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Universal Mobile Telecommunication System Radio Network Planning for the Case of Addis Ababa City

A thesis Submitted to the School of Graduate Studies of Addis Ababa University in
Partial fulfillment for the degree of Master of Science in Communication Engineering

By

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February 25, 2016

Addis Ababa

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ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
INSTITUTE OF TECHNOLOGY

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Declaration

I, the undersigned, declare that the thesis comprises my own work. In compliance with internationally accepted practices, I have fully acknowledged and referred all materials used in this thesis work

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Abstract

In this research, Universal Mobile Telecommunication System (UMTS) radio access network planning is demonstrated taking Addis Ababa city as a case study. In this regard, the major planning problem for UMTS network is solved through an approach that makes use of the industry best practices adopted by the major equipment vendors currently working with ethio telecom (the sole telecom operator in Ethiopia), ZTE, Huawei, and Ericson. The main focus of the design research is on the network dimensioning aspect especially the radio link budget, capacity dimensioning and channel element dimensioning. On top of this, primary scrambling code planning is performed in parallel with coverage prediction and capacity simulation to verify the dimensioning outputs.

Except for the channel element dimensioning, all the other dimensioning results are less than what the operator is using in its live network. This is achieved through the proper design decision made at each stage of the planning process. On the other hand, the channel element estimation result looks a bit higher as compared to the value used in the live network. But the truth is, knowingly the operator chose to start with minimum channel element resource and plan to purchase more channel element resource as the traffic grows. Hence, the comparison in this regard fails to qualify the current dimension result.

In general, the main contributions of this research are two-fold: first it solves planning problem which is case specific to ethio telecom, second it demonstrate particular planning approaches using ethio telecom planning requirements as an input.

Acknowledgements

This thesis could not be successfully conducted without valuable assistance from various people. Therefore, I would like to express my sincere thanks and gratitude to my advisor, Dr. Yalemzewd Negash for his tremendous support and encouragement. And I would also want to thank Dr. Dereje Hailemariam for his invaluable criticisms towards the betterment of the research.

My endless gratitude would also extend to my mother, W/or Almaz Kebede, who has helped, encouraged and challenged me to complete this work successfully. My deep gratitude also goes to my colleagues at ethio-telecom for their endless material support and encouragement.

Finally, I would like to thank my wife, Rahel W/Georgis, for all the love, support and encouragement that she has given me. She always gave me hope and energy to complete my job with passion.

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List of Acronyms

3GPP	3rd Generation Partnership Project
AMR	Adaptive Multirate
ARIB	Association of Radio Industries and Businesses
ATIS	Alliance for Telecommunications Industry Solutions
BH	Busy Hour
BMC	Broadcast/Multicast Control
BS	Base station
C/I	Carrier to interference
CCSA	China Communications Standards Association
CDMA	Code Division Multiple Access
CE	Channel element
CHR	Call history record
CN	Core Network
CPICH	Common Pilot Channel
C-plane	Control plane
CS	Circuit switching
CW	Continuous wave
DL	Downlink
DU	Dense Urban
Eb/No	Energy of the bit per Noise
EIRP	Effective Isotropic Radiated Power
ENCP	Ericson Network capacity planner
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex)
GB	Gega Byte
GC	Gregorian calendar
GC	Gregorian Calendar
GSM	Global System for Mobile Communications
HSDPA	High-Speed Downlink Packet Access
HSUPA	High Speed Uplink Packet Access
IMT-2000	International Mobile Telecommunication at the year 2000
ITU	International Telecommunication Union
L1	Layer one
L2	Layer two
L3	Layer three
LoCHs	Logical Channels
MAC	Medium Access Control
MR	Measurement report
NF	Noise Figure
OSS	Operation Support System

OSS	Operation supports system
PCS	Personal Communication System
PDCP	Packet Data Convergence Protocol
PL	Path loss
PS	Packet Switching
PSC	Primary Scrambling Code
QoS	Quality of Service
RLB	Radio Link budget
RLB	Radio Link Budget
RLC	Radio Link Control
RNC	Radio Network Controller
TTA	Telecommunications Technology Association
TTC	Telecommunication Technology Committee

Chapter 1 INTRODUCTION

1.1 Introduction

In its first Growth and Transformational Plan (GTP I), the Government of Ethiopia set out its vision, objectives, and targets to extend the mobile phone subscriber from 6.5 million to 40 million and to reach service coverage of 90% by the end of 2015. Delivering this vision, and meeting the ambitious targets for coverage and service quality, will require significant efforts from ethio telecom to initiate and manage huge telecom expansion projects. In aligning with this objective ethio telecom signed off telecom expansion project deal with Chinese vendor, Huawei, in august 2013 with the commitment to finish the mobile network rollout for the capital city, Addis Ababa, within nine months time [1].

The Universal Mobile Telecommunication System (UMTS) network in Addis Ababa back in the year 2013 has its own limitations in terms of capacity, coverage and quality. To this end, the project aims to address the existing problems through complete swapping of the existing network elements along with a plan for additional capacity. Hence, the network planning will be done in such a way that the dimensioning part will start from scratch based on certain sets of requirements and the detailed planning will be done to maximize the capacity, coverage and service quality with minimum investment possible.

Having the information mentioned in the above paragraph as an opportunity, this thesis intended to explore and solve multiple design problems involving UMTS radio access network expansion project of Addis Ababa city. In general, radio access network planning addresses the following key design problems [2] [3] [4] [5].

1. The number and configuration of base stations required to meet the given coverage and capacity requirement;
2. Base station locations that will result in maximizing coverage, capacity, and service quality while minimizing investment;

3. Detail coverage analysis;
4. Detail capacity analysis;
5. Radio parameter design (scrambling code).

To address radio network planning problems listed here above, different vendors and operators might follow different approaches and methods depending upon their business requirement. In pursuit of an efficient method and approach, this research will explore for an efficient method and approach to managing Addis Ababa UMTS radio access network planning [6] [7] [4].

1.2 Statement of the problem

The ultimate goal for UMTS Radio Access Network (RAN) planning is to build radio access network that can handle high-level traffic generated by users while maintaining good service quality and user experience. Enabling this goal involves a complex trade-off between capacity, coverage, and quality, together with financial considerations and challenges relating to the multi-technology environment [4] [6] [3] [8].

From the business perspective, operators have the interest to minimize their infrastructure investment while equipment vendor's wants to sell more equipment's. These two extreme interests need to be settled through effective planning methods. Effective planning methods have the attribute of determining the minimum network resources required to meet the coverage, capacity and quality requirement of the operator [3] [4].

The proprietary algorithms used by different equipment vendors for their radio network planning tools mark the efficiency of the tool to identify minimum network resources. Most of these tools are not for sale especially tools used for network dimension part; rather the planning service is sold out in a nutshell. For instance Huawei Telecommunication Equipment Company has developed tools called Radio Network Dimensioning tool (RND tool) which is for the company internal use only. Similarly, Ericson Telecommunication Equipment Company has developed tools called Ericson

Network Capacity Planner (ENCP) and recently announced on the company website that the tools product is replaced by capacity planning service. To this end, this design research strives to demystify some of the algorithms used for UMTS RAN planning taking Addis Ababa city as case demonstration.

1.3 Objective

1.3.1 General Objectives

The objective of this research is to do UMTS radio network planning for Addis Ababa city taking the operator design requirements as an input. To qualify the planning output, coverage prediction and capacity simulation is conducted on commercial radio network planning tool.

To achieve this objective, different design decisions are made based on the industrial best practices adopted from various documentations. On top of this, the link budget parameter for coverage dimensioning is carefully determined in a way to maximize the operator best interest. In the same token, the traffic model required for capacity dimensioning and channel element dimensioning is determined by conducting a study on traffic statistics collected from the operator live network. Furthermore, the proprietary algorithm used by the equipment vendor for channel element dimensioning is drilled down in this research.

1.3.2 Specific Objectives

The scope of this design research is limited to the following specific radio network planning undertakings.

1. Dimensioning
 - 1.1 Number of sites estimation based on link budget calculation;
 - 1.2 A number of carrier determination based on capacity target and traffic model;
 - 1.3 Traffic model preparation;
 - 1.4 Channel element dimensioning.
2. Detail planning

- 2.1 Site layout design.
- 2.2 Propagation model tuning;
- 2.3 Primary scrambling code planning;
- 2.4 Coverage prediction;
- 2.5 Capacity simulation analysis.

1.4 Methodology

The methods employed to achieve the objectives of the research are:

- **Study UMTS cellular network technology:** to understand the challenges associated with the radio network planning of UMTS network it is required to understand the different wireless technologies employed in UMTS radio access network (UTRAN) network.
- **Review similar literature:** review different research papers help to fine tune the research problem. The problem that needs to be addressed through the current work needs to be well understood and for this, review similar literature helps to widen the viewpoints for the problem.
- **Define the planning problem for ethio telecom:** study the company business objective to define the planning target and to understand the challenges in regard to network planning. Most of the operators planning targets are aligned with the government growth and transformation plan hence it is also necessary to review GTP plan document.
- **Construct conceptual framework:** select an appropriate dimensioning algorithm based on the operator requirement and based on the reliability of the dimensioning output.
- **Practice on the planning tools:** for the coverage prediction and capacity simulation commercial radio network planning tools is required. And to use the planning tool effectively working knowledge of the tools should be developed.

- **Simulation and analysis:** Based on coverage prediction and capacity simulation result the efficiency of the planning output is evaluated.

1.5 Related Works

This section surveys previous work in UMTS Radio access network planning. The first work selected for review is the doctoral thesis by Jaana Laiho [1]. The thesis is published by Helsinki university of technology radio laboratory publications in July 2002. It focuses on Wide Band Code Division Multiple Access (WCDMA) (Frequency Division Duplex (FDD) mode) radio network planning and optimization process. For the planning part, the link budget model, radio network planning process using Radio Network Planning (RNP) tool is thoroughly discussed.

The second work selected for review is the Journal published in The International Journal of Computer and Telecommunications Networking in October 2006. This journal is coauthored by three scholars from Polytechnic School of Montreal, Marc St.Hilaire, Steven Chamberland, and Samuel Pierre. The paper introduces an approach called global approach to UMTS network planning. This approach is presented in comparison with the classical approach of doing the planning by partitioning the planning problem into several subproblems and solving them successively. The global approach is proved to yields better result as it gives a solution using mathematical programming models that address it as a whole.

The third paper is a journal published in the journal called Annals of Telecommunications. The title of the paper is Radio network planning process and methods for WCDMA. The paper describes the system dimensioning and the radio network planning methodology for a WCDMA system. This paper is a very useful piece of work to describe the overall process of UMTS dimensioning process.

In general, all the three papers reviewed reveals useful information on the overall process of radio access network planning for UMTS technology. Specifically, the first and the third paper discusses the planning approach

similar to the one followed in this research. The second paper, on the other hand, introduces the global approach to the planning problem which took the overall planning in a single mathematical model and deals with optimization problem. Further the paper does a comparison between the classical approach and the global approach based on the planning output.

1.6 Thesis Layout

Below is a short explanation of the contents and purpose of the four chapters in this thesis.

Chapter 2 briefly introduces the UMTS radio access technology. The Chapter introduces topics like mobile technology generation and radio technologies that are employed in UMTS system.

Chapter 3 discusses the network dimensioning result for the case of Addis Ababa. The chapter also contains one section dedicated for the coverage prediction and capacity simulation result. **Chapter 4** highlights major results of the design research along with the conclusion. On top of this, in the future research section recommendations and potential areas for future study are specified.

Chapter 2 UMTS Network: An Overview

2.1 Introduction to UMTS

Beginning from the time when it was first conceived in Bell laboratories in 1979 GC, cellular mobile systems has passed through different stages of development which is normally identified as a generation. First generation cellular mobile system were based on analog technology in which poor voice quality, large terminal size, low security, limited capacity and poor mobility support were the limitation of the system as the whole. Later with the advent of digital processing technology, the second generation cellular network introduced with the improved feature [9] [3] [10] [11].

The increase in demand for cellular mobile with wide-area communication supporting new applications leads to the development of the 3rd generation cellular network to fulfill the requirement set out by international telecommunication union (ITU) for IMT-2000. The 3rd generation cellular network that becomes popular worldwide was the UMTS (Universal mobile telecommunication system) developed under 3rd generation partnership project (3GPP) established by six regional standards development organization namely European Telecommunications Standards Institute (ETSI), Association of Radio Industries and Businesses (ARIB), Telecommunication Technology Committee (TTC), Telecommunications Technology Association (TTA), Alliance for the Telecommunications Industry Solutions (ATIS), and China Communications Standards Association (CCSA) [12] [13].

Unlike its 2nd generation predecessor (GSM), UMTS system used code division multiple access (CDMA) technology. And this enables a frequency reuse factor of one which leads to high spectral efficiency. But this comes with the cost that strong inter-cell interference management requirement. The other principle difference of UMTS cellular system design is its high bandwidth usage. In UMTS system, the transmission bandwidth is greater than the coherence bandwidth of the radio channel and this makes the

system more robust against multipath fading and narrow band interference [13].

In UMTS, there are two set of codes used for spreading. The first one is orthogonal code with zero cross-correlation characteristics between two codes generated at the same time. And the second one is non-orthogonal codes which are called scrambling codes. The orthogonal codes are selected and used in a tree-like structure to enable code sequences of different lengths to spread multi-rate applications data with a constant chip rate of 3.84 Mega chips per second (Mcps) [9].

The scrambling codes in the uplink are used to discriminate different sector of the mobile station and for this purpose scrambling code is statically assigned to each sector of the base station during network planning. Consequently, the primary scrambling codes assigned for each sector will be discovered by the UE before it can access the network [14]. The primary scrambling codes are grouped into 8 resulting in 64 groups. During cell search procedure the UE needs to identify to which group the primary scrambling code of the cell belongs to from synchronization channel of the cell. In the later stage of cell search procedure, the scrambling code will be identified exactly from the common pilot channel (CPICH) which is also broadcast from each cell [14] [15].

The other characterizing feature of UMTS network is the power control. As can be expected in CDMA system the different signal transmission potentially interfere with each other, Hence, the transmission power of each signal needs to be carefully controlled so that it arrives at the receiver with sufficient signal-to-interference ratio (SIR) to achieve the desired QoS yet not cause excessive interference to the other signal transmission [14] [16] .

The other advantage of using CDMA system in UMTS system is related to soft handover feature. In soft handover User Equipment (UE) can receive a transmission from multiple cells simultaneously in the downlink and in the same token UE's transmission can be received simultaneously by multiple cells in the uplink. For the case where UE receive a transmission

from multiple cells, UE combines the soft values in a log-likelihood ratio from different cells prior to decoding. Similarly same combining technique is applied to the case where two cells belong to the same site. But for two different sites involved selective combining will be used [11].

2.2 Network architecture

UMTS mobile system is realized by the introduction UMTS radio access network (UTRAN) to preexisting GSM core networks. Functionally UMTS network can be divided into three elements, UMTS Radio access network (UTRAN), Core network (CN) and the operations support system (OSS). The Radio Access Part (UTRAN) takes care of the radio transmission and reception, including segmentation, error protection, and general radio resource management, among other things [11].

The UMTS radio access network contains Radio network controller (RNC) which is hosted by core network through the lu interface (luCS for voice and luPS for data). And Base station's and RNC are connected through the lub interface [9] [2] [14].

Chapter 3 PLANNING RESULTS

The planning task in this design research is performed in two stages. The first stage is network dimensioning that involves coverage, capacity and channel element dimensioning. The second stage is detailed planning that involves site layout design, coverage analysis, capacity analysis and scrambling code planning. The planning output along with the details planning steps is presented in the subsequent sections.

3.1 Link budget calculation

The link budget is performed as part of coverage dimensioning process to acquire the maximum allowable path loss based on the given planning scenes. And the acquired maximum path loss will be further used to calculate the maximum cell radius based on the radio propagation model. In all these processes the final target is to estimate the number of required bases station to cover the target coverage area [17] [7] [18] [19].

Using the maximum cell radius the area covered by the single base station can be calculated through the hexagonal cellular layout. And as a final step, the number of bases station required for the target coverage area is estimated based on the coverage area of a single base station.

