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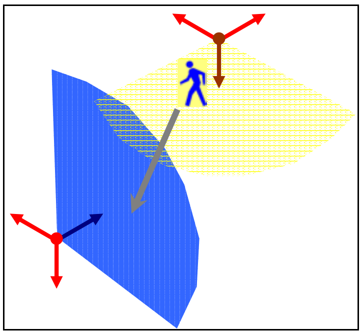

Analysis of the Influence of Multiservice Users' Mobility on UMTS Performance

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To my parents
for everything

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Abstract

This thesis analyses the impact of multiservice users' mobility in UMTS-FDD network performance. A system level dynamic simulator was developed in order to assess network performance by analysing key indicators, such as dropped call rate (DCR), blocked call rate (BCR), cell load in up- and downlinks, downlink power usage, handover performance and applications' average bit rates and delays, among others.

Four areas were chosen in Lisbon city as test scenarios. Multiservice and user density distributions were extracted from BHCA (Busy Hour Call Attempt) tables provided by IST-MOMENTUM project. Appropriate source models were implemented for each of the nine considered services: Speech, Video Telephony, Streaming Multimedia, HTTP, e-mail, FTP, SMS, MMS and Location Based Services. Both pedestrian and vehicular users were generated. For both, speed was generated randomly following a triangular distribution. Vehicular users' generation and movement were based on a real city streets database.

Network performance presents degradation with increasing users' average speed. An increase of 10 km/h in users' average speed increases DCR up to 0.6%. Users' indoor location was varied by moving 60% pedestrian users from outdoor to deep indoor, which increases DCR from 0.10% to 0.65%, and increases 60% maximum downlink transmitting power.

These results bring out the importance of having a correct users' characterisation regarding their speed and their location. The same amount of users in the network can imply a completely different network performance, and these effects must be known and considered by mobile communications operators in order to achieve the target network performance.

Keywords

UMTS-FDD, Traffic Models, Users' Mobility, Multiservice Users, Network Capacity

Resumo

A presente tese analisa o impacto da mobilidade de utilizadores multiserviço no desempenho da rede UMTS-FDD. Foi desenvolvido um simulador a nível de sistema com vista à avaliação do desempenho do sistema com base em indicadores fundamentais, tais como taxa de queda de chamadas, taxa de bloqueio, carga das células nos canais ascendente e descendente, utilização de potência em canal descendente, desempenho de passagem de chamadas e ritmos médios e atrasos a nível aplicacional, entre outros.

Foram definidas quarto áreas em Lisboa como cenários de teste. As distribuições de multiserviços e de densidade de utilizadores foram extraídas das tabelas BHCA (*Busy Hour Call Attempt*) disponibilizada pelo projecto IST-MOMENTUM. Foram implementados modelos de fonte apropriados a cada um dos nove serviços considerados: Voz, Video Telefonia, *Streaming Multimedia*, HTTP, e-mail, FTP, SMS, MMS e Serviços de Localização Geográfica. Foram gerados utilizadores pedestres e veiculares. Para ambos, a velocidade foi gerada de forma aleatória com base numa distribuição triangular. A geração e movimentação dos utilizadores veiculares foi baseada numa base de dados das ruas da cidade.

O desempenho da rede apresenta uma degradação com o aumento da velocidade média dos utilizadores. Um aumento de 10 km/h na velocidade média dos utilizadores aumenta a taxa de queda de chamadas de até 0.6%. A localização dos utilizadores em ambientes interiores foi variada, movendo 60% de utilizadores pedestres de ambiente exterior para o interior profundo de edifícios o que aumentou a taxa de queda de chamada de 0.10% para 0.65%, e aumentou 60% na potência máxima de transmissão em canal descendente.

Estes resultados realçam a importância de se possuir uma correcta caracterização dos utilizadores no tocante à sua velocidade e localização. O mesmo número de utilizadores pode provocar um desempenho da rede completamente diferente, e estes efeitos devem ser conhecidos e atendidos pelos operadores de comunicações móveis por forma a obter o desempenho desejado da rede.

Palavras-chave

UMTS-FDD, Modelos de Tráfego, Mobilidade de Utilizadores, Utilizadores Multiserviço, Capacidade de Rede

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List of Acronyms

3GPP	3^{rd} Generation Partnership Project
AMR	Adaptive Multi-Rate
BCR	Blocked Call Rate
BHCA	Busy Hour Call Attempt
BS	Base Station
BxLx	Downtown of Lisbon
CAC	Call Admission Control
CDMA	Code Division Multiple Access
CN	Core Network
CS	Circuit Switch
DCR	Dropped Call Rate
DL	Downlink
EIRP	Equivalent Isotropic Radiated Power
E-UMTS	Enhanced UMTS
FDD	Frequency Division Duplex
FTP	File Transfer Protocol
GGSN	Gateway GPRS Support Node
GIS	Geographical Information System
GMSC	Gateway MSC
GPRS	General Packet Radio System
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GUI	Graphic User Interface
HLR	Home Location Register
HODR	Handover Drop Rate
HOFI	Handover Flow Indicator
IHOW	Incoming Handover Weight
IST-SEACORN	Information Society Technologies – Simulation of Enhanced UMTS access and Core Networks
HLR	Home Location Register

HTTP	Hyper Text Transfer Protocol
ISP	Internet Service Provider
LBS	Location Based Services
ME	Mobile Equipment
MMS	Multimedia Messaging Service
ISDN	Integrated Services Digital Network
IST-MOMENTUM	Information Society Technologies - Models and Simulations for Network Planning and Control of UMTS
ME	Mobile Equipment
MSC	Mobile Switching Centre
MT	Mobile Terminal
NRT	Non-real Time
OVSF	Orthogonal Variable Spreading Factor
PDF	Probability Density Function
PLMN	Public Land Mobile Network
PS	Packet Switch
PSTN	Public Switched Telephony Network
QoS	Quality of Service
RAB	Radio Access Bearer
RAN	Radio Access Network
RF	Radio Frequency
RNC	Radio Network Controller
RRM	Radio Resource Management
RX	Receiver
SF	Spreading Factor
SGSN	Serving GPRS Support Node
SHO	Soft Handover
SMS	Short Message Service
SOHO	Small Office Home Office
SSHO	Softer Handover
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TX	Transmission
UDP	User Datagram Protocol

UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
USIM	UMTS Subscriber Identity Module
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register

List of Symbols

B_r	Service bit rate
d	Distance between base station and mobile terminal
E_b	Required bit energy
$EIRP$	Equivalent isotropic radiated power
f	Frequency
$F_{a\,m}$	Activity factor of user *m*
G_t	Transmitting antenna gain
G_{div}	Diversity antenna gain
G_p	Processing gain
G_r	Receiving antenna gain
G_{rdiv}	Receiving antenna gain with diversity
G_{SH}	Soft handover gain
h_b	Base station antenna height
H_B	Building height
h_m	Mobile terminal height
HO_in	Incoming handovers
HO_Out	Outgoing handovers
H_{roof}	Roof correction factor
$I_{inter\,n}$	Normalised inter-cell interference
$I_{inter\,n\,m}$	Normalised inter-cell interference for user *m*
k	Number of states
K_a	Path loss correction factor
K_d	Distance correction factor
K_f	Frequency correction factor
L_0	Free space path loss
L_{bsh}	Base station height correction factor
L_c	Losses due to cable between transmitter/receiver and antenna
$L_{C\,m}$	Load factor for a specific connection and user

$L_{C\,m}^{DL}$	Load factor for a specific connection and user in downlink
$L_{C\,m}^{UL}$	Load factor for a specific connection and user in uplink
L_{ind}	Indoor penetration losses
L_{ori}	Orientation correction factor
$\overline{L_p}$	Average path loss
L_p	Path loss
L_{pmax}	Maximum path loss
$L_{p\,tot}$	Total propagation attenuation
L_{rr}	Roof to roof correction factor for path loss
L_{rt}	Terminal to roof correction factor for path loss
L_u	Additional losses due to user's presence
M	Additional system margin
M_I	Interference margin
$M_{F\,SF}$	Slow fading margin
$M_{F\,FF}$	Fast fading margin
N_0	Average noise power
N	Total noise power
N_c	Number of coordinates to be generated for a particular user
N_u	Number of active users in the cell under analysis
P_b	Blocked call rate
P_d	Dropped call rate
P_{dHO}	Outgoing handover drop rate
P_e	Transmitting power at antenna port
P_{HO}	Handover flow indicator
P_{HOCall}	Handover per call
P_r	Available receiving power at antenna port
P_{Rx}	Input power at receiver
P_{Tx}	Output power of transmitter
R_b	Bit rate associated to the analysed service
$R_{b\,m}$	Transmission bit rate for the service of user *m*

R_c	Code rate
v_i	Mobile terminal speed
Vs	Volume generated by a user
X_{Time}	Extra Time Overhead Parameter
W_B	Distance between two consecutive buildings
W_S	Streets width
α_m	Orthogonality of codes used by user *m*
Δf	Signal bandwidth
ϕ	Street incidence angle
η	System's load
$\overline{\eta_{DL}}$	Average downlink system load

List of Programs

Microsoft Visual C++, Microsoft Corporation Corporation (http://www.microsoft.com)

MapBasic®, MapInfo Corporation (http://www.mapinfo.com)

MapInfo®, MapInfo Corporation (http://www.mapinfo.com)

Microsoft Office Excel®, Microsoft Corporation (http://www.microsoft.com)

Microsoft Office Word®, Microsoft Corporation (http://www.microsoft.com)

Chapter I

Introduction

This chapter starts by presenting an overview on the current status of the mobile communications market. The motivations for this thesis are presented, based on the diversity of users' services, their geographical distribution on urban areas, and distinct mobility profiles. The most recent related studies are summarised, followed by the description of the process used to assess the results in this thesis. The innovations brought by the analysis process used in this study are presented, and the document structure ends the chapter.

Mobile personal communication technologies have suffered a tremendous evolution over the last two decades. Starting from the analogue systems and their bulky equipments, the next step for a digital system (GSM – Global System for Mobile Communications) was a natural evolution. The acceptance of GSM was beyond all expectations, and created an activity sector that very often drives the up and down of financial markets. The will of having even more revenues in the mobile communications' market, led companies to a somehow rushed deployment of third generation communication systems – the UMTS (Universal Mobile Telecommunications System).

By the end of 2004, the mobile communications market lives now an "after the storm" situation, after three years of very strong uncertainty driven by several factors:

- technology took the natural time to produce stable equipments, while many suppliers and mobile communications operators were fighting to take the lead of the communications markets; even today, systems (specially mobile equipments) are still not sufficiently stable in order to allow a sustainable deployment of services;
- a generalised economical crisis lead investments to be frozen (or at least strongly decreased), and only now the guidelines seem to be clearer when indicating that this is the time to invest again;
- although UMTS networks have been officially launched one year ago across the Europe, only now real services are being offered to costumers, but still some doubts remain concerning the users' willingness for the type of services being provided;
- there is still the risk in having users that do not feel the need for such services, and operators face the burden of educating users for such needs.

The above factors are the main items concerning the status of UMTS business by the end of 2004, but the expectations for the usage of the system are still very high. The only difference (between today and four years ago, by the spectrum bidding) is that today people seem to have a clearer idea, concerning the fact that implementation of UMTS will be different and take longer than the one of GSM. In fact, UMTS demands that costumers have to use services other than voice, which must be felt as needed by users, and due to that, operators will have to educate costumers on that direction, as well as developing interesting applications and services.

One of the services that is expected to drive the growth of UMTS is the Internet access *via* a mobile terminal. This is a "dream come true", allowing people to access information anytime, anywhere, not requiring a personal computer to perform that access. However, the real “killer application” for UMTS is still unknown, and some observers are even sustaining that such application does not exist at all, but rather a mix of concurrent applications will be the basis for the success.

Although UMTS is standardised, there are still some open questions, from the technical perspective, concerning the behaviour of the system in certain usage scenarios. These open questions will be analysed in shorthand, as networks and services are becoming more and more stable, and the number of commercial users increases. Meanwhile, some theoretical studies can already provide answers to some of these questions.

UMTS is a system where multiservices usage is a reality and where network planning must cope with that specificity. Dimensioning a UMTS network demands not only a perfect knowledge of the geographical distribution of users, but also of the services’ type distribution, as each type of service demands differentiated Quality of Service (QoS) targets and imposes distinct load conditions to the system. This services differentiation brings some peculiarities, as for example, the same number of active users may bring completely distinct network load conditions, just because they are not using the same type of service. Furthermore, not only the type of service imposes limits to the performance of the network, but also to its usage profile. It is clear that the utilisation of an Internet access may be completely different, depending on the end user using it for business or domestic purposes. These are direct consequences of multiservice usage, and they must be carefully taken into account, in order to achieve a proper network planning. The structure of the radio network can only be adequately designed if the impact of these distinct types of usage is known from the start.

Mobile users impose distinct conditions to the radio network compared to the static ones, as they force the system to compensate for the varying propagation conditions along the session duration. The fact that users move when they use a service forces the system to guarantee the radio connection by using soft and softer handover[1] radio links, which will take extra capacity from the system. Also, system’s performance is dependent on the users’ mobile speed, as the equipments’ sensitivities and fading profiles depend on how fast the radio environment changes. The serving areas of the cells (specially in urban areas) can have very distinct mobility characteristics, even inside the same cell, as the cell can be guaranteeing coverage to a small street side by side with a big avenue. Also, a mobile user can, during a

[1] When a mobile is in the overlapping cell coverage area of two adjacent sectors, and the communication between it and the network is assured by one radio link for each sector, the mobile is said to be in soft or softer handover if the sectors belong to the same or to different sites, respectively.

session duration, move from outside a building to its interior, and this may cause an additional indoor penetration loss up to 25 dB, which have to be compensated by increasing the amount of power reserved for that user, hence, augmenting the downlink interference being generated in the cell. This multiplicity of mobility environments impacts on the networks' behaviour, as UMTS is all about sharing air interface resources; as such, it is of great interest and importance to study the response of the network to these factors, and to assess the impact they produce on the overall network behaviour. This characterisation assumes special relevance for mobile operators' network dimensioning processes. In fact, dimensioning a UMTS network demands quite a lot of further information than GSM networks do, as the network radio resources are shared among users, and the demands imposed by these, depend on their location, speed, and type of services being used.

The studies performed so far on this subject still leave some characterisations to be accomplished, which are not only important but also critical when operators need to design their radio networks. As an example, the Iub interface (linking Node Bs with RNC, according with Figure II.1) is usually guaranteed, in the commercial networks, by leased lines, which monthly fees play a very important role in the business plan of the companies. It is fundamental for operators to know in detail the amount of capacity the soft and softer handover links have in the network, and the variation they can assume when mobility is taken into account, as those links need to cope with the extra capacity needed for soft handover links. On the other hand, softer handover does not impact on those leased lines dimensioning, as it is performed at Node B level. One of the objectives of this thesis is to quantify the impact mobility has on soft and softer handover links usage weighting. Another characterisation still not answered by studies performed so far, is the impact different mobility profiles have on the network performance and resources utilisation, when linked with different network load conditions. The quantification of these impacts play an important role when operators have to design the radio network in areas with distinct traffic and mobility distributions. This thesis intends to provide some answers that clarify the concerns stated above.

Mobility and traffic modelling, and their impact on UMTS performance, have been the subject of an increasing number of studies and research projects. Just to mention the most recent ones:

- Allen Vasconcelos and Patrícia Carvalho's graduation project [VaCa02] studied the performance of distinct services (in a multiservice scenario), aiming at dimensioning a UMTS network, taking into account both traffic and propagation constraints. An application was developed to generate users spread throughout a city, based on the population characteristics concerning spatial concentration and age distribution (which was then related to specific usage of a certain type of services).

- The IST-MOMENTUM project addressed this matter, and in one of the project's deliverables (Deliverable 1.3 [FCSC02]) a multiservice traffic forecast for static users is developed, detailed results being shown for some selected European cities. Procedures to generate mobility and traffic scenarios are presented and discussed in detail. Users' mobility is introduced by defining mobility scenarios, characterised by distinct mobility types and models controlling users' movement on a motion grid. Users' mobility impact on traffic load is studied.
- Gonçalo Carvalho's Master Thesis [Carv03] mixed both multiservice and users' mobility to assess UMTS network performance. In this study, a cluster of seven omni-directional cells was considered and placed in distinct areas of Lisbon, in such a way that diversity in traffic mix and mobility profiles could be tested. Mobility was implemented considering that mobile users could move in one of four (orthogonal) possible directions. System performance was assessed through cell load, power usage, blocking probability and average bit rate. This is one of the most complete works found in this area.
- Leonardo Badia et al. [BaZF03] studied the improvement that could be achieved in CDMA systems when using known information of users' mobility in Call Admission Control (CAC) algorithms. Their study shows that increasing fairness (in the sense that ongoing connections are not released due to the admission of new connections) of the system can be reached. They show also that traditional approaches for CAC lead to unfairness in the system, if users with different mobility patterns coexist in the same system, and propose a new fairer CAC approach that tracks users' mobility patterns and uses it as input at call admission procedure.
- Jaime Ferreira et al. [FeGV03] presented a set of deployment scenarios and supported services for Enhanced UMTS (E-UMTS) in the scope of the IST-SEACORN (Information Society Technologies – Simulation of Enhanced UMTS access and Core Networks) project. Focus was also put on the importance of users' mobility characterisation by presenting a set of mobility models covering office environments, pedestrian and several vehicular environments. Those models and scenarios characterisation aim at defining the simulations' basis for the project, whose objective is addressing the next step in UMTS evolution, and clearly identifies the need to take into

special consideration the impact of non-uniform traffic and users with distinct mobility profiles.

The present work intends to go one step ahead from the most recent studies, by implementing a system level simulator, modelling both up- and downlink (UL and DL), associated to a more complete and realistic mobility model, which is attained by considering a radio network structure closer to the real ones. Multiservice users are generated in a way similar to [Carv03], and the area chosen to perform the simulations is also Lisbon city. The test network is, in this study, considered as a seven site cluster, each site consisting of three cells with orientations being 120º apart. This type of network configuration allows focusing on particular analyses, such as the weight softer handover has over the total amount of power and load used at cell level. Mobility generation is split into pedestrian and vehicular users: pedestrian users are free to move in any direction, ruled by a specific random variable distribution; vehicular users are restricted to move along the streets existing in the city. In order to achieve this purpose, the simulators rely on a map of the city streets, and by analysing it, the average speed of the vehicular users is suited to the type of street (it being, e.g., an avenue, a highway or a small street). Also based on this map, vehicular users are able to choose which street to go when they face crossroads. Users' speed (both pedestrian and vehicular users) has a triangular distribution with distinct values (the vehicular average speed is a function of the type of street in which they move along, and pedestrian users have a fixed, lower average speed). In Lisbon, four test scenarios were selected to cross both users density (high and low) with mobility level (high and low). Downtown (Baixa) was chosen for high traffic density low mobility area studies and Av. República distinguishes from it by having a higher mobility level. On the opposite, Moscavide was chosen to provide an area with low traffic density low mobility level, and Benfica differs from this one in the sense that it presents a higher mobility level.

In the implementation phase of the simulator some limitations were found in the programming platforms that could be chosen. In order to overcome those limitations it was decided to build two simulations platforms: the first one (SIMOTS) would be designed in MapBasic® for users generation and mobility characterisation; and the second one (CRUS) that would be designed in C++ for the system level analysis of the scenario under test. The two platforms would interact through open text format files for easy information processing and handling.

This increasing complexity (when comparing to a single, fully integrated simulator solution) aims at identifying more detailed trends in network behaviour. The network performance is assessed by analysing:

- Blocked and Dropped Call Rates;
- UL and DL loads (average and maximum values, as well as 5% and 95% percentiles);
- DL transmitting power (average and maximum values, percentage distribution per best server, soft and softer handover radio links);
- DL Channelisation codes utilisation (average value, percentage distribution per best server, soft and softer handover radio links);
- Handover performance (ratio between successful incoming and outgoing handovers, as well as dropped outgoing handovers);
- Packet Switched applications' performance (concerning average delay, UL and DL average bit rates, 5% and 95% percentiles of the bit rates);
- System trends are extracted for different mobility profiles concerning dropped call rate, blocked call rate, handovers performance and power level utilisation.

This thesis innovates by the process used to analyse mobility impact in real non-uniform traffic distribution scenarios. A single frequency UMTS-FDD network, with tri-sectorised sites is considered in this study. Mobility is generated in an innovative way (when compared with the studies presented so far) as it is based on a city streets database, which is used to generate vehicular users locations and define their average speed, based on the type of streets where each particular vehicular user moves on. Mobility is also generated for pedestrian users (with an appropriate speed distribution), and these are placed in several indoor environments, with the intention of modelling different levels of users indoor utilisation. Network performance and radio resources usage is analysed in this thesis in a systematic and global way, in order to assess network response trends on mobility conditions and traffic density variations. In this sense, network performance trends, measured by dropped and blocked call rates, are assessed as a function of average users' speed.

Chapter 2 initiates this journey by focusing on the basic aspects of UMTS. The network description is followed by a description of services and applications that can be provided by this system. Specificities of the system are then discussed, concerning multiple access scheme and frequency bands. A brief description of link budget is then introduced (with a deeper description presented in Annex A) in order to bring out the specificities of system design. Finally, the balance between system capacity and interference is analysed in detail. As a complement, Annex B presents a detailed description of the propagation model used in the system level simulator. Chapter 3 introduces the mobility models available in the most recent literature, which are described in detail with a special emphasis on the models that are implemented in the simulators. Traffic models are also presented, and special detail is given to those implemented in the simulation process as well. Chapter 4 gives all the details concerning the huge task of developing a system level simulator from scratch. This chapter contains the implementation strategy, and describes the input and output data of each simulator (the simulation process consists of two coordinated simulator platforms). Simulators' fluxograms are introduced to illustrate their functioning, and Annexes C to H present all the relevant data to support the accurate behaviour of the simulators. Still, Chapter 4 introduces simulators assessment, as well as results statistical and performance analyses. Chapter 5 presents the results obtained from the simulation scenarios analysis. First of all, the scenarios are characterised by users, services and mobility distributions. Test scenarios setup are then introduced, followed by the results showing the impact of mobility on the reference ones. The impact is analysed by comparing the system performance in the several configurations. Mobility profiles are changed in Downtown and Benfica, in order to increase the impact of extremely different mobility conditions. System response trends are then built, based on all the above results. Users' locations are changed, in order to assess system response. Annexes I to K provide extra data analysis and information to complete the study. Chapter 6 finalises the study by aggregating all the system trends coming from the variations imposed and by drawing some conclusions and guidelines for future work.

Chapter II

UMTS Basic Aspects

In this chapter the fundamentals of UMTS are presented. The network structure is presented in detail, followed by a close analysis of the services and applications that can be supported by UMTS networks. Codes and multiple access schemes adopted by the system are analysed, followed by details on operation modes and frequency bands. System’s link budget is presented with special emphasis on system’s specific parameters. The chapter ends with the analysis of system’s capacity and interference analysis.

II.1. Network Description

UMTS design was based on a set of network elements, each of them associated to specific functionalities, Figure II.1, allowing to have separated domains in the system [HoTo01]. This is, however, the same kind of concept that was behind the design of GSM.

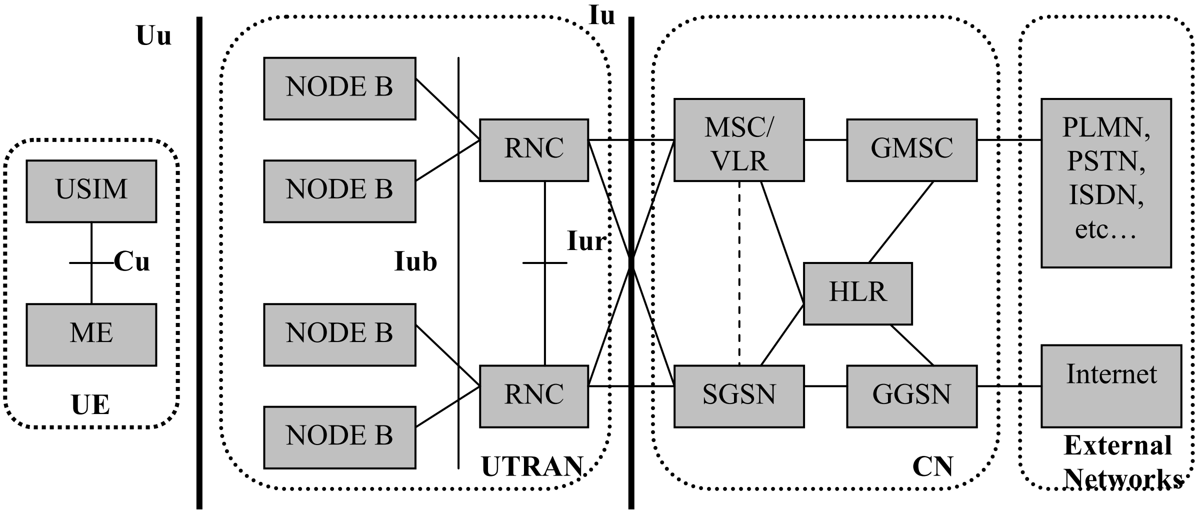


Figure II.1 - UMTS system architecture (extracted from [HoTo01]).

In the UMTS architecture, the following network elements can be identified:

- UE (User Equipment) responsible for interfacing the user with the system through the radio interface. The UE is constituted by the ME (Mobile Equipment), which is the radio terminal working over the Uu interface, and the USIM (UMTS Subscriber Identity Module) that holds the data concerning the subscriber identity and that performs the algorithms for authentication using the authentication and encryption keys that are stored in it.
- Node B, the Base Station (BS), performing the conversion of information between Iu and Uu interfaces, and taking part of the RRM (Radio Resource Management) process.
- RNC (Radio Network Controller), which controls radio resources allocated to its domain. It is responsible for establishing and maintaining radio connections in the Uu interface through the control of Node Bs depending on it. Some functions needed for maintaining the radio connections may be implemented in the Node Bs serving each UE (such functions being, for instance, softer handover and inner loop power control, which are further detailed). When comparing RNCs with similar network elements from GSM,

the existence of an interface that is transverse to the system is noted, connecting different RNCs; this is the Iur interface, which allows UMTS to perform soft handovers between Node Bs belonging to different RNCs.

- MSC/VLR (Mobile Switching Centre / Visitor Location Register) is responsible for switching (MSC) the CS (Circuit Switch) transactions for the UE in the respective location area, and for holding a copy (VLR) of the visiting user's service profile.
- GMSC (Gateway MSC) provides the connection to external networks for CS services, such as PLMN (Public Land Mobile Network), PSTN (Public Switched Telephony Network) and ISDN (Integrated Services Digital Network).
- HLR (Home Location Register) is simply a database holding a master copy of the user's services profile. Each user has his/her profile indicating the allowed services, supplementary service information, etc.. For each user, this database also holds the UE location (necessary for routing incoming calls).

The previous elements are the basis for the system providing CS services. For PS (Packet Switch) services, such as GPRS (General Packet Radio System) in GSM, two additional elements are added to perform the similar functions of MSC and GMSC: the SGSN (Serving GPRS Support Node) performs the switch of the PS services, and the GGSN (Gateway GPRS Support Node) grants the connection to external data networks (in a wide sense, the Internet).

RNCs along with the controlled Node Bs constitute the so-called UTRAN (UMTS Terrestrial Radio Access Network), which is responsible for all the radio-specific functions concerning the establishment, maintenance and ending of calls. The MSC/VLR, GMSC, HLR, SGSN and GGSN constitute the Core Network (CN), being responsible for routing the traffic (CS and PS) inside the operator's network as well as to external ones.

Relevant aspects of this system are the efforts put on the standardisation of all the relevant interfaces, allowing the opening of the system to a multitude of suppliers. Cu, Uu, Iub, Iu and Iur are open interfaces, and were standardised in order to allow having in the same network a mixture of different suppliers, as well as to foster the appearance of suppliers with focus on specific network elements. Specially Iub is a fully open interface, which makes UMTS the first commercial system where the connection between BSs (Node Bs) and the respective controller (RNC) is fully opened. This is expected to increase the competition among manufacturers, and potentially to lead to the appearance of new manufacturers that only develop RNCs. Nevertheless, Iub interoperability and specific support for RRM features make it difficult in practise to have different node B and RNC suppliers.

II.2. Services and Applications

Mobile telecommunication systems have suffered a tremendous evolution during the last decades, concerning the type of services offered to costumers. 1st generation systems only provided voice calls services. The appearance of 2nd generation brought, besides voice, data services with low bit rates, and its evolution (the so-called 2.5 generation) increased the available user bit rate (along with a better spectral efficiency). 3rd Generation communication systems were conceived having in mind the need for increased data bit rates, in order to allow and encourage the birth of new and appealing services. Four service classes have been defined for UMTS by 3GPP (3rd Generation Partnership Project – the international entity responsible for the standardisation of 3rd generation mobile communications systems), each of them having different QoS requirements [HoTo01], [Corr01], Conversational, Streaming, Interactive and Background.

The Conversational class supports delay-sensitive services. The most common of these services is the AMR (Adaptive Multi-Rate) speech service. Unlike former systems, the speech service is not assigned to a fixed bit rate; instead, a codec that can support eight different source rates (ranging from 12.2 to 4.75 kbps) controlled by RAN (Radio Access Network), is used. The source rate is chosen by RAN based on the QoS desired by the user and the measured radio quality of the network. The source rate can be up- or downgraded during the call by means of RAN's commands.

Video telephony is another service that is very delay-sensitive, requiring delay demands similar to speech. These services are delay-sensitive because their aim is to provide real-time connections between human peers; since human users are the "clients" of such services, the delay perceived by them is very important in evaluating the offered QoS. According to subjective tests, voice delay (in speech service) cannot be higher than 400 ms; otherwise, the user will feel unpleasant using the service. In the same way, when using video telephony, the user does not cope with image delay, because this creates difficulties in the usage of the service (forcing the user to pause during conversation, which, in extreme cases, can lead to very difficult dialogs). These services are symmetric, or almost, which is the normal situation when two persons interact talking with each other.

The Streaming class was thought to support services as, for instance, video streaming. Video streaming is visualized in the destination equipment (personal computer, suitable user equipment, etc.) by means of a suitable media player, which does not have to receive all the stream of data before being able to process and display it to the user. This service is highly asymmetrical (traffic majority in DL) having in and is not as delay-sensitive as the former ones, due to the queuing performed by the final application.

The Interactive class is less delay-sensitive than the first two ones, and it was defined in order to support services such as web-browsing, access to data servers, data retrieval from databases, or remote measurement equipment. For these types of services, the end-user can be either a person (e.g., Internet browsing) or a machine (for instance, a monitoring system for a fleet of self-serve machines). A lot of new services have already been thought to be included in this class of services. Many location-based services can be implemented, depending on the hardware available in the Mobile Terminal (MT). High precision location services may need the availability of GPS information at the MT, while low precision ones can be implemented based on the measurements performed in the network (e.g., signals' time of arrival). These services aim at providing information to the user depending on his/her current geographical position, which can be related to the nearest restaurant, hotel, or gas station. Hence, the network will send to the user information, whose deliverance delay is not much sensitive, but which must be delivered without any errors.

Finally, the Background class is not delay sensitive at all, because it was defined to support services that are not supposed to be delivered to the end-user within a certain time. Such services are SMS (Short Message Service), e-mail, downloading of databases, reception of measurement records (from remote systems), etc.. The delay in having the information delivered can range between a few seconds and some minutes. One very important requirement for these services is that information must be delivered error free.

The above classes of services are defined based on the requirements of the typical services to be carried by each of them. The main requirements are based on maximum allowed time delay, permissible error rates, and minimum service bit rate. Each specific service has a minimum requirement for each of these three figures.

Regarding the bit rate, several classes were defined [HoTo01]:

1) 32 kbps class, allowing basic speech service (including AMR services) and limited data rate services (up to 32 kbps);
2) 64 kbps class, serving as a basis for speech and data services, allowing simultaneous data and AMR applications;
3) 128 kbps class, being the basis for video telephony, as well as for other data services demanding more than the previous class;
4) 384 kbps class, supporting advanced packet methods;

5) 2 Mbps class, being the state of the art, but only supported in DL.

Table II.1 summarises the characteristics of the several service classes with examples for their target requirements (concerning bit rate) and proper application examples.

Table II.1 – UMTS Services and Applications (extracted from [Corr01]).

Service Class	Conversational	Streaming	Interactive	Background
Real Time	Yes	Yes	No	No
Symmetry	Yes	No	No	No
Switching	CS	CS	PS	PS
Guaranteed bit rate	Yes (16 kbps)	Yes (128 kbps)	No (384 kbps)	No (14.4 kbps)
Delay	Minimum Fixed	Minimum Variable	Moderate Variable	High Variable
Buffering	No	Yes	Yes	Yes
Bursty	No	No	Yes	Yes
Example	Voice	Video-clip	Web-Browsing	e-mail

II.3. Codes and Multiple Access

Multiple access of different users is achieved in UMTS by using Code Division Multiple Access (CDMA) technology. CDMA consists of multiplying user's data sequence by a well-determined bit sequence (the spreading sequence), whose bit rate is much higher than the user's bit rate. The achieved sequence holds the information provided by the user, but in an "encrypted" way. The only way of recovering the user's data sequence is by multiplying the achieved sequence by the spreading sequence (which is called dispreading operation). If this last operation is performed using a different sequence, the user's information is not recovered, and the resulting sequence will have a very low correlation with the user's original sequence, meaning that, from the information's point of view, it will be seen as noise. Regarding bit rates analysis, the result of the first operation has a bit rate higher than the original sequence, meaning that the corresponding spectrum has been widened, and became as wider as the spectrum of the spreading sequence. This is why CDMA is called a spread spectrum technique. This widening would not happen if both signals had the same bit rate. Regarding the second operation, when using the appropriate spreading sequence the original sequence is recovered, meaning that its spectral properties are also recovered.

As mentioned above, spreading is performed using a sequence called spreading code [HoTo01]. In UMTS, the spreading (or channelisation) codes are based on the Orthogonal Variable Spreading Factor (OVSF) technique, being designated by WCDMA (Wideband Code Multiple Access). This technique arranges the several codes (with different lengths) in a structured tree, and allows the spreading factor to be changed, while maintaining the orthogonality among them. It is a major issue to guarantee, as much as possible, the orthogonality among the different spreading codes, in order to ensure that only one of the available codes decodes the spreaded information.

Channelisation codes have different lengths, leading to different spreading factors. The number of bits (called chips in CDMA) constituting each code gives the associated spreading factor. Hence $C_{4,X}$ codes (length 4 chips) ensure a spectrum spread of 4 times, and $C_{512,X}$ (length 512 chips) codes provide a spectrum spread of 512 times. Channelisation codes' length ranges between 4 and 256 chips in UL and 4 and 512 chips in DL. The codes' length is always a base 2 number, and the number of available codes per cell is equal to the associated spreading factor per each assigned scrambling code in the cell. In UL, different channelisation codes are used in order to separate physical data channels from physical control ones coming from the same MT. In DL, channelisation codes allow the separation of different connections to different users within the same cell.

Figure II.2 shows that channelisation is performed upon the data to be transmitted, after which the signal is once more multiplied by another code. This second operation is performed using now a scrambling code, whose function is to scramble the information in such a way that it can only be de-scrambled when multiplying it by the same scrambling code; in UL, this operation allows for the separation of MTs, and in DL for the separation of different sectors (or cells). In UL, scrambling codes can be either short (having a length of 256 chips chosen from the extended S(2) code family [3GPP02a]) or long ones (generated by 25 degree generator polynomials and truncated to the 10 ms frame length, giving 38400 chips – Gold codes [3GPP02a]).

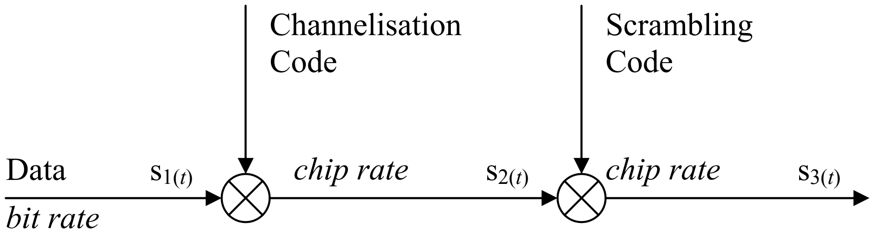


Figure II.2 – Channelisation and Spreading processes (extracted from [HoTo01]).

Long scrambling codes are used when a normal receiver is at the BS, and short ones are used if complex operations (such as multiuser detection or interference cancellation) are used at the BS in order to allow a simpler hardware implementation of the receiver. Either of the families have millions of codes, meaning that UL does not need code planning, their utilisation being managed by the RNC.

The channelisation codes can have different lengths and are constructed in a recurrent way. They constitute a so-called "code tree", which has a limited number of branches [HoTo01]. Each cell of the network has allocated a code tree for each assigned scrambling code. The channelisation codes in use in that cell are picked up from the associated code tree, which has a limited number of codes. The appropriate code for a particular connection depends on the bit rate (spreading factor) associated to that connection. For every code picked from the code tree, all codes "under" it are no longer able to be used in that particular cell because they are not orthogonal to the referred code. This may lead, in some cases, to a capacity limitation in the cells, meaning that no more codes are available from the code tree. When this situation is reached, it has to be overcome by activating another frequency in the cell and associating it to another channelisation code, or OVSF code usage optimization procedures.

In DL, Gold codes are used. The cell search procedure is based on the detection of the scrambling associated to each cell, and in order to maintain the time needed for this search process in an acceptable range, the set of primary scrambling codes is limited to 512 codes. Hence, planning is necessary for DL scrambling codes, but such process is expected to be simple to implement due to the high number of available codes.

The required radio bandwidth to transmit the signal (5 MHz) is not affected by the scrambling process, as it is applied to a data sequence that has the same chip rate as the scrambling sequence (3.84 Mcps)

II.4. Operation Modes and Frequency Bands

Two different duplex transmission modes were considered for UMTS, Time Division Duplex (TDD) and Frequency Division Duplex (FDD) [HoTo01].

The TDD mode is based on the common Time Division Multiple Access (TDMA) technique, but with a CDMA component. The access to the system is made on a “per time slot” basis, and the signals from different users are separated in both the time and code domains. This transmission mode has some particularities compared with FDD; just to mention some of the differences, the TDD mode does not support soft handover, and the set of spreading factors is smaller than the one supported by FDD. The TDD mode is thought to be used in hotspots (especially indoors), with a high bandwidth demand as a way of enhancing an already existing FDD network, and it is expected to be deployed in a mature phase of UMTS.

The TDD mode has reserved, in Europe, a total bandwidth of 25 MHz. The reserved bands are 1900-1920 MHz and 2020-2025 MHz. Each channel occupies 5 MHz, thus, leading to 5 available TDD channels.

The other duplex mode, FDD, is based on the usual frequency duplex division with a CDMA multiple access method. Each user uses different frequency bands for UL and DL. Unlike the first method, FDD supports soft handover, and is based on a faster power control scheme, with a larger set of spreading factors available.

FDD has been reserved two blocks of 60 MHz, one for UL and the other for DL. The first block, for UL, is in 1920-1980 MHz and the second one, for DL, is in 2110-2170 MHz. The duplex distance (the distance between corresponding UL and DL channels) is 190 MHz [HoTo01]. This spectrum is reserved for UMTS in Europe, Japan and Korea, enforcing the idea that UMTS may, in fact, become a success case of global communications system.

Today, FDD networks have been already launched and operators are still studying the most suitable timing to start deploying TDD. The present study is developed for the FDD mode, due to a combination of the former considerations (FDD networks are already operating whereas TDD ones are still to be deployed) and the fact that users’ mobility have a wider range of variation in FDD networks when compared with TDD ones, as vehicular users are preferably served by the first ones.

II.5. Link Budget

This section aims at identifying the parameters that are specific of WCDMA [HoTo01], and to draw some considerations on them. In Annex A, the link budget is presented in a detailed way.

Cell coverage in WCDMA depends on the cell load, it being as small as higher the number of users in the cell is. This happens because increasing the number of users also increases the total amount of interference, which has to be compensated by an increase in the transmitted power (which is limited) in order to achieve the target ratio between bit energy and noise power density (E_b/N_0). An interference margin (M_I) is introduced in the link budget, aiming to reserve part of the available power to compensate for the raise of interference in the cell. This margin is as high as higher is the allowed load in the cell, and is related to the cell load (η) according to

$$M_{I[\mathrm{dB}]} = -10 \cdot \log(1 - \eta) \qquad \text{(II.1)}$$

Typically an interference margin of 1 to 3 dB is considered, corresponding to a cell load of 20 to 50%.

Fast fading is compensated in UMTS by using closed loop fast power control. This is especially efficient in slow-moving pedestrian users. In order to guarantee adequate headroom for this feature, a fast fading margin (or power control headroom) is considered in the link budget. Typical values for fast fading margin are from 0 to 5 dB.

Slow fading between an MT and two different BSs is partially uncorrelated. Hence, if handover (either soft or hard) is used, a gain against slow fading can be achieved, because the reception can always be done based on the best of the received links. Also, a gain against fast fading is achieved by means of reducing the required E_b/N_0 relative to a single link, because soft handover provides a macro diversity combining effect in the receiver. Typical values considered for soft handover gain are between 2 and 3 dB.

The processing gain is specific of CDMA, being calculated by

$$G_{P[\mathrm{dB}]} = 10 \cdot \log(R_c / R_b) \qquad \text{(II.2)}$$

where:

- R_c is the system chip rate (3.84 Mcps);
- R_b is the bit rate of the signal to be transmitted (in kbps).

Processing gain ranges from 10 to 25 dB.

Unlike in GSM, UMTS supports distinct radio bearers. When calculating a link budget for GSM, a fixed value is considered for the target signal to noise ratio (or E_b/N_0) at the receiver, i.e., sensitivity. When performing the same operation for UMTS, the target signal to noise ratio (or E_b/N_0) is no longer a fixed value, depending on the service under analysis. Different services (circuit switch and packet switch) demand distinct target E_b/N_0 values for the same system conditions; moreover, they can run at different bit rates. In short, the wide offer of services and bit rates has, as consequence, different sensitivity requirements for the system. E_b/N_0 figures range typically between 2 and 8 dB.

Another particularity of WCDMA is the fact that all DL channels in a cell (common control channels as well as dedicated ones) share the available power, leading to a regulation process between cell coverage range and cell capacity (increasing one of these two factors means reducing the other).

Link budget calculation allows one to achieve the maximum allowable cell path loss that can be used to determine the cell coverage range, based on a suitable propagation model. In the present study, the COST231 - Walfisch – Ikegami model [DaCo99] is considered, its description being provided in Annex B.

II.6. Capacity and Interference

The concept of capacity in UMTS is quite different from the one considered in 2G networks, because the sharing of resources performed by the system is different. In fact, three factors can be identified as being responsible for limitations on the number of users served by the system: total DL available transmitting power, the number of channelisation codes (OVSF), and system load (both up- and downlinks). Each UMTS BS is typically equipped with a power amplifier whose total power (usually 43 dBm) must be shared among all users within the cell’s serving area (including users in soft and softer handover). The number of users in the cell and the power required by each one of them (which depends on the type of service, location and speed of the mobile) puts limits on the maximum number of users that can be simultaneously served by the cell. This is the process by which the power usage can limit the system capacity.

Channelisation codes are the second type of resource that can limit the capacity in the air interface: the code tree associated to each scrambling code defined in a cell is being shared by all users being served in the cell coverage area (as explained in Section II.3). If, in a cell, 7 users are being served with 384 kbps DL radio bearers, and they are very near the BS (meaning that the DL power limitation will not be reached in the cell), then an 8th user will not be able to be served in the same cell (despite the fact that the cell still may have plenty of DL power available), because the code tree will not have enough channelisation codes to guarantee such a bit rate to him/her. This is the process by which channelisation codes can limit the system capacity.

System load is the third factor that can bound the system radio capacity, and the interference margin introduced in the link budget calculation, reflects that limitation. The interference margin is evaluated based on the system's load, as stated by (II.1). The system's load is calculated by considering the contribution of all active connections according to the following expression[2]

$$\eta = \left(1 + I_{inter\ n}\right) \cdot \sum_{m=1}^{N_u} L_{C\ m} \tag{II.3}$$

being:

- $I_{inter\ n}$: normalised inter-cell interference (ranging from 0 to 1); if DL is considered, its value is 0 but, if UL is being analysed, a value between 0.4 and 0.6 must be considered;
- $L_{C\ m}$: load factor for a specific connection and user *m*, ranging from 0 to 1, and being calculated by using (II.4) (UL) or (II.5) (DL);
- N_u: number of active users in the analysed cell.

Each specific connection has associated to it a load factor (meaning that it contributes to the total cell load). If UL is being analysed, it is calculated by using

$$L_{C\ m}^{UL} = \frac{1}{1 + \dfrac{R_c / R_{b\ m}}{\left(E_b / N_0\right)_m \cdot F_{a\ m}}} \tag{II.4}$$

where:

- $R_{b\ m}$: is the transmission bit rate for the service of user *m*;
- $\left(E_b / N_0\right)_m$: is the signal to noise ratio for the service of user *m*;
- $F_{a\ m}$: is the activity factor of user *m*, typically 0.5 for voice services, and 1.0 otherwise.

If DL is the one to analyse then one must consider

$$L_{C\ m}^{DL} = F_{a\ m} \cdot \frac{\left(E_b / N_0\right)_m}{R_c / R_{b\ m}} \cdot \left[\left(1 - \alpha_m\right) + I_{inter\ n\ m}\right] \tag{II.5}$$

---

[2] All the parameters shown in (II.3), (II.4) and (II.5) are presented in detail in Annex A.

being:

- α_m : orthogonality of codes used by user *m*, typical values ranging between 0.5 and 0.9;
- $I_{inter\,n\,m}$: normalised inter-cell interference for user *m*, typical values ranging from 0.4 to 0.6.

The following relations can be identified:

- Direct proportionality, both in UL and DL, between system's load and:
  - activity factor for the considered service, meaning that data services have a impact in system's load higher (negative) than voice services;
  - sensitivity (E_b/N_0) for the considered service, services demanding higher sensitivity values leading to a more constrained system;
  - bit rate for the service being analysed, the general effect being that the voice service is the least demanding one and that data services are more demanding as higher the provided bit rate is;
- Inverse proportionality in DL between system's load and:
  - orthogonality of codes used by the analysed user;
  - inter-cell interference as seen by the user under consideration.

All the above factors have impact in the system's load, which is usually limited to 50% in UL and 75% in DL. System's load is very dependent on the mix of services and bit rates present in the cell under analysis. In fact, in DL, even if a fixed mix of services is considered, the cell load factor is still depending on the geographical position of each user, through the factor that considers the inter-cell interference seen by the user. This gives an idea of the complexity of analysing capacity issues in UMTS. This complexity is, due to the intimate relation existing between interference, mix of services, number of users, and capacity. Hence, the analysis of such issue is only possible (in an accurate approach) if system simulators are used.

In UMTS, the available power in the Node B is shared among all the radio connections in the cell. The common control channels take, from the very beginning, part of the power available in the cell. The remaining power is then shared among dedicated channels to be used by each of the users in the cell coverage area. The total DL transmitting power (P_{TX}), can be calculated by

$$P_{Tx[W]} = \frac{N_0 \cdot R_c \cdot \overline{L_p}}{1 - \overline{\eta_{DL}}} \cdot \sum_{m=1}^{N_u} \left(F_{a\,m} \frac{(E_b/N_0)_m}{R_c/R_{b\,m}} \right) \tag{II.6}$$

being:

- $\overline{\eta_{DL}}$: average DL system load, calculated by applying (II.3) to all N_u users and averaging it;
- $\overline{L_p}$: average path loss for the users in the cell;
- N_0: is the noise spectral density.

The analysis of (II.6) allows establishing a very close relation between the number of users being served in the cell (expressed by N_u) and the average distance between the users and the BS (expressed by $\overline{L_p}$). Furthermore, a maximum distance can be identified (*via* $\overline{L_p}$) for each number of users N_u being served in the cell. This close relation is known and commonly referred to in the literature as "cell breathing" as it reveals that the maximum cell radius depends on the number of users being served by it, and, as this number varies along the day, the cell coverage area also varies, giving an idea that the cell in fact is shrinking and expanding along time.

In a real live network, the radio capacity limitation can be reached by one of the three identified limiting factors or by the combination of more than one, depending on the offered traffic conditions and on the design of the radio network.

Cell capacity limitation due to DL transmitting power is more likely to happen in areas were the intersite distance is too high, not completely guaranteeing a continuous coverage for all the services (especially the more demanding ones – the highest bit rates). Also, in places where deep indoor environments exist, users in places with too high indoor attenuation can demand unreachable DL transmitting power levels.

Cell load limits the system radio interface capacity whenever the UL or DL load reaches a pre-defined value by the operator. This is the most common situation in a network with an intersite distance suited to the users' indoor environment and the local aggregation of users. This means that, by hypothesis, in this situation the system is being able to cope with the DL power variations imposed by the users, and that the users' geographical density is low enough in order not to compromise the radio interface capacity by lack of channelisation codes.

DL channelisation codes can be the factor limiting the radio interface capacity especially in hotspots (e.g., places with very good coverage level but with very high concentration of users – usually mall centres). In this case, DL transmitting power and channelisation codes may not be the limiting factors, but a high concentration of users accessing the network with high bit rates (384 kbps DL radio bearers) can limit the cell capacity. A perfect example is (as referred before) a set of 7 users accessing the network in a cell with 384 kbps DL radio bearers, in a mall centre, with very good indoor coverage (with a dedicated coverage project). If an 8^{th} user tries to access the system in the same place, using the same cell, it will not be able to provide him/her with an 384 kbps DL radio bearer, without taking some actions, downgrading one of the other users for instance, as the code tree does not have enough free channelisation codes to guarantee such a radio bearer for this new user.

Naturally, a combination of two or even three factors above indicated will also limit the radio interface capacity.

Chapter III

Models and Performance Indicators

This chapter presents the mobility models available in the literature, followed by the considerations taken to choose the models to implement in the simulators. Traffic source models are presented and implementation choices are justified. The performance indicators used to perform system analysis are then defined, and the chapter ends with some considerations on the interaction between mobility and capacity.

III.1. Mobility Models

Mobility modelling has been treated in many studies and projects, as it is essential to perform convenient studies of non-static scenarios. Each particular approach results in slightly different models that can be used either in isolated or combined ways. In general, mobility models do not rely on streets database, rather being composed, of distribution functions that apply to both users' speed and direction.

In [JaZH98], a discrete two-dimensional random walk process is described. The MT is considered to travel a constant distance during each defined time period, in one of four defined directions: right, left, up and down. This approach assumes orthogonal travel with constant speed, being of reasonable applicability to a Manhattan-like scenario, where streets are orthogonal among each other. The evaluation of the direction to be taken by the MT after each travelling period is done based in a four states discrete-time Markov chain, where the four states represents the four possible directions.

Vehicular highway traffic is modelled in [CvGa98] by considering a two way highway with multiple entrances and exits, where MTs using this highway are modelled based on a deterministic fluid model. The system is, hence, described by differential equations that are numerically solved. MTs can be classified as calling or non-calling ones, depending whether they have a call in progress or not. The simulation of this system allows calculating the densities of the calling and non-calling vehicles, assuming some particular velocity pattern. The parameters required for this model are: traffic statistics for each MT, vehicle speed, cell size, and distance between entrance and exit points.

ETSI has defined a set of four different mobility models [ETSI98]:

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

The Indoor Office model considers a large office building with an open space layout. Each office cubicle is delimited by moveable partitions, and they are organised along main corridors. The building is assumed to have three floors and MTs move at a speed of 3 km/h. MTs cannot move between floors, and they are either stationary or moving with constant speed from an office cubicle to corridors or vice versa. A probability is assigned to an MT to be stationary, which is higher if it is in an office cubicle and lower for a corridor. The Outdoor to Indoor and Pedestrian model considers an MT mean speed of 3 km/h for both indoor and outdoor. The considered environment is a Manhattan-like structure, MTs move along streets, and at the crossroads they can turn with a certain probability. The speed of the MT can be changed at any position update according to a certain probability. The Vehicular model considers a pseudo random mobility model with semi-directed trajectories. MT's direction can be changed at each position update according to a given probability. The Mixed-cell Pedestrian/Vehicular model considers an urban area covered with micro-cells, and overlaid by macro-cells. The area is considered to have an open area whose coverage is granted by umbrella macro-cells and an urban area which is covered by the micro-cells. The users located in the open area are considered to move according to the vehicular mobility model, and users located in the urban area are assigned to the Outdoor to Indoor and Pedestrian mobility model.

A mobility model with a triangular velocity distribution is presented in [ChLu95], the speed Probability Density Function (PDF) being given by (III.1). Five scenarios are defined with distinct parameters $V_{av} =(V_{max}+V_{min})/2$ and $\Delta = (V_{max}-V_{min})/2$, Table III.1 and Figure III.1. Vav assumes the average value between the maximum (V_{max}) and minimum (V_{min}) of the distribution, whereas Δ assumes the half difference between maximum and minimum values of the distribution. The range of variation of the speed is equal to the average value, with exception of the highway scenario where the range of variation is smaller than the average speed value.

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

Table III.1 – Scenarios of Mobility Characteristics.

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

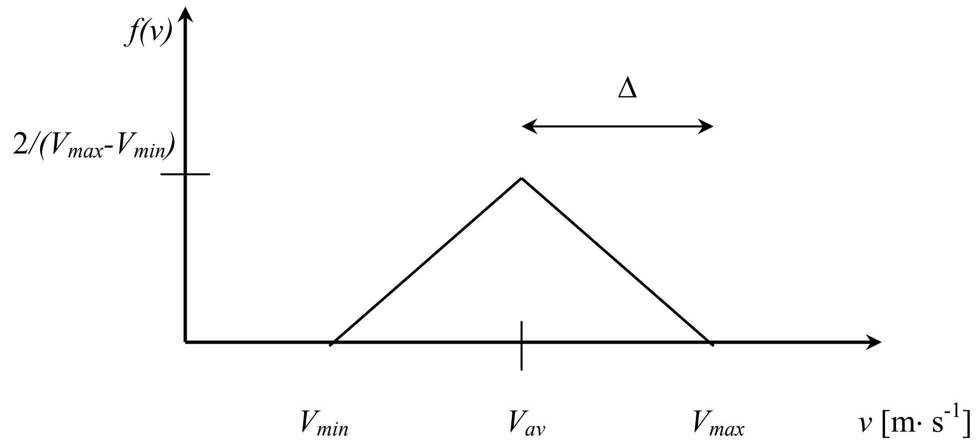


Figure III.1 – Speed probability density function.

COST259 describes a mobility model [Corr99] that incorporates the heterogeneity of subscribers and traffic systems. MTs move along major roads and crossroads. The input parameters of the model are the following:

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

Figure III.2 illustrates the behaviour of the model. An MT call can be initiated at any point within the cell along the path of the vehicle, which is modelled by vectors $\vec{d_i}$, which include the street length value between crossroads and the direction of movement. The direction of an MT (including the starting angle) is uniformly distributed in [-π, π[.

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

$$f(\varphi_i)=\frac{1}{1+w_{90^\circ}+w_{-90^\circ}+w_{180^\circ}}\cdot\frac{1}{\sigma_\varphi\sqrt{2\pi}}\left(e^{-\frac{\varphi_i^2}{2\sigma_\varphi^2}}+w_{90^\circ}\cdot e^{-\frac{\left(\varphi_i-\frac{\pi}{2}\right)^2}{2\sigma_\varphi^2}}+w_{-90^\circ}\cdot e^{-\frac{\left(\varphi_i+\frac{\pi}{2}\right)^2}{2\sigma_\varphi^2}}+w_{180^\circ}\cdot e^{-\frac{(\varphi_i-\pi)^2}{2\sigma_\varphi^2}}\right) \quad \text{(III.2)}$$

where 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 assumed to be equal for the four variables.

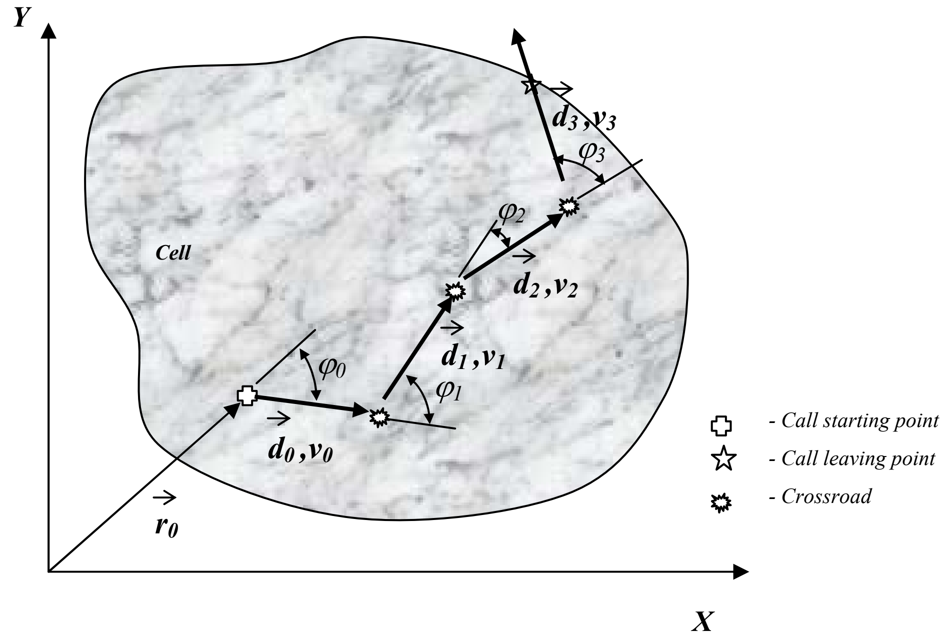


Figure III.2 – Tracing an MT within the cell (extracted from [CaCo02]).

The PDF of d_i is given by a Rayleigh distribution, assuming that streets take a random course with respect to the axis of the co-ordinate system,

$$f(d_i)=\begin{cases}\dfrac{d_i}{\sigma_d^2}\cdot e^{-\left\{\frac{d_i^2}{2\cdot\sigma_d^2}\right\}} & , \quad d_i>0\\ 0 & , \quad d_i\leq 0\end{cases} \tag{III.3}$$

where $\sigma_d=\bar{d}\sqrt{\dfrac{2}{\pi}}$

The PDF of MT speed (v_i) is given by a Rayleigh/Rice distribution, (III.4), assuming that the MT does not change speed while covering distance d_i. The existence of major roads is weighted by w_{mr}, which is the fraction of MTs travelling on this type of roads.

$$f(v_i)=\begin{cases}\dfrac{1}{1+w_{mr}}\left[\dfrac{v_i}{\sigma_v^2}\cdot e^{\left\{\frac{v_i^2+\bar{v}^2}{2\sigma_v^2}\right\}}\cdot I_0\left(\dfrac{v_i\bar{v}}{\sigma_v^2}\right)+w_{mr}\cdot\left\{\dfrac{v_i^2+\bar{v}^2}{\sigma_v\sqrt{2\pi}}\right\}\cdot e^{\left\{-\frac{\left(v_i^2-\bar{v}_{mr}\right)^2}{2\sigma_{\bar{v}}^2}\right\}}\right] & , \quad v_i>0\\ 0 & , \quad v_i\leq 0\end{cases} \tag{III.4}$$

Given the models presented, choosing one or another to implement in a mobility simulator depends on the final objectives required in the simulation process and on the modelling accuracy required in the mobility analysis, and is also limited by the existing information to characterise the geographical area that will be analysed. ETSI models have the advantage of considering a wide set of situations, and the only one for indoor offices is the one presented by ETSI. Pedestrian users can be modelled either based on ETSI (outdoor to indoor & pedestrian or mixed-cell pedestrian/vehicular) or COST 259, to generate movement direction and a triangular distribution to generate users' speed.

ETSI approach for pedestrian users modelling seems a logical choice when trying to model very regular urban areas, with orthogonal streets, besides being very easy to implement. On the other hand, if the objective is to model an area not so regular, the COST 259 approach along with a triangular distribution for users' speed seems to provide more realistic results.

Concerning vehicular users modelling, if no streets database is available, both ETSI vehicular scenario and COST 259 approaches can be taken. In the case of the COST 259 approach, also a triangular distribution can be assumed for speed generation. If, on the other hand, a streets database of the area under test is available, one should use it as to increase the realism of the simulation process. In this case, vehicular users should be generated on streets and move along them. Furthermore, the users' speed can be generated with a triangular distribution, and the average speed value should be suited to the type of street present in the database, which will maximise the realism that can be achieved with this simple information base. Further realism improvement would need real live traffic measurements, such as speed distributions and traffic directions for each street, etc..

These considerations were taken into account in order to select the most suitable mobility models to implement in the simulator developed to perform the current study.

As a starting point, the city of Lisbon was chosen to be the basis for the study. Full information regarding characterisation of traffic type and users' density distribution in the busy hour was already available from previous studies conducted in the IST-MOMENTUM project [MOME04]. Using that information to characterize users' traffic distribution was vital to bring extra added value to the study.

Modelling both vehicular and pedestrian users was fundamental for a complete characterisation of mobility. Lisbon is characterised by a complex net of streets with different characteristics (regarding their width, profile and maximum allowable traffic speed) and the information regarding the position of each street and its type (e.g., an avenue or a street) is known and available as a database, thus, giving a clear indication of the type of mobility model to choose for vehicular users. The choice was modelling vehicular users, in the scope of this study, by generating and moving them according to the streets location. Concerning vehicular users' speed, the most suited choice was randomly generating it by employing the triangular speed distribution proposed in [ChLu95] with average and variation parameters fitted to each street type. Based on the description of the models and the considerations presented above, it would not have been wise modelling vehicular mobility by employing the random walk mobility model proposed in [JaZH98] or by one of the models proposed by ETSI [ETSI98], having the city streets characterisation available, as these models define movement direction using statistical distributions, rather than taking into account real streets' network information. Implementing the highway model proposed in [CvGa98] would not have been suitable for the case of Lisbon', because that type of street is not applicable to any of the streets in Lisbon.

Concerning pedestrian users, the final objective was having them walking along the city, without being constrained to the streets locations, as pedestrian users can also walk inside buildings and open areas for instance. The model generating the direction along which pedestrian users walk, in accordance with the final objectives of the current study, ended up being the model described by COST 259 [Corr99]. Pedestrian users' speed was generated by using a triangular distribution with 3 km/h for Δ and average speed. Pedestrian users could also have been generated using the same model chosen for vehicular users, but that would crowd the streets locations and no users would be generated in areas where buildings exist; having users inside buildings is a reality that can not be forgotten and discarded in this study. The random walk mobility model proposed in [JaZH98], and the ones proposed by ETSI [ETSI98], are not the most suitable for this study, as they consider that users walk in an environment of the Manhattan-like. ETSI also presents a model specific for indoor scenarios, but it demands a correct characterisation of the indoors environment by defining where the walls are placed, etc., and that type of characterisation is out of the scope of this study.

III.2. Traffic Models

As in the case of mobility, also in traffic source modelling there is an enormous number of studies and publications presenting several modelling approaches to users' traffic behaviour. A compilation of several traffic source models was published in [SeFC02], which, along with other publications, was taken as the basis for choosing and defining the models to be implemented for each of the services considered in the present study. The complete list of the services considered here is as follows:

1. Speech
2. Video Telephony

3. Streaming Multimedia
4. HTTP (usually referred as web-browsing)
5. E-mail
6. FTP
7. Short Message Service (SMS)
8. Multimedia Message Service (MMS)
9. Location Based Service (LBS)

Figure III.3 characterises these services concerning DL session volume and service bit rate, and it shows that this set of services guarantees covering a wide range of data rates and data volumes per session. Other services could be considered, but their characteristics would overlap with these ones.

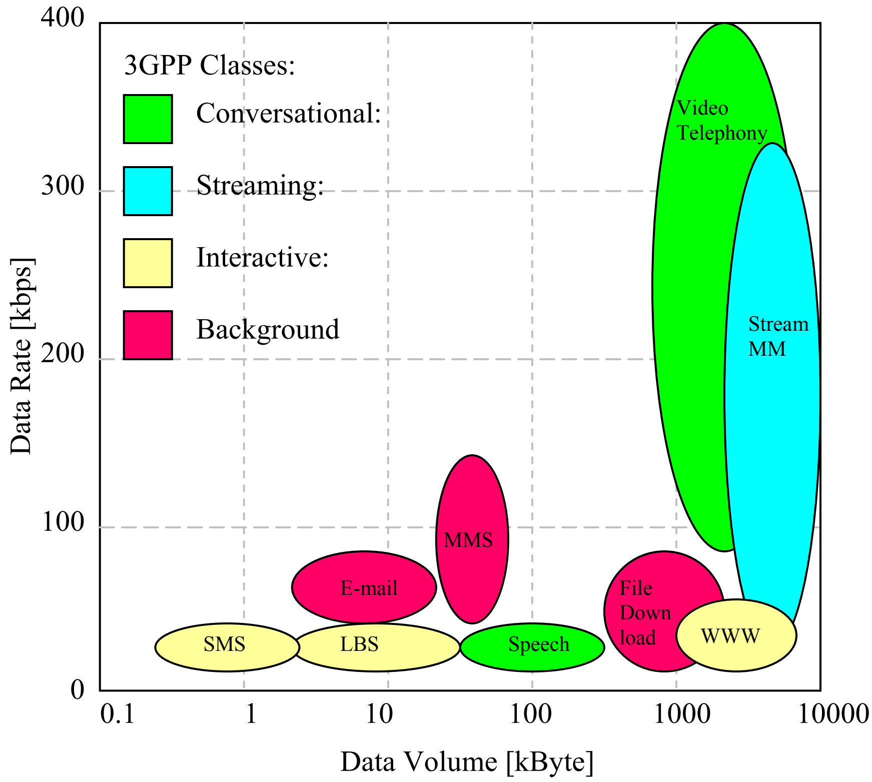


Figure III.3 – Service set bit rate range and DL session volume (extracted from [FCXV03]).

A detailed description of the models applicable to the generation of each one of these services is presented in what follows.

A Speech source model in mobile communications is presented in [VaRF99]. This model includes the ON-OFF behaviour of the service and the effect of the voice encoder, compression devices and air interface of the system. It uses a four-state model for packet generation, each of these states generating packets of a fixed size, and the transition between two states being ruled by suited probability functions. The packets bursts resulting from this model have different bit rates, and distinct mapping between logical and physical channels must be applied in accordance.

Video Telephony and Streaming Multimedia services are modelled in [ChRe98]. It presents a Variable Bit Rate (VBR) video traffic source model based on a finite-state Markov chain. It assumes that video frames can be split into two different types, I frames and P frames. I frames are driven by scene changes, and do not depend on the video encoder, but rather on the video source, i.e., the scenes sequence being captured. The remaining ones are the P frames, and consecutive P frames are expected not to have significant changes in the information, thus, a high correlation is expected to exist in the bit rates characterising these frames. I frames are modelled by a Gaussian distribution, and P frames are generated by a mechanism of k states, each one of them with specific average and variance values. That model allows then characterising a video source with respect to the size of the packets being generated by it, and the speed at which they are generated.

HTTP has been characterised by many models available in the literature, such as those described in [ETSI98], [RaMe01], [ViCa97], [DiLS01], [MWIF01], [JeJe01], [ShRJ02], [FäBC98], [KlLL01] and [ZSMH00]. In what follows, only the model chosen to be implemented is described, i.e., the model proposed in [KlLL01], which characterises generic non-real time (NRT) applications. The model is flexible, and different parameterisations allow characterising not only HTTP but also e-mail and FTP applications. The model and setting definitions is based on measured trace data from the University of Dortmund ISP (Internet Service Provider). The analysis of that data allows concluding that the data flow received by the user depends a lot on the type of application being used. Figure III.4 presents an example of the different behaviour a data session can have, depending on the type of application being accessed by the user. Inside each data session, each application has different statistics associated to the reception of data packets. The model describes statistically the interarrival time between consecutive packets and their size.

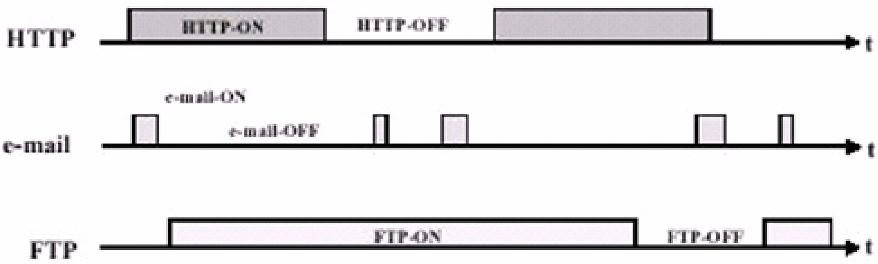


Figure III.4 – Session level user traffic characterisation (extracted from [KlLL01]).

