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ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

Nominal and Detailed LTE Radio Network Planning: Case of Kirkos Sub-City in Addis Ababa

By

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Advisor

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A thesis submitted to the School of Electrical and Computer Engineering in Partial Fulfillment of the requirements for the Degree of Masters of Science in Communication Engineering

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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 refereed all materials used in this thesis work.

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Place: Addis Ababa University, Ethiopia

Date of Submission: May 26, 2016

This thesis has been submitted for examination with my approval as a university advisor.

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Abstract

The requirements of higher data rate, low latency system, and all-IP (Internet Protocol) network architecture evolves the third generation mobile communication towards the Fourth Generation (4G). Being part of 4G, Long Term Evolution (LTE) is the evolution of 3G counterparts, Universal Mobile Telecommunications System (UMTS) and Code division multiple access (CDMA), to provide a seamless connectivity between two end User Equipments (UE).

The advancement of wireless communication technologies and the increasing size of radio network make the tasks of radio network planning more challenging and, hence, special attention has to be given for ***nominal*** and ***detailed*** LTE radio network planning so as to achieve the desired requirements after deployment. The nominal and detailed LTE radio network planning involves consideration of basic network requirements in terms of coverage, capacity and Quality of Service (QoS).

In this study, the importance of such basic requirements has been illustrated using mathematical analysis as well as computer-aided simulations in order to disclose the LTE's radio network planning strategies to the operator and local practicing engineering in the planning area. The study considers Kirkos sub city in Addis Ababa, Ethiopia, in view of new deployment scenario for the sub city. After analysis of the data taken from the sub city and using the nominal parameters in the detailed planning, the study resulted in target area coverage prediction and capacity evaluation in terms of a given subscriber future growth. The result shows a better network coverage with an optimum network capacity can be achieved in due consideration of network parameters starting from the nominal planning stage till the detailed planning phases in combination of pre optimization requirements at the initial stage. As there will be a similar need in the other part of the country, these findings can be used as reference for new build as well as expansion of the existing LTE network in the future.

Keywords: ***Long Term Evolution, LTE Planning, Nominal Planning, Detailed Planning, LTE Radio Link Budget, Cellular Network Planning, and 4G.***

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List of Acronyms

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
AAiT	Addis Ababa Institute of Technology
AMC	Adaptive Modulation & Coding
AS	Access Stratum
BPSK	Binary Phase Shift Keying
CA	Carrier Aggregation
CA	Carrier Aggregation
CAPEX	Capital Expenditure
CCE	Control Channel Element
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
COST	Cooperative Scientific Research
CP	Cyclic Prefix
CS	Circuit-Switched
CW	Continues Wave
DL	Downlink
DL-SCH	Downlink Shared Channel
DU	Dense Urban
eICIC	enhanced Inter-Cell Interference Coordination
EIRP	Equivalent Isotropic Radiated Power
eMBMS	evolved Multimedia Broadcast & Multicast Services
EPC	Evolved Packet Core
EPS	Evolved Packet System
ET	Ethio Telecom
E-UTRA	Evolved Universal Terrestrial Radio Access
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FDD	Frequency Division Duplex
GSM	Global System for Mobile Communication
HSPA	High Speed Packet Access
HSS	Home Subscription Server

IEEE	Institute Of Electrical And Electronics Engineers
IFFT	Inverse Fast Fourier Transform
IMS	IP Multimedia Subsystem
IMT	International Mobile Telecommunications
IP	Internet Protocol
IRC	Interference Rejection Combining
ISI	Inter-Symbol Interface
ITU	International Telecommunication Union
KPI	Key Performance Indicators
LCS	Location Services
LTE	Long Term Evolution
MAPL	Maximum Allowable Path Loss
MCS	Modulation and Coding Scheme
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
NAS	Non-Access Stratum
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Domain Multiple Access
OPEX	Operational Expenditure
PAPR	Peck to Average Power Ration
PBCH	Physical Broadcasting Channel
PCFG	Policy and Charging Resource Function
PDCCH	Physical Downlink Control Channel
PDSCH	Physical Downlink Shared Channel
P-GW	Packet Data Network Gateway
PL	Path Loss
PRB	Physical Resource Block
PS	Packet-Switched
PUSCH	Physical Uplink Shared Channel
QAM	Quadrate Amplitude Modulation
QoS	Quality of Services
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RB	Resource Blocks
RE	Resource Element
REG	Resource Element Group
RF	Radio Frequency

RFPA	RF Power Amplifier
RLB	Radio Link Budget
RLC	Radio Link Controller
RNPO	Radio Network Planning & Optimizations
RRU	Remote Radio Units
RSRP	Reference Signal Received Power
RU	Rural
SAE	System Architecture Evolution
SC-FDMA	Single-Carrier Frequency Domain Multiple Access
SDO	Standards Development Organizations
S-GW	Serving Gateway
SINR	Signal to Interference plus Noise Ration
SMS	Short Message Services
SNR	Signal to Noise Ratio
SON	Self Organizing Network
SU	Suburban
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TTI	Transmit Time Interval
U	Urban
UE	User Equipment
UICC	Universal Integrated Circuit Card
UL	Uplink
UL-SCH	Uplink Shared Channel
UMTS	Universal Mobile Telecommunications System
USIM	Universal Subscriber Identity Module
UTRAN	Universal Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access
WiFi	Wireless Fidelity
WLAN	Wireless Local Area Networks

Chapter 1: Introduction

1.1. Introduction

Cellular network technologies have been evolving for many years. These evolved technologies are named and differentiated from one another using the term “Generation”, like First Generation, Second Generation, Third Generation, etc…., this naming is appropriate since these technologies have a very quite development gap among each other.

The initial cellular networks are called First Generation (1G). They were designed based on transmission technologies to offer speech services only and they were incompatible to each other [1]. Due to the incompatibility and limited services, the second evolution came into picture. The Second Generation (2G) cellular network technologies are the first step to move forward to digital wireless communication era. 2G cellular networks are widely adopted globally and they provide voice services, Short Message Services (SMS), and packet data service with low data rate (in the order of tens of kilobits per seconds).

The need for high speed data rate and multimedia connectivity among subscribers brought an evolution of the cellular network technologies into third generation. The Third Generation (3G) cellular network standards are defined by the International Telecommunication Union (ITU) by initiative called International Mobile Telecommunications (IMT)-2000. They have been designed being capable on providing high speed packet data services in the ranges of 144 kbps up to larger than 2Mbps [2].

The requirements of higher data rate and low latency system with all-IP (Internet Protocol) network architecture evolve the third generation mobile communication towards the Fourth Generation (4G). Being part of 4G, Long Term Evolution (LTE) is the evolution of 3G counterparts, Universal Mobile Telecommunications System (UMTS) and Code division multiple access (CDMA), to provide a seamless connectivity between two end User Equipments (UE). LTE is defined based on the LTE Release 8 of the 3rd Generation Partnership Project (3GPP) which enables flexible transmission bandwidth from 1.4MHz to 20MHz to utilize operators' available spectrum. This enhances the service capacity compared to previous cellular technologies [3].

The demand for transmitting data in higher rate, capacity and a better Quality of Services (QoS) drives the network service providers to upgrade their cellular network using the most up to date technologies, especially in their urban areas. As a natural upgrade path, the Ethiopian telecom operator, Ethio Telecom (ET), has deployed LTE hotspots in the capital Addis Ababa and became one of the operators in Africa that joined the upgrade path. As the capital hosts multi international conferences and events, it is required to implement an LTE network by considering continues coverage, enough capacity as well as good QoS throughout the capital. To contribute in the upgrading process, this thesis has been proposed to elaborate the LTE radio network planning by considering one of the sub cities as a new deployment area in the capital.

1.2. Statement of the Problem

Addis Ababa, the capital city of Ethiopia, is one of an increasingly growing capital in Africa and often hosting many international conferences and events. Due to this and the increasing usage of smart devices in the city, mobile users are demanding to use the data service all over the places. To meet this ever increasing demand, recently ET has made telecom infrastructures expansion for the existing 2G & 3G networks and introduces a new 4G LTE network for Addis Ababa.

Since LTE network is the first 4G network for the country, all of the parameters and requirements were mainly suggested by the vendors in a fully controlled manner. They use their own experience and findings to accomplish the nominal planning, detailed planning, and implementation strategies. There is undoubted need to disclose these strategies to the operator and local practicing engineering in the planning area.

In addition, the implemented LTE network in the capital was primarily intended to cover only hotspot areas in the capital. However, the increasing usage of smart devices as well as demand for high data rate multimedia services in the capital/country means that continues LTE coverage through the capital is required in the future. These points have also motivated this study to demonstrate on how an optimized LTE network can better be designed. To achieve that, one of the sub cities in Addis Ababa is selected as a case study, which can be considered as reference for future expansion programs in the country. Therefore, this study strives to address the above mentioned problems through nominal and detailed LTE radio network planning that considers the current situations of Kirkos sub city using Radio Network Planning and Optimization (RNPO) tool. Thus, this work can be considered as a step towards a practical realization.

1.3. Thesis Objectives

1.3.1. General Objective

The general objective of the study is to do nominal and detailed LTE radio network planning in consideration of possible network implementation for Kirkos sub city in Addis Ababa.

1.3.2. Specific Objectives

This study is carried out specifically to accomplish the followings:

- To define target network requirements in terms of radio coverage, capacity, and quality of service;
- To illustrate nominal and detailed LTE radio network planning from a given target network requirements in terms of:
  - Radio Link Budget (RLB) parameters;
  - Coverage-based sites count for target area;
  - Network capacity dimensioning and capacity based sites count computation;
  - Radio Network Planning & Optimizations (RNPO) tool to evaluate the target network performance based on nominal planning parameters.

- To demonstrate the importance of pre-deployment optimization which helps to reduce extra effort during deployment as well as after the network becomes on air for commercial use.

1.4. Literature Review

Different studies have been made in the area of LTE technologies, among others the following are the ones reviewed to frame the current study in line with the problem on hand.

The dimensioning of LTE radio access networks and the development of tool for dimensioning purpose presented in [4]. In this work, an easy-to-use tool customized for dimensioning using Microsoft Excel. The unavailability of reliable LTE network simulators at the time of the study was a big challenge in full calibration of the developed tool. However, the study does not incorporate the coverage prediction as well as capacity evaluation to accommodate the ever-increasing subscriber growth by considering target area terrain conditions.

The capacity of the LTE network considering average transmission data rate, peak transmission data rate and subscriber numbers supported by the system is done on [5]. In this work, the coverage of the LTE system also calculated based on base station parameters and different propagation models. In this study, cells are represented by circular structure model instead of hexagonal structure, which is far from the theoretical point of view. In addition, the cell radius estimation does not consider the penetration losses as well as the fading margin. The study only evaluates the capacity performance of each base station without considering the capacity future growth during estimation and it does not show how the network is capable enough to accommodate ever-increasing subscriber growth.

LTE radio network planning by considering Addis Ababa as a case study presented in [6]. The ultimate target of this work is to give a good understanding of LTE radio network planning in order to improve the existing network deployment. The study addressed the LTE radio network planning to do coverage estimation, capacity evaluation and frequency planning by focusing on selected 53 km^2 area around the National Hotel. In this study, Matlab simulation environment was used to investigate the Radio Access Network (RAN) nominal planning and radio link budget calculation. Due to the limitation of Matlab, in this study, the network prediction and capacity evaluations were not performed as it is done these days by using RNPO tools. More over the study does not show the capability of target network against the subscriber's future growth.

LTE radio network capacity and coverage analysis has been performed by considering possible network implementation in the South-Asian city Dhaka [7]. This study focused only on the nominal planning without consideration of the deployment area actual terrain conditions. Moreover, the study does not involve the detailed planning phase; as a result, the calculated eNodeB's capabilities in terms of coverage and capacity were not performed.

A detailed LTE radio network planning procedure has been elaborated in [8] considering possible network implementation as an extension of the work in [7] within the same city. In this work small number of subscribers was considered as initial network deployment, this remains a challenge for future capacity enhancement. Similarly, LTE radio network planning where done in consideration of possible network implementation for Khartoum city [9]. However, the study does not integrate the coverage prediction as well as capacity evaluation in consideration of future subscriber growth in the target area.

Automatic planning tools for the planning of LTE radio networks and Evolved Packet Core (EPC) are presented in [10] and [11] respectively based on realistic traffic by set of equations to generate realistic traffic profile in consideration of practical aspects. A mathematical model is created to solve the planning problems of the radio access part as well as the EPC while minimizing the cost. However in both studies, the realistic traffic based consideration doesn't involve the effect of subscriber growth during realistic traffic estimation.

In general, the input retrieved from the above literature reviews and other related previous works on [12] and [13] helps to design the methodology of this study as presented in the following subsection.

1.5. Methodology

In this study, related secondary sources of data such as different books in LTE, 3GPP standardization documents, previous researcher's studies, different Institute of Electrical And Electronics Engineers (IEEE) articles, and journals have been used to explore the latest development in 4G cellular technology in general, and the overall technological aspects of LTE and basics of radio network planning, in particular.

Based on the inputs retrieved from review of related literatures and the statement of the problem in mind, the methodology of this study is designed as follows:

System design

- Outline workflows for coverage and capacity planning;
- Setup target network requirements in terms of coverage and capacity;
- Prepare a mathematical model for RLB, cell radius calculation, and cell capacity estimation;
- Identify all input parameters including digital map for simulation.

Simulations:

- Outline simulation workflows that can be used in RNPO tool;
- Perform target network coverage prediction simulations;
- Simulate target network to evaluate the capacity.

Result Analysis & Interpretations:

- Perform coverage prediction results and capacity evaluation analysis to conclude whether the target network requirement achieved or not.

1.6. Scopes and Limitations

1.6.1. Scopes of the Thesis

Although the LTE system is designed to work with both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) radio access modes, the focus of this study is only based on

FDD mode due to the advantage of FDD over TDD in terms of lower interference between neighbor base stations and greater spectral efficiency as there is no guard band in FDD [14]. Besides, even though completion of LTE network planning requires actual site survey, in this study the detailed radio network planning is approached only using RNPO tool.

1.6.2. Limitations of the Thesis

The LTE nominal and detail planning in this study is done by using a simulation environment. Thus, the actual on sites conditions and issues related to land acquisition are not taken into consideration. Hence, the outcomes of the study don’t consider the impact of such conditions on the target network performance evaluation using the RNPO tool.

In addition, propagation models comparisons have been done to get the worst case signal propagation in the target area. But due to lack of Continues Wave (CW) and drive test data for the target area, the selected propagation model parameters are not optimized. This might also affect the overall prediction output of the target area. Furthermore, lack of forecasted subscriber data users forced the study to estimate the total LTE subscribers from population projection with an assumption of projected population growth per sub-city which is taken or considered in line with the population census ratio as of 1st July 2007.

1.7. Contributions

Cellular radio network planning is one of the challenging tasks in telecommunication industry due to technologies advancement as well as the increasing network size arising from wireless communication service demand from the public at large. Hence, special attention has to be given for nominal and detailed radio network planning. To achieve the desire target network requirements after deployment, this study contributes on how to perform LTE radio network planning for new build scenario to help operators and local practicing engineers in the area of LTE network planning. It gives detail consideration of ***SINR*** and ***Shadow Fading Margin*** during RLB calculations. Furthermore, three kinds of average eNodeB throughput calculation approaches are demonstrated to illustrate the importance of cell throughput during capacity planning. Finally, this study contributes in way that it necessitates the importance of pre-deployment optimization to reduce extra effort during network deployment and after the network becomes on air for commercial use.

1.8. Thesis Outline

This thesis work is composed of five chapters. The first chapter deals with an introduction of this thesis. It introduces problems of the statement, thesis objectives, methodologies used, scopes, and limitations of the study. Basics of LTE technologies, including overview of the LTE technologies, system architecture evolution, and LTE frame structure are discussed in the Chapter 2. Chapter 3 explains the radio network planning process, coverage, and capacity planning of LTE.

As a main section of this study, Chapter 4 illustrates the results and discussion points of the study. It covers the Radio Link Budget, the related methods, and factors to calculate the number of sites count from the coverage point of view. It also describes the capacity planning by elaborating the methods used and factors impacting the capacity planning process; like average cell throughput calculation, traffic demand estimation, and estimation of capacity based site counts. Finally, the conclusion remarks and the future works are discussed in Chapter 5.

Chapter 2: Basics of Long Term Evolution (LTE)

2.1. Introduction

LTE, commonly known as 4G LTE, is a standard given for wireless communication of high speed data for mobile phones and data terminals. The starting point for this standard was the workshop held in November 2004 for 3GPP RAN evolution in Toronto Canada. The study was started one month later, in December 2004, with the objective of developing a framework for the evolution of the 3GPP Radio Access Network (RAN) with the intention of reducing cost per bit, increased service provisioning, flexible use of new and existing frequency bands, reasonable terminal power consumption, and simplified architecture with open interfaces [15].

The 3GPP has been progressing to setup the standardization and evolution of the LTE after the first standard frozen in 2008 for the Release 8. The standardization and evolution has continued with the releases of LTE-Advanced and beyond. This study is based on Release 8 and the summarized characteristics of different 3GPP LTE releases are presented in [16] and adopted as in the below sections.

2.2. LTE System Architecture

One of the main driving forces for a 4G system is the evolution of the network architecture. As being part of the 4G system, LTE's network architecture is introduced to be all-IP (Internet Protocol) based simplified network architecture (flat) with open interfaces. This flat architecture is designed to be more simplified and compact when it is compared to the previous 3GPP releases. Since LTE is the evolution of UMTS, its equivalent components are named Evolved Universal Terrestrial Radio Access (E-UTRA). This is the air interface including the user equipment (UE) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and it is used to describe RAN. However, in the new architecture instead of a radio controller, 3GPP introduced a new architecture called System Architecture Evolution (SAE). Due to this new architecture, the E-UTRAN is not only just as a RAN, as it is in the UMTS, since the SAE defines a new all-IP packet-only core network called Evolved Packet Core (EPC) [17].

The combination of the EPC, the E-UTRA, and the E-UTRAN is called Evolved Packet System (EPS). The EPS network architecture is made of different interfaces in order to meet the design targets of the LTE system. These interfaces are constructed by different protocol such as Layer 1, Layer 2, and others as described in [18]. Figure 2.1 shows the LTE network architecture and the network components are discussed in the following subsections.

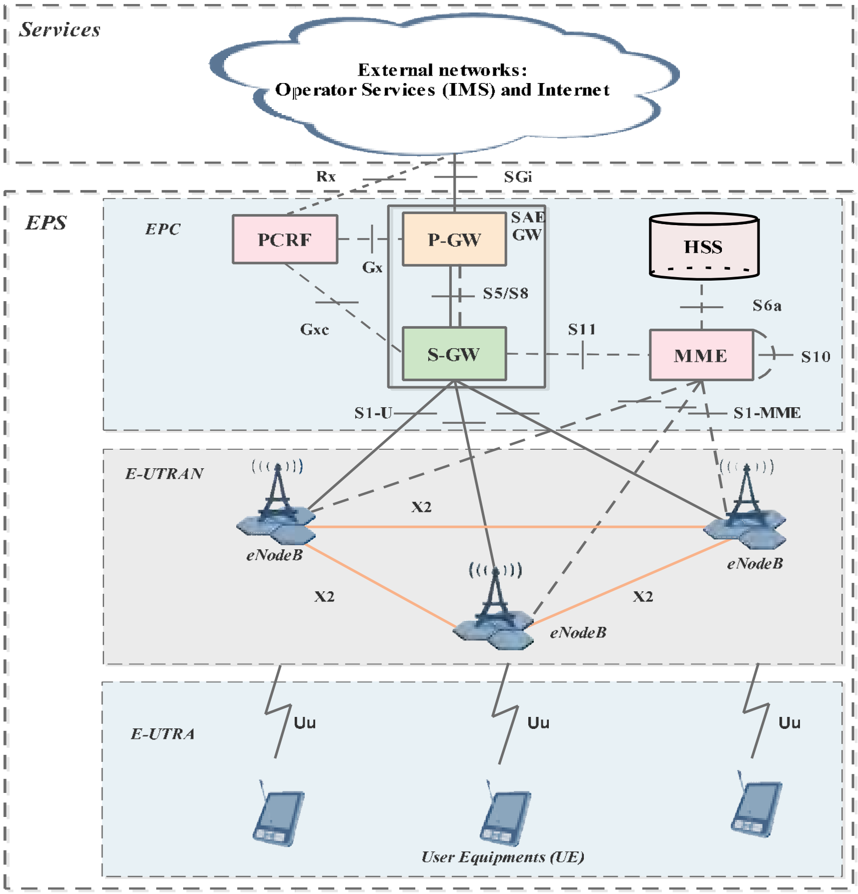


Figure 2. 1: LTE Evolved Packet System (EPS) architecture [18].

2.2.1. Evolved Packet Core (EPC)

In previous mobile generations (2G, 3G), the mobile core functionality has been realized using two separate sub-domains; Circuit-Switched (CS) and Packet-Switched (PS) for voice and data respectively. When designing the evolution of the core network, the 3GPP decided to use IP as the key protocol to transport all services by excluding the circuit-switch domain. In LTE, these two different mobile core sub-domains are unified as a single IP domain and becomes Evolved Packet Core (EPC). EPC is a new, all-IP mobile core network specified by 3GPP Release 8 for LTE and enables communication with the outside world such as Internet, private corporate networks or an IP Multimedia Subsystem (IMS) with packet data.

2.2.2. Evolved Universal Terrestrial Radio Access Network (E-UTRAN)

As part of the EPS, the E-UTRAN consists of LTE base station called eNodeB. Unlike the predecessor Universal Terrestrial Radio Access Network (UTRAN) in the UMTS, in LTE, which is E-UTRAN, the RAN functions and decisions are handled by the eNodeB, while the relevant functions of the core are processed by the core network. To identify the boundaries between the two network managements, there is a functional split between E-UTRAN and EPC as shown in the Figure 2.2. The control stratums called Access Stratum (AS) are mostly handled by the eNodeB and the Non-Access Stratum (NAS) handled by various entities of the core network [19].

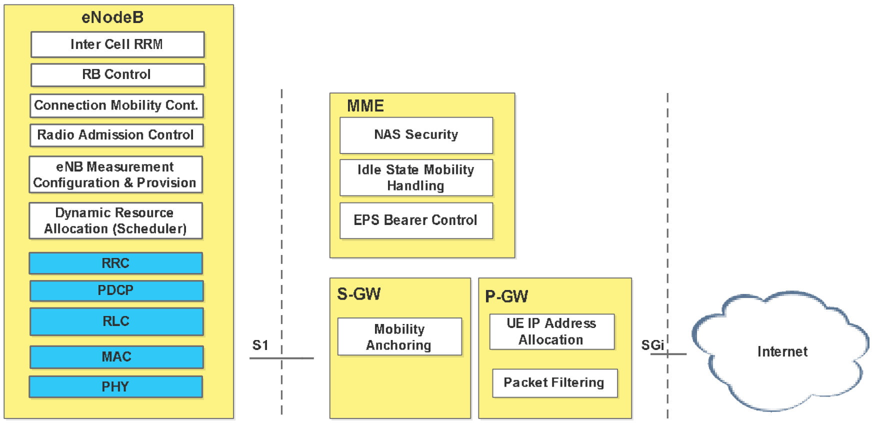


Figure 2. 2: Functional split between E-UTRAN and EPC [19].