3.1.1 Link budget parameters

Based on the signal propagation path from the transmitting end to receiving end, there are two paths, Uplink path, and a downlink path. The uplink path is for the path between the mobile station and base station antenna where the mobile station is designated as transmitter and base station as a receiver. Similarly, the downlink path is for the path between the bases station and the mobile station where the base station is designated as a transmitter and the mobile station as a receiver.

UMTS system could be uplink limited or downlink limited based on the system loading. In a lightly loaded system, the User equipment transmits power sets a coverage limitation, therefore, it is uplink-limited. In a heavily

loaded system, the base station transmits power limits the number of user equipment it can serve therefore it is downlink-limited. Generally, the uplink is limiting link in terms of radio bearer coverage. But practically the link budget analysis is also performed on the downlink path to verify the assumption [8].

The link budget calculation involves various link parameters associated with gains, losses and design margins of the particular signal transmission path. The major link parameters are illustrated in the simplified block diagram shown here below [17].



Figure 1 A simplified block diagram of the link budget calculations

Transmitter parameters

1. User equipment maximum transmits power (dBm)

The maximum transmits power of the mobile station is dictated by the UE power class. Table 1 shows the standard specification of the maximum transmits power of the user equipment for each power class and the associated tolerances. On any given network there exists different mobile equipment from different power class. But usually voice-centric UE is class 3 or 4 and data-centric UE is class 3. Therefore, in the link budget calculation, the transmit power parameter for the uplink path is specified as 21dBm for voice terminal while for data terminal it is specified as 24dBm.

Accordingly for this design research, the value selected for the uplink link budget parameter called Maximum TCH power is 21dBm [10].

Power level of UE (TS 25.101 v3.7.0 (2001-06) 6.2.1)		
Power Class	Nominal maximum output power	Tolerance
1	+33dBm	+1/-3dB
2	+27dBm	+1/-3dB
3	+24dBm	+1/-3dB
4	+21dBm	+2/-2dB

Table 1 User Equipment Power Classes [10]

2. Transmit power of the base station (dBm)

The common pilot channel (CPICH) is used by the base station to provide a reference to all mobile stations and aid the channel estimation at the terminals. For this reason, the CPICH channel is used to define the maximum possible coverage of a particular cell. In this design research the value for "transmit power of the base station" is taken as 33dBm which is the typical CPICH power configuration of a cell [7] [17].

3. Required Eb/No

For the Uplink link budget calculation, the Eb/No value assumption reflect the performance of the Base station receiver and the value may vary from one vendor to the other. Accordingly the Eb/No figures used for this link budget calculation are taken from Huawei company product documentation. And it is shown in Table-2 [20] [21].

	Downlink	Uplink
CS 12.2k	7.5	4.2
CS 64K	5.2	2.7
PS 64K	4.8	1.6
PS 128K	4.5	1.1
PS 384K	4.3	0.6

Table 2 Required Eb/No Values [20]

4. Body loss (dBm)

Body loss occurs at the UE side. Its value depends on usage habit of the user. In the link budget calculation, the default setting of body loss is 3dB for speech service and 0dB for data services because data services are mainly read and watched and the UE is far away from the human body. Hence, the for this link budget calculation body loss of 3dB is assumed [8].

5. Antenna gains (dBi)

Antenna gain is one of the important attributes of antenna characteristic that is used in the link budget calculation. Normally the antenna gain for the user equipment is taken as 0dBi whereas for the Base station antenna the value is chosen based on the type of antenna selected for each propagation scenario. For this particular case or research, the Base station antenna selected for all propagation scenarios has an 18dBi gain [22].

Receiver parameters

The main receiver parameters are the following:

1. The noise figures

Noise figure is an index used to evaluate whether noise performance of the amplifier is good or not. It is expressed by Noise Figures (N) and defined as the ratio of input Signal-to-Noise ratio (SNR) and output Signal-to-Noise ratio (SNR) of an amplifier. The noise figure for Huawei Base station DBS3900 is taken as 2.1dB for the case where there is no TMA (Tower mounted Amplifier) [17].

2. Thermal noise density –

The thermal noise density is computed from the equation:

$$\text{Thermal Noise Density} = B \times T \times BW$$

Equation 1

Where:

- B Boltzmann's constant
- T Temperature
- BW Bandwidth

Parameter	UE	Node B
(a) Rx antenna gain (dBi)	0	18
(b) Cable and connector losses (dB)	0	0.5
(c) Noise figure (dB)	0	7
(d) Thermal noise density (dBm/Hz)	-174	-174
(e) Total effective noise (dBm/Hz)	(c) +(d)	
(f) receiver thermal sensitivity (dBm)	(e) + 10 log (information rate) + Eb/Io	

Table 3 Receiver parameters [11].

The total effective noise indicated in Table-3 is computed from the sum of the thermal noise density and the receiver noise figure. It is used to define the noise floor when computing the receiver sensitivity. Similarly, the receiver thermal sensitivity is computed based on equation number two.

$\text{Receiver Thermal Sensitivity} = TEN + 10 \log(R) \times \frac{E_b}{I_o}$	Equation 2
---	------------

Where:

- TEN Total Effective Noise
- R Information rate
- E_b Energy of the bit
- I_o Interference other

Loading Factor and interference margin

The link budget includes an interference margin that is based upon the load factor and is given by equation 3:

$$Interference\ Margin = 10 \log \left(\frac{1}{1 - loadfactor} \right)$$

Equation 3

The load factor is the ratio of actual load to the pole capacity¹.

Figure 2 shows the interference margins as a function of cell load.

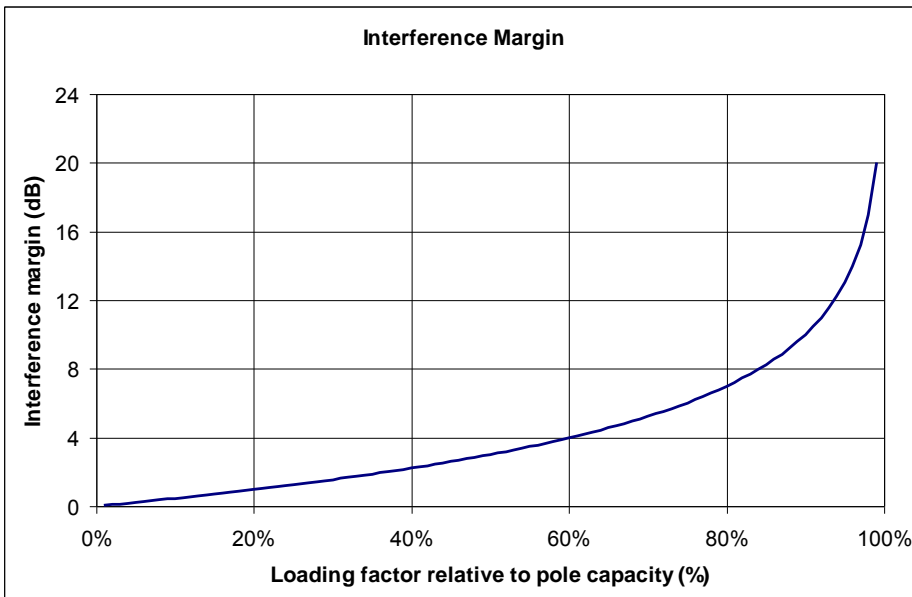


Figure 2 Interference margin as a function of the system loading [17].

As coverage is generally uplink limited, the assumed uplink loading will impact the cell ranges and site density. In this design research, the typical uplink load factors of 75% are assumed for all propagation scenario. On the other hand, the downlink loading is taken as 90%.

Other Margins and Gains

1. Slow fading / log-normal fading margin

Slow fading or shadowing is the variation in the local mean of the received signal that is caused by terrain irregularity and is typically log-normally distributed. In this design research, the standard deviation of

¹ The uplink noise increases with the loading exponentially. When the uplink noise approaches infinity then no more users can be added to a cell – and the cell loading is close to 100% and has reached its “pole capacity”.

shadowing is taken as 10 dB in a dense urban propagation environment. And for the urban and suburban propagation environment, 8dB and 6dB is taken respectively. And these values are typical for the respective propagation environment. On top of this, some allowance is taken for the rise in standard deviation due to in-building operation in the dense urban propagation environment [2] [7] [17].

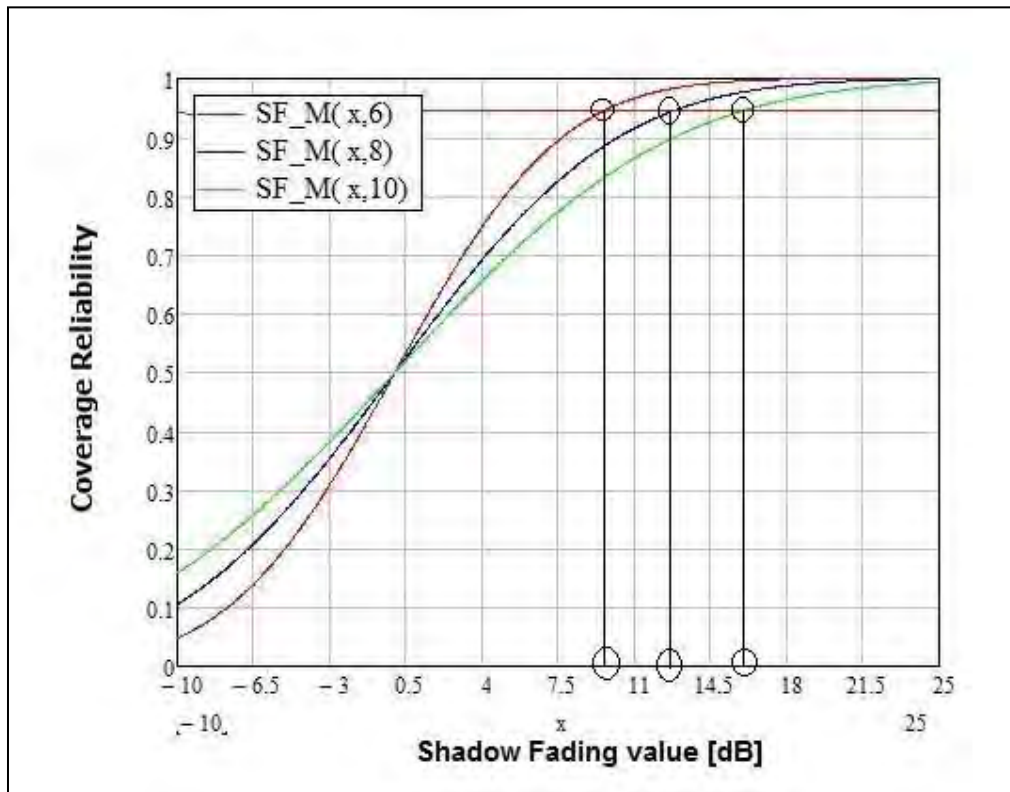


Figure 3 Shadowing fading value.

The graph in Figure-4 illustrates the variation between coverage probability and shadow fading for three standard deviation values(10dB, 8dB, and 6dB) used for the three propagation scenario which is Dense urban, Urban and suburban respectively.

The Coverage area availability assumed for all the propagation environment is 95%. The graph in Figure-4 is made based on equation 4.

$$M_{SF} = \sigma_S \times Q^{-1}(P_{out})$$

Equation 4

Where

- M_{SF} is the shadow fading margin
- σ_S is the standard deviation of shadowing
- P_{out} The coverage area probability

2. Fast fading margin

Fast fading refers to the attenuation of the signals due to multipath reflections and diffractions. The short-term average of fast fading can typically be represented by a Rayleigh distribution.

In slow moving environments, the UE's closed-loop fast power control can effectively compensate for fast fading. This would require appropriate headroom in the UE transmission power. For the current link budget calculation, 2.0 dB is considered for all propagation scenarios.

3. Soft Handoff Gain

Depending upon the degree of slow fading correlation between base stations, soft handoff results in a reduction of the required slow fading margin. In addition, due to macro diversity combining, soft handoff provides gain against fast fading by reducing the required Eb/No.

Typical values for soft handoff gain are around 2-4 dB. A figure of 4dB, 3 dB, and 2dB has been used in this link budget calculation for Dense urban, urban and suburban scenario respectively [2] [3] [25].

4. Receiver antenna diversity gain

It is assumed that the receiver antenna diversity gain is taken into account in the required Eb/No values [13] [15].

5. Penetration loss

The in-building penetration losses are assumed to be dependent upon the building construction. In all the propagation environment a mean

penetration loss is assumed to provide good indoor coverage for the outdoor macro cells. The figure 15dB, 12dB, and 10 dB is assumed for dense urban, urban and suburban respectively [17] [15].

6. Cable and Connector Losses

Cable and connector losses in the link budget attribute to the losses in RF jumper cable that connects Remote Radio Unit (RRUs) of the Base station to the antenna system .RF jumpers transmit signals between a base station and an antenna system. The RF jumper comes with a standard length of 2 m, 3m, 4 m, 6 m, and 10 m. For this design research 3m, standard length is selected. Accordingly a cable loss of 0.5 dB is considered [21] [17].

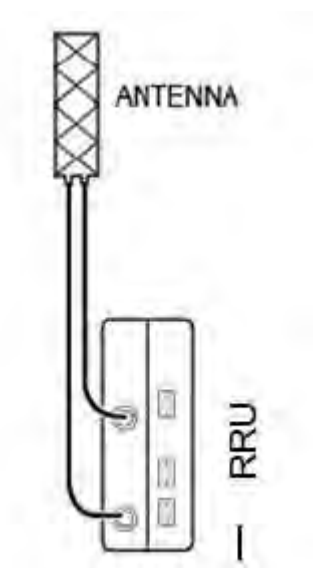


Figure 4 Connection between Remote Radio Unit of Base stations with Antenna system [21]

3.1.2 Coverage requirement analysis

The way the propagation scenario is defined has a significant impact on the coverage dimensioning output. Hence, the propagation scenario for a given city should be done based on certain sets of criteria to ensure good coverage and avoid unnecessary investment. For this design research the

clutter type, the building density, and the average building height is taken into consideration to demarcate different propagation environments for Addis Ababa city. Basically, three propagation scenarios are selected to characterize Addis Ababa propagation environment. The First one is Dense Urban scenario that attributes to the city center where there is a high density of large office buildings. The second one is an urban scenario that attributes areas just outside the city center with a high density of buildings but not as many high office blocks as dense urban. The third one is a suburban scenario that includes areas with light industry and housing areas.

Scenario	Total Coverage area (km ²)	Building density (#Building /Km ²)	Average Building height (AGL)Meter
Dense Urban	40.9	494	5.67
Urban	215.4	473	5.14
Sub Urban	410.6	61	5.01

Table 4 Propagation scenario definition

Based on Addis Ababa building map received from ethio telecom the building density and the average building height is calculated using MapInfo tools for each scenario. The building density for the dense urban scenario is 494 buildings per square kilometer and it is slightly bigger than urban scenario which is 473 buildings per square kilometer. In terms, total coverage area urban scenario is 215.4 Km² whereas dense urban scenario covers only 40.9 km². The suburban scenario has the smallest building density of all the three scenarios which is 61 buildings per square kilometer. But it is the biggest in terms of the area it covers which is 410.6 km². In general table -4 quantitatively describe the three propagation scenarios in terms of building density and average building height. For the average building height, there is no as such big variation among the different scenarios and this case might be unique to Addis Ababa city.

Similarly, Figure -5 shows the boundary for the three scenarios overlaid on the clutter map. Most of the forest clutter found in the outskirts of the city are excluded from the suburban boundary. The suburban boundary contains mainly open clutter; village clutter and forest clutter. On the other

hand, the dense urban and urban scenarios contain dense individual clutter, Industrial clutter, Open urban clutter and mean individual clutter types.

