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Advanced Performance Analysis of GSM and UMTS Radio Networks

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To my parents, sister, girlfriend and friends

"Without hard work, nothing grows but weeds."

(Gordon B. Hinckley)

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Abstract

The main purpose of this thesis was to study and analyse a mobile operator radio network, GSM and UMTS, in order to optimise it in terms of performance on coverage, quality of service and capacity, in collaboration with Ericsson. For this purpose, a list of Key Performance Indicators (KPIs) was provided. Algorithms were developed in order to process the data collected from the database and the output results, in order to evaluate the KPIs with the ultimate goal of establishing a correlation between them. The results from January 2010, show that the throughput KPIs are those that have a more unsatisfactory performance. EDGE DL throughput has an average value of 27.77 kbps, a standard deviation of 36.93 kbps, and a ratio of total number of problematic BSs multiplied by the number of problematic hours over the total number of BSs multiplied by the total number of hours of 6.74%. The correlation between CDR and HSR is a good example of the successful application of the developed models, with a value of 91.24% in BS 2. The process of establishing correlations had better results in GSM due to the technical specifications related to the UMTS that hinder this type of analysis.

Keywords

GSM, UMTS, KPI, Correlation, Capacity, Interference

Resumo

O principal objectivo desta tese foi estudar e analisar a rede rádio de um operador móvel, GSM e UMTS, com o intuito de optimizar a sua performance ao nível de cobertura, qualidade de serviço e capacidade, em colaboração com a Ericsson. Para isso, uma lista de *Key Performance Indicators* (KPIs) foi fornecida. Foram desenvolvidos algoritmos de modo a processar os dados recolhidos de uma base de dados e os resultados obtidos, de modo a avaliar os KPIs, com o objectivo final de estabelecer uma correlação entre eles. Os resultados de Janeiro de 2010, mostram que os KPIs de *throughput* são aqueles cuja performance é mais insatisfatória. EDGE DL throughput tem um valor médio de 27.77 kbps, um desvio padrão de 36.93 kbps e um valor de número total de EBs problemáticas multiplicado pelo número de horas problemáticas sobre o número total de EBs multiplicado pelo número total de horas de 6.74%. A correlação entre CDR e HSR é um bom exemplo da aplicação bem sucedida dos modelos desenvolvidos, com um valor de 91.24% na EB 2. O processo de estabelecimento de correlações entre KPIs teve melhores resultados em GSM devido às especificações técnicas relacionadas com UMTS que dificultam este tipo de análise.

Palavras-chave

GSM, UMTS, KPI, Correlação, Capacidade, Interferência

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List of Acronyms

3G	Third Generation
3GPP	Third Generation Partnership Project
ASE	Air Speech Equivalent
BCCH	Broadcast Control Channel
BS	Base Station
BSC	Base Station Controller
BSS	Base Station Subsystem
BTS	Base Transceiver Station
CIR	Carrier to Interference
CN	Core Network
CP	Central Processor
CS	Circuit Switch
DL	Downlink
DS-CDMA	Direct-Sequence CDMA
DTX	Discontinuous Transmission
E-AGCH	E-DCH Absolute Grant Channel
E-DCH	Enhanced Dedicated Channel
EDGE	Enhanced Data for GSM Evolution
E-DPCCH	Enhanced DPCCH
E-DPDCH	E-DCH Dedicated Physical Data Channel
E-HICH	E-DCH HARQ Indicator Channel
E-RGCH	E-DCH Relative Grant Channel
FACH	Forward Access Channel
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FER	Frame Error Ratio
GGSN	Gateway GPRS Support Node
GMSC	Gateway MSC
GMSK	Gaussian Minimum Shift Keying
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HARQ	Hybrid Automatic Repeat Request
HLR	Home Location Register
HO	Handover

HS	High Speed
HSys	Home System
HSDPA	High Speed Downlink Packet Access
HS-DPCCH	High-Speed Dedicated Physical Control Channel
HS-DSCH	High-Speed Downlink Shared Channel
HSPA	High Speed Packet Access
HS-PDSCH	High-Speed Physical Downlink Shared Channel
HS-SCCH	High-Speed Shared Control Channel
HSUPA	High Speed Uplink Packet Access
HW	Hardware
IRAT HO	Inter-Radio Access Technology HO
KPI	Key Performance Indicator
LLC	Logical Link Control
MAC	Medium Access Control
MDB	Measurement Database
ME	Mobile Equipment
MO	Managed Objects
MS	Mobile Station
MSC	Mobile Switching Centre
MT	Mobile Terminal
O&M	Operation and Maintenance
OSS	Operation and Support System
OVSF	Orthogonal Variable Spreading Factor
PDCH	Packet Data Channel
PDU	Protocol Data Unit
PLMN	Public Land Mobile Network
PS	Packet Switch
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RAB	Radio Access Bearer
RAN	Radio Access Network
RL	Radio Link
RLC	Radio Link Control
RNC	Radio Network Controller
RRC	Radio Resource Control
RRM	Radio Resource Management
RSSI	Received Signal Strenght Indicator
RXQUAL	Received Quality of Speech
SC	Scrambling Code
SDCCH	Stand-Alone Dedicated Control Channel

SF	Spreading Factor
SGSN	Serving GPRS Support Node
SHO	Soft HO
SMS	Short Message Service
SQL	Structured Query Language
SQS	Speech Quality Supervision
SRB	Signalling Radio Bearer
STS	Statistics and Traffic Measurement Subsystem
SW	Software
TA	Timing Advance
TCH	Traffic Channel
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
THP	Traffic Handling Priority
TN	Transport Network
TS	Time Slot
TTI	Transmission Time Interval
UE	User Equipment
UL	Uplink

List of Symbols

$D_{E_{BGE_{DL}}}$	Accumulated total LLC data received on the downlink in EDGE mode transfers for QoS class Background
$D_{E_{BGE_{UL}}}$	Accumulated total LLC data received on the uplink in EDGE mode transfers for QoS class Background
$D_{E_{THP1_{DL}}}$	Amount of IP data for all downlink EDGE mode transfers for QoS class Interactive THP1
$D_{E_{THP1_{UL}}}$	Amount of IP data for all uplink EDGE mode transfers for QoS class Interactive THP1
$D_{E_{THP2_{DL}}}$	Amount of IP data for all downlink EDGE mode transfers for QoS class Interactive THP2
$D_{E_{THP2_{UL}}}$	Amount of IP data for all uplink EDGE mode transfers for QoS class Interactive THP2
$D_{E_{THP3_{DL}}}$	Amount of IP data for all downlink EDGE mode transfers for QoS class Interactive THP3
$D_{E_{THP3_{UL}}}$	Amount of IP data for all uplink EDGE mode transfers for QoS class Interactive THP3
$D_{G_{BGG_{DL}}}$	Accumulated total LLC data received on the downlink in GPRS mode transfers for QoS class Background
$D_{G_{BGG_{UL}}}$	Accumulated total LLC data received on the uplink in GPRS mode transfers for QoS class Background
$D_{G_{THP1_{DL}}}$	Amount of IP data for all downlink GPRS mode transfers for QoS class Interactive THP1
$D_{G_{THP1_{UL}}}$	Amount of IP data for all uplink GPRS mode transfers for QoS class Interactive THP1
$D_{G_{THP2_{DL}}}$	Amount of IP data for all downlink GPRS mode transfers for QoS class Interactive THP2
$D_{G_{THP2_{UL}}}$	Amount of IP data for all uplink GPRS mode transfers for QoS class Interactive THP2
$D_{G_{THP3_{DL}}}$	Amount of IP data for all downlink GPRS mode transfers for QoS class Interactive THP3
$D_{G_{THP3_{UL}}}$	Amount of IP data for all uplink GPRS mode transfers for QoS class Interactive THP3
$N_{MS_{SDCCH_S}}$	Successful Mobile Station channel establishments on SDCCH
$N_{samples_{PS_{RLC_{DL}}}}$	Number of RLC Downlink Samples
$N_{samples_{PS_{RLC_{UL}}}}$	Number of RLC Uplink Samples
$N_{Ab\_RAB_R}$	Number of Abnormal RAB speech releases
$N_{BS_{Total}}$	Total number of BSs
$N_{CS64Ab\_RAB_R}$	Number of Abnormal RAB CS64 releases.

$N_{CS64RAB_R}$	Total number of all the RAB CS64 releases
$N_{C_{min}}$	Minimum number of calls
$N_{HOI_{DL}}$	Number of intra cell handover attempts (decisions) at bad downlink quality
$N_{HOI_{DL\_UL}}$	Number of intra cell handover attempts (decisions) for both links with bad quality
$N_{HOI_{UL}}$	Number of intra cell handover attempts (decisions) at bad uplink quality
N_{HO_I}	Number of successful intra cell handovers
$N_{HO_{MS}}$	Number of handover commands sent to the MS
N_{HO_N}	Number of successful handover to the neighbouring cell
$N_{Hours_{Total}}$	Total number of hours
$N_{IRAT\_HO_{S_O}}$	Number of all the success of outgoing (to GSM) IRAT for RAB Speech and Multi RAB
$N_{IRAT\_HO_{A_I}}$	Number of total of incoming IRAT Handover Successful attempts for CS RAB total attempts
$N_{IRAT\_HO_{A_O}}$	Number of total of outgoing (to GSM) IRAT for RAB Speech and Multi RAB attempts
$N_{IRAT\_HO_{S_I}}$	Number of incoming IRAT Handover Successful attempts for CS RAB
$N_{MS_{TCH_A}}$	Number of first assignment attempts on TCH for all MS power classes
$N_{MS_{FR}}$	Number of assignment complete messages for all MS power classes in underlaid subcell, full-rate
$N_{MS_{HR}}$	Number of assignment complete messages for all MS power classes in underlaid subcell, half-rate
N_{PDCH_A}	Number of packet channel allocation attempts
N_{PDCH_F}	Number of packet channel allocation failures
$N_{Problematic\_Hours_{BS}}$	Number of problematic hours per BS
$N_{RAB\_PS\_DCH\_FACH_R}$	Total number of all the RAB PS DCH/FACH releases
$N_{RAB\_PS\_HSDPA_R}$	Total number of all the RAB PS HSDPA releases
$N_{RABAb\_PS\_DCH\_FACH_R}$	Number of all the abnormal RAB PS DCH/FACH releases
$N_{RABAb\_PS\_HSDPA_R}$	Number of all the abnormal RAB PS HSDPA releases
N_{RAB_R}	Total number of all the RAB speech releases
N_{RL_A}	Total number of RL addition attempts
N_{RL_S}	Total number of RL addition success
N_{SDCCH_D}	Total number of dropped SDCCH channels in a cell
N_{TCH_D}	Total amount of TCH drops
$N_{samples_{HS_{RLC}}}$	Number of RLC HS Samples
N_C	Total number of terminated calls in a cell
$N_{Problematic\_BS}$	Total number of problematic BSs

R_{C_D}	Call Drop Rate
$R_{CS64\_RAB_S}$	RAB Establishment Success Rate for CS64
R_{CS64C_D}	CS64 Call Drop Rate
R_{CS64_S}	CS64 Call Setup Success Rate
R_{CSRRC_S}	CS RRC Success Rate
R_{CS_S}	Call Setup Success Rate
R_{HO_S}	Handover Success Rate
$R_{HSDPA\_IC_D}$	HSDPA Interactive Call Drop Rate
$R_{HSDPA\_ICS_S}$	HSDPA Interactive Call Setup Success Rate
$R_{IRAT\_HOS_I}$	IRAT CS Handover Success Rate Incoming
$R_{IRAT\_HOS_O}$	IRAT CS Handover Success Rate Outgoing
R_{PDCH_S}	Packet Data Channel Assignment Success Rate
$R_{PSR99\_IC_D}$	PS R99 Interactive Call Drop Rate
$R_{PSR99\_ICS_S}$	PS R99 Interactive Call Setup Success Rate
R_{PSRRC_S}	PS RRC Success Rate
$R_{RAB\_PS\_DCH\_FACH_S}$	RAB Establishment Success Rate PS DCH/FACH
$R_{RAB\_PS\_HS_S}$	RAB Establishment Success Rate PS HS
R_{RAB_S}	RAB Establishment Success Rate Speech
R_{SC_D}	Speech Call Drop Rate
R_{SCS_S}	Speech Call Setup Success Rate
R_{SDCCH_D}	SDCCH Drop Rate
R_{SDCCH_D}	Percentage for drop on SDCCH
R_{SHO_S}	Soft Handover Success Rate
R_{TCH_F}	TCH Assignment Failure Rate
$T_{EDGE_{DL}}$	EDGE Downlink Throughput
$T_{EDGE_{UL}}$	EDGE Uplink Throughput
$T_{GPRS_{DL}}$	GPRS Downlink Throughput
$T_{GPRS_{UL}}$	GPRS Uplink Throughput
$T_{HS_{RLC}}$	RLC HSDPA Throughput
T_{HSDPA}	HSDPA Interactive User Throughput
$T_{PSR99_{DL}}$	PS R99 Interactive Downlink User Throughput
$T_{PSR99_{UL}}$	PS R99 Interactive Uplink User Throughput
$T_{PS_{RLC_{DL}}}$	RLC Downlink Throughput
$T_{PS_{RLC_{UL}}}$	RLC Uplink Throughput
$TD_{E_{BGE_{UL}}}$	Accumulation of (LLC throughout x LLC data volume) for all uplink EDGE mode transfers for QoS class Background

$TD_{E_{BGG_{DL}}}$	Accumulation of (LLC throughout x LLC data volume) for all downlink EDGE mode transfers for QoS class Background
$TD_{E_{THP1_{DL}}}$	Accumulation of (LLC throughput x LLC data volume) for all downlink EDGE mode transfers for QoS class Interactive THP1
$TD_{E_{THP1_{UL}}}$	Accumulation of (LLC throughput x LLC data volume) for all uplink EDGE mode transfers for QoS class Interactive THP1
$TD_{E_{THP2_{DL}}}$	Accumulation of (LLC throughput x LLC data volume) for all downlink EDGE mode transfers for QoS class Interactive THP2
$TD_{E_{THP2_{UL}}}$	Accumulation of (LLC throughput x LLC data volume) for all uplink EDGE mode transfers for QoS class Interactive THP2
$TD_{E_{THP3_{DL}}}$	Accumulation of (LLC throughput x LLC data volume) for all downlink EDGE mode transfers for QoS class Interactive THP3
$TD_{E_{THP3_{UL}}}$	Accumulation of (LLC throughput x LLC data volume) for all uplink EDGE mode transfers for QoS class Interactive THP3
$TD_{G_{BGG_{DL}}}$	Accumulation of (LLC throughout x LLC data volume) for all downlink GPRS mode transfers for QoS class Background
$TD_{G_{BGG_{UL}}}$	Accumulation of (LLC throughout x LLC data volume) for all uplink GPRS mode transfers for QoS class Background
$TD_{G_{THP1_{DL}}}$	Accumulation of (LLC throughput x LLC data volume) for all downlink GPRS mode transfers for QoS class Interactive THP1
$TD_{G_{THP1_{UL}}}$	Accumulation of (LLC throughput x LLC data volume) for all uplink GPRS mode transfers for QoS class Interactive THP1
$TD_{G_{THP2_{DL}}}$	Accumulation of (LLC throughput x LLC data volume) for all downlink GPRS mode transfers for QoS class Interactive THP2
$TD_{G_{THP2_{UL}}}$	Accumulation of (LLC throughput x LLC data volume) for all uplink GPRS mode transfers for QoS class Interactive THP2
$TD_{G_{THP3_{DL}}}$	Accumulation of (LLC throughput x LLC data volume) for all downlink GPRS mode transfers for QoS class Interactive THP3
$TD_{G_{THP3_{UL}}}$	Accumulation of (LLC throughput x LLC data volume) for all uplink GPRS mode transfers for QoS class Interactive THP3

List of Software

Microsoft Word	Text editor tool
Microsoft Excel	Calculation tool
Microsoft Visio	Design tool (e.g., flowcharts, diagrams, etc.)
MySQL	Relational database management tool
Matlab	Computational math tool
MapInfo	Geographic Information Systems (GIS) software

Chapter 1

Introduction

This chapter gives a brief overview of the work. Before establishing work targets and original contributions, the scope and motivations are brought up. At the end of the chapter, the layout of the work is presented.

1.1 Overview and Motivation

Wireless communications is, by any measure, the fastest growing segment of the communications industry. As such, it has captured the attention of the media and the imagination of the public. Cellular networks have experienced an exponential growth for many years. Indeed, mobile phones have become a critical business tool and part of everyday life in most developed countries, as they are rapidly supplanting the old wire line systems. The explosive growth of wireless systems, coupled with the proliferation of laptop and palmtop computers, indicate a bright future for wireless networks, both as stand-alone systems and as part of the larger networking infrastructure. However, many technical challenges remain in designing robust wireless networks that deliver the performance necessary to support emerging applications [Gold05].

Second-generation (2G) telecommunication systems, such as the Global System for Mobile Communications (GSM), enabled voice traffic to go wireless, with the number of mobile phones exceeding the number of landline ones, and the mobile phone penetration going beyond 100% in several markets. However, the data-handling capabilities of 2G systems are limited, and third-generation (3G) ones were needed to provide the high bit-rate services that enable high-quality images and video to be transmitted, and to provide access to the Internet with higher data rates.

In 1999, the 3rd Generation Partnership Project (3GPP) launched Universal Mobile Telecommunication System (UMTS), one of the 3G systems, also called Release ’99, as a response to the needs of higher data rates, being usually deployed on top of GSM networks. The air interface is Wideband Code Division Multiple Access (WCDMA), featuring a data up to 384 kbps for the Downlink (DL) and Uplink (UL), despite having a theoretical maximum for DL of 2 Mbps. Although packet-data communications were already supported in this first release of the standard, an evolution emerged in 2002, Release 5, introducing the High Speed DL Packet Access (HSDPA) and bringing further enhancements to the provisioning of packet-data services, both in terms of system and end-user performance. This release enables a more realistic 2 Mbps and even beyond, with data rates up to 14Mbps. The DL packet-data enhancements of HSDPA are complemented by Enhanced UL, introduced in Release 6, also known as High Speed UL Packet Access (HSUPA). HSDPA and HSUPA are often jointly referred to as High-Speed Packet Access (HSPA), being build upon the basic structure, and with a requirement on backwards compatibility, since it is implemented on already deployed networks.

3GPP is also working to specify a new radio system called Long-Term Evolution (LTE). Release 7 and 8, solutions for HSPA evolution, will be worked in parallel with LTE development, and some aspects of LTE work are also expected to reflect on HSPA evolution. HSPA evolution in Release 7 brings a maximum throughput of 28 Mbps in DL and 11 Mbps in UL, [HoTo07]. LTE will then push further the peak rates beyond 100 Mbps in DL and 50 Mbps in UL by using a 20 MHz bandwidth and 2x2 MIMO, and beyond 300 Mbps in DL by using a 40 MHz bandwidth and 4x4 MIMO instead of a 5MHz one as in HSPA, Figure 1.1.

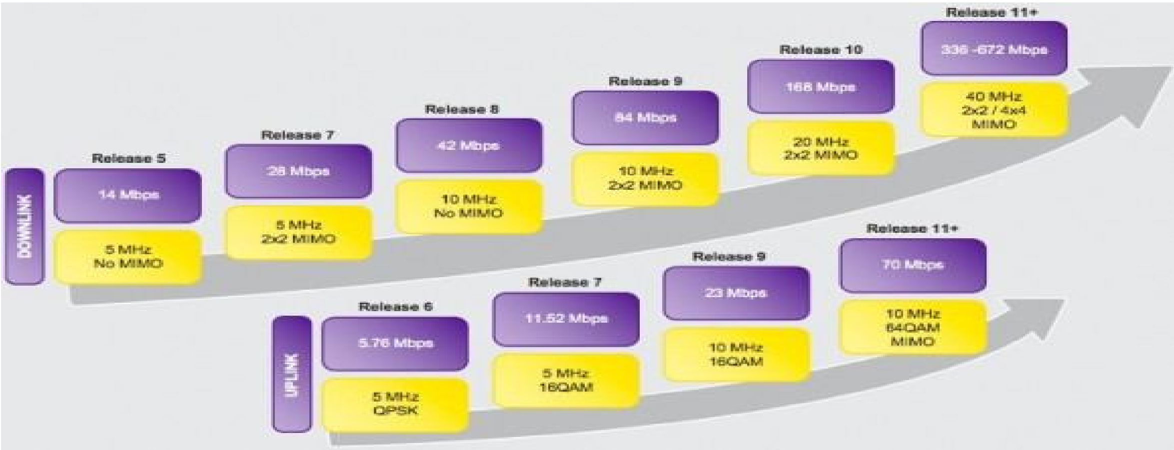

Figure 1.1 Peak data rate evolution for WCDMA (extracted from [SG11]).

In order to establish a new global platform to build the next generation (4G) of mobile services, the International Telecommunication Union (ITU) Radiocommunications Sector (ITU-R), has established a group named International Mobile Telecommunications-Advanced (IMT-Advanced). These systems include the new capabilities of IMT that go beyond those of IMT-2000 (3G systems). This new generation of mobile services will bring fast data access, unified messaging and broadband multimedia, in the form of new interactive services. Such systems provide access to a wide range of telecommunication services, including advanced services supported by mobile and fixed networks, which are packet-based [BoTa07].

In [LaNW06], an approach for the role of the radio network planning and optimisation phase into the whole UMTS mobile network business concept is given. In terms of technological expertise, mobile networks represent a heavy investment in human resources. However, not only are mobile networks technologically advanced, but the technology has to be fine-tuned to meet demanding coverage, quality, traffic and economic requirements. Operators naturally expect to maximise the economic returns from their investment in the network infrastructure, i.e., from Capital Expenditure (CAPEX). One should note two important aspects of network performance: planning and optimisation. Any network needs to be both planned and optimised.

The planning phase leads to the implementation one, where all the technical issues that have been developed by the engineer have to be implemented. When all the aspects and objectives related to the planning and implementation phases are well accomplished, the operation phase starts – the system starts to work.

Network optimisation is much easier and much more efficient if the network is already well-planned initially. A poorly laid out network will prove difficult to optimise to meet long-term business or technical expectations. Optimisation is a continuous process that is part of the operating costs of the network, i.e., its Operational Expenditure (OPEX). However, the concept of autotuning offers new opportunities for performing the optimisation process quickly and efficiently, with minimal contribution from OPEX, in order to maximise network revenues.

Operators face the following challenges in the planning of 3G networks:

- Planning means not only meeting current standards and demands, but also complying with future requirements in the sense of an acceptable development path.
- There is much uncertainty about future traffic growth and the expected proportions of different kinds of traffic and different data rates.
- New and demanding higher bit rate services require the knowledge of coverage and capacity enhancement methods, and advanced site solutions.
- Network planning faces real constraints. Operators with existing networks may have to co-locate future sites for either economic, technical or planning reasons. Greenfield operators are subject to more and more environmental and land use considerations, in acquiring and developing new sites.
- In general, all 3G systems show a certain relation between capacity and coverage, so the network planning process itself depends not only on propagation but also on cell load. Thus, the results of network planning are sensitive to capacity requirements, which makes the process less straightforward. Ideally, sites should be selected based on network analysis with the planned load and traffic/service portfolio. This requires more analysis with the planning tools and immediate feedback from the operating network. The 3G revolution forced operators to abandon the 'coverage first, capacity later' philosophy. Furthermore, because of the potential for mutual interference, sites need to be selected in groups.

The optimisation of a radio network can only be done by using performance analysis reports of the network itself. This thesis addresses this issue, in order to provide optimisation solutions to the operator.

The main purpose of this thesis is to study a way to establish an algorithm for the tuning of radio parameters in GSM/UMTS networks, in order to optimise the radio network performance on coverage, quality of service and capacity in a defined region. These objectives are accomplished through the development of a model that considers the provided Key Performance Indicators (KPIs) responsible for evaluating the radio network performance, and collects and analyses the information from the operator's database. A list of nine GSM KPIs and fourteen UMTS KPIs was provided by the operator: Call Drop Rate, SDCCH Drop Rate, Call Setup Success Rate, Handover Success Rate, GPRS DL User Throughput, GPRS UL User Throughput, EDGE DL User Throughput, EDGE UL User Throughput and PDCH Assignment Success Rate for GSM; Speech Call Setup Success Rate, CS64 Call Setup Success Rate, PS R99 Interactive Call Setup Success Rate, HSDPA Interactive Call Setup Success Rate, Speech Call Drop Rate, CS64 Call Drop Rate, PS R99 Interactive Call Drop Rate, HSDPA Interactive Call Drop Rate, Soft Handover Success Rate, IRAT HO Success Rate Outgoing, IRAT HO Success Rate Incoming, PS R99 Interactive DL User Throughput, PS R99 Interactive UL User Throughput and HSDPA Interactive User Throughput for UMTS. These KPIs were grouped according to the type of service (voice and data).

Besides the possibility of identifying the reasons that may lead the KPIs to be above/below the pre-defined threshold values, such as, bad quality, low signal strength and sudden loss of connection, the main results of the model are the establishment of correlations between different KPIs – the model enables the identification of the cases where a KPI has a poor performance due to the fact that a different KPI has also a poor performance. This means, e.g., that besides the possibility of assigning percentages to the different reasons that may lead to a voice call drop (through the combination and comparison of different radio network counters), it is also possible to identify the percentage of voice call drops due to handover (HO) issues or to control channel drops. The data parameters are also taken into account by the throughput KPIs analysis.

This thesis was made in collaboration with Ericsson. Several aspects were discussed together, including suggested values for several parameters that have been used throughout this thesis; the type and content of the results analysis had also been discussed, the presented analyses being the ones that fit better the aim of this work, therefore, providing the most relevant results.

The main contribution of this thesis is the analysis of a radio network, the identification of its problems and the possibility of providing solutions to the operator in order to improve its performance. Several algorithms were implemented in order to analyse KPIs performance and to correlate them. The models allow to analyse several radio network counters variation, enabling the identification of some critical Base Stations (BSs), as well as the associated reasons that may lead to a poor performance.

1.2 Structure of the Dissertation

This work is composed by 5 Chapters, followed by a set of Annexes.

In Chapter 2, an introduction to GSM, UMTS and HSDPA is performed. UMTS basic aspects are explained, and afterwards HSDPA new features are presented. Following this, the QoS classes of UMTS are presented as well as bit rates and applications of different services. In the last two sections, one presents the list of performance parameters that is analysed, distinguishing 2G and 3G KPIs, and the type of service, and giving a brief explanation of the counters involved in the calculation. The chapter ends with a brief state of the art.

Chapter 3 starts by presenting the database search algorithm, useful to know the precise location of the counters involved in the KPIs calculation. An algorithm to address the network analysis issues is presented next. The idea is to create an algorithm that allows facing the problem in a generalised way – identify the problem and try to offer solutions in order to fix it. The last section of the chapter provides the description of the developed models to analyse GSM and UMTS KPIs. All issues related to the implementation of the models are also in this chapter, as well as the description of the scenarios that were taken for simulations.

In Chapter 4, the query's output results are described. The results concerning January 2010 are presented, starting with the GSM analysis where the KPIs average value, standard deviation, monthly weight and the percentage of problematic BSs are identified. In the following parts of the chapter, the correlation process is implemented according to the models and algorithms developed in Chapter 3. The results are presented with some useful graphic representations and the properly explanation. The chapter ends with the results presentation and explanation of UMTS analysis.

This thesis concludes with Chapter 5, where the main conclusions of the work are drawn and suggestions for future work are pointed out.

A set of Annexes with auxiliary information and results is also included. In Annex A, Ericsson's KPIs definition is given, according to the User Description. Annex B contains the graphic results obtained from the database algorithm application. It consists of the illustration of the KPIs performance throughout seven specific days. In Annex C, the results related to the daily analysis are presented, being an introduction to the monthly analysis presented in Annex D, which contains the results presentation and explanation related to the BSs identified as problematic that were not analysed in Chapter 4.

Chapter 2

Basic Concepts

This chapter provides a brief overview of the main technologies that are related with the scope of this thesis. A brief introduction of GSM and UMTS network architecture is given, supplemented by the main characteristics of the GSM/UMTS radio interface. Later, HSDPA main features and characteristics are introduced, and current services and application in GSM/UMTS are approached. At the end of the chapter, the performance parameters that are discussed throughout this thesis are presented and described, as well as the current State-of-the-Art concerning the scope of the work.

2.1 Network Architecture

In this section, GSM and UMTS (Release 99) basic concepts are presented, based on [HoTo04] and [HarM03], regarding the network architecture and radio interface. Concerning the network architecture, more emphasis is given to the radio related modules, due to the scope of the thesis.

UMTS network is built upon GSM's. The network elements can be grouped, based on similar functionalities, into three high-level modules, which are specified by 3GPP: User Equipment (UE), UMTS Terrestrial Radio Access Network (UTRAN) and Core Network (CN).

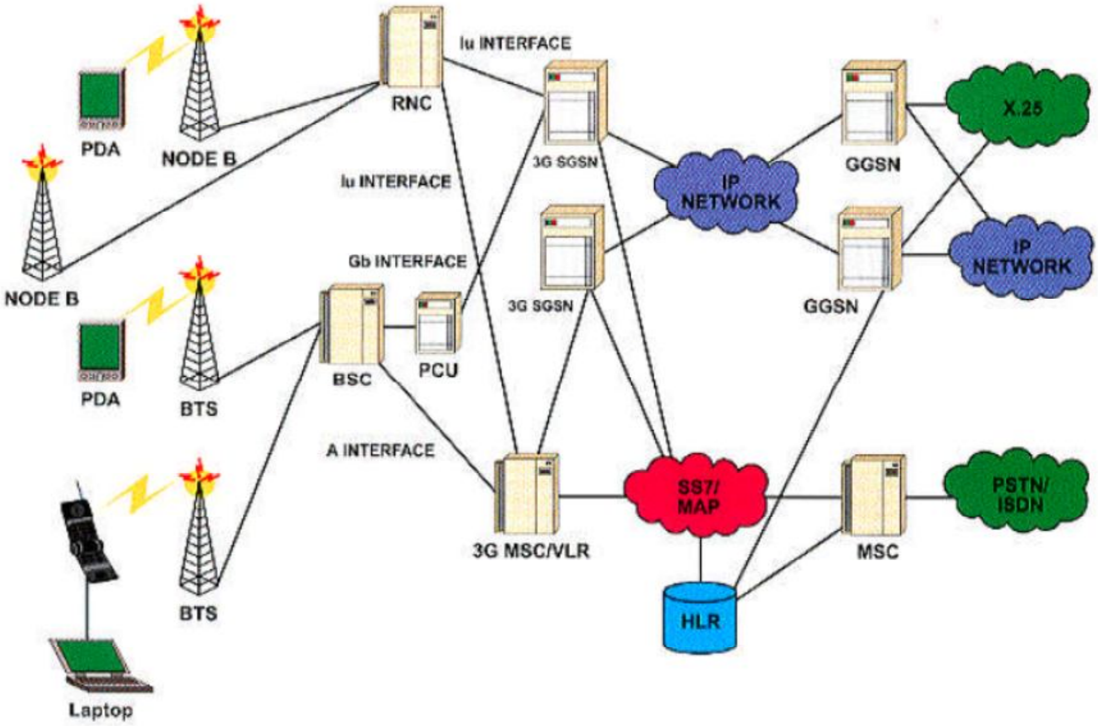

Figure 2.1 UMTS network architecture (extracted from [Corr10]).

For UE and UTRAN completely new protocols were made, because they are based on the needs of WCDMA. On the contrary, CN is updated from GSM/General Packet Radio Service (GPRS).

The UE consists of two parts:

- The Mobile Equipment/Mobile Station (ME/MS) is the radio terminal or Mobile Terminal (MT), used for radio communication over the Uu interface, i.e., the WCDMA radio interface.
- The UMTS Subscriber Identity Module (USIM) is a smartcard that holds the subscriber identity, performs authentication algorithms, stores authentication, encryption keys, and some subscription information that is needed at the MT.

UTRAN is responsible for the entire radio interface. Consists of two distinct elements:

- The Node B (i.e., the Base Station (BS)) converts the data flow between the Iub and Uu interfaces. It also participates in Radio Resource Management (RRM). In GSM the BTS has the same role.
- The Radio Network Controller (RNC) owns and controls the radio resources in its domain (the Node Bs connected to it). The RNC carries out the RRM, e.g., outer loop power control, packet scheduling and handover control. In GSM, the Base Station Controller (BSC) handles the allocation of radio channels, receives measurements from the MTs, and controls handovers from BTS to BTS.

In UTRAN, all RNCs are connected by the Iur interface with each other.

The CN, upgraded from GSM, is responsible for switching and routing calls and data to external networks, like the Internet (Packet Switch (PS) network) and public switched telephone network (Circuit Switch (CS) network). CN main elements are:

- Home Location Register (HLR) is a database where the operator subscriber's information is stored, such as allowed services, user location for routing calls, and preferences.
- Mobile Switching Centre/Visitor Location Register (MSC/VLR) is the switch (MSC) and database (VLR) that serves the UE in its location.
- Gateway MSC (GMSC) is the switch at the point where UMTS Public Land Mobile Network (PLMN) is connected to external CS networks. All incoming and outgoing CS connections go through GMSC.
- Serving GPRS Support Node (SGSN) has similar functionalities to the MSC, but for PS.
- Gateway GPRS Support Node (GGSN) is analogous to that of GMSC, for PS.

The innovations made on UE and UTRAN make possible to Release '99 support soft handover, opposite to GSM, where only hard handover is possible. At hard handover the connection between the old BS and the MT is interrupted before the MT establishes a connection to the new BS. In UMTS, hard handover can be inter-frequency or inter-system. In the former, the BSs have different carriers and in the latter it is a handover to another system, e.g., GSM [Molis04]. Soft and softer handovers are very similar: at soft handover the MT is connected to more than one BS at the same time, while at softer the MT is transferred from one sector to another of the same cell.

2.2 Radio Interface

2.2.1 GSM

Physically, the information flow takes place between the MS and the BTS, but, logically, MSs are communicating with the BSC, the MSC and the SGSN. The gross transmission rate over the radio interface is 270.833 kbps, due to the efficient modulation technique (Gaussian Minimum Shift Keying (GMSK), a variant of Minimum Shift Keying). Separate 200 kHz carrier frequencies are used for UL and DL. Different channel access methods are used:

- Frequency Division Duplex (FDD): currently, there are several frequency bands defined, and operators may implement networks that operate in a combination of these bands to support multi band MSs. The band for Europe, Africa, Asia and some Latin American countries is [890, 915] MHz for UL and [935, 960] MHz for DL in the 900 MHz band and [1710, 1785] MHz for UL and [1805, 1880] MHz for DL in the 1800 MHz band.
- Frequency Division Multiple Access (FDMA): both available frequency bands are partitioned into a 200 kHz grid.
- Time Division Multiple Access (TDMA): the physical channels are associated to a Time-Slot (TS), with a duration of 0.57692 ms (156.25 bits). A set of eight timeslots forms the frame, with a duration of 4.615 ms.

GSM radio interface channels are classified as radio (channel associated to a carrier frequency), physical (channel transporting any kind of system information, associated to a time-slot) and logical (channel transporting a specific kind of system information), being TCH and SDCCH part of the last group. Concerning addressing, one distinguishes common channels (exchange of information between the BS and MTs in general) and dedicated channels (exchange of information between the BS and one or several specific MTs). Concerning content, one distinguishes traffic channels (contain users' information, e.g., voice, data, and video) and control channels (contain system's information, e.g., signaling, synchronism, control and identity).

In GPRS, different coding schemes (CS–n) are used, leading to different transmission rate, Table 2.1.

Table 2.1 GSM/GPRS transmission rate with different coding schemes (extracted from [LeMa01]).

Technology	Transmission Rate per TS [kbps]	Medium Transmission Rate [kbps]	Maximum Transmission Rate [kbps]
Voice	22.80	-	-
Data	9.60	-	-
Data (HSCSD)	14.40	58	115.20
GPRS CS-1	9.05	32	72.40
GPRS CS-2	13.40	48	107.20
GPRS CS-3	15.60	58	124.80
GPRS CS-4	21.40	80	171.20
Enhanced GPRS	69.60	275	559.20

2.2.2 UMTS

The communications between the MT and the BS via the UMTS air interface are based on WCDMA, which is a wideband Direct-Sequence Code Division Multiple Access (DS-CDMA) system. The WCDMA air interface uses codes to distinguish between different users and also between users and some control channels. The user information bits are spread over a wide bandwidth by multiplying the user data with quasi-random bits (called chips) derived from CDMA spreading codes.

The chip rate of 3.84 Mcps leads to a carrier bandwidth of approximately 4.4 MHz. The carrier spacing can be selected on a 200 kHz grid between approximately 4.4 and 5 MHz, depending on interference between the carriers. The data capacity among users can change from frame to frame, which allows to support highly variable user data rates in PS data services. It uses FDD and the band for Europe, Africa, Asia and some Latin American countries is [1920, 1980] MHz for UL and [2110, 2170] MHz for DL.

The spreading operation, known as channelisation, results on spreading data with the same random appearance as the spreading code. The channelisation code increases the transmission bandwidth, using the Orthogonal Variable Spreading Factor (OVSF) technique to change the Spreading Factor (SF). The orthogonality between different spreading codes of different length is maintained. Scrambling codes are mainly used to distinguish signals from MTs and/or BSs. Scrambling is used on top of spreading so that the signal bandwidth is not changed and the symbol rate just makes signals from different sources separable from each other. This allows the use of identical spreading codes for several transmitters. In DL, it differentiates the sectors of the cell, and in UL, it separates MTs from each other. The scrambling code (SC) can be either a short or a long one, the latter being a 10 ms code based on the Gold family, and the former being based on the extended S(2) family. UL scrambling uses both short and long codes, while DL employs only long ones.

UMTS radio interface channels are classified as logical, transport and physical. Logical channels are mapped onto transport channels, which are again mapped onto physical ones. Logical to Transport channel conversion happens in the Medium Access Control (MAC) layer, which is a lower sublayer in Data Link Layer (Layer 2).

Power control is an essential part of any CDMA system, as it is necessary to control mutual interference. Without power control, a single MT could block a whole cell, giving rise to the so-called near-far problem of CDMA. There are two different types of power control, open and closed-loops. The former is used to supply the initial power to the MT that is initiating a connection, and the latter performs the continuous adjustements.

The data rate depends on the spreading factor, according to Table 2.2.

Table 2.2 UMTS transmission rate (extracted from [Corr10]).

Service [kbps]	SF	# codes (256)
12.2	128	2
64	32	8
128	16	16
384	4	64

HSDPA [HoTo06] presents some differences on the radio interface, compared to the initial version of WCDMA. It was designed to be deployed together with Release 99 and it works as an enhancement of UMTS, increasing DL packet data throughput by means of fast physical layer (L1) retransmission and transmission combining, as well as fast link adaptation controlled by the Node B. In order to allow higher data rates, this new technology supports the 16 Quadrature Amplitude Modulation (16QAM) with 4 bits per symbol, which can only be used under good radio signal quality, due to additional decision boundaries.

While in Release 99, the scheduling is based on the RNC and Node B has power control functionalities, in HSDPA, the BS has a buffer that first receives the packet and keeps it after sending it to the user, allowing the BS to retransmit the packet, if needed, without RNC intervention, this way minimising latency. RNC-based retransmission can still be applied on top in case of physical layer failure, using a Radio Link Control (RLC) acknowledged mode of operation. Concerning scheduling and link adaptation, these operations take place after the BS estimates the channel quality of each active user, based on the physical layer feedback in UL.

With these new functionalities, the need to introduce new channels emerged. A new user data channel was created, and two others were added for signalling purposes. HSDPA is always operated with Release ’99 in parallel, which can be used to carry CS services and the Signalling Radio Bearer (SRB), but does not support features like power control and soft handover. The new channels are High-Speed Downlink Shared Channel (HS-DSCH), for data, which is mapped onto the High-Speed Physical Downlink Shared Channel (HS-PDSCH), and for signalling, the High-Speed Shared Control Channel (HS-SCCH) and the High-Speed Dedicated Physical Control Channel (HS-DPCCH), for DL and UL, respectively. When only packet services are active in DL, other than the SRB, for lower rates, the DL DCH introduces too much overhead, and can also consume too much code space (if looking for a large number of users using a low data rate service, like Voice over IP (VoIP)), so the system uses the Fractional-DPCH (F-DPCH), that handles power control.

The HS-DSCH is the transport channel used to carry the user data in HSDPA. This channel supports 16QAM, besides QPSK, which is used to maximise coverage and robustness, and it has a dynamic resource sharing based on the BS scheduling with a Transmission Time Interval (TTI) of 2 ms. During the TTI there is no Discontinuous Transmission (DTX). It uses a fixed SF of 16 for multicode operation, with a maximum of 15 codes per MT one is needed for HS-SCCH and common channels, and only turbo-coding is used, since it outperforms the convolutional one for higher data rates.

A comparison between the main features of the transport channels of Release 99 and HSDPA is shown in Table 2.3.

Table 2.3 R99 and HSDPA comparison Table (adapted from [HoTo06]).

Feature	R99	HSDPA (HS-DSCH)
Variable SF	Yes	No
Fast Power Control	Yes	No
Adaptative Modulation	No	Yes
BS based scheduling	No	Yes
Fast L1 HARQ	No	Yes
Soft Handover	Yes	No
TTI length [ms]	80, 40, 20, 10	2

HSDPA performance depends on network algorithms, deployment scenarios, traffic generated, QoS and MT receiver performance and capability. In the MT until 5, 10 or 15 codes can be allocated, but in the BS the 15 codes can be allocated. There are 12 HSDPA UE categories, as shown in Table 2.4.

Table 2.4 HSDPA terminal capacity categories (adapted from [HoTo06]).

UE Category	Maximum number of parallels codes per HS-DSCH	Modulation	Minimum inter-TTI interval	Achievable maximum data rate [Mbps]
1	5	QPSK & 16QAM	3	1.2
2	5	QPSK & 16QAM	3	1.2
3	5	QPSK & 16QAM	2	1.8
4	5	QPSK & 16QAM	2	1.8
5	5	QPSK & 16QAM	1	3.6
6	5	QPSK & 16QAM	1	3.6
7	10	QPSK & 16QAM	1	7.2
8	10	QPSK & 16QAM	1	7.2
9	15	QPSK & 16QAM	1	10.2
10	15	QPSK & 16QAM	1	14.4
11	5	QPSK only	2	0.9
12	5	QPSK only	1	1.8

2.3 Services and Applications

3G systems are characterised by supplying the user with services beyond voice, or simple data transmission, which are characteristic of 2G. A service is a set of capabilities that work in a complementary or cooperative way, in order to allow the user to establish applications. An application is a task that needs communication among two or more points, being characterised by parameters associated to services, communications, and traffic. There are 3 basic service components: audio, video, and data. A service is composed of one or more basic components, which are grouped into classes, according to their characteristics [Corr10]. Table 2.5 shows the 4 classes of services.

Table 2.5 QoS classes of UMTS (adapted from [3GPP00]).

Class of Service	Conversational	Streaming	Interactive	Background
Fundamental Characteristics	- Preserve time relation between information entities of the stream - Conversational pattern (stringent and low delay)	- Preserve time relation between information entities of the stream	- Request response pattern - Preserve payload content	- Destination is not expecting the data within a certain time - Preserve payload content
Real Time	Yes	Yes	No	No
Symmetric	Yes	No	No	No
Switching	CS	CS	PS	PS
Guaranteed bit rate	Yes	Yes	No	No
Traffic Handling Priority	No	No	Yes	No
Maximum bit rate	Yes	Yes	Yes	Yes
Delay	Minimum, Fixed	Minimum, Variable	Moderated, Variable	Large, Variable
Buffer	No	Yes	Yes	Yes
Bursty	No	No	Yes	Yes
Example	Voice	Streaming Video	Web browsing	Background download of emails

The Conversational class is the one that raises the strongest and most stringent QoS requirements, as it is the only one where the required characteristics are strictly given by human perception. Therefore, the maximum end-to-end delay has to be less than 400 ms [HoTo04]. Although the most well known use of this scheme is telephony speech over CS, there are a number of other applications that fit this scheme, e.g., VoIP and video conferencing.

The Streaming class includes real-time audio and video sharing, and is one of the newcomers in data communications. Like the Conversational class, it requires bandwidth to be maintained, but tolerates some delay variations that are hidden by a buffer in the receiver.

The Interactive class includes, e.g., web browsing, and is characterised by the request response pattern of the end user. At the message destination, there is an entity expecting the message (response) within a certain time. Round trip delay time is therefore one of the key attributes. Also, the content of the packets must be transparently transferred, i.e., with low bit error rate.

The Backgroung class assumes that the destination is not expecting the data within a certain time; therefore, it is the least delay sensitive class (there is no special requirement for delay). Like in the Interactive class, the content of the packets must be transparently transferred. Examples are the delivery of e-mails or Short Message Service (SMS).

UMTS QoS classes are not mandatory for the introduction of any low delay service. It is possible to support streaming video or conversational VoIP from an end-to-end performance view point by using just the Background class. QoS differentiation becomes useful for the network efficiency during high load, when there are services with different delay requirements.

It is also important to know the usual bit rates and typical file dimensions associated to the different services. Table 2.6. shows some examples, which also includes the QoS priority list. If data rates reduction strategies are applied, the first services to be reduced are the ones with the lower QoS priority (that corresponds to a higher priority value), according to the traffic classes shown in Table 2.5.

Table 2.6 Bit rates and applications of different services (adapted from [Lope08] and [3GPP05]).

Service	**Bit rate [kbps]**		**QoS priority**	**Characteristics**		
	DL	**UL**		**Average volume/duration**	**DL**	**UL**
Voice	12.2		1	Call duration [s]	120	
Web	[512, 1536]	[128, 512]	2	Page size [kB]	300	20
Streaming	[512, 1024]	[64, 384]	3	Video size [MB]	9.60	0.02
Email	[384, 1536]	[128, 512]	4	File size [kB]	100	
FTP	[384, 2048]	[128, 512]	5	File size [MB]	10	
Chat	[64, 384]		6	MSN message size [B]	50	
P2P	[128, 1024]	[64, 384]	7	File size [MB]	12.5	

2.4 GSM Performance Indicators

2.4.1 Performance Monitoring

Monitoring and statistical measures is a very important part of the Operation and Maintenance (O&M) of a radio network. The radio network statistic and recording functions can be used for monitoring and optimisation of the radio network performance, evaluation and optimisation of the radio network features, dimensioning of the radio network, and troubleshooting.

In an Ericsson GSM network, different events occur being counted and collected by a subsystem called Statistics and Traffic Measurement Subsystem (STS), which is implemented in the BSC and MSC, and gives statistics about events in different parts of the network, such as cells and equipment. By continuously supervising the results from STS, the operator can obtain a very good overview of the radio network performance. The central part in STS is the Measurement Database (MDB), where all measurements are collected from different blocks in the Central Processor (CP). The contents of the MDB are written to STS report files defined by the user. These STS files are then fetched from the BSC and processed by OSS (Operation and Support System) or a user defined external tool.

Due to the scope of this thesis, Key Performance Indicators (KPIs) related to statistical results about GSM and UMTS radio network performance are analised. In this section, the performance parameters are identified and a brief description is given. In the following sections, the main objective is to find a correlation between the parameters, in order to optimise the radio network performance.

The main focus is on how to monitor the GSM radio network performance in areas of accessibility, retainability and speech quality, taking the subscriber perceived quality into account.

- Acessibility: the accessibility area in a radio network covers random access, congestion on SDCCH (Stand-alone Dedicated Control Channel) and TCH (Traffic Channel) and call setup.
- Retainability: covers the ability to keep up a call; call drop rate, handover performance and interference are included in this area.
- Speech Quality: although it is very difficult to measure the speech quality, the Speech Quality Supervision function (SQS) provides STS with counters, giving an objective measure of it.

A special reference is given to GPRS/EGPRS radio network performance monitoring. The terms accessibility, retainability and integrity work well for CS networks; accessibility relates to blocked calls, retainability to dropped calls and integrity to speech quality. All of these can be measured in the BSS and roughly translated into a user perception of service quality. For PS networks, it is much more difficult to define STS counters in the BSS and relate this to the users perception of service quality. There are two main reasons for this:

- The GPRS/EGPRS system has many layers of protocols. A session where a TBF (a PS connection, that can be either UL or DL) is dropped for some reason, a retainability problem on BSS (Base Station Subsystem) level will normally be kept alive by TCP (Transmission Control Protocol) until a new TBF is established. To the user, this seems like an integrity problem, one session that included a short delay.

- The GPRS/EGPRS network is a bearer for a number of different applications. These are affected by events in the radio network in different ways, e.g., if the BSS failed to transfer any data for 5 s this would appear as a serious performance problem to a WAP user but it would hardly be noticed by a user performing downloading of e-mails in the background.

Accessibility, retainability and integrity can be applied also to GPRS/EGPRS, but only on higher layers, and by considering events that are invisible to the BSS. A full set of end-to-end KPIs have been defined, but cannot be fully measured in the BSS. Basically all IP service KPIs in BSS are experienced as integrity problems to the end user. Rather, the counters focus on the main task of the BSS, which is the transfer of IP packets between the core network and the terminals. The counters are grouped into three performance indicators:

- Level one: These counters are directly related to the ability of the BSS to transport IP packets. Typically, they are sets of counters that focus on one area of BSS performance (which could usually be affected by a number of different factors), which impacts on the user perception of the service. For example, the IP throughput counters on cell level measure the speed with which the BSS can transfer IP packets.
- Level two: These counters are indirectly related to the ability of the BSS to transport IP packets. They should be used for trouble-shooting purposes to identify the specific factors that are causing the level one indicators to show poor performance. For example, the GPRS traffic load counters show how the number of users sharing the available PDCHs is affecting the measured IP throughput. They should not be used on their own for any dimensioning purposes.
- Additional: Are usual for monitoring of specific features and impacts.

Figure 2.2 indicates the factors that can affect the users perception of the GPRS/EGPRS service. The KPIs that are analysed are listed below, Tables 2.7 and 2.8, and Figure 2.3 illustrates how the STS counters are grouped into the three areas (along with the object type names).

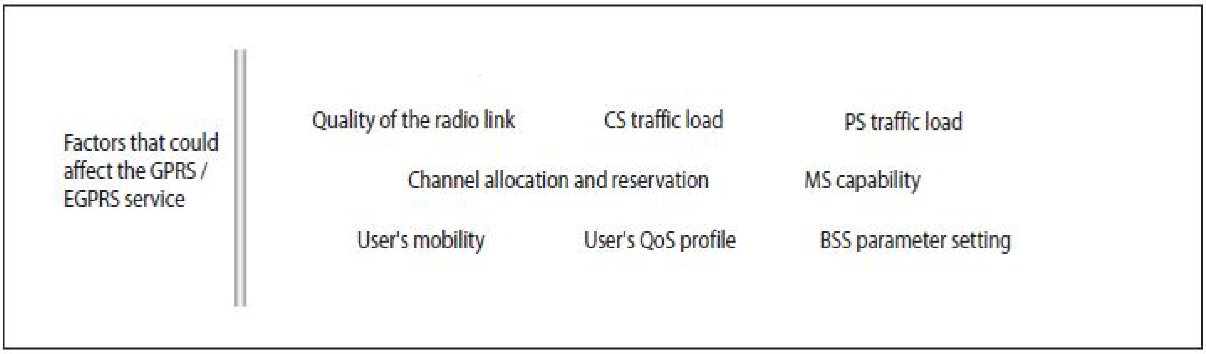

Figure 2.2 The structure for GPRS/EGPRS counters with object types (extracted from [Eric06]).

It is also important to mention that the mobile operator establishes a target value and a range of values considered valid in order to evaluate the behavior of the KPIs. The data collection is done with a Δt = 1 h for GSM and UMTS.

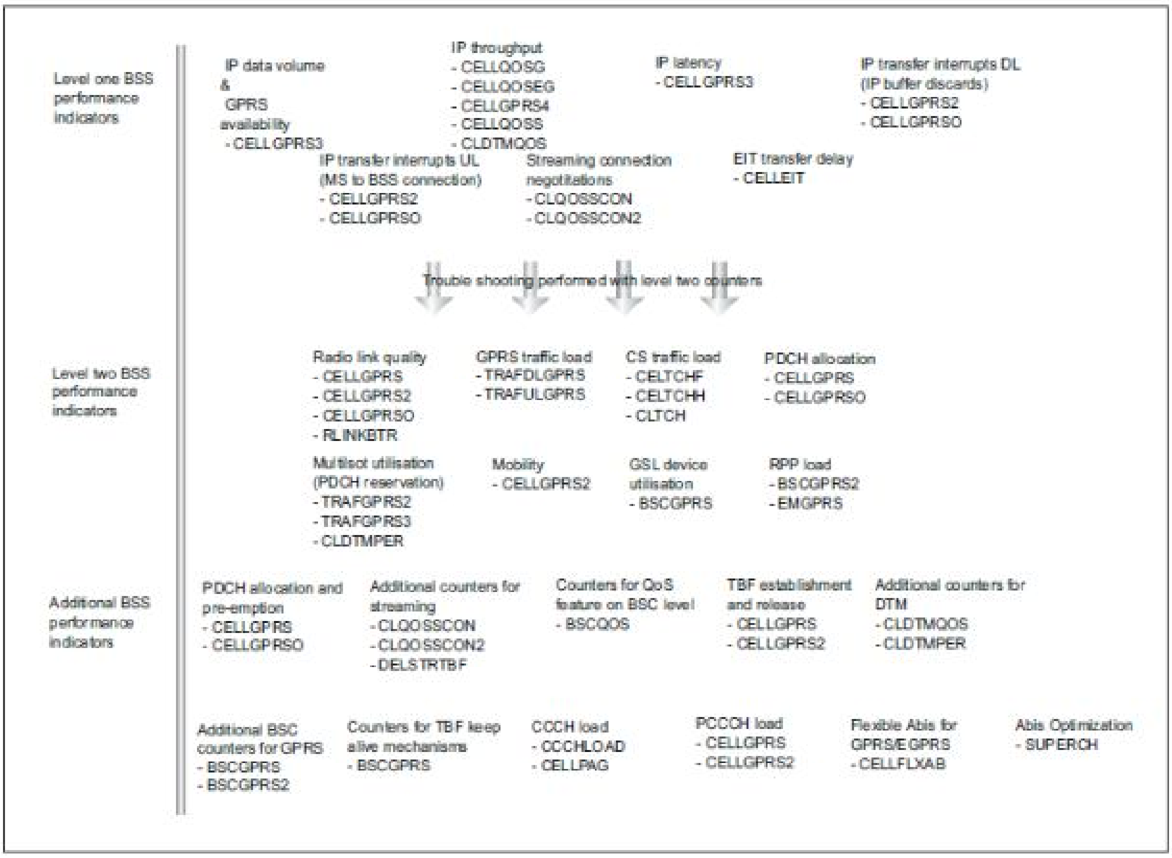

Figure 2.3 Factors that can affect the GPRS/EGPRS user perceived performance perception (adapted from [Eric06]).

Table 2.7 GSM KPIs Target and Range of Values.

GSM	Target Value	Range of Values
R_{C_D} [%]	1	[0, 3]
R_{SDCCH_D}[%]	1	[0, 3]
R_{CS_S} [%]	98.5	[95, 100]
$T_{GPRS_{DL}}$ [kbps]	25	[20, 45]
$T_{GPRS_{UL}}$ [kbps]	-	[10, 25]
$T_{EDGE_{DL}}$ [kbps]	80	[40, 260]
$T_{EDGE_{UL}}$ [kbps]	-	[30, 60]
R_{PDCH_S} [%]	-	[70, 100]
R_{HO_S} [%]	98	[95, 100]

2.4.2 Voice Call Performance Indicators

The expression for subscriber perceived drop on TCH can be written as:

$$R_{C_D} = \left(\frac{N_{TCH_D}}{N_C}\right) \times 100[\%] \qquad (2.1)$$

where:

- N_{TCH_D} is the total amount of TCH drops (including the total number of dropped full and half-rate TCH in underlaid and overlaid subcells).

- N_C is the total number of terminated calls in a cell (including the number of initiated calls in a cell and the sum of all incoming and outgoing handovers to a cell from all its neighbours (successful assignments to worse and better cell)).

This parameter shows the ratio of drops due to low signal strength on either DL, UL or both links on TCH compared to the total number of TCH drops.

The expression for drop on SDCCH, drop due to TCH congestion excluded, is:

$$R_{SDCCH_D} = \left(\frac{N_{SDCCH_D}}{N_{MS_{SDCCH_S}}} \right) \times 100[\%] \qquad (2.2)$$

where:

- N_{SDCCH_D} is the total number of dropped SDCCH channels in a cell.
- $N_{MS_{SDCCH_S}}$ is the successful Mobile Station (MS) channel establishments on SDCCH.

The different drop reasons are ranked in the order excessive Timing Advance (TA), low signal strength, bad quality or sudden loss of connection. This means that if the connection suffers from excessive TA and low signal strength, and drops, the drop reason will be registered as excessive TA. The urgency condition bad quality is triggered by a high bit error rate on UL or DL.

The expression for Call Setup Success Rate is given by:

$$R_{CS_S} = \left((1 - R_{SDCCH_D}) \times (1 - R_{TCH_F}) \right) \times 100[\%] =$$

$$\left(\left(1 - \left(\frac{N_{SDCCH_D}}{N_{MS_{SDCCH_S}}} \right) \right) \times \left(1 - \left(1 - \left(\frac{N_{MS_{FR}} + N_{MS_{HR}}}{N_{MS_{TCH_A}}} \right) \right) \right) \right) \times 100[\%] \qquad (2.3)$$

where:

- R_{TCH_F} is the TCH Assignment Failure Rate.
- R_{SDCCH_D} indicates the percentage for drop on SDCCH.
- $N_{MS_{FR}}$ is the number of assignment complete messages for all MS power classes in underlaid subcell, full-rate.
- $N_{MS_{HR}}$ is the number of assignment complete messages for all MS power classes in underlaid subcell, half-rate.
- $N_{MS_{TCH_A}}$ is the number of first assignment attempts on TCH for all MS power classes.

R_{CS_S} is very important in the call establishment, being commonly used by operators due to its importance in terms of performance and system availability.

2.4.3 Data Performance Indicators

The expression used to calculate the weighted average DL IP throughput for QoS classes Interactive and Background for GPRS is given by:

$$T_{GPRS_{DL}} = \frac{TD_{G_{THP1_{DL}}}+TD_{G_{THP2_{DL}}}+TD_{G_{THP3_{DL}}}+TD_{G_{BGG_{DL}}}}{D_{G_{THP1_{DL}}}+D_{G_{THP2_{DL}}}+D_{G_{THP3_{DL}}}+D_{G_{BGG_{DL}}}}\,[kbit/s] \quad (2.4)$$

where:

- $TD_{G_{THP1_{DL}}}$ is the accumulation of (LLC (Logical Link Control) throughput x LLC data volume) for all DL GPRS mode transfers for QoS class Interactive THP1 (Traffic Handling Priority).
- $TD_{G_{THP2_{DL}}}$ is the accumulation of (LLC throughput x LLC data volume) for all DL GPRS mode transfers for QoS class Interactive THP2.
- $TD_{G_{THP3_{DL}}}$ is the accumulation of (LLC throughput x LLC data volume) for all DL GPRS mode transfers for QoS class Interactive THP3.
- $TD_{G_{BGG_{DL}}}$ is the accumulation of (LLC throughout x LLC data volume) for all DL GPRS mode transfers for QoS class Background.
- $D_{G_{THP1_{DL}}}$gives the amount of IP data for all DL GPRS mode transfers for QoS class Interactive THP1.
- $D_{G_{THP2_{DL}}}$gives the amount of IP data for all DL GPRS mode transfers for QoS class Interactive THP2.
- $D_{G_{THP3_{DL}}}$gives the amount of IP data for all DL GPRS mode transfers for QoS class Interactive THP3.
- $D_{G_{BGG_{DL}}}$ is the accumulated total LLC data received on the DL in GPRS mode transfers for QoS class Background.

The expression used to calculate the weighted average UL IP throughput for QoS classes Interactive and Background for GPRS is given by:

$$T_{GPRS_{UL}} = \frac{TD_{G_{THP1_{UL}}}+TD_{G_{THP2_{UL}}}+TD_{G_{THP3_{UL}}}+TD_{G_{BGG_{UL}}}}{D_{G_{THP1_{UL}}}+D_{G_{THP2_{UL}}}+D_{G_{THP3_{UL}}}+D_{G_{BGG_{UL}}}}\,[kbit/s] \quad (2.5)$$

where:

- $TD_{G_{THP1_{UL}}}$ is the accumulation of (LLC throughput x LLC data volume) for all UL GPRS mode transfers for QoS class Interactive THP1.
- $TD_{G_{THP2_{UL}}}$ is the accumulation of (LLC throughput x LLC data volume) for all UL GPRS mode transfers for QoS class Interactive THP2.
- $TD_{G_{THP3_{UL}}}$ is the accumulation of (LLC throughput x LLC data volume) for all UL GPRS mode transfers for QoS class Interactive THP3.
- $TD_{G_{BGG_{UL}}}$ is the accumulation of (LLC throughout x LLC data volume) for all UL GPRS mode transfers for QoS class Background.
- $D_{G_{THP1_{UL}}}$gives the amount of IP data for all UL GPRS mode transfers for QoS class Interactive THP1.
- $D_{G_{THP2_{UL}}}$gives the amount of IP data for all UL GPRS mode transfers for QoS class Interactive THP2.

- $D_{G_{THP3_{UL}}}$ gives the amount of IP data for all UL GPRS mode transfers for QoS class Interactive THP3.
- $D_{G_{BGG_{UL}}}$ is the accumulated total LLC data received on the UL in GPRS mode transfers for QoS class Background.

The expression used to calculate the weighted average DL IP throughput for QoS classes Interactive and Background for EDGE is given by:

$$T_{EDGE_{DL}} = \frac{TD_{E_{THP1_{DL}}}+TD_{E_{THP2_{DL}}}+TD_{E_{THP3_{DL}}}+TD_{E_{BGE_{DL}}}}{D_{E_{THP1_{DL}}}+D_{E_{THP2_{DL}}}+D_{E_{THP3_{DL}}}+D_{E_{BGE_{DL}}}} [kbit/s] \quad (2.6)$$

where:

- $TD_{E_{THP1_{DL}}}$ is the accumulation of (LLC throughput x LLC data volume) for all DL EDGE mode transfers for QoS class Interactive THP1.
- $TD_{E_{THP2_{DL}}}$ is the accumulation of (LLC throughput x LLC data volume) for all DL EDGE mode transfers for QoS class Interactive THP2.
- $TD_{E_{THP3_{DL}}}$ is the accumulation of (LLC throughput x LLC data volume) for all DL EDGE mode transfers for QoS class Interactive THP3.
- $TD_{E_{BGE_{DL}}}$ is the accumulation of (LLC throughout x LLC data volume) for all DL EDGE mode transfers for QoS class Background.
- $D_{E_{THP1_{DL}}}$ gives the amount of IP data for all DL EDGE mode transfers for QoS class Interactive THP1.
- $D_{E_{THP2_{DL}}}$ gives the amount of IP data for all DL EDGE mode transfers for QoS class Interactive THP2.
- $D_{E_{THP3_{DL}}}$ gives the amount of IP data for all DL EDGE mode transfers for QoS class Interactive THP3.
- $D_{E_{BGE_{DL}}}$ is the accumulated total LLC data received on the DL in EDGE mode transfers for QoS class Background.

The expression used to calculate the weighted average UL IP throughput for QoS classes Interactive and Background for EDGE is given by:

$$T_{EDGE_{UL}} = \frac{TD_{E_{THP1_{UL}}}+TD_{E_{THP2_{UL}}}+TD_{E_{THP3_{UL}}}+TD_{E_{BGE_{UL}}}}{D_{E_{THP1_{UL}}}+D_{E_{THP2_{UL}}}+D_{E_{THP3_{UL}}}+D_{E_{BGE_{UL}}}} [kbit/s] \quad (2.7)$$

where:

- $TD_{E_{THP1_{UL}}}$ is the accumulation of (LLC throughput x LLC data volume) for all UL EDGE mode transfers for QoS class Interactive THP1.
- $TD_{E_{THP2_{UL}}}$ is the accumulation of (LLC throughput x LLC data volume) for all UL EDGE mode transfers for QoS class Interactive THP2.
- $TD_{E_{THP3_{UL}}}$ is the accumulation of (LLC throughput x LLC data volume) for all UL EDGE mode transfers for QoS class Interactive THP3.

- $TD_{E_{BGE_{UL}}}$ is the accumulation of (LLC throughout x LLC data volume) for all UL EDGE mode transfers for QoS class Background.
- $D_{E_{THP1_{UL}}}$gives the amount of IP data for all UL EDGE mode transfers for QoS class Interactive THP1.
- $D_{E_{THP2_{UL}}}$gives the amount of IP data for all UL EDGE mode transfers for QoS class Interactive THP2.
- $D_{E_{THP3_{UL}}}$gives the amount of IP data for all UL EDGE mode transfers for QoS class Interactive THP3.
- $D_{E_{BGE_{UL}}}$ is the accumulated total LLC data received on the UL in EDGE mode transfers for QoS class Background.

The packet data channel assignment success rate can be calculated as:

$$R_{PDCH_S} = \left(1 - \frac{N_{PDCH_F}}{N_{PDCH_A}}\right) \times 100[\%] \quad (2.8)$$

where:

- N_{PDCH_F} is the number of packet channel allocation failures. A failure is when zero PDCH could be allocated due to the lack of basic physical channels over the air interface. The failure relates to the inability of the system to allocate resources and, in most cases, not to any failure to reserve channels experienced by the user. “Failures” are normal, frequent, occurrences in a situation where PS traffic must compete with CS traffic for basic physical channels.
- N_{PDCH_A} is the number of packet channel allocation attempts. The counter value is incremented at each request to allocate PDCHs in the cell. The counter value is incremented by one independently of the number of channels requested and the result of the request. Requests to allocate PDCHs occur when the operator increases the number of dedicated PDCHs and when the packet data traffic demands on-demand PDCHs. No request to allocate PDCHs is done if there are no deblocked traffic channels in the cell.

2.5 UMTS Performance Parameters

2.5.1 Performance Monitoring

This section provides the KPIs that are studied for UMTS, taking in consideration that observability in Ericsson UTRAN covers all functions that serve to monitor and analyse the performance and characteristics of the system. Figure 2.4 illustrates the observability model:

- The KPIs represents the end-user perception of a network on a macro level, being typical of interest for top-level management within an operator. They are typically used to detect problem areas.

- The Performance Indicators level represents information on a system level that does not explicitly qualifies in the macro level end-user perspective model, but can indicate whether the system performs good or bad.
- The Procedure level represents deeper troubleshooting and measure system characteristics measurements. The amount of data in these measurements is enormous. They are generally user-initiated for a specific purpose and area of the network, thereby limiting the scope of the measurements.

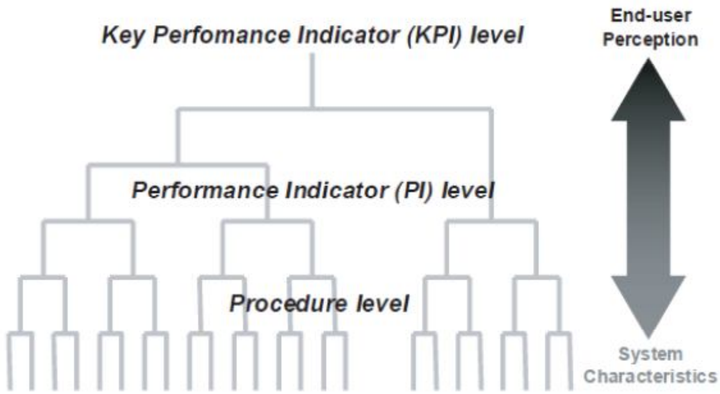

Figure 2.4 UTRAN observability model (extracted from [Eric08]).

The model to evaluate the Performance Observability considers the three ITU-T areas for QoS from an end-user perspective, accessibility, retainability and integrity, complemented with three more: mobility, utilization and availability.

- Mobility: shows the handover performance divided into Intra-Frequency, Inter-Frequency and IRAT HO for CS and PS services.
- Utilization: describes the network utilization by means of Traffic level and Capacity Management (congestion, admission/load control).
- Availability: shows In-Service-Performance for the main Managed Objects (MO) in UTRAN.

Table 2.8 UMTS KPIs Target and Range of Values

UMTS	Target Value	Range of Values
R_{SCS_S} [%]	98	[95, 100]
R_{CS64_S} [%]	96	[93, 100]
$R_{PSR99\_ICS_S}$ [%]	96	[93, 100]
$R_{HSDPA\_ICS_S}$ [%]	96	[93, 100]
R_{SC_D} [%]	1	[0, 3]
R_{CS64C_D} [%]	2	[0, 4]
$R_{PSR99\_IC_D}$ [%]	2	[0, 4]
$R_{HSDPA\_IC_D}$ [%]	2	[0, 4]
$T_{PSR99_{DL}}$ [kbps]	-	[200, 384]
$T_{PSR99_{UL}}$ [kbps]	-	[50, 384]
T_{HSDPA} [kbps]	1000	[500, 7200]
R_{SHO_S} [%]	96	[90, 100]
$R_{IRAT\_HO_{S_O}}$ [%]	85	[80, 100]
$R_{IRAT\_HO_{S_I}}$ [%]	85	[80, 100]

2.5.2 Voice Call Performance Indicators

The accessibility success rate for the speech service can be seen as the product of two rates: "CS RRC (Radio Resource Control) Success Rate" and "RAB (Radio Access Bearer) Establishment Success Rate Speech". It is given by:

$$R_{SCS_S} = \left(R_{CSRRC_S} \times R_{RAB_S}\right) \times 100[\%] \quad (2.9)$$

where:

- R_{CSRRC_S} is the CS RRC Success Rate.
- R_{RAB_S} is the RAB Establishment Success Rate Speech.

The accessibility success rate for the CS64 services can be seen as the product of two rates: "CS RRC Success Rate" and "RAB Establishment Success Rate for CS64". It is given by:

$$R_{CS64_S} = \left(R_{CSRRC_S} \times R_{CS64\_RAB_S}\right) \times 100[\%] \quad (2.10)$$

where:

- $R_{CS64\_RAB_S}$ is the RAB Establishment Success Rate for CS64.

The drop rate for RAB speech can be seen as the ratio between all the abnormal RAB speech releases over the total number of all the RAB speech releases. It is given by:

$$R_{SC_D} = \left(\frac{N_{Ab\_RAB_R}}{N_{RAB_R}}\right) \times 100[\%] \quad (2.11)$$

where:

- $N_{Ab\_RAB_R}$ is the number of Abnormal RAB speech releases.
- N_{RAB_R} is the total number of all the RAB speech releases.

The drop rate for RAB CS64 Data can be seen as the ratio between all the abnormal RAB CS64 releases over the total number of all the RAB CS64 releases. It is given by:

$$R_{CS64C_D} = \left(\frac{N_{CS64Ab\_RAB_R}}{N_{CS64RAB_R}}\right) \times 100[\%] \quad (2.12)$$

where:

- $N_{CS64Ab\_RAB_R}$ is the number of Abnormal RAB CS64 releases.
- $N_{CS64RAB_R}$ is the total number of all the RAB CS64 releases.

A CS data call works in a very similar way to a normal voice call in a GSM network. A single dedicated radio time slot is allocated between the MT and the BS. A dedicated "sub-time slot" (16 kbps) is allocated from the BS to the transcoder, and finally another time slot (64 kbps) is allocated from the transcoder to the MSC.

2.5.3 Data Performance Indicators

The accessibility success rate for the PS Data Interactive services, only R99, considers in the total amount of PS Data Interactive RAB attempts all the contribution related to the PS data calls originated on R99 only. It can be seen as the product of two rates: “PS RRC Success Rate” and “RAB Establishment Success Rate PS DCH/FACH (Dedicated Channel/Forward Access Channel)”. It is given by:

$$R_{PSR99\_ICS_S} = \left(R_{PSRRC_S} \times R_{RAB\_PS\_DCH\_FACH_S}\right) \times 100[\%] \quad (2.13)$$

where:

- R_{PSRRC_S} is the PS RRC Success Rate.
- $R_{RAB\_PS\_DCH\_FACH_S}$ is the RAB Establishment Success Rate PS DCH/FACH.

The accessibility success rate for the PS Data Interactive services, HSDPA only, considers in the total amount of PS Data Interactive RAB attempts all the contribution related to the PS data calls originated on HSDPA. It can be seen as the product of two rates: “PS RRC Success Rate” and RAB Establishment Success Rate PS HS, which indicates the success rate of RAB establishments for PS HS calls. It is given by:

$$R_{HSDPA\_ICS_S} = \left(R_{PSRRC_S} \times R_{RAB\_PS\_HS_S}\right) \times 100[\%] \quad (2.14)$$

where:

- $R_{RAB\_PS\_HS_S}$ = “RAB Establishment Success Rate PS HS”.