The main functions of eNodeB are:

- Act as a Layer 2 bridge between UE and the EPC, which means, it is the termination point of all the radio protocols towards the UE and data relaying between the radio connection and the corresponding IP based connectivity towards the EPC;
- Serves as a Radio Resource Management controlling the usage of the radio interface including allocating resources based on requests, prioritizing, and scheduling traffic according to required QoS. Constant monitoring of the resource usage situation;
- Performs Mobility Management: Controls and analyses radio signal level measurements carried out by the UE, make similar measurements itself, and based on those makes decisions to handover UEs between cells;
- Bearer handling and user plane data delivery, Forwarding of downlink data during handovers;
- Securing and optimizing radio interface delivery.

2.2.3. LTE User Equipments

In 3GPP LTE and UMTS, user equipments are defined as any devices which are used directly by the end users for communications. They can be hand held device like smart phones or a data cards or they could be embedded into a laptop or tablets. A UE contains the Universal Subscriber Identity Module (USIM), which is an application placed into a removable smart card called the Universal Integrated Circuit Card (UICC). The USIM derive a security keys for protecting, identifying, and authenticating the users in the radio interface transmission.

3GPP has defined about five UE categories for LTE user equipments in Release 8 [20]. As show in the Table 2.1, the specification considers features such as downlink (DL) and uplink (UL) physical layer parameters, supported modulation types, type of MIMO used, and so on. In this study, all UE parameters in the simulation and discussions part are based on LTE UE category 3 due to the performance specification of this category is sufficient enough, as indicated in Table 2.1, to demonstrate the objectives of the study.

Features	Category 1	Category 2	Category 3	Category 4	Category 5
Data Rate(Mbps)	DL:10 UL: 5	DL:50 UL: 25	DL:100 UL: 50	DL:150 UL: 50	DL:300 UL: 75
Modulation type supported	DL: QPSK, 16QAM, 64QAM UL:QPSK, 16QAM	DL:QPSK, 16QAM, 64QAM UL:QPSK, 16QAM	DL: QPSK, 16QAM, 64QAM UL:QPSK, 16QAM	DL:QPSK, 16QAM, 64QAM UL:QPSK, 16QAM	DL:QPSK, 16QAM, 64QAM UL:QPSK, 16QAM,64QAM
2x2 MIMO	Not supported	Supported	Supported	Supported	Supported
4x4 MIMO	Not supported	Not supported	Not supported	Not supported	Supported
Max. No. of bits of a DL-SCH transport block received within a TTI	10296	51024	75376	75376	149776
Max. No. of supported layers for spatial multiplexing in DL	1	2	2	2	4
Max. No. of bits of an UL-SCH transport block transmitted within a TTI	5160	25456	51024	51024	75376

Table 2. 1: LTE UE categories [21].

2.3. LTE Requirements and Targets

In order to enhance the capability of the 3GPP system and to cope up with the rapid growth in IP data trafficking, packet switched technologies used in 3G cellular network requires further enhancement. The name “Long Term Evolution” indicates the new LTE technology requirements and targets shows an improved long term changes including reduced latency, higher data rates usage, improved system capacity and coverage, and reduced overall cost to the operators. The highlights of the LTE main performance metrics are [22]:

- Reduced delays, both in terms of connection establishment and transmission latency;
- Increase user data rate both in uplink and downlink;
- Increase cell-edge bit rate for uniformity of service provision;
- To have reduced cost per bit;

- Flexibility of spectrum utilization to use existing and new band;
- Simplified network architecture;
- Seamless mobility between different radio-access technologies;
- Mobile terminal reasonable power consumptions.

2.4. Spectrum Allocation in LTE

One of the main factors to be considered in deploying cellular networks is the choice of frequency spectrum. There are multiple band options for 2G, 3G, and 4G systems and the choice depends on the regulatory arrangement in each country and the availability of the spectrum. The 3GPP LTE frequency band specifications are divided as paired bands and unpaired bands. The paired bands are used by the FDD and the unpaired spectrums are used by TDD; Table 2.2 and 2.3 shows the unpaired and paired frequency spectrums of 3GPP LTE system respectively [23].

Operating Band	3GPP Name	Total Spectrum	Uplink and Downlink (MHz)
Band 33	UMTS TDD1	1x20 MHz	1900-1920
Band 34	UMTS TDD2	1x15 MHz	2010-2025
Band 35	US1900 UL	1x60 MHz	1850-1910
Band 36	US1900 DL	1x60 MHz	1930-1990
Band 37	US1900	1x20 MHz	1910-1930
Band 38	2600	1x50 MHz	2570-2620
Band 39	UMTS TDD	1x40 MHz	1880-1920
Band 40	2300	1x50 MHz	2300-2400

Table 2. 2: 3GPP LTE system unpaired spectrums [24].

Operating Band	3GPP Name	Total Spectrum	Uplink Range (MHz)	Downlink Range (MHz)
Band 1	2100	2x60MHz	1920-1980	2110-2170
Band 2	1900	2x60MHz	1850-1910	1930-1990
Band 3	1800	2x75MHz	1710-1785	1805-1880
Band 4	1700/2100	2x45 MHz	1710-1755	2110-2155
Band 5	850	2x25 MHz	824-849	869-894
Band 6	800	2x10 MHz	830-840	875-885
Band 7	2600	2x70 MHz	2500-2570	2620-2690
Band 8	900	2x35 MHz	880-915	925-960
Band 9	1700	2x35 MHz	1750-1785	1845-1880
Band 10	1700/2100	2x60MHz	1710-1770	2110-2170
Band 11	1500	2x25MHz	1427.9-1452.9	1475.9-1500.9
Band 12	US700	2x18 MHz	698-716	728-746
Band 13	US700	2x10 MHz	777-787	746-756
Band 14	US700	2x10 MHz	788-798	758-768
Band 17	US700	2x10 MHz	704-716	734-746
Band 18	Japan800	2x30 MHz	815-830	860-875
Band 19	Japan800	2x30 MHz	830-845	875-890

Table 2. 3: 3GPP LTE system paired spectrums [24].

2.5. Technologies used in LTE

As discussed in Section 2.3, the fulfillment of these extensive ranges of requirements became possible by introducing advancement in the underlying mobile radio technologies. The three fundamental technologies that have shaped the LTE radio interface design are Multicarrier Technology, Multiple Antenna Technology, and Radio Access Technologies [22]. These three technologies are discussed in this section briefly.

2.5.1. Multicarrier Technology

Adopting a multicarrier design approach was the major design choice to provide multiple accesses in LTE system. During the proposal development, the candidate schemes for downlink communication were Orthogonal Frequency Division Multiple Access (OFDMA) and Multiple Wideband Code Division Multiple Access (WCDMA). While the candidate for the uplink communications were Single-Carrier Frequency Division Multiple Access (SC-FDMA), OFDMA, and Multiple WCDMA. According to the choice made on December 2005, OFDMA being selected as a multiple access scheme for downlink and SC-FDMA as multiple access schemes in the uplink. Both OFDMA and SC-FDMA multicarrier access technologies open up the frequency domain as a new dimension of flexibility in the system [22]. Figure 2.3 illustrate the schematically diagram for OFDMA and SC-FDMA.

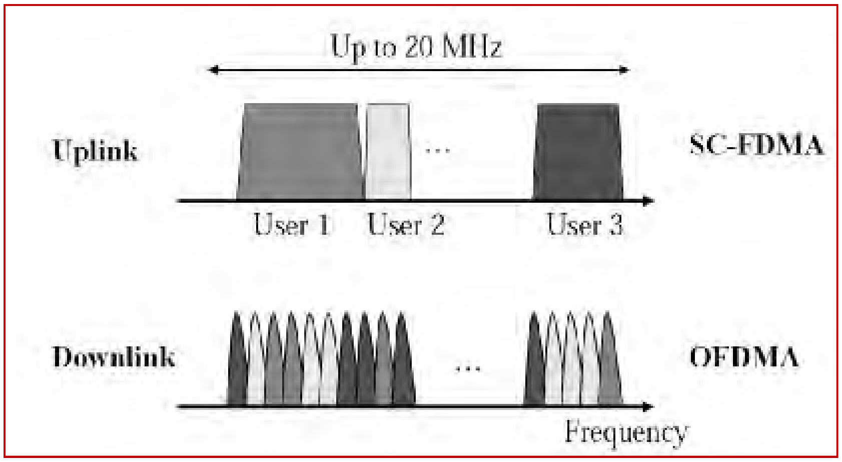


Figure 2. 3: LTE multiple access technologies schematic diagram [23].

OFDMA has provided a very flexible multiple access schemes by extending the multicarrier technology Orthogonal Frequency Division Multiplexing (OFDM). Signal transmission using OFDM is done by subdividing the bandwidth available into a multitude of narrowband subcarriers in such a way that they are mutually orthogonal. Thus independent information streams can be carried either individually or in group and this subdivision facilitate sharing of subcarrier(s) among multiple users [25]. Such bandwidth flexibility in OFDMA used to utilize different spectrum bandwidths without fundamental change on system parameters or equipment design, and also to allocate transmission resources of variable bandwidth in the frequency domain. Some of the key advantages of OFDM are [25]:

- Robustness to time-dispersive radio channels, enabling inter-symbol interference to be constrained within a guard interval at the beginning of each symbol;
- Using frequency-domain equalization, receivers can be designed with minimized complexity;

- Signals from multiple transmitters can be combined simple in broadcast networks.

Despite the above advantages, OFDM transmitter designs are highly complicated and expose to a higher Peak-to-Average Power Ratio (PAPR) of an OFDM signal. To solve this, it is required to implement a highly linear RF power amplifier to handle the power variation. However, this limitation is not considered as a constraint for the downlink transmission as compared to the uplink. This is because the implementation cost of OFDM in the base station side has a lower priority than the cost of implementing the OFDM in the user equipment side [18].

Since the high PAPR of OFDM is difficult to tolerate for the transmitter of the mobile terminal, it is necessary to find a solution to compromise between the required output power and the expected good outdoor coverage, the power consumption, and the cost of the power amplifier. Thus in the uplink direction the 3GPP uses SC-FDMA for multiple access which is valid for both FDD and TDD modes of operation [26].

SC-FDMA can be seen as equal to the Quadrate Amplitude Modulation (QAM) where each symbol is sent one at a time similarly to Time Division Multiple Access (TDMA) systems such as GSM. As compared to the regular QAM modulator, the frequency domain generation of the signal adds the OFDMA property. Therefore the need for guard bands between different users can be avoided like the downlink OFDMA principle and instead a Cyclic Prefix (CP) is added periodically to the transmission to prevent inter-symbol interference [27].

2.5.2. Multiple Antennas Technology

One of the advanced technologies introduced in the LTE is the use of multiple antenna technology called Multiple Input Multiple Output (MIMO). MIMO systems uses more than one transmitting antenna (Tx) to send a signal to more than one receiving antenna (Rx) using the same frequency. Thought MIMO has been deployed for years in Wireless Local Area Networks (WLAN), it is a new feature introduced in cellular network and it is used to increase the ability of LTE to further improve the data throughput and spectral efficiency that are already obtained by using OFDM technology [28].

MIMO operation includes spatial multiplexing, pre-coding and transmits diversity. In spatial multiplexing, the basic principle is that signals from two or more different antennas with different data streams are transmitted and at the receiver side the data streams will be separated by using signal processing means. This increases the peak data rates by a factor of 2 for two by two (2x2) antenna configurations and by a factor of 4 for four by four (4x4) antenna configurations [27].

In pre-coding the signals transmitted from the different antennas are weighted in order to maximize the received Signal-to-Noise Ratio (SNR). Whereas transmit diversity relies on sending the same signal from multiple antennas with some coding in order to take advantage of the gains from independent fading between the antennas.

2.5.3. Radio Access Technology

3GPP outlined two radio access modes for the LTE system; FDD and TDD. FDD enables a device to transmit and receive data at the same time by allocating separate uplink and downlink channels. As shown in Figure 2.4, the spacing between these two channels is called the duplex spacing.

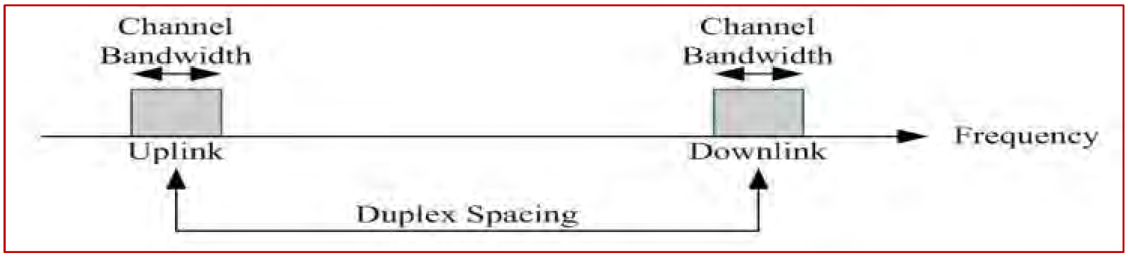


Figure 2. 4: Radio Access Technology, FDD [28].

Since higher frequencies are suffered with greater attenuation than the lower frequencies, the uplink channels operates on the lower frequencies, which enables the mobile terminals to utilize lower transmit power.

TDD mode uses a single frequency band to enable full duplex operation by time division multiplexing of the uplink and downlink signals. Due to the same uplink and downlink frequency characteristics, TDD provides asymmetrical uplink and downlink allocation. Figure 2.5 shows this asymmetrical uplink and downlink allocation.

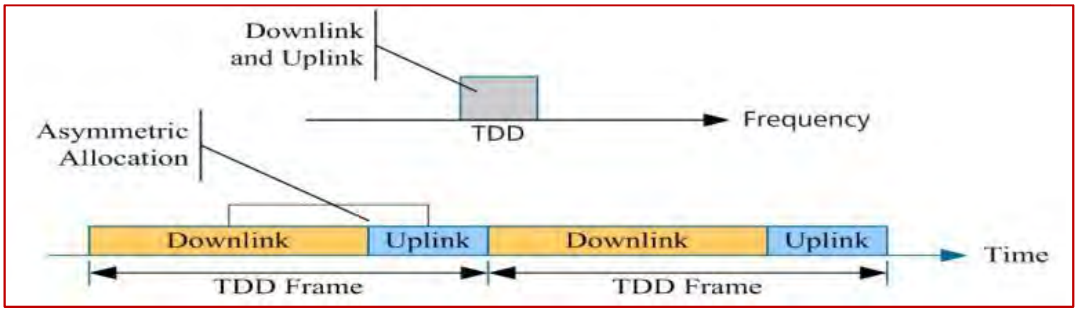


Figure 2. 5: Radio Access Technology, TDD [29].

2.6. LTE Frame Structure

To support transmission in both paired and unpaired spectrum in LTE, two duplexing modes are used as discussed in Section 2.5.3. Thus, the 3GPP defines two radio frame structure called Type 1 and Type 2 to support the two duplex modes. Radio frame structure Type 1 is used for FDD (for both full duplex and half duplex) and radio frame structure Type 2 is used for TDD. As this study is based on FDD, only radio frame structure Type 1 is discussed here and further details on this and Type 2 are available in [26].The radio frame structure Type 1 has 10 milliseconds (ms) duration and it consists of 20 slots (numbered from 0 to 19) with slot duration of 0.5ms. Two adjacent slots form one sub-frame of length 1ms; where sub-frame i consists of slots $2i$ and $2i + 1$. Depending on whether the normal or extended cyclic prefix is employed, slots consist of either 6 or 7 OFDM symbols as shown in the Figure 2.6. In each 10ms interval, 10 sub-frames are available for downlink transmission and 10 sub-frames are available for uplink transmissions, as uplink and downlink transmissions are separated in FDD.

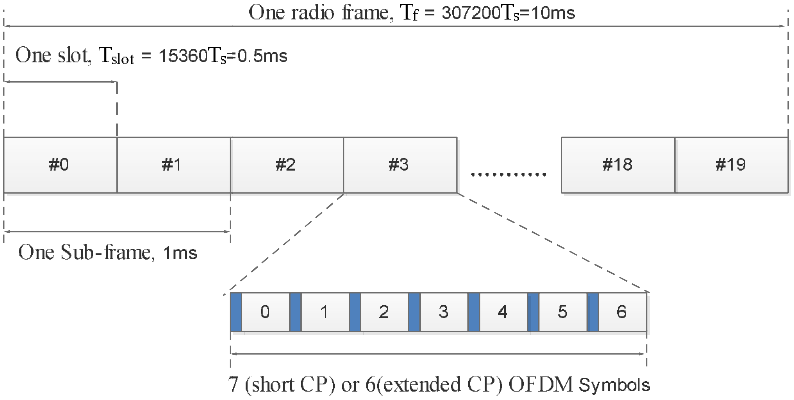


Figure 2. 6: LTE frame structure Type 1 [26].

The LTE radio frame mapped into time and frequency domains before being transmitted over the air. Downlink OFDMA enables multiple devices to receive information at the same time but on different parts of the radio channel. This is referred to as a “sub-channel” in most systems that are using OFDMA. However in EUTRA, the term sub-channel is replaced with the term Physical Resource Block (PRB) [18].

A PRB is used to describe the physical resource in the time and frequency grid as illustrated in Figure 2.7. The Resource Element (RE) is used to describe one subcarrier by one symbol in the time-frequency grid. They are used to carry modulated information, reference information, or nothing depending on the assignment [18].

A PRB consists of 12 consecutive sub-carriers spaced by 15 KHz in one slot of length, 0.5ms. The N_{RB}^{DL} parameter is used to define the number of Resource Blocks (RB) used in the downlink which is dependent on the channel bandwidth. On the contrary the N_{RB}^{UL} parameter is used to identify the number RB in the uplink. Each resource block consists of N_{SC}^{RB} subcarriers, which are 12 (a total of (12x15)180 KHz in one slot duration of 0.5ms [15].

The RB resources are assigned by the eNodeB scheduler. The assigned resources to a specific UE can be contiguous, where sub-carriers from one RB to another are sequential, and called as localized virtual resource block. On the other hand, the RB resources scheduled to a UE can be distributed in such a way that some resources are continuous and some are assigned at a pre defined distance away, this referred to as distributed virtual resource blocks [30].

In the time-frequency grid, a control information channel, such as Physical Downlink Control Channel (PDCCH) shares parts of the bandwidth with the data channels. Thus, the control region is limited to the first 3 symbols of the sub-frame for large bandwidth and to 4 symbols for small bandwidth. The allocation is defined by the Control Channel Element (CCE) and the Resource Element Group (REG) [31].

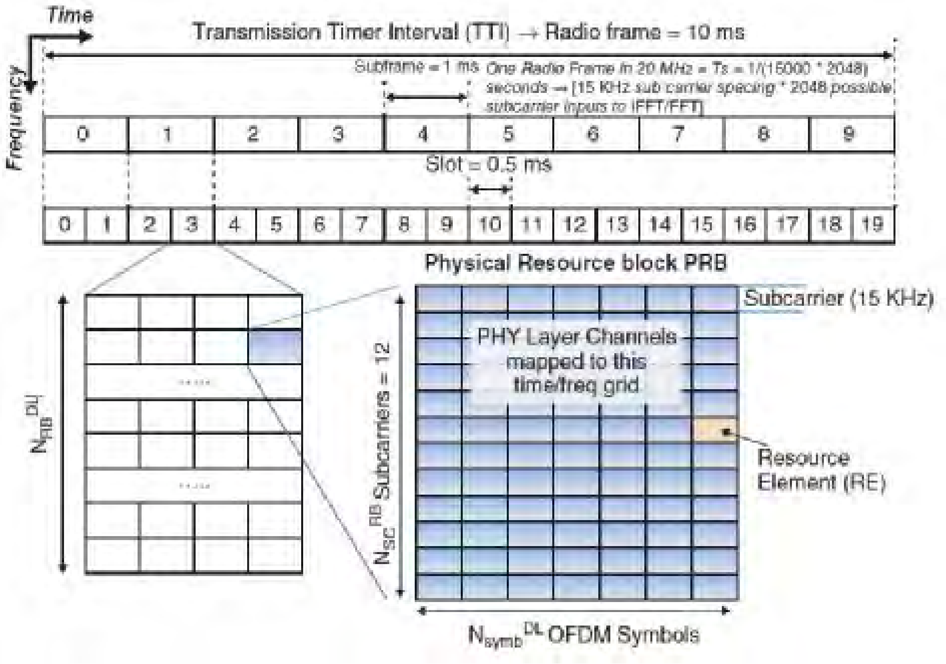


Figure 2. 7: Physical Resource Block (PRB) and Resource Element (RE) [18].

As there are various channel bandwidths considered in LTE deployment, the illustrated time-frequency grids in Figure 2.7 summarized in the Table 2.4 shown below.

Channel Bandwidth (MHz)	Number of Resource Block (N_{RB})	Number of Sub-carriers ($N_{SC} = 12xN_{RB}$)
1.4	6	72
3	15	180
5	25	300
10	50	600
15	75	900
20	100	1200

Table 2. 4: LTE Frequency Domain Configuration [18].

Chapter 3: LTE Radio Network Planning

3.1. Overview

The LTE radio network is part of the LTE network that includes the eNodeB, the UE, and the interface between them. As this is the part of the network directly connected to the UE, it should be capable enough to communicate with the UE within a certain coverage area with acceptable QoS.

In the context of cellular radio communication systems, Radio Frequency (RF) planning is the process of designing transmitter locations, assigning frequencies, and radio parameters of a wireless communications system to provide sufficient coverage and capacity to meet the required services [32]. Coverage planning refers to the geographical footprint within the network that provides adequate RF signal strength to provide voice or data services, whereas capacity refers to the capability of the network to sustain a given number of subscribers [32].

There are sequential steps in cellular radio network planning starting from simple analysis to a computer aided mathematical computation and simulation; i.e., from nominal planning to detailed planning and continues optimization. To deploy a new cellular network or expansion of an existing network, radio network planning process is not the only process in the whole network planning and design process; it has to work in close coordination with the planning processes of the core network as well as the transmission network. But in this study, the nominal and detailed radio network planning are investigated from the practical aspects of coverage and capacity planning in LTE network.

3.2. Radio Network Planning Process

The main objective of radio network planning is to provide a cost effective solution for the radio network in terms of coverage, capacity, and quality. Depending on the dominating factor, either capacity or coverage or both the radio network planning process and design criteria vary from region to region. Whatever the case is, the coverage objectives should meet the business requirement by minimizing the expenditure. On the other hand, the network should be capable enough to meet the current and future capacity requirements [33].