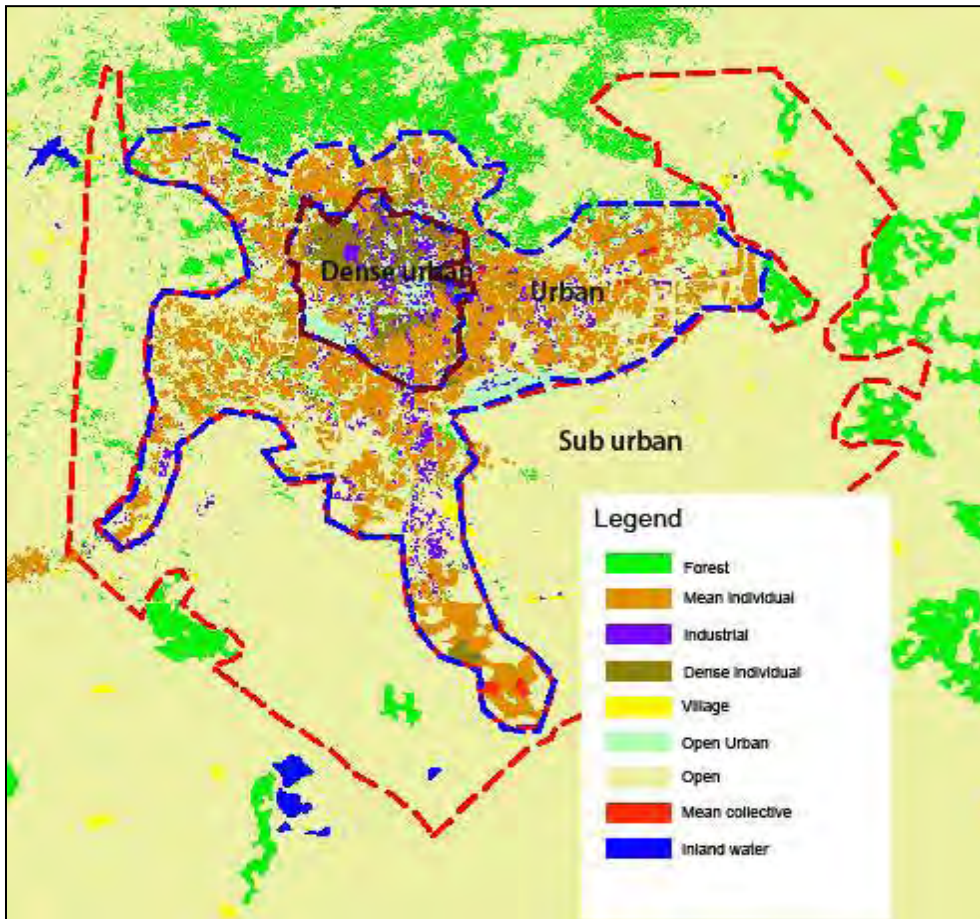


Figure 5 Propagation scenario classification based on clutter type.

The summary of the coverage requirement for the three propagation environment is shown in Table-5. The pilot coverage requirement along with the coverage probability is shown in Table-5 is taken from Scope of work (SoW) definition document that ethio telecom gave for its equipment vendor for Addis Ababa expansion project.

The antenna height for dense Urban, Urban, and the suburban scenario is selected as 25m, 30m and 35m respectively. The selected values are within the standard antenna height range indicated on Table-5.

Scenario	Pilot coverage	Coverage probability	Antenna Height(m)
Dense urban (DU)	>-85dBm	95%	25-30 (25)
Urban (U)	>-90dBm	95%	30-35(30)
Sub urban (SU)	>-95dBm	95%	35-45 (35)

Table 5 Coverage target and antenna height selection

3.1.3 Propagation model

Signal propagation through a wireless media varies significantly depending on the operating terrain, frequency of transmission, sources of interference, speed of the mobile unit and many other dynamic factors. Each individual wireless communication link generally encounters different paths, terrain, obstructions, atmospheric conditions and other phenomena. So it is difficult to compute the radio wave propagation from the transmitter to the receiver analytically [13] [2]. This is the typical case for a macro cellular network where the transmitter and receiver separation is significantly large. In this regard, an empirical or semi-empirical model is used to predict the signal field strength of the transmitter within the computation area. Usually, these models use free parameters and different correction factors that can be tuned by using measurements. The measurement data is obtained by receiving the signal from the base station at various locations. The measurement data is gathered over different clutter type, at different distances from the transmitter and at different clutter heights. The correction factors are tuned according to these measurements by comparing the modeled and measured signal strengths. In the case that the area of the transmitter changes so that the actual properties of the propagation environment change, the tuned parameters must be changed to another estimation set [3].

In general standard propagation models comprise of three components, as depicted in Figure-6: The basic propagation loss, Base station effective antenna height and correction factor. The correction components will be tuned based on the measurement data. And the base station effective antenna height is calculated based on the clutter height information from the digital map [9] [13].

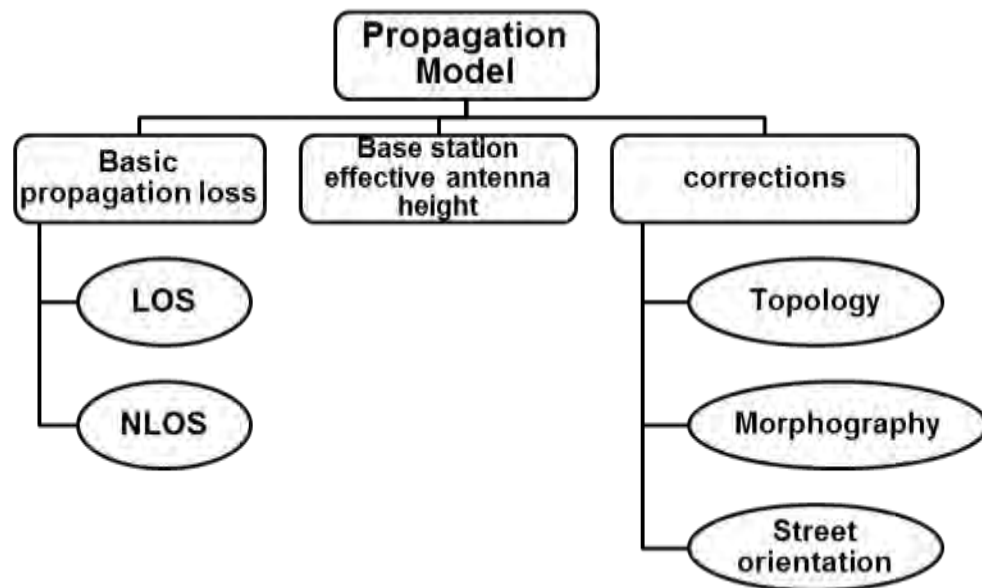


Figure 6 Propagation model components [13].

There are two most widely used propagation models, namely the Okumura-Hata and Walfisch-Ikegami models. These models are the most typical means of calculating basic propagation loss. For the link budget calculation in this research one special variety of the Okumura-Hata model called Cost 231 – Hata is selected. The reason why Okumura –Hata variety is selected is its usability with different clutter type and terrine type [23].

Okumura-Hata model is based on measurements carried out by Okumura in and around Tokyo. These measurements were later fitted by Hata into mathematical formulas. The resulting model is referred to as the

Okumura-Hata model. Hata's formulas are only valid for frequencies up to 1000 MHz. However, it has been extended to the cost 231 activities to frequencies between 1500MHz and 2000 MHz, which is applicable to UMTS 2100 radio networks.

The COST-231 Hata model equation expressed in terms of the propagation loss is indicated in Equation 5 [4].

$$L_p = 46.3 + 33.9 \log_{10} f - 13.82 \log_{10} h_b - a(h_m) + (44.9 - 6.55 \log_{10} h_b) \log_{10} d + C_m$$

Equation 5

Where

- L_p is the path loss(dB)
- f is the frequency (MHz),
- H_b and h_m are the base and mobile station antenna heights respectively(m)
- $a(h_m)$ is the mobile antenna gain function (dB)
- d is the distance in km
- C_m is defined as 0 dB for medium cities and suburban area and 3dB for metropolitan environments.

$a(h_m)$ is defined for the metropolitan area as in Equation 6

$$a h_m = 3.20(\log_{10}(11.75 h_m))^2 - 4.97 ,$$

for frequency > 400MHz

Equation 6

The link budget calculation in the next section assumes the simplified version of the Cost-231 Hata propagation model indicated in Equation 7.

$$L_p = 166.6 + 44.9 \log_{10}(d) - 2.96 \log_{10}(h_m) - 13.82 \log_{10}(h_b) - 6.55 \log_{10}(h_b) \log_{10}(d)$$

Equation 7

3.1.4 Radio Link budget (RLB) result

Based on the link budget parameter description and selection in section 2.1.1, the link budget calculation is done on the Excel macro adopted from ZTE Corporation. Generally, the uplink is limiting link in terms of radio bearer coverage hence in this section the uplink link budget calculation is shown in the separate table for different propagation scenario.

Table-6 shows the uplink RLB calculation for different services for Dense Urban scenario. The link budget calculation in Table-6 is divided into three parts. The first part is for the link in the transmitter chain which is the User equipment. The second part is for the link in the receiver chain which is the Base station and the third part is for different design margins in the wireless interface.

The first link budget element for the transmitter chain attributes to the User equipment maximum transmit power which is 21 dBm for voice centric user equipment and 24 dBm for data centric user equipment. For this particular case, 21dBm is considered for all R99 services and 24 dBm is considered for High-Speed Uplink Packet Access (HSUPA) service. The second attributes in the transmitter chain are the user equipment antenna gain and this is considered as 0dBi for all R99 service and 2dBi for HSUPA data cards. For the body loss attributes of the link budget, 3dB loss is used for voice service which is Adaptive Multi-Rate 12.2 (AMR 12.2) but for the other services 0dB is considered. Since there is no feeder loss in the user

equipment, the feeder loss for all the service is considered as 0dB. The last element in the transmitter link budget is the effective isotropic radiated power (EIRP) which is calculated based on equation –8 taking the losses and gains factors in the user equipment.

$$EIRP[dBm] = T_x Power[dBm] + Antenna Gain[dBi] - Body Loss[dB] - Feeder Loss[dB]$$

Equation 8

		Dense Urban scenario					
		UPLINK					
		CS12.2K	CS64K	PS64K	PS128K	PS384K	HSUPA
TX	Tx Power [dBm]	21.00	21.00	21.00	21.00	21.00	24.00
	Antenna Gain [dBi]	0.00	0.00	0.00	0.00	0.00	2.00
	Body Loss [dB]	3.00	0.00	0.00	0.00	0.00	0.00
	Feeder Loss [dB]	0.00	0.00	0.00	0.00	0.00	0.00
	EIRP [dBm]	18.00	21.00	21.00	21.00	21.00	26.00
RX	Thermal Noise Density [dMm/HZ]	-174.00	-174.00	-174.00	-174.00	-174.00	-174.00
	Thermal Noise [dBm]	-108.16	-108.16	-108.16	-108.16	-108.16	-108.16
	Receiver Noise Figure [dB]	2.10	2.10	2.10	2.10	2.10	2.10
	Receiver Noise [dBm]	-106.06	-106.06	-106.06	-106.06	-106.06	-106.06
	Bit Rate [kbit/s]	12.20	64.00	64.00	128.00	384.00	200.00
	Process Gain [dB]	24.98	17.78	17.78	14.77	10.00	-13.00
	Required Eb/No [dB]	4.20	2.70	1.60	1.10	0.60	-119.06
	Receiver Sensitivity [dBm]	-126.84	-121.14	-122.24	-119.73	-115.46	
	Interference Margin [dB]	6.02	6.02	6.02	6.02	6.02	6.02
	Antenna Gain [dBi]	18.00	18.00	18.00	18.00	18.00	18.00
	Feeder Loss [dB]	0.50	0.50	0.50	0.50	0.50	0.50
	Body Loss [dB]	0.00	0.00	0.00	0.00	0.00	0.00
Margin	Power control headroom [dB]	2.00	2.00	2.00	2.00	2.00	2.00
	Soft Handover Gain [dB]	4.00	4.00	4.00	4.00	4.00	4.00
	Shadow Fading Margin [dB]	16.40	16.40	16.40	16.40	16.40	16.40
	Penetration Loss [dB]	15.00	15.00	15.00	15.00	15.00	15.00
Max Allowable Outdoor Path Loss [dB]		141.92	139.22	140.32	137.81	133.54	142.14
Outdoor Coverage Cell Raius [km]		0.76	0.64	0.69	0.58	0.44	0.77
Max Allowable Indoor Path Loss [dB]		126.92	124.22	125.32	122.81	118.54	127.14
Indoor Coverage Cell Raius [km]		0.29	0.24	0.26	0.22	0.17	0.29
		Less than 50km/h					
Max Allowable Incar Path Loss [dB]		138.92	136.22	137.32	134.81	130.54	139.14
Incar Coverage Cell Raius [km]		0.63	0.53	0.57	0.48	0.36	0.64
Design threshold							
	Outdoor	123.92	118.22	119.32	116.81	112.54	116.14
	Indoor	108.92	103.22	104.32	101.81	97.54	101.14
	Incar	120.92	115.22	116.32	113.81	109.54	113.14

Table 6 Uplink Link budget calculation for dense urban scenario

Among the different components of the receiver link budget parameters the receiver sensitivity, interference margin, antenna gain, and cable losses are the basic one. The receiver sensitivity is calculated based on equation-9 taking the receiver noise, the Eb/No requirement for the services and

processing gain of each service rate into consideration. The interference margin, on the other hand, is calculated based on Equation -3 for the uplink load of 75%.

$ \begin{aligned} & \text{Receiver Sensitivity [dBm]} \\ & = \text{Receiver Noise [dBm]} \\ & + \text{Required } \frac{E_b}{N_o} \text{ [dB]} - \text{Process Gain [dB]} \end{aligned} $	Equation 9
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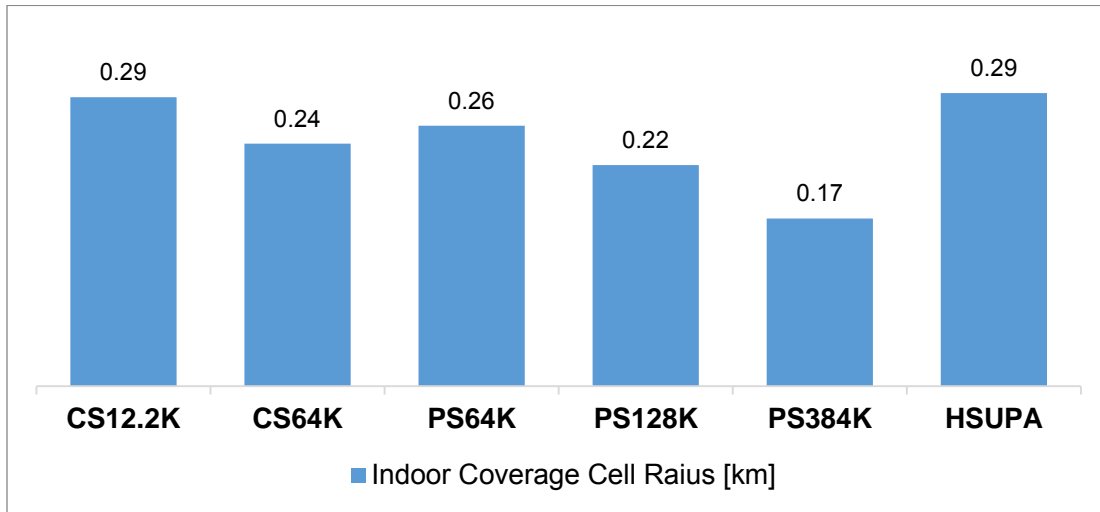
The last components of the link budget are the maximum allowable path loss which is calculated based on the transmitter, the receiver, and the design margin parameters all put in one equation, Equation 10.

$ \begin{aligned} & \text{Max Allowable Outdoor Path Loss [dB]} \\ & = \text{EIRP [dBm]} \\ & - \text{Receiver Sensitivity [dBm]} \\ & - \text{Interference Margin [dB]} \\ & + \text{Antenna Gain [dBi]} - \text{Feeder Loss [dB]} \\ & - \text{Body Loss [dB]} \\ & - \text{Power control headroom [dB]} \\ & + \text{SoftHandover Gain [dB]} \\ & - \text{Shadow Fading Margin [dB]} \end{aligned} $	Equation 10
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Graph-1 illustrates the maximum cell radius for different services. The cell radius is calculated based on the Cost-231 Hata model presented in Equations 5 & 6 and considers the maximum allowable path loss and the penetration loss. So the cell radius, in this case, stands for the indoor coverage.