In PS HS RAB, establishments attempts and success have been counted also relatively PS EUL RAB establishment ones.

The drop rate for all the PS RAB’s only R99 on Cell basis (all counters defined in MO class “UtranCell”) can be seen as the ratio between all the abnormal RAB PS DCH/FACH releases over the total number of all the RAB PS DCH/FACH releases (including all the normal releases due to all the upswitchs from DCH/FACH state to HS). It is given by:

$$R_{PSR99\_IC_D} = \left(\frac{N_{RABAb\_PS\_DCH\_FACH_R}}{N_{RAB\_PS\_DCH\_FACH_R}}\right) \times 100[\%] \quad (2.15)$$

where:

- $N_{RABAb\_PS\_DCH\_FACH_R}$ is the number of all the abnormal RAB PS DCH/FACH releases.
- $N_{RAB\_PS\_DCH\_FACH_R}$ is the total number of all the RAB PS DCH/FACH releases.

This KPI defines the drop rate for RAB PS HSDPA on Cell basis (all counters defined in MO class “UtranCell”). It can be seen as the ratio between all the abnormal RAB PS HSDPA releases over the total number of all the RAB PS HSDPA releases. The expression is given by:

$$R_{HSDPA\_IC_D} = \left(\frac{N_{RABAb\_PS\_HSDPA_R}}{N_{RAB\_PS\_HSDPA_R}}\right) \times 100[\%] \quad (2.16)$$

where:

- $N_{RABAb\_PS\_HSDPA_R}$ is the number of all the abnormal RAB PS HSDPA releases.
- $N_{RAB\_PS\_HSDPA_R}$ is the total number of all the RAB PS HSDPA releases.

In PS, HS RAB releases have been counted also relatively PS EUL ones.

$$T_{PSR99_{DL}} = \frac{T_{PSRLC_{DL}}}{N_{samples_{PSRLC_{DL}}}} \; [kbit/s] \quad (2.17)$$

This expression evaluates the average user throughput for PS Data in DL (kbps). It includes user data, excluding retransmissions, padding bits, data PDU (Protocol Data Unit) headers and RLC control PDU's. It is measured in the best cell in the active set.

$$T_{PSR99_{UL}} = \frac{T_{PS_{RLC_{UL}}}}{N_{samples_{PS_{RLC_{UL}}}}} \; [kbit/s] \tag{2.18}$$

This expression evaluates the average user throughput for R 99 PS Data in UL (kbps). It includes user data, excluding retransmissions, padding bits, data PDU headers and RLC control PDU's. It is measured in the best cell in the active set.

The PS Interactive HS user DL throughput is given by:

$$T_{HSDPA} = \frac{T_{HS_{RLC}}}{N_{samples_{HS_{RLC}}}} \; [kbit/s] \tag{2.19}$$

2.6 GSM and UMTS Handover Performance Parameters

Handover parameters are independent of the type of service. These KPIs are composed of counters which task is to count the number of radio link establishments between the MT and the BS.

The expression for Handover Success Rate is given by:

$$R_{HO_S} = \left(\frac{N_{HO_N} + N_{HO_I}}{N_{HO_{MS}} + N_{HO_{I_{DL}}} + N_{HO_{I_{UL}}} + N_{HO_{I_{DL\_UL}}}}\right) \times 100[\%] \tag{2.20}$$

where:

- N_{HO_N} is the number of successful handover to the neighbouring cell.
- N_{HO_I} is the number of successful intra cell handovers.
- $N_{HO_{MS}}$ is the number of handover commands sent to the MS.
- $N_{HO_{I_{DL}}}$ is the number of intra-cell handover attempts (decisions) at bad DL quality.
- $N_{HO_{I_{UL}}}$ is the number of intra-cell handover attempts (decisions) at bad UL quality.
- $N_{HO_{I_{DL\_UL}}}$ is the number of intra-cell handover attempts (decisions) for both links with bad quality.

The intra-cell handover feature can be triggered by bad quality (if the signal strength is above predefined levels), which in most cases means a high level of interference. If the number of intra-cell handovers due to bad quality becomes too high, the cell and/or frequency planning needs to be improved. In cells with congestion, intra-cell handover should be switched off, as two TCHs are seized during the handover process.

The rate of successful RL addition for the target cell, computed for RL addition or replacement, can be seen as the rate between the total number of RL addition success and the total number of RL addition attempts, defined as the sum of success and failures. It is given by:

$$R_{SHO_S} = \left(\frac{N_{RL_S}}{N_{RL_A}}\right) \times 100[\%] \quad (2.21)$$

where:

- N_{RL_S} is the total number of RL addition success.
- N_{RL_A} is the total number of RL addition attempts.

The success rate for IRAT (Inter Radio Access Technology) HO for RAB Speech and MultiRAB can be seen as the rate between all the success of outgoing (to GSM) IRAT for RAB Speech and Multi RAB and the total of attempts. It is given by:

$$R_{IRAT\_HOS_O} = \left(\frac{N_{IRAT\_HOS_O}}{N_{IRAT\_HOA_O}}\right) \times 100[\%] \quad (2.22)$$

where:

- $N_{IRAT\_HOS_O}$ is the number of all the success of outgoing (to GSM) IRAT for RAB Speech and Multi RAB.
- $N_{IRAT\_HOA_O}$ is the number of total attempts.

The following KPI defines the percentage of incoming IRAT Handover Successful attempts for CS RAB, over the total attempts. Its expression is given by:

$$R_{IRAT\_HOS_I} = \left(\frac{N_{IRAT\_HOS_I}}{N_{IRAT\_HOA_I}}\right) \times 100[\%] \quad (2.23)$$

where:

- $N_{IRAT\_HOS_I}$ is the number of incoming IRAT Handover Successful attempts for CS RAB.
- $N_{IRAT\_HOA_I}$ is the number of total attempts.

Note that all the KPIs can be computed on a per RNC basis, as well as on a per cell one. When computing the RNC result, individual cell counters should be summed on a RNC basis before applying KPI calculation. This is in contrast to applying the KPI equation to each cell and then taking an average across the RNC. The latter can give poor performances.

Being the establishment of correlations between different KPIs one of the main goals of this work, it is necessary to present the correlation expression.

$$Correl(X,Y) = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}} \quad (2.24)$$

where *x* and *y* are the sample means of the analysed parameters.

2.7 State of the Art

A brief overview of the state of the art is presented in this section, in order to show what has been done in this field up to now, thus, emphasising the importance of this work.

In wireless communication systems, QoS is one of the most important issues from both users and operators point of view. Not all the parameters related to QoS have the same importance for all users and applications. However, to meet QoS requirements accurately, all the parameters of a service should work properly, and network resources must be used more efficiently.

All mobile operators use KPIs to judge their network performance and evaluate the QoS. In [Seyt10], GSM network RF performance evaluation is done based on some major KPIs, such as call setup success rate (CSSR), call drop rate (CDR), handover success rate (HSR) and Traffic Channel Congestion Rate. Issues that might affect and degrade the KPIs are presented, and the authors also present methods that can be employed in order to improve the performance of the KPIs in a live network, analytically proving that it is possible to optimise an existing cellular network using different methodologies and fine parameter tuning.

In order to characterise QoS parameters for 3G Wireless Networks, [CISL08] assume that CDR is the most important QoS parameter for all types of services. A soft-QoS scheme is proposed to reduce CDR: the call will be accepted by a network only when the required bandwidth for that call is less than or equal to this releasable bandwidth. The results show that the proposed soft-QoS scheme can reduce not only dropped call rate but also blocked call rate for medium traffic condition.

In [VaHN03], five key UMTS radio network parameters were simultaneously optimised with an automatic control method, guided by heuristic expert-defined rules, which apply specific trade-off policies and statistics of poor quality calls, blocking rates, power and interference levels and terminal measurements to qualify the parameter values. The method was validated using a dynamic WCDMA system simulator with a deployment of 17 cells in the Helsinki city centre. The simulations were carried out with four different loadings that were produced with 1000, 2000, 3000 or 4000 subscribers in the network. Each one of them made 11 calls or call attempts in an hour on the average, and 70% of the calls used 8 kbps speech service and 30% used 64 kbps CS data service. The average length of speech calls was 30 s and that of CS data calls 20 s. With 1000 subscribers, the average number of simultaneous calls in a cell was about five, assuming that no calls were blocked. The simulated time was 2 h and the parameter control was performed every 100 s. The results show that the number of started calls was increased significantly with control, the ratio of poor quality calls was at most 1% with the initial parameters and 2.2% with control, call quality was regarded as poor if over 2% of the frames were received incorrectly during the whole converse time. The blocking ratio was significantly reduced with control. Requiring that at most 5% of the calls are either blocked or suffer from poor quality then the number of subscribers that the network tolerated was between 1000 and 2000 with the initial parameters, while with control the number was increased to between 2000 and 3000. The capacity was much improved by trading off quality for reduced blocking and the combined improvement of capacity was 9% with 2000, 17% with 3000 and 19% with 4000 subscribers – the capacity of the network was improved close to 20% with slightly decreased but still acceptable quality of calls.

In [ABGC03], soft handover performance for UMTS operations was studied. It consists of a sensitivity analysis for determining the optimum setting of parameters controlling the performance of the soft handover procedure. The final results show that the parameters involved in the handover algorithm had a major bearing on the network traffic handling capacity and their optimisation was considered essential, in order to improve some aspects such as dropped calls and failed handovers.

In [Siom05] and [SiVY06], the authors studied other ways of addressing the optimisation issues that could be seen, due to the scope of this thesis, as possible solutions for implementation – the Primary Common Pilot Channel (P-CPICH) Power and antenna tilt optimisation. The P-CPICH is a fixed rate DL physical channel that carries a pre-defined bit/symbol sequence and the measurements are used in the cell search and handover procedures. The MTs scan for the CPICH signals continuously and measure the Carrier-Interference Ratio (CIR) of all pilot signals they can detect. If a MT is unable to clearly receive one dominant CPICH signal, due to interference or coverage problems, the result is likely to be dropped calls, failed initiations, poor voice quality and/or poor data throughput. The BS antenna height, azimuth, and tilt are the important configuration parameters that have a strong impact on network coverage and system capacity thus, they must be carefully planned in the topology planning phase. The antenna configuration can be also changed in the network operation and optimisation phase, but these changes require additional site visits, which is expansive and therefore least desirable. So, antenna tilting is the easiest and the most practical way of changing the antenna configuration in order to improve network performance. In [SiVY06], the results show that for a UMTS planning scenario in Lisbon, automated optimisation saves up to 70% of the CPICH power used in the network configuration, offering significant performance improvement in terms of fewer overloaded cells and lower downlink load factor. In [Siom05], the results show that the effect of electrical tilt on interference reduction is greater than that of mechanical tilt, suggesting that mechanical tilt can be used in addition to electrical tilting, e.g., when a further increase of the electrical antenna tilt is impossible.

It is important to note that this is a theme whose information is usually confidential and restricted to the mobile operators. So the available information is scarce, which is understandable since it is unnatural companies make available something that might be useful to its development and performance improvement.

Chapter 3

Model Development and Implementation

This chapter provides an overview of the models that are related to the scope of this thesis. First the database search algorithm is described, followed by its application with some results presentation. The development and application of the radio network analysis algorithms are presented, distinguishing 2G from 3G models.

3.1 Database Search Algorithm

In order to access the information contained in the operator's database, programmed in SQL language, an algorithm was built, Figure 3.1. The algorithm can be described in four steps:

1 – Search in the database the counter involved in the KPI expression: a table contains all the information referred to all the other tables existing in the database. Access this table to obtain the precise location of the counter in the database.

2 – Describe the tables where the counters are located, in order to do the "match" between them (*join* instruction): always search for the "*primary key*", which indicates the field where the "match" has to be done; *join* collected real network data.

3 – Use the expression to calculate the KPI.

4 – Apply the necessary filters to define range of values, target values, etc.

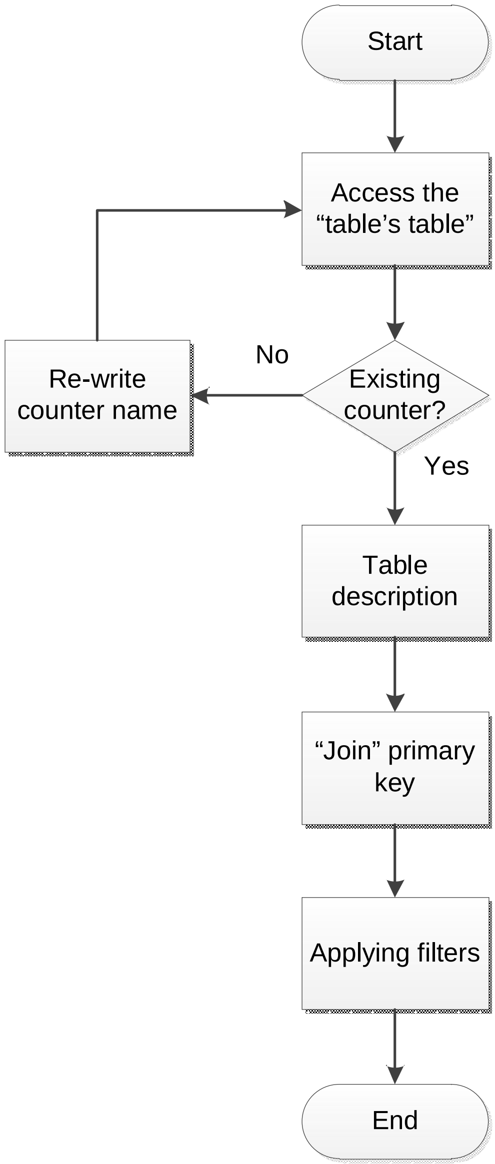

Figure 3.1 Database search algorithm.

Based on this algorithm, it is possible to access the counters involved in the KPIs calculation, as shown in the previous chapter. For example, to calculate call drop rate, the first step is to find the counters that represent the total amount of traffic channel drops (N_{TCH_D}) and the total number of terminated calls in a cell (N_C). The second step is to program a *query* in order to turn possible to the programmer know the precise location of the table that contains the counter information. After that, it is just math, applying the call drop rate expression, as shown in (2.1). The output of the program gives all the information needed to move on: the area where the cell is located, the name of the cell, the date, the hour and the value of the KPI for the specified conditions. A list of nine GSM KPIs and fourteen UMTS KPIs was provided by the operator.

The operator sets $N_{C_{min}}$ (minimum number of calls) as 10% of the maximum daily value for a site place, which is important to know in order to evaluate a KPI that uses the counter with the information related to all the terminated calls in a cell. The region in study is covered by 328 GSM 900 BSs, 306 GSM 1800 BSs and 224 UMTS BSs, as shown in Table E.1. The results obtained from the database search algorithm application are shown in Annex B.

3.2 GSM Network Analysis

The main goal is try to explain the network performance analysing the KPIs performance throughout time. A strategy has to be defined in order to adress the KPIs performance issues. Initially the KPIs are analysed in a total radio network perspective, which means selecting a random day (the chosen one was the September 2nd 2010) and analyse the network performance in all BSs. An algorithm has to be built to define the way of "attacking" KPIs performance, providing solutions to solve future problems, introducing the performance comparison between the different parameters, in order to detect any kind of correlation between them. The final step is the generalisation of results considering larger time intervals.

The proposed analysis flow is given in Figure 3.2, applicable to both GSM and UMTS. The objective is to apply the ideas inherent to the algorithm of Figure 3.2 in the performance analysis of all KPIs. After the characteristics of the problem being identified, it is necessary to think about what to do next. The benchmarking process consists of the evaluation of the overall KPI performance and compare it with the desired performance established by the pre-defined thresholds. If the analysed results do not match with the desired ones, there is a need to develop specific algorithms to analyse the KPIs individually based on detailed statistics of the problem areas. The ultimate goal is to identify the problem reason and if possible to give recommendations to the operator in order to solve it.

Dropped calls show the number of abnormal disconnections during call setup or during conversation. In [Eric98], three steps to provide a good dropped call analysis are presented:

1) Check dropped calls per cell. Select cells with high dropped call rate.
2) Check reason to dropped calls for selected cells.

3) Check ratio of lost handovers to dropped calls. The reason is to determine if the high dropped call rate is related to handover performance. Check also which cell relations that have more dropped calls than the average neighbour relation.

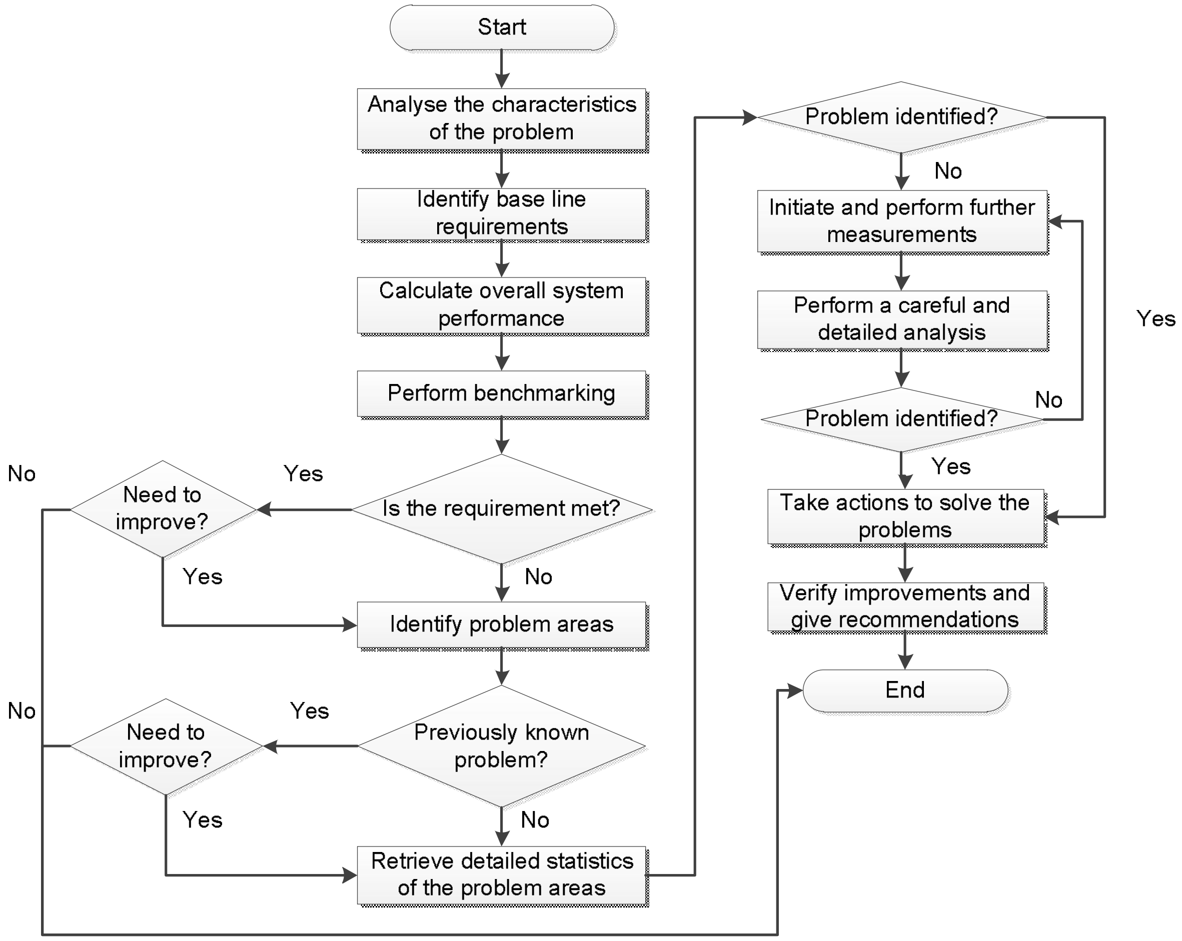

Figure 3.2 Analysis flow chart (adapted from [Eric98]).

In order to get an indication of the reason for possible bad performance and according to [Eric06], both call drop rate on TCH and on SDCCH will be above the threshold level due to excessive TA, low signal strength, bad quality and sudden loss of connection. R_{C_D} can also be above the threshold level due to high Frame Error Ratio (FER) and R_{SDCCH_D} can also be above the threshold level due to TCH congestion. Figures 3.3 and 3.4 show the procedure to address the problem on TCH and SDCCH, respectively, with the properly identification of the counters associated to the reasons that may lead to a poor performance of the KPI.

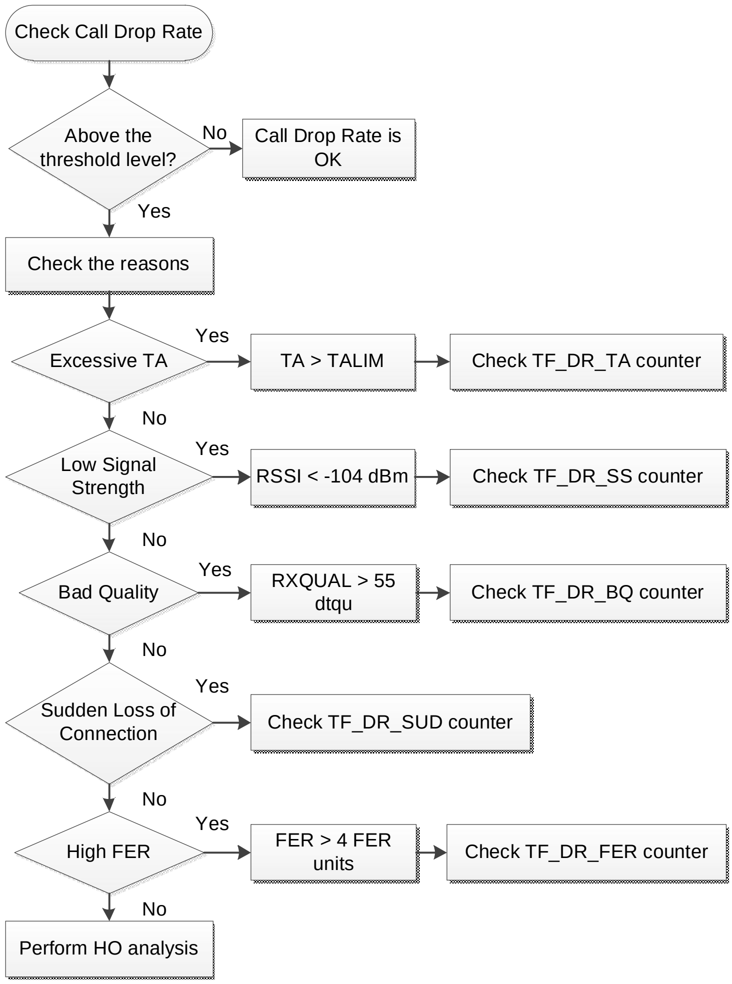

Figure 3.3 Analysis algorithm of R_{C_D}.

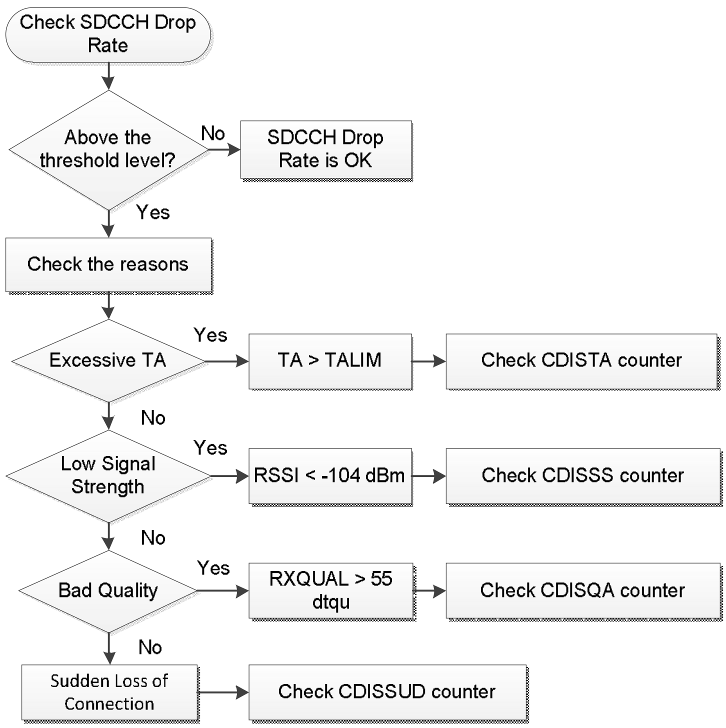

Figure 3.4 Analysis algorithm of R_{SDCCH_D}.

R_{CS_S} is related to R_{SDCCH_D}, which is easily understandable when analysing the call establishment process. Figure 3.5 illustrates it in a very simplistic way.

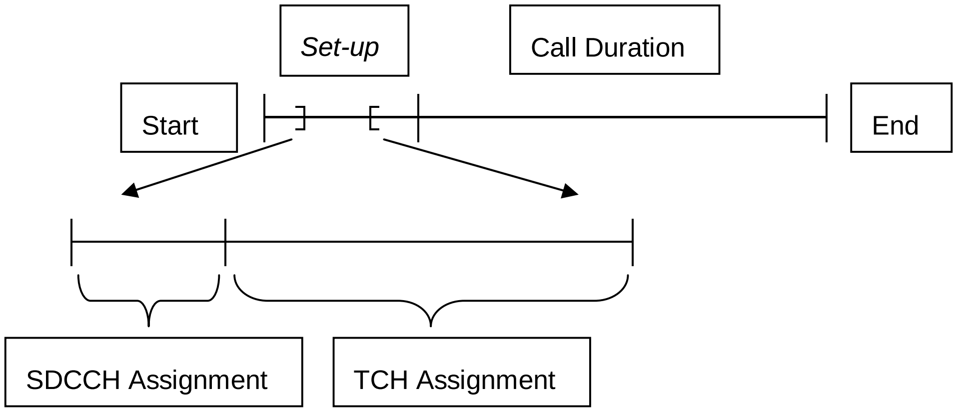

Figure 3.5 Call establishment process.

Thus, (2.3) is now understandable. The two KPIs are almost symmetric. The difference is in the $(1 - R_{TCH_F})$ factor, R_{TCH_F} being the TCH assignment failure. In perfect conditions the TCH assignment failure rate is equal 0, which never happens in real radio networks. Figures 3.6 and 3.7 illustrate the algorithm to address the problems related to R_{CS_S}. Analysing Figure 3.6, the reasons identified that may lead to a poor performance of the call setup success rate KPI are a low TCH assignment success rate or a high SDCCH drop rate. In case of high SDCCH drop rate, the analysis to be made is equal to the developed model in Figure 3.4. In case of low TCH assignment success rate, Figure 3.7 suggests actions to the operator that may lead to the problem solution. Those actions can only be implemented by the operator, many of them only on the field.

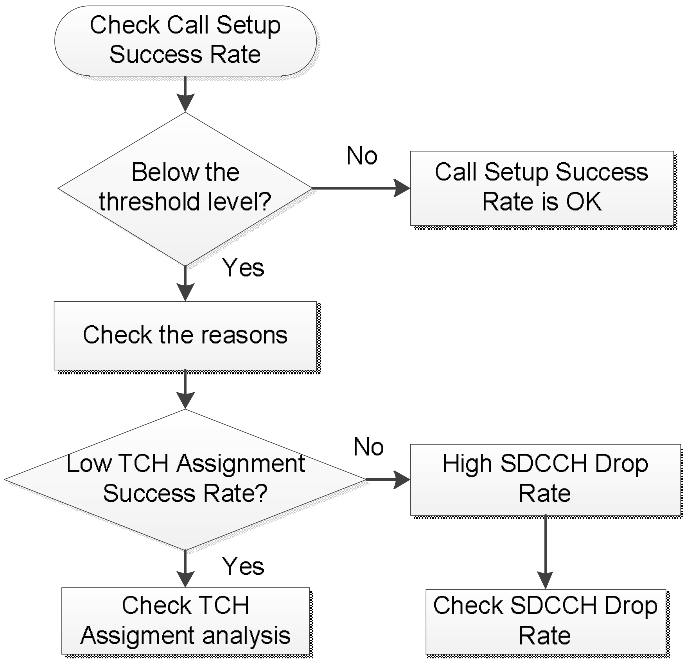

Figure 3.6 Analysis algorithm of R_{CS_S}.

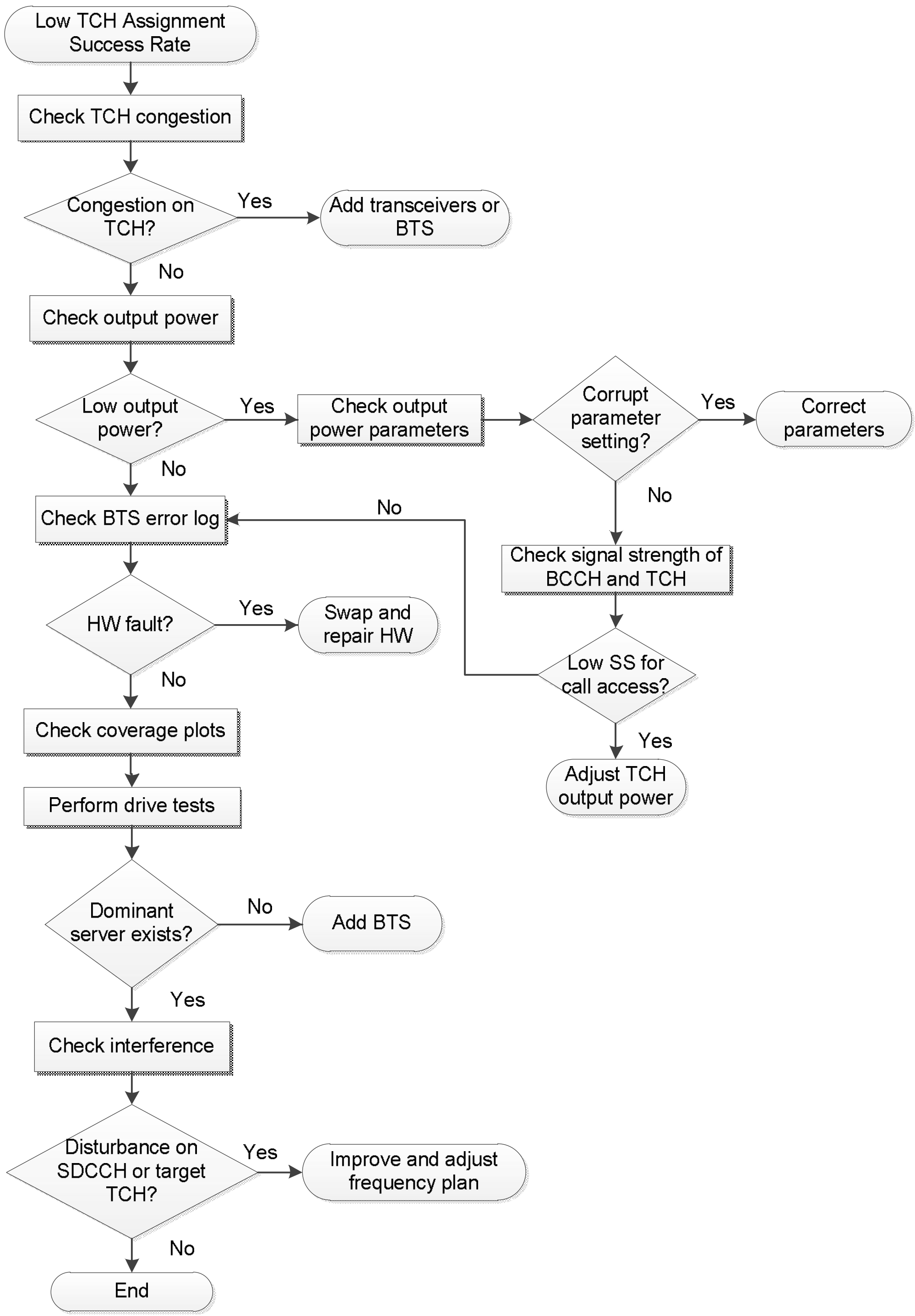

Figure 3.7 Low TCH Assignment Success Rate analysis (adapted from [Eric98]).

Handover is a key function in a network. If the handover performance is poor, the subscriber will perceive the quality of the network as bad. The $\boldsymbol{R_{HO_S}}$ parameter will be below the threshold value due to intra-cell handover (normally performed in cells with high signal strength and bad quality) or handover to the neighbouring cell problems. The HO performance analysis is illustrated in Figure 3.8. The first decision to be taken is related to the HO activity. When analysing the HO performance it is imperative to define if there are few HO attempts, by checking the HOVERCNT counter. This decision will guide future decisions, since it will be given a greater importance to a cell with many HO attempts over another cell with few. Figure 3.9 illustrates the actions to be taken if there are few HO attempts. The steps contained in this algorithm are not implemented when running the simulations. The operator will be responsible for that.

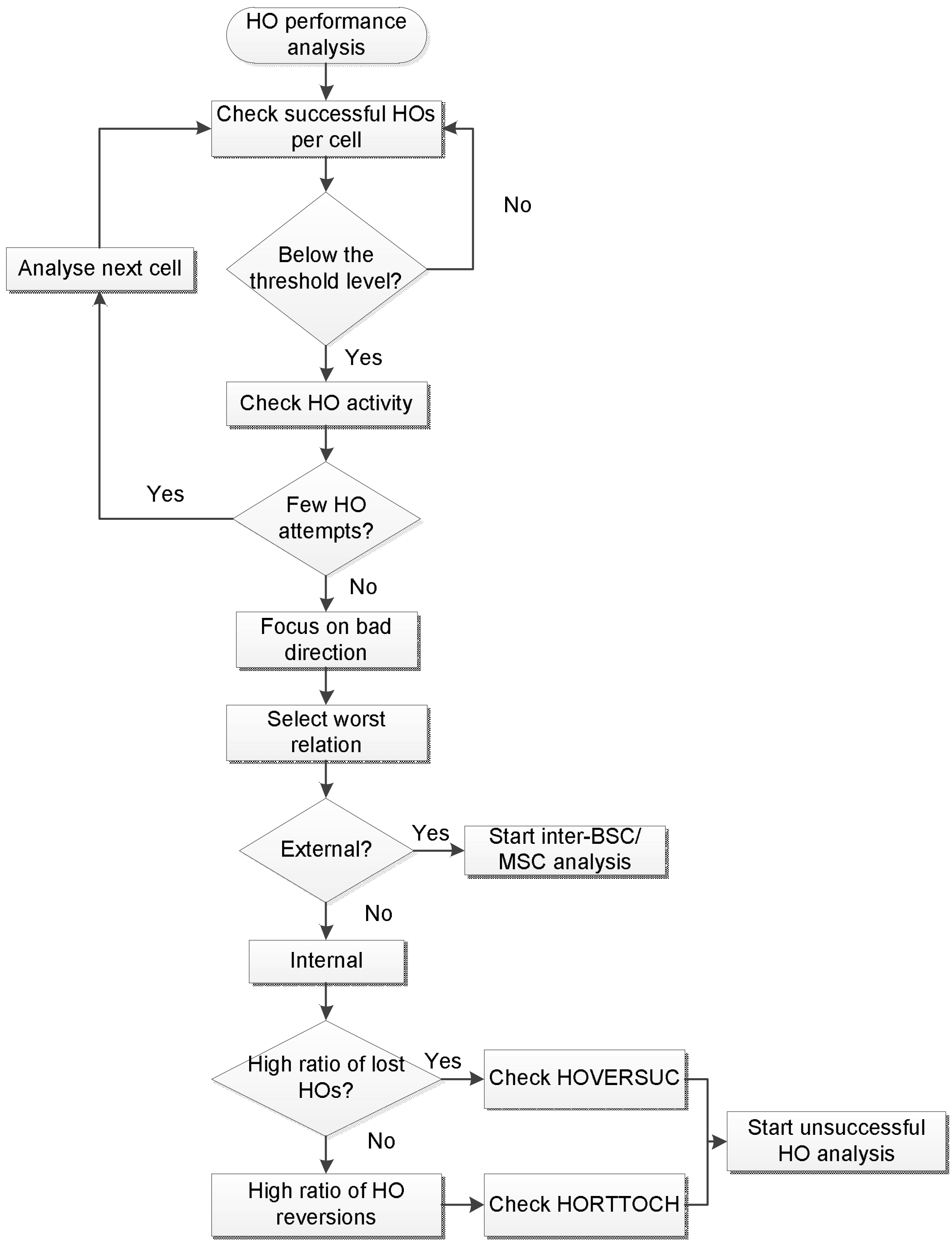

Figure 3.8 HO performance analysis (adapted from [Eric98]).

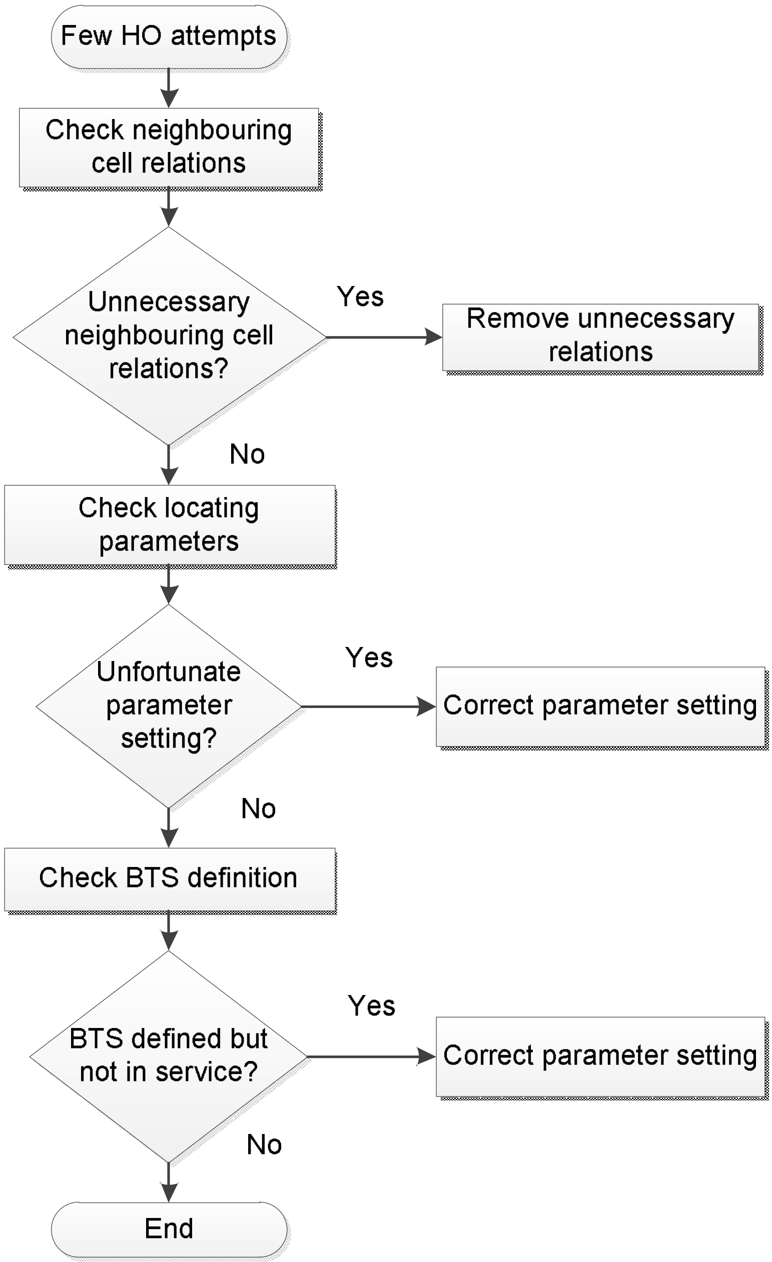

Figure 3.9 Few HO attempts (adapted from [Eric98]).

The next step is to identify the worst relation: internal or external. If the worst relation is the external, the operator has to start an inter-BSC/MSC analysis. If the worst relation is the internal, there are two reasons why an attempt is counted as unsuccessful: either the MT was lost (Lost HO) or the call was reverted to the old cell and channel (HO reversion). Unsuccessful HOs may lead to a dropped call and the lost handovers are registered at outgoing handover – dropped call counters are stepped. Figures 3.10 and 3.11 illustrate how to address the problem. A HO reversion is when the MT is going back to the old channel. This happens when the MT fails to establish itself on the new traffic channel, but succeeds to return to the old traffic channel. If the MT does not succeed to return, it will be lost. In simulations, it is only possible to identify if a unsuccessful HO is considered lost or a reversion. The developed models illustrated in Figures 3.10 and 3.11 can only be implemented by the operator.

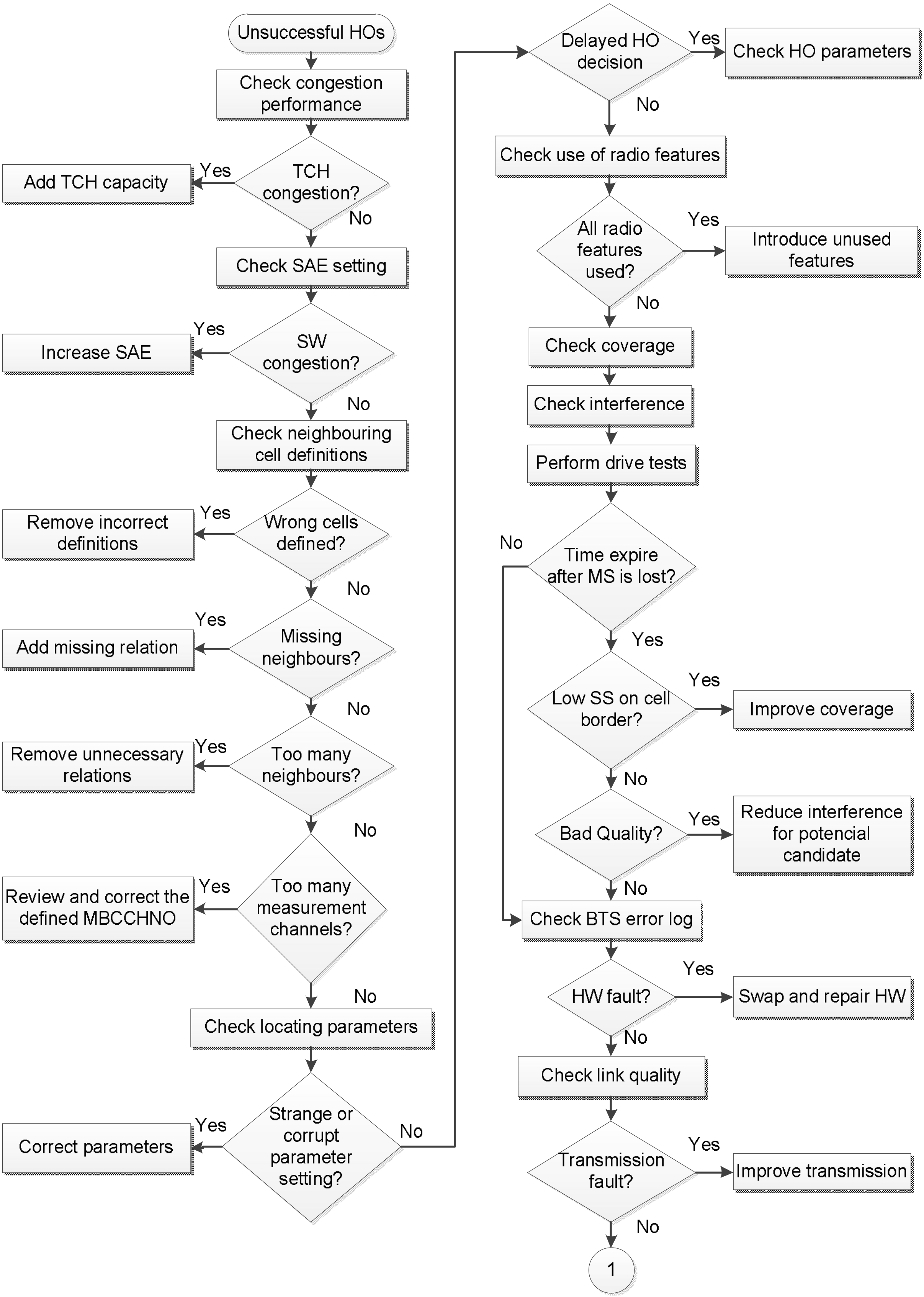

Figure 3.10 Unsuccessful HOs analysis – part I (adapted from [Eric98]).

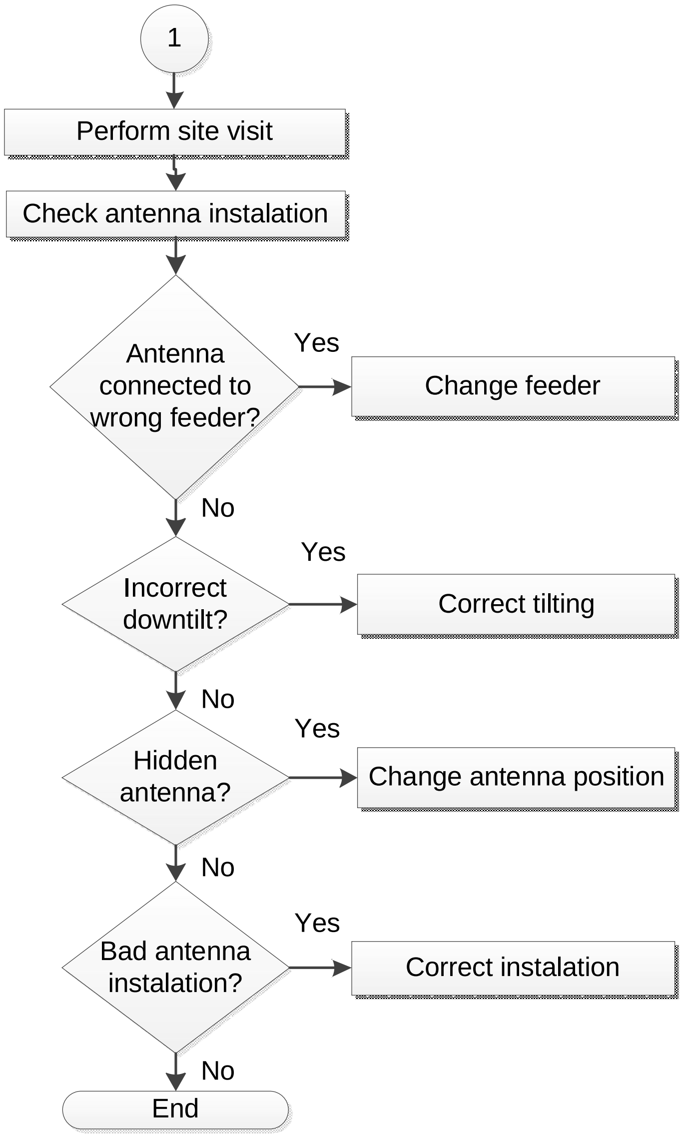

Figure 3.11 Unsuccessful HOs analysis – part II (adapted from [Eric98]).

The objective with the set of counters responsible for evaluate the IP throughput is to allow the operator to check the speed with wich the BSS manages to transport IP packets to the users in each cell. According to [Eric06], a number of factors can affect the measured IP throughput, for example:

- Poor radio link quality (level two counters — “Radio link quality”).
- Less PDCH reserved than requested by the user (level two counters —”Multislot utilisation”, “PDCH allocation”, “GSL device utilisation” and “RPP load”).
- Reserved PDCH shared by other users (level two counters —“GPRS traffic load”).
- QoS scheduling prioritising another user (there are separate IP throughput counters for each QoS Traffic Class. Also level two counters — “GPRS traffic load” give the average QoS weight per PDCH).

- Delays in setup of DL TBFs, e.g., no allocated PDCHs or no CCCH capacity to send the assignment/channel request messages (included in the IP throughput counters). A very minor effect compared to those listed above.

The MS capability is another factor that can impact the measured IP throughput (in a rather complex way). Factors are:

- GPRS or EGPRS capable.
- Multi-slot capability (level two counters— “Multislot utilisation” can help).
- Frequency band capability.
- 3GPP Release of the mobile.

Figure 3.12 illustrates the algorithm to address the issues related to all GSM throughput KPIs.

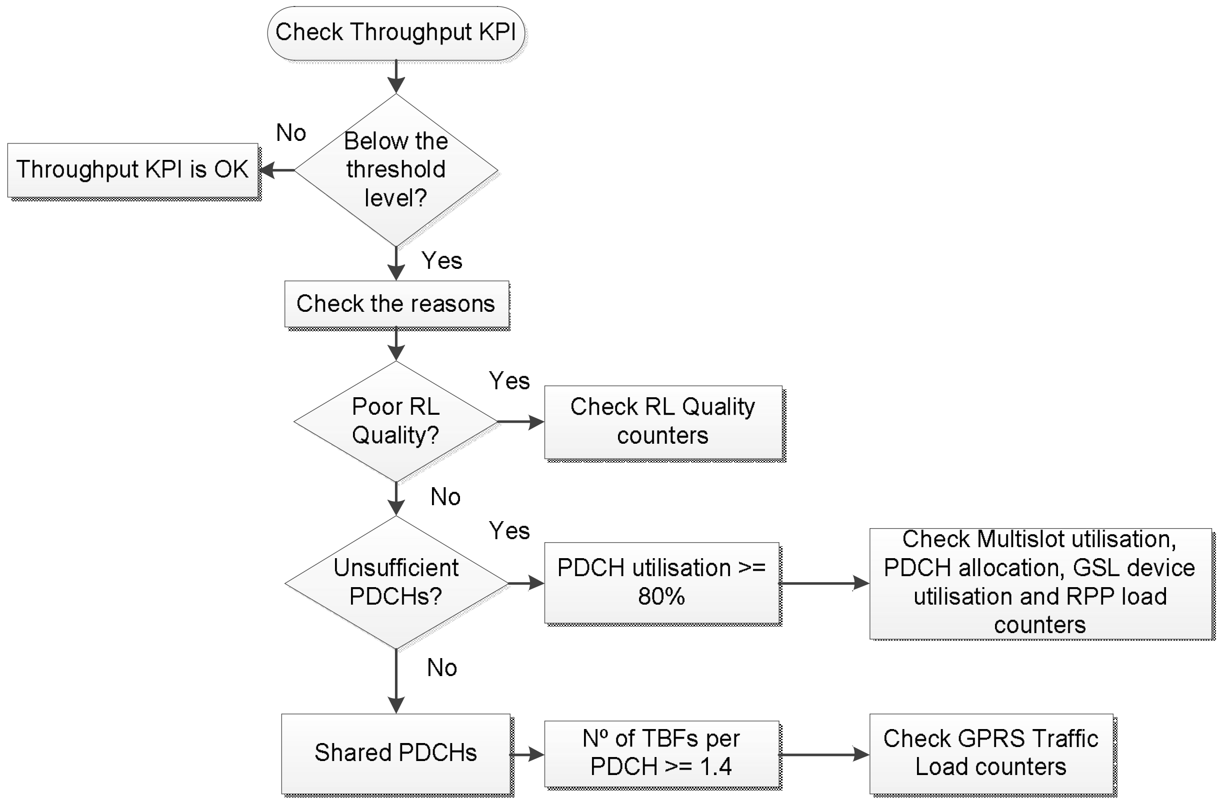

Figure 3.12 Analysis algorithm of GSM IP throughput KPIs.

Being the R_{PDCH_S} below the threshold value when the number of packet channel allocation failures is too high, and analysing the issues illustrated in Figure 3.12 that may affect the throughput KPIs performance, one can easily conclude that there is a strict relation between the PDCH assignment process and the throughput performance. Saying that the number of allocated PDCHs is insufficient for the requirements needed to obtain a good throughput performance is the same as saying that the number of PDCH allocation failures is too high. Figure 3.13 illustrates the algorithm to address the problems in the PDCH assignment success rate KPI performance. Intense Half-Rate (HR) traffic, TCH congestion and an excessive number of TBFs per user are the mains causes for a poor KPI performance.

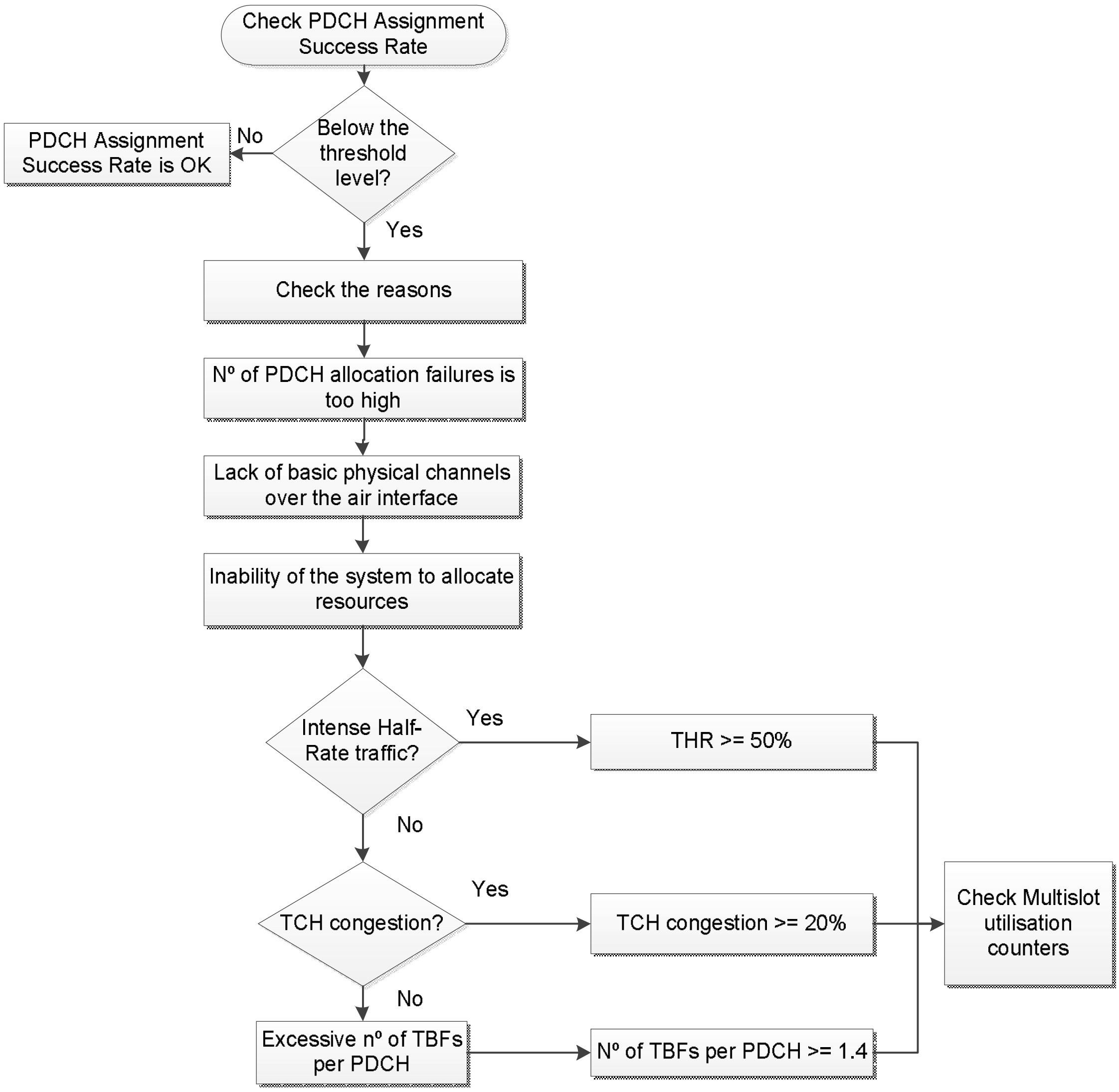

Figure 3.13 Analysis algorithm of R_{PDCH_S}.

3.3 UMTS Network Analysis

In the 3G analysis, the list of provided KPIs contains two major groups: the group of the call setup success rate KPIs and the group of the call drop rate KPIs. In the first, the analysis is focused on the "RRC&RAB Success Rate", taking into account the RRC/RAB connection/establishment scenario. It is possible to identify two main reasons for the performance degradation: failures after admission and requests denied due to admission. The counter pmNoFailedAfterAdm is responsible for counting the number of rejected RRC connections and RAB establishment requests failed after being admitted by admission control, respectively, and the counter pmNoReqDeniedAdm is responsible for counting the number of RAB establishment and RRC connections requests denied due to admission. The idea is to identify the cases where the failures are associated to radio reasons, because they are the one that really matter, due to the scope of the thesis. The reasons associated to failures after admission are usually due to Iub configuration problems and are not analysed. The call setup success rate KPIs

(Speech, CS64, R99 and HSDPA) can be seen as the product of two rates: the “RRC Success Rate” and the “RAB Establishment Success Rate”, varying only the type of service. Figures 3.14 and 3.15 illustrate the developed algorithm for evaluate those type of KPIs, addressing the RRC connection setup and RAB establishment scenarios. The difference between the KPIs analysis is only the counters involved in the process. The counter associated to node blocking also considers cases that are not related to radio reasons, which helps to understand some apparently inconsistent results.

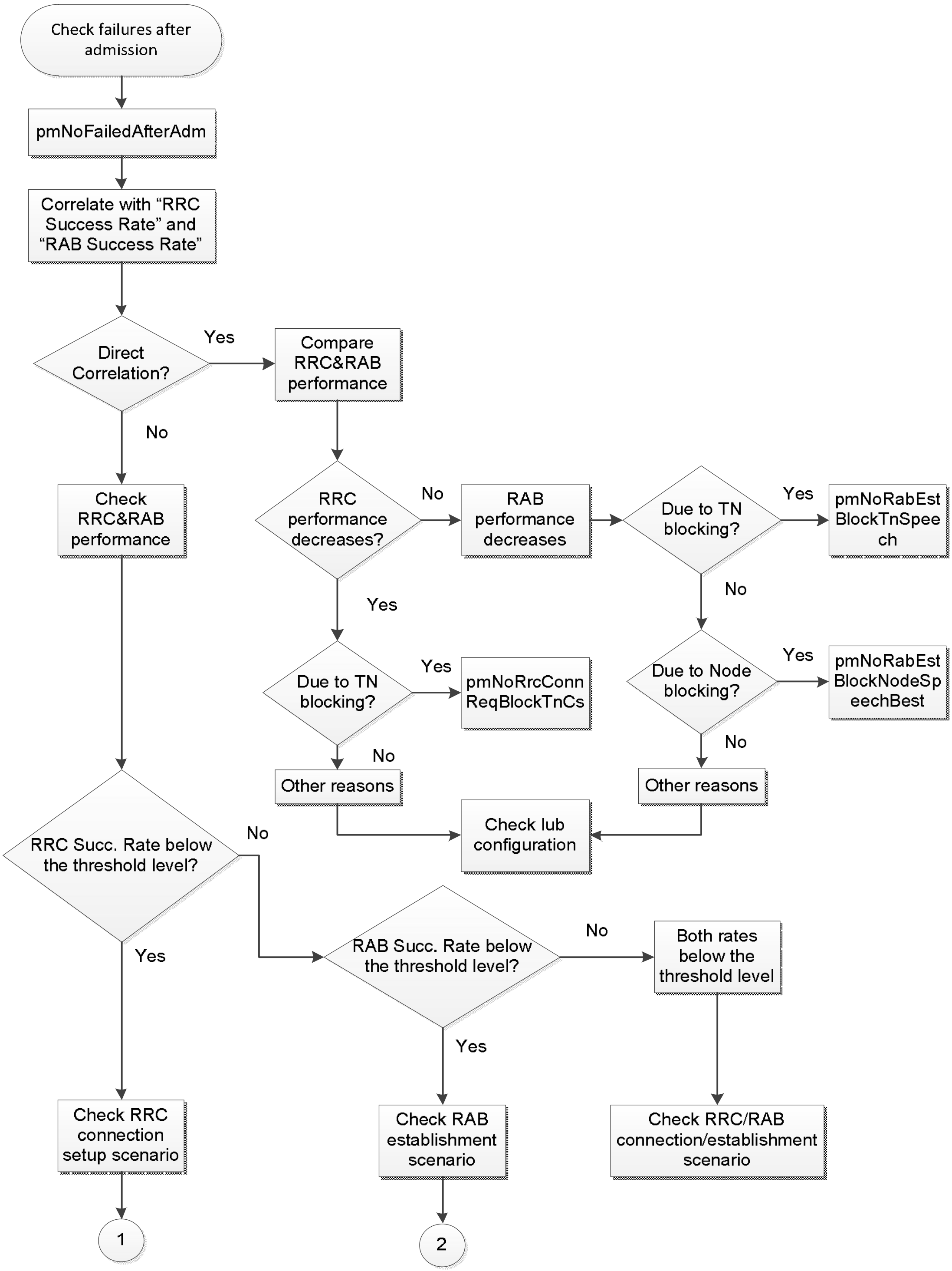

Figure 3.14 RRC/RAB connection/establishment scenario algorithm – part I (adapted from [Eric09]).

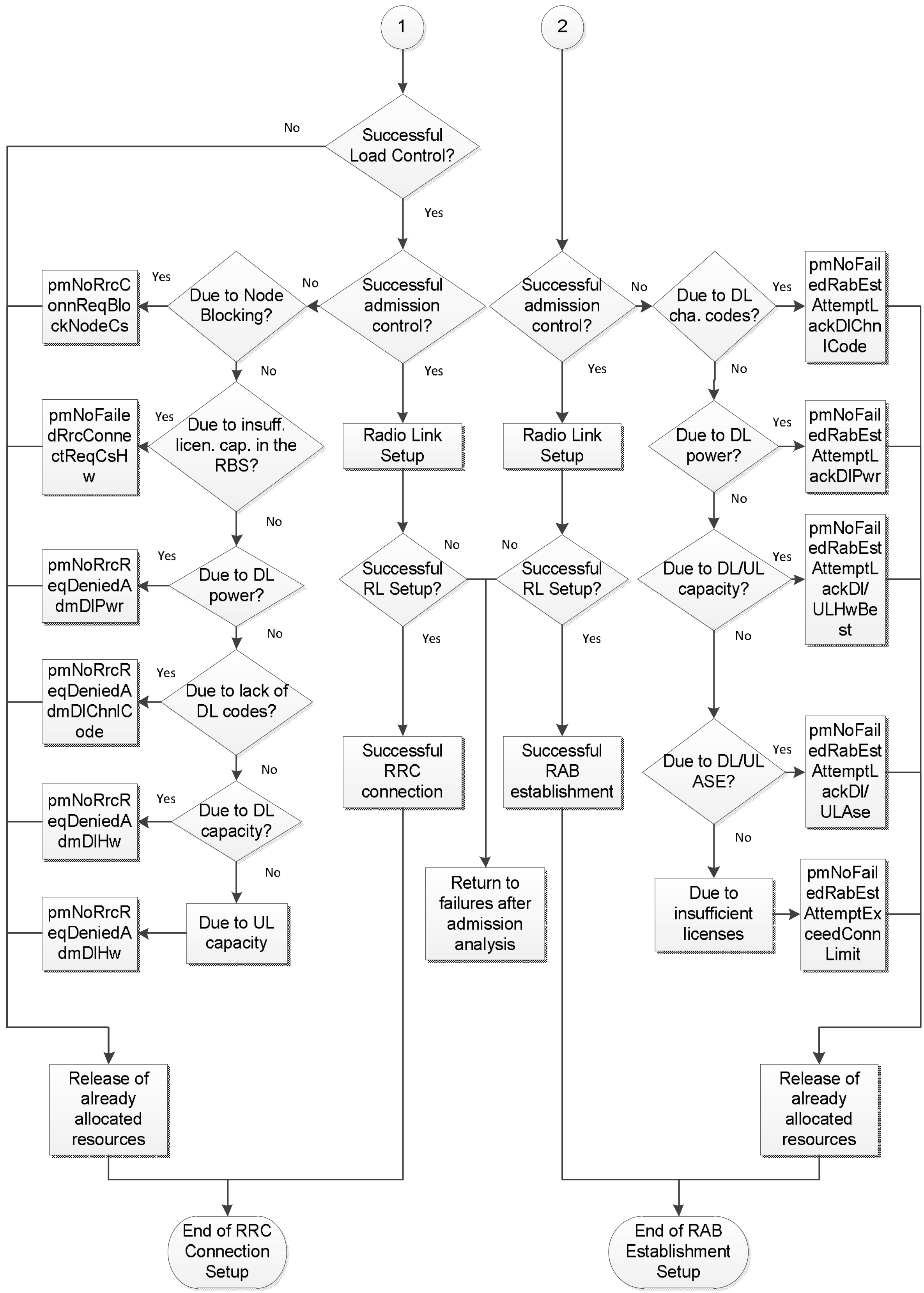

Figure 3.15 RRC/RAB connection/establishment scenario algorithm – part II (adapted from [Eric09]).

The reasons identified as responsible for unsuccessful admission control in the RRC setup connection scenario are failures due to node blocking, i.e., node configuration error, node limitation or transport network layer service unavailability, to insufficient licensed capacity in the RBS, to insufficient DL power, to lack of DL channelisation codes and to DL/UL lack of capacity. The reasons identified as responsible for unsuccessful admission control in the RAB establishment scenario are failures due to insufficient licensed capacity, to insufficient DL power, to lack of DL channelisation codes, to DL/UL lack of capacity and to lack of DL/UL Air Speech Equivalent (ASE), which is a measure of air-interface utilisation relative to the utilisation of one speech user (for instance, a connection using 3 ASEs in DL generates the same interference level as the one generated by three voice users).

In the second group of KPIs, the RAB drop performance is the analysis starting point, since all the KPIs can be seen as the ratio between the abnormal RAB releases over the total number of RAB releases. The algorithm to address the speech call drop rate problems is shown in Figure 3.16. The reasons that may lead to call drops are cell congestion, lost of UL synchronism, missing cell neighbours and soft HO action.

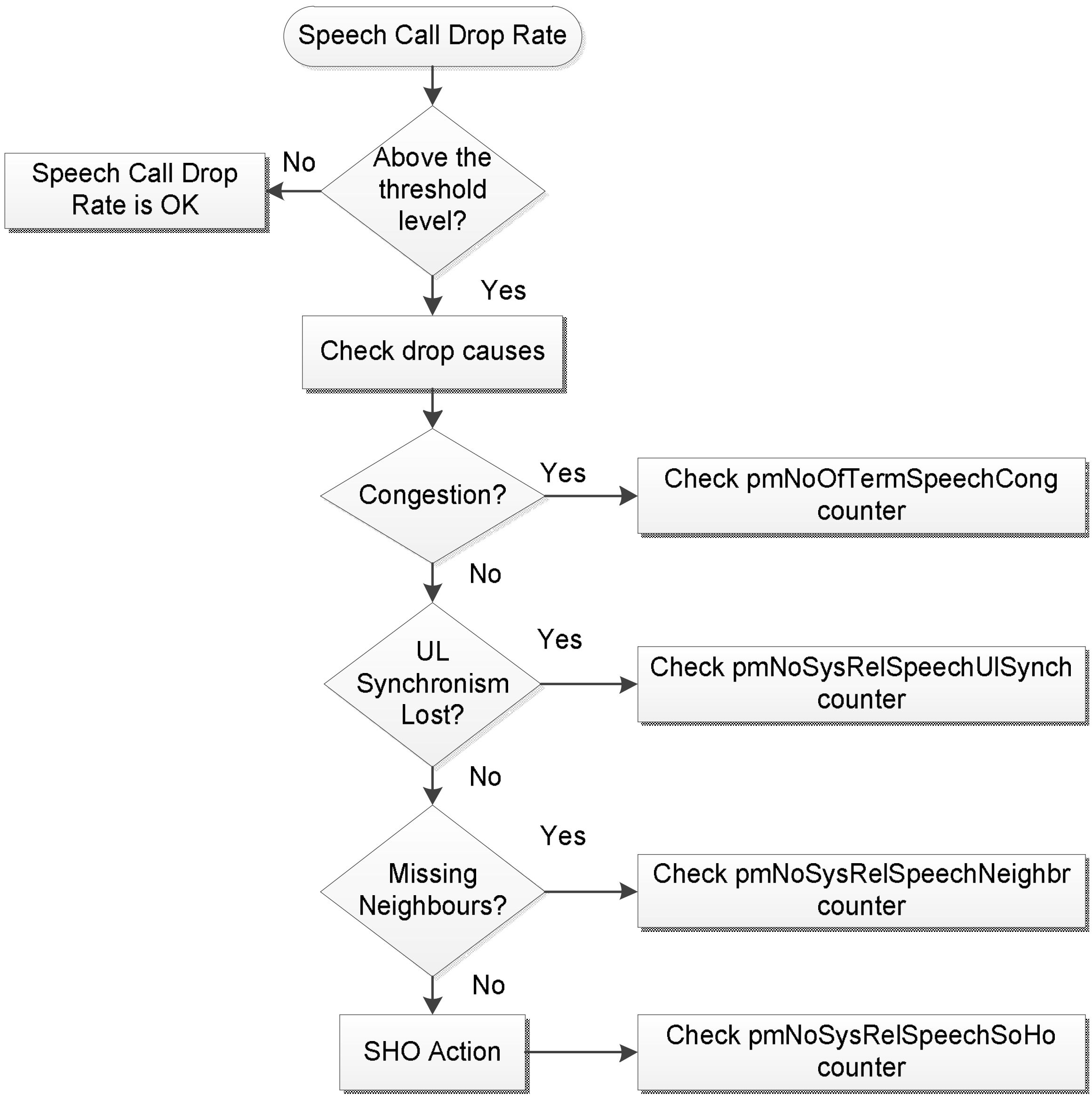

Figure 3.16 Speech Call Drop Rate algorithm.

When analysing call drop rate KPI for data services, the approach has to be a little different. Since there are no counters directly associated to the reasons that may lead to a poor performance, during optimisation activity, and especially in case of parameter changes, it is recommended to monitor other KPIs, since the absolute value of RAB or RRC call drop rate can give a partial vision of the performances, because it is not taken into consideration service time length. The KPI “Minutes per Drop” plays an important role in this matter: it gives the average time length (in minutes) between 2 consecutive drops of data calls. It is very useful to report real end user perception of drop call because it gives the idea how often a user is experiencing a drop call. The pre-defined thresholds are 12 minutes for PS connections and 9 minutes for HS connections. Per example, an user can connect to the data network in the morning (1 establishment), stay connected for 8 h with multiple transitions between cell FACH and cell DCH (0 establishments) and 1 drop is counted – this means a call drop rate of 100% and a call completion success rate of 0%. However, the number of minutes between drops will be 480. This means that in addiction of analysing the CDR for PS or HS the KPI “Minutes per Drop” has to be analysed as well as the transitions that occur between different states.

When dealing with the channel switching issues, two KPIs are taken into account: the Channel Downswitch Failure Rate, which evaluates the probability that the channel downswitch transitions fail during the channel switching procedure, and the Channel Upswitch Failure Rate, which evaluates the probability that the channel upswitch transitions fail due to admission control reject or failures during the channel switching procedure. The last one can be analysed according to the type of transition and the traffic direction (DL/UL). The Channel Upswitch Failure Rate DL/UL Low Rate is analysed, which evaluates the failure probability of the transitions in DL between FACH and CELL DCH with DL/UL rate up to 64 kbps, the Channel Upswitch Failure Rate DL/UL Medium Rate, which evaluates the failure probability of the channel upswitching transitions due to throughput in DL/UL CELL DCH to CELL DCH with DL/UL target rate between 64 and 256 kbps, the Channel Upswitch Failure Rate DL/UL High Rate, which evaluates the failure probability of the channel upswitching transitions due to throughput in DL/UL CELL DCH to CELL DCH with DL/UL target rate higher than or equal to 256 kbps (not including HS in DL and excluding EUL in UL), the Channel Upswitch Failure Rate DL HS, which evaluates the failure probability of the channel upswitching transitions due to throughput in DL from CELL FACH or CELL DCH R99 to any HS state, and the Channel Upswitch Failure Rate FACH-HS, which evaluates the failure probability of the transitions in UL between FACH and HSDPA.

Figure 3.17 illustrates the procedures to analyse the performance of the data call drop rate KPIs. Besides this, the call setup success rate performance has also to be analysed according to Figures 3.10 and 3.11 as well as the speech call drop rate performance, since when a speech call request arrives the data call will be in preemption.

Throughput problems are usually associated to capacity problems. In the 3G throughput analysis, the PS/HS throughout performance is compared to parameters, such as the average cell traffic volume, the number of users, in order to analyse the variations in the throughput data rate with the variations in the number of users, and the PS/HS call drop rate performance, in order to analyse the effect of a data call drop in the throughput performance. Figure 3.18 illustrates the process.