In order to design and dimension a commercial LTE network for new deployment scenario, the fundamental radio network planning and rollout of an LTE network is divided into preparation, nominal planning, detailed planning, network rollout, and network optimizations phases as shown in Figure 3.1 and each will be discussed briefly as in the below subsections.

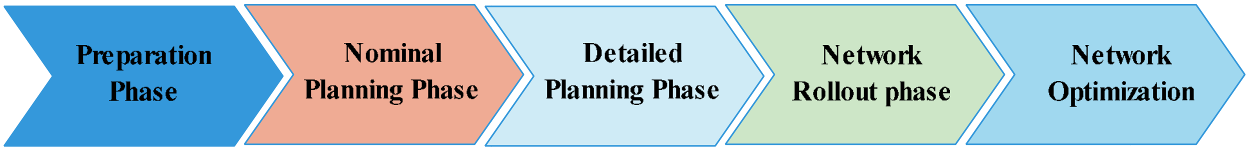


Figure 3. 1: Radio Network Planning Process [18].

3.2.1. Preparation Phase

As this phase is the beginning of the phase, it starts with the preparing the requirements of coverage and capacity. Coverage requirement include defining the coverage areas, the service probability, and related signal strength such as Reference Signal Received Power (RSRP). On the other hand, the capacity requirements include traffic forecast (total number of subscriber supported by the network) and the traffic profile in the selected area. The availability of frequency bands, the selection of terrain morphology (Dense Urban (DU), Urban (U), Suburban (SU), or Rural (RU)), and propagation model selection are also done at this phase [34].

3.2.2. Nominal Planning Phase

In this phase, the definition of Radio Link Budget (RLB) parameters and determination of their optimal values based on the selected area properties and other factors will be done. From the RLB, the maximum ***allowable path loss*** and ***cell range*** can be estimated and becomes an input for the detail planning phase to conduct the RF prediction using RNPO tools. The network capacity dimensioning also conducted at this phase to determine the number of required sites which satisfy the capacity requirements [35].

The outcomes of this phase is the cell radius for different clutters and supported number of subscribers per site, thereby determines the number of required sites which satisfies both the coverage and capacity requirements defined in the preplanning phase as shown in the Figure 3.2.

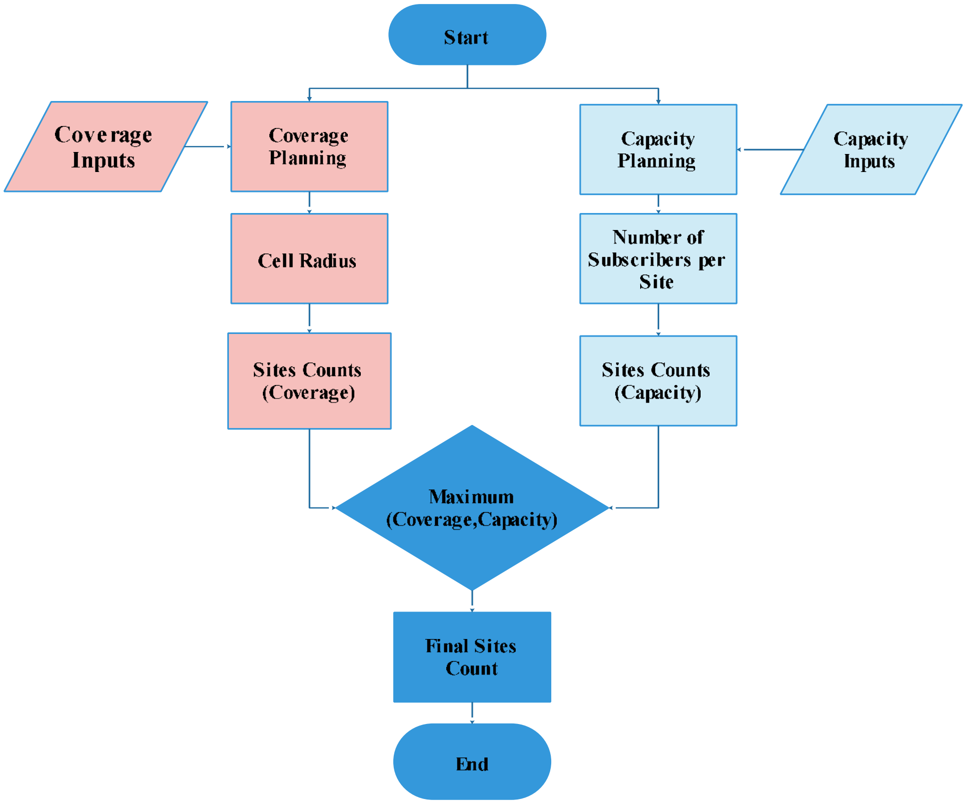


Figure 3. 2: Nominal planning overall process [36].

3.2.3. Detailed Planning Phase

By using the outputs from the nominal planning phase, in this phase the initial sites placement, antenna type selection including azimuth, mechanical tilt, and electrical tilt are defined. After this, the RF prediction will be conducted using RNPO tool by incorporating the selected propagation model and RLB parameters found in nominal planning phase [35].

Since the nominal planning phase considers the area as being geographically flat (only mathematical computation), during coverage prediction by using RNPO tool, we may face holes due to the selected area terrain situation. Thus, as discussed in Section 3.5, pre-deployment optimization is required in order to achieve an optimal prediction result.

To make the sites ready for the network rollout phase, in this phase sites survey will also be conducted to select the proper candidates that meet both the coverage and capacity requirement. During sites survey, the requirements for land acquisition, sites solutions, and road access conditions will be determined.

3.2.4. Network rollout phase

In this phase the network rollout and sites construction is done based on the results found in the detailed planning phase. By determining a pilot site (rollout model), the whole network rollout will be conducted and network acceptance is performed.

3.2.5. Network optimizations

The network optimization is not a one time job but as a pre-optimization, validation of the cell parameters, coverage targets, and throughput will be conducted to pre-optimize the target network. In this phase comparisons of nominal and detailed planning results with the actual network performance will be conducted and network parameters tuning is done to meet the agreed Key Performance Indicators (KPI) before commercial launch. Once the network put to commercial use, the operator continues to perform network optimization again and again to meet its customer demand or avoid network complains (coverage issues, call success rate and performance degradation, etc) [18].

3.3. LTE Coverage Planning

Coverage planning objective is to determine the geographical footprint within the network to provide an adequate RF signal strength for the users at the cell-edge. This is done by evaluating the DL and UL radio link budget to get the Maximum Allowable Path Loss (MAPL) based on the required Signal-to-Interference-Noise Ratio (SINR) level at the receiver and by putting interference into consideration.

Both downlink and uplink MAPL used to calculate the cell radius for different terrain morphologies based on the appropriate propagation model for the deployment area. Since the UL and DL capabilities are different, the effective cell radius must be taken into account to determine the cell area and hence the total sites count from the coverage perspective. Figure 3.3 summarizes the overall process of LTE coverage planning. A good coverage planning requires selection of appropriate path loss prediction models and details are provided in the next subsection.

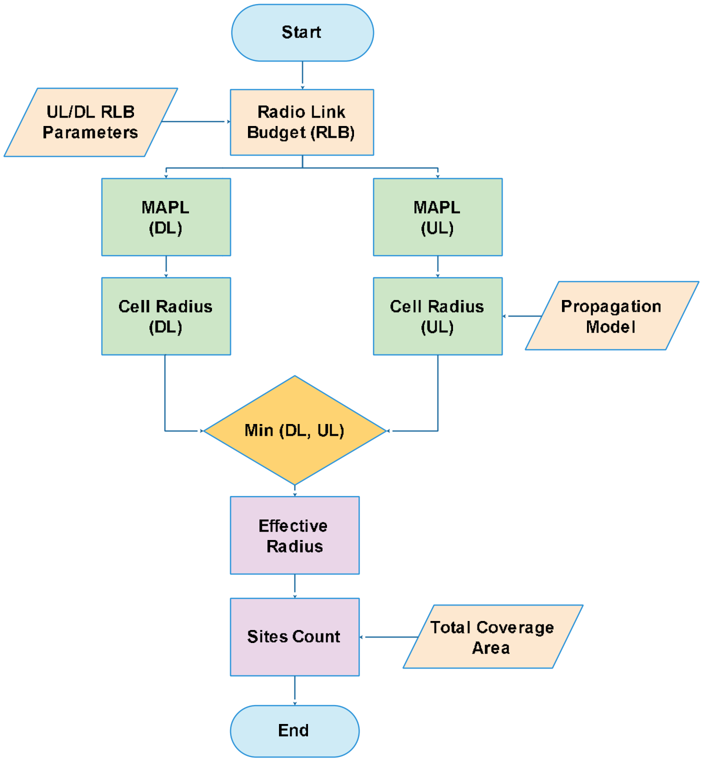


Figure 3. 3: Summarized LTE coverage planning process [36].

3.3.1. Propagation Models

In a wireless cellular communications system, the information (either voice or data) is transmitted by using electromagnetic waves between transmit and receive antennas. The electromagnetic waves signal strength becomes weak during its propagation through the environment [37]. The signal strengths difference from the transmitter antenna to the receiver antenna is called Path Loss (PL).

In order to determine the PL, a radio wave propagation models (path loss models) are used. Propagation models are mainly classified in two major categories, i.e., empirical models and deterministic models. Empirical models are based on practically measured data and consider all environment factors, whereas the deterministic models are based on theoretical analysis and they can be applied in different scenarios without affecting the accuracy [38].

This study is based on the empirical model and the main empirical RF propagation models that are currently used with LTE path loss prediction are briefly discussed here.

3.3.1.1. Okumura-Hata Model

This model applies for macro-cell coverage planning where the configuration of the base station antenna height is usually higher than the surrounding obstacles. The main propagation loss for this model is the diffraction and scattering over rooftops near the mobile station. This model can be used for a frequency range 150 – 1000 MHz and 1500 – 2000 MHz, either DU, U, SU, or RU terrain morphologies, with mobile antenna height of 1 – 10 m and 30 – 200 m BTS antenna height. Path loss predictions based on the Okumura-Hata model can be done by using the following formula [34]:

$$PL = A + BLog(f) - 13.82Log(h_{bs}) - a(h_m) + [44.9 - 6.55Log(h_{bs})]Log(d) + L_o \qquad (3.1)$$

Where, f is the frequency in MHz, h_{bs} is the BTS antenna height in meter (m), $a(h_m)$ is a function of the mobile station antenna height (h_m). The distance between the BTS and MS is given by d in kilometer (km) and L_o give the attenuation due to land usage classes. The function of the mobile station antenna height $a(h_m)$ has different values depend on the size of the area and given by the general formula as:

For Small/Medium-sized city:

$$a(h_m) = (1.1Log(f_c) - 0.7)h_m - (1.56Log(f_c) - 0.8) \qquad (3.1a)$$

For a large-sized city:

$$a(h_m) = 8.25[Log(1.54h_m)]^2 - 1.1, \quad \text{for } f_c \leq 200MHz \qquad (3.1b)$$

$$a(h_m) = 3.2[Log(11.75h_m)]^2 - 4.97, \quad \text{for } f_c \geq 200MHz \tag{3.1c}$$

The constants A & B varies with frequencies:

For 150 – 1000 MHz, A=69.55, B=26.16

For 1000 – 2000 MHz, A=46.3 and B=33.9

3.3.1.2. COST231 - Hata Model

European Union Forum for Cooperative Scientific Research (COST) has developed this model to extend the frequency range of Okumura –Hata propagation model. The path loss prediction for COST231 – Hata model is give by the following formula [34]:

$$PL = 46.3 + 33.9Log(f) - 13.82Log(h_{BS}) + [44.9 - 6.55Log(h_{BS})]Log(d) - a(h_{UE}) - C_m \tag{3.2}$$

Where d is the distance (Km) between the transmitter and the receiver antenna, f is the frequency used in MHz, $h_{UE}$is UE antenna height (m), $h_{BS}$is BTS antenna height (m), C_m is 0 dB for suburban and 3 dB for urban areas. The parameter $a(h_{UE})$ is mobile station antenna height correction factors and it is defined for different areas as follows:

Urban areas: $a(h_{UE}) = 3.2[Log(11.75 * h_{UE})]^2 - 4.79$ (3.2a)

Suburban/Rural: $a(h_{UE}) = [1.11Log(f) - 0.7]h_{UE} - [1.5Log(f) - 0.8]$ (3.2b)

3.3.1.3. Ericsson 9999 Model

This model was developed to improve the Okumura – Hata and COST231 – Hata models by considering the propagation environment. It adds clutter adjustment to accommodate more morphology (DU, U, SU, and RU). This model was developed by Ericsson and it can be applied with a frequency range of 150 MHz to 2 GHz, with BTS antenna height from 20 to 200 m and a mobile antenna height from 1 to 5m. The PL of this model can be estimated by the following formulas [18]:

$$PL = A_0 + A_1Log(d) + A_2Log(h_{eNB}) + A_3Log(h_{eNB})Log(d) - 3.2[Log(11.75 * h_{UE})]^2 + g(f) \tag{3.3}$$

$$g(f) = 44.49Log(f) - 4.78[Log(f)]^2 \tag{3.3a}$$

Where d is the distance between the eNodeB and the UE, h_{eNB} and h_{UE} are the effective height of the eNodeB and the UE antennas respectively. f is the frequency in MHz and the parameters, A_0- A_3 are constants with default values 36.3, 30.2,-12.0 and 0.1 respectively.

There are other propagation models that can be used in LTE coverage prediction as shown in the Table 3.1. These propagation models are differing to each other by the frequency range and the applicable geographical property. The main point here is that, in order to have good coverage prediction, it is important to select the appropriate propagation model by comparing propagation models suitable for planned area using simulation (for instant in Matlab). If the model is not selected correctly, either it is overestimating or underestimating the path loss and hence the predicted coverage. It is also advisable to tune the selected propagation model using CW data.

Model	Frequency range (MHz)	Geo data	Recommended use
ITU 529-3	300 – 1500	Terrain profile, Statistical clutter at the receiver	$1 < d < 100\ km$
Standard Propagation Model	150 – 3500	Terrain profile, Statistical clutter	$1 < d < 20\ km$
Sakagami Extended	3000 – 8000	Terrain profile, Statistical clutter	$1 < d < 20\ km$
CrossWave Model	150 – 5000	Terrain profile, Statistical or deterministic clutter	For all cell types
WinProp-ProMan	150 – 3500	Building database, terrain profile	$0.02 < d < 35\ km$

Table 3. 1: Propagation Models applicable to LTE [39].

3.3.2. Radio Link Budget (RLB) Parameters and Formulas

The objective of the RLB is to identify the Maximum Allowable Path Loss (MAPL) between the transmitter and receiver for both the UL and DL direction. By comparing the MAPL with the PL of the appropriate propagation model, the cell radius can be calculated for different terrain morphologies. The RLB considers many factors that affect the final cell coverage. These factors includes building penetration loss, feeder loss, antenna gain, and the interference margin of radio links to calculate all gains and losses.

The RLB parameters can be grouped as propagation related parameters, equipment related parameters, and LTE specific parameters. Propagation related parameters include the penetration loss, body loss, feeder loss, and background noise. The equipment related parameters are the specification given by the manufacturer such as transmitter power, receiver sensitivity, and antenna gain. The LTE specific parameters include interference margin, fast fading margin, edge coverage rate and MIMO type used. In this section the main parameters are discussed.

- ***eNodeB Maximum Total Transmitter Power***: Refers to the transmit power value per transmitting (TX) path. Typical value is either 43dBm (20W) or 46 dBm (40W) [18].
- ***eNodeB Antenna Gain:*** The selection of antenna gain depends on the clutter type and coverage requirement. The low gain antenna (15–17 dBi) can be used in dense urban and urban clutters while a high gain antenna (18–20 dBi) can be used in rural areas and highways to extend the RF coverage.
- ***UE Maximum Total Transmitter Power***: It refers to the UE transmit power which depends on the power class of the UE. Currently only one power class is defined in 3GPP TS 36.101; class 3 with maximum transmitter power of 23 dBm.
- ***UE Antenna Gain***: Based on the specifications of 3GPP, UE(s) are assumed to have an integral antenna only with a gain of 0 dBi for each antenna port(s) [24].
- ***Body Loss***: It is a loss generated due to signal blocking and absorption, when UE antenna is close to the body of the user. For UE such as USB dongle, Wireless Fidelity (WiFi) device, and an LTE fixed router the position of the antenna is far from the user's body and thus the body loss is ignored. Whereas for mobile terminals (smart phones for instant) they are close to the user's body and the body loss must be considered in the link budget; typical value 3 dB.

- ***Feeder Loss***: Feeder loss considers the losses due to RF feeder, RF jumpers and connectors in the path between the antenna and the eNodeB. In a distributed eNodeB, the baseband unit and RF unit (Remote Radio Units (RRU)) are separated, only the loss of the jumper between the RRU and antenna is considered with typical value of 0.5 dB loss. On the other hand, if the eNodeB is not a distributed type, feeder losses may be 3 dB or more according to the feeder and its connectors characteristics [23].
- ***Equivalent Isotropic Radiated Power (EIRP)***: Indicates the power that would be radiated by the theoretical isotropic antenna to achieve the peak power density observed in the direction of maximum antenna gain. In LTE the EIRP in the DL is calculated based on the total number of RB due to the OFDMA while in the UL the allocated RB are only used due to the SC-FDMA (3 RBs). The EIRP per subcarrier in the DL and UL are calculated as follows [18]:

$$EIRP_{DL}^{SC} = P_{eNB(sc)} + AG_{eNB} - F_L + M_G \tag{3.4}$$

$$EIRP_{UL}^{SC} = P_{UE(sc)} + AG_{UE} - B_L \tag{3.5}$$

  Where $P_{eNB(sc)}$ and $P_{UE(sc)}$ are the power per subcarrier in the DL and UL respectively, AG_{eNB} is the eNodeB antenna gain, F_L is feeder loss, M_G is the MIMO gain, AG_{UE} is the UE antenna gain, and the $B_L$is the body loss.

- ***Cell Edge User Throughput***: It is the minimum net single UE target throughput requirement to be achieved at the cell edge. It determines the service that can be provided at the cell edge; accordingly it can limit the minimum Modulation and Coding Scheme (MCS) to be used. This parameter usually provided by the network operator based on the required services at cell edge. A typical value for UL can be 512 kbps to 1 Mbps where as in the DL it can be 1 Mbps up to 4 Mbps.
- ***Signal to Interference Noise Ration (SINR)***: It is the threshold of the receiver that can demodulate the signal for the UL and it is related to the MCS for the DL. SINR values are obtained from the system level simulation result and it depends on the receiver design. Thus SINR is a vendor specific parameter.

- ***Noise Figure***: It is a key factor to measure the receiver performance. It is defined as the ratio of the input SINR at the input end to the output SINR at the output end of the receiver. The noise figure depends on the bandwidth and the eNodeB capability. A typical value for the noise figure is between 6 to 8 dB [15].
- ***Receiver Sensitivity***: Receiver sensitivity determines the signal level (threshold) at which the RF signal can be detected with a certain quality. It refers to the antenna connector and should take into account the further demodulation and the required output signal quality. The receiver sensitivity per subcarrier can be calculated as follows [15]:

$$Rx_{S(SC)} = SINR + NF + NP + 10Log(SC) \qquad (3.6)$$

Where SINR is the threshold of the receiver that can demodulate the signal, NP is the density of the thermal white noise power which is -174 dBm/Hz, SC is the subcarrier and it is 15 KHz in LTE, and NF is the noise figure in dB.

- ***Penetration Loss***: The penetration loss indicates the fading of radio signals due to building obstruction from an indoor terminal to the eNodeB and vice versa. It depends on the nature of the buildings and the clutter type of the targeted coverage area. Table 3.2 summarizes a typical penetration losses range for different clutters [18].

Clutter type	Penetration loss range (dB)	Typical values (dB)
Dense urban	19 – 25	19
Urban	15 – 18	15
Suburban	10 – 14	11
Rural	5 – 8	8

Table 3. 2: Penetration losses range based on clutter type [18].

- ***Shadow Fading Margin***: Indicates the fading due to obstruction like building. To minimize the effect of shadow fading and ensure a certain edge coverage probability, certain allowance is required. This allowance is called the “slow fading margin” or the “shadow fading margin”. The Standard deviation of slow fading is used to determine the slow fading difference and it shows the distribution of the radio signal strength at different test points at similar distance from the transmitter. The standard deviation of slow fading varies from 5 dB to 12 dB depending on the clutter type [36]. Table 3.3 shows the typical value of standard deviations based on the clutter type.

Clutter Type	Standard deviation of slow fading (dB)
Dense urban	10
Urban	8
Sub urban	6
Rural	6

Table 3. 3: Standard deviation of slow fading typical value [36].

The slow fading margin can be obtained by using a Q function[1] from the cell edge coverage probability and standard deviation of slow fading as shown in the following formula [36]:

$$E_{cp} = 1 - Q\left(\frac{F_M}{Std_{sf}}\right) \quad \textbf{(3.7)}$$

$$F_M = [Q^{-1}(1 - E_{cp})] \times Std_{sf} \quad \textbf{(3.8)}$$

Where: -

E_{cp}: $Cell\ Edge\ Coverage\ Probability$

F_M: $Fading\ margin$

Std_{sf}: $Standard\ deviation\ of\ slow\ fading$

The cell edge coverage probability (edge reliability) depends on the assumed standard deviation of slow fading and the shadow fading margin. When the standard deviation grows for same fading margin, the edge reliability is reduced where as to maintain the same edge reliability, as the standard deviation grows; a larger fading margin is required. Figure 3.4 shows the Cumulative Distribution Function (CDF) for shadow fading when the shadow fading standard deviation is 10, 8, and 6 dB for dense urban, urban, and suburban/rural clutter type respectively.