Data packets being received by the user can then be analysed in three different levels:

- **Session-level:** it describes the users' dial-in behaviour with respect to each application type. It is fully characterised by the interarrival-time and the session data-volume distributions.
- **Connection-level:** it describes, for each session, based on the specific application being modelled, the individual connections' interarrival-time and connection data-volume. Each application type is characterised by a distinct parameterisation of the distribution functions.
- **Packet-level:** it describes, for each connection, the interarrival-time and packet data-volume. This is the lowest level of analysis of this model, and the packets size distribution is suited for each modelled application.

A mapping is performed between the traffic measured in the ISP and the traffic carried in a UMTS network, based on the throughput characteristics of this network. The same service is mapped with slightly different statistical distributions according to the radio bearer on which it is mapped. Table III.2, Table III.3, Table III.4, Table III.5 and Table III.6 present the detailed parameterisation for each service of interest in the current study. One should note that the referred study also comprises other data services (such as Napster and UDP), but since they are not considered in the current study, their characterisation is not introduced here.

Table III.2 – Distribution of Session interarrival-time (in s).

Distribution	
Lognormal (μ; σ^2)	(0.9681; 4.3846)

Regarding packet size characterisation, its distribution for HTTP, e-mail and FTP follows in a great extent a discrete distribution, where packets of size 40, 576 and 1500 Byte constitute the largest amount of the overall packet sizes. This is due to the maximum transfer units of Ethernet and SLIP (Serial in Line IP) networks. The remaining packet sizes are uniformly distributed between 40 and 1500 Byte.

Table III.3 – Distribution of Session Volume (in Byte).

	Data Rate		
Distribution	64 kbps	144 kbps	384 kbps
Lognormal(μ; σ^2)	(11.1170;1.9095)	(11.4107;1.9509)	(11.6795;1.9781)

Traffic source models for SMS and MMS were not found in the literature. A close analysis of these services allows one to consider they are somehow similar to e-mail, aside a convenient scale factor affecting data volumes transferred in each of these services. SMS and MMS are then modelled, within the current study, by the e-mail traffic source model, applied to the traffic volumes that characterise these services.

Table III.4 – Distribution of Connection Volume and interarrival time (in Byte and s).

			Data Rate		
Service	Parameter	Distribution	64 kbps	144 kbps	384 kbps
HTTP	Interarrival time	Lognormal($\mu;\sigma^2$)	(0.5967; 2.6314)	(0.1580; 3.1507)	(-0.4760; 3.8787)
	Volume	Lognormal($\mu;\sigma^2$)	(7.4343; 3.4714)	(7.4708; 3.7598)	(7.5458; 3.9745)
e-mail	Interarrival time	Pareto(k; α)	(14.4360; 2.1345)	(15.1334; 2.1254)	(16.0229; 2.1223)
	Volume	Lognormal($\mu;\sigma^2$)	(8.1934; 3.3852)	(8.2944; 3.5288)	(8.4124; 3.6439)
FTP	Interarrival time	Not available			
	Volume	Lognormal($\mu;\sigma^2$)	(8.4944; 3.6674)	(8.6403; 4.1059)	(8.8409; 4.3343)

Table III.5 – Distribution of Packet interarrival-time (in s).

		Data Rate		
Service	Distribution	64 kbps	144 kbps	384 kbps
HTTP	Lognormal($\mu;\sigma^2$)	(-3.2441; 4.5137)	(-3.9124; 5.1794)	(-4.8507; 6.1159)
e-mail	Lognormal($\mu;\sigma^2$)	(-4.4052; 4.4970)	(-4.8790; 4.9687)	(-5.4096; 5.4978)
FTP	Lognormal($\mu;\sigma^2$)	(-3.6445; 4.9564)	(-3.9076; 5.2186)	(-4.1089; 5.4194)

Table III.6 – Distribution of Packet size (in Byte).

	Fraction of packets in overall traffic [%]			
Service	40 Byte	576 Byte	1500 Byte	Other
HTTP	46.77	27.96	8.10	17.17
e-mail	38.25	25.98	9.51	26.26
FTP	40.43	18.08	9.33	32.16

Models for Location Based Services were not found as well. This type of services is similar to HTTP, as long as a scale factor respecting the information volume is used, thus, based on this fact, LBS are modelled by implementing the HTTP model, but with average session volumes that adequately characterise them.

Given the existence of multiple traffic models, some considerations had to be done to perform a suitable selection of the ones to be implemented in the simulator. Starting by the available information, Lisbon's busy hour traffic distribution is based in a set of 9 services: Speech, E-mail, SMS, MMS, LBS, Video Telephony, Streaming Multimedia, FTP and HTTP.

CS services (Speech and Video Telephony) were implemented by the ON-OFF model. In fact, Speech modelling could have been done with the four-state model described above, but it would imply to implement Adaptive Multi-Rate (which would increase and decrease the bandwidth allocated for each speech user depending on its activity), and Video Telephony modelling could have considered the generation of different type of frames, as described above, but as these services are CS ones, the network resources are always reserved for each ongoing session. This solution was, on the other hand, the simplest and fastest way of implementing these services, and on the other, it would provide the worst case situation for the network analysis.

Concerning PS services, the models described above for E-mail, SMS, MMS, LBS, Streaming multimedia, FTP and HTTP were implemented in the simulator to characterise each user's session. The key points for choosing [KlLL01] modelling were the fact of being flexible (as the different parameters in the same model allow modelling several distinct services) and based on measured trace data from an ISP. A closer relation to real network traffic is, thus, achieved by choosing this model.

III.3. Performance Indicators Definition for System Analysis

The definition of performance indicators is fundamental for a consistent analysis of system response, thus, in what follows, indicators that are used to assess and compare the results of the simulations are introduced.

- **Handover Flow Indicator** (P_{HO})

  This indicator aims at measuring the weighting between incoming and outgoing handovers. It accounts incoming handovers and successful outgoing handovers in accordance with

$$P_{HO}\left[\%\right] = \frac{\sum HO\_in}{\sum HO\_in + \sum HO\_Out} \qquad \text{(III.5)}$$

where:

- *HO_in* – Total number of incoming handovers in to the cell. A handover is considered to be triggered in the instant that a cell becomes the best server of one connection;
- *HO_Out* – Total number of successful outgoing handovers, i.e. outgoing handovers that did not result in dropped call.

Figure III.5 presents the behaviour of this indicator with the variation of the ratio between *HO_in* and *HO_Out*. The indicator presents values higher than 50% if incoming handovers are higher than outgoing ones, and values lower than 50% in the other case. This indicator presents one singularity when both incoming and outgoing handovers are null.

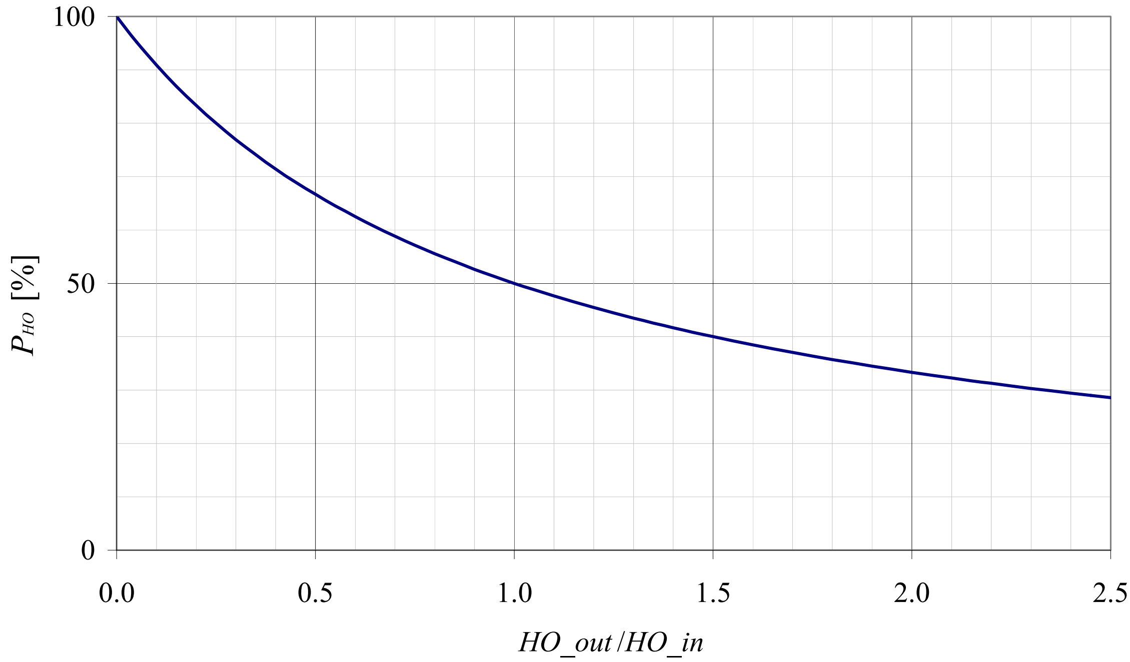


Figure III.5 – Handover flow indicator function.

- **Incoming Handover Weight** (P_{HOin})

This indicator aims at measuring the weight incoming handovers have over the calls being generated in the cell. The formulation of the indicator is given by

$$P_{HOin}\left[\%\right] = \frac{\sum HO\_in}{\sum HO\_in + \sum New\_Calls} \qquad \text{(III.6)}$$

where:

- *New_Calls* – The number of calls originated in the cell.

- **Dropped Call Rate** (P_d)

  Dropped Call Rate weights all the dropped calls in the cell (including calls that dropped during a handover attempt) over the ongoing calls in the cell. The formulation of the indicator is given by

$$P_d\,[\%] = \frac{\sum Dropped\_Calls + \sum HO\_Out\_Dropped}{\sum New\_Calls + \sum HO\_in + \sum HO\_Out} \tag{III.7}$$

  where:

  - *Dropped_Calls* – The number of calls that drop excluding calls dropped when trying to perform a handover;
  - *HO_Out_Dropped* – The number of calls that drop when trying to perform an outgoing handover from the cell.

- **Blocked Call Rate** (P_b)

  Blocked Call Rate weights all the CS call attempts blocked in the cell due to lack of resources. The formulation of the indicator is given by

$$P_b\,[\%] = \frac{\sum CS\_Blocked\_Calls}{\sum CS\_Blocked\_Calls + \sum New\_Calls} \tag{III.8}$$

  where:

  - *CS_Blocked_Calls* – The number of CS calls that are blocked on the cell due to lack of resources.

- **Handover per Call** (P_{HOCall})

  Handover per call measures the weight of successful outgoing handovers over the total number of cells generated in the cell. The formulation of the indicator is given by

$$P_{HOCall} = \frac{\sum HO\_Out}{\sum New\_Calls} \tag{III.9}$$

- **Outgoing Handover Drop Rate** (P_{dHO})

  Outgoing Handover Drop Rate measures the weight of outgoing handover attempts that ended up in dropped call over the total amount of outgoing handover attempts. The formulation of the indicator is given by

$$P_{dHO}\,[\%] = \frac{\sum HO\_Out\_Dropped}{\sum HO\_Out\_Dropped + \sum HO\_Out} \tag{III.10}$$

III.4. Mobility and Capacity Interaction

The analysis indicators defined in the previous section, together with other simpler indicators (such as the amount of DL power used by the BS, the up- and downlinks average interference levels, etc.) are the available instruments to assess the impact of mobility and traffic heterogeneity as well as distinct densities in system's capacity.

Previous studies have been performed in order to assess the impact of different traffic mix and densities on system capacity, [VaCa02], and mobility has also been modelled in other approaches, [FCSC02], [Carv03]. Common results indicate a degradation of system's performance with increasing users' density and mobility, which is reflected on the increasing blocking probability and dropped call rate for CS services. PS services have QoS degradation due to increasing average delay, rather than increasing dropped call rate, in networks not coverage limited.

Users' generation process plays a vital role in the results attained for system's performance on non-uniform users' distribution. In fact, not only the geographical distribution must be suited to the scenario characteristics (with higher and lower density areas) but also the statistics used to generate them. [Carv03] generated users based on a geographical database containing information of users' and services densities. For each simulation instant, the number of users per service type to be placed in the scenario was randomly generated by an exponential random variable, and their locations were also randomly generated following the geographical density distribution stored in the database. The same process was followed in the current study.

[BaZF03] studied applications' performance also focusing on the question of fairness when mobility increases. Increasing mobility leads to a higher probability of on-going connections being delayed or dropped due to the admission of new calls, and in that study a performance improvement is shown to be achievable if CAC takes into account known information regarding users' mobility, which can be collected by the BS. However, such a solution implies acting on the system CAC algorithms, and those are exclusively held and managed by the manufacturers, very often using proprietary features and algorithms. Hence, characterising the impact of the mobility in the system's performance is still a fundamental issue for operators' radio networks dimensioning, as it provides them with knowledge that allows to adequate their engineering processes, by taking into consideration additional margins to cope with the mobility impact.

The importance of having an accurate knowledge of mobility impact and its modelling is also sustained by the fact that new projects that identify the next directions to take in evolving UMTS (such as IST-SEACORN, [FeGV03]), put a special emphasis on modelling mobility, and consider it as one of the important factors to take into account in those studies.

Chapter IV

Simulators' Description

This chapter starts by presenting the structure of the simulation process based on the limitations imposed by the programming platforms. The mobility generator simulator (SIMOTS) is then fully described, followed by the detailed description of system-level simulator (CRUS). Validation tests performed on the simulators are presented, followed by simulations' setup. Performance analysis of the simulation process closes the chapter.

IV.1. Programming Platform Choices

The main objective of building a simulator in the scope of this thesis was to achieve the implementation of Radio Access Network algorithms of UMTS. An additional condition was that all the relevant parameters of the system could be changed without requiring the recompilation of the simulator's source code. The result is a simulator based on two different platforms (MapBasic® [MAPB04] and C++ [MICR04]), which interact with each other through configuration files, and where BSs configurations, geographical study area, users' densities, antennas, and propagation models, among many other parameters, can be changed in that perspective.

MapInfo® [MAPI04] is a standard GIS (Geographical Information System) platform to manipulate geographical data. The fact that a lot of information is available in MapInfo® format (data tables with specific format) and that MapInfo® supports a programming language (MapBasic®) could lead considering that the whole project would be implemented in MapBasic®. However, going into the details of the programming language revealed several weak points, which lead to the conclusion MapBasic® is not adequate to carry the whole project. The following points were identified as problematic and inhibited the choice of MapBasic® as the single programming platform for this simulator:

1) MapBasic® is an interpreted language, and due to this, it is very slow in run time (compared to a compiled language, such as C++),
2) The programming development environment is very basic, and does not allow simple operations as introducing code breakpoints. It is up to the programmer to develop ways of tracing the behaviour of the program. Due to this the development time is too long,
3) The language does not support complex variable types (such as multidimensional arrays). Even simple arrays are limited to 32767 elements. This limitation is too hard to be overcome in the present project.

The reasons stated above lead to using MapBasic® only in processes were some profit could be taken from the several geographical functions[3] offered by the application. Hence, MapBasic® was used for generating users and their mobility, and to provide a graphical interface to the simulator user without having to develop it from the scratch.

Once solved the problem of generating mobility, a language had to be identified that should be fast and efficient enough (from the memory usage view point) in order to use it as

[3] MapInfo® provides (through MapBasic®) several functions returning the distance between objects and the intersection between geographical areas and objects.

the platform for simulating UMTS, with all its relevant features for the current study. C++ has always been the excellence programming language providing excellent execution times, very good memory management schemes, and for which a lot of very complete development environments are available in the market. At that stage, it became very clear that C++ would be used for the hard task of heavy simulation and data processing. The course of the study clearly identified that many scenarios would be tested by the simulator, hence, an automatic process of calculating statistics over the output of the simulations was also developed in C++, in order to avoid as much as possible the manual intervention on data manipulation, because manual processing of big amounts of data are not error-free processes, besides being very time consuming.

Figure IV.1 presents in a schematic way the relation between both programming platforms and simulators, and the two simulators can be clearly identified. The simulation process is guaranteed by the coordination of both simulators. The acronyms of the simulators are as follows:

- **SIMOTS** – **SI**mulator for **MO**bility in UM**TS**
- **CRUS** – **C**ommon **R**esource for **U**MTS **S**imulations

SIMOTS is responsible for generating mobility information for all the users in the system, i.e., coordinates and speed values for each user for each simulation time instant. CRUS is the UMTS simulator, loading all the information that was previously generated by SIMOTS (and is available in configuration files), and processing it in order to generate as output data the statistics for the network behaviour upon those configuration files.

Some concern was put on measuring the performance of these simulators, in order to achieve that each simulator writes a log file whenever it is working. The information stored in this log file allows measuring the simulation time for both simulators and as CRUS demands a memory space dependent on the simulation conditions, it also allows measuring the memory used by CRUS. Measuring the memory occupied by CRUS in each tested scenario was vital, in order to dimension hardware needs for the machines that ran the several hundreds simulations.

CRUS is also responsible for the statistical analysis of the simulations' results. The output of this statistical analysis is a simple text file that is loaded in pre-formatted Excel® sheets, which automatically calculate high level statistics (such as drop call rate) and generate graphs.

The structure chosen for the simulation process, based on these two platforms allowed getting "the best of two worlds", i.e., the easiness of using pre-existent information in

MapInfo® formats, displaying the information in maps by simply using the available MapInfo® functions, and interface and access to the high processing speed provided by C++, in order to achieve a fast and efficient system simulator. Figure IV.2 presents the user interfacing of SIMOTS.

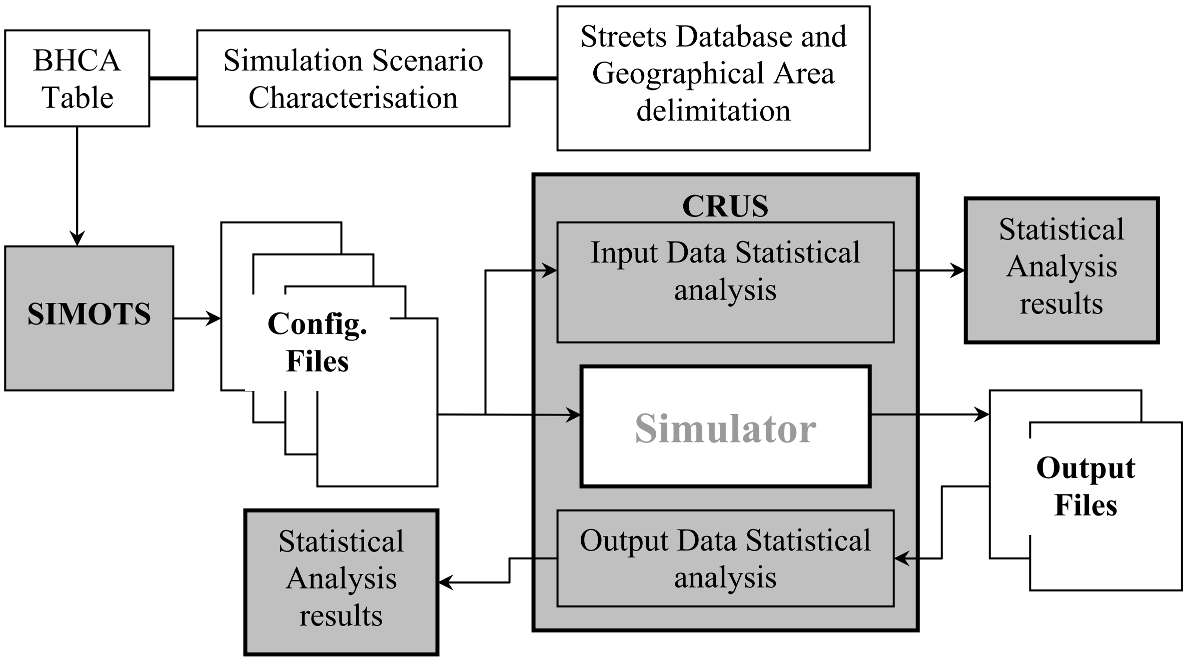


Figure IV.1 – Simulation process.

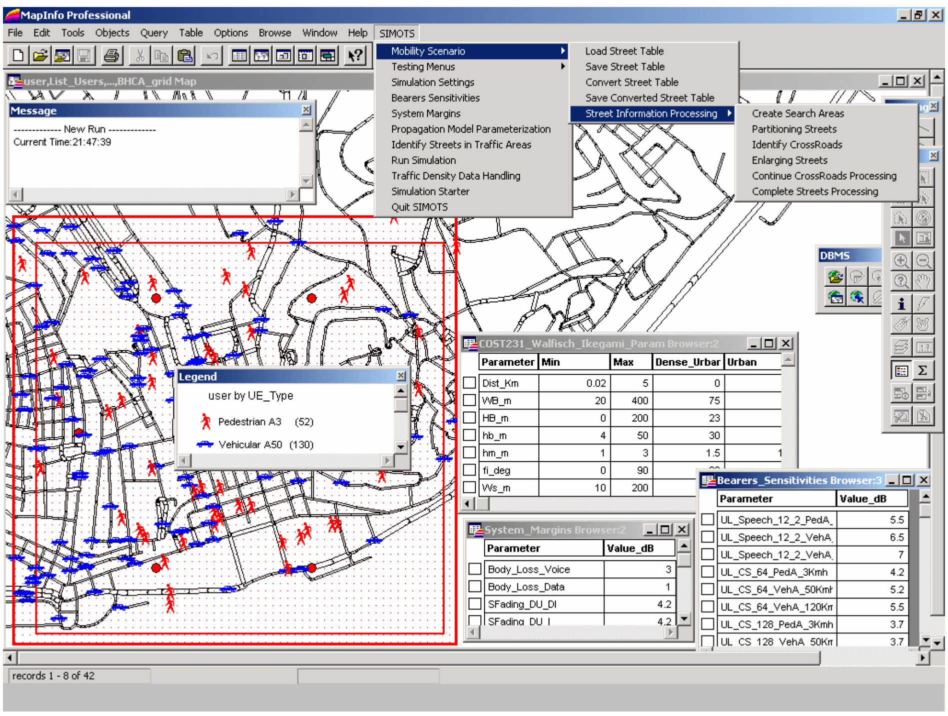


Figure IV.2 – Sample of SIMOTS user interfacing.

Some of the menus that were developed can be identified, as well as a general aspect of the application. Describing in detail the whole set of functions that were developed would be a cumbersome task, and would not be essential for the understanding of the engineering work as a whole. Hence, the emphasis is put on the definition of the processes designed inside SIMOTS, rather than on explaining the GUI (Graphic User Interface) that was developed to interact with the application.

IV.2. SIMOTS' Description

IV.2.1 Users' and Coordinates' Generation

SIMOTS implements all the necessary functions to allow generating the appropriate configuration files that are needed by CRUS to simulate any particular simulation scenario.

A simulation scenario is characterised by a geographical area, a corresponding users' density (users/km^2/hour), and distribution weights amongst the available services (E-mail, Speech, etc.). The geographical area under analysis needs further to be characterised by a map containing the streets available on it.

SIMOTS generates both pedestrian and vehicular users inside the geographical area under study. Pedestrian users move randomly (according to specific distribution functions previously detailed in Chapter III), and vehicular users move along the streets that form the simulation scenario. Pedestrian users are randomly distributed between indoor and outdoor scenarios, respecting target values established at the beginning of the simulation process.

When a user is generated, it is associated to a service according to the information that is available in a pre-existing traffic database (BHCA – Busy Hour Call Attempt – table).

The outputs of SIMOTS are configuration files (in text format, tab delimited) that are used by CRUS as input files. All the parameters needed for CRUS (users characterisation, network structure, system parameters, etc.) are available in these configuration files.

The simulation process handled by SIMOTS starts by verifying that all the information needed for a complete simulation is correctly defined, so that the users' generation can take place. In Figure IV.3, the general fluxogram of SIMOTS is presented. A high level insight is provided by this figure allowing to understand how the simulator works. In Annex C, additional fluxograms are presented. Those fluxograms detail the functioning of SIMOTS general behaviour and the criteria used in the generation of new coordinates.

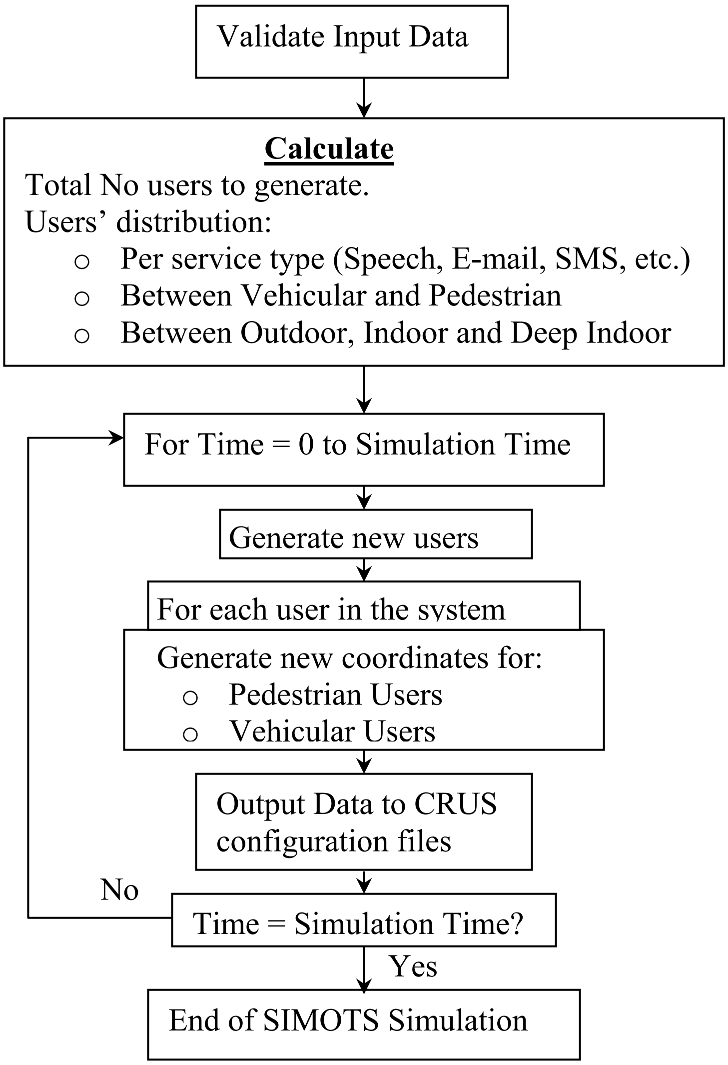


Figure IV.3 – SIMOTS general fluxogram.

If the input information is coherent, SIMOTS calculates the total number of users to be generated based on the information stored in the BHCA table (more precisely in calculates the geographical intersection of the BHCA table with the study area defined in the simulation scenario, and from this intersection, the number of users per service is stored by SIMOTS). The calculation of the amount of vehicular and pedestrian users is based on parameters MobUserGen and BH_Traffic_Percentage stored in table "Traffic_Areas.tab". The distribution of pedestrian users among all the possible indoor scenarios, in accordance with the weights defined in table "SIMOTS_Indoor_Distrib.tab" is computed. At this stage SIMOTS starts users' generation and positioning. The time granularity used by SIMOTS is one second. At each new time instant of simulation, SIMOTS generates (with a Poisson random variable) the number of new users that must be created, and places them inside the study area based on the users' densities defined in BHCA table. Every new user to be generated is associated to a service, following the services' distributions calculated previously. As the user's service is defined, SIMOTS randomly generates the service volume (duration for speech users and volume for data ones) based on an exponential random variable, whose average value is given by the average volume of the user's service. Next, the number of coordinates (or number of time instants given the speed) the user will be present in the system is calculated, for data users, by the ratio between the user's service volume and service's base bit rate. Parameter X_{Time} was introduced in order to allow generating extra users' coordinates, especially in the scenarios with highest system load where service delays can be considerable, aiming at avoiding draught of users' coordinates. In short, SIMOTS calculations are as follows:

$$N_c = (V_s / B_r)\,(1 + X_{Time}) \tag{IV.1}$$

where:

- N_c – Number of coordinates to be generated for a particular user;
- V_s – Volume (kbit) generated by that particular user;
- B_r – Service bit rate (kbps) associated to the service;
- X_{Time} – Extra Time Overhead Parameter.

For each service type, there is a BHCA users' density geographical distribution, and new users are placed according to that distribution. Once placed in the study area, users will have their coordinates updated each time instant according to their speed and movement direction, until the number of necessary coordinates previously calculated is achieved.

The coordinates for pedestrian users are generated randomly, according to the pedestrian model described in Section III.1, i.e., for each new instant of simulation the user's coordinate is determined assuming that he/she has walked linearly, with a constant speed (determined by a triangular distribution) along a random direction determined by the "four normal". Figure IV.4 illustrates the movement of a pedestrian for several instants of simulation. This user was taken at random from a simulation.

Concerning vehicular users, it is assumed that they move along streets (and that is why the street database is needed) with a random speed (described by the triangular distribution) whose average and variation values depend on the type of street. For each vehicular user, SIMOTS generates the coordinates for each new simulation instant by identifying the type of street where the user is. Based on the street type, the average and variation parameters are identified and fed into the triangular random variable generator, in order to get the speed that will be considered for that particular user in that particular instant. The coordinates of the user are then calculated by analysing the direction and length of the street. When a user reaches the end of a street, SIMOTS looks for new possible streets that connect to it (it looks for streets that constitute a crossroads together with the street that has just reached the end). If such streets are found, SIMOTS randomly chooses one of them, and identifies the type and average speed associated to it in order to generate a new speed to be applied to the remaining time left to be travelled by the user. If the street that has just ended is not connected (in that point) to any other street, the user will reverse its way and continue moving along the same street.

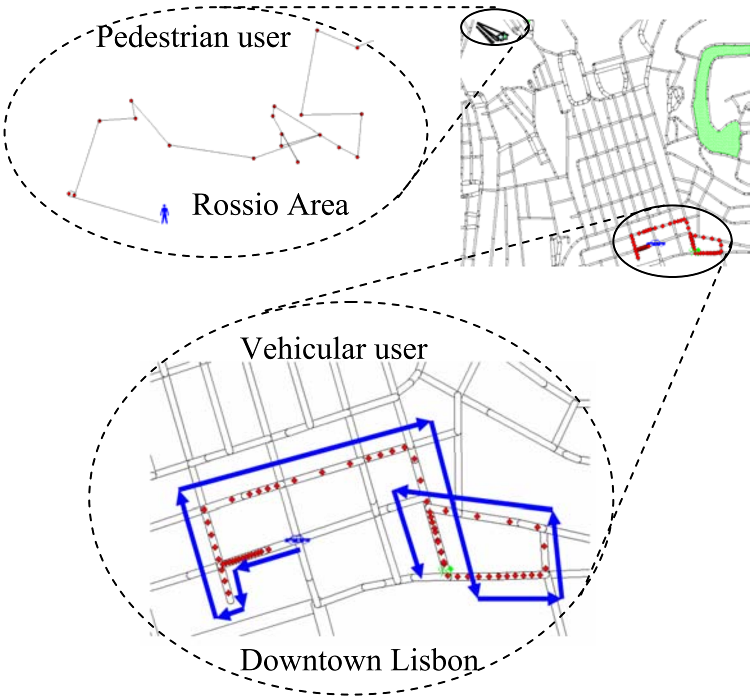


Figure IV.4 – Examples of generated users (pedestrian and vehicular).

All the randomly generated variables are listed in Annex D, where the correlation between the variable generator and the theoretical probability distribution function is analysed.

Figure IV.4 shows the movement of a vehicular user, and Figure IV.5 schematically presents how changing vehicular users' direction is performed, and what kind of information is taken into account.

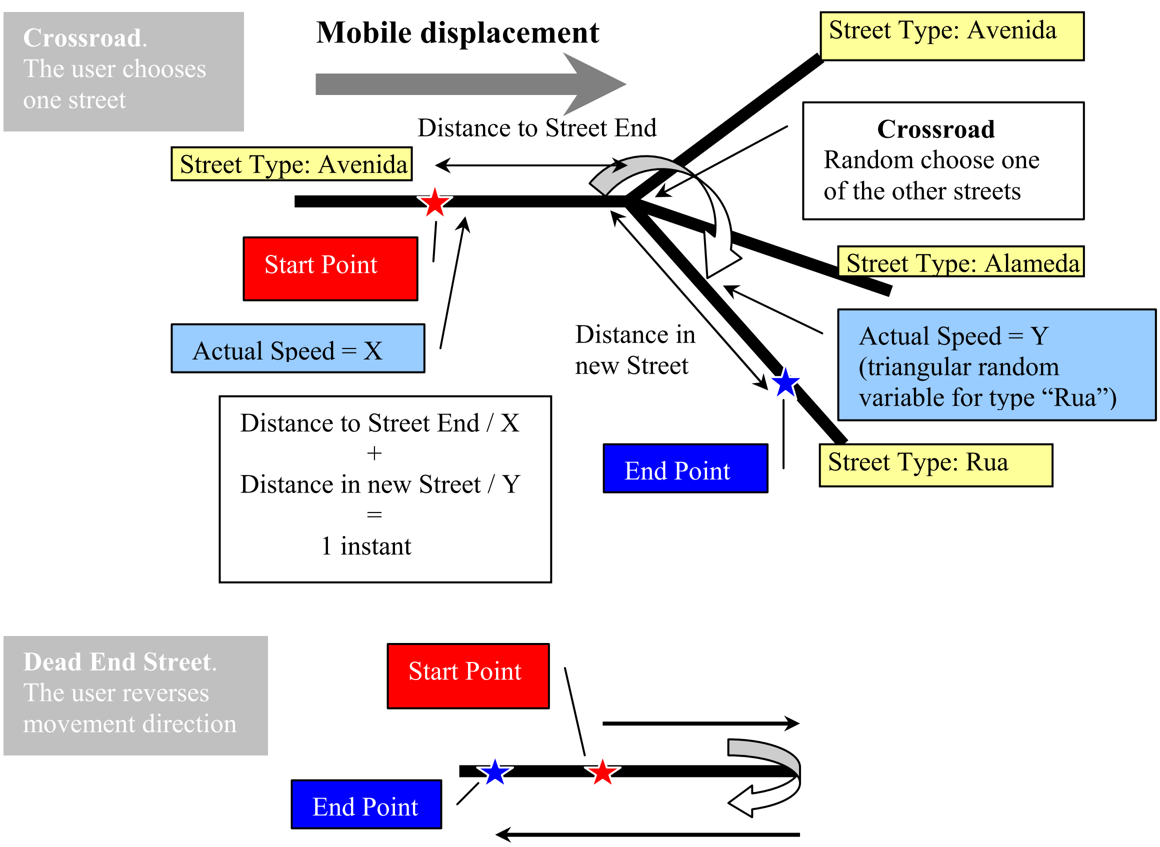


Figure IV.5 – Examples of vehicular users changing direction.

IV.2.2 Input and Output Data

SIMOTS was designed to generate users' distributions according to target parameters, as well as the mobility information associated to them. In order to achieve this goal, the following data sets must be provided to SIMOTS:

1) Definition of the geographic area under study;
2) Services mix and number of users in the system's busy hour;
3) Simulation duration;
4) Streets Database;
5) Vehicular users' percentage.

The definition of the geographic area under study is performed through the user interface of SIMOTS, i.e., MapInfo® GUI. The geographic area under study is given as a table with geographically referenced information. The area is delimited by a set of points that define a closed area (not necessarily a regular one).

Information regarding services mix and number of users in the system's busy hour is needed by SIMOTS, in order to determine the number of users that must be generated for each service type defined in the area under study. This is achieved by providing SIMOTS a table that has, on a "pixel[4] basis", the number of users per service type that are generated in the busiest hour of the network. In fact, this information is used as a reference, since the final number of users SIMOTS generates is calculated based on a scale factor that allows generating different users' densities following the same distribution of users amongst the several service types. This scale factor is needed to easily control the number of necessary users that, for a certain network configuration, ensure a target load in the network. Simulation duration is a basic parameter that defines, in seconds, the length of the simulation.

One of the most important information sources for SIMOTS is the streets database (as important as the users' services' distribution). Mobility analysis being the main objective of this study, it is crucial to have information regarding the streets structure in the area under analysis. This database provides SIMOTS information regarding the location of each street existing in the city under study (in the current study, only Lisbon is considered, but changing it to any other city is straightforward, just by providing the table with that information). Each street is characterised by starting and ending points, its shape and its type. The type of the street is also essential to SIMOTS, as it will generate the users' speeds according to statistical distributions that are conditioned by the street type. More specifically, the average speed value is adapted (and configurable by the simulator user) to the street type e.g., the average speed allowed in a highway is higher than the one in a street inside the city; this is considered by SIMOTS.

The vehicular users' percentage is used by SIMOTS in order to determine the target amount of vehicular users that must be generated. Pedestrian and vehicular users have distinct mobility behaviours, as pedestrian have lower average speeds than vehicular ones, and the latter are constrained to move along streets that are defined in the database; also, vehicular users have a higher average speed.

SIMOTS applies the traffic and mobility models suited to each case for generating users and mobility. When SIMOTS generates a user, it will place him/her randomly in the area under test, according to the users' density defined in the BHCA table (as previously explained). The service associated to that user is also based in the same table while being a vehicular or pedestrian user depends on the parameterisation defined in SIMOTS. The

[4] A pixel is here considered to be a square with 20×20 m^2

allocation of the so-called "user lifetime" is based on the service type, the radio access bearer onto which it is mapped, and the service volume. SIMOTS is configured to generate as many coordinates as the number of instants the user has, according to his/her "lifetime".

The data coming out of SIMOTS is not yet the achievement of the main goal of the simulation process. In fact, the output of SIMOTS is a little bit less than halfway, since it only generates the scenarios to be analysed, in the sense that only mobility is generated by it.

The output data of SIMOTS is a set of files that will be used to configure CRUS, the simulator that performs the analysis of the data from the system perspective. SIMOTS output files are presented and discussed in detail in Annex E.

The network configuration is provided by SIMOTS to CRUS by using files defining the type of antennas to be used (file Antennas_List.cfg), the location of the sites and BSs configurations (files Site_List.cfg and BS_List.cfg), and the list of network global parameters as well as engineering margins (provided in file CRUS_UMTS_Param.cfg).

For the same network structure and settings, several distinct sets of users can be offered. This is achieved by providing users' information in separated files. Users' list and characterisation (both temporal and geographical) is provided by files UE_List.cfg (which hold the initial position for each user, as well the type of service associated to him/her) and UE_Coord.cfg (which holds the information regarding the consecutive users' locations along all the simulation time).

The general behaviour of CRUS is provided by SIMOTS through file CRUS_Settings.cfg. This file provides CRUS with the type of messages that shall be put into the log file, to which periodicity results must be saved, which propagation model type shall be considered, etc..

This output data is the bridge between the two platforms, and, as such, care has been taken in order to guarantee and verify that data generated by SIMOTS was in line with the target scenarios. Hence, the statistical analysis of the files holding users' description (files UE_List.cfg and UE_Coord.cfg) was intensively used to guarantee that random generation of the users is verifying the target scenarios.

IV.3. CRUS' Description

IV.3.1 System Simulation

CRUS is the second step in the simulation's process that was designed to execute the calculations needed to support the current thesis. Figure IV.1 introduced the complete simulation process, where one can see that CRUS has the task of performing system level simulations (the "real" UMTS simulator) and statistics performing.

At a high level, CRUS integrates three distinct modules that are used in different phases of the simulation process: two statistical analysis modules (one for input data and another for output data), and the UMTS simulator itself.

The objective of the input data statistical analysis module is to provide a means of verifying that data produced by SIMOTS is according to the initial target scenario conditions. This module analyses traffic volume per service type (in order to validate the volume generation distributions), users' distributions per indoor scenario and per user type (pedestrian or vehicular) and speed histograms for pedestrian users, vehicular ones, and both.

The objective of the output data statistical analysis module is to provide an automatic process for calculating simulations' statistics. Table F.1, in Annex F, presents a complete list of the statistics performed for each output variable of CRUS. The total number of simulation indicators that must be calculated is very high, and the simulation process produces very large output files (each output file occupies approximately 50 MB), hence, calculating them manually would be neither efficient nor reliable, as the probability of introducing errors due to manual handling of data is high. This module allows automating the statistical analysis process, which is very important, because more than 900 simulations were performed throughout this study. Further in this chapter, a detailed list of the operations performed by this module is presented.

The simulator module itself is the real reason for CRUS' existence. The simulator reads the information characterising the simulation scenario, executes the system's algorithms (regarding power control, admission control, etc.) and outputs files with counters for statistical analysis. CRUS' simulation process starts by measuring the memory occupied in the machine. CRUS then loads the configuration files and verifies the coherence of the information contained in them. Each variable has a validity range associated to it, and if input values fall outside the allowed ranges, the simulator aborts the simulation indicating that the variables are outside the validity range.

If all the variables (loaded from the configuration files) are correctly set, CRUS starts the simulation by opening a log file and the output files for the BSs statistical data. CRUS enters then into a closed loop that ends only when the simulation time has reached the "Simulation Length"[5]. Inside this closed loop, CRUS:

- writes the log file every time instant (with the occupied memory and time stamp);
- loads all users that have been generated (by SIMOTS) for the actual time stamp. ("UE_List.cfg" and "UE_Coord.cfg" files);.
- once identified the user's service, generates data packets stores in the user's application buffer; the structure of a User Equipment/MT is depicted in Figure IV.6.

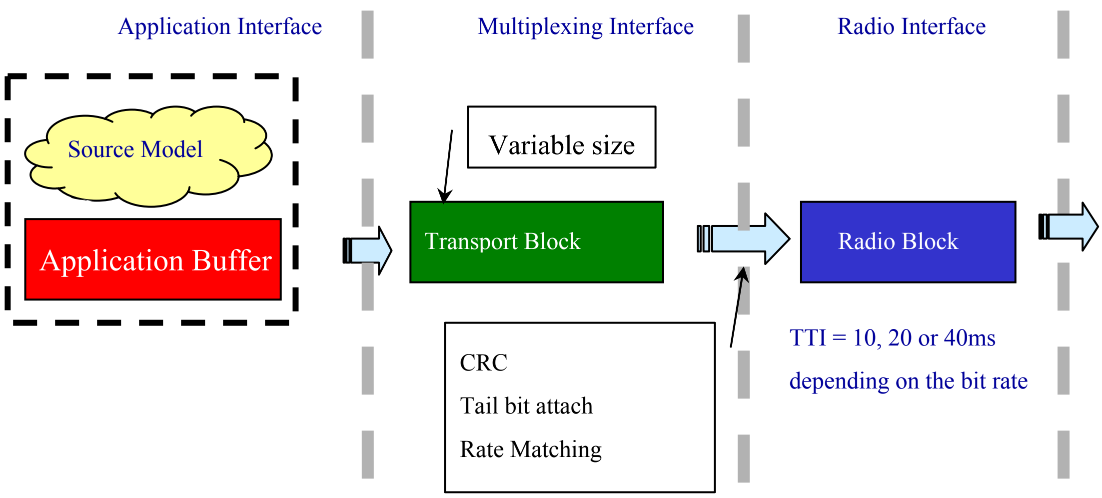


Figure IV.6 – User Equipment structure implemented in CRUS.

For a given service, the appropriate source model is chosen (based on Section III.2) and data packets are generated for both UL and DL in such a way that the so-called "application buffer" retains packets' information (volume and arriving time). For CS services, data packets have a fixed value and inter-arrival time is constant. The application interface provides data volumes for the multiplexing block at a constant bit rate in order to fill in each transport block; radio blocks are also filled in. As this process advances, the application buffer is emptied, and when all the generated packets (for both UL and DL) are sent on the radio interface, the UE is deleted from the system. Transport

[5] Simulation Length is a variable that holds the number of time instants the simulation shall run.

and Radio blocks considered in this model are according to the mapping defined in 3GPP specifications [3GPP02c], and vary according to the radio bearer on to which the service is being mapped. This model allows measuring the amount of data in each interface, and this information can be used later do calculate the signalling overhead imposed by UMTS.

- Calculates the pathloss between the MT and near BS based on COST231 Walfisch-Ikegami [DaCo99] (with the parameterisation present in file "CRUS_UMTS_Param.cfg"). After that a sorting is performed on the active set.

Once reached this stage, CRUS performs operations on a per frame basis, meaning that before the above operations are repeated, CRUS performs the following:

- Execute application buffering – this means that CRUS identifies the packets generated by the source model that felt into the time interval of the current frame and adds it to the application buffer.
- Measure the amount of power needed to establish the connection (this is performed for UL as well as for DL as long as there is any information to be carried from the application buffer to the transport block). The amount of power needed to establish the connection is calculated based on the propagation loss, fading margins, and all the other factors identified in the link budget. A special attention was put in the interference margin. As interference changes along the simulation, in each frame the margin corresponding to the average of the interference measured in the last ten frames is used rather than a fixed value. These calculations are performed independently for UL and DL.
- Sorting of the active set.
- Physical Channel Mapping, consisting of moving data packets from transport blocks to radio blocks.
- CS and PS connections are evaluated in the following order (the complete cycle is performed for CS and then for PS):
  1. Ongoing calls;
  2. Hard handover calls;
  3. New calls;
  4. Soft/softer handover calls;

  As calls are being evaluated by this order this establishes the priority that is assigned for each connection type (CS or PS, and ongoing call, hard handover, new call or soft/softer handover). In case system resources become scarce, the connections will be delayed (if PS connections), blocked (if CS connections) or dropped (both PS and CS) by the inverse order of the one stated above.

- Statistical handler routine is responsible for gathering all the information needed from the system in order to maintain the counters defined in the system (regarding power and codes usage, handovers performed, dropped calls, etc).
- Users that get the application buffer empty are deleted from the system.

The behaviour of CRUS is illustrated in Annex C.

IV.3.2 Input and Output Data

CRUS' input data is the list of files generated by SIMOTS, as described in Section IV.2.2. After analysing the data provided by SIMOTS, CRUS generates for each configured BS[6] output statistics regarding cell behaviour.

Several aspects of BS performance are being monitored, which can be splitted into the following sets:

1) offered traffic;
2) resources allocation;
3) QoS performance.

Offered traffic is monitored by counting the number of users that are offered to the cell, distinguishing them by type (pedestrian and vehicular). The number of users served as Best Server are distinguished from the ones served with a soft or a softer handover link.

Resources allocation aggregates all the analysis performed on power and codes allocated to traffic channels in the cell. This analysis is split into the several types of links the cell can provide: Best Server, Soft Handover, and Softer Handover. Also UL and DL load is monitored.

QoS performance is monitored by counting the number of CS calls that are blocked (and distinguishing them by cause type – lack of power in DL, lack of power in UL, etc.), the success rate of outgoing handovers (splitted by the several speed intervals), measuring the total carried traffic in UL and DL (splitted per application type), and measuring also average throughput and delay per application type.

[6] Statistics are only generated for BSs that have the field "Statistics_Status" set to "T".

It is important to clarify that BSs are configured with only one radio channel, i.e., this simulator does not considers multiple carriers.

An additional "feedback" measurement was introduced, by counting the number of users that became "out of coordinates" after the system analysis. As the mobility data is being generated in advance by SIMOTS, it might happen that for PS connections some users (due to high load in the system) could be heavily delayed by the system, and due to that, the number of coordinates generated by SIMOTS would not be enough. It such a case CRUS assumes that the user keeps its last known coordinate while the connection lasts. This "feedback" measurement gives, in fact, per service type the number of users that "ran out of coordinates" for each simulation. This information was used to fine tune the generation of coordinates (so that the number of generated coordinates would be enough for all the users being fed into the system, regardless of the network load).

IV.4. Simulators' Assessment

The simulation process developed in the scope of the current thesis is considerably complex, as it relies on the coordinated usage of two independent simulators, developed in two independent platforms, as previously mentioned. Due to this particularity, the development of the simulators was carried with extreme caution, in order to guarantee that the coordination between the platforms was fulfilled, and that all results (from both platforms) were consistent and numerically exact in accordance with the implemented models. Introducing here the results of all tests that were performed on the two simulators would lead to an enormous extension of the text and would be too time consuming, because all output variables are tested with more than one test case. Also the distributions of users' types, services, volumes, etc., of SIMOTS were analysed in detail, in order to guarantee they were being generated according to the target scenarios.

Therefore, this section presents only selected tests, which allow demonstrating the validation of selected variables and functionalities.

The total number of counters exported by CRUS exceeds 130 (Annex G presents a full detailed list of the output variables) as many entities are being monitored by the simulator (entities such as DL transmitting power, DL channelisation codes, users' speed histograms, etc.). As the goal of this thesis is mobility modelling and analysis, the test case presented herein is focused on testing the behaviour of a handover situation.

Figure IV.7 illustrates a mobility situation. A mobile user is considered to travel from a Source cell to a Target one, while performing a speech call. In this particular case, the coordinates of this user were forced to be along that line, but in a normal simulation they would have been randomly generated. Regarding random generation, both simulators have internal random variables generator whose behaviour is documented in Annex H by a list of all random variables generators, along with some measures of correlation between generated numbers and theoretical distributions. Two tri-sectorised sites are represented along with the area of the two sectors serving the test mobile. The blue dotted line represents the path travelled by the MT and four time instants are indicated in the figure for further reference. The time instants represented in the figure identify that the user starts the call when the system time is 60 s (t = 60 s) and it ends at t = 110 s, meaning that the speech call has a duration of 50 s. The figure clearly identifies the coverage area of both cells, based on which a soft handover area (the area overlapped between the serving areas of both cells) is shaded slightly darker; the MT passes in that area between time instants t = 81 s and t = 84 s. It must be noted that the illustration is not scaled.

The user moves, then, from the Source cell to the Target one at a constant speed of 10.8 km/h, and no other user is being served by any of the Source or the Target cells. As Source and Target cells do not belong to the same site, the overlapping area is a soft handover area rather than a softer handover one. In what follows, all references to the soft handover situation would become references to a softer handover one if both cells would belong to the same site; despite the softer handover situation is not described here, it was verified (with other specific test cases) that the response of the simulator to a softer handover situation is working properly and providing correct results.

Figure IV.8 represents the DL transmitting power of the Source and Target cells introduced in Figure IV.7, as well as the distance of the MT to each one of these BSs. The analysis of the DL transmitting power reveals the usual increasing propagation loss as the distance between the MT and the BS increases, which leads to an increase in the transmitting power. In instant t = 81 s, the difference between the propagation losses provided by the Source and the Target cells is below the soft handover margin (parameterised to be 3 dB in this simulation), and, as such, the system now considers that the MT is served by an extra radio link accounting for the gain provided by it. With this extra gain considered in the link budget, the system now allocates a lower DL transmitting power for this MT. As the scenario is symmetric, there is also symmetry in the allocated power in each BS.

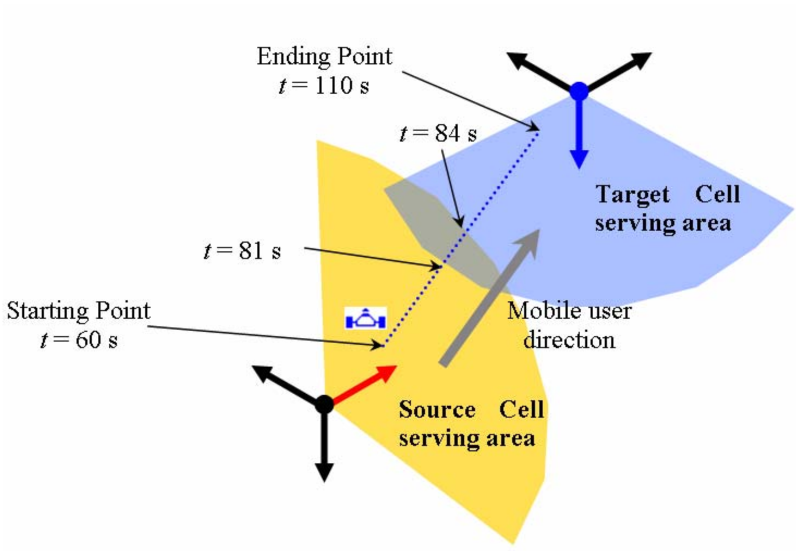


Figure IV.7 – Handover test scenario illustration.

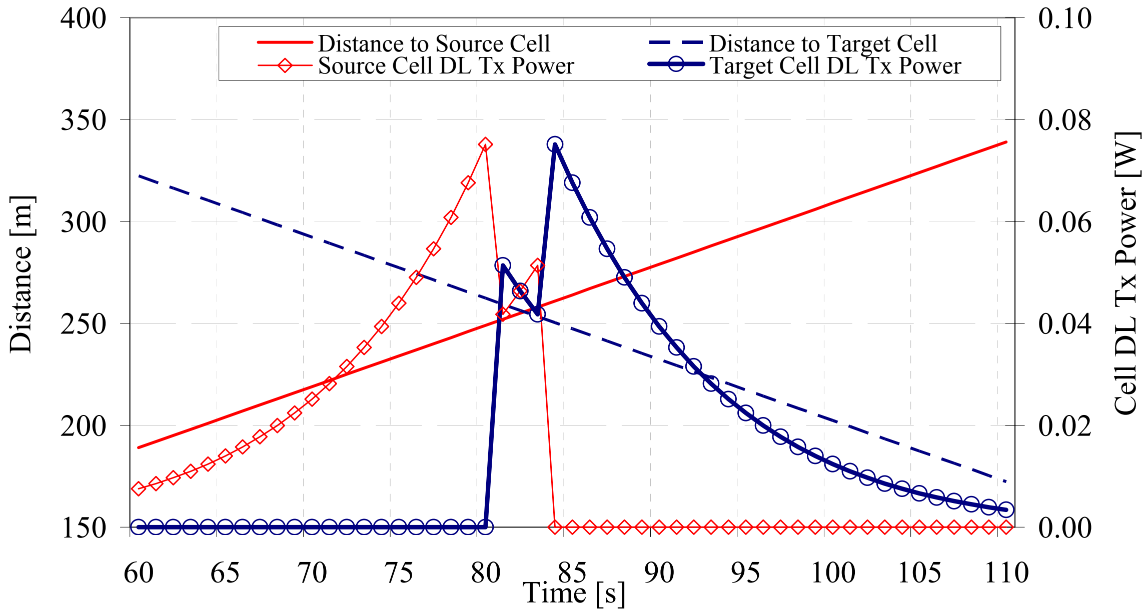


Figure IV.8 – UE distance and transmitting power during handover.

Figure IV.9 presents, besides the DL transmitting power of each cell, the DL load calculated for each of the cells. Cell load is constant and equal in both cells in this case reflecting the fact that cell load is being calculated by using (II.3). According to this expression, the cell load depends on the inter-cell interference factor $I_{inter\ n}$, which is being accounted in CRUS by a fixed, parameterised margin, rather than a value depending on the instantaneous network users' distribution.

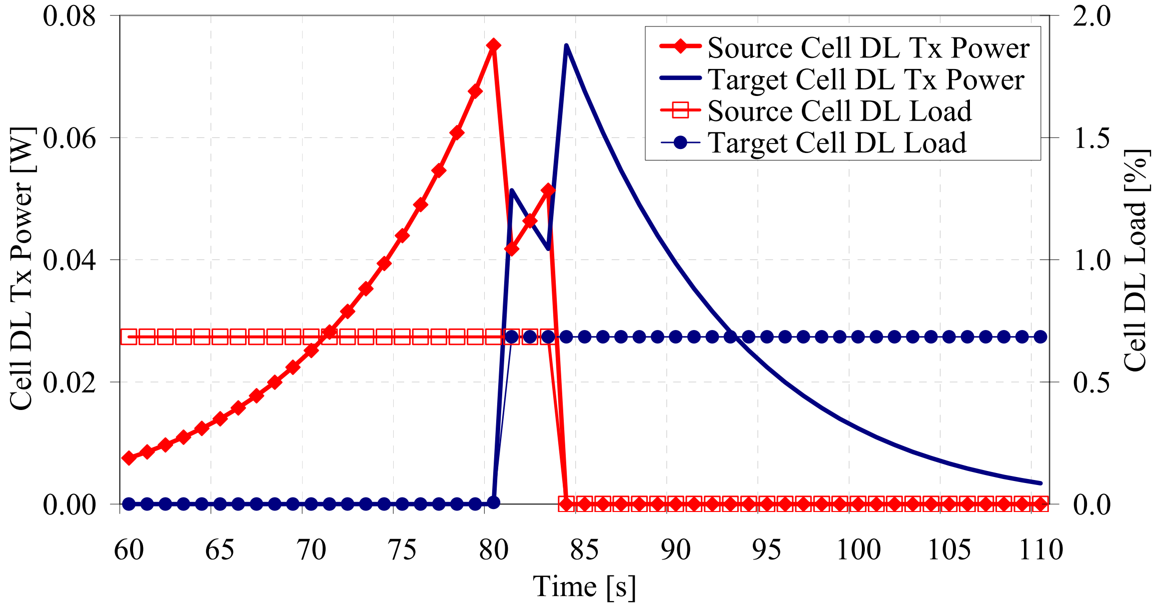


Figure IV.9 – DL Load and Transmitting Power during handover.

As the same formulation applies to all cells in the system, a user will produce the same amount of load in any cell by which he/she is being served, and that is reflected on the fact that during soft handover (t = 81, 82 and 83 s) both cells have exactly the same DL load.

In Figure IV.10, the DL allocated channelisation codes and the incoming handovers counter are represented. Regarding the DL channelisation codes, as the test was performed with a speech user, each serving cell has to allocate 4 basic channelisation codes. It is important to mention that in order to manage the allocation of channelisation codes of different spreading factors, when the simulator needs to allocate a certain channelisation code (no matter which spreading factor it is associated to) it calculates the equivalent number of channelisation codes with spreading factor 512, and tries to allocate that number of channelisation codes from the pool of available codes. Due to this, the output of the simulator is the number of allocated DL channelisation codes associated to spreading factor 512, and for a speech user one DL channelisation code of spreading factor 128 corresponds to 4 spreading factor 512 channelisation codes.

The incoming handover counter of the target cell is triggered by successful incoming calls from other cells only in the instant that the cell is the only serving cell for each of those calls. All the instants before the cell is the only serving cell of a call are accounted as soft or softer handover situations, thus, are not yet considered as a "conventional" handover.

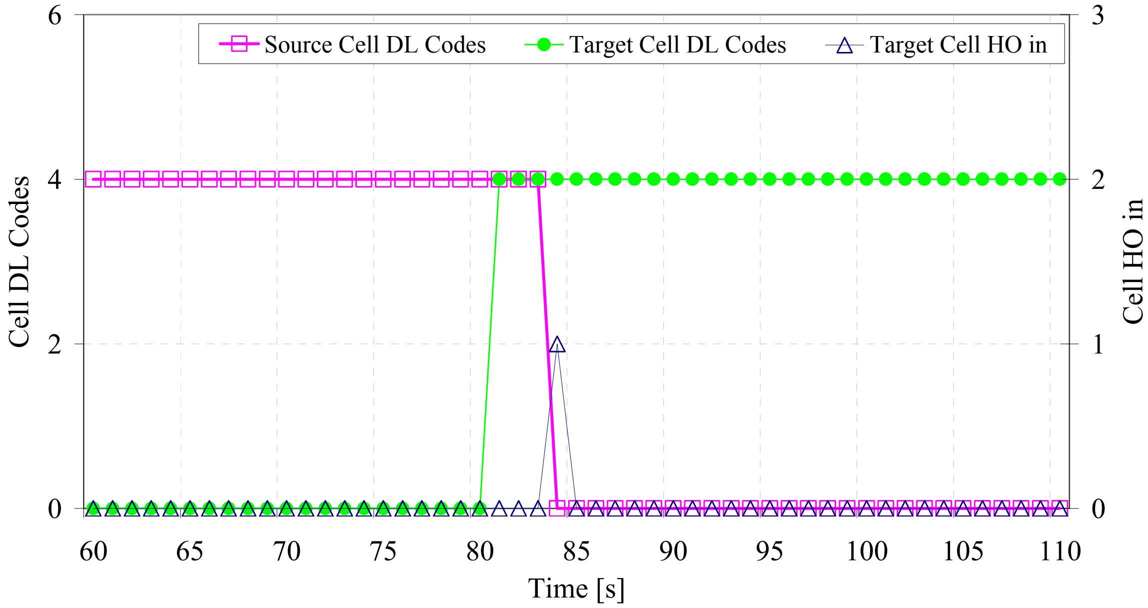


Figure IV.10 – DL allocated codes and Handover counter during handover.

CRUS has several counters implemented in it, which monitor the speed of the MTs being served by each BS. That is the case of the speed histograms for pedestrian and vehicular users, and the successful outgoing handover histogram, which is triggered as a function of the user's speed. In order to illustrate the behaviour of this counter, another test scenario was built. The scenario is the same as described in Figure IV.7, but now the mobile user had a non-constant speed. In Figure IV.11, the instantaneous MT speed is represented, where it should be recalled that the handover is executed at instant t = 84 s; it can be verified, by analysing the successful outgoing handovers' counters of the Source cell, that only the one corresponding to the MT speed in t = 84 s was triggered (i.e., counter HO_Out_OK_20_25, as the instantaneous mobile speed is 24.5 km/h). None of the other successful outgoing handovers' counters (from HO_Out_OK_0_5 to HO_Out_OK_more_135, as described in Annex G) are triggered due to this mobile user.

All the above examples are the result of a well known setup, for which the expected results were previously known. Another example, of the output for a longer simulation is presented in Figure IV.12. In this particular case, the simulation duration is 70 minutes, and the behaviour of variables DL transmitting power, DL and UL cell loads are presented.

Again, it should be stressed the fact that all the output variables from the simulator were submitted to different test scenarios, whose results were previously known, and evaluated by calculations external to the simulator, prior to be considered as ready to use for simulation purposes.

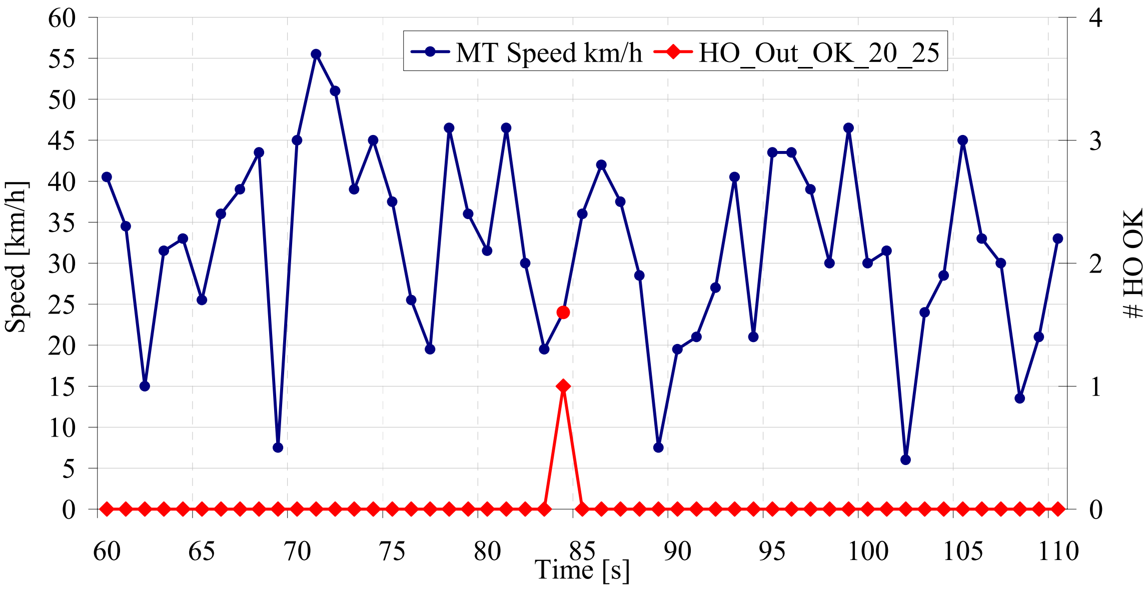


Figure IV.11 – Example of UE speed and handover counter during handover.

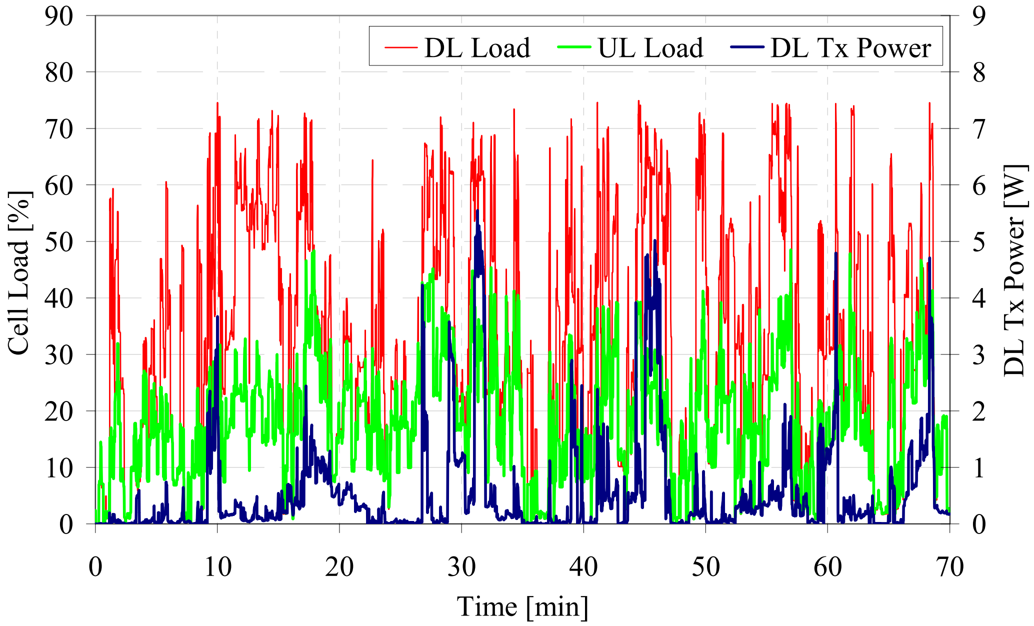


Figure IV.12 – Example of DL Tx power and cell load during one simulation.

IV.5. Simulations' Setup and Results' Statistical Analysis

Once the simulators were ready to work, a dimensioning process took place, in order to define the minimum simulation time that would be required to perform in each simulation.

System simulations must be long enough, in order to be representative of the system's behaviour. As a rule of thumb, the simulations should take one hour as if the entire busy hour of the system would be under analysis. The statistical analysis of the simulations' results must be based on a coherent data collection, which means that the first instants of simulation must be filtered out, because they represent a transient response of the system (which is empty of traffic at the beginning). The time needed to stabilise the number of simultaneous active users in the system depends on the size of the study area (which leads to different average number of simultaneous users). Figure IV.13 presents an example of the evolution of simultaneous number of users during one hour. In general, the 5 initial minutes of simulation are sufficient to stabilise the number of users in the system, nevertheless, it was decided to ignore all the first 10 initial minutes of simulation in order to filter out all the transient fluctuations that might appear.

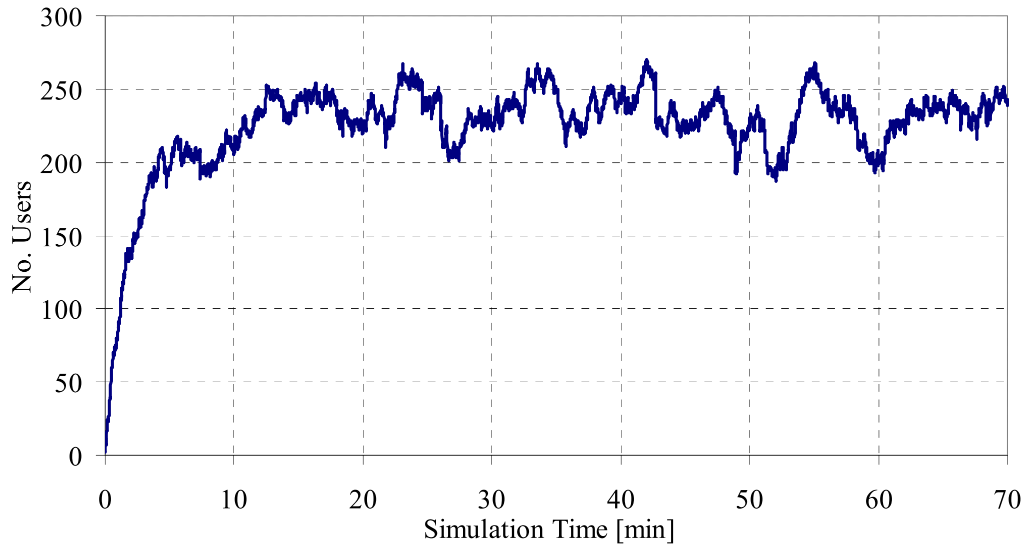


Figure IV.13 – Number of simultaneous users in the system.