As it is shown on graph-1 PS384K has the smallest coverage. Whereas AMR 12.2 (voice service) and HSUPA service have the largest coverage. In this regard the limiting service is PS384K but it is more conservative to

ensure continues voice coverage in this design. Hence, the site density is calculated based on the cell radius for voice service.



Graph 1 Cell Radius result for Indoor coverage

Similarly, the link budget calculation for the urban and suburban scenario is illustrated on Table-7 and Table-8 respectively. The differentiating parameters for the three link budget tables are the values considered for the design margins (soft handover gain, Shadow Fading Margin, and penetration loss). For the other entries of the link budget parameters similar values are taken.

The maximum allowable path loss increases as the propagation scenario changes from dense urban to urban and from urban to suburban. Accordingly the maximum cell radius changes with a similar pattern.

		Urban scenario					
		UPLINK					
		CS12.2K	CS64K	PS64K	PS128K	PS384K	HSUPA
TX	Tx Power [dBm]	21.00	21.00	21.00	21.00	21.00	24.00
	Antenna Gain [dBi]	0.00	0.00	0.00	0.00	0.00	2.00
	Body Loss [dB]	3.00	0.00	0.00	0.00	0.00	0.00
	Feeder Loss [dB]	0.00	0.00	0.00	0.00	0.00	0.00
	EIRP [dBm]	18.00	21.00	21.00	21.00	21.00	26.00
RX	Thermal Noise Density	-174.00	-174.00	-174.00	-174.00	-174.00	-174.00
	Thermal Noise [dBm]	-108.16	-108.16	-108.16	-108.16	-108.16	-108.16
	Receiver Noise Figure [dB]	2.10	2.10	2.10	2.10	2.10	2.10
	Receiver Noise [dBm]	-106.06	-106.06	-106.06	-106.06	-106.06	-106.06
	Bit Rate [kbit/s]	12.20	64.00	64.00	128.00	384.00	200.00
	Process Gain [dB]	24.98	17.78	17.78	14.77	10.00	-13.00
	Required Eb/No [dB]	4.20	2.70	1.60	1.10	0.60	-119.06
	Receiver Sensitivity [dBm]	-126.84	-121.14	-122.24	-119.73	-115.46	
	Interference Margin [dB]	6.02	6.02	6.02	6.02	6.02	6.02
	Antenna Gain [dBi]	18.00	18.00	18.00	18.00	18.00	18.00
	Feeder Loss [dB]	0.50	0.50	0.50	0.50	0.50	0.50
	Body Loss [dB]	0.00	0.00	0.00	0.00	0.00	0.00
Margin	Power control headroom [dB]	2.00	2.00	2.00	2.00	2.00	2.00
	Soft Handover Gain [dB]	3.00	3.00	3.00	3.00	3.00	3.00
	Shadow Fading Margin [dB]	13.20	13.20	13.20	13.20	13.20	13.20
	Penetration Loss [dB]	12.00	12.00	12.00	12.00	12.00	12.00
Max Allowable Outdoor Path Loss [dB]		144.12	141.42	142.52	140.01	135.74	144.34
Outdoor Coverage Cell Radius [km]		1.55	1.29	1.39	1.18	0.89	1.57
Max Allowable Indoor Path Loss [dB]		132.12	129.42	130.52	128.01	123.74	132.34
Indoor Coverage Cell Radius [km]		0.47	0.40	0.43	0.36	0.27	0.48
Less than 50km/h							
Max Allowable In-car Path Loss [dB]		141.12	138.42	139.52	137.01	132.74	141.34
In-car Coverage Cell Radius [km]		1.27	1.06	1.14	0.95	0.73	1.29
Design threshold							
	Outdoor	126.12	120.42	121.52	119.01	114.74	118.34
	Indoor	114.12	108.42	109.52	107.01	102.74	106.34
	In-car	123.12	117.42	118.52	116.01	111.74	115.34

Table 7 Uplink Link budget calculation for the urban scenario.

		Suburban scenario					
		UPLINK					
		CS12.2K	CS64K	PS64K	PS128K	PS384K	HSUPA
TX	Tx Power [dBm]	21.00	21.00	21.00	21.00	21.00	24.00
	Antenna Gain [dBi]	0.00	0.00	0.00	0.00	0.00	2.00
	Body Loss [dB]	3.00	0.00	0.00	0.00	0.00	0.00
	Feeder Loss [dB]	0.00	0.00	0.00	0.00	0.00	0.00
	EIRP [dBm]	18.00	21.00	21.00	21.00	21.00	26.00
RX	Thermal Noise Density [dMm/HZ]	-174.00	-174.00	-174.00	-174.00	-174.00	-174.00
	Thermal Noise [dBm]	-108.16	-108.16	-108.16	-108.16	-108.16	-108.16
	Receiver Noise Figure [dB]	1.60	1.60	1.60	1.60	1.60	1.60
	Receiver Noise [dBm]	-106.56	-106.56	-106.56	-106.56	-106.56	-106.56
	Bit Rate [kbit/s]	12.20	64.00	64.00	128.00	384.00	200.00
	Process Gain [dB]	24.98	17.78	17.78	14.77	10.00	-13.00
	Required Eb/No [dB]	4.20	2.70	1.60	1.10	0.60	-119.56
	Receiver Sensitivity [dBm]	-127.34	-121.64	-122.74	-120.23	-115.96	-119.56
	Interference Margin [dB]	3.01	3.01	3.01	3.01	3.01	3.01
	Antenna Gain [dBi]	18.00	18.00	18.00	18.00	18.00	18.00
	Feeder Loss [dB]	0.50	0.50	0.50	0.50	0.50	0.50
Body Loss [dB]	0.00	0.00	0.00	0.00	0.00	0.00	
Margin	Power control headroom [dB]	2.00	2.00	2.00	2.00	2.00	2.00
	Soft Handover Gain [dB]	2.00	2.00	2.00	2.00	2.00	2.00
	Shadow Fading Margin [dB]	9.90	9.90	9.90	9.90	9.90	9.90
	Penetration Loss [dB]	10.00	10.00	10.00	10.00	10.00	10.00
Max Allowable Outdoor Path Loss [dB]		149.93	147.23	148.33	145.82	141.55	150.15
Outdoor Coverage Cell Raius [km]		3.25	2.71	2.92	2.47	1.86	3.29
Max Allowable Indoor Path Loss [dB]		139.93	137.23	138.33	135.82	131.55	140.15
Indoor Coverage Cell Raius [km]		1.20	1.00	1.08	0.91	0.69	1.22
Less than 50km/h							
Max Allowable Incar Path Loss [dB]		146.93	144.23	145.33	142.82	138.55	147.15
Incar Coverage Cell Raius [km]		2.66	2.22	2.39	2.02	1.52	2.70
Design threshold							
	Outdoor	131.93	126.23	127.33	124.82	120.55	124.15
	Indoor	121.93	116.23	117.33	114.82	110.55	114.15
	Incar	128.93	123.23	124.33	121.82	117.55	121.15

Table 8 Uplink Link budget calculation for the urban scenario.

Table-9 presents the summary result for the link budget output for AMR 12.2 (voice service). The single site area coverage is calculated based on three sectors cellular configuration and the equation to calculate area is given in equation -11. The total area for each scenario and the single site area is shown in the different column. The total site number from coverage dimensioning perspective is 605 sites.

Radius	0.3	0.5	1.8
Morphology	Dense Urban	Urban	Sub Urban

Morphology	Area [km ²]	Area Per site[km ²]	Number of site
Dense Urban	40.9	0.1755	233
Urban	215.4	0.702	307
Sub Urban	410.6	6.318	65
Total	666.9		605

Table 9 Link budget result & site density calculation

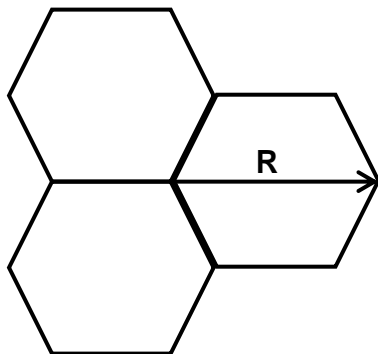


Figure 7 Three sectors cellular configuration [2]

$Area = 1.95 * R^2$

Equation 11

3.2 Capacity dimensioning

The capacity dimensioning is another vital part of the network planning process. The purpose of capacity dimensioning is to estimate the approximate base station number needed from the capacity perspective. Similar to the link budget, the capacity estimation should be performed from the uplink and downlink based on the traffic model and service traffic demand [18] [27] [8] [19].

There are multiple services in the UMTS network, their rates and required Eb/No are diversified, the effects on the system load and consumed base station resources are different, so the estimation of the cell capacity cannot adopt the method of estimating the cell capacity in a pure voice network. As a result of this, a special type of algorithm adopted from Huawei company is used for this design research. The algorithm took the throughput per carrier as an input from laboratory test result. The laboratory test objective is to measure how much throughput per single carrier can be obtained with specific sets of user equipment categories served at the same time. Similarly, the throughput per user is calculated based on the traffic model and the monthly data allowance per user. Finally, the total number of user that can be served by a single carrier is calculated comparing the throughput per user with the throughput per carrier [8] [19].

3.2.1 Capacity requirement analysis

For this design research, the capacity target along with the capacity distribution per sub city is taken as an input. And in the following few

paragraph, the capacity distribution will be presented taking the operator design document as a reference.

The UMTS capacity target for the year 2015-2018 is set according to the marketing analysis and it is estimated to be 1.5 million subscribers for Addis Ababa city. This figure as compared to the capacity back in the year 2013 is five times greater [19] [8].

The target subscriber is distributed per each sub-city based on eight different factors. The percentage share of each sub-city is calculated for each factor in a separate row. Based on the percentage share calculation the score for different sub city is calculated in such a way that the percentage share is weighted against the maximum percentage share.

The score calculated in Table-10 used in Tables 11 & 12 to divide the total subscriber into the ten sub-cities of Addis Ababa. In Tables 11 &12 each of the eight factors is assigned specific percentage weights depending on the importance of the factor in for the mobile customer base.

Factors		Akaki Kality	Nefas Silk Lafto	Kolfe Keraniyo	Gulele	Lideta	Kirkos	Arada	Addis Ketema	Yeka	Bole
Population	Population	201,216	351,086	476,089	297,073	223,908	245,578	234,774	283,472	384,810	342,996
	Percentage	7%	12%	16%	10%	7%	8%	8%	9%	13%	11%
	Score	42	74	100	62	47	52	49	60	81	72
Number of House Hold	No. of House Hold	55,662	91,646	114,977	73,239	54,695	64,420	58,421	61,613	106,727	93,427
	Percentage	7%	12%	15%	9%	7%	8%	8%	8%	14%	12%
	Score	48	80	100	64	48	56	51	54	93	81
Housing	Condo.	45,837	33,302	10,700	1,327	3,965	4,372	2,990	1,105	32,672	49,468
	Percentage	25%	18%	6%	1%	2%	2%	2%	1%	18%	27%
	Score	93	67	22	3	8	9	6	2	66	100
Education	Pri. & Sec. Schools	200	342	325	153	93	153	142	116	320	260
	Percentage	10%	16%	15%	7%	4%	7%	7%	6%	15%	12%
	Score	58	100	95	45	27	45	42	34	94	76
	Higher Education	9	13	12	11	14	27	30	5	19	23
	Percentage	6%	8%	7%	7%	9%	17%	18%	3%	12%	14%
	Score	30	43	40	37	47	90	100	17	63	77
Business	S & M Business	5,428	17,761	7,584	11,286	6,335	13,442	10,712	12,464	15,766	18,604
	Percentage	5%	15%	6%	9%	5%	11%	9%	10%	13%	16%
	Score	29	95	41	61	34	72	58	67	85	100
	Big Business	1,594	5,698	4,159	2,221	3,061	10,963	5,857	8,235	3,951	10,090
	Percentage	3%	10%	7%	4%	5%	20%	10%	15%	7%	18%
	Score	15	52	38	20	28	100	53	75	36	92
	Financial Intuitions	17	65	25	20	35	101	67	69	37	107
	Percentage	3%	12%	5%	4%	6%	19%	12%	13%	7%	20%
Score	16	61	23	19	33	94	63	64	35	100	

	Entertainment	8	8	15	19	17	20	33	19	23	16
	Percentage	4%	4%	8%	11%	10%	11%	19%	11%	13%	9%
	Score	24	24	45	58	52	61	100	58	70	48
Health	Hosp	3	1	2	4	5	7	9	3	6	10
	Percentage	6%	2%	4%	8%	10%	14%	18%	6%	12%	20%
	Score	30	10	20	40	50	70	90	30	60	100
	Clinics	48	92	113	47	55	111	77	72	103	92
	Percentage	6%	11%	14%	6%	7%	14%	10%	9%	13%	11%
	Score	42	81	100	42	49	98	68	64	91	81
Others	Diff. Org.	6	26	5	8	28	69	24	4	19	62
	Percentage	2%	10%	2%	3%	11%	27%	10%	2%	8%	25%
	Score	9	38	7	12	41	100	35	6	28	90
	NGO	157	74	17	137	61	29	34	31	14	8
	Percentage	28%	13%	3%	24%	11%	5%	6%	6%	2%	1%
	Score	100	47	11	87	39	18	22	20	9	5
Area in Sq.Km	Area	118	68	61	30	9	15	10	7	86	122
	Percentage	22%	13%	12%	6%	2%	3%	2%	1%	16%	23%
	Score	97	56	50	25	8	12	8	6	70	100

Table 10 Demand distribution per sub city [8] [19].

Demand Distribution for 3G Service																		
Rating Factors	Population		House Hold		Condo.		Education				Business							
							Primary & Secondary		Higher Education		Small & Medium Business		Big Business		Financial Instutions		Entertainment	
Weight	12%		5%		10%		2%		7%		8%		10%		10%		8%	
Sub City	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Bole	72	8.65	81	4.06	100	10.00	76	1.52	77	5.37	100	8.00	92	9.20	100	10.00	48	3.88
Kirkos	52	6.19	56	2.80	9	0.88	45	0.89	90	6.30	72	5.78	100	10.00	94	9.44	61	4.85
Arada	49	5.92	51	2.54	6	0.60	42	0.83	100	7.00	58	4.61	53	5.34	63	6.26	100	8.00
Nefas Silk Lafto	74	8.85	80	3.99	67	6.73	100	2.00	43	3.03	95	7.64	52	5.20	61	6.07	24	1.94
Yeka	81	9.70	93	4.64	66	6.60	94	1.87	63	4.43	85	6.78	36	3.60	35	3.46	70	5.58
Addis Ketema	60	7.15	54	2.68	2	0.22	34	0.68	17	1.17	67	5.36	75	7.51	64	6.45	58	4.61
Akaki Kality	42	5.07	48	2.42	93	9.27	58	1.17	30	2.10	29	2.33	15	1.45	16	1.59	24	1.94
Kolfe Keraniyo	100	12.00	100	5.00	22	2.16	95	1.90	40	2.80	41	3.26	38	3.79	23	2.34	45	3.64
Lideta	47	5.64	48	2.38	8	0.80	27	0.54	47	3.27	34	2.72	28	2.79	33	3.27	52	4.12
Gulele	62	7.49	64	3.18	3	0.27	45	0.89	37	2.57	61	4.85	20	2.03	19	1.87	58	4.61

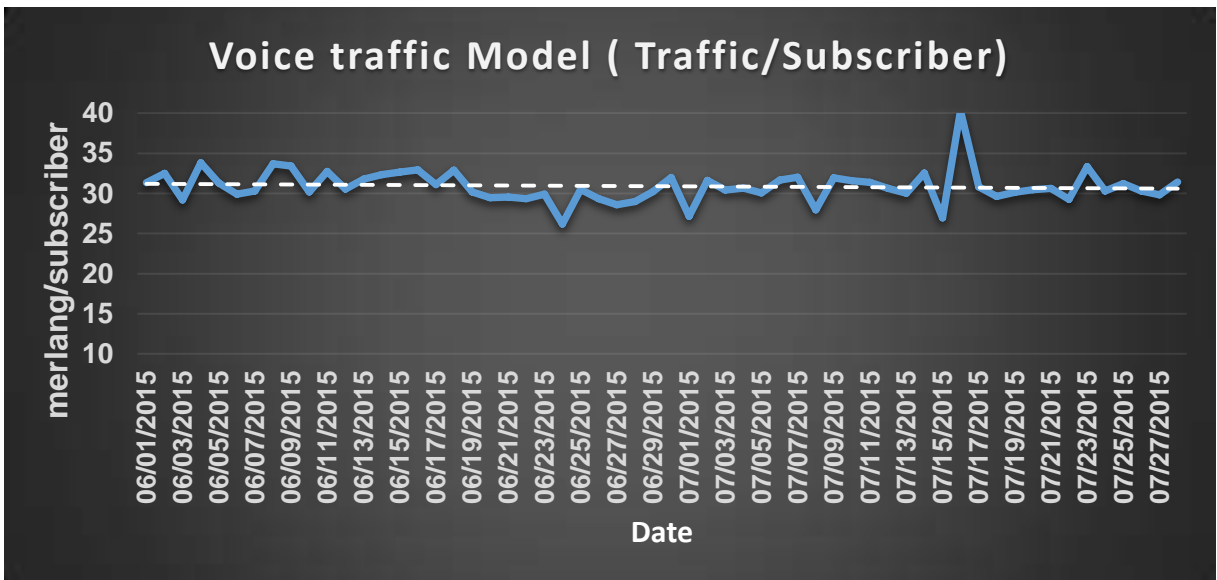
Table 11 Demand distribution for 3G service-1 [8] [19].