---

[1] The Q function is expressed as $Q(z) = \int_z^\infty \frac{1}{\sqrt{2\pi}} * e^{(-\frac{y^2}{2})} dy$

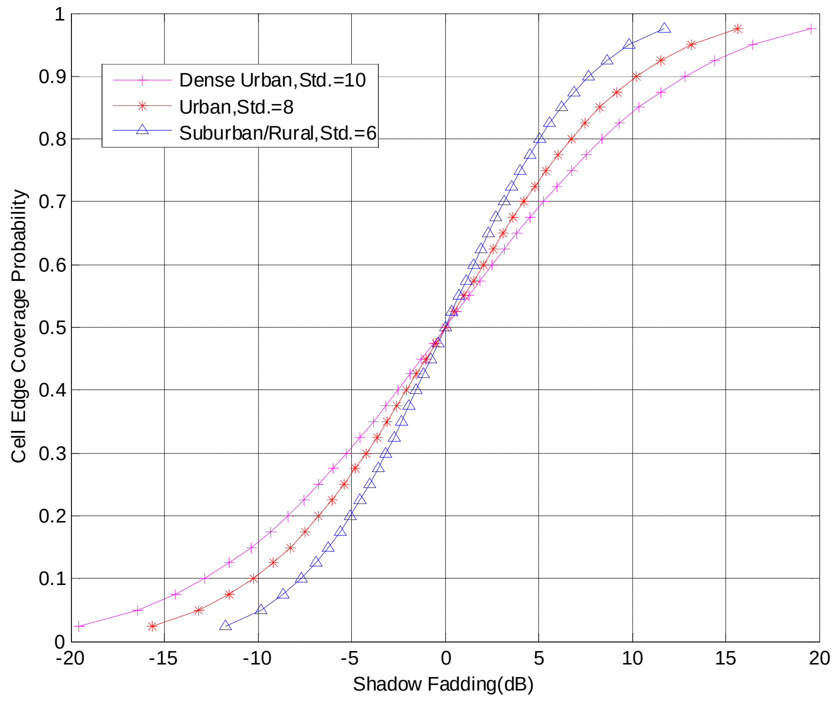


Figure 3. 4: Cumulative distributions function for shadow fading.

Based on the above described main link budget parameters and the common parameters, the MAPL will be calculated as the difference between the EIRP and the overall loss. Table 3.4 demonstrate the link parameters and the formulas used for both UL and DL by classifying parameters as general parameters, transmitter side parameters, receiver side parameters, and clutter parameters. In Chapter 4, this table will be used separately for the UL and DL to clearly show the parameter difference between the UL and DL budget.

LTE Radio Link Budget	
Parameters	Downlink/Uplink Budget Variable
General Parameters	
Morphology	DU,U,SU,RU
Data Channel Type	PDSCH/PUSCH
Duplex Mode	FDD,TDD
User Environment	Indoor, Outdoor
System Bandwidth (MHz)	LTE Bandwidths
Cell Edge Rate (kbps)	1024/512
Transmitter(eNB/UE) Side Link Budget Parameters	
Max Total Tx Power (dBm)	A
Allocated RB (Radio Resource)	B
RB to Distribute Power	C
Subcarriers to Distribute Power	D=12*C
Subcarrier Power (dBm)	E=A-10*Log10(D)
Transmitter Antenna Gain (dBi)	G
Transmitter Cable Loss (dB)	H
Transmitter Body loss (dB)	I
EIRP per Subcarrier (dBm)	J=E+G-H-I
Receiver(UE/eNB) Side Link Budget Parameters	
SINR (dB)	K
Receiver Noise Figure (dB)	L
Receiver Sensitivity (dBm)	M=K+L-174+10*Log10(15KHz)
Receiver Antenna Gain (dBi)	N
Receiver Cable Loss (dB)	O
Receiver Body loss (dB)	P
Interference Margin(dB)	Q
Minimum Signal Reception Strength(dBm)	R=M-N+O+P+Q
Clutter Link Budget Parameters	
Indoor Penetration Loss (dB)	S
Shadow Fading Margin (dB)	T
Maximum Allowable Path Loss (MAPL)	
MAPL(dB)	U=J-R-S-T

Table 3. 4: LTE Radio Link Budget DL/UL Parameters [18].

3.3.3. Cell Area and Site Count

Once the MAPL value is calculated for both UL and DL based on Table 3.4, the next step in the coverage planning is to determine the cell radius by using the appropriate propagation model. With the assumption that cell coverage area as being hexagonal in shape, the cell area can be calculated using the cell radius found from the MAPL.

As shown in the Figure 3.5, cell area depends on the site configuration. It can be Omni-directional, 2-sector, or 3-sector sites and thus the cell radius is calculated for each configuration. Finally the total site count is calculated by dividing the targeted coverage area by single site area as shown in the formula (3.12).

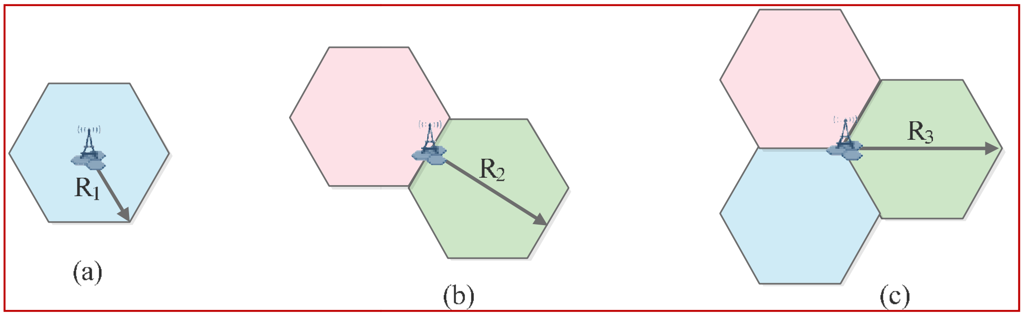


Figure 3. 5 : Type of site configurations, (a) Omni-directional, (b) 2-sector, (c) 3-sector.

For each type of site configuration shown above in Figure 3.5, the site area is calculated as follows [4]:

For Omni-directional

$$Site\ Area\ (A_{S1}) = \frac{3}{2}\sqrt{3} * [R_1]^2 \qquad \textbf{(3.9)}$$

For 2 - Sectors (Bi-sector)

$$Site\ Area\ (A_{S2}) = \sqrt{3}[R_2]^2 \qquad \textbf{(3.10)}$$

For 3 - Sectors (Tri-sector)

$$Site\ Area\ (A_{S3}) = \frac{9}{8}\sqrt{3} * [R_3]^2 \qquad \textbf{(3.11)}$$

Finally, the site count based on coverage is calculated as follows:

$$Total\ Number\ of\ Site(NS_C) = \frac{Target\ Coverage\ Area}{Site\ Area} \qquad \textbf{(3.12)}$$

3.4. LTE Capacity Planning

After the estimation of the cell size and sites count from the coverage prediction, the capacity estimation is carried out to verify whether the given sites count can carry the estimated users capacity. According to Shannon capacity definition, capacity is the maximum achievable set of rates in multiple access channels with a randomly small probability of error. As this metric represents a bound in performance, an aggregated transmitted data rates is considered. With the increased data usage all over the world, the system capacity could be defined as the maximum aggregated data rate subject to the given QoS target [40].

3.4.1. Capacity Dimensioning Process

The aim of LTE capacity dimensioning is to obtain the packet switch throughput supported by the network based on the available bandwidth and channel condition of each user. A summarized capacity planning process is shown in the Figure 3.6.

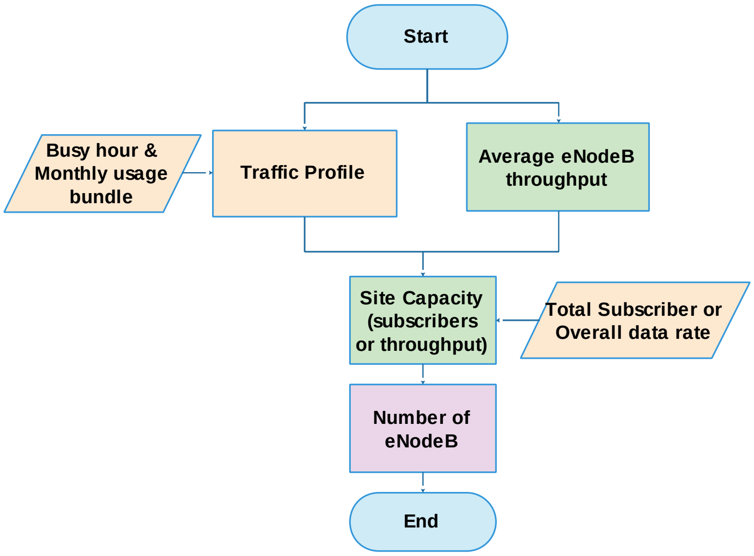


Figure 3. 6: Summarized capacity planning process [36].

As shown in the process the evaluation of capacity needs two tasks to complete the estimation; namely:

- Throughput estimation corresponding to the configuration analysis;
- Estimating the supported subscriber per cell or sites depending on the traffic model.

Given that the required total subscriber capacity is known, which can be a forecasted subscriber, capacity based sites counts will be determined to cater the total traffic demand in the network.

3.4.2. Average Sector/Cell Throughput Calculations

The average sector/cell throughput is an important factor in the LTE capacity dimensioning. The estimation can be obtained via simulation or based on the field measurement. There are three approaches which can be used to get the average sector throughputs in LTE [4] [18] [40].

1. Vendor's Approach

In this approach, the vendors assume the average eNodeB throughput form their experience, either from the simulation environment or field measurement. Once the eNodeB throughput is known, the maximum subscriber supported per eNodeB can be estimated by assuming the data volume of each subscriber per month and their throughput during busy hour. A simplified calculation of this approach is shown in the Table 3.5.

Parameter	Variable	Remarks
Data volume/Month/Subscriber	a	Given by the operator
Days/Month	b	30 days
Busy hour to whole day traffic ratio (%)	c	Given by the operator
Busy hour throughput per subscriber (kbps)	d	d=(((a*8*10^6)/b)*c)/3600
Average eNodeB throughput (Mbps)	e	Given by the vendor
Maximum subscriber supported per eNodeB	f	f=(e*1000)/d
Total subscriber	g	Given by the operator
eNodeB required	h	h=g/f

Table 3. 5: Capacity based sites count based on vendor's approach [40].

2. Simulation-based Approach

This approach derive cell throughput by using simulations. It requires two simulations; a system level simulation, which provides the SINR probability from the average SINR distribution table and a link level simulation, which provided the average throughput or spectral efficiency versus average SINR table.

A link level simulation emulates all the aspects of a communication link between a transmitter and receiver. It allows for the investigation of MIMO gains, Adaptive Modulation & Coding (AMC) feedback, modeling of the channel code, and retransmissions. On the other hand, the system level simulations gives the performance of the whole network by analyzing a multitude of eNodeBs that cover a specific area in which many mobile terminals are located and moving around [41].

In this capacity approach, the SINR probability obtained by calculating the probability of occurrences of a given SINR value at cell edge. Then the SINR values to support each MSC are derived from look-up tables that are generated from link level simulations. Thus, the cell throughput can be derived as follows [4]:

$$Cell_{Throughput} = \sum_{SINR}\left(SINR_{OccPro} * SINR_{AveThroughput}\right) \tag{3.13}$$

Where: $SINE_{OccPro}$ is SINR occurrence probability of a specific SINR value at cell edge obtained using the simulation and $SINR_{AveThroughput}$ is the average throughput corresponding to SINR values. Once the cell throughput is calculated by the above formula, the capacity based sites count can be calculated using Table 3.6:

Parameter	Variable	Remarks
Average cell throughput	a	From equation 3.13
Peak to Average data rate	b	%
Utilization factor	c	%
Overbooking factor	d	d=b*c
Number of users	e	Given by the operator
Peak data rate	f	
Overall data rate	g	g=d*e*f
Site capacity	h	h=a*Number of Sectors
eNodeB required	i	i=g/h

Table 3. 6: Capacity based sites count based on simulation based approach [4].

3. Based on the available Traffic Channel RB

The DL and UL achievable throughput are impacted by the total BW (1.4, 3, 5, 10, 15, and 20 MHz), the total overheads, and the spectral efficiency. In LTE system, the UL capacity is divided between control channels (signals) and the traffic channel, that is, Physical Uplink Shared Channel (PUSCH). Likewise, the DL capacity is divided between control channels (signals) and the traffic channel, Physical Downlink Shared Channel (PDSCH).

This approach determines the average sector throughput by calculating the available RB of the traffic channels. Here the computation of the PDSCH is shown as follows and a similar technique can be employed to get the average sector throughput based on the available RB for PUSCH [18]:

- Determine the available RB for PDSCH

$$Available\ RB_{PDSCH} = Total_{RB} - Fixed_{Overhead} - Control\_CH_{Overhead} - Pagging\_Ch_{overhead} \tag{3.14}$$

- Calculate the available symbols for PDSCH

$$Available_{Symbols} = Available\ RB_{PDSCH} * NSC_{RB} - NSY_{SC} \tag{3.15}$$

- Total PDSCH throughput capacity per sector carrier

$$Total_{Throughput} = Available_{Symbols} * Spectral\ efficiency \tag{3.16}$$

Where: $Available\ RB_{PDSCH}$ is the available RB for PDSCH by subtracting the overhead from the total RB. $Available_{Symbols}$ is the available symbols, NSC_{RB} is the number of subcarrier per RB=12, NSY_{SC} is the number of symbols per subcarrier (6 or 7).

Thus, the average sector throughput, in Mbps, at a certain DL loading can be calculated as follow:

$$Average\_S_{Throughput} = \left[AvailableRB_{PDSCH} * DL_{Loading} * Total_{Throughput}\right]/1000 \tag{3.17}$$

Once the cell throughput is calculated by the above formula, the capacity based sites count can be calculated by using Table 3.7.

Parameter	Variable	Remarks
Average Sector throughput	a	From equation 3.17, Mbps
Peak to Average data rate	b	%
Average DL busy hour throughput per Subscriber	c	From traffic profile (kbps)
Number of Sector per Site	d	(6,3,2, or 1)
Subscribers Supported per a site	e	e=(a*d)/((1+b)*c)
Total number of Subscribers in the network	f	Given by the operator
eNodeB required	g	g=f/e

Table 3. 7: Capacity based sites count based on available traffic channel RB [18].

3.4.3. Capacity Based Sites Count

The capacity based sites count can be calculated using two methods. The first method is to get the subscriber number supported per site as shown in the 1st and 3rd approaches above and then the capacity based site count is calculated by the following formula:

$$Capacity\ based\ sites\ Count\ = \frac{Total\ subscriber\ supported\ in\ the\ network}{Subscriber\ supportd\ per\ site} \qquad \textbf{(3.18)}$$

On the other hand, the second method uses the simulation-based approach by determining the site throughput and calculates the sites count as follows:

$$Capacity\ based\ sites\ Count\ = \frac{Netowrk\ overall\ data\ rate}{Site\ data\ rate} \qquad \textbf{(3.19)}$$

3.5. Pre-deployment Optimizations

Like other cellular networks, such as GSM or UMTS, LTE network also requires optimization after deployment in order to provide better coverage and throughput. The optimization process incorporates several steps. It starts with drive testing (data service) where all performance parameters are tested and logged-in after the network is on-air. Based on the collected data, the RF planning engineers analyze the network performance and may suggest parameter optimization such as antenna height, azimuth, tilt (mechanical or/and electrical), and neighboring cell parameters [42].

Usually, the optimization process is an iterative one with no specific steps involved; rather it is a set of consistent procedures that characterizes network performance and coverage in the target area. Target network performance can be evaluated in terms of RSRP, SINR, and handover success rate as described in [43]. A summarized LTE optimization process is shown in Figure 3.7. The process starts by establishing optimization objective for RSRP, SINR, and handover success rate. Then, drive test and radio measurement will be performed to check whether the desire KPI is achieved or not. If KPI targets are not achieved, problem analysis in terms of coverage and handover will be performed to find out the root causes. Finally, parameter adjustment and implementation will be done based on proposed solutions to finalize the optimization task.

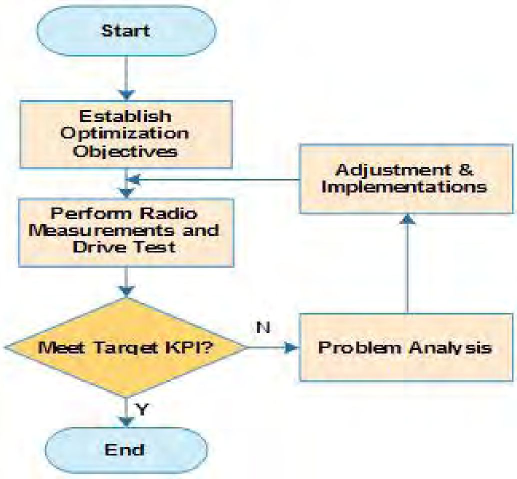


Figure 3. 7: A summarized LTE optimization process [43].

As this study revolves on radio network planning for green-filed scenarios (new deployment), the above optimization process are not entertained here; rather a pre-deployment optimization is carried out as an early optimization. The pre-deployment optimization focuses on determining appropriate sites locations and physical configuration to meet the network objectives defined in the nominal planning and link budget. This can be achieved by sites location rearrangements and initial antenna parameters adjustments as stated below [18]:

3.5.1. Sites location rearrangements

In case of green filed scenarios, initial sites placement is done with the help of RNPO tools to get the initial sites footprint. These initial sites footprint may be positioned inappropriate places such as roads, rivers, and others restricted areas. As part of the early optimization these inappropriate site locations should be rearranged at least to feasible locations that can be further verified during sites survey.

3.5.2. Initial antenna parameters adjustments

In the initial green-filed planning, antenna parameters such as azimuth and tilts are used uniformly thought the entire sites in the target area for simplicity during early planning works. These parameters are required to be adjusted based on target network terrain condition and coverage analysis result from the RNPO tool. These adjustments can be achieved either manually, by treating each sites individually, or for the whole network by using the RNPO tool.

In general, all the issues addressed under Chapter three showed on how to get the sites count in terms of coverage and capacity. As it is described in Figure 3.2, the maximum of the two will be taken to further analyze and make the prediction by incorporating the selected area clutter conditions. This is done by simulating the parameters using network planning tool to get the optimal value. Since the sites count is determined by considering the area as being geographically flat (only mathematical computation), during prediction we may face holes due to the selected area terrain situation. Thus a pre-deployment optimization, i.e. rearrangement of antenna height, azimuth, tilt, site initial location rearrangements or increasing the number of sites will be considered until the optimal prediction result is obtained.

In the next chapter, Chapter 4, the required parameters are determined for both coverage and capacity. Based on the maximum sites count, the coverage prediction and capacity evaluation are done using RNPO tool. In addition, the analysis and interpretation of simulation results are discussed to evaluate the result based on the given requirements.

Chapter 4: Simulation and Result Analysis

4.1. Overview

The nominal and detailed planning process (including the input and output parameters) from coverage and capacity perspective were discussed in Chapter 3 above. By using Chapter 3 as guidance, in this chapter the actual planning task for both nominal and detailed planning will be performed.

The chapter starts by defining the target network requirements and continue to show all the required input and output parameters for both coverage and capacity planning. The coverage based sites count will be calculated using the RLB and considering the capacity requirement of the target network, the sites count based on the capacity will be calculated. Finally, the maximum of the two will be taken as the final sites count for the target area.

Once the final sites count found, the nominal planning phase is completed and the parameters found in the nominal planning phase will be an input to the detailed planning phase. In the detailed planning phase, the parameters will be simulated by using RNPO tool. Finally, the planned network result will be evaluated whether it meets the target requirement or not.

4.2. Target Network Requirements

In this study one of the sub cities in Addis Ababa called Kirkos sub city is selected to study the coverage and capacity characteristics of the LTE network. The morphology of this sub city is considered as dense urban with a requirements of continues coverage area of 14.91 km^2. In this sub city, there are different hotspot areas including international hotels, government offices, different banks and the Economic Commission for Africa (ECA). Thus the choice of LTE network for this sub city is the right decision as users in this area would require substantial Internet speed and connectivity.

In LTE network planning, the target radio network should compromise between coverage and capacity. The coverage objectives should meet the business requirements of the operator by minimizing the expenditure; on the other hand, the target network should also be evaluated to know how the network is capable to meet the current and future capacity requirements. Thus, the target network requirement is divided into coverage requirement and capacity requirement and both presented separately as follows:

4.2.1. Coverage Requirements

- ***Frequency Band***

Band 3 (1800 MHz) is selected to use in this study. This band is the most promising LTE band as it can be used for nationwide coverage with dense urban, urban, and suburban convergence. Since it is widely used for GSM 1800 MHz, it must be re-farmed to be used for LTE 1800 MHz's. This band is preferred to be used in the deployment of LTE networks. Some of the main advantages for this choice are [18]:

  - Coverage area is about 2x larger than LTE 2.6 GHz with better indoor coverage;
  - 35% improvement in cell edge throughput compared to LTE 2.6 GHz;
  - Availability of LTE terminals in this band.

- ***Reference Signal Received Power (RSRP)***

In LTE network, each UE's are required to measure the signal strength of its own and neighbor cells in order to keep the signal quality to be constant while it is in idle mode, connected mode, or during handover. One of the measurements that UE's perform during handover, cell selection or re-selection is the RSRP. RSRP is the linear average of the downlink reference signals across the channel bandwidth. It provides information about signal strength.

According to the 3GPP specification [44], the reporting range of RSRP is defined from -140 dBm to -44 dBm. In this thesis, the RSRP is assumed to be greater than/or equal to -110 dBm (≥-110 dBm) in order to have a better signal strength through the selected area.

- ***Cell-edge Coverage Probability***

All radio coverage is based on probability theory. Since radio coverage cannot be guaranteed 100%; radio coverage at a specific location, some distance away from a transmitter, can be specified as 50%, 90%, or more. As it is discussed in Chapter 3, the cell edge coverage probabilities depend on the fading margin, it is the safety factor used to determine the level of probability of successful radio communication. Thus in this thesis work, it is assumed to have a cell-edge coverage probability of 83%, and hence a fading margin of 9.34 dB is used during RLB calculation.

- ***Area Coverage Probability***

Area coverage probability tells how much present of the target area will be covered by the planned network. In this study, the coverage probability is assumed to cover 95% of the target area. That is, the target network would cover 95% of the selected area for the above mentioned value of RSRP.

4.2.2. Capacity Requirements

- ***Cell-edge throughput in Downlink (DL) and Uplink (UL)***

Cell-edge throughput design target in the downlink and uplink are assumed to be 1024 kbps & 512 kbps respectively. From the downlink perspective the target network provides 1 Mbps anywhere at any time in the target deployment area.

- ***Total number of subscriber***

The number of subscribers is highly relevant input for capacity planning in determining the sites count. In order to have a network, capable enough to accommodate the upcoming subscriber's growth, subscriber forecasting is a very important task to be completed before starting network planning. Thus, understanding which social and economic factors affects the number of subscribers for the given market and predicting how the subscriber number will evolve within the upcoming years are extremely important.

In order to show the contribution of all such factors for successful network capacity planning, in this study the following assumptions are made.

Assumptions:

- Total LTE subscriber in Addis Ababa is assumed to reach 400,000 in the year 2022;
- Age group of potential LTE subscribers is assumed to be 20-65 years old;
- Population census data per sub city taken on 1st July 2007 [45] is considered to assume population growth per sub city in the year 2022;
- Accordingly, the projected population growth of Addis Ababa city in the year 2022 [46] is considered and distributed per sub city using population ratio as indicated in Table 4.1.