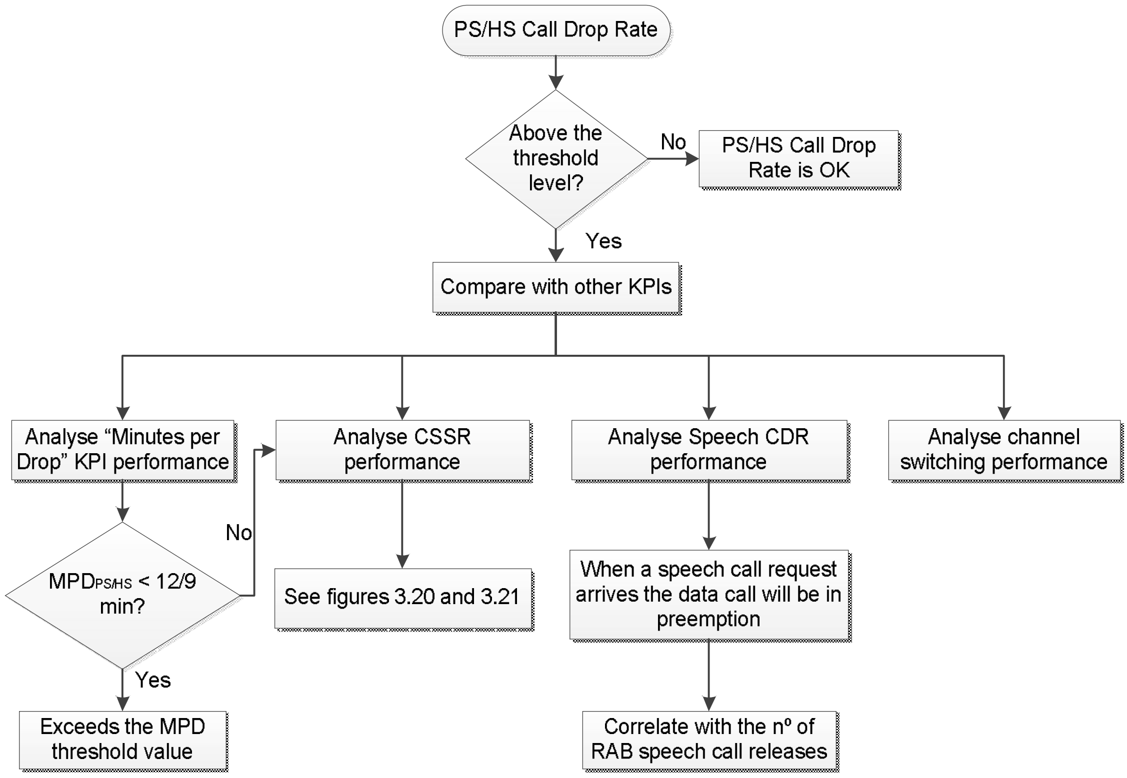

Figure 3.17 Data call drop rate analysis algorithm.

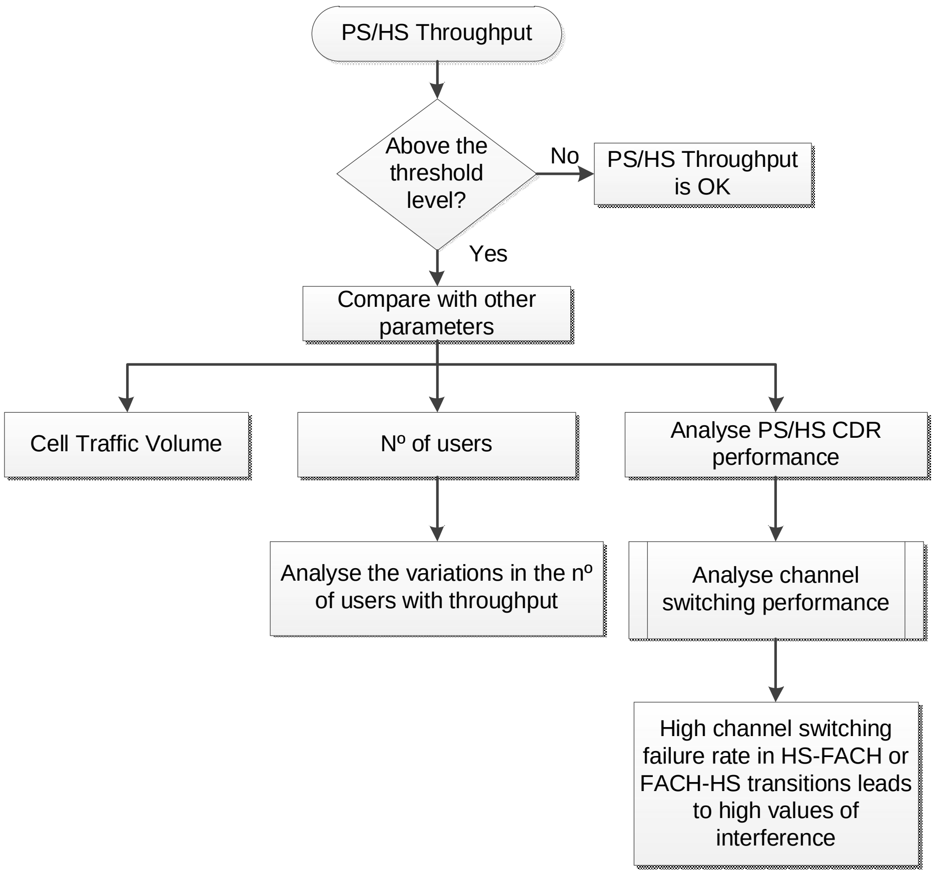

Figure 3.18 PS/HS Throughput analysis algorithm.

The soft HO issues are analysed according to Figure 3.19. The counter responsible for counting the HO failures is incremented if, during an attempt to add a RL, any of the following occur: admission is not granted due to lack of DL channelisation code, the RL setup procedure fails, RL addition procedure fails, RL setup or addition procedure times out in the RBS, the active set update procedure fails or active set update procedure times out in the UE.

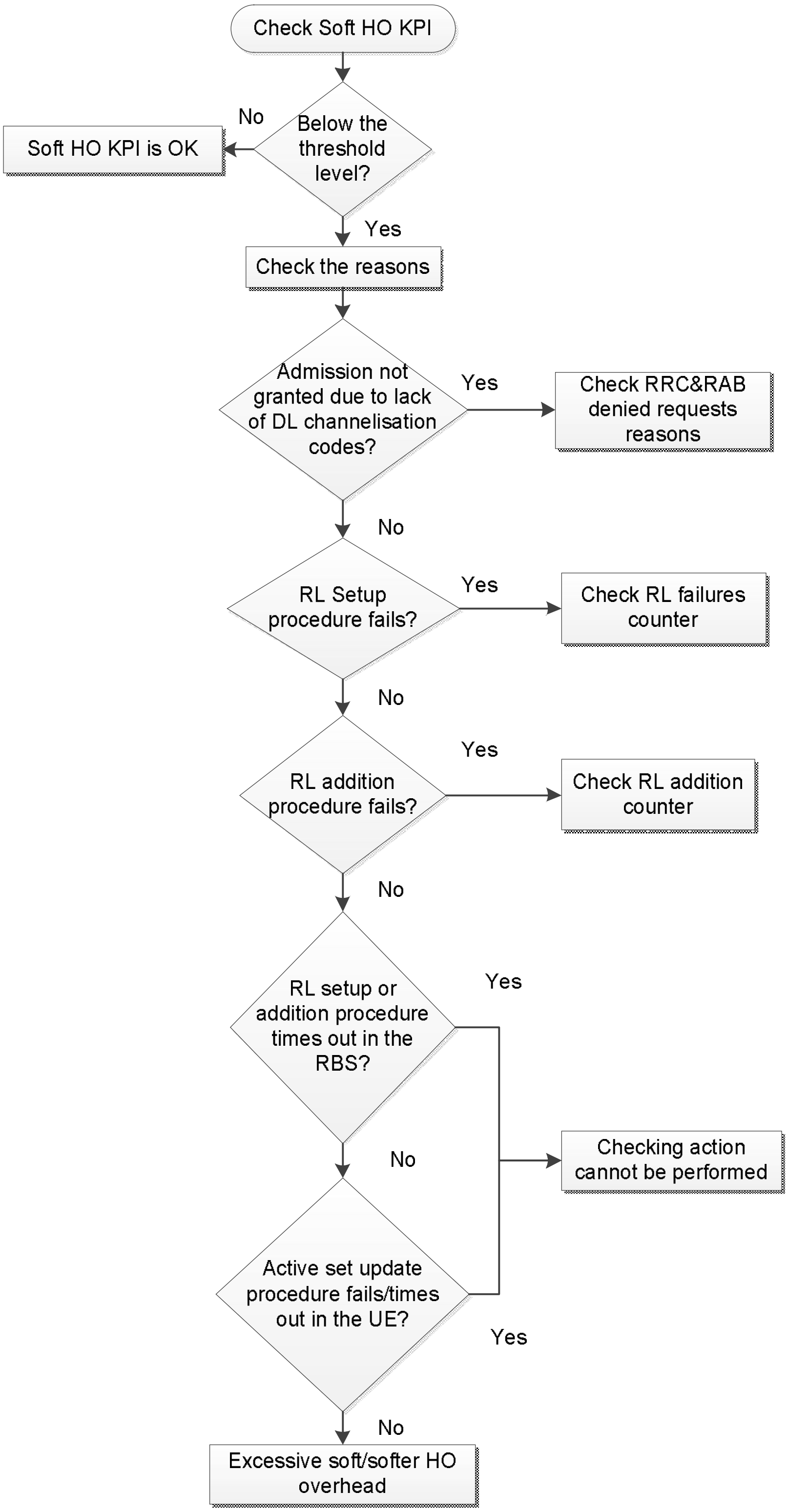

Figure 3.19 Soft HO analysis algorithm.

Chapter 4

Results Analysis

This chapter contains the descriptions of the used scenarios and the results analysis. First the simulation scenarios are presented, followed by the simulation output results. The results concerning the correlation between different KPIs are presented in this chapter.

4.1 GSM Analysis

4.1.1 Voice Call Performance

In this chapter, one presents the results obtained from the application of the algorithms illustrated in the previous chapter. Taking into account the huge dimension of the radio network that is being studied in this thesis, the analysis has to be done step by step, which means to start the results analysis from a smaller time interval (e.g, a day), increasing progressively the time interval as the analysis is being made. The final analysis is done for the month of January 2010, since the operator identified January as one of the most problematic months in 2010, concerning the total radio network performance.

The main goal being to establish a correlation between the different KPIs, the final analysis is made according to four steps:

1. Monthly KPI analysis, which consists in analysing the KPIs performance separately in a total radio network perspective.
2. KPI analysis after “filtering”, which consists in analysing the KPIs performance in the most critical BSs, i.e., BSs where the KPI has a poorer performance.
3. BS analysis, which consists in identifying the problem in a sectoral or BSC level.
4. Correlation between KPIs, i.e., analysis of the cases where different KPIs values are below/above the threshold level at the same time and try to establish a correlation between them.

It is important to enhance the fact that the results analysis is made from the *query's* output data. This is a very lengthy process, each query lasts on average about 2 h. It is also important to refer that the number of queries is directly proportional to the number of KPIs and each KPI is analysed together with other KPIs, thus, further increasing the time spent with the analysis. The results concerning the September 2nd, 2010 are presented in Annex C. In Sections 4.1 and 4.2, just one BS from the total of BSs identified as problematic is analysed. The results presentation and explanation concerning January 2010 related to the remaining BSs are in Annex D. Table 4.1 contains the results of the KPIs performance. The values are concerning only the cases where the KPIs are above/below the threshold level.

Table 4.1 Monthly KPIs performance.

KPI	Average Value	Standard Deviation	Monthly Weight (%)
R_{C_D}	7.26%	4.43%	0.64
R_{SDCCH_D}	6.77%	4.08%	1.49
R_{CS_S}	80.75%	12.55%	0.64
R_{HO_S}	87.12%	7.69%	2.15
$T_{GPRS_{DL}}$	10.46 kbps	10.28 kbps	6.80
$T_{GPRS_{UL}}$	8.30 kbps	1.20 kbps	3.34
$T_{EDGE_{DL}}$	27.77 kbps	36.93 kbps	6.74
$T_{EDGE_{UL}}$	23.90 kbps	4.31 kbps	20.11
R_{PDCH_S}	29.81%	28.42	8.86

Analysing Table 4.1 it is possible to conclude that R_{C_D} and R_{CS_S} poor performance has a very reduced impact in the total radio network performance contrary to $T_{EDGE_{UL}}$ poor performance, which represents 20.11% of the entire month performance. This impact is calculated using (4.1):

$$Monthly\ Weight = \frac{N_{Problematic\_Hours_{BS}} \times N_{Problematic\_BS}}{N_{BS_{Total}} \times N_{Hours_{Total}}} [\%] \quad (4.1)$$

where:

- $N_{Problematic\_Hours_{BS}}$ is the number of problematic hours per BS.
- $N_{Problematic\_BS}$ is the total number of problematic BSs.
- $N_{BS_{Total}}$ is the total number of BSs.
- $N_{Hours_{Total}}$ is the total number of hours.

$T_{EDGE_{DL}}$ has the highest value of standard deviation (36.93kbps), being the KPI with measured values more dispersed from the target one. The "filtering" action was applied to all the KPIs, individually. Table 4.2 indicates the percentage of "problematic BSs".

Table 4.2 KPIs analysis after filtering.

KPI	"Problematic BSs" (%)
R_{C_D}	5.18
R_{SDCCH_D}	13.42
R_{CS_S}	17.68
R_{HO_S}	12.80
R_{HO_S} (external)	17.38
$T_{GPRS_{DL}}$	29.27
$T_{GPRS_{UL}}$	28.05
$T_{EDGE_{DL}}$	39.94
$T_{EDGE_{UL}}$	81.40
R_{PDCH_S}	42.99

Throughout the process of running the analysis, it was possible to identify the percentages associated to the number of hours where the KPIs performance value were above the threshold level at the same time as others KPIs. Those percentages are represented in tables contained in Annex D. Analysing Table 4.2, it is possible to conclude that R_{C_D} has the lowest percentage of problematic BSs, while in the $T_{EDGE_{UL}}$ analysis 81.40% of the total BSs were identified as problematic. It is now possible to start the correlation process. For obvious reasons, it is not necessary to correlate all the parameters between them – e.g., a voice call does not drop due to throughput performance problems. Therefore, analysing the results, it is possible to identify the percentage associated to the number of hours where the KPI value is above the threshold level at the same time as others KPIs, Annex D. It is also possible to identify the correlation values between the R_{C_D} and R_{HO_S}, R_{SDCCH_D}, R_{CS_S} KPIs, Table 4.3. For confidentiality reasons the BSs are numbered in random order (note that BS 1 in call drop rate analysis may not be the same in SDCCH drop rate analysis).

Table 4.3 shows the correlation values of the BSs that were considered most critical. Looking at the results related to call drop rate and HO success rate, it is possible to conclude that in BS 2 the correlation value between the two KPIs performance throughout the analysed hours is -91.24%, which indicates a high dependence between them. Figure 4.1 shows R_{C_D} and R_{HO_S} performance evolution in that period.

Table 4.3 R_{C_D} correlation analysis.

BS	R_{C_D} and R_{HO_S} (%)	R_{C_D} and R_{SDCCH_D} (%)	R_{C_D} and R_{CS_S} (%)
6	-69.80	-50.92	53.38
2	-91.24	45.16	-
3	-100.00	7.62	-15.66
11	100.00	51.71	-46.85
12	2.72	38.59	-78.70
13	-48.28	12.44	-81.49
17	-	-52.03	28.19

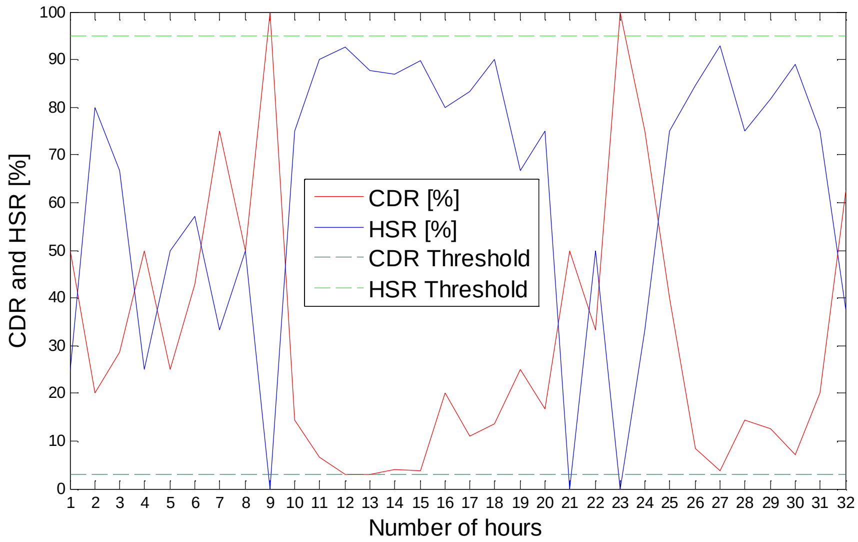

Figure 4.1 BS 2 – R_{C_D} and R_{HO_S} performance analysis: correlation value of -91.24%.

In BS 2, only sector A in GSM 1800 is affected. Call drop rate has an average value of 30.93% and HO success rate has an average value of 62.44%. 99.38% of the HO failures are Lost HOs and 0.62% are HO reversions. According to Figure 3.8, the HO performance analysis has to be done. The first step is to analyse the number of HO attempts. There are 283 HO attempts, which is considered a low number. According to the HO algorithm, the analysis stops here, and so another cell will be analysed. However, just to check where the source of the problem could be, the call drop rate performance is analysed. A total sample of 819 terminated calls with 72 TCH drops. Figure 4.2 illustrates the "contribution" given by each call drop reasons.

It allows to conclude that poor quality on DL or UL is the major reason for TCH drops. Poor signal quality or bad quality of a call are triggered by a high bit error rate on UL or DL – CIR or intersymbol interference (ISI). It is closely related to the interference between BSs and sometimes it can be due to bad cellular planning. The type of interference should be identified:

- Internal: Internal interference, co-channel or adjacent channel interference means that the problem exists within the own network due to a bad frequency plan, bad site location, congestion or too high antenna location.

- External: External interference means that there is another transmitter or something else acting as a transmitter outside the network, such as TV transmission, repeaters microwave links, or other mobile systems. To solve this problem, the operator either has to change frequencies to avoid the disturbance or to negotiate with the owner of the source of the disturbance. It is due to out of band transmissions.
- Intermodulation: If the interference is intermodulation the signal is reflected in an undesired way. There might be problems with the combination of different transmitters on the same BA or faulty equipment.

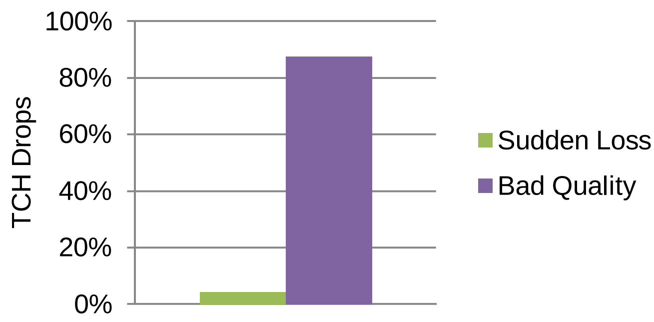

Figure 4.2 TCH Drops analysis.

Figure 4.3 illustrates how to address the interference issues.

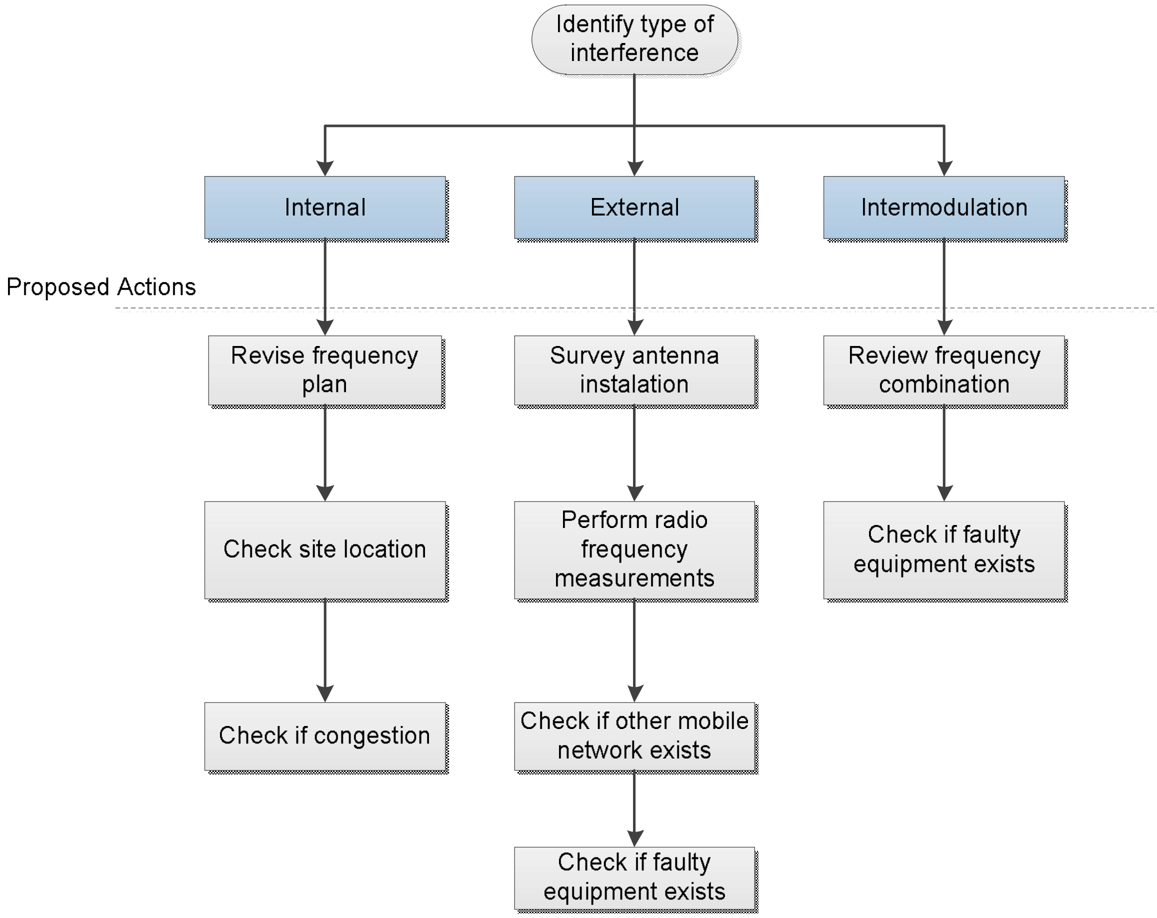

Figure 4.3 Type of interference (adapted from [Eric98]).

At first sight, looking at the results concerning BSs 3 and 11, the almost automatic conclusion is that in those BSs the call drops due to HO problems with 100% sure. Analysing the results in more detail, in those BSs there are only 2 h in the entire month with call drop rate and HO success rate performance values above/below the threshold levels at the same time, respectively, which represents a minor impact in the entire month performance of those BSs (monthly weight of 0.09%) so it can be considered as misleading results that will not be taken into account.

Looking at the results related to call drop rate and SDCCH drop rate, it is possible to conclude that in BSs 3, 11, 12, 13 and 17 the correlation values between the two KPIs performance throughout the analysed hours are 7.62%, 51.71%, 38.59%, 12.44% and -52.03%. Figure 4.4 shows R_{C_D} and R_{SDCCH_D} performance evolution in that period for BS 17. Since the analysis to be made is equal for different BSs, the remaining BS's analysis is in Annex D.

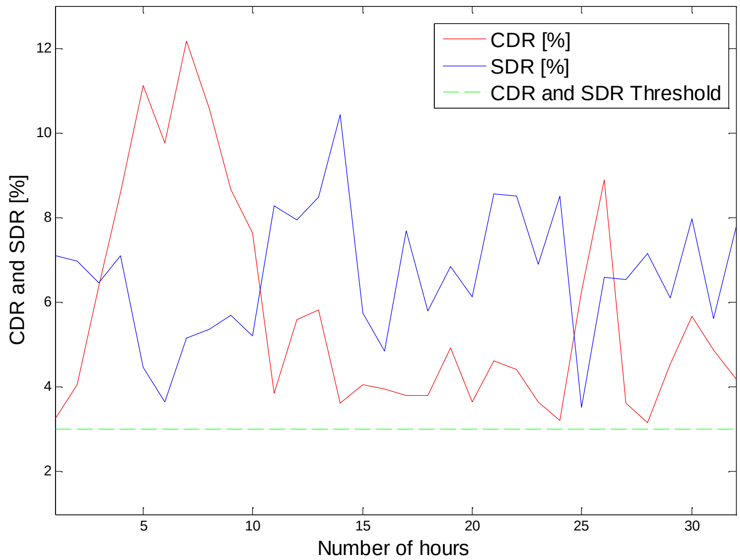

Figure 4.4 BS 17 – R_{C_D} and R_{SDCCH_D} performance analysis: correlation value of -52.03%.

Although the correlation value between the two parameters is too high, this result is inconsistent with the expected. This value indicates that when the call drop rate increases the SDCCH drop rate decreases or vice-versa. This was not supposed to happen. The increase of SDCCH drops being a possible reason for an increase in the number of dropped calls, the correlation value was supposed to be positive and so this can be a misleading result. Only sector B is affected. Call drop rate has an average value of 5.70% and SDCCH drop rate has an average value of 6.66%. There is practically no TCH and SDCCH congestion. 73.88% of the TCH drops are due to low signal strength and 57.12% of the SDCCH drops are due to the same reason – 42.39% are due to sudden loss of connection and 0.49% are due to bad quality.

The results of the third column try to show some relation between the inability to successfully end the call setup process and the drop of the TCH. In this case, there are high values of positive and negative correlation between the parameters in different BSs. This means that there are two situations: the call setup process can be successfully terminated and yet the TCH drops, and the TCH can drop due to the fact that the call setup process was unsuccessfully terminated. BS 6 performance is a case of positive correlation and BS 13 is a case of negative correlation. Figures 4.5 and 4.6 show the performance of the two KPIs. Analysing Figure 4.6, it is easily identifiable the correlation between the two KPIs. However, the number of problematic hours only represents 4.08% of the entire month performance of that BS. The call setup success rate has an average value of 93.09%, which does not represent a high difference compared to the threshold level. With a total of 1236 TCH drops, the call drop rate has an average value of 5.23%. 60.74% of the drops are due to low signal strength, 18.07% due to sudden loss of connection and 21.19% are due to bad quality. There is practically no TCH congestion, and the SDCCH congestion has an average value of 3.61%. In BS 6, the number of problematic hours only represents 1.34% of the entire month performance of that BS. The call setup success rate has an average value of 85.07%. With a total of 27095 TCH drops, the call drop rate has an average value of 27.20%, which is a high value. 0.68% of the drops are due to low signal strength, 82.39% due to sudden loss of connection and 16.93% are due to bad quality. There is no TCH or SDCCH congestion.

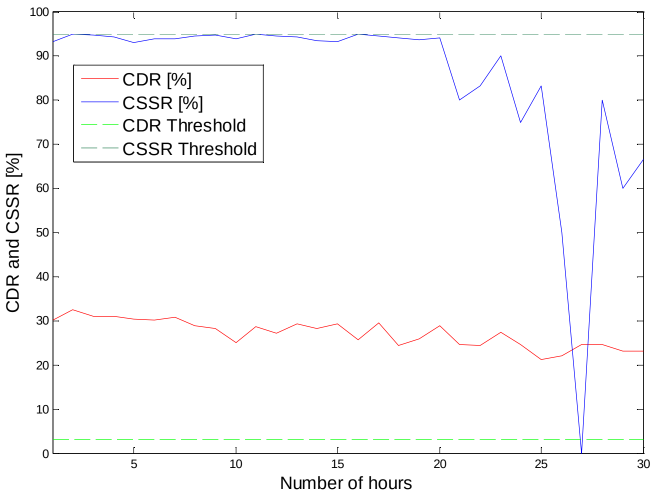

Figure 4.5 BS 6 – R_{C_D} and R_{CS_S} performance analysis: correlation value of 53.38%.

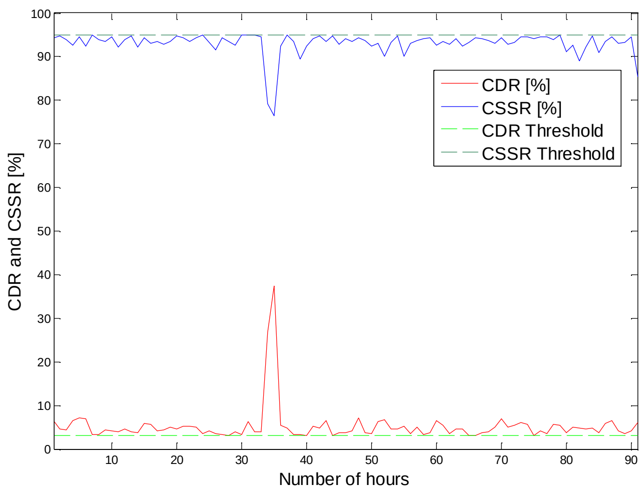

Figure 4.6 BS 13 – R_{C_D} and R_{CS_S} performance analysis: correlation value of -81.49%.

The correlation values between the R_{SDCCH_D} and R_{CS_S} KPIs are shown in Table 4.4. Figure 4.7 shows R_{SDCCH_D} and R_{CS_S} performance evolution in that period for BS 36. Since the analysis to be made is equal for different BSs, the remaining BS's analysis is in Annex D.

Table 4.4 R_{SDCCH_D} correlation analysis.

BS	R_{SDCCH_D} and R_{CS_S} (%)	BS	R_{SDCCH_D} and R_{CS_S} (%)
6	-90.17	25	-97.85
7	12.48	36	-96.68
8	-85.03	40	-96.31
17	-98.35	43	-92.55
19	-99.30	44	11.34

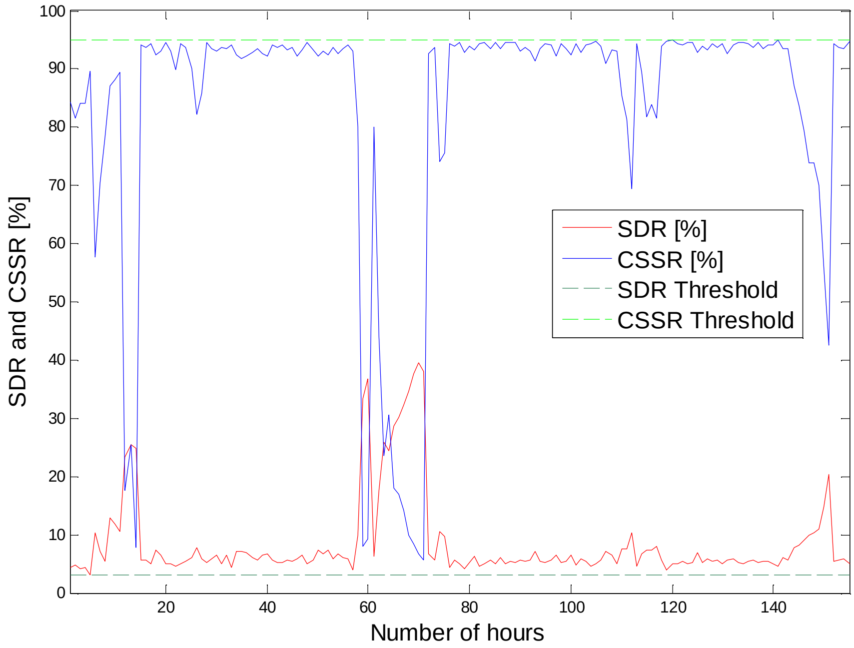

Figure 4.7 BS 36 – R_{SDCCH_D} and R_{CS_S} performance analysis: correlation value of -96.68%.

Looking at the majority of the results of Table 4.4 the correlation values are very high, close to 100%. This fact can be easily explained remembering Section 3.2 and Figure 3.5: the call establishment process is well succeeded if the SDCCH assignment process is well succeeded as well as the call setup process. The results show that in the majority of the cases the call setup process is unsuccessful due to drop of the control channel. In BS 36, the majority of the problems are in sector C in GSM 900. SDCCH drop rate has an average value of 8.61% and call setup success rate has an average value of 83.00%. TCH assignment success rate has an average value of 0.91%. TCH congestion has an average value of 10.19% and SDCCH congestion has an average value of 3.88%. 62.64% of the control channel drops are due to sudden loss of connection, 24.26% are due to bad quality and 13.10% are due to low signal strength.

The HO performance analysis is done according to Figure 3.8. The average number of internal HO attempts being 89246, one considers the cases with a number that equals or exceeds the average number of internal HO attempts and cases with a number up to 20% below the average number. Table 4.5 shows the results concerning BSs 21, 9, 16, 17, 7, 19, 30, 32, 12 and 1. BS 21 is analysed in this section, and the others in Annex D.

Table 4.5 HO performance results.

BS	Internal HO Attempts	Internal HSR (%)	External HO Attempts	External HSR (%)
21	1243667	92.82	180495	93.22
9	394952	89.12	1460	75.58
16	340465	88.47	1599	92.10
17	273368	82.75	4424	89.12
7	249998	91.87	44	80.34
19	226421	91.78	54	62.34
30	180097	84.73	13342	84.94
32	102916	91.01	735	80.83
12	89842	81.29	0	-
1	74881	90.42	56128	91.00

In BS 21, internal HO attempts represents 87.33% of total HO attempts, Figure 4.8. Being internal the worst relation, 95.76% of the unsuccessful HOs are reversions and 4.24% are lost HOs, Figure 4.9. The TCH congestion has an average value of 0.48%, which excludes capacity problems. From a total of 22 neighbouring cells defined, none of them have relevant HO problems, since none of them is identified as problematic. In this case a possible solution for the operator is to check the analysed area map in order to identify coverage problems, and if possible, a visit to the field in order to detect any kind of HW problems, such as bad antenna orientation.

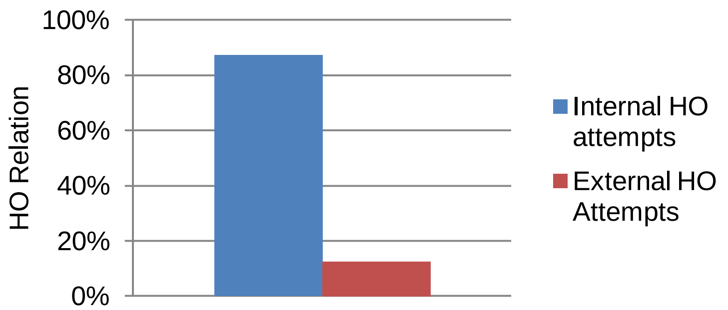

Figure 4.8 BS 21 – HO relation.

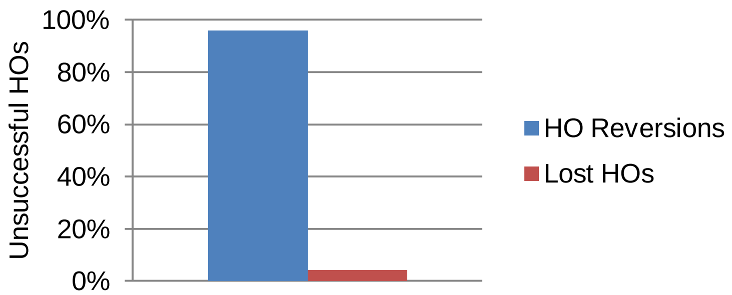

Figure 4.9 BS 21 – Unsuccessful HOs.

4.1.2 Data Performance

The throughput performance analysis will be done according to Figure 3.12. Table 4.6 shows the results concerning GPRS throughput on January 2010 related to BSs 49, 45, 41, 40, 24, 37 and 23.

Table 4.6 $T_{GPRS_{DL}}$, $T_{GPRS_{UL}}$ and R_{PDCH_S} correlation values.

BS	$T_{GPRS_{DL}}$ and R_{PDCH_S} (%)	$T_{GPRS_{UL}}$ and R_{PDCH_S} (%)
49	42.65	-10.41
45	-11.37	-11.04
41	5.61	13.56
40	-5.81	-0.64
24	0.38	-2.74
37	-22.53	-4.18
23	-2.18	-32.66

Looking at the results, related to GPRS DL throughput and PDCH assignment success rate, it is possible to conclude that in BSs 49, 45, 41, 40, 24, 37 and 23 when the PDCH assignment success rate is below the threshold level the throughput value is below the threshold level at the same time with a correlation value of 42.65%, -11.37%, 5.61%, -5.81%, 0.38%, -22.53% and -2.18%, respectively. The same analysis is done to the GPRS UL throughput. In this section, only BS 49 is analysed. The remaining BS's analysis is in Annex D. Figures 4.10 and 4.11 show $T_{GPRS_{DL}}$, $T_{GPRS_{UL}}$ and R_{PDCH_S} performance evolution in that period. BSs 49, 37 and 23 have the higher correlation values – the first two in DL and BS 23 in the UL. This means that in the other cases, in spite of the probability of the KPIs being below/above the threshold level at the same time is very high it does not represent a direct relation between them. In Figure 4.10, it is possible to identify a notorious correlation between the two KPIs: when the PDCH assignment success rate increases, the GPRS DL throughput available also increases, which supports the developed algorithm in Figure 3.12, where an insufficient number of available PDCHs is one of the reasons responsible for a poor throughput performance.

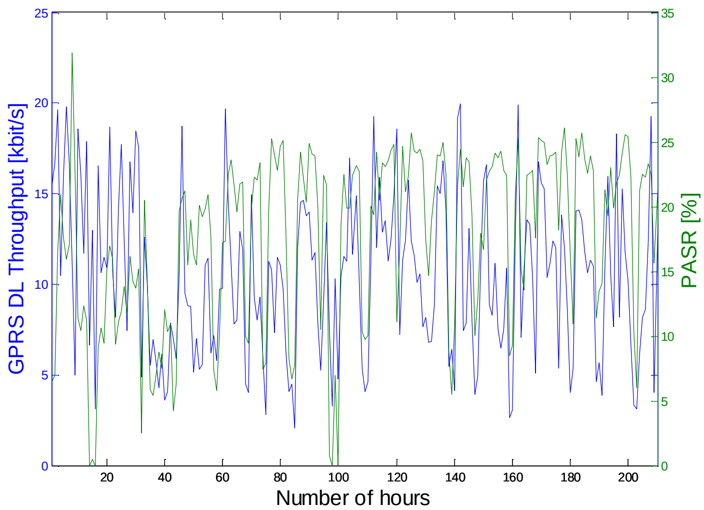

Figure 4.10 BS 49 - $T_{GPRS_{DL}}$ and R_{PDCH_S} performance analysis: correlation value of 42.65%.

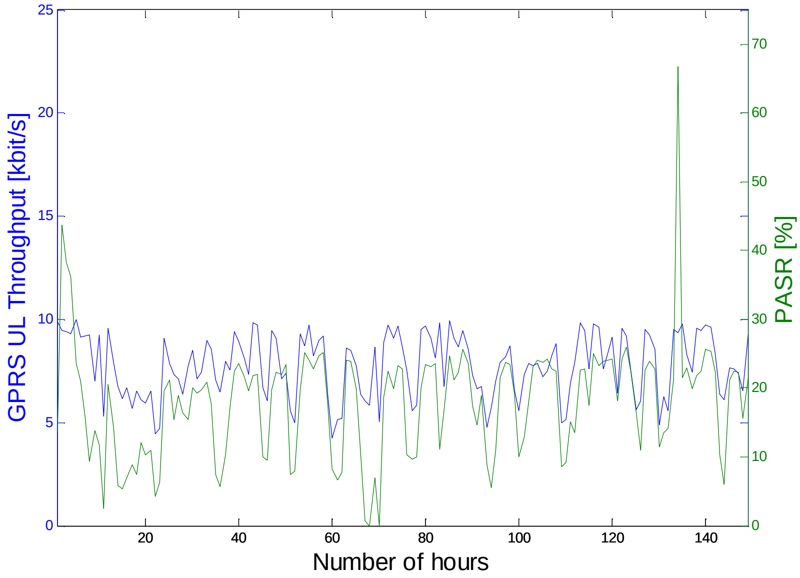

Figure 4.11 BS 49 - $T_{GPRS_{UL}}$ and R_{PDCH_S} performance analysis: correlation value of -10.41%.

Analysing the PDCH assignment success rate performance, it has an average value of 17.65%, which is a very low value. TCH congestion has an average value of 2.41%, which is a low value compared to the pre-defined threshold. The HR traffic represents 95.41% of the total traffic, which means that the HR traffic can be one of the reasons to have a high number of PDCH fails. Figure 4.12 illustrates the RLC data volume distribution of this BS.

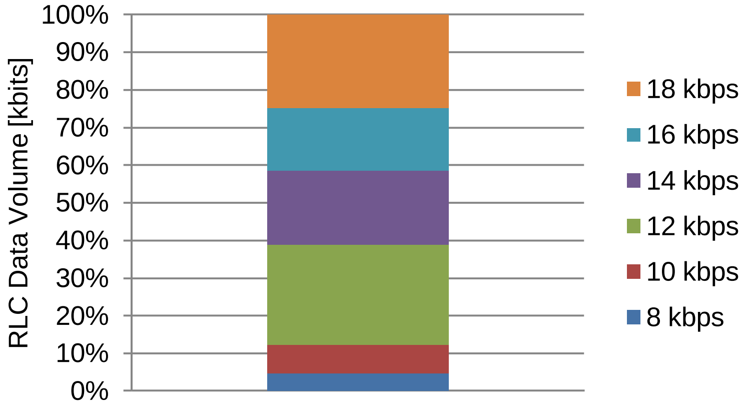

Figure 4.12 BS 49 – DL Radio Link Quality analysis.

Analysing the GPRS DL throughput (average value of 10.47 kbps), the GPRS RLC average data volume is distributed in this way: 0.050 kbits in the 8 kbps interval, 0.080 kbits in the 10 kbps interval, 0.278 kbits in the 12 kbps interval, 0.207 kbits in the 14 kbps interval, 0.174 kbits in the 16 kbps interval and 0.261 kbits in the 18 kbps interval. Looking at the results the major "slice" of the traffic is in the higher bit rate intervals (61.13% of the total traffic is in the three higher bite rate intervals), which means good radio link quality. The average PDCH utilisation ratio is 85.73% (above the 80% threshold value) and there are 5.24 simultaneous users per active PDCH, which is clearly superior compared to the 1.4 threshold value, which proves there is in fact a high capacity problem. In the UL direction, PDCH assignment success rate has an average value of 17.94%. There is practically no TCH congestion and the HR traffic represents 95.19% of the total traffic. In this case, the HR traffic is clearly one of the reasons to have a high number of PDCH fails and so a poor throughput performance.

Table 4.7 shows the results concerning EDGE throughput on January 2010 related to BSs 20, 34, 71, 87, 80, 51 and 83.

Table 4.7 $T_{EDGE_{DL}}$, $T_{EDGE_{UL}}$and R_{PDCH_S} correlation analysis.

BS	$T_{EDGE_{DL}}$and R_{PDCH_S} (%)	$T_{EDGE_{UL}}$and R_{PDCH_S} (%)
20	-41.28	-65.37
34	-1.91	-14.20
71	-18.82	-6.15
87	-32.10	-34.66
80	-25.08	-39.91
51	-31.41	-50.61
83	-4.50	-3.25

Looking at the results, related to EDGE DL throughput and PDCH assignment success rate, it is possible to conclude that in BSs 20, 34, 71, 87, 80, 51 and 83 when the PDCH assignment success rate is below the threshold level the throughput value is below the threshold level at the same time with a correlation value of -41.28%, -1.91%, -18.82%, -32.10%, -25.08%, -31.41% and -4.50%, respectively. The same analysis is done to EDGE UL throughput. In this section, only BS 20 is analysed. The remaining BS's analysis is in Annex D. Figures 4.13 and 4.14 show $T_{EDGE_{DL}}$, $T_{EDGE_{UL}}$and R_{PDCH_S} performance evolution in that period for BS 20. BSs 20 and 51 have the higher correlation values – the first one in both links and BS 51 in the UL. This means that in the other cases, in spite of the probability of the KPIs being below/above the threshold level at the same time is very high, it does not represent a direct relation between them. In Figure 4.13, it is possible to identify a strange correlation between the two KPIs: when the PDCH assignment success rate increases, the EDGE DL throughput available decreases, which was not supposed to happen, since higher the PDCH assignment success rate, higher the available throughput should be. Analysing the PDCH assignment success rate performance, it has an average value of 11.22%, which is a very low value. TCH congestion has an average value of 59.32%, which is a very high value compared to the pre-defined threshold. The HR traffic represents 54.82% of the total traffic, which means that the TCH congestion and the HR traffic could be two of the reasons to have a high number of PDCH fails. Figure 4.15 illustrates the RLC data volume distribution of this BS.

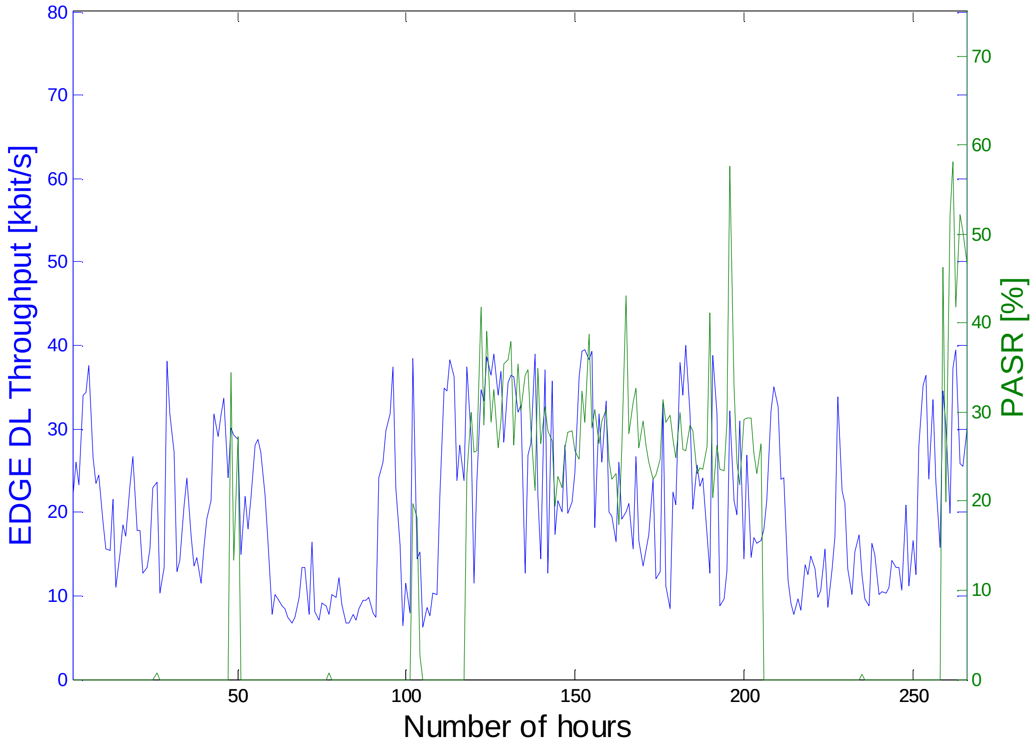

Figure 4.13 BS 20 - $T_{EDGE_{DL}}$ and R_{PDCH_S} performance analysis: correlation value of -41.28%.

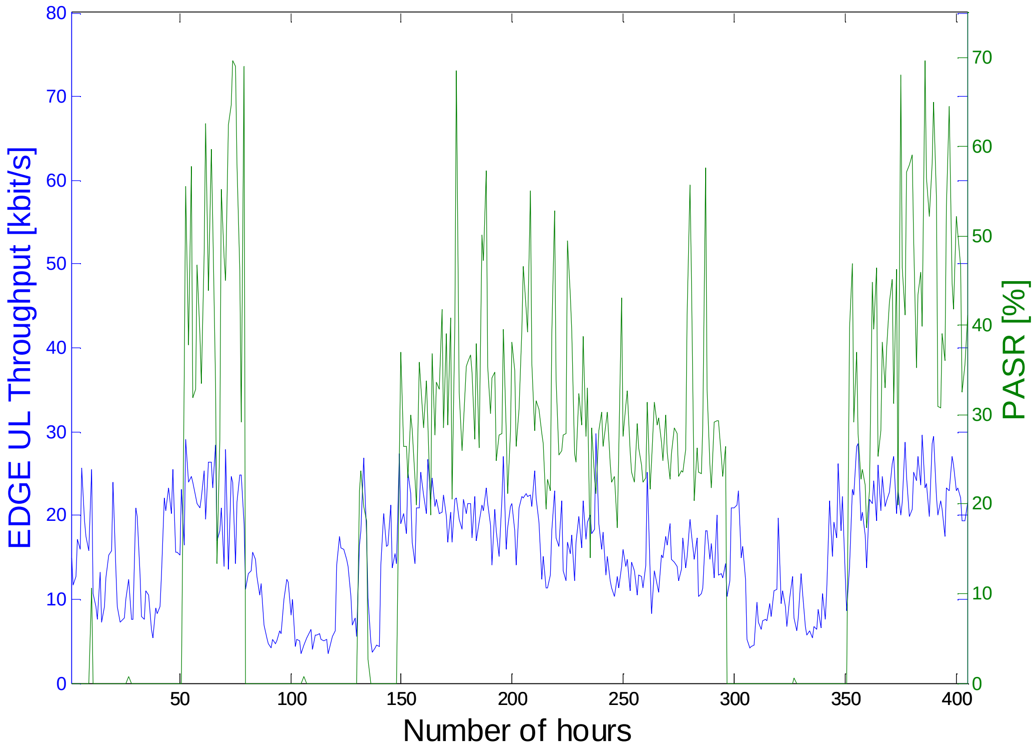

Figure 4.14 BS 20 - $T_{EDGE_{UL}}$ and R_{PDCH_S} performance analysis: correlation value of -65.37%.

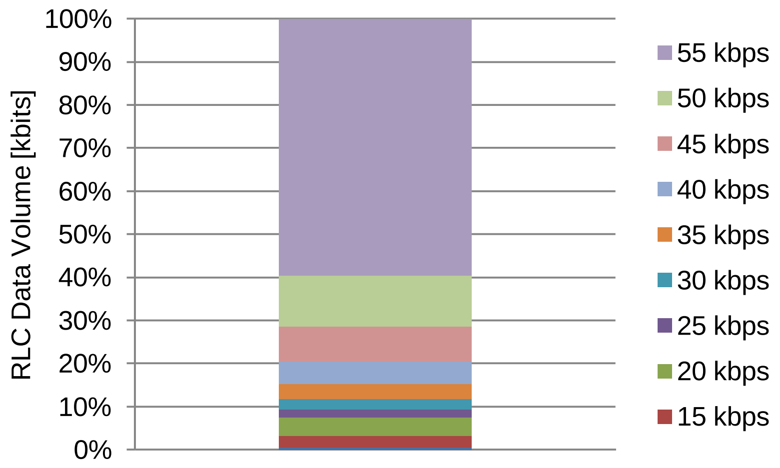

Figure 4.15 DL Radio link quality analysis.

Analysing the EDGE DL throughput (average value of 20.77 kbps), the EDGE RLC average data volume is distributed in this way: 0.0058 kbits in the 10 kbps interval, 0.2702 kbits in the 15 kbps interval, 0.0420 kbits in the 20 kbps interval, 0.0180 kbits in the 25 kbps interval, 0.0260 kbits in the 30 kbps interval, 0.0338 kbits in the 35 kbps interval, 0.0518 kbits in the 40 kbps interval, 0.0816 kbits in the 45 kbps interval, 0.1190 kbits in the 50 kbps interval and 0.5951 kbits in the 55 kbps interval. Looking at the results the major "slice" of the traffic is in the higher bit rate intervals (84.74% of the total traffic is in the four higher bite rate intervals), which means good radio link quality. The average PDCH utilisation ratio is 87.55% (above the 80% threshold value) and there are 4.77 simultaneous users per active DL PDCH – above the 1.4 threshold value, which proves there is in fact a high capacity problem. In UL, PDCH assignment success rate has an average value of 20.37%. The TCH congestion has an average value of 40.19% and the HR traffic represents 48.63% of the total traffic. In this case, TCH congestion is very high so it is possible to have here a capacity problem. Figure 4.16 illustrates the analysis of the UL radio link quality.

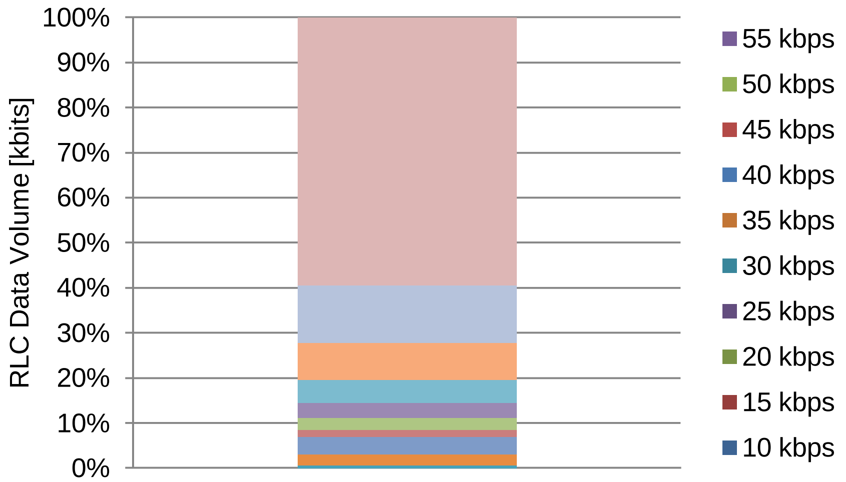

Figure 4.16 UL Radio link quality analysis.

Analysing the EDGE UL throughput (average value of 15.90 kbps), the EDGE RLC average data volume is distributed in this way: 0.0056 kbits in the 10 kbps interval, 0.0238 kbits in the 15 kbps interval, 0.0398 kbits in the 20 kbps interval, 0.0167 kbits in the 25 kbps interval, 0.0249 kbits in the 30 kbps interval, 0.0339 kbits in the 35 kbps interval, 0.0519 kbits in the 40 kbps interval, 0.0818 kbits in the 45 kbps interval, 0.1272 kbits in the 50 kbps interval and 0.5945 kbits in the 55 kbps interval. Looking at the results the major "slice" of the traffic is in the higher bit rate intervals (85.54% of the total traffic is in the four higher bite rate intervals), which means good radio link quality. The average PDCH utilisation ratio is 80.49% (above the 80% threshold value) and there are 2.92 simultaneous users per active DL PDCH – above the 1.4 threshold value, which proves there is in fact a capacity problem.

4.2 UMTS Analysis

4.2.1 Voice Call Performance

Table 4.8 contains the results of the KPIs performance during January 2010. The values are concerning only the cases where the KPI is above/below the threshold level.

Table 4.8 Monthly KPIs.

KPI	Average Value	Standard Deviation	Monthly Weight (%)
R_{SCS_S}	71.79%	18.53%	0.84
R_{CS64_S}	46.36%	35.10%	0.06
$R_{PSR99\_ICS_S}$	64.31%	22.41%	4.06
$R_{HSDPA\_ICS_S}$	71.34%	17.44%	3.41
R_{SC_D}	13.33%	8.72%	1.80
R_{CS64C_D}	44.39%	29.97%	0.01
$R_{PSR99\_IC_D}$	16.48%	10.24%	1.51
$R_{HSDPA\_IC_D}$	47.49%	32.17%	18.74
R_{SHO_S}	54.10%	29.63%	0.18
$T_{PSR99_{DL}}$	17.41 kbps	129.11 kbps	56.65
$T_{PSR99_{UL}}$	13.84 kbps	25.57 kbps	56.25
T_{HSDPA}	186.06 kbps	575.54 kbps	51.69
$R_{IRAT\_HO_{S_I}}$	3.16%	57.87%	0.01
$R_{IRAT\_HO_{S_O}}$	52.02%	23.32%	0.38

Analysing Table 4.8, it is possible to conclude that R_{SCS_S}, R_{CS64_S}, R_{CS64C_D}, R_{SHO_S}, $R_{IRAT\_HO_{S_I}}$ and $R_{IRAT\_HO_{S_O}}$ poor performance has a very reduced impact in the total radio network performance contrary to $T_{PSR99_{DL}}$, $T_{PSR99_{UL}}$and T_{HSDPA} poor performance, which represents 56.65%, 56.25% and 51.69% of the entire month performance, respectively. T_{HSDPA} has the highest value of standard deviation (575.54 kbps), being the KPI with measured values more dispersed from the target value. Analysing Table 4.9, it is possible to conclude that R_{CS64C_D} has the lower percentage of problematic BSs, while in the $T_{PSR99_{DL}}$, $T_{PSR99_{UL}}$ and T_{HSDPA} analysis 58.48%, 59.38% and 56.25% of the total BSs were identified as problematic, respectively. The "filtering" action was applied to all the KPIs, individually. Table 4.9 indicates the number of “problematic BSs” identified, which is a variable number according to the type of KPI, as expected.

Table 4.9 KPIs analysis after filtering.

KPI	"Problematic BSs" (%)
R_{SCS_S}	4.46
R_{CS64_S}	0.89
$R_{PSR99\_ICS_S}$	35.71
$R_{HSDPA\_ICS_S}$	30.36
R_{SC_D}	28.13
R_{CS64C_D}	0.45
$R_{PSR99\_IC_D}$	20.09
$R_{HSDPA\_IC_D}$	48.66
R_{SHO_S}	3.57
$T_{PSR99_{DL}}$	58.48
$T_{PSR99_{UL}}$	59.38
T_{HSDPA}	56.25

Analysing the results concerning speech call setup success rate, it is now possible to identify the percentage associated to the number of hours where the KPI value is above the threshold level at the same time as others KPIs. In this case the correlation is made with speech call drop rate and the correlation values are presented in Table 4.10.

Table 4.10 R_{SCS_S} correlation analysis.

BS	R_{SCS_S} and R_{SC_D} (%)
8	-51.31
10	-36.84
2	-67.64
3	0.00
4	-97.46
5	49.33
6	-0.71
1	-
7	-
9	-

Looking at the results, it is possible to conclude that in BSs 8 and 10 when the speech call setup process is interrupted for some reason the call drops with a correlation value between the two parameters of -51.31% and -36.84%, respectively. BSs 1, 7 and 9 do not have any correlation between the parameters, because there are no coincident problematic hours for both KPIs. Besides the fact that BSs 2, 4 and 5 have correlations values of -67.64%, -97.46% and 49.33%, respectively, those BSs are not analysed because the poor performance monthly weight is only 0.67%, 0.27% and

0.22%, respectively. Figure 4.17 shows R_{SCS_S} and R_{SC_D} performance evolution for BS 8. The BS 10 analysis is in Annex D.

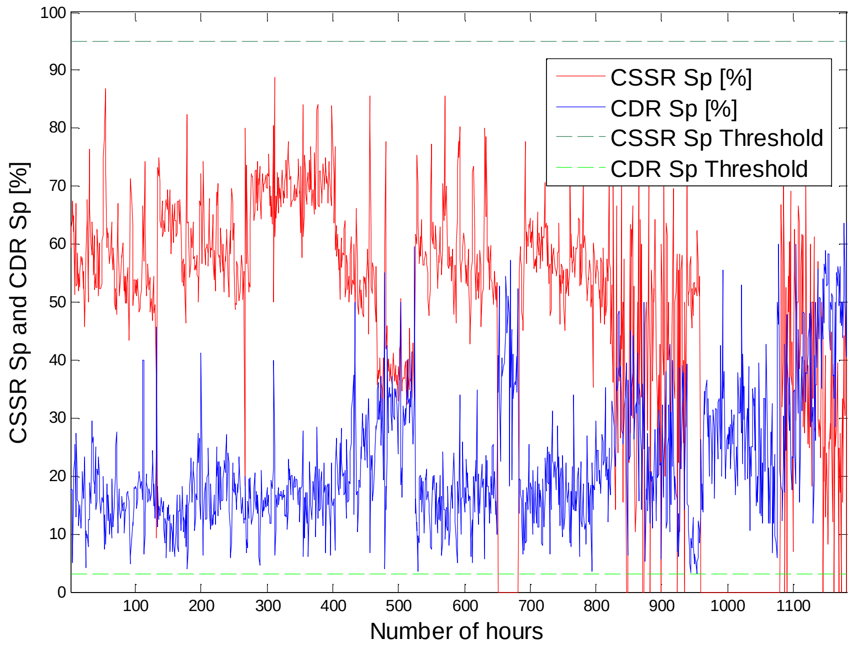

Figure 4.17 BS 8 – R_{SCS_S} and R_{SC_D} performance analysis: correlation value of -51.31%.

Speech call drop rate has an average value of 22.02%. 0.30% of the speech call drops are due to lost of UL synchronism, 0% due to congestion and due to missing neighbours, 10.84% due to SHO action and 88.86% due to other reasons. Since the majority of the drops are due to unknown reasons, the call setup success rate performance is analysed. With an average value of 46.96% (the RRC connection success rate has an average value of 47.58% and the RAB establishment success rate has an average value of 98.05%), the first thing to be done, according to the developed algorithm illustrated in Figures 3.14 and 3.15, is to analyse the number of failures after the admission control throughout time. One compares only with the RRC connection success rate. Figure 4.18 represents a "zoom" of the total performance. The idea is to achieve a better perspective of the problem. It is possible to see that when the number of failures increases, the RRC success rate decreases, with a correlation value between them of -76.53%. With a total number of 2.419.775 RRC or RAB failures after admission control, none of them are RRC failures due to transport network blocking, which leads to the conclusion that all problems are probably related to the Iub configuration. With a total number of 74869 RRC or RAB requests denied due to admission control, 99.91% are related to RRC issues and 0.09% are related to RAB issues (which confirms the initial observation: the majority of the problems are due to RRC problems). 86.33% of the failures are due to lack of DL channelisation codes, 7.14% are due to insufficient DL power and 6.53% are due to node blocking.

The results concerning CS64 service are not analysed. This decision was made taking into account the fact that there are very few results, which may lead to the conclusion that this service is rarely used, probably because when dealing with voice the 2G technology is the most often used and when dealing with data it is all reported to 3G.

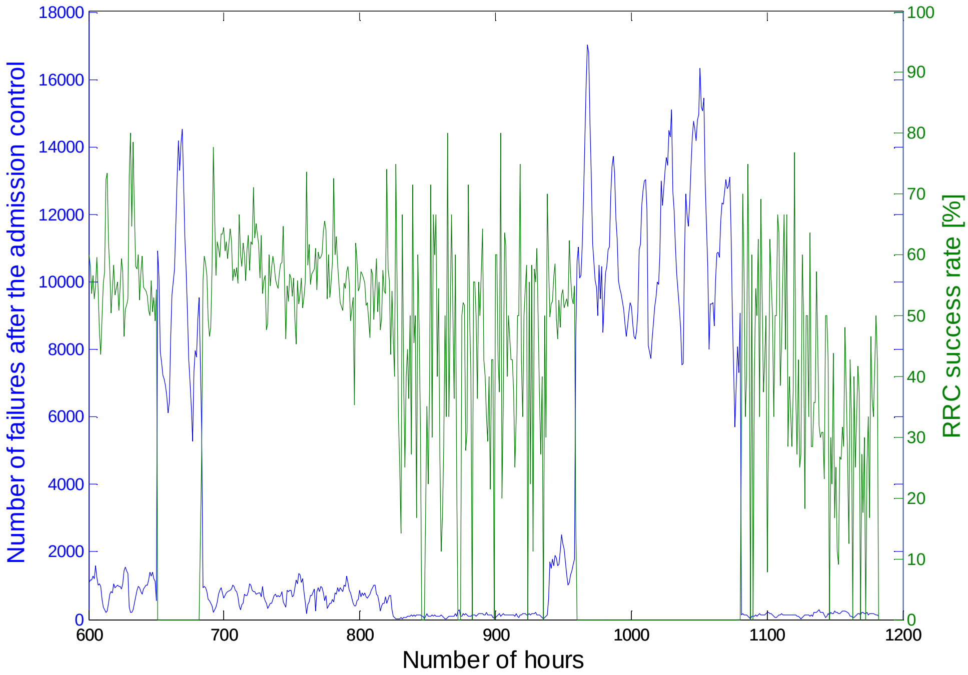

Figure 4.18 BS 8 – Total number of failures after admission control versus “RRC success rate”.

4.2.2 Data Performance

Analysing the results concerning $R_{PSR99\_ICS_S}$ parameter, it is possible to identify the percentage associated to the number of hours where the KPI value is above the threshold level at the same time as others KPIs. In this case, the correlation is made with PS R99 Interactive call drop rate and the correlation values are presented in Table 4.11. BS 58 is the only BS that is analysed, since all the others have a poor performance monthly weight with low impact. Looking at the results, it is possible to conclude that in BS 58 when the PS R99 Interactive call setup success rate is below the threshold level the PS R99 Interactive call drop rate is also below the threshold level with a correlation value between the two cases of -65.00%.

Figure 4.19 shows $R_{PSR99\_ICS_S}$ and $R_{PSR99\_IC_D}$ performance evolution. PS R99 interactive call drop rate has an average value of 33.73%. With a number of 10154 abnormal RAB PS DCH/FACH releases and according to the “Minutes per Drop” KPI, a user experiences a drop call, in average, in every 5min58s, which exceeds the predefined threshold of 12min, allowing to verify the KPI poor performance. The channel downswitch failure rate has an average value of 12.09%. Figures 4.20 and 4.21 represent the percentage distribution of the channel upswitch failure rate. Analysing the results, it is possible to conclude that the DL/UL PS transitions fail very few times, with average values of 0% in medium and high rate and around 1.50% in low rate, which may lead to the conclusion that the channel upswitch issues do not contribute for the KPI poor performance. Analysing the call setup success rate performance, with an average value of 39.14%, the RRC connection success rate has an average value of 39.63% and the RAB establishment success rate has an average value of 95.79%. Figure 4.22 illustrates the comparison between the total number of failures after the admission control and the RRC success rate.

Table 4.11 $R_{PSR99\_ICS_S}$ correlation analysis.

BS	$R_{PSR99\_ICS_S}$ and $R_{PSR99\_IC_D}$ (%)
58	-65.00

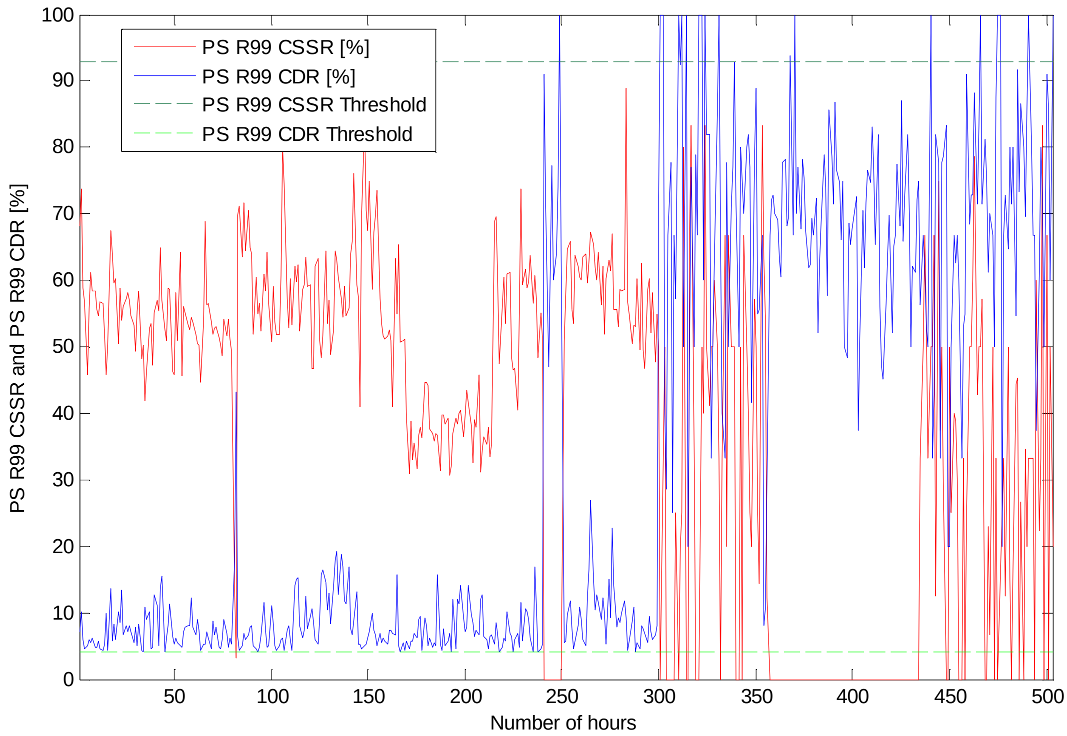

Figure 4.19 BS 58 – $R_{PSR99_ICS_S}$and $R_{PSR99\_IC_D}$ performance analysis: correlation value of -65.00%.

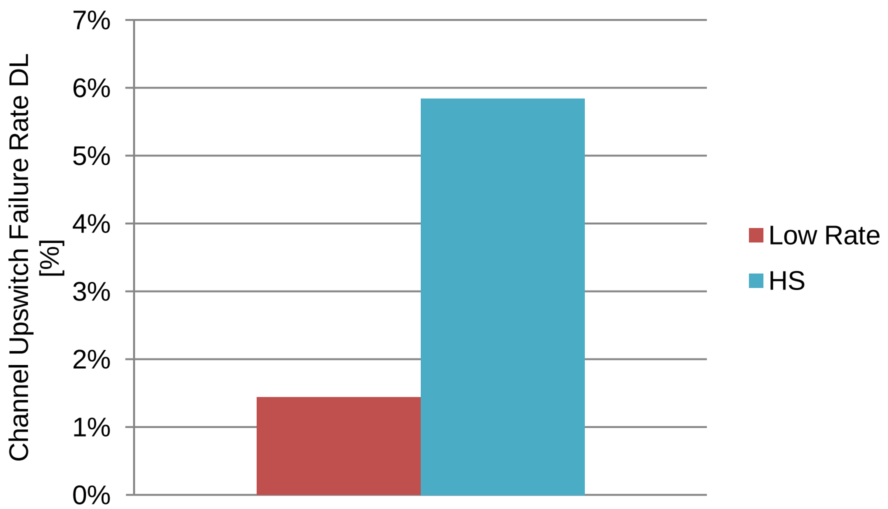

Figure 4.20 Channel Upswitch Failure Rate DL.

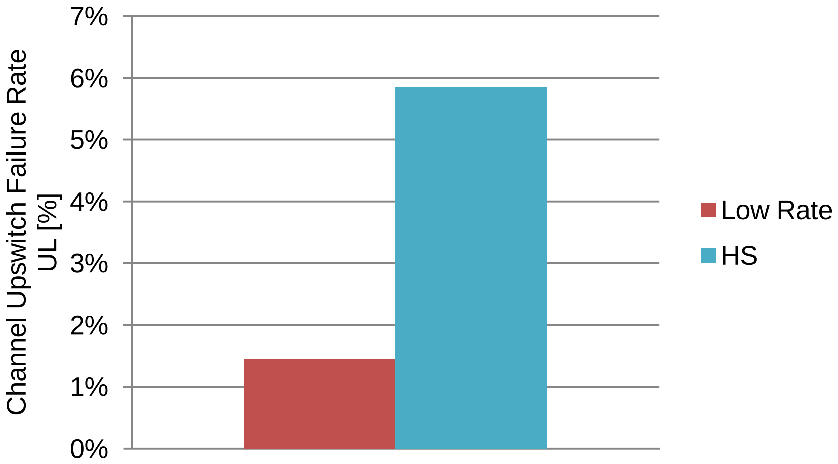

Figure 4.21 Channel Upswitch Failure Rate UL.

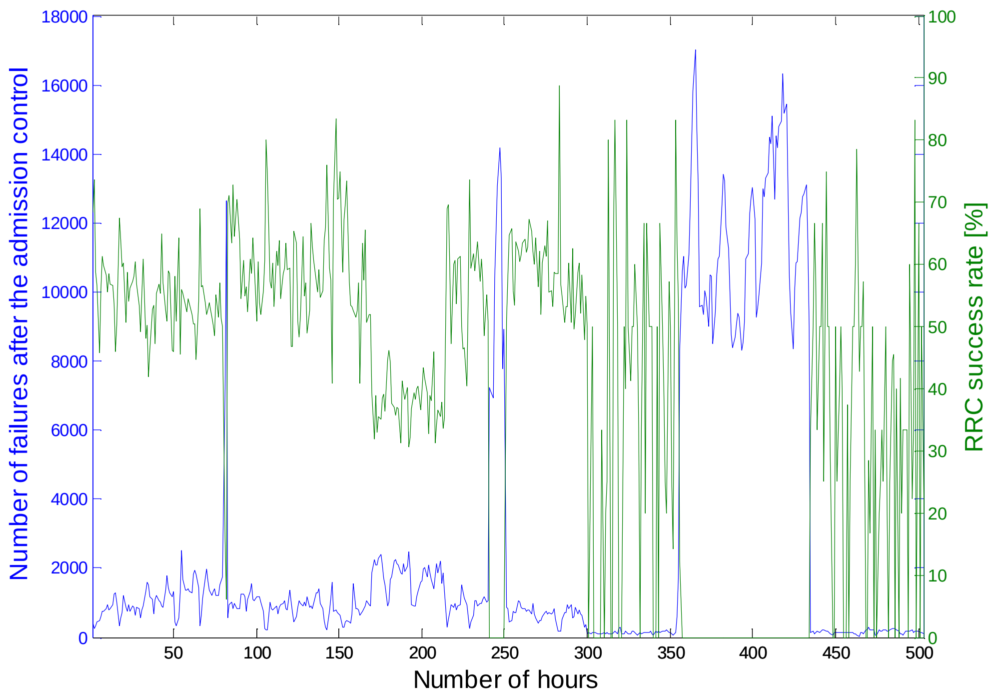

Figure 4.22 BS 58 – Total number of failures after admission control versus “RRC success rate”.

