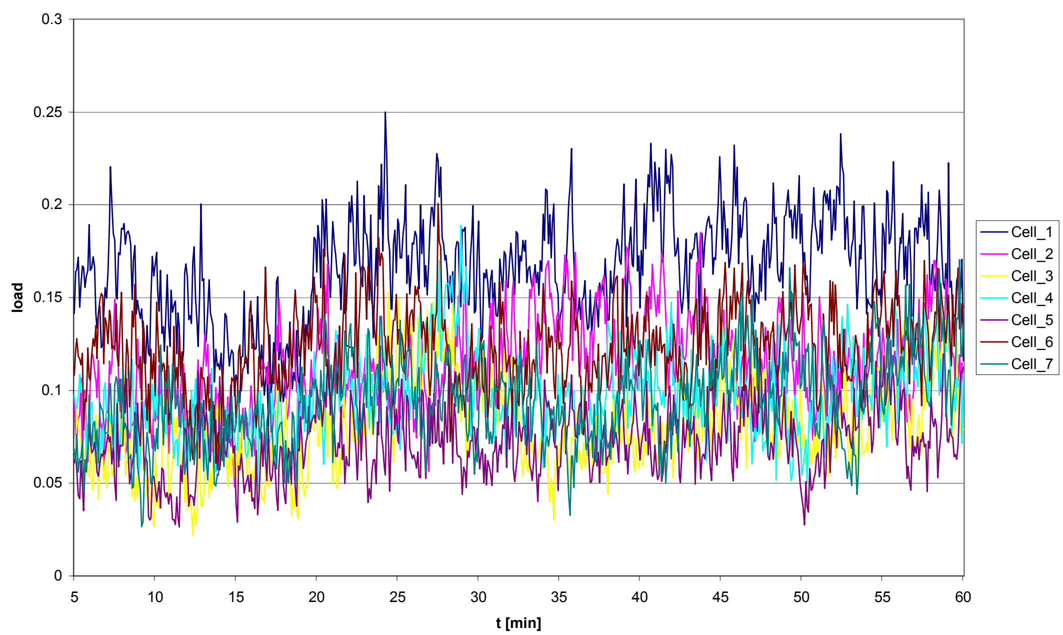


Figure 5.41. Handover DL load w/ 30% handover radius (average of 10 simulations).

Figures 5.40 and 5.41 clearly show how an increase in the handover radius will impact the system. This is an issue that has to be taken in consideration when the network is deployed since higher handover radius increase the performance of the system in terms of having lower percentages of handover failure but on the other hand, it increases the total load of the BS, taking out capacity for additional users or higher bit rates.

Chapter 6

Conclusions

This chapter finalises this work, summarising conclusions and pointing out aspects to be developed in future work.

The objective of this project was to evaluate the influence of non-uniform traffic distributions on UMTS performance and to analyse the impact of user mobility in the system.

In order to evaluate system performance, it was necessary to define which parameters to compute. The chosen parameters were UL and DL load, UL and DL handover load, Blocking Probability and Average Bit Rate, which are described in Chapter 3. In order to evaluate the impact of user mobility, it was necessary to choose an appropriate mobility model; all the evaluated models are listed also in Chapter 3, together with their main characteristics.

The next step was to build a dynamic simulator that would take all the necessary inputs and provide the required results. The main input parameters are: BHCA grid (traffic data per pixel per service), operational environment (terrain classification per pixel), mobility profile (correspondence between operation environment and mobility type), user service (list of the available service and their characteristics), call generation (average generation per pixel per service) and call duration (average duration per pixel per service), cell data (location, radius and handover radius), load and BS transmission power thresholds (to define capacity boundaries) and simulation resolution and duration (step duration and total number of steps).

The main output parameters are: UL load (cell occupation in terms of capacity for the UL channel, calculated per cell and for each simulation step), DL load (same as UL but for the downlink channel), BS transmission power (BS transmission power calculation per cell and for each time step), UL handover load (same as UL load but only for the handover region), DL handover load (same as UL handover load but for the downlink channel), Blocking Probability (QoS indicator for CS calls calculated per cell and for each time step) and Average Bit Rate per service (QoS indicator for PS calls calculated per service at each time step for the central cell).

The simulator covers a region of a seven-cell cluster in order to evaluate all the user transitions between the central cell and the 1st cell ring. The chosen mobility model is built into the simulator and is based on a triangular distribution for the user velocity and on a discrete probability function to change user direction. The simulator was programmed using MapBasic, a language built into the program MapInfo, a GIS application (a brief description of GIS applications is included in Chapter 4). The simulator runs using traffic information generated in the IST-MOMENTUM project. These BHCA grids give traffic load in a pixel-based configuration, and include also the operational environment for each pixel, which has a resolution of 20×20 m^2. Simulation step and maximum number of steps are also inputs. At the end of each simulation, a table is generated for each of the outputs; each table contains results from the seven cells and for each time step. In order to keep the simulator complexity at a reasonable level several simplifications had to be made: there is no power control for the MT (i.e., transmission power is always the same regardless of distance to BS), there is no Radio Resource Management (RRM) and no Call Admission Control like in a real UMTS system. Also, the mobility model chosen does not take in consideration the city geometry in terms of streets and buildings (e.g., vehicles can cross buildings).