Finally, the number of LTE subscriber per sub city is determined based on the following formula:

$$T_{SS} = \left(\frac{T_{SA}}{T_{PA}}\right) \times P_{PS} \quad \textbf{\textit{(4.1)}}$$

Where: - T_{SS} : The total LTE subscriber per sub city

T_{SA} : The total LTE subscriber in Addis Ababa city

T_{PA} : The total population in Addis Ababa city

T_{PS} : The projected population of a sub city

Thus, the total number of LTE subscriber for Kirkos sub city is found to be 34,072 as shown in Table 4.1. Which means the sub city will have 8.52% share from the total LTE subscribers assumed in the capital.

Geographical Area (Sub-City)	Population of sub city's 20-65 Year Age 1 July 2007	Population Ratio	Projected Population of sub city's 20-65 Year Age 1 July 2022	Total Projected Subscriber (Based on population ratio)	Subscriber (%)
AKAKI KALITI	101,873	0.06	154,496	25,296.24	6.32%
NEFAS SILK-LAFTO	182,188	0.11	276,298	45,239.37	11.31%
KOLFE KERANIYO	235,071	0.15	356,498	58,370.83	14.59%
GULELE	158,346	0.10	240,140	39,319.13	9.83%
LIDETA	128,689	0.08	195,164	31,954.96	7.99%
KIRKOS	137,214	0.09	208,092	34,071.81	8.52%
ARADA	130,307	0.08	197,618	32,356.72	8.09%
ADDIS KETEMA	150,105	0.09	227,642	37,272.79	9.32%
YEKA	204,388	0.13	309,966	50,751.89	12.69%
BOLE	182,699	0.11	277,073	45,366.26	11.34%
Total (ADDIS ABABA CITY)	1,610,880	1.00	2,442,987	400,000.00	100.00%

Table 4. 1: LTE subscriber number distribution assumption per sub cities.

- ***Data volume per month***

Data volume per month is an accounting solution by which a user can buy a certain amount of data service. In the capacity estimation, the data service is expressed by a certain amount of data volume per month per subscriber. In this study, three types of data service packages are offered for users; Gold, Silver, and Bronze with a data volume per month per subscriber of 20 GB, 15 GB, and 10 GB respectively as it is shown in Table 4.2.

Parameters description	User Service Category		
	Gold	Silver	Bronze
Data Volume per Month per Subscriber (GB)	20	15	10

Table 4. 2: Users service category.

4.3. Coverage Planning

As it was mentioned in Chapter 3, the coverage planning evaluates the DL and UL RLB to get the MAPL in order to calculate the cell radius. As part of the nominal planning, the coverage planning starts by setting RLB parameters value. Using the RLB parameters and appropriate propagation model the cell radius is calculated.

4.3.1. Radio Link Budget

The RLB parameters for the DL and UL are treated in here separately. According to the definition and formulas in Chapter 3, the assumed and calculated values are shown in Table 4.5 and Table 4.6 for DL and UL respectively. However, a special attention has been given for SINR and Shadow fading margin as they contribute much towards achieving cell edge throughput and cell edge coverage probability requirements respectively.

4.3.1.1. SINR Calculation

As it was discussed in Chapter 3, SINR values are obtained from the system level & link level simulation result. Since they are dependent on the receiver design, the SINR values are fully vendor specific. However in this study, a modified Shannon capacity formula is used to get the SINR values for both UL & DL with the following assumptions and formula [47]:

Assumptions:

- Cell edge users are allocated 10% of the radio resources (i.e. 10 PRB out of 100 PRB in 20MHz);
- Data rate on cell edge to be 1024 Kbps and 512 Kbps for DL and UL respectively ;
- DL use MIMO 2x2 and UL use SIMO 1x2.

Formula:

$$TP = BW \times M \times A \times Log_2(1 + \frac{SINR}{B}) \qquad \textbf{(4.2)}$$

$$TP = N_{PRB} \times BW_{PRB} \times SE \qquad \textbf{(4.3)}$$

Where: - TP : Cell edge throughput

BW : Bandwidth in terms of PRBs

M : Number of data streams

A & B: Constant factors which are dependent on the number of antennas and physical layer performance. M, A, & B values are given in Table 4.3

MIMO	M	A	B
SIMO 1x2	1	0.62	1.8
MIMO 2x2	2	0.42	0.85
MIMO 4x4	4	0.40	1.1
MIMO 8x8	8	0.33	1.4

Table 4. 3: SINR calculation constant factors A, B, & M [47].

Based on the formula in equation 4.2, and the assumptions made above, the SINR value for UL and DL found to be -1.83 dB and -3.06 dB respectively as shown in the Table 4.4 below:

Parameters Descriptions	Variable	DL	UL
Allocated RB (10% Radio Resource)	B	10	10
Factor A	FA(DL)=2*0.42, FA(UL)=1*0.62	0.84	0.62
Factor B	FB	0.85	1.80
PRB bandwidth (MHz)	PRB	0.18	0.18
Rate per PRB (Mbit/s)	RpP=CER/B	0.1	0.05
Required spectral efficiency (bit/s/Hz)	SE=RpP/PRB	0.56	0.28
SINR (linear)	SL=FB*(2^(SE/FA)-1)	0.49	0.66
SINR (dB)	K	-3.06	-1.83

Table 4. 4: SINR to achieve cell edge throughput.

4.3.1.2. Shadow fading margin Calculation

The slow fading margin can be obtained by using a Q function from the cell edge coverage probability and standard deviation of slow fading as shown in Chapter 3, Equation (3.8). In this work, since the selected area is considered as dense urban, the standard deviation of slow fading will be 10 dB as per the Table 3.3 and with the assumption of 83% cell edge coverage probabilities, the shadow fading margin is found to be 9.34 dB.

LTE Downlink (DL) Radio Link Budget		
Parameters	Variable	Value
General Parameters		
Morphology	DU	
Data Channel Type	PDSCH	
Duplex Mode	FDD	
User Environment	Indoor	
System Bandwidth (MHz)	20	
MIMO Scheme (MS)	2x2	
Cell Edge Rate (kbps)	1024	
Transmitter Side Link Budget: eNodeB Parameters		
Max Total Tx Power (dBm)	A	46
Allocated RB (10% Radio Resources)	B	10
RB to Distribute Power	C	100
Subcarriers to Distribute Power	D=12*C	1200
Subcarrier Power (dBm)	E=A-10*Log10(D)	15.21
Transmitter Antenna Gain (dBi)	G	17
Transmitter Cable Loss (dB)	H	0.5
Transmitter Body loss (dB)	I	0
EIRP per Subcarrier (dBm)	J=E+G-H-I	31.71
Receiver Side Link Budget: UE Parameters		
Factor A	FA=2*0.42	0.84
Factor B	FB	0.85
PRB Bandwidth (MHz)	PRB	0.18
Rate per PRB (Mbit/s)	RpP=CER/B	0.1
Required Spectral Efficiency (bit/s/Hz)	SE=RpP/PRB	0.56
SINR (linear)	SL=FB*(2^(SE/FA)-1)	0.49
SINR (dB)	K	-3.06
Receiver Noise Figure (dB)	L	8
Receiver Sensitivity (dBm)	M=K+L-174+10*Log10(15KHz)	-127.30
Receiver Antenna Gain (dBi)	N	0
Receiver Cable Loss (dB)	O	0
Receiver Body loss (dB)	P	3
Interference Margin(dB)	Q	3
Minimum Signal Reception Strength(dBm)	R=M-N+O+P+Q	-121.30
Clutter Link Budget Parameters		
Indoor Penetration Loss (dB)	S	20
Cell Edge Coverage Probability (%)	Cp	83
Standard deviation of slow fading (dB)	St	10
Shadow Fading Margin (dB)	T	9.34
Maximum Allowable Path Loss (MAPL)		
MAPL(dB)= $\boldsymbol{MAPL_{DL}}$	U=J-R-S-T	123.67

Table 4. 5: LTE Downlink (DL) radio link budget [18].

LTE Uplink (UL) Radio Link Budget		
Parameters	Variable	Value
General Parameters		
Morphology	DU	
Data Channel Type	PUSCH	
Duplex Mode	FDD	
User Environment	Indoor	
System Bandwidth (MHz)	20	
MIMO Scheme (MS)	1x2	
Cell Edge Rate (kbps)	512	
Transmitter Side Link Budget: UE Parameters		
Max Total Tx Power (dBm)	A	23
Allocated RB (10% Radio Resource)	B	10
RB to Distribute Power	C	3
Subcarriers to Distribute Power	D=12*C	36
Subcarrier Power (dBm)	E=A-10*Log10(D)	7.44
Transmitter Antenna Gain (dBi)	G	0
Transmitter Cable Loss (dB)	H	0
Transmitter Body loss (dB)	I	3
EIRP per Subcarrier (dBm)	J=E+G-H-I	4.44
Receiver Side Link Budget: eNodeB Parameters		
Factor A	FA=1*0.42	0.62
Factor B	FB	1.80
PRB Bandwidth (MHz)	PRB	0.18
Rate per PRB (Mbit/s)	RpP=CER/B	0.05
Required Spectral Efficiency (bit/s/Hz)	SE=RpP/PRB	0.28
SINR (Linear)	SL=FB*(2^(SE/FA)-1)	0.66
SINR (dB)	K	-1.83
Receiver Noise Figure (dB)	L	2.3
Receiver Sensitivity (dBm)	M=K+L-174+10*Log10(15KHz)	-131.77
Receiver Antenna Gain (dBi)	N	17
Receiver Cable Loss (dB)	O	0.5
Receiver Body loss (dB)	P	0
Interference Margin(dB)	Q	3
Minimum Signal Reception Strength(dBm)	R=M-N+O+P+Q	-145.27
Clutter Link Budget Parameters		
Indoor Penetration Loss (dB)	S	19
Cell Edge Coverage Probability (%)	Cp	83
Standard deviation of slow fading (dB)	St	10
Shadow Fading Margin (dB)	T	9.34
Maximum Allowable Path Loss (MAPL)		
MAPL(dB)=$MAPL_{UL}$	U=J-R-S-T	121.37

Table 4. 6: LTE Uplink (UL) radio link budget [18].

From the above two tables, the MAPL in the UL path is found to be 121.37 dB and 123.67 dB in the DL path. From this we can see that the downlink path loss is greater than the uplink path and this points out that the area covered by the eNodeB antenna radiation is more than the area covered by the UE antenna; thereby more coverage can be given by the downlink direction.

In order to compute the cell radius, the next action is to accomplish a comparison between the MAPL's with one of the selected empirical models discussed in Chapter 3 for both the DL & UL path. But before that, the propagation model must be selected to identify the appropriate model for the selected area terrain.

4.3.1.3. Propagation Model Selection

There are many different radio propagation models which are available for 1800 MHz band that can be used in different terrains. It is good practice to make a comparison between different radio propagation models in order to find out the model which is suitable for the selected area terrain condition. Thus, in this study the three propagation models, Okumura-Hata, COST231-Hata, and Ericsson 9999 are chosen for the comparison.

The propagation model comparison is done by using Matlab on the basis of path loss, antenna height and transmission frequency. The graph in Figure 4.1 shows the path loss verse cell radius between eNodeB and UE for the above mentioned empirical propagation models. Accordingly, COST231-Hata model shows the maximum path loss as compared to the other two models. Since the worst case scenario must be chosen for a better radio coverage, the COST231-Hata model is selected in the calculation of the cell radius.

In fact not only propagation model comparison but also propagation model tuning is also required in order to estimate optimum cell radius for the target deployment area. But due to lack of continuous wave propagation data (CW) for the target area, this propagation model tuning not made and it is considered as one of the limitation in this study to achieve the compromised cell radius for the target area.

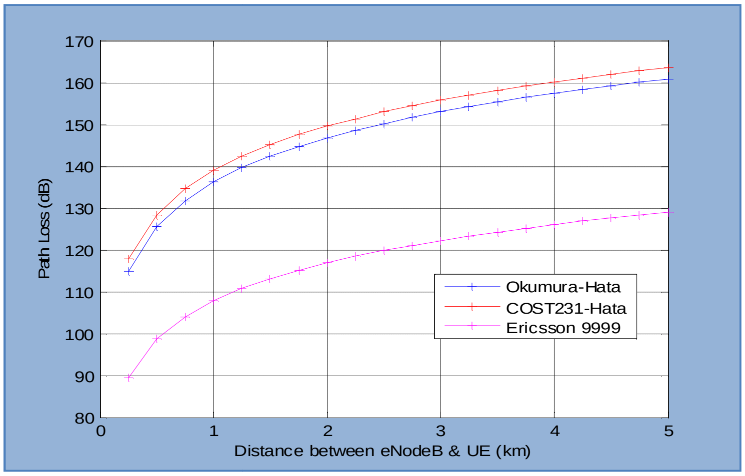


Figure 4. 1: Propagation model comparison.

4.3.1.4. Coverage Based Sites Count

Using the selected propagation model and the UL and DL MAPL, we can calculate the cell radius governed by both the UL and DL path. As it was said earlier in Chapter 3, the effective radius will be the minimum of the radiuses found in the UL and DL path.

Let us consider the eNodeB and UE antenna height to be 30m and 1.5m respectively. The cell radius in the UL path, d_{UL} and the cell radius in the DL path, d_{DL} can be calculated by using COST231- Hata path loss formula in Equation (3.2) as follows:

$$d_{UL} = 10^{[PL_{UL} - 46.3 - 3 - 33.9*\log(f) + 13.02*\log(h_{BS}) + 3.2*((\log(11.75*\log(h_{UE})))^2 + 4.97)/(44.9 - 6.55*\log(h_{BS}))]}$$

$$d_{UL} = 0.41 \text{ Km}$$

$$d_{DL} = 10^{[PL_{DL} - 46.3 - 3 - 33.9*\log(f) + 13.02*\log(h_{BS}) + 3.2*((\log(11.75*\log(h_{UE})))^2 + 4.97)/(44.9 - 6.55*\log(h_{BS}))]}$$

$$d_{DL} = 0.47 \text{ Km}$$

Thus, the effective radius ($R_{ef} = Min\,(d_{UL}, d_{DL})$) becomes 0.41 Km. Table 4.7 shows the summery of the cell radius for UL and DL path as well as the effective cell radius that we can use to calculate the coverage based sites count.

Parameter	UL	DL
eNodeB Antenna Height (m)	30	
UE Antenna Height (m)	1.5	
Frequency (MHz)	1800	
MAPL (dB)	121.37	123.67
Cell Radius (Km)	0.41	0.47
Effective Cell Radius ($\boldsymbol{R_{ef}}$) (Km)	0.41	

Table 4. 7: Cell radius summary (UL & DL).

Now by assuming that all eNodeB's are a three sectored sites (Tri-sector), the site area and the total number of coverage based sites count are calculated by using equations (3.11) & (3.12) respectively as follows:

$$Site\ Area = \frac{9}{8}\sqrt{3} * [R_{ef}]^2 = \frac{9}{8}\sqrt{3} * [0.41]^2 = 0.33\ Km^2$$

$$Total\ Number\ of\ Site = \frac{Target\ Coverage\ Area}{Site\ Area} = \frac{14.91}{0.33} = 45.51 \cong 46\ eNodeBs$$

Therefore, a total of 46 (Forty Six) coverage based eNodeB's are required to provide the radio coverage for 14.91 Km^2 area of Kirkos Sub City.

4.4. Capacity Planning

The capacity planning can be started by estimating the daily traffic as a percentage of the busy hour traffic. As the LTE users in this study are considered to be users that are using smart phones, dongles, and other kind of terminals (fixed or portable), the busy hour assumed to be in different three time segment within the 24 hours of a day. The first segment is from 10:00 AM to 11:00 AM in the morning, the second segment is from 3:00 PM to 4:00 PM in the afternoon, and the third segment is assumed to be from 08:00PM to 09:00PM in the evening. Thus, a total of 3 hours are consider to be the busy hours within 24 hours of a day, which makes the busy hour traffic to be 12.5% of the daily traffic.

The next step in the capacity planning is to determine the average sector/cell throughput by selecting one of the approached discussed in Chapter 3. For this study, the "vendor's" approach is selected for its simplicity and also as it is being exercised by many commercially launched networks in different countries. Since this study doesn't have the intention to reflect any vendor's value, a modification has been made to get the average sector/cell throughput in order to determine the capacity based sites counts as follows:

4.4.1. Data volume/Month/Subscriber

From the given target network requirement, the three service categories mentioned in Section 4.2, are used in the data volume per month per subscriber. From practical point of view, a category couldn't utilize all the 100% service throughout all the time, thus service usage distribution is required and assumed to be 10%, 40%, 50% for Gold, Silver, and Bronze users respectively as shown in the Table 4.8.

Parameters description	User Service Category		
	Gold	Silver	Bronze
Data Volume per Month per Subscriber (GB)	20	15	10
Service usage (%)	10	40	50

Table 4. 8: Users service usage category.

4.4.2. Average eNodeB throughput (Mbps)

Considering a channel bandwidth of 20 MHz, and by assuming the available RB for PDSCH as 85% with 80% downlink loading and an average spectral efficiency of 2.8, the average sector throughput according to equation 3.17 can be calculated as follows:

Average sector throughput (Mbps) = available PDSCH RB%× DL loading% × average spectral efficiency × number of subcarriers per symbol × twice the number of symbols × number of total RB/1000

$= 0.80\times1\times2.8\times12\times14\times100/1000$

$= 37.63$ Mbps

Therefore, for a three sector with 20 MHz channel bandwidth, the average eNodeB throughput can be found by multiplying the above average sector throughput by three. Thus, the average eNodeB throughput for this particular case will be 3×37.63 Mbps = 112.89 Mbps ≅ 113 Mbps.

4.4.3. Capacity Based Sites Count

By taking the values of the user's service category from Table 4.8 and the average eNodeB throughput of 113 Mbps, the maximum subscriber supported per eNodeB can be calculated by using the formula given in Table 3.5 of Chapter 3. Table 4.9 shows the competition of maximum subscribers supported per eNodeB based on the capacity requirements given so far.

Parameters	User Service Category			Remarks
	Gold	Silver	Bronze	
Data Volume per Month per Subscriber (GB)	20	15	10	a
Days per Month	30			b
Traffic Ratio of Busy Hour to Whole Day (%)	12.5			c
Busy Hour Throughput per Subscriber (kbps)	185.19	138.89	92.59	d=(((a*8*10^6)/b)*c)/3600
Service Usage (%)	10	40	50	P
Total Average Busy Hour Throughput per Subscriber (Kbps)	120.37			T=Sum of {Package Percentage(P) × Busy Hour Throughput per Subscriber}
Average eNodeB Throughput for 20 MHz (Mbps)	113			e
Max. Subscriber Supported per eNodeB	939			f=(e*1000)/T

Table 4. 9: Maximum subscribers supported per eNodeB.

From the above Table, a total of 939 subscribers can be supported per eNodeB. Thus the number of eNodeBs required to accommodate the given total number of subscriber (34,072) can be calculated by using Equation (3.18) as follows:

$$Capacity\ based\ sites\ Count\ =\frac{Total\ subscriber\ supported\ in\ the\ network}{Subscriber\ supportd\ per\ site}$$

$$Capacity\ based\ sites\ Count\ =\frac{34{,}072}{939}\cong 37\ \text{eNodeBs}$$

Thus, a total of 37 (Thirty Seven) eNodeB's are required to meet the capacity demand.

In this nominal planning stage, it is shown that a total of 46 (Forty Six) eNodeBs are required to meet the coverage requirement and on the other hand a total of 37 (Thirty Seven) eNodeB’s are required to meet the capacity requirement. Since the target network should satisfy both the requirements of coverage & capacity, the total number of eNodeB’s that will be used in order to analyze the target network further in the detail planning stage becomes 46 (Forty Six) eNodeB’s.

The following Subsections will show the detailed planning stage to further analyze the target network by exploit the parameters found in the nominal planning phase using radio network planning and optimization tool.

4.5. Simulation: Designing an LTE Network

In order to analyze a complex system, it is required to incorporate simulations. From cellular network deployment perspective, simulation is a practical and scientific approach that a network planner needs to accomplish before mass deployment [48]. Thus the parameters found in the nominal planning phase must be premeditated further to evaluate the target network performance before network rollout using RNPO tool.

4.5.1. Simulation Workflow

RNPO tool enables the network planner to design wireless access networks. It is used to predict radio coverage, manage mobile and fixed subscriber’s data, and evaluates the network capacity. Figure 4.2 depict an optimized simulation workflow used in this study to design and evaluate an LTE network using the RNPO tool.

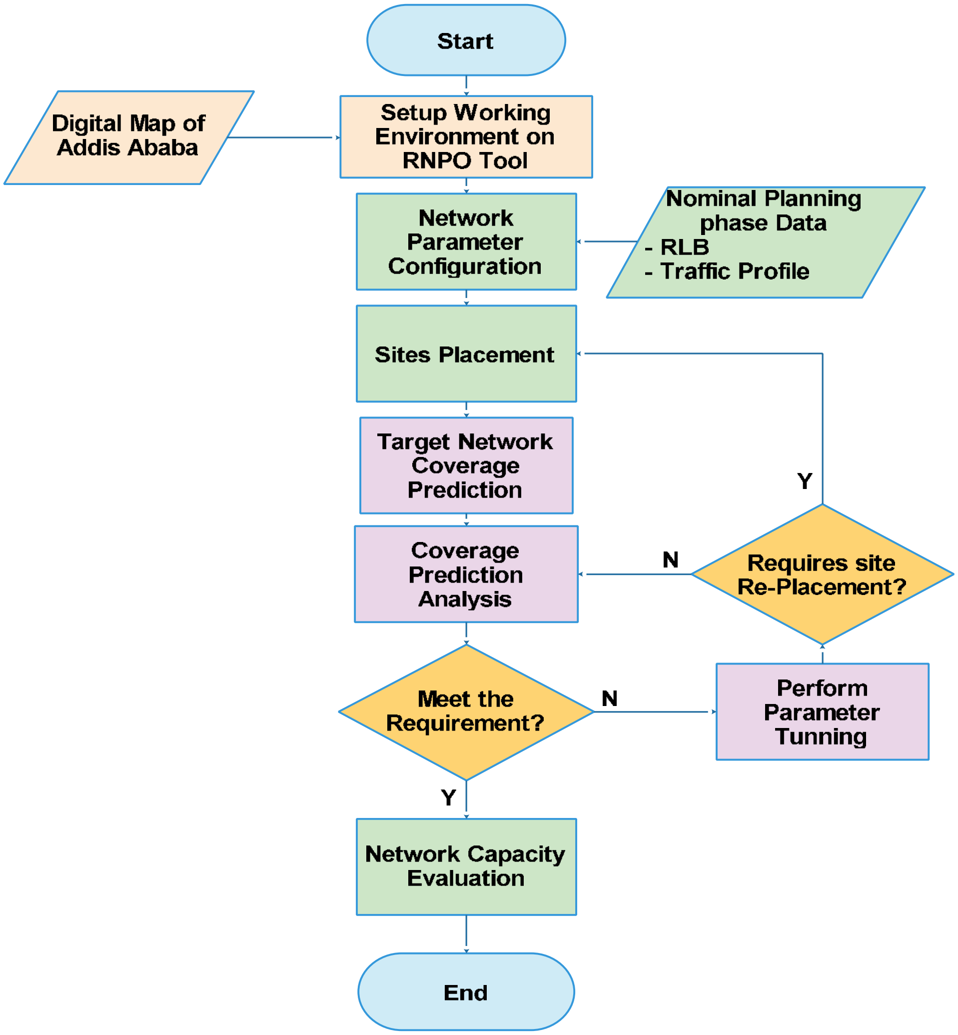


Figure 4. 2: LTE network simulation workflow.