It is possible to see that when the number of failures increases, the RRC success rate decreases, with a correlation value between them of -70.38%. With a total number of 1350625 RRC or RAB failures after admission control, none of them are RRC fails due to transport network blocking, which means that all problems are related to the Iub configuration. With a total number of 55590 RRC or RAB requests denied due to admission control, 99.89% are related to RRC issues and 0.11% are related to RAB issues. 87.16% of the fails are due to lack of DL channelisation codes, 5.96% are due to insufficient DL power and 6.88% are due to node blocking. When a user is making a PS call and another user is starting a speech call, the speech call has priority – the PS call stays in a preemption state. To obtain a better perspective of the process the number of abnormal RAB PS DCH/FACH releases was correlated with the number of normal RAB speech releases, Figure 4.23. With a correlation value of 19%, it is possible to see that in some hours when the number of normal RAB speech releases increases, the number of abnormal RAB PS DCH/FACH releases also increases, which indicates that this factor could have a low impact in the $R_{PSR99\_IC_D}$ performance.

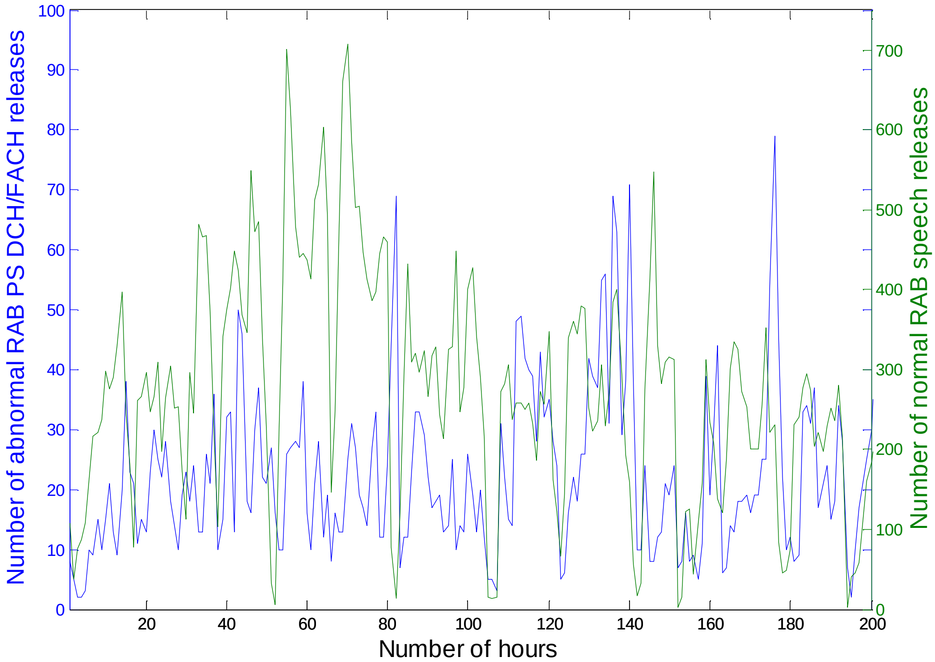

Figure 4.23 BS 58 – Abnormal RAB PS DCH/FACH releases and normal RAB speech releases.

Analysing the results concerning $R_{HSDPA\_ICS_S}$ parameter, it is possible to identify the percentage associated to the number of hours where the KPI value is above the threshold level at the same time as others KPIs. In this case the correlation is made with HSDPA Interactive call drop rate and the correlation values are presented in Table 4.12.

Table 4.12 $R_{HSDPA\_ICS_S}$ correlation analysis.

BS	$R_{HSDPA\_ICS_S}$ and $R_{HSDPA\_IC_D}$ (%)
67	-0.80
42	-18.39
55	-18.63
39	-7.23
51	-28.31
8	-0.85

Looking at the results it is possible to conclude that in BSs 67, 42, 55, 39, 51 and 8 when the HSDPA Interactive call setup success rate is below the threshold level the HSDPA Interactive call drop rate is also above the threshold level with a correlation value between the two parameters of -0.80%, -18.39%, -18.63%, -7.23%, -28.31% and -0.85%, respectively. Figure 4.24 shows $R_{HSDPA\_ICS_S}$ and $R_{HSDPA\_IC_D}$ performance evolution in that period for BS 51. The remaining BS's analysis is in Annex D.

HSDPA Interactive call drop rate has an average value of 60.93%, which is a very high value. With a number of 16462 abnormal RAB PS HSDPA and according to the "Minutes per Drop" KPI, a user experiences a drop call, in average, in every 11min42s, which does not exceed the predefined threshold. The channel donswitch failure rate has an average value of 6.98%. Figures 4.25 and 4.26 represent the percentage distribution of the channel upswitch failure rate.

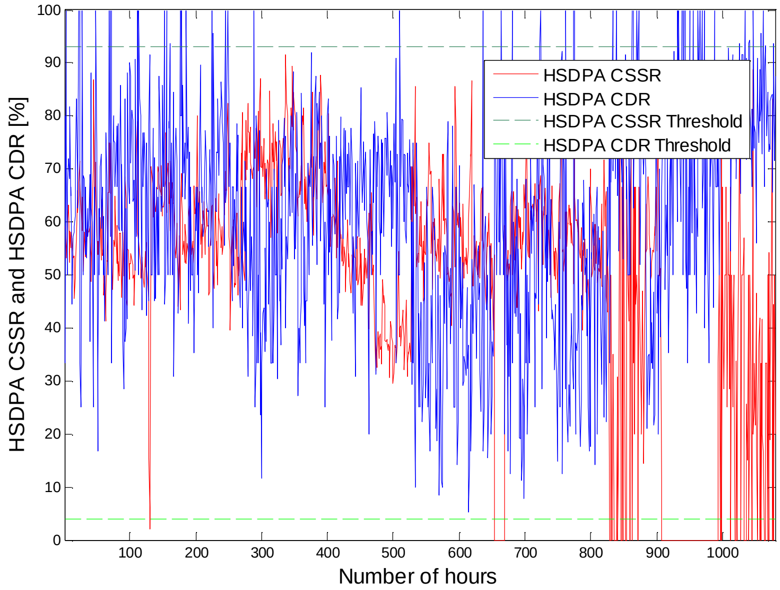

Figure 4.24 BS 51 – $R_{HSDPA\_ICS_S}$ and $R_{HSDPA\_IC_D}$ performance analysis: correlation value of -28.31%.

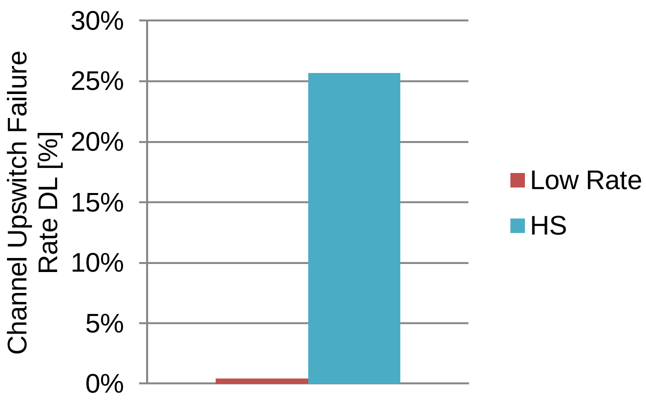

Figure 4.25 BS 51 – Channel Upswitch Failure Rate DL.

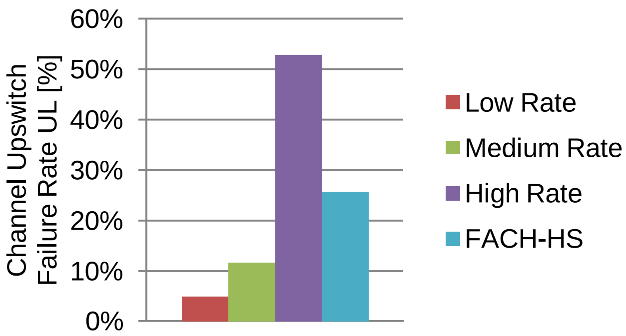

Figure 4.26 BS 51 – Channel Upswitch Failure Rate UL.

It is possible to conclude that the DL/UL HS transitions fail very often, with average values of around 25%. This could be one of the major contributions for the KPI poor performance. Analysing the call setup success rate performance, with an average value of 49.12%, the RRC connection success rate has an average value of 49.91% and the RAB establishment success rate has an average value of 98.22%.

Figure 4.27 illustrates the comparison between the total number of failures after the admission control and the RRC success rate. It is possible to see that when the number of failures increases, the RRC success rate decreases, with a correlation value between them of -68.31%. With a total number of 1914406 RRC or RAB failures after the admission control, only one failing reason can be identified: it is due to RAB node blocking issues, which means the others are related to Iub configuration problems. With 68224 requests denied due to admission control, 99.91% are related to RRC: 84.32% are due to lack of DL channelisation codes, 8.11% are due to insufficient DL power and 7.57% are due to node blocking problems. Figure 4.28 illustrates the correlation between the number of abnormal RAB PS HSDPA releases and the number of normal RAB speech releases. With a correlation value of 10.20%, it is possible to see that in some hours when the number of normal RAB speech releases increases, the number of abnormal RAB PS DCH/FACH releases also increases, but this correlation has a minor impact in the KPI performance.

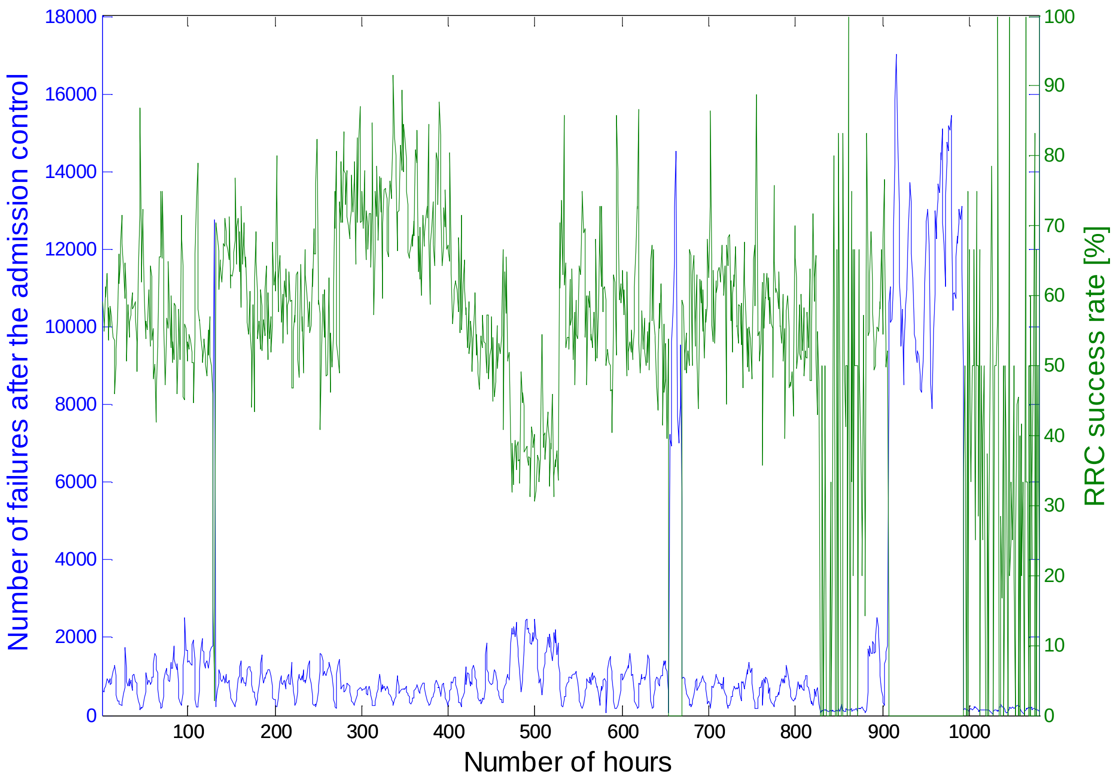

Figure 4.27 BS 51 – Total number of failures after admission control versus “RRC success rate”.

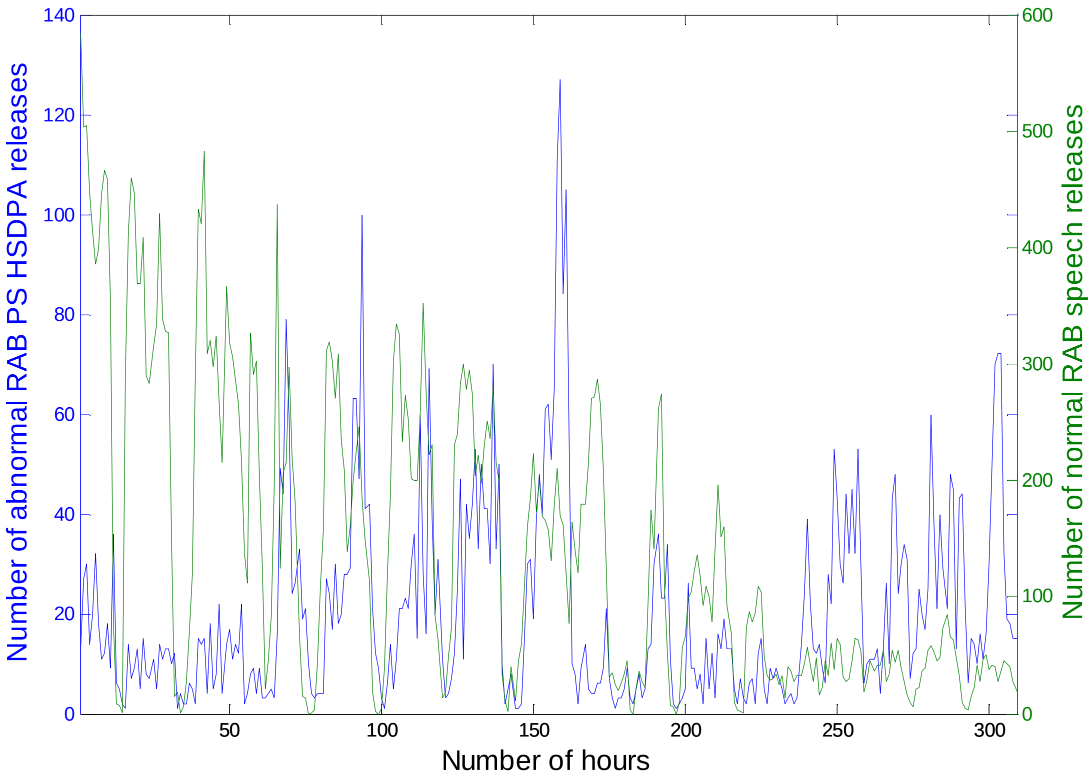

Figure 4.28 BS 51 – Abnormal RAB PS HSDPA releases and normal RAB speech releases.

Similar to what is done in the 2G analysis, the existence of any kind of correlation between a drop call and HO issues is checked. Analysing the results concerning R_{SC_D} and R_{SHO_S} parameter, it is possible to identify the percentage associated to the number of hours where the KPI value is above the threshold level at the same time as others KPIs. In this case, the correlation is made with Speech call drop rate and the correlation values are presented in Table 4.13. Looking at the results, it is possible to conclude that in BS 6 when the speech call drop rate KPI is above the threshold level the soft HO KPI is below the threshold level with a correlation value between the two parameters of -68.55%.

Figure 4.29 shows R_{SC_D} and R_{SHO_S} performance evolution in that period. Soft HO success rate has an average value of 52.70%. This KPI is calculated as the rate between the total number of RL addition success and the total number of RL addition attempts, defined as the sum of success and failures. The counter responsible for counting the failures is incremented if, during an attempt to add a RL, any of the following occur: admission is not granted due to lack of DL channelisation code, the RL setup procedure fails, RL addition procedure fails, RL setup or addition procedure times out in the RBS, the active set update procedure fails or active set update procedure times out in the UE. Analysing the query's output results, there is no RRC or RAB requests denied due to admission control procedure, and so the problem is not related to the lack of DL channelisation codes. There are no RL failures due to admission and the KPI that defines the success rate for speech RL addition, defined for the source best cell in the active set has no value, which means this is not the best cell in the active set. The soft/softer HO overhead speech has an average value of 43.38%. According to [HoTo07], soft HO overhead can be regarded as a measure of the additional hardware/transmission resources required for implementation of soft HO, planned to be in the order of 20 – 40% for a standard hexagonal cell grid with three sector sites. So, in BS 6, the value of soft/softer HO overhead speech can be considered excessive, which could decrease the DL capacity by the increasing of the transmitted interference to the network. An action that has to be taken into account is the increase of the active set update rate because they are related: smaller overhead can be obtained at the expense of a higher active set update rate.

Table 4.13 R_{SC_D} and R_{SHO_S} correlation analysis.

BS	R_{SC_D} and R_{SHO_S} (%)
6	-68.55

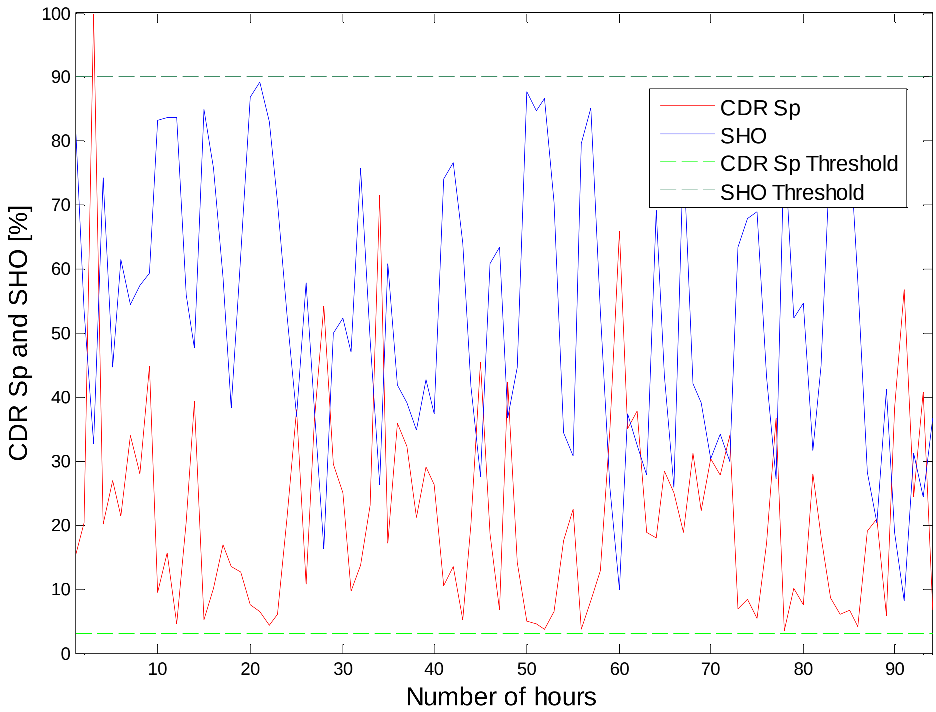

Figure 4.29 BS 6 – R_{SC_D} and R_{SHO_S} performance analysis: correlation value of -68.55%.

The CS64 analysis is not done due to the reduced impact of this parameter in the network performance.

Analysing the results concerning $\boldsymbol{R_{PSR99\_IC_D}}$ parameter, it is possible to identify the percentage associated to the number of hours where the KPI value is above the threshold level at the same time as others KPIs. In this case the correlation is made with PS R99 call drop rate and the correlation values are presented in Table 4.14. There is a considerable number of BSs with problems associated to PS R99 call drop rate KPI but that problems are not related to SHO problems, e.g., in BS 15, which is the BS with more critical hours in the entire month when compared with the others identified as critical, when the PS R99 call drop rate KPI is above the threshold level the soft HO KPI is below the threshold level only in 2.14% of the cases and the correlation value between the two parameters is -9.07%. A more exhaustive analysis is not needed in this case.

Table 4.14 $R_{PSR99\_IC_D}$ and R_{SHO_S} correlation analysis.

BS	$R_{PSR99\_IC_D}$ and R_{SHO_S} (%)
15	-9.07

Analysing the results concerning $R_{HSDPA\_IC_D}$ parameter, it is possible to identify the percentage associated to the number of hours where the KPI value is above the threshold level at the same time as others KPIs. In this case the correlation is made with HSDPA call drop rate and the correlation values are presented in Table 4.15. Although there is a considerable number of BSs with problems associated to HSDPA call drop rate KPI, that problems are not related to SHO problems, e.g., in BS 9, when the HSDPA call drop rate KPI is above the threshold level the soft HO KPI is below the threshold level only in 13.39% of the cases and the correlation value between the two parameters is -38.47%. This correlation value indicates that the problems concerning RAB PS HSDPA call drop rate have to be analysed. However, the maximum number of RAB PS HSDPA releases is 73, which is a very low value, and so a more exhaustive analysis is not needed in this case.

Table 4.15 $R_{HSDPA\_IC_D}$ and R_{SHO_S} correlation analysis.

BS	$R_{HSDPA\_IC_D}$ and R_{SHO_S} (%)
9	-38.47

The R99 throughput analysis is made only to identify possible bidirectional problems, since the correlation between throughput KPIs and the all the others from the provided list is unnecessary.

Analysing the results concerning $T_{PSR99_{DL}}$and $T_{PSR99_{UL}}$ parameters, it is possible to identify the percentage associated to the number of hours where the KPI value is above the threshold level at the same time as others KPIs, Table 4.16. Easily conclude that in all the BSs identified as problematic in the T_{PSR99} performance analysis there are problems in both DL and UL, which does not necessary mean a correlation between the two different KPIs. As said before, the idea is not to identify a correlation between the two KPIs, but just conclude if there is a bidirectional problem. The analysis is made according to the one made in 2G. Only BS 11 is analysed, since the procedure is the same for the others BSs.

With a total of 91798 users the average cell traffic volume in DL and UL is illustrated in Figures 30 and 31. It is possible to conclude that in DL the majority of the traffic volume is in the 384 kbps range and in UL the majority of the traffic volume is in the 16 kbps range. With an average number of maximum PS Interactive, PS Interactive DCH and PS Interactive FACH users of 19.61, 1.90 and 12.04, respectively, Figure 4.32 illustrates the variation of the throughout in the cell with the variation of the number of users. This comparison is made with the objective of identify possible capacity problems.

Table 4.16 $T_{PSR99_{DL}}$ and $T_{PSR99_{UL}}$ analysis.

BS	$T_{PSR99_{DL}}$ and $T_{PSR99_{UL}}$ (%)	BS	$T_{PSR99_{DL}}$ and $T_{PSR99_{UL}}$ (%)	BS	$T_{PSR99_{DL}}$ and $T_{PSR99_{UL}}$ (%)	BS	$T_{PSR99_{DL}}$ and $T_{PSR99_{UL}}$ (%)
11	99.90	**75**	98.60	**47**	97.66	**81**	96.41
20	99.76	**49**	98.59	**105**	97.62	**112**	96.34
94	99.66	**33**	98.58	**25**	97.60	**69**	96.24
28	99.49	**73**	98.50	**98**	97.55	**30**	96.21
44	99.47	**95**	98.49	**10**	97.53	**120**	96.17
52	99.41	**114**	98.48	**61**	97.48	**57**	96.04
101	99.37	**107**	98.37	**43**	97.47	**19**	95.94
39	99.24	**85**	98.35	**40**	97.46	**124**	95.78
7	99.24	**32**	98.33	**67**	97.42	**90**	95.76
100	99.23	**23**	98.31	**5**	97.40	**118**	95.73
72	99.18	**53**	98.29	**126**	97.37	**87**	95.69
93	99.14	**66**	98.28	**128**	97.37	**89**	95.47
65	99.10	**18**	98.28	**92**	97.30	**50**	95.29
99	99.00	**123**	98.16	**36**	97.29	**122**	95.16
106	98.95	**2**	98.16	**6**	97.29	**24**	95.09
1	98.93	**78**	98.13	**108**	97.29	**79**	95.01
58	98.92	**46**	98.10	**117**	97.28	**9**	94.98
103	98.91	**60**	98.10	**37**	97.27	**21**	94.97
27	98.90	**13**	98.08	**41**	97.21	**26**	94.84
86	98.88	**35**	98.02	**16**	97.18	**12**	94.72
3	98.87	**51**	98.00	**83**	97.13	**115**	94.67
119	98.82	**74**	97.98	**64**	97.11	**110**	94.48
91	98.77	**62**	97.83	**82**	97.01	**59**	94.44
116	98.77	**113**	97.81	**76**	97.00	**127**	94.07
125	98.75	**29**	97.77	**54**	96.95	**104**	93.66
96	98.74	**14**	97.77	**38**	96.87	**84**	93.33
42	98.73	**8**	97.77	**71**	96.80	**34**	93.30
56	98.67	**68**	97.75	**22**	96.75	**80**	93.21
70	98.67	**48**	97.73	**88**	96.72	**109**	92.74
121	98.65	**45**	97.73	**63**	96.71	**102**	91.40
55	98.64	**111**	97.67	**31**	96.61	**17**	90.64
15	98.61	**97**	97.67	**77**	96.55	**4**	90.60

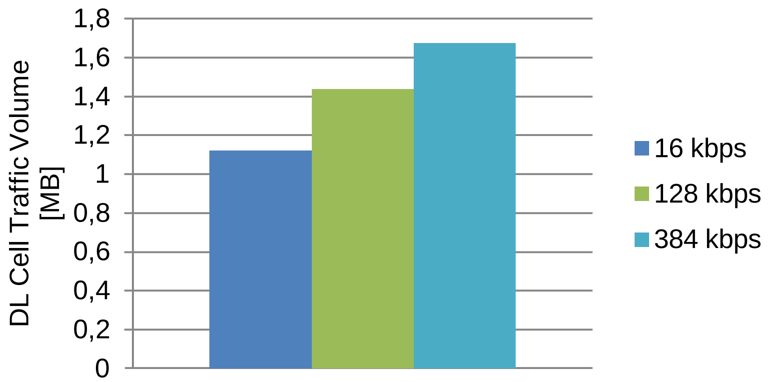

Figure 4.30 DL cell traffic volume.

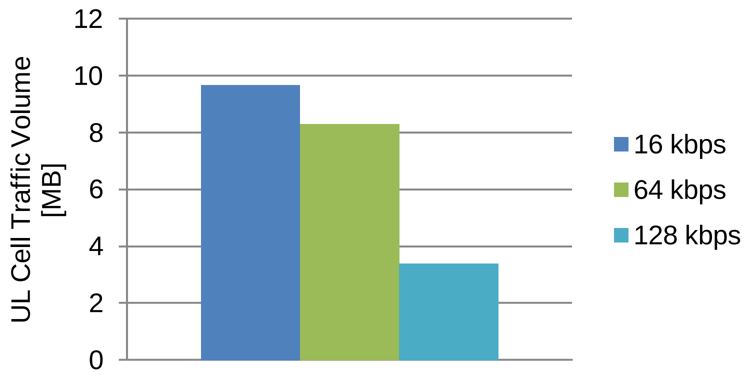

Figure 4.31 UL cell traffic volume.

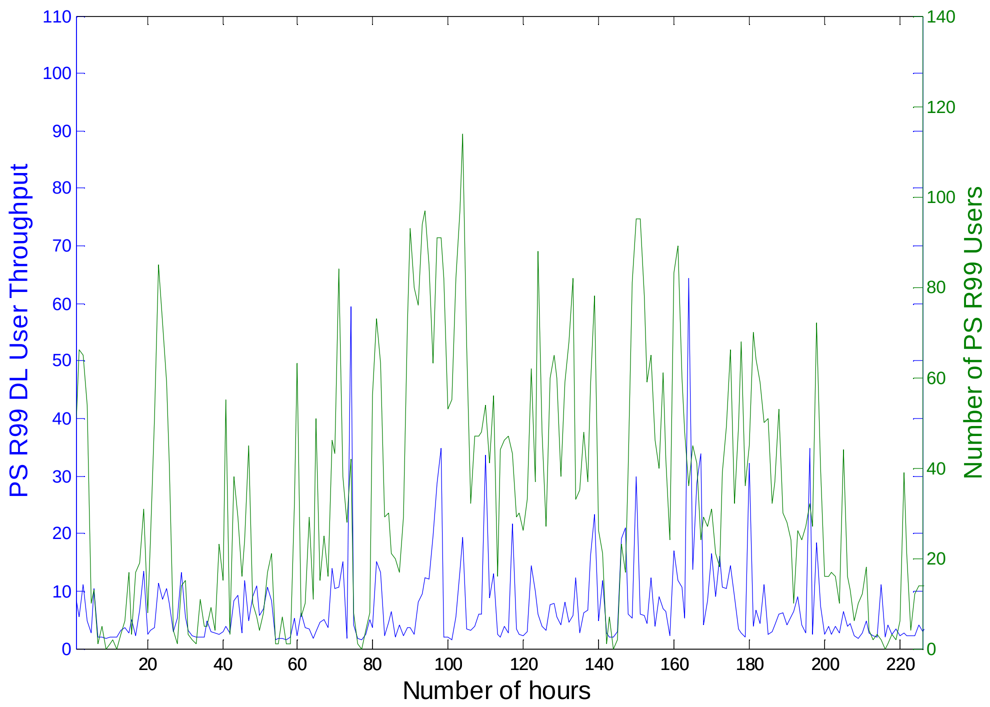

Figure 4.32 BS 11 – Throughput versus number of users.

Figure 4.33 represents a "zoom" from the total 2026 problematic hours. With a correlation value of 8.47%, it appears to be no correlation between the two parameters. Analysing the performance of the PS R99 call drop rate KPI, with an average value of 0.37% it can be considered a very good performance. "Minutes per Drop" KPI average value is 47min31s which means a user experiences a drop call in almost every 47min which is a very good parameter performance. Channel downswitch failure rate has an average value of 0.97%, which is a very low value, and Figures 4.33 and 4.34 illustrate the channel upswitch performance. It is possible to conclude that in DL the PS transitions fail very few times, with a maximum value of 0.25% in the low rate range and in UL the transitions fail in almost 27.50% of the cases in the high rate range, which is a very high percentage. This means that the channel upswitching transitions due to throughput in UL CELL_DCH to CELL_DCH with UL target rate higher than or equal to 256 kbps (excluding EUL) fail due to admission control reject or failures during the channel switching procedure with a probably of 27.50%.

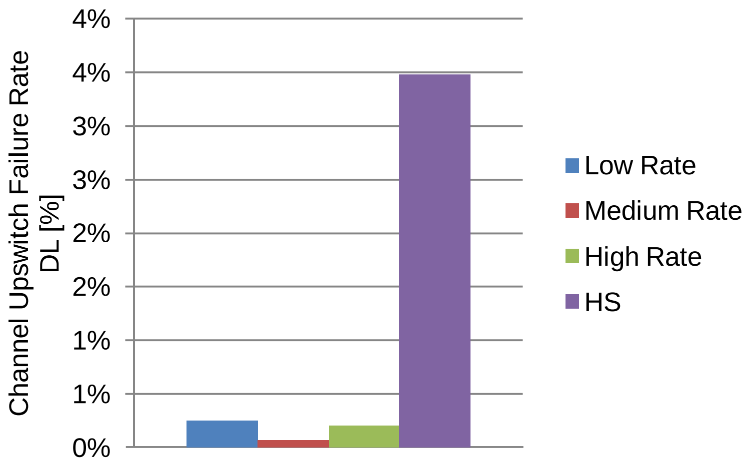

Figure 4.33 Channel upswitch failure rate DL.

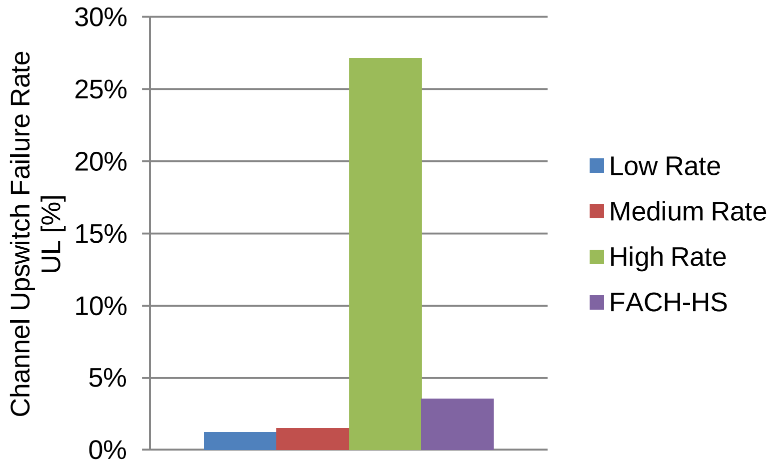

Figure 4.34 Channel upswitch failure rate UL.

In the case of T_{HSDPA} parameter, none correlation with other KPI has been made. An analysis will be performed for the BS with the highest number of problematic hours (2073 hours = 92.88% of the entire month). With a T_{HSDPA} average value of 144.78kbps and a total number of 277428 users, the transmitted bits are all in the spi03 (scheduling priority indicator 03), which is the one associated to the RAB PS Interactive. 9.30% of the total bits are “non acked”, which means 9.30% of the total bits are received but non acknowledged by the UE. Analysing the performance of the HSDPA call drop rate KPI, with an average value of 17.69% it is clearly above the threshold level. “Minutes per Drop” KPI average value is 28min53s which means a user experiences a drop call in almost every 29min which is a very good parameter performance. Channel downswitch failure rate has an average value of 1.08% and the channel upswitch performance is represented in Figures 4.36 and 4.37. It is possible to conclude that in DL and UL the HS transitions fail very few times, with a maximum value of 2.43% in the DL and 2.53% in the UL. This means that the channel down/upswitch transistion do not have a significant impact in the throughput performance.

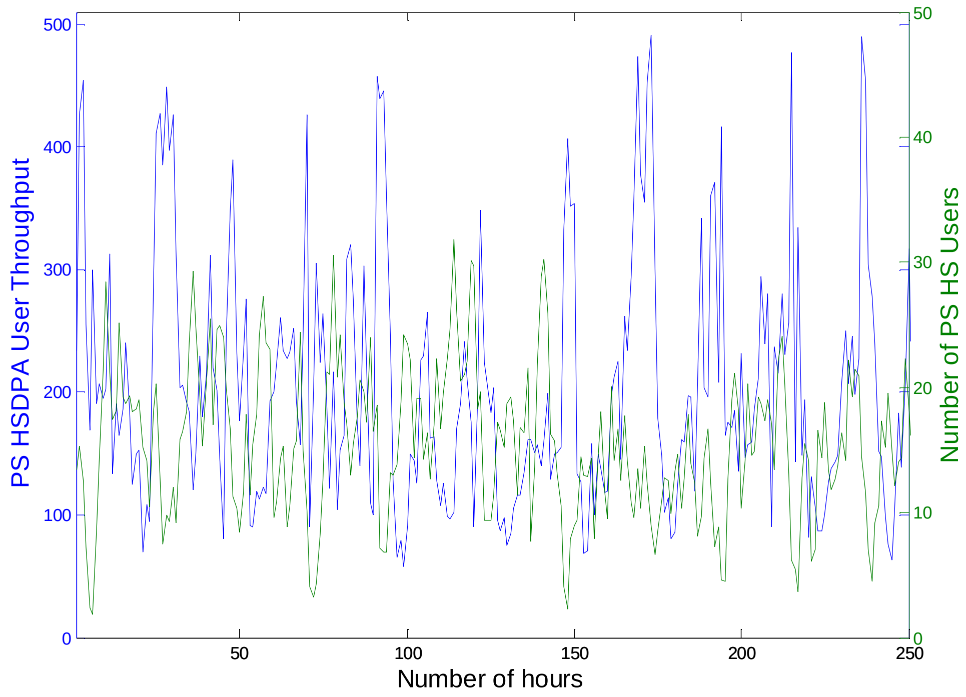

Figure 4.35 HS user throughput and number of HS users..

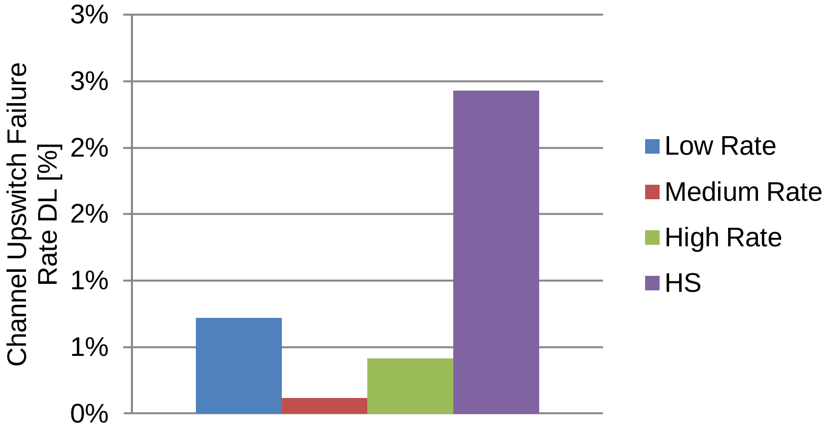

Figure 4.36 Channel upswitch failure rate DL.

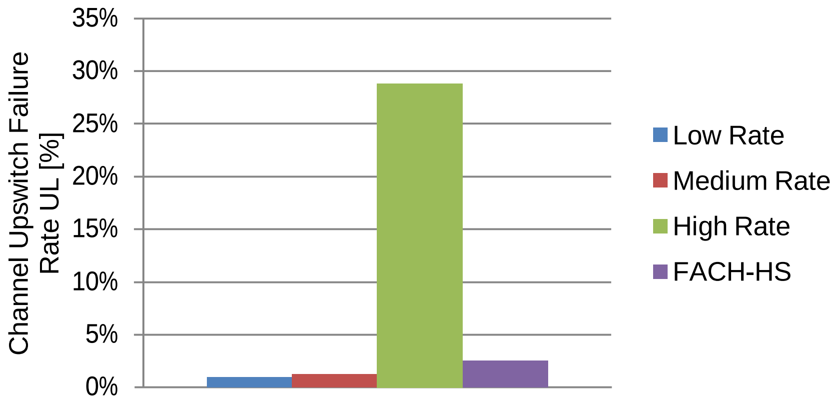

Figure 4.37 Channel upswitch failure rate UL.

When the reason that leads to a throughput poor performance is not easily identifiable, an action that has to be taken into account is the licensing process analysis. The variation of the number of users per cell has to be analysed as well as the number of defined codes in the network. The comparison between the total of licensed users and the available user throughput allows to identify any kind of correlation between the parameters. The comparison between the number of HS users and the number of PS R99 users is also important, since when the lincesed users in HS increases the number of R99 users decreases leading to a decrease in the codes utilisation. This means that the available resources increases, leading to a decrease in the number of RAB failures due to lack of DL channelisation codes.

In this BS, the number of HSDPA codes per cell is 5 and the maximum number of HSDPA users is 16 throughout the entire month. Being a zoom from the total 2073 problematic hours, Figure 4.35 illustrates the comparison between the variation of the HS user throughput and the number of HS users. The average number of maximum PS HS users is 11.62 which means that the average monthly value of the maximum number of HSDPA users is below the defined one. Analysing Figure 4.35, with a correlation value of -17.63% between the two parameters, it is possible to see that in some of the problematic hours when the number of users increases the available HS throughput decreases. In the cases of throughput analysis a trade-off relation has to be established, since the decision to increase the total number of allowed users has to be taken according to the variation of the average user throughput – this solution is well taken if the expected decrease in the average user throughput is not significant compared to the number of new allowed users.

Chapter 5

Conclusions

In this chapter, the main conclusions of this thesis are pointed out, as well as some future work suggestions.

The aim of this work was to perform advanced analysis to GSM and UMTS radio networks in order to establish an algorithm for the tuning of the radio parameters. The main purpose was to optimise the radio network performance in terms of coverage, quality of service and capacity in a defined region. Bearing this in mind, a great amount of information (around 400 GB) was gathered in order to develop a model that considers the provided Key Performance Indicators (KPIs) responsible for evaluate the radio network performance, and through collecting and analysing the information from the operator's database that turns possible the model implementation.

An introduction to GSM, UMTS and HSDPA is performed. UMTS basic aspects are explained, and afterwards HSDPA new features are presented. Following this, the QoS classes of UMTS are presented as well as bit rates and applications of different services. A list of nine GSM KPIs and fourteen UMTS KPIs was provided by the operator, giving a brief explanation of the counters involved in the calculation. The developed model enables to identify the reasons that lead to the KPIs poor performance as well as all the cases were a KPI poor performance is directly related with other KPI poor performance.

Parallel to the model development and implementation, information was gathered concerning radio network opimisation aspects, i.e., several approaches and literature results were chosen and analysed, with the objective to provide information regarding the changes and/or improvements that have to be performed in order to implement the proposed optimisation actions. However, this is a theme whose information is confidential and restricted to the mobile operators and so the available information is scarce, which is understandable since it is unnatural companies make available something that might be useful to its development and performance improvement, which constraints the search about this scope.

The model development and implementantion chapter was the bulk of the work since the obtained results and their further analysis is nothing less than a consequence of the designed algorithms application. The main thought was to create something that would allow to analyse all the KPIs performance at the same time and correlate all that information. If the KPI performance was not the desired one there was a problem.

The developed algorithms allowed to analyse the KPIs individually based on detailed statistics of the problematic areas. In order to access the information contained in the mobile's operator database, programmed in SQL language, an algorithm was built. It allowed searching in the database the counter involved in the KPI expression and using that expression to calculate the KPI, applying all the necessary filters to define range of values and target values defined by the operator.

Six algorithms were developed to analyse the GSM KPIs although the list provided by the operator included nine GSM KPIs. This fact can be easily explained, since there are four throughput KPIs in the list and the procedures to address the throughput performance problems are the same for all of them. Five algorithms were developed to analyse UMTS KPIs although the list provived by the operator included fourteen UMTS KPIs. This fact can be easily explained, since the KPIs were divided into two major groups: the group of the call setup success rate KPIs and the group of the call drop rate KPIs. In the first the analysis is focused on the "RRC&RAB Success Rate", taking into account the RRC/RAB connection/establishment scenario and in the second group of KPIs the RAB drop performance is the analysis starting point since all the KPIs can be seen as the ratio between the abnormal RAB releases over the total number of RAB releases. Both groups included four KPIs. An algorithm was built to analyse the call setup success rate KPIs and two algorithms were built to analyse the call drop rate KPIs since the speech call drop rate analysis was made according to a individual algorithm developed for the purpose. The remaining two algorithms were built to analyse the soft HO success rate KPI and the four throughput KPIs.

A first group of queries was performed in order to put in practice the developed database search algorithm. In Annex B, one presentes the graphic results of the KPIs related to measures made on the days 3, 4, 6, 9, 10, 11 and 12 of July 2010, always in the same sector of two specific BSs. In cases of success rate KPIs, when a database field is NULL, it was considered as 100% because when doing mathematical averages if the average was made with a 0% value instead of 100% it may lead to undesired and incoherent results. In cases of throughput KPIs, when a field is NULL, it was considered 0 kbps, in order to achieve a better understanding. At this point, the idea was to visualise and to understand how the KPIs performance varies throughout the time and compare the obtained results with the desired ones.

Due to the huge dimension of the radio network that was studied in this thesis, the analysis was made in two distinct time intervals. It started with a daily analysis for September 2nd, 2010 only in GSM. The idea of the daily analysis was to verify if the developed models were applicable and so it was made the assumption that if it would result in GSM in UMTS it was also applicable. The daily results played an introductory role to the monthly results.

The main goal being the establishment of correlations between the different parameters, followed to the monthly analysis, where the KPIs performance was analysed separately in a total radio network perspective, the “filtering” process was applied, being analysed only the BSs with the most critical performances. The filtering criteria was related with the value of the monthly weight which means that the greater the number of analysed hours that were below/above the threshold level associated to the performance of the KPI that was being analysed more critical was the performance of the BS.

The problem was identified in a sector or BSC level and than were analysed the cases where different KPIs performance values were below or above the pre-defined threshold levels at the same time. At most four KPIs were compared at the same time. It is very important to enhance the fact that the results analysis are made from the *query’s* output data. This is a very lengthy process, each query lasts on average about 2 h. It is also important refer that the number of queries is directly proportional to the number of KPIs and each KPI is analysed together with other KPIs, thus further increasing the time spent with the analyses. In order to maximize the efficiency the *query’s* were optimised and the simulation process was made in different computers at the same time.

In the GSM analysis call setup success rate, GPRS DL throughput, EDGE DL throughput and PDCH assignment success rate had the poorer performance concerning the standard deviation parameter, with values of 12.55%, 10.28 kbps, 36.93 kbps and 28.42%, respectively. However, the call setup success rate poor performance had a very low impact in the performance of the total radio network, with a monthly weight of 0.64%. The other three KPIs had a monthly weight value of 6.80%, 6.74% and 8.86%, respectively. EDGE UL throughput being the KPI with the highest value of monthly weight (20.11%) it was also the KPI with the highest percentage of problematic BSs after the filtering process. 81.40% of the total radio network BSs were considered critical only considering the performance of this KPI.

The call drop rate correlation process was very efficient. The correlations were made between this KPI and HO success rate, SDCCH drop rate and call setup success rate. The results concerning BS 2 showed a correlation between the dropped calls and the HO process of -91.24%, which means that in the majority of the cases the reasons for a dropped call in this BS were related to HO issues. It was also concluded that the main reason associated to the drops and consequently to the HO issues was the bad quality, which is associated to interference. A proposed action in this type of problems was the identification of the type of interference in order to the operator to be able to know the solution to be adopted in such cases. In some BSs, the results were misleading since the almost automatic conclusion in those BSs was that the call drops due to HO problems with 100% sure. However those BSs poor performance had a very minor impact, in the total radio network performance perspective, with a monthly weight value of 0.09% and so the results were not taken into account.

The increase of SDCCH drops being a possible reason for an increase in the number of dropped calls, the correlation value was supposed to be positive and so the negative correlation results were considered misleading.

The correlation process between the call drop rate and the call setup success rate tried to show some relation between the inability to successfully end the call setup process and the drop of the TCH, two possible cases were identified: the call setup process can be successfully terminated and yet the TCH drops, and the TCH can drop due to the fact that the call setup process was unsuccessfully terminated. In BSs 6 and 13 the correlation values were 53.38% and -81.49%, respectively, which could be considered an excellent value in the correlations establishment process. However in BSs 13 and 6 the number of problematic hours only represented 4.08% and 1.34% of the entire month performance and the call setup success rate had an average value close to the pre-defined threshold. This means that in those BSs although the correlation results were very satisfactory, leading to the conclusion that in the majority of the case BS 6 call setup process is successfully terminated and yet the TCH drops and in BS 13 the TCH drops due to the fact that the call setup process is unsuccessfully terminated, the performance of those BSs can be considered satisfactory.

The correlation made between the SDCCH drop rate and the call setup success rate corresponded to what was expected. The call establishment process is well succeeded if the SDCCH assignment process is well succeeded as well as the call setup process. The results show that in the majority of the cases the call setup process was unsuccessful due to drop of the control channel with correlation values close to 100%.

The correlation process in the throughput KPIs analysis was made by the comparison with the PDCH assignment success rate. The logical thought is that if the PDCH is successfully assigned the probability of an increase in the available troughput increases. The results show that the correlation values between GPRS DL throughput and PDCH assignment success rate in BSs 49, 37 and 23 had the highest values – the first two in DL direction and BS 23 in the UL direction. This means that in the other cases, in spite of the probability of the KPIs being below/above the threshold level at the same time is very high it does not represent a direct relation between them. In BS 49 it was possible to identify a notorious correlation between the two KPIs: when the PDCH assignment success rate increased, the GPRS DL throughput available also increased, which supported the statement that an insufficient number of available PDCHs is one of the reasons responsible for a poor throughput performance. The HR traffic have been identified as one of the possible reasons for having a high number of PDCH assignment fails, since it represented 95.41% of the total traffic, clearly above the threshold level of 50%. The average PDCH utilisation ratio was 85.73% (above the 80% threshold value) and there were 5.24 simultaneous users per active PDCH which was clearly superior compared to the 1.4 threshold value, which proved that there was in fact a high capacity problem. The HR traffic represented 95.19% of the total traffic, clearly above of the threshold level and affecting the throughput performance.

In the UMTS analysis CS64 call setup success rate, HSDPA Interactive call drop rate, PS R99 Interactive DL user throughput and HSDPA Interactive user throughput had the poorer performance concerning the standard deviation parameter, with values of 35.10%, 32.17%, 129.11 kbps and 575.54 kbps, respectively. However, the CS64 call setup success rate poor performance had a very low impact in the performance of the total radio network due to the low traffic, with a monthly weight of 0.06%. The other three KPIs had a monthly weight value of 18.74%, 56.65% and 51.69%, respectively. Being PS R99 Interactive DL user throughput the KPI with the highest value of monthly weight it was the second KPI with the highest percentage of problematic BSs after the filtering process. 58.48% of the total radio network BSs were considered critical. The KPI with the highest value of problematic cells was the PS R99 Interactive UL user throughput with a value of 59.38%.

The Speech Call Setup Success Rate correlation process was also very efficient. The correlation was made between this KPI and speech call drop rate. In BS 8, 88.86% of the speech call drops were due to unknown reasons, which excludes lost of UL synchronism, congestion, missing neighbours and SHO action. Analysing the call setup success rate performance it was possible to conclude that there were problems in the establishment of the RRC connection. There were no fails associated to transport network blocking, which leads to the conclusion that the majority of the problems that were detected after the admission process are associated to the Iub configuration. 86.33% of the fails in the establishment of the RRC connection are due to lack of DL channelisation codes.

The results concerning CS64 service were not analysed. This decision was made taking into account the fact that the traffic was residual and therefore not statistically significant in the total network traffic. When dealing with voice the 2G technology is the most often used and when dealing with data it was all reported to 3G.

The correlation results concerning PS R99 Interactive call setup success rate show that BS 58 was the only BS with a significant poor performance impact in the total radio network perspective. The correlation between this KPI and PS R99 Interactive call drop rate in this BS had a value of -65.00%.

A user experienced a drop call, in average, in every 5min58s. The channel downswitch failure rate had a value of 12.09% which could be considered a high value, leading the operator to review the transistions to lower bit rates. There were no significant problems in the upswitch transitions and the majority of the denied requests during the admission control process were due to RRC problems and 87.16% of those fails were due to lack of DL channelisation codes.

In the soft HO correlation process, the KPI was correlated with the call drop rate KPIs in order to continue the process initiated in the GSM analysis. The obtained results allowed to conclude that in BS 6 the correlation between this KPI and speech call drop rate had a value of -68.55%. The value of soft/softer HO overhead was identified as the major reason that contributed to the KPI poor performance since a value of 43.38% could decrease the DL capacity by the increasing of the transmitted interference to the network. An action that has to be taken into account by the operator is the increase of the active set update rate because they are related: smaller overhead can be obtained at the expense of a higher active set update rate.

There were not identified significant correlations between soft HO success rate and PS R99 or HSDPA Interactive call drop rate, which lead to the conclusion that the HO problems did not contribute significantly to those KPIs poor performance.

Since the problems associated to user throughput poor performance are most of the times related to capacity issues, it was not established any correlation between the throughput KPIs and other KPIs because that was considered unnecessary. The analysis was similar to the one made on GSM. Analysing PS R99 DL/UL user throughput in BS 11 the channel upswitch transitions due to throughput in UL CELL_DCH to CELL_DCH with UL target rate higher than or equal to 256 kbps (excluding EUL) failed due to admission control reject or failed during the channel switching procedure in 27.50% of the analysed cases. This is a very high value and so the operator has to review the upswitch transitions in this range of bit rates.

When the reason that leads to a throughput poor performance is not easily identifiable, an action that have to be taken into account is the licensing process analysis. The variation of the number of users per cell has to be analysed, as well as the number of defined codes in the network. In the BS with most problematic hours during the analysis of HSDPA Interactive user throughput the number of HSDPA codes per cell was 5 and the maximum number of HSDPA users was 16 throughout the entire month. In the cases of throughput analysis a trade-off relation has to be established since the decision to increase the total number of allowed users has to be taken according to the variation of the average user throughput – this solution is well taken if the expected decrease in the average user throughput is not significant compared to the number of new allowed users.

The correlation establishment process between KPIs revealed to be very useful and efficient. In GSM, the correlation between dropped voice calls and HO issues is very high, as well as between dropped voice calls and the drop of the control channel. In BS 2, call drop rate and HO success rate has a correlation value of -91.24% and in BS 17 call drop rate and SDCCH drop rate has a correlation value of -52.03%. In UMTS, the correlation between dropped calls and the call setup success rate is also very high, e.g., in BS 58, PS R99 call drop rate and call setup success rate has a correlation value of -

65.00%.

This work allowed the operator to easily identify the call drop reasons due to HO issues and due to unsucceeded call setup establishment process as well as the major reasons that lead to the throughput KPIs performance in both GSM and UMTS technologies. This work can represent a high contribution in terms of economical impact in the performance optimisation and development of a mobile operator in two different levels. In the network operation level, since it provides to the operator models and algorithms that allows him to optimise the troubleshooting process in terms of time, and in this business saving time means making money. In the service to the user level, since the problems can be more easily and more quickly identified, which means that can also be more easily and quickly solved and the user experience and QoS to the user will be more satisfactory, reducing the complaints.

Underlying the variety of still possible studies that can be performed for this subject, it can be concluded that this is not a finalised work at all. For future work, it is suggested that the IRAT CS HO success rate incoming and outgoing has to be studied. Although it was part of this work the time turned out to be a key aspect in the work development and it was not possible to analyse those KPIs performance. The data collection with Δt = 0h15 min will provide a different kind of data processing allowing to identify future problems in smaller time intervals. In the HO analysis the site availabily can be checked in the analysis of the neighbouring cells which allows to save time in the problems search. In the 3G throughput analysis, recommendations can be established for the increase of the number of maximum HS licensed users: cells with a number of HSDPA users more than 80% of the license in use during 5% of the day and an average value of HS RAB establishments rejected by admission control throughout the week higher than 100 during two consecutive weeks have to see their license expanded.

Annex A

Ericsson's KPIs Definition

In Annex A, one gives the definition of the Key Performance Indicators and of the counters involved in the process, according to the Ericsson's User Description.

GSM KPIs (all these KPIs are introduced in [Eric06])

- ### Voice Parameters:

$$R_{C_D} = \left(\frac{N_{TCH_D}}{N_C}\right) \times 100[\%]$$

- N_{TCH_D} is referred as $TFNDROP + TFNDROPSUB + THNDROP + THNDROPSUB$.
- N_C is referred as $TFMSESTB + THMSESTB$.

$$R_{SDCCH_D} = \left(\frac{N_{SDCCH_D}}{N_{MS_{SDCCH_S}}}\right) \times 100[\%]$$

- N_{SDCCH_D} is referred as $CNDROP$.
- $N_{MS_{SDCCH_S}}$ is referred as $CMSESTAB$.

$$R_{CS_S} = \left((1 - R_{SDCCH_D}) \times (1 - R_{TCH_F})\right) \times 100[\%]$$
$$= \left(\left(1 - \left(\frac{N_{SDCCH_D} - N_{SDCCH_R}}{N_{MS_{SDCCH_S}}}\right)\right) \times \left(1 - \left(1 - \left(\frac{N_{MS_{FR}} + N_{MS_{HR}}}{N_{MS_{TCH_A}}}\right)\right)\right)\right) \times 100[\%]$$

- R_{TCH_F} is referred as $TAFR$.
- $N_{MS_{FR}}$ is referred as $TFCASSALL$.
- $N_{MS_{HR}}$ is referred as $THCASSALL$.
- $N_{MS_{TCH_A}}$ is referred as $TASSALL$.

- ### Data Parameters:

$$T_{GPRS_{DL}} = \frac{T_{G_{THP1_{DL}}} + T_{G_{THP2_{DL}}} + T_{G_{THP3_{DL}}} + T_{G_{BGG_{DL}}}}{D_{G_{THP1_{DL}}} + D_{G_{THP2_{DL}}} + D_{G_{THP3_{DL}}} + D_{G_{BGG_{DL}}}} [kbit/s]$$

- $T_{G_{THP1_{DL}}}$ is referred as $DLTHP1GTHR$.
- $T_{G_{THP2_{DL}}}$ is referred as $DLTHP2GTHR$.
- $T_{G_{THP3_{DL}}}$ is referred as $DLTHP3GTHR$.
- $T_{G_{BGG_{DL}}}$ is referred as $DLBGGTHR$.
- $D_{G_{THP1_{DL}}}$ is referred as $DLTHP1GDATA$.
- $D_{G_{THP2_{DL}}}$ is referred as $DLTHP1GDATA$.
- $D_{G_{THP3_{DL}}}$ is referred as $DLTHP1GDATA$.
- $D_{G_{BGG_{DL}}}$ is referred as $DLBGGDATA$.

$$T_{GPRS_{UL}} = \frac{T_{G_{THP1_{UL}}} + T_{G_{THP2_{UL}}} + T_{G_{THP3_{UL}}} + T_{G_{BGG_{UL}}}}{D_{G_{THP1_{UL}}} + D_{G_{THP2_{UL}}} + D_{G_{THP3_{UL}}} + D_{G_{BGG_{UL}}}} [kbit/s]$$

- $T_{G_{THP1_{UL}}}$ is referred as $ULTHP1GTHR$.
- $T_{G_{THP2_{UL}}}$ is referred as $ULTHP2GTHR$.
- $T_{G_{THP3_{UL}}}$ is referred as $ULTHP3GTHR$.
- $T_{G_{BGG_{UL}}}$ is referred as $ULBGGTHR$.
- $D_{G_{THP1_{UL}}}$ is referred as $ULTHP1GDATA$.
- $D_{G_{THP2_{UL}}}$ is referred as $ULTHP1GDATA$.
- $D_{G_{THP3_{UL}}}$ is referred as $ULTHP1GDATA$.
- $D_{G_{BGG_{UL}}}$ is referred as $ULBGGDATA$.

$$T_{EDGE_{DL}} = \frac{T_{E_{THP1_{DL}}}+T_{E_{THP2_{DL}}}+T_{E_{THP3_{DL}}}+T_{E_{BGE_{DL}}}}{D_{E_{THP1_{DL}}}+D_{E_{THP2_{DL}}}+D_{E_{THP3_{DL}}}+D_{E_{BGE_{DL}}}} [kbit/s]$$

- $T_{E_{THP1_{DL}}}$ is referred as $DLTHP1EGTHR$.
- $T_{E_{THP2_{DL}}}$ is referred as $DLTHP2EGTHR$.
- $T_{E_{THP3_{DL}}}$ is referred as $DLTHP3EGTHR$.
- $T_{E_{BGE_{DL}}}$ is referred as $DLBGEGTHR$.
- $D_{E_{THP1_{DL}}}$ is referred as $DLTHP1EGDATA$.
- $D_{E_{THP2_{DL}}}$ is referred as $DLTHP2EGDATA$.
- $D_{E_{THP3_{DL}}}$ is referred as $DLTHP3EGDATA$.
- $D_{E_{BGE_{DL}}}$ is referred as $DLBGEGDATA$.

$$T_{EDGE_{UL}} = \frac{T_{E_{THP1_{UL}}} + T_{E_{THP2_{UL}}} + T_{E_{THP3_{UL}}} + T_{E_{BGE_{UL}}}}{D_{E_{THP1_{UL}}} + D_{E_{THP2_{UL}}} + D_{E_{THP3_{UL}}} + D_{E_{BGE_{UL}}}} [kbit/s]$$

- $T_{E_{THP1_{UL}}}$ is referred as $ULTHP1EGTHR$.
- $T_{E_{THP2_{UL}}}$ is referred as $ULTHP2EGTHR$.
- $T_{E_{THP3_{UL}}}$ is referred as $ULTHP3EGTHR$.
- $T_{E_{BGE_{UL}}}$ is referred as $ULBGEGTHR$.
- $D_{E_{THP1_{UL}}}$ is referred as $ULTHP1EGDATA$.
- $D_{E_{THP2_{UL}}}$ is referred as $ULTHP2EGDATA$.
- $D_{E_{THP3_{UL}}}$ is referred as $ULTHP3EGDATA$.
- $D_{E_{BGE_{UL}}}$ is referred as $ULBGEGDATA$.

$$R_{PDCH_S} = \left(1 - \frac{N_{PDCH_F}}{N_{PDCH_A}}\right) \times 100[\%]$$

- $N_{PDCH_{Fail}}$ is referred as $PCHALLFAIL$.
- $N_{PDCH_{Attemp}}$ is referred as $PCHALLATT$.

UMTS KPIs (all these KPIs are introduced in [Eric08])

- Voice Parameters:

R_{SCS_S} = $\left(R_{CSRRC_S} \times R_{RAB_S}\right) \times 100[\%]$

- R_{CSRRC_S} is referred as $\left(\frac{pmTotNoRrcConnectReqCsSucc}{pmTotNoRrcConnectReqCs - pmNoLoadSharingRrcConnCs}\right)$.
- R_{RAB_S} is referred as $\left(\frac{pmNoRabEstablishSuccessSpeech}{pmNoRabEstablishAttemptSpeech - pmNoDirRetryAtt}\right)$.

Note that de counter $pmNoLoadSharingRrcConnCs$ allows distinguish load sharing events for CS RAB's in case Load Sharing feature is enabled.

R_{CS64_S} = $\left(R_{CSRRC_S} \times R_{CS64\_RAB_S}\right) \times 100[\%]$

- $R_{CS64\_RAB_S}$ is referred as $\left(\frac{pmNoRabEstablishSuccessCS64}{pmNoRabEstablishAttemptCS64}\right)$.

R_{SC_D} = $\left(\frac{N_{Ab\_RAB_R}}{N_{RAB_R}}\right) \times 100[\%]$

- $N_{Ab\_RAB_R}$ is referred as $pmNoSystemRabReleaseSpeech$.
- N_{RAB_R} is referred as $pmNoNormalRabReleaseSpeech + pmNoSystemRabReleaseSpeech$.

Note that the $pmNoNormalRabReleaseSpeech$ and $pmNoSystemRabReleaseSpeech$ counters are only increased due to a RANAP (*Radio Access Network Application Part*) Iu Release Command or RAB Assignment Request message for RAB speech respectively with "release cause" = 'Normal Release', 'Successful Relocation', 'Resource Optimisation Relocation', 'User Inactivity' or 'release-due-to-UE-generated-signaling-connection-release' for the first one or anything except the previous causes for the second one. For UtranCell class these counters are incremented for the best cell in the Active Set in the SRNC (*Serving Radio Network Controller*).

R_{CS64C_D} = $\left(\frac{N_{CS64Ab\_RAB_R}}{N_{CS64RAB_R}}\right) \times 100[\%]$

- $N_{CS64Ab\_RAB_R}$ is referred as $pmNoSystemRabReleaseCS64$.
- $N_{CS64RAB_R}$ is referred as $pmNoNormalRabReleaseCS64$+ $pmNoSystemRabReleaseCS64$.

Note that the $pmNoNormalRabReleaseCS64$ and $pmNoSystemRabReleaseCS64$ counters are only increased due to a RANAP Iu Release Command or RAB Assignment Request message for a conversational 64 kbps RAB, respectively with "release cause" = 'Normal Release', 'Successful Relocation', 'Resource Optimisation Relocation', 'User Inactivity' or 'release-due-to-UE-generated-signaling-connection-release' for the first one or anything except the previous causes for the second one. For UtranCell MO, these counters are incremented for the best cell in the Active Set in the SRNC.

- Data Parameters:

$R_{PSR99\_ICS_S}$ = $\left(R_{PSRRC_S} \times R_{RAB\_PS\_DCH\_FACH_S}\right) \times 100[\%]$

- R_{PSRRC_S} is referred as $\left(\frac{pmTotNoRrcConnectReqPsSucc}{pmTotNoRrcConnectReqPs - pmNoLoadSharingRrcConnPs}\right)$.
- $R_{RAB\_PS\_DCH\_FACH_S}$ is referred as $\left(\frac{pmNoRabEstSuccessPsIntNonHs}{\substack{pmNoRabEstAttempPsIntNonHs+ \\ pmNoOfNonHoReqDeniedHs+pmNoRabEstBlockTnPsIntHsBest}}\right)$.

$R_{HSDPA\_ICS_S}$ = $\left(R_{PSRRC_S} \times R_{RAB\_PS\_HS_S}\right) \times 100[\%]$

- $R_{RAB\_PS\_HS_S}$ is referred as $\left(\frac{pmNoRabEstablishSuccessPacketInteractiveHs}{pmNoRabEstablishAttemptPacketInteractiveHs}\right)$.

$R_{PSR99\_IC_D}$ = $\left(\frac{N_{RABAb\_PS\_DCH\_FACH_R}}{N_{RAB\_PS\_DCH\_FACH_R}}\right) \times 100[\%]$

- $N_{RABAb\_PS\_DCH\_FACH_R}$ is referred as $pmNoSystemRabReleasePacket - pmNoSystemRbReleaseHs - pmNoSystemRabReleasePacketUra$.
- $N_{RAB\_PS\_DCH\_FACH_R}$ is referred as $pmNoNormalRabReleasePacket - pmNoNormalRabReleasePacketUra - pmNoNormalRbReleaseHs + pmNoSystemRabReleasePacket - pmNoSystemRabReleasePacketUra - pmNoSystemRbReleaseHs + pmUpswitchFachHsSuccess + pmDlUpswitchSuccessHs$.

The $pmNoNormalRabReleasePacket$ and $pmNoSystemRabReleasePacket$ counters are only increased due to a RANAP Iu Release Command or RAB Assignment Request message for all PS RAB's respectively with "release cause" = 'Normal Release', 'Successful Relocation', 'Resource Optimisation Relocation', 'User Inactivity' or 'release-due-to-UE-generated-signaling-connection-release' for the first one or anything except the previous causes for the second one. The $pmNoSystemRabReleasePacketUra$ counter represents the number of system release of packet RAB's while on URA (*Utran Registration Area*) state. The $pmNoSystemRbReleaseHs$ counter is stepped for the Serving HS-DSCH (*Home System – Downlink Shared Channel*) cell at RAB/RB combination transition from PS Interactive 64/HS (or 384/HS or EUL/HS) – HS-DSCH to SRB-DCH or to Idle mode due to the same reasons as for stepping the existing counter $pmNoSystemRabReleasePacket$.

For UtranCell class, this counter is stepped for the Serving HS-DSCH cell. The same counter has not been released on Iur link level. The $pmNoNormalRbReleaseHs$ counter is only increased at RAB/RB combination transition from PS Interactive 64/HS – HS-DSCH to SRB-DCH or to Idle mode, due to a RANAP Iu Release Command or RAB Assignment Request message for RAB Speech respectively with "release cause" = 'Normal Release', 'Successful Relocation', 'Resource Optimisation Relocation', 'User Inactivity' or 'release-due-to-UE-generated-signaling-connection-release'. The $pmUpswitchFachHsSuccess$ counter provides the number of successful upswitches from FACH to any HS state. The counter is stepped for successful upswitch from CELL_FACH to a RB combination containing HS. The counter is only incremented in all cells of the active set. The $pmDlUpswitchSuccessHs$ counter provides the number of successful DL upswitches to any HS state. The counter is stepped for successful DL upswitch to a RB combination containing HS. The counter is only incremented in all cells of the active set.

$$R_{HSDPA\_IC_D} = \left(\frac{N_{RABAb\_PS\_HSDPA_R}}{N_{RAB\_PS\_HSDPA_R}}\right) \times 100[\%]$$

- $N_{RABAb\_PS\_HSDPA_R}$ is referred as $pmNoSystemRbReleaseHs$.
- $N_{RAB\_PS\_HSDPA_R}$ is referred as $pmNoNormalRbReleaseHs + pmNoSystemRbReleaseHs$.

$$T_{PSR99_{DL}} = \frac{T_{RLC_{DL}}}{N_{samples_{RLC_{DL}}}} \; [kbit/s]$$

- $T_{RLC_{DL}}$ is referred as $pmSumDchDlRlcUserPacketThp$. The counter values are read periodically from an internal level counter and added to this counter. The level counter maintains the current DL RLC throughput for PS Interactive on R99 DCH, including user data only. This counter is not incremented when the throughput is 0 kbps. For a multiRAB combination containing more than one PS Interactive RB, this counter is incremented for only one of the R99 PS Interactive RB's in the combination. It has a sample rate of 0.5 s.
- $N_{samples_{RLC_{DL}}}$ is referred as $pmSamplesDchDlRlcUserPacketThp$. This counter represents the number of samples in $pmSumDchDlRlcUserPacketThp$ (that is, $pmSamplesDchDlRlcUserPacketThp$ = $pmSamplesDchDlRlcUserPacketThp$ +1, whenever $pmSumDchDlRlcUserPacketThp$ is to be updated). It is measured two times/second and incremented by one if $pmSumDchDlRlcUserPacketThp > 0$ for the same polling time duration.

$$T_{PSR99_{DL}} = \frac{T_{PS_{RLC_{UL}}}}{N_{samples_{PS_{RLC_{UL}}}}} \; [kbit/s]$$

- $T_{PS_{RLC_{UL}}}$ is referred as $pmSumDchUlRlcUserPacketThp$. The counter values are read periodically from an internal level counter and added to this counter. The level counter maintains the current UL RLC throughput for PS Interactive on R99 DCH, including user data only. This counter is not incremented when the throughput is 0 kbps. For a multiRAB combination containing more than one PS Interactive RB, this counter is incremented for only one of the R99 PS Interactive RB's in the combination. It has a sample rate of 0.5 s.
- $N_{samples_{PS_{RLC_{UL}}}}$ is referred as $pmSamplesDchUlRlcUserPacketThp$. This counter represents the number of samples in $pmSumDchUlRlcUserPacketThp$ (that is, $pmSamplesDchUlRlcUserPacketThp$ = $pmSamplesDchUlRlcUserPacketThp$ +1, whenever $pmSumDchUlRlcUserPacketThp$ is to be updated). It is measured two times/second and incremented by one if $pmSumDchUlRlcUserPacketThp > 0$ for the same polling time duration.

$$T_{HSDPA} = \frac{T_{HS_{RLC}}}{N_{samples_{HS_{RLC}}}} \; [kbit/s]$$

- $T_{HS_{RLC}}$ is referred as $pmSumHsDlRlcUserPacketThp$. The counter sums all values recorded during a ROP for HS-DSCH RLC throughput measurements, excluding retransmissions. It is reported on the best cell in the active set. Values are read periodically from an interval level counter and added to this counter. The level counter maintains the current HS-DSCH RLC throughput, excluding retransmissions. It has a sample rate of 0.1 seconds.
- $N_{samples_{HS_{RLC}}}$ is referred as $pmSamplesHsDlRlcUserPacketThp$. This counter represents the number of samples in $pmSumHsDlRlcUserPacketThp$ (that is, $pmSamplesHsDlRlcUserPacketThp$ = $pmSamplesHsDlRlcUserPacketThp$ +1, whenever $pmSumHsDlRlcUserPacketThp$ is to be updated, this means if no data is transmitted the counter is not incremented).

GSM and UMTS Handover Parameters (all these KPIs are introduced in [Eric06] and [Eric08])

$$R_{HO_S} = \left(\frac{N_{HO_N} + N_{HO_I}}{N_{HO_{MS}} + N_{HO_{I_{DL}}} + N_{HO_{I_{UL}}} + N_{HO_{I_{DL\_UL}}}} \right) \times 100[\%]$$

- N_{HO_N} is referred as $HOVERSUC$.
- N_{HO_I} is referred as $HOINSUC$.
- $N_{HO_{MS}}$ is referred as $HOVERCNT$.
- $N_{HO_{I_{DL}}}$ is referred as $HOINDQA$.
- $N_{HO_{I_{UL}}}$ is referred as $HOINUQA$.
- $N_{HO_{I_{DL\_UL}}}$ is referred as $HOINBQA$.

$$R_{SHO_S} = \left(\frac{N_{RL_S}}{N_{RL_A}} \right) \times 100[\%]$$

- N_{RL_S} is referred as $pmNoTimesRlAddToActSet$.
- N_{RL_A} is referred as $pmNoTimesRlAddToActSet + pmNoTimesCellFailAddToActSet$.