Demand Distribution for 3G Service													
Rating Factors	Health				Others				Area in Sq.km		Total Weighted Score	%ge of the total weight	Capacity Distrion (1.5Million)
	Hosp		Clinics		Diff.Org.		NGO						
Weight	3%		1%		9%		7%		8%				
Sub City	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score			
Bole	100	3.00	81	0.81	90	8.09	5	0.36	100	8.00	81	16%	238,566
Kirkos	70	2.10	98	0.98	100	9.00	18	1.29	12	0.96	61	12%	181,193
Arada	90	2.70	68	0.68	35	3.13	22	1.52	8	0.65	50	10%	146,734
Nefas Silk Lafto	10	0.30	81	0.81	38	3.39	47	3.30	56	4.48	58	11%	170,164
Yeka	60	1.80	91	0.91	28	2.48	9	0.62	70	5.63	58	11%	171,301
Addis Ketema	30	0.90	64	0.64	6	0.52	20	1.38	6	0.49	40	8%	117,154
Akaki Kality	30	0.90	42	0.42	9	0.78	100	7.00	97	7.74	44	9%	130,253
Kolfe Keraniyo	20	0.60	100	1.00	7	0.65	11	0.76	50	4.01	44	9%	129,445
Lideta	50	1.50	49	0.49	41	3.65	39	2.72	8	0.60	35	7%	101,701
Gulele	40	1.20	42	0.42	12	1.04	87	6.11	25	1.98	39	8%	113,489
											509	100%	1,500,000

Table 12 Demand distribution for 3G service -2 [19] [8].

3.2.2 Traffic modeling

The traffic model is prepared based on the operator business requirement and the current network data traffic pattern. The traffic statistics illustrated on the Graph-2 shows the voice traffic per subscriber characteristics of the network. The statistics are captured for two months from the operator operation support system and the value slightly fluctuates around 30 Mili Erlang /subscriber. Hence, for this design 30 Mili erlang per subscriber is considered for CS Voice traffic per subscriber value of the traffic model.



Graph 2 Voice traffic model (Voice traffic /subscriber) .

Table 13 summarizes all the traffic model parameters for both data and voice service. Some of the traffic model parameters are taken from network statistics and the rest assumed a value from the standard book.

Attribute	Proportion	Remark
CS Voice penetration ratio	100%	Activated for all user
CS Video penetration ratio	100%	Activated for all user
CS Voice traffic per sub(Erlg)	0.030	Network statistics
CS Video traffic per sub(Erlg)	0.002	
PS penetration ratio	100%	
Proportion of uplink PS throughput	22%	Network statistics
Proportion of downlink PS throughput	78%	Network statistics
R99 Share of DL PS throughput per sub	16%	Network statistics
HSDPA+ share of DL PS throughput per sub	84%	Network statistics
R99 share of UL PS throughput per sub	40%	Network statistics
HSUPA share of UL PS throughput per sub	60%	Network statistics
DL Load	90%	
UL Load	70%	

Table 13 Traffic model for capacity calculation.

3.2.3 Capacity dimensioning result

Table -14 shows how the data throughput per user at a busy hour is calculated from monthly data allowance. The monthly data allowance is specified based on the operator marketing analysis. Accordingly 10Gigabyte per month is set for data card users and 1Gigabyte per month is set for smartphone (SP) users. The percentage share of data card compared to smartphone user is 37% and this information is taken from the operator design document. The data rate per user at a busy hour is calculated based on equation-12.

$ \begin{aligned} & \text{Data Volume per month per user@BH[kbps]} \\ & = (\text{Data Volume per month per user[GByte]} \\ & \times \text{Busy hour ratio}[\%] \times 1024 \times 1024) / (30 \text{ days} \\ & \times 3600 \text{ Sec}) \end{aligned} $

Equation 12

The active user ratio represents the percentage of users which are actively using service. The active user ratio used in this design research is 70%. Similarly, the uplink to downlink data ratio is 70% and selected based

on the network statistics. At last, the data-Throughput per user calculated based on Equation-13 for uplink and downlink.

<p><i>DL Throughput per user@BH [kbps]</i> <i>= Active user Data Volume per user@BH[kbps] × 70%</i></p> <p><i>UL Throughput per user@BH[kbps]</i> <i>= Active user Data Volume per user@Bh[kbps] × 30%</i></p>	Equation 13
--	-------------

Type	Data Dongle	Data SP
Data per month (GB)	10	1
Proportion (%)	37%	63%
Data Volume per month per user	3.7	0.63
Data Volume per month per user (GB)	4.33	
Busy hour ratio(%)	10%	
Data Volume per month per user@BH (kbps)	33.88	
Active user ratio(%)	70%	
Active user Data volume per user@BH(kbps)	33.88	
DL/UL Ratio	70%	
DL Throughput per user @BH (kbps)	23.68	
UL Throughput per user @BH (kbps)	10.20	

Table 14 Throughput per user at busy hour calculation.

The dimensioning result summary in Table-15 shows the number of user per carrier. The number of user per carrier described into two columns in Table-15. The first column represents the number of active subscribers served by a single carrier whereas the second column represents the total subscriber including the active and non-active subscriber. To calculate the total subscriber, an active user ratio of 70% is considered.

According to orange telecom laboratory test	
DL Throughput per cell (Mbps)	3.60
UL Throughput per cell (Mbps)	1.90

	Active Subs/Cell	Total Subs/Cell
DL User per carrier (User)	155.67	222.39
UL User per carrier (user)	190.80	272.57

Table 15 Number of user per carrier result.

Considering the capacity distribution result on table-12, the number of carrier per each sub-cities is calculated by dividing target subscriber number with subscriber per carrier calculated in Table-15.

Sub City	Forecasted 3G Subscribers	Number of carriers
Bole	238,566	962
Kirkos	181,193	731
Yeka	171,301	691
Arada	146,734	592
Nefas Silk Lafto	170,164	686
Kolfe Keraniyo	129,445	522
Addis Ketema	117,154	472
Akaki Kality	130,253	525
Gulele	113,489	458
Lideta	101,701	410
Total	1,500,000	6048

Table 16 carrier distribution per each sub-cities.

3.3 Single site CE dimensioning

3.3.1 CE calculation algorithm

The diagram in Figure-8 explains the calculation flowchart for the number of a channel element in a single Base station. Overall there are four computational-branches in the iterative process, beginning with calculating

average channel-element requirement for Circuit switching (CS) service and finishing with calculating channel element for High-Speed Packet Access (HSPA) service. The calculation at each block represents the calculation of channel element for both uplink and downlink direction. Combining these branches gives the channel element requirement per single Base station. Combining the four branches involves equation-14 and equation-15 for uplink and downlink direction respectively. In general, little modification is introduced to the original algorithm. The major modification introduced is on the subscribers per NodeB value and the data throughput consideration. In the original algorithm, these values are iteratively tradeoff whereas on the modified version which is used in this research the number of subscribers is fixed based on capacity dimensioning output and also the throughput is set to a reasonable value and the number of Channel Element (CE) is calculated with the same formula.

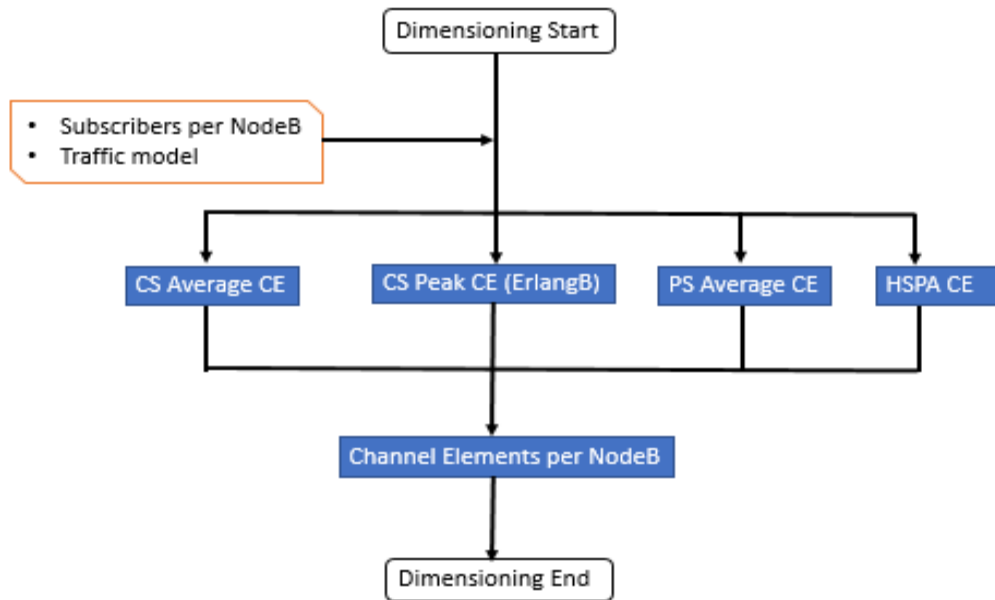


Figure 8 Channel element dimensioning algorithm

$$CE_{ULTotal} = \text{Max}(CE_{CSPeakUL}, CE_{CSAverageUL} + CE_{PSUL} + CE_{AUL} + CE_{HSUPA})$$

Equation 14

$$CE_{DLTotal} = \text{Max}(CE_{CSpeakDL}, CE_{CSAverageDL} + CE_{PSDL} + CE_{ADL})$$

Equation 15

Going into the details, The average channel element number for CS service is calculated based on Equation 14. And the values for the soft handover factor and the CE consumption for CS service is specified in the traffic model. The traffic per NodeB calculation is done base on Equation 17 and the number of user per node in Equation 17 is taken from the capacity dimensioning output. But for Huawei Company proprietary algorithm the

number of user per NodeB is an assumed value at the beginning of the iteration process in Figure-8.

$$CS_{AverageCE} = Roundup(Traffic\ per\ NodeB \times (1 + SoftHoFactor)) \times CE\ Consumption$$

Equation 16

Similarly, the average channel element number for PS service is calculated based on Equations 18 & 19. The burst rate, the soft handover factor, and the CE consumption is the values specified in the traffic model. The PS traffic per NodeB is calculated based on the capacity dimensioning result. On top of this, the retransmission rate and CE utilization rate is the service characteristics values which are referred from standard books.

$$PS_{AverageCE} = Roundup(TrafficPerNodeB \times (1 + BurstRate) \times (1 + SoftHOFactor) \times CEConsumption)$$

Equation 17

$$PSTrafficPerNodeB(Erlang) = NumOfUser \times \frac{TrafficVolumePerUser \times (1 + RetransmissionRate)}{TypicalRate \times CEUtilizationRate \times 3600}$$

Equation 18

The average channel element number of HSDPA service follows the same calculation pattern and given in Equation 20 & 21.

$$DLHSDPACE = NumOfHSPAUser \times CEConsumption$$

Equation 19

$$\begin{aligned}
 & \text{NumOfHSPAUser} \\
 & = \text{RoundDown}(\text{NumOfUserPerNodeB} \\
 & \quad \text{TrafficVolPerUser} \times (1 + \text{HSPA Retransmission}) \times \\
 & \quad (1 + \text{HSPABurstRate}) \\
 & \times \frac{\quad}{\text{TargetRate} \times 3600}
 \end{aligned}$$

Equation 20

The calculation for CS peak connection is different from the other three methods of calculations shown in the above paragraph. The CS peak connection is calculated based on the ErlangB table taking average traffic and the GoS into consideration. The formula is shown in Equation 22.

$$\begin{aligned}
 & \text{CS Peak Connection} \\
 & = \text{ErlangB}(\text{AverageTraffic} \\
 & \quad \times (1 + \text{SoftHOFactor}), \text{GoS})
 \end{aligned}$$

Equation 21

3.3.2 Traffic model

Tables 17 and 18 illustrate the basic traffic model parameters useful for channel element calculation. Table-17 in particular shows served traffic per each radio bearers. The served traffic per each bearer is prepared based on two-month network traffic statistics taken from the operator live network. In addition to this, the grade of service assumed in this design, 2% is almost a standard.

Service	Unit	DL	UL	GoS
AMR 12.2k	Erlang	0.03	0.03	2%
CS64k	Erlang	0.02	0.02	2%
PS64k /64k	Kbit	472.69	15157.1	
PS128k/128k	kbit	5974.4	9458.7	
PS 144k/144k	Kbit	2635.01	5420.2	
PS 256k/256k	Kbit	723.13	7600.6	
PS384k/384K	kbit	1381.44	15970.6	
HSDPA/HSUPA	kbit	471107.7	78765.6	

Table 17 Traffic model-1.

In table-18, the values specified for subscribers number per base station is calculated based on the site configuration. The basic result taken from the capacity dimensioning is the subscriber number per carrier. In this regard, the number of the carrier corresponding to each set of configuration is multiplied with the subscriber per carrier value to calculate the total subscriber number per base station. The other parameters like R99 PS traffic burst, Retransmission rate and overhead of soft handover is the service characteristics parameters which are specified in standard references.

Attribute	Value
Subscribers number per Base station(U222)	1488
Subscribers number per Base station (U333)	2232
Subscribers number per Base station (U444)	2976
Overhead of SHO	30%
R99 PS traffic burst	20%
Retransmission rate of R99 PS	5%
PS Channel element utilization rate	0.7
Average throughput requirement per user of HSDPA	600 kbps
HSDPA traffic burst	25%
Retransmission rate of HSDPA	10%

Table 18 Traffic model -2.

3.3.3 CE dimensioning result

The CE calculation has two stages, the first stage is calculating the average CE number and the CS peak connection number. And the second

stage is to compare the summation of the average CE for all the bearer service to that of the CS peak CE number required and finally take the maximum of the two result.

The CE calculation is summarized and presented on Tables-19-20-21-22.

Site Configuration U222				
Bearer Types	Traffic Per Base station(Erlang)		Average # CE	
	UL	DL	UL	DL
AMR 12.2k	44.64	44.64	59	59
CS64k	29.76	29.76	117	78
PS64k /64k	146.83	4.58	529	11
PS128k/128k	45.82	28.94	275	139
PS 144k/144k	23.34	11.35	141	55
PS 256k/256k	18.41	1.75	221	17
PS384k/384K	25.79	2.23	310	22
HSDPA/HSUPA				446
Site Configuration U333				
Bearer Types	Traffic Per Base station (Erlang)		Average # CE	
	UL	DL	UL	DL
AMR 12.2k	66.96	66.96	88	88
CS64k	44.64	44.64	175	117
PS64k /64k	220.25	6.87	793	17
PS128k/128k	68.72	43.41	413	209
PS 144k/144k	35.01	17.02	211	82
PS 256k/256k	27.61	2.63	332	26
PS384k/384K	38.68	3.35	465	33
HSDPA/HSUPA				669
Site Configuration U444				
Bearer Types	Traffic Per Base station (Erlang)		Average # CE	
	UL	DL	UL	DL
AMR 12.2k	89.28	89.28	117	117
CS64k	59.52	59.52	233	155
PS64k /64k	293.67	9.16	1058	22
PS128k/128k	91.63	57.88	550	278
PS 144k/144k	46.67	22.69	281	109
PS 256k/256k	36.82	3.50	442	34
PS384k/384K	51.57	4.46	619	43
HSDPA/HSUPA				892

Table 19 Channel element calculation -1.