As it is shown in the workflow above, the process requires two inputs. The first input is a digital map, which is used to setup working environments on the RNPO tool. In this study digital map of Addis Ababa with a resolution of 5m is used, in particular, the area under Kirkos sub city is focused, to perform the simulation and the selected area is shown in Figure 4.3, circled in red color. A digital map is an electronic database containing geographical information such as land usage (clutter information), height data, and vector data (streets, main roads, secondary roads, highways, and railways).

Figure 4. 3: Digital MAP of Target Area.

The second inputs are the parameters found from the nominal planning phase. They are used to configure network parameters such as site parameters, transmitter & cell parameters, and global parameters. Table 4.10 shows some of the main parameters used to configure the target network in the RNPO tool.

Parameters	DL	UL
Frequency	1800 MHz	
Bandwidth	20 MHz	
Duplex Mode	FDD	
Propagation Model	Cost-Hata	
Frequency Reuse	1	
Scheduling	Proportional Fair	
MIMO Configuration	2x2	1x2
Transmit Power	46 dBm	23 dBm

Table 4. 10: Network configuration sample parameters.

Once the network parameters configurations completed, the sites placement will be performed to know the geographical location of each sites. In practical case, a site survey will be performed to study the feasibility of the location in terms of land acquisition and facilities such as road access and availability of power supply.

After the sites placement step is completed, target network prediction and capacity evaluation will be done. The target network prediction result will be evaluated to validate the target network requirement. If the requirements are not achieved yet, a parameter tuning as well as sites geo location rearrangement will be carried out to get an optimal coverage prediction result.

4.5.2. Sites Placement

Based on the nominal planning phase, a total of 46 eNodeB’s are created in the RNPO tool. These sites are initially configured by the parameters shown in Table 4.11. Depending on the coverage prediction results ahead, we may affect the initial assumptions of these parameters for better results. Figure 4.4 shows the sites placement of these 46 eNodeB’s on the target deployment area. The list of the sites with their initial geographical coordinate information (Longitude, Latitude, and Altitude) is shown in Annex A.

Sector Configuration	Antenna Configuration	Antenna Height	Azimuth	Mechanical Down tilt	Electrical Down tilt
Sector 1	65deg 17 dBi 1800MHz	30 m	0°	0°	0°
Sector 2	65deg 17 dBi 1800MHz	30 m	120°	0°	0°
Sector 3	65deg 17 dBi 1800MHz	30 m	240°	0°	0°

Table 4. 11: Initial Sites Sectors Parameters.

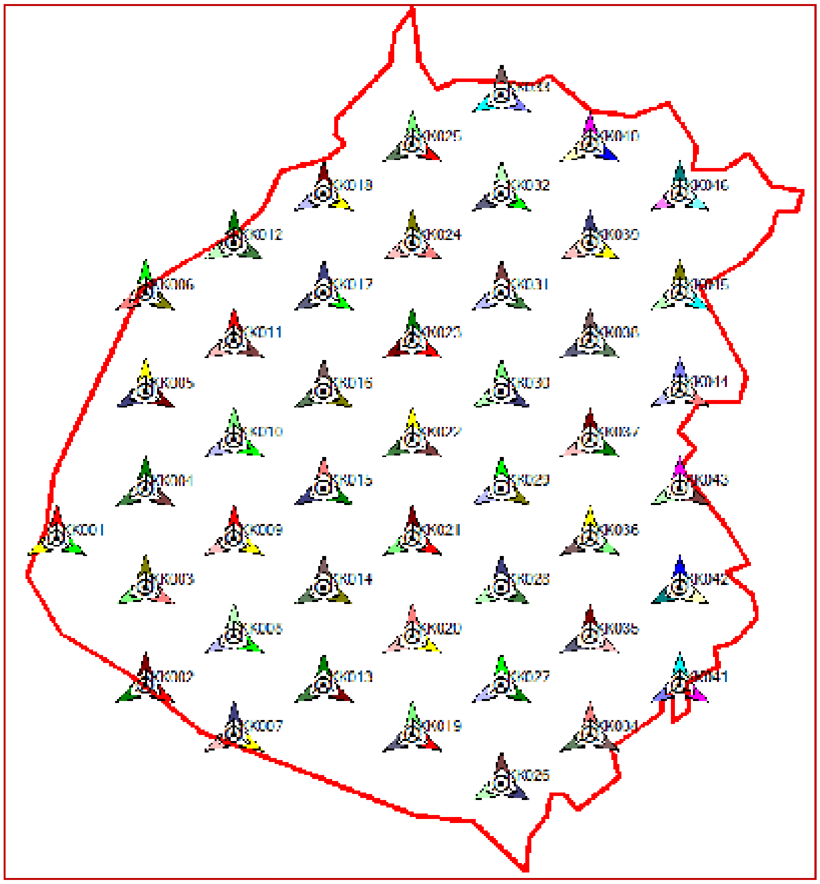


Figure 4. 4: Initial sites placement.

4.5.3. Sites location rearrangements

As part of the pre-deployment optimization discussed on Section 3.5, the initial sites placement shown in Figure 4.4 is exported to GoogleEarth to check the feasibility of the initial sites footprint. Accordingly, it is found that a total of six sites were placed on the main road during initial sites placement. These sites are rearranged to be placed to a different location as shown in Figure 4.5 and Figure 4.6 as an example for two sites (KK006 and KK045 are the initial location where as KK006N and KK045N are the new locations of the two sites after rearrangements). In the same manner, the rearrangement has been done for the remaining 4 sites as shown in Table 4.12.

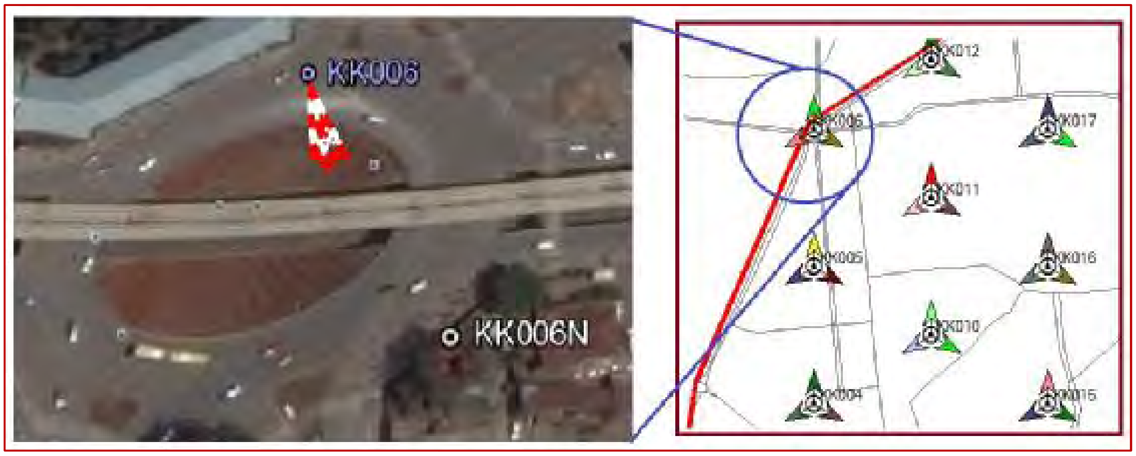


Figure 4. 5: Sample initial sites location rearrangement (Site KK006).

Figure 4. 6: Sample initial sites location rearrangement (Site KK045).

Name	Initial Location			New Location		
	Longitude	Latitude	Altitude(m)	Longitude	Latitude	Altitude(m)
KK002	38°44'40.66"E	8°59'17.64"N	2,278	38°44'41.87"E	8°59'18.36"N	2,279
KK006	38°44'40.6"E	9°0'37.71"N	2,356	38°44'41.73"E	9° 0'36.06"N	2,356
KK020	38°45'32.99"E	8°59'27.67"N	2,303	8°45'33.64"E	8°59'26.98"N	2,305
KK033	38°45'50.37"E	9°1'17.81"N	2,402	8°45'51.18"E	9° 1'17.33"N	2,401
KK043	38°46'25.31"E	8°59'57.76"N	2,325	38°46'24.69"E	8°59'57.92"N	2,326
KK045	38°46'25.28"E	9°0'37.78"N	2,349	38°46'24.04"E	9° 0'38.27"N	2,350

Table 4. 12: Initial sites location rearrangement.

4.6. Target Area Coverage Prediction and Analysis

A coverage prediction displays the results of a defined coverage conditions. It is calculated based on coverage conditions and coverage resolutions using the path loss matrices. As shown in Figure 4.7, the RNPO tool used in this study considerer the geographical profile between the eNodeB and UE to perform the coverage prediction calculations and then it displays the results as a graphical representation of the pixels for which the defined coverage conditions are satisfied. In this study each pixel is considered as a non-interfering user with a defined service, mobility, and terminal type.

As per the target network requirements set in Chapter 4 Section 4.1, the nominal planning phase will be evaluated by the following coverage predictions results:

- Coverage by Signal Level;
- Effective Signal Analysis;
- Coverage by C/(I+N).

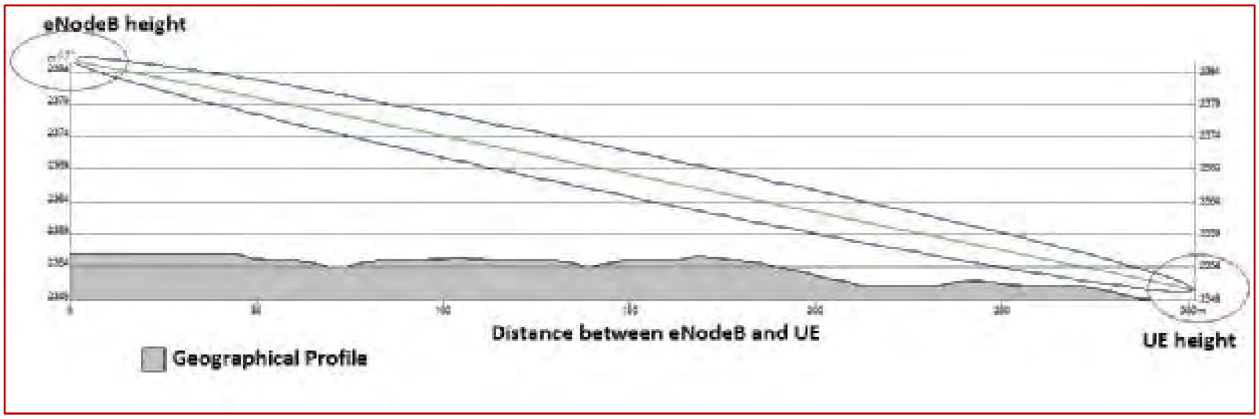


Figure 4. 7: Geographical profile between eNodeB and UE.

4.6.1. Initial Prediction Results

1. Coverage by Signal Level

Target network Signal Level coverage prediction is performed by considering the “Best Signal Level” throughout the target area using coverage condition shown in Table 4.13. Figure 4.8 shows the result of the coverage prediction based on “Best Signal Level” in the target area.

In this figure, the red color represents the signal level ≥ -70 dBm that accounts for the best signal level where as the blue color plots represents the signal level ≥ -130 dBm that shows the poor coverage signal on the target area.

Conditions	Values
Signal Level	≥-130 dBm
Server	Best Signal
Shadowing Taken into Consideration?	Yes
Indoor coverage considered	Yes
Cell edge coverage probability	83%

Table 4. 13: Prediction conditions, "Coverage by Signal Level".

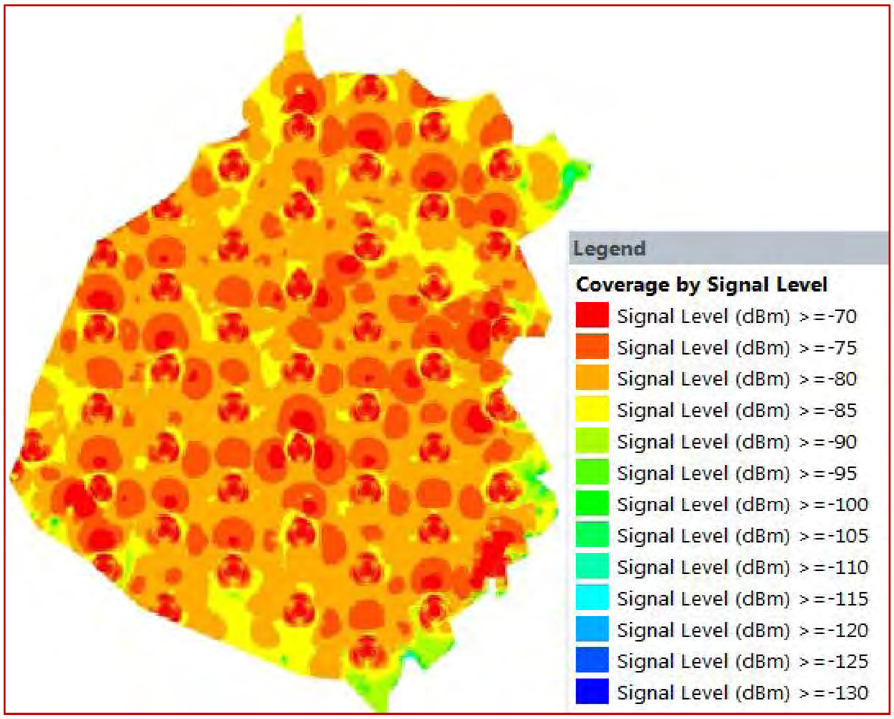


Figure 4. 8: Coverage prediction, "Best Signal Level".

According to the result shown by the histogram statistical results in Figure 4.9, the simulation result illustrate that 97.46% of the area is covered by a signal ≥ -85 dBm. This shows a better signal can be received by UE’s as compared to the calculated Minimum Signal Reception Strength of -121.30 dBm from the RLB; with a mean of -54.25 dBm and standard deviation of -32.8 dBm.

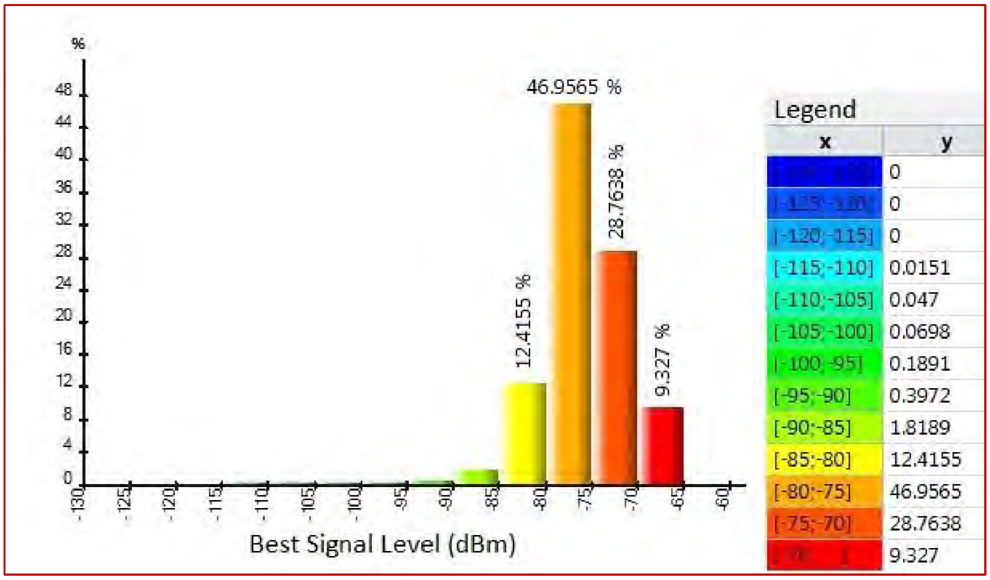


Figure 4. 9: Best Signal Coverage Prediction (%).

When the analysis is done in terms of covered area per km², it is found that 14.5196 km² is covered by a signal level ≥ -85 dBm as shown in Figure 4.10. This result shows that the planned network provide good signal strength within the target area.

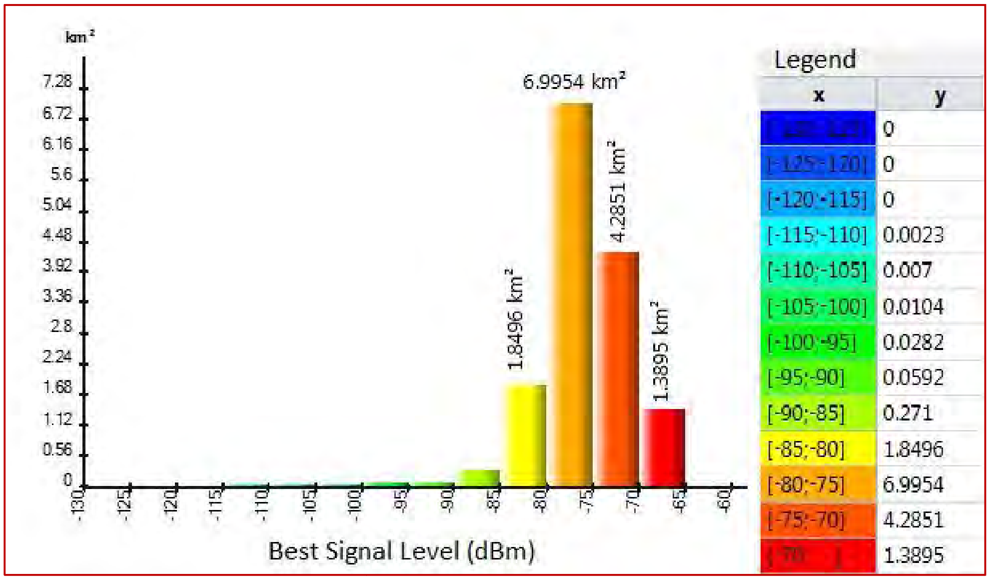


Figure 4. 10: Best Signal Coverage Prediction (Covered Area, km2)

Table 4.13 shows the predicton result for coverage by signal level. 97.46% of the area is covered by the best signal level ≥ -85 dBm. This shows the area coverage probability requirement (95%) has been already achieved by this best signal level value.

Coverage by Signal Level	Surface (km²)	% of Covered Area
Signal Level (dBm) >=-70	1.3895	9.32704
Signal Level (dBm) >=-75	5.6746	38.09083
Signal Level (dBm) >=-80	12.66997	85.04734
Signal Level (dBm) >=-85	14.51957	97.46281
Signal Level (dBm) >=-90	14.79055	99.28177
Signal Level (dBm) >=-95	14.84972	99.67894
Signal Level (dBm) >=-100	14.8779	99.8681
Signal Level (dBm) >=-105	14.8883	99.93791
Signal Level (dBm) >=-110	14.8953	99.9849
Signal Level (dBm) >=-115	14.89755	100

Table 4. 14: Prediction result for Coverage by Signal Level.

The cell edge coverage probability (%) versus covered area (%) CDF presented in Figure 4.11. As shown in the figure, if the cell-edge coverage probability requirement is less than 90%, the target area will have a full coverage with specified cell-edge coverage probability (for instance 50%, 80%). While the requirement goes beyond 90%, the area coverage percentage decreases as shown in the graph for a specified cell-edge coverage probability between 90% and 100 % (for instance 90%, 95%). This implies that a better cell-edge coverage probability can be achieved when point on the graph moved to the right in the “cell edge coverage probability (%)” axis, however, the covered area percentage decreases at the same time as it can be seen in “covered area (%)” axis. Which means all signals can be usable but it requires more number of sites to meet the requirement.

Accordingly, the red circle in the Figure 4.11 shows 97.457% of the target network cell edge is covered by a cell-edge coverage probability of 90%. This simulation output clearly shows the cell edge coverage probability reaches more than the value set by the target network requirement in Section 4.1, (83%).

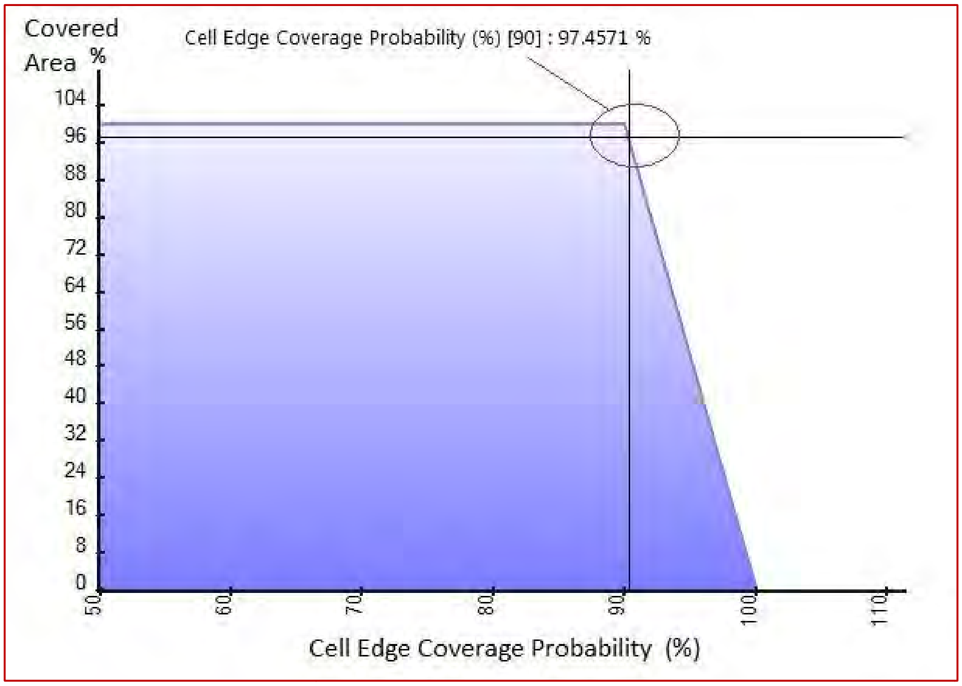


Figure 4. 11: Cell edge coverage probability (%).

2. Effective Signal Analysis

“Effective signal analysis” coverage predictions allows to predict the effective signal levels in the UL & DL direction for different types of signals (Reference Signals (RS), Synchronization Signals (SS), Physical Broadcasting Channel (PBCH), PDCCH, & Physical Uplink Shared Channel (PUSCH)) for the network being studied.