The $pmNoTimesRlAddToActSet$ counter is increased when a new RL is successfully added to an active set. The counter is increased after a handover proposal has been received from the handover evaluation function, admission control has been granted, DL channelisation code has been allocated for the new cell, RL Setup or RL Addition procedure is successfully completed with the RBS (NBAP (*Node B Application Part*) RL Setup Response or RL Addition Response received), the Active Set Update procedure is successfully completed with the UE (RRC Active Set Update Complete received), and the appropriate parameters are available. If an RL is replaced in an active set, this counter is increased for the cell which is added. The $pmNoTimesCellFailAddToActSet$ is increased if, during an attempt to add an RL, any of the following occur: admission is not granted, no DL channelisation code is allocated, the RL Setup procedure fails (NBAP RL Setup Failure received), RL Addition procedure fails (NBAP RL Addition Failure received), RL Setup or Addition procedure times out in the RBS, the Active Set Update procedure fails (RRC Active Set Update Failure received) or Active Set Update procedure fails (RRC Active Set Update Failure received) or Active Set Update procedure times out in the UE. If affects cells which can not enter into the active set. Both counters only monitor UEs in the SRNC.

$$R_{IRAT\_HO_{S_O}} = \left(\frac{N_{IRAT\_HO_{S_O}}}{N_{IRAT\_HO_{A_O}}}\right) \times 100[\%]$$

- $N_{IRAT\_HO_{S_O}}$ is referred as $pmNoSuccessOutIratHoSpeech$ + $+pmNoSuccessOutIratHoMulti$.
- $N_{IRAT\_HO_{A_O}}$ is referred as $pmNoAttOutIratHoSpeech$ + $pmNoAttOutIratHoMulti$.

The $pmNoAttOutIratHoSpeech$ and $pmNoAttOutIratHoMulti$ counters are increased when RNC has received “HANDOVER FROM UTRAN COMMAND” respectively for RAB speech and MultiRAB. These counters will only be incremented in the SRNC and for the best cell in active set. The trigger $pmNoSuccessOutIratHoSpeech$ is when IU RELEASE COMMAND is received with cause ‘Normal release’ or ‘Successful relocation’ and based on the CS RAB state. This counter will only be incremented in the SRNC and for the best cell in the active set. The trigger of the counter $pmNoSuccessOutIratHoMulti$ is reception of “HANDOVER FROM UTRAN COMMAND”. This counter will only be incremented in the SRNC and for the best cell in the active set.

$$R_{IRAT\_HO_{S_I}} = \left(\frac{N_{IRAT\_HO_{S_I}}}{N_{IRAT\_HO_{A_I}}}\right) \times 100[\%]$$

- $N_{IRAT\_HO_{S_I}}$ is referred as $pmNoInCsIratHoSuccess$.
- $N_{IRAT\_HO_{A_I}}$ is referred as $pmNoInCsIratHoAtt$.

The $pmNoInCsIratHoSuccess$ counter provides the number of successful CS incoming Inter System Handovers. The counter is increased after reception of both RRC message “handover to UTRAN complete” (UE responds after completed RANAP procedure for Relocation Request) and NBAP message “RL restore ind” (RBS has received UL synchronisation with the UE). The $pmNoInCsIratHoAt$ counter provides the number of attempted CS incoming Inter System Handovers (counted before module and central MP load control, after SCCP (*Signaling Connection Control Part*) MP if the cell is recognised as being controlled by this RNC (after the stepping also central MP and module MP is checked for overload).

Annex B

Database Algorithm Application

In Annex B, one presentes the graphic results related to the database algorithm application mentioned in Section 3.1.

One presentes the graphic results of KPIs related to measures made on the days 3, 4, 6, 9, 10, 11 and 12 of July 2010, always in the same sector of two specific BSs, in order to obtain a better visual perspective of the KPI behaviour throughout the time. These BSs and these days were chosen randomly in order to make up seven days (one week). These are not consecutive days because there were days with data network statistics corrupted.

Note that in cases of success rates, when a field is NULL, it was considered 100%; in cases of throughput, when a field is NULL, it was considered 0 kbps, in order to achieve a better understanding.

At this point, it can only be made an objective and simple evaluation of the obtained results. The primary analysis focuses on cases with two or more consecutive hours with performance results below the predefined threshold. All the KPIs have a range of values considered valid, in order to evaluate their performance. As it can be seen in the graphics, the thresholds represent the minimum goal to reach a valid level of performance. Considering call drop on GSM, Figure B.1, the results can be classified as generally good, since it never exceeds the threshold, while speech call drop rate on UMTS, Figure B.2, the results are very close of the low value of satisfaction, even exceeding in some cases. The handover results are very good in both technologies, never exceeding the defined threshold. Analysing the downlink throughput measures for both technologies, the results are not so good. R99 Downlink User Throughput results never reach the minimum acceptable value of 200 kbps, which indicates that something has to be done to address the situation. The same problem occurs with $T_{GPRS_{DL}}$ results, since they barely reach the minimum threshold of 20 kbps.

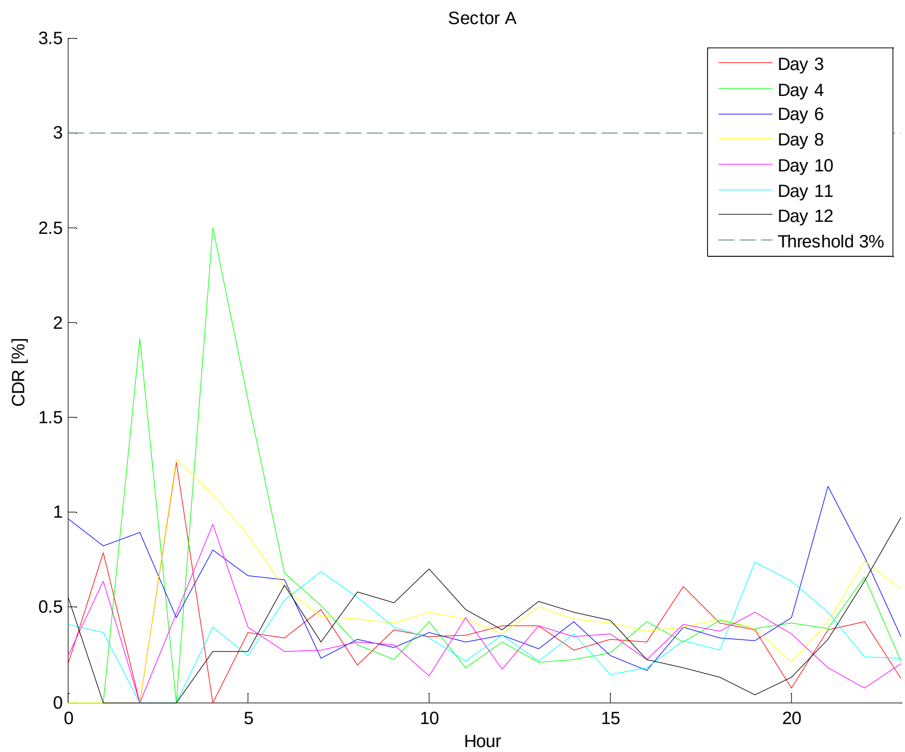

Figure B.1 Call Drop Rate.

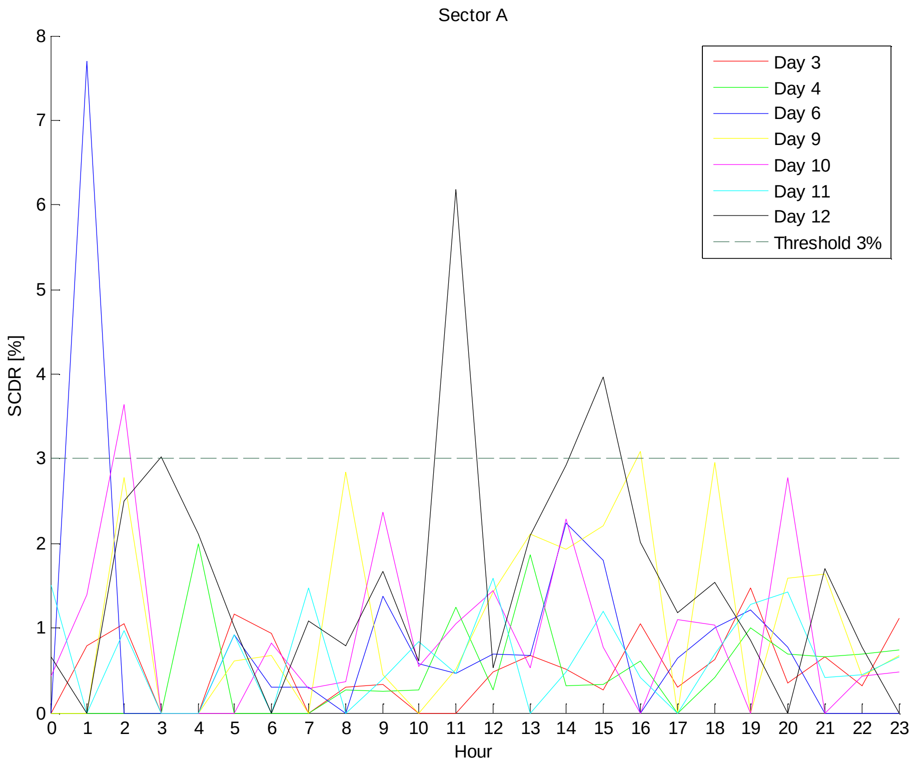

Figure B.2 Speech Call Drop Rate.

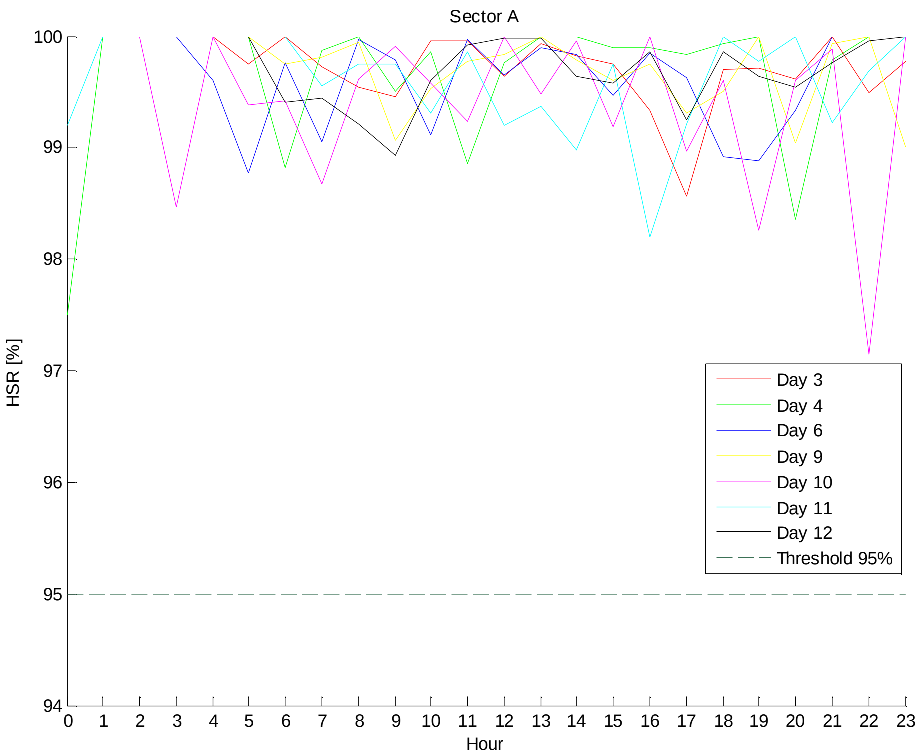

Figure B.3 Handover Success Rate.

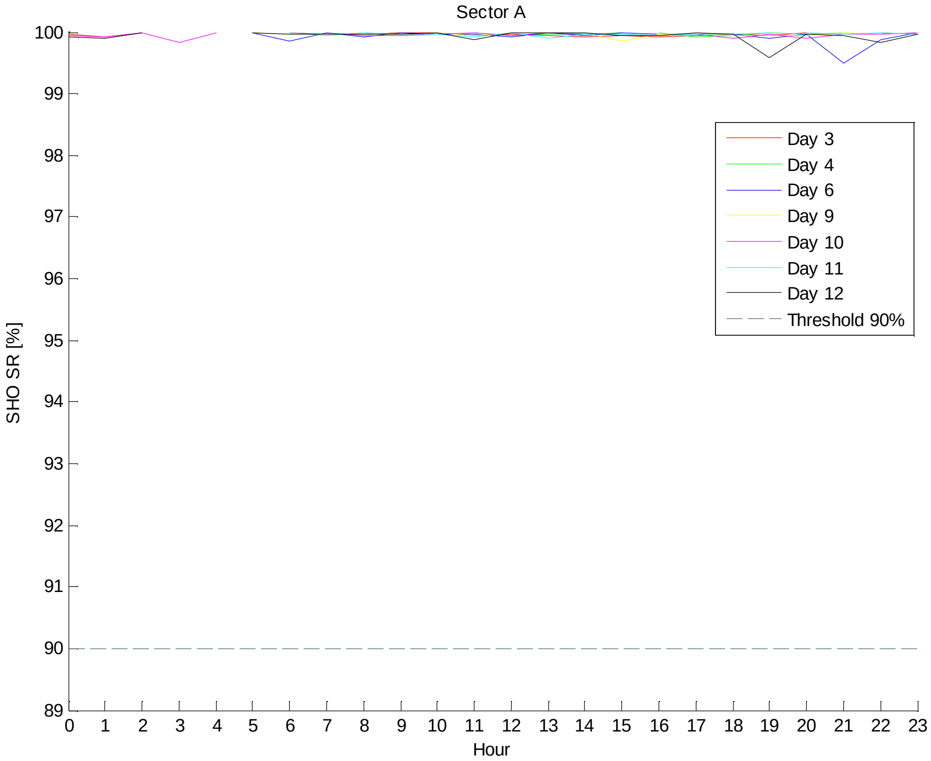

Figure B.4 Soft Handover Success Rate.

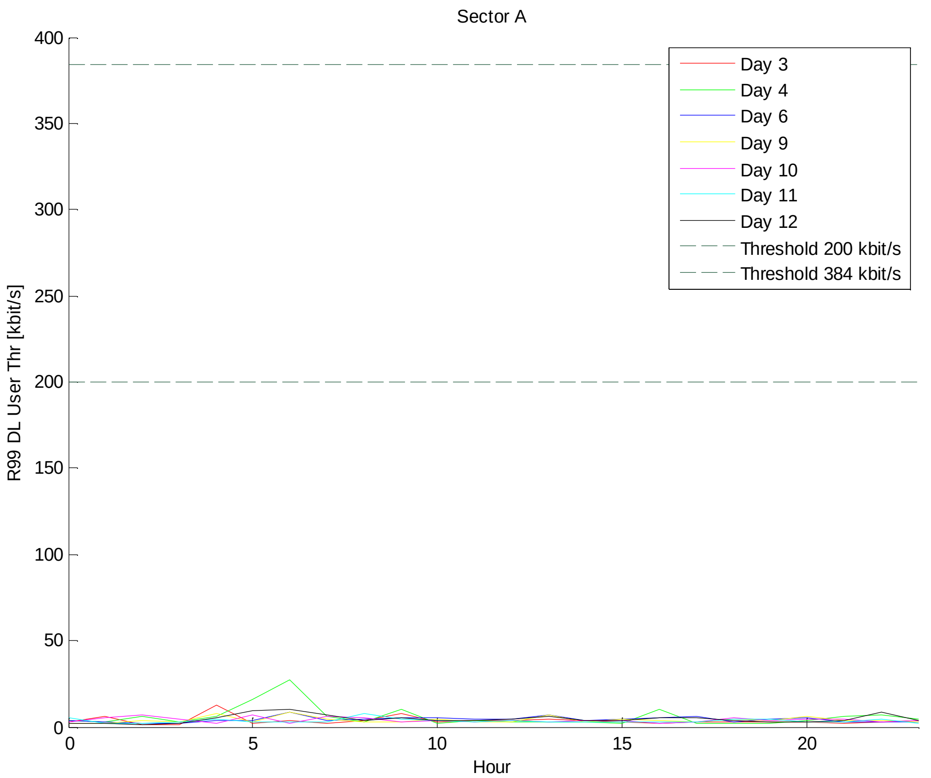

Figure B.5 R99 Downlink User Throughput.

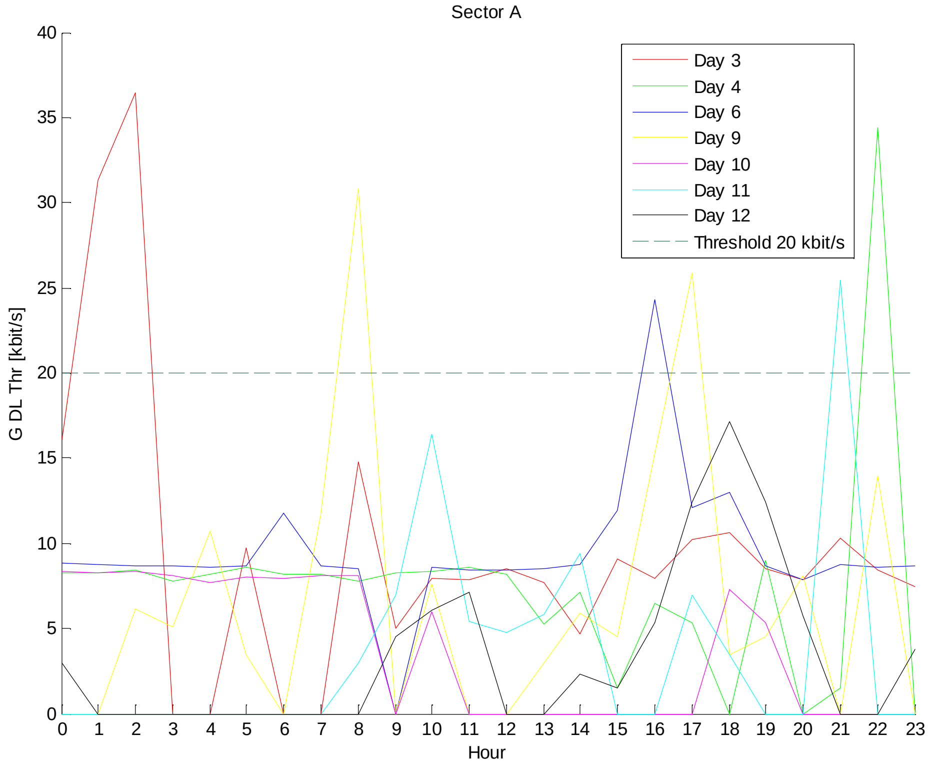

Figure B.6 GPRS Downlink Throughput.

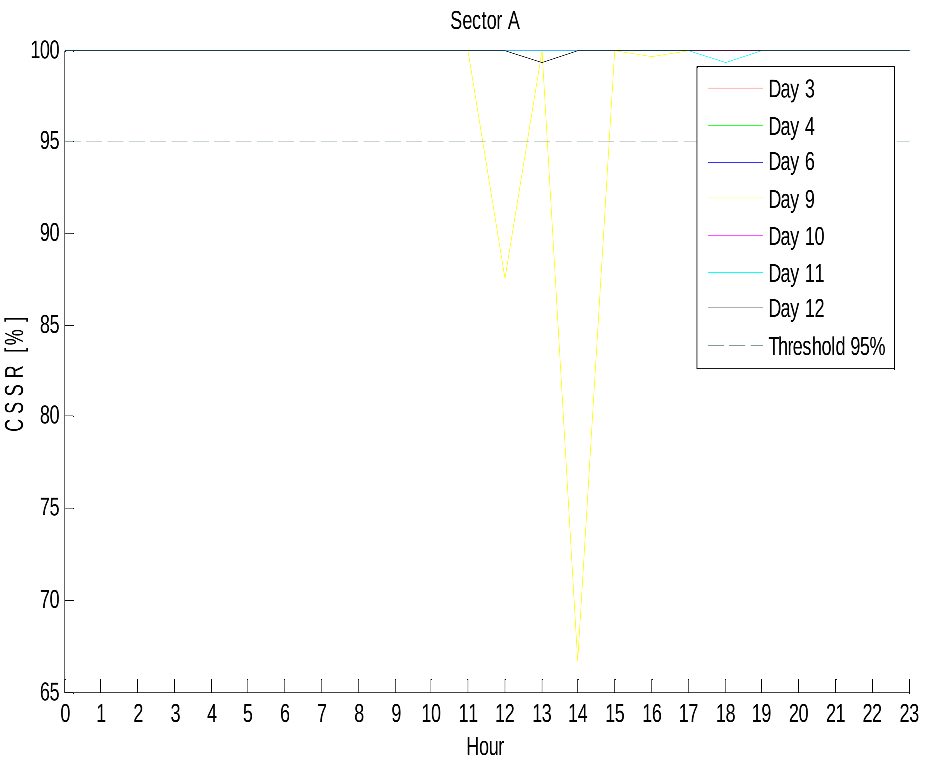

Figure B.7 Call Setup Success Rate.

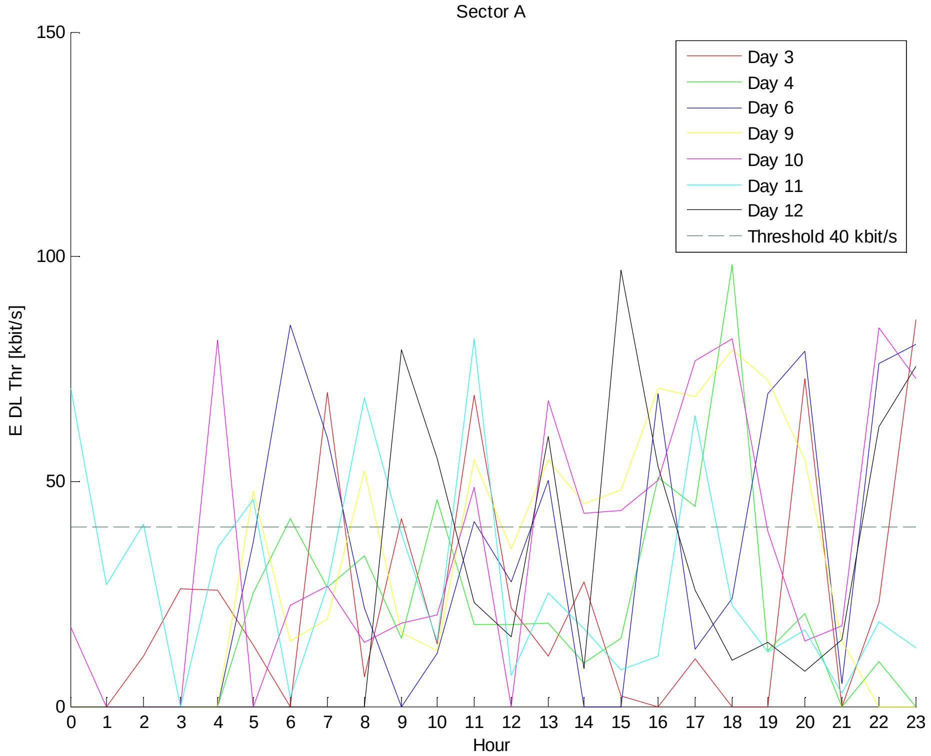

Figure B.8 Edge Downlink Throughput.

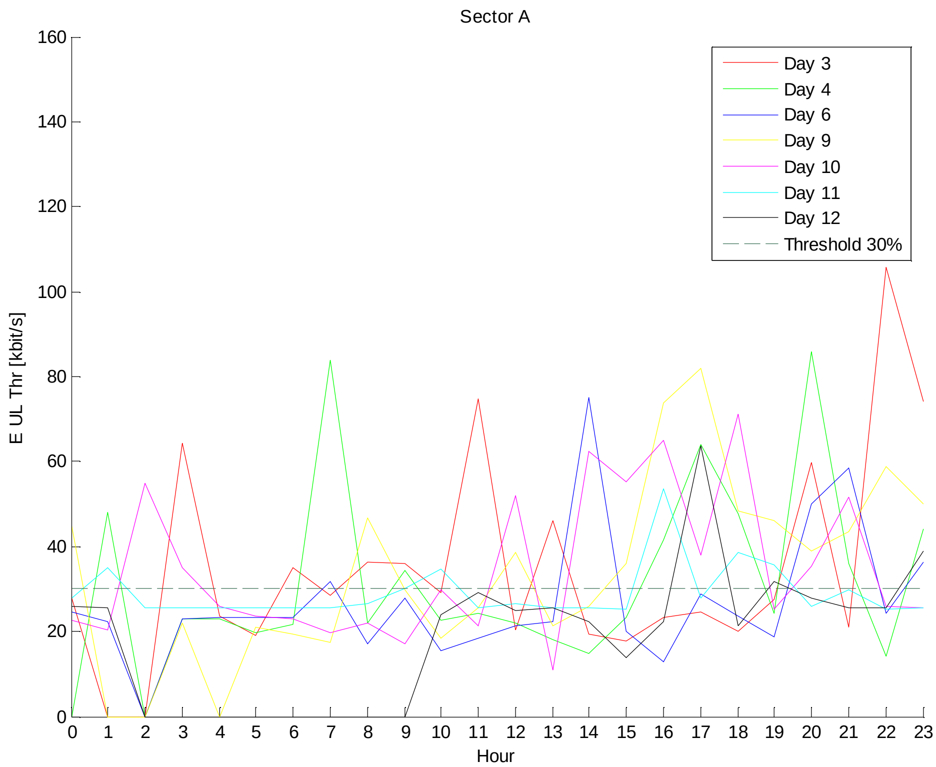

Figure B.9 Edge Uplink Throughput.

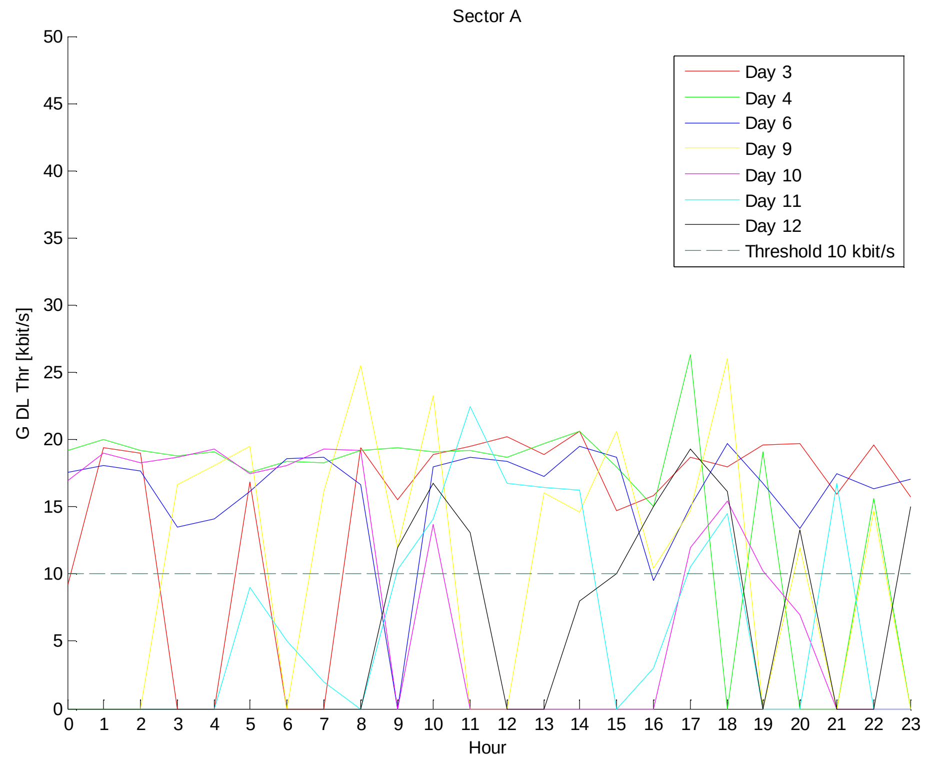

Figure B.10 GPRS Uplink Throughput.

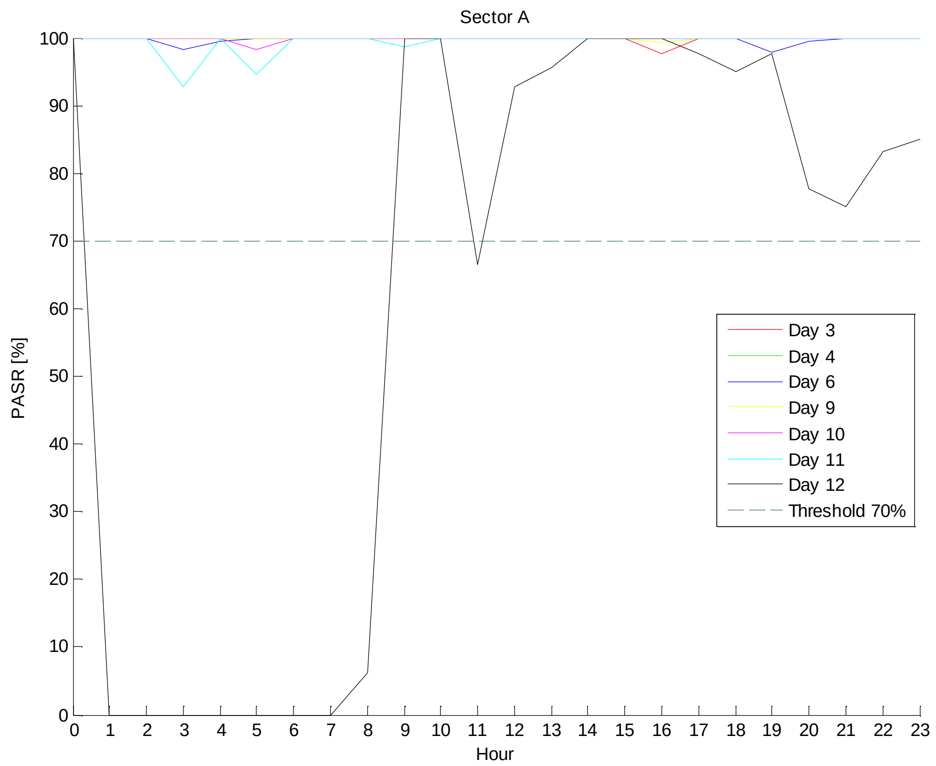

Figure B.11 PDCH Assignment Success Rate.

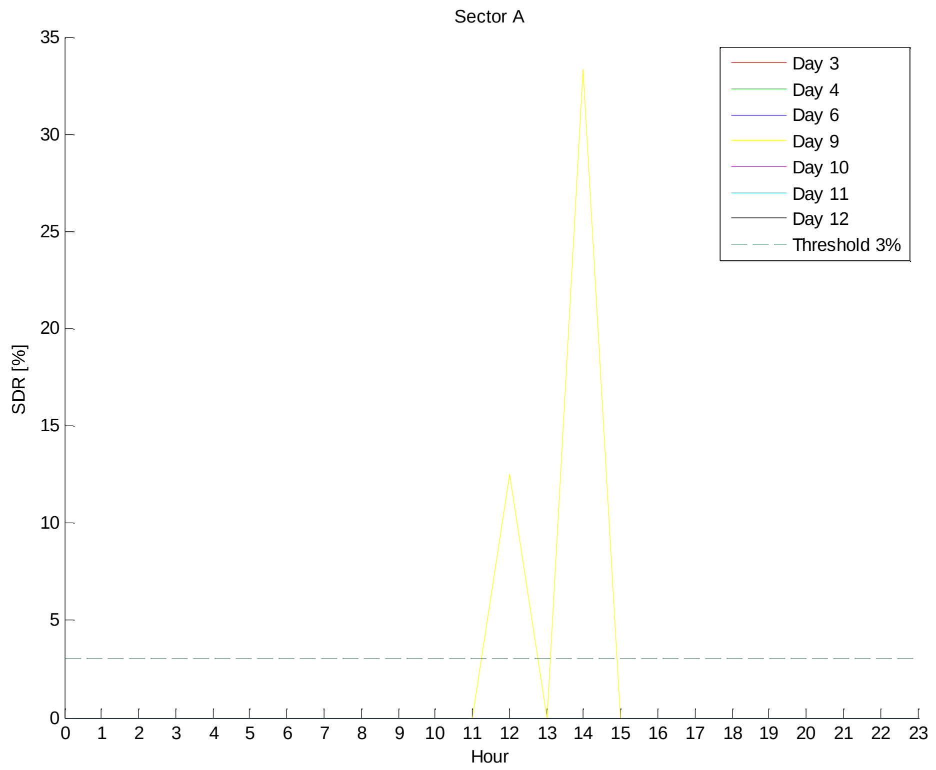

Figure B.12 SDCCH Drop Rate.

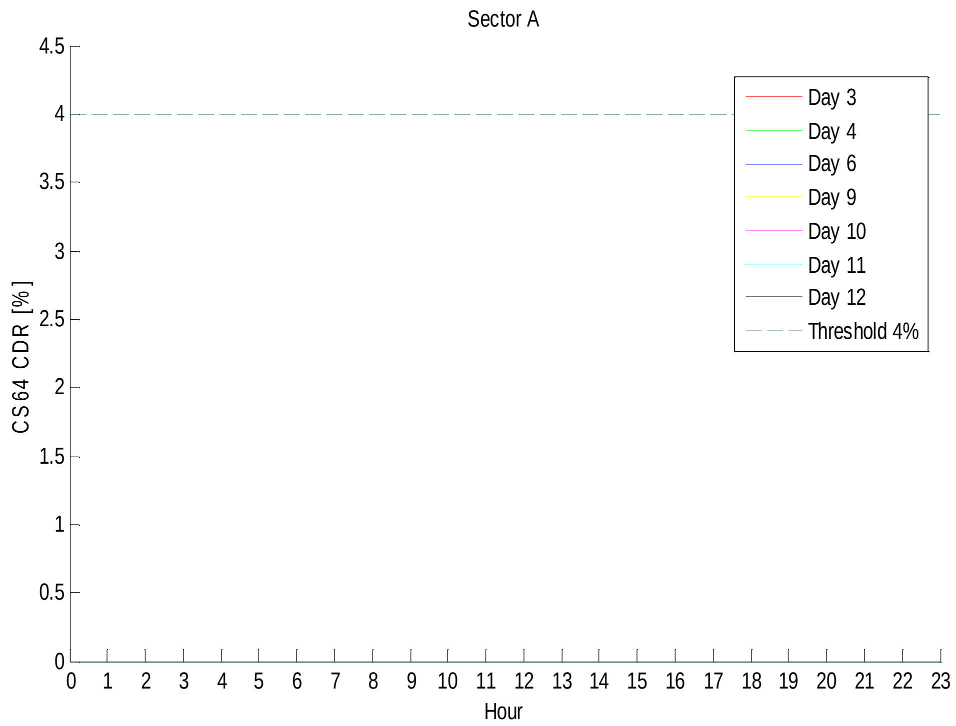

Figure B.13 CS64 Call Drop Rate.

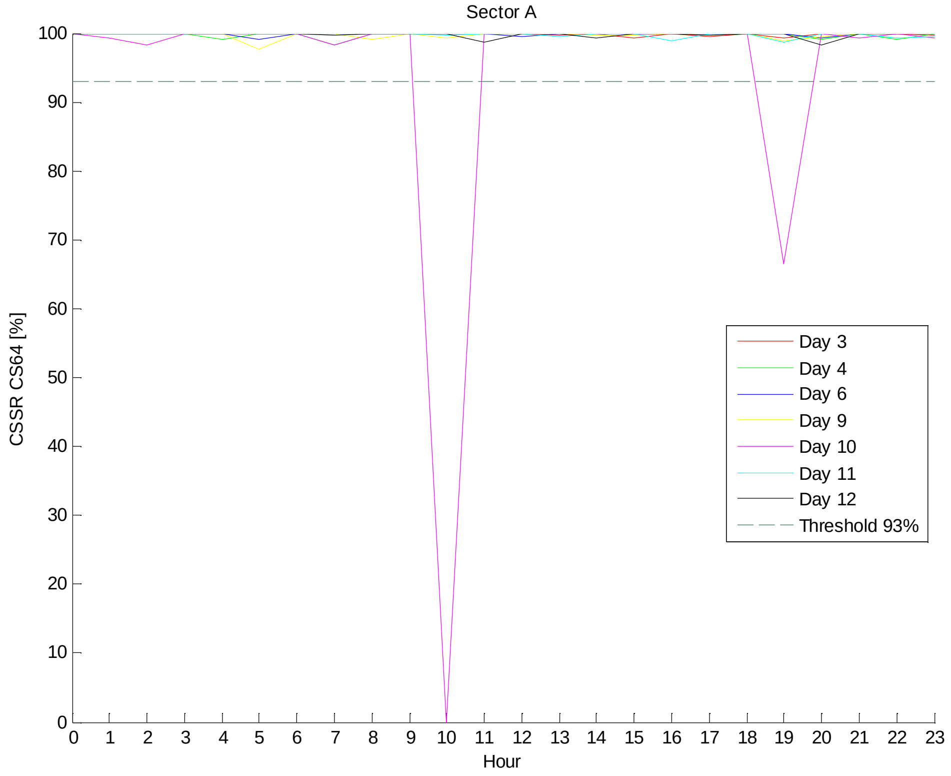

Figure B.14 CS64 Call Setup Success Rate.

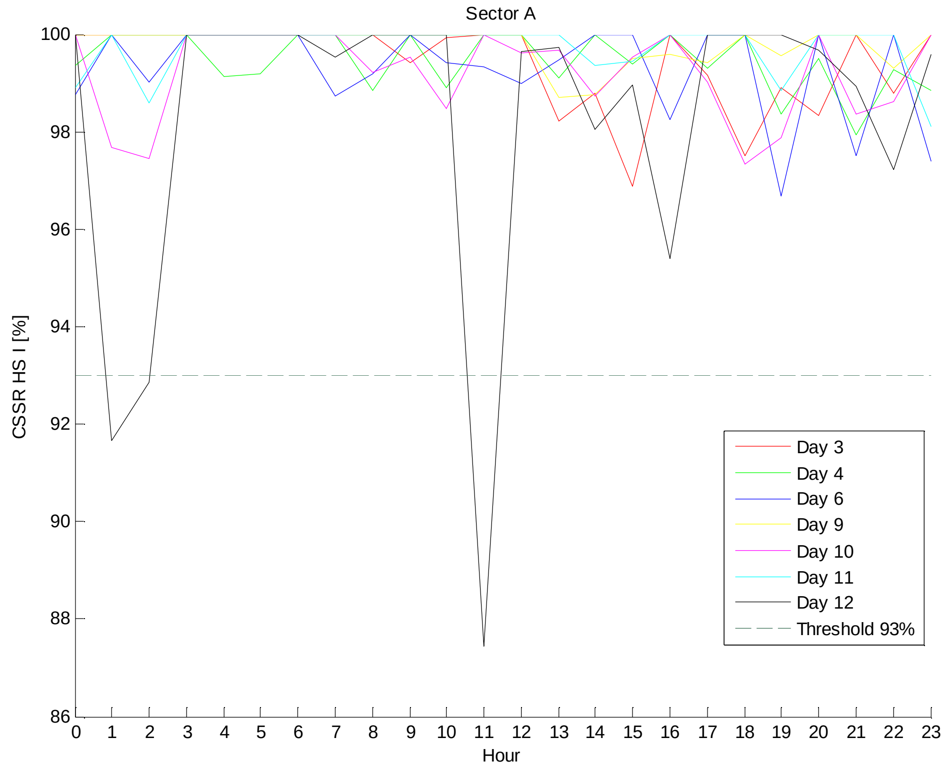

Figure B.15 HSDPA Interactive Call Setup Success Rate.

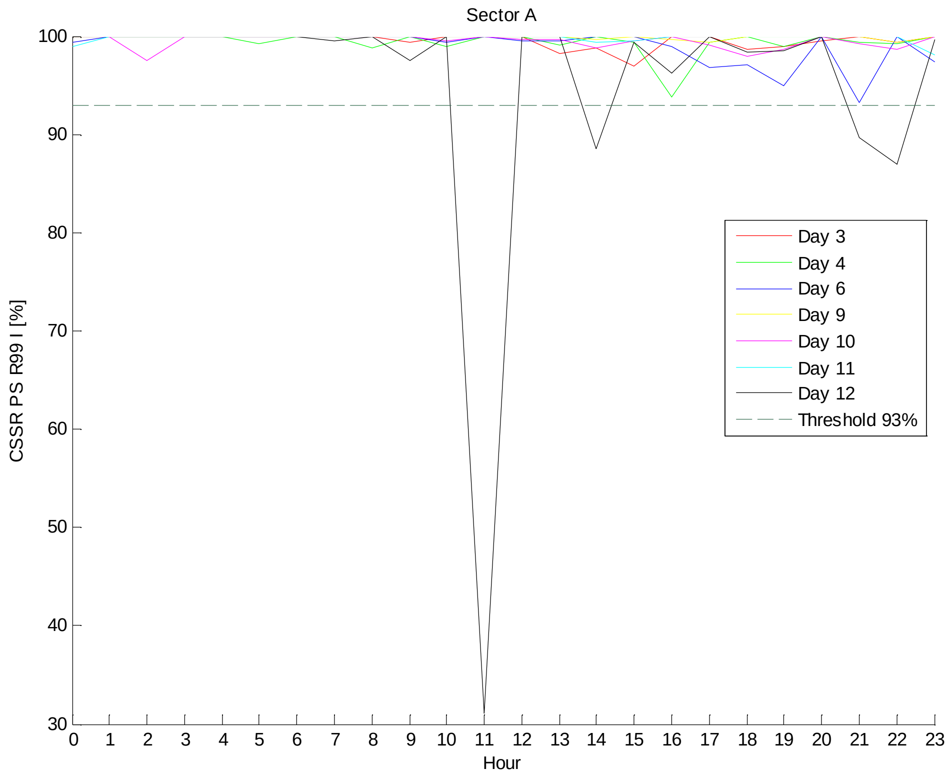

Figure B.16 PS R99 Interactive Call Setup Success Rate.

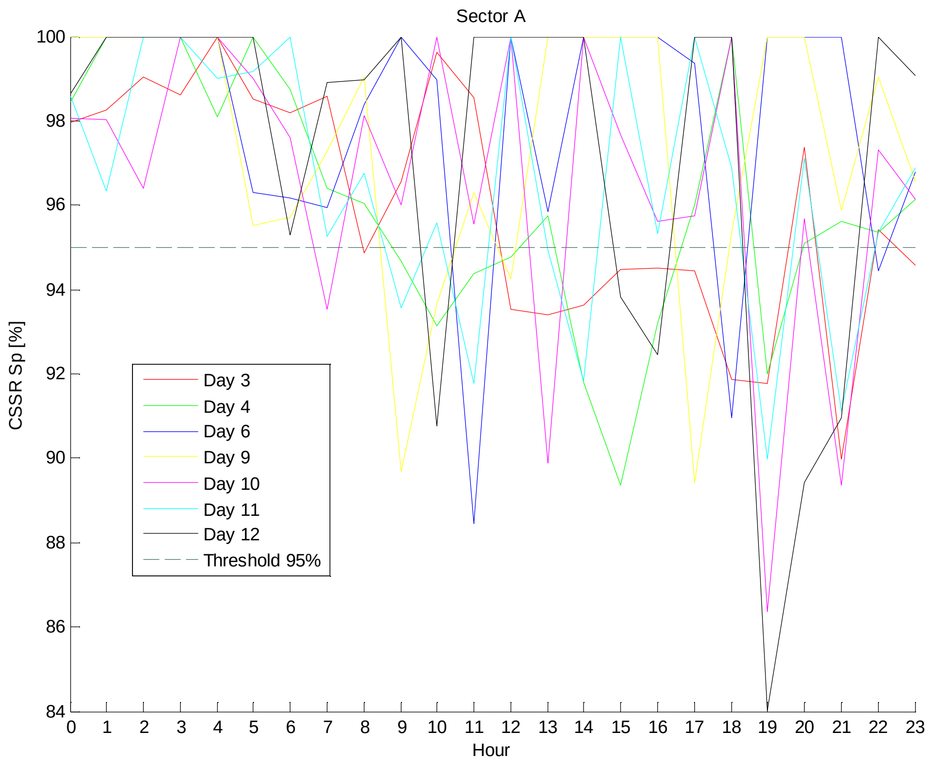

Figure B.17 Speech Call Setup Success Rate.

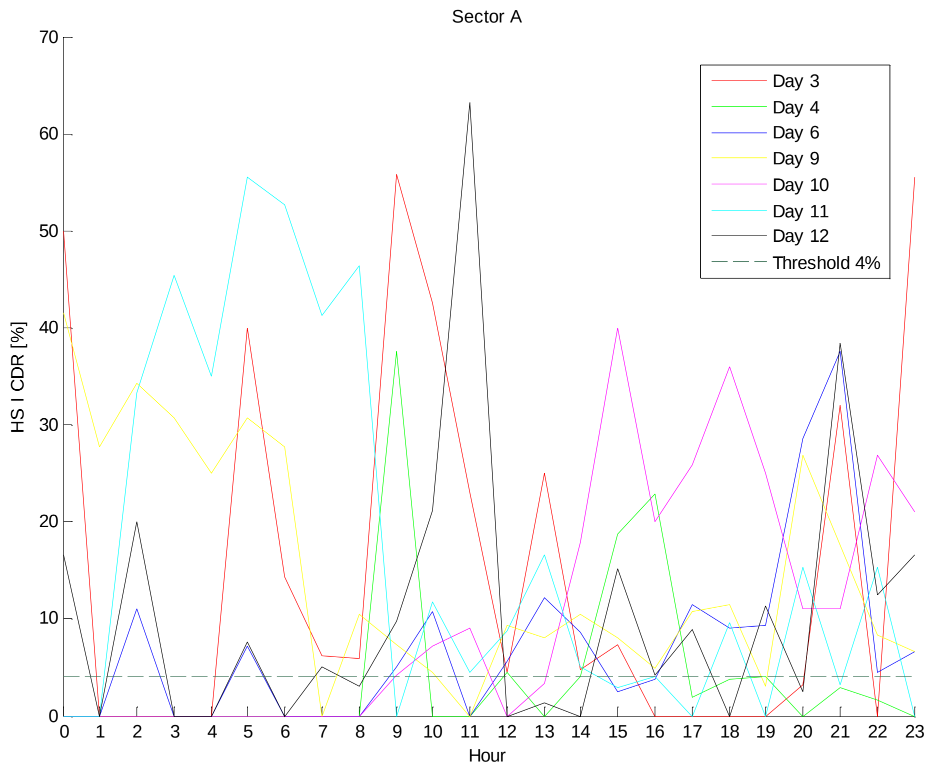

Figure B.18 HSDPA Interactive Call Drop Rate.

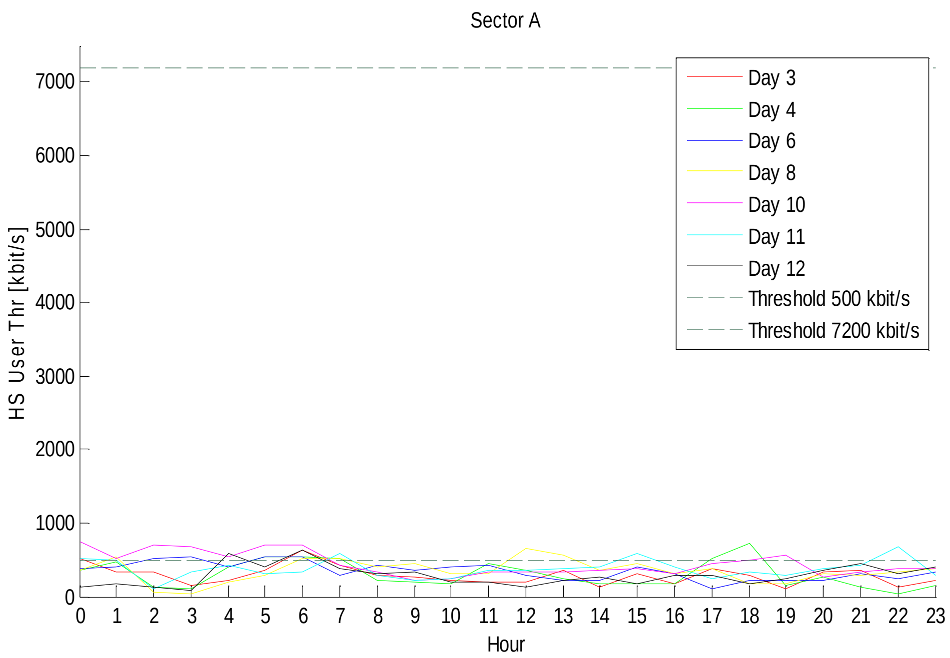

Figure B.19 HSDPA Interactive User Throughput.

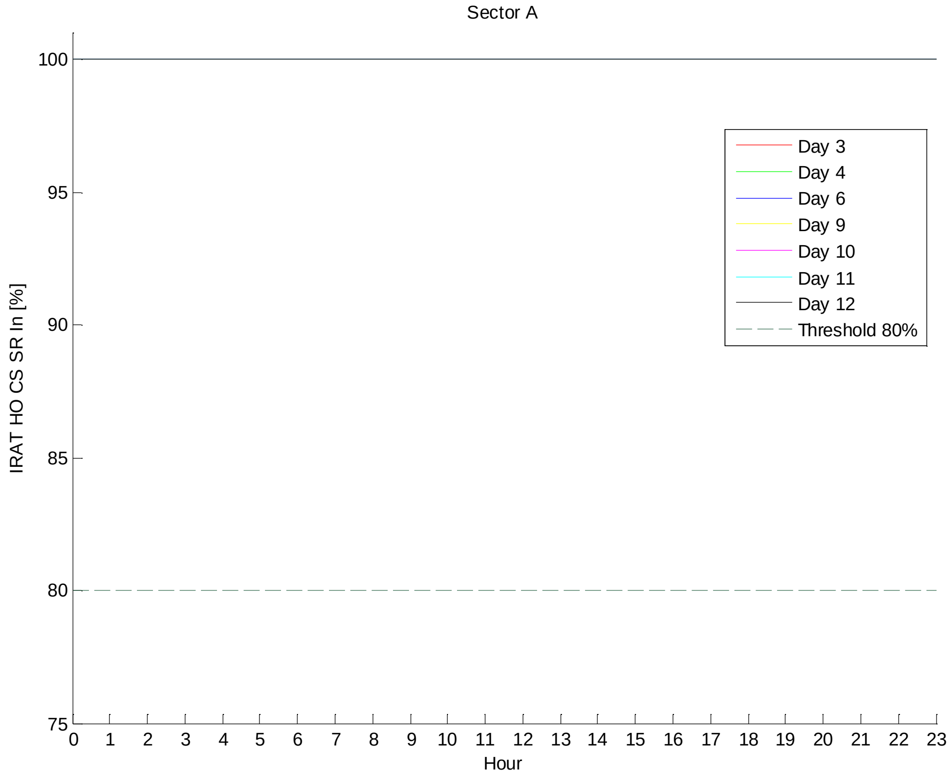

Figure B.20 IRAT HO Success Rate Incoming.

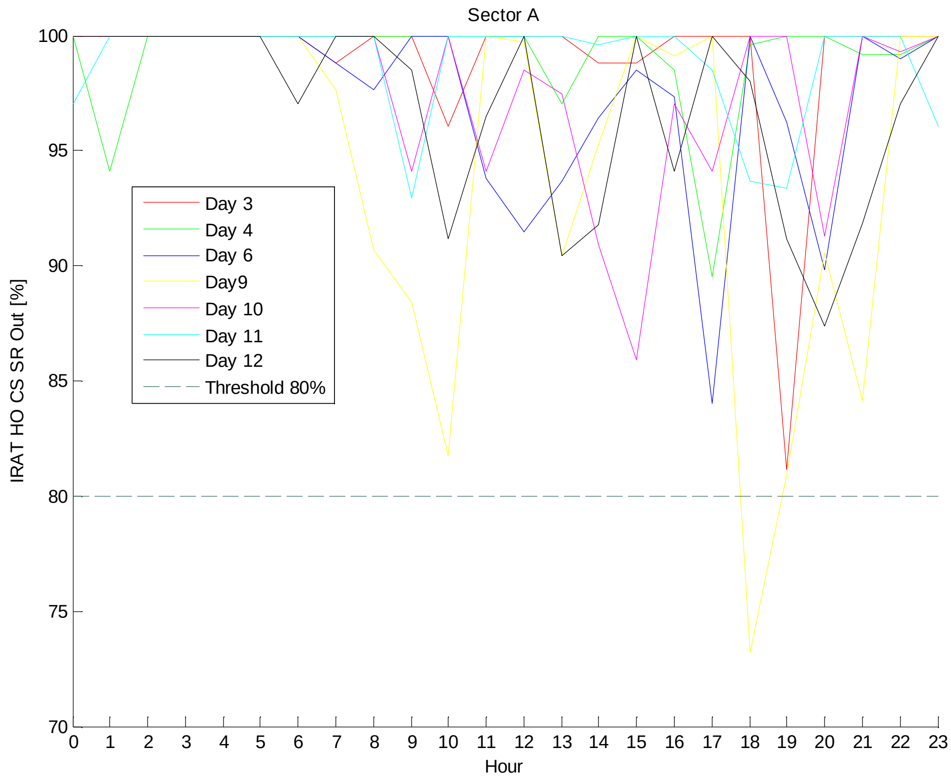

Figure B.21 IRAT HO Success Rate Outgoing.

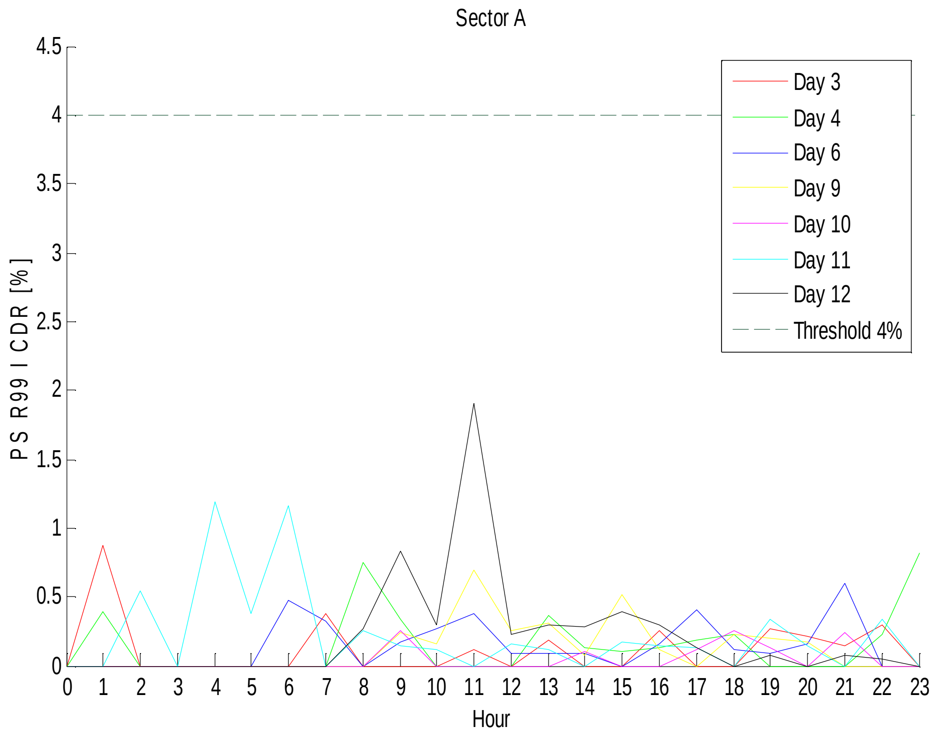

Figure B.22 PS R99 Interactive Call Drop Rate.

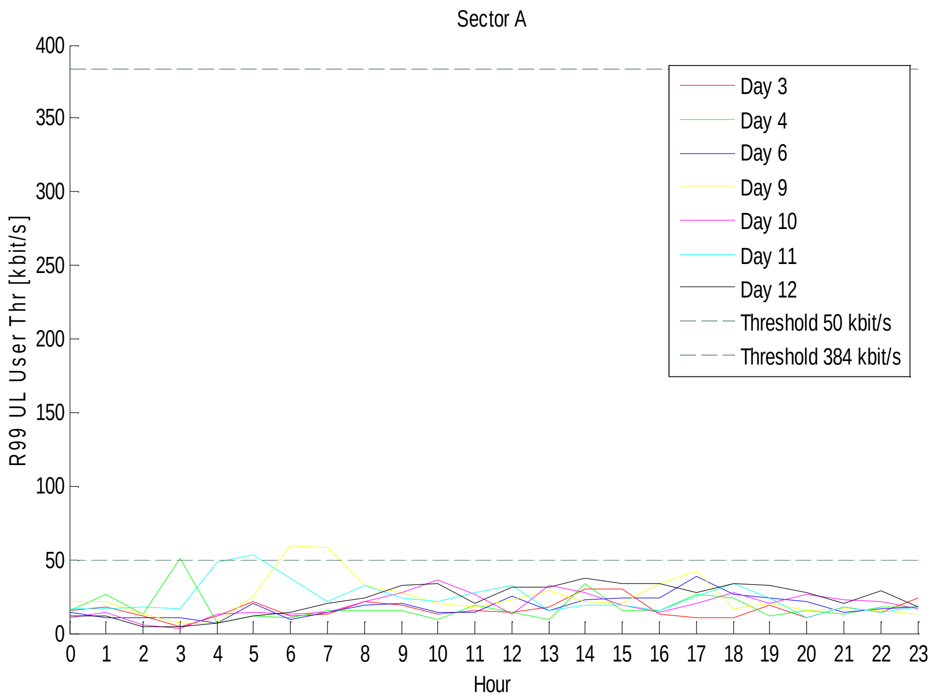

Figure B.23 PS R99 Interactive Uplink User Throughput.

Annex C

Daily Analysis Results

In Annex C, one presentes the results related to a single day, September 2nd, 2010, for GSM and UMTS.

In this annex, one presentes the results related to a single day, September 2nd, 2010.

Analysing the output results after executing the SQL *query* it is possible to detect all the cases where the R_{C_D} is above the threshold value and the network cell where it occurs as well as the "contribution" given by each call drop reasons to the total number of TCH drops. A specified cell has the following performance: a total sample of 82798 terminated calls with 3865 TCH drops. Figure C.1 illustrates the "contribution" given by each call drop reasons.

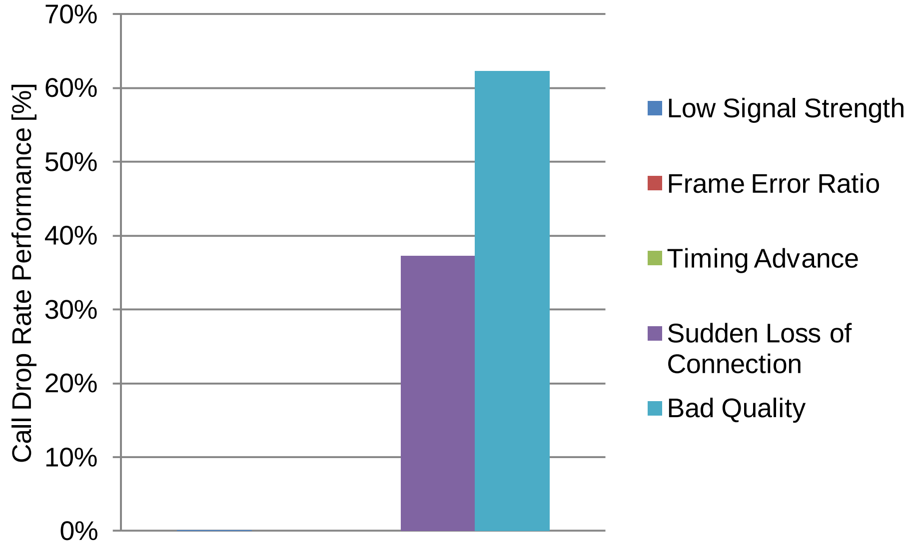

Figure C.1 TCH Drops analysis.

The previous graphic allows to conclude that poor quality on down or uplink is the major reason for TCH drops. The counter responsible for countig the number of terminated calls in a cell gives the information needed to conclude if the existing problem is due to capacity/congestion, without taking into account HO issues. P.e., if in the previous analysed cell R_{C_D} is about 4.5% with 3262 terminated calls at 5h00 and the same 4.5% with 7584 terminated calls at 17h00 there is no capacity problem – if there was a capacity/congestion problem in the cell, it was expected an increase of R_{C_D} with the increase of the number of terminated calls. Combining the information from the radio network area map and database it is possible to check other type of handover/coverage problems, such as undefined BSs in the neighbouring of a BS which can lead to a dropped call due to low signal strenght.

Comparing any KPI with R_{HO_S} is an acceptable way of correlate a KPI performance with handover issues. For example, if in a cell R_{C_D} is above the threshold level in a period larger than 2 or 3 hours and the R_{HO_S} is below the threshold level in the same period and it is possible to identify no coverage problems then he call drop reason may be due to handover issues. Figure C.2 shows R_{C_D} and R_{HO_S} performance in the same cell on the same day.

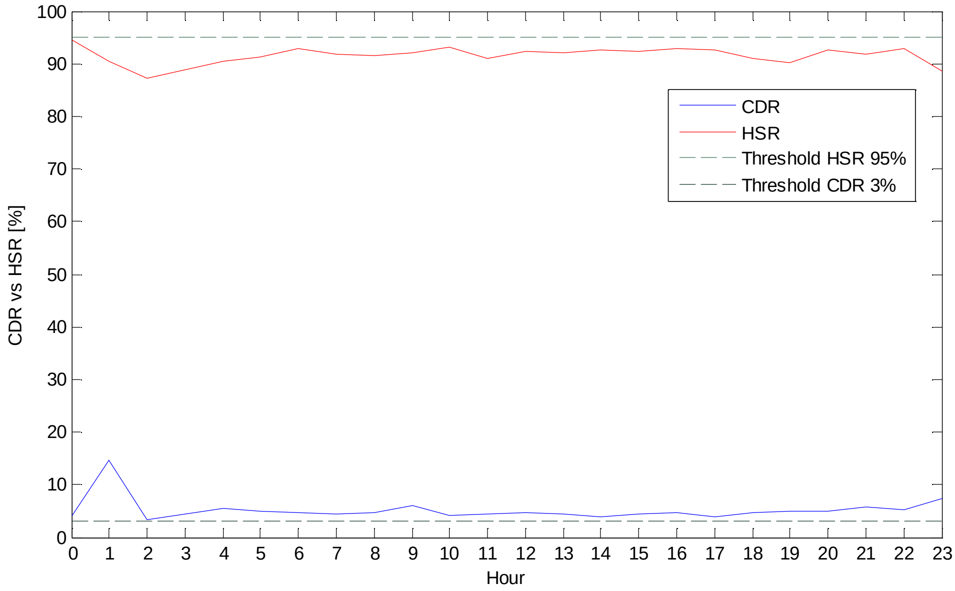

Figure C.2 Comparing R_{C_D} and R_{HO_S} performance.

As it can be seen in Figure C.2 whenever R_{C_D} is above the threshold level R_{HO_S} is below the threshold level which indicates an obvious relation between them: the probability of calls drop due to handover problems is very high. A careful analysis of the HO data will be done when analysing HO success rate.

Analysing the output results after executing the SQL *query* it is possible to detect all the cases where the R_{SDCCH_D} is above the threshold value and the network cell where it occurs as well as the "contribution" given by each call drop reasons to the total number of SDCCH drops. Using the same example as before, a total sample of 186470 MS successful establishments on SDCCH with 10090 SDCCH drops. Figure C.3 illustrates the "contribution" given by each call drop reasons.

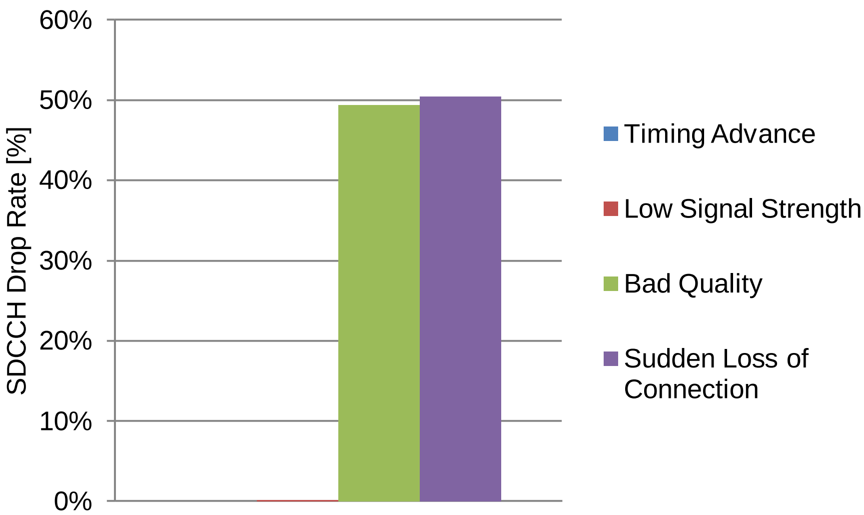

Figure C.3 SDCCH Drops analysis.

Analysing the previous graphic results it is possible to conclude that sudden loss of connection and bad quality are the major reasons for SDCCH drops. The bad quality issues are due to interference problems and the way to address the problem is similar to the TCH drops. Sudden loss of connection can be seen as a quick reduction in signal strength. Can be the result of moving into a garage, elevator or even behind a street corner. Bad indoor coverage will result in dropped calls. Building shadowing could be one reason.

Figures C.4 and C.5 illustrate the measurement results for R_{SDCCH_D} and R_{CS_S} in a particular day and BS in order to achieve a better perspective of the relation between them.

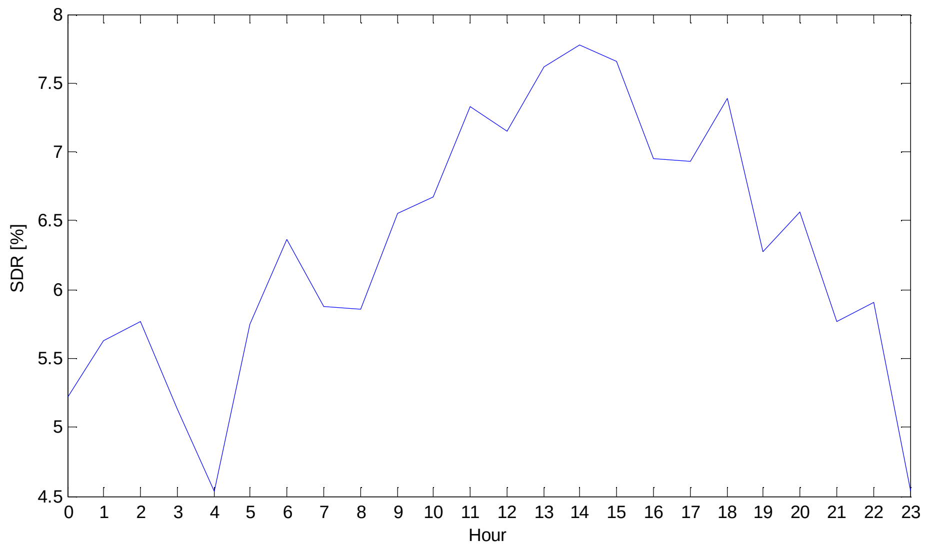

Figure C.4 SDCCH Drop Rate.

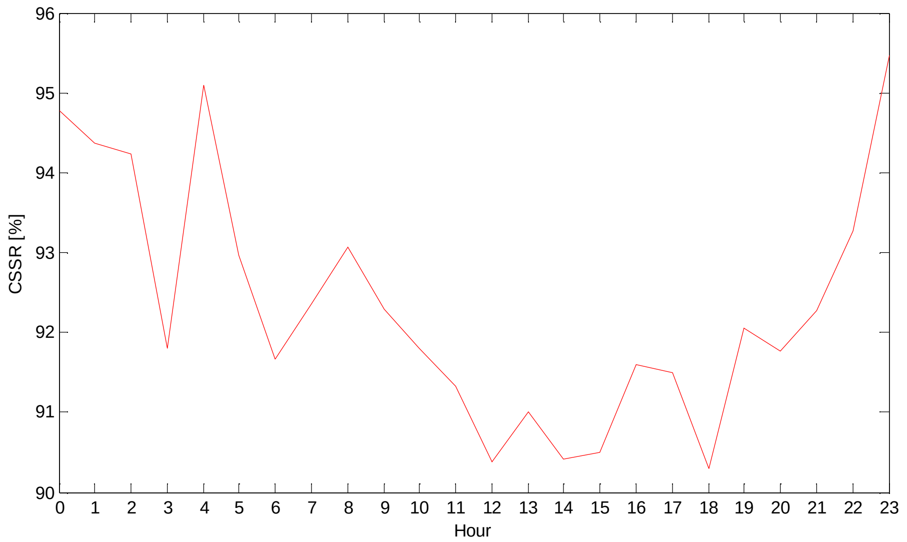

Figure C.5 Call Setup Success Rate.

The graphic results show that R_{CS_S} has an apparently symmetric performance compared to R_{SDCCH_D} which indicates a poor influence of the TCH assignment failure rate in the expression – the number of assignment complete messages for all MS power classes full and half rate is similar to the number of first assignment attempts on TCH for all MS power classes – and so $R_{CS_S} \approx \left(1 - R_{SDCCH_D}\right)$. Figure C.6

illustrates the results of R_{CS_S} if R_{CS_S} = $(1 - R_{SDCCH_D})$. The probability of R_{SDCCH_D} being below the threshold level is very high when the R_{CS_S} is below the threshold level and vice versa – probability of - 95.24%.

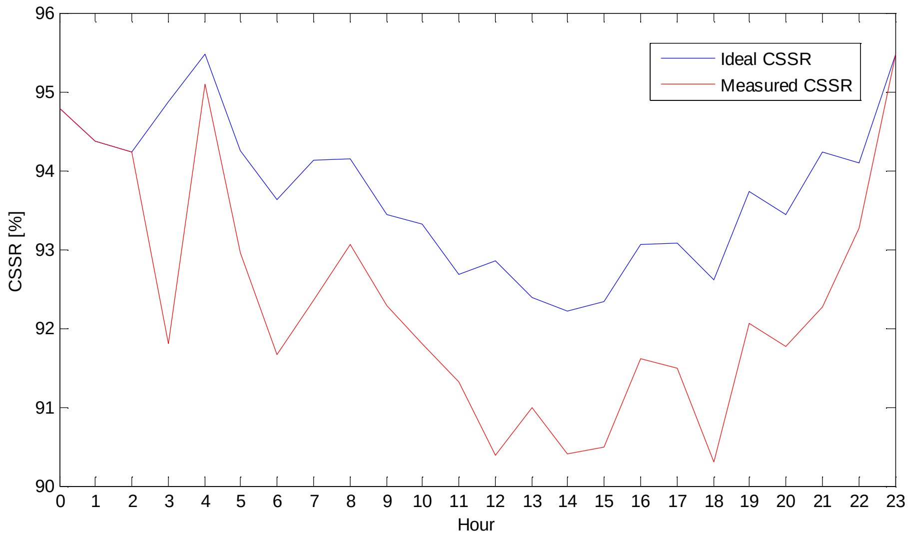

Figure C.6 R_{CS_S} results if R_{CS_S} = $(1 - R_{SDCCH_D})$.

In UMTS there is none direct mathematical correlation between the KPI as in GSM because there is none KPI directly involved in other KPI calculation. Although there are cases where the same counter is used for different KPIs which does not represent a direct correlation.

Analysing the output results after executing the SQL *query* it is possible to detect all the cases where the R_{HO_S} is above the threshold value and the network cell where it occurs. In order to follow up the results previously presented the same BS was choosed to evaluate R_{HO_S} performance. An average of the daily values was made for a better understanding of the results. With an average of 0,017% of daily TCH congestion, 66721 HO attempts/commands to the neighbouring cell (there were no intra-cell HO attempts). The average R_{HO_S} was 91.66% which means 8.34% was the percentage of unsuccessful HOs to the neighbouring cells. Figure C.7 illustrates the results. Analysing the unsuccessful HOs it can be due to lost HOs or HO reversions. Figure C.8 shows the "percentage distribution" of the type of unsuccessful HOs. It is possible to see that 88.25% of the unsuccessful HOs are HO reversions and 11.75% are lost HOs. The next step is to check the neighbouring cell definitions. The analysed cell has 14 neighbouring cells defined and 9 of these do not have HO problems – the HO success rate has a daily average value above the threshold level. Taking into account only the cases where the HO success rate is below the target value, the daily average TCH congestion is 0% for all cells and there are 0 intra-cell HO attempts for all cells. Numbering the cells from 1 to 5 and analysing the data collected only from the cases where the HO success rate is below the target value, in cell 1 94.69% of the unsuccessful HOs are due to reversions, in cell 2 86.74% of the unsuccessful HOs are due to reversions, in cell 3 90.58% of the unsuccessful HOs are due to reversions, in cell 4 86.06% of the unsuccessful HOs are due to reversions and in cell 5 86.06% of the unsuccessful HOs are due to reversions. Since the daily average TCH congestion is 0% there is no capacity problem.

