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3G Radio Network Planning for a Mobile Network Operator

Miguel Monteiro Antunes França Martins

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Supervisor: Prof. António José Castelo Branco Rodrigues

Examination Committee

Chairperson: Prof. Fernando Duarte Nunes

Supervisor: Prof. António José Castelo Branco Rodrigues

Members of the Committee: Prof. Paulo Luís Serras Lobato Correia

Eng. Artur Paulo Goulart Vargas

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To my family and friends

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Abstract

Mobile telecommunications are in a strong development. The total number of mobile subscriptions is reaching the world's population all along with an exponential scale of the data traffic. However, there are countries still dominated by second-generation networks, which are not sufficient to follow this continuous growth. The purpose of this work is to develop a radio network planning design project for a third-generation network, based on the requirements of a real Alcatel-Lucent's customer, which are related to coverage, quality and interference. Network configuration inputs and assumptions are presented, in order to perform services predictions with Alcatel-Lucent design tool. Initial third-generation design is based on the already existing second-generation network configurations. Optimization processes had to be developed not only to optimize the network to have best fitted third-generation configurations, but also to achieve the requirements of both Alcatel-Lucent and the customer. There are three optimization phases described in the project: tilt optimization, new sites proposal and power optimization phase. Electrical tilt optimization was performed to improve signal level covered area. Then new 3G sites were proposed within the already existing 2G only sites of the network, as the requirements had not yet been achieved. Finally, power optimization was performed, only in urban and dense urban areas, to sectors with low covered area. After all the optimization phases, it can be concluded that all the design project requirements were achieved.

Keywords

Radio Network Planning; Signal Coverage; Quality; Interference; Optimization

Resumo

As comunicações móveis estão em forte desenvolvimento. O número total de subscrições móveis está a atingir o volume da população mundial, em conjunto com a escalada exponencial do tráfego de dados. No entanto, existem países, onde as redes de segunda geração ainda são dominantes e que não são suficientes para acompanhar este crescimento contínuo. O objetivo deste trabalho é o desenvolvimento de um projeto de planeamento para uma rede de terceira geração baseado nos requisitos de um cliente real da Alcatel-Lucent, que dizem respeito à cobertura, qualidade e interferência. São apresentados os pré requisitos e pressupostos de configuração para uma rede, a fim de executar as predições de serviços utilizando a ferramenta de planeamento da Alcatel-Lucent. O projeto inicial de terceira geração baseia-se nas configurações da rede de segunda geração existente. Houve a necessidade de desenvolver processos de otimização não só para otimizar a rede para as configurações de uma rede de terceira geração, mas também para cumprir os requisitos da Alcatel-Lucent e do cliente. No projeto são descritas três fases de otimização: otimização de *tilts*, proposta de novos *sites* e otimização de potência. A otimização de *tilts* elétricos foi realizada, para melhorar a área com cobertura de sinal. Em seguida, foi proposto que os sites que originalmente iriam suportar apenas 2G, passassem a sites 3G, uma vez que os requisitos não tinham sido ainda cumpridos. Por fim, foi levada a cabo a otimização de potência, apenas em áreas urbanas de maior densidade populacional, em setores com baixa área de cobertura. Após todas as fases de otimização, poder-se-á concluir que todos os requisitos do projeto foram cumpridos.

Palavras-chave

Projeto de Planeamento; Cobertura de Sinal; Qualidade; Interferência; Otimização

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List of Acronyms

3GPP – 3rd Generation Partnership Project
ACK – Acknowledgement (data networks)
AMC – Adaptive Modulation and Coding
AMR – Adaptive Multi-Rate
AMRWB – Wideband AMR
ANSI – American National Standards Institute
ARQ – Automatic Repeat Request
ATM – Asynchronous Transfer Mode
BER – Bit Error Rate
BLEP – Block Error Probability
BLER – Block Error Rate
BPSK – Binary Phase Shift Keying
BS – Base Station
BTS – Base Transceiver Station
CDMA – Code Division Multiple Access
CN – Core Network
CPICH – Common Pilot Channel
CQI – Channel Quality Information
CS – Circuit Switched
DCH – Dedicated Channel
DL – Downlink
DPC – Dedicated Physical Channel
DSSS – Direct Sequence Spread Spectrum
DTM – Digital Terrain Model
DTX – Discontinuous Transmission
E-AGCH – E-DCH Absolute Grant Channel
E-DCH – Enhanced Dedicated Channel
E-DPCCH – Enhanced Dedicated Physical Control Channel
E-DPDCH – Enhanced Dedicated Physical Data Channel
E-HICH – E-DCH HARQ Indicator Channel
E-RGCH – E-DCH Relative Grant Channel
E-TFCI – E-DCH Transport Format Combination Indicator
ECR – Effective Code Rate
EDGE – Enhanced Data Rate for GSM Evolution
EiRP – Equivalent Isotropic Radiated Power Parameters
ETSI – European Telecommunications Standards Institute
F-DCH – Fractional-DCH
FDD – Feature-driven development
FER – Frame Error Rate
FRC – Fixed Reference Channel
Gb – Packet Switched
GPRS – General Packet Radio Services
GSM – Global System for Mobile Communications
HARQ – Hybrid ARQ
HS-DPCCH – High-Speed Dedicated Physical Control Channel
HS-DSCH – High-Speed Downlink Shared Channel
HS-SCCH – High-Speed Shared Control Channel
HSDPA – High Speed Downlink Packet Access
HSPA – High Speed Packet Access

HSUPA – High-Speed Uplink Packet Access
IMS – IP Multimedia Sub-system
ISDN – Integrated Services for Digital Network
ISDN – Services Digital Network
ITU – International Telecommunication Union
LTE – Long Term Evolution
MAPL – Maximum Allowable Propagation Losses
MC-RRH – Multi-Carrier Remote Radio Head
MCPA – Multi-Carrier Power Amplifier
ME – Mobile Equipment
MI – Interference margin
MMS – Multimedia Message Service
MS – Mobile Station
MTs – Mobile Terminals
NACK – Negative ACK
OOK – Off Keying
OPEX – Operational Expenditure
OVSF – Orthogonal variable spreading factor
P-CPICH – Primary-CPICH
PLMN – Public Land Mobile Network
PS – Packet Switched
PSCs – Primary Scrambling Codes
PSTN – Public Switched Telephone Network
QAM – Quadrature Amplitude Modulation
QoS – Quality of Service
QPSK – Quaternary Phase Shift Keying
R99 – 3GPP Release 99
RAN – Radio Access Network
RLC/ACK – Radio Link Control/Acknowledgment
RLS – Radio Link Set
RNC – Radio Network Controller
RNP – Radio Network Planning
RRC – Radio Resource Control
RRN – Radio Resource Management
RSCP – Received Signal Code Power
RT – Real Time
RTT – Round Trip Time
RTU – Radio Terminal Unit
SDR – Software-Defined Radio
SF – Spreading Factor
SHO – Soft Handover
SINR – Noise Ratio
SIP – Session Initiation Protocol
SNR – Signal to Noise Ratio
SPM – Standard Propagation Model
SRB – Signal Radio Bearer
TDD – Time Division Duplex
TTI – Transmission Time Interval
UE – User Equipment
UL – Uplink
UMTS – Universal Mobile Telecommunications System
UPH – UE Power Headroom
USIM – Universal Subscriber Identity Module
UTRA – Universal Terrestrial Radio Access
UTRAN – UMTS Terrestrial Radio Access Network
WCDMA – Wideband code division multiple access

Chapter 1

Introduction

This chapter presents a brief overview of the mobile communications evolution, regarding the technology and consumer demands, with special focus on UMTS. It discusses, as well, the motivation and approach for this work and the structure of the thesis.

1.1 Overview

In the past few years the growth in the number of mobile subscribers has been enormous. One of the factors that led towards this evolution was the continuous development of mobile phones. Of the mobile phones sold worldwide, in the first quarter of 2014, 65% were smartphones. So, this evolution translates into a 65% growth in mobile data traffic amid the first quarters of 2013 and 2014 [1].

Global System for Mobile Communications (or *Group Spécial Mobile*, GSM) is a digital circuit-switched network that was responsible for the major deployment of mobile communications in the world. European Telecommunications Standards Institute (ETSI), created in 1988, was the organization responsible for the standardization process of the GSM that was mainly directed to voice communications. Packet data through cellular systems became a reality with General Packet Radio Services (GPRS) introduced in GSM. With a strong base in the GSM standard a third generation mobile system was created, the Universal Mobile Telecommunications System (UMTS). The UMTS was developed and maintained by the 3rd Generation Partnership Project (3GPP). UMTS uses wideband code division multiple access (WCDMA) radio access technology that offers a higher bandwidth, which introduces a new range of services that weren´t possible with the previous mobile systems.

Data traffic volume has exceeded the voice traffic volume since 2008 and now there is an evident dominance of data traffic as it can be seen in the Figure 1.1.

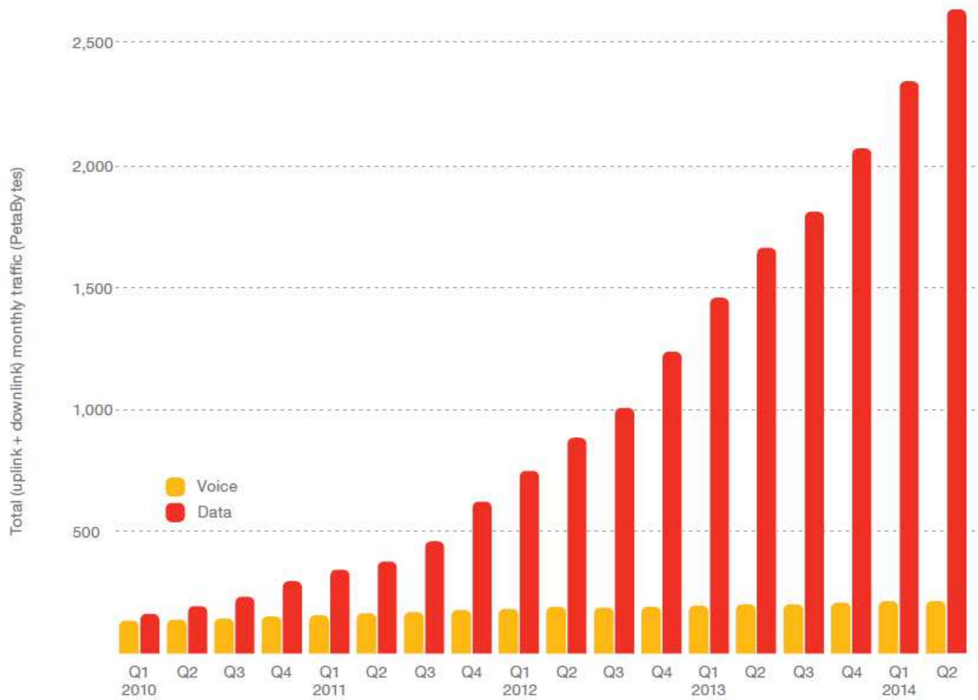


Figure 1.1 – Global traffic in mobile networks [1]

This boost in mobile data usage was due mainly to the introduction of High Speed Downlink Packet Access (HSDPA) in the third generation mobile networks. HSDPA growth is driven by high-speed radio capacity, flat rate pricing schemes and simple device installation, according to [2]. This usage is mainly driven by the numberless applications available, including Internet, file sharing, streaming services to deliver video content and mobile TV and interactive gaming.

In relation to the capacity and efficiency, an average voice subscriber uses 300 minutes per month, which is about 30 megabytes of data, with the voice rate of 12.2kbps. On the other hand, a data user can easily consume more than 1 gigabyte of data. The strong data use takes between ten and one hundred more capacity than voice usage. Thus, it sets high requirements for the capacity and efficiency of data networks.

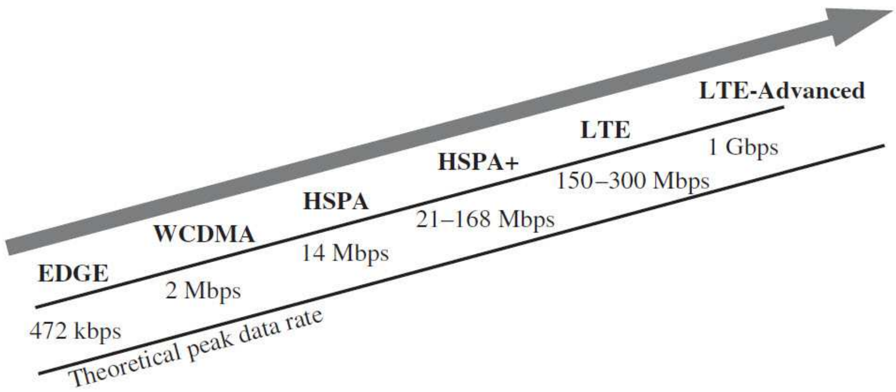


Figure 1.2 – Peak data rate evolution of 3GPP technologies [2]

With these high requirements, the new generations of technologies push the data rates higher. The evolution of the peak data rate can be seen in Figure 1.2. In the beginning of third generation technologies deployments in 2002, WCDMA offered around 384 kbps with a maximum of 2 Mbps later on. At the end of 2005, the first HSDPA network offered between 3.6 and 14 Mbps what was already seven times higher than the first WCDMA network. With the introduction of HSPA evolution, first deployments during 2009, the peak data rate took one step further and offered peaks within 21 and 168Mbps, theoretically. The standards for the next generation of mobile communications were approved in the end of the year 2007 and the first commercial networks started during 2010, which push the data rates to 150-300Mbps. However, the LTE networks are currently offering a maximum of 150Mbps. The next step is the LTE Advanced that will allow rates up to 1Gbps, which means that over a period of ten years the data rate will be more than two thousand times higher.

Global mobile networks face a challenging evolution with the constant growth of new subscriptions. In the first quarter of 2014 the total number of mobile subscriptions reached 6800 million and is expected to grow to 9200 millions, by the end of 2019. WCDMA/HSPA networks had the highest new addition in the first quarter of 2014 with around 70 million. Third generation networks will continue to have a major importance in the market and it is expected that, by the end of 2019, the total number of subscriptions reach 4500 million, representing a market share of around 50% of the total number of mobile subscribers. LTE continues to expand greatly and has reached 240 million subscriptions worldwide, with more than 35 million new additions only in the first quarter of 2014. With LTE being deployed in all regions it is foreseeable that the total number of subscribers rises to 2900 million, which represents around 30% of the total mobile subscriptions. The Figure 1.3 describes the total number of mobile subscriptions worldwide, divided by technology, and also the forecast for the future evolution.

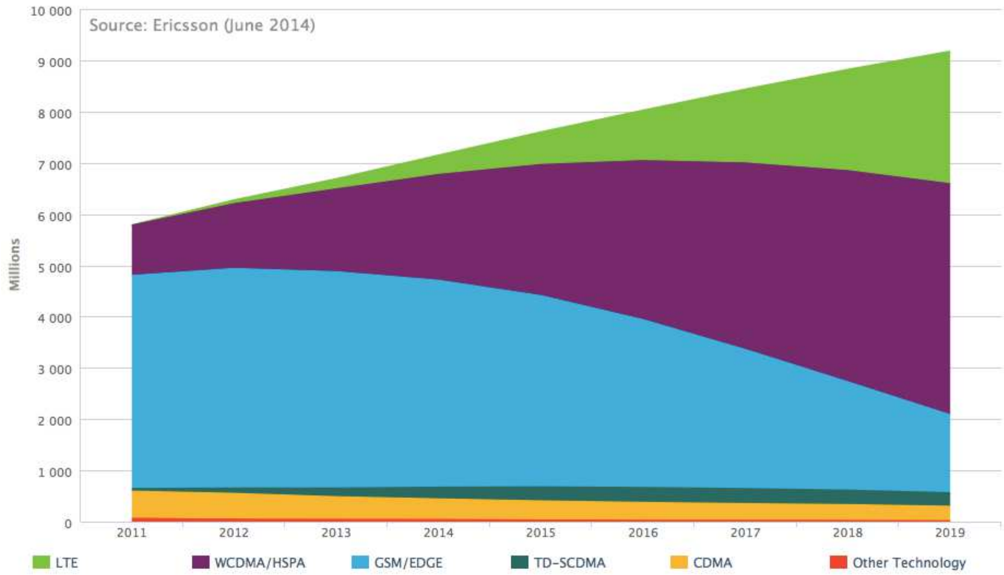


Figure 1.3 – Mobile subscriptions worldwide by technology [1]

The main share of subscriptions today is represented by GSM/EDGE-only subscriptions. However, as it was already described, the need for more demanding requirements from the mobile networks led to a quick migration to more advanced technologies, resulting in a decline in GSM/EDGE-only subscriptions. It is anticipated that by the end of 2019 the GSM/EDGE-only subscribers decreases to not more than 2000 million subscribers, which represents a reduction of more than 50% in subscriptions share.

Nevertheless, GSM/EDGE networks will continue to represent a considerable share of total mobile subscriptions, in the next few years. This phenomenon takes place due to the new less prosperous users, in developing markets, which will likely choose a more economical mobile phone and subscription. But, it also has to be taken into account the time that it takes for the installed base of phones to upgrade. It is highly unlikely an upgrade for a more advanced technology if the mobile phones state of the art, in that area, does not support the new technology. GSM/EDGE networks will also carry on being important in complementing WCDMA/HSPA and LTE network’s coverage in all the markets, according to [2].

1.2 Motivation and Contents

Although the total number of mobile subscriptions is reaching the world's population, around 7200 million people, there are still countries that have a low penetration percentage of mobile network coverage. Each region's maturity level is reflected in its radio technology mix. Emerging regions are mainly dominated by second-generation technologies like GSM/EDGE, while developed regions are strongly dominated by WCDMA/HSPA. Not forgetting, that both operators and subscribers are very quickly adopting LTE. In all regions, second-generation networks will stand as fallback technology for third and forth subscriptions where coverage is missing.

The actual state of the network concerning the world population coverage is an important issue to address as the worldwide population coverage is constantly increasing. GSM/EDGE technology covered, in 2013, more than 85% of the world's population. In the same year, WCDMA/HSPA covered nearly 60% of the world's population. When compared with 2012, there is an increase of almost 10% of coverage. Future developments in the WCDMA/HSPA coverage worldwide, will be motivated by the unstopping demand for Internet access, the rising 2600 million smartphone users and also demanding requirements to connect the unconnected. According to [1], by the end of 2019, about 90% of the world's population will have the opportunity to access the internet using WCDMA/HSPA networks.

Currently, all WCDMA networks deployed worldwide have already been upgraded with HSPA. It is estimated that 85% of these new HSPA networks have been enhanced to a peak downlink speed of 7.2Mbps and 70% of these networks have been upgraded to 21 Mbps or higher.

Upgrading the downlink speed was not the only enhancement made to the WCDMA installed networks. Multi-carrier HSPA is the ability to have simultaneous transmission for a given terminal on more than one carrier in the downlink and/or uplink. By combining radio resources of multiple carriers it can be noticed a considerable increase in peak data rates and in the capacity of the network. Thirty percent of the HSPA networks now support 2x5 MHz multicarrier, with speeds up to 42 Mbps. It is expected that the evolution in HSPA networks with multicarrier support will not stop. It seems that we will see improvements to support 3x5 MHz multicarrier, with speeds escalating up to 63 Mbps in downlink and 12 Mbps in the uplink.

One of the regions that is still dominated by GSM/EDGE-only subscribers is Africa. At the end of 2013 there were 500 million GSM/EDGE subscriptions, which represent 90% of African mobile subscriptions. With a strong second-generation dominated network, Africa only had a little more than 100 million WCDMA/HSPA subscriptions, by the end of 2013. With the increasing middle class and low cost smartphones becoming a reality in these regions' mobile market, mobility came to be indispensable to people's lives. WCDMA/HSPA technology is strongly starting to be the best option to overcome this situation. Thus, it is predicted that by the end of 2019 the number of WCDMA/HSPA subscriptions will reach 600 million.

The project work was developed at Alcatel-Lucent Portugal, which is part of a multinational company that is a global communications solutions provider, with the most complete, end-to-end portfolio of solutions and services in the industry. This project is a real network planning project requested by one of Alcatel-Lucent's customers in Africa.

The motivation of this project is to design and optimize a third generation network for a mobile operator[1] in the Cameroon. The Cameroon is an Africa country with 22 million people and a total area of 475 thousand kilometres. Yaoundé is the capital, but its largest and most populated city is Douala. The location of Cameroon in the African continent is illustrated in the Figure 1.4.

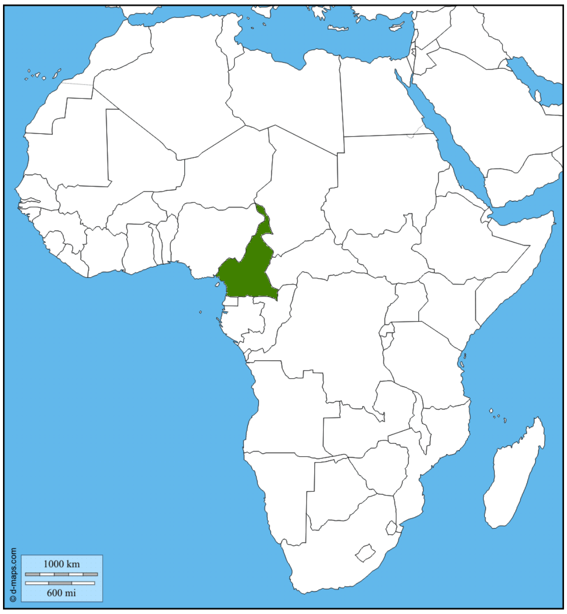


Figure 1.4 – Cameroon location in the African continent [3]

The customer has already a second-generation mobile network implemented in the country. This second-generation network is a dual-band network operating at 900 MHz (GSM-900) and at 1800 MHz (GSM-1800 also described as DCS).

The project was divided in two separate parts. First it was provided a second-generation Radio Network Planning (RNP) design project for the refresh of the second-generation network. The second phase of the project consists in the third-generation Radio Network Planning (RNP) design project for the new third-generation network requested by the customer. This new network is going to operate at 2100MHz and was based, at the beginning, on the existing second-generation GSM900 sites location. Regarding the refresh project, the main objectives were to upgrade the existing antennas and to guarantee similar coverage in order to maintain all previous zones covered. The strategy will rely on maintaining the same power configurations before and after the swap. For the new third-generation

[1] The operator will be referred from now on as the customer.

project, the essential goal is to ensure good coverage, quality and interference for the customer desired services.

The project work is divided into five chapters that present the work performed, simulations and methods used and what results were obtained. The first chapter supports the overview of mobile communications systems, their evolution and integration throughout the world. Justifying the need to continue studying and developing new techniques in order to maintain the continuous progress of technology.

The second chapter has a description of the Universal Mobile Telecommunications System (UMTS) fundamentals. Basic concepts are examined, in the beginning of the chapter, addressing concepts like network architecture, radio interface, capacity and interference. Finally, services and applications are also covered in basic concepts. Then, High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Packet Access (HSUPA) are introduced, with an explanation of their main features, performances and capacity. At the end of the chapter an overview of propagation models is made accordingly to the project scope of work.

In the third chapter, the third-generation radio network planning (RNP) design project is introduced. Following this introduction, a description of the tools used in the project is made. Then, the project inputs and assumptions are clarified. Lastly, the predictions for the initial design configurations are present for the most important project services.

Fourth chapter is the one that have the optimization and results analysis of the project. First an explanation of the project objectives and network optimization criteria are presented. Then the three optimization phases are presented, tilt optimization, new sites proposal and power optimization. Explaining the processes and criteria involved in each optimization phase. In this chapter are also specified the customer requirements for the design project.

Project conclusions based on the obtained results are exposed in the fifth chapter. A summary of all the work performed is also presented, in order to deliver a general understanding of the project and the retrieved conclusions in the end.

Four annexes were considered. The Annex A where are demonstrated the other services predictions and results for Tilt Optimization. Results are displayed for Speech, PS128, HSDPA Category 8, HSDPA Category 24 and HSUPA. In Annex B can be seen the other services predictions as Speech, PS128, HSDPA category 8 and 24 and HSUPA for New Sites Proposal Results. The Annex C includes Power Optimization Results for Speech, PS128, HSDPA category 8 and 24 and HSUPA. Annex D incorporates a document with the RNP 3G Guidelines for Alcatel-Lucent containing the lessons learned from this project.

Chapter 2

UMTS Fundamentals

This chapter provides a description of the UMTS and HSDPA fundamentals. Starting with the basic concepts of network architecture, radio interfaces and improvements introduced by HSDPA. Later, it is presented a summary of the services and applications of UMTS. For the conclusion of this chapter, it was an overview of the interference and the propagation models for UMTS.

2.1 Basic concepts

In this section a brief overview of the UMTS basic concepts is provided. Starting with network architecture description then, the radio interface is specified with a WCDMA interface overview. Capacity and interference is the following topic to be approached, in this section, where the interference margin is described. The final subject addressed in this section is UMTS main services and applications.

2.1.1 – Network Architecture

The UMTS system lies in a number of logical network elements where each has a defined functionality. According to the standards, network elements are defined at the logical level and can be classified based on similar functionality.

The network elements are grouped into the Radio Access Network (RAN), in this case is also referred as UMTS Terrestrial RAN (UTRAN), that handles all radio-related functionalities, and the Core Network (CN), which is responsible for switching and routing calls and data connections to external networks. To complete the system, the User Equipment (UE) interfaces with the user and the radio interface. [4]

Another method to group UMTS network elements is to divide them into sub-networks. The UMTS system is segmental in the sense that it is possible to have several network elements of the same type. At first, the minimum requirement for a fully featured and operational network is to have at least one logical network element of each type. The possibility of having several entities of the same type allows the division of the UMTS system into sub-networks that are operating either on their own or together with other sub-networks. Such a sub-network is called a UMTS PLMN (Public Land Mobile Network). Typically one PLMN is operated by a single operator, and is connected to other PLMNs as well as to other types of network, such as ISDN, PSTN, the Internet, and so on.

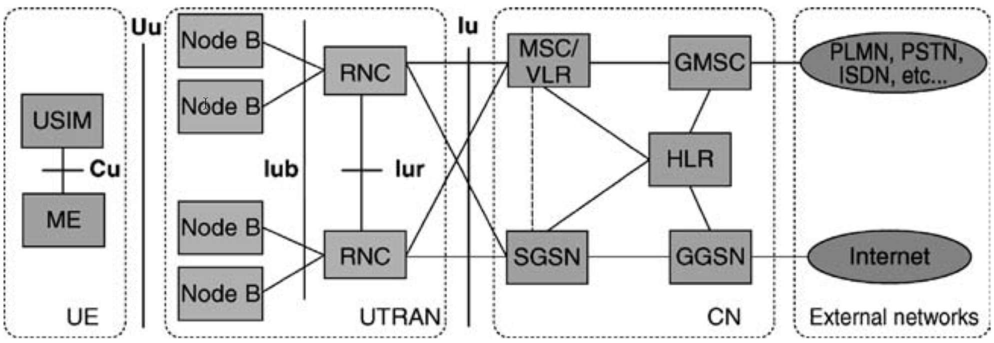


Figure 2.1 – Network elements in a Public Land Mobile Network (PLMN) [4]

The User Equipment (UE) consists of two parts. One is the Mobile Equipment (ME) that represents the radio terminal used for radio communication over the Uu interface. The other is the UMTS Subscriber Identity Module (USIM), which is a smartcard that holds the subscriber's identity, performs authentication algorithms, stores authentication, encryption keys and some subscription information that is needed at the terminal.

The UTRAN is also composed by two separate elements. The NodeB, that converts data flow between the Iub and Uu interfaces and the Radio Network Controller (RNC) that maintains and controls the radio resources in its domain, basically the NodeBs that are connected to it. RNC is the service access point for all services UTRAN provides to the Core Network (CN), for example, management of connections to the UE [5].

Core Network (CN) is out of the scope of this work. Even though Core Network (CN) has a very significant position in UMTS architecture. It was adapted from the GSM Core Network, and its mission is to switch and route calls and data connections to external networks. These networks can either be Circuit Switched (CS), such as Integrated Services Digital Network (ISDN) and Public Switched Telephone Network (PSTN), or Packet Switched (PS), such as the Internet.