In this study only the Reference Signals (RSRP) effective signal analysis is done and it is shown in Figure 4.12 below. Based on the result, 99.9% of the area achieves the RSRP greater than -110 dBm and from this, 93.83 % obtains the RSRP greater than -105 dBm. Thus the RSRP target requirement is achieved.

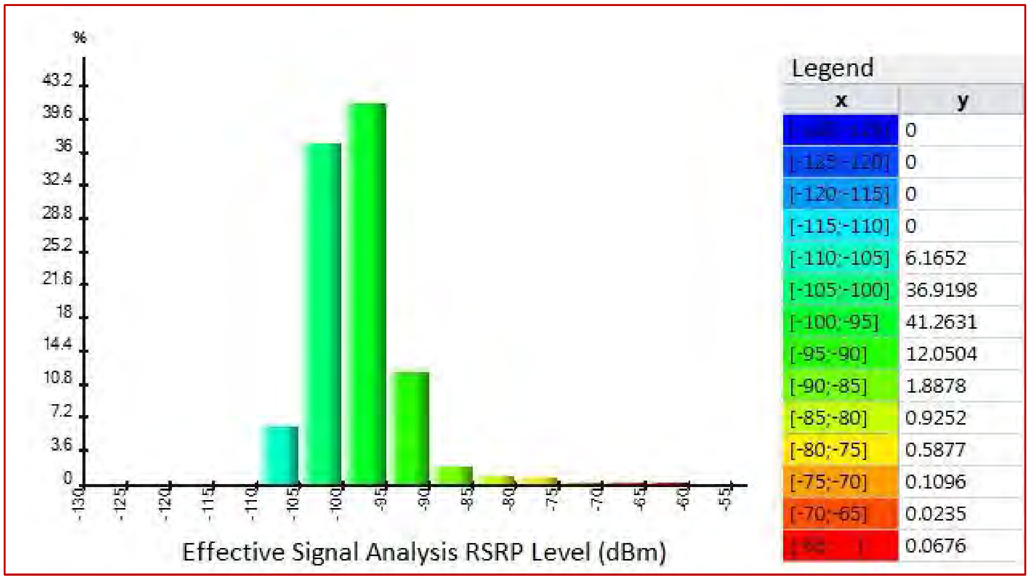


Figure 4. 12: Effective signal analysis, RSRP level.

3. Coverage by C/(I+N)

Downlink and uplink coverage predictions by C/(I+N) level evaluates the interference levels and the signal-to-interference levels of the target network being studied. It calculates the co-channel interference as well as the adjacent channel interference.

The C/(I+N) in the downlink is calculated for different channels using their respective transmission powers and by calculating the interference received by the resource elements corresponding to these channels from interfering cells. In the uplink, the C/(I+N) is calculated using the terminal power calculated and the uplink noise rise values.

Figure 4.13 shows coverage prediction by the C/(I+N) value for both downlink and uplink signals. The chart shown in Figure 4.14 and Figure 4.15 tells the C/(I+N) is above -7 dB and -6 dB for downlink and uplink signal respectively.

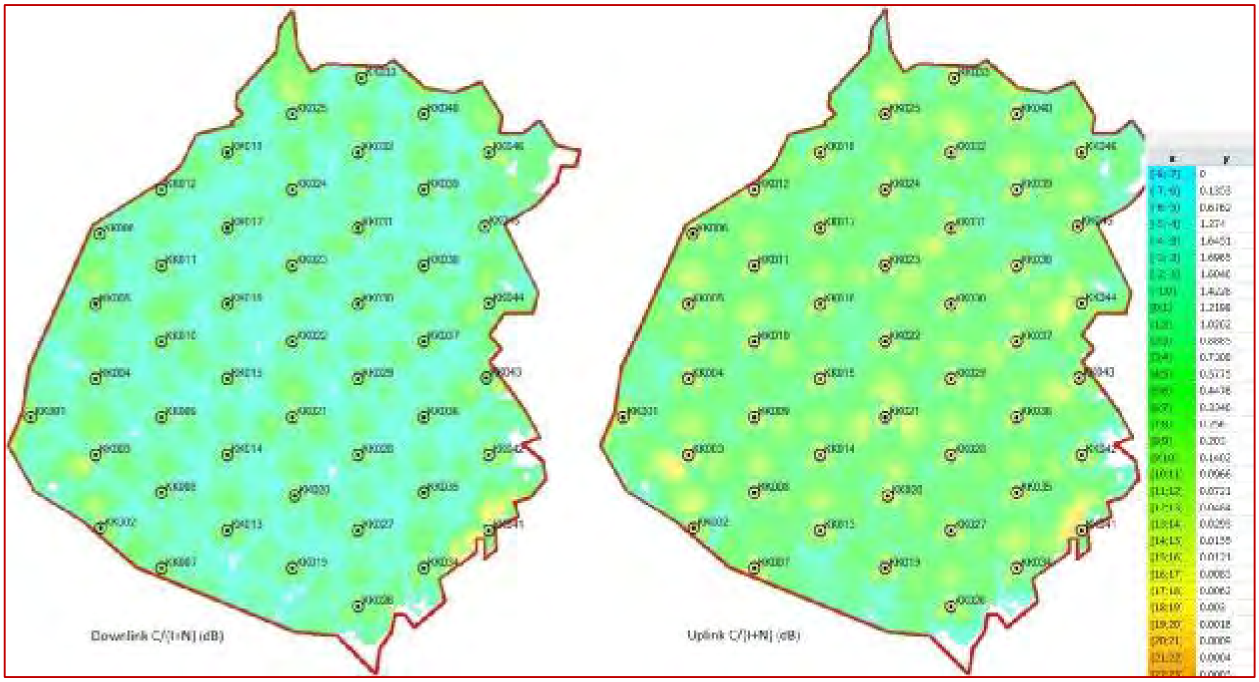


Figure 4. 13: Coverage prediction by C/(I+N) level (DL & UL)

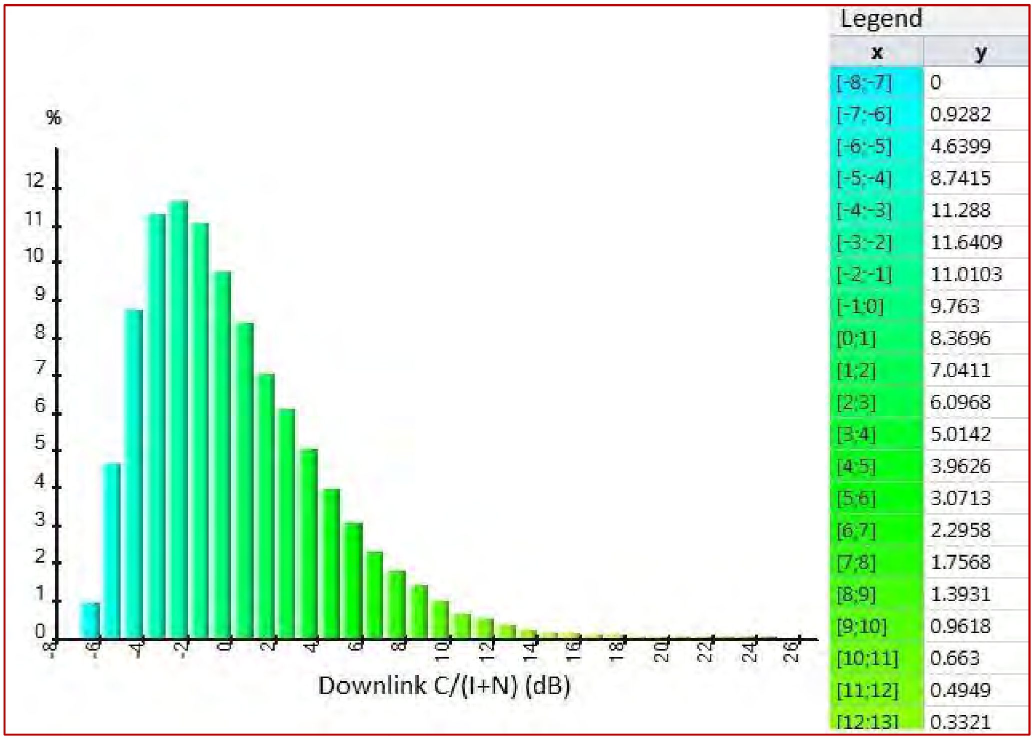
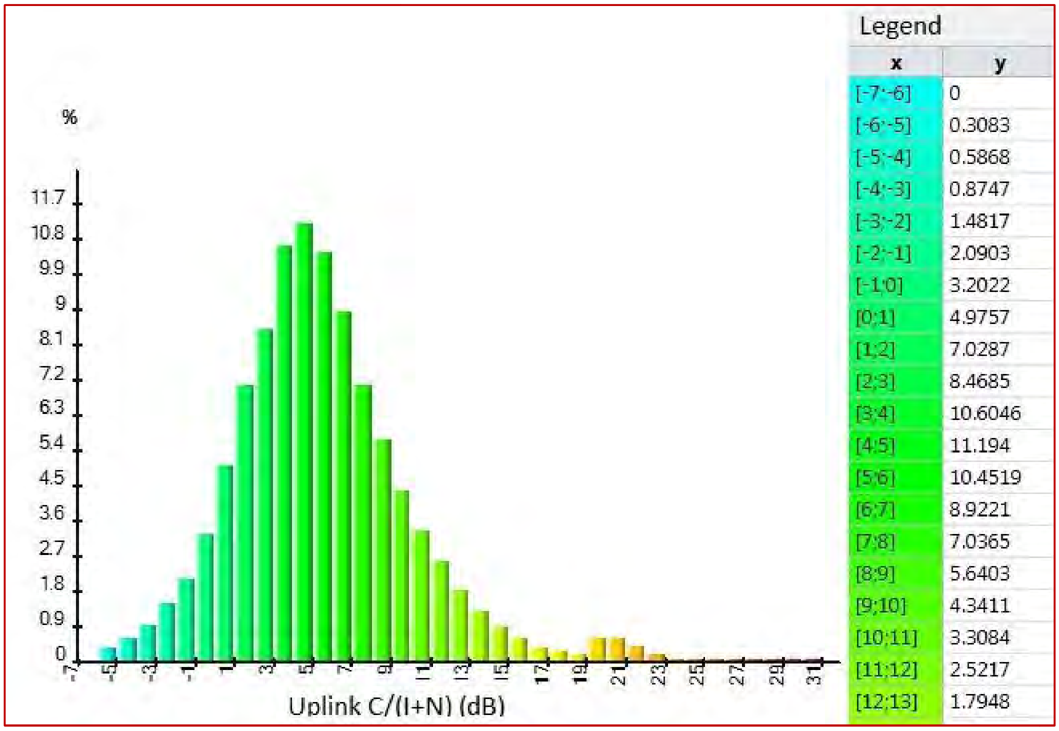


Figure 4. 14: Percentages of downlink C/(I+N) level.



Legend

x	y
[-7;-6]	0
[-6;-5]	0.3083
[-5;-4]	0.5868
[-4;-3]	0.8747
[-3;-2]	1.4817
[-2;-1]	2.0903
[-1;0]	3.2022
[0;1]	4.9757
[1;2]	7.0287
[2;3]	8.4685
[3;4]	10.6046
[4;5]	11.194
[5;6]	10.4519
[6;7]	8.9221
[7;8]	7.0365
[8;9]	5.6403
[9;10]	4.3411
[10;11]	3.3084
[11;12]	2.5217
[12;13]	1.7948

Figure 4. 15: Percentages of uplink C/(I+N) level.

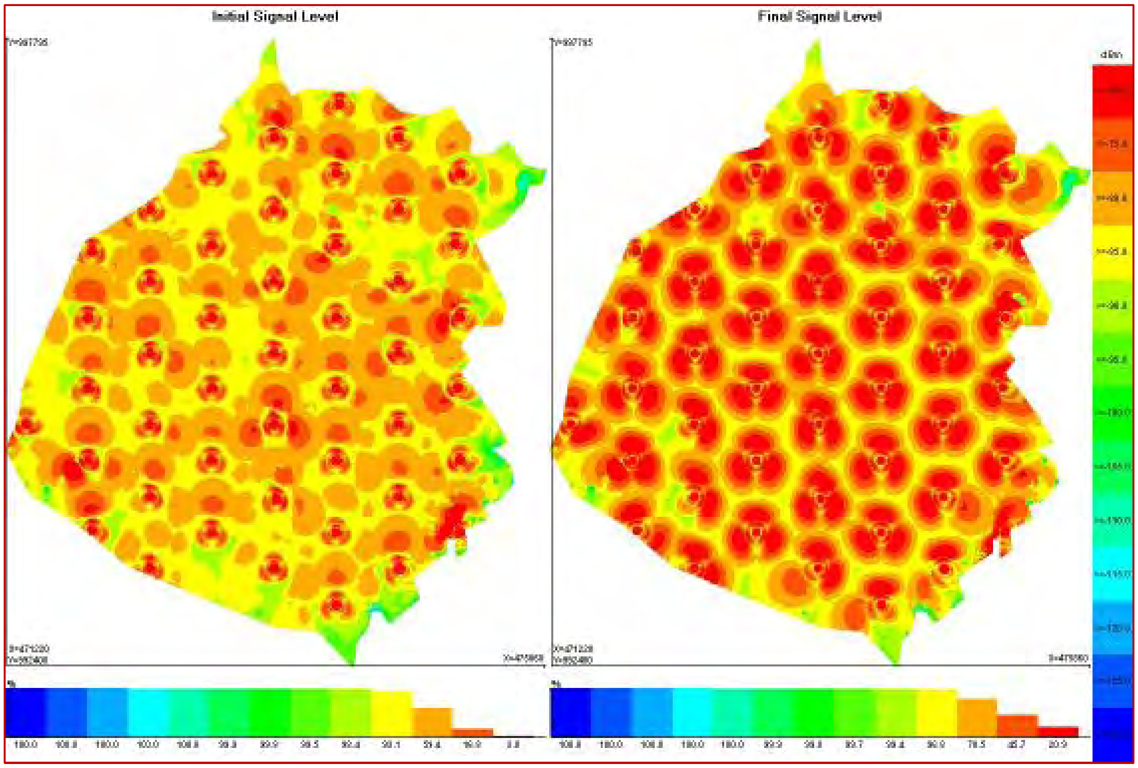
4.6.2. Pre-Deployment Optimizations Results

RNPO tool enables radio engineers to optimize initial network parameters in terms of network coverage and quality. For existing network deployment, the operators can reconfigure the main parameters, for instant, the antennas electrical tilts and transmission pilot power, which are controlled remotely. In a new deployment scenario (green-field planning), the initial parameters such as antenna types, azimuths, heights, mechanical tilts, and electrical tilts can be tuned to get optimal network parameters in the detailed planning stage. In this study, even if the target network requirements such as, area coverage probability, cell edge coverage probability and RSRP value are achieved, pre-deployment optimization is required to get strong network performance in terms of signal level, C/(I+N) and RSRP to avoid extra efferent to optimize the network after deployment. Thus with the help of RNPO tool, the transmitter parameters, such as antenna azimuths, antenna mechanical down tilt, and electrical down tilt are modified as attached in the Annex B.

After the pre-deployment optimization is completed, the target network performance was evaluated in terms of network performance key indicators such as, coverage signal level, RSRP effective signal analysis, and the C/(I+N). Accordingly, significant improved network performance is achieved as compared to the initial prediction results before pre-deployment optimization. This significant improvement is illustrated as follows:

1. Coverage Signal Level Improvements

Figure 4.16 shows the comparison between the initial signal level and the final signal level after pre-deployment optimization. It shows 69.18 % improvement for signal level ≥ -70 dBm and 36.07 % improvement for signal level ≥ 75 dBm. Other signal levels improvements are also illustrated on Table 4.15.



Initial Signal Level

Final Signal Level

Figure 4. 16: Signal level before and after pre-deployment optimizations.

Signal Level (dBm)	% of Covered Area(Initial)	% of Covered Area (Final)	Improvement
Signal Level ≥ -70	9.32704	30.27142	69.19%
Signal Level ≥ -75	38.09083	59.57893	36.07%
Signal Level ≥ -80	85.04734	90.34405	5.86%
Signal Level ≥ -85	97.46281	98.51264	1.07%
Signal Level ≥-90	99.28177	99.60242	0.32%
Signal Level ≥-95	99.67894	99.76976	0.09%
Signal Level ≥-100	99.8681	99.89307	0.02%
Signal Level ≥-105	99.93791	99.9755	0.04%
Signal Level ≥-110	99.9849	100	0.02%
Signal Level ≥-115	100	100	0.00%

Table 4. 15: Coverage signal level improvements after pre-deployment optimizations.

2. RSRP Level Improvements

Figure 4.17 shows the comparison between the initial RSRP value and the final RSRP level after pre-deployment optimization. It shows 81.75 % improvement for RSRP level ≥ -90 dBm and 72.25 % improvement for RSRP level ≥ 85 dBm. Other RSRP levels improvements are also illustrated on Table 4.16.

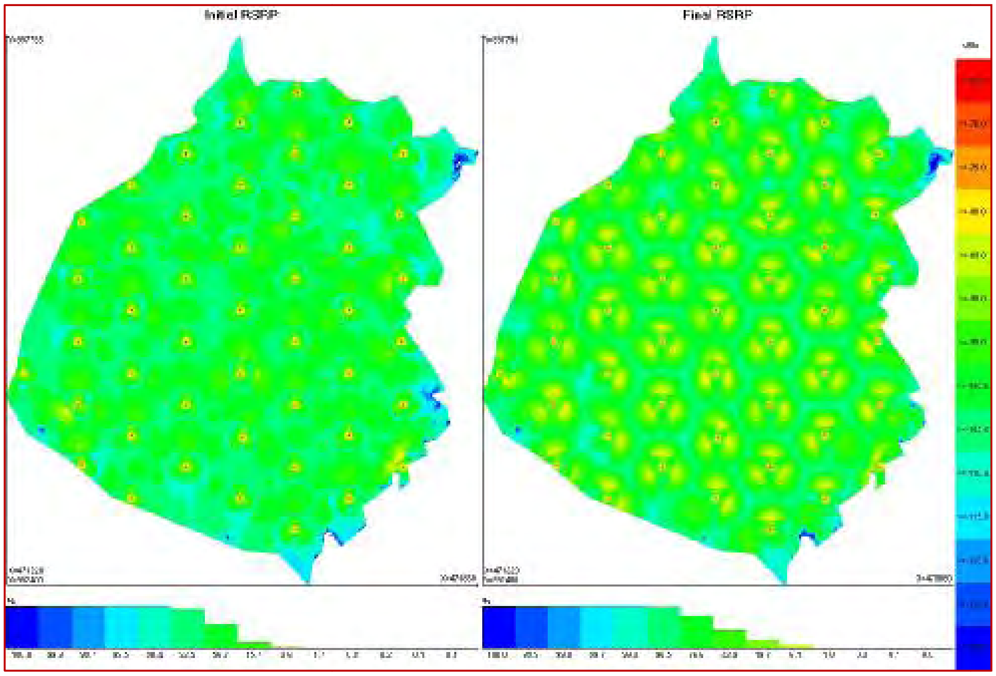


Figure 4. 17: RSRP level before and after pre-deployment optimizations.

RSRP Level (dBm)	% of Covered Area (Initial)	% of Covered Area (Final)	Improvement
RSRP Level ≥-70	0.09112	0.10691	14.77%
RSRP Level ≥-75	0.20067	0.32879	38.97%
RSRP Level ≥-80	0.78836	0.97602	19.23%
RSRP Level ≥-85	1.71357	6.17429	72.25%
RSRP Level ≥-90	3.60132	19.72798	81.75%
RSRP Level ≥-95	15.65179	44.10466	64.51%
RSRP Level ≥-100	56.91495	77.16318	26.24%
RSRP Level ≥-105	93.83478	97.185	3.45%
RSRP Level ≥-110	100	100	0.00%

Table 4. 16: RSRP improvements after pre-deployment optimizations.

3. C/(I+N) Improvements

Finally, C/(I+N) improvement is shown in Figure 4.18. Before the pre-deployment optimization, the C/(I+N) values which are greater than or equal to -3 dB (≥ -3 dB) covers 85.72%, whereas after the optimization, the C/(I+N) coverage above -3 dB reached to 97.64%. This shows C/(I+N) coverage improved by 11.92% from the initial value as shown in the histogram on Figure 4.19.

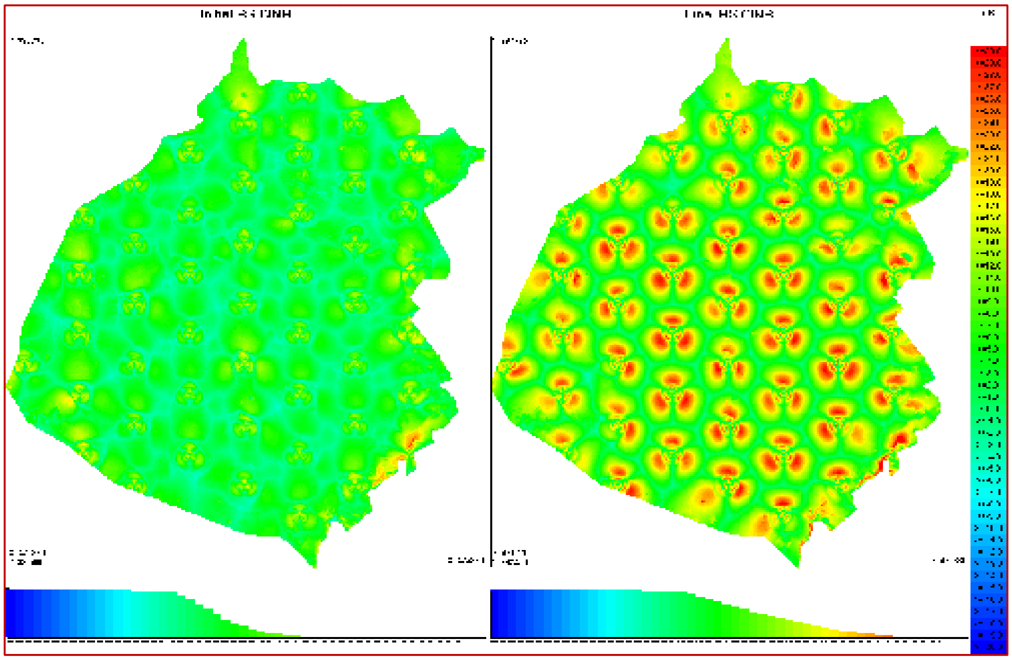


Figure 4. 18: C/(I+N) before and after pre-deployment optimizations.