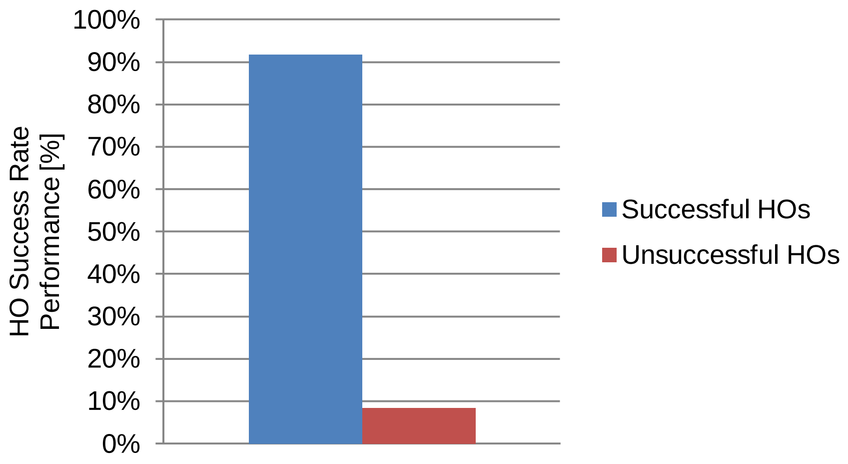

Figure C.7 HO success rate performance.

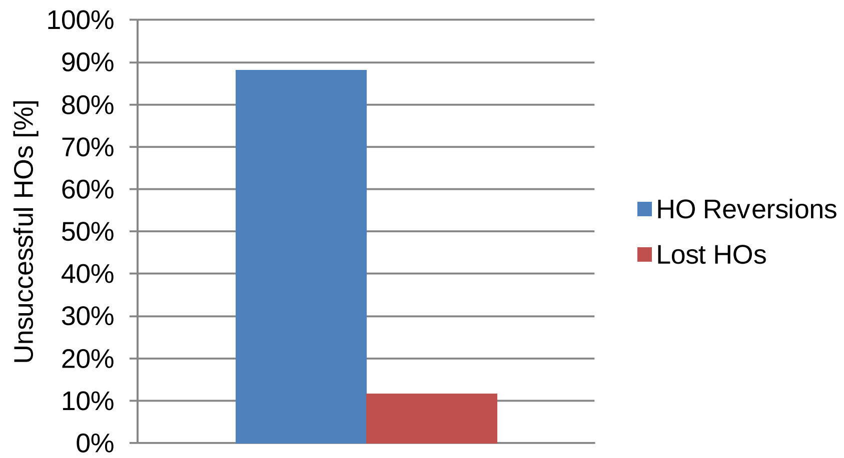

Figure C.8 Unsuccessful HOs.

As it can be seen in Figure 3.12 the measured throughput will be below the threshold level due to poor radio link quality, less PDCH reserved than requested by the users and reserved PDCH shared by other users. To evaluate radio link quality, there are counters that provide the measure of radio link bit rate and RLC data volume. It will be analysed the distributions of the radio link bit rate versus RLC data volume in the whole cell for downlink CS-1/2/3/4 and downlink EGPRS transfers. These are interval counters (the INTx counters) that count the downlink RLC data volume in certain bit rate intervals, allowing a distribution of the radio link bit rate to be presented. This gives an excellent picture of the distribution of the radio link quality in the cell.

To evaluate the number of PDCH's reserved and requested by the users, the PDCH utilisation ratio as to be analysed. This means that if the number of used channels over the number of allocated channels is higher than 80% (this threshold value is defined by Ericsson), there is a capacity problem.

To evaluate the number of reserved PDCH shared by other users the number of TBFs (a PS connection that can be either uplink or downlink) per PDCH as to be analysed, since one TBF is associated to one user. If the average number of simultaneous users per active PDCH on the DL/UL is higher than 1.4 (threshold value defined by Ericsson) there is a capacity problem.

Analysing the output results after executing the SQL *query* it is possible to detect all the cases where the GPRS and EDGE throughput is below the threshold value and the network cell where it occurs. P.e., a specified cell on 2nd September 2010 has the following performance: 21 hours with the GPRS/EDGE throughput value below the threshold level with an average value of 10.4526 kbps on the DL and 15.5392 kbps on the UL for GPRS and 34.4239 kbps on the DL and 23.7961 kbps on the UL for EDGE. Figures C.9 and C.10 illustrate the analysis of the radio link quality.

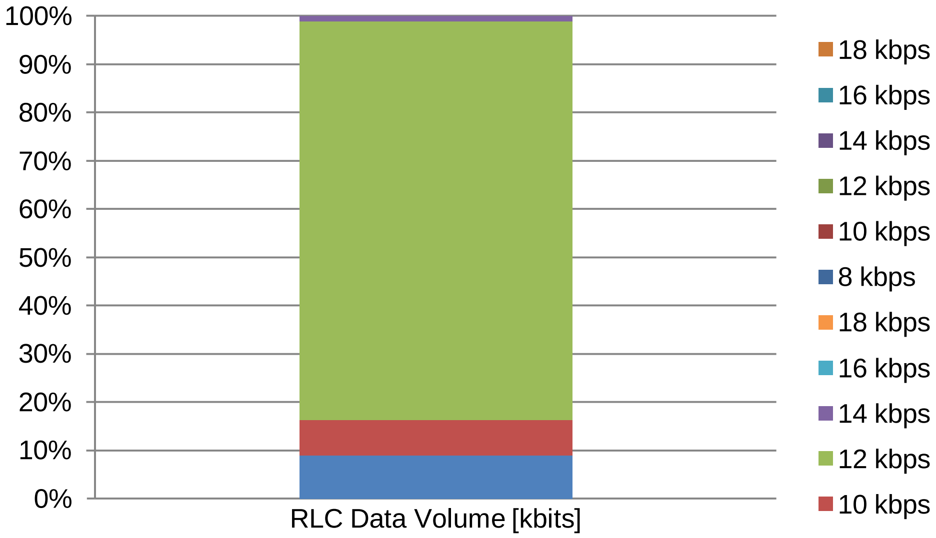

Figure C.9 Radio Link Quality analysis (GPRS).

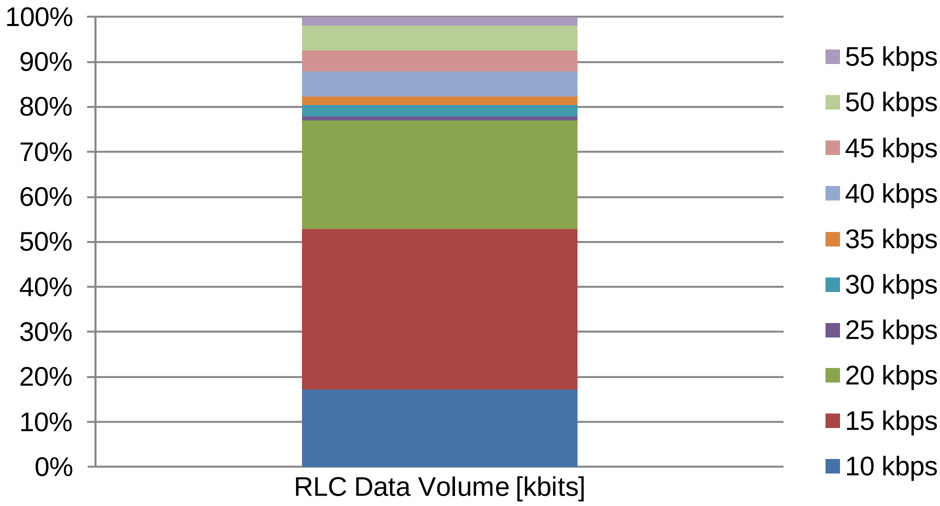

Figure C.10 Radio Link Quality analysis (EDGE).

The GPRS RLC average data volume is distributed in this way: 0.0984 kbits in the 8 kbps interval, 0.0795 kbits in the 10 kbps interval, 0.9093 kbits in the 12 kbps interval, 0.0113 kbits in the 14 kbps interval and 0 kbits in the 16 and 18 kbps interval. Looking at the results the major “slice” of the traffic is in the lower bit rate intervals (98.97% of the total traffic is in the three lower bite rate intervals) which means poor radio link quality – the larger the bit rate range in which data are processed, the better the quality of radio link. At this point, the reason for poor GPRS DL Throughput is identified. Yet the other possibilities have to be checked. The average PDCH utilisation ratio is 39.85% (below the 80% threshold value) and there are 1.034 simultaneous users per active B-PDCH (there are no active G-PDCH) – below the 1.4 threshold value.

The EDGE RLC average data volume is distributed in this way: 0.1715 kbits in the 10 kbps interval, 0.3581 kbits in the 15 kbps interval, 0.2398 kbits in the 20 kbps interval, 0.0094 kbits in the 25 kbps interval, 0.0260 kbits in the 30 kbps interval, 0.0179 kbits in the 35 kbps interval, 0.0561 kbits in the 40 kbps interval, 0.0476 kbits in the 45 kbps interval, 0.0542 kbits in the 50 kbps interval and 0.0194 kbits in the 55 kbps interval. Looking at the results the major “slice” of the traffic is in the lower bit rate intervals (76.94% of the total traffic is in the three lower bite rate intervals) which means poor radio link quality. The average PDCH utilisation ratio is 40.07% (below the 80% threshold value) and there are 1.035 simultaneous users per active B-PDCH (there are no active G-PDCH) and 1.1721 simultaneous users per active E-PDCH – below the 1.4 threshold value.

Analysing the output results after executing the SQL *query* it is possible to detect all the cases where the R_{PDCH_S} is below the threshold value and the network cell where it occurs. The main reason for PDCH allocation failures is when zero PDCH could be allocated due to lack of basic physical channels over the air interface. The failure relates to the inability of the system to allocate resources since requests to allocate PDCHs occur when the operator increases the number of dedicated PDCHs and when the packet data traffic demands on-demand PDCHs. If the system cannot respond properly to traffic demands there is a capacity problem. A good way to find the reasons that leads to failures on the PDCH assignment is to compare the performance of the KPI with the TCH congestion and the total traffic in half-rate. If the TCH congestion values are very high it is expected that there are problems in the PDCH assignment and if the total traffic percentage in HR is higher than 50% (Ericsson’s threshold) it is also expected that there are problems in the PDCH assignment. P.e., a specified cell on 2nd September 2010 has the following performance: 18 hours with the PDCH Assignment Success Rate value below the threshold level with an average value of 39.83%. 48.05% of PDCH utilization, a TCH congestion of 0.001% and a HR traffic of 81.42% – the failures in PDCH assignment are due to the high percentage of HR traffic.

Annex D

Monthly Analysis Results

In Annex D, one presentes the results concerning January 2010 related to the remaining BSs that are not analysed in chapter 4.

D.1 GSM KPI Analysis

Table D.1 indicates the percentage associated to the number of hours where the KPI value is above the threshold level at the same time as others analysed KPIs. The BSs were analysed according to the monthly weight criteria.

Table D.1 R_{C_D} analysis.

BS	R_{C_D} and R_{HO_S} (%)	R_{C_D} and R_{SDCCH_D} (%)	R_{C_D} and R_{CS_S} (%)	BS	R_{C_D} and R_{HO_S} (%)	R_{C_D} and R_{SDCCH_D} (%)	R_{C_D} and R_{CS_S} (%)
6	83.87	35.48	32.26	**7**	16.22	10.81	0.00
2	76.19	9.52	9.52	**9**	15.87	15.87	6.35
15	36.67	0.00	0.00	**10**	14.29	7.14	7.14
13	34.91	64.57	23.88	**3**	9.52	61.90	61.90
5	31.82	40.91	47.73	**16**	5.13	17.95	28.21
8	30.00	25.00	13.33	**11**	4.26	78.72	57.45
14	20.06	20.34	16.95	**12**	2.86	65.00	17.86
4	17.33	22.67	25.33	**17**	0.00	100.00	84.38

Looking at the results it is possible to conclude that in BS 6 83.87% of the total analysed hours do not meet the minimum criteria required for both R_{C_D} as for R_{HO_S}. Figure D.1 shows R_{C_D} and R_{HO_S} performance evolution in that period.

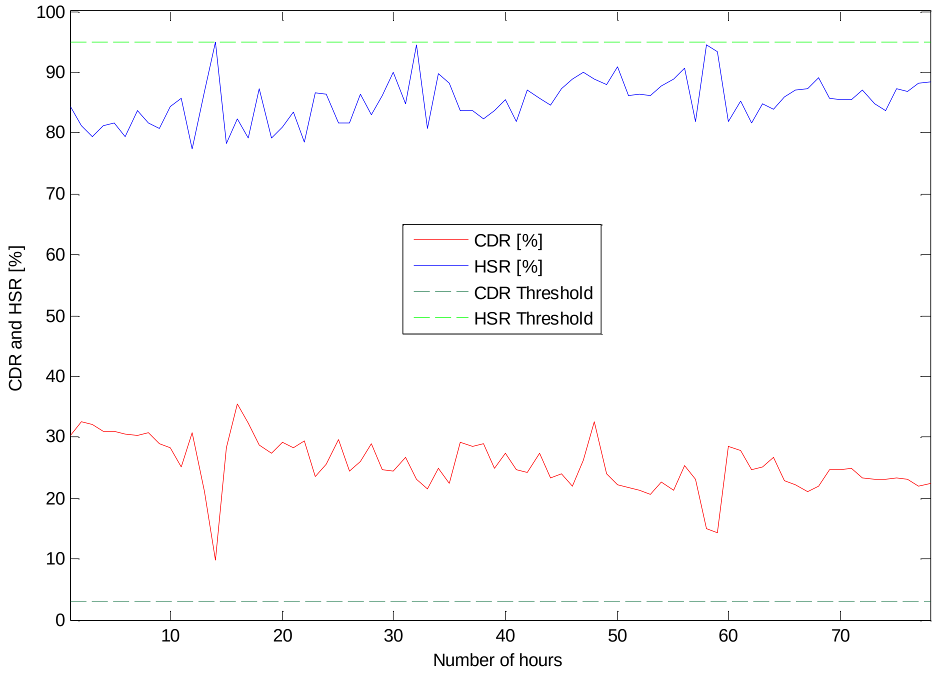

Figure D.1 BS 6 – R_{C_D} and R_{HO_S} performance analysis: correlation value of -69.80%.

In BS 6, only sector A in GSM 1800 is affected. Call drop rate has an average value of 25.47% and HO success rate has an average value of 85.24%. 95.66% of the HO failures are Lost HOs and 4.34% are HO reversions. There are 65143 internal HO attempts, which is the worst relation. There is no

TCH congestion and 82.08% of the TCH drops are due to sudden loss of connection. None of the defined neighbouring cells has HO problems.

Looking at the results of call drop rate and SDCCH drop rate, it is possible to conclude that in BSs 3, 11, 12 and 13 a call drops in 61.90%, 78.72%, 65.00% and 64.57% of the cases due to control channel drop reasons, respectively. Figures D.2 to D.5 shows R_{C_D} and R_{SDCCH_D} performance evolution in that period.

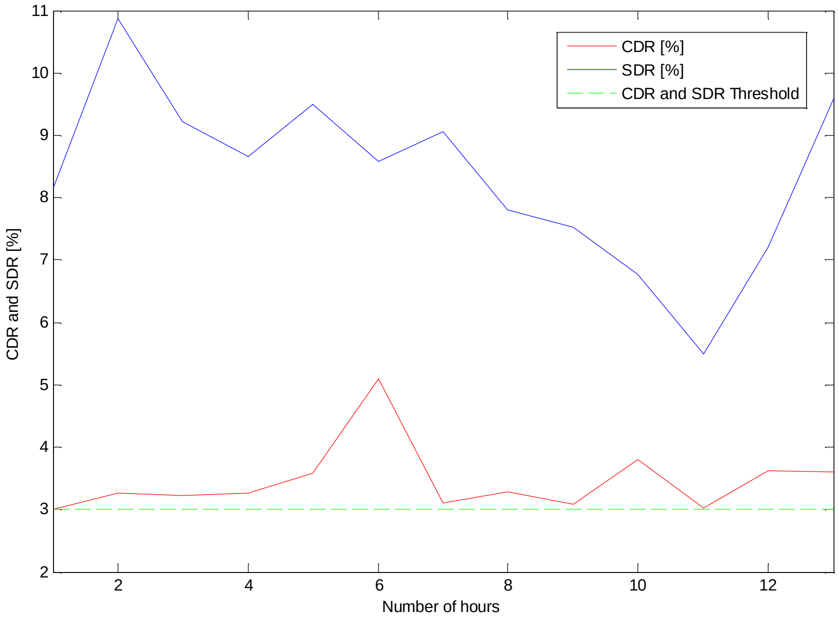

Figure D.2 BS 3 – R_{C_D} and R_{SDCCH_D} performance analysis: correlation value of 7.62%.

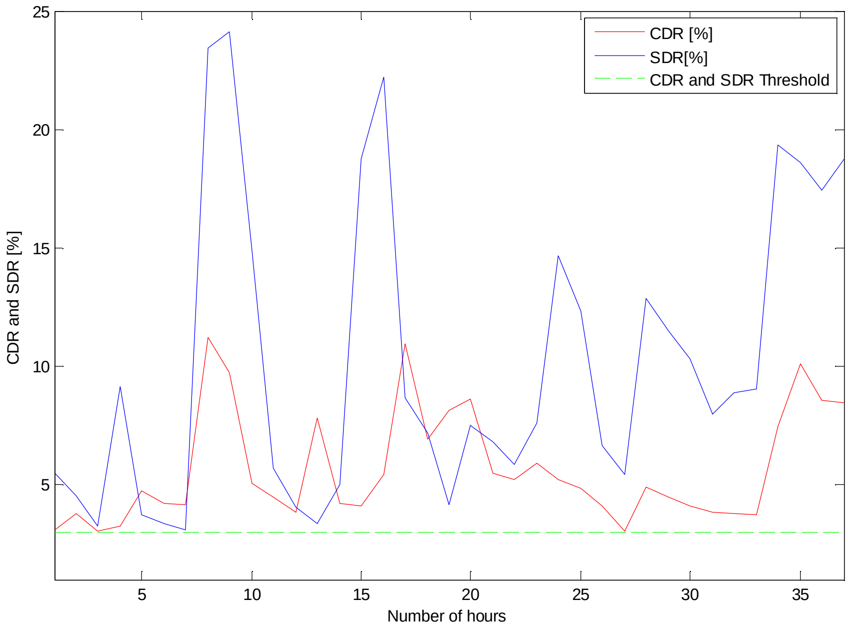

Figure D.3 BS 11 – R_{C_D} and R_{SDCCH_D} performance analysis: correlation value of 51.71%.

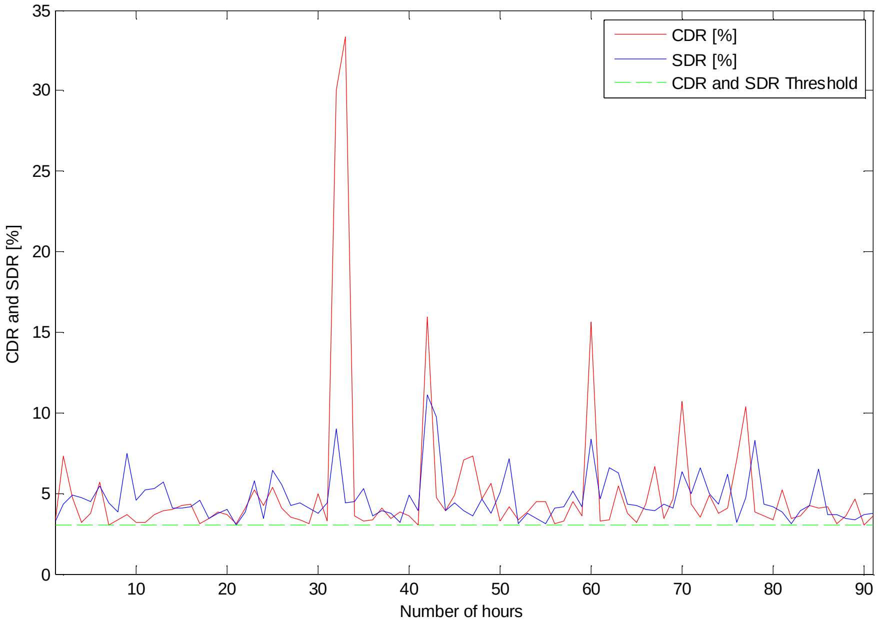

Figure D.4 BS 12 – R_{C_D} and R_{SDCCH_D} performance analysis: correlation value of 38.59%.

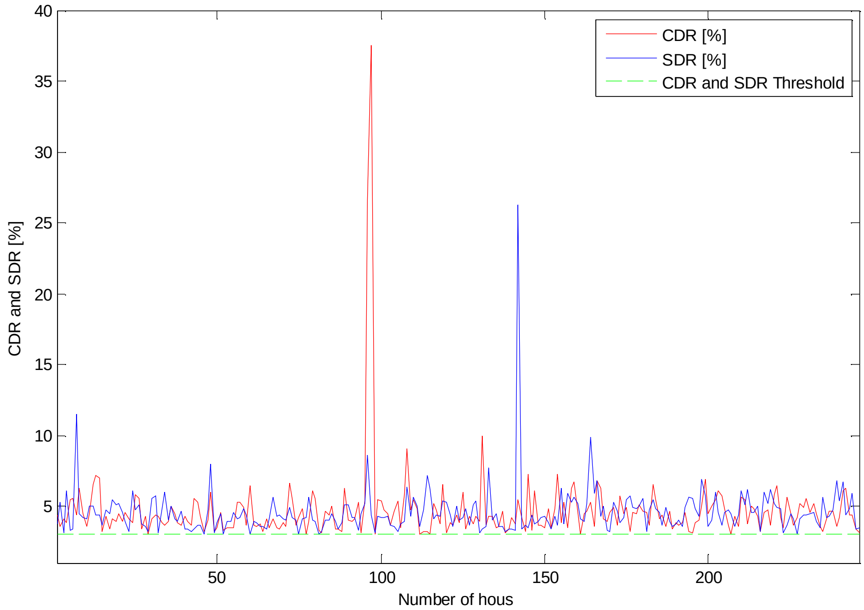

Figure D.5 BS 13 – R_{C_D} and R_{SDCCH_D} performance analysis: correlation value of 12.44%.

In BS 3, only sector C in GSM 900 is affected. Call drop rate has an average value of 3.46% and SDCCH drop rate has an average value of 8.34%. There is no TCH or SDCCH congestion and 53.65% of the TCH drops are due to low signal strength while only 38.59% of the SDCCH drops are due to the same reason – 57.85% are due to sudden loss of connection. In BS 11, on January 31st both B and C sectors are affected at the same time while in the other days only sector C is affected. Call drop rate has an average value of 5.68% and SDCCH drop rate has an average value of 10.15%.

TCH congestion has an average value of 19.66% and SDCCH congestion has an average value of 7.79%. The largest slice of call drop percentage is due to low signal strength issues (32.75%) while only 30.24% of the SDCCH drops are due to the same reason – 64.51% are due to sudden loss of connection. In BS 12, both B and C sectors have problems, but there is not any kind of behavior pattern between them. Call drop rate has an average value of 5.09% and SDCCH drop rate has an average value of 4.70%. There is practically no TCH and SDCCH congestion. 73.64% of the TCH drops are due to low signal strength while only 41.11% of the SDCCH drops are due to the same reason – 58.57% are due to sudden loss of connection. In BS 13, only sector A is affected. Call drop rate has an average value of 4.68% and SDCCH drop rate has an average value of 4.58%. There is practically no TCH and SDCCH congestion. 61.44% of the TCH drops are due to low signal strength and 47.50% of the SDCCH drops are due to the same reason – 47.15% are due to sudden loss of connection and 5.35% are due to bad quality.

Table D.2 indicates the percentage associated to the number of hours where the KPI value is above the threshold level at the same time as others KPIs.

Table D.2 R_{SDCCH_D} analysis.

BS	R_{SDCCH_D} and R_{CS_S} (%)	BS	R_{SDCCH_D} and R_{CS_S} (%)	BS	R_{SDCCH_D} and R_{CS_S} (%)	BS	R_{SDCCH_D} and R_{CS_S} (%)
7	100.00	**26**	47.96	**23**	27.00	**41**	17.18
6	94.00	**13**	46.84	**14**	26.09	**12**	13.11
19	87.78	**4**	44.26	**16**	25.86	**38**	12.03
40	87.39	**1**	43.00	**28**	25.42	**9**	11.16
36	78.28	**18**	42.21	**39**	23.46	**20**	10.36
17	71.14	**22**	37.80	**21**	22.39	**2**	9.43
25	66.78	**5**	35.22	**33**	22.22	**32**	9.38
44	64.21	**42**	31.58	**30**	21.15	**10**	7.22
8	58.80	**24**	31.21	**27**	20.50	**34**	6.93
43	55.93	**29**	29.44	**3**	19.26	**15**	3.09
35	48.44	**37**	29.19	**11**	18.93	**31**	1.56

Looking at the results, related to SDCCH drop rate and call setup success rate, it is possible to conclude that in BSs 6, 7, 8, 17, 19, 25, 36, 40, 43 and 44, when the stand-alone dedicated control channel drops the call setup process is automatically stopped with a probability of 94.00%, 100.00%, 58.80%, 71.14%, 87.78%, 66.78%, 78.28%, 87.39%, 55.93% and 64.21%, respectively. Figures D.7 to D.15 show R_{SDCCH_D} and R_{CS_S} performance evolution in that period.

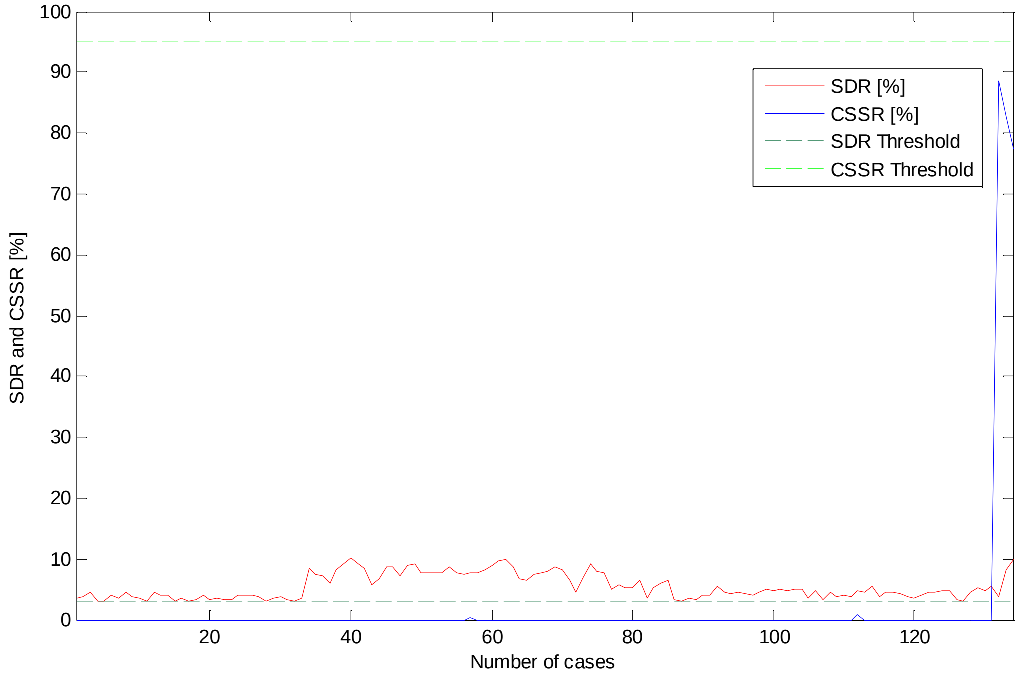

Figure D.6 BS 7 – R_{SDCCH_D} and R_{CS_S} performance analysis: correlation value of 12.48%.

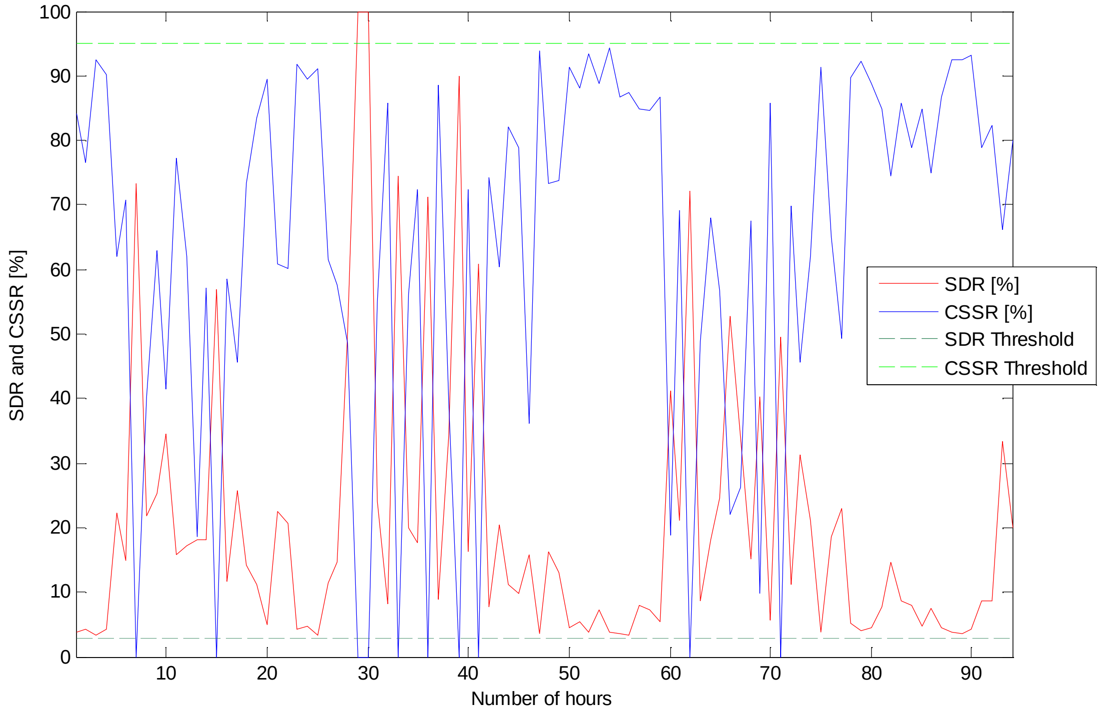

Figure D.7 BS 6 – R_{SDCCH_D} and R_{CS_S} performance analysis: correlation value of -90.17%.

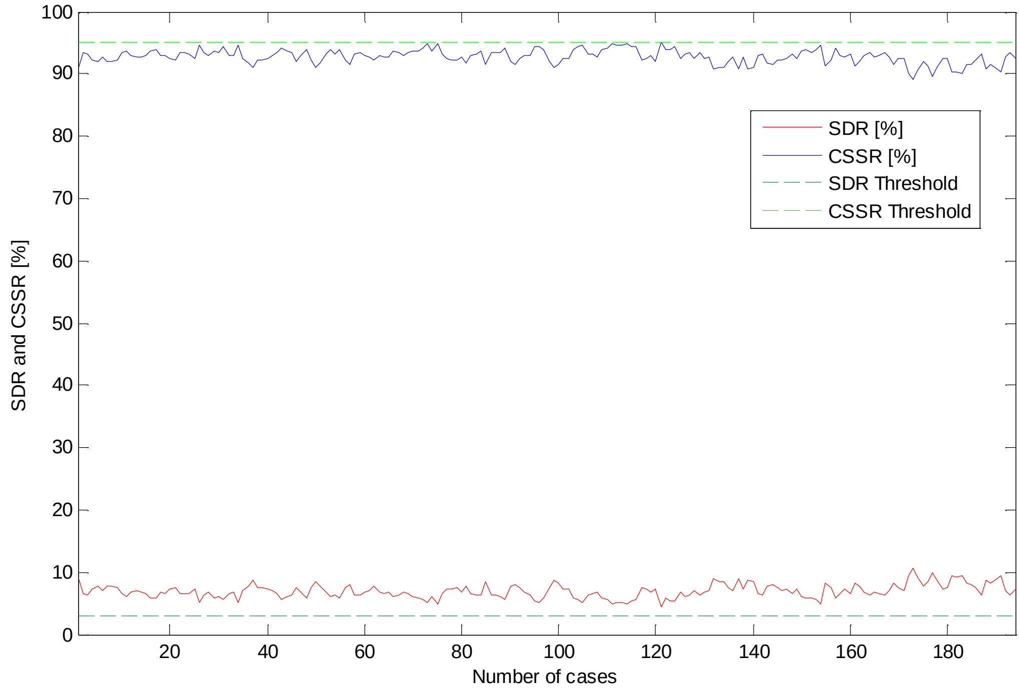

Figure D.8 BS 19 – R_{SDCCH_D} and R_{CS_S} performance analysis: correlation value of -99.30%.

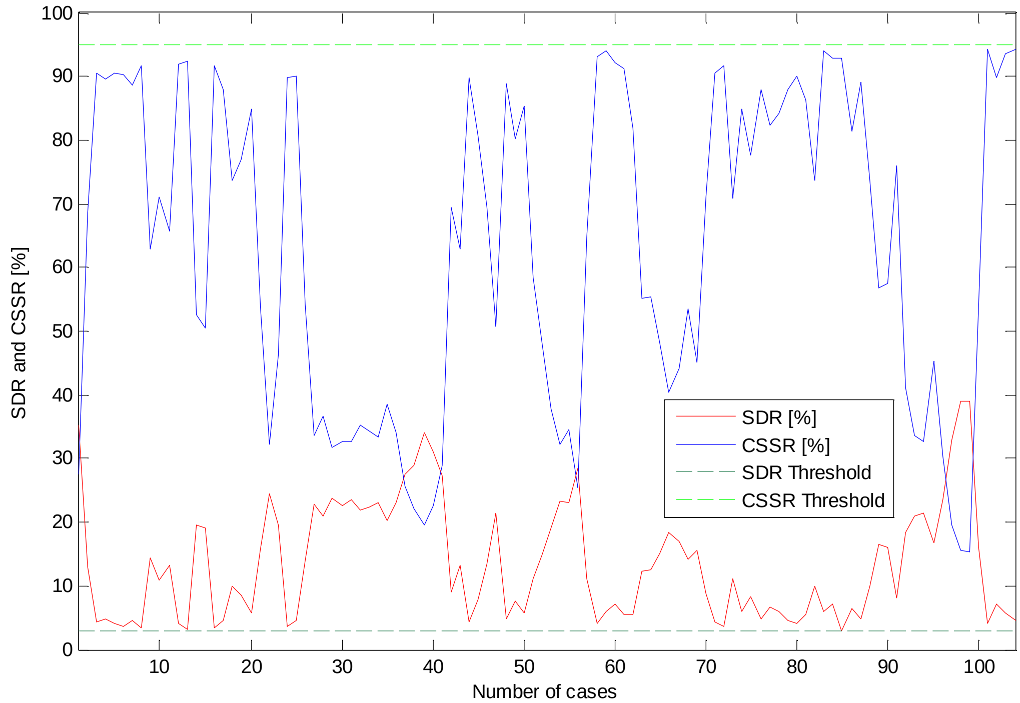

Figure D.9 BS 40 – R_{SDCCH_D} and R_{CS_S} performance analysis: correlation value of -96.31%.

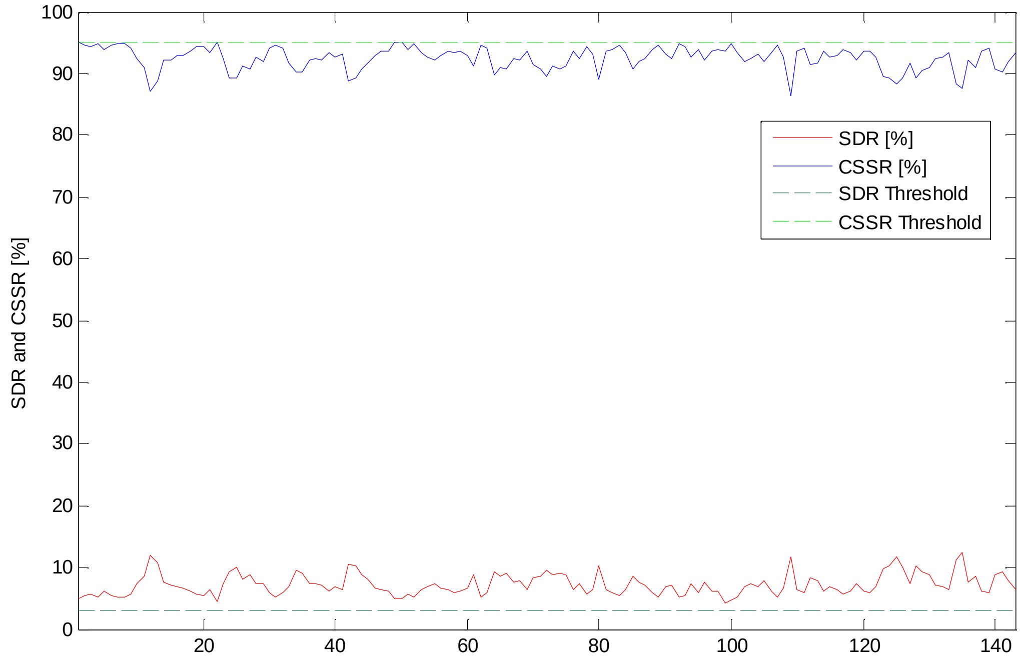

Figure D.10 BS 17 – R_{SDCCH_D} and R_{CS_S} performance analysis: correlation value of -98.35%.

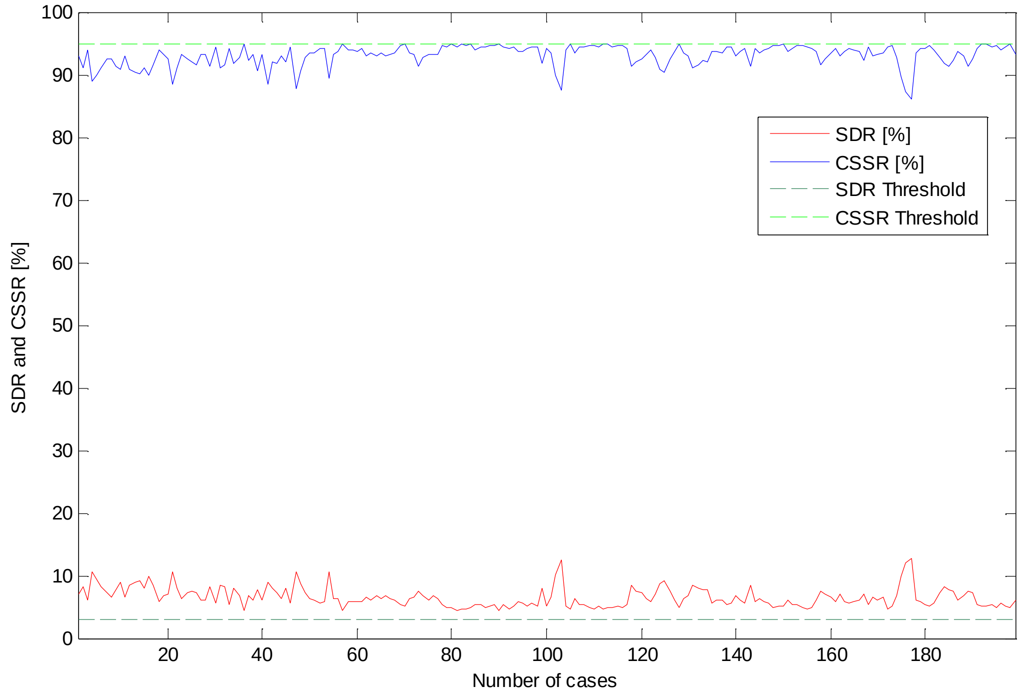

Figure D.11 BS 25 – R_{SDCCH_D} and R_{CS_S} performance analysis: correlation value of -97.89%.

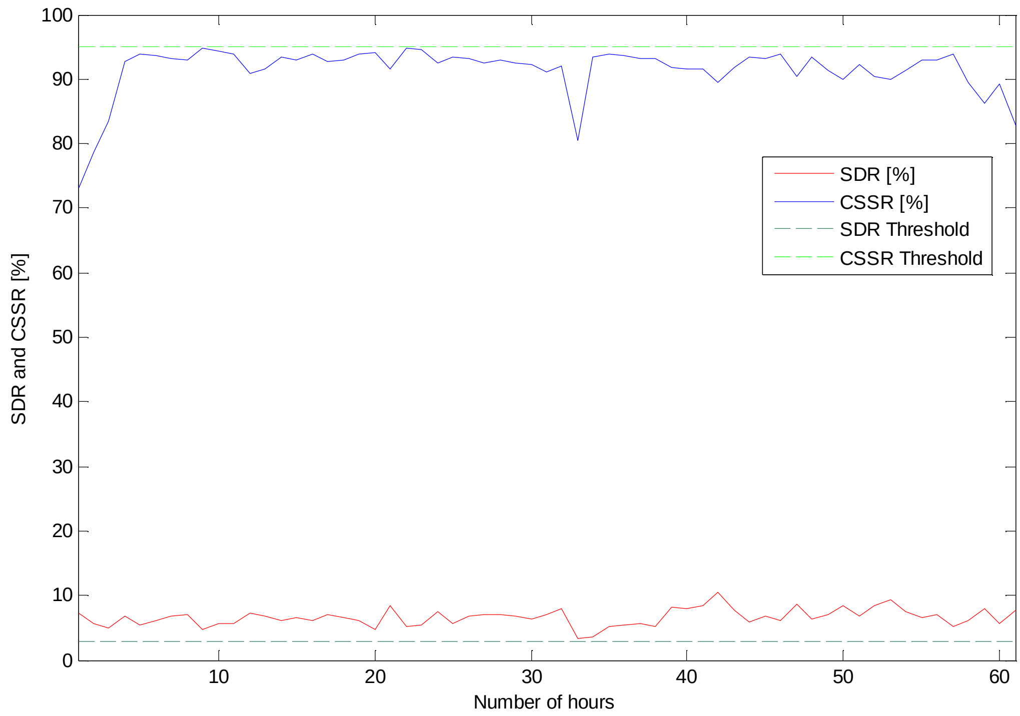

Figure D.12 BS 44 – R_{SDCCH_D} and R_{CS_S} performance analysis: correlation value of 11.34%.

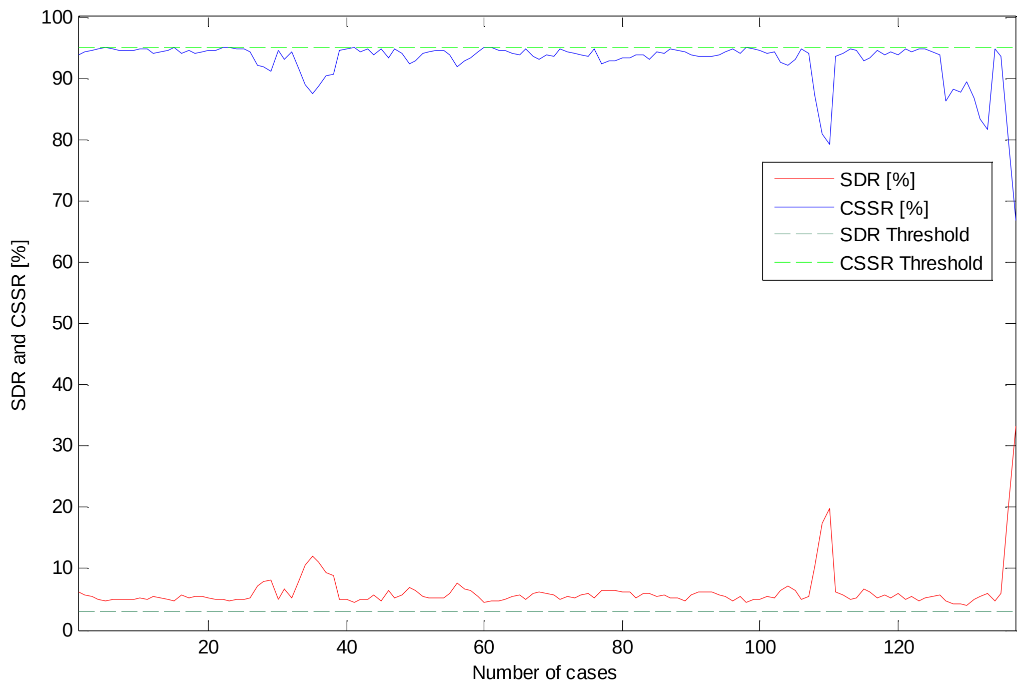

Figure D.13 BS 8 – R_{SDCCH_D} and R_{CS_S} performance analysis: correlation value of -85.03%.

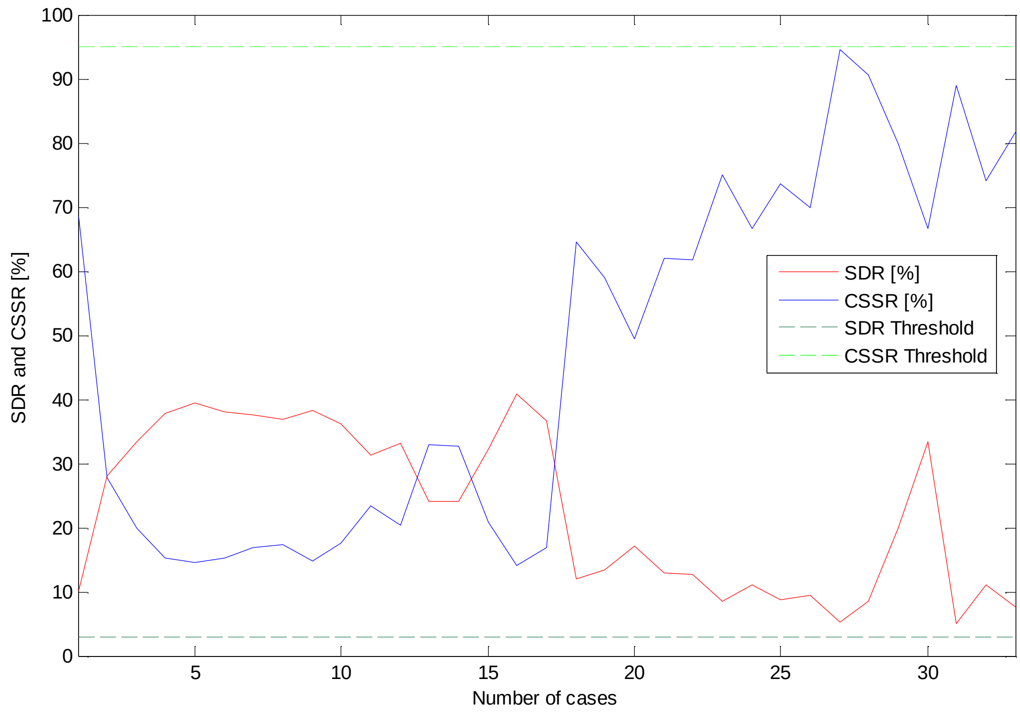

Figure D.14 BS 43 – R_{SDCCH_D} and R_{CSS_S} performance analysis: correlation value of -92.55%.

In BS 6, the sectors A, B and C are affected at the same time in GSM 900. SDCCH drop rate has an average value of 20.79%% and call setup success rate has an average value of 63.49%. According to Figures 3.10 and 3.12 an analysis to “high SDCCH drop rate” and “low TCH assignment success rate” has to be done. Analysing the remaining output results, TCH assignment success rate has an average value of 0.8%. TCH congestion has an average value of 11.02% and SDCCH congestion has an average value of 23.25%. 93.94% of the control channel drops are due to sudden loss of connection.

In BS 7, the sectors A, B and C are affected at the same time in GSM 900. SDCCH drop rate has an average value of 5.45% and call setup success rate has an average value of 1.87%. TCH assignment success rate has an average value of 0.02%. TCH congestion has an average value of 94.19% and SDCCH congestion has an average value of 0.47%. 90.65% of the control channel drops are due to sudden loss of connection.

In BS 8, the majority of the problems are in sector B in GSM 900. SDCCH drop rate has an average value of 6.26% and call setup success rate has an average value of 92.89%. TCH assignment success rate has an average value of 0.99%. TCH congestion has an average value of 0.47% and SDCCH congestion has an average value of 0.01%. 51.97% of the control channel drops are due to sudden loss of connection and 36.67% are due to bad quality.

In BS 17, sector B in GSM 1800 is the only sector affected with problems. SDCCH drop rate has an average value of 7.20% and call setup success rate has an average value of 92.42%. TCH assignment success rate has an average value of 1.00%. There is no TCH congestion and SDCCH congestion has an average value of 0.18%. 53.93% of the control channel drops are due to sudden loss of connection and 39.29% are due to low signal strength.

In BS 19, sector C in GSM 900 is the only sector affected with problems. SDCCH drop rate has an average value of 6.95% and call setup success rate has an average value of 92.75%. TCH assignment success rate has an average value of 1.00%. There is practically no TCH and SDCCH congestion. 54.76% of the control channel drops are due to bad quality and 42.04% are due to sudden loss of connection.

In BS 25, on the first 6 days of the month there are problems in sector B in GSM 900 and sector C in GSM 1800 at the same hours while in the rest of the month sector B in GSM 900 is the only sector affected with problems. SDCCH drop rate has an average value of 6.51% and call setup success rate has an average value of 93.06%. TCH assignment success rate has an average value of 1.00%. There is no TCH and SDCCH congestion. 57.23% of the control channel drops are due to sudden loss of connection, 23.85% are due to bad quality and 18.92% are due to low signal strength.

In BS 40, sector A in GSM 900 is the only sector affected with problems. SDCCH drop rate has an average value of 13.53% and call setup success rate has an average value of 63.39%. TCH assignment success rate has an average value of 0.73%. TCH congestion has an average value of 28.32% and SDCCH congestion has an average value of 19.33%. 87.45% of the control channel drops are due to sudden loss of connection.

In BS 43, sector A in GSM 900 is the only sector affected with problems. SDCCH drop rate has an average value of 22.87% and call setup success rate has an average value of 46.89%. TCH assignment success rate has an average value of 0.61%. TCH congestion has an average value of 42.80% and SDCCH congestion has an average value of 1.70%. 92.91% of the control channel drops are due to sudden loss of connection.

In BS 44, sector B in GSM 900 is the only sector affected with problems. SDCCH drop rate has an average value of 6.62% and call setup success rate has an average value of 91.41%. TCH assignment success rate has an average value of 0.98%. TCH congestion has an average value of 1.16% and there is practically no SDCCH congestion. 53.02% of the control channel drops are due to low signal strength, 46% due to sudden loss of connection and 0.98% due to bad quality.

The HO performance analysis will be done according to Figure 3.8. Table D.3 shows the results concerning January 2010, obtained after executing the *query's*. In BS 9, internal HO attempts represents 99.63% of total HO attempts. With an internal HO success rate of 89.12% and an external HO success rate of 75.58%, external is apparently the worst relation. However since external HO attempts represents only 0.37% of total, the internal relation will be analysed. 97.32% of the unsuccessful HOs are reversions and 2.68% are lost HOs. There is practically no TCH congestion, which excludes capacity problems. From a total of 17 neighbouring cells defined, BSs 18 and 34 are identified as neighbouring cells. BS 18 has few HO attempts, an internal HO success rate of 92.17% and no external problems so it is possible to conclude that does not negatively affects the performance of BS 9. Although BS 34 has few HO attempts, the external relation represents 61.89% of the total HO attempts. Would be advisable to start an inter-BSC/MSC analysis.

Table D.3 HO performance results.

BS	Internal HO Attempts	Internal HSR (%)	External HO Attempts	External HSR (%)	BS	Internal HO Attempts	Internal HSR (%)	External HO Attempts	External HSR (%)
21	1243667	92.82	180495	93.22	**2**	18416	91.27	30214	87.63
9	394952	89.12	1460	75.58	**38**	18240	90.92	2134	89.35
16	340465	88.47	1599	92.10	**24**	17243	91.55	16516	86.83
17	273368	82.75	4424	89.12	**35**	16894	90.69	2571	60.66
7	249998	91.87	44	80.34	**26**	13532	87.35	0	-
19	226421	91.78	54	62.34	**28**	12994	89.65	0	-
30	180097	84.73	13342	84.94	**13**	11012	78.62	5061	84.75
32	102916	91.01	735	80.83	**42**	10504	87.13	4981	79.22
12	89842	81.29	0	-	**36**	9137	84.57	0	-
1	74881	90.42	56128	91.00	**18**	9074	92.17	0	-
15	63778	92.80	3086	90.84	**10**	7245	88.54	4239	89.89
3	59669	94.02	0	-	**4**	6104	90.79	6864	90.42
8	59508	88.35	5247	92.78	**41**	5999	86.69	2265	89.18
29	40798	91.18	38	75.91	**27**	5986	92.41	17	74.75
33	36794	91.90	1042	76.35	**37**	4665	85.46	11050	86.37
22	25555	86.44	3859	87.48	**20**	3253	89.11	0	-
5	22997	91.20	11236	88.44	**11**	3169	91.15	7132	85.32
23	22021	89.54	46308	93.24	**25**	3002	91.54	0	-
34	21837	68.26	35466	75.52	**40**	1590	90.08	145	89.06
14	20432	88.81	158193	93.09	**6**	955	73.44	0	-
31	18921	89.62	30337	90.03	**39**	403	77.47	0	-

In BS 16, internal HO attempts represents 99.53% of total HO attempts. Being internal the worst relation, 57.97% of the unsuccessful HOs are reversions and 42.03% are lost HOs. There is practically no TCH congestion, which excludes capacity problems. From a total of 12 neighbouring cells defined, BSs 27 and 5 are identified as neighbouring cells. BS 27 has few HO attempts, an internal HO success rate of 92.41% and an external HO success rate of 74.75%, but with only 17 external HO attempts. It is possible to conclude that does not negatively affect the performance of BS 16. BS 5 has few HO attempts and has no TCH congestion so also does not affect the performance of BS 16.

In BS 17, internal HO attempts represents 98.41% of total HO attempts. Being internal the worst relation, 95.60% of the unsuccessful HOs are reversions and 4.40% are lost HOs. There is practically no TCH congestion, which excludes capacity problems. From a total of 16 neighbouring cells defined, BSs 8, 4, 12, 29, 33 and 30 are identified as neighbouring cells. BS 8 has an internal HO success rate of 88.35% (worst relation) with 91.90% of the total HO attempts being internal. 91.52% of the unsuccessful HOs are due to reversions and there is no TCH congestion. BS 4 has an internal HO success rate of 90.79% and an external HO success rate of 90.42% but both with few HO attempts, and so does not affect the performance of BS 17. BS 12 has an internal HO success rate of 81.29% (worst relation) with 100.00% of the total HO attempts being internal. 92.05% of the unsuccessful HOs are due to reversions and TCH congestion has an average value of 0.02%. BS 29 has an internal HO success rate of 91.18% with 97.25% of the total HO attempts being internal. 95.03% of the unsuccessful HOs are due to reversions and TCH congestion has an average value of 0.09%. BS 33 has an internal HO success rate of 91.90% with 97.25% of the total HO attempts being internal. 67.18% of the unsuccessful HOs are due to reversions and 32.82% are due to lost HOs. TCH congestion has an average value of 0.78%. BS 30 has an internal HO success rate of 84.73% with 93.10% of the total HO attempts being internal. 95.71% of the unsuccessful HOs are due to reversions and TCH congestion has an average value of 0.26%.

In BS 7, internal HO attempts represents 99.98% of total HO attempts. 97.50% of the unsuccessful HOs are reversions and 2.50% are lost HOs. There is practically no TCH congestion, which excludes capacity problems. From a total of 17 neighbouring cells defined, BSs 22, 31, 32, 35 and 34 are identified as neighbouring cells. BS 8 has an internal HO success rate of 88.35% (worst relation) with 91.90% of the total HO attempts being internal. 91.52% of the unsuccessful HOs are due to reversions and there is no TCH congestion. BS 22 has an internal HO success rate of 86.44% with 86.88% of the total HO attempts being internal. 97.61% of the unsuccessful HOs are due to reversions and there is no TCH. BS 31 has an internal HO success rate of 89.62% and an external HO success rate of 90.03% with 61.59% of the total HO attempts being external. This difference advises an inter-BSC/MSC analysis. 92.68% of the unsuccessful HOs are due to reversions and there is no TCH congestion. BS 32 has an internal HO success rate of 91.01% with 99.29% of the total HO attempts being internal. 96.65% of the unsuccessful HOs are due to reversions and TCH congestion has an average value of 1.66%. BS 35 has an internal HO success rate of 90.69% with 86.79% of the total HO attempts being internal. 98.80% of the unsuccessful HOs are due to reversions and there is practically no TCH congestion. BS 34 has been already analysed.

In BS 19, internal HO attempts represents 99.98% of total HO attempts. Internal HO success rate has an average value of 91.78%. The number of external HO attempts is very low and so the external relation is not taken into account. 94.17% of the unsuccessful HOs are reversions and 5.83% are lost HOs. TCH congestion has an average value of 0.11%, which excludes capacity problems. From a total of 20 neighbouring cells defined none of them is identified as a problematic BS.

In BS 12, internal HO attempts represents 100.00% of total HO attempts since there is no external HO attempts. Internal HO success rate has an average value of 81.28%. 92.05% of the unsuccessful HOs are reversions and 7.95% are lost HOs. TCH congestion has an average value of 0.02%, which excludes capacity problems. From a total of 12 neighbouring cells defined, BSs 4, 8, 17, 29 and 30 are identified as neighbouring cells. All of them have been already analysed.

Table D.4 shows the results concerning GPRS throughput on January 2010, obtained after executing the *query's*. Looking at the results it is possible to conclude that in BSs 45, 41, 40, 24, 37 and 23 when the assignment of the PDCH assignment success rate is below the threshold level the throughput value is also below the threshold level with a probability of 84.77%, 81.75%, 80.76%, 65.43%, 61.37% and 50.52%, respectively. The same analysis is done to the GPRS UL throughput. Figures D.16 to D.27 show $T_{GPRS_{DL}}$, $T_{GPRS_{UL}}$ and R_{PDCH_S} performance evolution in that period. Only BS 37 will be analysed since the analysis to the other BSs is made in a similar way.

Table D.4 GPRS throughput performance results.

BS	$T_{GPRS_{DL}}$ and R_{PDCH_S}	$T_{GPRS_{UL}}$ and R_{PDCH_S}	$T_{GPRS_{DL}}$ and $T_{GPRS_{UL}}$ and R_{PDCH_S}	BS	$T_{GPRS_{DL}}$ and R_{PDCH_S}	$T_{GPRS_{UL}}$ and R_{PDCH_S}	$T_{GPRS_{DL}}$ and $T_{GPRS_{UL}}$ and R_{PDCH_S}
49	90.13	78.42	60.52	**15**	18.30	24.24	0.86
45	84.77	97.92	2.87	**11**	16.58	11.58	0.00
41	81.75	76.96	38.32	**17**	16.18	0.00	5.43
40	80.76	96.89	12.76	**7**	15.40	0.00	0.00
24	65.43	66.67	6.32	**21**	14.97	18.42	4.19
37	61.37	62.63	21.68	**36**	14.37	9.30	2.35
23	50.52	78.57	3.09	**25**	13.85	9.41	2.05
51	41.09	33.06	11.39	**19**	12.44	39.29	7.83
31	37.57	51.50	17.13	**12**	11.15	0.00	0.00
1	34.82	28.57	15.18	**20**	9.09	58.33	2.16
34	33.60	26.03	7.80	**39**	8.19	16.34	6.41
48	32.08	52.91	20.75	**29**	6.87	9.76	3.00
54	30.55	58.64	7.68	**35**	6.25	8.74	0.66
46	30.21	37.50	5.14	**6**	6.08	43.88	2.59
52	29.61	24.70	8.15	**27**	5.73	6.59	0.00
43	28.44	46.88	9.63	**14**	5.08	35.07	3.79
53	28.32	40.83	4.30	**2**	4.52	14.06	5.98
32	27.50	45.83	10.50	**4**	3.57	34.85	0.00
5	25.59	0.00	0.95	**47**	3.57	21.79	1.79
44	25.32	36.28	9.74	**30**	3.40	12.00	0.85
22	24.59	23.00	6.89	**16**	3.00	20.45	3.76
18	23.47	38.10	5.61	**13**	1.26	7.22	1.44
50	21.93	20.79	6.14	**9**	1.21	32.14	4.90
42	21.64	0.00	0.00	**10**	0.66	6.25	1.01
33	20.14	36.14	7.07	**3**	0.57	15.71	0.00
38	19.57	45.83	13.62	**8**	0.00	32.14	0.00
26	18.92	0.00	6.08	**28**	0.00	16.67	0.00

In BS 37, PDCH assignment success rate has an average value of 36.00%. The TCH congestion has an average value of 0.22% and the HR traffic represents 18.27% of the total traffic. In this case, since the two verifiable conditions of PDCH assignment success rate are not above the threshold value, it is not possible to establish a direct correlation between the two KPIs. Analysing the GPRS DL throughput (average value of 11.62 kbps) the GPRS RLC average data volume is distributed in this way: 0.0490 kbits in the 8 kbps interval, 0.0435 kbits in the 10 kbps interval, 0.8774 kbits in the 12 kbps interval, 0.0342 kbits in the 14 kbps interval, 0.0183 kbits in the 16 and 0.0266kbits in the 18 kbps interval. Looking at the results the major "slice" of the traffic is in the lower bit rate intervals (88.39% of the total traffic is in the three lower bite rate intervals) which means poor radio link quality – the larger the bit rate range in which data are processed, the better the quality of radio link. At this point, one of the possible reasons for poor GPRS DL throughput is identified. Yet the other possibilities have to be checked. The average PDCH utilisation ratio is 50.63% (below the 80% threshold value) and there are 1.9 simultaneous users per active DL PDCH – above the 1.4 threshold value, which means that the number of users per active channel is excessive, being another reason for poor GPRS DL throughput. In BS 23, PDCH assignment success rate has an average value of 22.06%. There is no TCH congestion and the HR traffic represents 1.59% of the total traffic. Analysing the GPRS UL throughput (average value of 8.66 kbps) the GPRS RLC average data volume is distributed in this way: 0.0300 kbits in the 8 kbps interval, 0.0771 kbits in the 10 kbps interval, 0.6896 kbits in the 12 kbps interval, 0.1167 kbits in the 14 kbps interval, 0.0102 kbits in the 16 and 0.1065 kbits in the 18 kbps interval. Looking at the results the major “slice” of the traffic is in the lower bit rate intervals (77.35% of the total traffic is in the three lower bite rate intervals) which means poor radio link quality – the larger the bit rate range in which data are processed, the better the quality of radio link. At this point, one of the possible reasons for poor GPRS DL throughput is identified. Yet the other possibilities have to be checked. The average PDCH utilisation ratio is 50.26% (below the 80% threshold value) and there are 1.57 simultaneous users per active DL PDCH – above the 1.4 threshold value, which means that the number of users per active channel is excessive, being another reason for poor GPRS DL throughput.

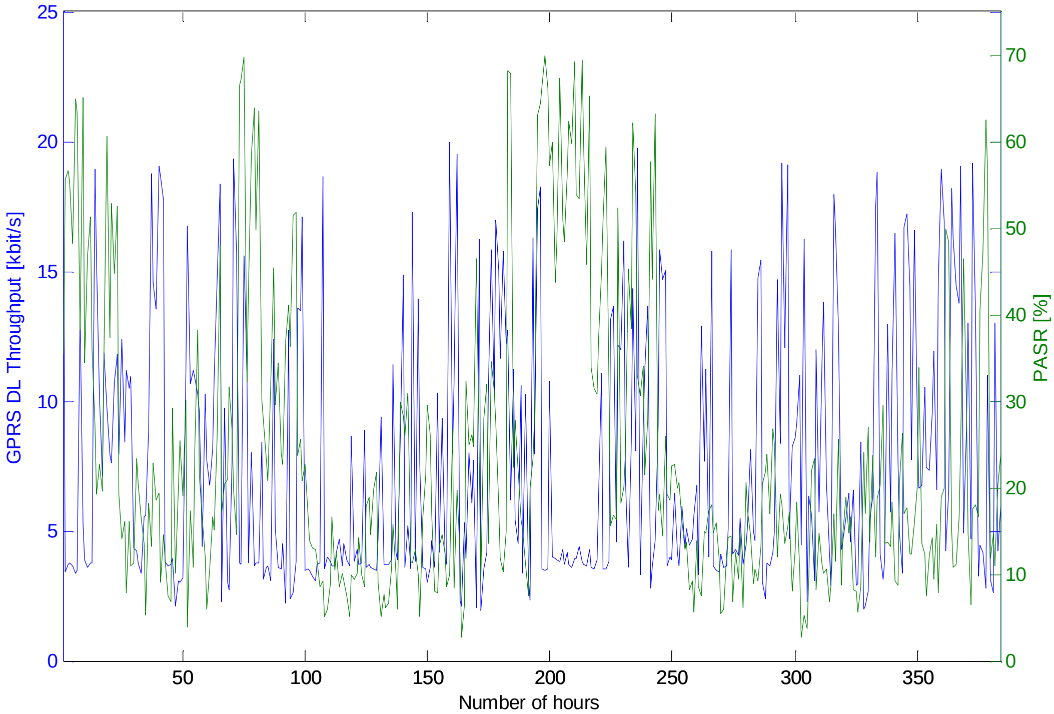

Figure D.15 BS 45 - $T_{GPRS_{DL}}$ and R_{PDCH_S} performance analysis: correlation value of -11.37%.

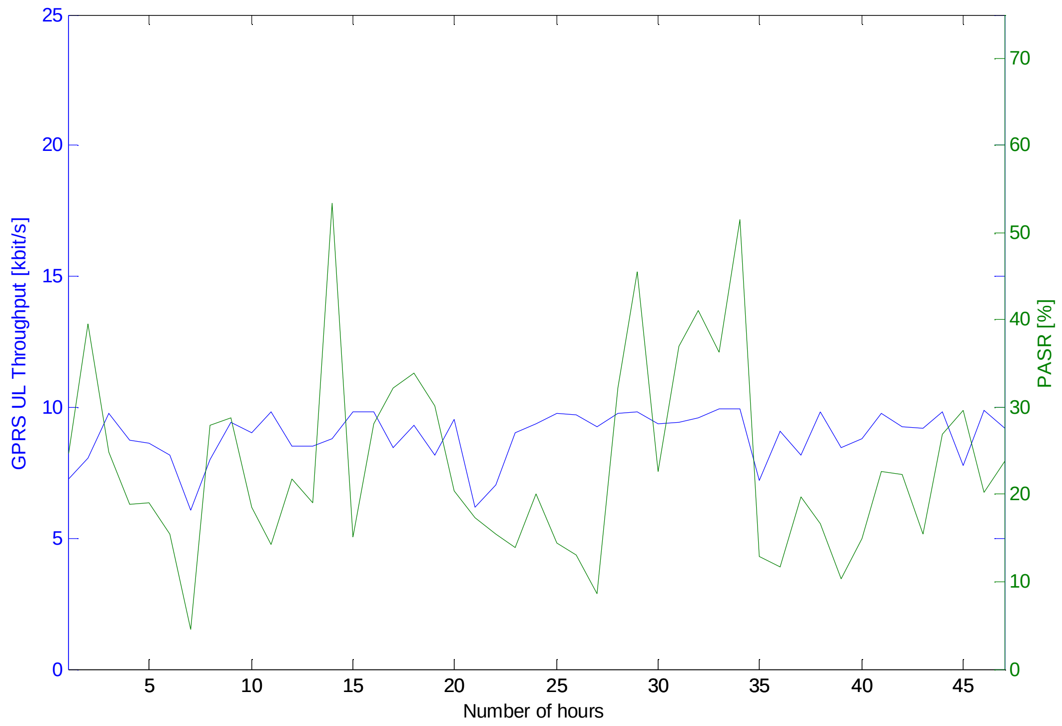

Figure D.16 BS 45 - $T_{GPRS_{UL}}$ and R_{PDCH_S} performance analysis: correlation value of -11.04%.

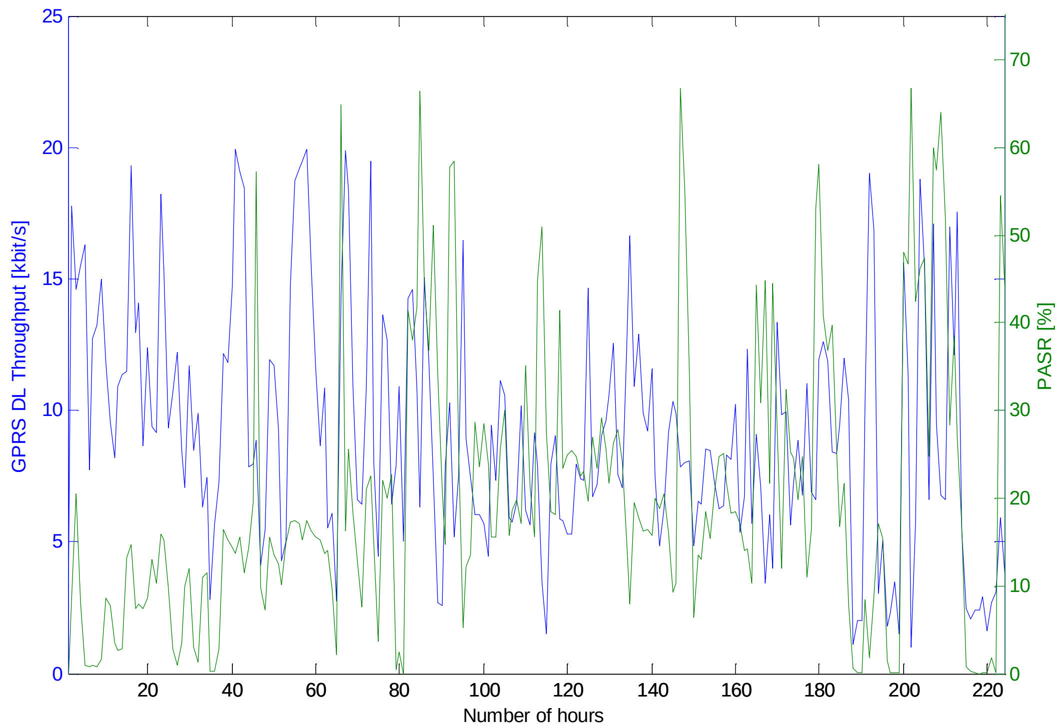

Figure D.17 BS 41 - $T_{GPRS_{DL}}$ and R_{PDCH_S} performance analysis: correlation value of 5.61%.

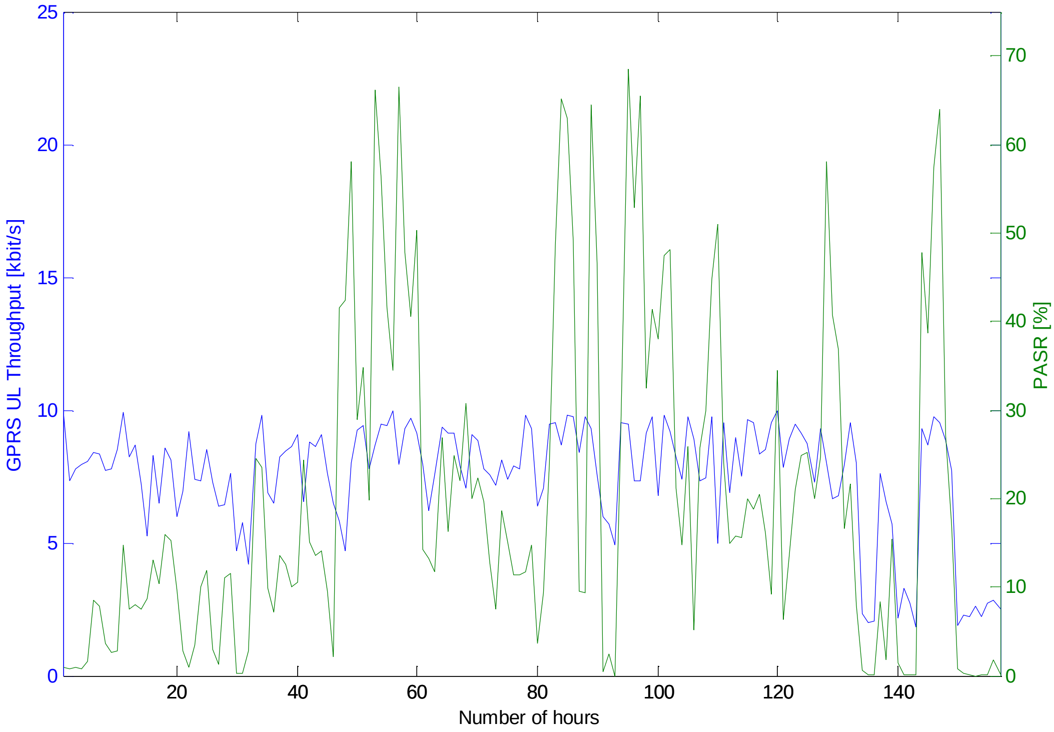

Figure D.18 BS 41 - $T_{GPRS_{UL}}$ and R_{PDCH_S} performance analysis: correlation value of 13.56%.