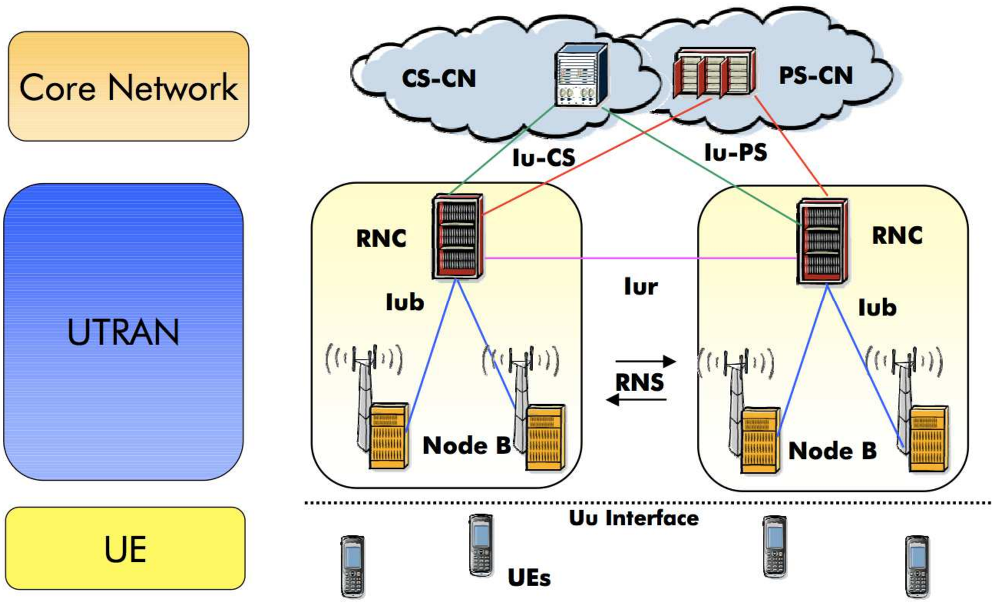


Figure 2.2 – UTRAN Logical Architecture [5]

The UMTS standards are planned so that internal functionality of the network elements is not specified in detail. Instead, the interfaces between the logical network elements have been defined.

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

- *Uu interface.* Is the interface through which the UE accesses the fixed part of the system and thus, is probably the most important open interface in UMTS.
- *Iu interface*. This interface connects UTRAN to the Core Network (CN). Similarly to the corresponding interfaces in GSM, A (Circuit Switched) and Gb (Packet Switched), the open Iu interface gives UMTS operators the possibility of acquiring UTRAN and CN from different manufacturers.
- *Iur interface*. The open Iur interface allows soft handover between RNCs from different manufacturers, and therefore complements the open Iu interface.
- *Iub interface*. The Iub connects a Node B and an RNC.

It is important to identify the main characteristics of UTRAN that have also been the main requirements for the design of the UTRAN architecture, functions and protocols. One of the major requests was to support Universal Terrestrial Radio Access (UTRA) and all the related functionality. Specifically, the major effect on the design of UTRAN has been the necessity to support *soft handover* and the WCDMA Radio Resource Management algorithms. Another important requisite was the maximization of the common points between the handling of PS and CS data. It was possible with the use of a single air interface protocol stack and with the use of the same interface for the connection from UTRAN to both the PS and CS domains of the core network. The use of Asynchronous Transfer Mode (ATM) as the main transport mechanism in UTRAN was another important demand for the design of the UTRAN architecture. ATM is a telecommunications concept defined by ANSI and ITU standards for transport of a complete range of user traffic, including voice, data, and video signals. As an alternative transport mechanism in UTRAN, the use of IP-based transport became a reality.

Radio Network Sub-system (RNS) is a sub-network within UTRAN and consists of one Radio Network Controller (RNC) and one or more NodeBs. RNCs may be connected to each other via an Iur interface. RNCs and NodeBs are connected with an Iub interface. The Radio Network Controller (RNC) is the network element responsible for the control of the radio resources of UTRAN. It interfaces the Core Network (CN) and also ends the Radio Resource Control (RRC) protocol that defines the messages and procedures between the mobile and UTRAN.

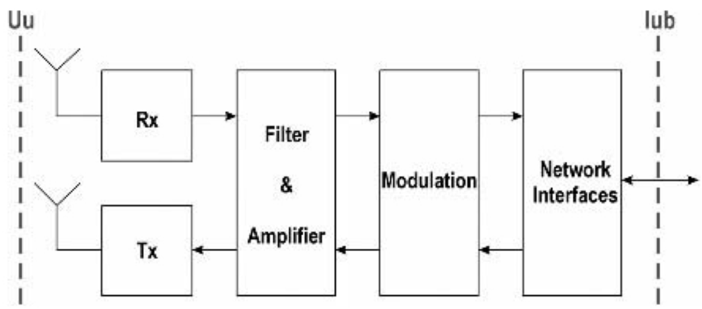


Figure 2.3 – Basic structure of the NodeB [6]

NodeB can be considered as the radio edge of the UTRAN and, therefore, its fundamental mission is to perform radio signal receiving and transmitting, signal filtering and amplifying, signal modulation and demodulation, and interfacing to the RAN.[6] It also performs some basic Radio Resource Management (RRM) operations such as the inner loop power control. The internal structure of the NodeB is very vendor-dependent, but essentially consists of the components presented in Figure 2.3.

2.1.2 – Radio Interface

UMTS is more than a single technology or access method. Rather, it is a combination of certain technologies and the drift is to find mechanisms by which these selected access methods can work together. So that, the end-user is always able to experience adequate coverage and services may have the suitable spectrum and platform for their functions.

The main radio technology employed in UMTS is WCDMA whose variants Frequency Division Duplex (FDD) and Time Division Duplex (TDD) were selected by the European Telecommunications Institute (ETSI). However, likewise traditional Code Division Multiple Access (CDMA), the spread spectrum forms the fundamental technique for WCDMA but employing a different control channel and signalling, wider bandwidth, and a set of enhanced futures for fulfilling the requirements of 3G systems, it is significantly different from its equivalent.

The fundamental technique used in WCDMA is the Direct Sequence Spread Spectrum (DSSS). Its main principles are demonstrated in the Figure 2.4. To explain this technique, it will be assumed that the radio signal is transmitted from the Base Station (BS) to the Mobile Station (MS). At the BS, the transmitted signal, with rate R, is broadcasted by combining it with a wideband-spreading signal. This combination creates a spread signal with bandwidth W.

On the mobile station side, the received signal is multiplied by the same spreading signal. So, If the spreading signal, locally generated at the mobile, is synchronized with the spread signal, the result is the original signal plus possibly some incorrect higher frequency components which are not part of the original signal and, thus, can easily be filtered. On the other hand, If there is any undesired signal at the mobile the spreading signal will affect it as the original signal at the BS, spreading it to the bandwidth of the spreading signal.

This basic process makes WCDMA more robust, flexible and resistant to interference. WCDMA also becomes more solid against congestion and concurrent interception. However, to realize its efficiency WCDMA occupies a wider bandwidth compared with basic CDMA.

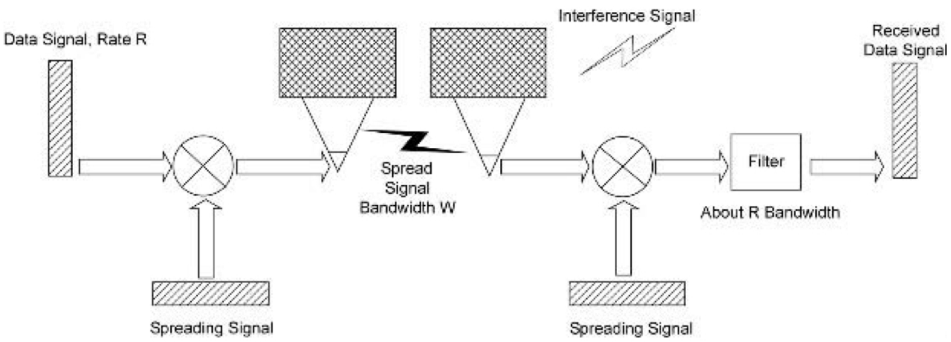


Figure 2.4 - The basic technique of the Direct Sequence Spread Spectrum (DSSS) [6]

How the desired signal is captured at the receiver is quite a straightforward process. Every receiver uses its unique code to choose the desired signal. The received signal is multiplied by a receiver-specific code, resulting in the data to be multiplied. If the right code and desired received signal are multiplied, the result will be post-integrated data with clear peaks on the signal. Otherwise, the post-integrated data will not include clear signal peaks for further processing.

How extensively the signal is spread varies on the spreading factor used in association with it. The spreading factor is a multiplier describing the number of chips used in the WCDMA radio path per 1 symbol. The spreading factor (SF) can be expressed mathematically as follows:

$$SF = 2^k, \qquad \text{Where } k = 0, 1, 2, \dots, 8 \tag{2.1}$$

For instance, if k = 6 the spreading factor (SF) gets a value of 64 indicating that 1 symbol uses 64 chips in the WCDMA radio path in the uplink direction. [6] An alternative name for spreading factor is processing gain (G_p), and it can be expressed as a function of the bandwidths used:

$$Gp = \frac{B_{Uu}}{B_{Bearer}} = \frac{System\ chip\ rate}{Bearer\ bit\ rate} = Spreading\ factor \tag{2.2}$$

In the formula, B_{Uu} stands for the bandwidth of the Uu interface and B_{Bearer} is the bandwidth of rate-matched baseband data. In other words, B_{Bearer} already contains excessive information, like channel coding and error protection information. WCDMA system uses several codes. In theory, one type of code should be enough, but, in practice, radio path physical characteristics require that the WCDMA system use different codes for different purposes, and that these codes have such features as orthogonality and autocorrelation, making them appropriate for their specific use. There are fundamentally three kinds of codes available, channelization codes, scrambling codes and spreading code(s). These channels usage is specified in the Table 1.

Table 1 – WCDMA code types usage [6]

	Downlink direction	Uplink direction
Scrambling Codes	Cell Separation	User Separation
Channelization Codes	Users within one cell	Data and control channels from the same terminal
Spreading Codes	Channelization Code x Scrambling Code	Channelization Code x Scrambling Code

Scrambling code is used in the downlink direction for cell/sector separation. Scrambling codes are also used in the uplink direction. In this case, the users are separated from each other using this code. In addition, as each user's data stream requires the entire frequency band, the right signal has to be selected with the minimum distortion. To separate different transmissions spread over the frequency band, spreading codes are used. A spreading code is a unique code assigned to the beginning of the transaction by the network. From the spreading code point of view, the capacity of a cell depends on the downlink scrambling code amount allocated for the cell. Every downlink scrambling code then has a set of channelization codes under it and every call/transaction requires one channelization code to function. If channelization codes are not used, the spreading code is the same as the scrambling code.

WCDMA radio access allocates bandwidth for users. This allocated bandwidth and its controlling functions are handled using a channel. The functionality implemented through WCDMA defines what kinds of channels are required and how they are organized. WCDMA categorizes the channels in three layers: logical channels, transport channels and physical channels. Figure 2.5 illustrates these three channel layers.

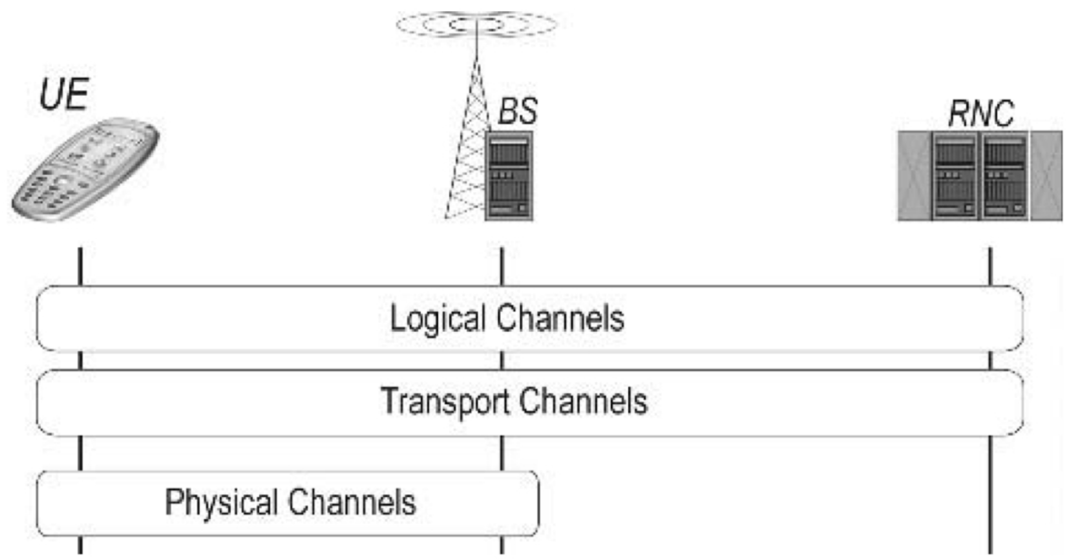


Figure 2.5 - Logical, transport and physical channels in WCDMA UTRAN [6]

Logical channels define the type of information to be transmitted, transport channels describe how the logical channels are being transferred and physical channels are the ‘‘transmission media’’ delivering the radio platform through which information is really transferred.

The allocation of different kinds of bandwidths for different purposes over the Uu interface characterizes a physical channel. In other words, physical channels really form the physical existence of the Uu interface between the User Equipment (UE) domain and the access domain. Transport channels carry different information flows over the Uu interface. NodeB is the physical element responsible for mapping these information flows to the physical channels. Logical channels are not real channels as the name may suggest. They can be assumed as different tasks that the network and the terminal need to carry out at different times. These structures are then mapped to the transport channels that perform the actual information transfer between the UE domain and access domain.

2.1.3 – Capacity and Interference

In UMTS, capacity depends on the number and type of users that are connected to the NodeB. The number of users is limited by three factors:

- The number of channelization codes, that could not be sufficient for all users
- The transmitted power from the NodeB, which is restricted
- The system load, that affects the cell coverage

The number of available channelization codes restricts the number of simultaneous active users within the cell sector, because these codes are given by the Spreading Factor (SF). As data rate increases, Spreading Factor (SF) must decrease to allow higher data rates, leading to a decrease of the allowed number of users in the network. The maximum value for the Spreading Factor (SF) is limited to ensure a minimum QoS, because high Spreading Factor (SF) values would increase interference.

Concerning system load, it is essential to distinguish the uplink (UL) from the downlink (DL), since in the DL there is a limit on the transmission power, and traffic flow is not symmetric between UL and DL. As the load rises in UL, a larger interference margin is needed, leading to a decrease of the cell coverage area. The network load is defined by the UL and DL load factors. The UL load factor can be defined as:

$$\eta_{UL} = (1 + i_{UL}) \cdot \sum_{j=1}^{N_U} \frac{1}{1 + \frac{G_{P_j}}{\left(E_b/N_0\right)_j} \cdot V_j} \tag{2.3}$$

Where:

- i_{UL}: Ratio of inter-to intra-cell interference ratio for UL,
- N_U: Number of users per cell,
- G_{Pj}: Processing gain of user j , given by R_c / R_{bj} ,
- E_b: Bit energy,
- N_0: Spectral noise density,
- V_j: Activity factor for user j,
- R_c: WCDMA chip rate,
- R_{bj}: Bit rate for user j,

Regarding the DL load factor, it can be defined as:

$$\eta_{DL} = \sum_{j=1}^{N_U} V_j \cdot \frac{\left({E_b}/{N_0} \right)_j}{G_{P_j}} \cdot \left[\left(1 - \alpha_j \right) + i_j \right] \tag{2.4}$$

Where:

- α_j: DL channel orthogonality of user j,
- i_j: Ratio inter-to intra-cell interference ratio for user j,

The principal difference between UL and DL load factors is that, in the DL load factor, the maximum transmission power does not change with the number of active users, being shared by all users, while in UL, each mobile terminal (MT) has its own power transmitter. Coverage in rural areas depends more on the UL load factor and on the limited mobile terminal (MT) transmission power. For urban micro- or pico-cells, intended for high data rates, capacity is limited by the DL load factor.

The interference margin (M_I) is defined by (2.5) and qualifies the interference caused by all users' interference. When the load factor tends to one, the system reaches its pole capacity and the noise tends to infinity. Usual values for the interference margin, in the case of coverage limitation, are between 1 and 3 dB, corresponding to 20-50% of load according to [7].

$$M_{I\,[dB]} = -10\,.\log(1-\eta) \tag{2.5}$$

In downlink (DL), cell coverage depends more on the load than in the uplink (UL), once there is a maximum transmission power delivered by the NodeB. So, it is fundamental to calculate the total transmission power expressed through:

$$P_{TX_{[W]}} = \frac{N_{rf} \cdot R_c \cdot \sum_{j=1}^{N_u} V_j \cdot \frac{\left({E_b}/{N_0} \right)_j}{G_{P_j}} \cdot L_{P_j}}{1 - \overline{\eta_{DL}}} \quad (2.6)$$

Where:

- N_{rf}: noise spectral density of the MT receiver,
- L_{pj}: path loss between the NodeB and the MT,
- $\overline{\eta_{DL}}$: average DL load factor value across the cell,

Increasing the Node B transmitter power, in order to increment cell capacity, is not the most efficient method. Dividing the transmitter power among several frequencies is a suitable approach to increase capacity, although it is only possible when more than one frequency can be allocated per cell.

2.1.4 – Services and Applications

Universal Mobile Telecommunications System (UMTS) was planned to provide flexible services, alternatively to second-generation systems that were mainly conceived for an efficient delivery of the voice service. Advanced services can emerge without a particular network optimization. The implementation of IP Multimedia Sub-system (IMS) associated with Session Initiation Protocol (SIP) empowers the fast introduction of new services based on Internet applications and protocols, bringing together the Internet and the mobile world.

According to 3GPP, UMTS services were subdivided in four classes. These classes are common known as traffic classes and have different QoS requirements. They are: Conversational, Streaming, Interactive and Background. Delay sensitivity is the differentiating factor among the traffic classes, the Conversational class is destined for voice traffic, being the most delay sensitive, in the other hand Background class is designed for data information exchanges, being the most delay tolerant. UMTS traffic classes are described in Table 2. However, these classes are not fixed. If a conventional interactive application has a constricted delay requirement, it can use the Conversational class.

Table 2 – Main characteristics of UMTS traffic classes (adapted from [8] and [9])

Traffic Class	Conversational	Streaming	Interactive	Background
Real-time	Yes	Yes	No	No
Symmetry	Yes	No	No	No
Switching	CS	CS	PS	PS
Guaranteed rate	Yes	Yes	No	No
Delay	Minimum and fixed	Minimum and variable	Moderate and variable	High variable
Example of application	Voice	Streaming video	Web browsing	E-mail

Voice is comprised in Conversational class, as it is the one that has strained delay requisites like the conservation of temporal relations in dataflow and short delay (fewer than 400 ms [4]) to guarantee fine voice quality. UMTS uses Adaptive Multi-Rate (AMR) as speech code with eight source data rates. To decrease the bit rate it uses Discontinuous Transmission (DTX), which leads to an interference reduction and to enhance the capacity. The Wideband AMR (AMR-WB) codec is equally provided with quality increase comparatively to the standard AMR or yet the fixed telephone line owing to an audio bandwidth between 50 and 7000 Hz. VoIP is other function included in Conversational class. This is a function that runs over IP, which supposedly works on the PS domain and demands IP header compression and QoS differentiation to reach the small delays required for Conversational service requisites. Another application that fits Conversational class is Video telephony since it holds identical delay requirements as voice, and still tighter Bit Error Rate (BER) requisites, owing to video constriction. In a near future video telephony can be transmitted in CS or PS.

The Streaming class contains RT audio and video allocation, and may be acknowledged as a new effort in telecommunications systems. This class, as the Conversational class, demands maintenance of time relation between packets, although supporting higher delay requirements. That is reached over the utilization of buffers in the closing demands. Video sharing may equally be comprised in this class. In the Interactive class is contained web browsing and online multiplayer gaming. Such class is distinguished for demanding reply samplers and protection of payload chapters. Despite Web browsing supports high delays they should be inferior to 4 to 7 seconds [10] in order to achieve a great experiment. RTT is quite a significant parameter for multiplayer video games, particularly in multiplayer action games that should have an end-to-end delay lower than 100 ms [11]. The Background class sustains the greatest delays, being nearly delay insensitive because virtually there are no delay requisites. This class, as the Interactive class, is not tolerant to transmission errors. In this traffic class applications only use resource transmission whenever any of the classes are operative. For this class the exchange of e-mails, the Multimedia Message Service (MMS) and the transfer of database are commonly applications.

Between the UMTS applications introduced previously it is early to appoint the “killer” application or yet if there will be one. Nevertheless the presentation of HSDPA and HSUPA in recent releases and their new characteristics brings the expectation of the arising of new applications.

2.2 HSDPA

In this section, HSDPA main characteristics are presented, based on [12]. First, the main features and new channels are introduced. Then, performance, coverage and capacity are analysed.

2.2.1 – Main Features

With the request for higher data rates and covering first HSDPA specifications, 3GPP launched Release 5 in March 2002 with awaited peak data rates further 10 Mbps. HSDPA upgrades capability and spectral efficiency, being implemented herewith Release 99, sharing all network components. Software improvement is demanded for network's elements and yet a new MT on the user´s behalf. Simulations display that HSDPA supplies sufficient ability for low bit rate and low latency applications, like VoIP, despite being designed for non-RT traffic.

While in Release 99 the scheduling control is based on the RNC, and the NodeB only has power control functionality, in HSDPA, scheduling and fast link adaptation based on physical layer retransmissions were moved to the NodeB, minimizing latency and changing the RRM architecture. With HSDPA, RNC-based retransmission can still be applied on top of physical layer, using Radio Link Control/Acknowledgment (RLC/ACK) in case of physical layer failure.

An additional and significant modification is the fact that HSDPA does not support Soft Handover (SHO). To achieve upper data rates is applied a new higher order modulation, the 16 Quadrature Amplitude Modulation (16 QAM) with 4 bits per symbol, which can just be utilized over great radio channel circumstances, due to the extra decision boundaries: phase and amplitude balance. For maximizing the coverage and the robustness it is mostly used the Quaternary Phase Shift Keying (QPSK). The Adaptive Modulation and Coding (AMC) is presented by HSDPA to fit the modulation and codification design to the radio channel position, which along with 16QAM permits higher data rates.

Just as determined in Release 5, the DCH is required for HSDPA to operate, as the Signal Radio Bearer (SRB) is carried on DCH for packet data; however HSDPA does not support DCH characteristics such as fast power control or SHO. Regarding Release 6, the Fractional-DCH (F-DCH) was designed for generating power control while just packet facilities are operative, accepting a great number of users with smaller data rates.

In order to set HSDPA in function it was introduced a new user data channel. The High-Speed Downlink Shared Channel (HS-DSCH) designed for the High-Speed Physical Downlink Shared Channel (HS-PDSCH). For signalling were introduced two different channels the High-Speed Shared Control Channel (HS-SCCH) in the DL, and the High-Speed Dedicated Physical Control Channel (HS-DPCCH) in the UL.

HS-DSCH is described as a transport channel for user's data, assisting the new 16QAM modulation. NodeB scheduling with a Transmission Time Interval (TTI) of 2 ms, and fast physical layer transmission utilizing Hybrid ARQ (HARQ) with two sorts of retransmission combining are used: identical retransmission, also called Chase (soft), or non-identical retransmission, also called

Incremental Redundancy (IR). There is no power control or SHO while there is just one HS-DSCH serving cell. Only a fixed SF16 is utilized, for a maximum of 15 codes per MT enabling a theoretical peak bit rate of 14.4 Mbps. Just turbo-coding is applied with superior achievement for upper data rates than the convolution one.

The HS-SCCH carries time critical signalling information, having a 2 slot offset compared to the HS-DSCH, to allow the MT to demodulate the correct codes. It uses QPSK modulation and a SF128 with 40 bits per slot, and does not have power control bits, even though power control can be used, based on Channel Quality Information (CQI) or on the associated Dedicated Physical Channel (DPCH). The HS-SCCH is divided into two parts: the first one carries information needed for the spreading of the correct codes, and the second one carries less important information, such as the Automatic Repeat Request (ARQ) process being transmitted. For the use of code multiplexing, especially in the first deployment phase with limited MTs capabilities, more than one HS-SCCH needs to be transmitted, with the maximum number of HS-SCCH per MT being limited to 4.

The UL channel required for physical layer feedback to carry link adjustment and physical layer retransmissions is the HS-DPCCH. This channel was designed to let the DCH channels from Release 99 unaltered. It owns a fixed SF256 and a three-slot composition, the first slot is used to HARQ information that is regularly sent when there is a right decoding of the HS-SCCH and the remaining two slots for CQI. The CQI is transmitted from the MT to guide the NodeB scheduler of the prospective data rate to be collected by the MT in the upcoming TTI.

2.2.2 – Performance, Coverage and Capacity

HSDPA performance relies on network algorithms, implementation scenarios, traffic generated, QoS and MT receiver accomplishment and competence. As a shared channel used, consumer performance is also related with the quantity of active users. There are 12 HSDPA MT categories, with distinct maximum DL bit rates.

With the purpose of measuring HSDPA performance, the E_b/N_0 metric is not employed, once HS-DSCH bit rate differ each TTI with the utilization of distinct modulations and coding schemes, Effective Code Rate (ECR) and number of HS-PDSCH channels. The Signal to Interference plus Noise Ratio (SINR) is utilized as an alternative of E_b/N_0 for HSDPA connection budget planning and network proportion.

Regarding performance analysis, the necessary instantaneous HS-DSCH SINR measurement is also utilized, described as the SINR on the HS-DSCH channel to perform a particular Block Error Rate (BLER) aim for the number of HS-DPSCH codes, modulation and codification scheme used.

While in Release 99, to achieve the necessary data rate for the type of service considered, voice or data, there is a requirement on E_b/N_0, [13], in HSDPA the data rate is a continuous function of the available HS-DSCH SINR, due to the use of AMC. Figure 2.6, presents the average data rate as a function of the average HS-DSCH SINR, including the effects of link adaptation and HARQ with chase combining, for MTs with 5, 10 and 15 HS-PDSCH codes. For lower SINR values QPSK is used, while for higher SINR values and hence, better radio channel conditions, 16QAM is used.

In network dimensioning, the pilot E_c/I_0, which stands for energy per chip to interference, based on the average wideband Primary-CPICH (P-CPICH), is also used to measure the average single user throughput. The average SINR can be expressed as a function of the average P-CPICH using (2.7) and the average throughput can then be calculated by using Figure 2.7.

The supported effective data rate achieved with 15 HS-PDSCH codes approaches the theoretical Shannon limit – the maximum error-free data rate that can be transmitted within a specific bandwidth in the presence of noise and interference – with an approximate 2 dB difference.

$$SINR = SF_{16} \frac{P_{HSDPA}}{\frac{P_{pilot}}{\rho_{pilot}} - \alpha P_{Tx}} \tag{2.7}$$

Where:

- SF_{16}: is the HS-PDSCH spreading factor of 16,
- P_{HSDPA}: HSDPA transmission power,
- P_{Tx}: total Node B transmission power,
- P_{pilot}: P-CPICH transmitted power,
- ρ_{pilot}: P-CPICH Ec/I0 when HSDPA is active,
- α: is the downlink orthogonality factor,

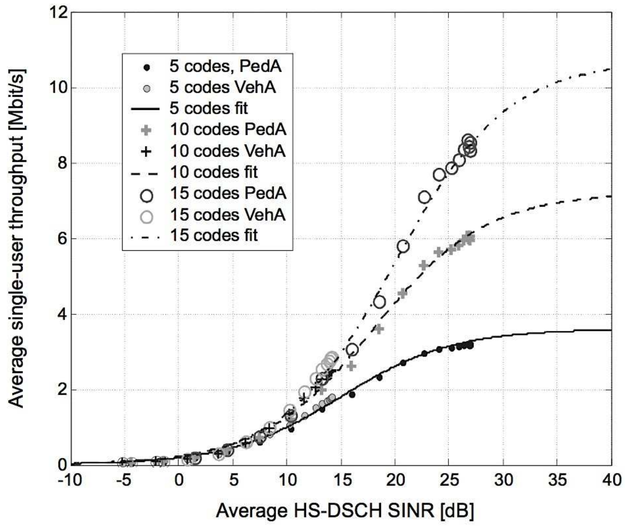


Figure 2.6 – HSDPA data rate as a function of average HS-DSCH SINR [12]

The result of the utilized modulation, QPSK or 16QAM, in the throughput is introduced in Figure 2.7, as a function of the HS-DSCH SINR supporting two types of ITU channels: the pedestrian-A, for short MT speed and micro-cellular environment, and the vehicular-A, for high speed MT and macro-cellular environment (greater delay power form). When SINR values are higher, the throughput improves caused by 16QAM is about 2 Mbps.

In the first stage of HSDPA with MTs sustaining just 5 HS-PDSCH codes, HSDPA is supposed to provide a capacity increase in order of 70%, mostly because of fast link adaptation, to HARQ, and to the multiple users capacity increase acquired with the utilization of Proportional Fair (PF) scheduling. With an HSDPA dedicated carrier, capacity depends on the number of HS-PDSCH codes used, on the type of scenario considered, type of service, and if code multiplexing is used (considering 5 code multiplexing). As predicted, if the number of HS-PDSCH codes is higher, a better average throughput is achieved. With the use of 5 codes multiplexing the entire capacity is decreased, due to the necessity of transferring 2 HS-SCCH channels and having to schedule more than one user per TTI.