The simulation scenario chosen was the city of Lisbon. Three locations were selected inside the city in order to consider different traffic situations: "Marquês de Pombal" (business area), "Monsanto" (open space area) and "Olivais" (residential area). For each of these locations ten simulations were ran with the same parameters (e.g., cell radius, load thresholds, simulation duration) in order to make the results comparable.

"Marquês de Pombal" is obviously the area with higher load values. As it can be seen from the UL load graphs (Chapter 5), values go above the threshold for some of the cells. But the impact to the system performance is on the DL side since load for this simulation is being limited by the UL. Concerning the DL load variation, it can be observed that the load in some cells goes above the 70% threshold, causing the cell to block CS calls and to decrease bit rates in ongoing PS calls. The significant difference between UL and DL load is due to the asymmetry of PS services. From the BS transmission power values obtained one may observe that values are well below the 43 dBm threshold, never causing the cell to saturate due to power reasons. This reinforces the fact that the system will be limited in terms of capacity and not coverage. Coming now to handover loads, one can see that the highest values are for the central cell, since this one has user transitions with all the other six cells. Blocking probability rises when the DL load reaches the threshold. Average bit rates decrease due to the same reason but to lower loads on the PS side.

"Monsanto", is dramatically different from "Marquês de Pombal". Since the region covered by the seven-cell cluster is mostly green area, load values are extremely low. On the other hand, the ratio of handover load to total load is higher in this case since most of the generated traffic comes from the highway that crosses the cluster. Users are mostly crossing the cells at high speeds causing frequent handovers between cells. As expected, blocking probability is zero since load values never reach the threshold. Average bit rates are equal to the nominal service value throughout the whole simulation due to the same reason, since the load control routines do not have to lower the PS calls bit rate to keep cell load within limits.

“Olivais”, is mostly a residential area. As such, load values are average, oscillating between 2 and 12% for the downlink. Load is also limited by the DL channel but never reaches the 70% threshold; therefore, CS calls are never blocked.

Besides running the simulator in different areas of the city, two other aspects were evaluated and the respective conclusions taken. One of the aspects was to study the influence of load threshold. As it was said before, simulations were run limiting the load in the DL channel. To compare data, values were computed for “Marquês de Pombal” but putting the load limitation in the UL (50% load limit). The results show that the UL threshold is also reached as for the DL case, causing CS calls to be blocked. This is shown by the evolution of the Blocking Probability, especially in the case of cell 2. DL values go beyond the 70% limit since it is not being controlled for this channel.

The other aspect evaluated was the impact of soft handover. To do this evaluation two more simulation conditions were considered: one with 20% and the other with 30% handover radius, both for “Marquês de Pombal” to compare with the initial data with 10% handover radius. Results show that the handover load duplicated when the radius was increased to 20%. The central cell was once more the one with the highest handover loads. This situation is even clearer in the simulation that considered a handover radius of 30%.

After the completion of this study, it is clear that an engineering work of this type is incredibly vast and it is deeply linked with resolving issues such as collecting data or defining models (propagation, traffic, mobility) appropriate to the situations being studied. Specially regarding issues related to the study of UMTS, there are few experimental results to compare with the theoretical and/or simulated results. This study also gave the opportunity to gain knowledge on the compromise between the number of users on a determined BS and the QoS available for them.

With this project, the complexity of a good network dimensioning in UMTS becomes clear, due to the multiplicity of available services in this system. It is necessary to make a compromise between interference and coverage through a good management and optimal distribution of resources to the users, very different from GSM. As soon as the first UMTS networks start operating, these simulations can be compared to real results, giving in this manner a mean to improve the application accuracy.

As an evolution to the work here described, a way to improve the "realness" of the simulation would be to modify the mobility model in a way that it would take in consideration the geography of the city for moving the users (i.e. consider roads, buildings, etc). The mobility model used in this simulation does not take into consideration the city structure, and the possible directions for the MT to take are only dependent on the probability assigned to each direction. For this reason, vehicular users can move through buildings or pedestrians can walk on highways.

Another point to improve would be to have the propagation model adapted to the area of the city being studied, since for this simulation the parameters were constant and independent of the chosen location. An additional grid could be created with propagation data for the city of Lisbon that would be taken into account when doing the path loss calculations.

Finally, the simulator could be extended to perform its calculations to the whole city so that user mobility could be considered on a wider and realistic extension. The current program only takes into consideration the central cell and the 1st ring of six cells. With this modification, the system would suffer the impact of users not only generated on the seven cells here considered. The simulation period could also be extended to a whole day and traffic variations across the 24 hours could be incorporated.

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