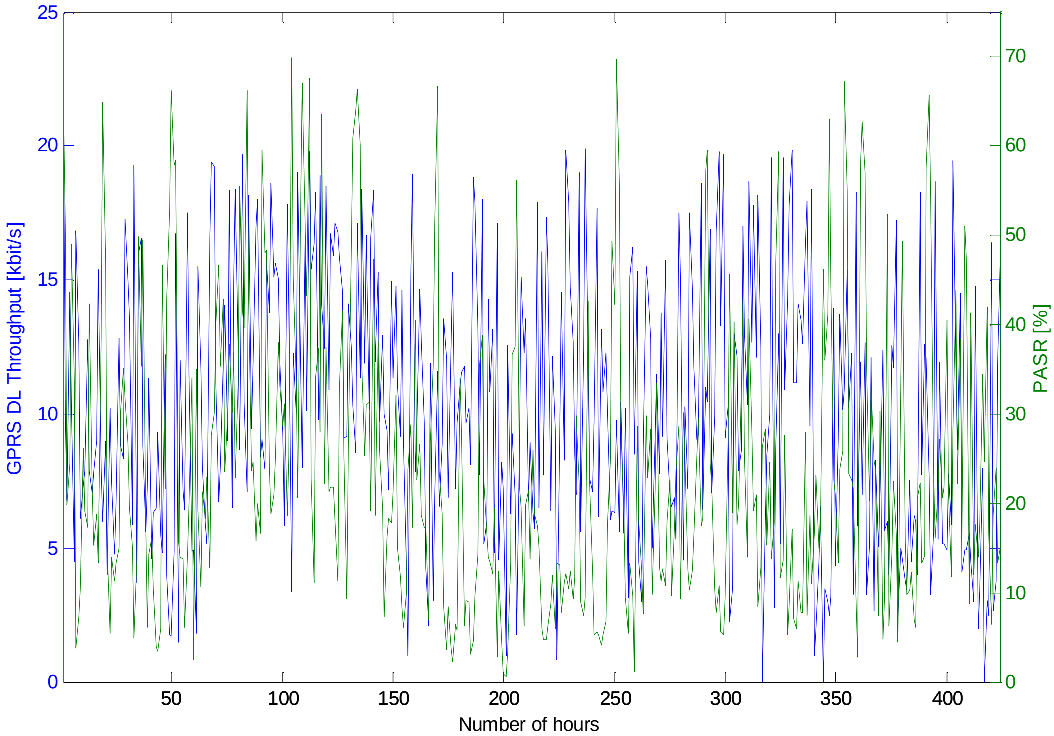

Figure D.19 BS 40 - $T_{GPRS_{DL}}$ and R_{PDCH_S} performance analysis: correlation value of -5.81%.

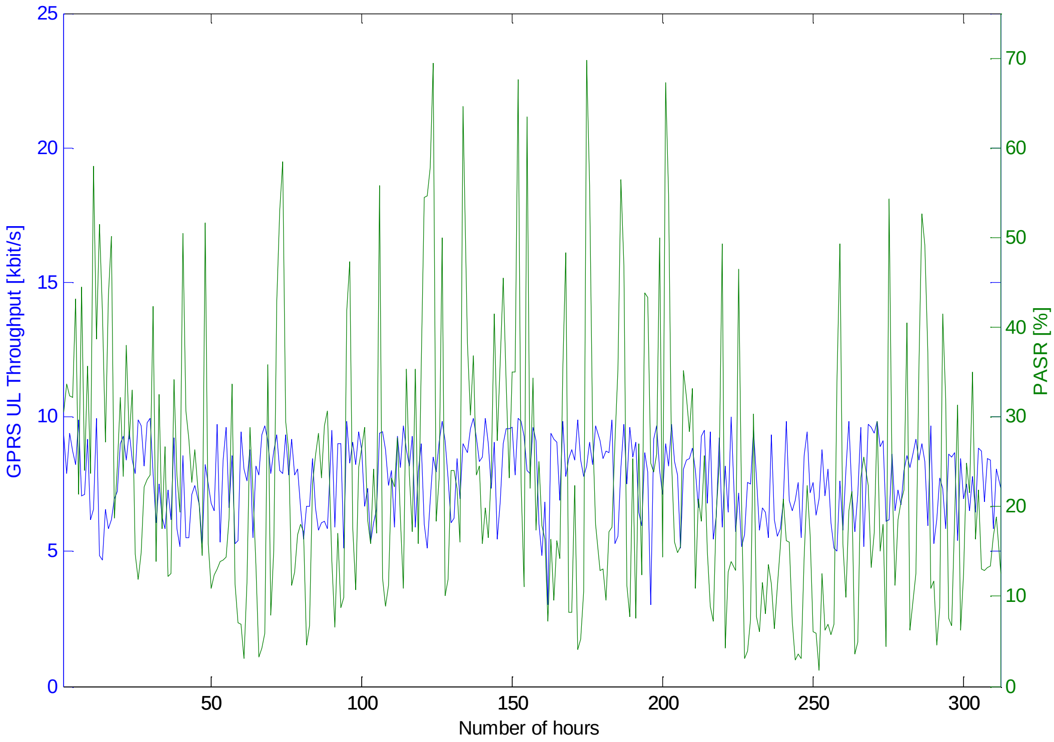

Figure D.20 BS 40 - $T_{GPRS_{UL}}$ and R_{PDCH_S} performance analysis: correlation value of -0.64%.

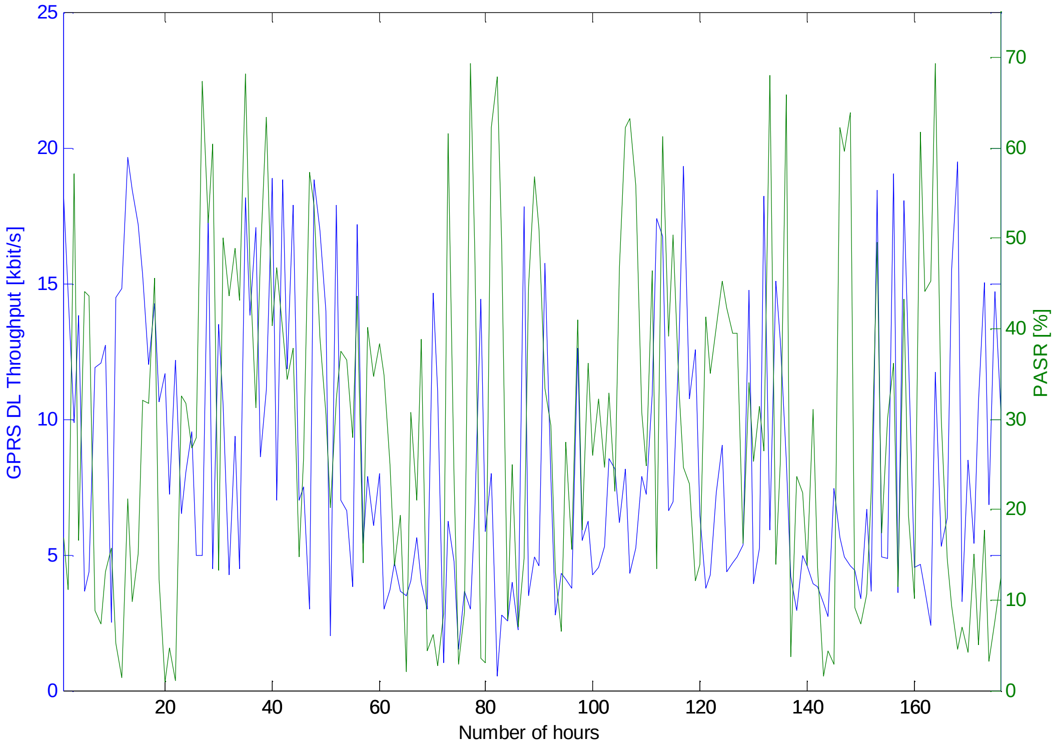

Figure D.21 BS 24 - $T_{GPRS_{DL}}$ and R_{PDCH_S} performance analysis: correlation value of 0.38%.

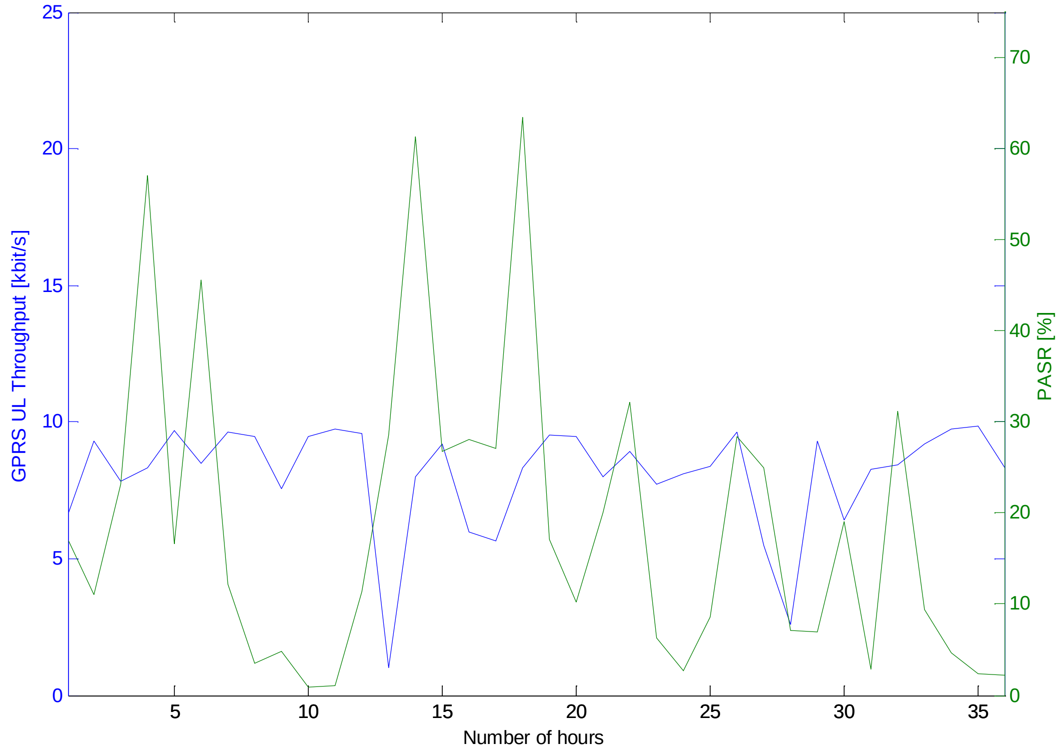

Figure D.22 BS 24 - $T_{GPRS_{UL}}$ and R_{PDCH_S} performance analysis: correlation value of -2.74%.

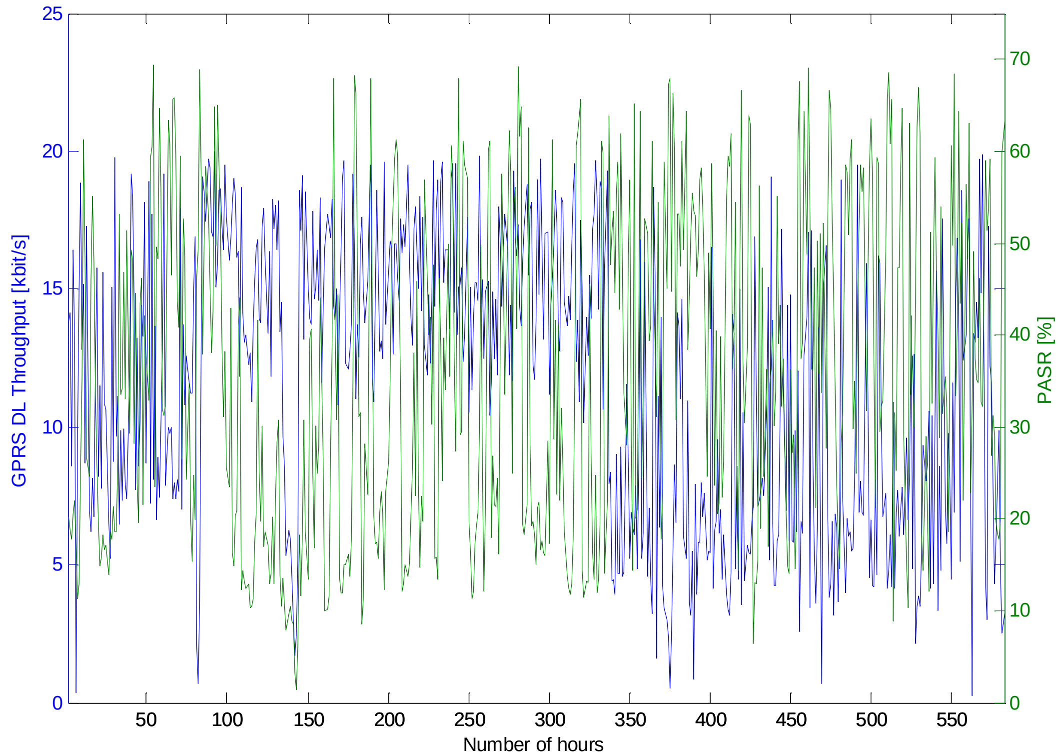

Figure D.23 BS 37 - $T_{GPRS_{DL}}$ and R_{PDCH_S} performance analysis: correlation value of -22.53%.

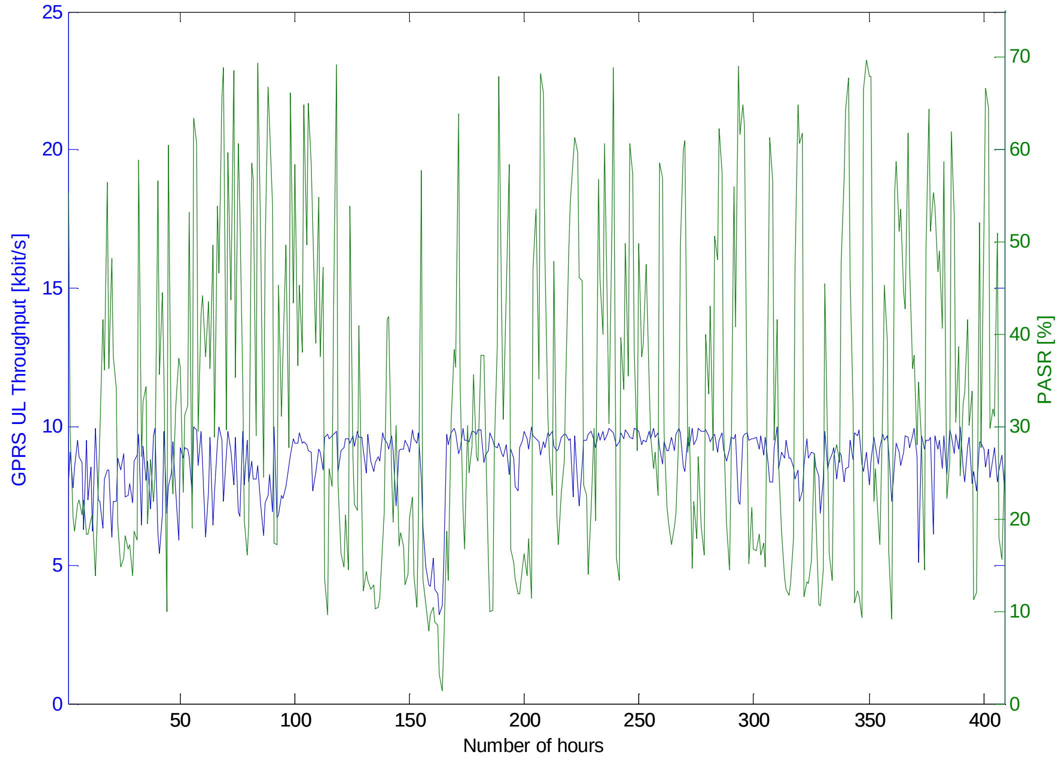

Figure D.24 BS 37 - $T_{GPRS_{UL}}$ and R_{PDCH_S} performance analysis: correlation value of -4.18%.

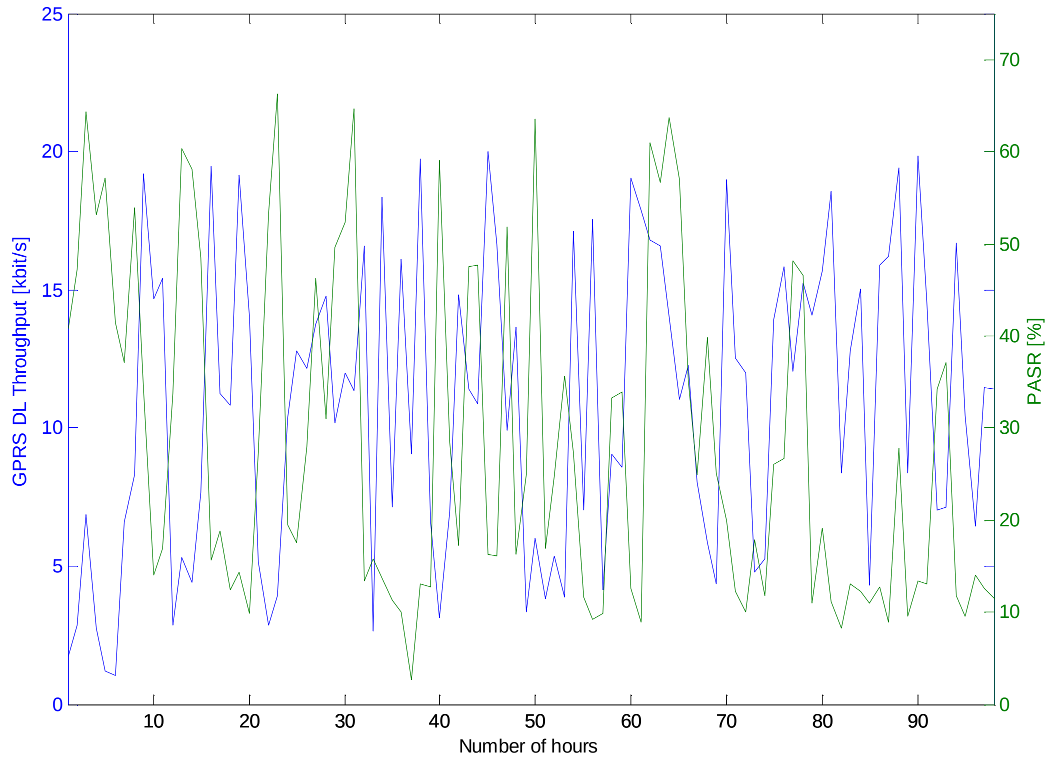

Figure D.25 BS 23 - $T_{GPRS_{DL}}$ and R_{PDCH_S} performance analysis: correlation value of -2.18%.

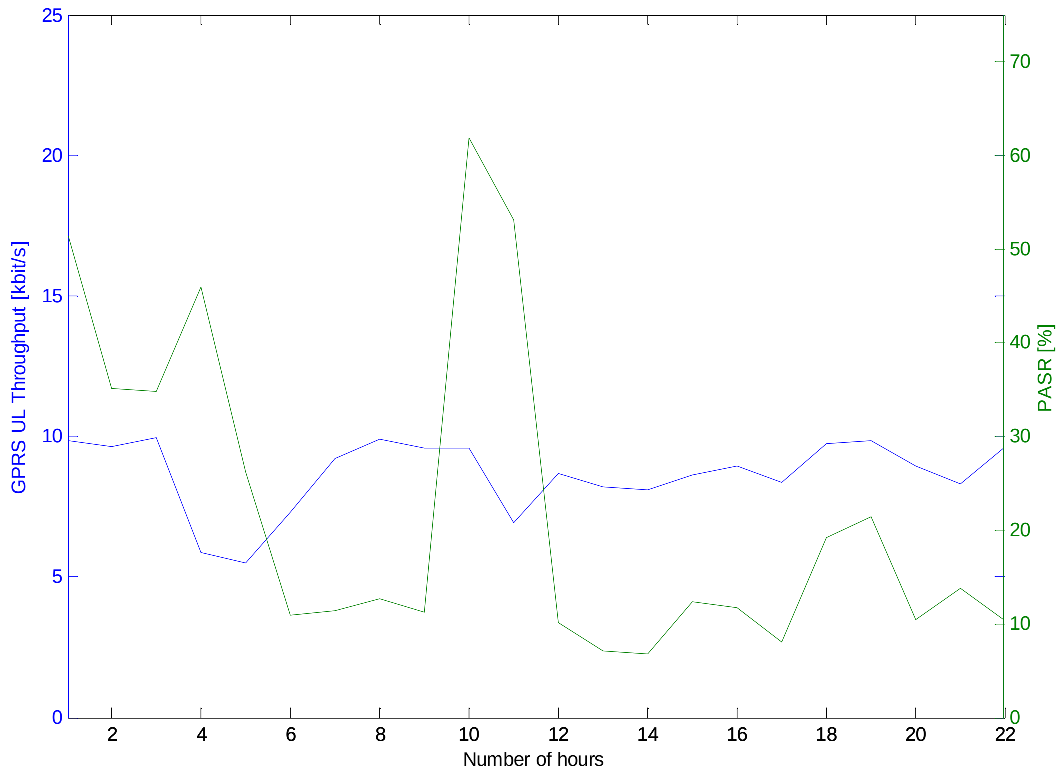

Figure D.26 BS 23 - $T_{GPRS_{UL}}$ and R_{PDCH_S} performance analysis: correlation value of -32.66%.

Table D.5 shows the results concerning EDGE throughput on January 2010, obtained after executing the *query's*. Looking at the results it is possible to conclude that in BSs 20, 34, 71, 87, 80, 51 and 83 when the assignment of the PDCH assignment success rate is below the threshold level the throughput value is also below the threshold level with a probability of 98.15%, 98.01%, 94.30%, 90.18%, 89.89%, 89.00% and 88.68%, respectively. The same analysis is done to EDGE UL throughput. Figures D.28 to D.39 show $\boldsymbol{T_{EDGE_{DL}}}$, $\boldsymbol{T_{EDGE_{UL}}}$ and $\boldsymbol{R_{PDCH_S}}$ performance evolution in that period. Only BS 51 will be analysed since the analysis to the other BSs in made in a similar way. In BS 51 UL direction, PDCH assignment success rate has an average value of 35.24%. The TCH congestion has an average value of 0.45% and the HR traffic represents 47.57% of the total traffic. None of the criteria is exceeded. Analysing the EDGE UL throughput (average value of 20.67 kbps) the EDGE RLC average data volume is distributed in this way: 0.0189 kbits in the 10 kbps interval, 0.0389 kbits in the 15 kbps interval, 0.0402 kbits in the 20 kbps interval, 0.0516 kbits in the 25 kbps interval, 0.0580 kbits in the 30 kbps interval, 0.0663 kbits in the 35 kbps interval, 0.0853 kbits in the 40 kbps interval, 0.0936 kbits in the 45 kbps interval, 0.1222 kbits in the 50 kbps interval and 0.4252 kbits in the 55 kbps interval. Looking at the results the major "slice" of the traffic is in the higher bit rate intervals (72.63% of the total traffic is in the four higher bite rate intervals) which means good radio link quality. The average PDCH utilisation ratio is 50.42% (below the 80% threshold value) and there are 2.03 simultaneous users per active DL PDCH – above the 1.4 threshold value, which can mean less PDCH reserved than requested by the users.

Table D.5 EDGE throughput performance results.

BS	$T_{EDGE_{DL}}$ and R_{PDCH_S}	$T_{EDGE_{UL}}$ and R_{PDCH_S}	$T_{EDGE_{DL}}$ and $T_{EDGE_{UL}}$ and R_{PDCH_S}	BS	$T_{EDGE_{DL}}$ and R_{PDCH_S}	$T_{EDGE_{UL}}$ and R_{PDCH_S}	$T_{EDGE_{DL}}$ and $T_{EDGE_{UL}}$ and R_{PDCH_S}
20	98.15	72.84	98.15	**1**	52.53	48.56	48.48
34	98.01	93.91	92.69	**35**	50.00	31.08	48.58
71	94.30	84.81	80.42	**21**	48.07	29.17	47.21
87	90.18	71.98	89.73	**59**	46.87	49.85	45.85
80	89.89	69.93	79.78	**103**	45.09	39.64	43.46
51	89.00	46.67	72.00	**68**	45.00	12.88	44.00
83	88.68	87.56	78.16	**30**	42.74	38.49	35.48
77	87.53	81.18	79.65	**8**	42.55	33.84	36.88
44	85.12	10.16	73.55	**66**	41.41	26.21	37.63
92	84.41	52.26	83.27	**24**	41.41	4.44	40.23
10	83.15	64.73	81.54	**49**	41.36	53.23	28.64
39	81.82	60.92	76.42	**82**	40.64	23.95	37.44
75	77.63	76.40	75.39	**12**	40.11	19.39	31.07
41	76.47	64.94	57.01	**63**	38.22	24.35	35.47
67	74.59	69.37	64.29	**70**	38.04	11.83	36.20
52	74.39	45.27	73.78	**56**	37.87	23.49	33.73
76	73.78	48.80	69.33	**13**	36.77	26.01	32.26
7	73.36	51.40	70.93	**18**	34.55	26.24	31.82
100	69.86	59.42	66.31	**15**	34.19	26.48	28.06
50	68.65	44.54	65.95	**27**	33.56	24.14	31.88
26	68.22	69.57	53.39	**86**	33.19	28.10	30.44
84	68.16	70.41	58.71	**85**	33.06	22.65	29.03
60	66.33	41.53	65.32	**101**	32.81	30.36	24.61
88	65.43	38.46	65.43	**58**	31.01	19.26	25.32
25	63.96	0.00	54.82	**94**	30.69	26.84	24.48
90	63.92	46.13	57.22	**29**	30.00	12.18	26.32
74	63.40	56.29	60.95	**28**	29.97	0.00	28.01
5	62.54	27.97	59.87	**97**	29.80	29.19	26.67
79	62.02	39.40	56.59	**93**	29.20	29.05	25.91
95	61.73	59.04	57.54	**43**	28.14	12.30	24.55
99	61.01	54.64	59.75	**104**	27.82	19.39	27.07
102	60.91	50.00	56.68	**37**	25.87	12.55	24.48
69	60.69	11.17	55.94	**22**	24.76	21.86	22.46
98	60.28	44.99	59.81	**23**	24.58	47.77	22.88
45	60.25	24.75	57.14	**47**	24.16	19.27	23.49
2	57.52	29.78	53.98	**54**	24.03	10.95	23.26
105	56.68	40.20	49.05	**73**	23.90	12.01	22.93
38	55.43	55.37	47.43	**9**	23.81	14.35	15.87
17	54.77	45.27	52.05	**32**	22.49	28.98	22.01
96	53.73	30.64	51.49	**55**	53.31	31.39	43.01

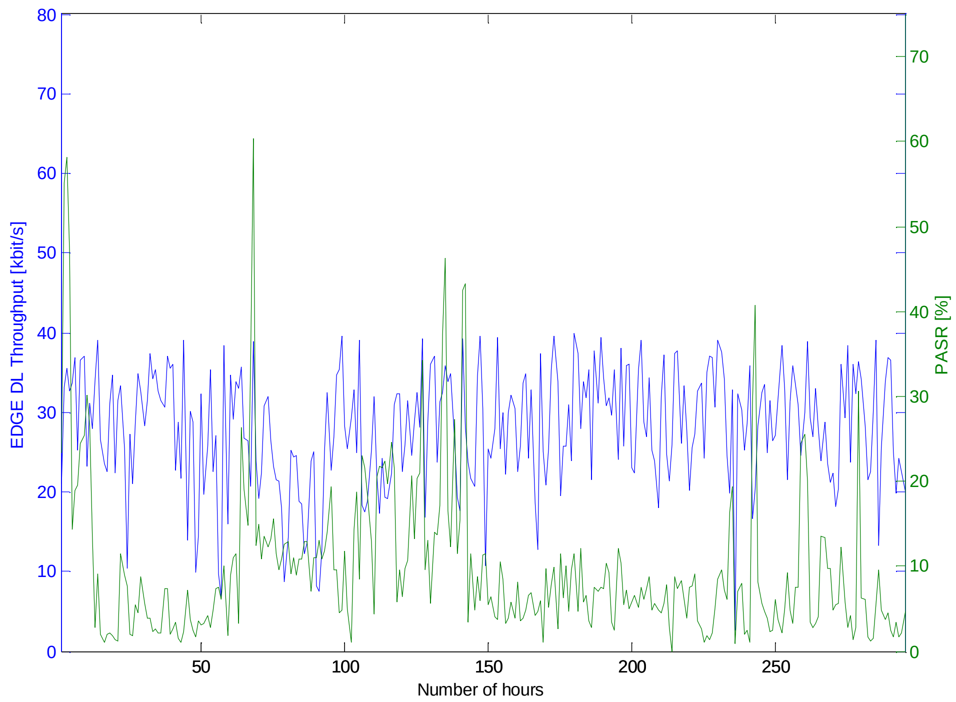

Figure D.27 BS 34 - $T_{EDGE_{DL}}$ and R_{PDCH_S} performance analysis: correlation value of -1.91%.

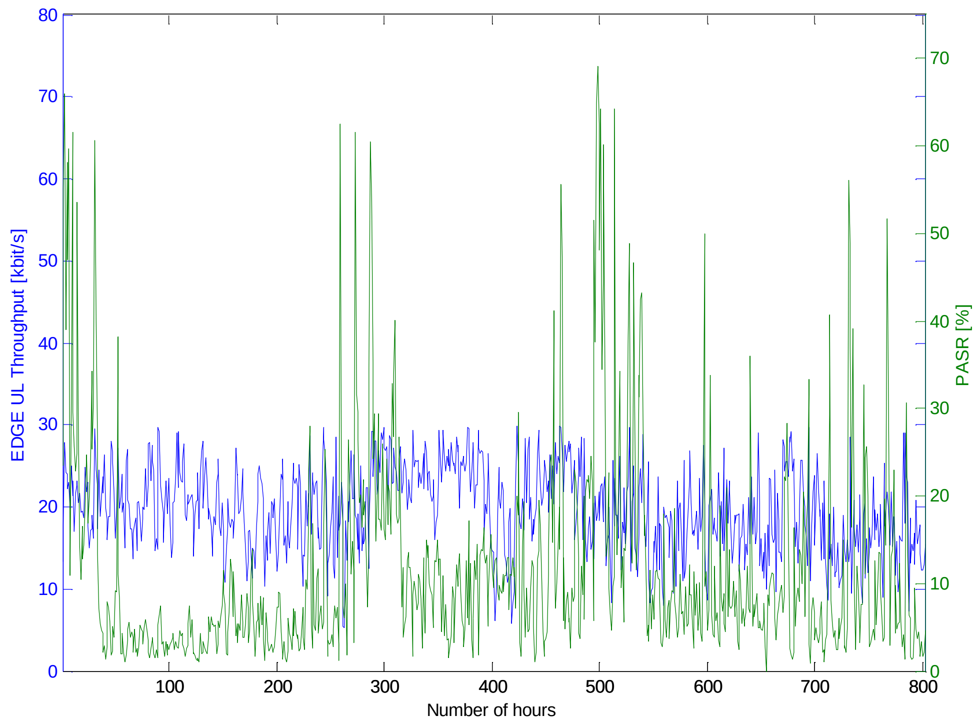

Figure D.28 BS 34 - $T_{EDGE_{UL}}$ and R_{PDCH_S} performance analysis: correlation value of -14.20%.

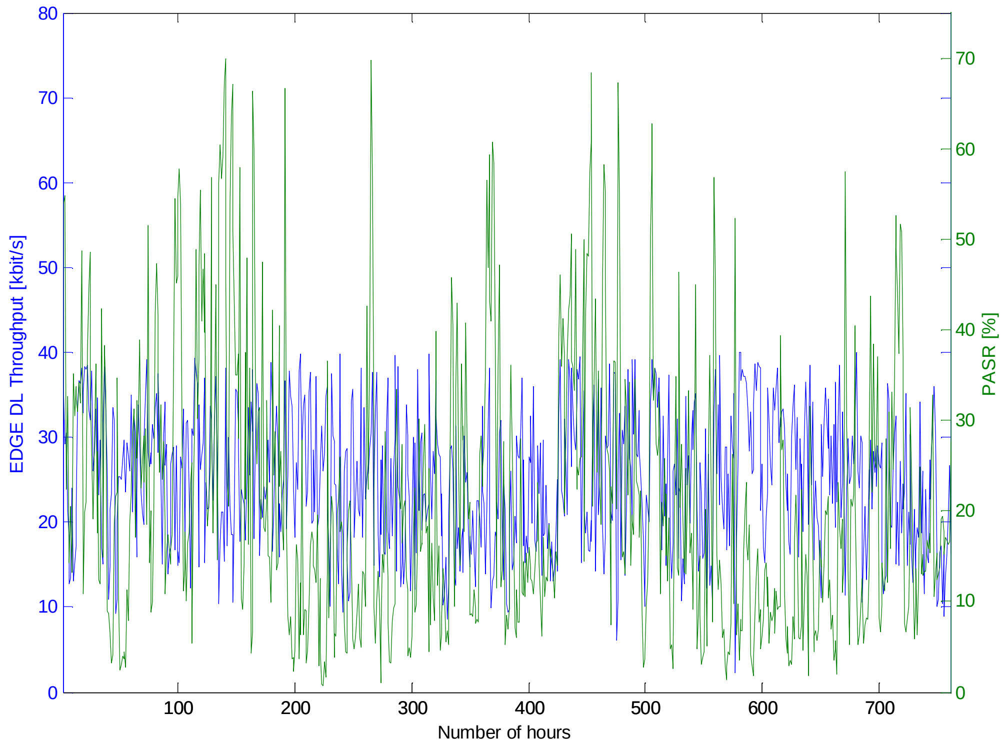

Figure D.29 BS 71 - $T_{EDGE_{DL}}$and R_{PDCH_S} performance analysis: correlation value of -18.82%.

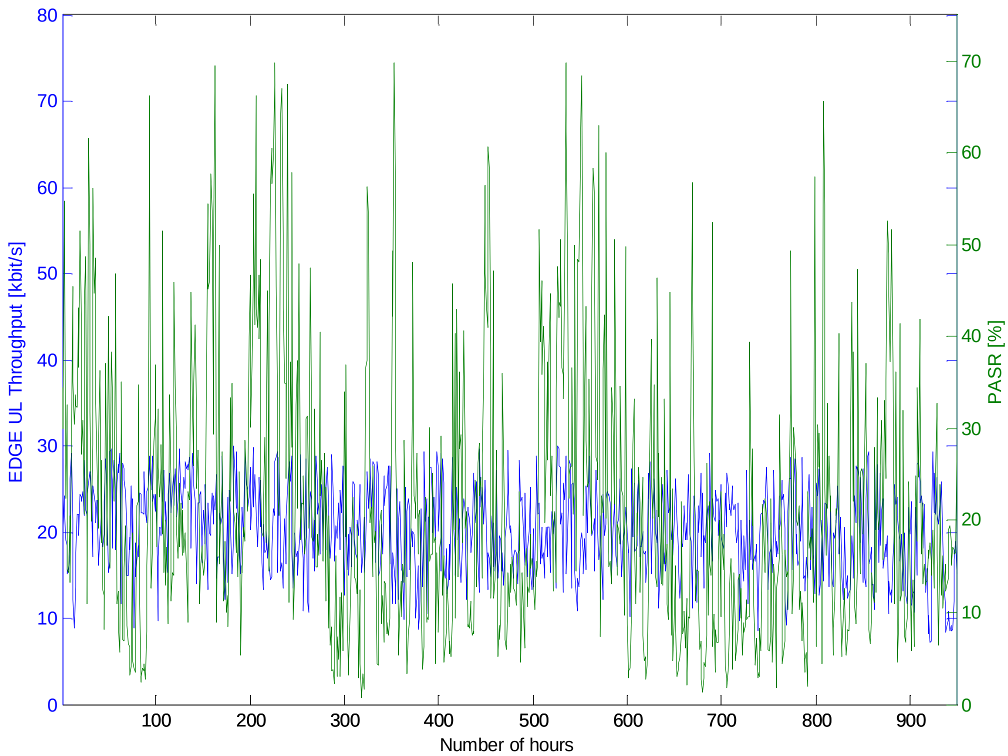

Figure D.30 BS 71 - $T_{EDGE_{UL}}$and R_{PDCH_S} performance analysis: correlation value of -6.15%.

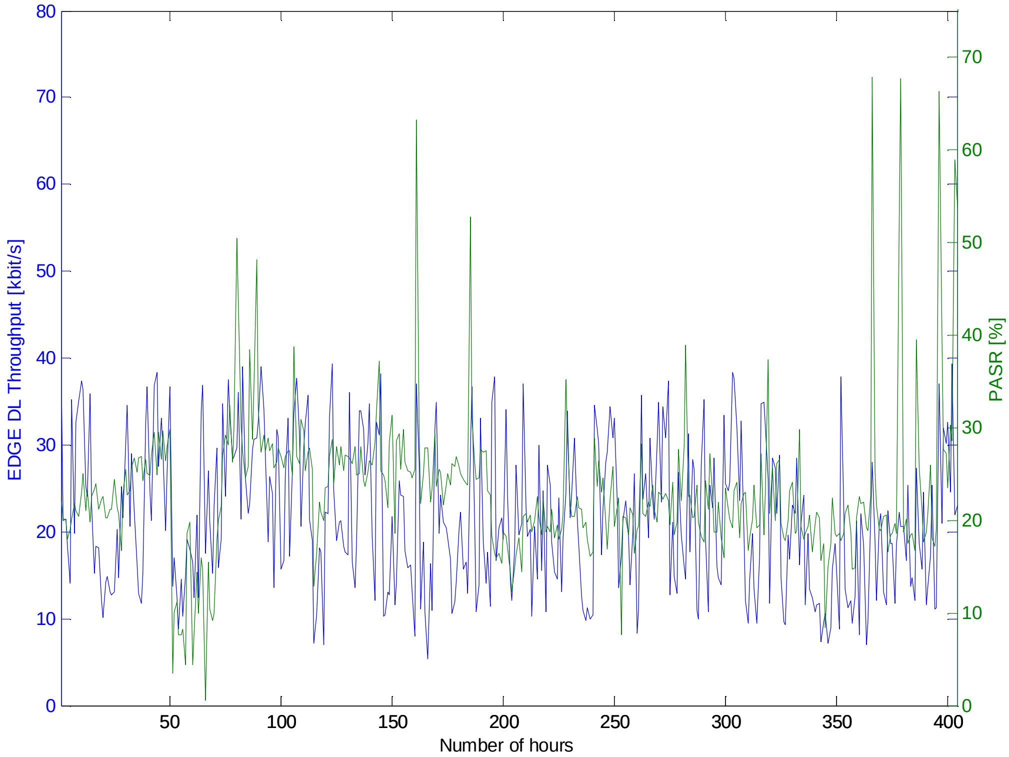

Figure D.31 BS 87 - $T_{EDGE_{DL}}$ and R_{PDCH_S} performance analysis: correlation value of -32.10%.

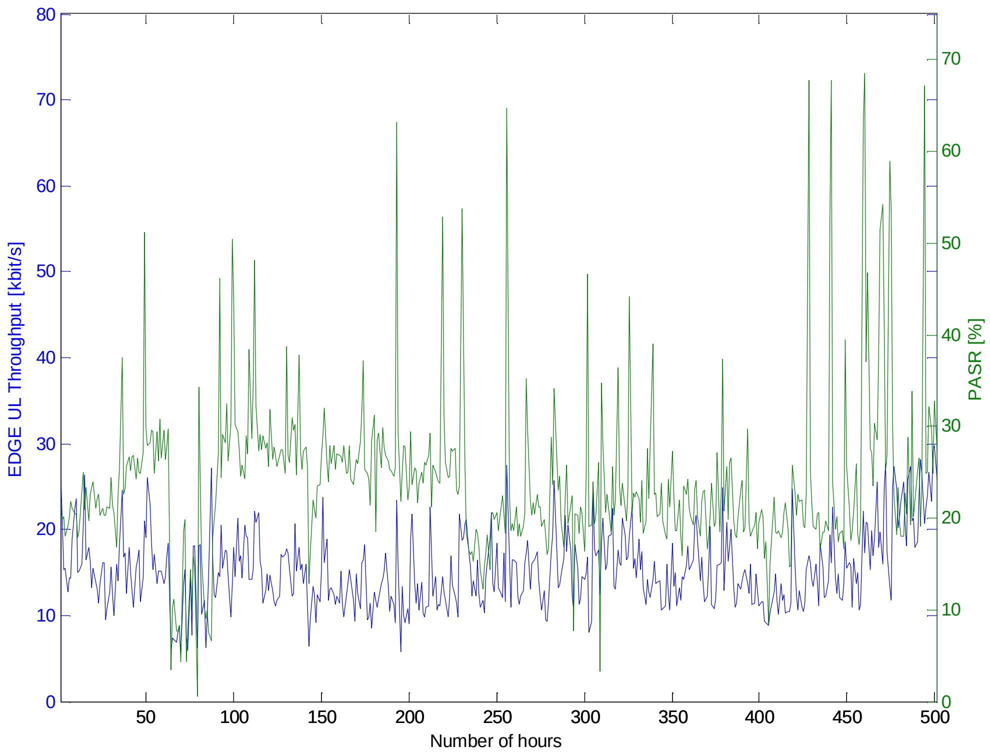

Figure D.32 BS 87 - $T_{EDGE_{UL}}$ and R_{PDCH_S} performance analysis: correlation value of -34.66%.

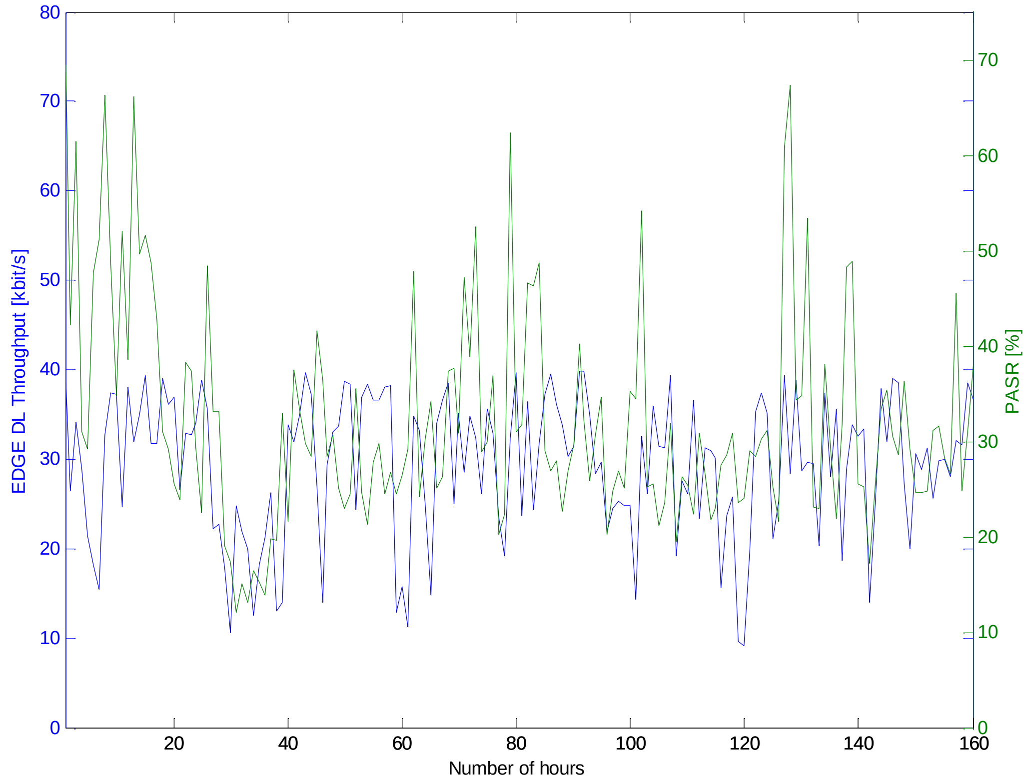

Figure D.33 BS 80 - $T_{EDGE_{DL}}$ and R_{PDCH_S} performance analysis: correlation value of -25.08%.

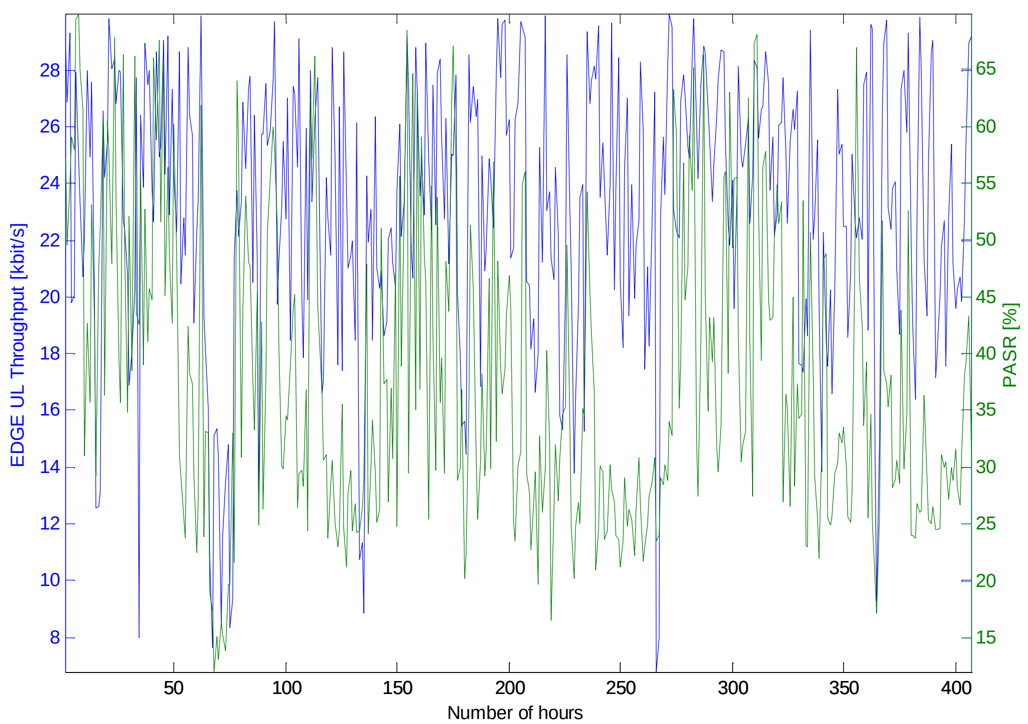

Figure D.34 BS 80 - $T_{EDGE_{UL}}$ and R_{PDCH_S} performance analysis: correlation value of -39.91%.

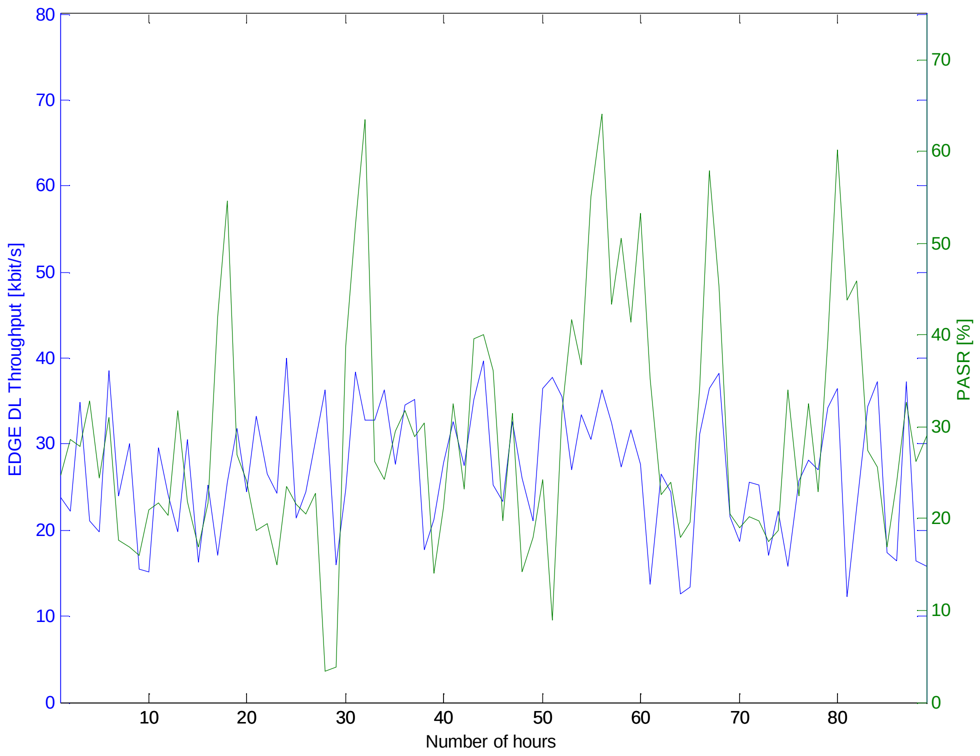

Figure D.35 BS 51 - $T_{EDGE_{DL}}$ and R_{PDCH_S} performance analysis: correlation value of -31.41%.

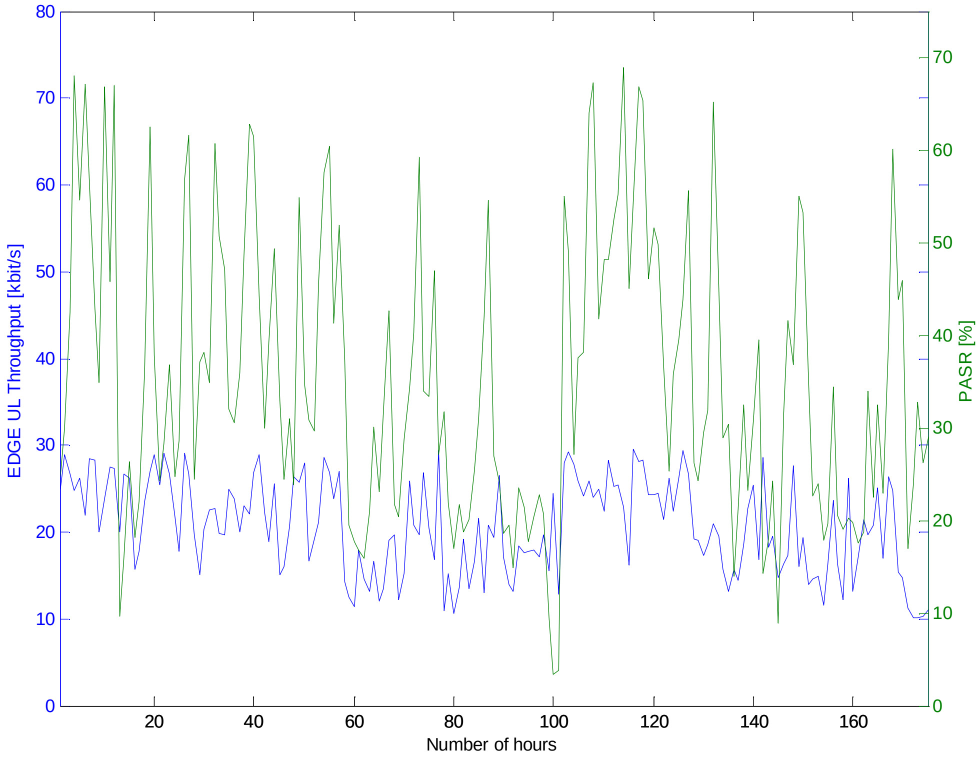

Figure D.36 BS 51 - $T_{EDGE_{UL}}$ and R_{PDCH_S} performance analysis: correlation value of -50.61%.

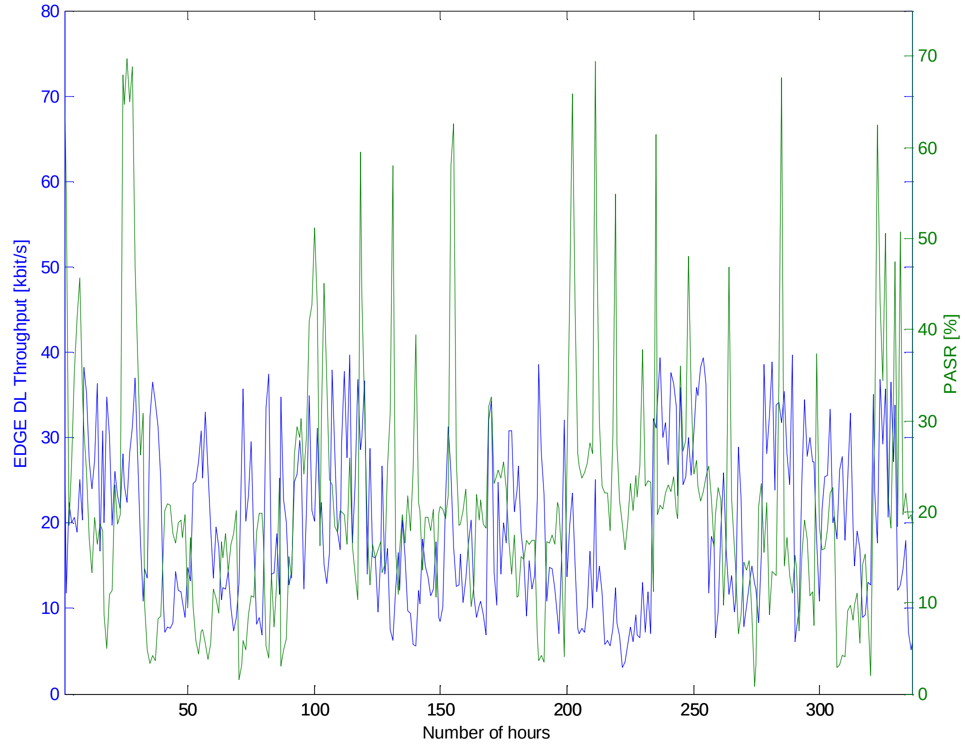

Figure D.37 BS 83 - $T_{EDGE_{DL}}$ and R_{PDCH_S} performance analysis: correlation value of -4.50%.

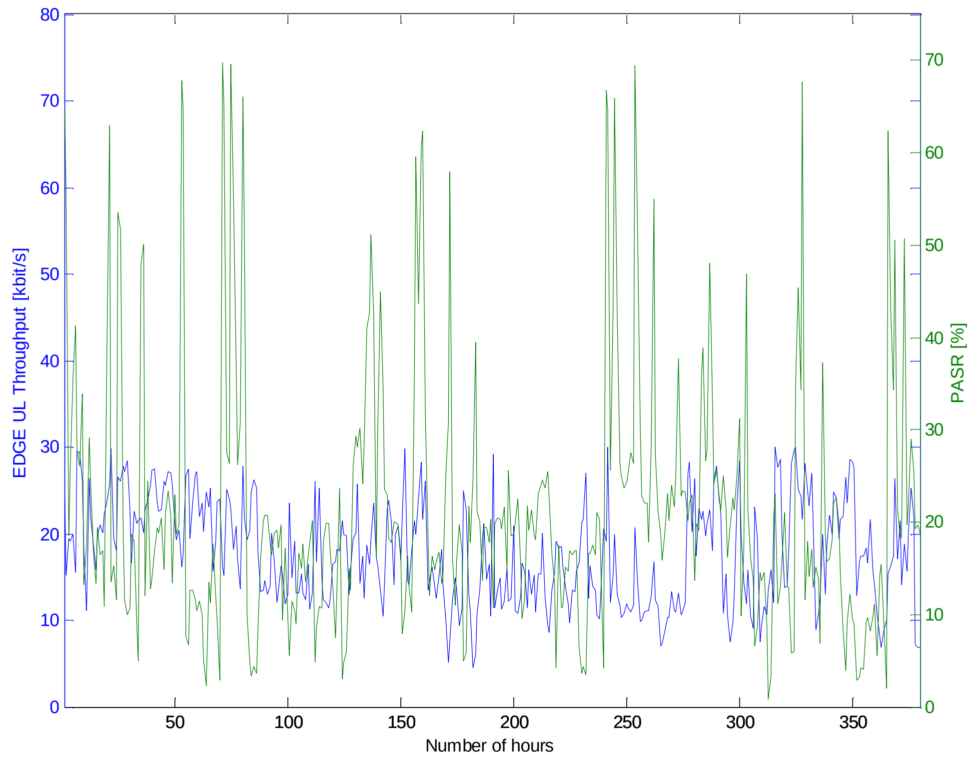

Figure D.38 BS 83 - $T_{EDGE_{UL}}$ and R_{PDCH_S} performance analysis: correlation value of -3.25%.

D.2 UMTS KPI Analysis

Analysing the results concerning speech call setup success rate, it is now possible to identify the percentage associated to the number of hours where the KPI value is above the threshold level at the same time as others KPIs, Table D.6.

Table D.6 R_{SCS_S} analysis.

BS	R_{SCS_S} and R_{SC_D} (%)
8	94.03
10	92.31
2	45.45
3	41.18
4	15.79
5	12.50
6	4.76
1	0
7	0
9	0

Looking at the results, it is possible to conclude that in BSs 8 and 10 when the speech call setup success rate is below the threshold level the speech call drop rate is also above the threshold level with a probability of 94.03% and 92.31%, respectively. Figure D.40 shows $\boldsymbol{R_{SCS_S}}$ and $\boldsymbol{R_{SC_D}}$ performance evolution in that period in BS 10.

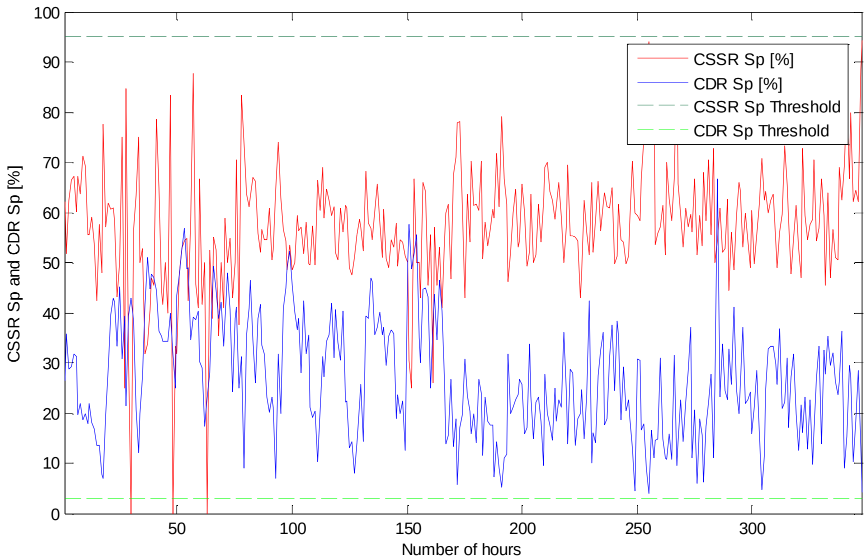

Figure D.39 BS 10 – R_{SCS_S} and R_{SC_D} performance analysis: correlation value of -36.84%.

In BS 10, speech call drop rate has an average value of 26.93%. 0.13% of the speech call drops are due to lost of UL synchronism, 0% due to congestion and due to missing neighbours, 9.68% due to SHO action and 90.19% due to other reasons. Since the majority of the drops are due to unknown reasons, the call setup success rate performance will be analysed. With an average value of 57.51%, the RRC connection success rate has an average value of 58.33% and the RAB establishment success rate has an average value of 98.56%. Figure D.41 illustrates the total number of failures after admission control and the RRC success rate.

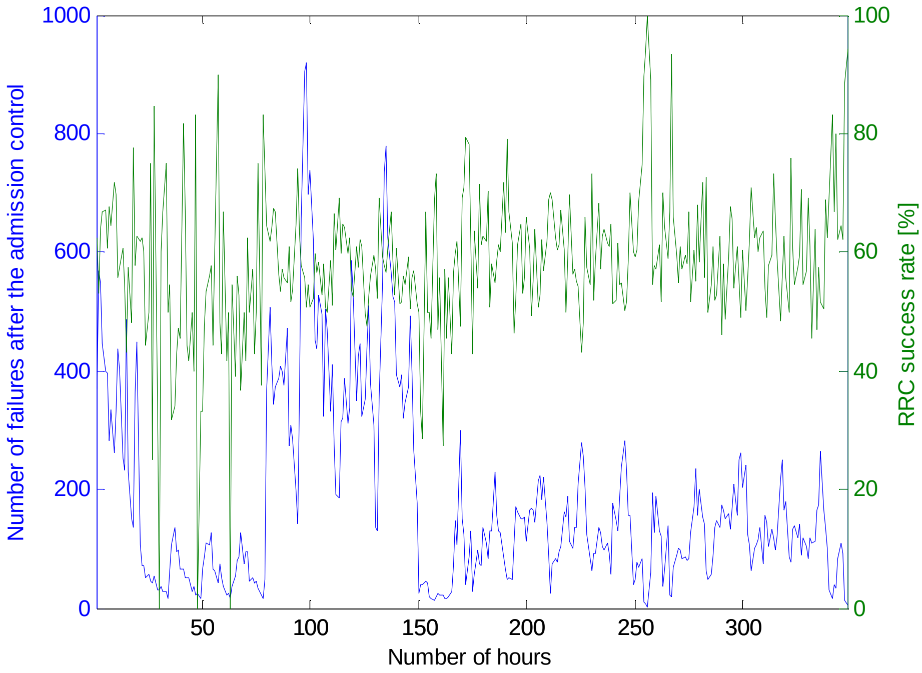

Figure D.40 BS 10 – Total number of failures after admission control versus “RRC success rate”.

The two parameters have a correlation value between them of -6.99% which appears to be a very low value. In this specific BS there are 466 fails due to MP load control (before the admission control process). With a total number of 63116 RRC or RAB failures after admission control, none of them are RRC fails due to transport network blocking, which means that all problems are related to the Iub configuration. There are no RRC or RAB requests denied due to admission control, which means there are no radio problems.

Analysing the results concerning $R_{PSR99\_ICS_S}$ parameter, it is possible to identify the percentage associated to the number of hours where the KPI value is above the threshold level at the same time as others KPIs, Table D.7.

Analysing the results concerning $R_{HSDPA\_ICS_S}$ parameter, it is possible to identify the percentage associated to the number of hours where the KPI value is above the threshold level at the same time as others KPIs, Table D.8. Looking at the results it is possible to conclude that in BSs 67, 42, 55, 39 and 8 when the HSDPA interactive call setup success rate is below the threshold level the HSDPA Interactive call drop rate is also above the threshold level with a probability of 94.32%, 93.69%, 92.11%, 91.82% and 90.96%, respectively. Figures D.42 to D.46 show $R_{HSDPA\_ICS_S}$ and $R_{HSDPA\_IC_D}$ performance evolution in that period.

Table D.7 $R_{PSR99\_ICS_S}$ analysis.

BS	$R_{PSR99\_ICS_S}$ and $R_{PSR99\_IC_D}$ (%)	BS	$R_{PSR99\_ICS_S}$ and $R_{PSR99\_IC_D}$ (%)	BS	$R_{PSR99\_ICS_S}$ and $R_{PSR99\_IC_D}$ (%)	BS	$R_{PSR99\_ICS_S}$ and $R_{PSR99\_IC_D}$ (%)
58	45.64	**6**	0.00	**32**	0.00	**57**	0.00
80	7.95	**9**	0.00	**33**	0.00	**59**	0.00
78	6.83	**10**	0.00	**34**	0.00	**60**	0.00
3	4.05	**11**	0.00	**35**	0.00	**61**	0.00
55	3.88	**13**	0.00	**36**	0.00	**62**	0.00
12	2.27	**14**	0.00	**37**	0.00	**63**	0.00
51	1.99	**15**	0.00	**38**	0.00	**64**	0.00
8	1.61	**16**	0.00	**39**	0.00	**65**	0.00
2	1.42	**17**	0.00	**40**	0.00	**66**	0.00
74	1.34	**18**	0.00	**41**	0.00	**67**	0.00
31	1.16	**19**	0.00	**44**	0.00	**68**	0.00
42	1.08	**20**	0.00	**45**	0.00	**69**	0.00
53	0.99	**22**	0.00	**46**	0.00	**70**	0.00
43	0.98	**23**	0.00	**47**	0.00	**71**	0.00
21	0.97	**24**	0.00	**48**	0.00	**72**	0.00
4	0.96	**25**	0.00	**49**	0.00	**73**	0.00
7	0.82	**26**	0.00	**50**	0.00	**75**	0.00
28	0.82	**27**	0.00	**52**	0.00	**76**	0.00
1	0.00	**29**	0.00	**54**	0.00	**77**	0.00
5	0.00	**30**	0.00	**56**	0.00	**79**	0.00

Table D.8 $R_{HSDPA\_ICS_S}$ analysis.

BS	$R_{HSDPA\_ICS_S}$ and $R_{HSDPA\_IC_D}$ (%)	BS	$R_{HSDPA\_ICS_S}$ and $R_{HSDPA\_IC_D}$ (%)	BS	$R_{HSDPA\_ICS_S}$ and $R_{HSDPA\_IC_D}$ (%)	BS	$R_{HSDPA\_ICS_S}$ and $R_{HSDPA\_IC_D}$ (%)
67	94.32	**31**	80.35	**23**	81.12	**36**	69.81
42	93.69	**62**	78.09	**7**	80.58	**43**	68.31
55	92.11	**15**	77.65	**5**	67.98	**33**	56.67
39	91.82	**58**	76.34	**48**	67.74	**2**	54.47
51	91.76	**54**	76.13	**46**	67.53	**52**	51.52
8	90.96	**12**	75.15	**29**	67.27	**21**	50.88
1	89.83	**53**	73.10	**37**	66.13	**19**	47.51
64	89.64	**63**	72.73	**68**	65.84	**11**	42.61
60	85.88	**16**	71.75	**32**	63.78	**41**	41.78
38	85.03	**24**	71.73	**40**	62.07	**26**	40.46
28	82.93	**56**	71.43	**34**	60.77	**9**	38.01
35	82.81	**20**	71.34	**66**	60.69	**17**	37.28
61	81.92	**22**	71.19	**49**	60.48	**65**	35.38
6	81.76	**3**	70.83	**44**	58.88	**59**	34.86
50	81.67	**47**	70.25	**4**	58.73	**57**	33.33

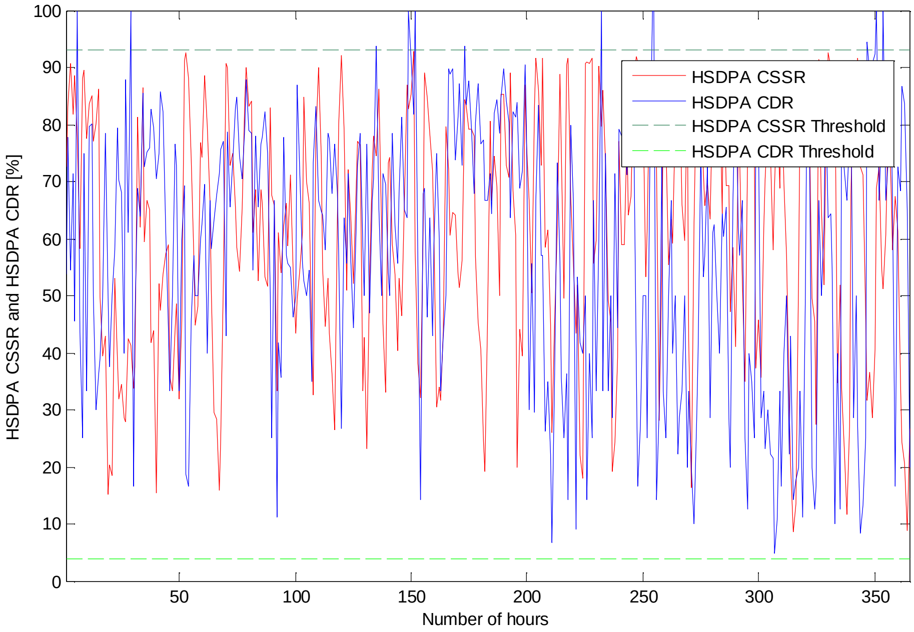

Figure D.41 BS 67 – $R_{HSDPA\_ICS_S}$ and $R_{HSDPA\_IC_D}$ performance analysis: correlation value of -0.80%.

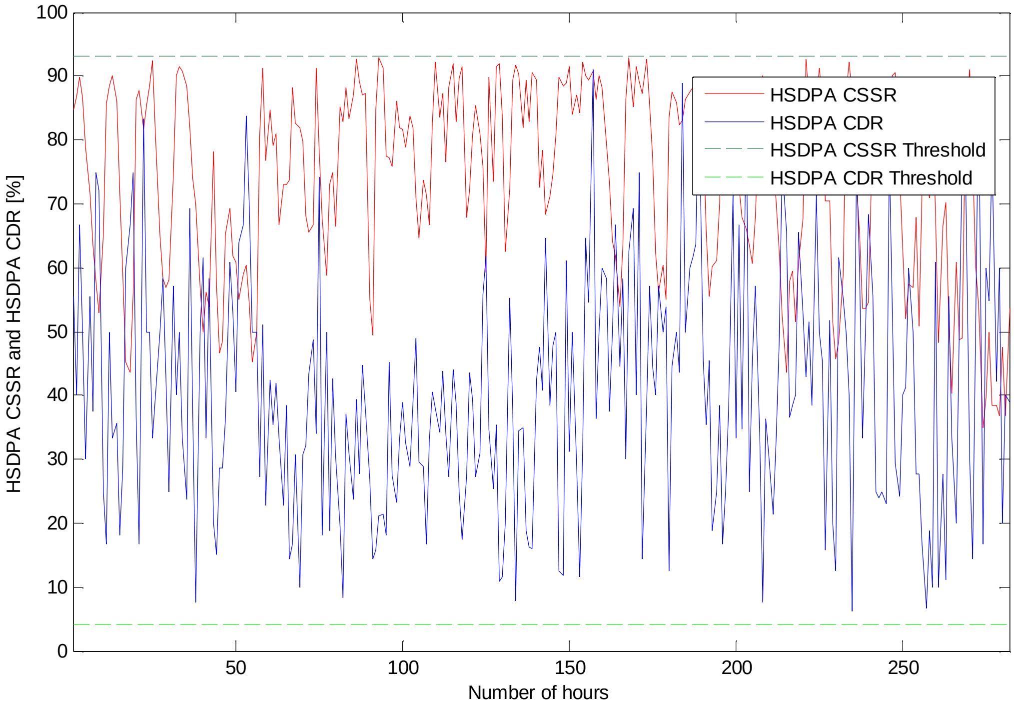

Figure D.42 BS 42 – $R_{HSDPA\_ICS_S}$ and $R_{HSDPA\_IC_D}$ performance analysis: correlation value of -18.39%.

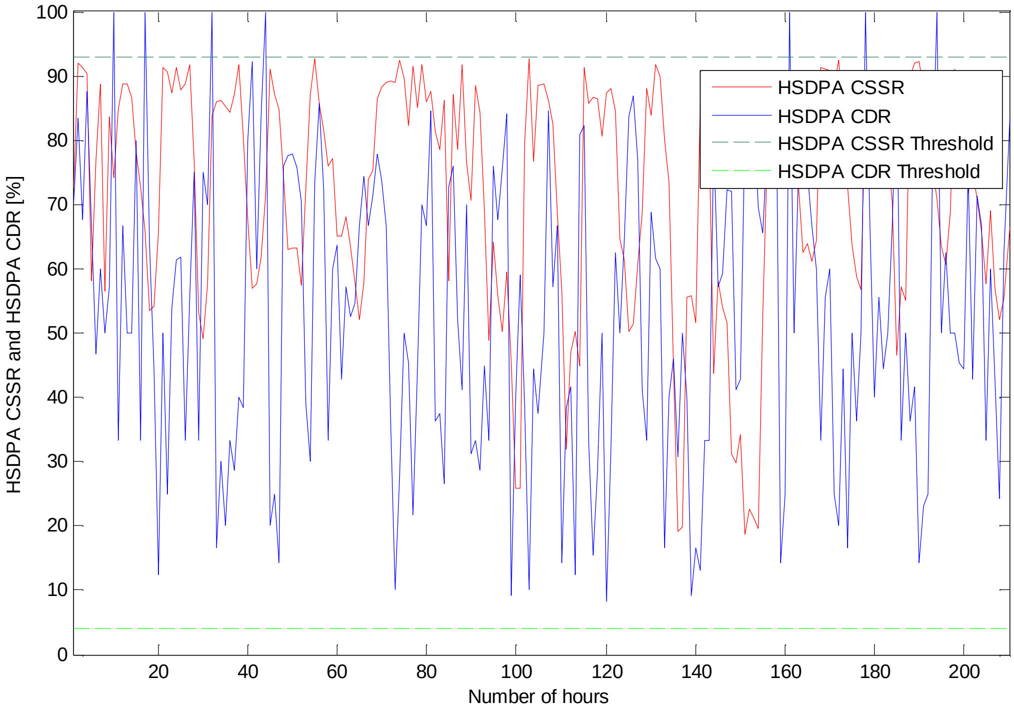

Figure D.43 BS 55 – $R_{HSDPA\_ICS_S}$ and $R_{HSDPA\_IC_D}$ performance analysis: correlation value of -18.63%.