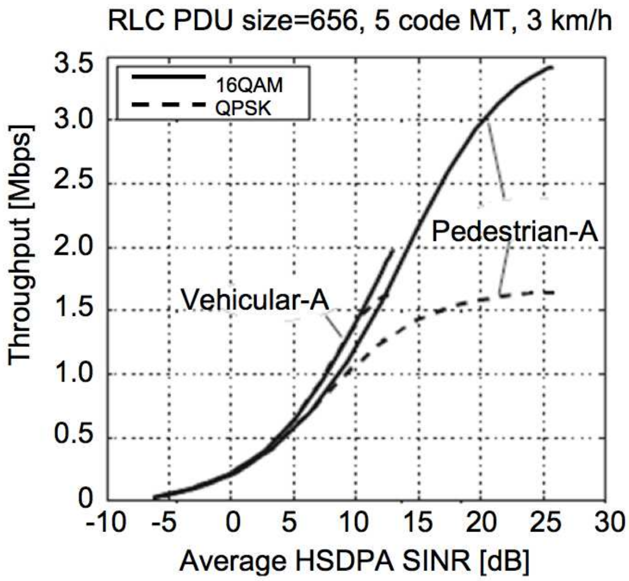


Figure 2.7 – Throughput as function of the average HS-DSCH SINR for QPSK and 16QAM [12]

Relatively to coverage aspects, it is essential to satisfy a minimum data rate at the cell border. According to Figure 2.7 the SINR is determined for an exact data rate. Through the use of 2.8 it is possible to express the NodeB HS-DSCH transmitted power as a function of the SINR, and therefore as a function of the required data rate at the cell border.

$$P_{HS-DSCH} \geq SINR\ [1-\alpha+G^{-1}]\cdot\frac{P_{Total}}{SF_{16}} \quad (2.8)$$

Where:

- G: geometry factor, with -3 dB being a typically value at the cell edge; higher values are obtained when the MT is closer to the Node B.

2.3 HSUPA

In this section, HSUPA main characteristics are presented, based on [12]. First, HSUPA main features and new channels are introduced. Then, performance, coverage and capacity are analyzed.

2.3.1 – Main Features

Following the improvement of HSDPA in DL, a similar approach was taken for UL. Although the term HSUPA was followed by the wireless industry as a consequence of the HSDPA successful result, in Release 6 the E-DCH was launched. The principal objectives of HSUPA were to enhance UL capacity, and to reach higher data rates, compared to Release 99's 384kbps, reaching 1 to 2 Mbps in early phases. HSUPA upgrades the radio interface, preserving each networking components unaltered. Like in WCDMA, power control is vital for HSUPA operation, along with support for Soft Handover (SHO).

A faster physical layer, a shorter TTI of 2 and 10 ms, and Node B scheduling were established in HSUPA like in HSDPA. The main difference between HARQ used in HSDPA and HSUPA is the fact that, HSUPA is completely synchronous, preventing the necessity for sequence numbering, and it can run in SHO. The Quadrature Phase Shift Keying (QPSK) is the modulation used and it was left unchanged since transmission with multiple channels was adopted, instead of using higher order modulation, avoiding complex implementations at the MT side.

In accordance to the HSDPA strategy, scheduling was as well transferred to Node B. For HSDPA one has a one-to-many structure, while in HSUPA one has a many-to-one structure, and because of that the dedicated channel method was selected. While in HSDPA, one of the criteria for admission of new users is the available power transmission, in HSUPA as every MT has its own transmitter, the shared resource is the UL noise factor, directly connected to the interference level. The scheduling principal purpose is to maintain the UL noise factor sufficiently high to permit a better cell capacity and guaranteeing that cell overload does not happen.

To guarantee HSUPA performance were presented new channels: the Enhanced Dedicated Physical Data Channel (E-DPDCH) for user data, and the Enhanced Dedicated Physical Control Channel (E-DPCCH) for control information. For scheduling objectives, the E-DCH Relative Grant Channel (E-RGCH) and the E-DCH Absolute Grant Channel (E-AGCH) were created. The E-DCH HARQ Indicator Channel (E-HICH) was added for retransmission feedback. The DCH channels from Release 99 were left unaltered. For HSDPA, a shared channel approach was used, while for HSUPA the E-DCH is a dedicated channel, like DCH from Release 99, but with fast retransmission and scheduling. Each E-DCH is independent of E-DCHs and DCHs from MTs.

The E-DPDCH is an UL physical channel for transmitting user information bits, earlier handled by the transport channel processing chain. As the DCH from Release 99, this channel uses Orthogonal Variable Spreading Factor (OVSF), supports multiple parallel transmissions, has fast power control loop, and uses QPSK modulation. The new properties are the fast physical layer HARQ and fast NodeB scheduling. The E-DPDCH supports SF2, which allows a more power efficient MT amplifier for high data rates. There are 2 TTI's for the E-DPDCH: 10 and 2ms. For the 10ms TTI, the frame is separated into five 2 ms sub-frames, each one corresponding to one E-DCH transport block. It needs the simultaneous transmission of the DPCCH for power and SIR estimation. The E-DPCCH is also required, to inform the NodeB receiver of the E-DPDCH format. The theoretical maximum bit rate achieved is 5.76 Mbps, with parallel transmission of 2 SF2 and 2 SF4 codes.

The E-DPCCH is an UL physical channel that transmits E-DPDCH decoding information to the NodeB. It has a fixed SF256 and transports 30 bits in a 2ms sub-frame. For the 10ms TTI, the 2ms sub-frame is repeated 5 times, allowing reduced power transmission. The E-AGCH is a DL physical channel used to control the MT transmission power in relation to the DPCCH, and consequently, control the available data rate for the MT. For the 2 ms TTI case, an additional bit, the absolute grant scope, may be used to allow or prohibit transmission for a specific HARQ process. It uses a fixed SF256.

The E-HICH is a DL physical channel to deliver HARQ feedback information for UL packet transmission. An ACK is delivered if there is a right decoding, in contrary, the NodeB reports a Negative ACK (NACK). This ACK/NACK process is just valid for NodeB's belonging to the user's active set. For other NodeB's, just ACKs are sent, and in case of wrong decoding there is no transmission. With this design the DL power transmission is reduced once for this Node Bs, there is a high probability of incorrect packets reception. The MT will maintain transmission till an ACK is received.

The modulation, SF and structure are identical as for the E-RGCH, with 40-bit long orthogonal sequence and admitting up to 40 E-HICH/E-RGCH on a single code channel, the differentiation being produced over high Radio Resource Control (RRC) signalling. All E-HICH transmitted from the same Radio Link Set (RLS) transport the same content and are soft combinable.

The E-RGCH is a DL channel for sending up, hold or down power commands, matching data rate adjustments. The modulation used is BPSK with On Off Keying (OOK) and SF128. The transmitted message depends on which cell is transmitting: for cells in the serving E-DCH RLS, the 3 power commands are valid while for the other cells, only the hold and down are valid, like ACK/NACK case in the E-HICH. In both cases, there is no transmission for the hold command. Every E-RGCHs transmitted from the serving E-DCH RLS transport the same command, and are soft combinable.

2.3.2 – Performance, Coverage and Capacity

HSUPA performance, like HSDPA performance, relies on parameters as network algorithms, development scenario, MT transmitter capability, NodeB receiver performance and capability, and the type of traffic contemplated. For HSUPA, 6 MT classes are determined, with UL bit rates among 69 kbps and above 4 Mbps, for category 1 and 6, particularly. For experimenting purposes, a group of E-DCH channel configurations, the Fixed Reference Channel (FRC), were defined by 3GPP. Considering there is no AMC in HSUPA, the performance metric is comparable to the Release 99 one, the E_C/N_0, energy per chip to noise spectral density ratio. To achieve high data rates, a high E_C/N_0 at the NodeB is required, which causes the UL noise to increase, and, as in WCDMA, leads to a decrease of the cell coverage area. Because of that, a maximum level for the UL noise may be defined for macro-cells, to guarantee the coverage area, therefore, restricting high data throughputs. In Figure 2.8 the expected throughput for medium speed MTs as a function of the available E-DCH E_C/N_0 is presented, where FRC5 is representative for first MT releases, while FRC2 and FRC6 are representative for future MTs with advanced capabilities, such as the support for 2 ms TTI and higher coding rate. As supposed, FRC2 reaches a higher throughput, with the maximum just under 3 Mbps, even though the upper data rates are only achieved for high E_C/N_0 values, which in real networks can be hard to reach. The E-DPCCH must also be correctly received, and since there is no error correction for this channel, it should be transmitted with high power to reduce decoding errors.

For HSUPA, new measurements were introduced: the UE Power Headroom (UPH), informing the Node B of the available power resources, and the E-DCH Transport Format Combination Indicator (E-TFCI), indicating the transport format being transmitted simultaneously on E-DPDCHs. The UPH measurement is similar to CQI in the HSDPA case, but due to delays and inaccuracy in measurements, it cannot be used with the same functionality as the CQI. As expected, HSUPA allows higher average throughput and improves the user bit rate, mainly due to fast physical layer HARQ retransmissions.

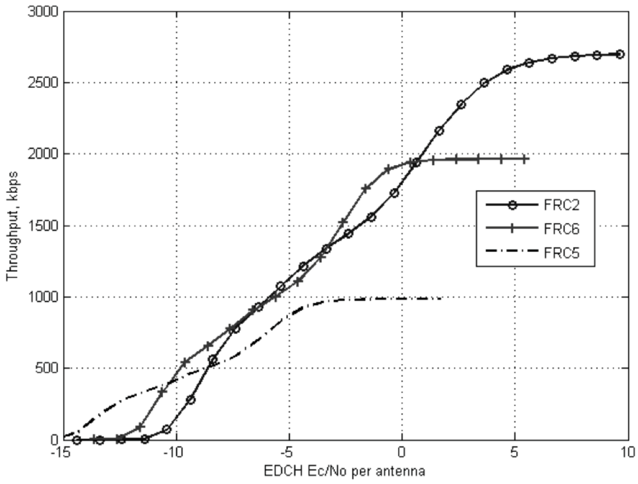


Figure 2.8 – HSUPA throughput in Vehicular A at 30 km/h, without power control [12]

In view of HSUPA efficiency, the utilization of HARQ and soft combination of HARQ retransmissions permits to substantially reduce the indispensable E_b/N_0 at the Node B, while comparing similar data rates with Release 99, which increases the UL spectral efficiency. Less delay and jitter in retransmissions is also accomplished, due to fast retransmissions. Enhancing the Block Error Probability (BLEP) at first retransmission, leads to lower effective E_b/N_0, and consequently, to increase of UL's spectral efficiency. Considering real traffic, the capacity improvement caused by the utilization of HARQ is supposed to be about 15 to 20%.

Using a fast NodeB scheduling permits fast adaptation to interference variations, and as well a greater resource sharing between users. The rigid UL noise factor command with Node B scheduling helps to prevent network overload and in case of overload situations it decreases the required time to return to a stable state.

As expressed previously, there are 2 TTIs available: the 2 ms for high data rates, only achieved under good radio channel conditions, and the 10 ms, the default value, for cell edge coverage and when, due to increase in path loss, there is a high number of retransmissions. To extend HSUPA coverage, the user can be downgraded from the 2 ms TTI to the 10 ms one.

2.4 Propagation Models

In mobile communications, the transmission medium greatly depends on the environment around them. Wave propagation models are particularly important to assure a good coverage and capacity planning, once they can be used to determine propagation characteristics. Propagation models can be theoretical or empirical. Theoretical propagation models deliver an approximation of the real environment founded on assumptions that simplify the problematic. However, when the scenario changes these models are not very adaptable. Empirical propagation models are based on measurements, which leads to best fitting equations, taking into account several parameters. Therefore, empirical models are usually very complicated. The disadvantage of these models is the limitation of boundaries in the parameters, since a group of equations is only valid under certain circumstances.

The use of models requests an environment classification, which takes into account some parameters like terrain morphology, vegetation concentration, building density and height, open areas and water areas density. Consequently, the environments are usually divided into three types: rural, urban and dense urban. The rural environment is the one with the largest open area, which usually consists of a flat terrain without any obstacles. Urban environment is characterized by the existence of a few obstacles, as for instance small cities and residential areas. Finally, dense urban, is a highly dense environment, consisting of buildings higher than 4 floors, such as large cities, commercial and industrial areas.

Classifying the cell type is also an important issue. For that reason, the cells used in the defined environments are usually classified respectively to their radius range and to the relative position of the base station antennas. In consequence, the cell type can be divided into four different types [14]: large macro-cell, small macro-cell, micro-cell and pico-cell. Table 3 specifies the cell type's radius and typical position.

Table 3 – Cell Types Definition [14]

Cell Type	Typical Cell Radius	Typical Position of BS Antenna
macro-cell	1km to 30 km	Mounted above medium roof-top level
small macro-cell	0.5 km to 3 km	Mounted above medium roof-top level
micro-cell	up to 1 km	Mounted below medium roof top level
pico-cell	up to 500 m	Mounted below roof-top level

The propagation models in this project scope of work are the COST 231–Hata Model and its extension the COST-Hata-Model. These propagation models are the basis for the standard propagation model used in this project. This standard propagation model will be specified in a next section.

COST 231–Hata Model is initially designed for GSM only use. The estimation of path loss is done with empirical models if land cover is only partial known, and the parameters required for semi-deterministic models cannot be determined. Four parameters are used for estimation of the propagation loss by Hata's well-known model:

- f: frequency [MHz]
- d: distance [km]
- h_{Base}: base station antenna height [m]
- h_{Mobile}: mobile antenna height [m]

In Hata's model, the basic transmission loss, L_b, in urban areas is given by:

$$L_b = 69{,}55 + 26{,}16 \cdot \log f - 13{,}82 \cdot \log h_{Base} - a\,(h_{Mobile}) + \ (44{,}9 - 6{,}55 \cdot \log h_{Base}) \cdot \log d \qquad (2.9)$$

Where:

$$a(h_{Mobile}) = (1{,}1 \cdot \log f - 0{,}7) \cdot h_{Mobile} - (1{,}56 \cdot \log f - 0{,}8) \qquad (2.10)$$

The COST 231–Hata Model limitations are:

- Frequency: $150 \ \leq \ f \ \leq 1000\ MHz$
- BS Antenna Height: $20 \ \leq \ h_{Base} \ \leq 200\ m$
- Mobile Antenna Height: $1 \ \leq \ h_{Mobile} \ \leq 10\ m$
- Distance: $1 \ \leq \ d \ \leq 20\ km$

COST 231 has prolonged Hata's model to the frequency $1500 \leq f \leq 2000\, MHz$ band by studying Okumura's propagation curves in the upper frequency band. This combination is called "COST-Hata-Model" and the basic transmission loss, L_b, is:

$$L_b = 46{,}3 + 33{,}9 \cdot \log f - 13{,}82 \cdot \log h_{Base} - a(h_{Mobile}) + (44{,}9 - 6{,}55 \cdot \log h_{Base}) \cdot \log d + C_m \qquad (2.11)$$

Where:

$a(h_{Mobile})$ is already defined in (2.11) and

$$C_m = \begin{cases} 0\ dB & \text{for medium size city} \\ 3\ dB & \text{for metropolitan centers} \end{cases} \qquad (2.12)$$

The COST–Hata–Model limitations are:

- Frequency: $1500 \leq f \leq 2000\, MHz$
- BS Antenna Height: $30 \leq h_{Base} \leq 200\, m$
- Mobile Antenna Height: $1 \leq h_{Mobile} \leq 10\, m$
- Distance: $1 \leq d \leq 20\, km$

COST-Hata-Model applications are restricted to large and small macro-cells, for example a base station antenna heights above rooftop levels adjacent to the base station. The defined Hata's formula and its modification are not recommended to be used for micro-cells.

Chapter 3

3G Radio Network Planning

In this chapter is described the process used for the Radio Network Planning project. Starting with a description of the simulation models and the tools provided by Alcatel-Lucent. Later, it is characterized the inputs and assumptions taken into account in the project, considering also the customer requirements. The Cameroon network is specified and, at the end, the initial design simulations for the required services are also presented.

3.1 Introduction

Third generation networks have already a solid foundation with more than 60% of coverage worldwide. However, this is not the reality in some continents, such as the African continent. By the end of 2013 85% of all the African mobile networks were second generation. This project is an example of the effort that mobile operators are making to improve mobile networks in developing regions.

The project consists in a third generation network deployment, with Alcatel-Lucent third generation network solution, in Cameroon. The plan, decided by the customer, was divided into three stages. The first stage was to do the radio network planning for Douala city with a particular focus in a pilot cluster, proposed by the customer. The second stage was to do the planning for the Cameroon's capital, Yaoundé city. The third and final stage of the project consisted of making the network planning for the rest of the country.

Radio network deployment, for this third generation network, has involved two new hardware components. First was the integration of a Multi-Carrier Remote Radio Head (MC-RRH), which is one of the core building blocks of the Alcatel-Lucent Converged Radio Access Network. The Multi-Carrier Remote Radio Head (MC-RRH) is an outdoor radio head that can be fixed near to the antenna to reduce feeder losses and increase coverage. In addition, it reduces the required base transceiver station (BTS) footprint. Based on Software-Defined Radio (SDR) and multi-carrier power amplifier (MCPA) technologies, this next-generation module enables carriers to handle two different technologies simultaneously. In Table 4 are specified the different Software-Defined Radio (SDR) modules that Alcatel-Lucent offers.

Table 4 – Alcatel-Lucent Software-Defined Radio Modules [15]

	BBU	RF MODULES						
	d2U	TRU	TRDU 60	RRH 40	RRH 60	RRH MIMO	MC-TRX MC-RRH	MCR B
SDR type	Mono	Multi	Multi	Mono	Multi	Multi	Multi	Multi
Frequencies (MHz)	Any	850, PCS, AWS	2100	850, 900, AWS, 1900, 2100	850, 900, 1900, 2100	700, 850, AWS, 1800, 1900, 2100, 2600	900, 1800	850, PCS, AWS

Alcatel-Lucent Software-Defined Radio (SDR) products allow customers to adjust their network's layers capacities quickly and easily, for each single cell, and control them from a unique management centre. They use the latest power amplifiers and processors to achieve a better capacity within existing rack space and with minimum power consumption to help maintaining your low OPEX targets. An operational expenditure (OPEX) is the money a company spends on an ongoing, day-to-day basis in order to run a business or system. The main benefits of implementing a Multi-Carrier Remote Radio Head are:

- It offers an outdoor radio head that can be attached close to the antenna using optical fibber links, this enables the installation where there is limited space.

- It provides a multi-technology solution. Supports two technologies, (Global System for Mobile Communications [GSM] and Wideband Code Division Multiple Access [WCDMA] or GSM and Long Term Evolution [LTE]) simultaneously in the same module.

- It is software-defined radio-based. This allows remote software configuration of modules to activate or deactivate GSM, WCDMA, or LTE carriers.

- It has shared power amplifier (one or two for each MC-RRH). This provides higher capacity or higher coverage, depending on what is needed.

The second hardware component that was implemented in this third generation network deployment is a new tri-band antenna with higher gain, which supports the second and third generation layers. The antenna is a RFS WindMaster™ cross-polarized triple band antenna, model name APXVERR26-C. This antenna is an excellent choice for triple band upgrades for high traffic areas. It can be used for multiple bands such as LTE800, CDMA850, GSM900, UMTS900, DCS1800, PCS1900 and UMTS2100. The high gain antenna includes an in-line antenna-radiating platform to provide a superior pattern symmetry and one phase shifter for each dipole to provide an exceptional pattern at all tilt ranges. The antenna pattern defines the variation of the power radiated by an antenna as a function of the direction away from the antenna. In the Figure 3.1 is illustrated an example of the antenna pattern for APXVERR26-C with 2 degrees electrical tilt.

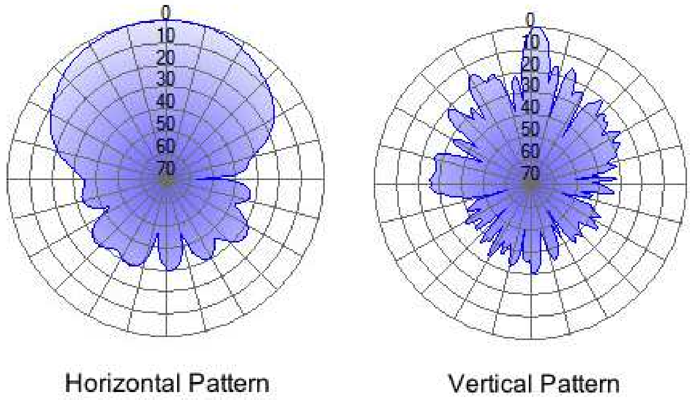


Figure 3.1 – Antenna radiation pattern for APXVERR26-C with 2 degrees electrical tilt [20]

Variable electrical tilt is one of the key features that this antenna provides, which allows an enhanced precision in the control of inter-cell interference. The electrical tilt range is from 2 to 12 degrees that is ideal for applications in dense areas. Additionally what contributes to reduce cell interference is the high suppression of upper side lobes that this antenna also incorporates.

Radio network planning design is important to evaluate and estimate the initial third generation coverage, based on some initial assumptions accorded with the customer. The starting point was to use tilt and azimuth configuration of the second-generation layer. From the second-generation layer GSM900 configuration was chosen. This choice was done based on the fact that GSM900 layer is more mature and is more optimized on the Cameroon network than the DCS1800 layer. A study was made and GSM900 tilts configuration offers more quality before optimization comparing to DCS1800 tilts usage. Initial design also takes into account the defined link budget for the different services; link budget calculation will be specified in the following work section.

After the first design, with the defined initial inputs, the next phase was to optimize the entire third generation network with the purpose to improve signal level coverage and quality. The optimization was done only at antenna’s electrical tilt. Due to specific requirements, from the customer, azimuth optimization was not permitted; these requirements are specified in section 4.1. When the optimization phase was finished the next, and final, stage of the design work was to fulfill the remaining interference and coverage holes after the first optimization process. To overcome these interference and coverage problems a new sites optimization phase was introduced. In this phase, new sites were proposed to surpass the existing problems, the sites that initially were not supposed to upgrade from second-generation to third-generation were include in the simulations.

The main goal of the Radio Network Planning (RNP) design project is to guarantee good coverage and quality for the defined services to achieve the best experience possible. Quality of Service (QoS) follow-up and optimization phase after the deployment is important in order to evaluate and improve the offered services. The deployment in Cameroon was planned to start in late 2014 or early 2015.

This project report main focus will be Douala city radio network planning only. Therefore, it would not be possible to address the entire Cameroon network in this report. Although, the same design project inputs and assumptions were assumed throughout the entire Cameroon project.

3.2 Tools Description

In this section will be described the tools used for the design project. First, Alcatel-Lucent Link Budget Tool main features will be described. This tool is responsible for the design levels computation. Then, Alcatel-Lucent A9955 design tool main functionalities are also specified.

3.2.1 – Link Budget Tool

Alcatel-Lucent link budget tool provides the Radio Network Planning (RNP) design level Common Pilot Channel (CPICH) Received Signal Code Power (RSCP) for the required service and terrain morphology.

The link budget is executed for the most limiting service in the uplink. A cell is usually dimensioned by its coverage and is defined by the maximum cell range at which a mobile station is received with enough quality by the base station. Figure 3.2 illustrates this concept.

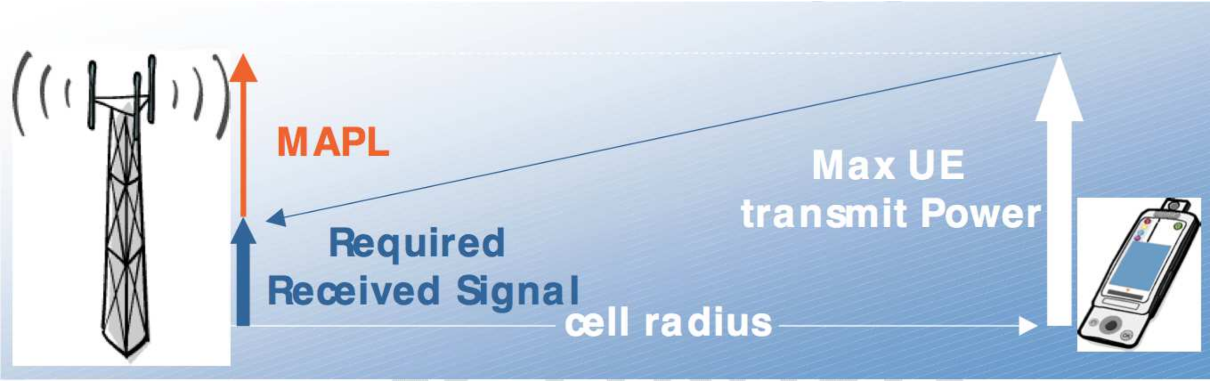


Figure 3.2 – Cell range concept [16]

Sensitivity can be defined as the signal threshold at which a signal is received with enough quality. Target quality, such as Bit Error Rate (BER) and Frame Error Rate (FER), is one of the factor in which this sensitivity figure will depend on. Sensitivity depends, as well, from the propagation environment conditions, multipath channel and mobile speed as an example. Node-B receiver's characteristics, like the noise figure, are also a contributively factor affecting the sensitivity.

The sensitivity figure will consequently depend on the service used by the mobile station. In UMTS, as various services are offered on the same radio interface, link budgets calculations must be derived for all the different services. The system will then be dimensioned for the worst case service, the most limiting one in terms of cell range.

Uplink link budget consists in calculating the Maximum Allowable Propagation Losses (MAPL) that a mobile at cell edge can reach while meeting the sensitivity level at the base station. Uplink link budget calculations consider all the gains and losses between the mobile transmitted power and the base station received power. However, some additional particularities of CDMA systems, such as soft-handover and fast power control, have to be considered.

Maximum Allowable Propagation Losses (MAPL), or path loss, calculation takes into account the user equipment (UE) transmitted power, losses and margins, gains, sensitivity and interference. An example of MAPL calculation can be seen in the following figure.

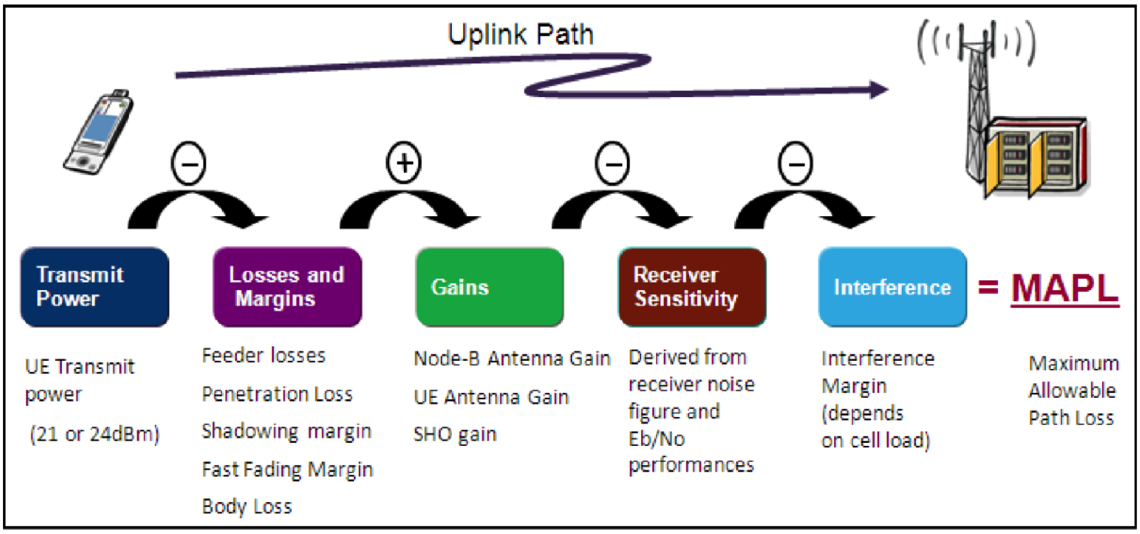


Figure 3.3 - Maximum Allowable Propagation Losses (MAPL) calculation [16]

3.2.2 – Alcatel-Lucent A9955

The A9955 working environment is powerful and flexible. It provides a complete and integrated set of tools and features that allow the user to create and define a microwave or radio-planning project in a single application. A9955 includes advanced multi-technology network planning features as CDMA and LTE, and a combined single-RAN, multi-RAT GSM/UMTS/ LTE Monte Carlo simulator and traffic model.

A9955 not only allows the user to create and work on a planning project, but also offers a wide range of options for creating and exporting results based on user's project. The working environment provides a wide selection of tools to simplify microwave or radio planning, such as a search tool to locate either a site, a point on the map, or a vector. A9955 has the ability to manage all objects in the database: sites, transmitters, calculations, as well as geographic data such as the Digital Terrain Model (DTM), traffic maps, and clutter classes. The design engineer can, for example, define various coverage predictions or configure parameters or display data objects.

The map is the working area for the database and provides several tools for working with it. Users can change the view by moving or zooming in or out and choose which objects are displayed and how they are displayed. Also has the capacity to export the current display definition, or configuration, to use it in other documents.

The main window, where map window, data tables and reports are displayed, and the explorer window compose A9955 working area, presented in Figure 3.4. The explorer windows contain the data, objects, and parameters of a document, arranged in folders.