The performance of the network (which is presented in the next chapter, and is shown in detail in Annex I) in different scenarios is assessed by analysing the statistical behaviour of the variables under analysis. The minimum number of simulations needed to be performed, in order to assess statistical meaningful results, was dimensioned by analysing the behaviour of Dropped Call Rate (DCR) and Blocked Call Rate (BCR) with an increasing number of simulations. A set of 30 simulations was performed for a fixed simulation scenario, and Figure IV.14 presents the average (Avg) and standard deviation (Stdev) of those indicators by grouping the simulations in a set of 5, 10, 20 or 30. The standard deviation of both indicators decreases as the number of simulations increases, as expected. The set of 10 simulations is the one that presents the highest decrease in standard deviation, and it constitutes the best trade-off between having a meaningful statistical sample and the time required to run the simulations.

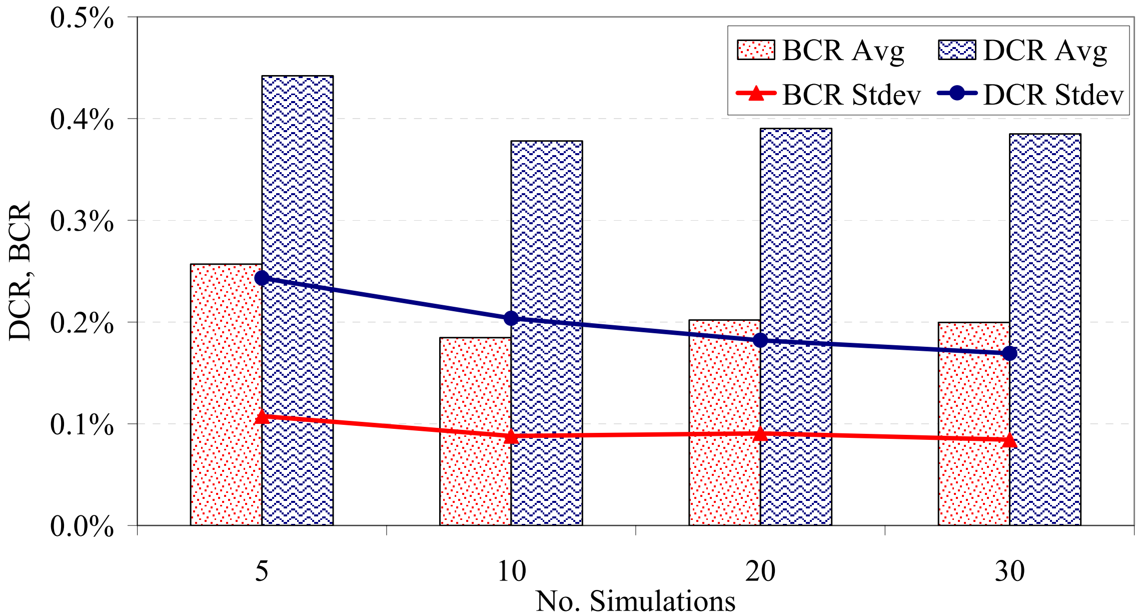


Figure IV.14 – Dropped and Blocked Call Rate for a set of 5, 10, 20 and 30 simulations.

It is common to analyse, apart from the average value of an output variable, its standard deviation as a means of knowing how much spread the values are. This approach gives a good insight into the variable's behaviour.

If the variable is not Gaussian distributed then the standard deviation may not provide such accurate information on the variable's behaviour, and in those cases the 5% and 95% percentiles are a better way of assessing the spread of the variable, defining a 90% confidence interval. Based on this approach, the statistical analysis performed by CRUS provides, aside from average and standard deviation values, the 5% and 95% percentiles of selected variables.

Apart from the system level tracing variables, CRUS also provides measured data regarding the instantaneous usage of resources it demands to the computer. These measurements include memory allocated by the simulation process and required processing time. Both measurements are important from the simulation dimensioning process standpoint, as the evaluation of the necessary memory for a certain simulation setup allows identifying the most adequate hardware setup to have in the machine used to carry it.

Figure IV.15 presents examples of the memory allocated by CRUS in four different scenarios, which correspond to the reference scenarios used in the study and that are characterised in the next chapter. It is important to note that these scenarios have an increasing higher number of users in the area analysed by CRUS, which is why AvRp needs roughly 3 times the memory required for Moscavide (700 MByte versus 250 MByte).

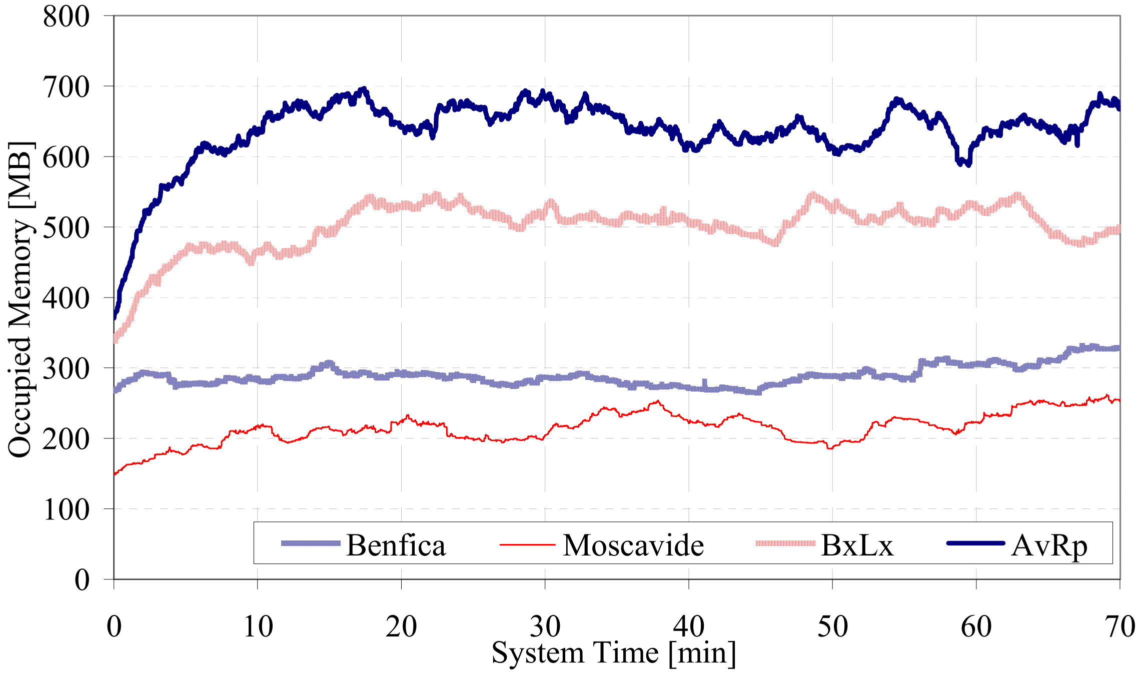


Figure IV.15 – Instantaneous Memory Required by CRUS.

This measure of the necessary memory allowed concluding that, for instance, simulations for AvRp scenarios could not be ran within a reasonable timeframe in a machine with less than 1 GByte memory. On the other hand, Benfica and Moscavide scenarios could be (and did) ran without any concerns in a machine with only 500 MByte memory.

Simulation time consumption was also monitored and used for adequately scheduling the 920 simulations that turned out to be necessary to perform, within the scope of the current study.

Concerning the required processing time, it is highly dependent on the number of users generated in the simulation. Table IV.1 presents, as an indication, the average values for the processing time and the volume occupied by the files that are necessary for information input and output, for four simulation conditions (the test scenarios used in the study). These results are averaged, and include the whole simulation process (SIMOTS and CRUS). The processing time taken by SIMOTS ranges between 12 and 45 % of the total, depending on the number of users. The files considered here are both the output files from SIMOTS (weighting on average 30 % of the total files volume) and CRUS. All those performance indicators are based in simulations running in a Pentium IV processor, equipped with a 1.6 GHz clock and 1 GByte memory.

Table IV.1 – Simulations' performance indicators for a single simulation.

No. Users	Processing Time [min]	Files Total Volume [MB]
2 000	11	67
3 000	19	73
7 000	64	90
11 000	125	112

As a final remark, the current study needed 920 simulations to be performed, which took around 71 GB of information (in file support) requiring around 718 hours of continuous processing time (roughly 30 days) on a single machine.

Chapter V

Analysis of Results

In this chapter, a full services and mobility characterisation of test scenarios is presented as well the network structure used in the simulations. The impact of mobility variation in the network performance is analysed in each of the test scenarios. Variations are applied to users' indoor locations in the densest traffic scenario in order to assess the system response. System response trends are obtained from both mobility and indoor location variations.

V.1. Scenarios' Characterisation

V.1.1 Users and Services

When working with simulation scenarios that have traffic distributions and users' geographical densities as inputs, as it is the case in the current study, there is an enormous added value by using real values instead of simple common sense ones. IST-MOMENTUM project [MOME04] dealt with, among other things, simulation scenarios' characterisation in some European cities, Lisbon and Porto being two of those cities. One of the deliverables of IST-MOMENTUM [FCXV03] is a traffic matrix of BHCA describing on a pixel basis, $20 \times 20 m^2$ square, the traffic density at the busy hour (i.e., the number of users that access a certain service within that $20 \times 20 m^2$ square during the system busy hour), and its results are used in this thesis. Figure V.1 presents the BHCA users' density distribution for Lisbon at busy hour of the network.

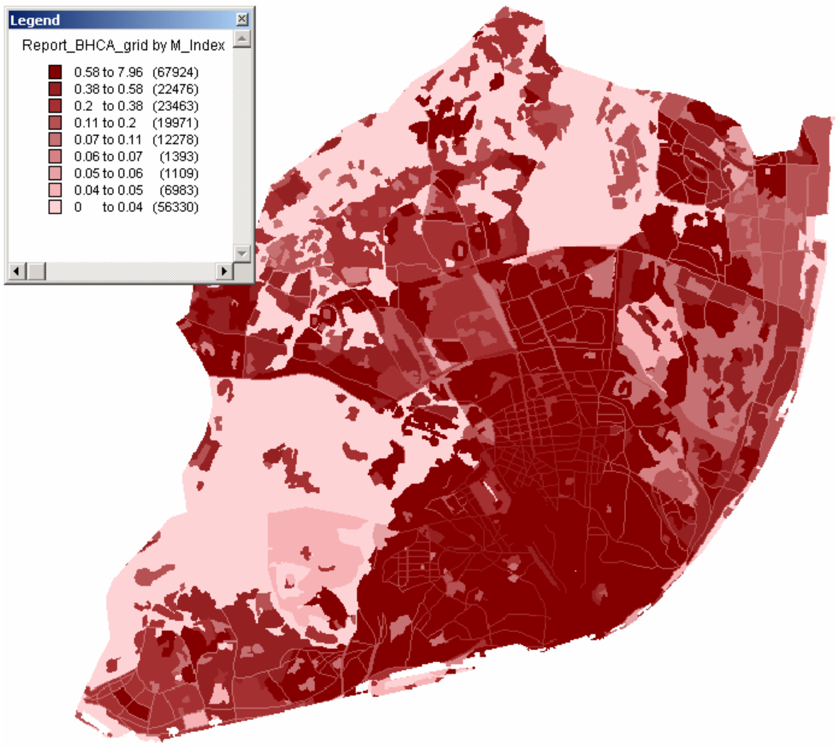


Figure V.1 – BHCA's density in Lisbon.

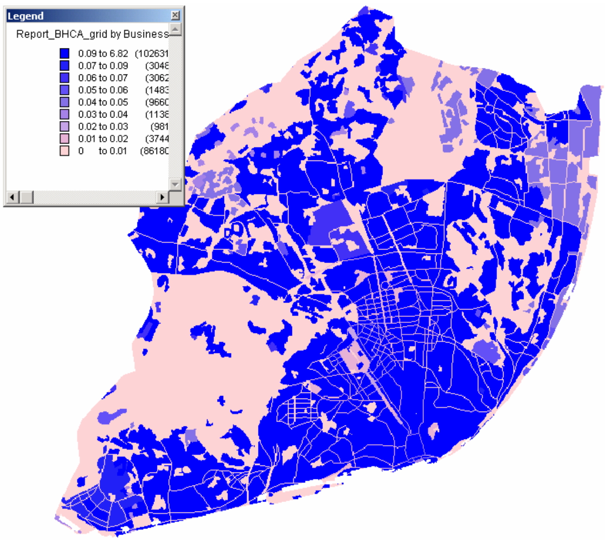
The analysis of the figure clearly shows the users' agglomeration in the centre of the city, being coincident with the areas with higher density of business areas. In the Western part of the city, a very low density area appears due to the existence of Monsanto (a big green area of the city, the so-called city's lung). In the Northern part of the city, another low density area identifies the city's airport. Remarkable is the fact that the wider streets of the city can be identified in this map, as they have a lower users' density. This high detail is possible due to the fact that a $20 \times 20 m^2$ square resolution was used to generate these maps.

Lisbon's BHCA was calculated in the scope of that project by weighting the information of resident population, age distribution and geo-economic status (related with the identification of the areas where offices and residential areas are established). By crossing this data with the services usage by people with a specific profile, the outcome is a grid that differentiates on a pixel per pixel basis the number of users that use a certain service during the busy hour.

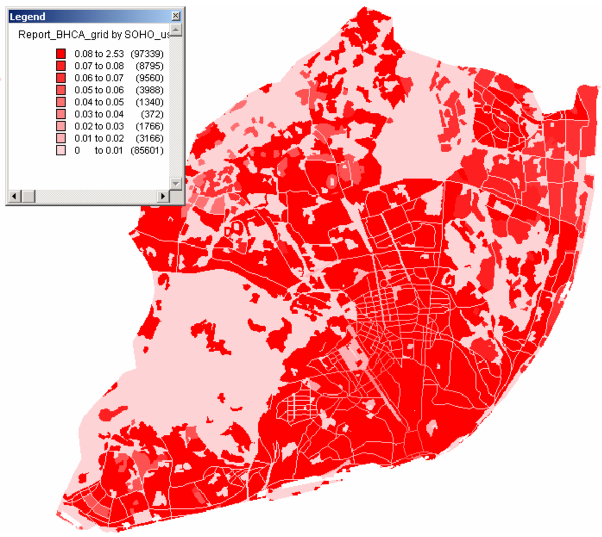
Annex J presents a brief description of the process employed in IST-MOMENTUM for BHCA table's generation, addressing also the users' segmentation weighting per operational environments and service types. Nevertheless, the reader is encouraged to look into [FCXV03] for details.

When analysing services characterisation, it is of common sense that the same service can be used differently by users with different profiles. As an example, a speech call from a business user can easily take more than 10 minutes, whereas a private speech call takes around 2 minutes. Another example can be the usage of a web access. The common residential user may use it once or twice per day, in order to verify the bank account or read some news in the Internet, whereas a business user may need to use it intensively in order to have continuous information concerning financial markets. Based on this approach, BHCAs were built based on the assumption that three different market segments co-exist in the city: Business, SOHO (Small Office Home Office), and Mass-market. These market segments differentiate themselves by the average utilisation for each of the available services. Figure V.2 presents the geographical distribution of the users for these three defined market segments in Lisbon at busiest hour; in this figure, the areas of Monsanto and the city's airport are again identified as the lowest users' density ones. The Business and SOHO distributions have a very low users' density on streets, as they are commonly concentrated in buildings rather than on streets, and due to that, streets are clearly identified on those maps. On the other hand, as Mass-market users are likely to walk without so many physical constraints, the city streets details are no longer so remarked in the map for this type of users. In a general way, in all three market segments distribution maps, a higher density is still identified in the centre of the city, in accordance with the distribution of Figure V.1.

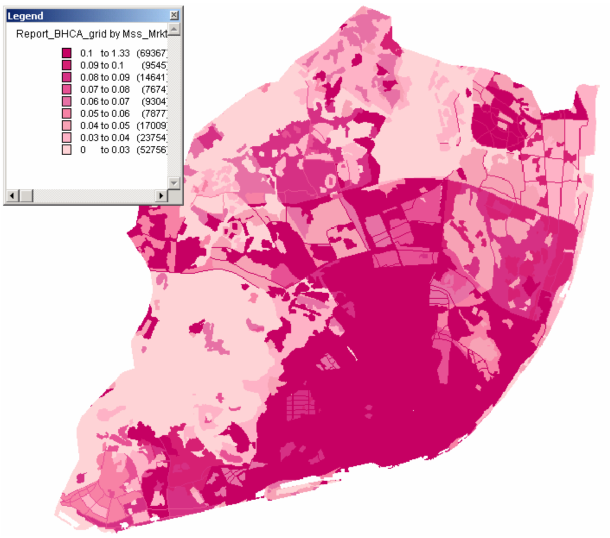
The information contained in the BHCA data table covers the geographical distribution for a set of nine distinct services: SMS, E-mail, Speech, MMS, LBS, FTP, Video Conference, Web-Browsing and Streaming Multimedia. Figure V.3 illustrates the traffic density for specific services and market segments aiming at giving a good insight into the available information. These figures follow the trends already identified in Figure V.1 and Figure V.2, in all of them the Monsanto and airport areas being identifiable; extra heterogeneity is now introduced as users' agglomeration is also dependent on the type of service being represented.



(a) Business



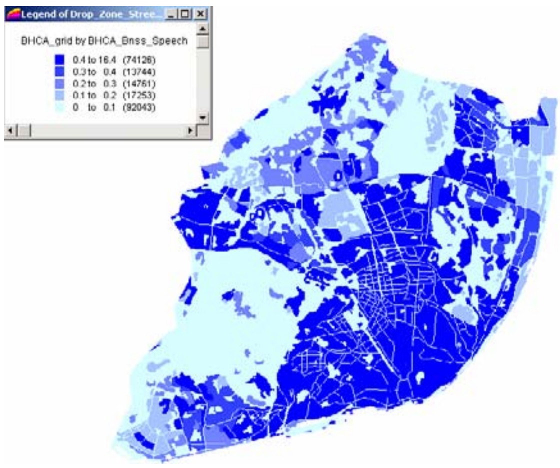
(b) SOHO



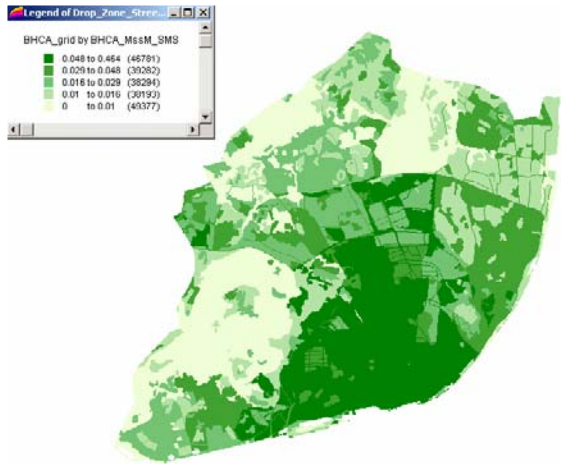
(c) Mass-market

Figure V.2 – BHCA distribution per market segment in Lisbon.

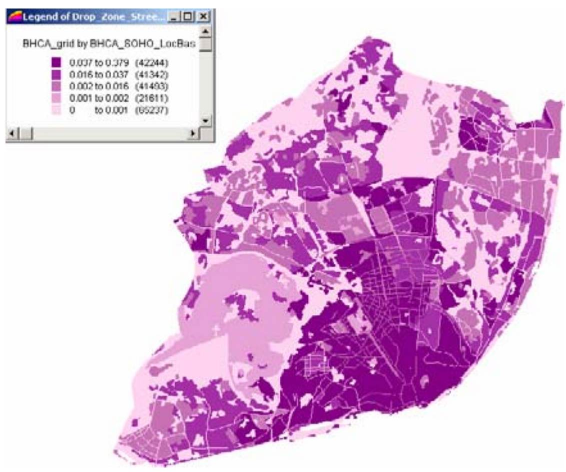
Aside from the traffic characterisation, the study relies on a streets' database as a mean of characterising the differentiated mobility conditions within the city. The information provided by this database is used to generate the coordinates of the vehicular users within the simulation process implemented in SIMOTS. It must be recalled that pedestrian users are generated randomly being located without any close relation to streets location.



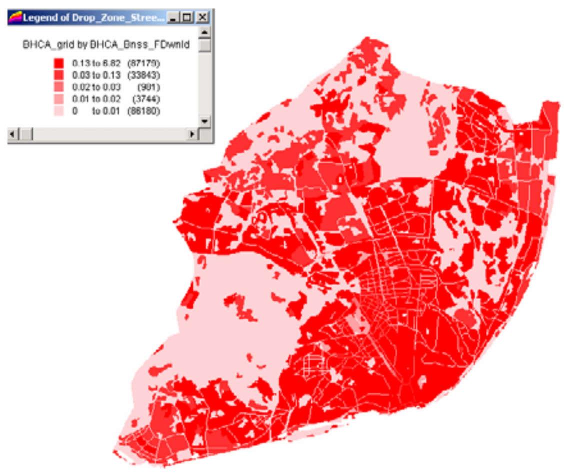
(a) Speech Business



(b) SMS Mass-market



(c) LBS SOHO



(d) FTP Business

Figure V.3 – BHCA distribution per service and market segment in Lisbon.

The main goal of the current study is mobility and its impact on the network capacity, therefore, differentiating types of users (Business, Mass-market and SOHO) was not an objective. As an implementation option, no distinction was made among users for the same service with different profiles, meaning that the mean holding time for (for instance) a speech user is the same, regardless of the fact of being a Mass-market, a Business or a SOHO one.

Table V.1 presents the values considered in the simulation scenarios regarding services' profile characterisation.

Table V.1 – Services characterisation (adapted from [FeCo03]).

Service	CS/PS	DL nominal Service Bit Rate [kbps]	DL session volume	UL nominal Service Bit Rate [kbps]	UL session volume
e-mail	PS	64	10 kB	64	10 kB
FTP	PS	384	1 000 kB	64	20 kB
HTTP	PS	128	1 200 kB	64	40 kB
LBS	PS	64	230 kB	64	30 kB
Streaming multimedia	PS	384	2 300 kB	64	120 kB
MMS	PS	64	60 kB	64	60 kB
SMS	PS	64	1 kB	64	1 kB
Video telephony	CS	64	120 s	64	120 s
Speech	CS	12.2	120 s	12.2	120 s

V.1.2 Mobility

Different mobility and users' density areas were envisaged at the beginning of this study, so that their impact on network performance could be analysed. Based on the city map, BHCA table information, and prior knowledge of the city, four areas were identified aiming at crossing high and low mobility profiles (*via* the distinct type of streets in each chosen area) with high and low users' density (*via* the users density provided by BHCA tables).

Figure V.4 presents the mobility characterisation of Lisbon based on the information provided by the streets' database [MOME04]. Each street type is associated to an average speed, following the triangular speed distribution previously mentioned. This mapping allows having a mobility scenario that can be highly correlated to the real mobility situation in the city, and results can be as much closer to reality as more realistic the values of average speed associated to each street type are. Table V.2 presents the values adopted to the speed of each street type.

After some research, Avenida da República and Downtown were identified as areas with high density of users (4 980 and 3 720 users/km^2, respectively), whereas Moscavide and Benfica areas were identified as low density ones (740 and 540 users/km^2, respectively). The geographical areas are presented in Figure V.5, and Figure V.6 illustrates those numbers. For easiness when referring to each of the these areas, in what follows, shorthands will be used:

BxLx will be used to identify Downtown, AvRp for Avenida da República, Benf for Benfica, and Mosc for Moscavide.

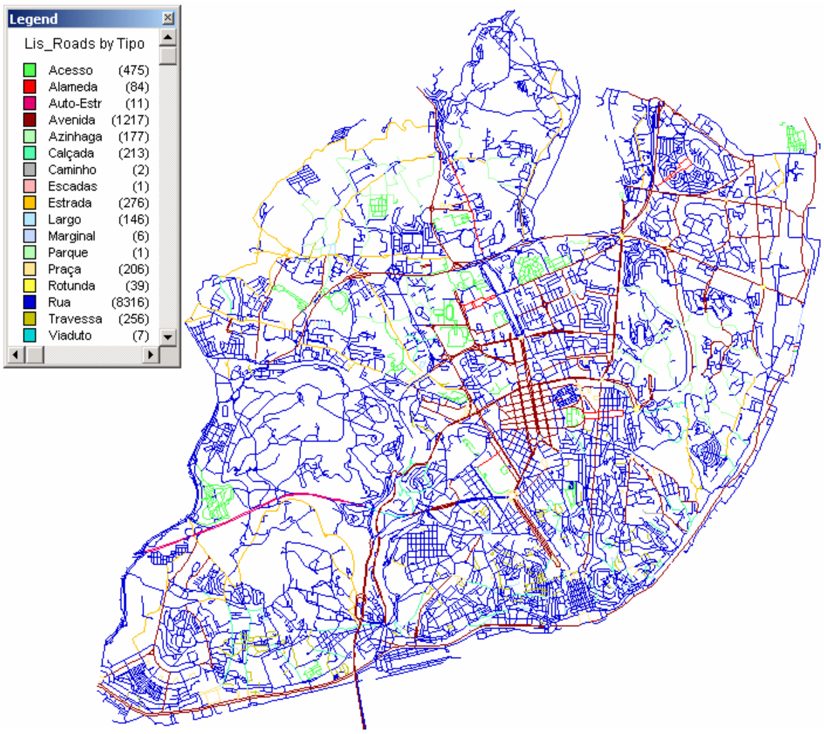


Figure V.4 – Mobility distribution characterisation for Lisbon.

Table V.2 – Streets characterisation in Lisbon mobility scenario.

Street Type	Width [m]	Speed [km/h]	
		Average	Variation
Street (Rua)	15	20.2	20.2
Avenue (Avenida)	40	45.0	45.0
Access Street (Acesso)	10	36.0	36.0
Road (Estrada)	10	45.0	45.0
Narrow Street (Travessa)	10	4.0	4.0
Old Street (Calçada)	10	4.0	4.0
Square (Praça)	30	15.1	15.1
Street without asphalt (Azinhaga)	5	4.0	4.0
Large open space (Largo)	30	15.1	15.1
Boulevard (Alameda)	40	45.0	45.0
Roundabout (Rotunda)	30	15.1	15.1
Highway (Auto-Estr)	50	79.9	40.0
Elevated road (Viaduto)	15	45.0	45.0
Path (Caminho)	10	4.0	4.0
Stairs (Escadas)	5	4.0	4.0
High speed access (Marginal)	15	45.0	45.0
Park (Parque)	30	4.0	4.0

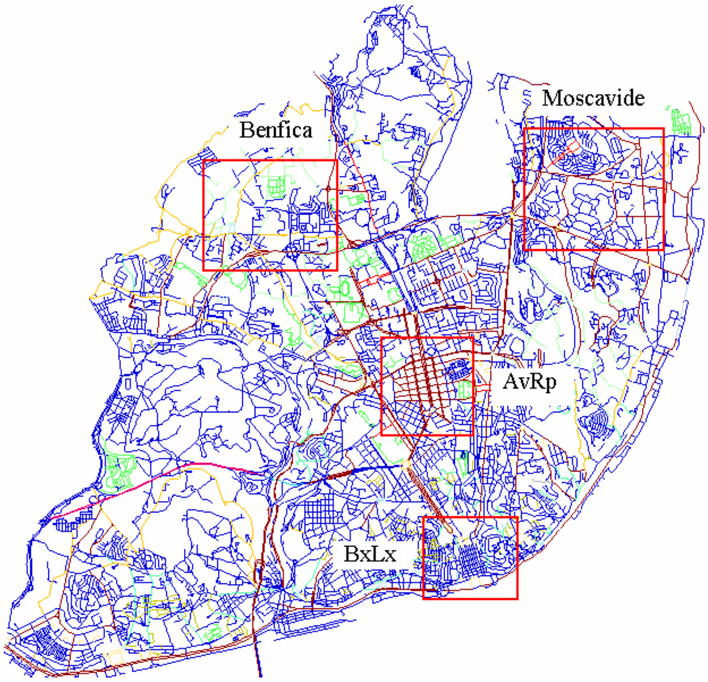


Figure V.5 – Test Areas identification.

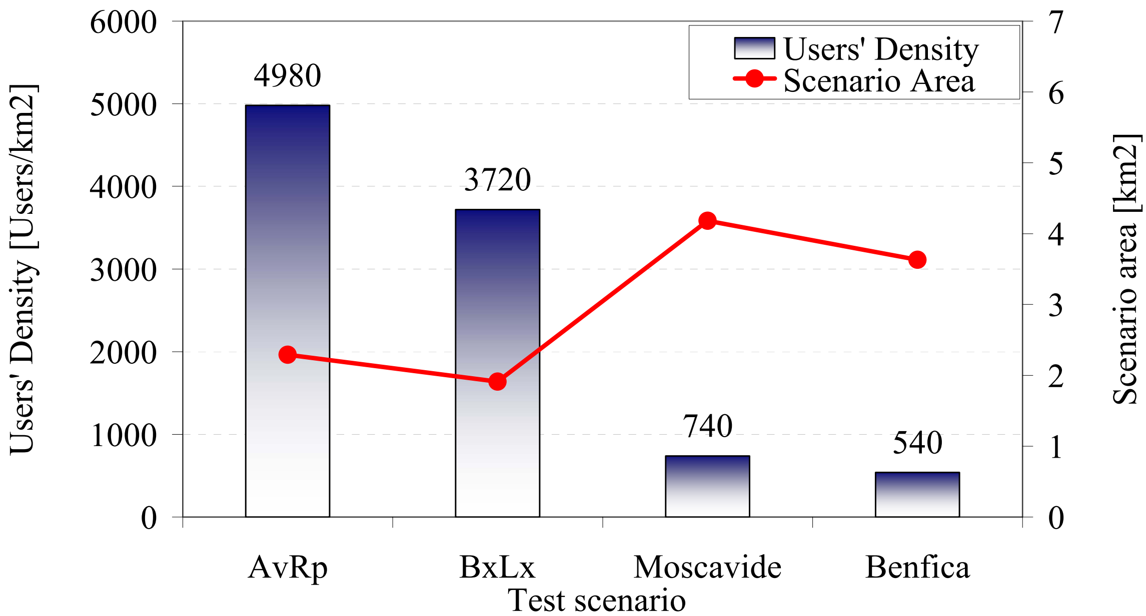


Figure V.6 – Users' density in the four test scenarios.

Regarding mobility profiles, the knowledge of the city dynamics indicates that Avenida da República and Benfica are areas of higher mobility, since they are crossed by large avenues (such as Avenida da República, Avenida de Roma or 2ª Circular), whereas Downtown and Moscavide have inherently lower mobility profiles, as they are areas with narrow streets. Figure V.7 presents the PDF of the users' speed generated for each one of the referred scenarios. The analysis of the PDFs confirms the assumptions taken, by verifying that

BxLx and Moscavide scenarios have a higher density of lower speed users, and that AvRp and Benfica have a higher density of higher speed ones.

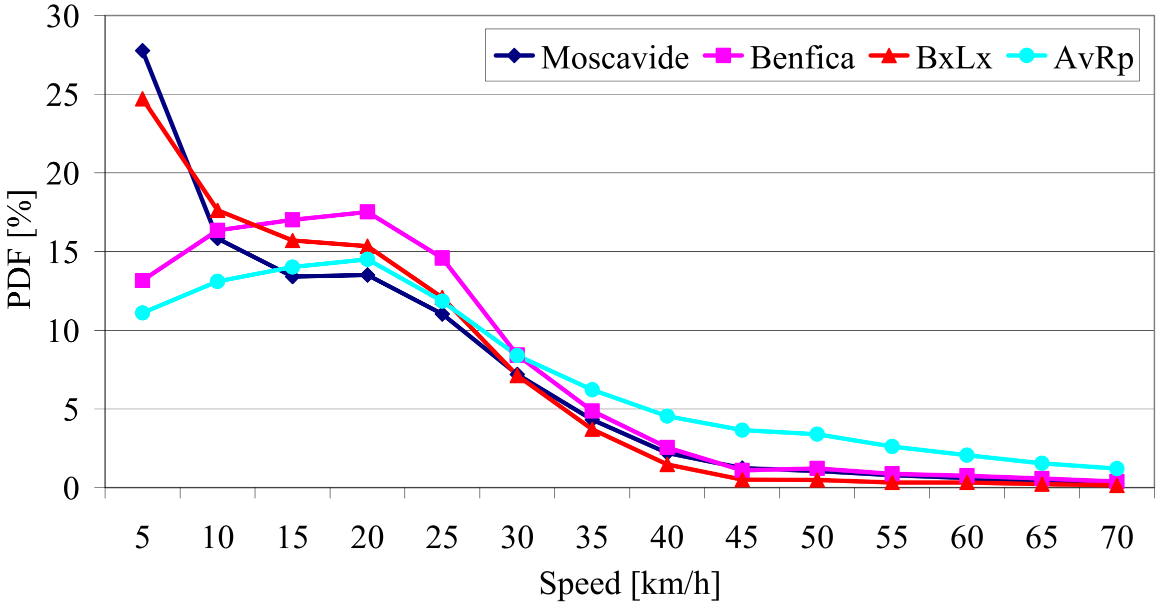


Figure V.7 – Speed distribution for 4 simulation areas.

Although no distinction was introduced for users from different market segments regarding services characterisation, the four test areas were analysed concerning the weight each of one these segments would have, in case they would have been considered differently. The result of that analysis is presented in Figure V.8.

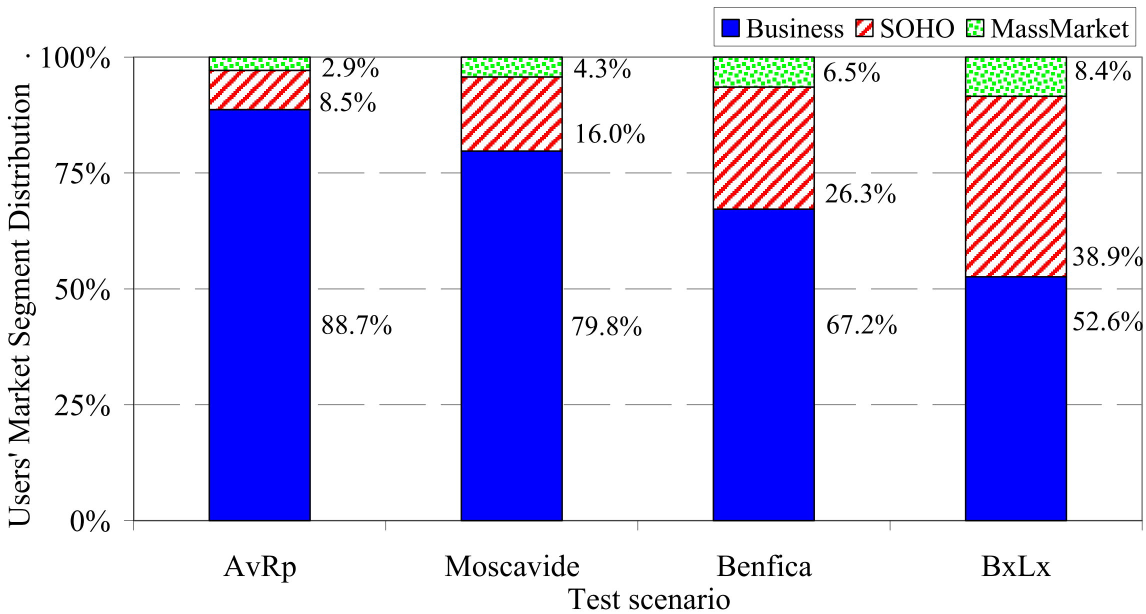


Figure V.8 – Users' distribution per market segment in the four simulated scenarios.

V.1.3 Scenarios Setup

Figure V.9 presents the average number of users and the average distribution of services in the set of ten simulations for each of the simulated scenarios.

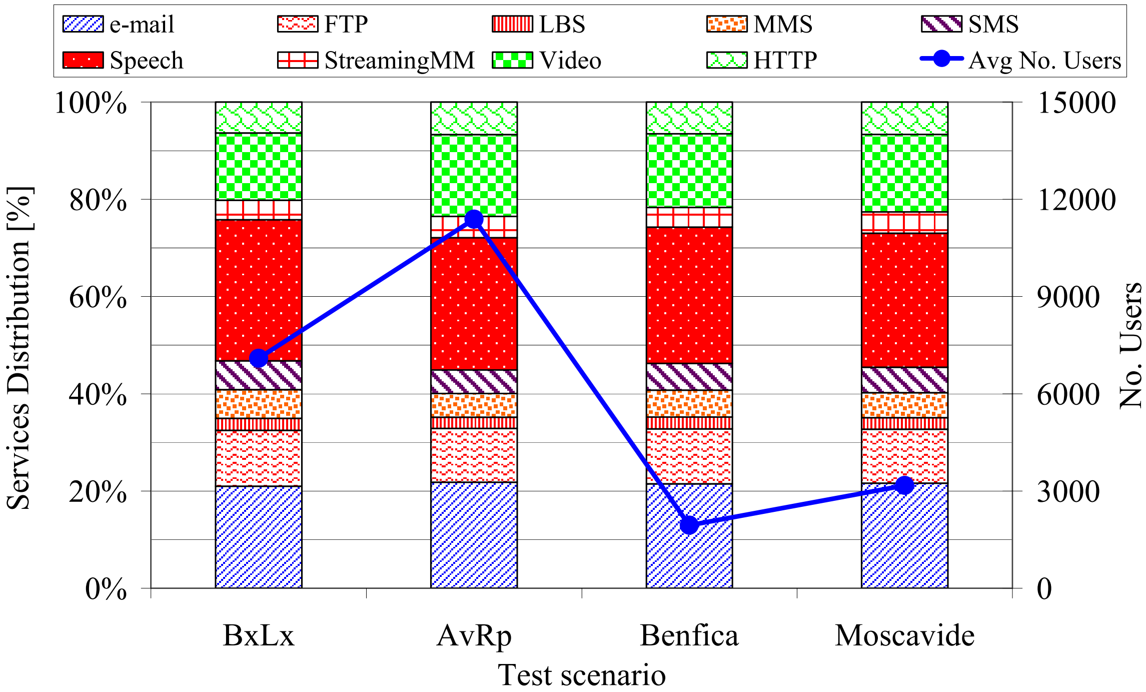


Figure V.9 – No. of users and services distribution characterisation.

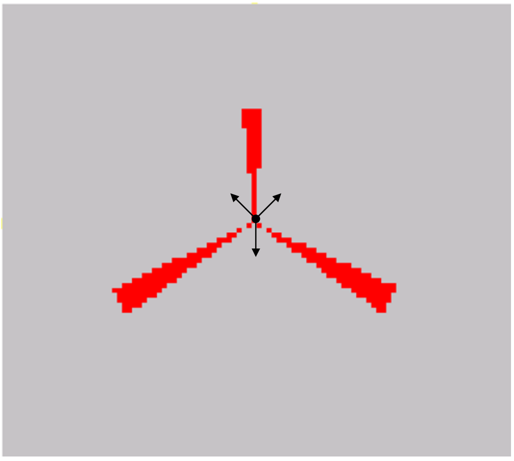
The selected areas provide two high users' density scenarios (BxLx and AvRp) and two low users' density ones (Benfica and Moscavide), as confirmed by Figure V.6. The representation of services mix in Figure V.9 shows that the distributions in the several scenarios are quite similar, and that Speech is the service with the highest percentage of utilisation, followed by E-mail and Video Telephony. Regarding mobility analysis, the speed PDF presented in Figure V.7 confirms the differentiation among the four test scenarios with higher amount of higher speed users in AvRp and Benfica ones; BxLx and Moscavide scenarios provide lower mobility profiles.

A specific analysis was intended to be performed regarding soft and softer handover which imposed that cells should overlap in the test network. The test network configuration had on the one hand, to be compliant with that condition, and on the other the number of sites should be kept at a sufficient low value that would allow performing all the necessary simulations within a affordable time frame. Hence, a regular 7 site cluster was defined, each site configured as a tri-sectorised site, i.e., as a 21 cell network. In Annex I, each study area is presented with the site configuration used in the simulations. System performance is assessed by analysing the central site (i.e., the three cells in the centre of the site cluster) as they are the ones serving in the uniform part of the network (all the other cells of this test network present some asymmetry in terms of surrounding neighbours). Also, information on these three cells is available regarding softer handover performance, which was one of the targeted analysis to be performed.

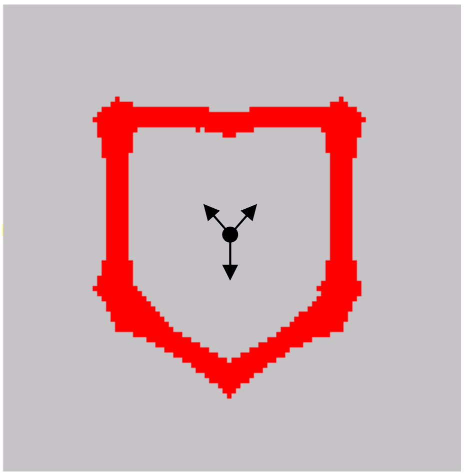
The naming convention chosen to distinguish cells in the network is of the type NLX_M, where N is a three digit integer starting in 000 and M can assume integer values between 1 and 3. In Figure V.10, coverage prediction plots for the central site are presented, and soft and softer handover areas are illustrated, as well the best server area of each cell and the combined serving area of the three central cells of the network. A commercial antenna radiation pattern was used to calculate these coverage predictions and to perform the simulations. In Annex I, Figure I.6, the radiation pattern used in the simulations is presented.

In order to design the network, i.e., choosing the coordinates where each site should be placed, cell radius was calculated for a chosen reference radio bearer. Although DL PS 384 kbps can be provided by the network, it is not commonly taken as a solution to deploy the network in order to provide such a high bit rate, as it implies a high investment to be done by the operators. Usually, a lower bit rate is taken as reference (DL PS 128 kbps), and, depending on the response of the network, local or more generalised upgrades are performed to achieve higher bit rates only where it reveals to be necessary the DL PS 128 kbps radio bearer is chosen to be the reference one.

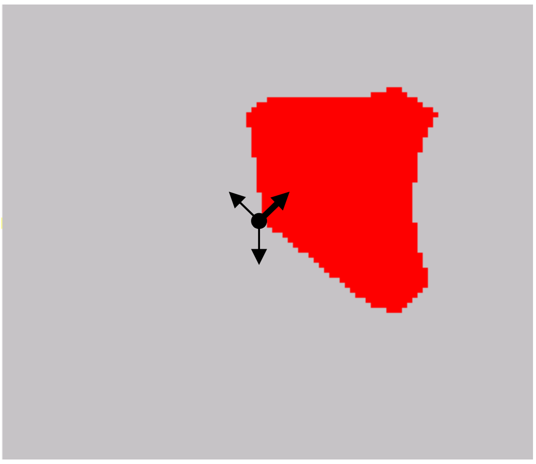
Both UL and DL link budgets were calculated in order to identify the most restrictive one, which determined the maximum cell radius. In Annex J, the details on the calculation of link budget are presented. Cell radius for all available radio bearers in a dense urban, indoor window scenario are presented in Figure V.11. The analysis of the figure allows confirming that PS 384 kbps is the most restrictive radio bearer, due to DL performance. It must be noticed that UL cell radius is similar for all PS services due to the fact that the UL is supported for all of them by a 64 kbps radio bearer. PS 128 kbps is the reference service and it is the most restrictive when PS 384 kbps is not considered. Based on these results, the targeted value for cell radius was 300 m (limited by DL PS 128 kbps) leading to an intersite distance of 520 m. In order to simplify calculations for site positioning, and to give an extra safety margin, inter-distance was then established to be 500 m, for the four scenarios.



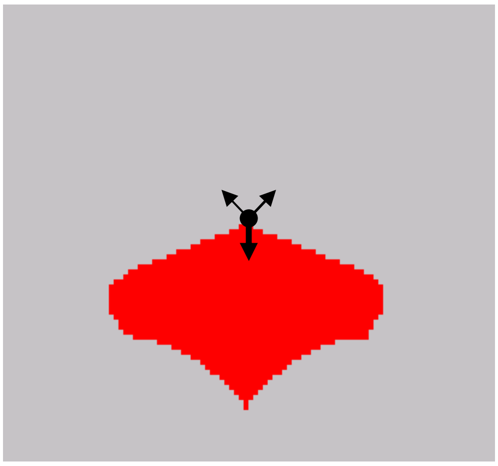
(a) Softer handover areas



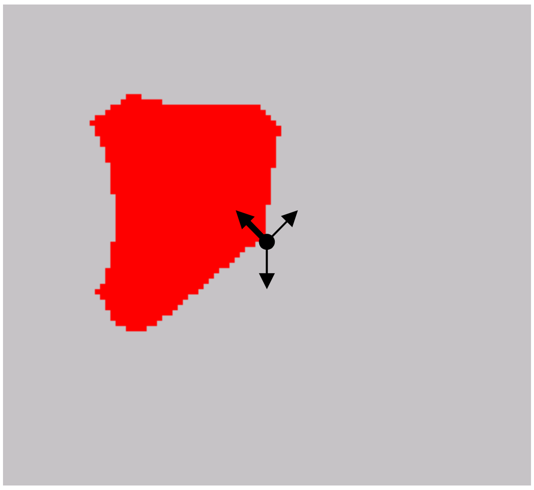
(b) Site combined soft handover areas



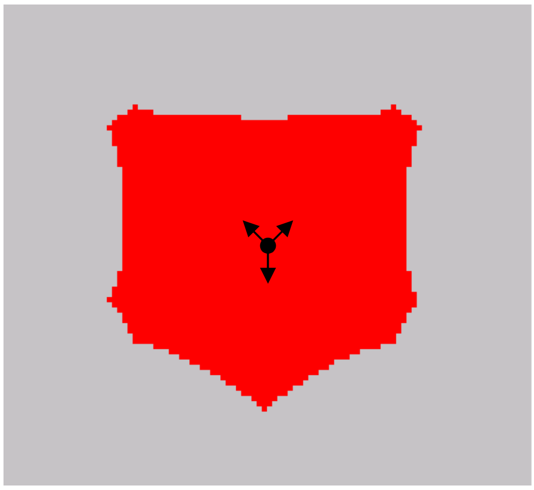
(c) Best Server area for cell 001LX_1



(d) Best Server area for cell 001LX_2



(e) Best Server area for cell 001LX_3



(f) Site combined Best Server area

Figure V.10 – Coverage prediction plots for the cluster's central cells.

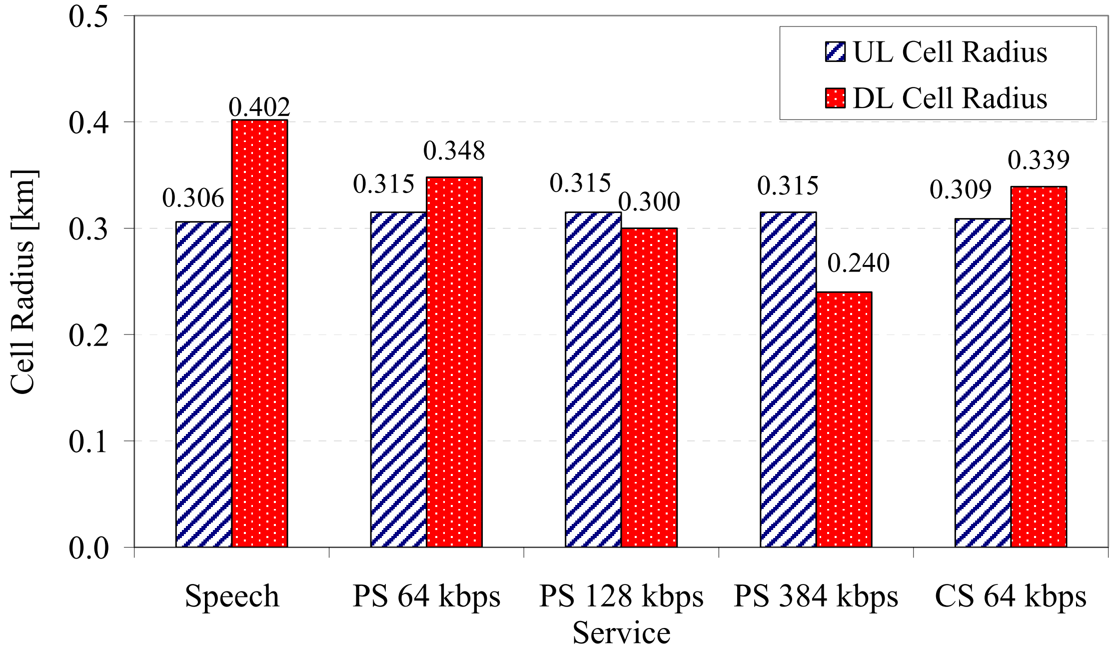


Figure V.11 – Cell radius for all available radio bearers.

System's load is highly dependent on the number of users that are generated for a particular test scenario, apart from the services' distribution. In order to define a convenient scenario to serve as the basis for this study, it was necessary to identify the number of users to generate in a single simulation. That number of users should be high enough in order to produce a non-null blocked call and dropped call ratio. As the BHCA table is based on the busy hour, several scenarios were prior tested in order to define the percentage of users (compared with the busiest hour) that should be generated in the test scenarios; the main indicators (DCR and BCR) are presented for those scenarios in Figure V.12. Typically, commercial mobile operators dimension their networks targeting a DCR and a BCR around 1%, thus, the scenario corresponding to 10% of the number of users in the busiest hour was the chosen one as it provides a DCR around 1% and a BCR around 0.2%. A higher number of users would take too much time for the simulations, and a lower one would not trigger the limitations of the system.

The number of generated users is based on BHCA information and was set to 10% of the number of users in the busy hour in all the simulations considered for the study. Mobility characterisation of the scenarios was changed by generating different percentages of pedestrian and vehicular users in each of the four test scenarios. Aside from the extreme combinations (100% pedestrian users and 100% vehicular users) combinations of 30% / 70%

and 70% / 30% were considered for pedestrian and vehicular users respectively. Table V.3 presents the identifiers used to distinguish each of the scenarios and the corresponding weights per user type.

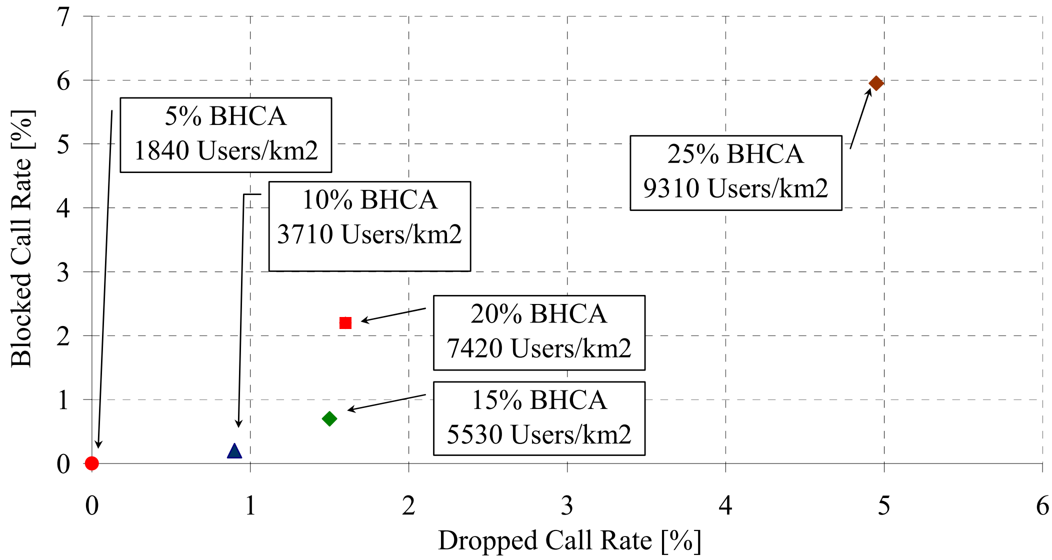


Figure V.12 – Network performance indicators for different user densities.

Pedestrian users were considered to be distributed in a differentiated way regarding indoors scenario. This leads to a different indoor attenuation margin to be considered in the link budget depending on the indoors scenario in which each pedestrian user falls in.

Table V.4 presents the weighting that was applied to pedestrian users on their generation when defining to which indoors scenario they should be assigned to. Regarding vehicular users, they were always accounted for with an indoor attenuation margin of 8 dB (Incar attenuation margin). Crossing the indoors users' distribution with different pedestrian users weighting lead to an overall users' distribution per indoor location illustrated in Figure V.13.

Table V.3 – Users' type weighting per test scenario type.

Scenario Identifier	Pedestrian Users [%]	Vehicular Users [%]
100Ped_0Veh	100	0
70Ped_30Veh	70	30
30Ped_70Veh	30	70
0Ped_100Veh	0	100

The simulator process structure (split into two different platforms) demanded that coordinates have to be generated (in SIMOTS) prior to the system performance analysis (by CRUS); as such, it could happen that some of the users would ran out of coordinates. In order to have a proper control on that situation, CRUS outputs the number of users that ran out of coordinates in each simulation, indicating to which service they belong to and for how much time they were out of coordinates. The analysis of this information was then used to indicate in SIMOTS the amount of additional coordinates that should be generated for each service in order to keep the situation of lack of coordinates within acceptable limits. For each scenario the additional amount of coordinates was then adjusted, and Figure V.14 presents for each reference scenario the worst case measured in the simulations. The amount of users with lack of coordinates did not exceed 0.6% of the total number of users in each scenario, and their distribution amongst all the services varies from scenario to scenario, as illustrated in Figure V.14.

Table V.4 – Users' type weighting per test scenario type.

Indoors Scenario	Attenuation Margin [dB]	Pedestrian users weight [%]
Deep Indoor	25	20
Indoor Window	11	40
Outdoor	0	40

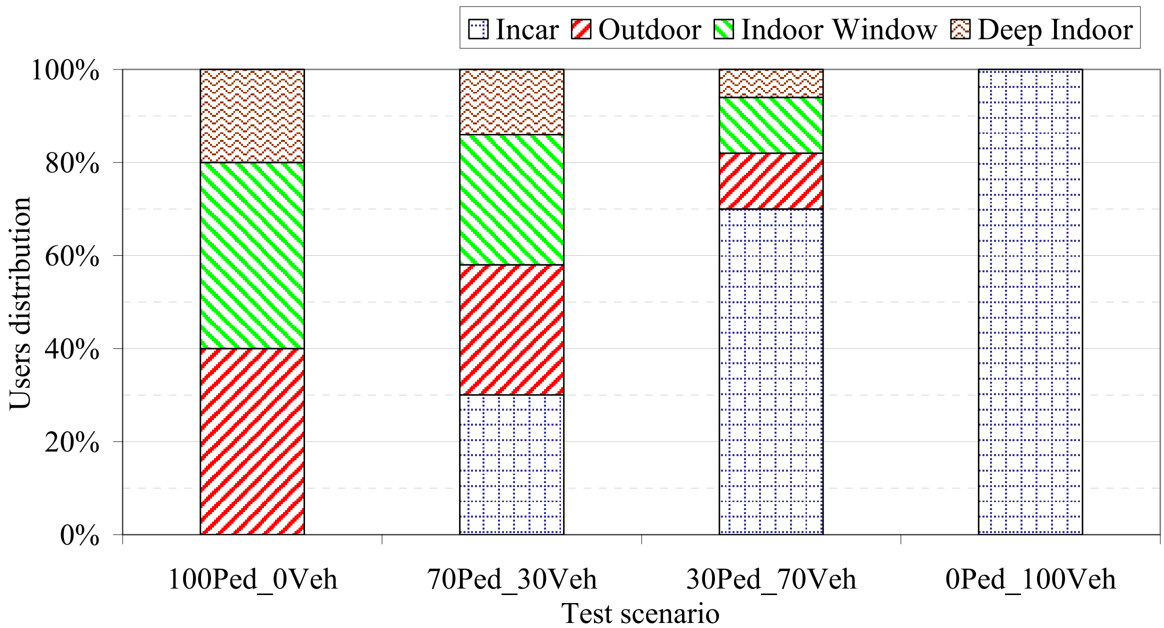


Figure V.13 – Users' distribution per indoor location.

Despite the fact that distinct scenarios are defined with different weights for pedestrian and vehicular users, the mobility scenarios in the four study areas are not as differentiated as it would be interesting from the study point of view, and that fact is confirmed by inspection of Figure V.15.

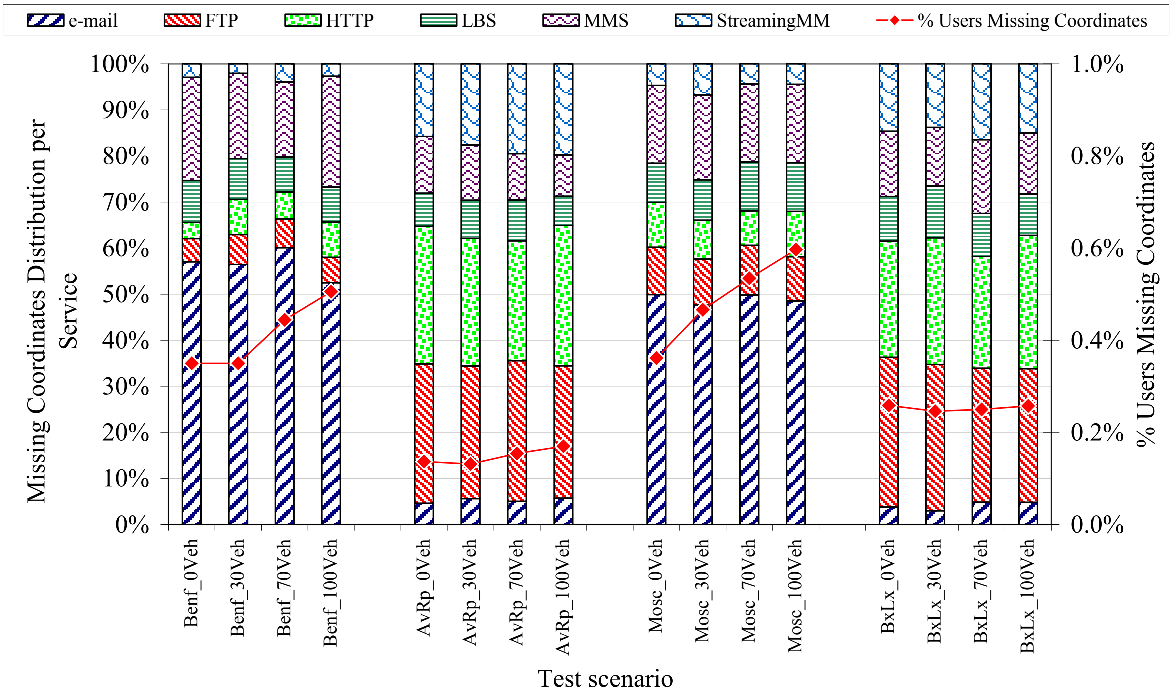


Figure V.14 – Missing Coordinates Distribution per Service.

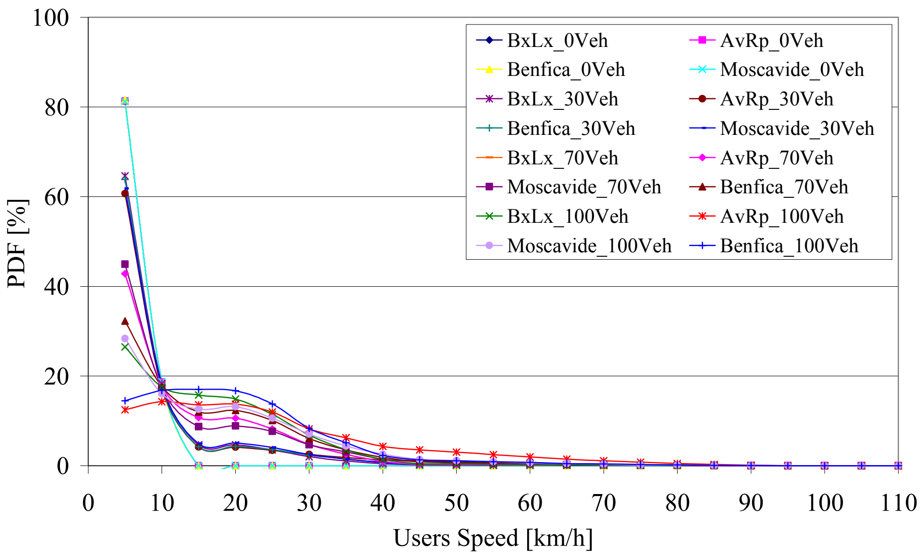


Figure V.15 – Users Speed distribution in the reference scenarios.

Mobility characterisation of the generated users can be assessed either by its PDF presented in Figure V.15 or CDF (Figure K.1) presented in Annex K. In these figures, each curve is identified by a label indicating the name of the scenario and the percentage of vehicular users generated in the test scenario. Regarding the PDF, it must be recalled that all curves related with 0% of vehicular users fall in the same points, and, as such, are not distinguishable.

In order to overcome this reduced diversity on users' speed distribution, it was decided to fictitiously attribute higher average speed values to specific types of streets, in selected test scenarios[7]. Table V.5 presents the mobility parameters associated to each street type, for the reference scenarios and for the "manipulated" mobility scenarios.

Table V.5 – Mobility parameters per street type in "manipulated" scenarios.

Scenario		Reference		Max Avg Speed 90km/h		Max Avg Speed 100km/h		Max Avg Speed 110km/h		Max Avg Speed 120km/h	
Street Type	Width [m]	Speed [km/h]									
		Avg	Delta	Avg	Delta	Avg	Delta	Avg	Delta	Avg	Delta
Rua	15	20.2	20.2	30.0	30.0	40.0	40.0	50.0	50.0	60.0	60.0
Avenida	40	45.0	45.0	60.0	60.0	70.0	70.0	80.0	80.0	90.0	90.0
Acesso	10	36.0	36.0	45.0	45.0	55.0	55.0	65.0	65.0	75.0	75.0
Estrada	10	45.0	45.0	60.0	60.0	70.0	70.0	80.0	80.0	90.0	90.0
Travessa	10	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Calçada	10	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Praça	30	15.1	15.1	25.0	25.0	35.0	35.0	45.0	45.0	55.0	55.0
Azinhaga	5	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Largo	30	15.1	15.1	25.0	25.0	35.0	35.0	45.0	45.0	55.0	55.0
Alameda	40	45.0	45.0	60.0	60.0	70.0	70.0	80.0	80.0	90.0	90.0
Rotunda	30	15.1	15.1	25.0	25.0	35.0	35.0	45.0	45.0	55.0	55.0
Auto-Estr	50	79.9	40.0	90.0	40.0	100.0	50.0	110.0	50.0	120.0	60.0
Viaduto	15	45.0	45.0	60.0	60.0	70.0	70.0	80.0	80.0	90.0	90.0
Marginal	15	45.0	45.0	60.0	60.0	70.0	70.0	80.0	80.0	90.0	90.0
Caminho	10	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Escadas	5	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Margina	15	45.0	45.0	60.0	60.0	70.0	70.0	80.0	80.0	90.0	90.0
Parque	30	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0

Figure V.16 shows that this option was correct, since the mobility scenarios became much more differentiated. In this figure, each curve is identified with a prefix identifying the scenario under analysis followed by the maximum average speed value considered in it, in accordance to the distributions presented in Table V.5. The analysis of the system's response upon these mobility scenarios is done in the next sections. Table V.6 presents, for each test

[7] The scenarios chosen for this specific test conditions variation were BxLx and Benfica.

scenario, the average speed of the generated users and Figure V.17 presents the same data in a graphical way in order to give a good insight into this subject.

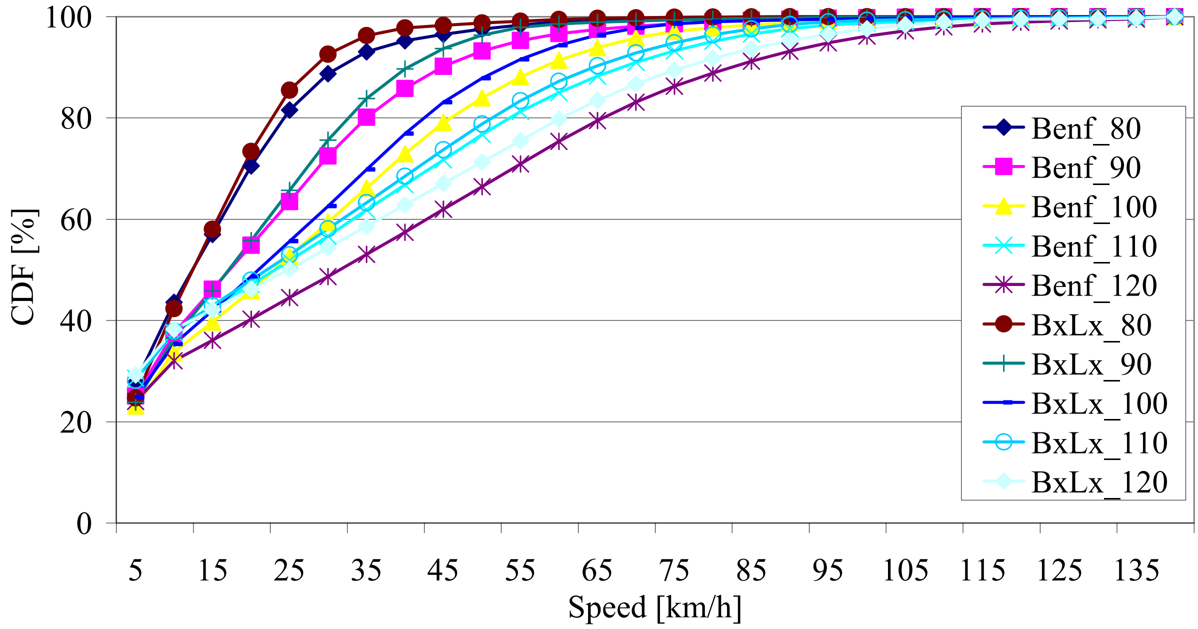


Figure V.16 – Speed distribution for differentiated mobility scenarios.

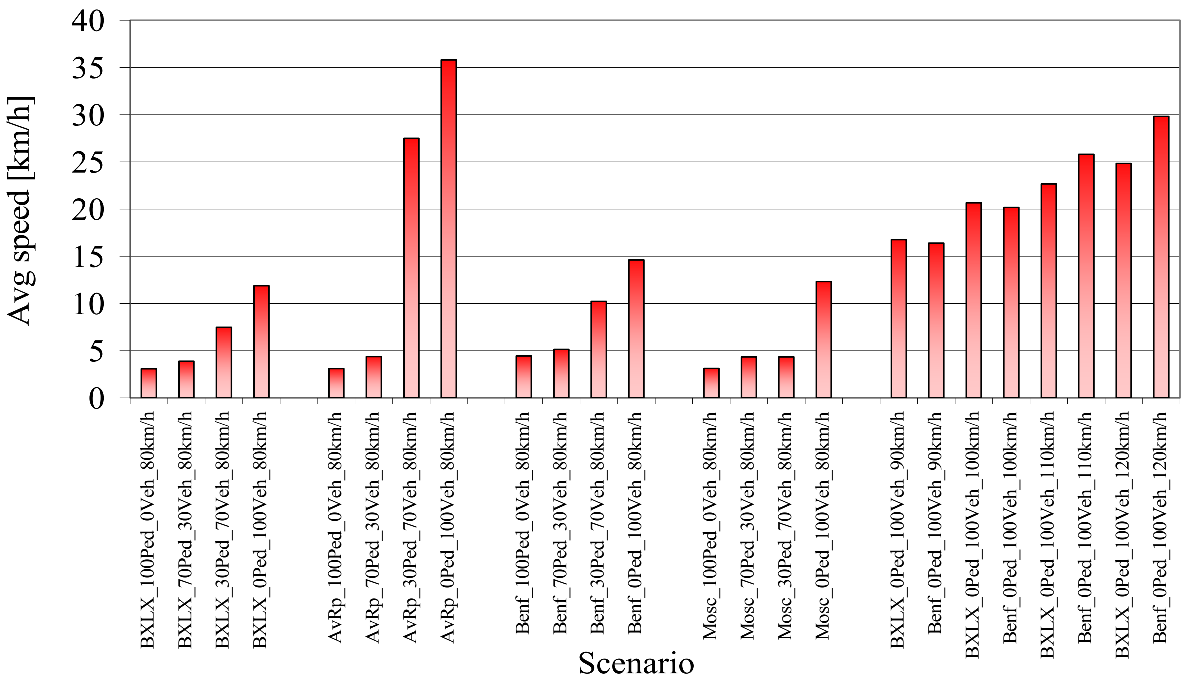


Figure V.17 – Average users' speed for each test scenario.

The complete characterisation of the test scenarios concerning the average users' speed is essential in order to correlate the results with the test conditions and assess the adequate conclusions.

Table V.6 –Average Speed in each test scenario.