Configuration	# user per Base station	# HSDPA User	# HSDPA CE
U222	1488	1	1
U333	2232	1	1
U444	2976	2	2

Table 20 Channel element calculation -2.

Configuration	# User per Base station	CS12.2 peak connection	#CS 12.2 Peak CE		CS 64 peak connection	#CS 64 Peak CE	
			UL	DL		UL	DL
U222	1488	69	58.03	58.03	49	38.69	38.69
U333	2232	100	87.05	87.05	69	58.03	58.03
U444	2976	129	116.06	116.06	90	77.38	77.38

Table 21 Channel element calculation -3.

Configuration	CS Peak CE		Average CE		Max CE		WBBP board
	UL	DL	UL	DL	UL	DL	
U222	216	167	1652	827	1652	827	WBBPb4(5)
U333	309	307	2477	1241	2477	1241	WBBPb4(6)
U444	399	309	3300	1650	3300	1650	WBBPb4(6)

Table 22 Channel element calculation -4.

3.4 Site Layout design

It is true that the spatial location of the site impacts the coverage and service performance of that particular site. In this regard, it is worth highlighting the fact that site layout design here in this section is only referred to the nominal site location design. Furthermore, the site layout decided in this section will be further optimized in the detailed planning using path loss based prediction result.

The site layout design considers the preexisting site location as the first choice and down the line site location based on hexagonal cell structure

along with clutter information will be used to place the site. Accordingly the site layout design result is presented as follow.

Figure -9 shows the distribution of sites back in the year 2013. The site design output depicted on Figure-10 follows the site distribution in Figure-9. Since there are more sites in the current design than the sites back in the year 2013 the addition sites are distributed following hexagonal cellular layout. Of course, there is some optimization done based on the coverage prediction result.

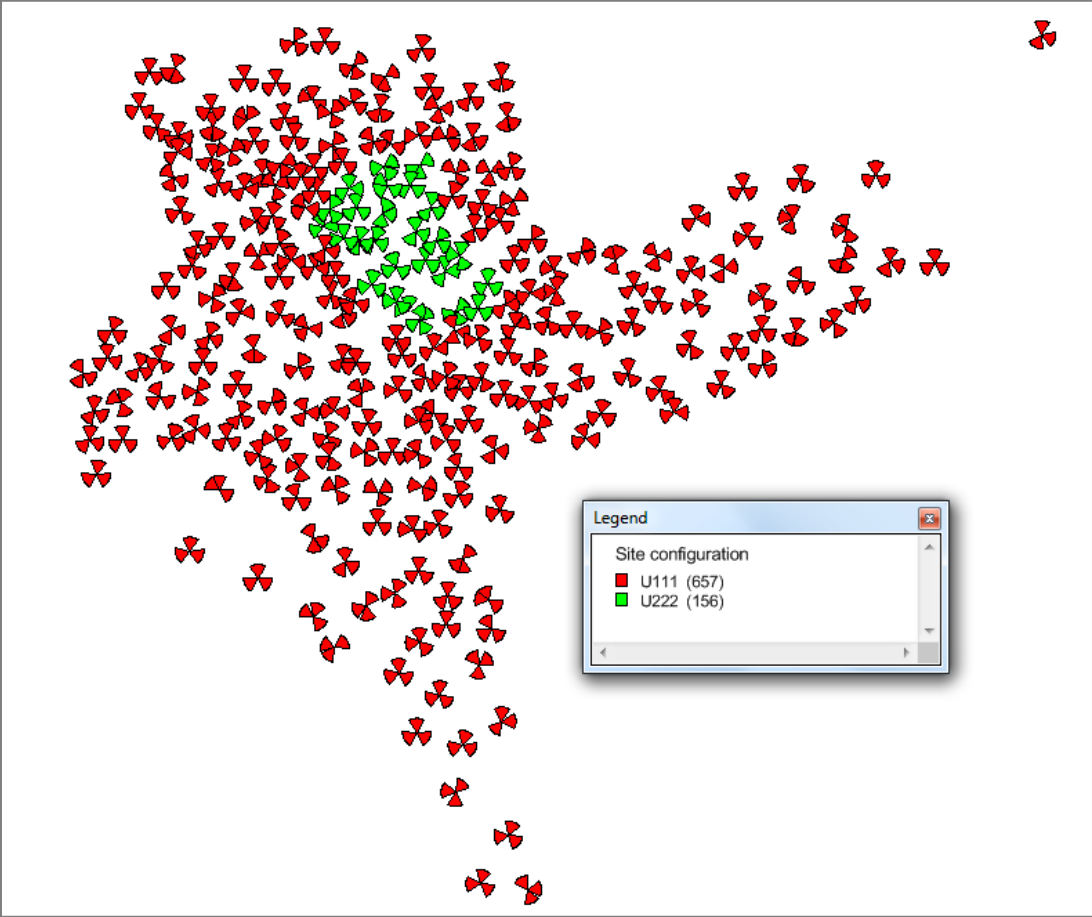


Figure 9 UMTS site distribution back in the year 2013.

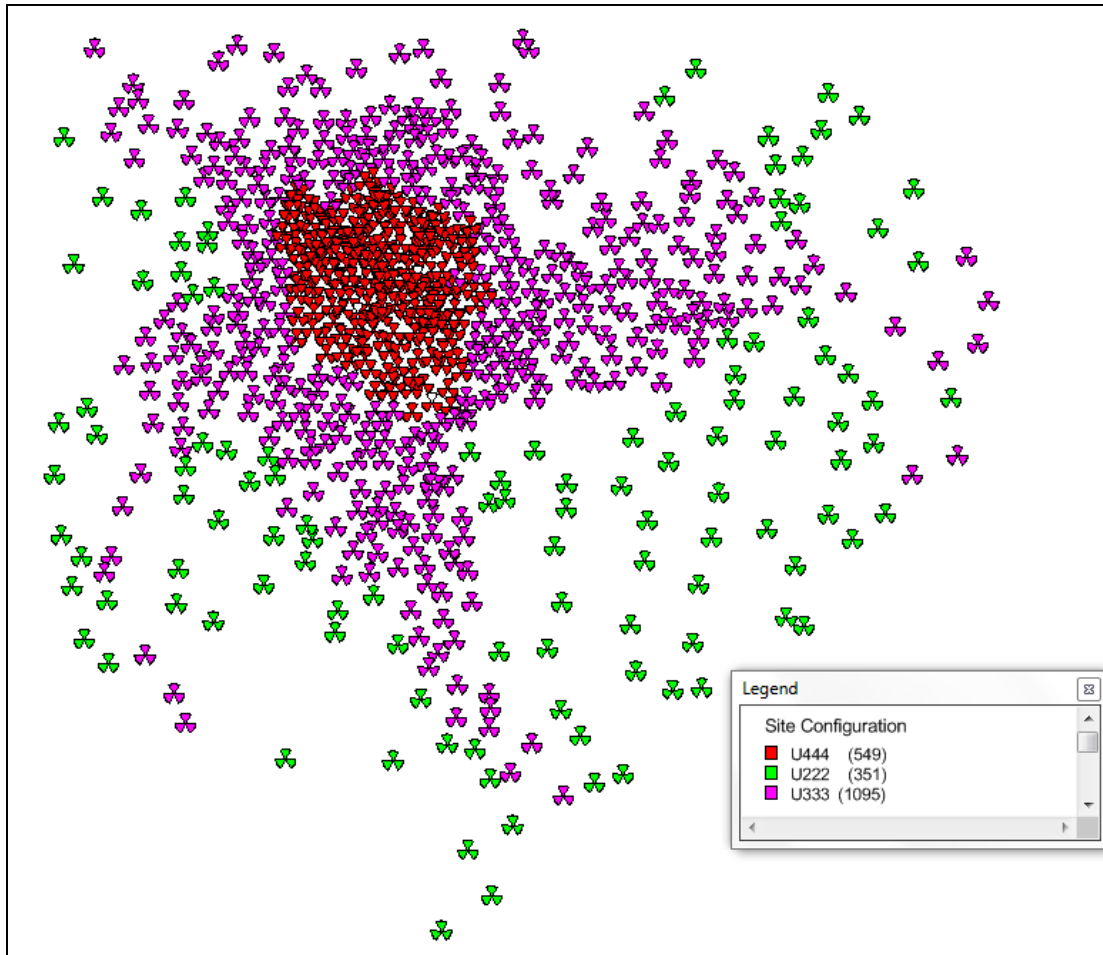


Figure 10 site layout design.

3.5 Primary Scrambling Code planning

Each sector in UMTS system has its unique code named Scrambling Code (SC). In the downlink direction, scrambling code is used to distinguish each sector and in the UL direction, scrambling code is used to distinguish each user equipment (UE). User equipment detects downlink scrambling code using cell search procedure after slot and frame synchronization process. In the downlink, there are 512 Primary Scrambling Code (PSC) that

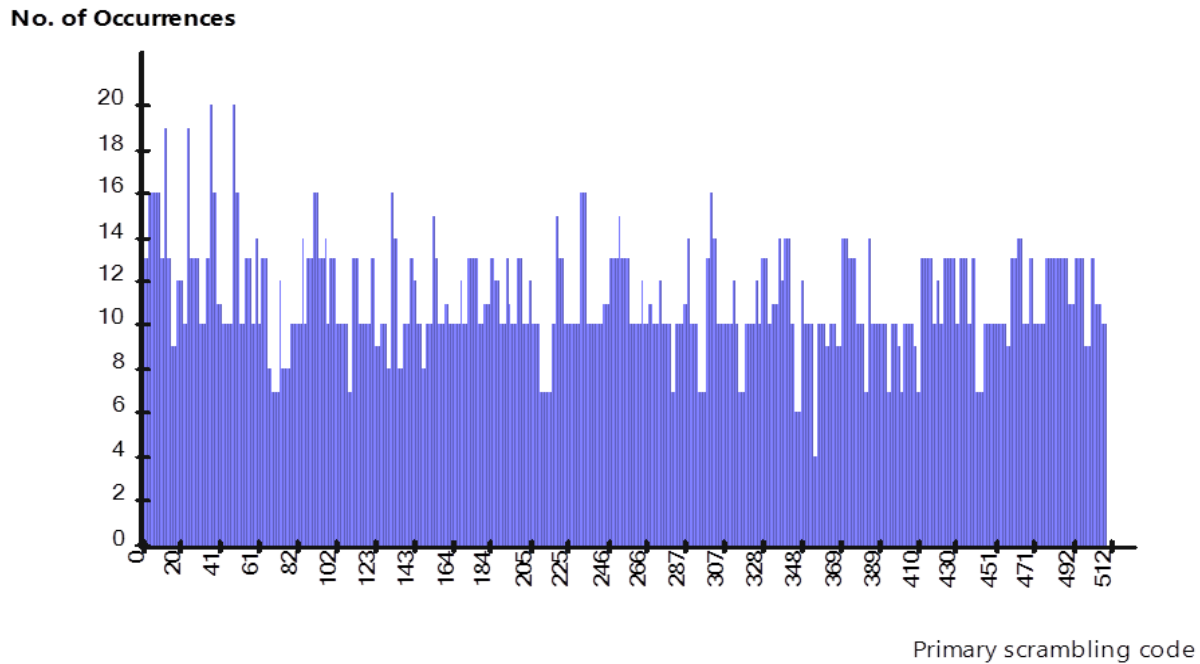
can be used in the network. The 512 primary scrambling codes are divided into 64 scrambling code Groups and each cell is allocated one primary scrambling code. Assigning such a code set to each sector should be carefully planned with a standard planning tool, because the number of cells in a UMTS network is usually much larger than the number of code sets, which is 512, and simultaneous use of the same code set for different sectors may cause scrambling code confusion [2] [13].

The scrambling code planning in this research is done automatically using Radio Network Planning tool (RNP). RNP tools provide a mapping tool based on an algorithm that takes into account the definition of groups and code domains, as well as additional restrictions based on the list of neighboring cells, second neighboring cells, criteria and minimum distance pairs exceptional.

Restrictions	Description	Value
Existing Neighbors	Using the table of neighborhoods, a cell can not have the same scrambling code to its neighboring cells, and between all codes must be different	16
Second Neighbors	The first restriction spreads to neighboring cells to their neighbors	20
Ec / Io conditions	All stations belonging to the active set of the reference cell in the area where it provides the best signal, they must have different codes	5dB
Reuse Distance	Minimum distance from which codes can be reused	10Km

Table 23 criteria for automatic primary scrambling code planning

The code groups and domains used for automatics code allocation is arranged in such a way that there are 150 groups and 3 codes in each group. For each code group, sequential code area assigned beginning from code number 4 and ends with 450.



Graph 3 Allocation of randomization codes for UMTS network.

Atoll generates statistics that show the number of times the algorithm has assigned a specific code. As it is shown in the Graph -3 a single code is assigned 10 times on average. And it is assigned 20 times maximum.

3.6 Coverage prediction

There are two fundamental approaches to do detail planning for UMTS radio access technology. These are the path loss-based approach and the simulation-based approach. The path loss-based approach is the simplest

and widely used in the industry. The path loss-based approach requires standard planning tools capable of calculating path loss and displaying areas where specific path loss thresholds are exceeded. The planning tool makes use of the digital description of the geographical environment in terms of the digital map. This information allows the transmitter to be placed at desired locations on the digital map, and to visualize the areas in which the signal reception can be observed. Those geographical data also contain crucial information to predict the radio-wave propagation in the area [15] [24].

For this design research, the radio planning software from Forsk Company is used for coverage prediction. The software is called ATOLL wireless network engineering software. To do the coverage prediction two sets of the digital map is used; one with 5-meter resolution and the other with 50-meter resolution. The 5-meter resolution map covers an area of 418.3 square kilometers while 50-meter resolution map covers the whole Ethiopia.

3.6.1 Propagation model tuning

Many commercially available radio planning tools sold out with standard propagation models package. Additionally, they have the option to import external propagation prediction models. And many of the standard propagation models used in cellular network planning are typically based on the Okumura-Hata formulas. For a given frequency band, the Okumura-Hata formulas are a simple function of distance, but the effect of the digital map is included by adding antenna height diffraction and clutter correction into the basic Okumura-Hata loss. The exact implementation of the antenna height,

diffraction and clutter correction, as well as another possible adjustment, varies from one planning tool to another [15] [24].

One of the important stages of using planning tools is selecting an accurate model for propagation losses calculation. There are two strategies for selecting propagation losses, one is to derive an empirical propagation model from measurement data and the other is to use a deterministic propagation model. In this design research, empirical propagation model called Standard Propagation Model (SPM) is used. The standard propagation model is used in many planning tools such as ATOLL, Asset, and Mentum Planet for several wireless telecommunication standard.

Standard propagation model (SPM) is based on Okumura-Hata models which support frequencies higher than 1500 MHz. The underlying formula for SPM model is given by Equation–23.

$$L_{model} = K_1 + K_2 \log(d) + K_3 \log(H_b) + K_4$$

$$* \text{Diffraction loss} + K_5(\log(d)$$

$$* \log H_b) + K_6 H_m + K_{clutter} f_{clutter}$$

Equation 22

Where ,

- K_1 frequency constant (dB)
- K_2 distance attenuation constant
- d distance between the receiver and transmitter(m)
- K_3, k_4 correction coefficient of height of mobile station antenna
- Diffraction loss due to diffraction over an obstructed path (dB)
- K_5, K_6 correction coefficient of height of base station antenna
- $K_{cluster}$ correction coefficient of clutter attenuation,
- H_b effective height of base station
- H_m effective height of mobile station

For this research, the standard propagation model is tuned based on continuous wave (CW) measurement data that ethio telecom uses to tune the propagation model currently in use in the company. The CW measurement data is collected for transmitter points located in five different locations. The transmitter location and their configuration are illustrated in Table –17.