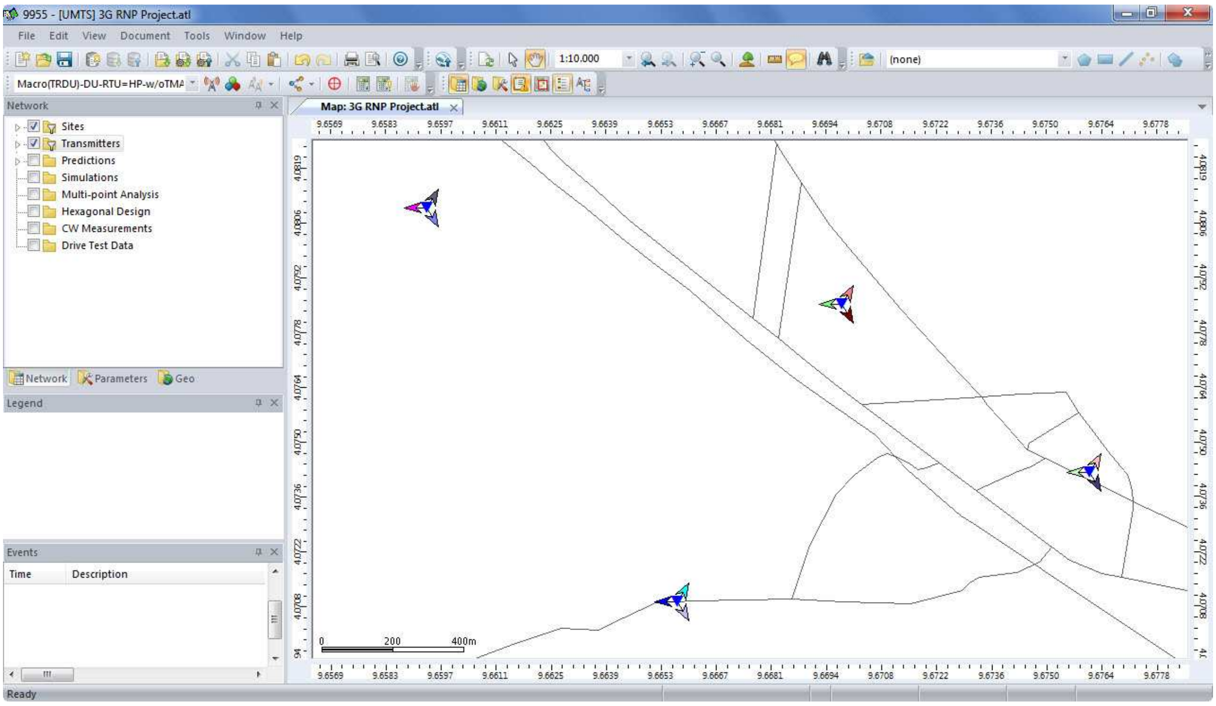


Figure 3.4 – A9955 working area [15]

Sites and transmitters information are accessible in the main window as well. So, it is easy to check and/or change some configurations without having to go to the configuration tables. Figure 3.5 shows an example of transmitter information. With this ability it is possible to do optimizations in the coverage area more easily.

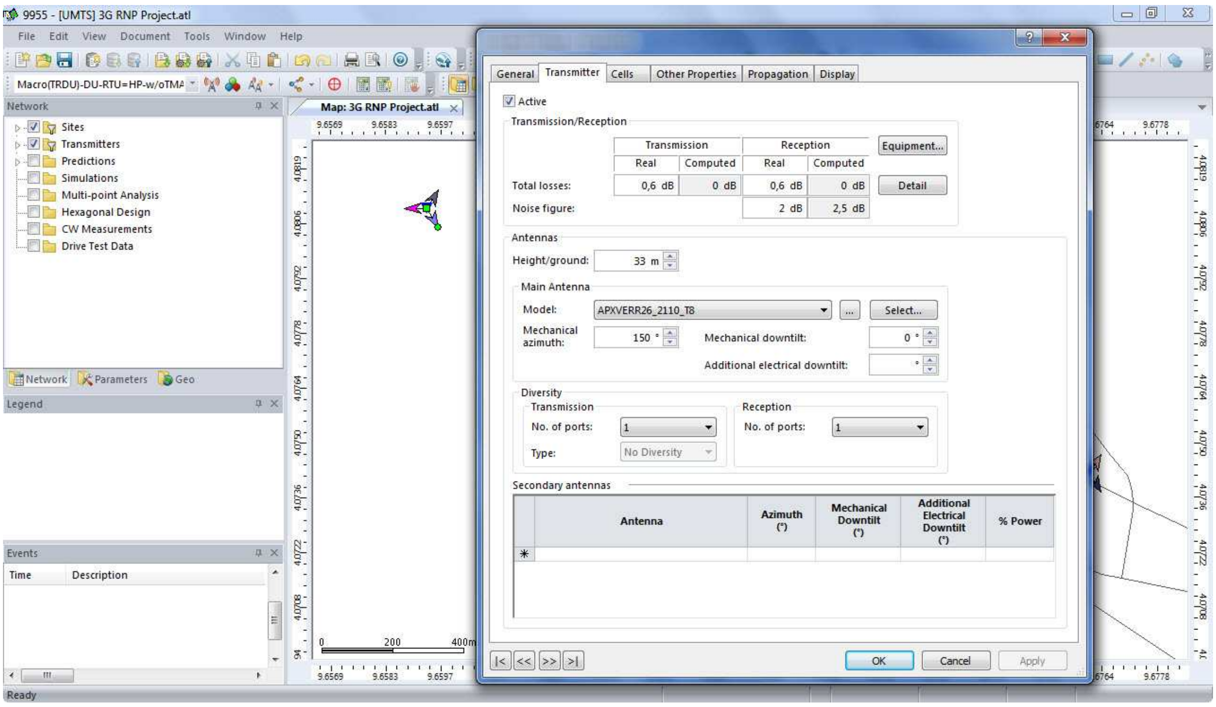


Figure 3.5 – Transmitter information in the main window [15]

It is also possible to see, at the main window, the terrain morphology in front of a sector. This is a very important feature from the optimization point of view. The reason for a coverage hole, in a certain area, could be due to terrain morphology. An example of this feature can be seen in Figure 3.6.

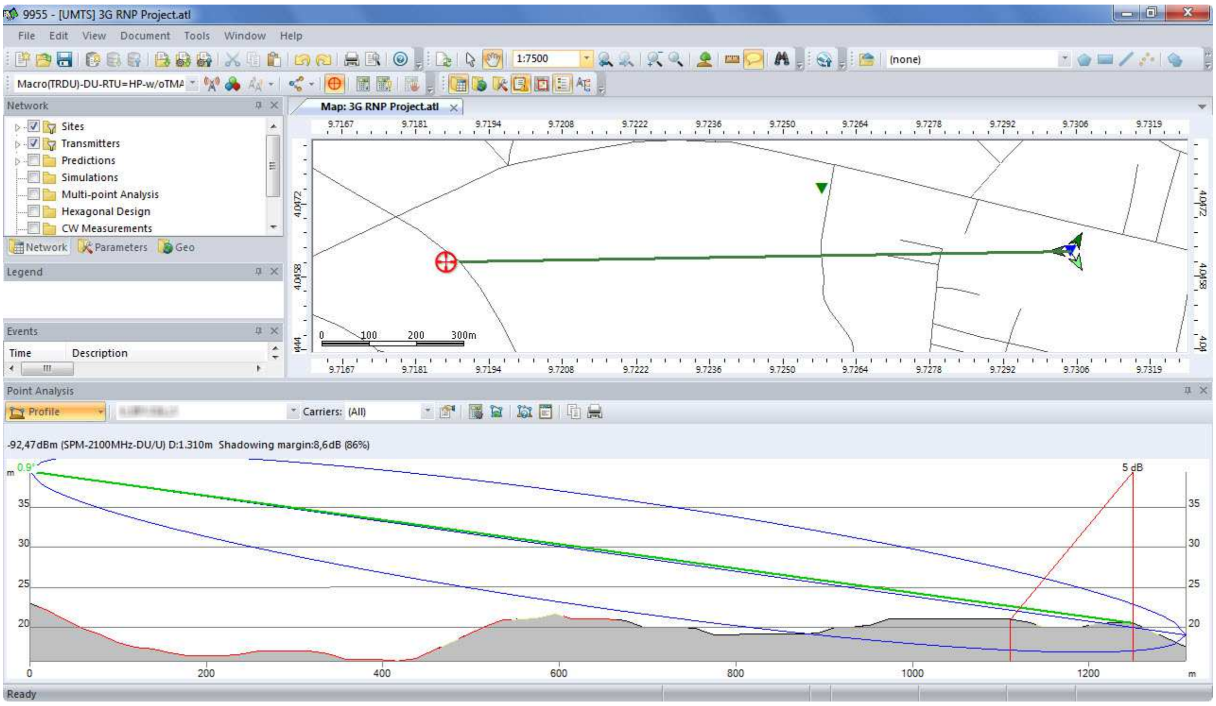


Figure 3.6 – Terrain Morphology in front of a sector at A9955 [15]

The starting point for every project is to create the network. Sites, transmitters and cells must be specified with all the required information. Then clutter classes and terrain morphology information, usually granted by the customer, should be imported to the project file. These topics will be specified in the next section.

Once the network is created, it is possible to do the predictions. There are two types of predictions:

- Point predictions using the Point Analysis tool: The Point Analysis tool allows to predict, at any point on the map, the profile between a reference transmitter and a receiver, the value of the signal levels of the surrounding transmitters, an active set analysis for UMTS, CDMA2000, and TD-SCDMA projects and an interference analysis for GSM/GPRS/ EDGE projects.

- Coverage predictions: this allows to calculate standard coverage predictions, coverage by transmitter, coverage by signal level and overlapping zones, and specific coverage predictions such as interference predictions for GSM/GPRS/EDGE projects or handover, service availability, etc. for UMTS, CDMA2000 and TD-SCDMA projects. Many customization features on coverage predictions are available in order to make their analysis easier.

A9955 facilitates the calculation of coverage predictions with support for multithreading and distributed calculating. A9955 also offers the possibility to use polygonal zones to limit the amount of resources and time used for calculations. The polygonal zones, such as the filtering zone and the computation zone, helps to restrict calculations to a defined set of transmitters, and to limit calculations and coverage predictions.

The propagation model adopted in this project was the A9955 Standard Propagation Model (SPM). The Standard Propagation Model is a propagation model based on the Hata formulas and is suited for predictions in the 150 to 3500 MHz band over long distances, from one to 20 km. It is best suited to GSM 900, DCS1800, UMTS, and CDMA2000 radio technologies.

The Standard Propagation Model is based on the following formula:

$$P_R = P_{TX} - \begin{pmatrix} K_1 + K_2 \cdot \log d + K_3 \cdot \log H_{TX_{eff}} + K_4 \cdot DiffractionLoss + K_5 \cdot \log d \cdot \log H_{TX_{eff}} + \\ K_6 \cdot H_{RX_{eff}} + K_7 \cdot \log H_{RX_{eff}} + K_{clutter} \cdot f(clutter) + K_{hill,LOS} \end{pmatrix} \quad (3.1)$$

Where:

- P_R: received power [dBm],
- P_{TX}: transmitted power (EIRP) [dBm],
- K_1: constant offset [dB],
- K_2: multiplying factor for $\log d$,
- *d* : distance between the receiver and the transmitter [m],
- K_3: multiplying factor for $\log H_{TX_{eff}}$,
- $H_{TX_{eff}}$: effective height of the transmitter antenna [m],
- K_4: multiplying factor for diffraction calculation, $K_4 \geq 0$
- $DiffractionLoss$: losses due to diffraction over an obstructed path [dB],
- K_5: multiplying factor for $\log d \cdot \log H_{TX_{eff}}$,
- K_6: multiplying factor for $H_{RX_{eff}}$,
- K_7: multiplying factor for $\log H_{RX_{eff}}$,
- $H_{RX_{eff}}$: mobile antenna height [m],
- $K_{clutter}$: multiplying factor for $f(clutter)$,
- $f(clutter)$: average of weighted losses due to clutter,
- $K_{hill,LOS}$: corrective factor for hilly regions (=0 in case of NLOS),

It is important to notice that the user can define all these parameters. In the next session it will be described the inputs and assumptions for this project, further in this chapter it will be specified all services predictions where the described tools were used.

3.3 Inputs and Assumptions

This section presents the Radio Network Planning (RNP) project inputs and assumptions. Network configuration, clutter classes and Digital Terrain Model (DTM), link budget calculation results, chosen propagation model and some another assumptions will be described in this section.

3.3.1 – Network Configuration

The Cameroon network is composed by over than five hundred sites. For Douala city there are two hundred and eighteen sites from which only one hundred and thirty five are originally planned to support second and third-generation technology. In the Table 5 is specified the network configuration.

Table 5 – Number of sites in the network

City	Total Sites	2G Only Sites	2G / 3G Sites
Douala	218	83	135
Yaoundé	180	75	105
Rest of the country	135	92	43
Total	533	250	283

3.3.2 – Clutter Classes and DTM

Clutter refers to a land use or land cover classification of surface features which impact on radio wave propagation. In this project case, the clutter classes are given by the customer, and based on this information some considerations can be taken. In Figure 3.7 is illustrated these clutter classes and in Table 6 it can be seen the clutter classes correspondent color scheme and statistics.

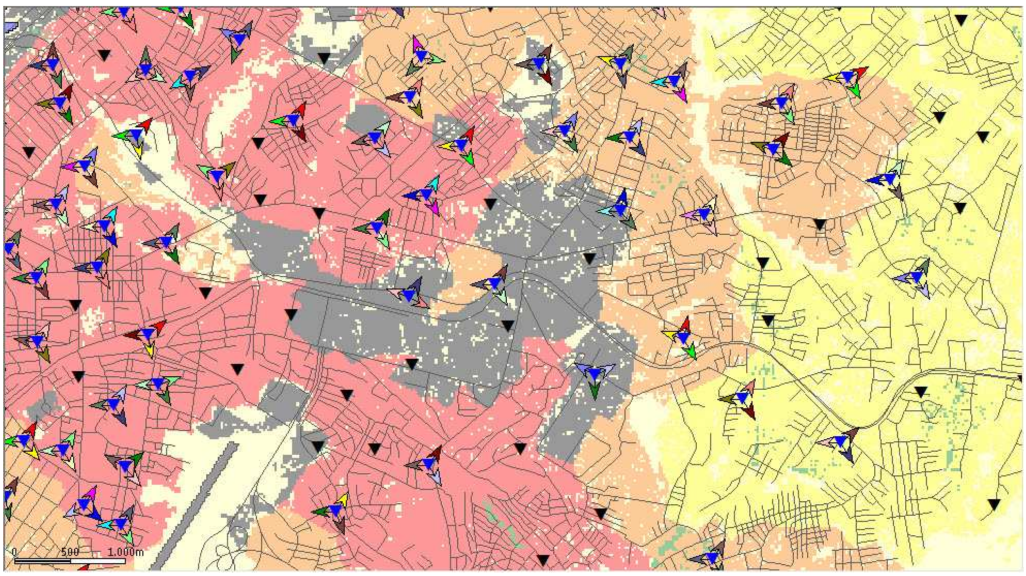


Figure 3.7 – Clutter classes characterization [15]

Table 6 – Clutter classification and statistics

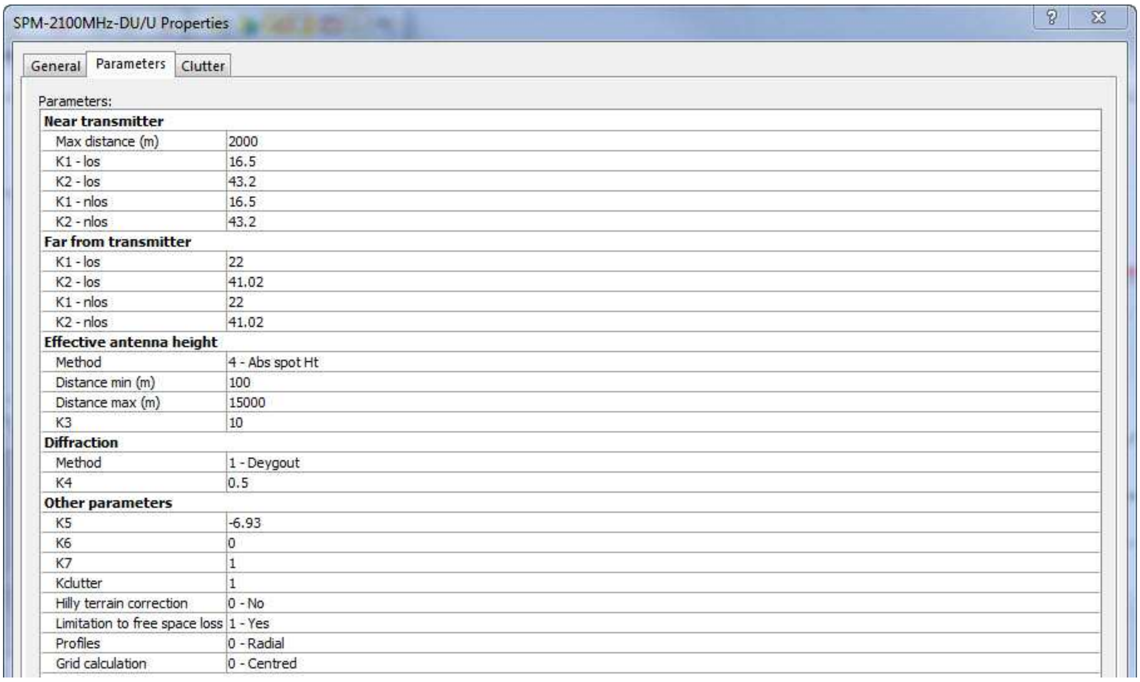
Name		Surface (km²)	Percentage (%)
	Sea	0,4064	0,2
	River	1,0728	0,5
	Seasonal Water Body	0	0
	Lake	0	0
	Inland Water	0	0
	Open Area	74,5964	34,5
	Agriculture	0	0
	Low Dense Vegetation	11,8064	5,5
	High Dense Vegetation	4,9192	2,3
	Village	0,2064	0,1
	Suburban	0,334	0,2
	Low Dense Urban	49,2684	22,8
	Medium Dense Urban	40,6628	18,8
	Dense Urban	23,5132	10,9
	Industrial	9,1452	4,2
	Airport	0,5876	0,3

From the statistics presented in the Table 6 it can be concluded that Douala populated area is mainly residential in suburban and rural areas. Based on this information, sites inside orange and red classes will be considered as dense urban and urban areas for the Radio Network Planning (RNP) project. So, this means that all the remaining sites will be assumed as suburban and rural areas for the project. It is important to notice that this surface area is the focus zone used for Doula city with a total focus zone area of around 216 km. The same classification was used throughout the entire Cameroon project. Associated with the defined areas for the Radio Network Planning (RNP) project is the Standard Propagation Model (SPM) definition. In other words, the sites that were classified as dense urban and urban will use the Standard Propagation Model - Dense Urban / Urban. The remaining ones will use the Standard Propagation Model – Sub-Urban / Rural. These specific propagation models parameters will be specified in the next section. Digital Terrain Model (DTM) is especially important to import into a Radio Network Planning (RNP) project. DTM has the information of the terrain heights for the entire workspace. Without the definition of the DTM, the feature that allows the user to see the terrain morphology in front of a site (introduced in section 3.2.2), will not be available.

3.3.3 – Standard Propagation Model Parameters

In the Cameroon project, as was introduced in section 3.3.2, were used two different classes of the Standard Propagation Model (SPM) defined in the A9955 tool. For dense urban and urban zones was used the SPM – 2100MHz – DU/U.

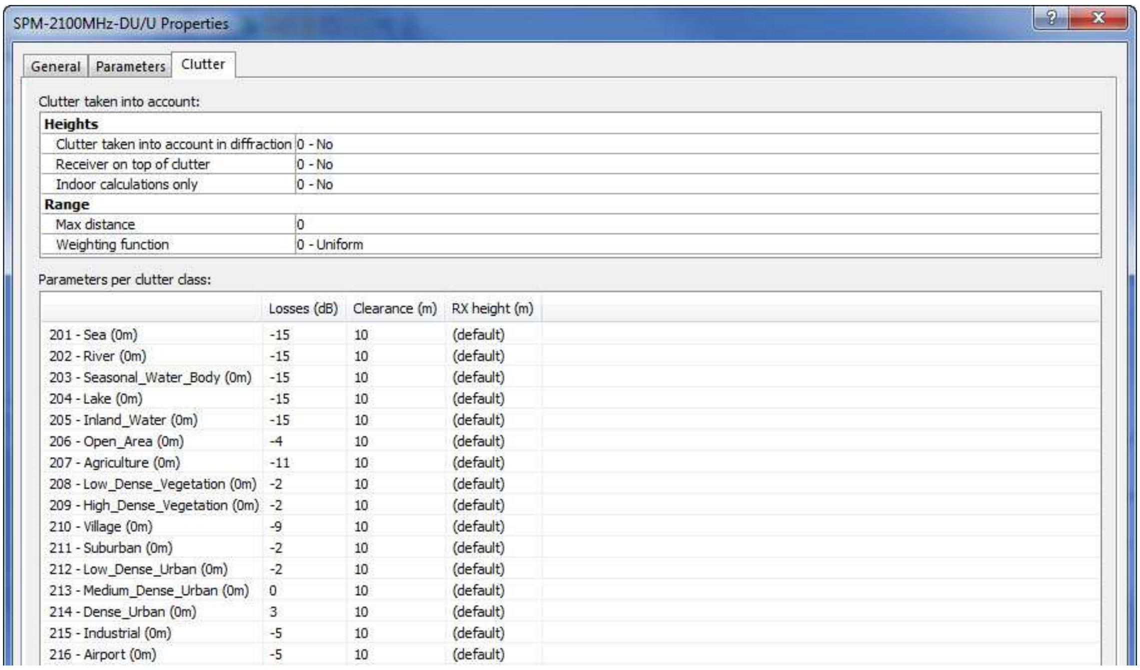
The parameters that characterize this propagation model are defined in the following figure. It is important to remember that the tool will use these parameters to compute the received power as described in the equation (3.1) in section 3.2.2.



Near transmitter	
Max distance (m)	2000
K1 - los	16.5
K2 - los	43.2
K1 - nlos	16.5
K2 - nlos	43.2
Far from transmitter	
K1 - los	22
K2 - los	41.02
K1 - nlos	22
K2 - nlos	41.02
Effective antenna height	
Method	4 - Abs spot Ht
Distance min (m)	100
Distance max (m)	15000
K3	10
Diffraction	
Method	1 - Deygout
K4	0.5
Other parameters	
K5	-6.93
K6	0
K7	1
Kclutter	1
Hilly terrain correction	0 - No
Limitation to free space loss	1 - Yes
Profiles	0 - Radial
Grid calculation	0 - Centred

Figure 3.8 - SPM-2100MHz-DU/U Parameters [15]

Each Standard Propagation Model (SPM) has its specific clutter classes attenuations, which are aggregated with the project clutter classes defined in the section 3.3.2. Figure 3.9 specifies the losses due to the defined clutter classes.



Heights	
Clutter taken into account in diffraction	0 - No
Receiver on top of clutter	0 - No
Indoor calculations only	0 - No
Range	
Max distance	0
Weighting function	0 - Uniform

Parameters per clutter class:

	Losses (dB)	Clearance (m)	RX height (m)
201 - Sea (0m)	-15	10	(default)
202 - River (0m)	-15	10	(default)
203 - Seasonal_Water_Body (0m)	-15	10	(default)
204 - Lake (0m)	-15	10	(default)
205 - Inland_Water (0m)	-15	10	(default)
206 - Open_Area (0m)	-4	10	(default)
207 - Agriculture (0m)	-11	10	(default)
208 - Low_Dense_Vegetation (0m)	-2	10	(default)
209 - High_Dense_Vegetation (0m)	-2	10	(default)
210 - Village (0m)	-9	10	(default)
211 - Suburban (0m)	-2	10	(default)
212 - Low_Dense_Urban (0m)	-2	10	(default)
213 - Medium_Dense_Urban (0m)	0	10	(default)
214 - Dense_Urban (0m)	3	10	(default)
215 - Industrial (0m)	-5	10	(default)
216 - Airport (0m)	-5	10	(default)

Figure 3.9 - SPM-2100MHz-DU/U Clutter Parameters [15]

For suburban and rural areas, SPM SU/RU AWS – 2100MHz A9955 propagation model was used. These propagation model parameters are similar to the ones presented for SPM-2100MHz-DU/U. They only differ in the K2-los, K2-nlos and K7 parameters. In SPM SU/RU AWS – 2100MHz, K2-los and K2-nlos takes the value 39.7, as for K7 the value in this propagation model is 0.

3.3.4 – Link Budget Assumptions

Link Budget has a large range of parameters assumptions that have to be taken into account for the final link budget calculations per service. First it is important to specify the frequency parameters that are described in Table 7.

Table 7 – Frequency Band Parameters

Frequency Band Parameters						
Frequency Band	Frequency		Propagation Model	3-Sector Antenna Gain	Cable Losses if no RRH	Cable Losses if RRH
	UL	DL				
2100	1950 MHz	2140 MHz	COST-231	18,0 dBi	3,0 dB	0,4 dB
Indoor Penetration Margin					Eb/No Delta to 2100MHz	
Dense Urban	Urban	Suburban Indoor	Suburban Incar	Rural	Veh A3	VehA50
20 dB	17 dB	14 dB	8 dB	8 dB	0,00 dB	0,00 dB

After the definition of frequency band parameters, NodeB parameters have also to be defined. Parameters like power amplifier, radio terminal unit (RTU) power step, maximum NodeB transmitted power and NodeB noise figure are specified in Table 8.

Table 8 – NodeB Parameters

NodeB Parameters	
Selected PA Type	60 W - RRH
NodeB RTU Power Step	20 W
Max NodeB Tx Power	43,0 dBm
NodeB Noise Figure w/o TMA	2,0 dB

Before the Link Budget tool is able to make the calculations it is necessary to introduce some inputs regarding the cell area coverage probability, the release-99 uplink (R99 UL) cell load and the High Speed Uplink Packet Access cell load. These values are specified in Table 9.

Table 9 – Link Budget Inputs

Cell Area Coverage Probability	R'99 UL Cell Load	HSUPA UL Cell Load
95%	50%	75%

The last step in the link budget calculations inputs preparation is to define the common pilot channel equivalent isotropic radiated power parameters (CPICH EiRP) parameters. The following table describes these parameters. It is important to notice that the percentage of CPICH power is always associated to the total transmitted power by the NodeB.

Table 10 – Common Pilot Channel Equivalent isotropic Radiated Power Parameters

CPICH EiRP	
Max NodeB power	43 dBm
% CPICH Power	10%
CPICH Power	33 dBm
CPICH EiRP w/o TMA	50,6 dBm

With all the necessary parameters defined, the link budget radio network design level (CPICH RSCP) can be computed. The tool makes this computation automatically. In Table 11 are described the RNP design level thresholds for the main services. These services will be further explained in the next section. However, is important to emphasise that was the customer who defines the PS128 & HSDPA 2Mbps and PS128 & HSDPA 1Mbps services thresholds. This makes PS128 & HSDPA 2Mbps the most restrictive service in the project.

Table 11 – Link Budget Calculations per Service

Link Budget - 2100 MHz					
RNP Design Level	**Speech**	**PS128**	**PS128 & HSDPA**	**PS128 & HSDPA 2 Mbps**	**PS128 & HSDPA 1 Mbps**
Dense Urban (Deep Indoor)	-82,5 dBm	-78,7 dBm	-81,2 dBm	-67,56 dBm	-70,9 dBm
Urban (Daylight Indoor)	-85,4 dBm	-81,7 dBm	-84,1 dBm	-74,45 dBm	-77,8 dBm
Incar	-94,4 dBm	-90,7 dBm	-93,1 dBm	-81,45 dBm	-84,8 dBm
Outdoor	-102,4 dBm	-98,7 dBm	-101,1 dBm	-89,45 dBm	-92,8 dBm
Rest	-110 dBm	-110 dBm	-110 dBm	-110 dBm	-110 dBm

3.3.5 – A9955 Assumptions

A9955 have an extensive range of parameters and assumptions that must be defined in order to make the predictions. Although the scope of this project is not a full description of the parameters, in Table 12 are described the main parameters that have to be considered in the A9955.

Table 12 – A9955 UMTS main parameters

UMTS Inputs	Values
Frequency Band	2100 MHz
Main Propagation Model (Dense-Urban / Urban)	SPM-2100MHz-DU/U
Main Propagation Model (Sub-Urban / Rural)	SPM-2100MHz-SU/RU
Main Calculation Radius (m)	15 000
Main Resolution (m)	20
Max Power (dBm)	43
Transmission Loss (dB)	0,6
Reception Loss (dB)	0,6
Noise Figure (dB)	2
NodeB Antenna	APXVERR26_2110
Body Loss Speech (dB)	3
Body Loss Data (dB)	0
UE Antenna Gain (dB)	0
UE Noise Gain (dB)	7
HSDPA Mobile Categories	8 (Max 7,2 Mbps)
	24 (Max 42 Mbps)
HSUPA Mobile Categories	6 (Max 5,7 Mbps)

There are two carriers defined for this project. The first carrier, carrier 0, is shared between R99 and HSDPA traffic with 50% to CCH and R99 traffic, 25% to HSDPA and 5% to HSUPA. On the other hand the second carrier, carrier 1, is dedicated to HSDPA with 20% to CCH, 75% to HSDPA and 5% to HSUPA. The parameters specification for A9955 definition is exposed in Table 13.