Scenario	Max Avg Speed [km/h]	Scenario Identifier	Pedestrian Users [%]	Vehicular Users [%]	Avg Speed [km/h]
BxLx	80	BxLx_100Ped_0Veh_80km/h	100	0	3.1
BxLx	80	BxLx_70Ped_30Veh_80km/h	70	30	3.9
BxLx	80	BxLx_30Ped_70Veh_80km/h	30	70	7.5
BxLx	80	BxLx_0Ped_100Veh_80km/h	0	100	11.9
AvRp	80	AvRp_100Ped_0Veh_80km/h	100	0	3.1
AvRp	80	AvRp_70Ped_30Veh_80km/h	70	30	4.4
AvRp	80	AvRp_30Ped_70Veh_80km/h	30	70	27.5
AvRp	80	AvRp_0Ped_100Veh_80km/h	0	100	35.8
Benf	80	Benf_100Ped_0Veh_80km/h	100	0	4.4
Benf	80	Benf_70Ped_30Veh_80km/h	70	30	5.1
Benf	80	Benf_30Ped_70Veh_80km/h	30	70	10.2
Benf	80	Benf_0Ped_100Veh_80km/h	0	100	14.6
Mosc	80	Mosc_100Ped_0Veh_80km/h	100	0	3.1
Mosc	80	Mosc_70Ped_30Veh_80km/h	70	30	4.3
Mosc	80	Mosc_30Ped_70Veh_80km/h	30	70	4.3
Mosc	80	Mosc_0Ped_100Veh_80km/h	0	100	12.3
BxLx	90	BxLx_0Ped_100Veh_90km/h	0	100	16.8
Benf	90	Benf_0Ped_100Veh_90km/h	0	100	16.4
BxLx	100	BxLx_0Ped_100Veh_100km/h	0	100	20.7
Benf	100	Benf_0Ped_100Veh_100km/h	0	100	20.2
BxLx	110	BxLx_0Ped_100Veh_110km/h	0	100	22.6
Benf	110	Benf_0Ped_100Veh_110km/h	0	100	25.8
BxLx	120	BxLx_0Ped_100Veh_120km/h	0	100	24.8
Benf	120	Benf_0Ped_100Veh_120km/h	0	100	29.8

V.2. Mobility Impact Analysis

V.2.1 Reference Scenarios' Performance Analysis

In this section, the four reference scenarios are considered (BxLx, AvRp, Moscavide and Benfica). System performance assessment presented in the current and following sections is based on key performance indicators (dropped call rate, blocked call rate, etc.) defined in Section III.3. The analyses are based on the behaviour of the average of those indicators. Performance indicators convergence testing is usually performed by analysing the behaviour of their standard deviation; this type of analysis is appropriate and usually provides good results when the variables under analysis are Gaussian distributed; however, when variables do not fulfil that requisite, the variables convergence testing must be performed also by other types of analysis. In the current study, the analysis of the standard deviation for the variables under analysis was considered; nevertheless, the results obtained revealed that other type of convergence analysis would suit better, and would provide better insight into the variables behaviour. Thus, an analysis based on variables distribution percentiles was performed, and in particular 5% and 95% percentiles were consistently analysed for UL and DL offered application bit rates. Furthermore, the UL and DL analysis was complemented by analysing the amount of time those variables presented values above 95% of the maximum defined for them. Each variable resulting from the simulation analysis was submitted to several statistical analysis processes, as described in Annex F. Nevertheless, presenting all the results of that analysis would be too extensive and would not bring a generalised added value for the analysis performed here. Hence, the results presented herein are a selection of all the available types of analysis performed and were chosen whenever they could reveal behaviours worth of analysis and that could enrich the considerations built upon the results.

Figure V.18 presents the behaviour of DCR (as defined in (III.5)) of the test scenarios for each of the four traffic distributions. AvRp presents a clear increase of DCR (ranging from 0.75 to 2.05%) as the amount of vehicular users increases from 0 to 100%.

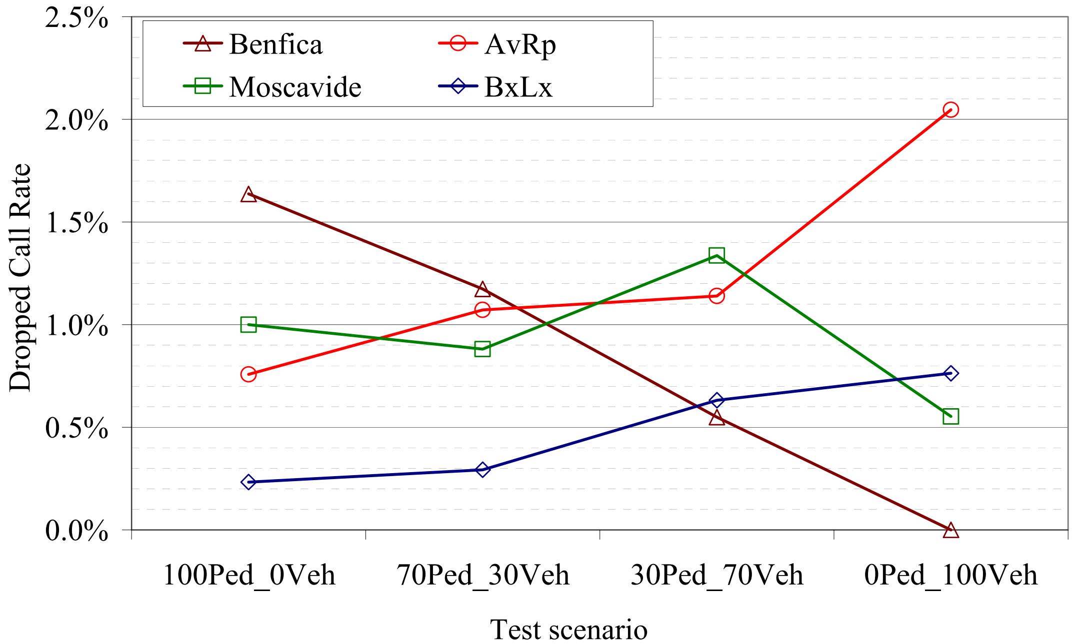


Figure V.18 – Dropped Call Rate (all reference scenarios).

BxLx's DCR has a similar behaviour ranging from 0.25 to 0.75%. DCR of BxLx is always lower than AvRp's, reflecting the lower users' density (3 720 users/km^2 for BxLx, whereas AvRp has 4 980 users/km^2).

A completely opposite behaviour is registered in the Benfica scenario. In fact, in this scenario DCR ranges from 1.65 to 0% with increasing vehicular users' percentage (from 0 to 100%). A detailed analysis on the behaviour of each factor used in the construction of the indicator is presented in Figure V.19, showing that this DCR decrease is due to the general decrease of offered traffic in the cell, as the number of new calls generated in the cell as well as incoming handovers decreases with the increasing amount of vehicular users (for comparison purposes, Figure K.2 presents the same analysis for the remaining scenarios: BxLx and AvRp). The reason for this decrease resides in the geographical distribution of the streets in the Benfica test area. Figure I.4 (Annex I) clearly shows that the surroundings of the cluster's central site have low streets density compared with the rest of the area where the users are generated.

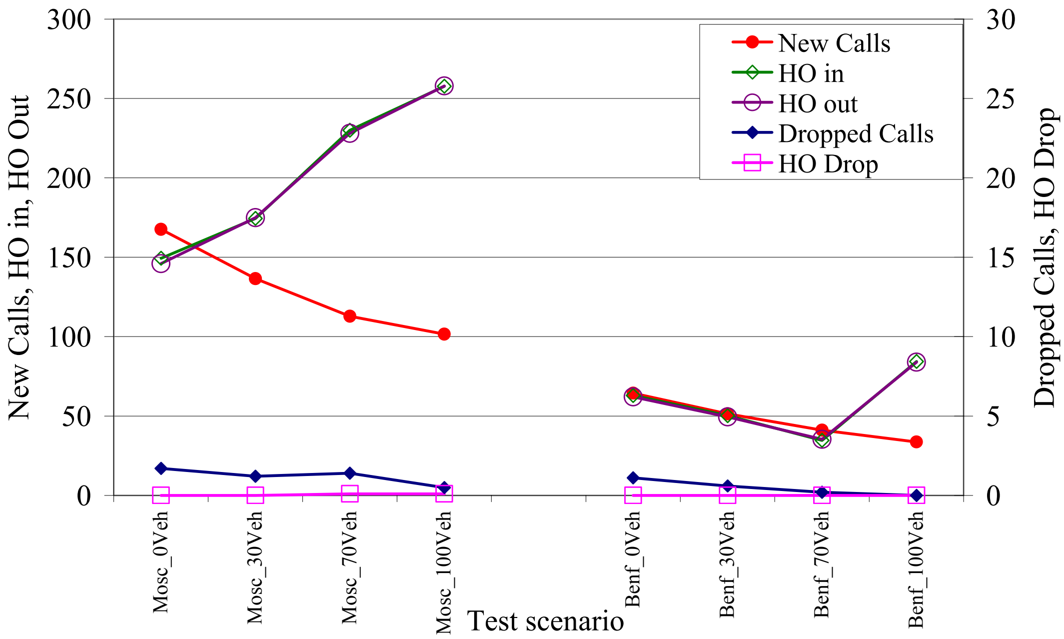


Figure V.19 – Statistical mobility data for Moscavide and Benfica.

Regarding Moscavide, as the amount of vehicular users increases DCR tends also to increase, but for the exclusively vehicular users scenario DCR decreases to the lowest value (0.55%). The cause for this behaviour is related to the geographical distribution of the streets in Moscavide (as in Benfica scenario). As the amount of vehicular users tends to reach 100%, the users being generated in the scenario tend to be concentrated in areas were the cells of the central site are not serving the users, thus, decreasing the amount of calls in these cells.

BCR in accordance with the definition given in (III.6) is analysed in Figure V.20. The general tendency is for increasing blocked call rate with increasing amount of vehicular users. AvRp follows a very stable trend, always increasing from 0.05 to 0.09%. On the other hand, BxLx and Moscavide present some instability in the indicator behaviour in the scenario of 70% vehicular users. As BCR assumes very low values (lower than 0.2%) and these specific test scenarios have a low number of users (compared with AvRp), the indicator presents some signs of instability. In fact, a BCR of 0.2% in Moscavide needs that 5 users are blocked in the whole area served by the 21 cells, whereas in AvRp it would increase to 25 users in a similar area. The behaviour observed here is, thus, a question related to how representative is the test area for such low indicator values. Finally, the Benfica scenario has a null BCR because it is the less dense scenario.

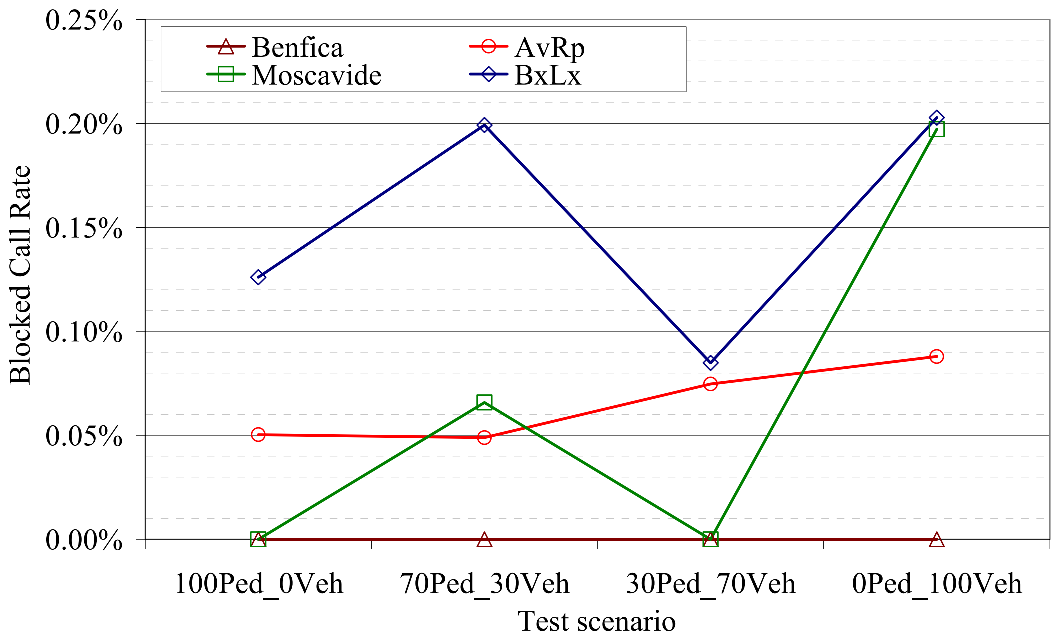


Figure V.20 – Blocked Call Rate (all reference scenarios).

Figure V.21 presents the analysis of the causes for the blocked calls. The only cause observed is limitation on the maximum allowable DL load (which is set to 75%). None of the other causes (maximum UL load, DL Channelisation codes, or maximum DL TX power) is observed. DL average power usage is analysed in Figure V.22. The average DL transmitting power presents a decreasing trend with the increasing amount of vehicular

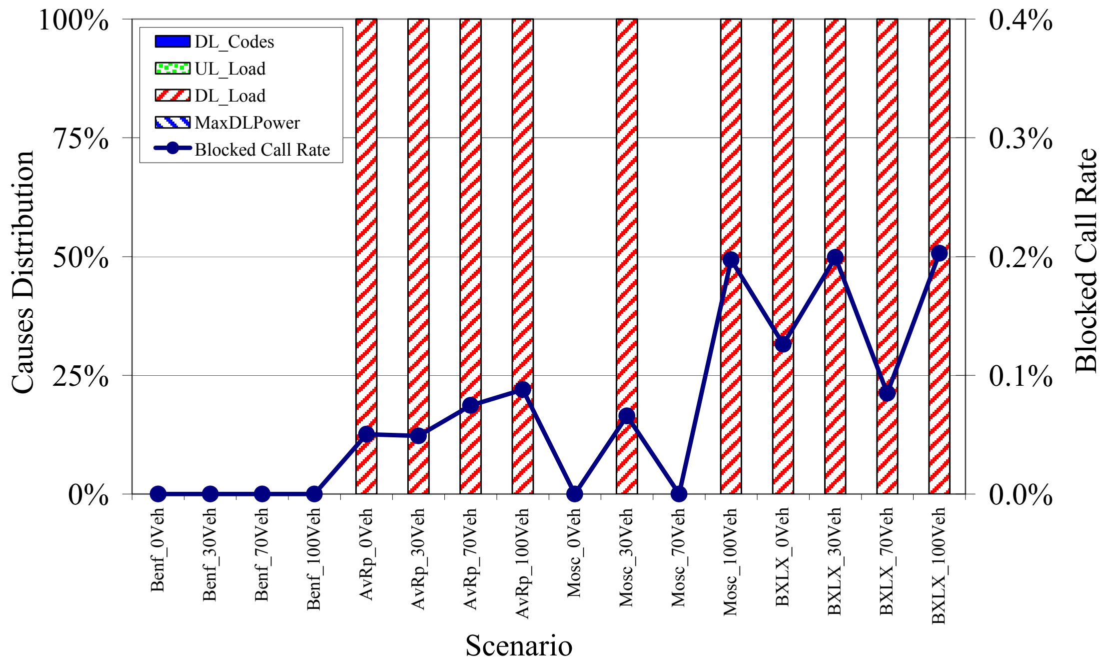


Figure V.21 – Blocked Call Rate causes distribution (all reference scenarios).

users. As the amount of vehicular users' increases, the average speed associated to the scenario (in accordance with Table V.6) also increases. The model implemented in CRUS considers a margin for fast fading which decreases with the users' speed (Table A.5). E_b/N_0 is also dependent on speed, as it increases with users' speed increase (Table A.2), however

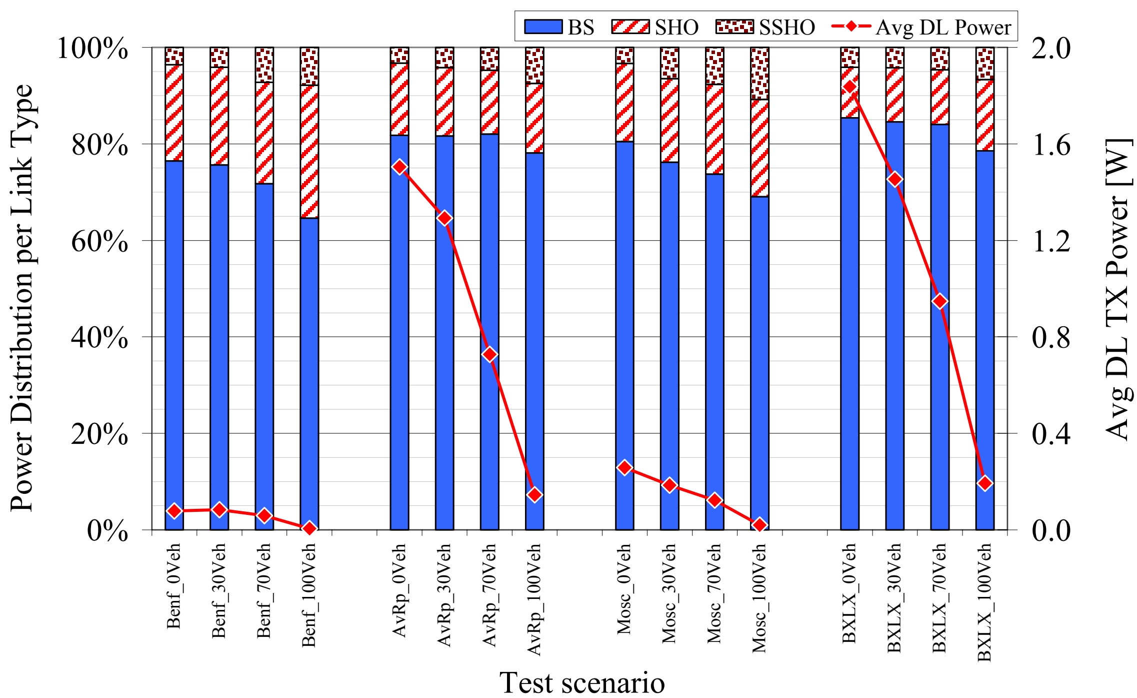


Figure V.22 – Power distribution per link type (all reference scenarios).

increasing ranges from 0.6 (speech service) to 1.6 dB (DL PS384) (as the users' speed increases from 3 to 50 km/h) which is not sufficient to counteract the decreasing tendency imposed by fast fading margin ranging from 4 to 0 dB in the same speed range. These combined effects lead to a reduction in the average DL transmitting power as the scenarios' mobility increases. An analysis of the average DL transmitting power values reveals that the higher mobility scenarios demand roughly 10% of the power in the lower mobility ones.

DL transmitting power is distributed among best server, soft handover and softer handover links, and their relative weight is impacted by the mobility grade of the scenarios. Best server links' weight is clearly reduced when the mobility grade increases. This reduction ranges (in the extreme mobility cases) from 5 (in AvRp) to 10% (in Benfica). The weight of soft and softer handover links is increased in the same amount. The more evident increases are observed in Benfica's soft handover and Moscavide's softer handover weight (both with 8%). In Figure K.3, a different representation of this data gives a good insight on these results.

A similar analysis is possible for DL channelisation codes with Figure V.23. Unlike the DL average transmitting power, the percentage of DL channelisation codes used in each scenario is not too sensitive to the mobility grade of the scenario. The DL channelisation codes used depend uniquely on the set of services that in a certain instant are being served in the cell. They are independent of the radio link characteristics, thus, the mobility does not

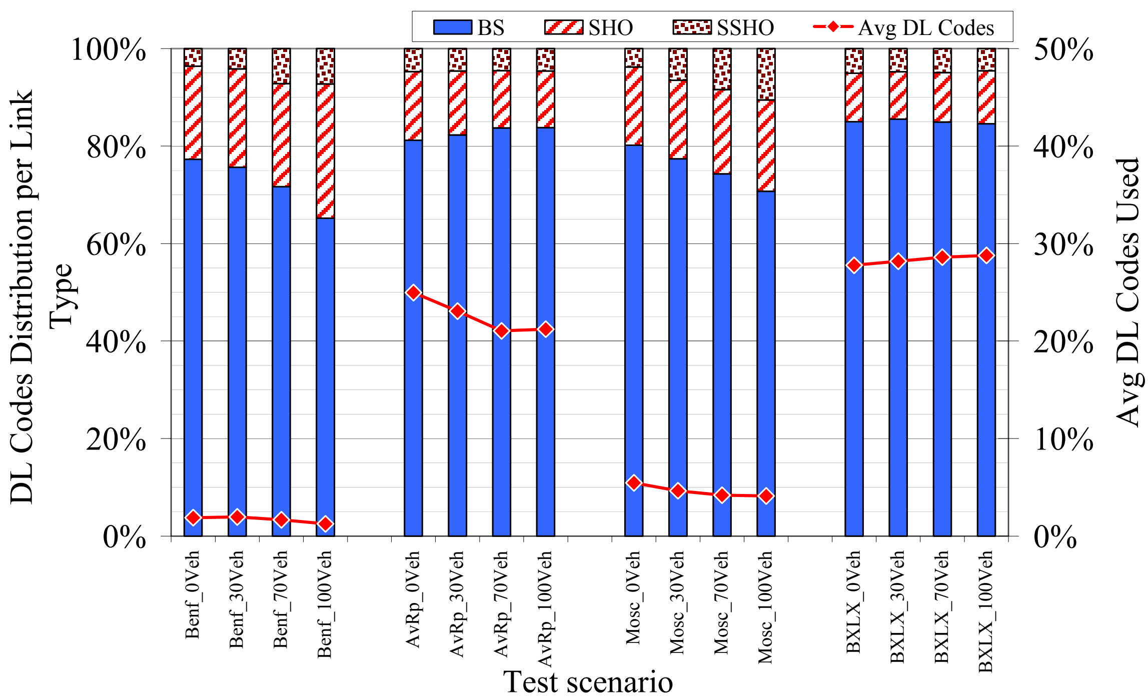


Figure V.23 – DL Codes distribution per link type (all reference scenarios).

have a major impact on their average occupancy. The slight fluctuations observed in the average values are due to the spatial non homogeneity of users' distribution. For a higher percentage of vehicular users, they tend to be concentrated along the streets, thus, producing these fluctuations. The distribution of DL channelisation codes among best server, soft and softer handover radio links assumes a similar behaviour as the one observed in DL transmitting power. Best server's weight decreases with the mobility grade increase of the scenarios, due to the conjugate increase of soft and softer handover's weight. Benfica and Moscavide are once more the scenarios with highest decrease in best server's weight (12 and 10%, respectively), and also in this case the highest increase in Benfica is observed in soft handover weight (9%), whereas in Moscavide softer handover weigh increase dominates (7%). AvRp is the only scenario where the tendency is in the opposite way, i.e., best server weight slightly increases with the mobility grade increase.

The justification for this behaviour relies on the topology of the streets in the service area of the sites analysed. Figure I.3 reveals that the streets in AvRp central site coverage are orthogonal among each other. A vehicular user is imposed to move along the streets, and as their structure is in majority radial in the site coverage area, as the user moves in those streets the time spent in soft and softer handover areas is lower than the time that would have been spent in Moscavide or Benfica. It must be noticed that BxLx has a similar behaviour, i.e., best server's weight is higher than the one observed in Moscavide and Benfica scenarios, due to the fact that also in BxLx the streets topology is mainly orthogonal and radial inside the central site's coverage area. In Benfica and Moscavide, on the other hand, it is clear that the streets do not have a major radial structure inside the central site's coverage area. When, in AvRp, the amount of vehicular users is set to 100%, all of them move along the streets and the time spent in the soft and softer handover areas is minimum. In the opposite situation, when all users are pedestrian ones, the distribution of users is then ruled by the traffic matrix and it results in higher soft and softer handover's weights.

UL and DL load behaviour is shown in Figure V.24. System load is mainly dependent on the number of users being served in the cell, and as consequence average DL load ranges from 3% (in Benfica) to 55% (in BxLx). Although AvRp has a higher users' density, the cell load is ruled by the local geographic distribution of the users, thus being, possible that locally BxLx has a higher density of users in the serving area of the cluster's central site. Average UL load does not exceed 35% in BxLx (the scenario with the highest UL average load). The Benfica scenario presents an average UL load between 1.3 and 2.0%. The maximum DL load for BxLx and AvRp is 75% (as imposed in the simulations' set-up).

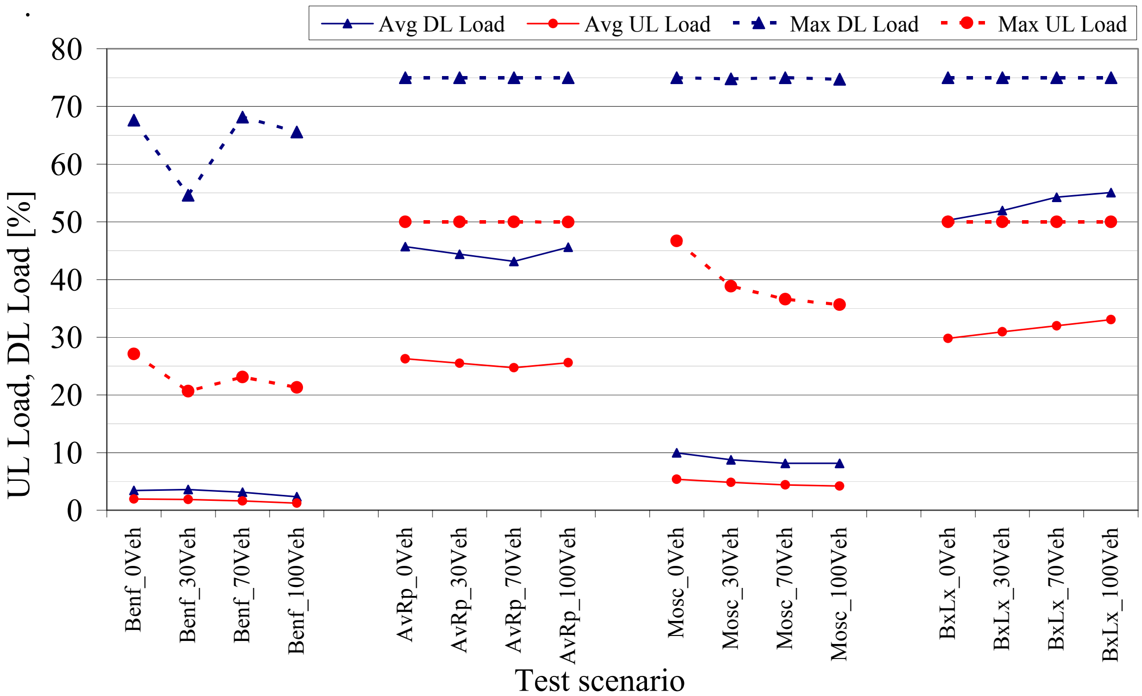


Figure V.24 – UL and DL average and maximum load (all reference scenarios).

In Moscavide, the maximum DL load is also 75%, but it is reached less often, and due to that the BCR (already analysed) is so irregular. Notice that all blocked calls are due to maximum DL load limitation, which is confirmed by these results. The maximum DL load for Benfica is 68% (which enforces the fact that no blocked calls are verified in Benfica). The maximum UL load is 50% for AvRp and BxLx, whereas for Moscavide and Benfica it is 47 and 27%, respectively. Despite the fact that the maximum UL load limit is reached (in BxLx and AvRp), it does not result in any blocked call due to the UL maximum load limitation. This is due to the fact that CS services (Speech and Video Telephony) weight around 40% of total services, they being prioritised over the PS ones. This means that a CS call is only blocked due to UL maximum load if this is exceeded by the ongoing CS calls plus the ones resulting from hard handover.

All PS calls are, in such a case, delayed while the UL maximum load is being exceeded. As the UL maximum load is not exceeded too often, and around 60% of the calls are PS ones, this limitation never results (in these test scenarios) in blocked calls. Figure V.25 presents the amount of time DL and UL load is above 95% of the allowed maximum, and it confirms that for BxLx and AvRp DL load is much more often above 95% of the maximum allowable load than UL load justifying, thus, the fact that DL load is the main limitation resulting in blocked calls. Benfica presents an identically null value in the four test cases (for the percentage of time both UL and DL load are above 95% of the maximum allowable values), whereas

Moscavide, although it is not distinguishable in the figure, presents very low values around 0.05% for DL load and null value for UL load.

Figure V.26 presents the number of handovers per call, in accordance to

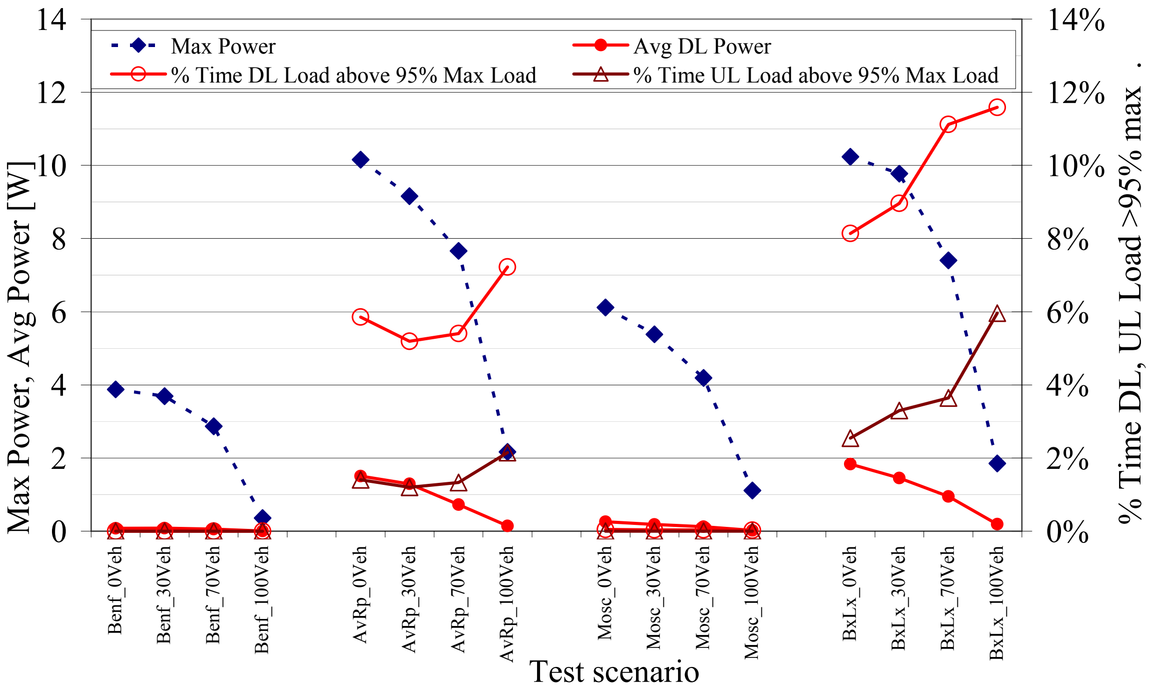


Figure V.25 – Resources utilisation limitations (all reference scenarios).

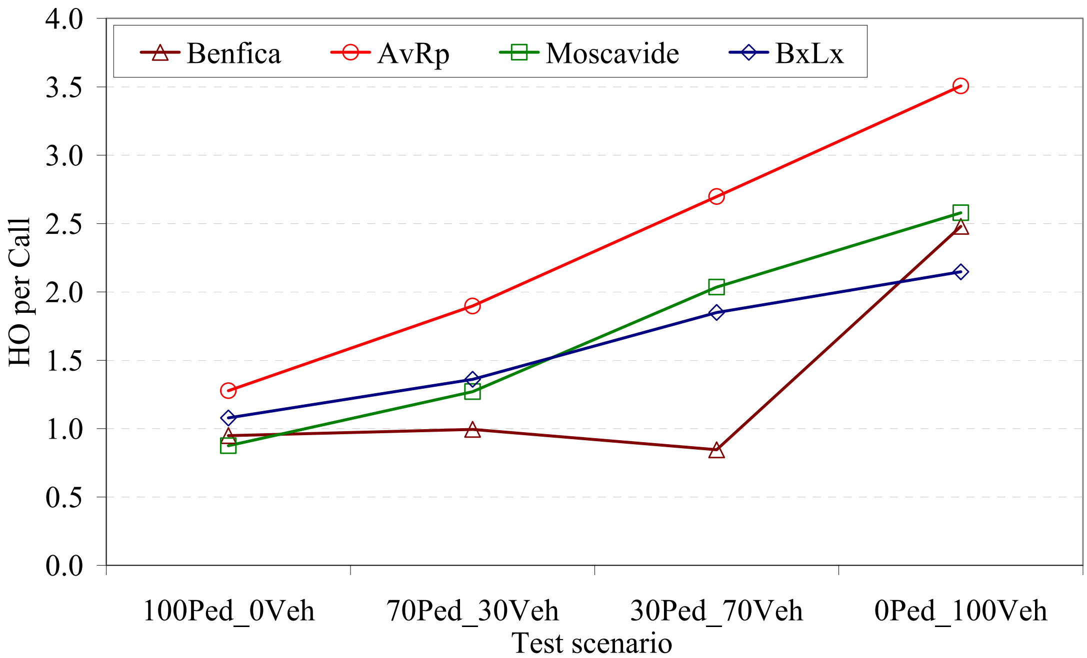


Figure V.26 – Handover per Call (all reference scenarios).

As the mobility grade of the scenarios increases (by increasing the amount of vehicular users generated in the scenario) the number of handovers also increases, leading to higher ratios of handover per call. AvRp is the leader in this indicator with values ranging between 1.28 and 3.51. BxLx and Moscavide have a very similar behaviour regarding this indicator; in this case the indicator ranged between around 1.0 and 2.5. Benfica presents a slightly different behaviour than the rest of the areas in the scenario of 70% vehicular users, as it decreases the number of handovers per call instead of the almost uniform rising tendency; this behaviour is once again due to non homogeneity in the traffic spatial distribution.

The indicator for outgoing handover drop rate is shown in Figure V.27, according to (III.9). Dropped calls during handover are highly dependent on both the mobility grade of the scenario under test and the load of the network. In fact, as the mobility grade increases, although the required link power decreases (as illustrated in Figure V.22 and Figure V.25), the amount of time the system verifies a DL load above 95% of the maximum established increases, and this increases also the probability of dropping the connection due to a lack of resources. Figure V.27 confirms and illustrates this behaviour, as the outgoing handover drop rate increases with an increasing mobility grade in all scenarios, with an exception for Benfica, which presents a constant null value and as such is not represented.

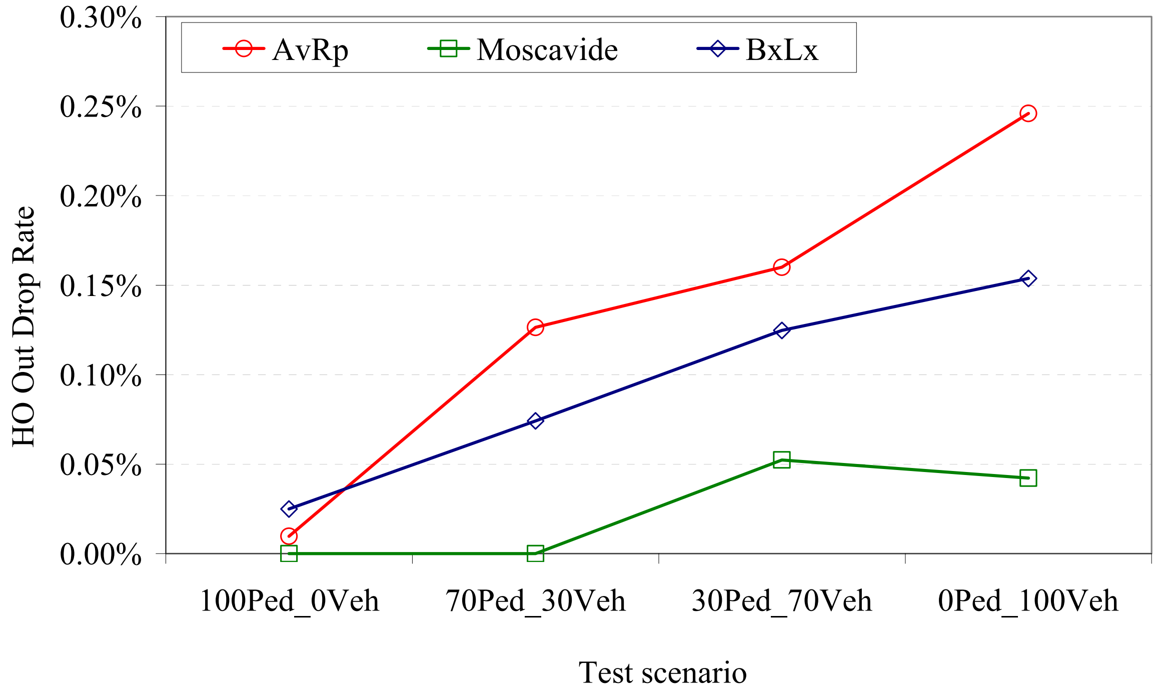


Figure V.27 – Outgoing Handovers Drop Rate (reference scenarios).

The indicator for AvRp ranges from 0.01 (in the lowest mobility grade) to 0.25% (in the highest mobility grade). BxLx ranges between 0.02 and 0.15% and Moscavide ranges from 0 to 0.05% (verified for 70% vehicular users). Benfica presents a constant null indicator. These results clearly indicate the existence of a relation between both the mobility grade and the network's traffic density. It translates the increasing drop call probability during the handover as the network's load increases.

The incoming handovers indicator was created aiming at measuring the asymmetry between incoming handovers and new calls generated in the cell. This indicator, defined in (III.5), is presented in Figure III.5, as a function of the ratio between incoming handovers and new calls generated in the cell. In short, whenever the indicator is higher than 50% the number of incoming handover is higher than the number of new calls. The results depicted in Figure V.28 show a clear trend for increasing the indicator value, meaning that incoming handovers have a higher weight than new calls generated in the cell. For AvRp, the indicator ranges between 55 and 78%, meaning that incoming handovers are between 1.22 to 3.55 times new calls. The same trend is followed by Moscavive and BxLx, but in a lower scale. Benfica has a slightly different evolution as only the full vehicular scenario (0Ped_100Veh) has higher incoming handovers than new calls.

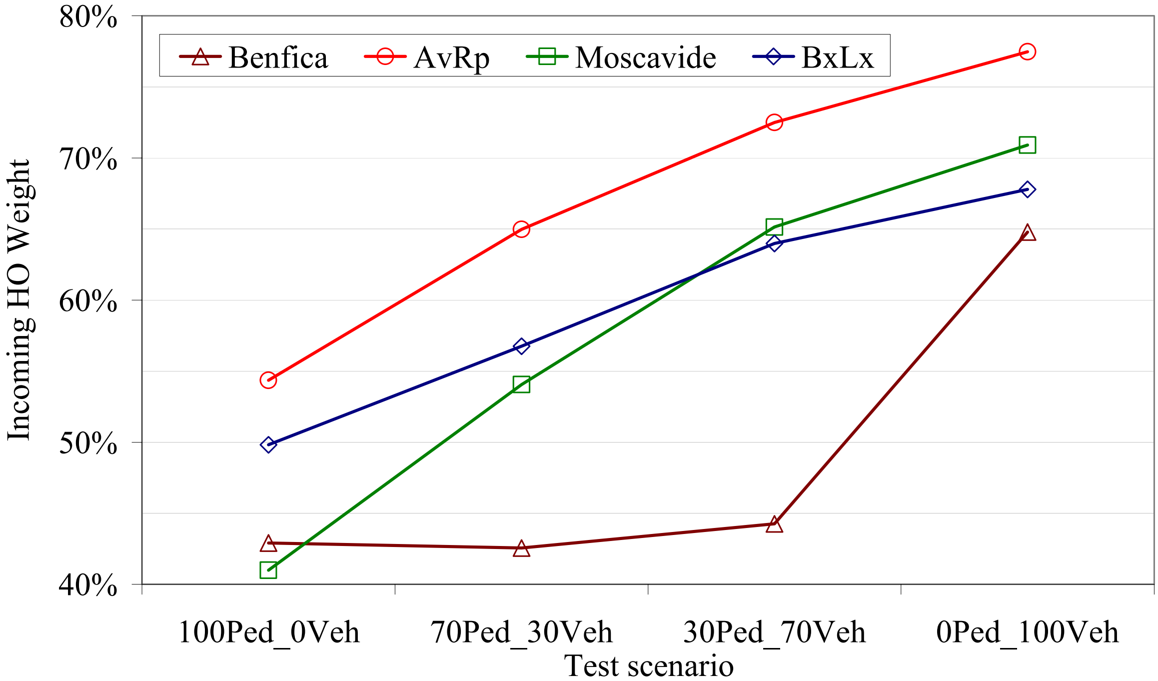


Figure V.28 – Incoming Handovers Weight (all reference scenarios).

A similar indicator was created to analyse the unbalance between incoming and outgoing handovers. The handover flow indicator is introduced in (III.5), and Figure V.29 presents its behaviour for all reference scenarios. There is no particular reason that could induce a considerable unbalance between incoming and outgoing handovers, and, in fact, the figure shows that the ratio between incoming and outgoing handovers is fairly balanced, always being around 50%. Only a slight different value is presented for Moscavide full pedestrian scenario (100Ped_0Veh), where the indicator reaches 51.5%, but even this value only translates a slight unbalance between incoming and outgoing handovers. Based on these results, mobility does not impact on the handovers balance of the network, as one would expect.

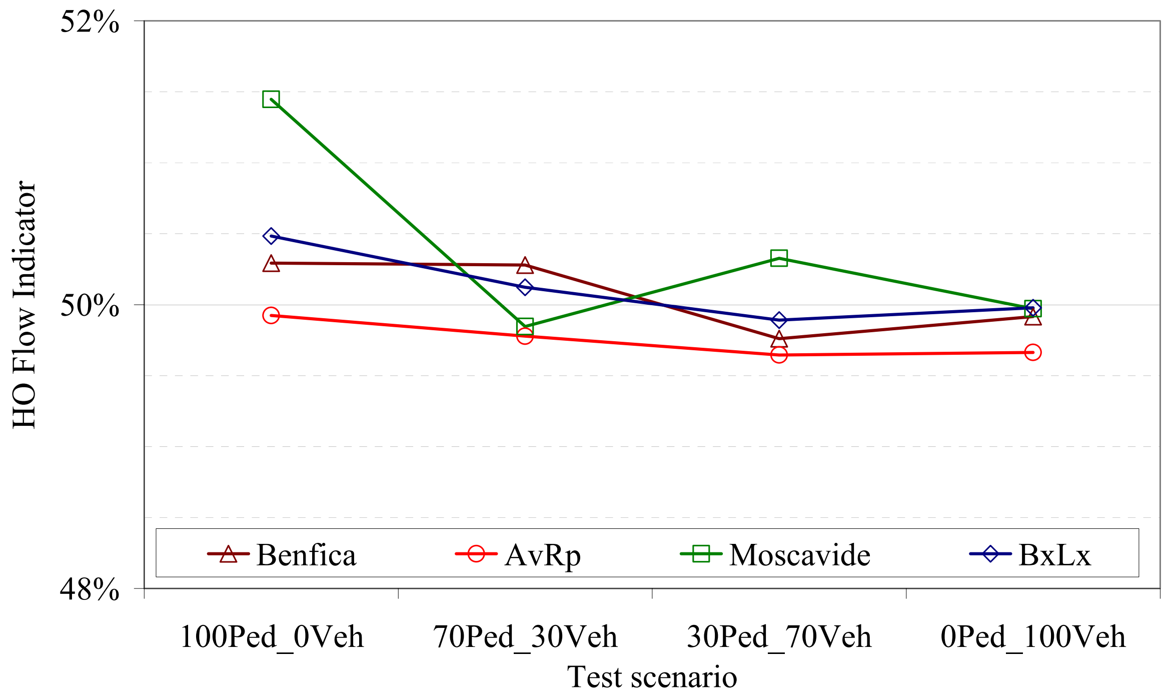


Figure V.29 – Handover flow indicator (all reference scenarios).

PS services performance is analysed in what follows. It must be recalled that all seven PS services are characterised in Table V.1 concerning UL and DL bit rates and traffic volumes. In the current analysis, the figures depict the behaviour of the UL and DL normalised bit rates, referred to the values presented in that table.

E-mail performance was unrestricted in Benfica and Moscavide, as these scenarios are low traffic density ones. The maximum bit rate both in UL and DL is used in all connections and the average delay is null; due to this, these scenarios are not represented in Figure V.30. The performance of E-mail in BxLx and AvRep suffers some restrictions (especially for

BxLx) as the UL bit rates are around 95% of the target one, and the DL bit rates are even lower (between 92 and 95% for AvRep, and between 84 and 91% for BxLx). The average service delay ranges between 0.15 and 0.30 s for AvRep, and between 0.35 and 0.60 s for BxLx. The performance of E-mail in a multiservice scenario gets worse as mobility grade increases. The increasing traffic density naturally lowers the performance of the application. As shown in Figure K.2, BxLx scenario has a slightly higher number of generated calls for a similar incoming and outgoing handovers in the central site, and this fact has impact by slightly decreasing the performance of the application (on average, roughly 5% lower in the normalised UL and DL throughputs).

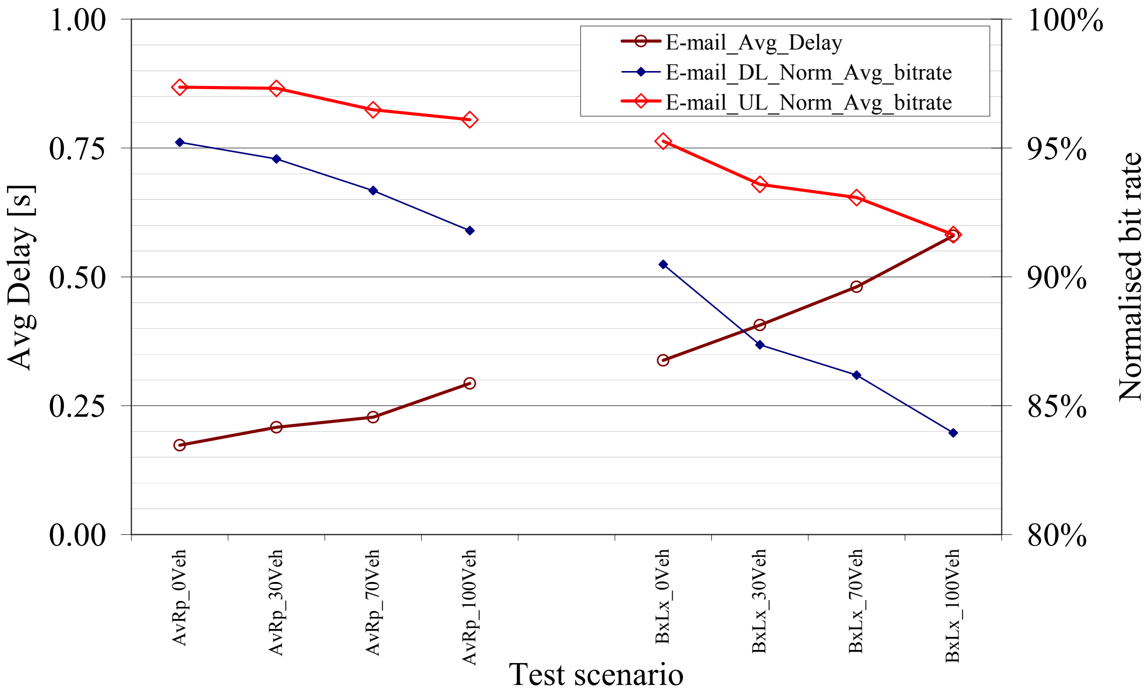


Figure V.30 – E-mail performance indicators (reference scenarios).

The impact in FTP performance, Figure V.31, is more intense than the one observed in e-mail. In fact, for FTP, Moscavide already presents some degradation in the available throughputs. FTP sessions take 23 s on average, whereas E-mail ones only take 3 s, implying that the user will be active in the network for a longer period, hence, being more exposed to network load limitations. Again, the trend regarding mobility is a degradation (reflected by a decreasing average bit rate and an increasing average service delay) in the application performance. In this case, the degradation of the bit rates is on average 10% for AvRp and BxLx, compared with the degradation observed for E-mail. The average bit rates are limited to 83.5% in AvRp and 76% to BxLx. Also in this case, the impact in BxLx scenario is higher than in AvRp, as it has a higher number of generated calls.

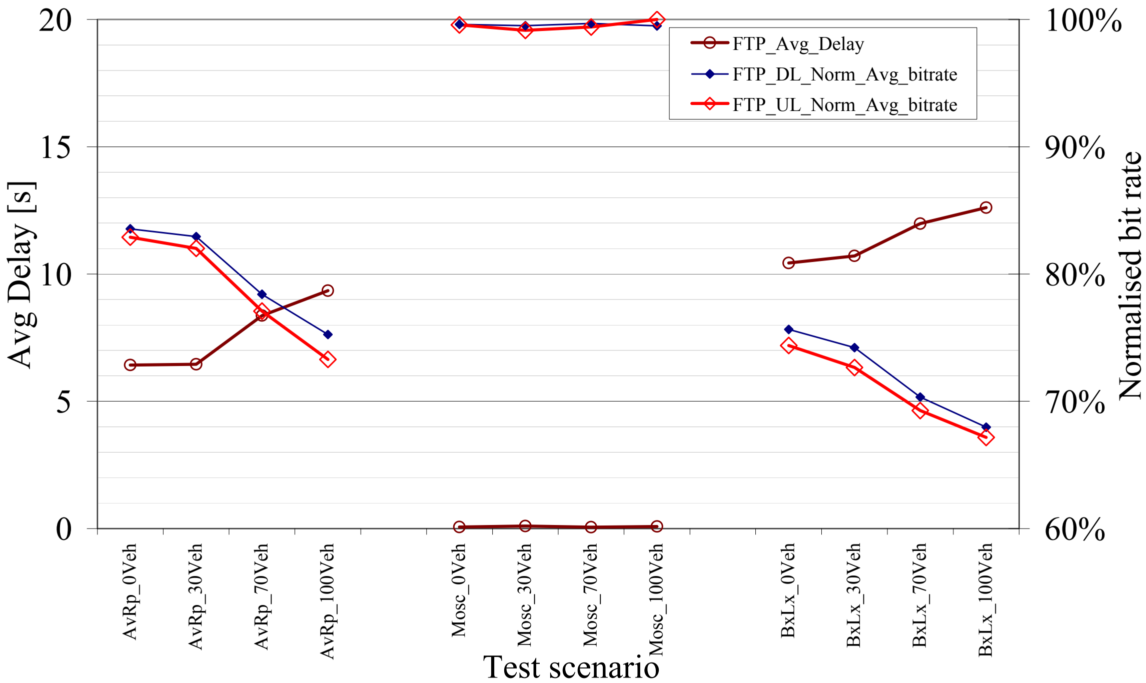


Figure V.31 – FTP performance indicators (reference scenarios).

The behaviour of the other PS applications is quite similar to the one observed for E-mail and FTP, thus, the figures with their parameters are presented in Figure K.5 to Figure K.9. Table V.7 summarises the performance of each application by presenting the maximum average delay, and minimum UL and DL normalised bit rates observed in all 16 tested conditions. In general, Benfica provides the maximum UL and DL throughputs for all applications, in all mobility profiles. Moscavide only presents a very slight reduction in UL and DL throughputs for some applications (FTP, HTTP and MMS).The observed degradations are still very small, as they are lower than 1%, and still do not show a trend with mobility variation. When comparing Benfica and Moscavide scenarios, the slightly higher users' density in the latter justifies that it already presents some degradation to the applications' performance, whereas the first one guarantees applications with maximum bit rates.

The maximum reduction in bit rates (and consequently, the maximum increasing in maximum average delay) is observed in BxLx, just slightly higher than the values observed in AvRp. Although the users density is higher in AvRp, Figure K.2 shows that, locally, the central cells of BxLx seem to have a tendency for generating a higher number of users, which explains the slightly higher values observed in it.

From Table V.7, the maximum average delay provides a good way of comparing applications performance and verifying the system consistency for different application types. In general, normalised bit rates seem to be more suggestive of the users' perception upon distinct services, but, nevertheless, by comparing them only one of the links is evaluated at the time; as the applications generate asymmetric traffic in UL and DL, average delay better reflects the user's perception of the network behaviour. By an analysing, the maximum average delay, the applications can be clearly split into three groups: HTTP, Streaming Multimedia and FTP, with average delays around 15 s, LBS and MMS with average delays ranging from 2.6 to 6.0 s, and, E-mail and SMS with average delays below 1 s.

Table V.7 – PS applications performance summary (reference scenarios).

Application	Max Avg Delay [s]	Min UL Normalised bit rate [%]	Min DL Normalised bit rate [%]
E-mail	0.58	91.6	83.9
FTP	12.61	67.2	68.0
HTTP	17.31	79.3	81.9
LBS	6.01	87.1	86.1
MMS	2.61	92.5	84.6
SMS	0.07	92.1	85.2
Streaming MM	15.19	85.1	96.6

HTTP, Streaming Multimedia and FTP appear as the ones with the highest delays (in descending order). HTTP has an average DL session volume of 1.2 MB, being mapped onto 128 kbps, whereas the other two applications are mapped onto 384 kbps and have average session volumes of 2.3 and 1.0 MB, respectively. This distribution of observed delays is consistent with the volumes and mapped bit rates.

LBS and MMS observed delays also present a high consistency with the applications' volumes. Both are mapped onto 64 kbps, and LBS average DL session volume (230 kB) is higher than MMS' one (60 kB).

Finally, E-mail and SMS are both mapped onto 64 kbps, and are also consistent with the average delays observed, 0.58 and 0.07 s, when taking into account the volume of each application (10 and 1 kB, respectively).

In general, increasing average users' speed (by increasing the amount of vehicular users in the scenario) leads to a decrease in offered bit rates (both UL and DL) and a consequent increase in average delay. Depending on the considered scenario, the decreasing rate of applications' offered bit rate with increasing average speed, can be more or less acute, due, basically, to its streets structure and non-uniformity in geographical users distribution.

Figure K.10, Figure K.11 and Figure K.12 in Annex K show in detail the applications' performance indicators.

All the above analysis concerning applications' bit rate behaviour only focuses on the average values. In what follows, some considerations are drawn concerning the dispersion of the values obtained in the simulations, namely the 5 and 95% percentiles.

Figure V.32 presents the 5% percentile of normalised DL bit rate. Benfica is not represented as the indicator is always 100% for all services and test scenarios, similarly, the 95% percentile presents for all services in all scenarios values higher than 99.8%. The analysis of Figure V.32 confirms that Benfica and Moscavide offer a very uniform DL bit rate for all applications. The analysis of Figure V.33 reveals the same behaviour in these two scenarios for UL bit rates (Benfica is not represented in this figure due to the same reasons stated for Figure V.32). The only service that somehow is distinguishable from the others is FTP, due to the fact that 5% of the users can be served with a DL throughput below 95% of the maximum defined for the service (384 kbps). Nevertheless, these two scenarios offer very consistent (in the sense that they are very concentrated) DL and UL bit rate values, due to the fact that they are the ones with lower traffic load. The analysis of BxLx and AvRp leads to slightly different conclusions. It must be recalled that these scenarios are the ones with the highest traffic load, and as such it is expectable that the UL and DL bit rates offered to the users are more disperse than in Benfica and Moscavide. From the analysis performed on a "per service" basis, it is concluded that average bit rates in these scenarios are clearly lower than in the lower traffic density scenarios.

The 95% percentiles in these two scenarios are (as already stated) above 99.8%. Figure K.13 reveals that the Streaming Multimedia service (which is mapped onto 384 kbps) has a more stable bit rate than the other service mapped onto 384 kbps (FTP). By analysing carefully the average number of users generated in the AvRp and BxLx scenarios for these two services (Figure K.14), the conclusion is that Streaming Multimedia users weight only around 37% of FTP ones (283 vs, 814 users for BxLx), although the average service time for Streaming is higher than for FTP, the fact is that they are less represented than FTP, which is reflected on the higher dispersion of user bit rates. In general, BxLx provides user bit rates (both UL and DL) that are more spread than in AvRp, Figure V.32 and Figure V.33, which indicates that 90% of the users have UL and DL normalised bit rates ranging between roughly

55 and 100% (with exception for Streaming Multimedia, which was already analysed), whereas AvRp decreases the variation range.

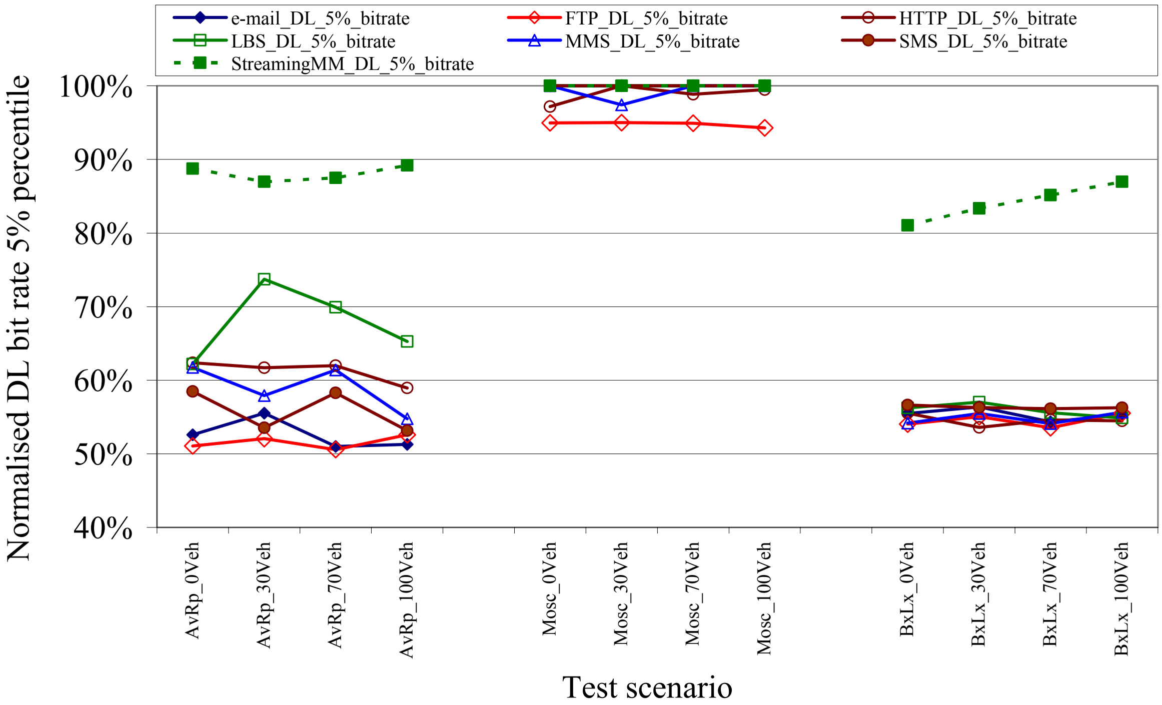


Figure V.32 – Normalised DL bit rate 5% percentile for all reference scenarios.

In AvRp, the variation range is much more dependent on the service under analysis, but the overall analysis indicates less spread bit rates in AvRp than in BxLx. It should be also noticed that the 90% confidence interval (bounded by the 5% and 95% percentiles) does not present a clear relation with the mobility grade of the test scenarios.

Figure V.34 presents for each test scenario the DL transported data volume, aggregated for the three cells of the cluster's central site, considering all services served by those cells during one hour (the length of the simulation). The data volume is measured at the application level (at the application interface defined in Figure IV.6). These results confirm the choices performed regarding test scenarios definition, as Benfica and Moscavide present themselves as low traffic areas and AvRp and BxLx are high traffic ones. As the network structure used in all the areas is exactly the same, these relations still remain if traffic density (measured in MB / km^2) is to be analysed.

The same figure represents the so-called transport efficiency, which is the ratio between the number of bytes sent or received by the application layer and the number of bytes

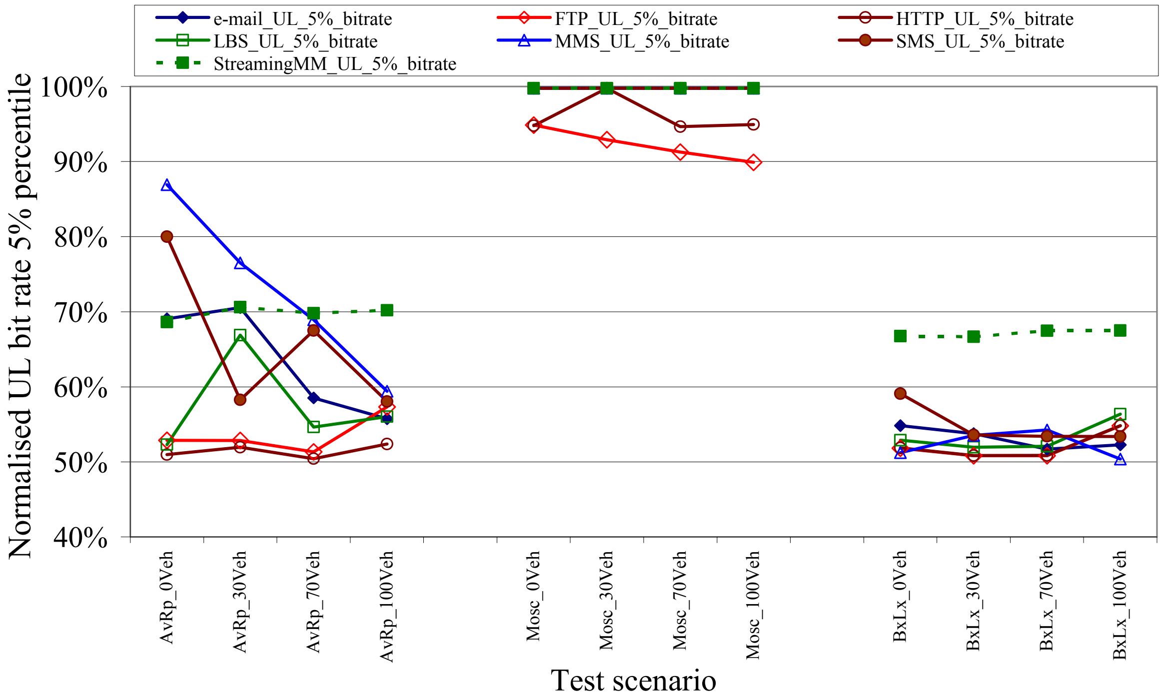


Figure V.33 – Normalised UL bit rate 5% percentile for all reference scenarios.

sent or received at radio interface. Calculations were performed for both UL and DL, and the slight fluctuations observed are due to similar fluctuations in the relative weights of the generated services.

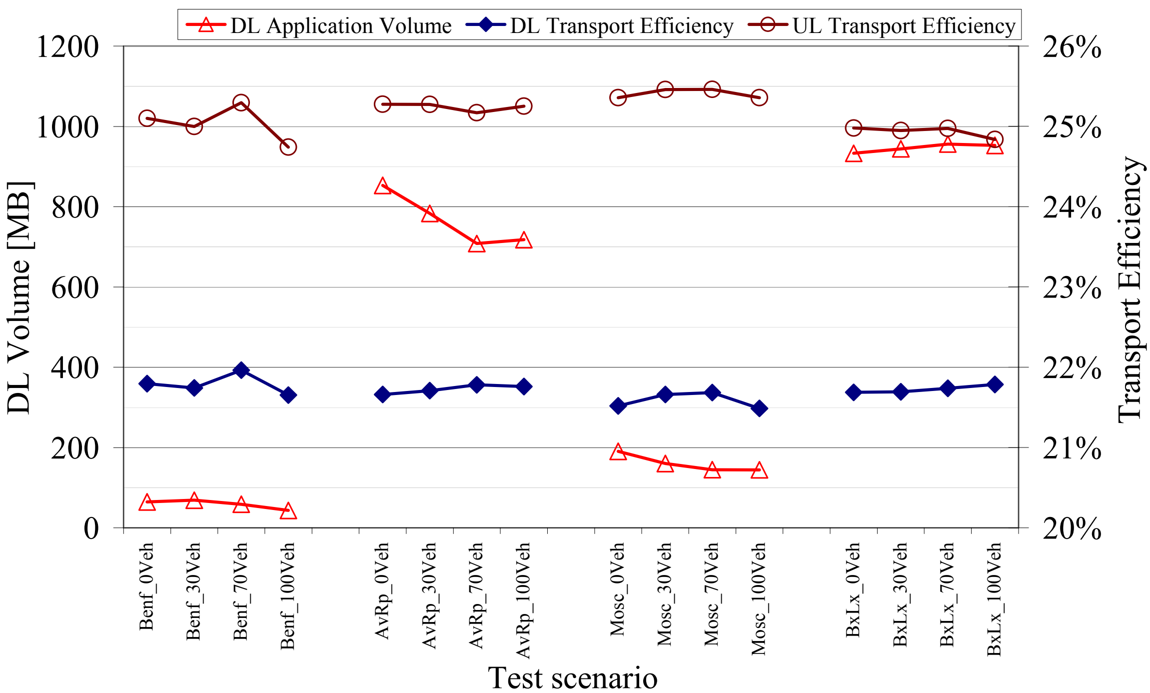


Figure V.34 – DL Total Application Volume and Transport Efficiency.

The transport efficiency, ranges between 21 and 22% in DL, and for UL it presents an average value between 25 and 25.5%. It is interesting to notice that the system was designed right from the beginning with the clear assumption that most of the services that it would carry would be heavily asymmetric, with higher volumes being transferred in DL, and even though the transport efficiency of DL is lower than the UL's. It is also worth to mention that the transport efficiency of UMTS-FDD is still far from the 40% attained in GSM.

V.2.2 Impact of Speed Profile in BxLx and Benfica

The four reference scenarios chosen to study the impact of mobility in the UMTS FDD network provided some differentiation regarding generated users' speed distribution, and, consequently, the average speed of the users generated in the test scenario. This differentiation was already deeply analysed in Section V.1.1 with the help of Figure V.7, Figure V.17, Table V.6 and Figure K.1, which allows concluding that the differentiation of these four scenarios does not provided a sufficiently high diversity regarding mobility profiles. In order to achieve a wider diversity in mobility profiles, BxLx and Benfica scenarios were taken and the speed profiles associated to each street type of these scenarios were changed aiming at increasing the average speed of the users generated in each scenario. Table V.3 and Figure V.15 present the different average speed values associated to each street type and the corresponding PDF of users' speed generated in the test scenarios. Table V.6 and Figure V.17 present the average speed of the users generated in these scenarios, confirming that the objective of increasing the diversity of mobility profiles in the test scenarios was fulfilled.

The dropped Call Rate evolution is presented in Figure V.35 for the BxLx and Benfica scenarios, with different maximum average speed values. One should recall that pedestrian users generated in these scenarios are static (scenarios BxLx_80km/h_Ped_Static and Benf_80km/h_Ped_Static), aiming at pushing mobility to the absolute possible minimum. In BxLx, DCR presents a clear increasing trend with increasing mobility. The analysis of BxLx shows that increasing the average speed in the scenario can double the DCR (from 0.75 to 1.5%) in the 100% vehicular users scenario, and the impact can even be more than doubling in scenarios with some pedestrian users (from 0.15 to 0.55% in 30% vehicular users scenario, or from 0.3 to 1.15% in 70% vehicular users scenario).

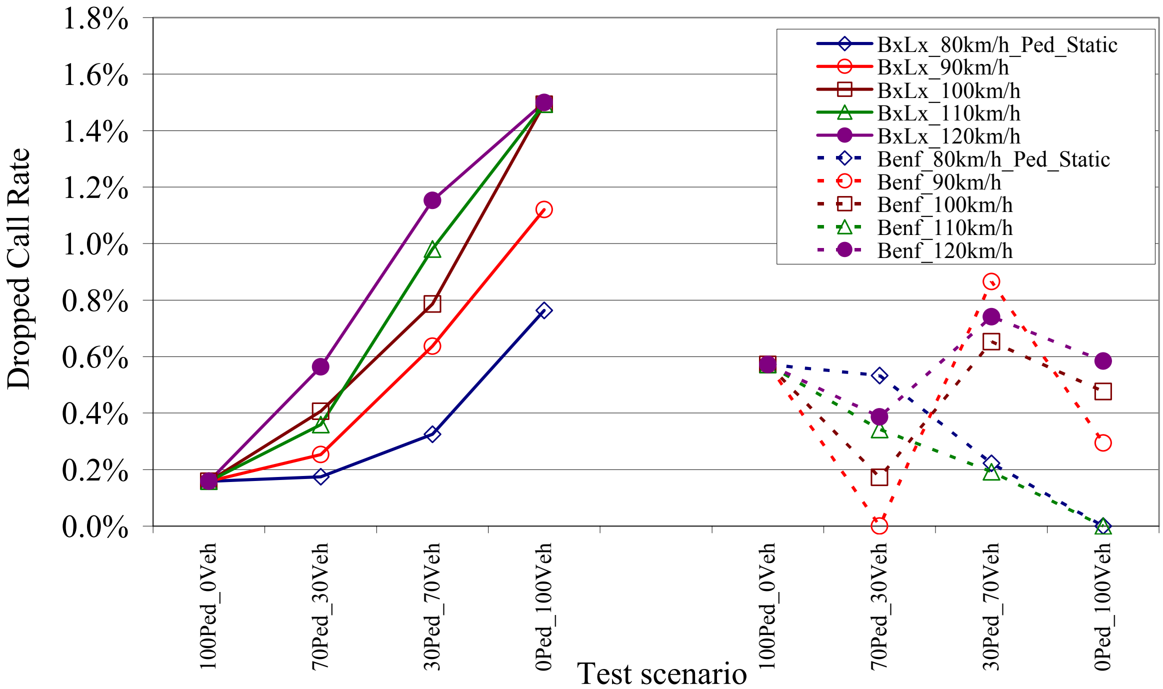


Figure V.35 – Dropped Call Rate evolution for distinct mobility profiles (BxLx and Benfica).