Transmitter location	EIRP 1950(dBm)	Antenna Height(m)
Addis Ababa University	40	36.2
Bible School	40	26.5
Commerce	40	38.5
Merkato	40	21.7
Sheraton Addis	40	40 m

Table 24 transmitter location and their configuration.

The objective of the model tuning activity is three-fold, first is to determine model parameters in accordance with the realistic propagation effect existing within selected coverage area, the second is to minimize the standard deviation error and the third is to make sure calibrated model correspond well with the collected data. ATOLL has automatic model tuning wizard that can be used to tune the model based on the given CW measurement data. Accordingly the standard propagation model is tuned and the resulting model parameters are illustrated in Table 18.

The correction made on the model parameters after model tuning is of two types the first is the effective antenna height correction on the mobile and

base station antenna and the second is the correction on clutter losses. The clutter loss is illustrated for each clutter type in the digital map.

Parameter	Description	Before	After
H_m	the effective height of antenna above mobile station	Height above average profile	Height above average profile
Diffraction loss	loss due to diffraction over an obstructed path	Deygout with correction(ITU 526-5	Deygout with correction(ITU 526-5
K1 (LoS)	frequency constant when Tx – Rx is in the line of sight	21.4	19.4
K1 (NLoS)		57.8	55.8
K2 (LoS)	Log(d)	41.6	41.6
K2 (NLoS)	Log(d)	29.9	29.9
K3	Log(H_{Tx})	-20	-20
K4	Diffraction	0.188	0.188
K5	Log(d)*Log(H_m)	-0.8	-0.8
K6	H_m	0	0
K7	Log(H_b)	0	0
1-open	Clutter Losses	13.8	13.8
2-sea	Clutter Losses	0	0
3-inland_water	Clutter Losses	0	0
4-mean_individual	Clutter Losses	17.8	17.8
5-mean_collective	Clutter Losses	20	20
6-dense_collective	Clutter Losses	0	0
7-building	Clutter Losses	0	0
8-village	Clutter Losses	0	0
9-industrial	Clutter Losses	13.8	13.8
10-open in urban	Clutter Losses	5.09	5.09
11-forest	Clutter Losses	19.3	19.3
12-park	Clutter Losses	0	0
13-dense_individual	Clutter Losses	19.1	19.1
14-block building	Clutter Losses	0	0
15-old town	Clutter Losses	0	0
16-scattered urban	Clutter Losses	0	0
17-agriculture	Clutter Losses	0	0
18-swmp	Clutter Losses	0	0
19-chott sebkha	Clutter Losses	0	0
20-airport	Clutter Losses	0	0
21-airport facilities	Clutter Losses	0	0

Table 25 propagation model parameters before and after model tuning.

The result in the Table -19 is used to present the performance of the tuned model prediction as compared to the model prediction before tuning in terms of statistical measures. For instance, the mean error indicates the average error in prediction using the tuned model and the model before turning. And as it is shown in the table the prediction error is reduced to zero value after the model is tuned.

Statistics Attribute	Before	After
Root mean square	10.955	9.725
Mean error	0.32	0
Standard deviation	10.95	9.725

Table 26 Model tuning result statistics.

3.6.2 Pilot coverage prediction result

A signal level coverage prediction estimates the received signal of the best server for each pixel of the area studied. To compute the best-received signal from the transmitter, the highest transmitter power of the carriers is taken in into consideration. The coverage prediction plot in Figure-9 is generated using radio planning tool.

The picture in Figure-9 illustrates pilot coverage plot based on five discrete signal ranges. Each color represents the received signal level range at the different geographic location. The best signal level range is depicted by red color while the poor signal level is depicted with dark blue color. Almost all the areas located in the city center is covered with the best signal (pilot power >-80dBm).

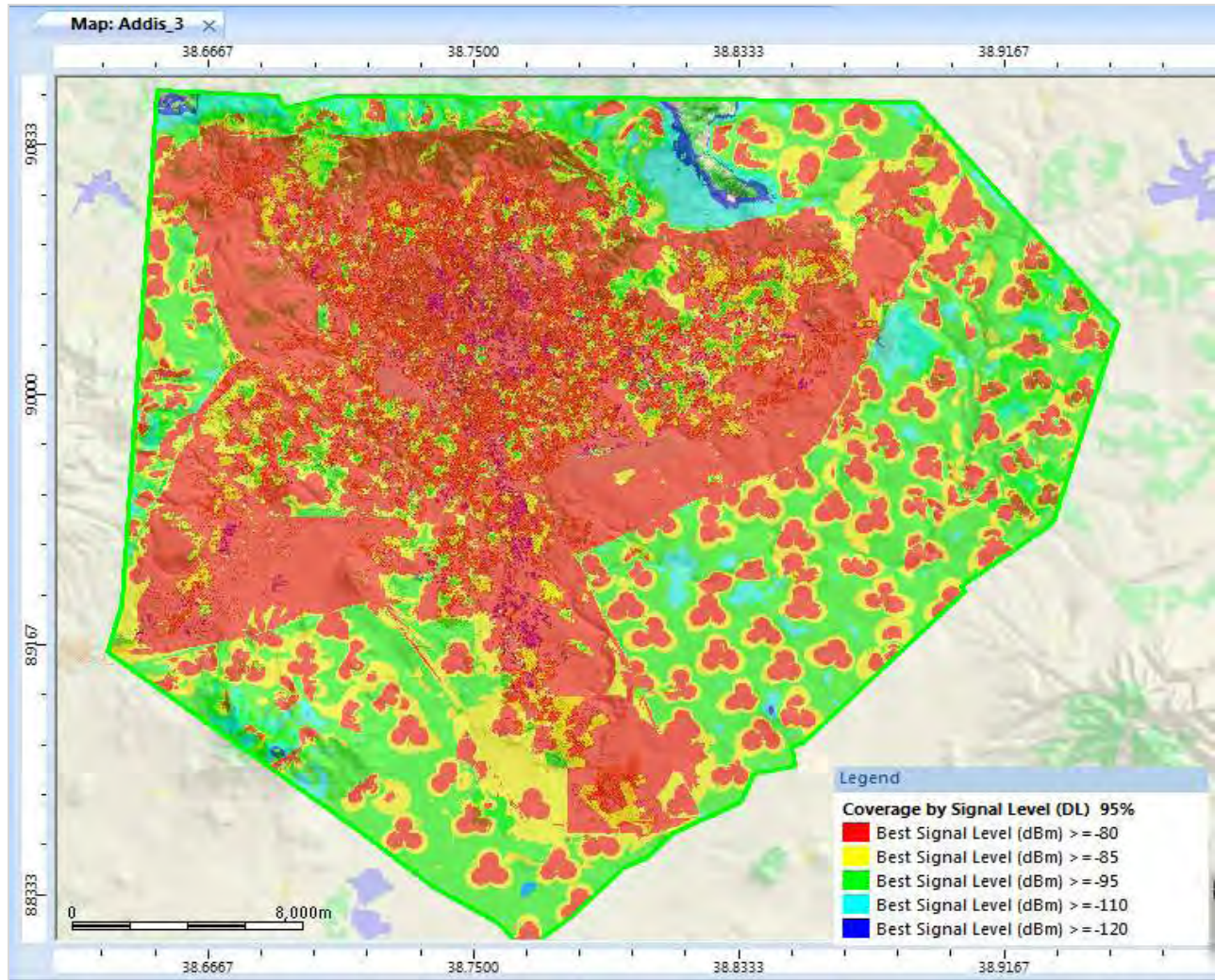
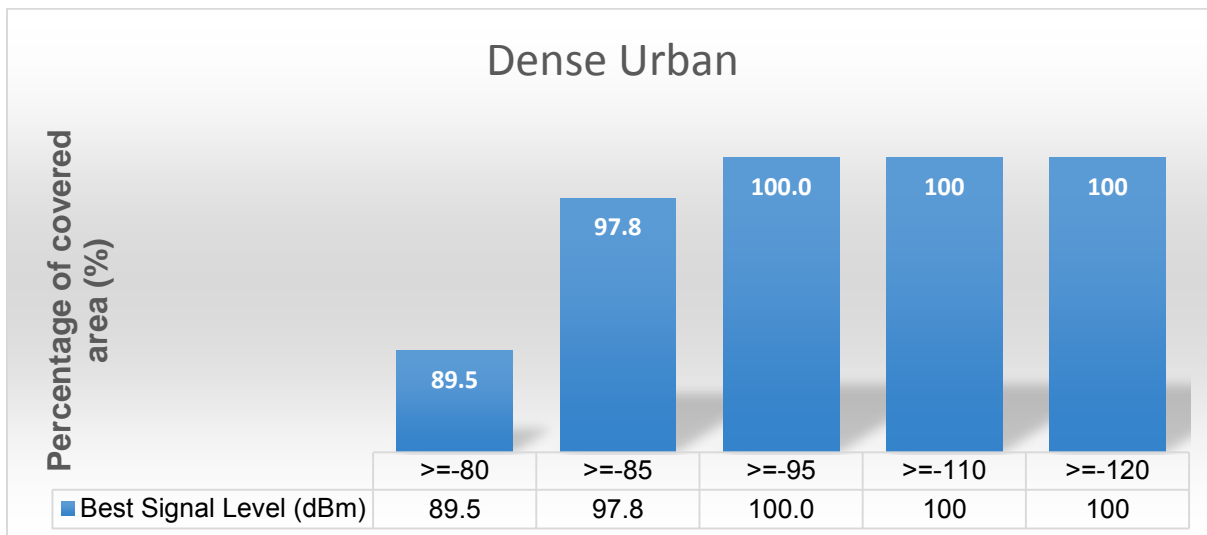


Figure 11 Coverage plot by signal level for cell edge coverage probability of 95%.

The main purpose of the coverage prediction is to verify whether the coverage requirement is met or not. Table-5 in the coverage requirement analysis section of this document, specifies the signal coverage probability for each propagation scenario. In order to verify the result, the statistical summary result for each propagation scenario is plotted into coverage distribution graph.

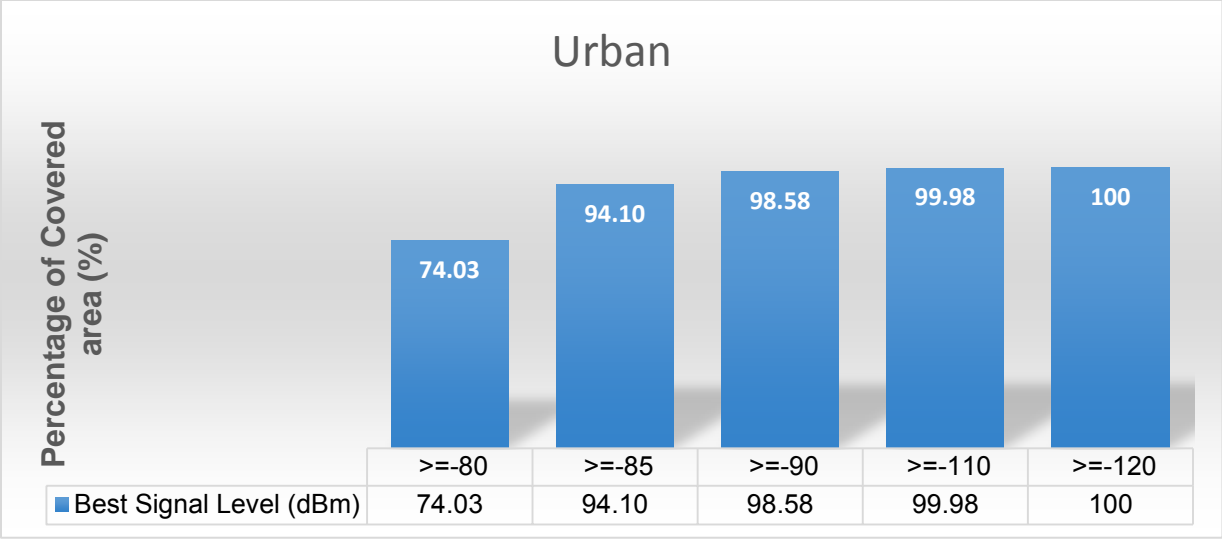
The bar graph in Graph-3 provides information about coverage statistics summary for dense urban propagation scenario. The bar graph gives figures for the percentage area for each signal ranges.

According to the result, about 97.8 % of the target area is covered with a signal level greater than or equal to -85 dBm. Hence based on this observation, it can be concluded that the coverage requirement for the dense urban scenario met the target.



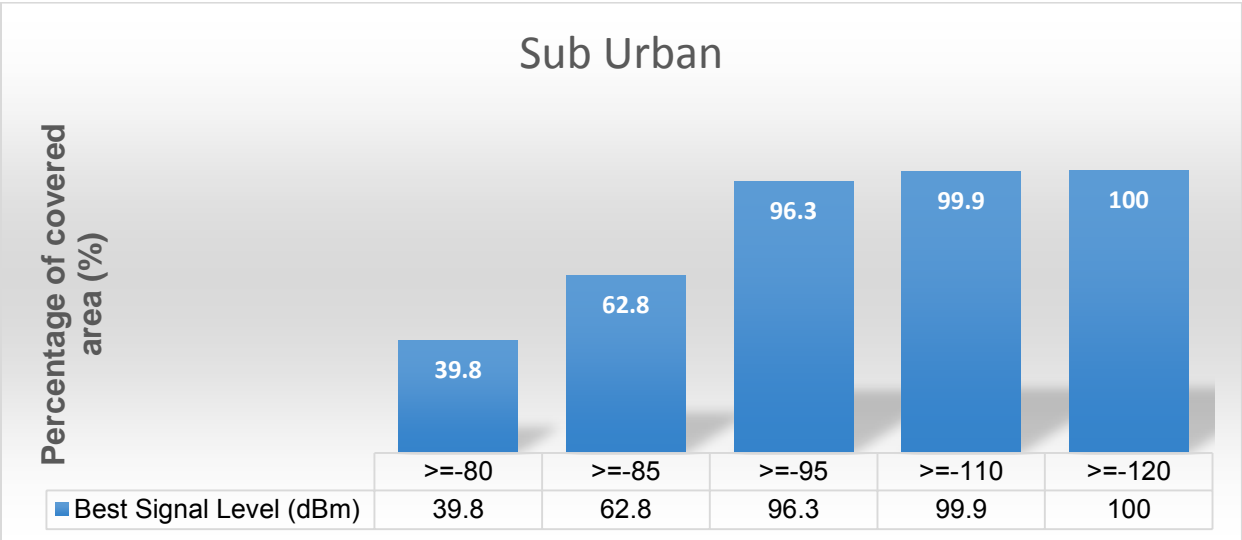
Graph 4 Pilot power coverage distribution for Dense Urban Morphology.

Similarly, Graph-4 illustrate the coverage statistics summary for urban propagation scenario. The graph shows that 98.58% of the urban area is covered with a signal level greater or equal to -90dBm. And this result is in accordance with the coverage target set for the urban scenario, which is 95% for signal coverage >=-90dBm.



Graph 5 Pilot power coverage distribution for Urban Morphology.

The coverage target set for the suburban scenario is 95% for signal coverage greater or equal to -95dBm. As it is shown on the graph 96.3 % of the suburban area is covered with a signal level greater or equal to -95dBm. Hence, it can be concluded that the signal coverage for all the three scenarios met the coverage target.



Graph 6 Pilot power coverage distribution for Sub-Urban Morphology.

3.6.3 Overlapping zone analysis

The overlapping zones are computed based on coverage prediction for the best serving cells and for the cells within predefined windows of coverage margin. Overlapping zones defined in terms of pixels that are covered by the signal of at least two transmitters. Accordingly the overlapping zones prediction is done for predefined windows of coverage margin,6dB. These coverage margins are selected to align the overlapping zone analysis with pilot pollution. Pilot pollution is the phenomena where the number of strong cells exceeds the active set size. This phenomenon leads to poor coverage and needs to be optimized.

The picture in Figure -10 is generated using the planning tool. The picture shows the number of best-serving cell distribution for each pixel within the coverage area. By definition, the best serving cell is the cell from which the strongest pilot signal is received at a particular pixel. With the same token, the pilot signal power received from different cells at a particular pixel is ranked based on signal strength and then cells for which their pilot power strength is within 6dB window in reference to the strongest signal are considered as best serving cells.