Table 13 – Carriers Parameters Definition

Carrier 0 (R99 & HSDPA)	Values
Total Power for Common Channels and R99 traffic Load (50%)	40 dBm
Remain power for HSDPA	39 dBm
UL Load Factor	50%
UL Load Factor due to HSUPA	25%
Max UL Load Factor	75%
Carrier 1 (Dedicated HSDPA)	**Values**
Total Power for Common Channels Load (20%)	36 dBm
Remain power for HSDPA	41,8 dBm
UL Load Factor	0%
UL Load Factor due to HSUPA	25%
Max UL Load Factor	75%

Each RNP Design Level, specified in the previous section, have a color scheme associated. So the A9955 will use this color scheme for the predictions calculation. The color scheme was an input from the customer and is illustrated in Table 14.

Table 14 – Coverage Signal Level Color Scheme

Coverage Signal Color Scheme	
	Dense Urban (Deep Indoor)
	Urban (Daylight Indoor)
	Incar
	Outdoor
	Rest

3.3.6 – Primary Scrambling Codes

Primary Scrambling Codes (PSCs) are used for sector separation, as described in section 2.1.2. The recommendation for the Primary Scrambling Codes allocation method was made for the customer. There are four defined domains: Future use, In-Building Picocells, Normal Planning and Temporary Use. In Table 15 are specified the allocation method for the Primary Scrambling Codes allocation.

Table 15 – Primary Scrambling Codes Domains

Domain	Group	Min	Max	Step
Future Use	53 to 63	424	511	1
In Building Picocells	52	416	423	1
Normal Planning	1 to 51	8	415	1
Temporary Use	0	0	7	1

It is important to notice that the defined reuse distance is 10 km, both carriers are identically allocated and there are three codes per cluster. For this project, only the Normal Planning domain was used and primary scrambling codes were reused from one city to another, as the distance between each other is more than the defined reuse distance.

3.3.7 – Design project goals

Alcatel-Lucent has design principles and criteria to achieve the main goal for third generation network design. The first criterion is related to the Received Signal Code Power (RSCP). Usually, the recommended dimensioning service is PS128. The goal is to have 95% of surface covered with outdoor RNP design level. However, in this project, the customer was more restrictive. The goal is also to have 95% of covered area with outdoor RNP design level, but in the PS128 & HSDPA 2 Mbps service. In addition, the customer introduced a new design goal that is to have more than 70% of surface covered with urban (daylight indoor) RNP design level, for PS128 & HSDPA 2Mbps. Other criterion defined by Alcatel-Lucent is related with the pilot quality, more specifically with Ec/I0 value. The goal is to have 95% of coverage area with an Ec/I0 value of -15dB. From the quality point of view, if an area has good signal coverage but has a poor Ec/I0 value the provided service will not be at the desired level, in other words, it will be a poor service. The final defined criterion is related to interference. The target is to minimize interference without impacting coverage and at the same time enhance quality. The interference criterion relies on the surface with cells within 4dB best server. The surface with 4 servers should be less or equal to 2%. All these criteria will be further discussed in the next section.

3.4 Initial Design Predictions per Service

In this section, are described the main services predictions to fulfill both Alcatel-Lucent and customer requirements. It is important to notice that the initial design predictions have the second-generation network configurations.

3.4.1 – Speech

From all RNP design services, Speech is the most inclusive one. This service is a standard third generation circuit-switch voice service. Also known as CS Voice, this service has an uplink user bit rate of 12.2 kbps. The coverage by signal level prediction calculated with A9955, with the thresholds computed with link budget and specified in the section 3.3.4, is illustrated in Figure 3.10.

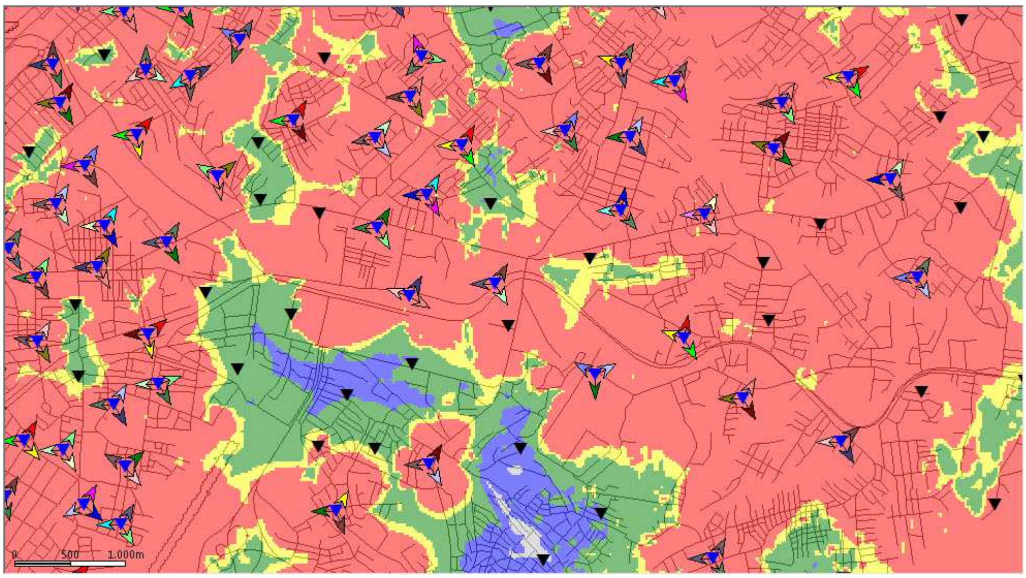


Figure 3.10 – Coverage by Signal Level, Speech Service, Initial Design [15]

All coverage maps have a coverage report with the coverage results, as percentage of focus zone coverage area. For Douala initial design the results are specified in Table 16.

Table 16 – Coverage by Signal Level, Speech Service, Initial Design Results

Coverage by Signal Level - Speech		% Focus Zone	Surface (km²)
		100	216,5188
(red)	Best Signal Level (dBm) ≥ -82.5	70,7	153,186
(yellow)	Best Signal Level (dBm) ≥ -85.4	80,6	174,5536
(green)	Best Signal Level (dBm) ≥ -94.4	97,1	210,4408
(blue)	Best Signal Level (dBm) ≥ -102.4	99,9	216,2984
(grey)	Best Signal Level (dBm) ≥ -110	100	216,5188

In the case of speech service, it had already an acceptable coverage area with outdoor design level. However, as speech is the less restrictive service, it can still be optimized to have the best deep indoor covered area possible. Because, as it can be seen in Figure 3.10, there are still some dense urban areas that do not have a deep indoor design level coverage.

3.4.2 – PS128

PS128 service is a Packet Switched service that offers a 128 kbps user bit rate. This means that it is more restrictive than speech service. This is the Alcatel-Lucent usual dimensioning service. The coverage by signal level prediction planned with A9955 can be observed in the Figure 3.11.

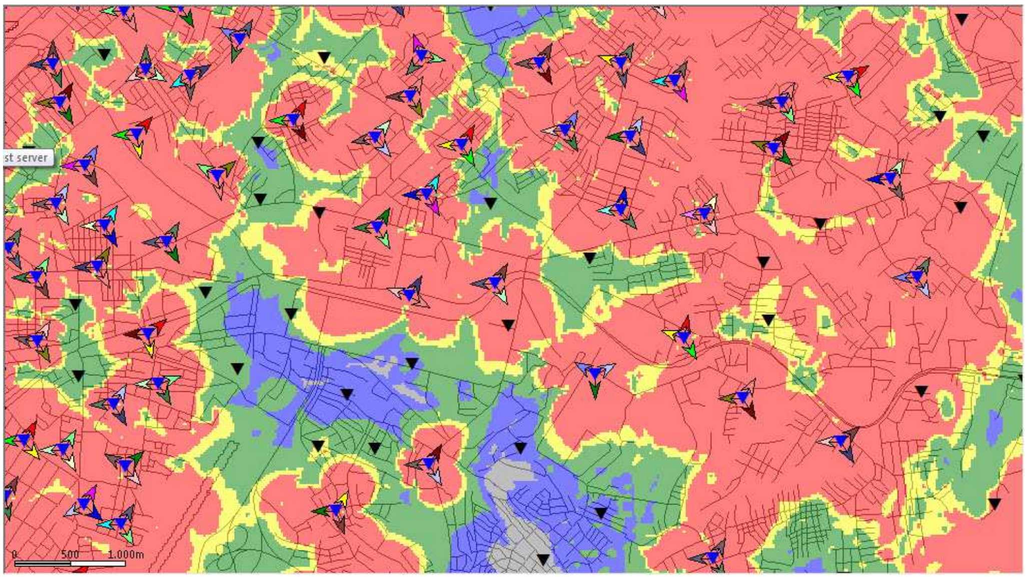


Figure 3.11 – Coverage by Signal Level, PS128 Service, Initial Design [15]

If a comparison between PS128 and Speech services is made, it can be easily noticed that the PS128 coverage prediction is more restrictive than the Speech in all the design levels. This comparison is supported by the Table 17, which specifies the predictions results for PS128 service.

Table 17 – Coverage by Signal Level, PS128 Service, Initial Design Results

Coverage by Signal Level PS128	% Focus Zone	Surface (km²)
	100	216,5188
Best Signal Level (dBm) ≥ -78.7	56,2	121,656
Best Signal Level (dBm) ≥ -81.7	67,5	146,3188
Best Signal Level (dBm) ≥ -90.7	93,2	201,7916
Best Signal Level (dBm) ≥ -98.7	99,1	214,682
Best Signal Level (dBm) ≥ -110	100	216,5188

With the results presented in Table 17, it can be noticed that PS128 service is indeed a more restrictive service than Speech, especially in dense urban and urban areas as it can reach a 20% less covered focus area than the Speech service for these urban areas. However, PS128 service already achieves the Alcatel-Lucent coverage design target for radio network planning which is more than 95% covered area with outdoor design level. Even so, as Douala city is mainly dense urban, this service still can be optimized to achieve the best deep indoor coverage possible.

3.4.3 – PS128 Pilot Quality (Ec/I0)

Pilot quality is estimated by the ration of energy chip over interference (Ec/I0). With a defined CPICH power ratio of 10% the target Ec/I0 is -15 dB. With the prediction computation of PS128 pilot quality it will be possible to see if this requirement is fulfilled. The Figure 3.12 illustrates this prediction.

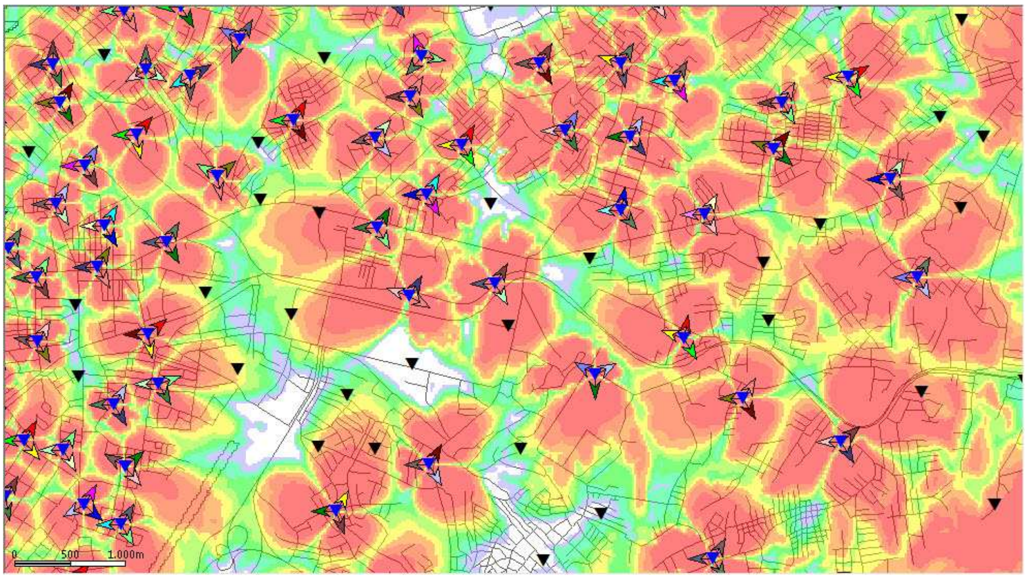


Figure 3.12 – PS128 Pilot Quality, Initial Design [15]

Analysing the PS128 Pilot Quality prediction computation it is clear that exist some areas that have a good PS128 signal coverage, deep indoor, but the Ec/I0 level is poor. This phenomenon occurs specially due to the interference between sectors. One of the obstacles in using a second-generation network planning in this third generation network is that the sectors are with a low tilt, between 0 and 4 degrees, which will come out as a high interference factor in the third generation network.

Table 18 - PS128 Pilot Quality, Initial Design Results

Pilot Quality (Ec/I0) PS128		% Focus Zone	Surface (km²)
		98,2	212,8124
	Ec/I0 (dB) ≥ -8	30,8	66,8236
	Ec/I0 (dB) ≥ -9	46,3	100,2276
	Ec/I0 (dB) ≥ -10	59,2	128,32
	Ec/I0 (dB) ≥ -11	73,3	158,726
	Ec/I0 (dB) ≥ -12	84,4	182,8644
	Ec/I0 (dB) ≥ -13	91,9	199,116
	Ec/I0 (dB) ≥ -14	96,3	208,5684
	Ec/I0 (dB) ≥ -15	98,2	212,8124

In spite of the interference issue in some coverage areas, with the observation of Table 18, it can be concluded that the Alcatel-Lucent goal for the interference criteria is satisfied. The percentage of covered focus zone with Ec/I0 greater than -15 dB is more than 95%. So, in future optimization work the goal is to at least maintain the same pilot quality and improve signal coverage.

3.4.4 – Overlapping Areas 4dB Criteria

The last Alcatel-Lucent radio network planning design criteria is the interference criteria. This criterion specifies a limitation on the number of servers covering the same area. The percentage of area with 4 servers within 4 dB of the best server should be less than 2% and also, for 2 servers should be less than 35%. Figure 3.13, illustrates the overlapping area prediction representing this interference criterion.

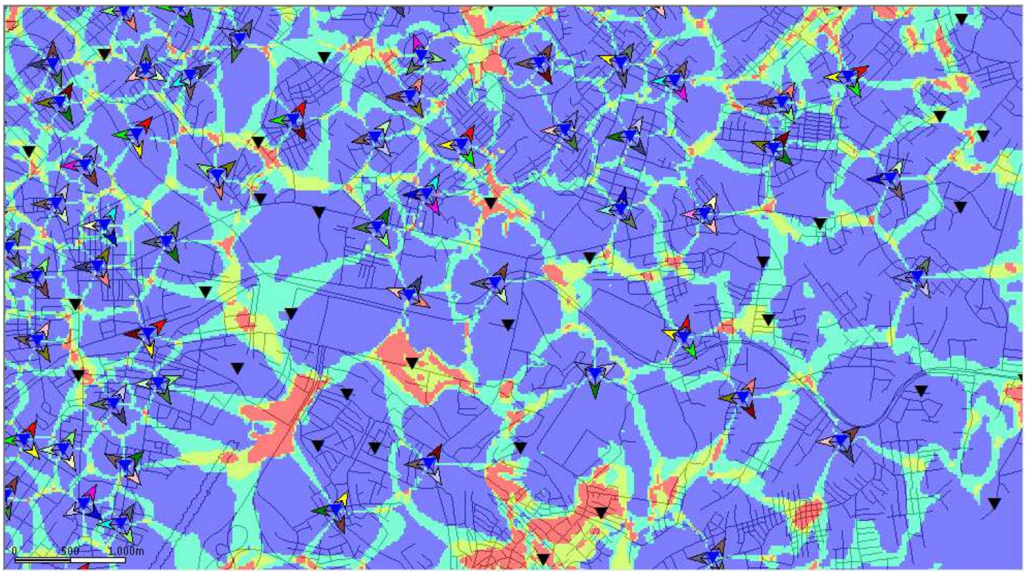


Figure 3.13 – Overlapping areas 4 dB criteria, Initial Design [15]

From prediction evaluation, it can be noticed that the overlapping areas with 4 servers within 4dB of the best server (red areas) are coincident with the areas with poor quality in the Figure 3.12. This evaluation is proven with the results presented in the Table 19.

Table 19 - Overlapping areas 4 dB criteria, Initial Design Results

Overlapping for 4dB criteria from best server		% Focus Zone	Surface (km²)
		100	216,5188
(red)	Number of Servers ≥ 4	3,5	7,636
(green)	Number of Servers ≥ 3	10,4	22,582
(light blue)	Number of Servers ≥ 2	32,8	70,9928
(blue)	Number of Servers ≥ 1	100	216,5188

With these results, the Alcatel-Lucent interference criterion is not fulfilled. The percentage of area with 4 servers within 4dB of the best server is 3,5%. Which means that optimization must be done to achieve these requirements. The starting point for this optimization process is to ensure that best server area is continuous and there is no interruption in best serving zone by a neighbour cell, which would have higher signal strength. Then, check if the more distant sites, which create interference, have the maximum down-tilt value applied. The highest sites must be the most down-tilted ones compared to low height sites. Further optimization process will be specified in the next chapter.

3.4.5 – PS128 & HSDPA 2 Mbps

At this stage, Alcatel-Lucent design principles and criteria have already been considered. Now, customer design requirements must be taken into account. PS128 & HSDPA 2 Mbps service is the most restrictive service in this project. The service is a PS128 service with HSDPA, which allows 2 Mbps user bit rate. The Figure 3.14 represents this service prediction.

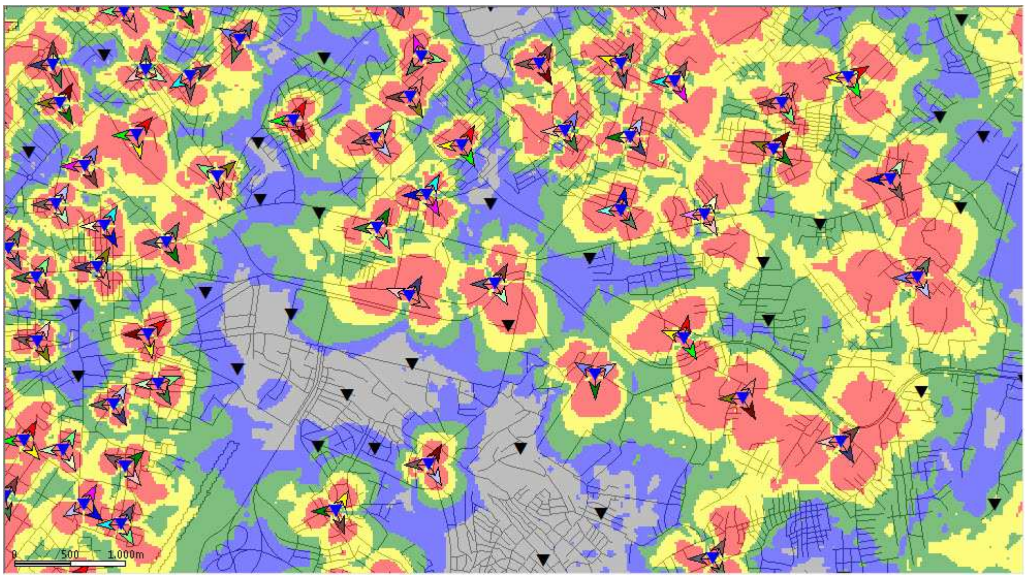


Figure 3.14 – Coverage by Signal Level, PS128 & HSDPA 2 Mbps Service, Initial Design [15]

With the observation of Figure 3.14 it is clear that PS128 & HSDPA 2 Mbps is the most constraint service. Thus, this service will be the chosen dimensioning service and the optimization process focus. Table 20 presents the prediction results for this service.

Table 20 - Coverage by Signal Level, PS128 & HSDPA 2 Mbps Service, Initial Design Results

Coverage by Signal Level PS128 & HSDPA 2Mbps (C)[1]		% Focus Zone	Surface (km²)
		100	216,5188
(red)	Best Signal Level (dBm) ≥ -67,56	18,5	40,082
(yellow)	Best Signal Level (dBm) ≥ -74,45	40,6	87,9144
(green)	Best Signal Level (dBm) ≥ -81,45	66,5	144,0924
(blue)	Best Signal Level (dBm) ≥ -89,45	91	197,0208
(grey)	Best Signal Level (dBm) ≥ -110	100	216,5188

With the initial network design, customer high requirements can not be achieved. The outdoor percentage of covered area for PS128 & HSDPA 2 Mbps is less than 95%, which was a customer requirement. But this was not the only requirement that was not fulfilled. The urban (daylight indoor) percentage of covered area is near thirty percentage points less than the 70% of covered area demanded by the customer.

Since, both Alcatel-Lucent and customer design goals are not entirely fulfilled an optimization should be done to the network in order to accomplish the radio network planning design project objectives. The next chapter will introduce the optimization process, specifying the optimization criteria used and will also have a result analysis with a comparison between the optimization done and the past network configurations.

[1] The "C" is to enhance that it was the customer to provide the design levels.

Chapter 4

Optimization & Results Analysis

In this chapter is presented the optimization criteria used to optimize the network. Then, the optimization results are analysed, presenting a comparison between the various optimization levels as well as the evolution of the network configuration due to the optimization.

4.1 Optimization Criteria & Objectives

In a radio network planning design project the ambition is not only to accomplish all the project requirements but also to provide the best service possible. With this motivation in mind an optimization criteria have to be specified, mostly because the initial design requirements are not fully achieved.

For Cameroon network, optimization criteria are limited to electrical up tilt / down tilt. The reason is because third-generation antenna is the same tri-band antenna for the second-generation. Second-generation layer is the most mature and critical network, since is a live network. Hence, physical optimizations for third-generation may impact second-generation coverage.

The optimization criteria are based on three points:

- Sectors in cluster border, with high electrical down tilt, may be optimized by decreasing the down tilt in order to increase coverage area. See Figure 4.1.

- Sectors which are overshooting may be optimized in order to improve quality, reduce interference to other sectors and address coverage in the best way. See Figure 4.2

- Sectors with an excessive electrical down tilt, may be up tilted in order to improve coverage. In this case, is important not to do over up tilting regarding the neighbour sectors.

Sectors must have a maximum down tilt of 10 degrees. For sectors with mechanical tilt, electrical tilt will be introduced in case of need, although the sum of electrical and mechanical tilt must not exceed 10 degrees.

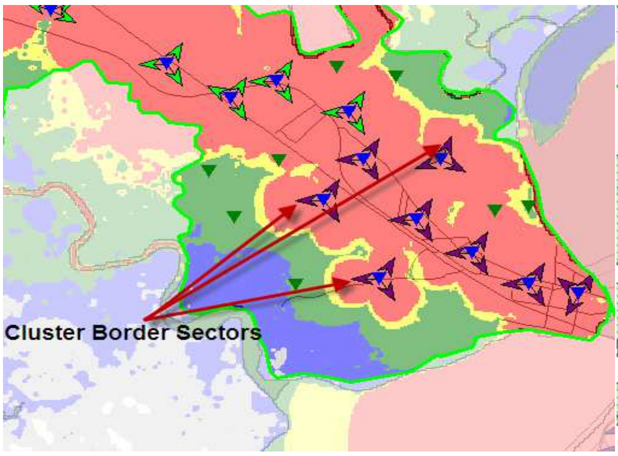


Figure 4.1 – Cluster Border Sectors [15]

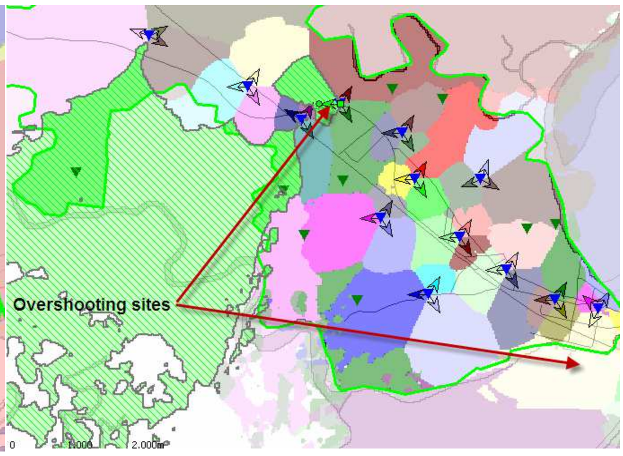


Figure 4.2 – Overshooting Sectors [15]

A9955 design tool offers a prediction to evaluate the sites that are with tilt excess, either exceeding down tilt or up tilt. The prediction is the Coverage by Transmitter, which permits to figure out these design problems in order to increase the user optimization capacity.

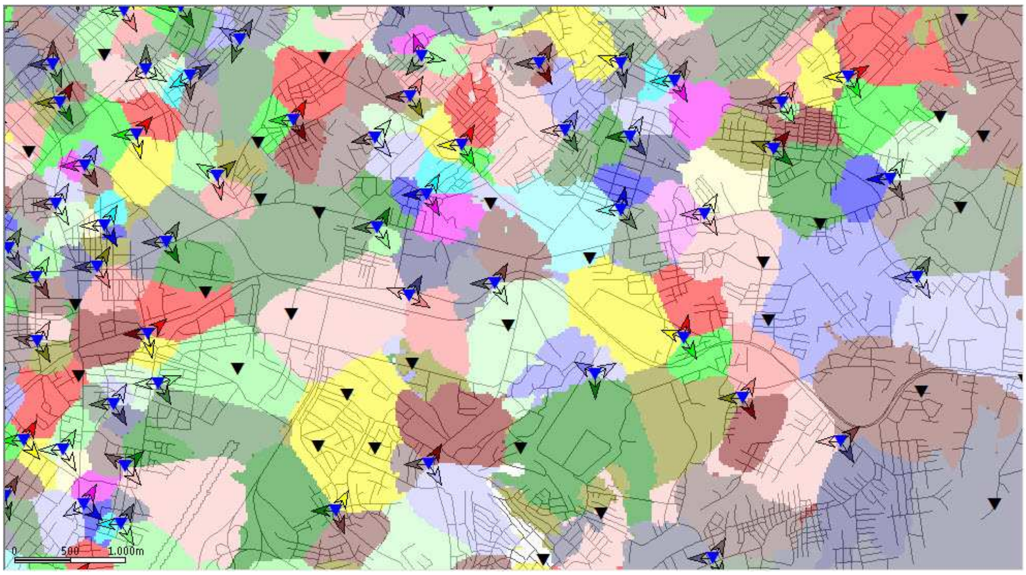


Figure 4.3 – Coverage by Transmitter, Initial Design [15]

With the prediction presented in figure 4.3, it is easy to identify the sectors that are overshooting (high up tilt value) and the ones that are with low coverage area, even in front of the sector, (high down tilt value).

Based on the optimization criteria there are three main optimization phases. The first optimization phase has as a starting point the initial design presented in the last chapter. Initial design has the GSM900 network configuration, so it is not optimized for a third generation network. Thus, the first point is to make electrical tilt optimization, not forgetting that the main goal is to increase the covered area by service and at the same time at least maintain the same quality (Ec/I0) level. Tilt optimization will be conducted by the most restrictive service, PS128 & HSDPA 2 Mbps. Because, if there is coverage increase in this service the other services coverage will increase as well.

After evaluating services predictions with tilt optimization and if design project requirements were not reached yet, a second optimization phase is needed. This second optimization phase consists in proposing the original second-generation only sites to become third generation sites, especially in coverage hole areas. A coverage hole area is considered to be an area that is not covered with the minimum outdoor design level by service. Still, this second optimization phase is very customer dependent. But, Cameroon network allows this kind of proposal. So, second-generation only sites are now considered as new third-generation sites and this second optimization phase is entitled new sites proposal optimization.

Lastly, if the design project requirements were not achieved after the new sites optimization phase a third optimization phase must be defined. As the network is already at its full capacity, since all the second-generation sites are already being used, the next alternative is to increase power in the coverage hole areas. Again, this optimization phase depends from customer to customer, still, Cameroon network admit this optimization phase. As already introduced in section 3.3.4, NodeB has a 20W power step defined for this design project. So, the intention is to increase the power step to 40W in areas with coverage holes. This optimization phase is considered the power optimization phase.

4.2 Tilt Optimization

Optimization process starts with the first optimization phase, the tilt optimization. The network at this stage is not optimized for a third-generation network. Based on the optimization criteria, specified in the last section, tilt optimization was preformed. The process is simple, in A9955 map window, the user has to select the sector that needs to be optimized and choose a better fitting electrical tilt. This process is a manual process and it was done in sections. When a section is optimized a prediction is done to check if the process reaches the desired optimization level. The optimization process ends when all the sections in the focus zone are optimized. Figure 4.4 illustrates the section tilt optimization process.