The BxLx scenario is the "well behaved" one, in comparison with Benfica. As already discussed in V.2.2, Benfica's behaviour is due to the topology of the streets in the test area. Furthermore, in the present speed parameters variation, as selected types of streets have their average speed changed (increased), the behaviour of the indicator tends to change in the increasing direction. Benfica's irregular behaviour reflects once more the low traffic density condition that was already identified.

BCR evolution is represented in Figure V.36. Benfica presented null values in all the test cases, hence it is not included in that figure. BxLx presents the same evolution trends as for the reference scenarios analysed in Section V.2.1. Increasing speed profiles imply a wider spread of the indicator. The indicator presents some inversions on the trend because the values measured are in fact very small. A closer analysis on the results from the simulations reveals that the values assumed by BCR are based on only 1 or 2 blocked calls among roughly 1100 calls in the three central cells of the cluster, therefore, the number of blocked calls being so small leads to a certain instability in the behaviour of the indicator.

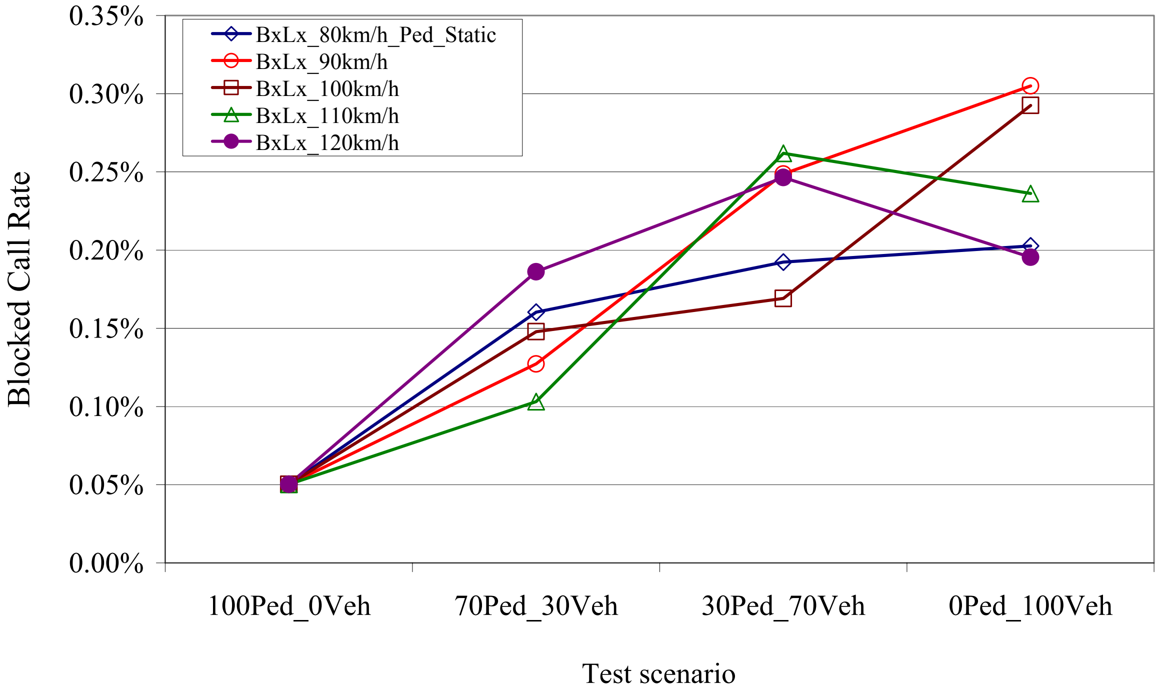


Figure V.36 – Blocked Call Rate evolution in distinct mobility profiles (BxLx).

The average DL transmitting power evolution is presented in Figure V.37. In both scenarios, the evolution follows the same decreasing trend as the amount of vehicular users increase. However, different mobility profiles do not have a visible impact on this indicator, due to the implementation of CRUS. Different users' speed is translated in CRUS by using a different fast fading margin and an E_b/N_0 adjusted to the users' speed (please refer to Table A.2 and Table A.5). The evolution of fast fading margin has the main role in the response of the system, and the impact higher speed values have on this margin is very low, thus it has also a low impact on average DL transmitting power.

The scenarios' mobility profile has a major impact on the number of handovers per call, Figure V.38. A natural limit is imposed by fully static users, with zero handovers being performed when all users are pedestrian static ones. Naturally, the indicator increases up to 3.7 HO/Call in BxLx when the maximum average speed of the streets is increased to 120 km/h. Benfica's maximum value remains slightly lower, around 3.2 HO/Call, confirming a natural trend for lower values. This trend is due to the fact that Benfica has a less dense street topology in the serving area of the central site compared with BxLx (please refer to Figure I.2 and Figure I.4). As the streets topology is less dense in that area, the generation of users is more intense in the areas outside the coverage area of the central site, and as such the number of new calls decreases, but not as much as handovers, leading to an increase in the indicator that is not so high as in BxLx (where new calls increase and handovers increase even more).

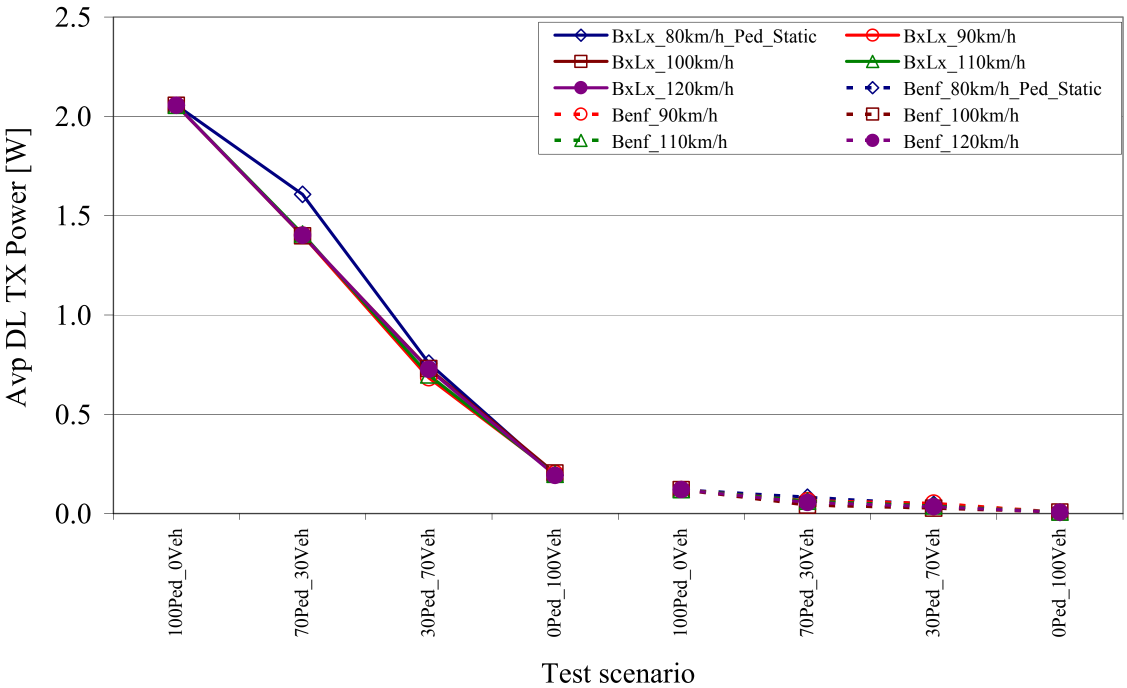


Figure V.37 – Average DL transmitting power in distinct mobility profiles (BxLx and Benfica).

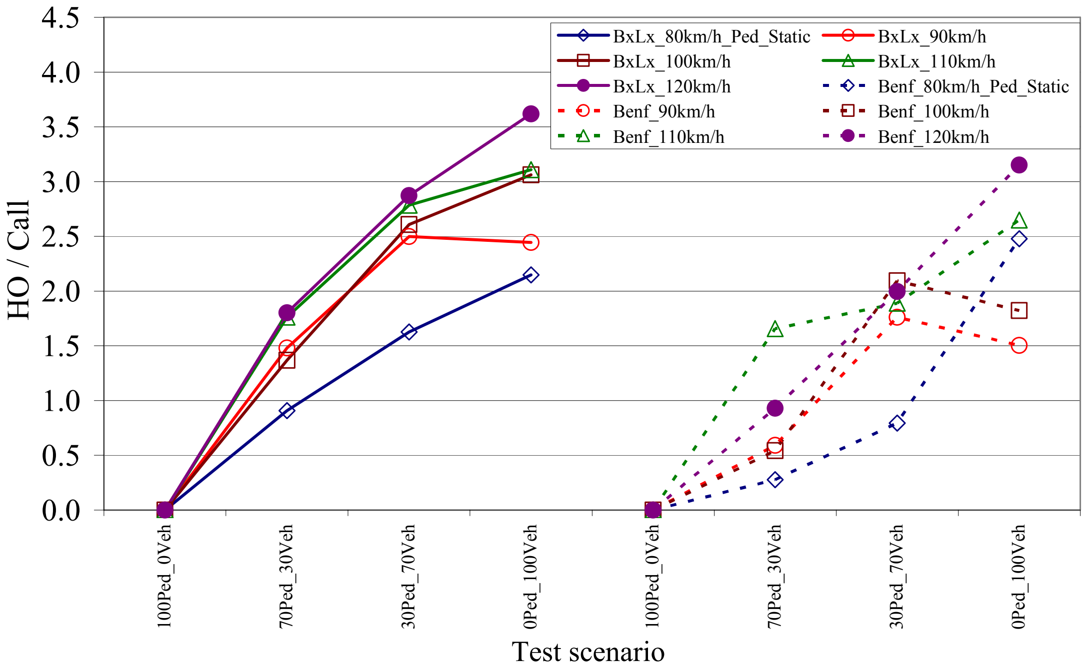


Figure V.38 – Handover per call in distinct mobility profiles (BxLx and Benfica).

Figure V.39 presents outgoing handovers drop rate. This indicator's behaviour in Benfica is null for all the test scenarios, reflecting the condition of being a low traffic density area, hence it is not included in Figure V.39. One of the conclusions from the analysis of this indicator in Section V.2.1 is the fact that low traffic density scenarios do not trigger outgoing handover dropped calls, and that conclusion is confirmed in this second analysis. In fact, not even an increasingly higher mobility profile triggers this type of dropped calls. BxLx shows that increasing higher users' speeds leads to higher dropped calls due to outgoing handovers. Also, this indicator presents some instability in its behaviour, due to the fact that the number of dropped calls due to outgoing calls is very low.

The incoming handover weight in distinct mobility profiles is presented in Figure V.40. Users' average speed plays a fundamental role in the behaviour of this indicator, and the difference between the extreme test scenarios can increase the indicator in 10.1% (from 67.8 to 77.9% in the 120km/h curve). Benfica keeps the trend for values lower than BxLx, resulting from the streets topology in this test scenario being less dense than in BxLx.

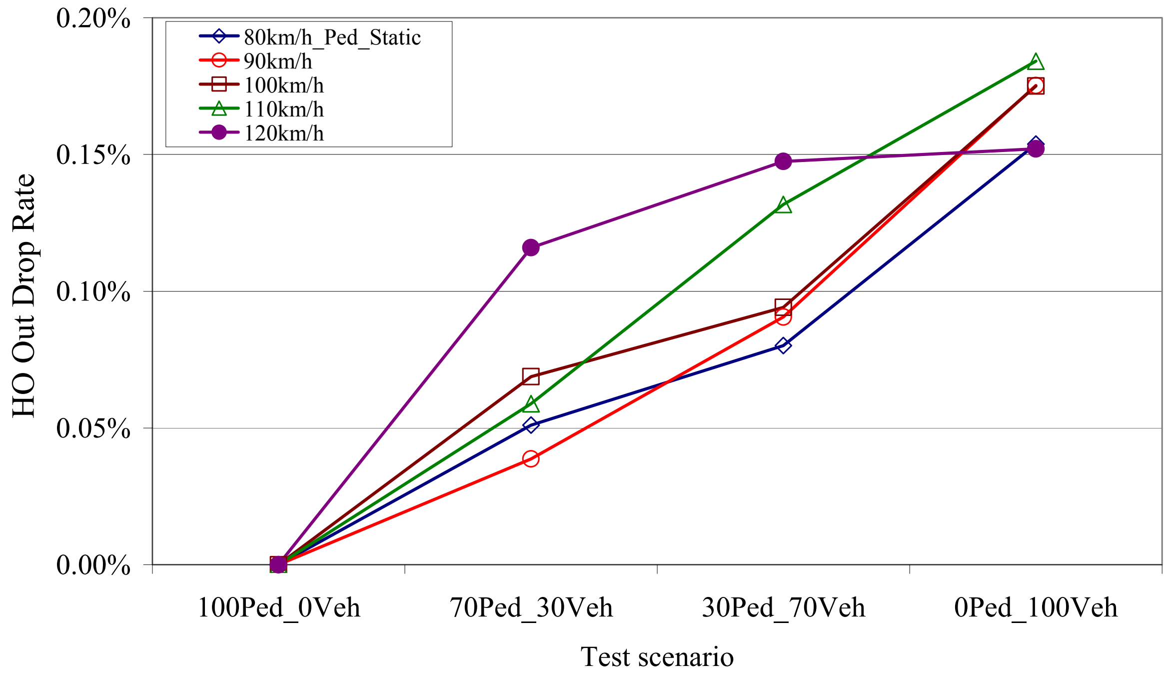


Figure V.39 – Outgoing handover drop rate in distinct mobility profiles (BxLx).

The handover flow indicator is represented in Figure V.41 for BxLx and Benfica with different mobility profiles.

The indicator does not present a big unbalance between incoming and outgoing handovers, as it is well concentrated around 50%. Nevertheless, Benfica seems to have a slight trend for having a slightly higher amount of incoming than outgoing handovers, but that is due to the traffic distribution imposed by the traffic matrix of the city, and does not present a strong correlation with distinct mobility profiles.

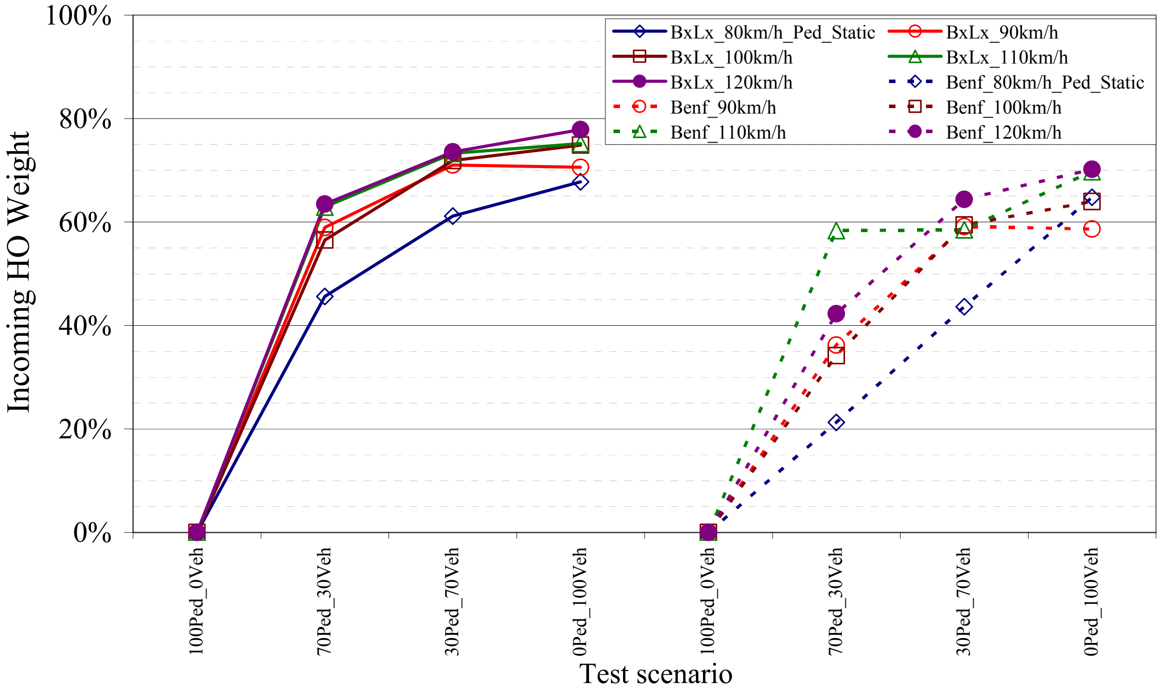


Figure V.40 – Incoming handover weight in distinct mobility profiles (BxLx and Benfica).

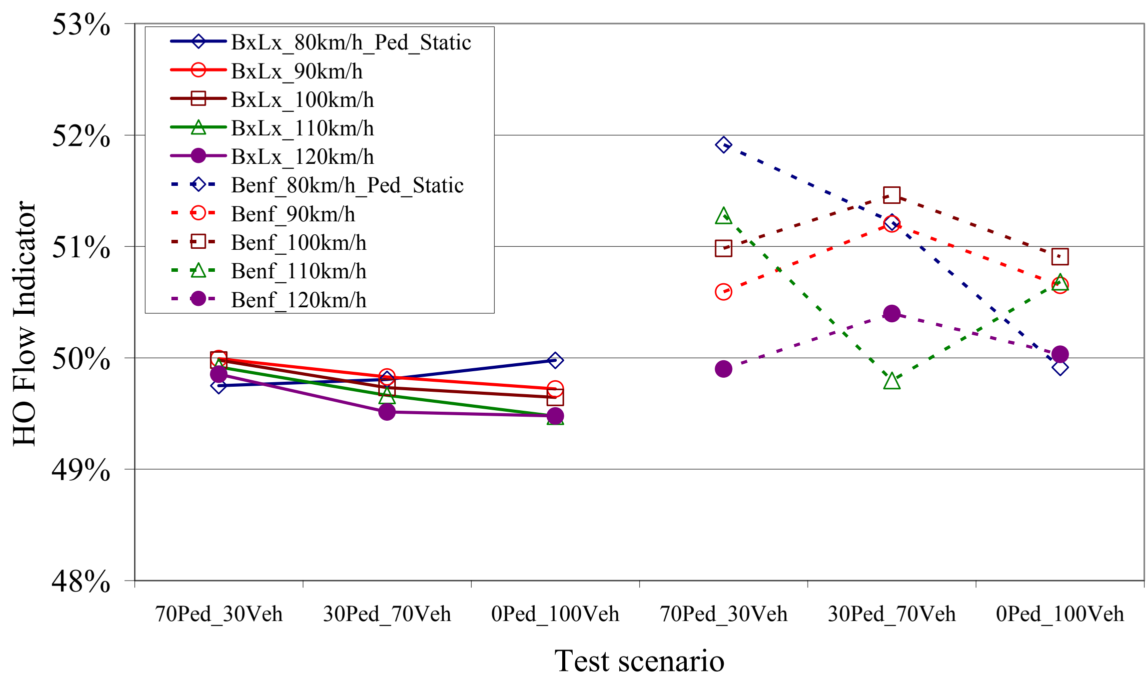


Figure V.41 – Handover flow indicator in distinct mobility profiles (BxLx and Benfica).

The average system UL and DL Load is presented in Figure V.42 and Figure V.43 for BxLx and Benfica. The behaviour observed is similar to the one registered in Section V.2.2, i.e., increasing mobility profiles lead to higher UL and DL system loads.

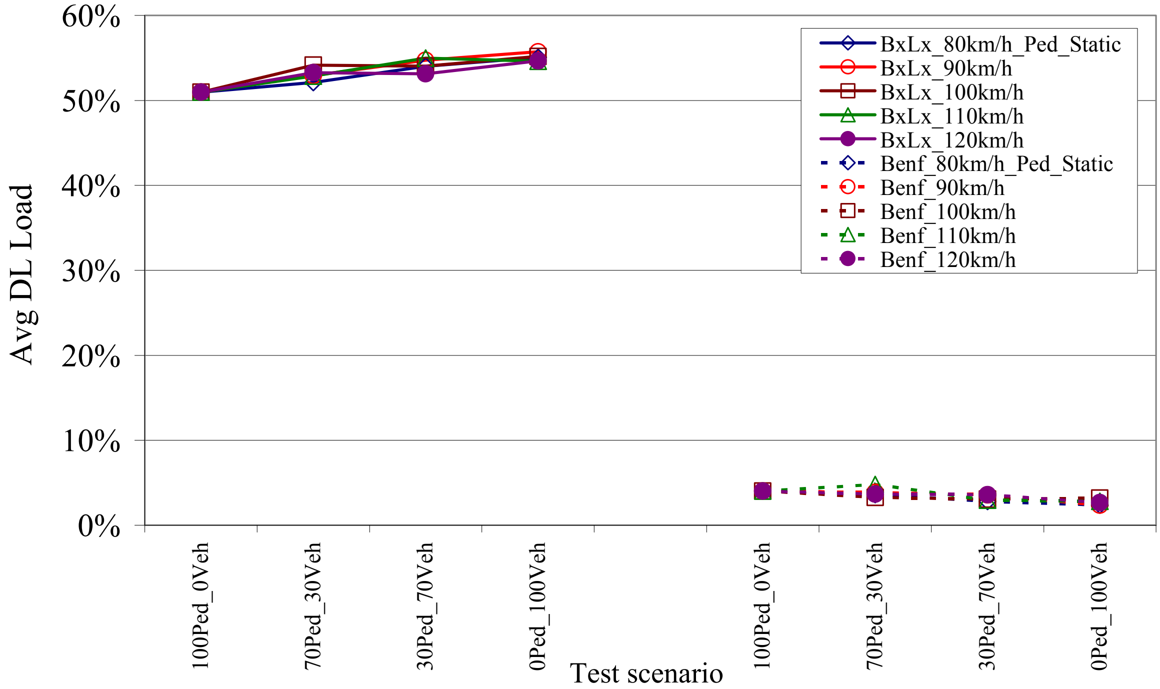


Figure V.42 – Average DL Load in distinct mobility profiles (BxLx and Benfica).

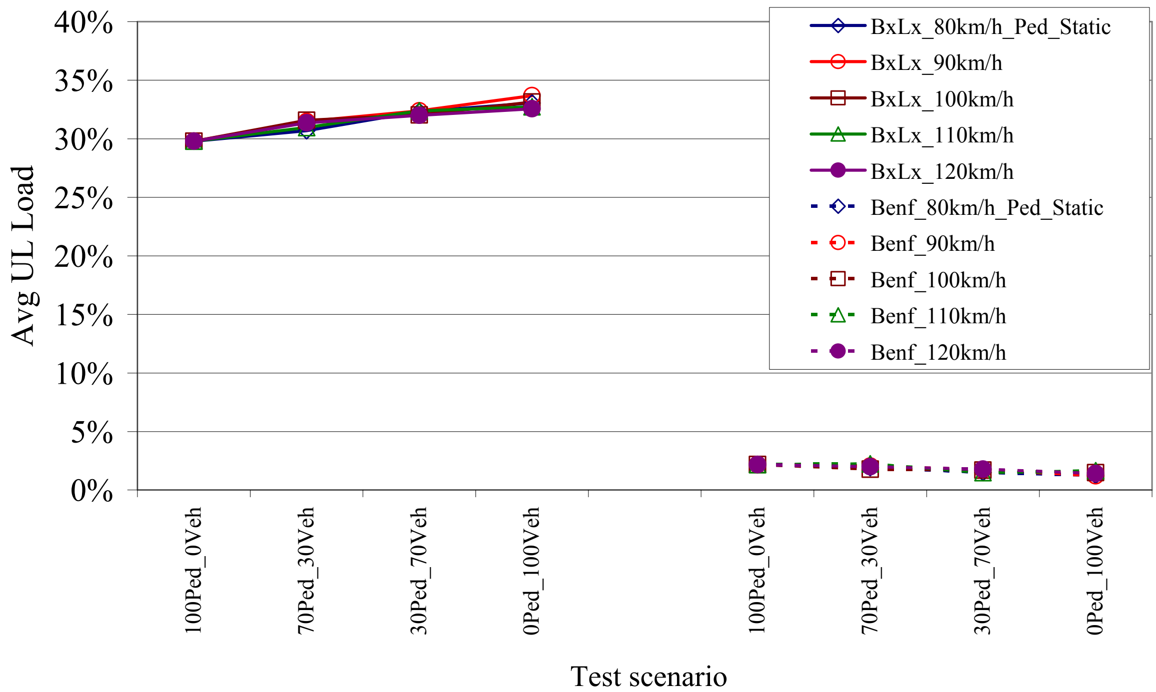


Figure V.43 – Average UL Load in distinct mobility profiles (BxLx and Benfica).

This DL load increasing ranges between 3.6 (for BxLx_110km/h) and 4.7% (for BxLx_90km/h), and UL load increase ranges between 2.8 (for BxLx_120km/h) and 3.9% (for BxLx_90km/h). Benfica presents again a decreasing behaviour, due to the fact that the number of calls in the central cluster cells decreases with increasing amount of vehicular users.

Applications' performance was also analysed, but the observed behaviour is quite similar to the one registered in reference scenarios, and as such it does not justifies the presentation of detailed analysis.

V.2.3 System Response Trends

The results obtained from the set of scenarios tested so far allow identifying some trends on the system behaviour as response to different input conditions.

Average users' speed presents some correlation with dropped call rate, but it must be crossed-correlated with users' density. Figure V.44 presents the distribution of DCR values obtained in the test scenarios, showing linear regressions, calculated with Excel®, in order to obtain the evolution tendencies. Moscavide's results are not interpolated as they present a very irregular behaviour. Regarding Benfica, as this scenario has a low users' density, the results from the scenarios with lowest users' speed seem to be out of the trend, and as such the two lowest values (i.e., average speed 4.4 and 5.1 km/h) were filtered out from the interpolation calculations (and are not represented in Figure V.44. AvRp scenario is also considered, despite the fact that it is represented by only four points; as it has a considerable high traffic density (it is one of the two most loaded scenarios) the resulting DCR values seem to follow a well defined trend. Respecting these constraints, the line that best fits the values from the simulations presents a slope ranging from 10^{-5} for low density scenarios as Benfica (in practice it is an horizontal line, meaning that DCR will tend to have a fixed value independently of the users' average speed) to 6×10^{-4} for the densest traffic scenarios. This slope means that for each increment of 10 km/h in users' average speed DCR will increase by 0.6%. Intermediate traffic density scenarios will have a DCR increase with average users' speed at a rate in between these two bounds. The parameterisation of this dependency for each of the test scenarios (Benfica, AvRp and BxLx) is given by (V.1), (V.2) and (V.3). The differentiation among them is given by the traffic density of each one.

$$P_{d\ \mathrm{Benf}}[\%] = V_{avg[\mathrm{km/h}]} \times 10^{-3} + 2.9 \times 10^{-1} \qquad \text{(V.1)}$$

$$P_{d\ \mathrm{AvRp}}\,[\%] = V_{avg[\mathrm{km/h}]} \times 3 \times 10^{-2} + 7.6 \times 10^{-1} \tag{V.2}$$

$$P_{d\ \mathrm{BxLx}}\,[\%] = V_{avg[\mathrm{km/h}]} \times 6 \times 10^{-2} + 0.8 \times 10^{-1} \tag{V.3}$$

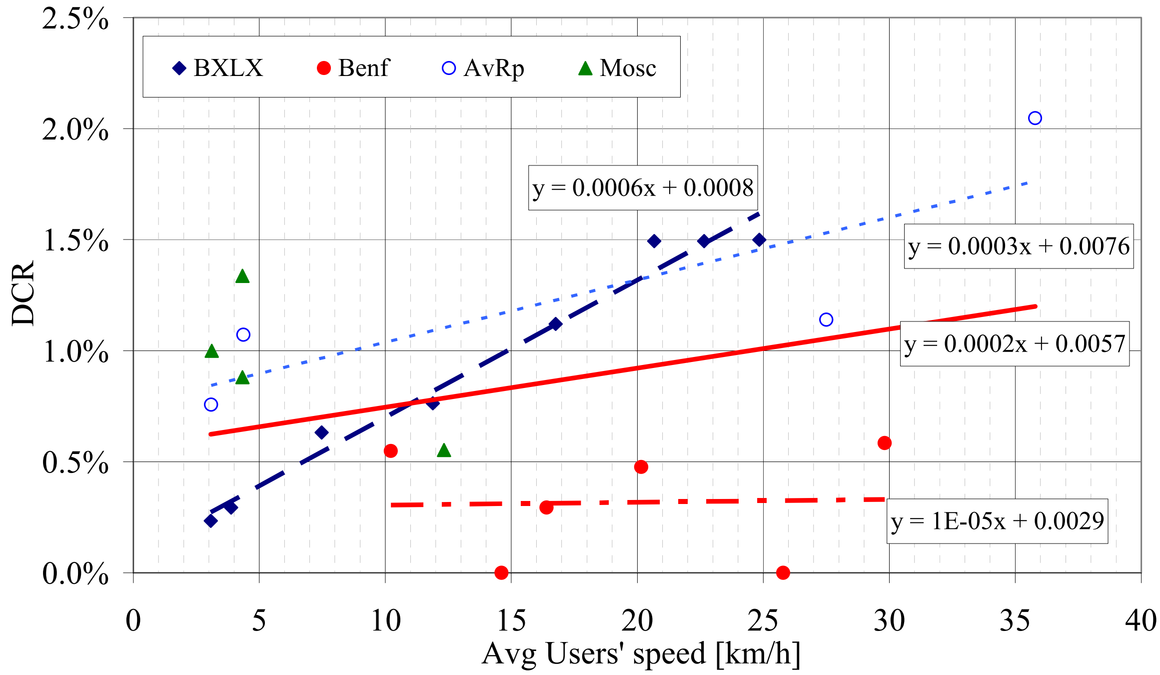


Figure V.44 – Dropped Call Rate dependency on average users' density and speed.

The global dependency (taking into account all the scenarios with exception to Moscavide) is given by

$$P_{d\ \mathrm{Global}}\,[\%] = V_{avg[\mathrm{km/h}]} \times 2 \times 10^{-2} + 5.7 \times 10^{-1} \tag{V.4}$$

Naturally, the global tendency presents a behaviour (if one takes into consideration the slope of the linear regression function) between the extremes established by Benfica and BxLx. In order to assess the fitness of the linear regressions to the set of values considered, the R-Squared was calculated (with Excel®) for each of the regressions.

Table V.8 – Fitness evaluation for DCR vs Avg Users' Speed linear regression.

Scenario	R-Squared
Benf	0.001
AvRp	0.699
BxLx	0.978
Global	0.109

One must recall that R-Squared measurement ranges between 0 and 1 and the higher the value achieved the better the linear regression fits the set of values being interpolated. The results obtained show that the regression for BxLx fits the values with a good accuracy. The results attained for AvRp show that the regression still presents a considerable good fit of the values. The linear regression for Benfica values presents very poor results as the R-Squared measure is almost zero. The global linear regression has a very low R-Square measure due to the impact of considering Benfica values.

Blocked call rate presented some stability in the analysis as the number of blocked calls is, in general, very small. Nevertheless, the same approach is followed in the analysis of BCR, and the same trends are also verified. Figure V.45 presents the BCR dependency on average users' density and speed. BCR evolution stability seems to be reached for higher traffic density scenarios (in this case AvRp and BxLx), are its relation with average users' speed can reach an increasing rate of 0.05 % per each 10 km/h increase.

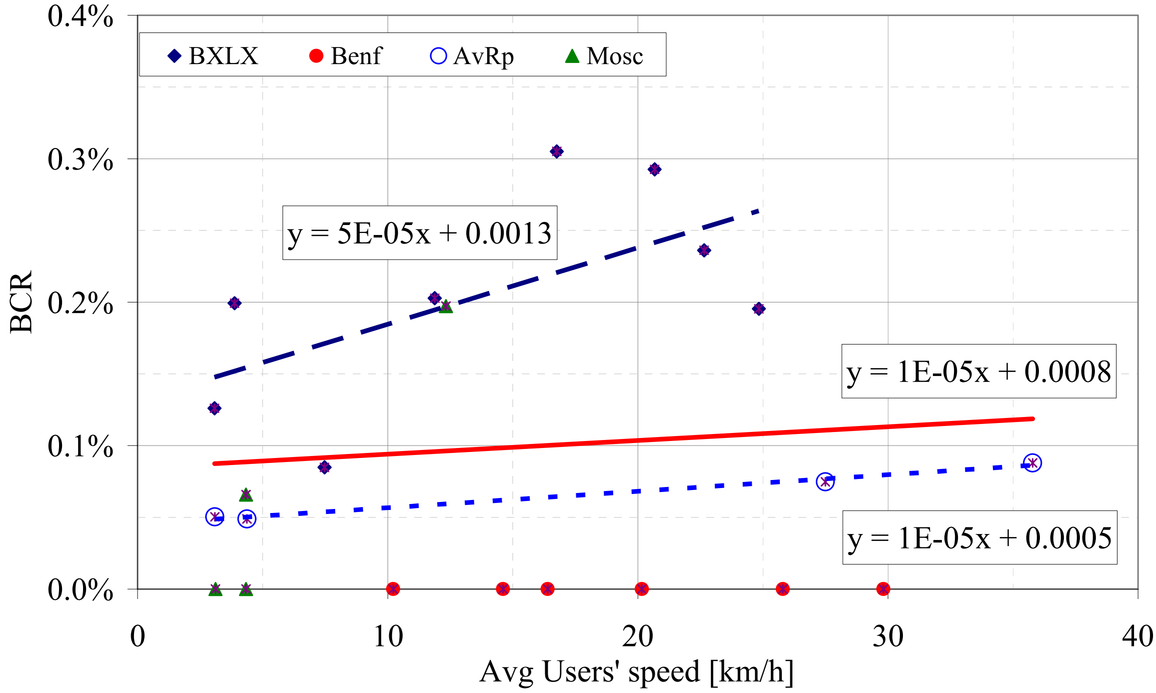


Figure V.45 – Blocked Call Rate dependency on average users' density and speed.

The relation between DCR and average users' speed is, hence, dependent on the traffic density and can be parameterised by (V.5) and (V.6), depending on the area considered.

$$P_{b\ \mathrm{BxLx}}[\%] = V_{avg[\mathrm{km/h}]} \times 5 \times 10^{-3} + 1.3 \times 10^{-1} \qquad \text{(V.5)}$$

$$P_{b\ \mathrm{AvRp}}[\%] = V_{avg[\mathrm{km/h}]} \times 10^{-3} + 0.5 \times 10^{-1} \qquad \text{(V.6)}$$

The global relation considering all points in Figure V.45 is given by

$$P_{b\ \mathrm{Global}}\,[\%] = V_{avg[\mathrm{km/h}]} \times 10^{-3} + 0.8 \times 10^{-1} \qquad \text{(V.7)}$$

The result of the fitness evaluation provided by R-Squared is presented in Table V.9. The results show that AvRp is well fitted by the linear regression but this information must be taken with special attention as it is based only in four values. The results for BxLx are low because the values are too spread. In order to improve the fit of the linear regression more points should be considered. The global regression has the lowest fitness evaluation result due to the impact of Benfica and Moscavide results.

Table V.9 – Fitness evaluation for BCR vs Avg Users' Speed linear regression.

Scenario	R-Squared
AvRp	0.990
BxLx	0.370
Global	0.009

Handover per call is also analysed in the scope of this global analysis, and the aggregated results are presented in Figure V.46. The handover per call being a direct indicator of mobility, there is no need to filter out any of the values (neither Moscavide nor Benfica results were filtered out): an increasing rate of 0.7 handovers per call per each 10 km/h increase is obtained. It is clear that this increasing rate is followed by all scenarios, but, lower traffic loaded scenarios tend to follow it with lower values (i.e., the Y axis crossing value is lower for lower loaded scenarios than for higher loaded ones). The global trend is:

$$P_{\mathrm{HOCall}} = V_{\mathrm{avg[km/h]}} \times 0.07 + 1.03 \qquad \text{(V.8)}$$

The evaluation of the fitness for the linear regression in this case results in 0.68 for the R-Squared measure. This value reveals that the linear regression provides considerably accurate results.

The relation obtained in (V.8) confirms, by means of simulations, the theoretical behaviour expected for the indicator HO/Call. In [Corr01] a simple theoretical approach is presented for the relation between HO/Call and the users' speed, resulting in a linear relation as represented in Figure V.46.

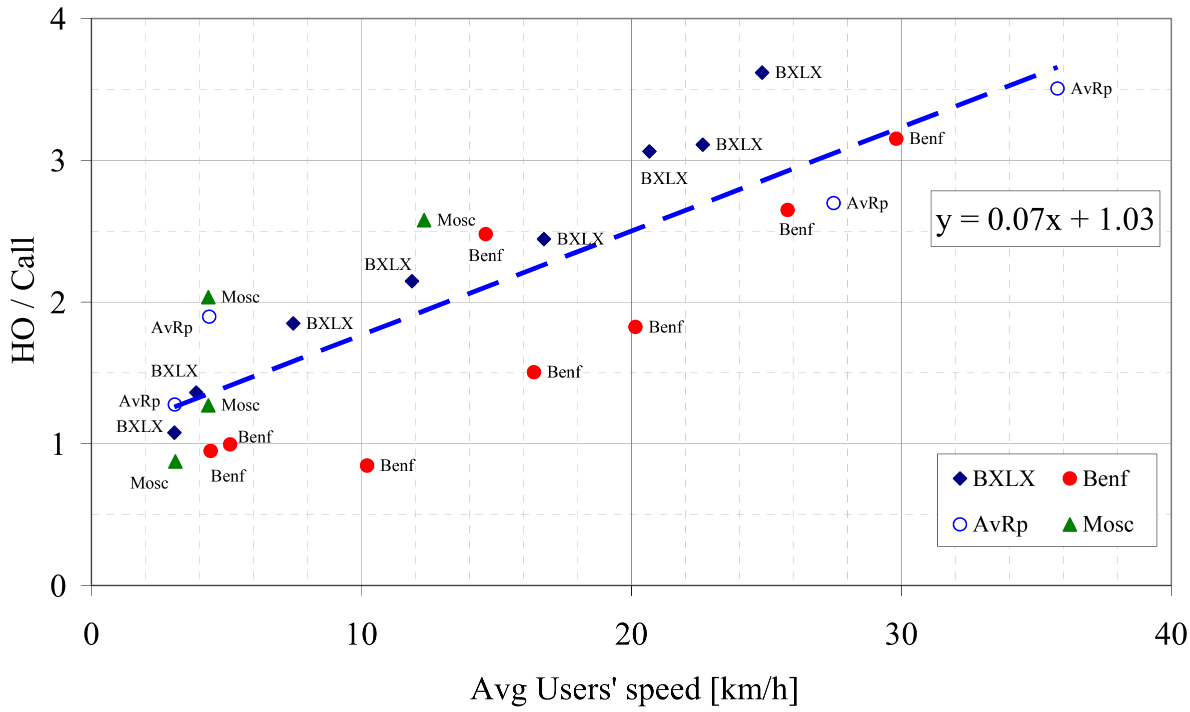


Figure V.46 – HO/Call dependency on average users' density and speed.

The outgoing handover drop rate dependency on average users' speed is presented in Figure V.47. The analysis of the data reveals a clear logarithmic relation between average users speed and outgoing handover drop rate. It is interesting to observe the clear evolution in the increasing rate of the indicator, with increasing traffic density of the scenarios. A scenario like Benfica (540 users/km^2) presents a constantly null indicator, but it starts increasing at a higher rate for denser traffic areas as AvRp (4 980 users/km^2); the highest increasing rate is verified for the densest scenario (AvRp). These results must, however, be considered carefully, as they were obtained for those users' densities with a network of 500 m intersite distance. Naturally, lower intersite distances will increase these dependencies and higher intersite distances will produce the opposite effect. Nevertheless, parameterisation of those interpolated relations is shown as well.

$$P_{dHO\ \mathrm{Mosc}}\,[\%] = 3 \times 10^{-2} \times \ln(V_{avg[\mathrm{km/h}]}) - 2 \times 10^{-2} \quad (V.9)$$

$$P_{dHO\ \mathrm{AvRp}}\,[\%] = 7 \times 10^{-2} \times \ln(V_{avg[\mathrm{km/h}]}) - 3 \times 10^{-2} \quad (V.10)$$

$$P_{dHO\ \mathrm{BxLx}}\,[\%] = 6 \times 10^{-2} \times \ln(V_{avg[\mathrm{km/h}]}) - 2 \times 10^{-2} \quad (V.11)$$

$$P_{dHO\ \mathrm{Global}}\,[\%] = 7 \times 10^{-2} \times \ln(V_{avg[\mathrm{km/h}]}) - 6 \times 10^{-2} \quad (V.12)$$

The linear regression presented in (V.12) only considered BxLx and AvRp values, and Table V.10 presents the fitness evaluation results for all the presented linear regressions.

Table V.10 – Fitness evaluation for HO Out Drop Rate vs Avg Users' Speed linear regression.

Scenario	R-Squared
Mosc	0.302
AvRp	0.764
BxLx	0.881
Global	0.740

AvRp and BxLx present the higher fitness evaluation results.

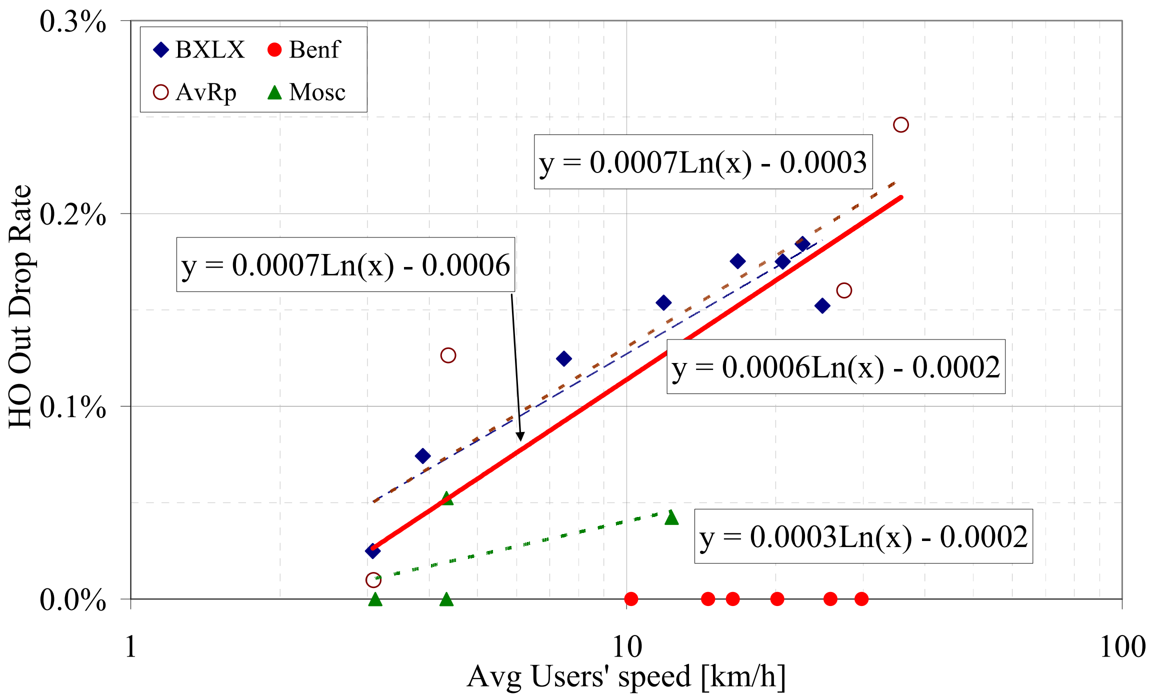


Figure V.47 – Outgoing handover drop rate dependency on average users' density and speed.

The incoming handover rate relation with average users' speed is presented in Figure V.48. Also in this case some data filtering was performed (the same points that were filtered out in DCR and BCR analysis are not considered here) and a fairly linear relation is found between average users' speed and incoming handover rate. In this case, it is not surprising to see the direct proportionality between incoming handover rate and average users' speed, as users will perform handovers more often when they move faster. The increasing rate is similar in BxLx and Benfica, but for denser traffic areas the absolute value is higher for higher traffic density areas, as one can see in Figure V.48 and verify by comparing the constant terms of (V.13) and (V.14):

$$P_{HOin\ \mathrm{Benf}}[\%] = 1.11 \times V_{avg[\mathrm{km/h}])} + 40.2 \qquad \text{(V.13)}$$

$$P_{HOin\ \mathrm{BxLx}}[\%] = 1.09 \times V_{avg[\mathrm{km/h}])} + 51.9 \qquad \text{(V.14)}$$

The R-Squared measure for these two linear regressions is 0.709 for Benfica and 0.914 for BxLx.

The handover flow indicator is shown in Figure V.49. All values are very close to 50%, and there is only a slight decreasing trend of the indicator. This behaviour of the indicator would suggest that at increasing average users' speed values, outgoing handovers in the central cells would be more than the incoming ones, but neither the trend is not sufficiently strong, nor the number of considered points can be considered enough, so that this trend can be considered realistic. One could not expect this trend behaviour, as it would mean that more users would be getting out of the cells compared to the incoming ones. In conclusion, this can be considered within the error margin of the obtained results.

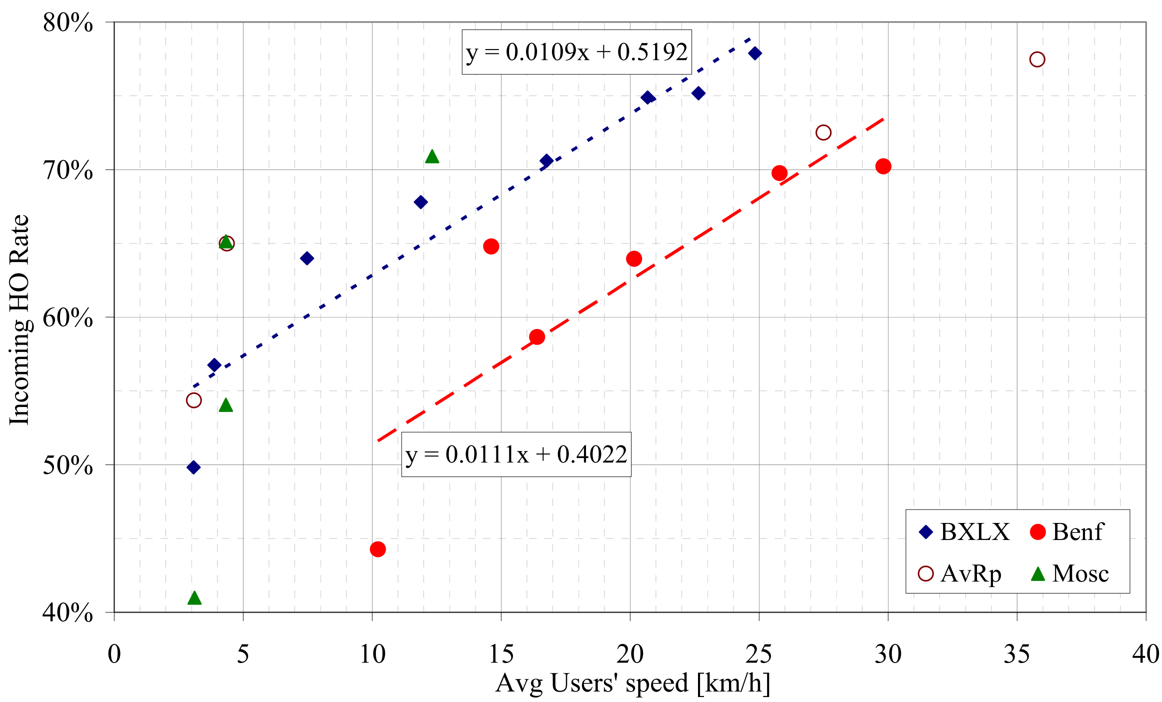


Figure V.48 – Incoming handover rate dependency on average users' density and speed.

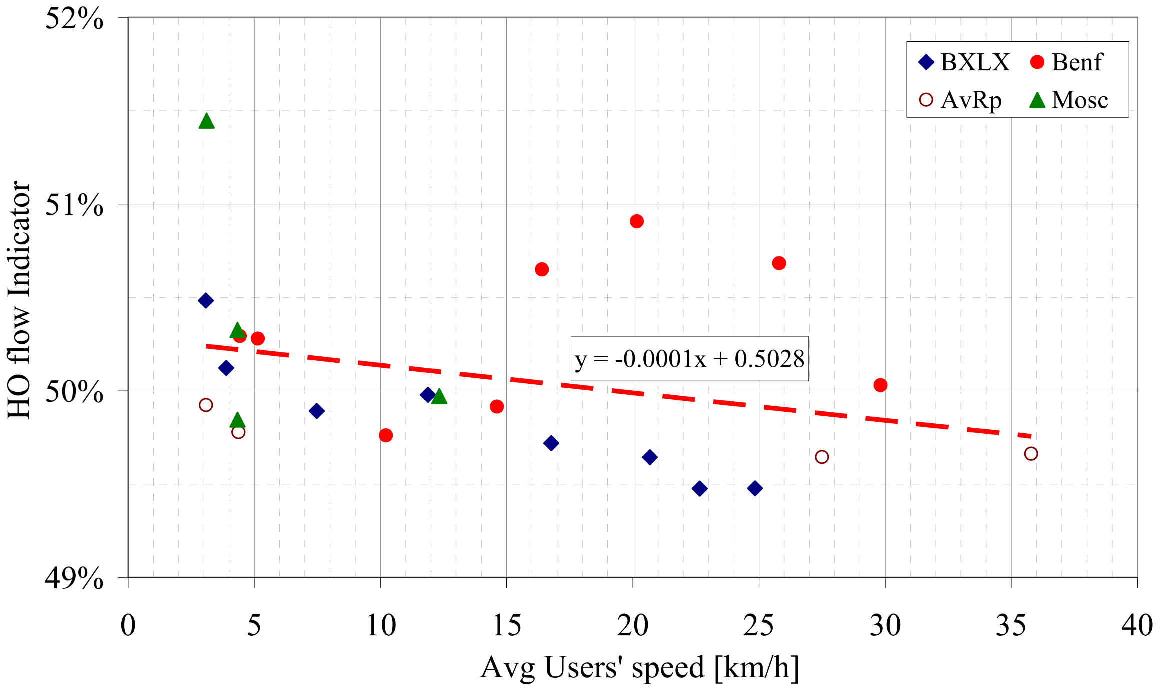


Figure V.49 – HO flow indicator dependency on average users' density and speed.

A special care must be taken when considering these parameterisations in further studies, in order to verify if the conditions of those hypothetical studies comply with the assumptions here taken. The idea is to show trends, rather than to look for actual values, which will help in the design of real networks.

V.3. Impact of Users' Indoor Locations

V.3.1 Simulation Scenarios Analysis

In Section V.2, mobility was modified in the test scenarios by varying users' type distribution and average speed. Another approach is explored in this section, in the sense that users' location (rather than their speed) is varied. Only one test scenario is taken, BxLx, as it is the one providing the most stable indicators (due to the fact of having a local traffic density higher than the other scenarios, above the level where indicators' behaviour is stable). In this scenario, the amount of pedestrian and vehicular users assumes four distinct combinations (as in the reference scenarios, it assumes the combinations 100% Pedestrian - 0% Vehicular, 70% Pedestrian - 30% Vehicular, 30% Pedestrian - 70% Vehicular and 0% Pedestrian - 100% Vehicular) intending to obtain information covering the wide range of possible combinations of these factors. Pedestrian users are distributed by Deep Indoor, Indoor Window and Outdoor locations, by defining different ratios. Indoor Window ratio is fixed and equals 40% (meaning that 40% of pedestrian users are always in Indoor Window locations), whereas the remaining 60% of pedestrian users are split between Outdoor and Deep Indoor locations ranging between the ratios 0% - 60% and 60% - 0%. Figure V.50 illustrates the distribution of users in 100% Pedestrian scenarios, and Figure V.51 presents the distribution for the combination of 30% Pedestrian users - 70% Vehicular users.

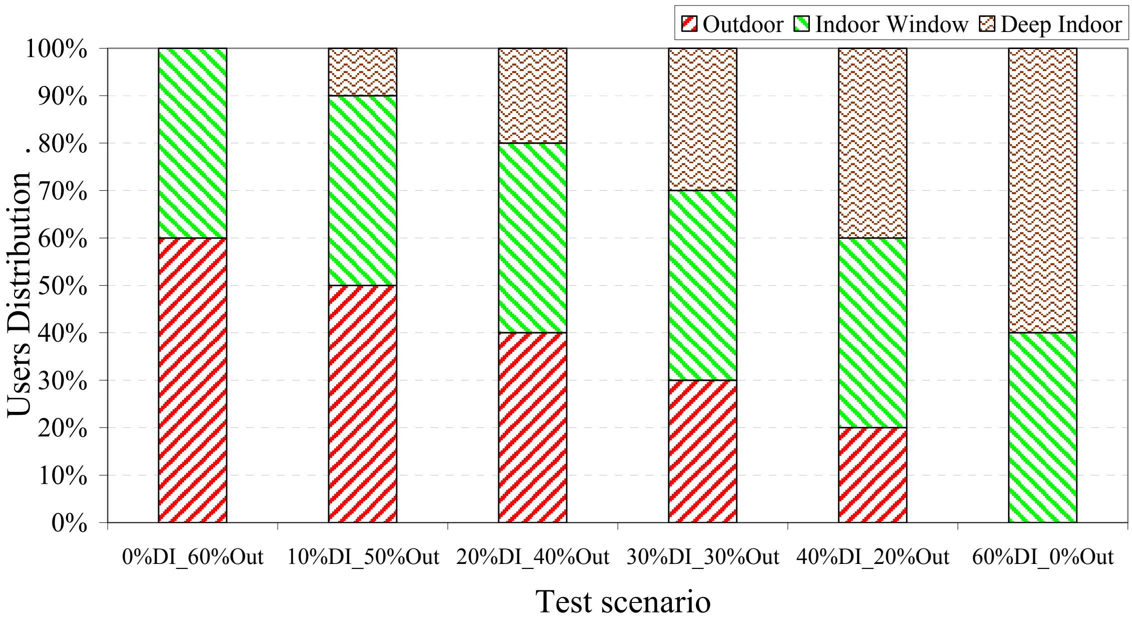


Figure V.50 – Users Indoor scenario distribution for 100% Pedestrian scenario.

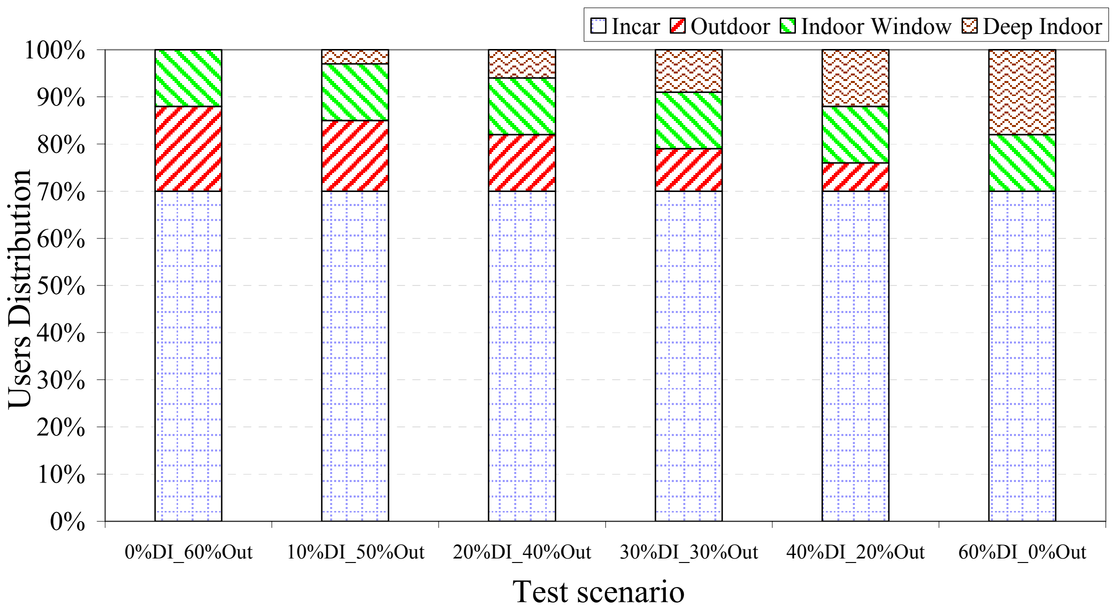


Figure V.51 – Users Indoor scenario distribution for 30% Pedestrian scenario.

In Annex K, Figure K.15 presents the remaining combinations for the scenario 70% Pedestrian users - 30% Vehicular users. The situation 100% Vehicular users is not shown as it represents a situation with no pedestrian users. Nevertheless, the extreme scenarios combinations for 60% Deep Indoor - 0% Outdoor and 0% Deep Indoor - 60% Outdoor Pedestrian users are presented in Annex K, Figure K.16 and Figure K.17, respectively, aiming at giving a good insight into the chosen variation tendencies.

V.3.2 System Performance Analysis

The dropped Call Rate variation representation in Figure V.52 shows a clear increasing tendency of the indicator as the amount of users in Deep Indoor locations increases.

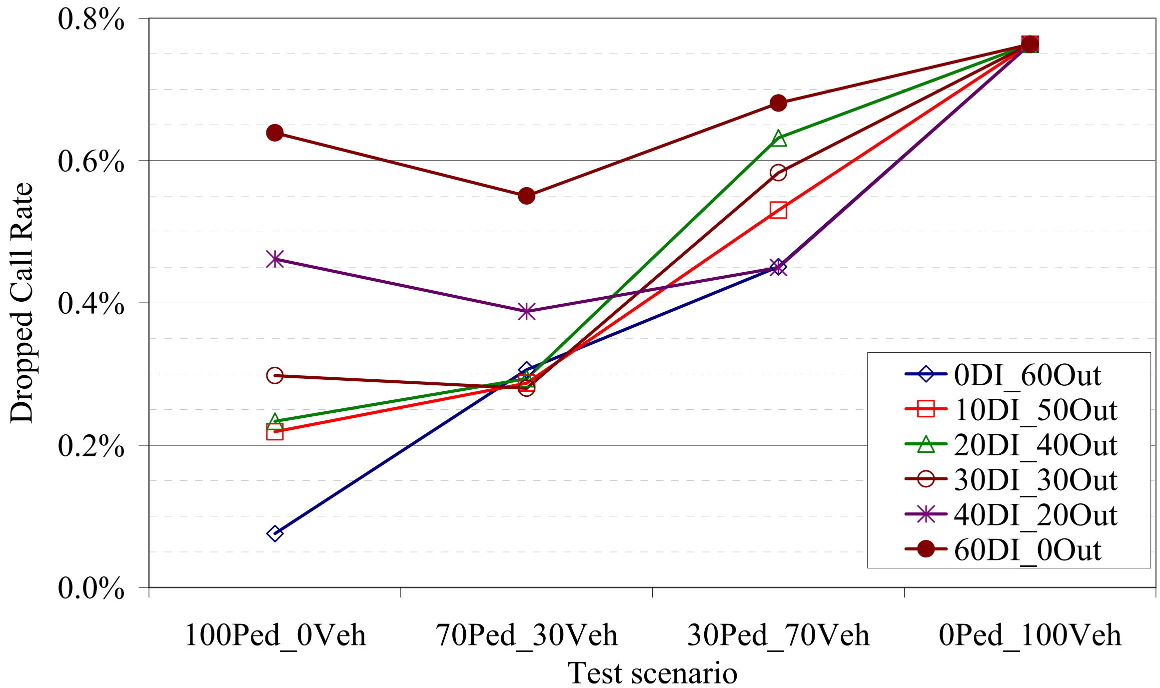


Figure V.52 – DCR variation in distinct Indoor locations' distributions (BxLx).

This increase is naturally dependent on the amount of pedestrian users, and can vary from 0.08 to 0.64% for 100% pedestrian scenarios, when 60% of users change from Outdoor to Deep Indoor locations. This represents increasing more than 8 times the DCR in such scenarios, but it must be recalled that this extreme situation implies that each outdoor user (in the 0DI_60Out scenario) is moved to a deep indoor location (in 60DI_0Out) where an additional 25 dB indoor attenuation is considered rather than 0 dB. Variations are lighter when the amount of pedestrian users is 70 or 30%; in these cases, DCR increases only 1.8 times (from 0.31 to 0.55%) and 1.5 times (from 0.45 to 0.68%), respectively. This analysis reveals the considerable dependency of network's performance on the geographical characteristics of the users.

The blocked Call Rate evolution presented in Figure V.53 shows again (as it did in reference scenarios) some behaviour's instability, meaning that is does not present a strong correlation with the different scenario conditions. The reason for this behaviour remains the same, i.e., the values of BCR are very low (around 0.2%) and are obtained due to the existence of few blocked calls (the analysis of the simulation files with statistical data reveals an average value of 2 blocked calls per simulation).

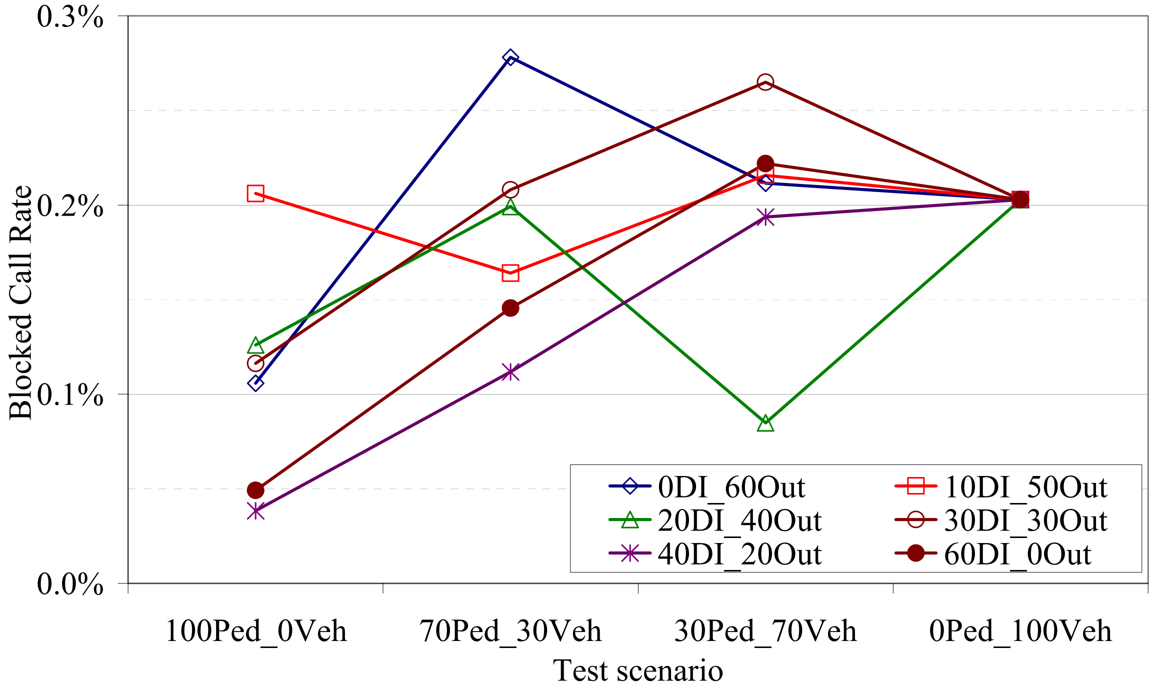


Figure V.53 – BCR variation in distinct Indoor locations' distributions (BxLx).

With such low average values of blocked calls, it is very likely that some simulations do not present any blocked call at all, which results in the observed instability of the indicator. The previous analysis of the reasons for blocked call indicated the maximum DL load of the cells in all simulations as the only one.

DL transmitting power usage is illustrated in Figure V.54, where average and maximum values for each scenario are both represented. There is a decreasing trend on both average and maximum DL transmitting power as the amount of outdoor located users increases. It is interesting to note that not even the worse case (60% pedestrian users in 100Ped_0Veh scenario) demands the maximum DL transmitting power to be higher than 14 W (the limit imposed for traffic channels utilisation). If this limit would have been reached, some blocked call could then be due to maximum DL transmitting power limitation (depending only if some CS calls would have been initiated in the time intervals where this limit was reached).

The UL and DL average load variation is presented in Figure V.55. Although some variations are observed in these indicators, they are not due to the different indoor locations generated in the simulations (as the cell load is only dependent on the mix and weighting of all services in the cell), but rather due to the slight variation of generated users in each scenario.

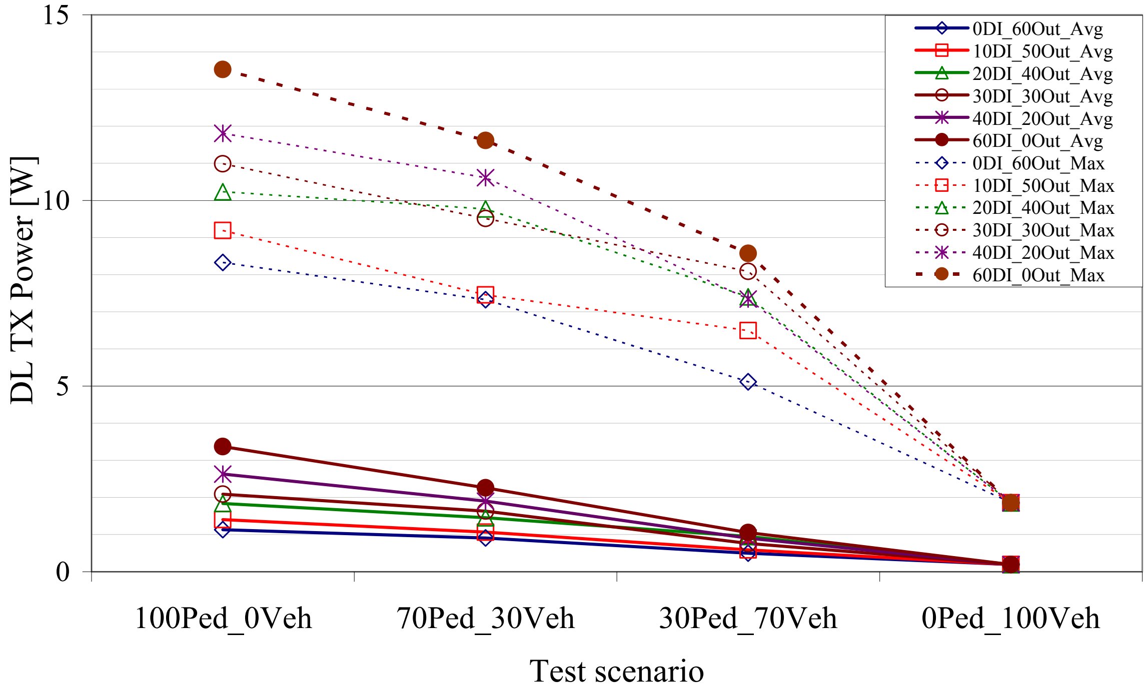


Figure V.54 – DL TX Power variation in distinct Indoor locations' distributions (BxLx).

In fact, cell load is modelled in CRUS by using (A.9), (A.10) and (A.11), which is only influenced by the number of users and the type of services being provided to them. As users are generated randomly in each simulation, some slight changes can occur in the total number of generated users, especially when the users' distribution is changed. In Annex K, Figure K.18 presents the average number of instantaneous users in the central cells of the cluster, showing the same behaviour as UL and DL cell load presents.

Mobility indicators (Handover per Call, Outgoing HO Drop Rate, Incoming HO weight and HO flow indicator) do not present any variation worth of notice, as the mobility conditions (average users' speed) are not changed in the different simulation scenarios. Hence, no correlation can be drawn between those indicators and variations on the users' locations based in these results. Nevertheless, in Annex K, Figure K.19 to Figure K.22 present the referred mobility indicators for this set of simulations.