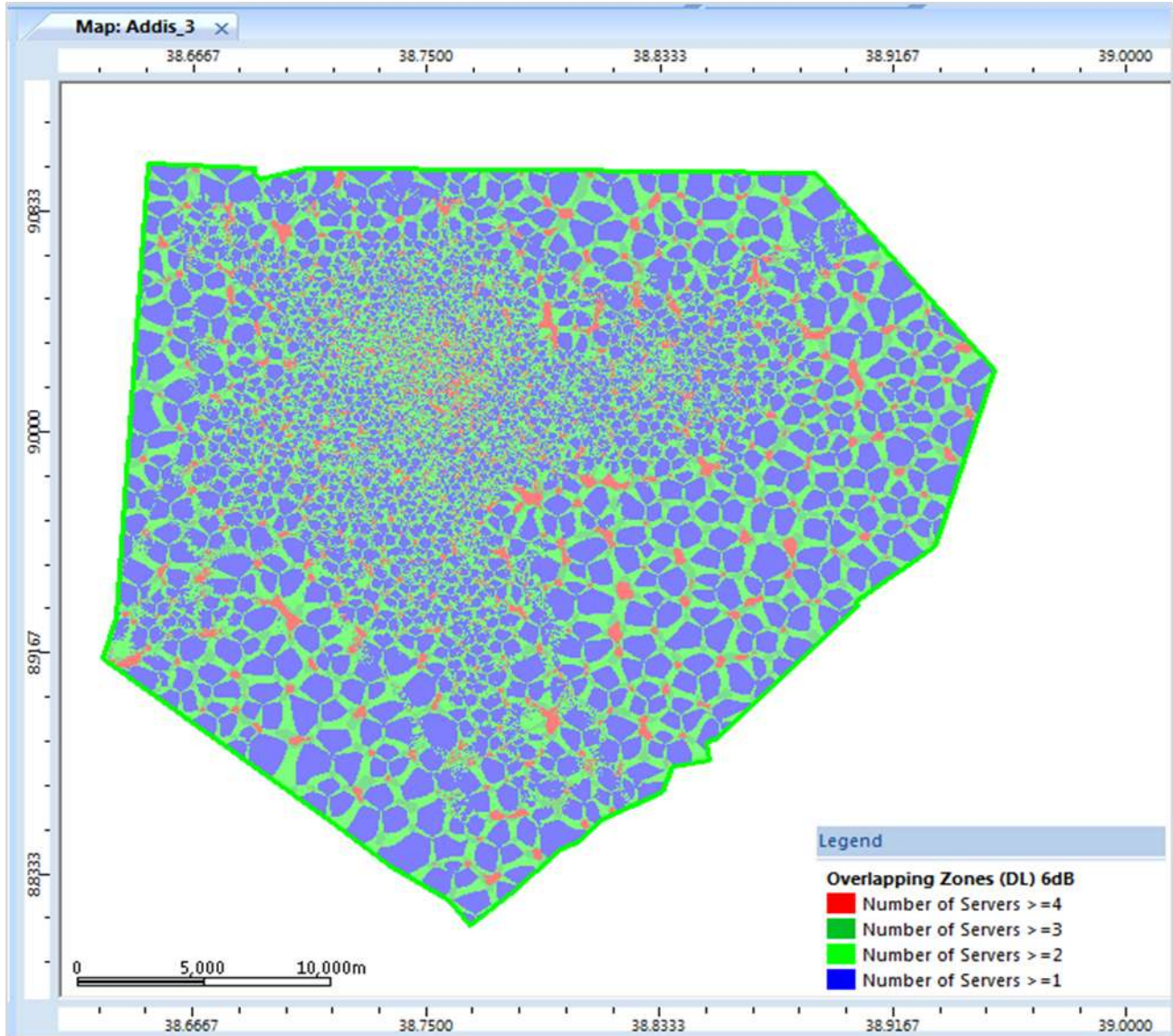


Figure 12 Overlapping zone with 6dB coverage windows margin.

Generally, it is good idea to maintain less than or equal to 3 best serving cell for each pixel. But for the city like Addis where frequent power interruption exists it is recommended to leave the reasonable overlapping region. In this regard the result in Figure-10 shows, there is reasonable areas

where there is more than 4 best-serving cell and it is recommended to leave it as it is.

3.7 Capacity simulation analysis

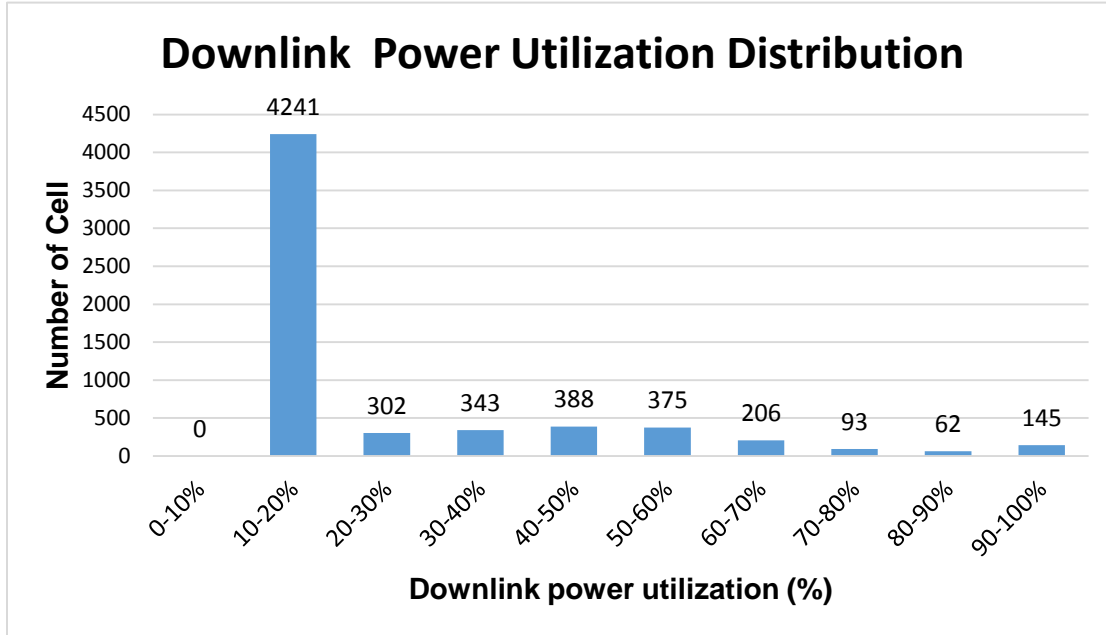
5.7.1 Downlink Load Analysis

The downlink load analysis is done in terms of the transmit power utilization of the cell. Each cell has the maximum power resource of 20W and this resource is divided into traffic channel and control channel. For downlink load calculation the power utilization of the traffic channel is used.

The bar chart in Graph-6 illustrates the number of cell distribution with different downlink power utilization range. There are around 145 cells with power utilization greater than 90%. And almost all other cells have less than 90% power utilization.

90% is the default threshold value set for call admission control policy based on downlink transmitter power resource. Consequently, there will be

call blocking for the 145 cells with power utilization greater than 90%.

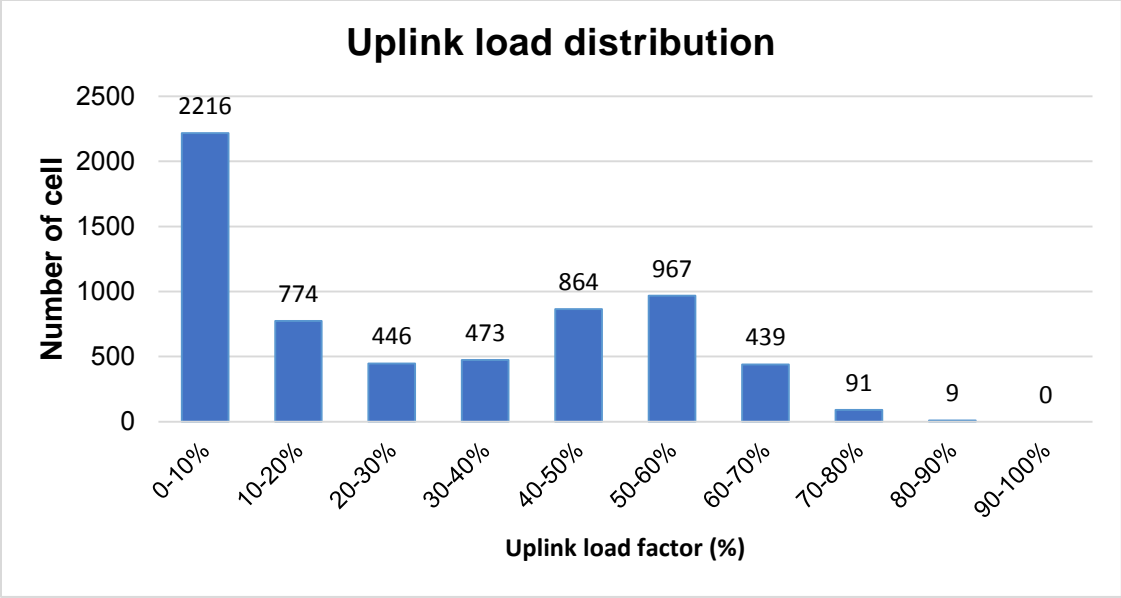


Graph 7 Downlink power utilization distribution.

5.7.2 Uplink load analysis

The uplink direction for code division multiple access (CDMA) cellular radio systems is often interference limited. The interference originates from users that establish an active radio link. The uplink cell load factor corresponds to the ratio between the uplink total interference and the uplink total noise.

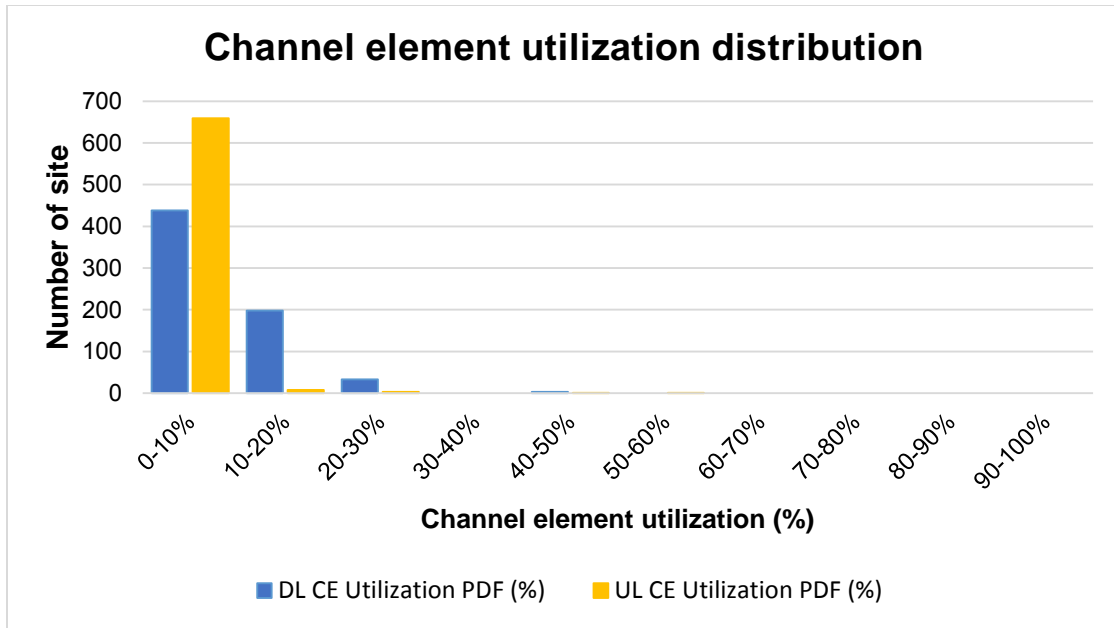
The bar graphs below shows the number of cell distribution for various uplink load ranges. Almost all cells have less than 90% uplink load. In general, it is recommended to maintain lower uplink load per each cell because the user equipment has limited transmission power. Besides at high noise rise level, the power control will be harder to operate.



Graph 8 Uplink load distribution.

5.7.3 Channel element utilization analysis

The bar chart in graph-8 gives information about the distribution of the sites based on uplink and downlink channel element utilization. Looking at the detail, the uplink channel element utilization is a little bit higher than the downlink channel element utilization. But still both the uplink and downlink channel element utilization are below 60%. So the result shows that there is no limitation in terms of channel element resource and the channel element dimensioning result is reasonable.



Graph 9 Channel element utilization.

Chapter 4 CONCLUSION

4.1. Introduction

This design research tries to demonstrate various design activities involving UMTS radio access network planning taking Addis Ababa City as case demonstration. In doing so, the general planning target is divided into different sub planning problems. The dimensioning problem, for instance, consists of three design problems, the link budget, the capacity calculation, and the channel element calculation part. Similarly, the detail planning part consists of the coverage prediction and capacity simulation subproblems.

4.2. Summary of main findings

In this section, the planning result is presented in comparison to the operator live network. Despite little modification on the traffic model, almost all the planning inputs assume similarly value to that of the live network. Hence, the comparison here in this section will have good rational ground.

As compared to the live network deployed in Addis, there is a difference of 51 sites. And the main reason why the coverage target is achieved with less number of sites in this research is the exclusion of forest clutter from the suburban morphology. And this is a reasonable design decision made by this research.

In terms of a number of cells result, there is a difference of 431 cells or carriers. And this result is achieved due to the uplink-downlink data volume ratio assumption made in the traffic model used for this design research. This

change is introduced based on the traffic pattern analysis on the live network and the decision is reasonable.

The CE dimensioning result in this research seems a little bit exaggerated as compared to the live network. But the truth is even the operators currently recognized that the CE was underestimated in its network dimensioning. And recently purchased 32000 additional channel element license to maintain good network accessibility performance. But still in times of big festival and holiday the operator couldn't maintain good service quality to its customer. Hence, it can be concluded that the result in this design research is reasonable.

Attribute	Live Network	Dimensioning output	Difference
Number of site	725	674	51
Number of Cell	6722	6291	431
No. of UL CEs	294288	766080	-471792
No. of DL CEs	99984	766080	-666096

Table 27 Comparison between the live network and the design output.

The coverage analysis is done from pilot coverage prediction and overlapping zone analysis perspective. The pilot coverage prediction result confirmed that the coverage target is met with 674 number of sites. The overlapping zone analysis result also confirmed that the current physical antenna parameter design is reasonable and maintain a reasonable amount of overlapping regions.

The Primary scrambling code planning part is also conducted in such a way that the codes are reused after reasonable reuse distance. This is

achieved through the proper setup of the wireless planning tool. The planning result summary verified the efficient usage of the code all over the network.

4.3. Future Research

In UMTS radio access network planning there are multiple design problems. In the current design work only the coverage, capacity and channel element dimensioning are covered. But in reality, there are many other dimensioning problems associated with interface and equipment dimensioning. Hence, as a recommendation for future research, this aspect of network dimensioning can be demonstrated taking real case scenario. Furthermore, for channel element dimensioning customized version of the dimensioning algorithm is employed in the current work. To this end, the customization is done taking fixed number of the subscriber from the capacity dimension results but this approach has its own drawback in terms of the system soft capacity. Again research can also be done taking iterative resource determination algorithm taking the number of the user as judgment criteria.

In the current design work, the algorithm makes use of the laboratory result to specify the cell throughput performance. But this laboratory result puts some dependency on the availability of laboratory facilities. Hence, it is recommended to pursue similar design research using a different algorithm without any dependency on laboratory result.

There are different planning inputs specified based on the operators strategic plan. And usually, this strategic plan is made based on thorough

analysis of the social, economic and political status of the country. In this regards, it is required to have as many researchers as possible on mobile broadband traffic and mobile terminal distribution.

Regarding radio parameter planning, the current work deals only with the scrambling code planning, but there are many other radio parameters associated with radio resource management that is not included in this research. In terms of its impact on the capacity, coverage and quality radio resource management parameters played a huge role. Hence exploring for radio parameter planning approach and methodology can be an area of future research.

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