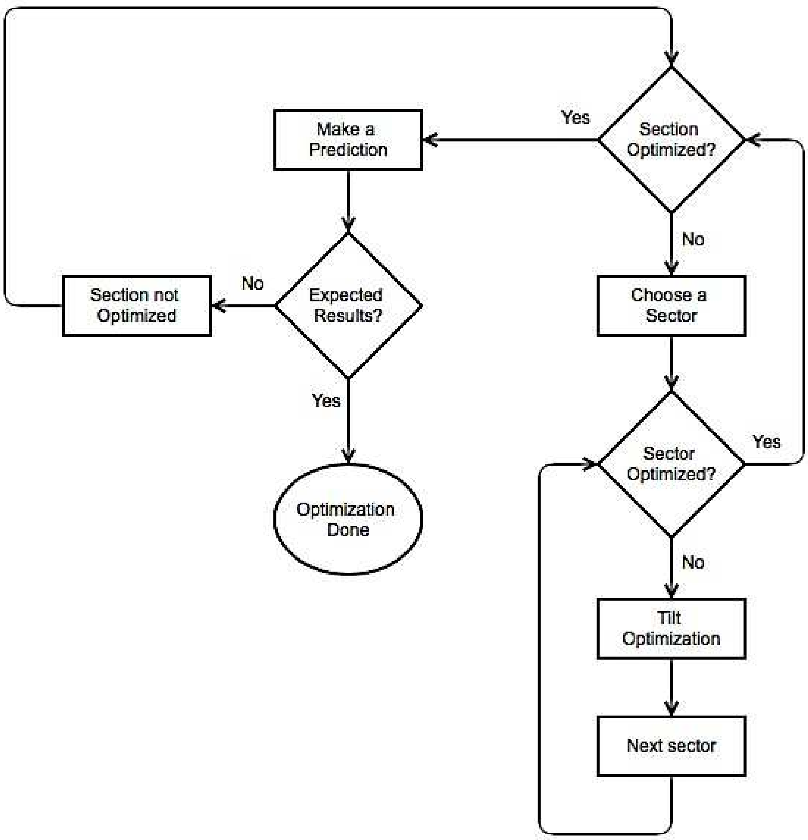


Figure 4.4 – Tilt optimization process

With the defined optimization process, all Douala sectors were optimized. Douala has a total of 402 sectors, existing 132 sites with 3 sectors and 3 sites with only 2 sectors. The initial design tilt distribution versus the tilt optimization distribution can be observed in Figure 4.5.

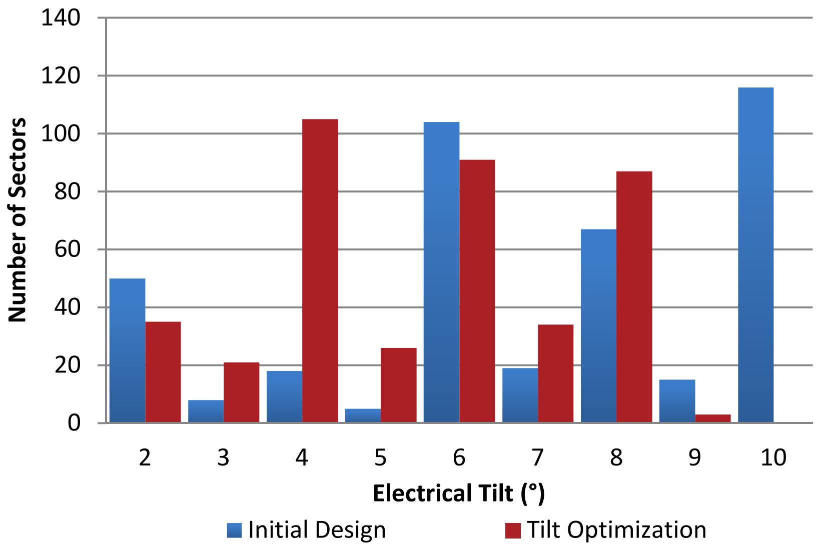


Figure 4.5 – Initial design tilt vs. tilt optimization distribution

As it was expected, it is notorious that initial design had a large number of sectors with 10° electrical tilt. This means that initial tilt configurations have an excessive down tilt. For sectors with high electrical tilt (higher than 7º), an average of 2° tilt reduction was performed. However, some of these sectors were at cluster borders and so a higher tilt reduction was made. In the other case, sectors with low tilt (2°) suffered an average tilt increase of 2°. Another tilt optimization was done, mainly in dense urban areas where a very good coverage is even more required.

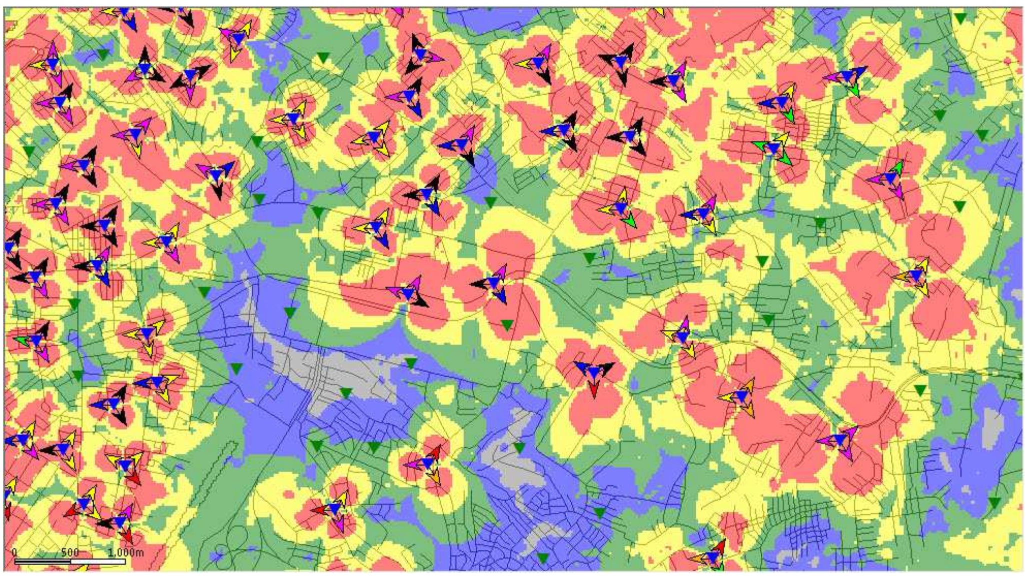


Figure 4.6 – Coverage by Signal Level, PS128 & HSDPA 2 Mbps Service, Tilt optimization [15]

In Figure 4.6 is illustrated the PS128 & HSDPA 2 Mbps coverage by signal level prediction with tilt optimization. Compared to the initial design it can be seen a good coverage improvement. To quantify this coverage area improvement, Table 21 discriminates the percentage of focus zone coverage area by design level.

Table 21 - Coverage by Signal Level, PS128 & HSDPA 2 Mbps Service, Tilt Optimization Results

Coverage by Signal Level PS128 & HSDPA 2Mbps With Tilt Optimization	% Focus Zone	Surface (km²)	Delta
	100	216,5188	0,00%
Best Signal Level (dBm) ≥ -67,56	20,8	45,0452	12,43%
Best Signal Level (dBm) ≥ -74,45	46,2	100,1504	13,79%
Best Signal Level (dBm) ≥ -81,45	72,8	157,7644	9,47%
Best Signal Level (dBm) ≥ -89,45	94,4	204,4764	3,74%
Best Signal Level (dBm) ≥ -110	100	216,5188	0,00%

In comparison with the initial design results, it can be seen an overall increase in coverage area. The area covered with urban (daylight indoor) RNP design level had an increase of 13,8% leading to an increase of more than $12km^2$ in the coverage area. A similar increase was registered in the outdoor RNP design level with an increase of 3,74%, which meant an increment in coverage area of 7 km. Even so, the customer high requirements were not yet achieved with tilt optimization. The covered area with outdoor design level is still less than 95%.

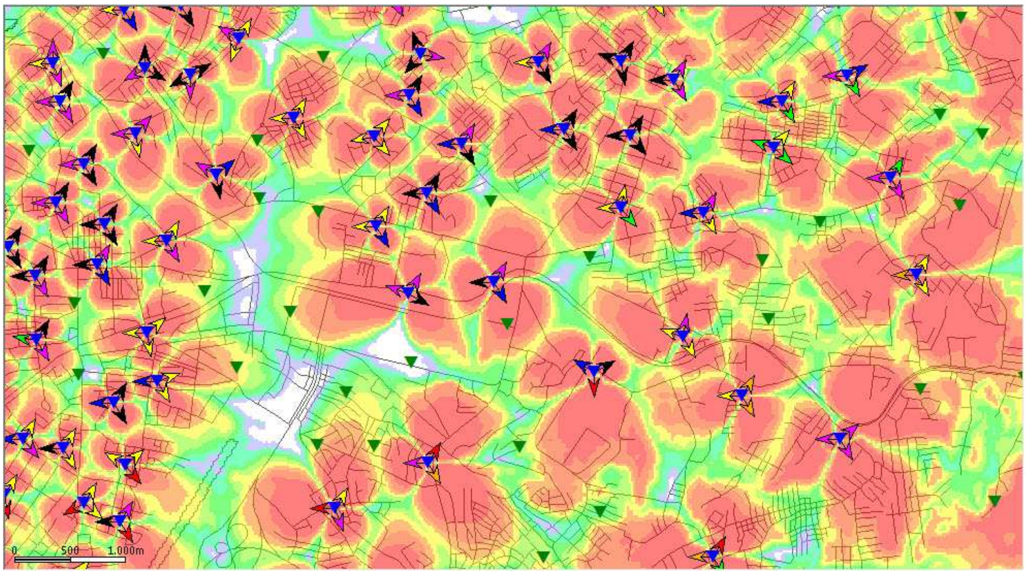


Figure 4.7 – PS128 Pilot Quality, Tilt Optimization [15]

In the case of pilot quality, with the observation of Figure 4.7, it seems that the quality was not degraded with this optimization process. This was one of the problems appointed to tilt optimization criteria. Alcatel-Lucent has a restrictive requirement when it comes to quality. Table 22 specifies the Ec/I0 level for PS128 service with tilt optimization.

Table 22 – PS128 Pilot Quality, Tilt Optimization Results

Pilot Quality (Ec/I0) PS128 With Tilt Optimization	% Focus Zone	Surface (km²)	Delta
	98,8	214,1232	0,61%
Ec/I0 (dB) ≥ -8	30	64,984	-2,60%
Ec/I0 (dB) ≥ -9	46,5	100,7204	0,43%
Ec/I0 (dB) ≥ -10	60,6	131,234	2,36%
Ec/I0 (dB) ≥ -11	74,5	161,4596	1,64%
Ec/I0 (dB) ≥ -12	85,3	184,6708	1,07%
Ec/I0 (dB) ≥ -13	92,7	200,7492	0,87%
Ec/I0 (dB) ≥ -14	96,9	209,9544	0,62%
Ec/I0 (dB) ≥ -15	98,8	214,1232	0,61%

Although the best quality level has suffered a slight decrease, it can be concluded that the overall Pilot Quality was maintained. Alcatel-Lucent quality requirement for a percentage of covered area of 95% with an Ec/I0 greater than -15 dB is still preserved even with a minor expansion.

From the interference point of view, overlapping criteria was also important to evaluate in the tilt optimization process. As from the initial design, the requirements were not obtained; it is also expected from the tilt optimization process to reduce the interference. Figure 4.8 represents the overlapping area criteria after the tilt optimization process.

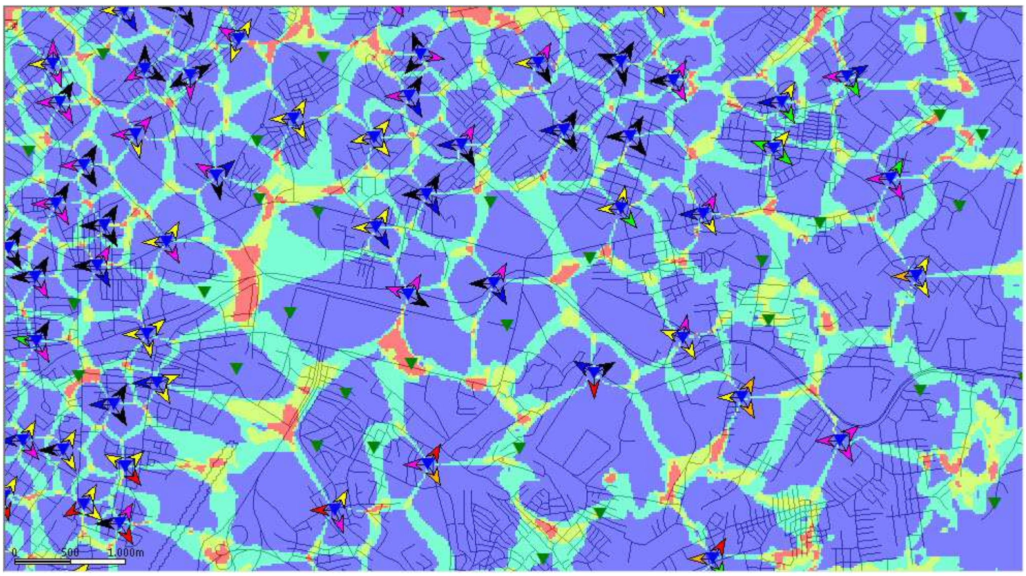


Figure 4.8 – Overlapping areas 4 dB criteria, Tilt Optimization [15]

From the observation of Figure 4.8, it can be immediately seen a decrease in interference. Compared with the initial scenario prediction, the areas with more than 4 servers within 4dB of the best server were reduced. This means that not only there are less areas without a clear dominant sector, but also that the tilt optimization process contributed to reduce the number of servers covering the same area. This is an improvement in the network efficiency.

Table 23 – Overlapping areas 4 dB criteria, Tilt Optimization Results

Overlapping for 4dB criteria from best server With Tilt Optimization	% Focus Zone	Surface (km²)	Delta
	100	216,5188	0,00%
Number of Servers ≥ 4	1,9	4,1136	-45,71%
Number of Servers ≥ 3	8,1	17,5552	-22,12%
Number of Servers ≥ 2	30,2	65,4936	-7,93%
Number of Servers ≥ 1	100	216,5188	0,00%

With the results presented in Table 23, it can be concluded that the Alcatel-Lucent interference criterion is now fulfilled. Regarding the initial design, the result with tilt optimization had a decrease of 46% in the percentage of area with 4 servers within 4 dB of the best server. This is a remarkable result considering that the overall quality level was maintained and the coverage area was enhanced in all service, once it was registered an increase in the most restrictive service (PS128 & HSDPA 2 Mbps). The other services predictions and results can be seen in the Annex A.

However, the customer coverage requirements for PS128 & HSDPA 2Mbps were not achieved. This means that further optimization must be done in order to accomplish all customer demands.

4.3 New Sites Proposal

When tilt optimization phase was over the need for additional optimization is still a reality. The actual third-generation Cameroon network, with all 2G/3G sites already in use and with optimized tilts, still does not meets the desired requirements. The Alcatel-Lucent proposal to the customer, in order to improve the network coverage area, was to introduce the 2G only sites in the optimization process. This means that at this point all 218 Douala sites are now considered to be 2G/3G sites. For the project, the impact was to define the 2G only sites in the A9955 tool as 2G/3G only sites. It is important to underline that these new sites were introduced in the project with the initial design configuration of the second-generation network. So, the first optimization phase has to be done again. Not only because the new sites have a configuration that is not the best suited for a third-generation network, but also because with the consideration of these sites, in the project, they will interfere with already defined neighbour sites. Mainly because the already existing sites were optimized not considering the 2G only sites and so the overlapping criteria will increase.

Consequently, the new sites proposal optimization phase consists in two processes. First to introduce the 2G only sites in the A9955 project as 2G/3G sites. Then, start the tilt optimization phase for these sites and for their neighbours in order to reduce interference and have the best covered area possible. In Figure 4.9 can be seen the coverage by signal level for PS128 & HSDPA 2 Mbps service after the new sites optimization phase.

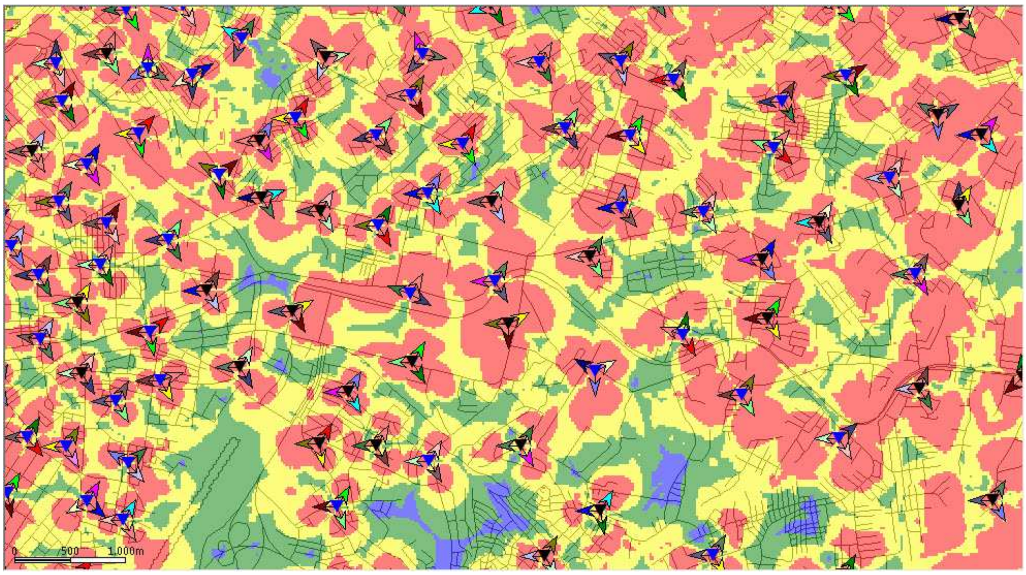


Figure 4.9 – Coverage by Signal Level, PS128 & HSDPA 2 Mbps Service, New Sites Proposal [15]

It is important to notice that in Figure 4.9 the new sites are distinguished from the already introduced 2G/3G sites by the color. Black sites in the map are the new 2G/3G sites introduced in the new sites proposal optimization phase. The increase in covered area by design level is notorious. In Table 24, new sites optimization results for this service are presented.

Table 24 – Coverage by Signal Level, PS128 & HSDPA 2 Mbps Service, New Sites Proposal Results

Coverage by Signal Level PS128 & HSDPA 2Mbps With New Sites Proposal	% Focus Zone	Surface (km²)	Delta
	100	216,5188	0,00%
Best Signal Level (dBm) ≥ -67,56	32,6	70,6008	56,73%
Best Signal Level (dBm) ≥ -74,45	63,6	137,8568	37,66%
Best Signal Level (dBm) ≥ -81,45	85,7	185,6224	17,72%
Best Signal Level (dBm) ≥ -89,45	97,6	211,4736	3,39%
Best Signal Level (dBm) ≥ -110	100	216,5188	0,00%

As it can be seen with Table 24 results, the new sites proposal optimization phase has contributed to an overall significant increase in all the RNP design levels. Is impressive the 57% increase in coverage area for dense urban (deep indoor) design level. With this outdoor covered area of 97,6% one of the customer restrained requirements was finally accomplished.

Even though the covered area with urban (daylight indoor) design level has registered an increase of almost 38%, leading to an increase in total coverage area of more than 37 km^2, the customer requirement of 70% covered area was not met yet. So, future optimization will be still needed.

Now, it is important to verify if pilot quality was not degraded and also if the Alcatel-Lucent interference criteria is still accomplished

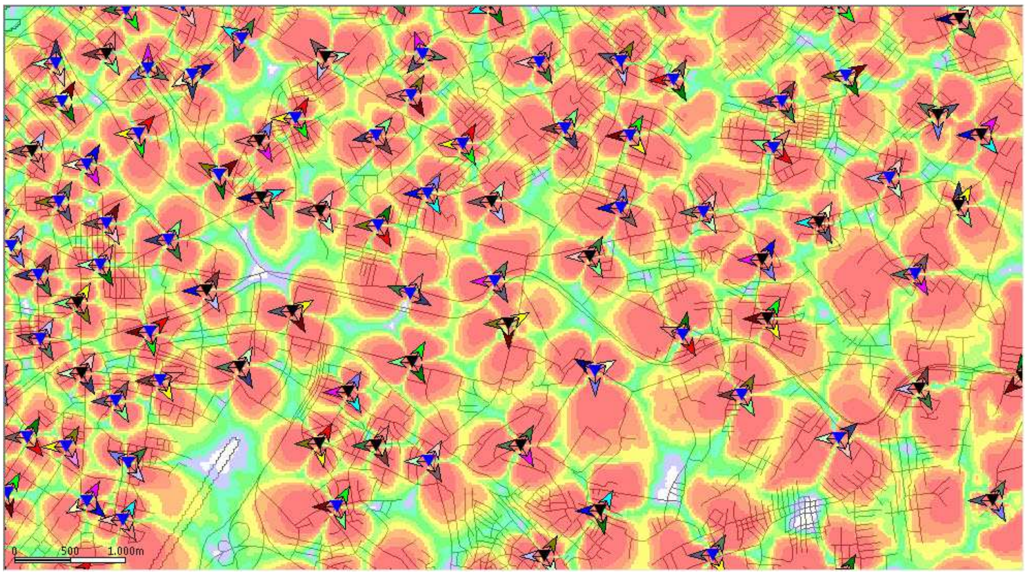


Figure 4.10 – PS128 Pilot Quality, New Sites Proposal [15]

Figure 4.10 represents the prediction for PS128 Pilot Quality for the new sites proposal optimization. With the new sites, is evident that the covered area with good Ec/I0 level has increased. This is mainly due to the existence of more sectors to cover the same area as the previous optimization process. In Table 25 is discriminated the prediction results as well as a delta comparison that accounts for the percentage increase/decrease regarding the tilt optimization anterior phase.

Table 25 – PS128 Pilot Quality, New Sites Proposal Results

Pilot Quality (Ec/I0) PS128 With New Sites Proposal	% Focus Zone	Surface (km²)	Delta
	99	214,4516	0,20%
Ec/I0 (dB) ≥ -8	30,1	65,2312	0,33%
Ec/I0 (dB) ≥ -9	48	103,9096	3,23%
Ec/I0 (dB) ≥ -10	61,9	134,0752	2,15%
Ec/I0 (dB) ≥ -11	76	164,5296	2,01%
Ec/I0 (dB) ≥ -12	86,7	187,7072	1,64%
Ec/I0 (dB) ≥ -13	93,7	203,0356	1,08%
Ec/I0 (dB) ≥ -14	97,3	210,7644	0,41%
Ec/I0 (dB) ≥ -15	99	214,4516	0,20%

The results presented in Table 25 prove that not only the overall Pilot Quality level was not degraded but also that it was registered a coverage area increase in the best Ec/I0 levels. Ec/I0 threshold, better than -9 dB, alone has contributed with a covered area increase of more than 3 km^2. It is also important to notice that the Alcatel-Lucent quality requirement is also achieved in a better value of Ec/I0, as more than 97% of the covered area has an Ec/I0 value better than -14 dB which is higher than the -15 dB Alcatel-Lucent requirement.

At this stage of the project, is important to evaluate the overlapping areas 4 dB criterion to ensure if the requisites were still contemplated.

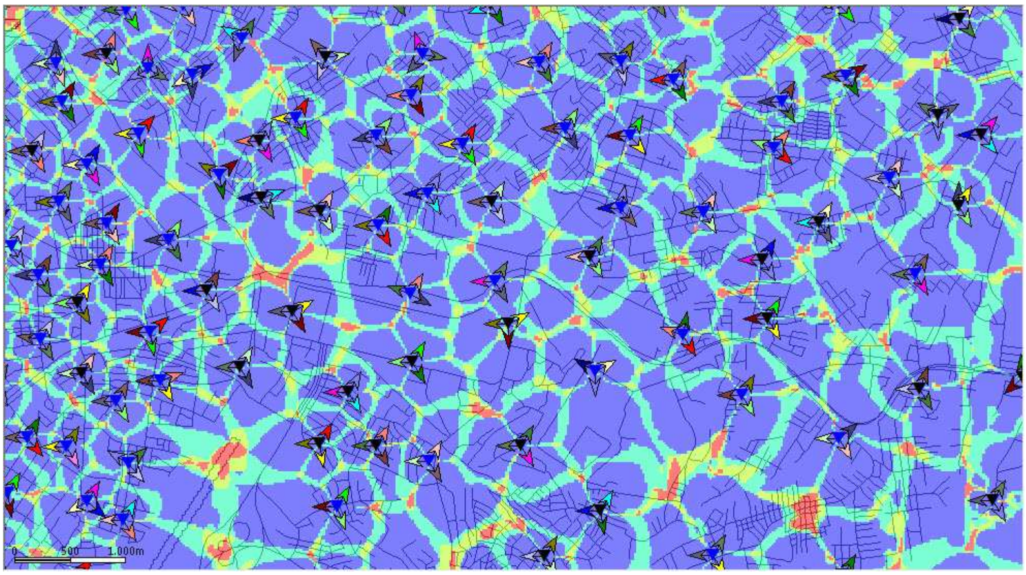


Figure 4.11 – Overlapping areas 4 dB criteria, New Sites Proposal [15]

It was expected that with the introduction of new sites the number of servers covering the same area increase. As the sites density increase it is more and more important to do a good tilt optimization, based on the overlapping criterion as in Figure 4.11, in order to control the interference increment. Comparing the new sites proposal overlapping areas 4 dB criteria with Figure 4.8 it can be concluded that the areas with 4 servers covering the same area (red spots in the map) are around the same. However, it can be seen a decrease in areas covered with 3 servers. Table 26, exposes the results for the overlapping areas 4 dB criteria for the new sites proposal optimization phase.

Table 26 – Overlapping areas 4 dB criteria, New Sites Proposal Results

Overlapping for 4dB criteria from best server With New Sites Proposal	% Focus Zone	Surface (km^2)	Delta
	100	216,5188	0,00%
Number of Servers ≥ 4	1,9	4,2204	0,00%
Number of Servers ≥ 3	7,3	15,8804	-9,88%
Number of Servers ≥ 2	28,9	62,6196	-4,30%
Number of Servers ≥ 1	100	216,5188	0,00%

The objective in this overlapping area criterion is to reduce as much as possible the number of servers covering the same area. So, the results in Table 26 show that this objective is being fulfilled. Not only the covered area with 4 servers within 4 dB of the best server has not increased, but also the areas with less serves has decreased. As an example, the covered area with 3 servers within 4 dB of the best server has registered a decrease of more than 9% in comparison to the tilt optimization result.

Other services predictions as Speech, PS128, HSDPA category 8 and 24 and HSUPA services can be seen in the Annex B.

4.4 Power Optimization

At this stage, the Radio Network Planning (RNP) design project is almost with all the requirements achieved. After the first tilt optimization phase, where the network become to be optimized for a third-generation network, there was still space to improvements. The second optimization phase was then started. However, even after the introduction of new sites in the design project the requisites were not totally accomplished. This is the starting point for the next, and final, optimization phase, power optimization.

Power optimization was agreed with the customer to be done only in dense urban and urban areas with coverage holes. The service that does not yet meet the requirements is the PS128 & HSDPA 2Mbps and the remaining requirement left to be accomplished is the 70% of covered area with urban (daylight indoor) design level. So, the areas of coverage holes were defined as all the areas that do not have urban coverage. Figure 4.12 illustrates these areas of coverage holes.

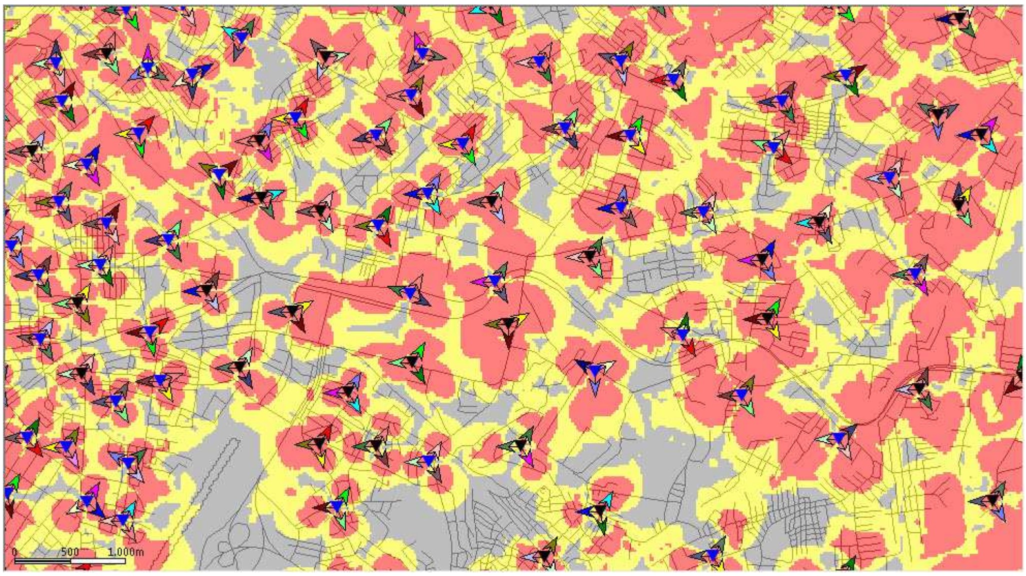


Figure 4.12 – Coverage holes, PS128 & HSDPA 2 Mbps Service, New Sites Proposal [15]

The optimization process involves three points:

- identify the sectors in dense urban (deep indoor) and urban (daylight indoor) areas
- identify the sectors that are pointing to an area with a coverage hole
- change the power in the identified sectors

All the identified sectors had to be labelled with a power optimization description to simplify the optimization process. After the power optimization process a tilt optimization had to be done due to sectors that became overshooting some areas. The power changes agreed with the customer are specified in the following tables.