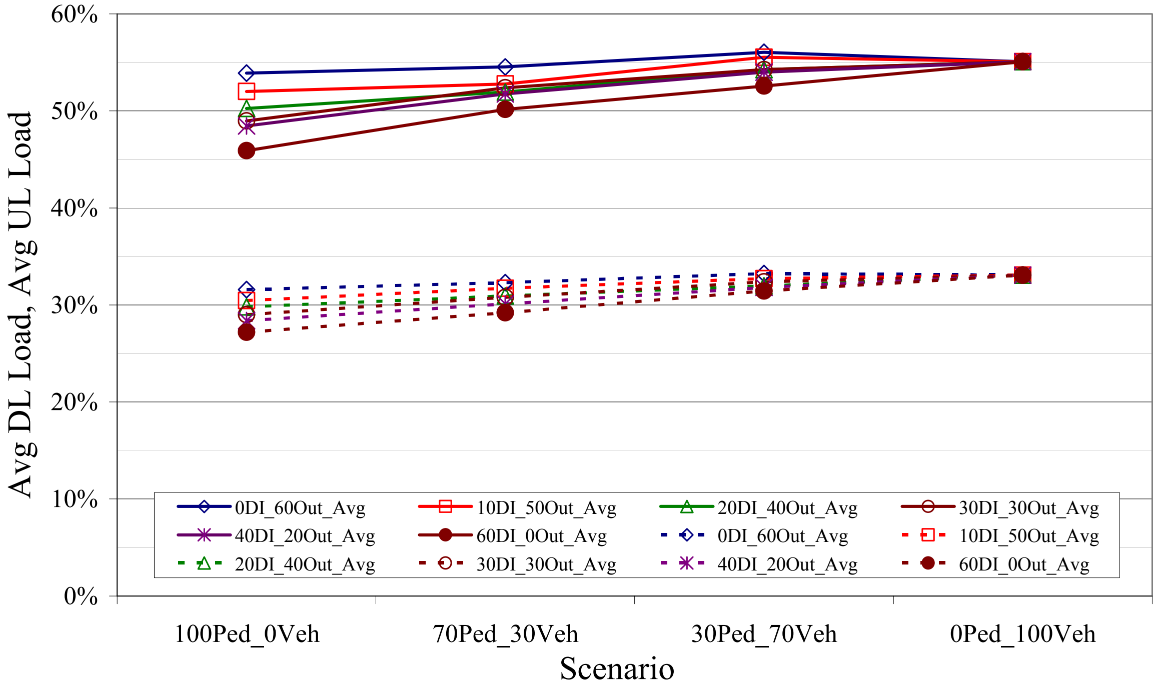


Figure V.55 – DL and UL load variation in distinct Indoor locations' distributions (BxLx).

V.3.3 System Response Trends

The analysis conducted so far indicates a straight correlation between some system performance indicators with users' location, specially dropped call rate and DL transmitting power. Dropped call rate dependence on the percentage of deep indoor users is presented in Figure V.56. The analysis of this set of data shows that in order to conclude about some correlation between DCR and the amount of deep indoor users (which appears as a measure of overall indoor penetration attenuation that must be compensated by the system by increasing the amount of transmitting power) some filtering of the points to be considered must be done. In fact, data obtained in the scenarios where vehicular users weighted 70%, present DCR values that are unusually high due to the impact of mobility (rather than being due to the impact of users' indoor location). On the other hand, when the weight of pedestrian users is high enough (in this case, the scenarios of 100 and 70% pedestrian users were considered) DCR seems to follow a well behaved trend as the figure shows. In fact, if vehicular users' weight is low enough in the system, a relation can be identified between the amount of deep indoor users and DCR. For the particular setting used in the simulations (i.e., Deep Indoor margin of 25 dB, Indoor Window margin of 11 dB and Incar Indoor margin of 8 dB) DCR increases with the increasing amount of Deep Indoor pedestrian users. In this relation, DCR is increased by 0.08% for each 10% increment in Deep Indoor users' percentage. The parameterisation of this relation is given by

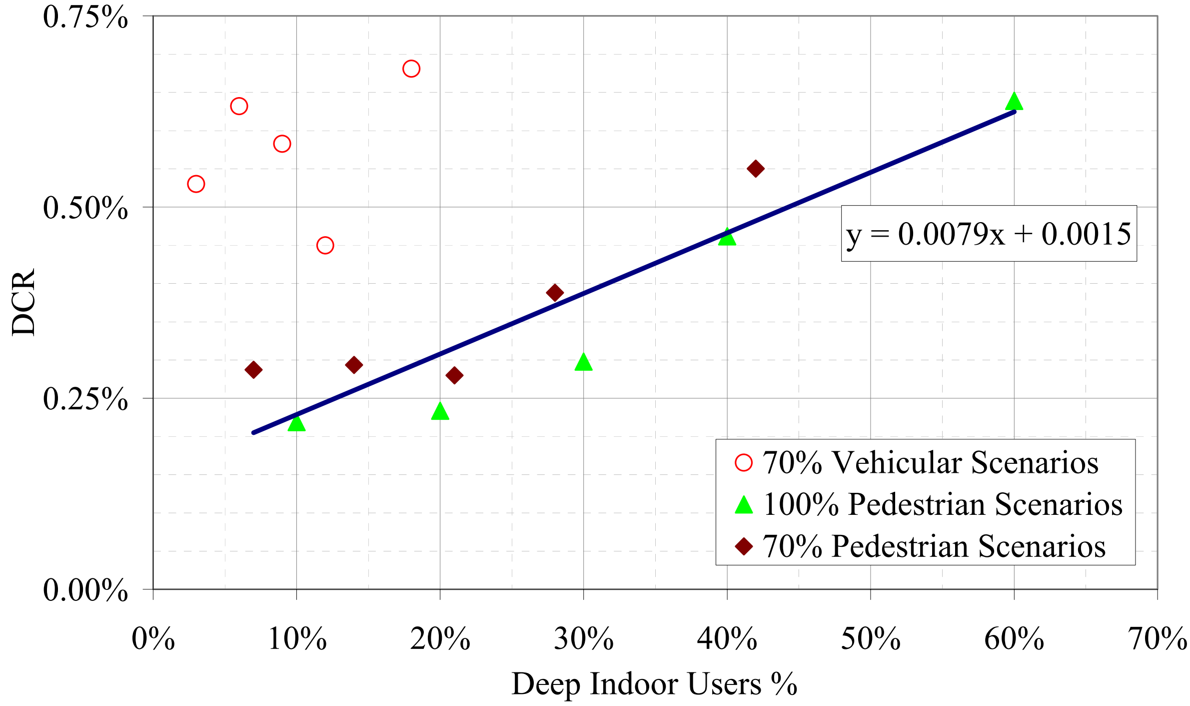


Figure V.56 – DCR indicator dependency on Deep Indoor users' percentage.

$$P_d\,[\%] = 7.9 \times 10^{-1} \times P_{DI[\%]} + 1.5 \times 10^{-1} \qquad \text{(V.15)}$$

The fitness evaluation of the linear regression to the values considered, by the R-Squared leads to the value 0.846. Regarding DL transmitting power, Figure V.57 characterises it, concerning average and maximum values, as well the amount of power used in best server links, in this analysis, scenarios with 70% vehicular users were also discarded. From the graphical representation in Figure V.57, DL transmitting power is seen to be directly proportional (both average and maximum values) with increasing Deep Indoor users percentage. Maximum DL transmitting power is more sensitive than average DL transmitting power to the amount of Deep Indoor users as it increases 0.97 W for every 10% increasing users, whereas average DL power only increases 0.40 W for the same users increase. The parameterisation of these identified relations is given by

$$P_{TXmax}\,[\mathrm{W}] = P_{DI[\%]} \times 9.68 + 7.84 \qquad \text{(V.16)}$$

$$P_{TXavg}\,[\mathrm{W}] = P_{DI[\%]} \times 3.98 + 0.88 \qquad \text{(V.17)}$$

The R-Squared evaluation applied to (V.16) results in 0.915. Regarding (V.17), the R-Squared evaluation result is 0.954. The amount of power used in best server radio links also presents an increasing tendency as the amount of Deep Indoor users increases. The increment for 10% users increase is 1.38%. Although this value is not too significant, in the sense that the variation is not too high, it clearly marks a tendency that must be taken into account in a regular network design process. The parameterisation for this relation is given by

$$P_{TXBS}\,[\%] = P_{DI[\%]} \times 0.07 + 83.9 \qquad \text{(V.18)}$$

The R-Squared evaluation of this linear regression is 0.832.

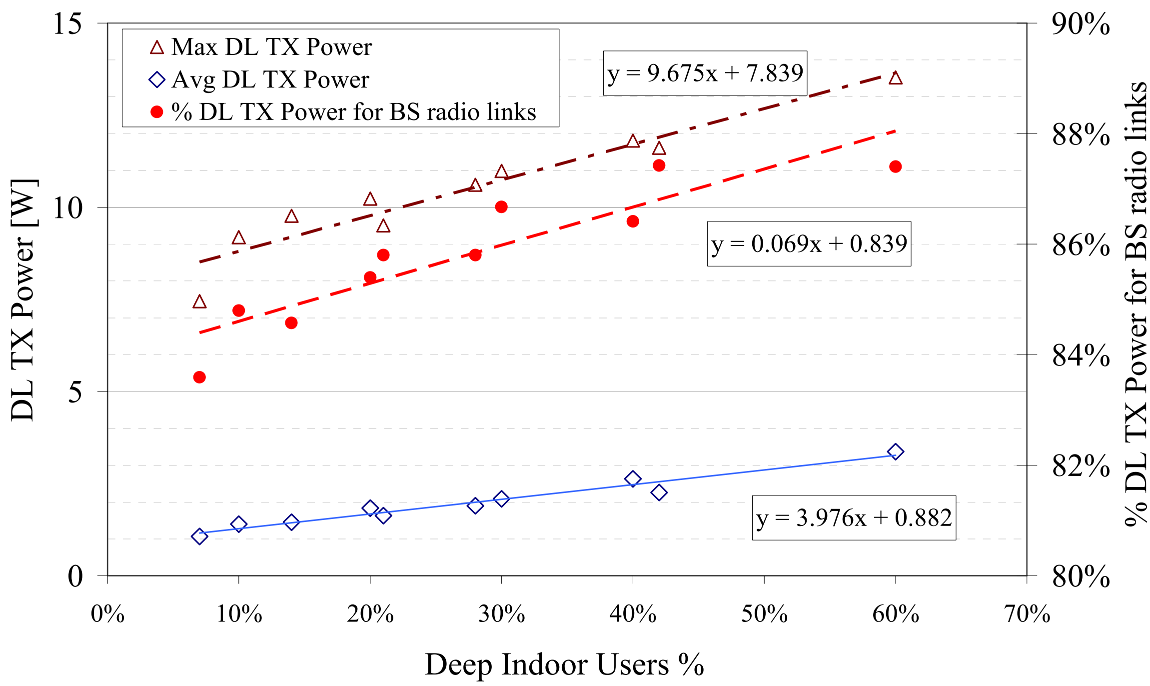


Figure V.57 – DL TX Power characterisation dependency on Deep Indoor users' percentage.

The considerations drawn in this section identify the tendencies of the network's response to the variations of users' characterisation, which must be taken into account while planning a network for UMTS FDD. The most significant conclusions are related with power usage in the radio network, as the same amount of users can demand completely different power levels from the network. In fact, the information regarding the geographic dispersion of users in the service area is as much important as the knowledge of the number of users to be served in the area. Figure V.57 clearly shows that the same amount of users can demand from the network almost the double of maximum DL transmitting power just by the fact that they are in a deep indoor environment. The result of that increased power demand reflects in the increase of DCR as depicted in Figure V.56. Although the results from the simulations do not show it, BCR is also expected to increase, as long as the maximum DL transmitting power reaches the physical limits of the equipment, which is usually set to 14 W for aggregated traffic channels.

Chapter VI

Conclusions

In this chapter, a summary of the results assessed in this study is presented. Ideas for deeper and future work under the scope of this study are presented as well.

The study developed in the scope of the current Thesis aimed at analysing the impact of multiservice users' mobility on UMTS-FDD networks' performance. Some studies have been already performed on this area, but the present work intended to go one step ahead by implementing a system level simulator considering both UL and DL, and a more realistic modelling of the network and mobility issues. The considered network structure is based on tri-sectorised sites with the purpose of analysing in detail the amount of resources reserved for soft, and especially softer, handover radio links. Mobility generation for vehicular users is based on the information provided by a city streets database. This is one of the major factors distinguishing the current study from the previous ones, as vehicular users are limited to move along the streets defined in the database, according with the speed profiles adapted to each street type. This approach provides a more realistic approach than the usually statistical methods used for vehicular users, and the impact of it is clearly identified and characterised in more than one of the scenarios tested in the study. Multiservice users' modelling is the other added value of the current study, as UMTS networks' performance is highly dependent on the offered traffic mix.

The impact of users' mobility is assessed by analysing in detail the behaviour of network's key performance indicators, such as blocked and dropped call rates, UL and DL cells load, DL channelisation codes utilisation, DL power utilisation, and handover performance. A deeper study is conducted at the application's level, the performance of each application being evaluated through the analysis of average application delay, UL and DL bit rates characterisation (average, 5% and 95% percentiles are analysed in detail). A set of indicators is defined to assess the performance of the network.

A literature survey was conducted in order to define the most suitable models to be used for both traffic and mobility modelling. Source models were identified and chosen for the seven PS applications implemented in the simulator (HTTP, FTP, e-mail, LBS, SMS, MMS and Streaming Multimedia) and for the two CS ones (Speech and Video Telephony). Mobility was modelled by a triangular speed distribution with a fixed average value for pedestrian users and a street type dependent average value for vehicular ones. Regarding the turning behaviour of the users, pedestrian users turn according to a specific statistical distribution (provided by one of the analysed mobility models), whereas vehicular ones move along streets defined in the streets database, their movement direction being dependent on the streets available in each crossroad, i.e., each time a vehicular user reaches a crossroads, one of the roads available in the crossroads is chosen to be the direction to follow.

Mobility generation is, according to this approach, as close to reality as reliable is the information contained in the streets database. As each street is associated to a specific type, the vehicular users' speed along each street is conditioned by the average speed value associated to that specific street type. By analysing the mobility generation process, one can conclude that a generation process closer to reality could only be achieved if the characterisation of the speed profile would be performed at a street level (rather than at a street type level), based on measurements performed on the real streets network; as far as it is known, such information is not available in any entity. Nevertheless, the increasing relation to the real mobile scenario is not expected to bring substantial added value, compared with the degree of specificity included in the current study.

Two complementary simulators were developed in order to achieve a complete simulation process that could be extensively used in order to conduct the current study. A major concern was taken when developing the simulators in order to guarantee their reliability as the set of simulations to perform was considerably high (several hundred simulations). Designing the interface between both simulators was vital to guarantee a completely consistent and reliable simulation process. An additional effort was developed in characterising the simulators performance in order to allow extrapolating their applicability limitations.

The city of Lisbon was chosen to develop the test cases, since many diversified environments (related to both traffic density and mobility profiles) are available. Furthermore, a lot of information is available from other projects (such as IST-MOMENTUM) for the city of Lisbon, providing the traffic generation geographic distribution. Using that information is both a choice of reliable information and a considerable advance, considering the amount of time needed to obtain the data that must be used as input into the simulation process.

Inside Lisbon, four areas were identified to obtain a mix between traffic density and mobility profiles: Downtown was chosen as representative of a high traffic density area with low mobility profile; Avenida da República is representative of a high traffic density and high mobility profile area; Moscavide was then chosen to represent a low mobility low traffic density area; finally, Benfica was chosen to be representive of low traffic density, high mobility profile areas. A careful analysis of these four scenarios revealed that although the trends were as expected at the beginning, the differentiation among them concerning traffic profiles is not high enough; as such, two extreme areas (Downtown and Benfica) were chosen to be "manipulated" in such a way that the asymmetries in the mobility profiles could be enhanced. The "manipulation" consisted on assuming higher average speed values for selected street types in a way that the average speed of the users generated in the test areas could be increased. This strategy proved to produce coherent results and the simulation results, obtained from this approach are quite interesting, revealing important trends.

Regarding the main results from the simulations, the analysis of reference scenarios shows that DCR increases with increasing mobility. In dense scenarios (as BxLx), DCR increases 0.6% each time average users' speed increases 10 km/h. As the scenario density decreases, DCR tends to have a constant value. In the less dense scenario (Benfica), DCR remains around 0.3%.

Blocked call rate presents an increasing tendency of 0.05% for an increase in users' average speed of 10 km/h. This tendency is, however, very dependent on the traffic density area under analysis. This reflects the fact that the radio network is well designed regarding intersite distance, as the amount of blocked calls is in fact very low.

The handover per call indicator presents a very stable trend. In fact, as the average users' speed increases by 10 km/h, the indicator increases by 0.7. The indicator presents higher absolute values for denser traffic scenarios. Outgoing handover drop rate presents an interesting trend, as it increases with the logarithm of users' average speed; the trend is ruled by the factor $0.0007 \times \ln(\text{users speed})$. Incoming handover weight increases by 10% for each 10km/h increase in users' average speed. The minimum value ranges between 40 (in Benfica) and 50% (in BxLx), depending on the scenario's traffic density. Handover flow indicator presents a very stable behaviour.

When varying the indoor locations users' distributions, very interesting results are found. For 100% pedestrian scenarios, moving 60% of the users from outdoor to deep indoor locations causes the DCR to increase from 0.10 to 0.65%. This high variation in the indicator clearly identifies the importance of having a good characterisation of the users. The average number of users in these test scenarios is quite stable, even though the indicator suffers a big impact due to the different location of the users.

BCR does not present a variation worth to be noted, being around 0.2%, which is a low value. Due to this, the indicator shows some instability as the number of blocked calls in the system is low.

The analysis of DL transmitting power in these test scenarios reveals that its maximum value assumes usually a value 10 times higher than the average one. This means that the DL transmitting power has a too large amplitude range. When moving 60% of the users from deep indoor to outdoor, the maximum DL transmitting power is reduced by from 13.5 to 8.5 W (a reduction of 37%). Once more, this reduction is due to the fact that users are placed in a different place. The maximum value being lower than 14 W confirms the situation of having no blocked calls due to limitations in DL transmitting power, and also that the radio network is designed to comply with the quality requirements of the system.

Analysis on UL and DL load reveals slight fluctuations that a closer investigation shows to be related to the fluctuation on the total number of users generated in each test scenario.

Looking at some trends, increasing the amount of users in deep indoor locations by 10% leads to an increase of 0.8% in DCR and 0.97 W in maximum DL TX power. Regarding the impact of the same variation in the amount of power reserved for best server radio links, it only weights 0.7%, meaning that the impact is very small, although being present.

The work performed in the scope of the current thesis presents a step ahead of the knowledge existing so far, but still more aspects can be addressed in further studies. The implemented mobility model introduced a more realistic approach to the mobility issue, but other approaches can be exploited if more detailed information regarding speed profile at street level rather than at street type level is available from measurements performed on real streets networks. The absence of such information can be a considerable obstacle to this evolution, but it would be especially important for a proper environment characterisation to be available for mobile communications operators. This approach would allow differentiating a street in Downtown from another in Moscavide or Benfica, regardless of being of the same street type.

In the current system level simulator, UL and DL loads are calculated in each frame time interval, but intra- and inter-cell interferences are accounted by constant average values resulting from previous studies. A more realistic approach would be to calculate the intra- and inter-cell interference levels as a function of the instantaneous users distribution in the network, rather than using average values. This would increase the complexity of the simulator and demand extra processing time, but results would be closer to the ones that can be measured in a real live network.

Fast Fading was accounted in the link budget as a constant margin that had to be compensated by the transmitting power of the Node B (in DL) and the UE (in UL). Although the dependence on the speed was taken into account, a rather better approach would be to generate a random variable inside the simulator with a distribution that characterises the fast fading phenomenon, still taking into account the speed impact on it. Once again, although this different approach would increase the processing time for each simulation, it would bring results closer to the ones verified in a real live network.

Simultaneity in multiservice users is already a reality today. Nevertheless, the model implemented in the simulation process assumes that each user has, at a time, a single service. No simultaneous multiservice users are considered in the simulations, and these types of users impose different constraints to the network. Also the network performance must be analysed in a different way, as the satisfaction level of the user is dependent on the mixed performance of both services (for instance a mix of speech and HTTP sessions). Thus, considering such a mix of simultaneous multiservice users must be analysed to assess the real impact imposed by such users.

Comparing the results and trends obtained in this work with real network performance measurements is an interesting study that may allow verifying the assumptions taken throughout the study, and validating the models implemented.

This study was performed on UMTS-FDD, taking into account the specificities of this System operation mode, nevertheless, extending this study to UMTS-TDD is a natural way forward as the TDD mode will be following the UMTS-FDD implementation.

The services mix considered in this study was based in the information provided by IST-MOMENTUM project, but considering a different set of services or, instead, the same set of services but with different weighting would allow studying the sensitivity of mobility impact to the services mix.

Only Lisbon was considered in this thesis but the simulators that were developed can easily be used to perform the same analysis in a different city, with a different services weighting and mobility profile.

The system performance was assessed, in the scope of this thesis, by analysing the performance of CS and PS services. For Ps services, the performance analysis was based on services' throughput and average delay. When a PS handover is performed and some delay is introduced due to temporary shortage of resources, extra signalling exists in the network but its impact was not analysed in the scope of the current thesis as that specificity of the system was not modelled. Hence, modelling the signalling part of the system, in future work, would allow to better assess the system response in such situations.

Finally, the propagation model implemented in the system level simulator is very simple (COST 231 – Walfisch Ikegami), and as such the whole network is seen as very "uniform" (from the radio propagation point of view). A step ahead would be to provide as inputs to the simulator a propagation attenuation grid generated by either an external calibrated propagation model or real radio measurements. The simulator would then use this information for the link budget calculations, rather than calculating internally the attenuation with this propagation model, and the results would be much closer to the real network behaviour. In this assumption, some effects as building shadowing or reflections, could be simulated by that external model or effectively measured and reflected on the propagation attenuation grid.

Annex A

Detailed Link Budget

In this annex, system's link budget is presented with the indication of variables' ranges and the values adopted in the simulation process.

Link budget for UMTS takes into account some factors that are system's specific. Because of that, in this annex a detailed link budget for UMTS is presented. In what follows, [Corr01] is taken unless other source is referred to.

Total propagation attenuation is calculated for each link (UL and DL) using the usual expression:

$$L_{p\,\mathrm{tot}[\mathrm{dB}]} = P_{t[\mathrm{dBm}]} + G_{t[\mathrm{dBi}]} - P_{r[\mathrm{dBm}]} + G_{r[\mathrm{dBi}]} = EIRP_{[\mathrm{dBm}]} - P_{r[\mathrm{dBm}]} + G_{r[\mathrm{dB}]} \tag{A.1}$$

where:

- $L_{p\,\mathrm{tot}}$: total propagation attenuation
- P_t : transmitting power at antenna port
- G_t : transmitting antenna gain
  - Typical Node B antenna's gain is 18 dBi
  - Typical UE antenna's gain is 0 dBi
- P_r : available receiving power at antenna port
- G_r : receiving antenna gain
- $EIRP$: equivalent isotropic radiated power

$EIRP$ can be calculated using (A.2a) or (A.2b) if UL or DL is considered, respectively.

$$EIRP_{[\mathrm{dBm}]} = P_{e[\mathrm{dBm}]} + G_{e[\mathrm{dBi}]} = P_{Tx[\mathrm{dBm}]} - L_{u[\mathrm{dB}]} + G_{e[\mathrm{dBi}]} \tag{A.2a}$$

$$EIRP_{[\mathrm{dBm}]} = P_{e[\mathrm{dBm}]} + G_{e[\mathrm{dBi}]} = P_{Tx[\mathrm{dBm}]} - L_{c[\mathrm{dB}]} + G_{e[\mathrm{dBi}]} \tag{A.2b}$$

The additional factors are:

- P_{Tx} : output power of transmitter.
  - UE is assumed to transmit maximum 21 dBm for Speech service and 24 dBm for data services, referring to the four power class terminal defined in [3GPP02b].
  - Node B is assumed to have a maximum transmit power of 43 dBm, which is shared among all connections and control channels. It is assumed that CPICH is be transmitted with 33 dBm.
- L_u : in UL, additional losses due to user's presence.
  - Voice service is accounted with 3.0 dB for L_u
  - Data service is accounted with 1.0 dB for L_u

Typical values are presented in Table A.1.

Table A.1 – Typical losses due to user's presence (extracted from [Corr01]).

Service Type	L_u [dB]
Voice	3.0 – 10.0
Data	0.0 – 3.0

- L_c: in DL, losses due to cable between transmitter and antenna

  3.0 dB were considered for L_c.

If receiving diversity is used, G_r must account for that extra gain, being replaced in (A.1) by G_{rdiv} defined in (A.3), where G_{div} is the achieved diversity gain.

$$G_{rdiv[\mathrm{dB}]} = G_{r[\mathrm{dBi}]} + G_{div[\mathrm{dB}]} \tag{A.3}$$

- Typical values for G_{div} are in the range [1.0 , 3.0]dB. This factor is equal to 0 dB when it is included in service's sensitivity (E_b/N_0).

The received power can be calculated by (A.4a) for UL and by (A.4b) for DL.

$$P_{Rx[\mathrm{dBm}]} = P_{r[\mathrm{dBm}]} - L_{c[\mathrm{dB}]} \tag{A.4a}$$

$$P_{Rx[\mathrm{dBm}]} = P_{r[\mathrm{dBm}]} - L_{u[\mathrm{dB}]} \tag{A.4b}$$

The receiver's sensitivity depends on the considered service. It can be calculated by:

$$P_{Rx\min[dBm]} = N_{[dBm]} - G_{p[dB]} + E_b/N_{0[dB]} \tag{A.5}$$

where:

- N : total noise power, calculated with (A.6)
- G_p: processing gain calculated by (A.9)
- E_b/N_0 : required signal to noise ratio depending on the considered service and environment. This parameter is very sensitive to many factors such as speed of the mobile, the existence of diversity in the receiver, the type of environment (rural, urban, suburban, etc.). Also the fact of considering the Node B or the UE leads to different values, because the hardware implementation in the UE does not allow achieving sensitivities as low as those achieved in the Node B. Table A.2 presents typical UL sensitivities for different services. Based on reserved information provided by UMTS equipment suppliers an interpolation was performed in order to define the adopted values for the present study. The adopted values already account with receiver diversity.

Total noise power is evaluated using:

$$N_{[dBm]} = N_{0[dBm]} + M_{I[dB]} \tag{A.6}$$

where N_0 is the average noise power (estimated by (A.7)), and M_I the interference margin depending on the system load (calculated by (A.8)).

Table A.2 – Typical Node B service's sensitivities (extracted from [Corr01]).

Service	Bit Rate [kbps]	QoS	E_b/N_0 [dB]	Adopted E_b/N_0 [dB]		
				Pedestrian A (3 km/h)	Vehicular A (50 km/h)	Vehicular A (120 km/h)
Voice	12.2	BER=10^{-3}	5.8 – 9.1	6.8	7.8	8.1
Data Circuit Switch	64	BER=10^{-6}	3.4 – 5.4	4.4	4.4	5.1
	128	BER=10^{-6}	2.8 – 4.7	3.7	---	4.7
	384	BER=10^{-6}	1.6 – 4.7	3.0	---	4.7
Data Packet Switch	64	BLER=10^{-2}	3.0 – 7.3	4.0	5.2	5.1
	128	BLER=10^{-2}	2.3 – 6.8	3.4	4.6	4.6
	384	BLER=10^{-2}	1.9 – 6.2	2.3	2.3	3.6

The average noise power N_0 (in dBm) is given by:

$$N_{0[\mathrm{dBm}]} = -174 + 10 \cdot \log\left(\Delta f_{[\mathrm{Hz}]}\right) + F_{[\mathrm{dB}]} \tag{A.7}$$

where:

- Δf : signal bandwidth, in UMTS it is equal to the code rate, R_c (3.84 Mcps)
- F: Receiver's noise figure

Typical values are presented in Table A.3.

Table A.3 – Typical Noise Figure values.

Receiver Type	F [dB]
Node B	2.0 – 5.0
User Equipment	8.0

- Noise figure for Node B was considered to be 3.5 dB
- Noise figure for User Equipment was considered to be 8.0 dB

Interference margin M_I is calculated using:

$$M_{I[\mathrm{dB}]} = -10 \cdot \log(1 - \eta) \tag{A.8}$$

η being the system's load. System load ranges from 0 to 1 (asymptotic limit), but networks are usually planned with load ranging between 0.2 and 0.5 (adopted value).

When system's dynamic analysis is performed system load is evaluated using:

$$\eta = \left(1 + I_{inter\ n}\right) \cdot \sum_{m=1}^{N_u} L_{C\ m} \tag{A.9}$$

being:

- $I_{inter\ n}$: normalised inter-cell interference (ranging from 0 to 1). If DL is considered, its value is 0, if UL is being analysed, a value between 0.4 and 0.6 must be considered (0.55 was adopted, corresponding to a macro-cell with omnidirectional antennas [HoTo01]);
- $L_{C\ m}$: load factor for a specific connection and user *m*. Ranges from 0 to 1 and is calculated using (A.10) (UL) or (A.11) (DL);
- N_u : number of active users in the analysed cell.

Each specific connection has associated to it a load factor (meaning that it contributes for the total cell load). If UL is being analysed, it is calculated using (A.10), if DL is the one to analyse, then (A.11) must be considered.

$$L_{C\ m}^{UL} = \frac{1}{1 + \dfrac{R_c / R_{b\ m}}{\left(E_b / N_0\right)_m \cdot F_{a\ m}}} \tag{A.10}$$

where:

- R_c : is the chip rate, 3.84 Mcps;
- $R_{b\ m}$: is the transmission bit rate for the service of user *m* (in bps) (refer to Table A.2);
- $\left(E_b / N_0\right)_m$: is the signal to noise ratio for the service of user *m* (in linear units);
- $F_{a\ m}$: is the activity factor of user *m*, typically 0.5 for voice services, 1.0 otherwise.

$$L_{C\ m}^{DL} = F_{a\ m} \cdot \frac{\left(E_b / N_0\right)_m}{R_c / R_{b\ m}} \cdot \left[\left(1 - \alpha_m\right) + I_{inter\ n\ m}\right] \tag{A.11}$$

being:

- α_m : orthogonality of codes used by user *m*, typical values range between 0.5 and 0.9;
- $I_{inter\ n\ m}$: normalised inter-cell interference for user *m*, typical values range from 0.4 to 0.6.

Processing gain G_p of the system is calculated using:

$$G_{p[\mathrm{dB}]} = 10 \cdot \log(R_c / R_b) \tag{A.12}$$

where:

- R_b : is the bit rate associated to the analysed service (in bps)

Total propagation attenuation is calculated with the expressions presented so far. Once the total propagation attenuation is calculated, maximum path loss can be evaluated taking into consideration the necessary margins of the system, as well as the additional soft handover gain. Having calculated maximum path loss, maximum cell radius estimation can be done using an appropriate propagation model.

Total propagation attenuation relates with maximum path loss according with:

$$L_{p\,tot[\mathrm{dB}]} = M_{[\mathrm{dB}]} + L_{p[\mathrm{dB}]} \tag{A.13}$$

being:

- M : additional system margin according with (A.14)
- L_p : maximum path loss (in dB)

System margin M is calculated with:

$$M_{[\mathrm{dB}]} = M_{F\,SF[\mathrm{dB}]} + M_{F\,FF[\mathrm{dB}]} + L_{ind[\mathrm{dB}]} - G_{SH[\mathrm{dB}]} \tag{A.14}$$

where:

- M_{FSF}: slow fading margin. This factor depends on the environment under analysis, the position of the mobile (indoor or outdoor) and the target coverage probability. Table A.4 presents the adopted values for the current study, for the different representative cases and coverage probabilities of 90% and 95%.

Table A.4 – Slow Fading Margin values

Slow Fading Margin [dB]	Dense Urban		Urban		Suburban		Rural	
	95%	90%	95%	90%	95%	90%	95%	90%
Deep Indoor	10.2	6.5	10.5	6.8	–	–	–	–
Indoor	9.3	5.9	9.6	6.1	9.6	6.1	–	–
Indoor Window	9.3	5.9	–	–	8.8	5.5	5.8	5.8
Outdoor	–	–	–	–	–	–	4.7	4.7

- M_{FFF}: fast fading margin. This margin depends essentially on the user's mobility profile. Table A.5 presents the adopted values for the current study.

- L_{ind}: indoor penetration losses. Table A.6 presents typical values commonly used in cellular systems dimensioning. The considered value depends on the location of each specific mobile.
- G_{SH} : soft handover gain
  - o Typical values range between 2.0 and 3.0 dB (adopted value)

Table A.5 – Fast fading margin values

User's Mobility profile	Fast Fading Margin [dB]
Pedestrian (3km/h)	3.6
Vehicular (50km/h)	1.0
Vehicular (120km/h)	0.0

Table A.6 – Indoor penetration losses

Indoor Environment Type	Indoor Penetration Losses [dB]
Deep Indoor	25
Indoor	21
Indoor Window	11
In-car (+body loss)	8
Outdoor	0

In UMTS, the available power of the BS is shared among all connections. Part of the total BS's power is assigned to the common control channels, and the rest is available for the users' connections. Each connection draws part of the available power, and as a result of that, the maximum number of users that can be served by a BS is not a fixed value. In fact, the total number of users depends on the mix of services being served at a certain time in a cell. Expression (A.12) allows to calculate the total power necessary for a set of N_u users, each of them with a particular service:

$$P_{Tx[W]} = \frac{N_0 \cdot R_c \cdot \overline{L_p}}{1 - \overline{\eta_{DL}}} \cdot \sum_{m=1}^{N_u} \left(F_{a\,m} \frac{\left(E_b / N_0\right)_m}{R_c / R_{b\,m}} \right) \tag{A.12}$$

being:

- $\overline{\eta_{DL}}$: average downlink system load calculated applying A.9 to all N_u users and averaging it;

- $\overline{L_p}$: average path loss (in linear units) for the users in the cell. According with [HoTo01], average path loss is typically 6 dB lower than maximum path loss given by (A.12).

Annex B

COST231 – Walfisch-Ikegami Propagation Model

This annex presents the propagation model implemented in CRUS.

Several propagation models were so far developed for mobile communications environments. One of the most used models is the COST231 – Walfisch – Ikegami [DaCo99], which is described in the current annex.

Figure B.1 depicts a typical propagation scenario.

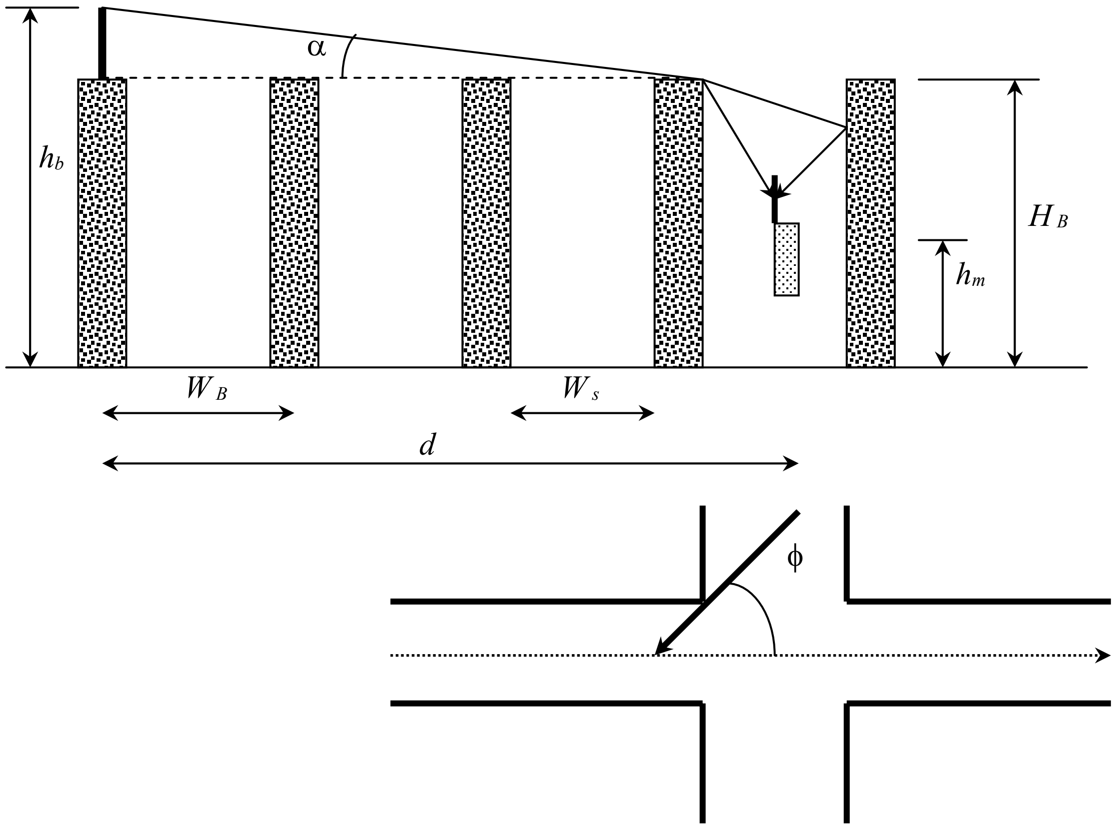


Figure B.1– Typical propagation scenario (extracted from [DaCo99]).

In this scenario, if propagation occurs along the street ($\phi = 0$) path loss can be computed using:

$$L_{p\,[\mathrm{dB}]} = 42.6 + 26 \cdot \log\left(d_{[\mathrm{km}]}\right) + 20 \cdot \log\left(f_{(\mathrm{MHz})}\right) \quad , \quad d > 0.02\mathrm{km} \tag{B.1}$$

being:

- d : distance between base station and the user equipment
- f : frequency

On the other hand, when propagation is not done along the street ($\phi \neq 0$) the following expression must be applied:

$$L_{p\,[\mathrm{dB}]} = \begin{cases} L_{0\,[\mathrm{dB}]} + L_{tt[\mathrm{dB}]} + L_{tm[\mathrm{dB}]} \quad , \quad L_{tt} + L_{tm} > 0 \\ L_{0\,[\mathrm{dB}]} \quad , \quad L_{tt} + L_{tm} \leq 0 \end{cases} \tag{B.2}$$

where L_0 is the free space path loss, given by:

$$L_{0\,[\mathrm{dB}]} = 32.44 + 20 \cdot \log\left(d_{[\mathrm{km}]}\right) + 20 \cdot \log\left(f_{(\mathrm{MHz})}\right) \tag{B.3}$$

and

$$L_{rt\,[\mathrm{dB}]} = -16.9 - 10 \cdot log\left(W_s\right) + 10 \cdot log\left(f_{(\mathrm{MHz})}\right) + 20 \cdot log\left(H_B - h_m\right) + L_{ori[\mathrm{dB}]} \tag{B.4}$$

where:

- W_s: streets width (in m)
- H_B: building height (in m)
- h_m: mobile receiver height (in m)

Orientation correction factor (L_{ori}) is calculated using:

$$L_{ori\,[\mathrm{dB}]} = \begin{cases} -10.0 + 0.354\,\phi_{[^o]} \quad , \quad 0^o \leq \phi < 35^o \\ 2.5 + 0.075\left(\phi_{[^o]} - 35\right) \quad , \quad 35^o \leq \phi < 55^o \\ 4.0 + 0.114\left(\phi_{[^o]} - 55\right) \quad , \quad 55^o \leq \phi \leq 90^o \end{cases} \tag{B.5}$$

where:

- ϕ : is the incidence angle (in degrees) in the horizontal plane according with Figure B.1.

Terminal to terminal correction factor (L_{tt}) and base station height gain (L_{bsh}) are given by:

$$L_{rr\,[\mathrm{dB}]} = L_{bsh[\mathrm{dB}]} + K_a + K_d \cdot log\left(d_{[\mathrm{km}]}\right) + K_f \cdot log\left(f_{(\mathrm{MHz})}\right) - 9 \cdot log\left(W_B\right) \tag{B.6}$$

being:

- W_B: distance between consecutive buildings (in m) according with Figure B.1.

$$L_{bsh\,[\mathrm{dB}]} = \begin{cases} -18 \cdot \log\left(h_b - H_B + 1\right) \quad , \quad h_b > H_B \\ 0 \quad , \quad h_b \leq H_B \end{cases} \tag{B1.7}$$

where:

- h_b: is the antenna's height (in m), relative to the ground

Path loss correction factor K_a is calculated using:

$$K_{a\,[\mathrm{dB}]} = \begin{cases} 54 & , \quad h_b > H_B \\ 54 - 0.8(h_b - H_B) & , \quad h_b \le H_B \wedge d \ge 0.5\,\mathrm{km} \\ 54 - 1.6(h_b - H_B) \cdot d_{[\mathrm{Km}]} & , \quad h_b \le H_B \wedge d < 0.5\,\mathrm{km} \end{cases} \tag{B.8}$$

Distance correction factor K_d is given by:

$$K_{d\,[\mathrm{dB}]} = \begin{cases} 18 & , \quad h_b > H_B \\ 18 - 15 \cdot \dfrac{h_b - H_B}{H_B} & , \quad h_b \le H_B \end{cases} \tag{B.9}$$

Frequency correction factor K_f is given by:

$$K_{f\,[\mathrm{dB}]} = \begin{cases} -4 + 0.7 \cdot \left(\dfrac{f_{[\mathrm{MHz}]}}{925} - 1 \right) & , \quad \textit{average size cities and suburban areas} \\ -4 + 1.5 \cdot \left(\dfrac{f_{[\mathrm{MHz}]}}{925} - 1 \right) & , \quad \textit{urban areas} \end{cases} \tag{B.10}$$

The validity ranges are:

- $h_b \in [4 , 50]$ m
- $d \in [0.002 , 5]$ km
- $h_m \in [1 , 3]$ m
- $f \in [800 , 2000]$ MHz

Regarding frequency validity range, this model does not cover the downlink band used by UMTS FDD mode, i.e. [2110 , 2170] MHz. However the results achieved with the model are expected to be somehow accurate with the measured results because the band under study is at maximum 170 MHz out of the validation limit and the propagation attenuation is this part of the spectrum does not suffer high variations.

In the absence of concrete data the following values are recommended:

- $W_B \in [20 , 50]$ m
- $W_s = W_B/2$
- $\phi = 90^o$
- $H_B = 3 \cdot (\text{Number of floors}) + H_{roof}$

where H_{roof} is the roof correction factor, given by:

- $$H_{roof} = \begin{cases} 3\ ,\ \text{tilted roof} \\ 0\ ,\ \text{plain roof} \end{cases}$$

Annex C

SIMOTS and CRUS' Fluxograms

This annex presents fluxograms indicating SIMOTS and CRUS general functioning. A detailed fluxogram indicates the new coordinates generation process implemented in SIMOTS.

Figure C.1 presents the general fluxogram of SIMOTS.

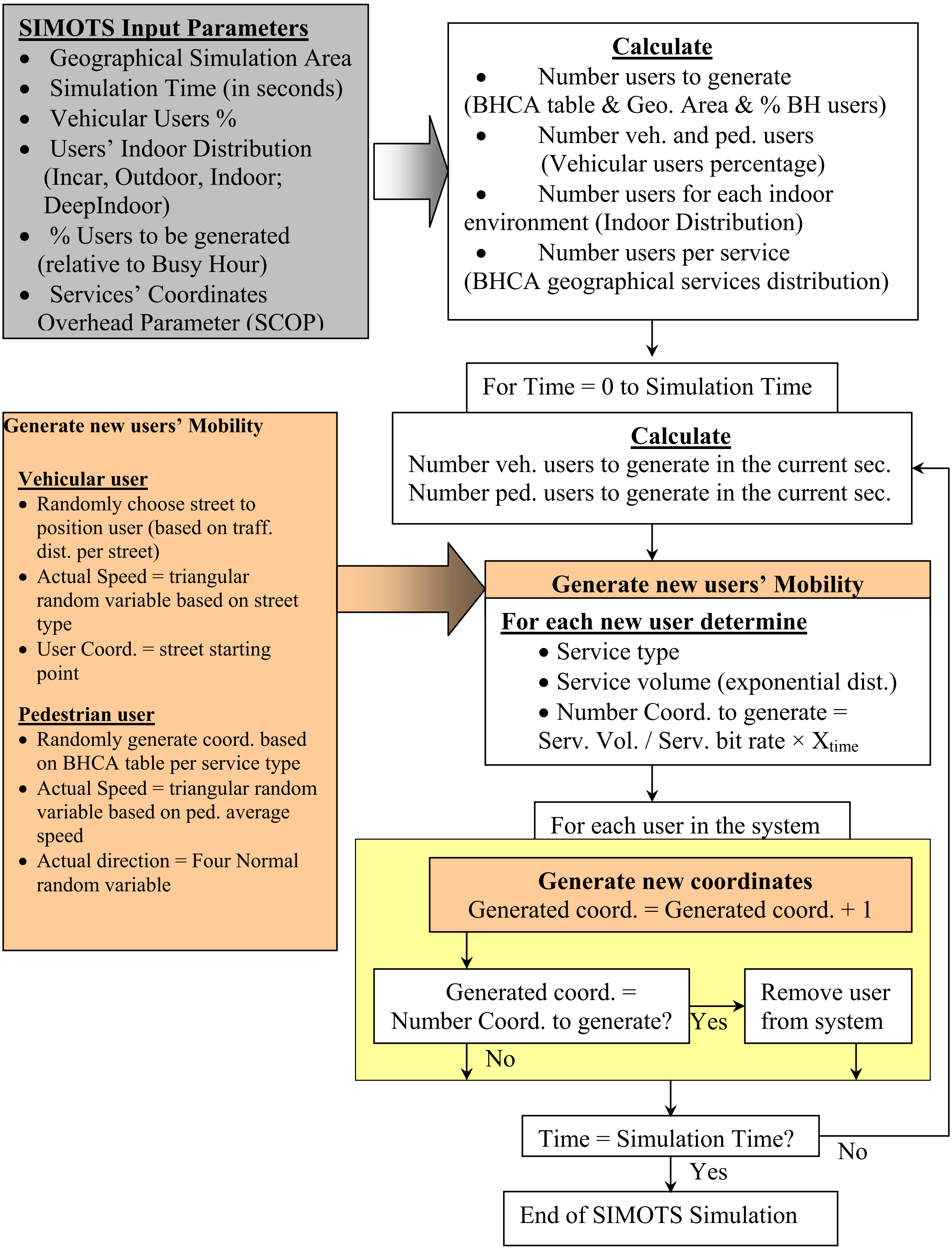


Figure C.1 – SIMOTS general fluxogram.

In Figure C.2, the process of generating new coordinates inside SIMOTS is described by a fluxogram.

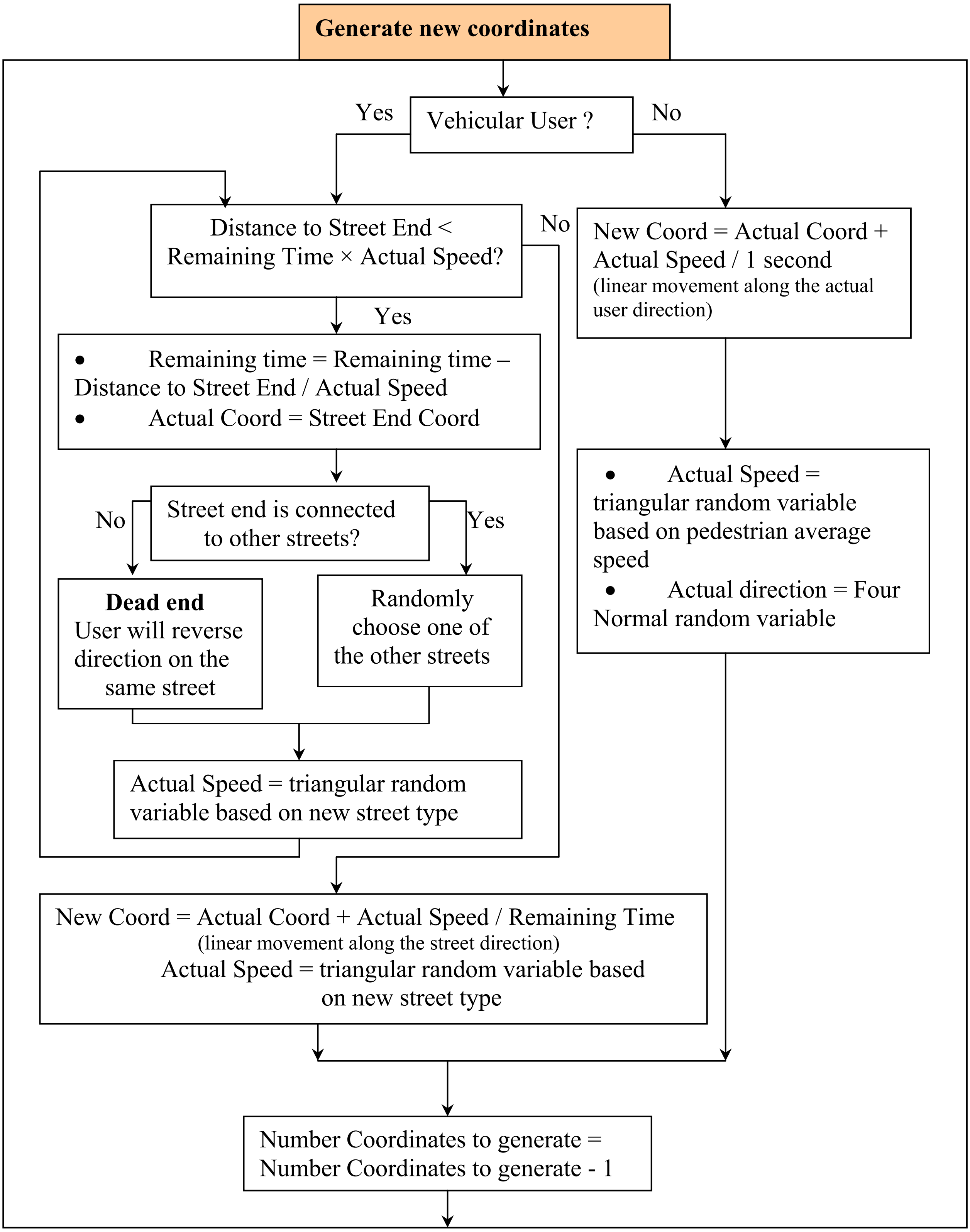


Figure C.2 – SIMOTS new coordinates generation fluxogram.

The fluxogram in Figure C.3 illustrates the algorithm implemented in CRUS.

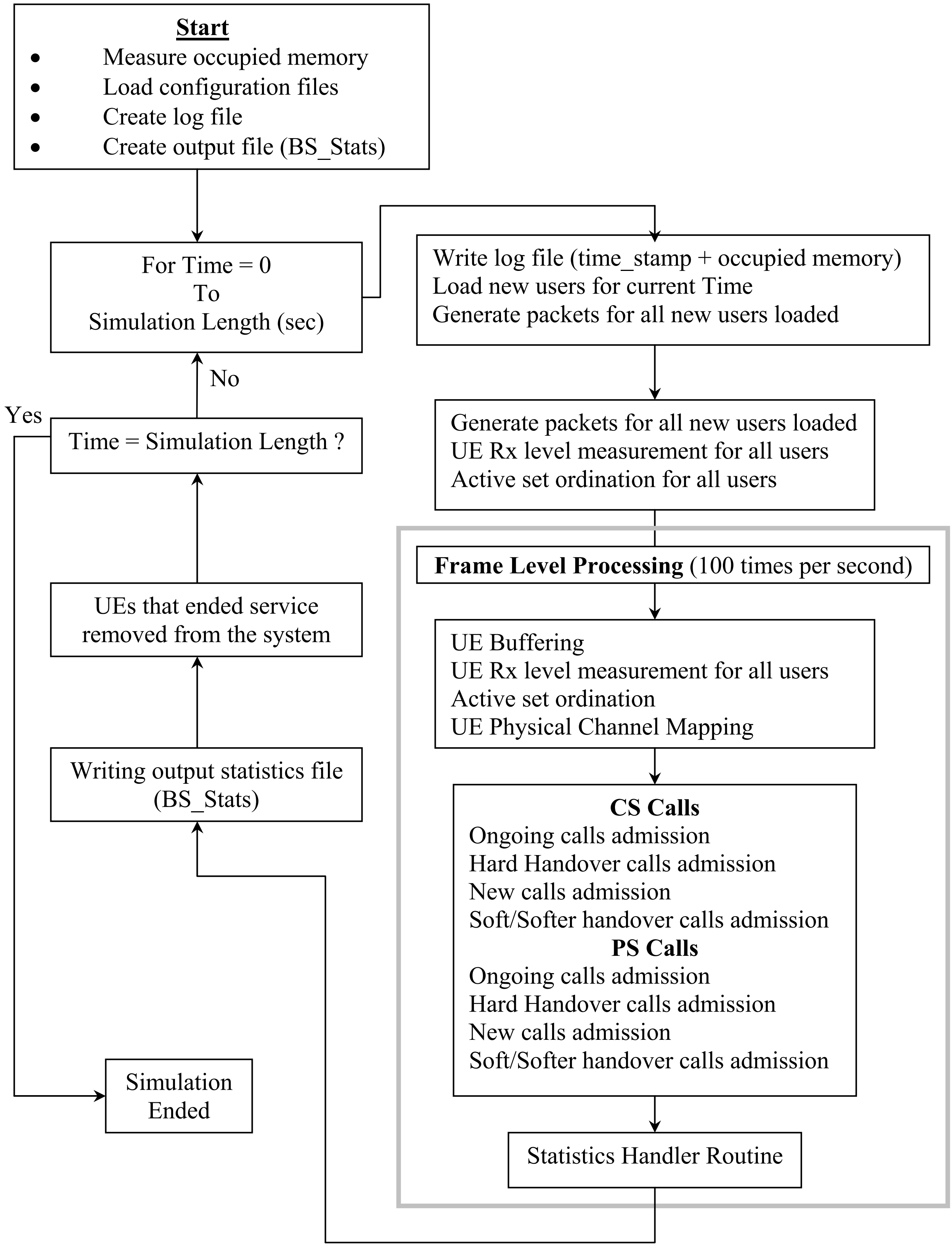


Figure C.3 – CRUS general fluxogram.

Annex D

SIMOTS' Detailed Input Data

This annex presents all the detailed data needed for the adequate functioning of SIMOTS and complete simulation process.

SIMOTS' role is generating mobility information for each user in the system and providing that information through configuration files that are necessary for CRUS adequate functioning. Hence, SIMOTS' input data can be divided in two sets:

- **Data to control CRUS' behaviour**
- **Data to control SIMOTS' behaviour**

The first set of data (Data for CRUS' behaviour) is only read by SIMOTS and directly outputted into CRUS' configuration files. It is not used to conditioning SIMOTS' behaviour.

The set of data to control CRUS' behaviour is constituted by:

- **COST 231-Walfisch Ikegami propagation model parameters**

  This is the propagation model implemented in CRUS. Table "COST231_Walfisch_Ikegami_Param.tab" is defined in SIMOTS and contains the model's parameters. The parameters defined in this table are:

  - distance range for model validity [km];
  - distance between consecutive buildings – *WB* [m];
  - streets width –*Ws* [m];
  - building height – *HB* [m];
  - mobile's antenna height – *hm* [m];
  - horizontal plane incidence angle - ϕ [º];
  - antenna's height relative to ground – *hb* [m].

  Each one of these parameters is defined for "Dense Urban", "Urban" and "Suburban" environments. Based on the environment defined for the study area CRUS will pick the adequate set of parameters to configure the propagation model in accordance.

- **Bearers' sensitivities**

  Eb/N_0 values are provided to the simulator through table "Bearers_Sensitivities.tab" for each bearer (PS64, PS128, PS384, CS64 or Speech 12.2). For uplink and downlink, values are defined in this table in [dB]. These sensitivities are defined for three different speeds (3km/h, 50km/h and 120km/h). In each particular instant CRUS will determine the E_b/N_0 to be used performing a linear regression based on these values and the user' speed in that instant.

- **System engineering margins**

  Table "System_Margins.tab" holds the information regarding the several system margins that are considered in the link budget. The system margins are:

  - Body Loss for Speech [dB];

- Body Loss for Data Services[dB];
- Slow Fading Margin [dB];
- Fast Fading Margin [dB] in function of the user's speed (3km/h, 50km/h and 120km/h);
- Indoor Penetration Loss [dB] for Deep Indoor, Indoor and Incar scenarios;
- Downlink Maximum Transmitting Power [dB_{CPICH}] for each radio bearer (AMR for Speech, CS64, PS64, PS128 and PS384);
- Soft handover statistical gain [dB];
- Downlink target Load (ranging in the interval [0, 1]);
- Uplink target Load (ranging in the interval [0, 1];
- Downlink orthogonality factor (parameter α_m considered in the link budget);
- Downlink normalised inter cell interference factor (parameter $I_{inter\,n\,m}$ considered in the link budget).

- **Antenna Database**

  Tables "Antennas_List.tab" and "Antennas_Gain.tab" hold for each available antenna, all the necessary information to characterise its' radiation pattern. The formats used are fully compliant with the information types provided by most UMTS antennas' suppliers allowing using commercially available antennas' information in the simulations. The fields defined in "Antennas_List.tab" are:
  - Antenna_Ref – holds antenna's name;
  - Frequency [MHz] - the frequency at which the radiation pattern information relates to;
  - Max_Gain [dBi] - Antenna's gain the maximum beam direction;
  - Antenna_Desc - a description field for simulator users' usage.

  The fields defined in "Antennas_Gain.tab" are:
  - Antenna_Ref - holds antenna's name also defined in "Antennas_List.tab";
  - Angle [º] - integer value in the range [0, 359];
  - Hor_Aten [dB] – antenna's attenuation relative to radiation pattern's maximum gain measured in the azimuth plane;
  - Ver_Aten [dB] – antenna's attenuation relative to radiation pattern's maximum gain measured in the elevation plane.

- **Site Database**

  A site is a geographical location that can hold one or several base stations. An UMTS cell is the geographical area served by one base station. Table "Site_List.tab" holds the information that allows characterise a site. Available fields are:
  - Site_ID – alphanumeric field holding a label that univocally defines each site;
  - SiteName – alphanumeric field holding a label that univocally defines each site providing some description of it;
  - Location – text field used by simulator's user to describe the location of the site;
  - X [m] – longitude of the site;
  - Y [m] – latitude of the site;
  - Z [m] – altitude of the site (the coordinates are set in UTM ED50 coordinates system);
  - Site_Desc – alphanumeric field holding a description of the site;
  - Occupied – text field holding "T" if the site is assigned with at least one base station or "F" if none base station is assigned to the site.
- **Base Station Database**

  An UMTS cell is the geographical area served by one base station. Base Stations are defined in table "BS_List.tab". The following fields are available:
  - BStID - alphanumeric field holding the code that univocally identifies each base station;
  - BStName - text field holding the name of each base station;
  - SiteID - alphanumeric field holding the code of the site to which the base station is connected;
  - BS_Desc - text field with description of the base station;
  - dX, dY, dZ [m] – distance offsets applied to the coordinates of the site to calculate the coordinates of the antenna;
  - AntennaRef – text field identifying the antenna used in the base station. The antenna here defined must be correctly defined in Antennas_list.tab and Antennas_Gain.tab tables;
  - Orient [º] – integer value defining the orientation of the antenna. Clockwise direction considered;
  - Tilt [º] – integer value defining the tilt of the antenna. Positive value means that the antenna is pointed above the horizon;

- maxTxPowerDl [dBm] – Total power available on the base station. This power must be shared amongst user traffic and common control channels;
- CmCtrChPwr [0; 1] – real value, defining the amount of power from TXPowerTot that is continuously reserved for Common Control Channels in the cell;
- BSNoiseFig [dB] – Base Station's noise figure;
- RadioCh1 [MHz] – Uplink carrier frequency. Is used in CRUS for propagation loss calculations;
- primaryCpichPower [dBm] – Power allocated for CPICH;
- maxActiveSet – integer value defining the maximum number of cells allowed to be in the active set of a mobile being served by the current base station;
- reportingRange1a [dB] – value defining the maximum difference that must be measured between the serving cell and a neighbouring one to add the neighbouring cell in the active set;
- Statistics_Status – integer value that defines if the statistics for the current base station shall be (1) or shall not be (0) exported by CRUS. In the limit, if all the base stations have this parameter set to 0 the output statistics file will only carry the header and no statistical information.

SIMOTS functioning is controlled by another set of data:

- **Geographical Area Definition**

Table "Traffic_Areas.tab" holds a polygon defined by SIMOTS' user that defines the study area. All the users that are created along the simulation process are generated inside this polygon. The fields available in this table are:

- Area_Identifier – text field used to univocally identify each defined area. Several areas can be defined but the area where users will be generated must be identified as "Drop Zone";
- Comments – text field to be filled with comments;
- AreaKm2 [km2] – real value field. SIMOTS calculates the study area's area in km2 and fills this field with that value;
- MobUserGen – real value in the range [0;1], defines the percentage of users to generate that will be vehicular ones;
- Morphology – text field to identify the type of environment of the study area. Legal values are "Dense Urban", "Urban" and "Suburban". COST 231 Walfisch Ikegami parameters that will be used in CRUS are chosen according with this field definition;

- BH_Traffic_Percentage – real value in the range]0; 10], defines the multiplying factor to be applied to the values stored in the BHCA table. This parameter allows controlling the number of users that will be generated along the simulation.

- **Streets Database**

  The streets existing in the study area are defined in table "Street_Table.tab". Each street is defined by a polyline. A polyline is a term used by MapInfo® to define a geographical object that can be defined by a set of straight lines where the following rules apply:

  - The beginning of one straight line is connected to the end of another;
  - Each straight line is connected, at maximum, with two other straight lines, one at the beginning and another at the end;
  - The set of lines does not constitute a closed area.

  Each polyline is defined by the following fields:

  - Line_ID – integer value, univocally identifying each street;
  - Next_St_Start_ID, Next_St_End_ID – integer value identifying the streets connected to the beginning and end of the current street. If multiple streets are connected, constituting a crossroad, a value in a specific range indicates the crossroad ID, stored in table "Cross_Roads_Table.tab", that holds the Line_ID's of the streets forming it;
  - Tipo – text field where the street type is identified. According with the street type associated to the street the respective average speed values will be applied by SIMOTS when generating vehicular users' coordinates. Available street types are defined in "Streets_Types.tab" table.

- **Streets Characterisation**

  Table "Streets_Types.tab" holds the information that characterises each street type. Defined fields are:

  - Street_Type – text field defining each street type;
  - Street_Width [m] – defines the street width. Information used by SIMOTS to graphically represent the street;
  - Avg_Speed_ms [ms-1] – average speed for each street type;
  - Delta_Speed_ms [ms-1] – variation speed parameter, defined in the triangular distribution.

- **Busy Hour Call Attempt (BHCA) table**

When working with simulation scenarios that have as inputs traffic distributions and users' geographical densities, as is the current study, there is an incontestable added value if reality related figures are used instead of simple common sense target values are chosen.

That is the case of traffic distribution in Lisbon. IST-MOMENTUM project [MOME04] has been dealing, among other things, with simulation scenarios characterisation in some European cities, and Lisbon and Porto have been two of those envisaged cities. One of the deliverables of IST-MOMENTUM [FCXV03] is a traffic matrix named BHCA – Busy Hour Call Attempt describing on a $20\times20\text{m}^2$ square the traffic density at busy hour (i.e. the number of users that use a certain service inside that $20\times20\text{m}^2$ square during the system busy hour) both in Lisbon and Porto.

Lisbon BHCA was calculated in the scope of that project weighting over the city area the information of resident population, age distribution and geo-economic information (related with the identification of the areas where offices are established as well as residential areas). Crossing these data with the appetence of services usage by people within specific age range the outcome was a grid that differentiates on a pixel per pixel[8] basis the number of users that use a certain service during the busy hour.

It is out of the scope of the current report to go deeper in detail the methodology used for BHCA table's generation however the reader is encouraged to clarify any implementation details in [FCXV03].

- **Indoor/Outdoor users' distribution**

  Table "SIMOTS_Indoor_Distrib.tab" holds the information regarding the distribution of users amongst the several indoor scenarios (Outdoor, Indoor, Deep Indoor or Incar). The fields available on this table are:

  - Area_Identifier – text field identifying each of the areas defined in the table "Traffic_Areas.tab";
  - Indoor_Situation – text field. Valid values are "Deep_Indoor", "Indoor", "Incar", "Outdoor" and "Incar";
  - Percentage – real value in the range [0;1] that is applied to calculate the number of users that will be classified in each indoor scenario;
  - Pen_Losses [dB] – indoor attenuation factor for each indoor scenario.

[8] A pixel is here considered to be a square with $20\times20\ \text{m}^2$

- **Simulation Time**

  Simulation time is hardcoded and equals 4200 seconds. This parameter is very easily changed but demands modifying the source code. The simulation time was set to be 4200 seconds (70 minutes) to allow discarding the first 10 minutes that usually have non-stable behaviour of the network. As the network starts with no users, the first minutes of simulation are used to bring the network to a stable regime.

- **Services' characterisation**

  Services are characterised in table "SIMOTS_Services_List.tab". The available fields are:

  - Service_Name – text field used to identify the service in question;
  - Avg_Duration_s – integer value defining the average duration of speech service (the only circuit switched service that is measured in seconds);
  - DL_Vol_kB [kB]– integer value defining the average downlink volume per each data service (either circuit switched or packet switched);
  - XTime – real value in the range [0; 4] defining the amount of extra coordinates that must be generated for a particular service. As illustrated in Figure IV.1 the mobility data (coordinates for a certain amount of time) is generated previously to the system's level analysis. SIMOTS generates one new coordinate for each new second of simulation. The number of coordinates to be generated for speech users is equal to the number of seconds the service lasts. For data services the number of coordinates to be generated is calculated based on the amount of data to be transferred and the base bit rate for that particular service. For simulations that imply a heavier loaded network some packet switched users may be delayed and some of them may be out of coordinates, meaning that the number of coordinates generated by SIMOTS are not enough. To solve this problem CRUS outputs for each of the packet switched services the number of users that ran out of coordinates in each simulation. For a specific users' density scenario this information is analysed and considered to set Extra Time Overhead parameter (identified in the following as X_{Time}) to an adequate value that allows for each service a very small number of users with lack of coordinates.
  - Bit_Rate [kbps] – integer value defining the bit rate on which a certain service is mapped9.

[9] Note: As speech is mapped on a 12.2kbps RAB, this parameter assumes the value 12 for speech.

Annex E

Simulators Interfacing Detailed Data

In this annex, the files used as interface between the two simulation platforms (SIMOTS and CRUS) are presented in detail. Units and range of values accepted for each variable are indicated in an extensive way.

The output of one SIMOTS' simulation is a complete set of files, with a very specific name structure, inside a directory created by SIMOTS. These files are at the same time the input data CRUS will use to run the system level simulation. Figure IV.1 illustrates the articulation between both simulators.

When SIMOTS starts one simulation the system time is fetched (date, hour, minutes and seconds). This information is taken to name all the files that will be generated for the simulation. If, for instance, the simulation starts on the 24th of May of 2004 at 23:21:19 SIMOTS generates an output directory called 20040524_23h21m19s and the name of all files generated for that simulation will start by 20040524_23h21m19s. Following, a list and description of the files generated by SIMOTS is presented. In Annex H an example of each one of these files is presented. Table E.1 identifies the files' name and contents generated by SIMOTS.

Table E.1 – SIMOTS' Output Data Files Description.

File Name	File Contents Description
Simulation.log	Log file of SIMOTS simulation. Contains time execution information and internal data structure occupation information.
Antennas_List.cfg	Radiation patterns (Vertical and Horizontal) for each antenna used in the simulation.
Site_List.cfg	List of all the sites used in the simulation.
BS_List.cfg	List of all the base stations used in the simulation and their respective parameters
CRUS_Settings.cfg	List of parameters that control the behaviour of the simulator
CRUS_UMTS_Param.cfg	List of all engineering parameters (margins, gains, sensitivities' values, etc.) used in the simulation
UE_List.cfg	List of all the UEs generated for a single simulation.
UE_Coord.cfg	For each simulated second this file contains the coordinates speed and indoor condition for the UEs that are active at that particular instant.

- **Simulation.log file description**

  This is a log file describing in real time all the actions SIMOTS is performing. It is used mainly for assessing the simulator's performance and for debugging purposes.

  Each line in this file starts with a timestamp (hour:minute:second) after which the current action being taken by the simulator is described. Annex H has an example of this file.

  Although this is an output file from SIMOTS it is not being used by CRUS.

  Each line in this file is self explaining.

- **Antennas_List.cfg file description**

  This file is generated by SIMOTS and is used by CRUS as a configuration file.

  The header of the file identifies the software name and version that generated it (SIMOTS V1.0 in the example provided in Annex H).

  This file contains the radiation patterns (both vertical and horizontal) for each antenna that might be used in the current simulation. The values outputted in this file are the ones provided to SIMOTS in table "Antenna.tab" (which was completely described in Annex D bullet "Antenna Database").