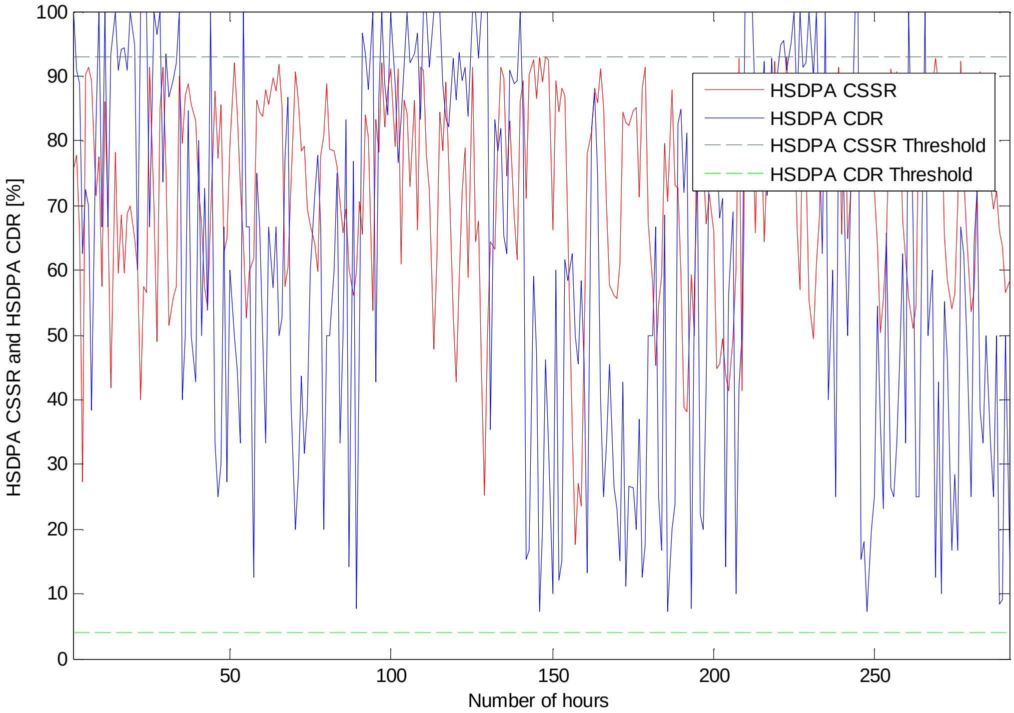

Figure D.44 BS 39 – $R_{HSDPA\_ICS_S}$ and $R_{HSDPA\_IC_D}$ performance analysis: correlation value of -7.23%.

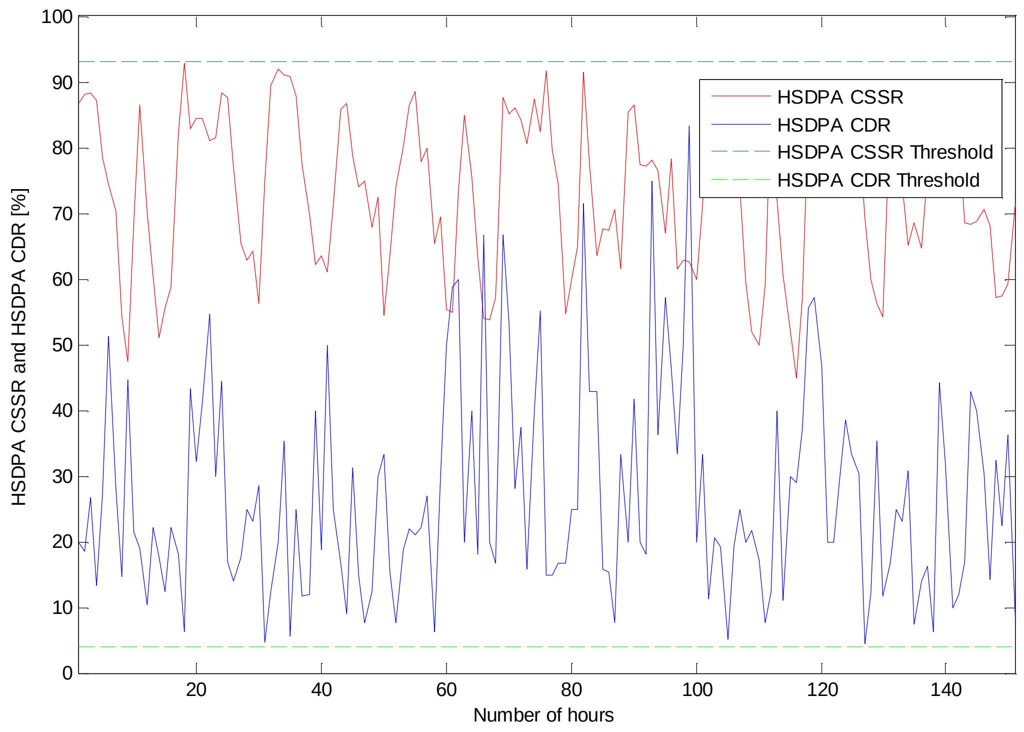

Figure D.45 BS 8 – $R_{HSDPA\_ICS_S}$ and $R_{HSDPA\_IC_D}$ performance analysis: correlation value of -0.85%.

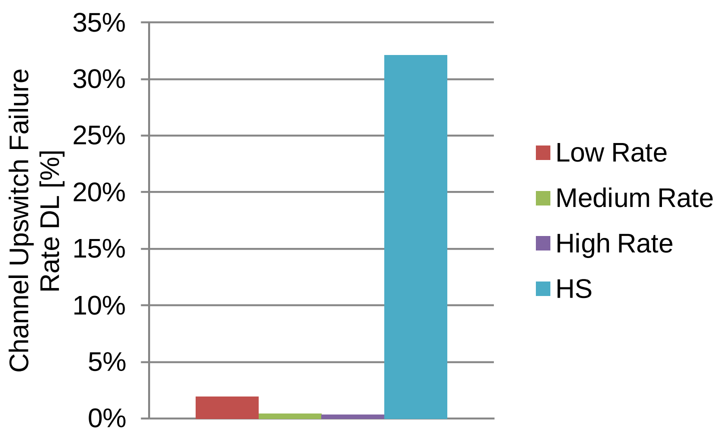

Figure D.46 BS 67 – Channel Upswitch Failure Rate DL.

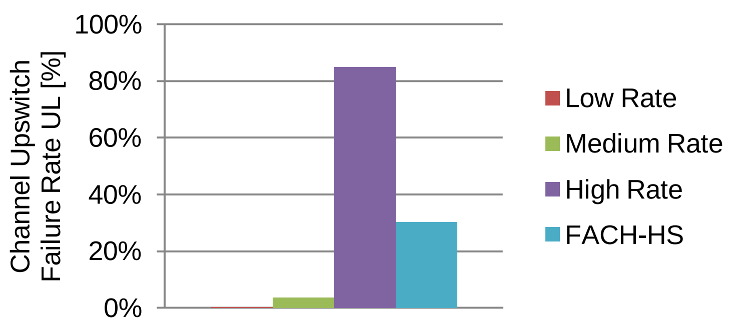

Figure D.47 BS 67 – Channel Upswitch Failure Rate UL.

In BS 67 HSDPA interactive call drop rate has an average value of 57.76%. With a number of 9457 abnormal RAB PS HSDPA releases and according to the “Minutes per Drop” KPI, a user experiences a drop call, in average, in every 1h33min9s, which does not exceed the predefined threshold. The channel downswitch failure rate has an average value of 0.25%. Figures D.47 and D.48 represent the percentage distribution of the channel upswitch failure rate for BS 58. It is possible to conclude that the DL/UL HS transitions fail very often, with average values of around 30%. Analysing the call setup success rate performance, with an average value of 61.73%, the RRC connection success rate has an average value of 99.71% and the RAB establishment success rate has an average value of 61.90%. Figure D.49 illustrates the comparison between the total number of failures after the admission control and the RAB success rate.

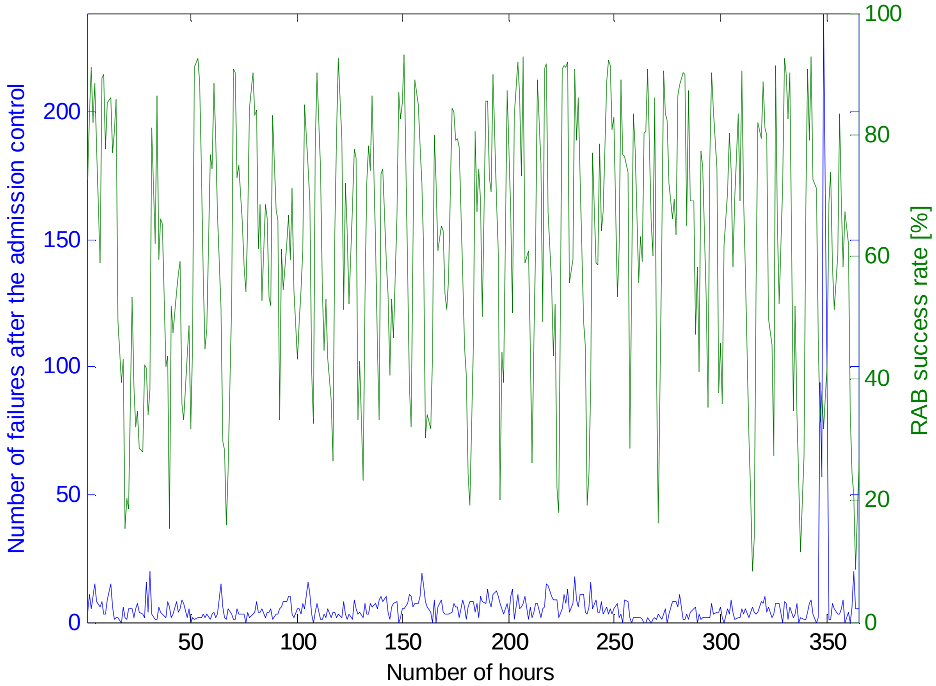

Figure D.48 BS 67 – Total number of failures after admission control versus “RAB success rate”.

Apparently there is not any kind of correlation between the two parameters. The correlation value between proves it: -9.59%. With a total number of 260 RRC or RAB requests denied due to admission control, all of them are related to RAB issues: 67.83% of the fails are due to lack of DL channelisation codes and 32.17% are due to insufficient licenses for the number of users that are attempting to access to the network. Figure D.50 illustrates the correlation between the number of abnormal RAB PS HSDPA releases and the number of normal RAB speech releases. With a correlation value of -4.93%, it appears to be no correlation between the parameters.

In BS 42 HSDPA interactive call drop rate has an average value of 40.65%. With a number of 3017 abnormal RAB PS HSDPA and according to the obtained results, a user does not experiences a drop call. The channel downswitch failure rate has an average value of 4.24%. Figures D.51 and D.52 represent the percentage distribution of the channel upswitch failure rate for BS 42.

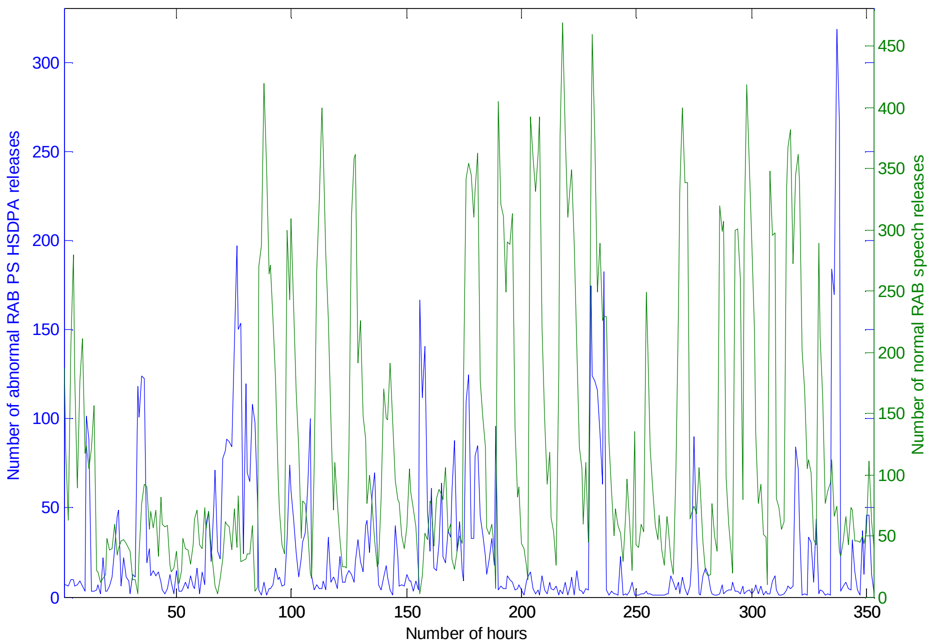

Figure D.49 BS 67 – Abnormal RAB PS HSDPA releases and normal RAB speech releases.

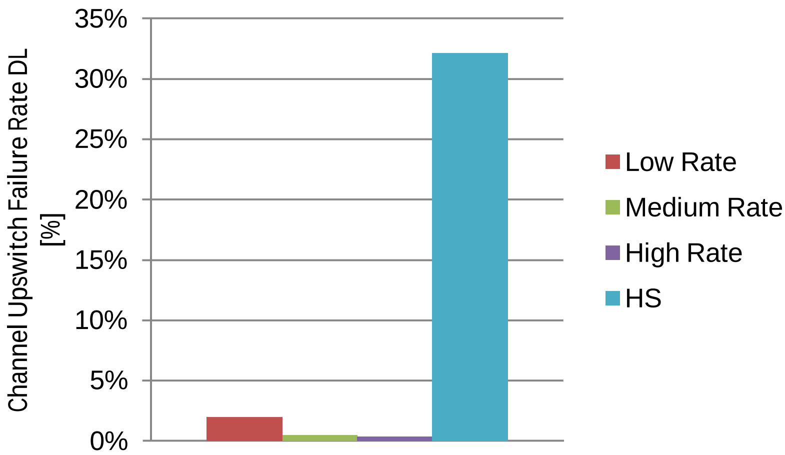

Figure D.50 BS 42 – Channel Upswitch Failure Rate DL.

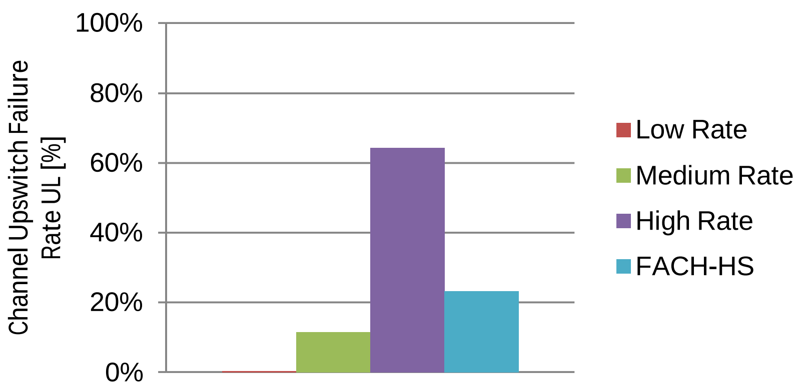

Figure D.51 BS 42 – Channel Upswitch Failure Rate UL.

It is possible to conclude that the DL/UL HS transitions fail very often, with average values of around 32% and 22%, respectively. Analysing the call setup success rate performance, with an average value of 73.86%, the RRC connection success rate has an average value of 99.86% and the RAB establishment success rate has an average value of 73.98%. Figure D.53 illustrates the comparison between the total number of failures after the admission control and the RAB success rate.

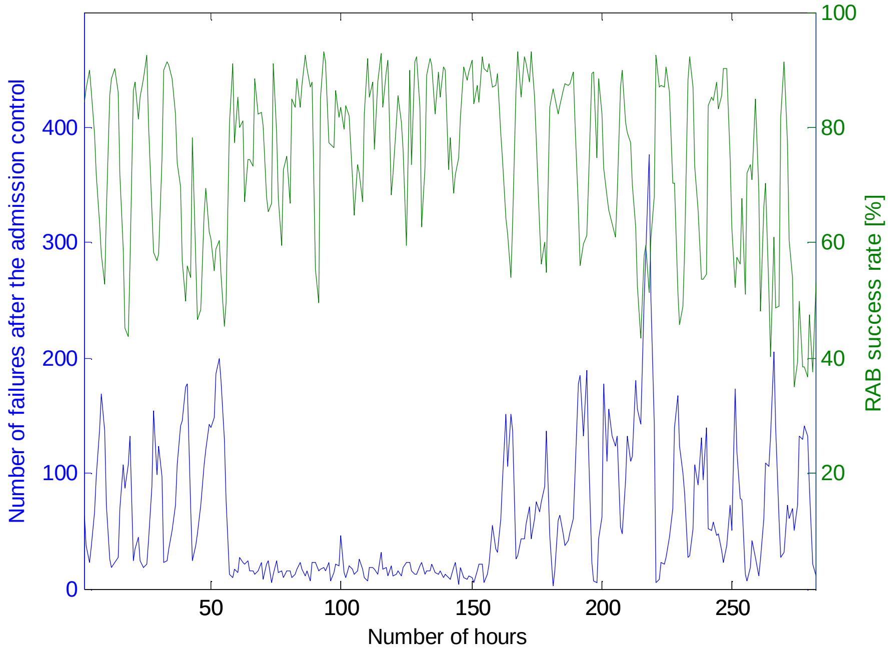

Figure D.52 BS 42 – Total number of failures after admission control versus “RAB success rate”.

It is possible to see that when the number of failures increases, the RAB success rate decreases, with a correlation value between them of -60.75%. With a total number of 17115 RRC or RAB failures after the admission control, 14306 are RAB fails due to transport network issues and 36 are due to node blocking problems. Analysing the number of requests denied due to admission control (total of 706), 72.35% are due to insufficient licenses for the number of users that are attempting to access to the network and 27.65% are due to lack of DL channelisation codes. Figure D.54 illustrates the correlation between the number of abnormal RAB PS HSDPA releases and the number of normal RAB speech releases. With a correlation value of -24.51%, it is possible to see that in some hours when the number of normal RAB speech releases increases, the number of abnormal RAB PS DCH/FACH releases decreases, which does not support the establishment of any relationship in accordance with the previsions.

In BS 55 HSDPA interactive call drop rate has an average value of 53.37%. With a number of 2092 abnormal RAB PS HSDPA releases and according to the “Minutes per Drop” KPI, a user experiences a drop call, in average, in every 31min35s, which does not exceed the predefined threshold. The channel donswitch failure rate has an average value of 5.30%. Figures D.55 and D.56 represent the percentage distribution of the channel upswitch failure rate for BS 55.

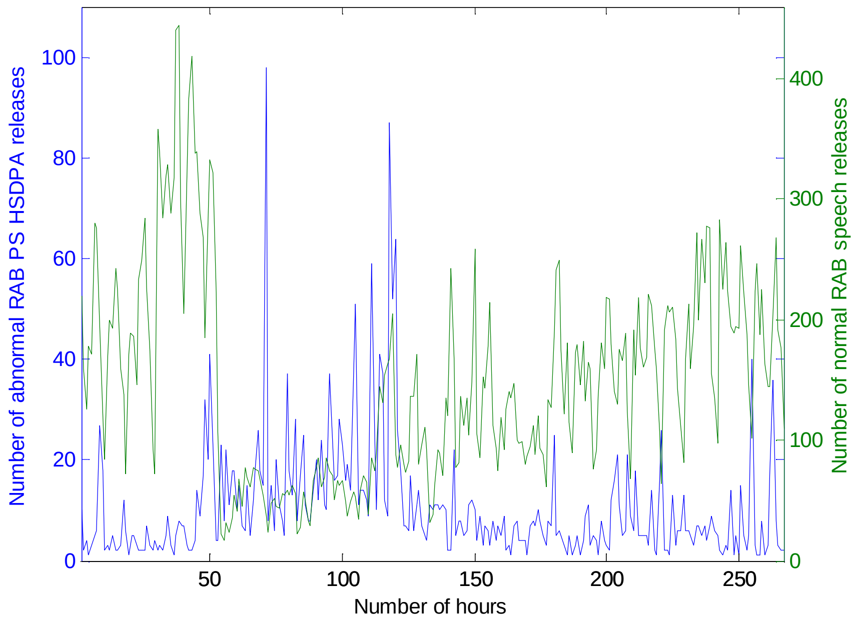

Figure D.53 Abnormal RAB PS HSDPA releases and normal RAB speech releases.

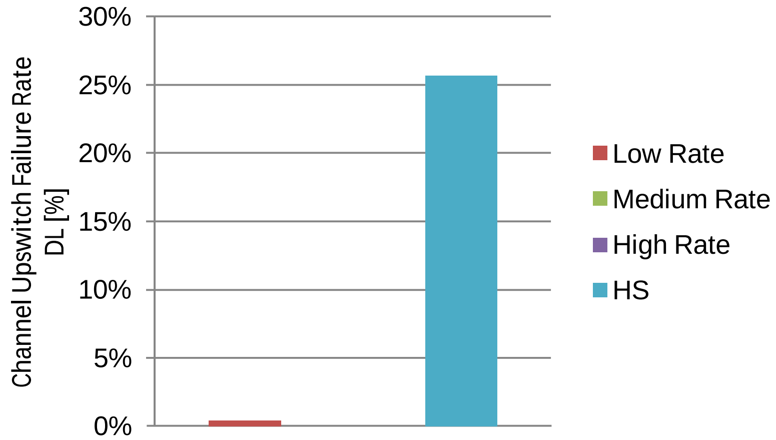

Figure D.54 BS 55 – Channel Upswitch Failure Rate DL.

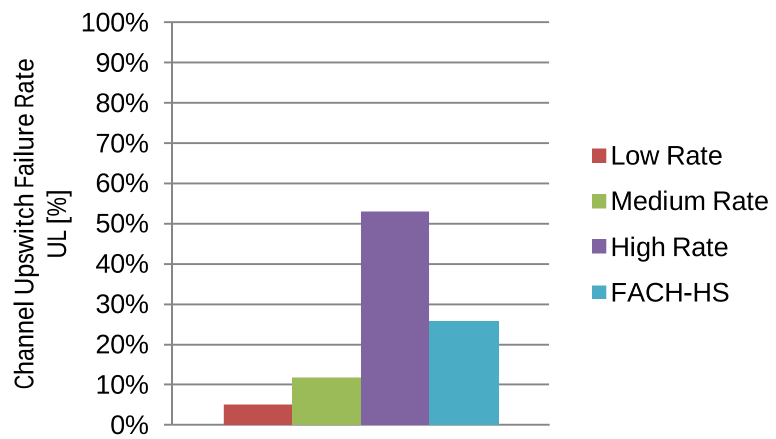

Figure D.55 BS 55 – Channel Upswitch Failure Rate UL.

It is possible to conclude that the DL/UL HS transitions fail very often, with average values of around 25%. Analysing the call setup success rate performance, with an average value of 71.87%, the RRC connection success rate has an average value of 99.23% and the RAB establishment success rate has an average value of 72.39%. Figure D.55 illustrates the comparison between the total number of failures after the admission control and the RAB success rate.

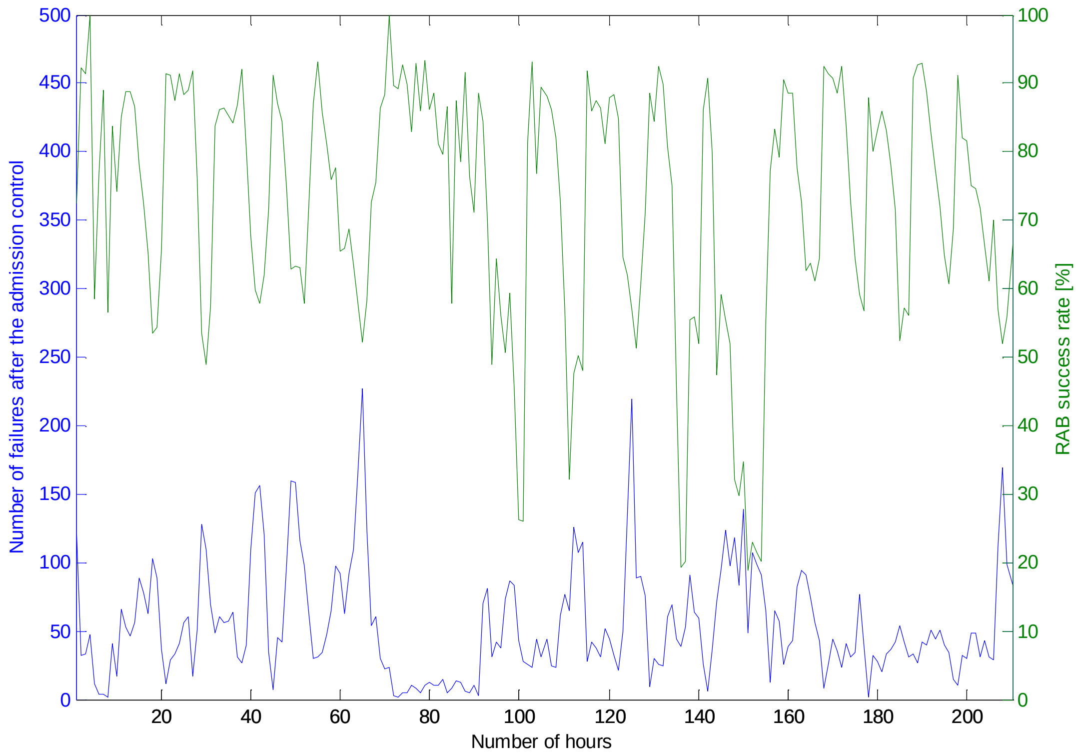

Figure D.56 BS 55 – Total number of failures after admission control versus “RAB success rate”.

It is possible to see that when the number of failures increases, the RAB success rate decreases, with a correlation value between them of -53.15%. With a total number of 11436 RRC or RAB failures after the admission control, 9477 are RAB fails due to transport network issues and 453 are due to node blocking problems. There are only 9 requests denied due to admission control so the analysis will not be done. Figure D.57 illustrates the correlation between the number of abnormal RAB PS HSDPA releases and the number of normal RAB speech releases. With a correlation value of 2.69%, it appears to be no correlation between the parameters.

In BS 39 HSDPA interactive call drop rate has an average value of 62.49%. With a number of 3488 abnormal RAB PS HSDPA and according to the “Minutes per Drop” KPI, a user experiences a drop call, in average, in every 27min40s, which does not exceed the predefined threshold. The channel donswitch failure rate has an average value of 3.59%. Figures D.58 and D.59 represent the percentage distribution of the channel upswitch failure rate for BS 39.

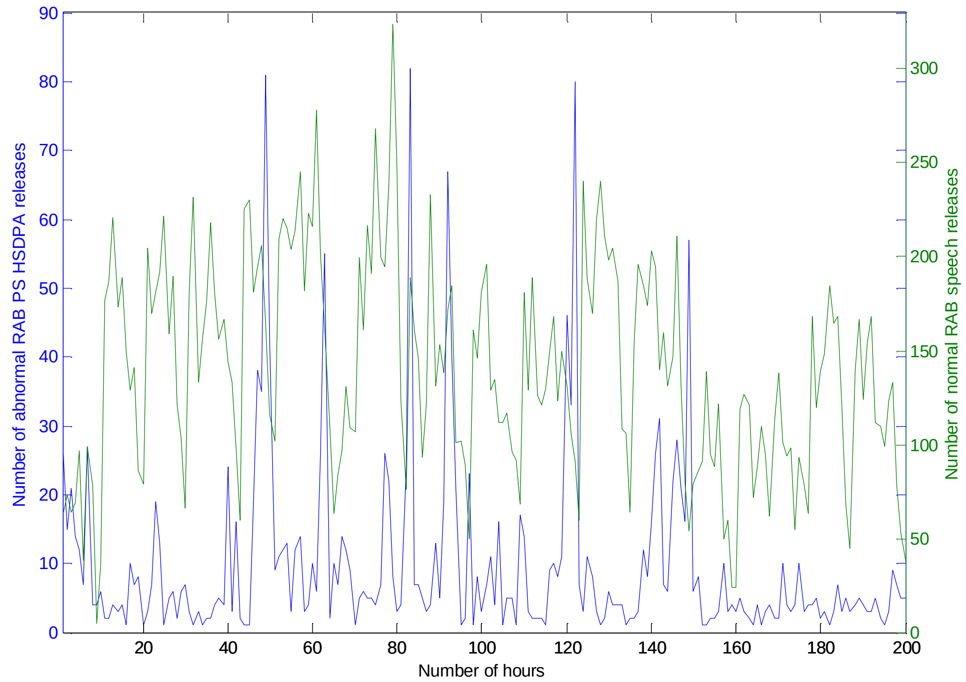

Figure D.57 BS 55 – Abnormal RAB PS HSDPA releases and normal RAB speech releases.

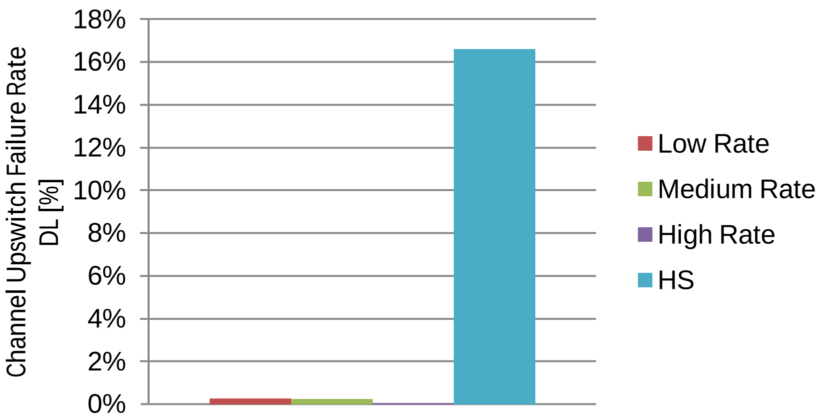

Figure D.58 BS 39 – Channel Upswitch Failure Rate DL.

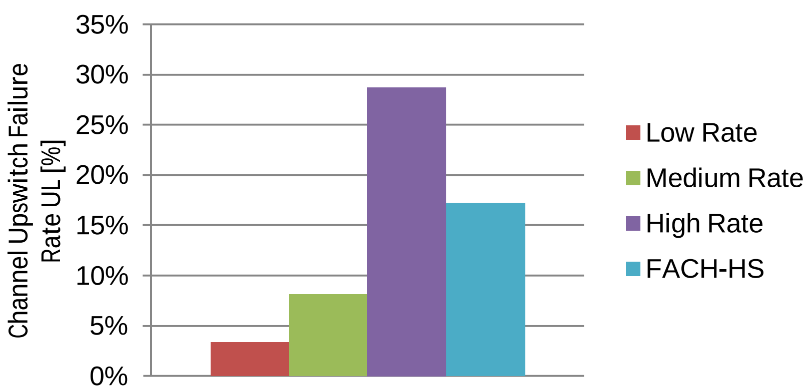

Figure D.59 BS 39 – Channel Upswitch Failure Rate UL.

It is possible to conclude that the DL/UL HS transitions fail very often, with average values of around 16%. Analysing the call setup success rate performance, with an average value of 72.34%, the RRC connection success rate has an average value of 97.95% and the RAB establishment success rate has an average value of 74.07%. Figure D.60 illustrates the comparison between the total number of failures after the admission control and the RAB success rate.

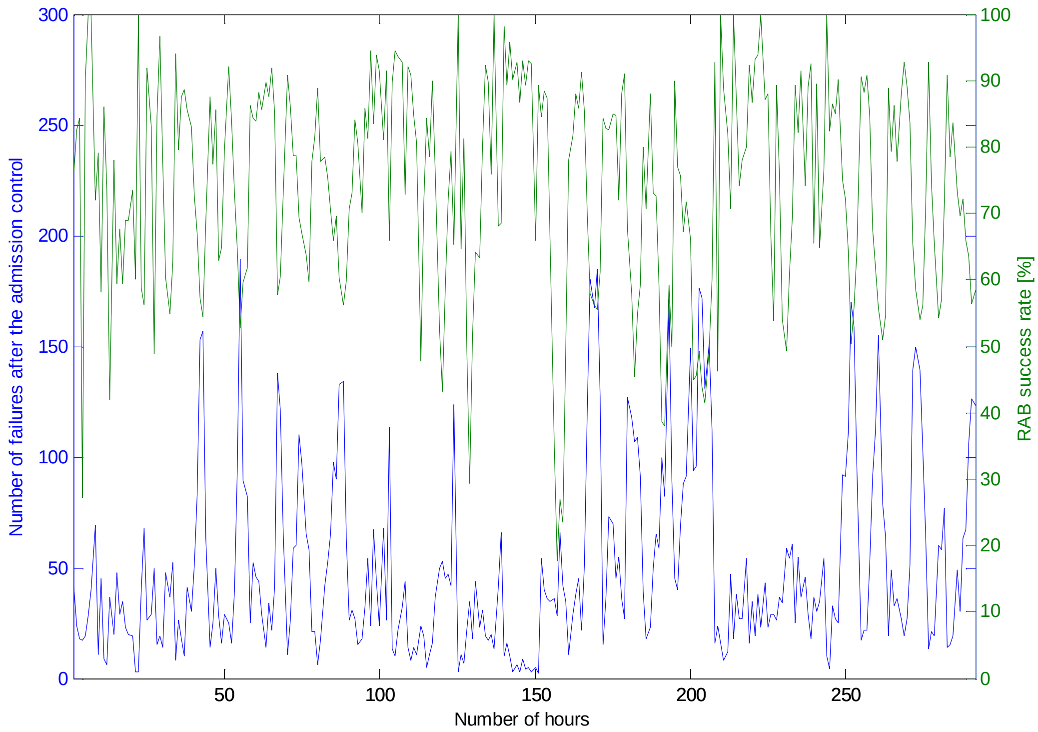

Figure D.60 BS 39 – Total number of failures after admission control versus “RAB success rate”.

It is possible to see that when the number of failures increases, the RAB success rate decreases, with a correlation value between them of -55.66%. With a total number of 14508 RRC or RAB failures after the admission control, 9943 are RAB fails due to transport network issues and 2330 are due to node blocking problems. There are only 19 requests denied due to admission control so the analysis will not be done. Figure D.62 illustrates the correlation between the number of abnormal RAB PS HSDPA releases and the number of normal RAB speech releases. With a correlation value of -28.71%, it is possible to see that in some hours when the number of normal RAB speech releases increases, the number of abnormal RAB PS DCH/FACH releases decreases, which does not support the establishment of any relationship in accordance with the previsions.

In BS 8 HSDPA interactive call drop rate has an average value of 27.00%. With a number of 1124 abnormal RAB PS HSDPA and according to the “Minutes per Drop” KPI, a user experiences a drop call, in average, in every 43min16s, which does not exceed the predefined threshold. The channel donswitch failure rate has an average value of 6.26%. Figures D.63 and D.64 represent the percentage distribution of the channel upswitch failure rate for BS 8.

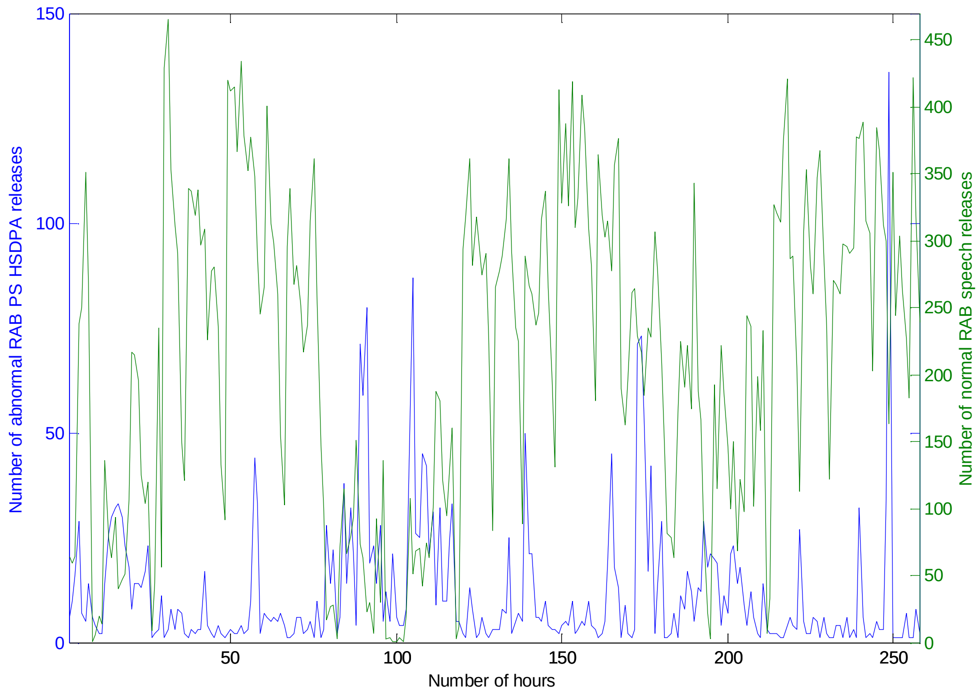

Figure D.61 BS 39 – Abnormal RAB PS HSDPA releases and normal RAB speech releases.

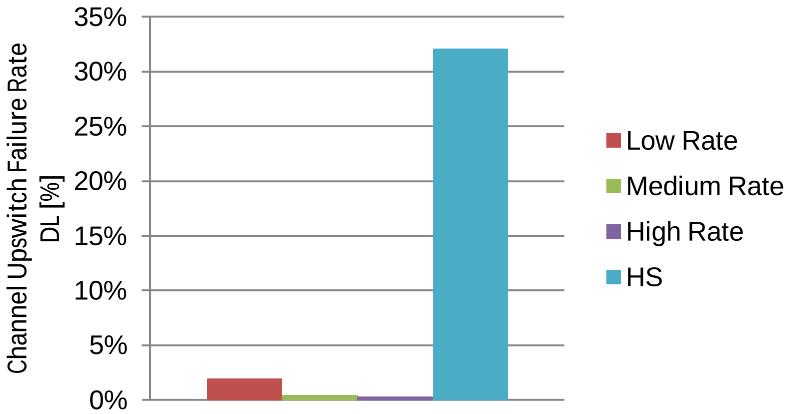

Figure D.62 BS 8 – Channel Upswitch Failure Rate DL.

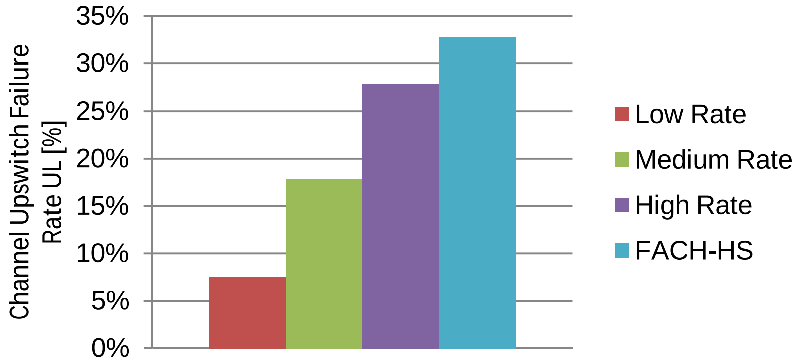

Figure D.63 BS 8 – Channel Upswitch Failure Rate UL.

It is possible to conclude that the DL/UL HS transitions fail very often, with average values of around 32%. Analysing the call setup success rate performance, with an average value of 73.40%, the RRC connection success rate has an average value of 99.81% and the RAB establishment success rate has an average value of 73.54%. Figure D.65 illustrates the comparison between the total number of failures after the admission control and the RAB success rate.

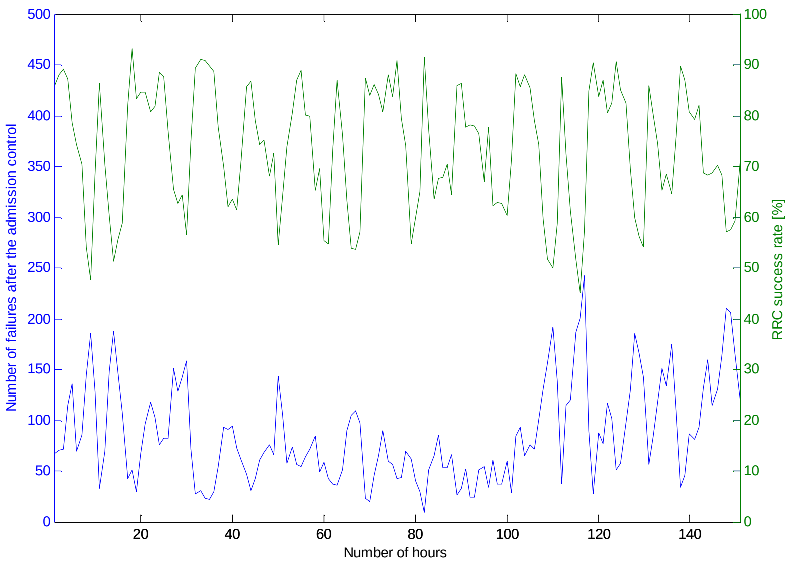

Figure D.64 BS 8 – Total number of failures after admission control versus “RAB success rate”.

It is possible to see that when the number of failures increases, the RAB success rate decreases, with a correlation value between them of -64.45%. With a total number of 12998 RRC or RAB failures after the admission control, two failing reasons can be identified: 1 fail is due to RAB node blocking issues and 10554 fails are due to transport network problems. The number of failures during the admission control process is irrelevant compared to the number of failures after the process so the analysis will not be done. Figure D.66 illustrates the correlation between the number of abnormal RAB PS HSDPA releases and the number of normal RAB speech releases. With a correlation value of 24.04%, the graphic representation is not very clear in order to identify any kind of relation between the two parameters.

Similar to what was done in the 2G analysis the existence of any kind of correlation between a drop call and HO issues will be checked. Analysing the results concerning R_{SC_D} and R_{SHO_S} parameter, it is possible to identify the percentage associated to the number of hours where the KPI value is above the threshold level at the same time as others KPIs, Table D.9. Looking at the results it is possible to conclude that in BSs 6, 38, 30, 11 and 21 when the speech call drop rate KPI is above the threshold level the Soft HO KPI is below the threshold level in 83.19%, 48.26%, 42.16%, 29.55% and 25.40% of the cases.

Analysing the results concerning $R_{PSR99\_IC_D}$ parameter, it is possible to identify the percentage associated to the number of hours where the KPI value is above the threshold level at the same time as others KPIs, Table D.10. Looking at the results, although there is a considerable number of BSs with problems associated to PS R99 call drop rate KPI, that problems are not related to SHO problems.

Analysing the results concerning $R_{HSDPA\_IC_D}$ parameter, it is possible to identify the percentage associated to the number of hours where the KPI value is above the threshold level at the same time as others KPIs, Table D.11. Looking at the results, although there is a considerable number of BSs with problems associated to PS R99 call drop rate KPI, that problems are not related to SHO problems.

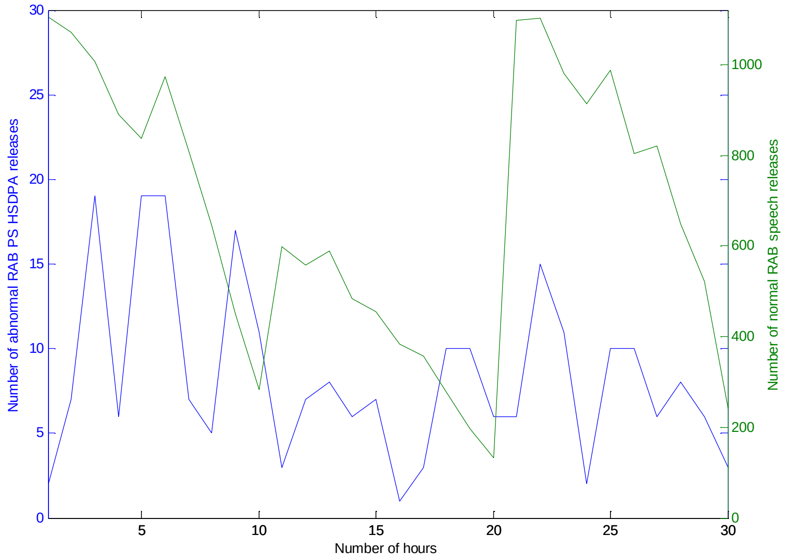

Figure D.65 BS 8 – Abnormal RAB PS HSDPA releases and normal RAB speech releases.

Table D.9 R_{SC_D} and R_{SHO_S} analysis.

BS	R_{SC_D} and R_{SHO_S} (%)	BS	R_{SC_D} and R_{SHO_S} (%)	BS	R_{SC_D} and R_{SHO_S} (%)	BS	R_{SC_D} and R_{SHO_S} (%)
6	83.19	**13**	0.83	**17**	0.00	**42**	0.00
38	48.26	**25**	0.71	**19**	0.00	**45**	0.00
30	42.16	**4**	0.37	**20**	0.00	**46**	0.00
11	29.55	**48**	0.30	**23**	0.00	**47**	0.00
21	25.40	**1**	0.00	**24**	0.00	**49**	0.00
37	19.63	**2**	0.00	**27**	0.00	**51**	0.00
43	18.18	**3**	0.00	**29**	0.00	**52**	0.00
44	9.20	**5**	0.00	**31**	0.00	**53**	0.00
32	6.98	**7**	0.00	**33**	0.00	**54**	0.00
50	6.67	**8**	0.00	**34**	0.00	**55**	0.00
22	5.13	**9**	0.00	**35**	0.00	**57**	0.00
26	4.55	**10**	0.00	**36**	0.00	**58**	0.00
18	2.82	**12**	0.00	**39**	0.00	**59**	0.00
56	1.33	**14**	0.00	**40**	0.00	**60**	0.00
28	1.27	**15**	0.00	**41**	0.00	**61**	0.00

Table D.10 $R_{PSR99\_IC_D}$ and R_{SHO_S} analysis.

BS	$R_{PSR99\_IC_D}$ and R_{SHO_S} (%)	BS	$R_{PSR99\_IC_D}$ and R_{SHO_S} (%)	BS	$R_{PSR99\_IC_D}$ and R_{SHO_S} (%)	BS	$R_{PSR99\_IC_D}$ and R_{SHO_S} (%)
15	2.14	**6**	0.00	**21**	0.00	**32**	0.00
19	1.96	**7**	0.00	**22**	0.00	**33**	0.00
41	1.61	**9**	0.00	**23**	0.00	**35**	0.00
14	1.53	**10**	0.00	**24**	0.00	**36**	0.00
8	1.52	**11**	0.00	**25**	0.00	**37**	0.00
34	0.55	**12**	0.00	**26**	0.00	**38**	0.00
1	0.00	**13**	0.00	**27**	0.00	**39**	0.00
2	0.00	**16**	0.00	**28**	0.00	**40**	0.00
3	0.00	**17**	0.00	**29**	0.00	**42**	0.00
4	0.00	**18**	0.00	**30**	0.00	**43**	0.00
5	0.00	**20**	0.00	**31**	0.00	**44**	0.00

Table D.11 $R_{HSDPA\_IC_D}$ and R_{SHO_S} analysis.

BS	$R_{HSDPA\_IC_D}$ and R_{SHO_S} (%)	BS	$R_{HSDPA\_IC_D}$ and R_{SHO_S} (%)	BS	$R_{HSDPA\_IC_D}$ and R_{SHO_S} (%)	BS	$R_{HSDPA\_IC_D}$ and R_{SHO_S} (%)
9	13.39	**21**	0.33	**49**	0.35	**18**	0.00
68	9.96	**11**	0.32	**19**	0.33	**22**	0.00
69	9.81	**43**	0.29	**24**	0.00	**72**	0.00
53	5.57	**77**	0.29	**25**	0.00	**73**	0.00
16	3.68	**81**	0.28	**27**	0.00	**75**	0.00
93	2.70	**59**	0.23	**28**	0.00	**78**	0.00
45	2.20	**30**	0.22	**29**	0.00	**80**	0.00
38	1.55	**79**	0.22	**31**	0.00	**82**	0.00
85	1.35	**32**	0.2	**34**	0.00	**84**	0.00
76	1.03	**23**	0.19	**35**	0.00	**86**	0.00
51	0.89	**39**	0.18	**36**	0.00	**87**	0.00
20	0.87	**98**	0.18	**40**	0.00	**88**	0.00
83	0.87	**26**	0.16	**44**	0.00	**89**	0.00
41	0.71	**33**	0.12	**46**	0.00	**90**	0.00
1	0.60	**4**	0.00	**47**	0.00	**91**	0.00
57	0.60	**5**	0.00	**48**	0.00	**92**	0.00
74	0.58	**6**	0.00	**50**	0.00	**94**	0.00
3	0.53	**7**	0.00	**54**	0.00	**95**	0.00
2	0.51	**8**	0.00	**55**	0.00	**96**	0.00
37	0.46	**10**	0.00	**56**	0.00	**97**	0.00
42	0.43	**12**	0.00	**60**	0.00	**100**	0.00
58	0.42	**13**	0.00	**61**	0.00	**101**	0.00
63	0.38	**14**	0.00	**62**	0.00	**102**	0.00
99	0.38	**15**	0.00	**64**	0.00	**103**	0.00
52	0.36	**17**	0.00	**65**	0.00	**104**	0.00

Annex E

Site Names

In Annex E, the table with the correct names from the analysed BSs from the covered region is presented. This annex is confidential.

Table E.1 Site Names.

2G		3G
900 MHz	1800 MHz	
21_JANEIRO	21_JANEIRO_DCS	21_JANEIRO_UMTS
AEROPORTO2	AEROPORTO2_DCS	AEROPORTO2_UMTS
ASA_BRANCA	ASA_BRANCA_DCS	ASA_BRANCA_UMTS
ATECNIC	ATECNIC_DCS	ATECNIC_UMTS
AUTO_WESA	AUTO_WESA_DCS	AUTO_WESA_UMTS
AV_BRASIL	AV_BRASIL_DCS	AV_BRASIL_UMTS
A_NGANGULA	A_NGANGULA_DCS	A_NGANGULA_UMTS
BAIRRO6	BAIRRO6_DCS	BAIRRO6_UMTS
BAIRRO_AZUL	BAIRRO_AZUL_DCS	BAIRRO_AZUL_UMTS
BAIRRO_MARTIRES	BAIRRO_MARTIRES_DCS	BAIRRO_MARTIRES_UMTS
BAIRRO_NOVO	BAIRRO_NOVO_DCS	BR_NOVO_UMTS
BANDEIRA	BANDEIRA_DCS	BANDEIRA_UMTS
BANGA_SUMO	BANGA_SUMO_DCS	BANGA_SUMO_UMTS
BCI	BCI_DCS	BCI_UMTS
BENFICA	BENFICA_DCS	BENFICA_UMTS
BENFICA_N	BENFICA_N_DCS	BENFICA_N_UMTS
BENFICA_SUL	BENFICA_SUL_DCS	BENFICA_SUL_UMTS
BESA	BESA_DCS	BESA_UMTS
BLUEHOUSE	BLUEHOUSE_DCS	BLUEHOUSE_UMTS
BOAVISTA1	BOAVISTA1_DCS	BOAVISTA1_UMTS
BOA_ESP_2	BOA_ESP_2_DCS	BOA_ESP_2_UMTS
BORGALHEIR	BORGALHEIR_DCS	BORGALHEIR_UMTS
BULA	BULA_DCS	BULA_UMTS
CAC4FEV	CAC4FEV_DCS	CAC4FEV_UMTS
CACPOL	CACPOL_DCS	CACPOL_UMTS
CACUACO	CACUACO_DCS	CACUACO_UMTS
CACUACO_CENTRO	CACUACO_CENTRO_DCS	CACUACO_CENTRO_UMTS
CACUACO_NE	CACUACO_NE_DCS	CACUACO_NE_UMTS
CAJUEIRO	CAJUEIRO_DCS	CAJUEIRO_UMTS
CALEMBA2	CALEMBA2_DCS	CALEMBA2_UMTS
CAMAMA	CAMAMA_DCS	CAMAMA_UMTS
CAMAMA2	CAMAMA2_DCS	CAMAMA2_UMTS
CAMBAMBA	CAMBAMBA_DCS	CAMBAMBA_UMTS
CARITAS	CARITAS_DCS	CARITAS_UMTS
CASA_DESPORTISTA	CASA_DESPORTISTA_DCS	CASA_DESPORTISTA_UMTS
CASSANGE	CASSANGE_DCS	CASSANGE_UMTS
CATORZE	CATORZE_DCS	CATORZE_UMTS
CAZAVI	CAZAVI_DCS	CAZAVI_UMTS
CAZAVI_N	CAZAVI_N_DCS	CAZAVI_N_UMTS
CAZENGA	CAZENGA_DCS	CAZENGA_UMTS
CERAMICA	CERAMICA_DCS	CERAMICA_UMTS
CERCO	CERCO_DCS	CERCO_UMTS
CFA	CFA_DCS	CFA_UMTS
CHICALA	CHICALA_DCS	CHICALA_UMTS
CHIMOCO	CHIMOCO_DCS	CHIMOCO_UMTS
CICA	CICA_DCS	CICA_UMTS
CIDADELA_NORTE	CIDADELA_NORTE_DCS	CIDADELA_NORTE_UMTS
CIDADE_ALTA	CIDADE_ALTA_DCS	CIDADE_ALTA_UMTS

CIMANGOLA	CIMANGOLA_DCS	CIMANGOLA_UMTS
CIMANGOL_T	CIMANGOL_T_DCS	CIMANGOL_T_UMTS
CODEM	CODEM_DCS	CODEM_UMTS
COINDA	COINDA_DCS	COINDA_UMTS
COMBATENTES	COMBATENTES_DCS	COMBATENTES_UMTS
COMBUSTIVEL	COMBUSTIVEL_DCS	COMBUSTIVEL_UMTS
COMBUST_NE	COMBUST_NE_DCS	COMBUST_NE_UMTS
CORIMBA	CORIMBA_DCS	CORIMBA_UMTS
COSTA	COSTA_DCS	COSTA_UMTS
COSTA_ESTE	COSTA_ESTE_DCS	COSTA_ESTE_UMTS
DANGEREAUX	DANGEREAUX_DCS	DANGEREAUX_UMTS
DIANGU	DIANGU_DCS	DIANGU_UMTS
ECLESIA	ECLESIA_DCS	ECLESIA_UMTS
EDU	EDU_DCS	EDU_UMTS
EDURBE	EDURBE_DCS	EDURBE_UMTS
ELF	ELF_DCS	Elf_UMTS
EPAL_BENFICA	EPAL_BENFICA_DCS	EPAL_BENFICA_UMTS
ESCOLA_RADIO	ESCOLA_RADIO_DCS	ESCOLA_RADIO_UMTS
ESSA	ESSA_DCS	ESSA_UMTS
ESTALAGEM	ESTALAGEM_DCS	ESTALAGEM_UMTS
ESTALAGEM2	ESTALAGEM2_DCS	ESTALAGEM2_UMTS
ESTALAGEM_SUL	ESTALAGEM_SUL_DCS	ESTALAGEM_SUL_UMTS
ESTALEI_EF	ESTALEI_EF_DCS	ESTALEI_EF_UMTS
ESTRADA_CACUACO	ESTRADA_CACUACO_DCS	ESTRADA_CACUACO_UMTS
ESTRELA_NOVA	ESTRELA_NOVA_DCS	ESTRELA_NOVA_UMTS
E_CIDADELA	E_CIDADELA_DCS	E_CIDADELA_UMTS
E_LDA_N_I	E_LDA_N_1_DCS	E_LDA_N_UMTS
E_LDA_N_I	E_LDA_N_2_DCS	E_LDA_N_UMTS
E_LDA_S_I	E_LDA_S_1_DCS	E_LDA_S_UMTS
E_LDA_S_I	E_LDA_S_2_DCS	E_LDA_S_UMTS
FAROL	FAROL_DCS	FAROL_UMTS
FAROL_DAS_LAGOSTAS	FAROL_DAS_LAGOSTAS_DCS	FAROL_DAS_LAGOSTAS_UMTS
FILDA_CC	FILDA_CC_DCS	FILDA_CC_UMTS
FILDA_CC_N	FILDA_CC_N_DCS	FILDA_CC_N_UMTS
FTU2	FTU2_DCS	FTU2_UMTS
FUTU_BELAS	FUTU_BELAS_DCS	FUTU_BELAS_UMTS
GAMEK_VIANA	GAMEK_VIANA_DCS	GAMEK_VIANA_UMTS
GOLF2	GOLF2_DCS	GOLF2_UMTS
GOLF_POLICE	GOLF_POLICE_DCS	GOLF_POLICE_UMTS
GOLF_SUL	GOLF_SUL_DCS	GOLF_SUL_UMTS
GRAFANIL	GRAFANIL_DCS	GRAFANIL_UMTS
GRAFANIL_SUL	GRAFANIL_SUL_DCS	GRAFANIL_SUL_UMTS
GRAFA_NORTE	GRAFA_NORTE_DCS	GRAFA_NORTE_UMTS
GRAFA_VIANA	GRAFA_VIANA_DCS	GRAFA_VIANA_UMTS
HOJIYAHENDA	HOJIYAHENDA_DCS	HOJIYAHENDA_UMTS
HOJI_LESTE	HOJI_LESTE_DCS	HOJI_LESTE_UMTS
HP	HP_DCS	HP_UMTS
ILHA	ILHA_DCS	ILHA_UMTS
IMBLSUL	IMBLSUL_DCS	IMBLSUL_UMTS
IMBONDEIRO	IMBONDEIRO_DCS	IMBONDEIRO_UMTS
INTERPARK	INTERPARK_DCS	INTERPARK_UMTS

ISE	ISE_DCS	ISE_UMTS
JARDI_EDEN	JARDI_EDEN_DCS	JARDI_EDEN_UMTS
JEMBAS	JEMBAS_DCS	JEMBAS_UMTS
JEMBAS	JEMBAS2_DCS	JEMBAS_UMTS
JIKA	JIKA_DCS	JIKA_UMTS
JPIMENTA	JPIMENTA_DCS	JPIMENTA_UMTS
JUMBO	JUMBO_DCS	JUMBO_UMTS
KABOCOMEU	KABOCOMEU_DCS	KABOCOMEU_UMTS
KAPALANCA	KAPALANCA_DCS	KAPALANCA_UMTS
KAPOLO	KAPOLO_DCS	KAPOLO_UMTS
KAPOLO2	KAPOLO2_DCS	KAPOLO2_UMTS
KIKOLO	KIKOLO_DCS	KIKOLO_UMTS
KIKOLO_SUL	KIKOLO_SUL_DCS	KIKOLO_SUL_UMTS
KIKUXI	KIKUXI_DCS	KIKUXI_UMTS
KWANZAS	KWANZAS_DCS	KWANZAS_UMTS
LEA	LEA_DCS	LEA_UMTS
LIGA_AFRICANA	LIGA_AFRICANA_DCS	LIGA_AFRICANA_UMTS
LOGITECNICA	LOGITECNICA_DCS	LOGITECNICA_UMTS
LUANDA_SUL	LUANDA_SUL_DCS	LUANDA_SUL_UMTS
LUSIADA	LUSIADA_DCS	LUSIADA_UMTS
MABOR	MABOR_DCS	MABOR_UMTS
MAIANGA	MAIANGA_DCS	MAIANGA_UMTS
MARCAL	MARCAL_DCS	MARCAL_UMTS
MARIN_ILHA	MARIN_ILHA_DCS	MARIN_ILHA_UMTS
MECANAGRO	MECANAGRO_DCS	MECANAGRO_UMTS
MECANAGR_N	MECANAGR_N_DCS	MECANAGR_N_UMTS
METRO	METRO_DCS	METRO_UMTS
MINISTERIO_AGRICULTU RA	MINISTERIO_AGRICULTURA_D CS	MINISTERIO_AGRICULTURA_UM TS
MINISTERIO_COMERCIO	MINISTERIO_COMERCIO_DCS	MINISTERIO_COMERCIO_UMTS
MIRAMAR	MIRAMAR_DCS	Miramar_UMTS
MORRO_AREIA	MORRO_AREIA_DCS	MORRO_AREIA_UMTS
MORRO_BENTO	MORRO_BENTO_DCS	MORRO_BENTO_UMTS
MORRO_BENTO_NORTE	MORRO_BENTO_NORTE_DCS	MORRO_BENTO_NORTE_UMTS
MORRO_LUZ	MORRO_LUZ_DCS	MORRO_LUZ_UMTS
MR_BENTO_2	MR_BENTO_2_DCS	MR_BENTO_2_UMTS
MULENVOS	MULENVOS_DCS	MULENVOS_UMTS
MULENVOS_BAIXO	MULENVOS_BAIXO_DCS	MULENVOS_BAIXO_UMTS
NOCAL_FACTORY	NOCAL_FACTORY_DCS	NOCAL_FACTORY_UMTS
NOVA_UNIVERSIDADE	NOVA_UNIVERSIDADE_DCS	NOVA_UNIVERSIDADE_UMTS
NOVA_VIDA	NOVA_VIDA_DCS	NOVA_VIDA_UMTS
NOVA_VIDA_ESTE	NOVA_VIDA_ESTE_DCS	NOVA_VIDA_ESTE_UMTS
NOVA_VIDA_N	NOVA_VIDA_N_DCS	NOVA_VIDA_N_UMTS
NOVA_VIDA_SUDESTE	NOVA_VIDA_SUDESTE_DCS	NOVA_VIDA_SUDESTE_UMTS
NV_E59	NV_E59_DCS	NV_E59_UMTS
NV_VIDA_O	NV_VIDA_O_DCS	NOVA_VIDA_OESTE_UMTS
OLIMPIA	OLIMPIA_DCS	OLIMPIA_UMTS
OPERARIO	OPERARIO_DCS	OPERARIO_UMTS
PAGA_POUCO	PAGA_POUCO_DCS	PAGA_POUCO_UMTS
PALANCA_R4	PALANCA_R4_DCS	PALANCA_R4_UMTS
PANGA	PANGA_DCS	PANGA_UMTS

PATRICIO	PATRICIO_DCS	PATRICIO_UMTS
PATRIOTA	PATRIOTA_DCS	PATRIOTA_UMTS
PETRANGOL	PETRANGOL_DCS	PETRANGOL_UMTS
POPULAR	POPULAR_DCS	POPULAR_UMTS
POPULAR_SUL	POPULAR_SUL_DCS	POPULAR_SUL_UMTS
POPULAR_W	POPULAR_W_DCS	POPULAR_W_UMTS
PRECOL	PRECOL_DCS	PRECOL_UMTS
PRENDA_NOVO	PRENDA_NOVO_DCS	PRENDA_NOVO_UMTS
PRENDA_SUL	PRENDA_SUL_DCS	PRENDA_SUL_UMTS
PRT_LUANDA	PRT_LUANDA_DCS	PRT_LUANDA_UMTS
QUIFICA	QUIFICA_DCS	QUIFICA_UMTS
REG_TRANSMISSOES	REG_TRANSMISSOES_DCS	REG_TRANSMISSOES_UMTS
REVOLUCAO_OUTUBRO	REVOLUCAO_OUTUBRO_DCS	REVOLUCAO_OUTUBRO_UMTS
ROCHA_PINTO	ROCHA_PINTO_DCS	ROCHA_PINTO_UMTS
ROQUE	ROQUE_DCS	ROQUE_UMTS
ROTRANS	ROTRANS_DCS	ROTRANS_UMTS
RUA_UM	RUA_UM_DCS	RUA_UM_UMTS
RUA_VERDE	RUA_VERDE_DCS	RUA_VERDE_UMTS
SAGRADA_ESPERANCA	SAGRADA_ESPERANCA_DCS	SAGRADA_ESPERANCA_UMTS
SAMBA	SAMBA_DCS	SAMBA_UMTS
SAMBA_LESTE	SAMBA_LESTE_DCS	SAMBA_LESTE_UMTS
SAMBA_NORTE	SAMBA_NORTE_DCS	SAMBA_NORTE_UMTS
SAMBA_SUL	SAMBA_SUL_DCS	SAMBA_SUL_UMTS
SAMBIZANGA	SAMBIZANGA_DCS	SAMBIZANGA_UMTS
SAO_PAULO	SAO_PAULO_DCS	SAO_PAULO_UMTS
SAPU	SAPU_DCS	SAPU_UMTS
SEMINARIO	SEMINARIO_DCS	SEMINARIO_UMTS
SHOPRITE	SHOPRITE_DCS	SHOPRITE_UMTS
SOCIBORDA	SOCIBORDA_DCS	SOCIBORDA_UMTS
SOMADANG	SOMADANG_DCS	SOMADANG_UMTS
SONANGOL_ESTA	SONANGOL_ESTA_DCS	SONANGOL_ESTA_UMTS
SONANGOL_PP	SONANGOL_PP_DCS	SONANGOL_PP_UMTS
SONEFE	SONEFE_DCS	SONEFE_UMTS
SOPOL	SOPOL_DCS	SOPOL_UMTS
TALA_HADY	TALA_HADY_DCS	TALA_HADY_UMTS
TCC	TCC_DCS	TCC_UMTS
TERRA_VERM	TERRA_VERM_DCS	TERRA_VERM_UMTS
TEXTANG_II	TEXTANG_II_DCS	TEXTANG_II_UMTS
TEXTANG_SUL	TEXTANG_SUL_DCS	TEXTANG_SUL_UMTS
TOURADA	TOURADA_DCS	TOURADA_UMTS
UNITEL	UNITEL_DCS	UNITEL_UMTS
UN_VIANA	UN_VIANA_DCS	UN_VIANA_UMTS
VIANA_CENTRO	VIANA_CENTRO_DCS	VIANA_CENTRO_UMTS
VIANA_KM12	VIANA_KM12_DCS	VIANA_KM12_UMTS
VIANA_KM30	VIANA_KM30_DCS	VIANA_KM30_UMTS
VIANA_LESTE	VIANA_LESTE_DCS	VIANA_LESTE_UMTS
VIANA_NORTE	VIANA_NORTE_DCS	VIANA_NORTE_UMTS
VIANA_OESTE	VIANA_OESTE_DCS	VIANA_OESTE_UMTS
VIA_4ABRIL	VIA_4ABRIL_DCS	VIA_4ABRIL_UMTS
VIA_CAOP	VIA_CAOP_DCS	VIA_CAOP_UMTS
VIA_MOTO	VIA_MOTO_DCS	VIA_MOTO_UMTS

VILAKIAXI	VILAKIAXI_DCS	VILAKIAXI_UMTS
V_CHINESA	V_CHINESA_DCS	V_CHINESA_UMTS
V_GAMEK	V_GAMEK_DCS	V_GAMEK_UMTS
ZANGA	ZANGA_DCS	ZANGA_UMTS
ZANGO	ZANGO_DCS	ZANGO_UMTS
ZANGO2	ZANGO2_DCS	ZANGO2_UMTS
ZONA10	ZONA10_DCS	ZONA10_UMTS
ZONA12	ZONA12_DCS	ZONA12_UMTS
ZONA16	ZONA16_DCS	ZONA16_UMTS
ZONA6	ZONA6_DCS	ZONA6_UMTS
ZONA_VERDE	ZONA_VERDE_DCS	ZONA_VERDE_UMTS
AUTOESTRA		
A_NGANGU_E		
BR_MUNDIAL		
CAC_PUNIV		
CHINAFUND2_I		
CITIC		
CNT_FRM_UN		
EST_RAMIRO		
FUNDA		
GISABEL		
ILHA_N		
JRD_EDEN2		
MONGO_NW		
NOVO_AEROPORTO		
PALACIO_CONGRESSOS		
QUENGUELA		
QUENGUEL_E		
SUPRA_MARINA		
VIANA_KM33		
14_DE_ABRIL	14_DE_ABRIL_DCS	
ALVALD_CTR	ALVALD_CTR_DCS	
BR_BOAVIST	BR_BOAVIST_DCS	
BR_BOA_ESP	BR_BOA_ESP_DCS	
BR_CERAM	BR_CERAM_DCS	
BR_MUNDIMB	BR_MUNDIMB_DCS	
BR_NOVO_W	BR_NOVO_W_DCS	
BR_OSSOS	BR_OSSOS_DCS	
CALEMBA2_ESTE	CALEMBA2_ESTE_DCS	
CAOP	CAOP_DCS	
CASSENDA	CASSENDA_DCS	
CASSEQUEL	CASSEQUEL_DCS	
CATORZE_W	CATORZE_W_DCS	
CAUELELE	CAUELELE_DCS	
CAXALA	CAXALA_DCS	
CAZENGA_SUL	CAZENGA_SUL_DCS	
CAZENGA_W	CAZENGA_W_DCS	
CAZENG_E	CAZENG_E_DCS	
CCTA	CCTA_DCS	
CHINA	CHINA_DCS	
CIDADELA	CIDADELA_DCS	

CIPAL	CIPAL_DCS	
COMBUST_N	COMBUST_N_DCS	
ENTREPOSTO	ENTREPOSTO_DCS	
ESCOLA612	ESCOLA612_DCS	
EST_NOV_N	EST_NOV_N_DCS	
FILDA_NORTE	FILDA_NORTE_DCS	
FRANCO_NOG	FRANCO_NOG_DCS	
HOJI_OESTE	HOJI_OESTE_DCS	
IMBONDER_N	IMBONDER_N_DCS	
INFINITY	INFINITY_DCS	
KIKOLO_SE	KIKOLO_SE_DCS	
KILAMBA_KIAXI	KILAMBA_KIAXI_DCS	
KWAME_NKRU	KWAME_NKRU_DCS	
LDA_SUL_KM30	LDA_SUL_KM30_DCS	
LIXEIRA	LIXEIRA_DCS	
MALANGINO	MALANGINO_DCS	
METRO_E	METRO_E_DCS	
MOAGEM	MOAGEM_DCS	
MO_AREIA_E	MO_AREIA_E_DCS	
NGANGULA_N	NGANGULA_N_DCS	
NOVA_SEDE_UNITEL_2	NOVA_SEDE_UNITEL_2_DCS	
NV_DESP	NV_DESP_DCS	
PALANCA2	PALANCA2_DCS	
PANGUILA	PANGUILA_DCS	
PANGUILA_S	PANGUILA_S_DCS	
PETRANGOL_OESTE	PETRANGOL_OESTE_DCS	
PONT_GOLF2	PONT_GOLF2_DCS	
REFINARIA	REFINARIA_DCS	
RT_ROQUE	RT_ROQUE_DCS	
SAMBZANG_E	SAMBZANG_E_DCS	
SAPU_KAPOL2	SAPU_KAPOL2_DCS	
SOFFICE_T	SOFFICE_T_DCS	
S_FAMILIA2	S_FAMILIA2_DCS	
TALAMAKU	TALAMAKU_DCS	
TCC_SO	TCC_SO_DCS	
TECNOTUNEL	TECNOTUNEL_DCS	
VIANA_SUL	VIANA_SUL_DCS	
VIDRUL	VIDRUL_DCS	
ZEE1	ZEE1_DCS	
ZEE2	ZEE2_DCS	
BANCOBESA_I		BANCOBESA_I_UMTS
BITA		BITA_UMTS
CCTA_I		CCTA_I_UMTS
CHINAFUND1_I		CHINAFUND1_I_UMTS
HOTEL_TROPICO		HOTEL_TROP_UMTS
NOVA_SEDE_UNITEL	12SAPU_DCS	NOVA_SEDE_UNITEL_UMTS
RESMIRAMAR	1_MAIO_DCS	RESMIRAMAR_UMTS
VIANA_KM27	AEROINTE_I_DCS	VIANA_KM27_UMTS
12SAPU	AEROPORT_O_DCS	NOVA_SEDE_UNITEL_UMTS
1_MAIO	ATLANTIC_N_DCS	ONDJWO_YET_UMTS
AEROPORT_O	BancoBPA_I_DCS	RESMIRAMAR_UMTS

ATLANTIC_N	BELASHOP_I_DCS	SONANGOL_OFFICE_UMTS
BR_HUAMBO	BR_HUAMBO_DCS	VIANA_KM27_UMTS
BTS_TESTE	CAMUXIBA_DCS	
CAMUXIBA	COMIT_PROV_DCS	
COMITE_PROVINCIAL_I	ENC_PRENDA_DCS	
COMIT_PROV	EPAL_GOLF_DCS	
EPAL_GOLF	ESTORIL_DCS	
ESTORIL	FEIRAO_AUT_DCS	
FEIRAO_AUT	FILDA_I_DCS	
FRESCURA	FINAL07_DCS	
GALILEIA	FRESCURA_DCS	
GENERAIS	GALILEIA_DCS	
IMPORAFRIC	GENERAIS_DCS	
KINAXIXI	JEMBAS_SUL_DCS	
LRG_AMBIEN_I	KINAXIXI_DCS	
MORRODOS_VEADOS	MORRODOS_VEADOS_DCS	
MULEMBA	MULEMBA_DCS	
M_TELECOM_I	NOVO_ROQUE_DCS	
NV_UNIVER2	PANGA_ESTE_DCS	
ONDJWO_YET	PATRIOTA_W_DCS	
PANGA_ESTE	PAVITERRA_DCS	
PATRIOTA_N	PETRO_DCS	
PATRIOTA_W	PRAIA_BISPO_DCS	
PAVITERRA	PRENDA_DCS	
PETRO	RUA_CINCO_DCS	
PRAIA_BISPO	R_CABINDA_DCS	
PRENDA	T_SONANG_I_DCS	
R_CABINDA	ZN_VERDE_N_DCS	
ZN_VERDE_N		

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