Table 27 – NodeB Parameters for Power Optimization

NodeB Parameters	
Selected PA Type	60 W - RRH
NodeB RTU Power Step	40 W
Max NodeB Tx Power	46,0 dBm
NodeB Noise Figure w/o TMA	2,0 dB

The main power optimization change was to increase the NodeB RTU Power Step to 40W. Which lead to a Max NodeB Tx Power of 46 dBm, as described in Table 27. This is the double power compared to the initial design. The changes in the CPICH EiRP are presented in Table 28; the CPICH power has increased to 36 dBm and the CPICH EiRP without TMA to 53,6 dBm.

Table 28 – CPICH Equivalent isotropic Radiated Power Parameters for Power Optimization

CPICH EiRP	
Max NodeB power	46 dBm
% CPICH Power	10%
CPICH Power	36 dBm
CPICH EiRP w/o TMA	53,6 dBm

After all the necessary set up done, it was important to evaluate the real impact that the power optimization process will introduce in the design project. Like in the other optimization processes the study of the optimization impact is done in the PS128 & HSDPA 2 Mbps service.

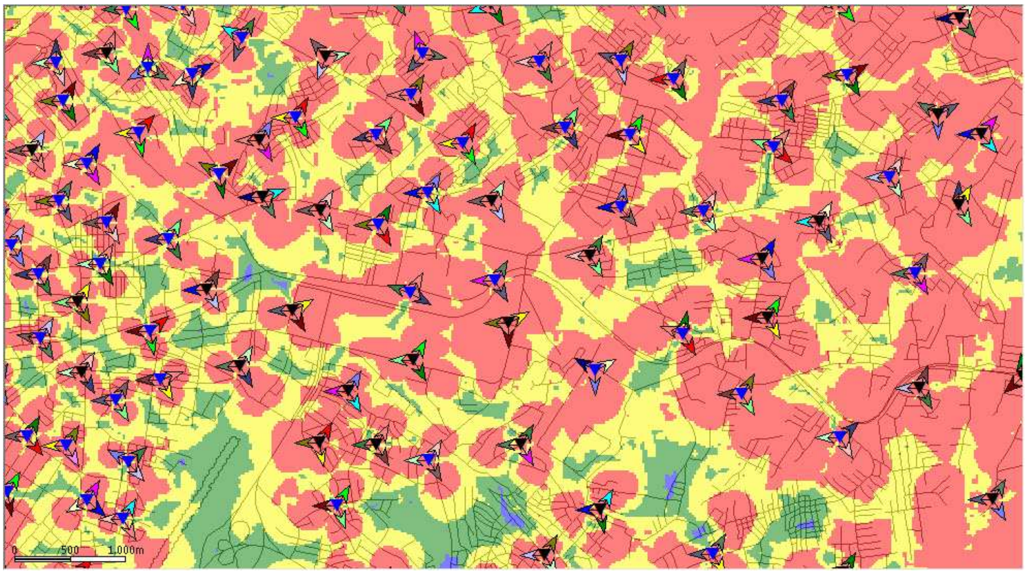


Figure 4.13 - Coverage by Signal Level, PS128 & HSDPA 2 Mbps Service, Power Optimization [15]

With twice the power in some areas, coverage is expected to increase specially in the areas with coverage holes. Figure 4.13 illustrates the coverage by signal level prediction for PS128 & HSDPA 2 Mbps service with power optimization and comparing to Figure 4.9 it can be seen an increase in dense urban (deep indoor) covered area (red zones in the map). Table 29 has the results values for this service prediction.

Table 29 – Coverage by Signal Level, PS128 & HSDPA 2 Mbps Service, Power Optimization Results

Coverage by Signal Level PS128 & HSDPA 2Mbps With Power Optimization		% Focus Zone	Surface (km²)	Delta
		100	216,5188	0,00%
(red)	Best Signal Level (dBm) ≥ -67,56	43,6	94,548	33,74%
(yellow)	Best Signal Level (dBm) ≥ -74,45	73,1	158,2728	14,94%
(green)	Best Signal Level (dBm) ≥ -81,45	91,6	198,3528	6,88%
(blue)	Best Signal Level (dBm) ≥ -89,45	99	214,4644	1,43%
(grey)	Best Signal Level (dBm) ≥ -110	100	216,5188	0,00%

Predictably, it can be seen an overall increase in the coverage area by design level. It is important to highlight that the covered area with dense urban (deep indoor) design level had an increase of more than 33%, which resulted in a 24km^2 coverage area increase. For urban (daylight indoor) design level covered area was registered an improvement of almost 15%, this was translated in a coverage area increase of more than 20km2. With this result, the customer requirement of more than 70% covered area with urban (daylight indoor) design level for PS128 & HSDPA 2 Mbps service was finally accomplished. However, it was still important to evaluate if pilot quality and interference were degraded with this power optimization process.

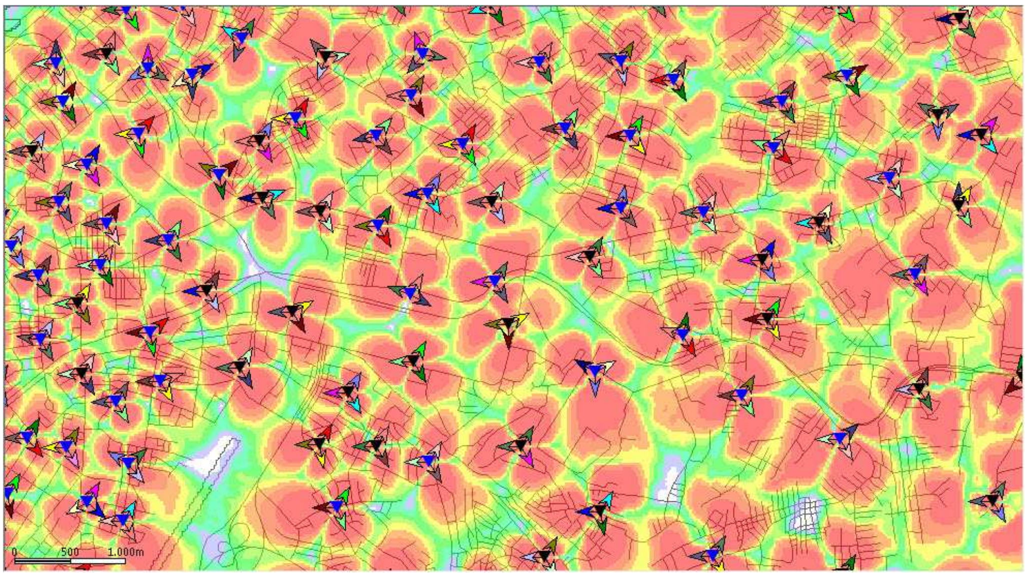


Figure 4.14 – PS128 Pilot Quality, Power Optimization [15]

From the quality point of view, represented in Figure 4.14, the Ec/I0 level appears to be at an acceptance level and in comparison to the new sites proposal prediction, Figure 4.10 the level was maintained. It can be also observed that areas with a gap of quality are correlated with coverage holes areas in the coverage by signal level prediction. On the other side, a good coverage in the coverage by signal level prediction corresponds to a good quality level in the Ec/I0 simulation, which was one of the important objectives to Alcatel-Lucent to deliver.

Table 30 – PS128 Pilot Quality, Power Optimization Results

Pilot Quality (Ec/I0) PS128 With Power Optimization	% Focus Zone	Surface (km^2)	Delta
	99	214,4984	0,00%
Ec/I0 (dB) ≥ -8	30,4	65,8376	1,00%
Ec/I0 (dB) ≥ -9	48,3	104,5928	0,62%
Ec/I0 (dB) ≥ -10	62,2	134,7284	0,48%
Ec/I0 (dB) ≥ -11	76,2	165,0032	0,26%
Ec/I0 (dB) ≥ -12	86,9	188,1468	0,23%
Ec/I0 (dB) ≥ -13	93,8	203,1872	0,11%
Ec/I0 (dB) ≥ -14	97,3	210,7956	0,00%
Ec/I0 (dB) ≥ -15	99	214,4984	0,00%

The results, presented in Table 30, show that the power optimization process had a minimum impact in the quality level. Therefore, the Alcatel-Lucent requirement of a 95% covered area with an Ec/I0 level better than -15 dB was still fulfilled after the power optimization was done. It is now important to evaluate if the interference was not degraded with the power optimization process.

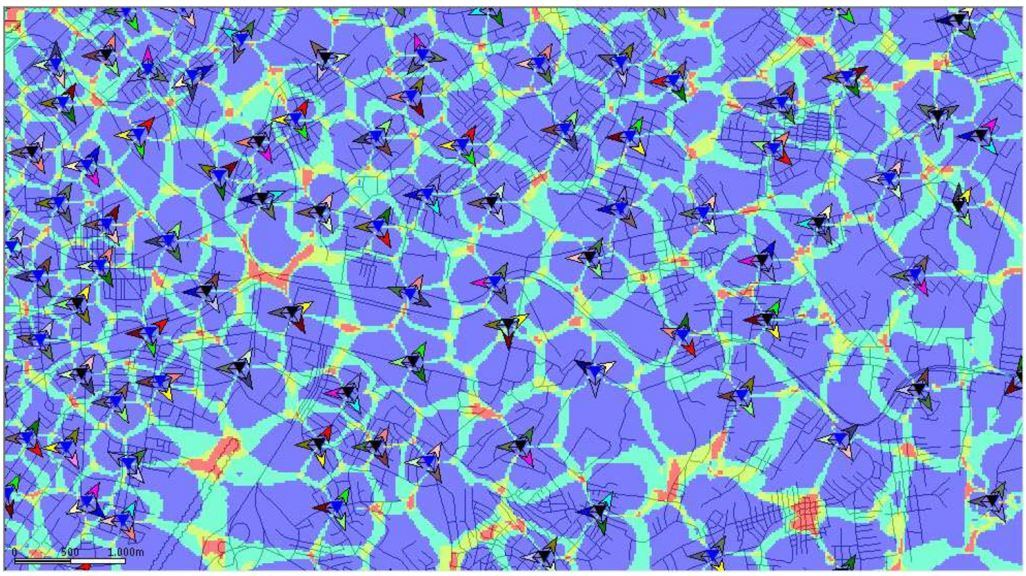


Figure 4.15 - Overlapping areas 4 dB criteria, Power Optimization [15]

Power optimization process made power twice as large for sectors in areas with coverage holes. This optimization will certainly make the power optimized sector as the dominant server in that specific area. However, that area already had a dominant sector, which will lead to an increase in the number of sectors covering the same area. Still, following the power optimization process a tilt optimization was done due to the referred problem. Although in Figure 4.15 can be seen a slight increase in the number of sectors covering the same area.

Table 31 – Overlapping areas 4 dB criteria, Power Optimization Results

Overlapping for 4dB criteria from best server With Power Optimization	% Focus Zone	Surface (km²)	Delta
	100	216,5188	0,00%
Number of Servers ≥ 4	2	4,2608	5,26%
Number of Servers ≥ 3	7,4	16,0068	1,37%
Number of Servers ≥ 2	28,9	62,5896	0,00%
Number of Servers ≥ 1	100	216,5188	0,00%

Although there is an increase in the area with more than one server within 4 dB of the best server, with an increase of around 5%, the real growth in surface area was only 0,04 km^2. This is not sufficient to affect the Alcatel-Lucent requirements in interference.

Consequently, it can be declared that all project requirements were achieved. Alcatel-Lucent Pilot Quality requirement of a covered area of 95% with an Ec/I0 level of -15 dB is fulfilled. As well as interference requirement of an area with 4 servers within 4 dB of the best server less or equal to 2% is accomplished. Finally, customer requirements regarding the PS128 & HSDPA 2 Mbps service were also achieved. Which were a covered area with outdoor design level of 95% and, the most restrictive requisite, a covered area of 70% with urban (daylight indoor) design level. As this last customer requirement was fulfilled then, the Alcatel-Lucent coverage area requisite of a 95% covered area with outdoor design level in PS128 service was also achieved as can be seen in the Annex C.

Chapter 5

Conclusions

The main motivation for this thesis was to execute a third-generation radio network planning design project for a mobile network operator in the Cameroon. The design project was done at Alcatel-Lucent and it was divided in two phases: a second-generation network refresh and a third-generation network deployment, which had as starting point the second-generation network configurations. However, the second-generation project was not in the scope of work of this thesis. Therefore, the main focus was to design the new third-generation network. The third-generation radio network planning design project was divided in two parts. The first was to step up all the third-generation network necessary configurations, in the Alcatel-Lucent design tools, in order to perform a prediction of the initial configurations design. Then, the next step was to do an overall network optimization that was divided into three processes: tilt optimization, new sites proposal and power optimization.

In the first chapter was provided an overview of the evolution in mobile telecommunication systems. It is known that the number of mobile subscribers has increased throughout the last few years and that this evolution represents a 65% increase in traffic data only between the first quarters of 2013 and 2014. However, at this moment the technology that represents the largest number of mobile subscriptions in the world is GSM/EDGE only subscribers. As a conclusion, it is important to continue developing and studying third-generation networks, as they will be the dominant technology in five years time.

The UMTS theoretical background was approached in the second chapter. Basic UMTS fundamentals were presented, considering the UMTS network architecture, radio interface, capacity and interference. Another important concept introduced in the basic UMTS fundamentals was the UMTS main services and applications. With UMTS network evolution new features were added to improve the network. So, an overview of HSDPA and HSUPA is also introduced in this chapter. With this study became clear that these features would be of great importance for the design project. Finally, a brief overview of propagation models importance and requirements was presented. To conclude, the presented propagation models were the background for the characterization of the project propagation model, therefrom their importance in this thesis.

The third generation radio network planning design project specifications were described in the third chapter. In order to have predictions with a good approximation to the real situation, parameters should be as well defined as possible. So, the inputs and assumptions of the project were defined in this chapter too. It is important to retain that the initial design was made with the network configurations of the existing second-generation network. However, as it was predicted, this network configuration was not the best suited for the third-generation network in study. To reach this conclusion, some design project goals were defined. Concerning the Alcatel-Lucent side there were three main design project goals:

- 95% of covered area with outdoor RNP design level for PS128 service
- 95% of covered area with an Ec/I0 value of -15 dB

- 2% of area with 4 servers within 4 dB of the best server

These project goals determine the most important aspects in a radio network planning design project: coverage, quality and interference. Despite the Alcatel-Lucent requirements, from the customer side there were two additional specific requirements:

- 95% of covered area with outdoor RNP design level for PS128 & HSDPA 2Mbps service
- 70% of covered area with urban (daylight indoor) RNP design level for PS128 & HSDPA 2Mbps service

To finalize the third chapter, the predictions for the initial design project were illustrated. The main conclusion was that effectively the initial design did not fulfill the project goals. Interference level was very high mainly due to high electrical up tilt (2 or 3 degrees) of the sectors. Customer project requirements were also not met due to poor coverage for PS128 & HSDPA 2Mbps service. Hence, at this point an optimization was strongly needed in order to achieve the project goals.

The need for optimization criteria definition was imminent. Optimization criteria, presented in chapter four, were based on three points:

- Sectors in cluster border, with high electrical down tilt, may be optimized by decreasing the down tilt in order to increase coverage area.
- Sectors which are overshooting may be optimized in order to improve quality, reduce interference to other sectors and address coverage in the best way.
- Sectors with an excessive electrical down tilt, may be up tilted in order to improve coverage. In this case, is important not to do over up tilting regarding the neighbour sectors.

With these criteria as background, three optimization phases were defined. The first optimization phase was the tilt optimization. In this phase, optimization was performed in sectors electrical tilt and a process of tilt optimization was created. After the optimization was finished a prediction for every service was performed. Because, PS128 & HSDPA 2Mbps is the most restrictive service, the optimization was done based on this service. With this optimization, was expected that the new network configuration better fit the third-generation network. However, not all the design project requirements were achieved, especially due to areas without any sector coverage. Which means that further optimization was needed. The second optimization phase was the new sites proposal. Initially, third-generation network did not count with all the sites available in the area, which means that there were sites in the network defined as second-generation only sites. Therefore, this optimization phase proposed, to the customer, the integration of the second-generation only sites in the third-generation network. With this optimization, a considerable improvement in coverage was registered. Quality and interference levels were maintained, which is an important result because best coverage level was achieved with the same quality and interference. Still, the customer high coverage requirements were not yet fulfilled. At this stage, all the existing sites were in use, which means that the network was in its full capacity. Even so, further optimization had to be done to achieve the customer demands. The next, and final, optimization phase was power optimization. Power optimization consists in increasing the power in the sectors that have coverage holes, only in urban and dense urban areas. The optimization process involves three points:

- identify the sectors in dense urban (deep indoor) and urban (daylight indoor) areas
- identify the sectors that are pointing to an area with a coverage hole
- change the power in the identified sectors

The results of power optimization were accordingly to what was expected. With twice the power in the optimized sectors, it was expected that the level of coverage increased considerably. After this optimization process, all customer requirements were finally fulfilled.

The main design project goal was to plan a third-generation network with the best coverage, quality and interference levels possible. To establish the project coverage, quality and interference thresholds some requirements were defined, by the Alcatel-Lucent and the customer. Achieving these demands became the main design project goal. After several optimization phases, all the design project requirements were fulfilled either with respect to coverage, quality and interference. Therefore, the project delivered to the customer had the best-suited network configuration for this new third-generation network.

Although this thesis had Douala as the focus city for the design project, the entire project count with nine more cities with a total of 533 sites and 1301 sectors. The procedures presented in this thesis, from the definition of the parameters to the optimization phases, were the procedures used in each city. All the optimization processes, for all the cities, were done within the partnership with Alcatel-Lucent. The customer was, also, provided with a report, for each city, describing the services predictions and improvements. Finally, when the third-generation project was finished, it was done a document with the RNP 3G Guidelines for Alcatel-Lucent with the lessons learned from this project.

Once the deployment of the third-generation network is scheduled for the end of 2014 / beginning of 2015, the future work is to perform a QoS follow-up where the network parameters and indicators are followed, during the deployment process, to evaluate if the design project goals are achieved in the real implemented network.

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Annex A

Tilt Optimization Results

Speech

Figure A1 illustrates the coverage by signal level, for the speech service, with tilt optimization.

Figure A 1 - Coverage by Signal Level, Speech Service, Tilt optimization

The coverage results are presented in Table A1.

Table A 1 - Coverage by Signal Level, Speech Service, Tilt Optimization Results

Coverage by Signal Level Speech With Tilt Optimization	% Focus Zone	Surface (km²)
	100	216,5188
Best Signal Level (dBm) >=-82.5	76,6	165,8672
Best Signal Level (dBm) >=-85.4	85,3	184,7772
Best Signal Level (dBm) >=-94.4	98,7	213,8416
Best Signal Level (dBm) >=-102.4	99,9	216,4224
Best Signal Level (dBm) >=-110	100	216,5188

PS128

Figure A2 illustrates the coverage by signal level, for the PS128 service, with tilt optimization.

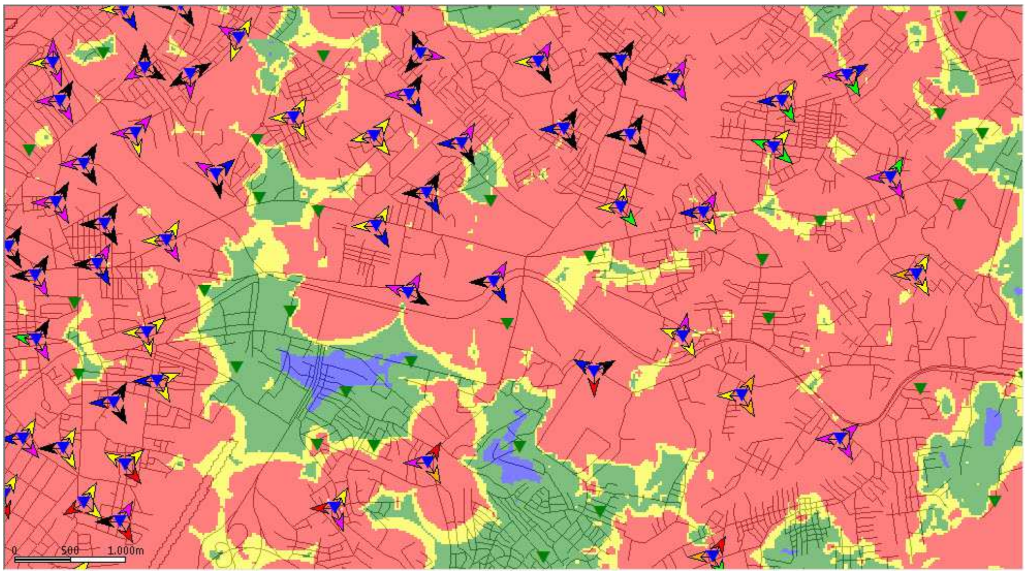

Figure A 2 - Coverage by Signal Level, PS128 Service, Tilt optimization

The coverage results are presented in Table A2.

Table A 2 - Coverage by Signal Level, PS128 Service, Tilt Optimization Results

Coverage by Signal Level PS128 With Tilt Optimization	% Focus Zone	Surface (km²)
	100	216,5188
Best Signal Level (dBm) >=-78.7	62,9	136,2048
Best Signal Level (dBm) >=-81.7	73,8	159,7708
Best Signal Level (dBm) >=-90.7	96	207,9528
Best Signal Level (dBm) >=-98.7	99,7	216,03
Best Signal Level (dBm) >=-110	100	216,5188

HSDPA Category 8

Figure A3 illustrates the Quality and Throughput Analysis, for the HSDPA Cat.8 service, with tilt optimization.

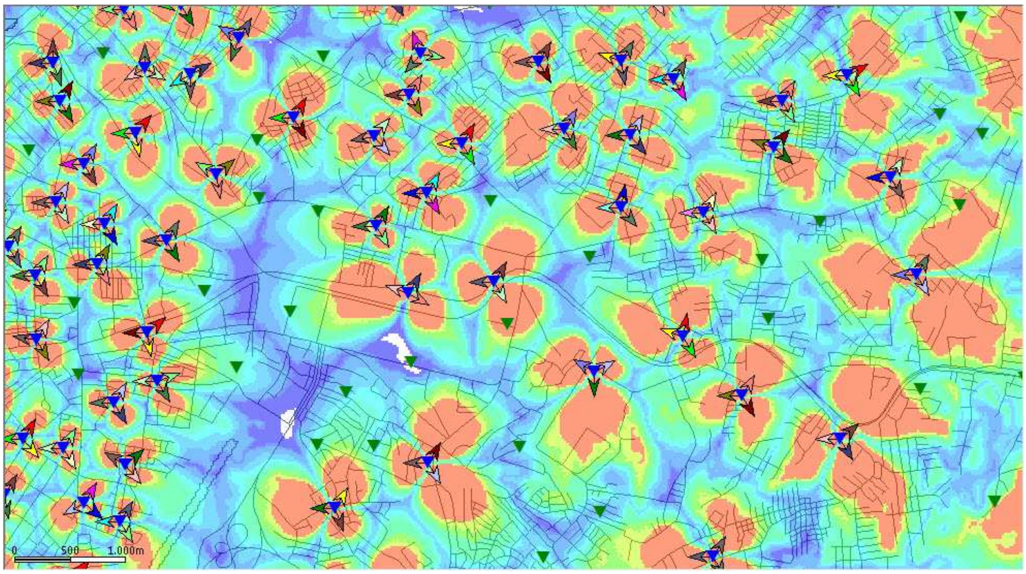

Figure A 3 - Quality and Throughput Analysis, HSDPA Cat.8 Service, Tilt optimization

The coverage results are presented in Table A3.

Table A 3 - Quality and Throughput Analysis, HSDPA Cat.8 Service, Tilt optimization Results

HSDPA Quality and Throughput Analysis Cat8 With Tilt Optimization	% Focus Zone	Surface (km²)
	99,8	216,1844
RLC Peak Rate (kbps) >=6,600	27,2	58,9536
RLC Peak Rate (kbps) >=6,200	27,2	58,9536
RLC Peak Rate (kbps) >=5,800	27,2	58,9536
RLC Peak Rate (kbps) >=5,400	27,2	58,9536
RLC Peak Rate (kbps) >=5,000	34,6	74,9524
RLC Peak Rate (kbps) >=4,600	34,6	74,9524
RLC Peak Rate (kbps) >=4,200	43,4	94,0332
RLC Peak Rate (kbps) >=3,800	43,4	94,0332
RLC Peak Rate (kbps) >=3,400	43,4	94,0332
RLC Peak Rate (kbps) >=3,000	60,7	131,5424
RLC Peak Rate (kbps) >=2,600	68,8	148,944
RLC Peak Rate (kbps) >=2,200	77,1	166,94
RLC Peak Rate (kbps) >=1,800	87,9	190,3928
RLC Peak Rate (kbps) >=1,400	96,8	209,7608
RLC Peak Rate (kbps) >=1,000	98,1	212,5764
RLC Peak Rate (kbps) >=600	99,8	216,1844

HSDPA Category 24

Figure A4 illustrates the Quality and Throughput Analysis, for the HSDPA Cat.24 service, with tilt optimization.

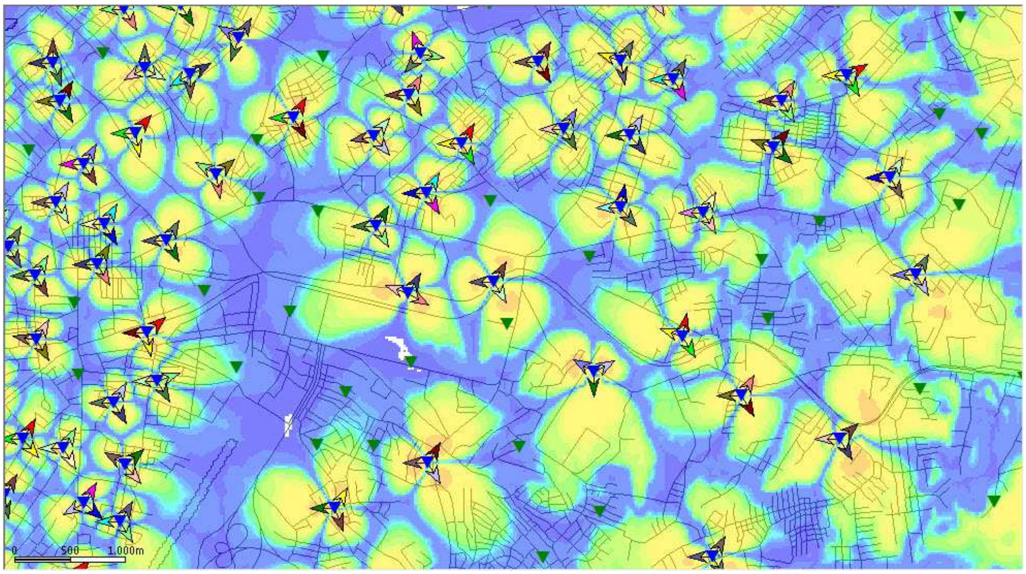

Figure A 4 - Quality and Throughput Analysis, HSDPA Cat.24 Service, Tilt optimization

The coverage results are presented in Table A4.

Table A 4 - Quality and Throughput Analysis, HSDPA Cat.24 Service, Tilt optimization Results

HSDPA Quality and Throughput Analysis Cat24 With Tilt Optimization	% Focus Zone	Surface (km²)
	99,9	216,3468
RLC Peak Rate (kbps) >=34,200	2,3	4,9744
RLC Peak Rate (kbps) >=31,800	19,7	42,5836
RLC Peak Rate (kbps) >=29,400	28,2	61,002
RLC Peak Rate (kbps) >=27,000	38,2	82,7344
RLC Peak Rate (kbps) >=24,600	47,7	103,2796
RLC Peak Rate (kbps) >=22,200	48,4	104,9288
RLC Peak Rate (kbps) >=19,800	49,7	107,6832
RLC Peak Rate (kbps) >=17,400	54,1	117,1956
RLC Peak Rate (kbps) >=15,000	54,9	118,8504
RLC Peak Rate (kbps) >=12,600	56	121,302
RLC Peak Rate (kbps) >=10,200	59	127,8596
RLC Peak Rate (kbps) >=7,800	62,6	135,5132
RLC Peak Rate (kbps) >=5,400	68,8	148,944
RLC Peak Rate (kbps) >=3,000	92,6	200,6028
RLC Peak Rate (kbps) >=600	99,9	216,3468

HSUPA

Figure A5 illustrates the Quality and Throughput Analysis, for the HSUPA service, with tilt optimization.