  In this file, each antenna is identified in a single line containing its reference (field "Antenna_Ref"), the frequency at which the radiation pattern was measured (field "Frequency"), its maximum gain (field "Max_Gain"), the electrical tilt (field "Elect_Tilt") which is non-zero for antennas with electrical tilt implemented, a short description field ("Antenna_Desc") that allows the introduction of short notes that may help the applications' users, the horizontal radiation pattern beamwidth (field "Hor_Beam_W") and the vertical radiation beamwidth (field "Ver_Beam_W").

  After this antenna description's block the radiation patterns (in vertical and horizontal planes) are "described" in the next 360 lines. Each line starts with the antenna name (as the same file will generally hold more than one antenna) after which an angle value (ranging from 0 to 359) is indicated. The next two values will indicate the attenuation of the antenna's radiation pattern for that angle in the horizontal plane and in the vertical plane. In this way the full horizontal and vertical radiation patterns (720 values) are presented in only 360 lines of the file.

- **Site_List.cfg file description**

  This file is generated by SIMOTS and is used by CRUS as a configuration file.

  The header of the file identifies the software name and version that generated it (SIMOTS V1.0 in the example provided in Annex H).

  This file contains the information of each site of the network. As a remainder, in the context of the current work, a site is a physical place where the equipment for one or more network cells can be installed. This means that the same site can be either used for a single cell (if omnidirectional cells are used) two three or eventually six cells (if sectorial antennas are used).

  The information exported in this file is the same that is provided to SIMOTS in table "Site_List.tab". The fields exported are: SiteID, SiteName, LocationX, LocationY, LocationZ, Site_Desc and Occupied. All these fields were already fully described in Annex D, bullet "Site Database".

- **BS_List.cfg file description**

This file is generated by SIMOTS and is used by CRUS as a configuration file.

The header of the file identifies the software name and version that generated it (SIMOTS V1.0 in the example provided in Annex H).

This file contains the information of each base station of the network. Each line of the file describes one base station. The parameters that describe each base station are the same that were defined in the table "BS_List.tab" described in AnnexD, bullet "Base Station Database"

- **CRUS_Settings.cfg file description**

This file is generated by SIMOTS and is used by CRUS as a configuration file.

The header of the file identifies the software name and version that generated it (SIMOTS V1.0 in the example provided in Annex H).

The parameters that are exported in this file are used by CRUS for its internal control. The parameters exported in this file are:

MobiAnalys [Active; Inactive] – Configures CRUS to use (if "Active") or not use (if "Inactive") users' mobility information. If users' mobility information is not used each user will be considered to be fixed in a particular coordinate (as if a snapshot has been taken to the network in a particular instant).

Prop_Model [COST231WALFISCH] – Although this is the only configuration supported in the current version of CRUS (V1.2) the main idea is allowing the implementation of other propagation models in further versions of the tool. This parameter identifies to CRUS the propagation model that shall be considered when performing propagation calculations.

SimTimeLen – Indicates to CRUS the number of seconds the simulation will last. This is used in CRUS to configure the main loop temporal cycle used in the simulation process.

DebugLev01, DebugLev02, DebugLev03, DebugLev04 [True; False] – Logical "switches" used by CRUS to filter the debug messages that will be outputted to the simulation log file. It was very useful in the development and debugging stages of the code.

PerSave [integer value] – Indicates to CRUS the periodicity (in seconds) that shall be used when saving the output results to output statistics files.

MobTimStep [integer value] – Indicates to CRUS the periodicity (in seconds) that it shall use when loading new coordinates for each user.

- **CRUS_UMTS_Param.cfg file description**

This file is generated by SIMOTS and is used by CRUS as a configuration file.

The header of the file identifies the software name and version that generated it (SIMOTS V1.0 in the example provided in Annex H).

This file contains all the engineering parameters used by CRUS. In this file, as in all the configuration files generated by SIMOTS, all files starting by a $ will be ignored by CRUS when loading the parameters in the simulation process. These lines can and were used to introduce in the configuration files some notes regarding the parameters. These notes include some short descriptions or the indication of the allowable range for each variable. Hence, in Annex H, bullet CRUS_UMTS_Param.cfg the majority of the fields are either self explained or described by in these commenting lines.

In this file several parameters' blocks can be identified. The first information block holds the information regarding system's bearers' sensitivities. Each line has the sensitivity of one bearer, for UL or DL, at a certain speed (as the bearers' sensitivities vary on the speed). The format of each field is XXXX_YYYY_ZZZZ where:

- XXXX – can be either "UL" or "DL" depending if the sensitivity is being defined for uplink or downlink;
- YYYY – can take be any of "Speech_12_2", "CS_64", "CS_128", "CS_384", or "PS_64", "PS_128" or "PS_384";
- ZZZZ – can be either "PedA_3kmh", "VehA_50kmh" or "VehA_120kmh"

The combination of all these different formats leads to a total of 42 fields that allow defining the sensitivity of all bearers in for 3km/h, 50km/h and 120km/h. Some combinations correspond to bearers that are not available in the systems currently commercialized (such as circuit switched services mapped on 128 kbps). For these cases, none of the generated users had any service mapped on such bearers.

This block of information olds, then information that CRUS loads and uses to calculate (based in a linear regression) the bearers' sensitivities to speeds different from the three values provided in this file. As an example, if a certain user has in a particular instant a speed of 67km/h, CRUS will calculate the bearer sensitivity for that user (both in UL and DL) based on the user's UL and DL bearer sensitivities that were defined for 50km/h and 120km/h assuming a linear progression between these two points.

Next parameter's block holds the body attenuation for voice (Body_Loss_Voice) and data (Body_Loss_Data) services, slow fading margins as a function of the environment type (dense urban, urban, suburban and rural) and the indoor scenario (deep indoor, indoor, indoor window or outdoor).Slow fading margins result in a set of sixteen different values that will be attributed by CRUS in accordance with the environment each user position is defined with.

A new block of parameters defines the fast fading margin to be used by CRUS as a function of the users' speed. FFading_PedA_3kmh, FFading_VehA_50kmh and FFading_VehA_120kmh define the fast fading "profile" as a function of the users' speed. Also in this case, for a particular connection, in a particular instant, CRUS will use these values to estimate (assuming a linear behaviour) the margin to introduce in the link budget of a user based on it's current speed.

Next block of parameters indicate CRUS which values must be accounted for indoor penetration losses for deep indoor (Ind_Loss_DI), indoor (Ind_Loss_I), indoor window (Ind_Loss_IW) and incar (Ind_Loss_IC) environments.

Maximum allowable downlink transmitting power is defined per each radio access bearer by the following parameters:

- dlMaxPower_SRB – applied to signalling links (not used in current CRUS version);
- dlMaxPower_AMR – applied to speech service;
- dlMaxPower_CS57_6 – applied to services mapped in CS at 57.6 kbps (not used in the current study, as it would be applied to Facsimile service);
- dlMaxPower_CS64 – applied to services mapped in CS 64 kbps;
- dlMaxPower_PS64 – applied to services mapped in PS 64 kbps;
- dlMaxPower_PS128 – applied to services mapped in PS 128 kbps;
- dlMaxPower_PS384 – applied to services mapped in PS 384 kbps;
- dlMaxPower_MultiRAB – applied to multi RAB connections (not used in current CRUS version as each user has only one active session at a time).

The next block of parameters consists on the following ones:

SHOC_Gain – soft handover gain. Introduced by CRUS in the link budget;

DL_Target_Load – downlink target load, ranging from 0 to 1 (included). This value for the load is never exceeded by none station in the network. Whenever a connection in a particular frame would increase this target load the system takes appropriate actions to prevent it – either delaying the session (for packet switched services) or dropping the connection (for circuit switched services);

UL_Target_Load – uplink target load, ranging from 0 to 1 (included). This value for the load is never exceeded by none station in the network. The system behaves is a similar way as with DL_Target_Load either delaying or dropping connections in order to guarantee that this target is never exceeded.

Alpha – orthogonality of codes used by different users. Parameter defined in expression A.11

Iinter – normalised inter-cell interference. Parameter defined in expression A.11.

- **UE_List.cfg file description**

This file is generated by SIMOTS and is used by CRUS as a configuration file.

The header of the file identifies the software name and version that generated it (SIMOTS V1.0 in the example provided in Annex H).

This file contains all the list of all users that must be taken into account by CRUS for the complete simulation. Each user is generated randomly by SIMOTS and after that is exported in this file. The parameters that characterize each user are:

UEID – a sequential integer number that univocally identifies each user in each simulation;

Xm, Ym and Zm – values that identify the coordinate where the user was generated;

UE_Type – this field can assume either the value “Vehicular A50” or “Pedestrian A3” depending if the user is a vehicular one or a pedestrian one (respectively);

EnvType – this field assumes integer values ranging between 1 and 5. Each one of these values identifies an environment type corresponding to the particular coordinates where the user is located (in this particular case, the place where it was generated). The correspondence between the valid values and the environment types are:

1. Dense Urban
2. Urban
3. Suburban
4. Rural
5. Axial

When CRUS calculates the propagation loss for a particular user the model settings chosen by it will be in accordance with the value present in this field.

IndOut – this field assumes integer values ranging between 1 and 5. Each one of these values identifies an indoor typology corresponding to the particular coordinates where the user is located (in this particular case, the place where it was generated). The correspondence between the valid values and the indoor typologies are:

1. Deep Indoor
2. Indoor
3. Indoor Window
4. Outdoor
5. Incar

Based on this field CRUS will account for with the indoor penetration margin corresponding to the particular indoor typology of the user.

UE_Speed – this field holds the value of the speed (in km/h) for the user in the instant it was generated. This is a random value generated by SIMOTS based in specific mobility models.

UEAntGain – this field indicates to CRUS which value must be considered for the terminal antenna's gain. This gain is expressed in dBi and it is differentiated for speech and data services.

TXPwrMax – this field indicates (in dBm) which is the maximum uplink allowable transmitting power for this particular user.

UENoiseFig – this field indicates (in dB) the noise figure of the user's receiver.

Born_Time – this field is an integer value indicating in which second of the simulation the user was generated.

ServName1 – this is the field that indicates to CRUS which service the user is operating in the network. Allowable values are "Speech" (identifying speech calls), "Video" (identifying video telephony service), "StreamingMM" (identifying Streaming Multimedia), "LBS" (for Location Based Services), "MMS" (for Multimedia Messaging Service), "SMS" (identifying Short Message Service), "e-mail" (for electronic mail) and "FTP" (for File Transfer Protocol). The "1" in the suffix of the field name was introduced because one of the intended future upgrades of the simulator is allowing multiservice users, meaning that the same user can perform, for instance, an FTP session at the same time as a speech call. In this way a second field named "ServName2" would identify the second simultaneous service for the same user. This upgrade has not yet been implemented but the names of the fields containing the information (service name, session volume, bit rate, downgrade and start time, the later four will be described in the following) were already created taking that into account.

VolumeS1 – this field holds an integer value that is expressed in seconds when the service associated to the user is “Speech” or kB if the service is a data service.

BitRateS1 – this field indicates to CRUS in which radio access bearer (RAB) the service allocated to the user shall be mapped on. Allowable values are 12 (for speech service that is mapped in 12.2 kbps RAB), 64 (for 64 kbps), 128 (for 128 kbps) and 384 (for 384 kbps).

DowngrdS1 – this field holds an integer value ranging from 0 to 10. This field will give CRUS an index that can be used in a congestion control algorithm to decide which users shall be downgraded at first place. This is another “open door” to an upgrade in CRUS that will allow in future versions of the software (as it is not yet implemented) to study the impact of defining user classes and controlling the network behaviour based on the users’ profile. Although the present version of the simulator does not, yet, process this type of information it was decided to create from the start the structure handling it as it would be easier than developing it in a latter stage.

StrTimeS1 – following the idea that a user will be able to run more than one service at the same time this field indicates to CRUS the time delay (in seconds) that must be introduced to the instant of creation of the user before service 1 starts. If the user has two or more services each one of them can start at a different instant from the other, forcing the system to reconfigure the transport channels mapping reserved for the user. This will be implemented, however, in a latter version of CRUS and was not taken into account in the current study which intended to assess the impact of users’ mobility in the network’s capacity.

As a final remark to UE_List.cfg file format it shall be referred the existence of a commented line (commented lines in the configuration files start with a $ character) after the header with the variables’ name that indicates to the simulators’ user which are the units being used by each of the variables. This line can be easily identified in Annex D, bullet “UE_List.cfg”.

- **UE_Coord.cfg file description**

  This file is generated by SIMOTS and is used by CRUS as a configuration file.

  The header of the file identifies the software name and version that generated it (SIMOTS V1.0 in the example provided in Annex H).

This file has the information regarding the coordinates of each user along all the simulation duration. During the generation process, for each new second of simulation SIMOTS writes in this file the information regarding position and speed of each active user in the network. The fields defined in this file are:

System Time – an integer identifying the simulation's second to which the position information relates to;

UEID – an integer that univocally identifies the user to which the information relates to;

Xm, Ym, Zm – real values that identify the geographical position of the user;

IndOut – this field holds the information regarding the indoor situation of the user for each particular second of the simulation. It has the same range and meaning as field IndOut in file UE_List.cfg. This field allows the simulation process to change user's indoor environment along the simulation time, i.e. a user can start a service outside a building (IndOut = 4) and after a few seconds enter into a building (to an Indoor environment IndOut = 2) and after a few more seconds passing into a deep indoor environment inside the same building (IndOut = 1). CRUS will then take all these different indoor position into account and for each one of them apply the proper indoor attenuation margin.

UE_Speed – this field holds (in a real value) the actual speed of the mobile. SIMOTS generates the user speed according with the user's type (either pedestrian or vehicular). For vehicular users the speed is generated according with the type of the street where it is positioned in each particular instant. In Figure C.2 the generation of users' positionand speed is illustrated.

EnvType. – this field indicates to CRUS the environment type on which the user is in every instant of the simulation. The range allowed to this field and their mapping to each environment type is the same as for the field "EnvType" in file UE_List.cfg. When SIMOTS generates one user it verifies in each simulation instant in which environment type the user is located and outputs that information in this field. This allows studying the variability of the network's behaviour when the same user changes, while the session lasts, the environment type.

The complete set of configuration files described in this Annex can be divided into the three distinct groups. "Antennas_List.cfg", "BS_List.cfg" and "Site_List.cfg" constitute the network configuration set of files. "CRUS_Settings.cfg" and "CRUS_UMTS_Param.cfg", by other hand, consist on the system level configuration files. "UE_List.cfg" and

“UE_Coord.cfg” are the files with the users’ characterisation information. Different simulation scenarios running in the same geographical area and with the same network configuration settings will in practice only need different “UE_List.cfg” and “UE_Coord.cfg” files as the network configuration is kept unchanged.

Annex F

CRUS' Detailed Output Data

This annex presents in detail CRUS output data, indicating for each variable the process used for its evaluation inside CRUS, the units and ranges.

CRUS simulations' outputs are text files with the counters' values for each simulation second.

In the following, a list of all variables that are output by CRUS is presented.

Table F.1 presents the metrics that are applied to each of the variables output by CRUS. These metrics are also calculated by CRUS in its output files statistical analysis module.

CRUS generates statistics for each simulation second and for each base station that was configured with parameter "Statistics_Status" set to "T" (true). The variables outputted by CRUS are described in the following.

Prior to describe the variables it is comfortable to introduce a writing rule. Many variables (such as AllocatedPower, AllocatedCodes, NbUsersPedestrian, etc.) were disaggregated in the cell in three different classes. The classes were called BS, SHO and SSHO and they are indicated in the variable output name by introducing as a suffix .BS, .SHO or .SSHO. This grade of detail was crucial to allow some of the analysis performed in the current thesis. As an example, suppose that a radio link was being monitored and a certain number of codes were being reserved for it. The variable AllocatedCodes needs to be incremented by the number of codes that were reserved for this radio link. However, the variable where they were added to would be AllocatedCodes.BS, AllocatedCodes.SHO or AllocatedCodes.SSHO depending if the monitored base station was providing this link as the best server (.BS), as a soft handover link (.SHO) or a softer handover link (.SSHO). Hence, in the following, whenever a variable has been monitored according with this approach it will be indicated as VariableName.X. It will be implicit that ".X" can be replaced by ".BS", ".SHO" or ".SSHO" depending on the type of link that was being monitored.

In a similar way, some variables (such packet switched connections delay, average throughput, etc.) were monitored by application type (e.g. e-mail, FTP, HTTP, etc). In those cases, the described variable will be written as Variable_App and it will implicit that suffix "App" will be replaceable by "e-mail", "FTP", "HTTP", "LBS", "MMS", "SMS", "StreamingMM", "Video" or "Speech". Whenever any of these services does not applies to the variable being described a proper note will be introduced.

- AllocatedPower.X – Total power (in Watt) used for traffic channels averaged in 1 second (100 system frames);
- AllocatedCodes.X – Number of channelisation codes used for traffic channels averaged in 1 second (100 system frames);
- UL_Load – Uplink cell load, averaged in 1 second (100 system frames);

- DL_Load – Downlink cell load, averaged in 1 second (100 system frames);
- NbUsersPedestrian.X – Number of pedestrian users served by the cell, averaged in 1 second (100 system frames);
- NbUsersVehicular – Number of vehicular users served by the cell, averaged in 1 second (100 system frames);
- New_Calls, Ended_Calls, Dropped_Calls – Number of calls initiated, ended or dropped (resp.) in the current second[10];
- CS_Blocked – Number of CS calls blocked in the current second;
- Block_DL_MaxTXLinkPower – Number of CS calls that were blocked due to maximum DL transmitting power limitation (imposed by parameters dlMaxPower_XXX, where XXX can assume "AMR", "CS64", "PS64", "PS128" or "PS384"). This limitation is verified for each link active in the cell;
- Block_DL_MaxTXTotPower – Number of CS calls that were blocked due to the fact that the power they demand from the network would exceed the total power available in the base station;
- Block_UL_MaxPower – Number of CS calls that were blocked due to the fact that they would needed to transmit in uplink a power level that is higher than the power available in the UE transmitter (set by parameter TXPwrMax defined for each user in file UE_List.cfg);
- Block_DL_Load – Number of CS calls that were blocked due to the fact that their acceptance in the network would oblige the cell to exceed the DL load above the maximum established by DL_Target_Load defined in file CRUS_UMTS_Param.cfg;
- Block_UL_Load – Number of CS calls that were blocked due to the fact that their acceptance in the network would oblige the cell to exceed the UL load above the maximum established by UL_Target_Load defined in file CRUS_UMTS_Param.cfg;
- Block_DL_Codes – Number of CS calls that were blocked due to lack of DL channelisation codes;
- HO_In, HO_Out_Drop – Number of successful HO incoming in the cell and HO outgoing from the cell that resulted in dropped call;
- PS_Delay_App – Average of the delay that all data sessions ending in that particular cell in that particular second and for that particular application have "suffered". The delay is only registered in the BS cell where the session ends (the counters of SHO and SSHO

[10]Note: One dropped call will also increment the Ended_Calls counter

cells are not incremented). This variable does not applies to Speech and Video services (circuit switched services);

- HO_Out_OK_BB_EE – Number of outgoing successful handovers that occurred in a particular second for a particular cell. The handovers are classified according with the speed the UE had in the moment of the HO. EE assumes values in the range [5; 135] and is divisible by 5. BB equals EE minus 5.
- HO_Out_OK_more_135 – Number of outgoing successful handovers that occurred in a particular second for a particular cell whose UEs' speed was higher than 135km/h.
- DLVolume.Layer.App – Number of bytes counted in the interface "Layer" for the application "App" in the current cell in the current simulation second. The "Layer" word is replaceable by "Application", "MAC" or "Radio" and they are measured for each application (App defined in this variable follows the rule established in the beginning of this Annex) in the Application interface, Multiplexing interface and radion interface, respectively, as described in Figure IV.6. This variable is incremented for all types of connections (Best Server, Soft Handover and Softer Handover);
- ULVolume.Layer.App – Number of bytes counted in the interface "Layer" for the application "App" in the UEs served by the current cell in the current simulation second. The "Layer" word is replaceable by "Application", "MAC" or "Radio" and they are measured for each application (App defined in this variable follows the rule established in the beginning of this Annex) in the Application interface, Multiplexing interface and radio interface, respectively, as described in Figure IV.6. This variable is incremented for all types of connections (Best Server, Soft Handover and Softer Handover);
- DLAvgBitRate.App – Average DL bit rate (in kbps) measured in each second for each base station, based on the UEs that have finished their sessions on that particular second. This average bit rate is measured per application type (not applicable to circuit switched services as they have constant bit rates).
- ULAvgBitRate.App – Average UL bit rate (in kbps) measured in each second for each base station, based on the UEs that have finished their sessions on that particular second. This average bit rate is measured per application type (not applicable to circuit switched services as they have constant bit rates).

Table F.1– CRUS output variables and metrics.

Variable Name	Units	Average	Standard Deviation	Max	Min	Sum	5% Percentile	95% Percentile	% Time above 95% of maximum Allowable
For each indoor environment: Incar, Outdoor, Indoor, Deep Indoor Number of User	# Users					☑			
For each service: e-mail, FTP, HTTP, LBS, MMS, SMS, Speech, StreamingMM, Video Number of User	# Users					☑			
Vehicular Users (cell level) for Speed [5X ; 5(X+1)[	# Users					☑			
Pedestrian Users (cell level) for Speed [0.5X ; 0.5(X+1)[	# Users					☑			
Number of Samples	# Samples					☑			
Total Traffic Allocated Power	W	☑	☑	☑			☑	☑	☑
(Best Server / Total) Allocated Power	%	☑	☑						
(Soft Handover / Total) Allocated Power	%	☑	☑						
(Softer Handover / Total) Allocated Power	%	☑	☑						
Total Traffic Allocated Codes	# Codes	☑	☑	☑	☑		☑	☑	☑
(Best Server / Total) Allocated Codes	%	☑	☑	☑	☑				
(Soft Handover / Total) Allocated Codes	%	☑	☑	☑	☑				
(Softer Handover / Total) Allocated Codes	%	☑	☑	☑	☑				
UL Load	%	☑	☑	☑	☑		☑	☑	☑
DL Load	%	☑	☑	☑	☑		☑	☑	☑
Total No of Users	# Users	☑	☑						
Total No of Pedestrian Users	# Users	☑	☑						
% of Pedestrian Users in Best Server Area	%	☑	☑						
% of Pedestrian Users in Soft Handover Area	%	☑	☑						
% of Pedestrian Users in Softer Handover Area	%	☑	☑						
Total No of Vehicular Users	# Users	☑	☑						
% of Vehicular Users in Best Server Area	%	☑	☑						
% of Vehicular Users in Soft Handover Area	%	☑	☑						
% of Vehicular Users in Softer Handover Area	%	☑	☑						
Total New Calls	# Calls					☑			
Total Ended Calls	# Calls					☑			
Total Dropped Calls	# Calls					☑			
Total CS Blocked Calls	# Calls					☑			
CS Out of Service (Cause: MaxTXLinkPower exceeded)	%					☑			

Table F.1 (contd.) – CRUS output variables and metrics.

Variable Name	Units	Average	Standard Deviation	Max	Min	Sum	5% Percentile	95% Percentile	% Time above 95% of maximum Allowable
CS Blocked Calls (Cause: MaxTXTotalPower exceeded)	%					☑			
CS Out of Service (Cause: MaxULPower exceeded)	%					☑			
CS Blocked Calls (Cause: MaxDLLoad exceeded)	%					☑			
CS Blocked Calls (Cause: MaxULLoad exceeded)	%					☑			
CS Blocked Calls (Cause: MaxDLCodes exceeded)	%					☑			
Handover in (cell level)	# HO					☑			
Drop on Handover Out (cell level)	# HO Drop					☑			
Successful HO Out (cell level) for Speed [5X ; 5(X+1)[	# HO					☑			
For each service: e-mail, FTP, HTTP, LBS, MMS, SMS, StreamingMM Delay	s	☑	☑				☑	☑	
For each service: e-mail, FTP, HTTP, LBS, MMS, SMS, Speech, StreamingMM, Video Total Volume UL Application Level	Byte					☑			
Total Volume UL MAC Level	Byte					☑			
Total Volume UL Radio Level	Byte					☑			
Total Volume DL Application Level	Byte					☑			
Total Volume DL MAC Level	Byte					☑			
Total Volume DL Radio Level	Byte					☑			
UL Bit Rate	kbps	☑	☑				☑	☑	
DL Bit Rate	kbps	☑	☑				☑	☑	
Missing Coordinates	# Coordinates					☑			
Maximum time for missing coordinates	s			☑					

Based on the information of the above table higher level statistical analysis is performed to achieve system's response to several simulation scenarios and conditions.

Annex G

File Formats of CRUS' Configuration Files

In this annex, an example of the several configuration files used for CRUS setup is presented.

- **Antennas_List.cfg**

```
#########################################################
#              SIMOTS Output File               #
#         SImulator for MObility in UMTS          #
#              V1.0 - Jan 2004                #
#               Programmed by:                #
#              Carlos Rodrigues               #
#           carlos_j_rodrigues@hotmail.com         #
#########################################################

Antennas_List.cfg        Ref_File:        Baixa_LX Traffic Case. Simulation No.1/40
$Number of Antennas in the present File:11
Current Date:    20040601        Current Time:    22:45:59
Antenna_Ref      Frequency       Max_Gain         Elect_Tilt        Antenna_Desc    Hor_Beam_W
        Ver_Beam_W
H65V7T2          1960    18      2                65      7
Antenna_Ref      Angle   Hor_Aten        Ver_Aten
H65V7T2          0       0       0
H65V7T2          1       0       0.1
H65V7T2          2       0       0
        ...      ...     ...     ...

H65V7T2          356     0       9.4
H65V7T2          357     0       5.9
H65V7T2          358     0       3.6
H65V7T2          359     0       2
$-----------------------------------------------------------------------
```

- **Site_List.cfg**

```
#########################################################
#              SIMOTS Output File               #
#         SImulator for MObility in UMTS          #
#              V1.0 - Jan 2004                #
#               Programmed by:                #
#              Carlos Rodrigues               #
#           carlos_j_rodrigues@hotmail.com         #
#########################################################

Site_List.cfg    Ref_File:        Baixa_LX Traffic Case. Simulation No.1/40
Current Date:    20040601        Current Time:    22:45:59
SiteID  SiteName        LocationX       Y       Z       Site_Desc       Occupied
001LX   CENTER_SITE     BAIXA_LX        488180  4284940 0       Reference Service PS64_128      T
002LX   RING_30_DEG     BAIXA_LX        488431.1        4285375 0       RefServ PS128   T
003LX   RING_90_DEG     BAIXA_LX        488682.3        4284940 0       RefServ PS128   T
004LX   RING_150_DEG    BAIXA_LX        488431.1        4284505 0       RefServ PS128   T
005LX   RING_210_DEG    BAIXA_LX        487928.9        4284505 0       RefServ PS128   T
006LX   RING_270_DEG    BAIXA_LX        487677.7        4284940 0       RefServ PS128   T
007LX   RING_330_DEG    BAIXA_LX        487928.9        4285375 0       RefServ PS128   T
```

- **BS_List.cfg**

```
##############################################################
#                SIMOTS Output File                #
#          SImulator for MObility in UMTS          #
#                V1.0 - Jan 2004                   #
#                 Programmed by:                   #
#                Carlos Rodrigues                  #
#          carlos_j_rodrigues@hotmail.com          #
##############################################################
BS_List.cfg      Ref_File:        Baixa_LX Traffic Case. Simulation No.1/40
Current Date:    20040601         Current Time:    22:45:59
BStID  BStName  SiteID  BS_Desc  AntennaRef  Orient  Tilt  CmCtrChPwr  BSNoiseFig  RadioCh1
maxTxPowerDl  primaryCpichPower  maxActiveSet  reportingRange1a  Statistics_Status
001LX_1  CENTER_SECT_1  001LX  RefServ PS128  K741784_T0  60  0  0.3  3.5  1945  430  330  3  6  1
002LX_1  RING_30D_SECT_1  002LX  RefServ PS128  K741784_T0  60  0  0.3  3.5  1945  430  330  3  6  1
003LX_1  RING_90D_SECT_1  003LX  RefServ PS128  K741784_T0  60  0  0.3  3.5  1945  430  330  3  6  1
004LX_1  RING_150D_SECT_1  004LX  RefServ PS128  K741784_T0  60  0  0.3  3.5  1945  430  330  3  6  1
005LX_1  RING_210D_SECT_1  005LX  RefServ PS128  K741784_T0  60  0  0.3  3.5  1945  430  330  3  6  1
006LX_1  RING_270D_SECT_1  006LX  RefServ PS128  K741784_T0  60  0  0.3  3.5  1945  430  330  3  6  1
007LX_1  RING_330D_SECT_1  007LX  RefServ PS128  K741784_T0  60  0  0.3  3.5  1945  430  330  3  6  1
001LX_2  CENTER_SECT_2  001LX  RefServ PS128  K741784_T0  180  0  0.3  3.5  1945  430  330  3  6  1
002LX_2  RING_30D_SECT_2  002LX  RefServ PS128  K741784_T0  180  0  0.3  3.5  1945  430  330  3  6  1
003LX_2  RING_90D_SECT_2  003LX  RefServ PS128  K741784_T0  180  0  0.3  3.5  1945  430  330  3  6  1
004LX_2  RING_150D_SECT_2  004LX  RefServ PS128  K741784_T0  180  0  0.3  3.5  1945  430  330  3  6  1
005LX_2  RING_210D_SECT_2  005LX  RefServ PS128  K741784_T0  180  0  0.3  3.5  1945  430  330  3  6  1
006LX_2  RING_270D_SECT_2  006LX  RefServ PS128  K741784_T0  180  0  0.3  3.5  1945  430  330  3  6  1
007LX_2  RING_330D_SECT_2  007LX  RefServ PS128  K741784_T0  180  0  0.3  3.5  1945  430  330  3  6  1
001LX_3  CENTER_SECT_3  001LX  RefServ PS128  K741784_T0  300  0  0.3  3.5  1945  430  330  3  6  1
002LX_3  RING_30D_SECT_3  002LX  RefServ PS128  K741784_T0  300  0  0.3  3.5  1945  430  330  3  6  1
003LX_3  RING_90D_SECT_3  003LX  RefServ PS128  K741784_T0  300  0  0.3  3.5  1945  430  330  3  6  1
004LX_3  RING_150D_SECT_3  004LX  RefServ PS128  K741784_T0  300  0  0.3  3.5  1945  430  330  3  6  1
005LX_3  RING_210D_SECT_3  005LX  RefServ PS128  K741784_T0  300  0  0.3  3.5  1945  430  330  3  6  1
006LX_3  RING_270D_SECT_3  006LX  RefServ PS128  K741784_T0  300  0  0.3  3.5  1945  430  330  3  6  1
007LX_3  RING_330D_SECT_3  007LX  RefServ PS128  K741784_T0  300  0  0.3  3.5  1945  430  330  3  6  1
```

• UE_List.cfg

```
##########################################################
#               SIMOTS Output File               #
#          SImulator for MObility in UMTS          #
#                V1.0 - Jan 2004                 #
#                 Programmed by:                  #
#                Carlos Rodrigues                 #
#          carlos_j_rodrigues@hotmail.com         #
##########################################################
UE_List.cfg    Ref_File:    Baixa_LX Traffic Case. Simulation No.1/40
Current Date:    20040601    Current Time:    22:45:59
UEID  Xm  Ym  Zm  UE_Type  EnvType  IndOut  UE_Speed  UEAntGain  TXPwrMax  UENoiseFig
Born_Time  ServName1  VolumeS1  BitRateS1  DowngrdS1  StrTimeS1
$Integer  [m]  [m]  [m]  [Vehicular A50]/[Pedestrian A3]  Integer  Integer  [km/h]  [dBi]  [dBm]  [dB]  [s]
String(see list of services)  Speech:[s]/Data:[kB]  [kbps]  Integer  [s]
1  488142.17  4285007.41  0  Vehicular A50  1  5  36.4906  1  24  8  0  e-mail  1  64  5  0
2  488774.36  4285082.83  0  Pedestrian A3  1  1  1.95406  1  24  8  0  e-mail  42  64  5  0
3  488074.08  4284763.15  0  Pedestrian A3  1  1  3.41825  2  24  8  1  Video  478  64  5  0
4  488113.89  4284642.8  0  Pedestrian A3  1  5  5.18692  2  21  8  2  Speech  17  12  5  0
5  487987.83  4285398.25  0  Vehicular A50  1  5  40.2668  2  21  8  2  Speech  1  12  5  0
6  488333.79  4284582.44  0  Pedestrian A3  1  4  0.784493  1  24  8  2  MMS  79  64  5  0
        ...        ...        ...        ...

7091  488191.83  4284674.2  0  Vehicular A50  1  5  34.1733  1  24  8  4198  HTTP  1771  128  5  0
7092  487881.54  4285196.33  0  Vehicular A50  1  5  42.9055  2  21  8  4199  Speech  26  12  5  0
7093  488874.62  4285037.74  0  Vehicular A50  1  5  47.9334  1  24  8  4199  LBS  1  64  5  0
7094  488355.3  4284736.77  0  Vehicular A50  1  5  38.5994  1  24  8  4199  FTP  171  384  5  0
$###################################################
$  Simulation Started at:   22:45:59
$  Loading BHCA Started at:          22:46:17
$  Loading Streets BHCA Started at:            22:47:53
$  Loading Streets into C DataBase Started at:           22:46:32
$  Streets Traffic Density Calculation Started at:        22:47:53
$  Streets Traffic Density Calculation Ended at:          22:48:01
$  Calculations Started at:  22:48:01
$  Calculations Ended at:   22:53:23
```

• UE_Coord.cfg

```
##########################################################
#               SIMOTS Output File               #
#          SImulator for MObility in UMTS          #
#                V1.0 - Jan 2004                 #
#                 Programmed by:                  #
#                Carlos Rodrigues                 #
#          carlos_j_rodrigues@hotmail.com         #
##########################################################
UE_Coord.cfg    Ref_File:    Baixa_LX Traffic Case. Simulation No.1/40
Current Date:    20040601    Current Time:    22:45:59
System_Time    UEID    Xm    Ym    Zm    IndOut   UE_Speed    EnvType
$  [s]    Integer   [m]    [m]    [m]    Integer   [Km/h]   Integer
0  1  488142.17  4285007.41  0  5  36.4906  1
0  2  488774.36  4285082.83  0  1  1.95406  1
1  3  488074.08  4284763.15  0  1  3.41825  1
1  1  488137.7  4285005.94  0  5  16.9181  1
1  2  488773.63  4285081.99  0  1  4.01114  1
2  4  488113.89  4284642.8  0  5  5.18692  1
```

```
2  5  487987.83  4285398.25  0  5  40.2668  1
2  6  488333.79  4284582.44  0  4  0.784493  1
2  2  488774.04  4285081.85  0  1  1.54945  1
2  3  488074.35  4284763.34  0  1  1.2071  1
3  7  488219.62  4285056.67  0  5  34.4534  1
3  2  488774.2  4285082.28  0  1  1.67529  1
3  3  488075.2  4284763.57  0  1  3.15995  1
3  4  488114.35  4284643.82  0  5  4.01636  1
3  5  487984.46  4285403.24  0  5  21.6767  1
3  6  488334.29  4284582.23  0  4  1.98199  1
        ...        ...        ...        ...
4200  7084  488638.26  4285344.01  0  5  8.89993  1
4200  7085  487679.79  4284579.68  0  5  5.223  1
4200  7086  488076.67  4285144  0  5  26.8565  1
4200  7087  488235.09  4285043.15  0  1  5.74263  1
4200  7088  487622.4  4285543.15  0  5  24.8751  1
4200  7089  487762.79  4285163.56  0  5  4.08597  1
4200  7090  487876.87  4285004.02  0  1  3.37177  1
4200  7091  488185.48  4284672.35  0  5  11.9172  1
4200  7092  487878.13  4285200.5  0  5  18.5639  1
4200  7093  488871.17  4285035.82  0  5  14.2337  1
4200  7094  488357.45  4284730.12  0  5  25.1523  1
```

- **CRUS_Settings.cfg**

```
############################################################
#              SIMOTS Output File                #
#         SImulator for MObility in UMTS          #
#               V1.0 - Jan 2004               #
#                Programmed by:                 #
#               Carlos Rodrigues                #
#          carlos_j_rodrigues@hotmail.com         #
############################################################

CRUS_Settings.cfg          Ref_File:            Baixa_LX Traffic Case. Simulation No.1/40
Current Date:      20040601           Current Time:      22:45:59
MobiAnalys         Active
Prop_Model         COST231WALFISCH
PathLsCalc         CRUS
SimTimeLen         4200
DebugLev01         True
DebugLev02         False
DebugLev03         False
DebugLev04         False
PerSave 1
MobTimStep         1
```

- **CRUS_UMTS_Param.cfg**

```
############################################################
#              SIMOTS Output File                #
#         SImulator for MObility in UMTS          #
#               V1.0 - Jan 2004               #
#                Programmed by:                 #
#               Carlos Rodrigues                #
#          carlos_j_rodrigues@hotmail.com         #
############################################################
```

```
CRUS_UMTS_Param.cfg Ref_File:        Baixa_LX Traffic Case. Simulation No.1/40
Current Date:    20040601        Current Time:    22:45:59
$ The Following Lines provide the several Bearers' Sensitivities
UL_Speech_12_2_PedA_3Kmh      5.5
UL_Speech_12_2_VehA_50Kmh     6.5
UL_Speech_12_2_VehA_120Kmh 7
UL_CS_64_PedA_3Kmh  4.2
UL_CS_64_VehA_50Kmh           5.2
UL_CS_64_VehA_120Kmh          5.5
UL_CS_128_PedA_3Kmh3.7
UL_CS_128_VehA_50Kmh          3.7
UL_CS_128_VehA_120Kmh         3.7
UL_CS_384_PedA_3Kmh0
UL_CS_384_VehA_50Kmh          0
UL_CS_384_VehA_120Kmh         0
UL_PS_64_PedA_3Kmh  4.2
UL_PS_64_VehA_50Kmh           4.8
UL_PS_64_VehA_120Kmh          5.2
UL_PS_128_PedA_3Kmh 4.4
UL_PS_128_VehA_50Kmh          4.4
UL_PS_128_VehA_120Kmh         4.4
UL_PS_384_PedA_3Kmh 1.9
UL_PS_384_VehA_50Kmh          1.9
UL_PS_384_VehA_120Kmh         1.9
DL_Speech_12_2_PedA_3Kmh      7.5
DL_Speech_12_2_VehA_50Kmh     8.1
DL_Speech_12_2_VehA_120Kmh 8.2
DL_CS_64_PedA_3Kmh  6.7
DL_CS_64_VehA_50Kmh           7.3
DL_CS_64_VehA_120Kmh          7.9
DL_CS_128_PedA_3Kmh6.2
DL_CS_128_VehA_50Kmh          6.6
DL_CS_128_VehA_120Kmh         6.8
DL_CS_384_PedA_3Kmh0
DL_CS_384_VehA_50Kmh          0
DL_CS_384_VehA_120Kmh         0
DL_PS_64_PedA_3Kmh  5.9
DL_PS_64_VehA_50Kmh           6.5
DL_PS_64_VehA_120Kmh          6.9
DL_PS_128_PedA_3Kmh 5.9
DL_PS_128_VehA_50Kmh          7
DL_PS_128_VehA_120Kmh         7.4
DL_PS_384_PedA_3Kmh 3.9
DL_PS_384_VehA_50Kmh          5.5
DL_PS_384_VehA_120Kmh         5.9
$ The Following Lines provide the several System Margins
$ The last lines stablish the maximum DL transmitting power for each radio connection type.
$ Values are relative to CPICH Transmitting Power. Values in deci-dB
$ Other Parameters:
$ SHO_Gain: Soft Handover Gain
$ DL_Target_Load: Target Load for Downlink [0;1[
$ UL_Target_Load: Target Load for Uplink [0;1[
$ Alpha: Orthogonality between codes used by each user Alpha [0.5 ; 0.9]
$ Iinter: Normalised inter-cell interference Iinter [0.4 ; 0.6]
Body_Loss_Voice          3
Body_Loss_Data 1
SFading_DU_DI 4.2
SFading_DU_I    4.2
SFading_DU_IW 4.2
SFading_DU_O   7.3
```

SFading_U_DI 4.2
SFading_U_I 4.2
SFading_U_IW 4.2
SFading_U_O 7.3
SFading_SU_DI 4.2
SFading_SU_I 4.2
SFading_SU_IW 4.2
SFading_SU_O 7.3
SFading_Ru_DI 4.2
SFading_Ru_I 4.2
SFading_Ru_IW 4.2
SFading_Ru_O 7.3
FFading_PedA_3Kmh 4
FFading_VehA_50Kmh 0
FFading_VehA_120Kmh 0
Ind_Loss_DI 25
Ind_Loss_I 21
Ind_Loss_IW 11
Ind_Loss_IC 8
dlMaxPower_SRB 0
dlMaxPower_AMR 0
dlMaxPower_CS57_6 28
dlMaxPower_CS64 32
dlMaxPower_PS64 34
dlMaxPower_PS128 40
dlMaxPower_PS384 48
dlMaxPower_MultiRAB 38
SHO_Gain 3
DL_Target_Load 0.75
UL_Target_Load 0.5
Alpha 0.65
Iinter 0.55
$ The Following Lines provide the Parameterization for COST231 - Walfisch Ikegami Propagation Model
$ Dense Urban Scenario
WB_DU75
HB_DU 23
hantenna_DU 27
hm_DU 1.5
fi_DU 90
WS_DU 10
$ Urban Scenario
WB_U 60
HB_U 23
hantenna_U 30
hm_U 1.5
fi_U 90
WS_U 30
$ Suburban Scenario
WB_SU 60
HB_SU 15
hantenna_SU 25
hm_SU 1.5
fi_SU 90
WS_SU 50

- **Simulation.log**

22:46:00###
22:46:00# SIMOTS V1.0 #

```
22:46:00##################################################
22:46:00=======================================================
22:46:00*** Creating Output File 20040601_22h45m59s_UE_List.cfg with UE information.
22:46:00File 20040601_22h45m59s_UE_List.cfg created with success.
22:46:00Creating Output File 20040601_22h45m59s_UE_Coord.cfg with UE Coordinates.
22:46:00File 20040601_22h45m59s_UE_Coord.cfg created with success.
22:46:00Creating Output File 20040601_22h45m59s_Site_List.cfg with Site data.
22:46:00File 20040601_22h45m59s_Site_List.cfg created with success.
22:46:00Creating Output File 20040601_22h45m59s_BS_List.cfg with Base Stations' data.
22:46:00File 20040601_22h45m59s_BS_List.cfg created with success.
22:46:00Creating Output File 20040601_22h45m59s_Antennas_List.cfg with Antennas' data.
22:46:01File 20040601_22h45m59s_Antennas_List.cfg created with success.
22:46:01Creating Output File 20040601_22h45m59s_CRUS_Settings.cfg with CRUS' parameters.
22:46:01File 20040601_22h45m59s_CRUS_Settings.cfg created with success.
22:46:01Creating Output File 20040601_22h45m59s_CRUS_UMTS_Param.cfg with UMTS parameters.
22:46:01File 20040601_22h45m59s_CRUS_UMTS_Param.cfg created with success.
22:46:01=======================================================
22:46:01DEBUG: Output Files Created with Success.
22:46:17Simulation Started at 22:46:17
22:46:17Analysing the existence of all necessary data...
22:46:17Loading BHCA information into internal data structures
22:46:32BHCA Data successfuly loaded.
22:46:32Loading Streets Into DataBase
22:46:34Street_Table_1 Loaded
22:46:36Street_Table_2 Loaded
22:46:38Street_Table_3 Loaded
22:46:42Street_Table_4 Loaded
22:46:57Street_Table_5 Loaded
22:47:14Street_Table_6 Loaded
22:47:16Street_Table_7 Loaded
22:47:36Street_Table_8 Loaded
22:47:53Street_Table_9 Loaded
22:47:53Loading Traffic density related with streets.
22:48:01Streets Traffic density loaded.
22:48:01=======================================================
22:48:01Drop Zone Area:   1.98367 Km2
22:48:01=======================================================
22:48:01Number of Users to be Created (along the busy hour):
22:48:01Busy Hour Traffic Percentage:      10%
22:48:01Speech Users:       1755
22:48:01Video Users:        839
22:48:01StreamingMM Users:         241
22:48:01HTTP Users:         393
22:48:01LBS Users:          152
22:48:01MMS Users:          357
22:48:01SMS Users:          357
22:48:01e-mail Users:       1271
22:48:01FTP Users:          690
22:48:01=======================================================
22:48:01Users Distribution per Service
22:48:01Speech Users:       28.9843%
22:48:01Video Users:        13.8563%
22:48:01StreamingMM Users:         3.98018%
22:48:01HTTP Users:         6.4905%
22:48:01LBS Users:          2.51032%
22:48:01MMS Users:          5.89595%
22:48:01SMS Users:          5.89595%
22:48:01e-mail Users:       20.9909%
22:48:01FTP Users:          11.3955%
22:48:01=======================================================
```

22:48:01 Users Density along the Busy Hour
22:48:01 Speech Users: 884.725 Users/Km2
22:48:01 Video Users: 422.954 Users/Km2
22:48:01 StreamingMM Users: 121.492 Users/Km2
22:48:01 HTTP Users: 198.118 Users/Km2
22:48:01 LBS Users: 76.6257 Users/Km2
22:48:01 MMS Users: 179.97 Users/Km2
22:48:01 SMS Users: 179.97 Users/Km2
22:48:01 e-mail Users: 640.732 Users/Km2
22:48:01 FTP Users: 347.84 Users/Km2
22:48:01===
22:48:01 Users Distribution:
22:48:01 BHCA Distribution for users' generation
22:48:01 Vehicular Users: 70%
22:48:01 Pedestrian Users: 30%
22:48:01 Deep Indoor Users: 20%
22:48:01 Indoor Users: 0%
22:48:01 Indoor Window Users: 5%
22:48:01 Outdoor Users: 5%
22:48:01===
22:48:01 Drop_Zone_X_Min: 487467.19
22:48:01 Drop_Zone_X_Max: 488898.61
22:48:01 Drop_Zone_Y_Min: 4284253.14
22:48:01 Drop_Zone_Y_Max: 4285638.94
22:48:01 Stat_Zone_X_Min: 487541.32
22:48:01 Stat_Zone_X_Max: 488858.69
22:48:01 Stat_Zone_Y_Min: 4284287.35
22:48:01 Stat_Zone_Y_Max: 4285553.39
22:48:01 Simulation Duration: 4200s ### Periodic Data Saving: 60s
22:48:01===
22:48:01 Service(1).XTime: 1.2 Volume: 120 BitRate: 12
22:48:01 Service(2).XTime: 1.2 Volume: 960 BitRate: 64
22:48:01 Service(3).XTime: 1.2 Volume: 2300 BitRate: 384
22:48:01 Service(4).XTime: 1.2 Volume: 1200 BitRate: 128
22:48:01 Service(5).XTime: 1.2 Volume: 230 BitRate: 64
22:48:01 Service(6).XTime: 1.2 Volume: 60 BitRate: 64
22:48:01 Service(7).XTime: 1.2 Volume: 1 BitRate: 64
22:48:01 Service(8).XTime: 1.2 Volume: 10 BitRate: 64
22:48:01 Service(9).XTime: 1.2 Volume: 1000 BitRate: 384
22:48:01===
22:48:01 Current Simulation Time: 0 s / Total: 4200 s
22:48:01 Current_Sim_Time: 0 Nb_Active_Users: 2
22:48:01 Current Simulation Time: 1 s / Total: 4200 s
22:48:01 Current_Sim_Time: 1 Nb_Active_Users: 2
22:48:01 Current Simulation Time: 2 s / Total: 4200 s
22:48:01 Current_Sim_Time: 2 Nb_Active_Users: 5
22:48:01 Current Simulation Time: 3 s / Total: 4200 s
22:48:01 Current_Sim_Time: 3 Nb_Active_Users: 5
22:48:01 Current Simulation Time: 4 s / Total: 4200 s
22:48:01 Current_Sim_Time: 4 Nb_Active_Users: 6
22:48:02 Current Simulation Time: 5 s / Total: 4200 s
22:48:02 Current_Sim_Time: 5 Nb_Active_Users: 7
22:48:02 Current Simulation Time: 6 s / Total: 4200 s
22:48:02 Current_Sim_Time: 6 Nb_Active_Users: 9
22:48:02 Current Simulation Time: 7 s / Total: 4200 s
22:48:02 Current_Sim_Time: 7 Nb_Active_Users: 10
22:48:02 Current Simulation Time: 8 s / Total: 4200 s
22:48:02 Current_Sim_Time: 8 Nb_Active_Users: 9
22:48:02 Current Simulation Time: 9 s / Total: 4200 s
22:48:02 Current_Sim_Time: 9 Nb_Active_Users: 13

```
22:48:02Current Simulation Time:  10 s / Total:      4200 s
22:48:02Current_Sim_Time:         10        Nb_Active_Users:       13
22:48:02Current Simulation Time:  11 s / Total:      4200 s
22:48:02Current_Sim_Time:         11        Nb_Active_Users:       14
22:48:02Current Simulation Time:  12 s / Total:      4200 s
        ...        ...        ...        ...

22:53:23Current_Sim_Time:         4198      Nb_Active_Users:       138
22:53:23Current Simulation Time:  4199 s / Total:    4200 s
22:53:23Current_Sim_Time:         4199      Nb_Active_Users:       139
22:53:23Current Simulation Time:  4200 s / Total:    4200 s
22:53:23Current_Sim_Time:         4200      Nb_Active_Users:       135
22:53:23Simulation Ended Properly.
22:53:23####################################################
22:53:23Simulation Started at:    22:45:59
22:53:23Loading BHCA Started at:22:46:17
22:53:23Loading Streets BHCA Started at:   22:47:53
22:53:23Loading Streets into C DataBase Started at:  22:46:32
22:53:23Streets Traffic Density Calculation Started at:      22:47:53
22:53:23Streets Traffic Density Calculation Ended at:        22:48:01
22:53:23Calculations Started at:     22:48:01
22:53:23Calculations Ended at:       22:53:23
```

Annex H

Random Variables Generation Analysis

The present annex presents the statistical analysis of random variables generated inside the simulators, aiming at confirming they were generated according to the target distributions.

Random variables generation is an issue that must be carefully analysed in order to guarantee that the events being simulated have the desired statistical behaviour.

It is very easy to find a very large number of references (either in specialized literature or in many Internet sites) explaining how random variables can be generated, no matter what distribution is intended to obtain. All the random variables were generated by source code implemented in C++. Table H.1, presents a summary of the random variables generation concerning the utilisation of each one and a measure of correlation between a random variable generation and the theoretical distribution. Following that table some graphical examples of distributions achieved for these variables are presented.

All those distributions' correlation values were calculated based on a set of 10 000 randomly generated values, following the correspondent distribution function.

Table H.1 – Random Variables generation information.

Distribution name	Variable utilisation	Measured correlation	PDF & CDF example
Uniform	Users generation	99.998%	Figure H.1
Poisson	Users' generation rate	99.942%	Figure H.2
Triangular	Users' Speed	99.472%	Figure H.3
Four Normal	Pedestrian users' direction	99.998%	Figure H.4
Exponential	Service duration	99.891%	Figure H.5
Pareto	Packets generation	99.871%	Figure H.6
Geometric	Packets generation	99.880%	Not Available
Lognormal	Packets generation	99.932%	Not Available

- **Uniform Random Variable Generation Analysis**

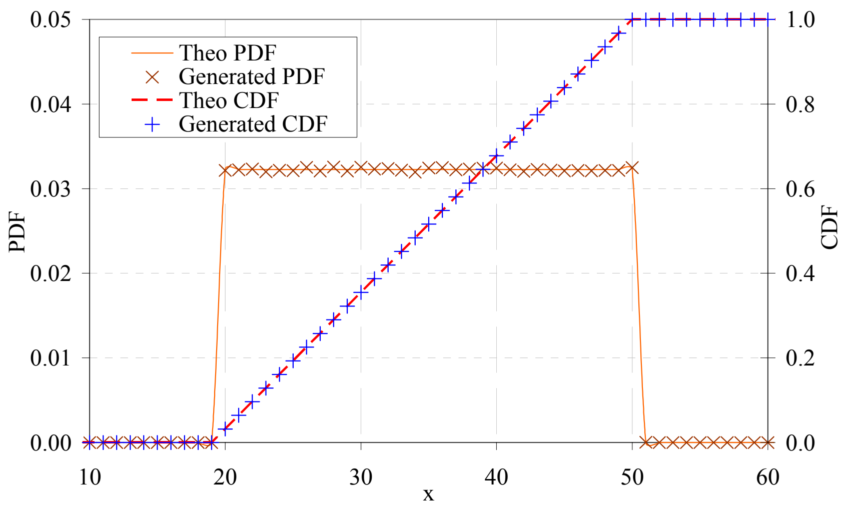


Figure H.1 – Comparison between Uniform's PDF and CDF with the equivalent modified histogram obtained from Uniform RNG in interval [20; 50].

- **Poisson Random Variable Generation Analysis**

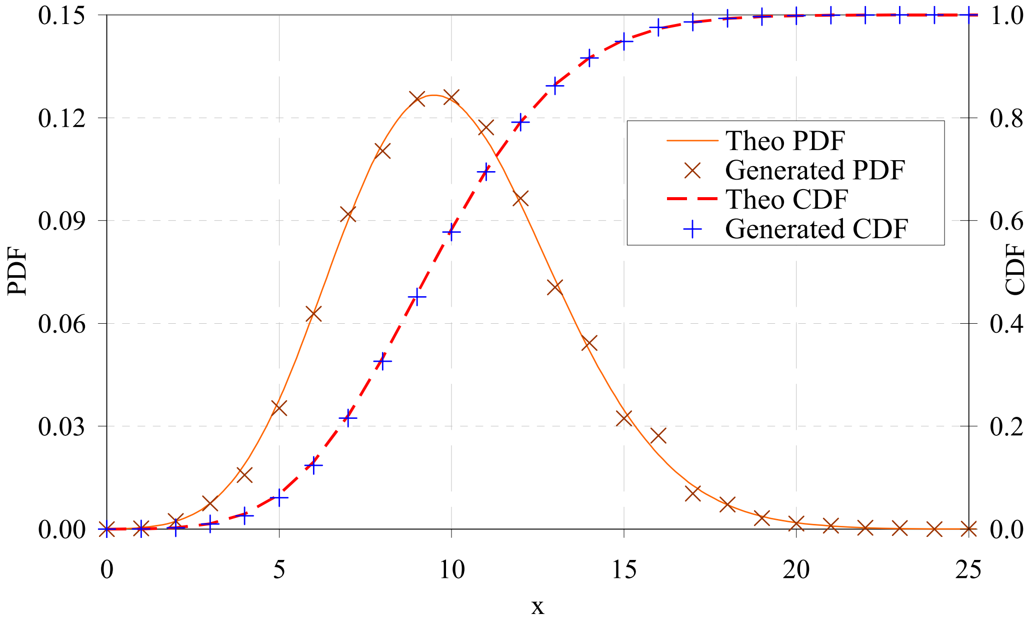


Figure H.2 – Comparison between Poisson's PDF and CDF with the equivalent modified histogram obtained from Poisson RNG ($\lambda_t = 10$).

- **Triangular Random Variable Generation Analysis**

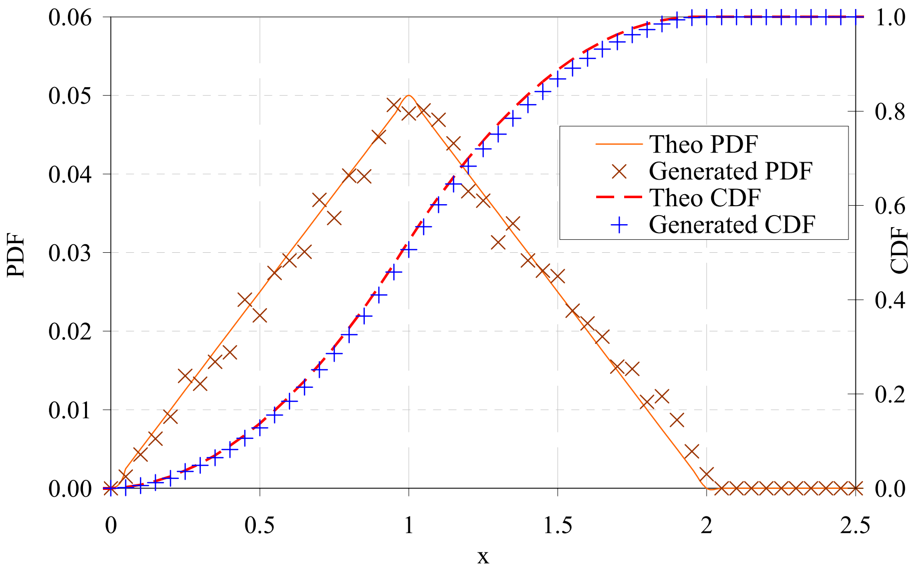


Figure H.3 – Comparison between Triangular PDF and CDF with the equivalent modified histogram obtained from Triangular RNG (Avg = 1, Δ = 1).

- **Four Normal Random Variable Generation Analysis**

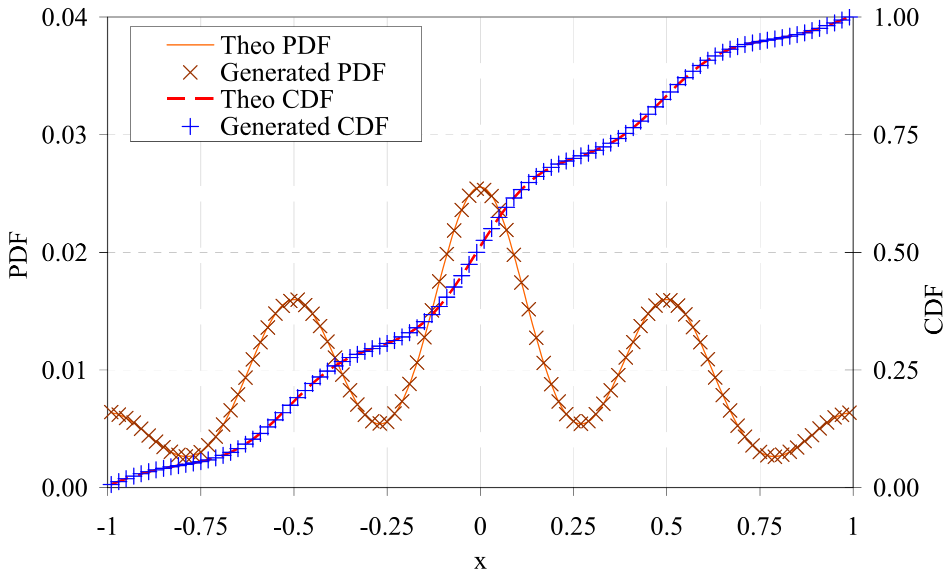


Figure H.4 – Comparison between Four Normal PDF and CDF with the equivalent modified histogram obtained from Four Normal RNG (w_{-90} = 0.6, w_{-180} = 0.6, w_{90} = 0.6, σ_φ = 0.3).

- **Exponential Random Variable Generation Analysis**

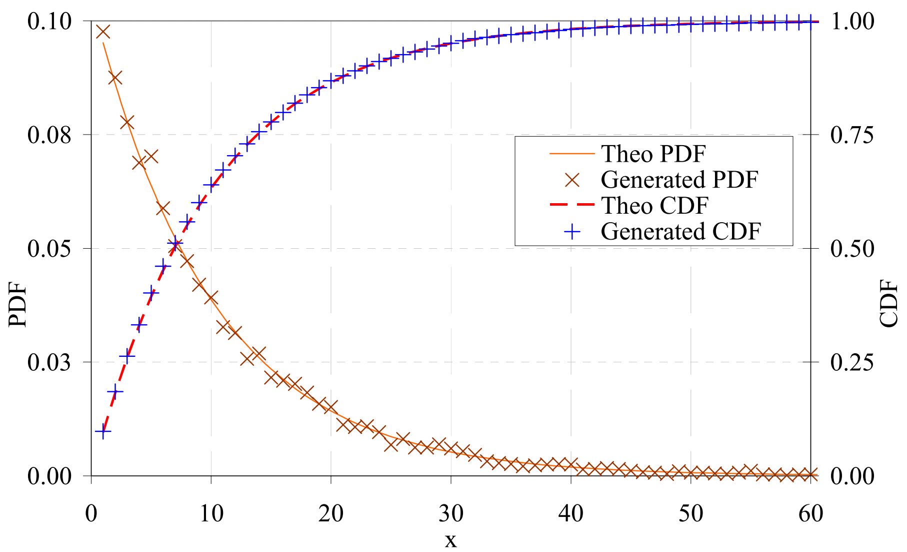


Figure H.5 – Comparison between exponential PDF and CDF with the equivalent modified histogram obtained from exponential RNG (Avg = 0.1).

- **Pareto Random Variable Generation Analysis**

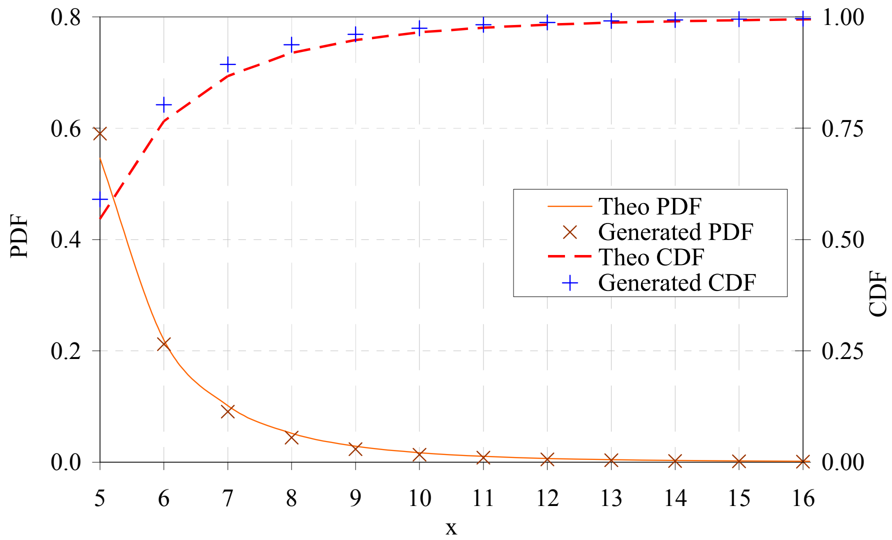


Figure H.6 – Comparison between Pareto PDF and CDF with the equivalent modified histogram obtained from Pareto RNG ($\alpha = 4$, $k = 4$).

Annex I

Test Networks' Configuration

In this annex, several maps of the Lisbon are presented indicating the localisation of the sites' cluster used in the several test scenarios. Further than indicating the geographical localisation of the test scenarios, it also indicates the configuration of the network in each case, as well the streets characterisation of each geographical area.

A map with Lisbon streets and the identification of the test areas is presented in Figure I.1. After it a zoom is performed in each of the test areas. Figure I.2 presents Downtown, Figure I.3 presents Av. Da República, Figure I.4 presents Benfica and Figure I.5 presents Moscavide.

- **Lisbon Overview**

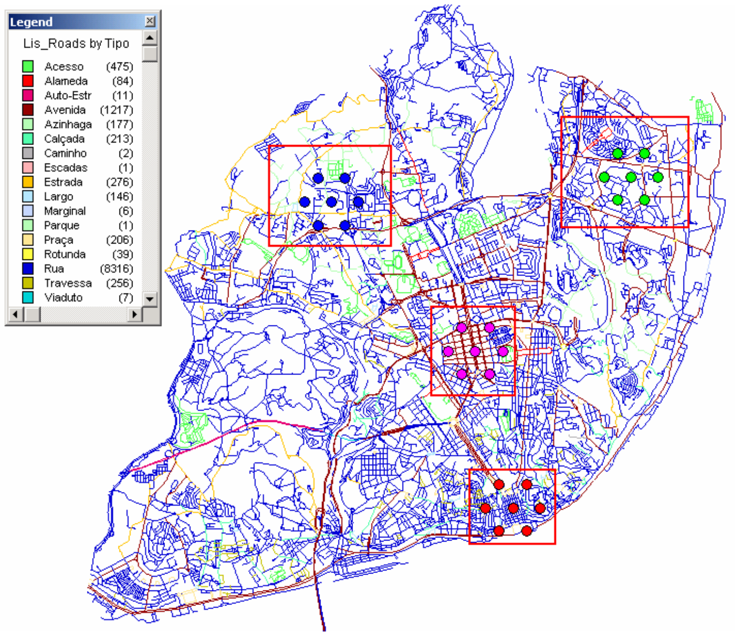


Figure I.1 – Overview of the test scenarios (integrated view).

- **Lisbon Downtown (BxLx) test scenario configuration**

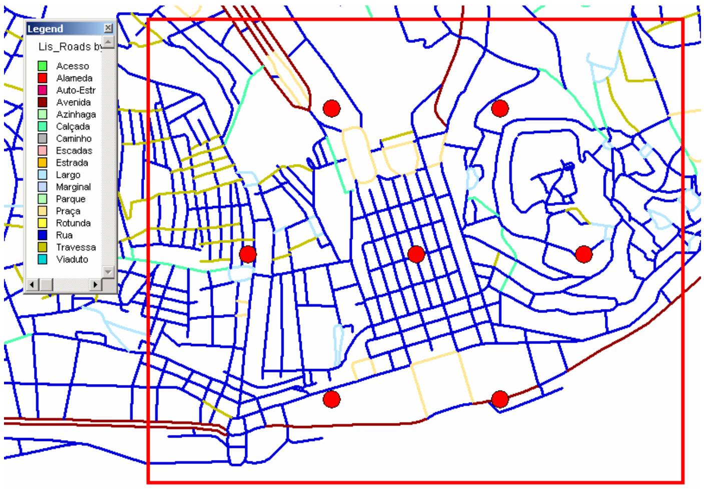


Figure I.2 – Lisbon downtown (BxLx) test scenario with 7 site (21 cells) cluster.

- **Avenida da República (AvRp) test scenario configuration**

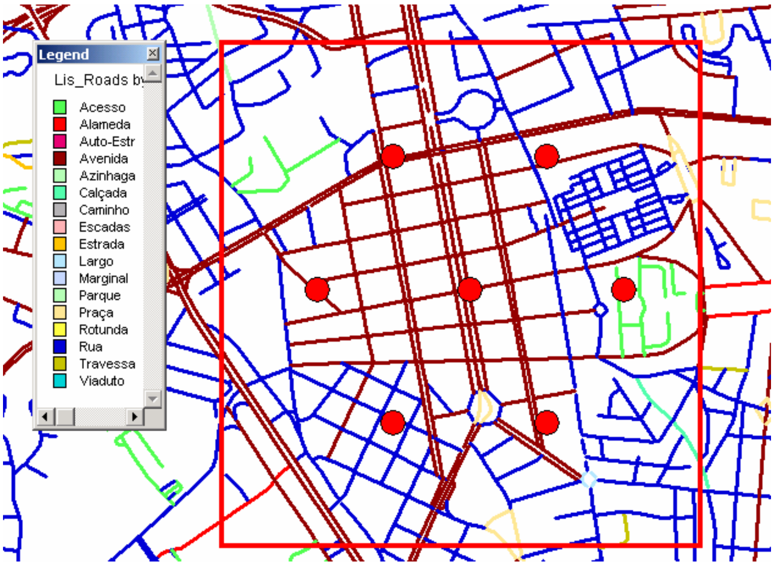


Figure I.3 – Avenida da República test scenario with 7 site (21 cells) cluster.

- **Benfica test scenario configuration**

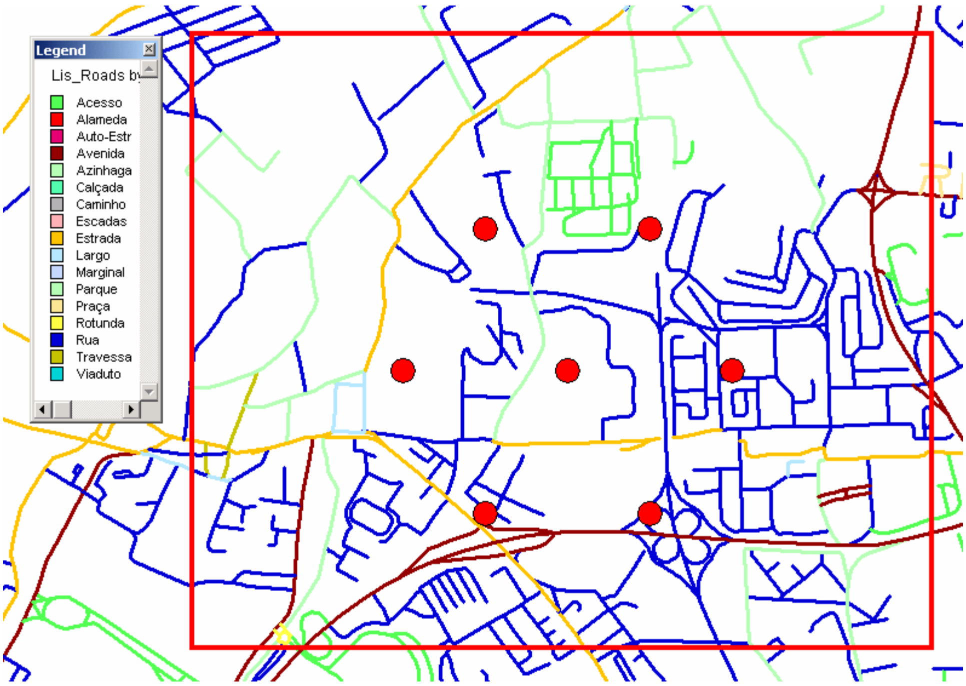


Figure I.4 – Benfica test scenario with 7 site (21 cells) cluster.