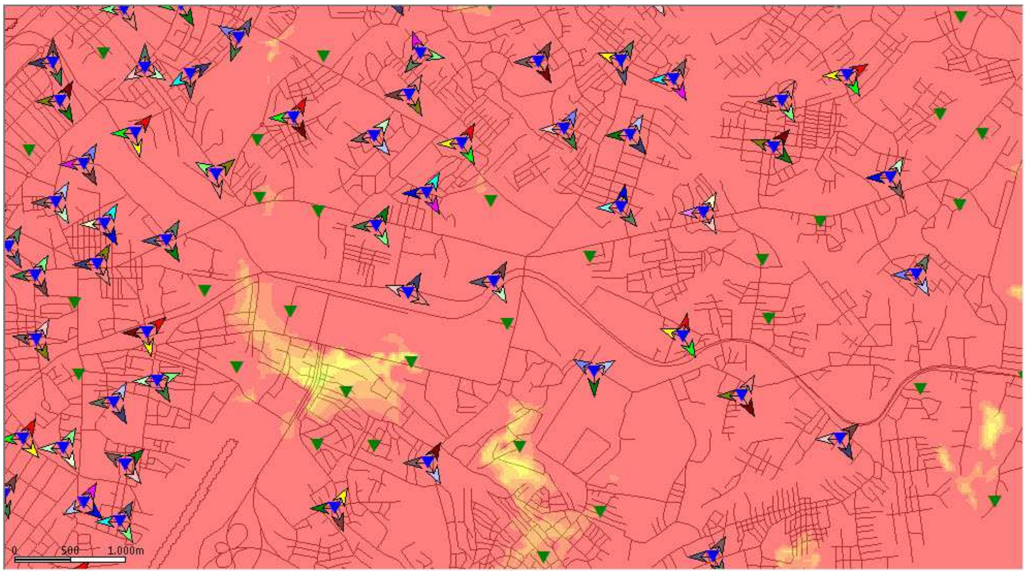

Figure A 5 - Quality and Throughput Analysis, HSUPA Service, Tilt optimization

The coverage results are presented in Table A5.

Table A 5 - Quality and Throughput Analysis, HSUPA Service, Tilt optimization Results

HSUPA Quality and Throughput Analysis With Tilt Optimization	% Focus Zone	Surface (km²)
	99,9	216,506
RLC Peak Rate (kbps) >=4,096	90,2	195,3824
RLC Peak Rate (kbps) >=3,584	94	203,6596
RLC Peak Rate (kbps) >=3,072	96,5	208,9428
RLC Peak Rate (kbps) >=2,560	98	212,3452
RLC Peak Rate (kbps) >=2,048	99	214,3624
RLC Peak Rate (kbps) >=1,792	99,3	215,1104
RLC Peak Rate (kbps) >=1,536	99,5	215,498
RLC Peak Rate (kbps) >=1,280	99,7	215,9904
RLC Peak Rate (kbps) >=1,024	99,8	216,2076
RLC Peak Rate (kbps) >=768	99,9	216,3652
RLC Peak Rate (kbps) >=512	99,9	216,4272
RLC Peak Rate (kbps) >=384	99,9	216,4548
RLC Peak Rate (kbps) >=256	99,9	216,4876
RLC Peak Rate (kbps) >=192	99,9	216,5
RLC Peak Rate (kbps) >=128	99,9	216,5028
RLC Peak Rate (kbps) >=64	99,9	216,5044
RLC Peak Rate (kbps) >=32	99,9	216,506

Annex B

New Sites Proposal Results

Speech

Figure B1 illustrates the coverage by signal level, for the speech service, with new sites proposal optimization.

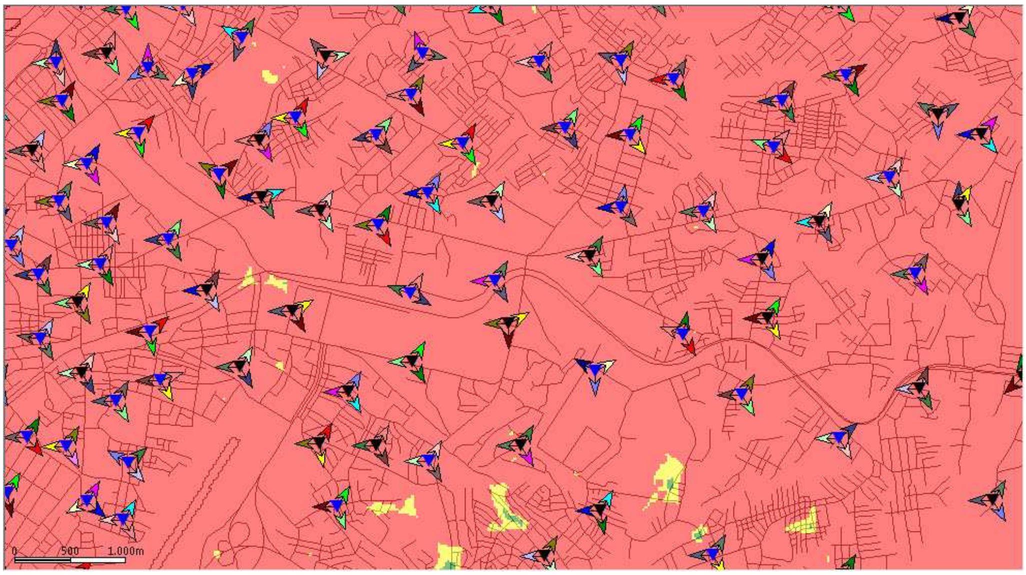

Figure B 1 - Coverage by Signal Level, Speech Service, New Sites Proposal

The coverage results are presented in Table B1.

Table B 1 - Coverage by Signal Level, Speech Service, New Sites Proposal Results

Coverage by Signal Level Speech With New Sites Proposal	% Focus Zone	Surface (km²)
	100	216,5188
Best Signal Level (dBm) >=-82.5	88,1	190,7724
Best Signal Level (dBm) >=-85.4	93,2	201,8184
Best Signal Level (dBm) >=-94.4	99,4	215,3876
Best Signal Level (dBm) >=-102.4	99,9	216,4652
Best Signal Level (dBm) >=-110	100	216,5188

PS128

Figure B2 illustrates the coverage by signal level, for the PS128 service, with new sites proposal optimization.

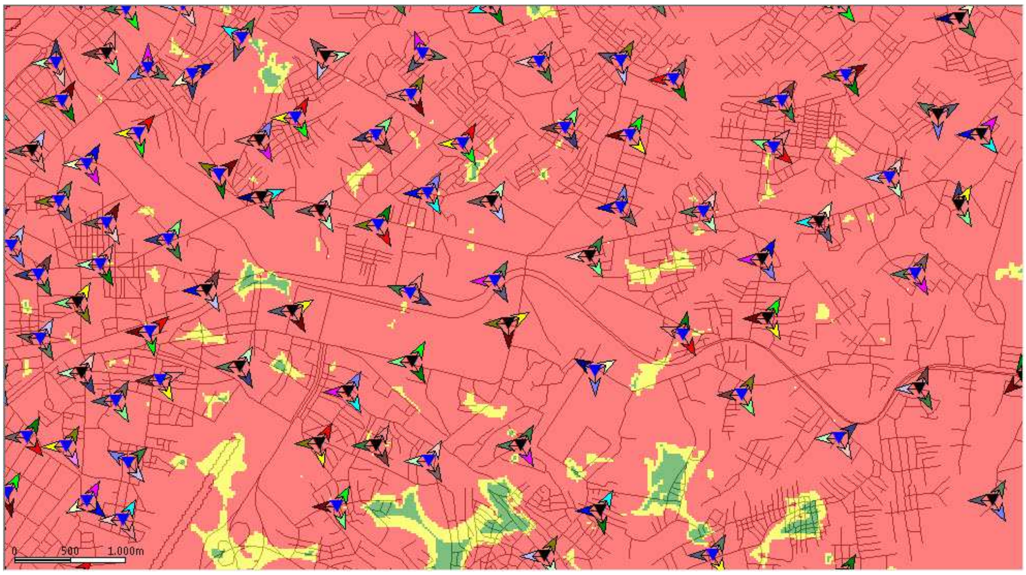

Figure B 2 - Coverage by Signal Level, PS128 Service, New Sites Proposal

The coverage results are presented in Table B2.

Table B 2 - Coverage by Signal Level, PS128 Service, New Sites Proposal Results

Coverage by Signal Level PS128 With New Sites Proposal	% Focus Zone	Surface (km²)
	100	216,5188
Best Signal Level (dBm) >=-78.7	78,4	169,7272
Best Signal Level (dBm) >=-81.7	86,3	186,9296
Best Signal Level (dBm) >=-90.7	98,4	213,0832
Best Signal Level (dBm) >=-98.7	99,8	216,27
Best Signal Level (dBm) >=-110	100	216,5188

HSDPA Category 8

Figure B3 illustrates the Quality and Throughput Analysis, for the HSDPA Cat.8 service, with new sites proposal optimization.

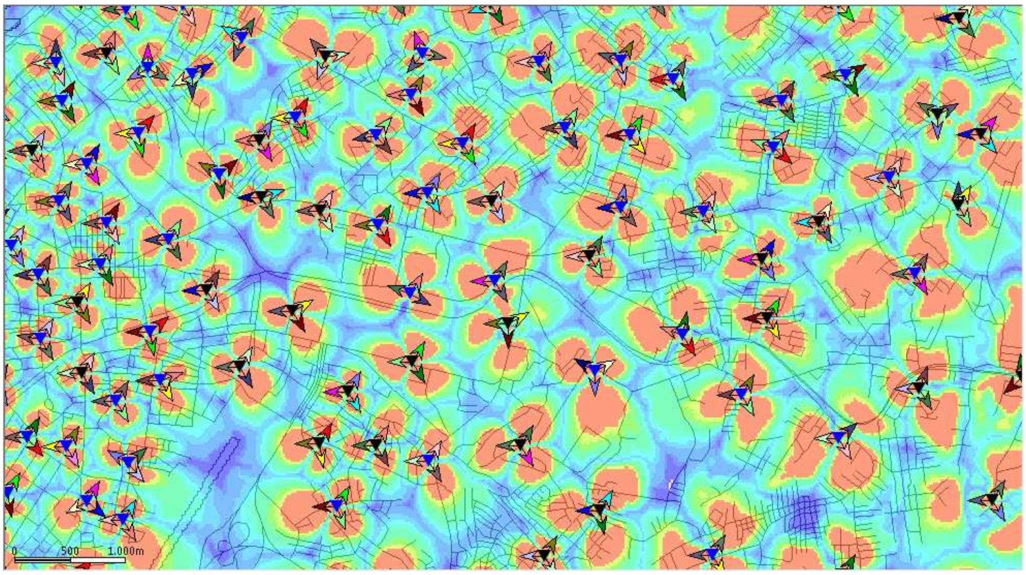

Figure B 3 - Quality and Throughput Analysis, HSDPA Cat.8 Service, New Sites Proposal

The coverage results are presented in Table B3.

Table B 3 - Quality and Throughput Analysis, HSDPA Cat.8 Service, New Sites Proposal Results

HSDPA Quality and Throughput Analysis Cat8 With New Sites Proposal	% Focus Zone	Surface (km²)
	99,9	216,4092
RLC Peak Rate (kbps) >=6,600	27,4	59,298
RLC Peak Rate (kbps) >=6,200	27,4	59,298
RLC Peak Rate (kbps) >=5,800	27,4	59,298
RLC Peak Rate (kbps) >=5,400	27,4	59,298
RLC Peak Rate (kbps) >=5,000	35,2	76,232
RLC Peak Rate (kbps) >=4,600	35,2	76,232
RLC Peak Rate (kbps) >=4,200	45	97,4296
RLC Peak Rate (kbps) >=3,800	45	97,4296
RLC Peak Rate (kbps) >=3,400	45	97,4296
RLC Peak Rate (kbps) >=3,000	62,3	134,9544
RLC Peak Rate (kbps) >=2,600	70,3	152,2772
RLC Peak Rate (kbps) >=2,200	78,6	170,3448
RLC Peak Rate (kbps) >=1,800	89,2	193,186
RLC Peak Rate (kbps) >=1,400	97,3	210,6916
RLC Peak Rate (kbps) >=1,000	98,3	212,9236
RLC Peak Rate (kbps) >=600	99,9	216,4092

HSDPA Category 24

Figure B4 illustrates the Quality and Throughput Analysis, for the HSDPA Cat.24 service, with new sites proposal optimization.

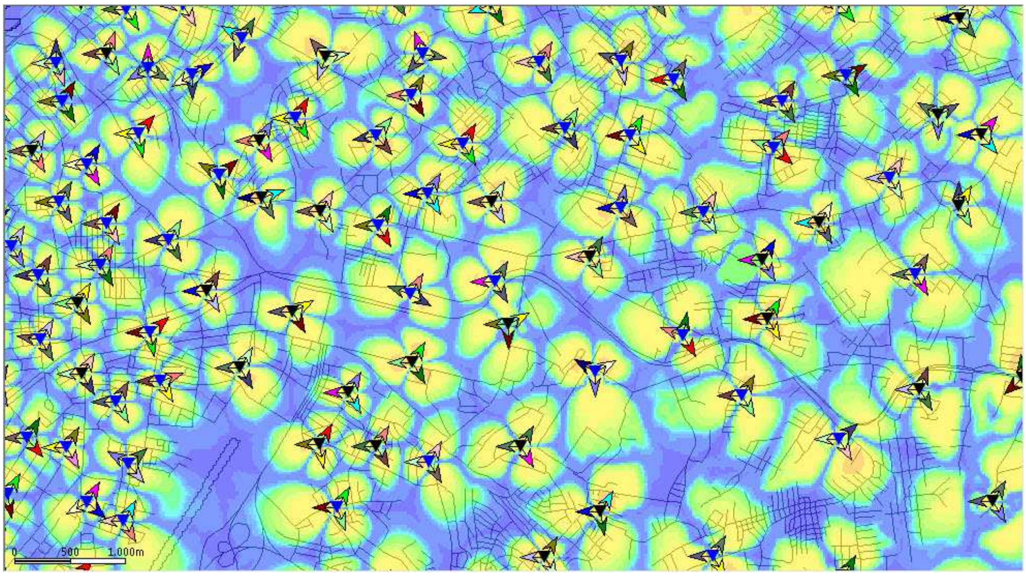

Figure B 4 - Quality and Throughput Analysis, HSDPA Cat.24 Service, New Sites Proposal

The coverage results are presented in Table B4.

Table B 4 - Quality and Throughput Analysis, HSDPA Cat.24 Service, New Sites Proposal Results

HSDPA Quality and Throughput Analysis Cat24 With New Sites Proposal	% Focus Zone	Surface (km²)
	99,9	216,4812
RLC Peak Rate (kbps) >=34,200	2,1	4,5152
RLC Peak Rate (kbps) >=31,800	19,6	42,38
RLC Peak Rate (kbps) >=29,400	28,3	61,2928
RLC Peak Rate (kbps) >=27,000	39,3	85,0264
RLC Peak Rate (kbps) >=24,600	49,4	107,05
RLC Peak Rate (kbps) >=22,200	50,3	108,8728
RLC Peak Rate (kbps) >=19,800	51,5	111,5528
RLC Peak Rate (kbps) >=17,400	55,8	120,9308
RLC Peak Rate (kbps) >=15,000	56,6	122,5692
RLC Peak Rate (kbps) >=12,600	57,7	125,038
RLC Peak Rate (kbps) >=10,200	60,7	131,4796
RLC Peak Rate (kbps) >=7,800	64,2	138,9732
RLC Peak Rate (kbps) >=5,400	70,3	152,3632
RLC Peak Rate (kbps) >=3,000	93,6	202,8592
RLC Peak Rate (kbps) >=600	99,9	216,4812

HSUPA

Figure B5 illustrates the Quality and Throughput Analysis, for the HSUPA service, with new sites proposal optimization.

Figure B 5 - Quality and Throughput Analysis, HSUPA Service, New Sites Proposal

The coverage results are presented in Table B5.

Table B 5 - Quality and Throughput Analysis, HSUPA Service, New Sites Proposal Results

HSUPA Quality and Throughput Analysis With New Sites Proposal	% Focus Zone	Surface (km²)
	99,9	216,506
RLC Peak Rate (kbps) >=4,096	95,6	207,0992
RLC Peak Rate (kbps) >=3,584	97,5	211,1116
RLC Peak Rate (kbps) >=3,072	98,5	213,4756
RLC Peak Rate (kbps) >=2,560	99,2	214,8776
RLC Peak Rate (kbps) >=2,048	99,5	215,5764
RLC Peak Rate (kbps) >=1,792	99,6	215,8596
RLC Peak Rate (kbps) >=1,536	99,7	216,0392
RLC Peak Rate (kbps) >=1,280	99,8	216,2532
RLC Peak Rate (kbps) >=1,024	99,9	216,3612
RLC Peak Rate (kbps) >=768	99,9	216,4304
RLC Peak Rate (kbps) >=512	99,9	216,468
RLC Peak Rate (kbps) >=384	99,9	216,4844
RLC Peak Rate (kbps) >=256	99,9	216,5012
RLC Peak Rate (kbps) >=192	99,9	216,506
RLC Peak Rate (kbps) >=128	99,9	216,506
RLC Peak Rate (kbps) >=64	99,9	216,506
RLC Peak Rate (kbps) >=32	99,9	216,506

Annex C

Power Optimization Results

Speech

Figure C1 illustrates the coverage by signal level, for the speech service, with power optimization.

Figure C 1 - Coverage by Signal Level, Speech Service, Power Optimization

The coverage results are presented in Table C1.

Table C 1 - Coverage by Signal Level, Speech Service, Power Optimization Results

Coverage by Signal Level Speech With Power Optimization	% Focus Zone	Surface (km^2)
	100	216,5188
Best Signal Level (dBm) >=-82.5	93,2	201,8564
Best Signal Level (dBm) >=-85.4	96,7	209,4244
Best Signal Level (dBm) >=-94.4	99,7	216,0736
Best Signal Level (dBm) >=-102.4	99,9	216,5044
Best Signal Level (dBm) >=-110	100	216,5188

PS128

Figure C2 illustrates the coverage by signal level, for the PS128 service, with power optimization.

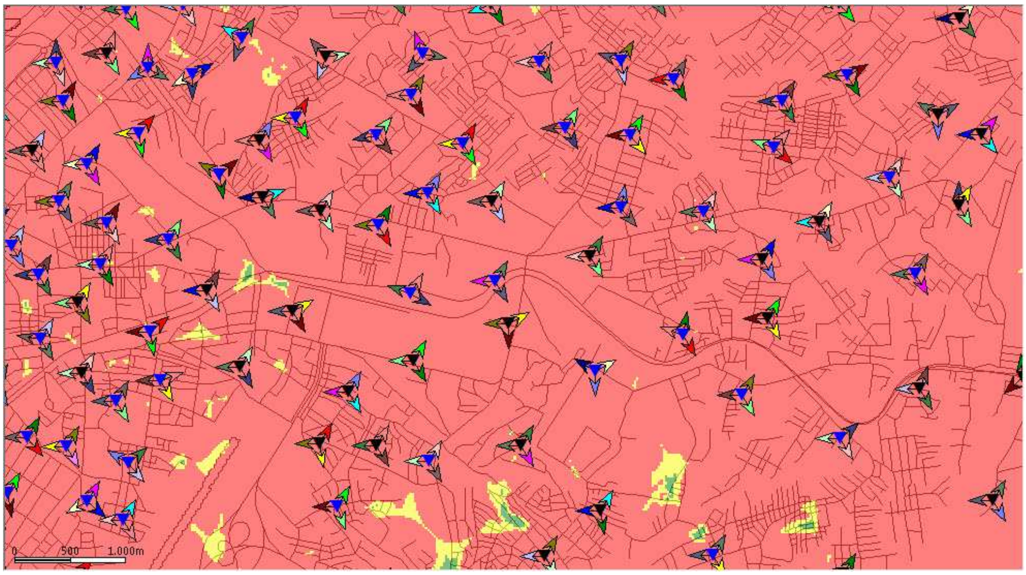

Figure C 2 - Coverage by Signal Level, PS128 Service, Power Optimization

The coverage results are presented in Table C2.

Table C 2 - Coverage by Signal Level, PS128 Service, Power Optimization Results

Coverage by Signal Level PS128 With Power Optimization	% Focus Zone	Surface (km²)
	100	216,5188
Best Signal Level (dBm) >=-78.7	85,9	186,0216
Best Signal Level (dBm) >=-81.7	92	199,2264
Best Signal Level (dBm) >=-90.7	99,3	215,1384
Best Signal Level (dBm) >=-98.7	99,9	216,4528
Best Signal Level (dBm) >=-110	100	216,5188

HSDPA Category 8

Figure C3 illustrates the Quality and Throughput Analysis, HSDPA Cat.8 Service, with power optimization.

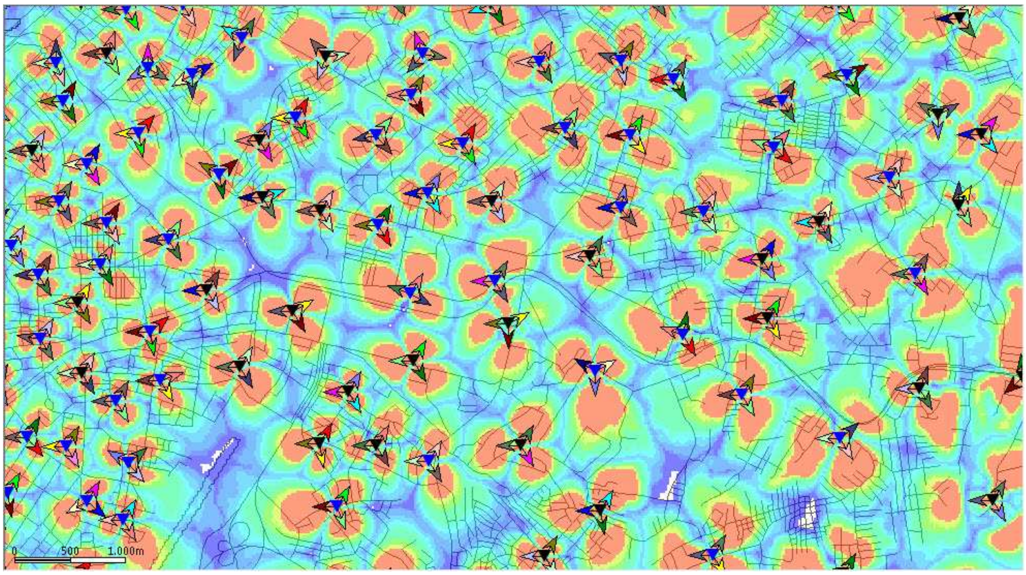

Figure C 3 - Quality and Throughput Analysis, HSDPA Cat.8 Service, Power Optimization

The coverage results are presented in Table C3.

Table C 3 - Quality and Throughput Analysis, HSDPA Cat.8 Service, Power Optimization Results

HSDPA Quality and Throughput Analysis Cat8 With Power Optimization	% Focus Zone	Surface (km²)
	99,6	215,7504
RLC Peak Rate (kbps) >=6,600	26,5	57,3624
RLC Peak Rate (kbps) >=6,200	26,5	57,3624
RLC Peak Rate (kbps) >=5,800	26,5	57,3624
RLC Peak Rate (kbps) >=5,400	26,5	57,3624
RLC Peak Rate (kbps) >=5,000	34,3	74,3292
RLC Peak Rate (kbps) >=4,600	34,3	74,3292
RLC Peak Rate (kbps) >=4,200	43,9	95,1148
RLC Peak Rate (kbps) >=3,800	43,9	95,1148
RLC Peak Rate (kbps) >=3,400	43,9	95,1148
RLC Peak Rate (kbps) >=3,000	60,7	131,4112
RLC Peak Rate (kbps) >=2,600	68,3	147,8976
RLC Peak Rate (kbps) >=2,200	76,1	164,8852
RLC Peak Rate (kbps) >=1,800	86,8	187,9972
RLC Peak Rate (kbps) >=1,400	95,6	207,0504
RLC Peak Rate (kbps) >=1,000	96,9	209,9368
RLC Peak Rate (kbps) >=600	99,6	215,7504

HSDPA Category 24

Figure C4 illustrates the Quality and Throughput Analysis, HSDPA Cat.24 Service, with power optimization.

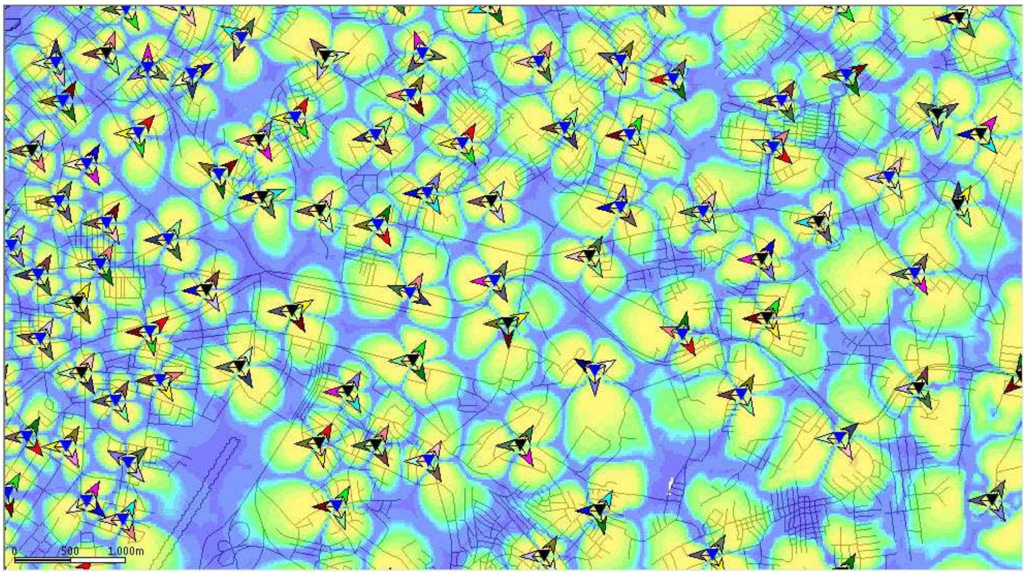

Figure C 4 - Quality and Throughput Analysis, HSDPA Cat.24 Service, Power Optimization

The coverage results are presented in Table C4.

Table C 4 - Quality and Throughput Analysis, HSDPA Cat.24 Service, Power Optimization

HSDPA Quality and Throughput Analysis Cat24 With Power Optimization	% Focus Zone	Surface (km²)
	99,9	216,3872
RLC Peak Rate (kbps) >=34,200	0,9	1,9856
RLC Peak Rate (kbps) >=31,800	18,6	40,224
RLC Peak Rate (kbps) >=29,400	27,4	59,42
RLC Peak Rate (kbps) >=27,000	38,4	83,1476
RLC Peak Rate (kbps) >=24,600	48,3	104,5844
RLC Peak Rate (kbps) >=22,200	54,2	117,3676
RLC Peak Rate (kbps) >=19,800	54,8	118,7276
RLC Peak Rate (kbps) >=17,400	59,2	128,1932
RLC Peak Rate (kbps) >=15,000	62	134,3148
RLC Peak Rate (kbps) >=12,600	64,2	139,0688
RLC Peak Rate (kbps) >=10,200	67,9	147,078
RLC Peak Rate (kbps) >=7,800	72,1	156,2024
RLC Peak Rate (kbps) >=5,400	76	164,6796
RLC Peak Rate (kbps) >=3,000	95	205,8772
RLC Peak Rate (kbps) >=600	99,9	216,3872

HSUPA

Figure C5 illustrates the Quality and Throughput Analysis, HSUPA Service, with power optimization.

Figure C 5 - Quality and Throughput Analysis, HSUPA Service, Power Optimization

The coverage results are presented in Table C5.

Table C 5 - Quality and Throughput Analysis, HSUPA Service, Power Optimization Results

HSUPA Quality and Throughput Analysis With Power Optimization	% Focus Zone	Surface (km²)
	99,9	216,506
RLC Peak Rate (kbps) >=4,096	95,6	207,0808
RLC Peak Rate (kbps) >=3,584	97,4	211,0816
RLC Peak Rate (kbps) >=3,072	98,5	213,472
RLC Peak Rate (kbps) >=2,560	99,2	214,868
RLC Peak Rate (kbps) >=2,048	99,5	215,5612
RLC Peak Rate (kbps) >=1,792	99,6	215,8492
RLC Peak Rate (kbps) >=1,536	99,7	216,0264
RLC Peak Rate (kbps) >=1,280	99,8	216,2492
RLC Peak Rate (kbps) >=1,024	99,9	216,362
RLC Peak Rate (kbps) >=768	99,9	216,4308
RLC Peak Rate (kbps) >=512	99,9	216,468
RLC Peak Rate (kbps) >=384	99,9	216,4844
RLC Peak Rate (kbps) >=256	99,9	216,5012
RLC Peak Rate (kbps) >=192	99,9	216,506
RLC Peak Rate (kbps) >=128	99,9	216,506
RLC Peak Rate (kbps) >=64	99,9	216,506
RLC Peak Rate (kbps) >=32	99,9	216,506