- **Moscavide test scenario configuration**

Figure I.5 – Moscavide test scenario with 7 site (21 cells) cluster.

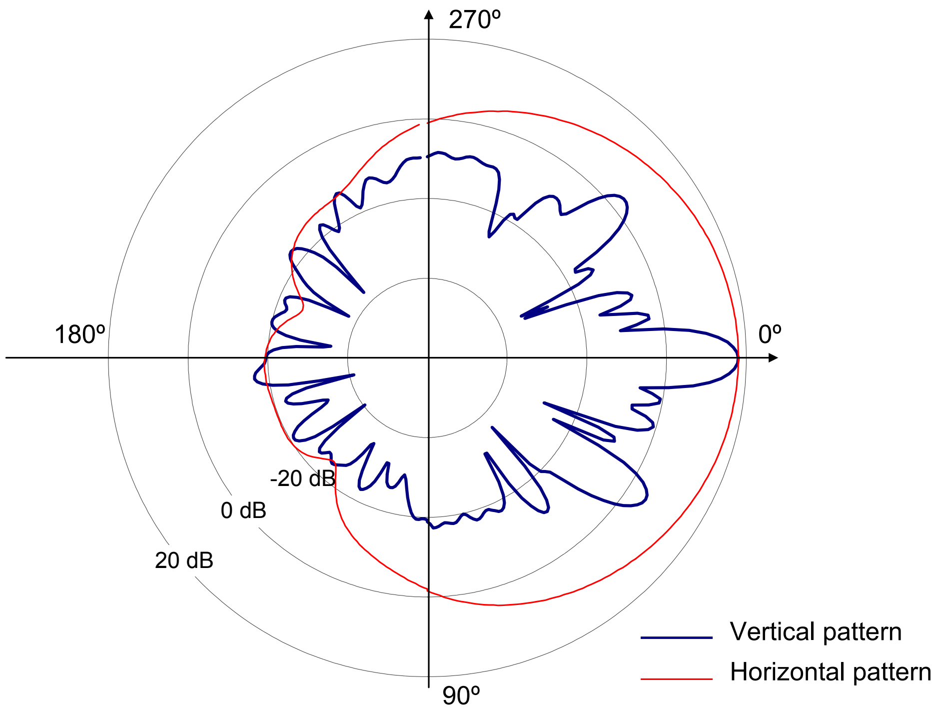


Figure I.6 – Antenna radiation pattern (18dBi) used in the simulations.

Annex J

Test Scenarios Traffic Characterisation and Link Budget Calculation

This annex introduces additional information regarding the traffic characterisation in the city of Lisbon, aiming at better characterising the traffic generation. Link budget concretisation is also presented in this annex, in order to justify the choices performed for the test network dimensioning.

- **Test scenarios traffic characterisation**

Information regarding traffic distribution in the city of Lisbon was provided by BHCA table and was generated by IST-MOMENTUM project, based on demographic, economic and geographical information of the city. The final result was presented in Figure V.1 to Figure V.3, nevertheless in what follows a brief characterisation segmented per users' and environmental classes is provided in order to have a better insight on the basis information used in the study.

IST-MOMENTUM project considered three classes of users based on the type of services usage: Business, Small Office Home Office (SOHO) and Mass-market. Lisbon was divided in operational environment classes, which were defined based on the city building layout and people's dynamics: Water, Railway, Highway, Highway with traffic jam, Main road, Street, Rural, Suburban, Open and Rural. The detailed characterisation of each one of these environment classes can be found in [FCXV03]. Table J.1 presents the weighting that was considered by MOMENTUM for users' distribution.

Table J.1 – Operational environment share between costumer segments (in %).

Operational Environment Class	Business	SOHO	Mass-market
Water	35	35	30
Railway	20	40	40
Highway	60	30	10
Highway with traffic jam	60	30	10
Main road	30	40	30
Street	10	20	70
Rural	2	3	95
Suburban	5	15	80
Open	25	40	35
Urban	25	40	35
Central Business District	80	10	10

This information was crossed with the busy hour usage per segment and users' utilisation profile for each service type in order to achieve BHCA geographical distribution. The values considered in MOMENTUM are presented in Table J.2 and Table J.3.

Table J.2 – Busy hour usage per segment.

Costumer Segment	Busy hour usage (%)
Business	20
SOHO	15
Mass-market	7

For each 20×20m^2 pixel considered in the city the type of clutter was identified (falling into one of the classes defined in Table J.1) and crossing it with the population distribution it was possible to calculate the number of users presented in that pixel. Based on the distribution per costumer segment, the number of busy hour usage per segment and number of calls per day (also defined per costumer segment, as indicated in Table J.3) the final number of call attempts in the busy hour on a pixel basis was achieved.

Table J.3 – Number of calls per day per costumer segment.

Service	Business	SOHO	Mass-market
Speech	4.167	2.400	1.768
Video-Telephony	0.900	0.864	0.679
Streaming MM	0.600	0.576	0.170
HTTP	0.400	0.256	0.075
Location Based Services	0.023	0.022	0.013
MMS	0.230	0.221	0.078
E-Mail	0.138	0.110	0.087
SMS	0.230	0.221	0.078
FTP	0.180	0.115	0.068

- **Link Budget calculations for reference radio bearers**

In this Annex UL and DL link budget calculations for reference radio bearers are presented in detail. These calculations were the basis for choosing the intersite distance to be used in the test network. All the parameters are explained in detail in Annex A, so the goal of this Annex is, by one hand, present the calculations used in the dimensioning process and, by other hand, remark some details of the calculations.

Table J.4 presents the UL link budget. The radio bearer indicated in the table’s top row refers to the nomenclature used to distinguish the radio bearers. It must be recalled, however, that all PS services are mapped, in UL, in a 64 kbps and that is why that value is considered in UL for all PS services (PS 64 kbps, PS 128 kbps and PS 384 kbps). This link budget was calculated for a Dense Urban, Indoor Window environment, and all the considered margins are the ones suited for that particular environment. UL target load was considered to be 50%, and that is reflected in 3.0 dB accounted for interference margin.

Table J.4 – UL link budget reference services.

Uplink	Radio Bearer				
	12.2 kbps	PS 64 kbps	PS 128 kbps	PS 384 kbps	CS 64 kbps
Transmitter (UE)					
MS output power [dBm]	21	24	24	24	24
Antenna gain [dBi]	0	0	0	0	0
Cable & Connector losses	0	0	0	0	0
EIRP [dBm]	21	24	24	24	24
Receiver (Node B)					
Thermal noise density [dBr	-174.0	-174.0	-174.0	-174.0	-174.0
Noise figure [dB]	3.5	3.5	3.5	3.5	3.5
Required Eb/No [dB]	6.8	4.0	4.0	4.0	4.4
Bit Rate [kbps]	12.2	64.0	64.0	64.0	64.0
10*log(bitrate)	40.9	48.1	48.1	48.1	48.1
Sensitivity Node B [dBm]	-122.8	-118.4	-118.4	-118.4	-118.0
Gains					
Receiver Antenna gain [dB	18	18	18	18	18
Soft HO gain [dB]	3	3	3	3	3
Total Gains [dB]	21	21	21	21	21
Margins & Losses					
Penetration loss [dB]	11.0	11.0	11.0	11.0	11.0
Shadowing margin [dB]	5.9	5.9	5.9	5.9	5.9
Body loss [dB]	3.0	1.0	1.0	1.0	1.0
Fast Fading Margin [dB]	3.6	3.6	3.6	3.6	3.6
Interference margin [dB]	3.0	3.0	3.0	3.0	3.0
Cable & connectors losses	3.0	3.0	3.0	3.0	3.0
Total Losses [dB]	29.5	27.5	27.5	27.5	27.5
Max PS Pathloss [dB]	135.3	135.9	135.9	135.9	135.5
Max Cell Radius [km]	0.306	0.315	0.315	0.315	0.309
Intersite distance [km]	0.530	0.546	0.546	0.546	0.535

Speech is the only service with 21 dBm for UL output power, in accordance with the description provided in Annex A.

Concerning DL link budget, it is presented in Table J.5. In this case, as DL is under analysis, the bit rate considered for each radio bearer is in accordance with the name used to identify it. As it now concerns DL, the radio bearers for PS are now 64 kbps, 128 kbps and 384 kbps. A fixed 33 dBm output power was considered to be used by the Node B for all the radio bearers.

Table J.5 – DL link budget reference services.

Downlink	Radio Bearer				
	12.2 kbps	PS 64 kbps	PS 128 kbps	PS 384 kbps	CS 64 kbps
Receiver (UE)					
Thermal Noise Density [dB	-174.0	-174.0	-174.0	-174.0	-174.0
Noise Figure [dB]	8.0	8.0	8.0	8.0	8.0
Required Eb/N0 [dB]	6.8	4.0	3.4	2.3	4.4
Bit Rate [kbps]	12.2	64.0	128.0	384.0	64.0
10*log(bit rate)	40.9	48.1	51.1	55.8	48.1
Sensitivity UE [dBm]	-118.3	-113.9	-111.5	-107.9	-113.5
Gains					
Receiver Antenna gain [dB	0	0	0	0	0
Soft HO gain [dB]	3	3	3	3	3
Total Gains [dB]	3	3	3	3	3
Margins & Losses					
Penetration loss [dB]	11.0	11.0	11.0	11.0	11.0
Shadowing margin [dB]	5.9	5.9	5.9	5.9	5.9
Body loss [dB]	3.0	1.0	1.0	1.0	1.0
Fast Fading Margin [dB]	3.6	3.6	3.6	3.6	3.6
Interference margin [dB]	6.0	6.0	6.0	6.0	6.0
Total Losses [dB]	29.5	27.5	27.5	27.5	27.5
Transmitter (Node B)					
Node B TX power [dBm]	33.0	33.0	33.0	33.0	33.0
Antenna gain [dBi]	18.0	18.0	18.0	18.0	18.0
Cable & Connector losses	3.0	3.0	3.0	3.0	3.0
Node B EIRP [dBm]	48.0	48.0	48.0	48.0	48.0
Max PS Pathloss [dB]	139.8	137.4	135.0	131.4	137.0
Max Cell Radius [km]	0.402	0.348	0.300	0.240	0.339
Intersite distance [km]	0.696	0.603	0.520	0.416	0.587

Table J.6 presents the results of the UL and DL cell radius calculations, aiming at identifying the limitative links and comparing the results.

From this table DL reveals to be the limitative link for both PS 128 kbps and PS 384 kbps. The cell radius difference between UL and DL for PS 128 kbps is not, however, so significant as in PS 384 kbps. PS 384 kbps is the most limitative radio bearer, followed by PS 128 kbps and Speech.

Table J.6 – Cell radius and limitative link for reference services.

	Radio Bearer				
	12.2 kbps	PS 64 kbps	PS 128 kbps	PS 384 kbps	CS 64 kbps
UL Cell Radius [kbps]	0.306	0.315	0.315	0.315	0.309
DL Cell Radius [kbps]	0.402	0.348	0.300	0.240	0.339
Cell Radius [km]	0.306	0.315	0.300	0.240	0.309
Limitative Link	UL	UL	DL	DL	UL
Intersite Distance	0.530 km	0.546 km	0.520 km	0.416 km	0.535 km

Cell radius was calculated with COST 231-Walfisch Ikegami with the set of parameters used in the simulations for dense urban scenario, which are presented in Table J.7.

Table J.7 – Propagation Model parameterisation.

Parameter	Value
f [MHz]	1945
W_B [m]	75
H_B [m]	23
h_b [m]	27
h_m [m]	1.5
ϕ[º]	90
W_s [m]	10
H_{roof}	3

Annex K

Additional Statistical Results of the Simulations

In this annex, one presents additional graphical representations of both input and output data of the simulations, performed and serve as a complement to the information presented in Chapter V.

Mobility characterisation of the reference scenarios

Figure K.1 presents the CDF for the users' generated in the reference scenarios. In that figure each line is identified by a label with that indicates the scenario (Benfica, Moscavide, etc.) and the percentage of vehicular users (100Veh, 70Veh, 30Veh or 0Veh) generated in the test scenario.

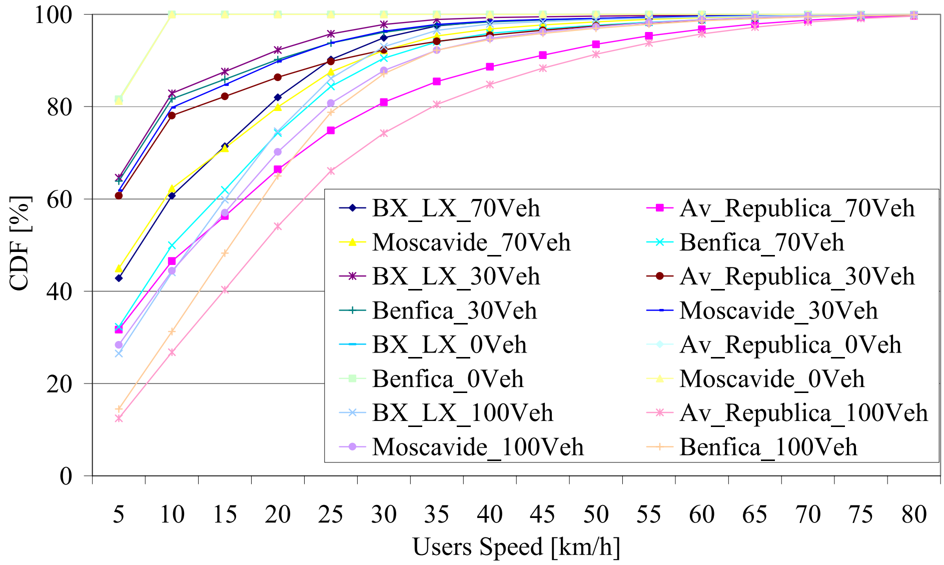


Figure K.1– Users Speed CDF in the reference scenarios.

- **Reference scenarios additional statistical data analysis**

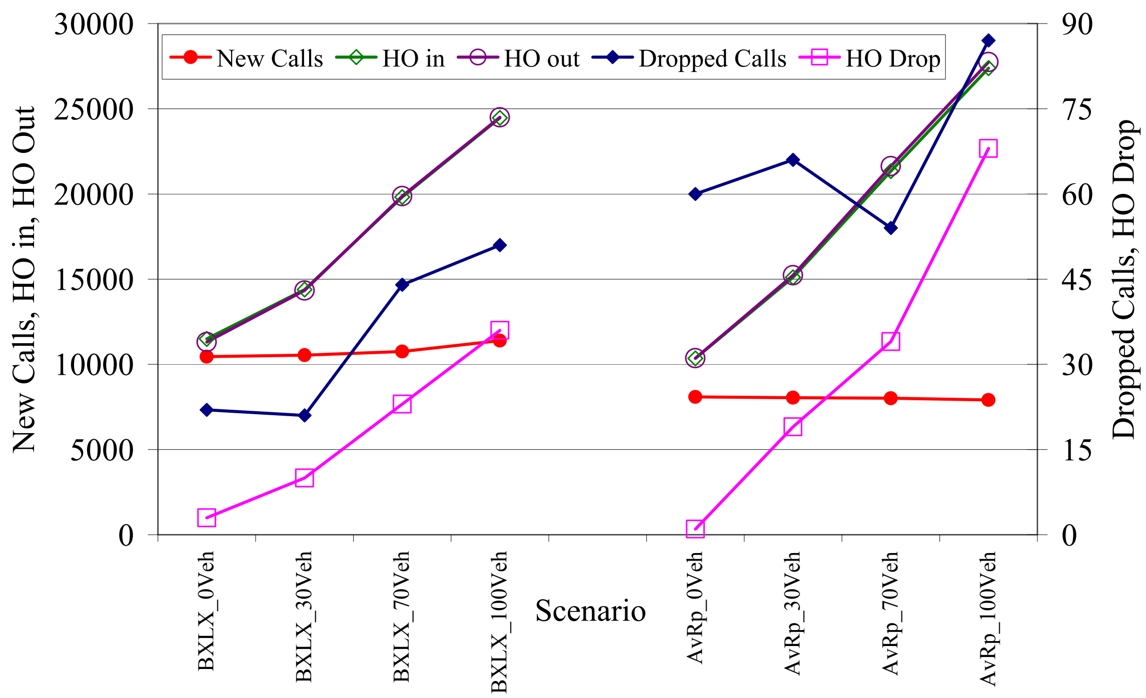


Figure K.2 – Statistical Data for reference scenarios (BxLx and AvRp).

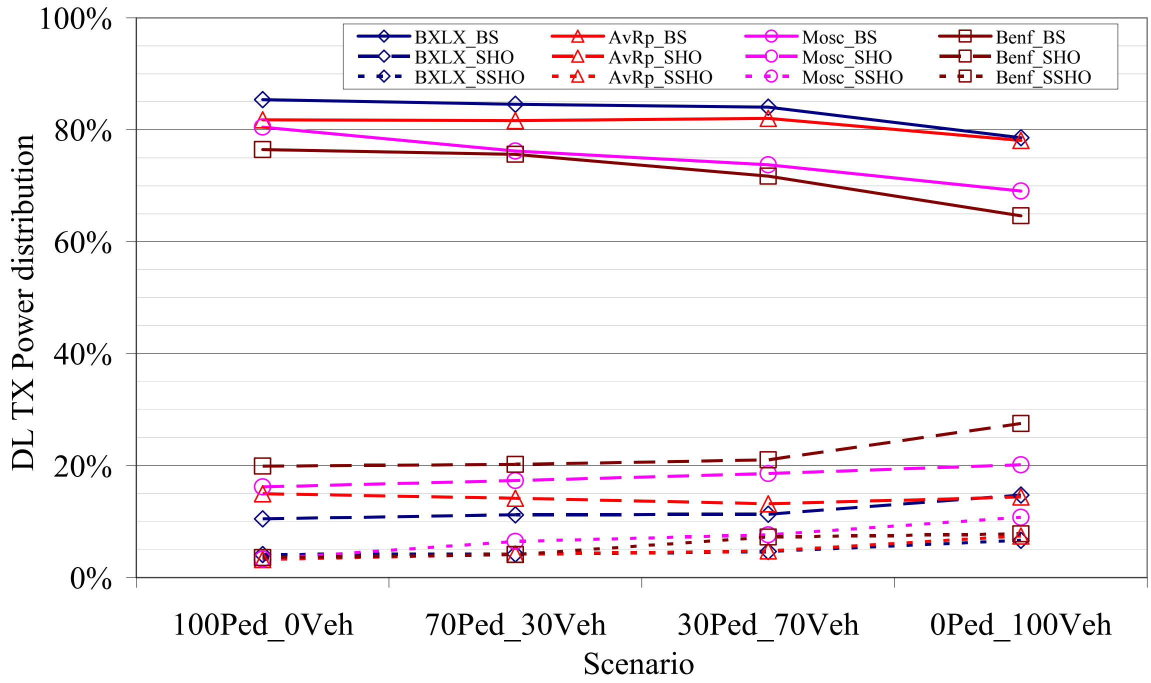


Figure K.3 – BS, SHO and SHO radio links power weight in reference scenarios.

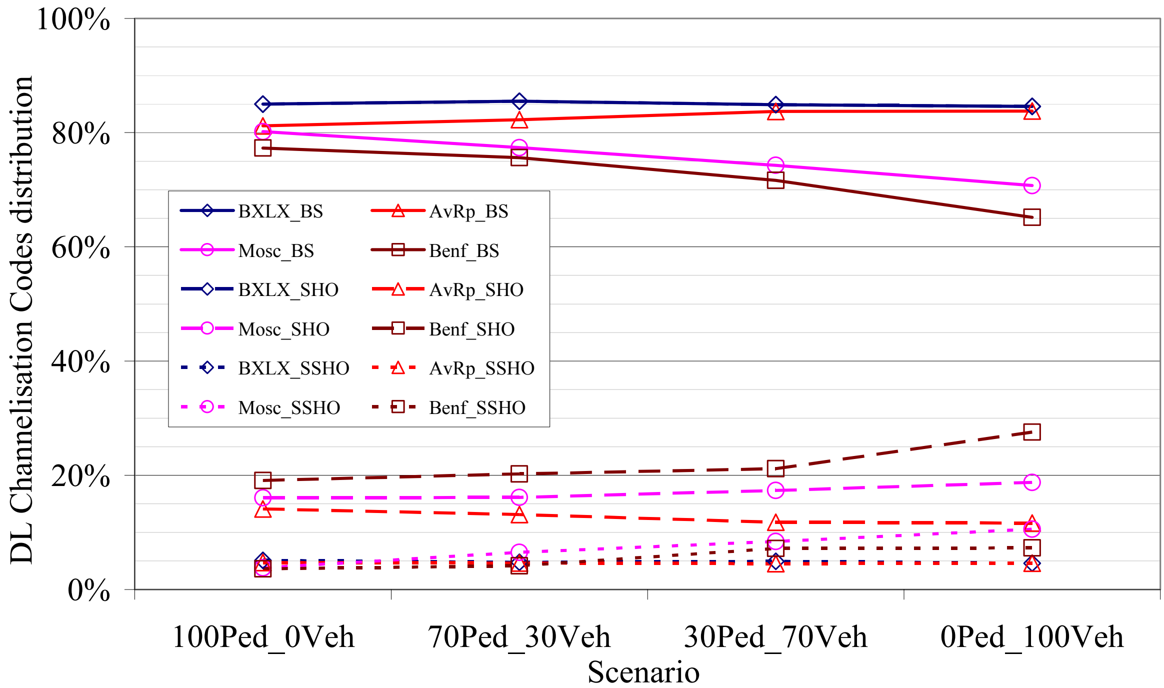


Figure K.4 – DL channelisation codes weight per BS, SHO and SHO radio links in reference scenarios.

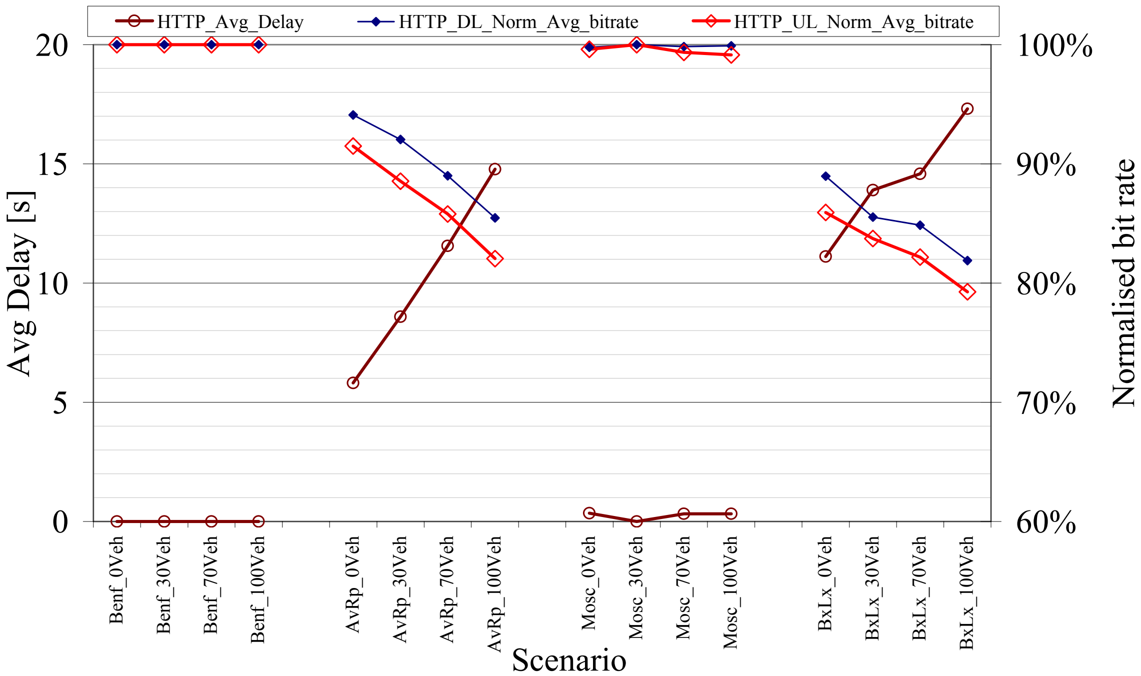


Figure K.5 – HTTP performance indicators (all reference scenarios).

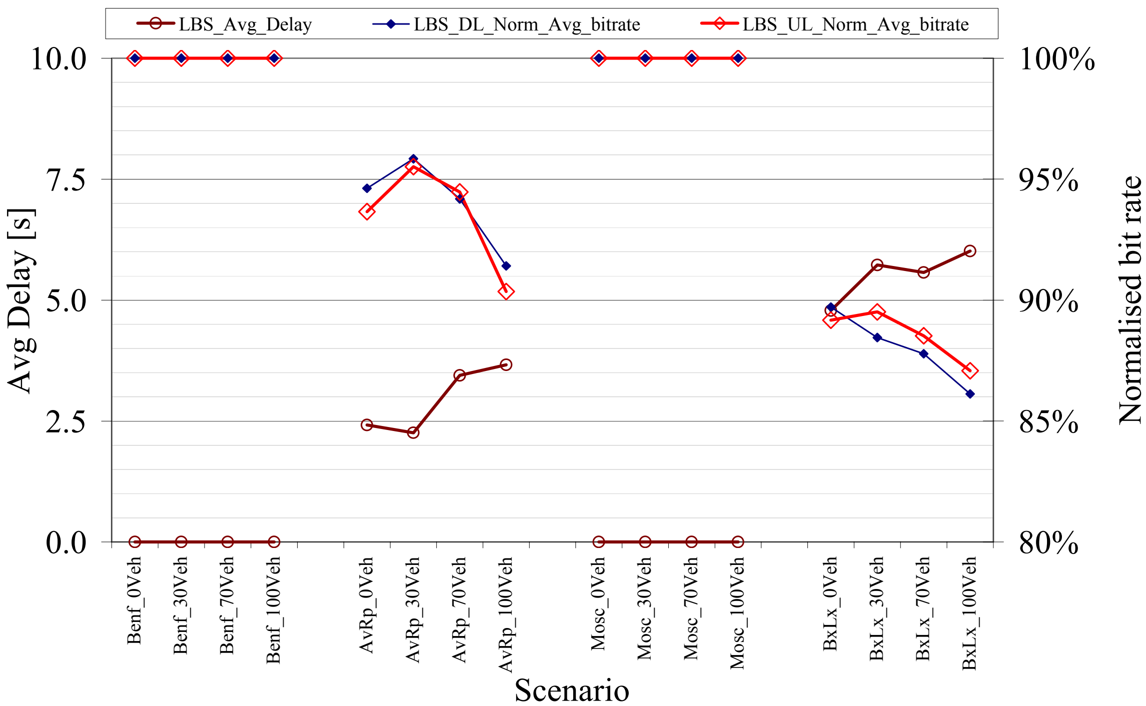


Figure K.6 – LBS performance indicators (all reference scenarios).

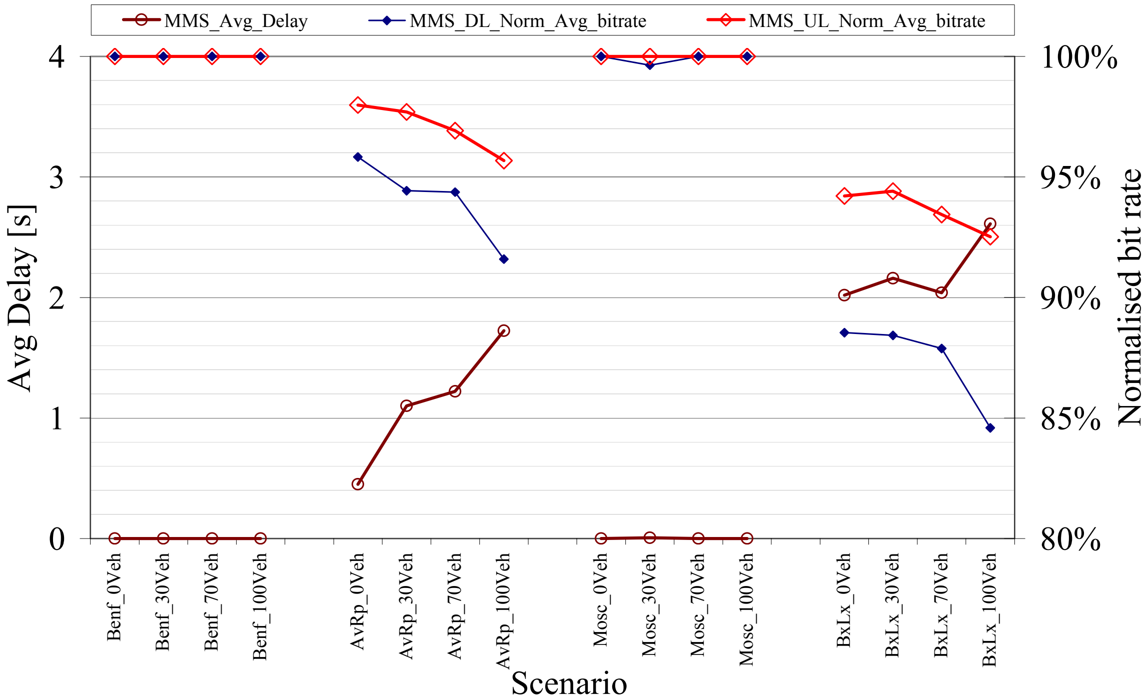


Figure K.7 – MMS performance indicators (all reference scenarios).

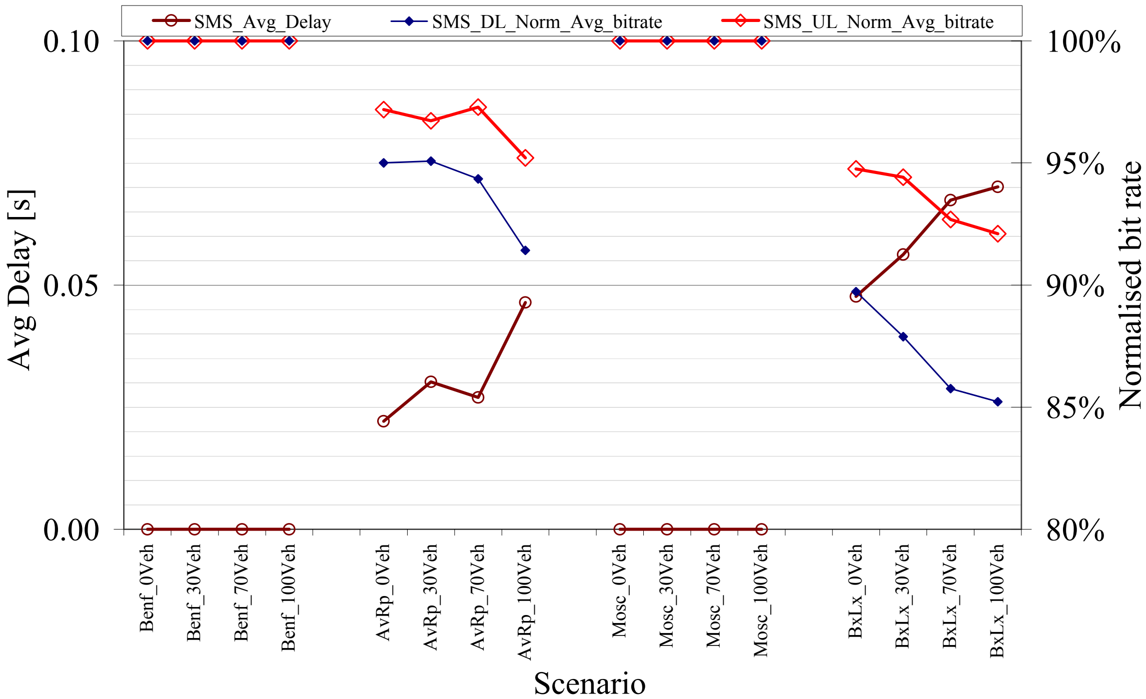


Figure K.8 – SMS performance indicators (all reference scenarios).

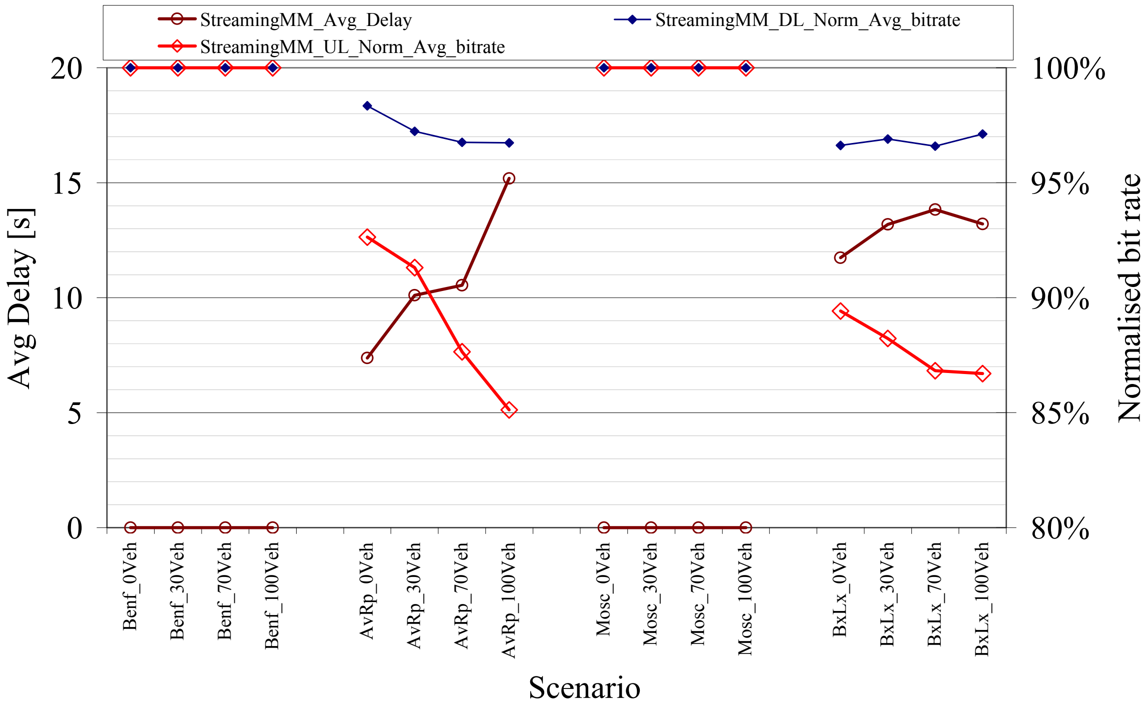


Figure K.9 – StreamingMM performance indicators (all reference scenarios).

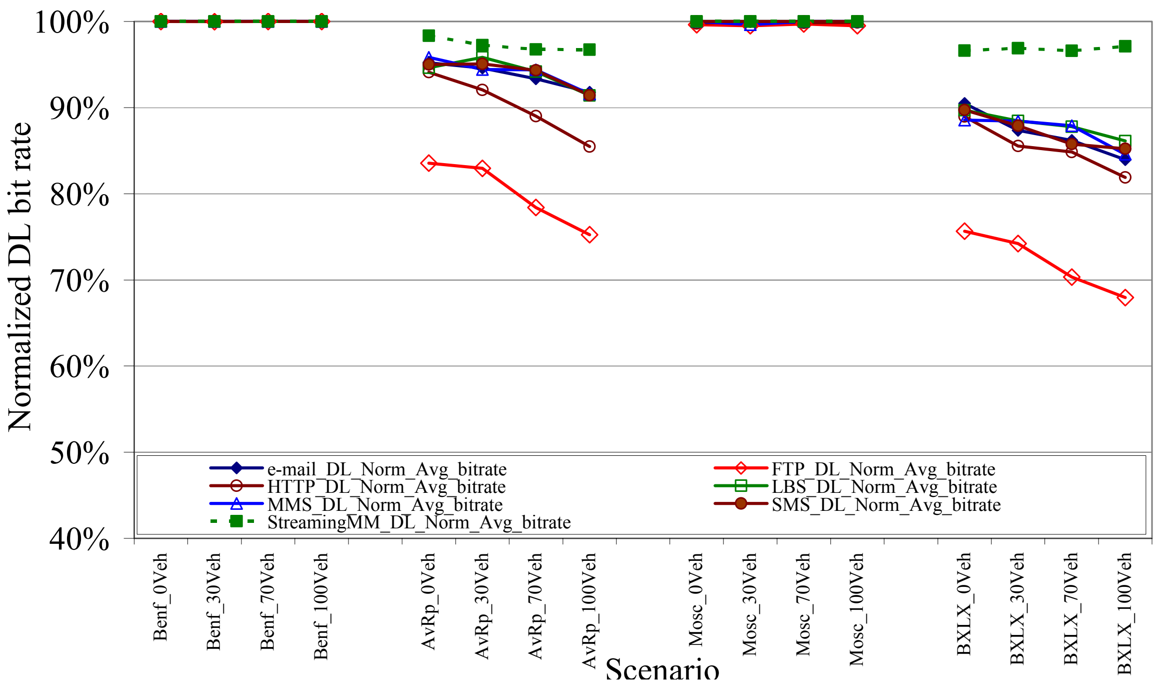


Figure K.10 – Average normalised DL bit rate in reference scenarios.

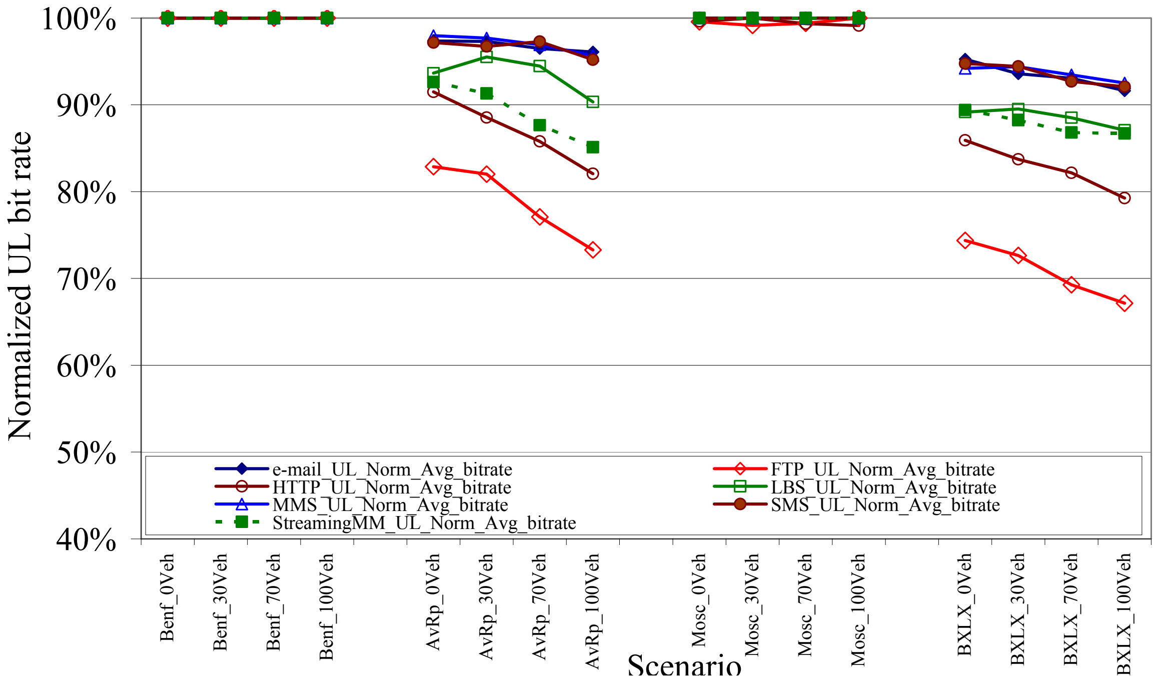


Figure K.11 – Average normalised UL bit rate in reference scenarios.

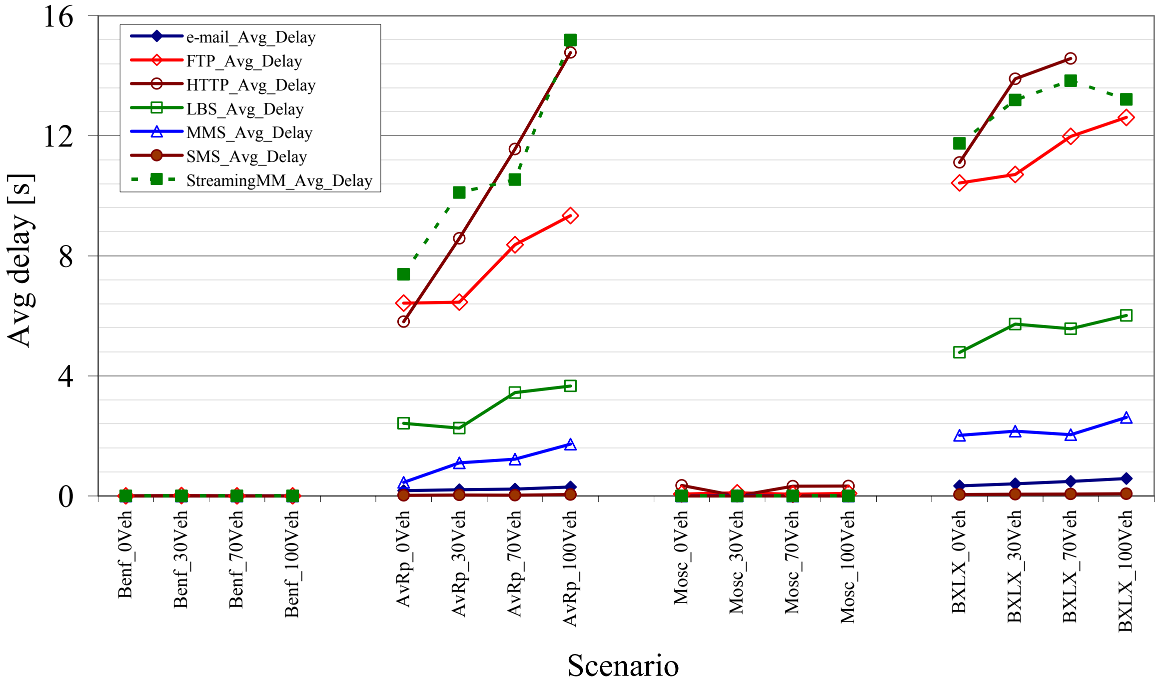


Figure K.12 – Average applications delay in reference scenarios.

- **PS Services Characterisation**

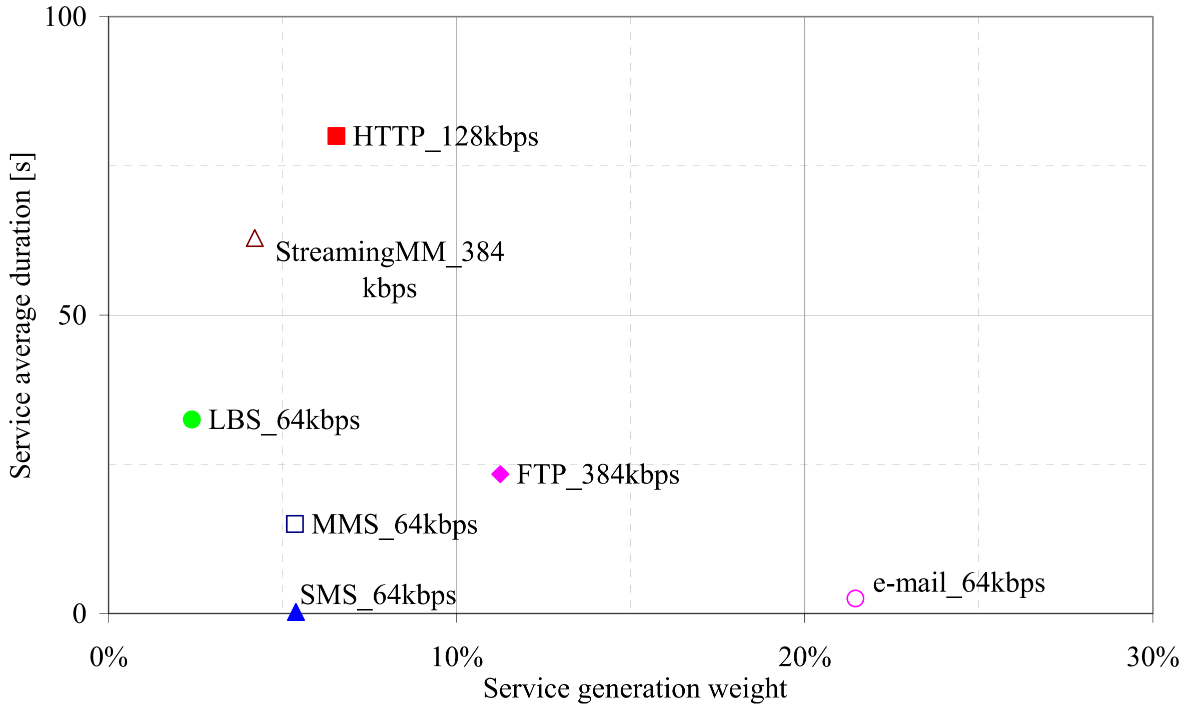


Figure K.13 – Average PS services duration vs generation weight.

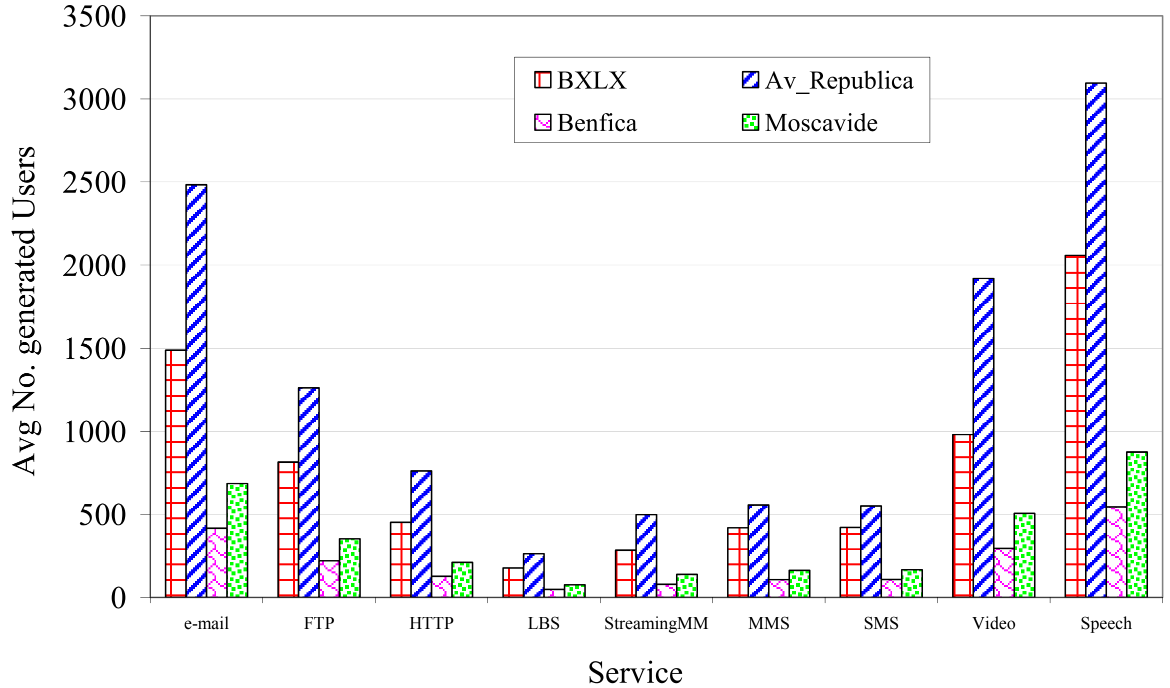


Figure K.14 – Average number of users generated per service and scenario.

- **Users distributions per Indoor location**

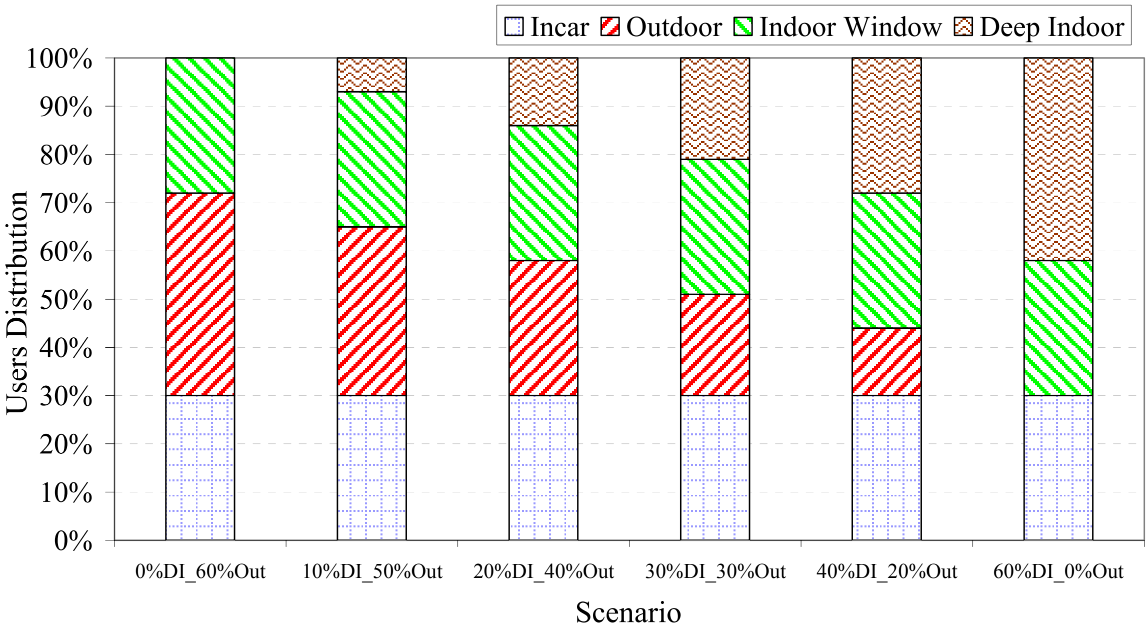


Figure K.15 – Users Indoor scenario distribution for 30% Vehicular scenario.

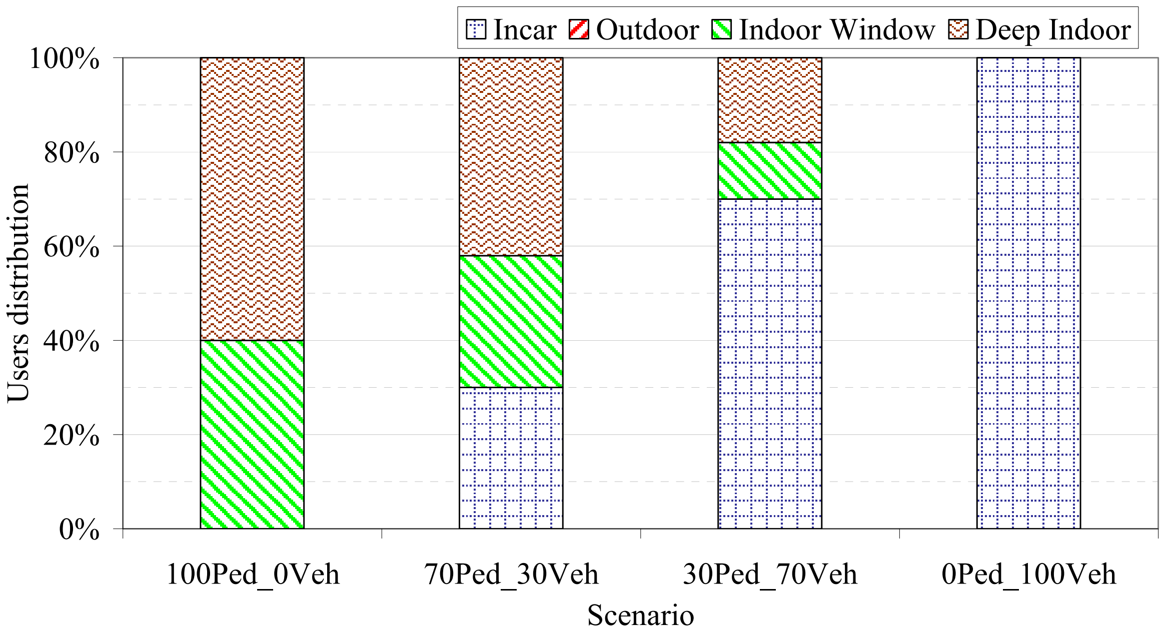


Figure K.16 – Users Indoor distribution for 60% Deep Indoor / 0% Outdoor combinations.

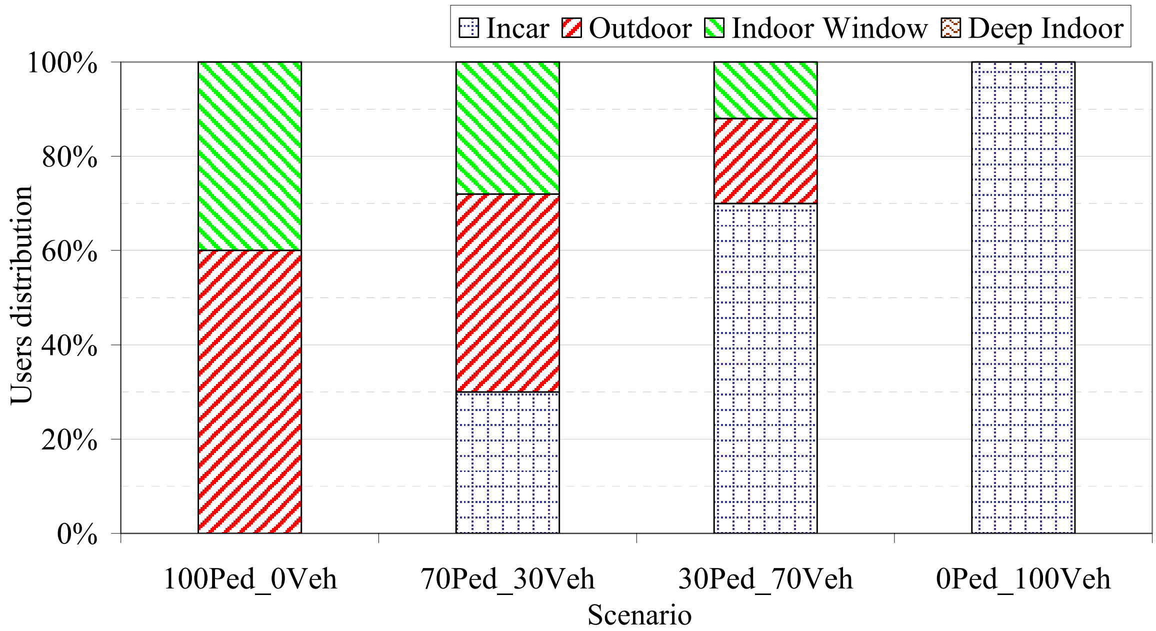


Figure K.17 – Users Indoor distribution for 0% Deep Indoor / 60% Outdoor combinations.

- **Differentiated indoor location scenarios statistical data analysis**

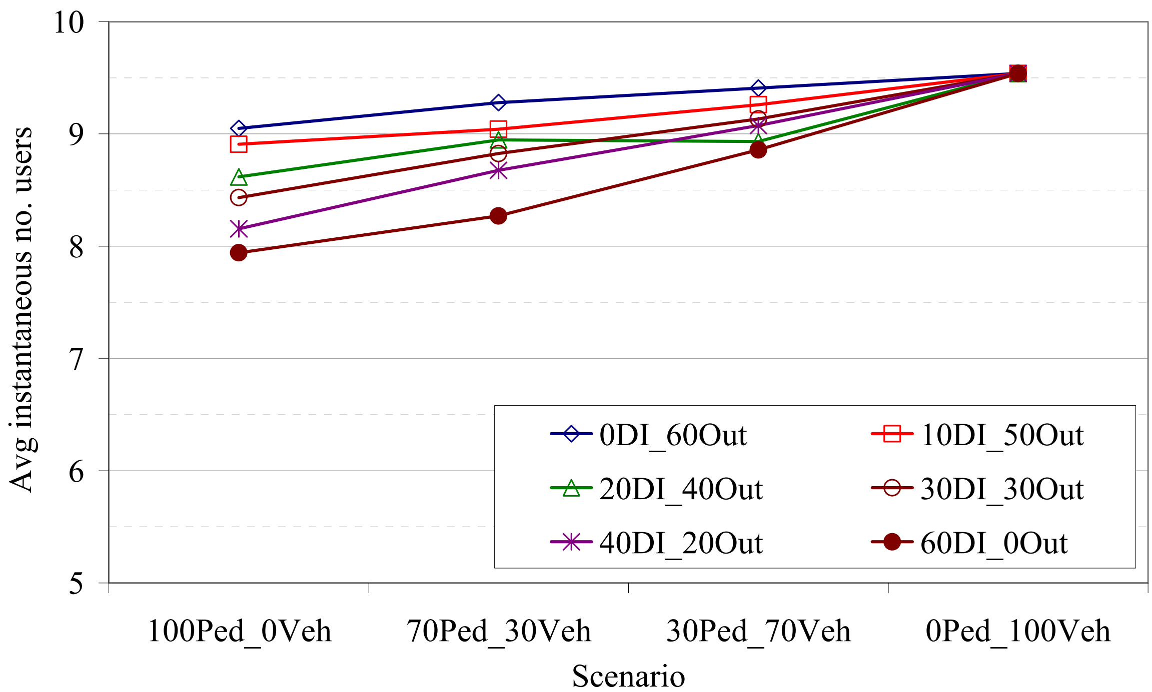


Figure K.18 – Avg instantaneous no. of users per cell in distinct Indoor locations' distributions (BxLx).

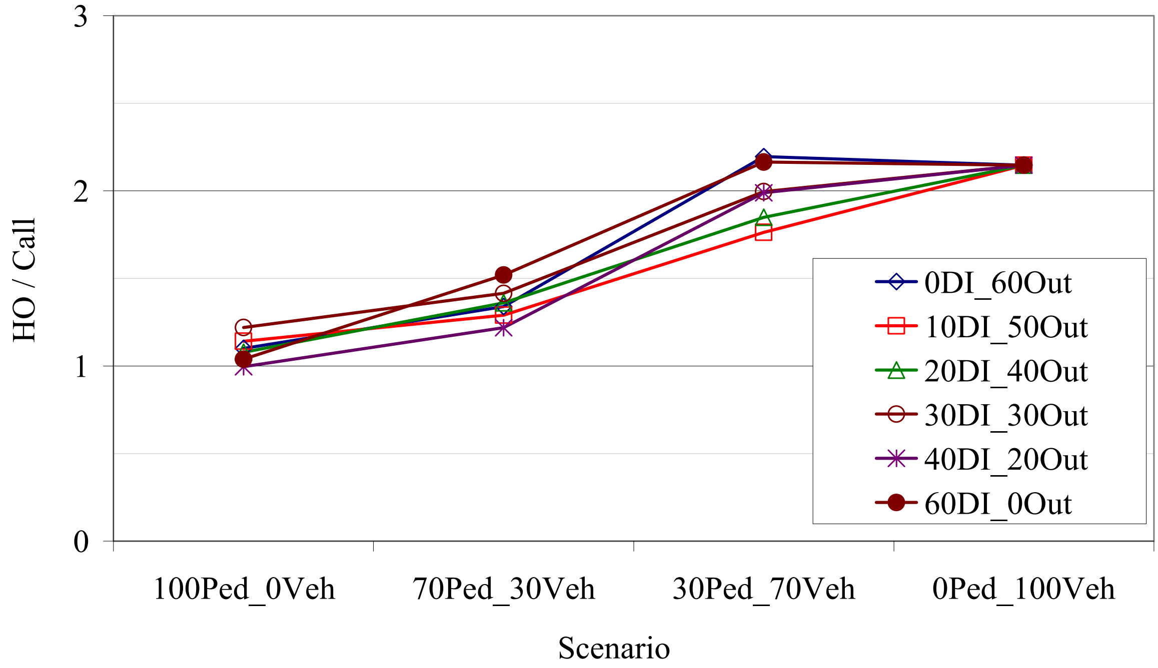


Figure K.19 – HO / Call variation in distinct Indoor locations' distributions (BxLx).

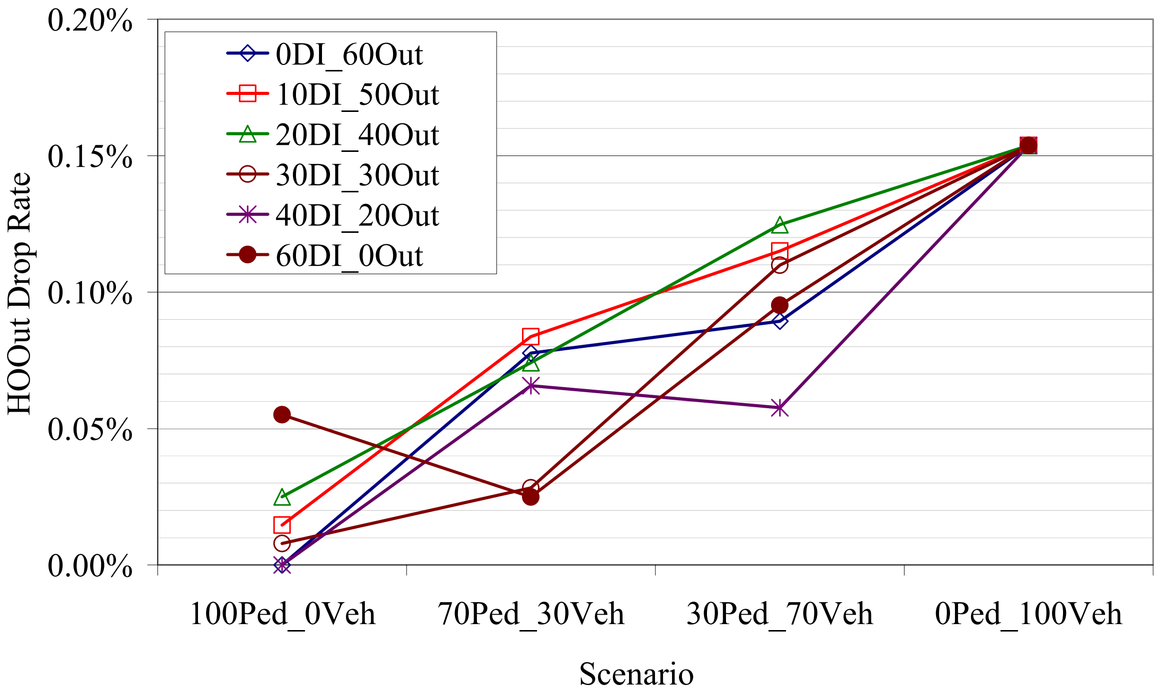


Figure K.20 – Outgoing HO drop rate variation in distinct Indoor locations' distributions (BxLx).

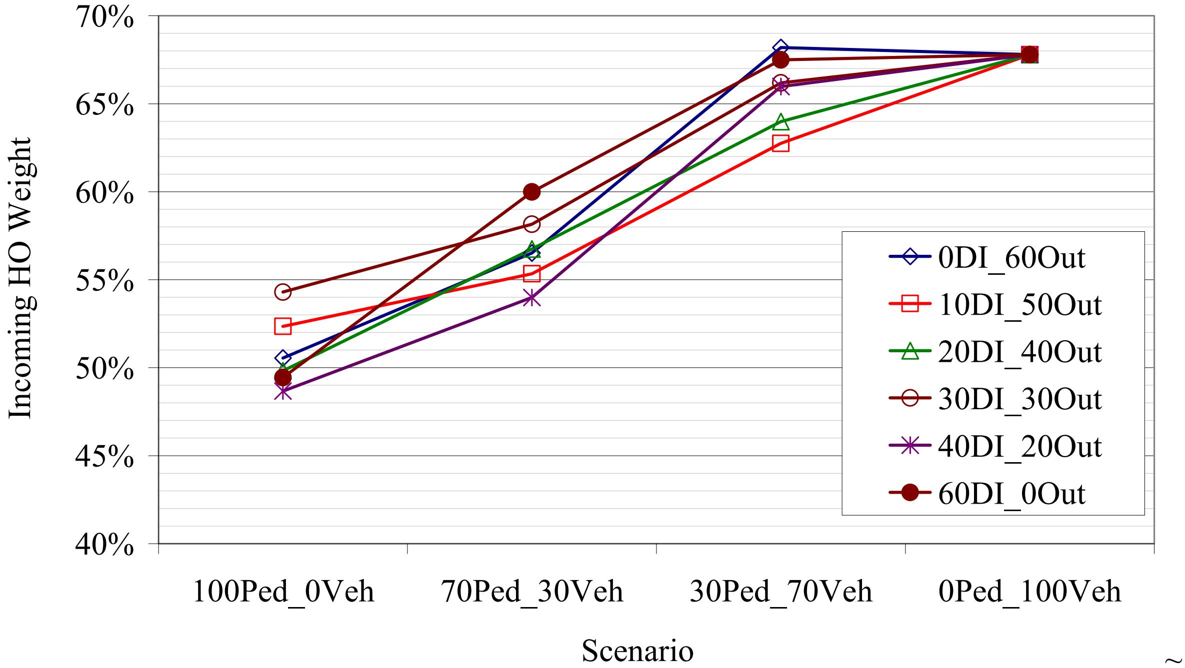


Figure K.21 – Incoming HO weight variation in distinct Indoor locations' distributions (BxLx).

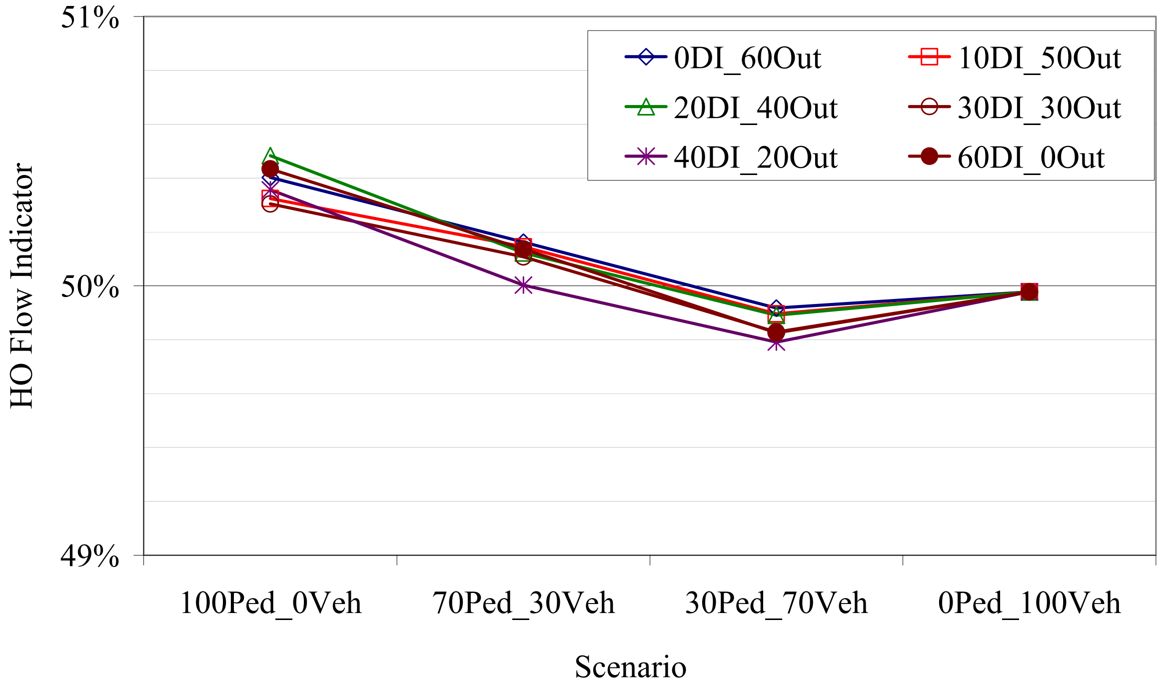


Figure K.22 – HO flow indicator variation in distinct Indoor locations' distributions (BxLx).

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