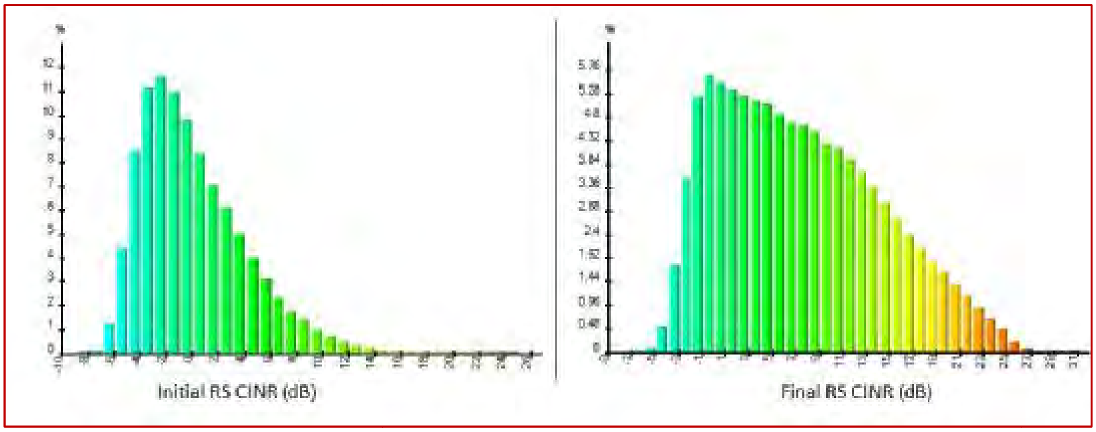


Figure 4. 19: C/(I+N) improvements after pre-deployment optimizations.

4.7. Network Capacity Evaluation & Analysis

An important step in the process of LTE network planning is to verify the network capacity. This is done using measurements of the downlink/uplink throughput predictions and simulations based on a realistic distribution of users at a given point in time. In this study, these two methods are used to evaluate the target network capacity using the RNPO tool.

1. Coverage Prediction by Throughput

In this method, the RNPO tools calculates the downlink and uplink throughput predictions to display the channel throughputs and cell capacities based on C/(I+N) and bearer calculations for each pixel. Considering the target network requirements, the cell edge coverage probability set to 83% to evaluate whether the target network meet the requirements of cell edge throughput of 512 kbps and 1024 kbps for uplink and downlink respectively.

Figure 4.20 shows the prediction result for uplink and downlink effective Radio Link Controller (RLC) throughput and Figure 4.21 and 4.22 shows the statistics of the throughput for both predictions. The result shows the cell edge throughput targets has been achieved and illustrate a better performance than the performance set by the target network requirement for both uplink and downlink.

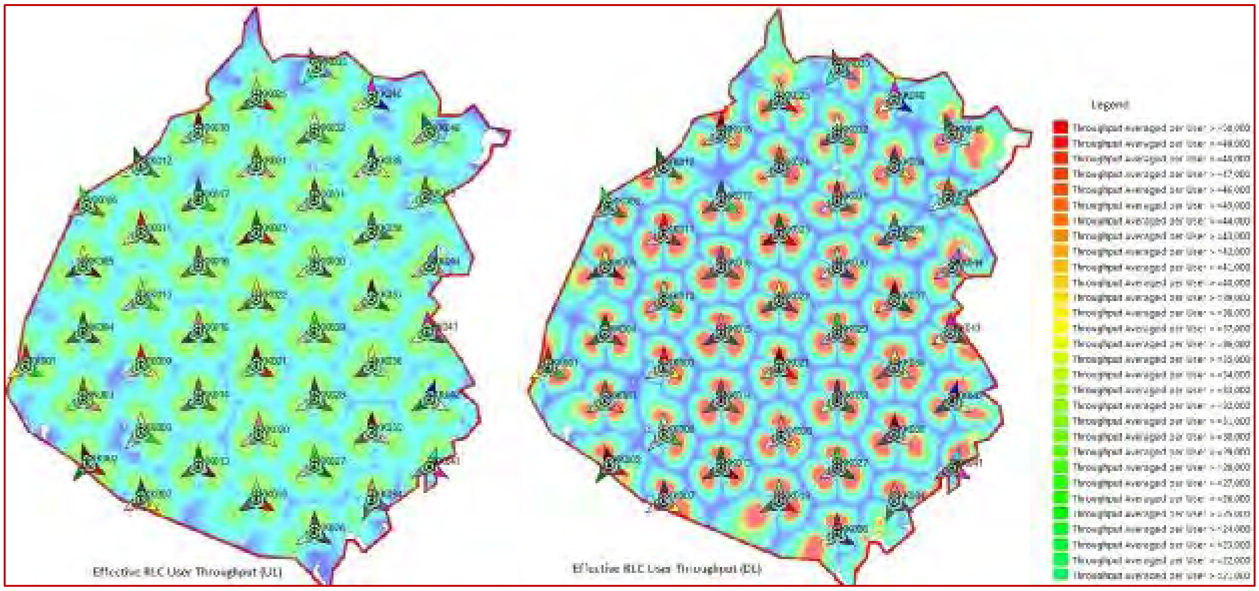


Figure 4. 20: Prediction result for uplink & downlink throughput

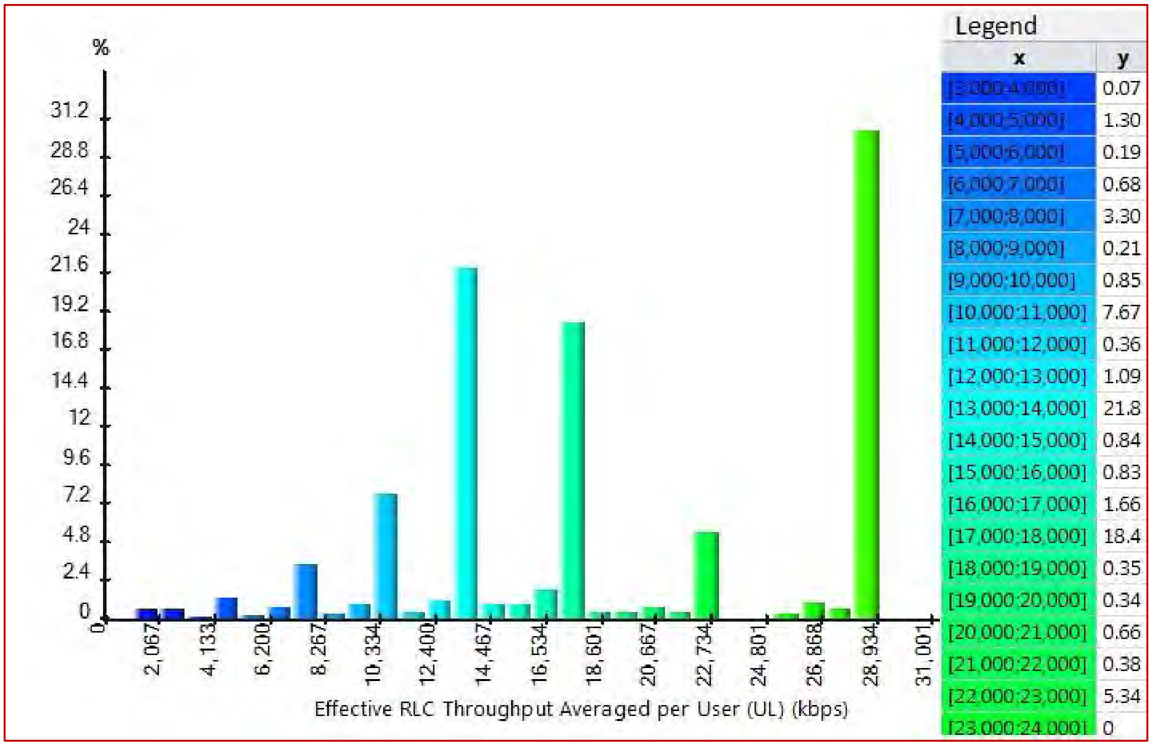


Figure 4. 21: UL effective RLC user throughput

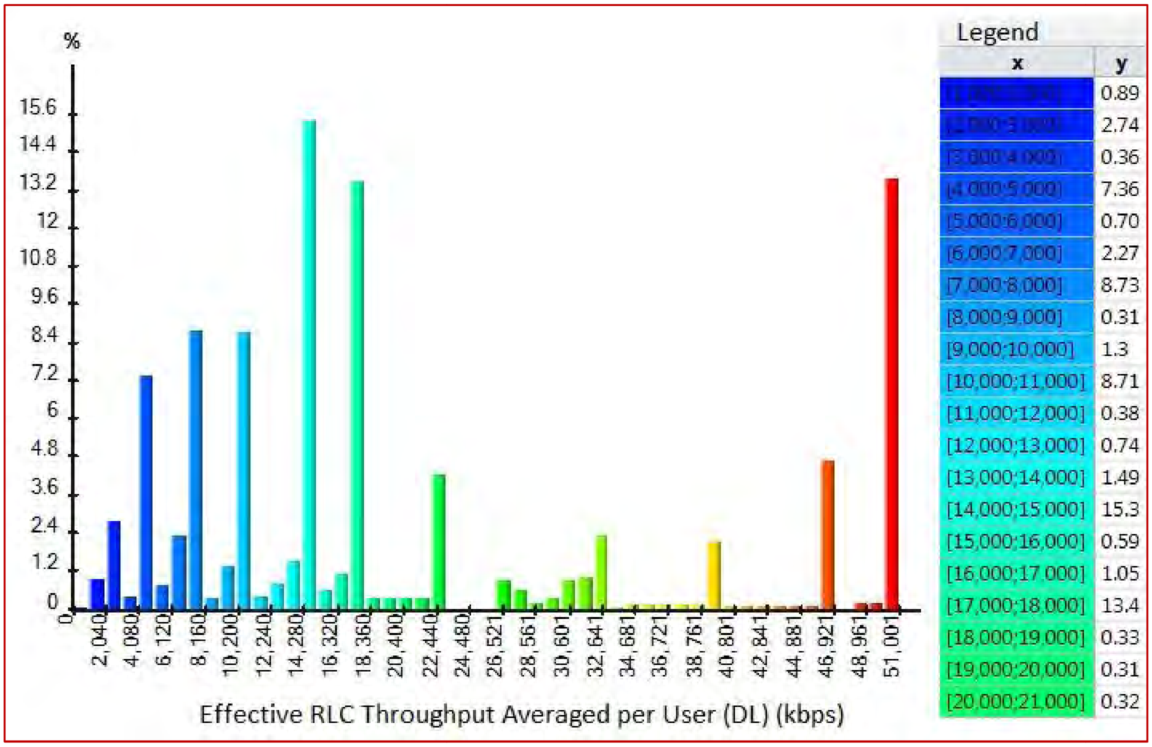


Figure 4. 22: DL effective RLC user throughput

2. Simulations based on a realistic distribution of users

This method is based on simulations on a realistic distribution of users in the target area. It calculates the user throughputs for various network parameters such as the downlink traffic loads, uplink traffic loads, and the user throughputs in an iterative fashion. The RNPO tool used in this study generates a user distribution based on traffic data input using a Monte Carlo algorithm. The geographical location of each user is determined randomly by using the traffic data from traffic maps.

Here sector traffic map is used to evaluate the target network capacity. It is created based on the total number of users simultaneously connected and it uses a coverage prediction by transmitter to create the traffic map user distribution. Based on user service category in Chapter 4, Section 4.1, the service type, priority and the uplink and downlink demand are assumed as shown in Table 4.17. These values are taken in to consideration to simulate the total number of simultaneously connected users when simultaneous active users are 10%, 20%, and 30% of the forecasted total subscribers distributed in the target network.

Service Category	Priority (0:lowest)	Service Type	DL Demand (kbps)		UL Demand (kbps)	
			Max Throughput	Min Throughput	Max Throughput	Min Throughput
Bronze	0	Data	128	64	64	32
Silver	1	Data	512	128	128	64
Gold	2	Data	1024	512	512	128

Table 4. 17: Downlink & Uplink demand based on service category.

Capacity Evaluation: When 10% of the total subscribers are active

Table 4.18 shows the percentage distribution for 10% of the total subscribers' status for each user service category. About 3,438 subscribers were trying to connect to the network. Among this, 3,430 users (99.8%) were connected. On the other hand, 8 users (0.2%) were not connected due to "no coverage" as shown in Figure 4.23. All eNodeB's shows a Connection Success Rate (CSR) of 100 %, this implies that the target network is capable to accommodate a simultaneous connection for the 10% of the total subscriber.

	10% of the total subscribers are active		
Services Type	Trying to connect	Connected	Rejected (No Coverage)
Bronze	1719	1715	4
Silver	1348	1344	4
Gold	371	371	0

Table 4. 18: Capacity evaluation (10% active users)

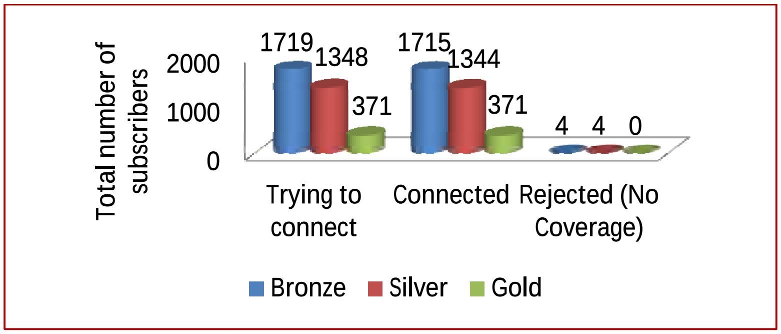


Figure 4. 23: Capacity evaluation (10% active users) chart

Capacity Evaluation: When 20% of the total subscribers are active

Table 4.19 shows the percentage distribution for 20% of the total subscribers' status for each user service category. About 6,872 subscribers were trying to connect to the network. Among this, 6,853 users (99.7%) were connected. On the other hand, 19 users (0.3%) were not connected due to "no coverage" as shown in Figure 4.24. All eNodeB's shows a CSR of 100 %, this implies that the target network is capable to accommodate a simultaneous connection for the 20% of the total subscriber.

	20% of the total subscribers are active		
Services Type	Trying to connect	Connected	Rejected (No Coverage)
Bronze	3475	3464	11
Silver	2697	2692	5
Gold	700	697	3

Table 4. 19: Capacity evaluation (20% active users)

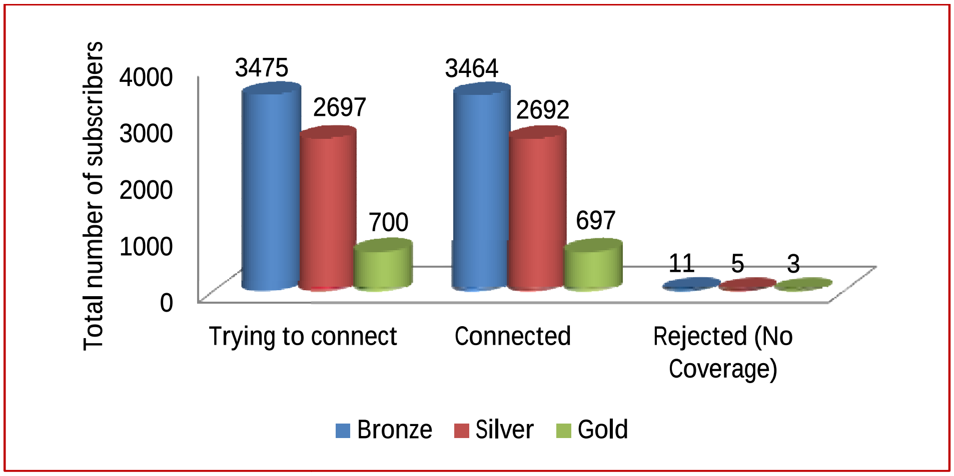


Figure 4. 24: Capacity evaluation (20% active users) chart

Capacity Evaluation: When 30% of the total subscribers are active

Table 4.20 shows the percentage distribution for 30% of the total subscribers' status for each user service category. About 10,337 subscribers were trying to connect to the network. Among this, 10,301 (99.7%) users were connected. On the other hand, 36 users (0.3%) were not connected due to "no coverage" as shown in Figure 4.25. All eNodeB's shows a CSR of 100 %, this implies that the target network is capable to accommodate a simultaneous connection for the 30% of the total subscriber.

	30% of the total subscribers are active		
Services Type	Trying to connect	Connected	Rejected (No Coverage)
Bronze	5242	5226	16
Silver	4048	4033	15
Gold	1047	1042	5

Table 4. 20: Capacity evaluation (30% active users)

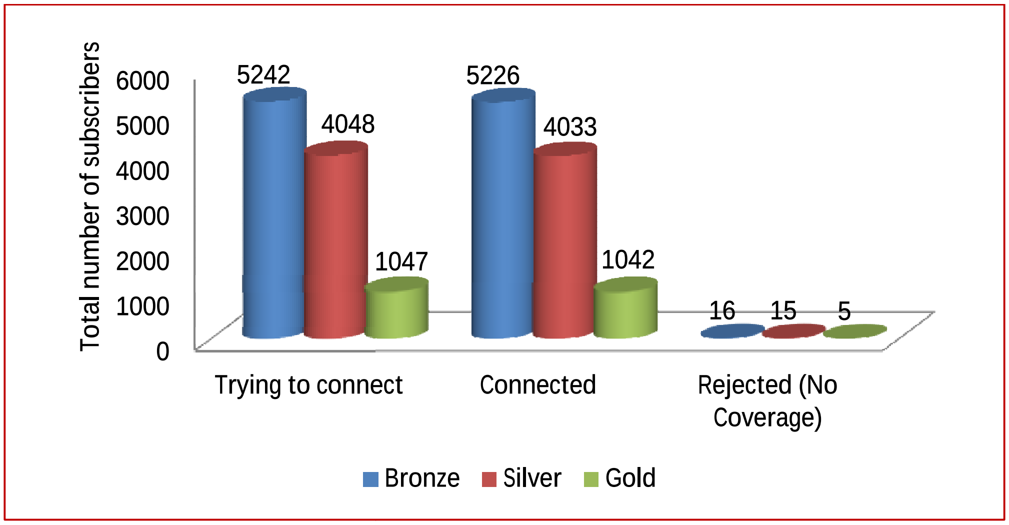


Figure 4. 25: Capacity evaluation (30% active users) chart.

Peak RLC Aggregate Throughput

Peak RLC Aggregate throughput is the maximum RLC layer throughput that can be achieved at a given location using the highest LTE bearer available. Figure 4.26 & Figure 4.27 shows the peak RLC aggregate throughput for both uplink and downlink respectively. The result shows each eNodeB's are well performing to accommodate the given traffic.

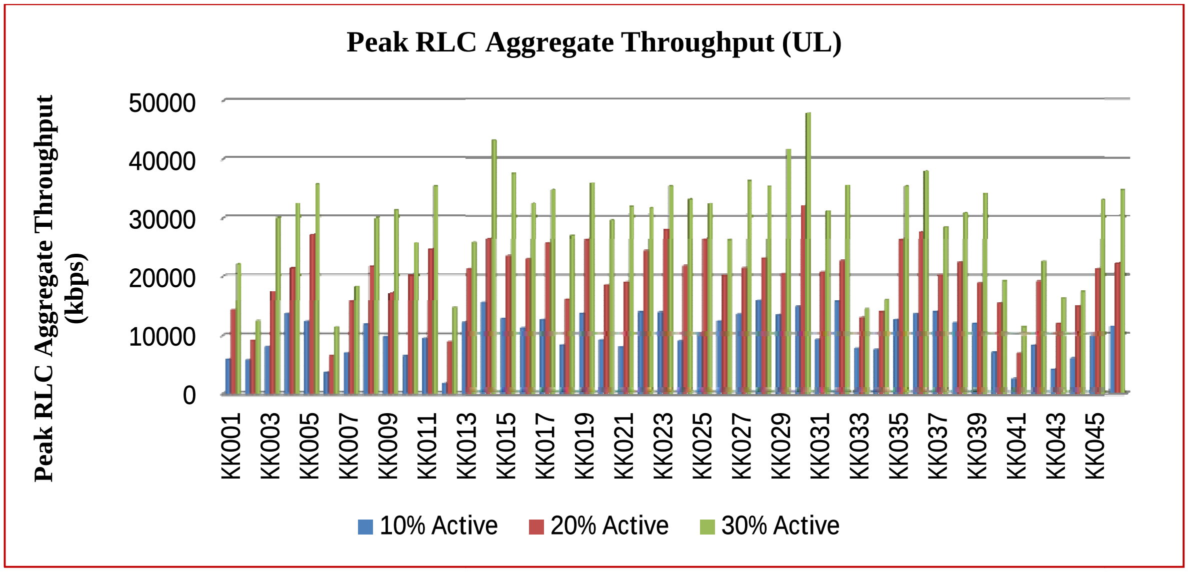


Figure 4. 26: Peak RLC Aggregate Throughput (UL).

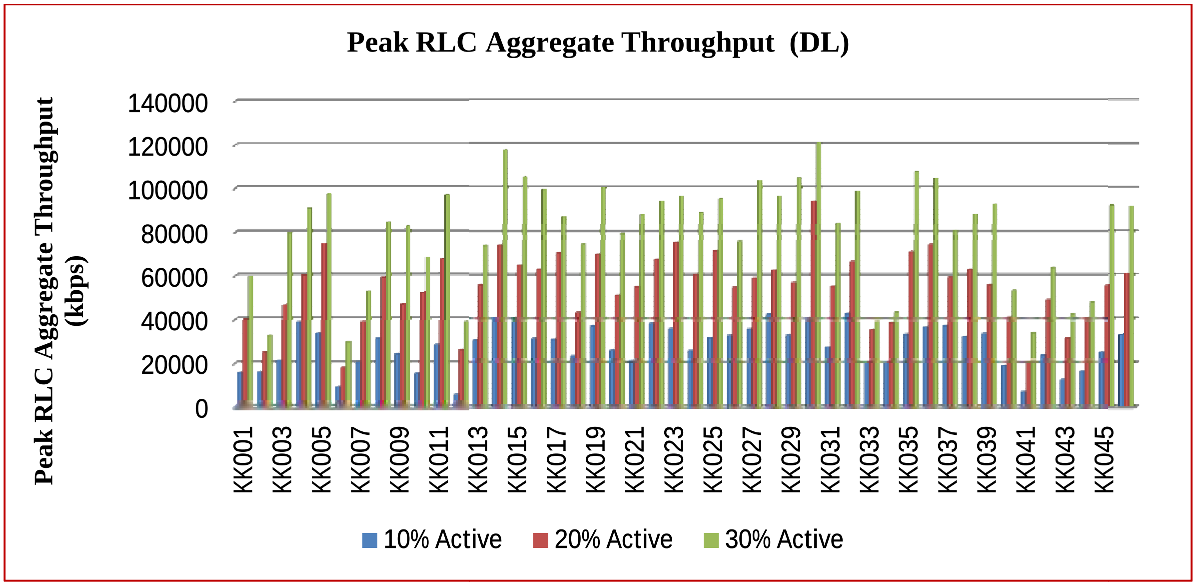


Figure 4. 27: Peak RLC Aggregate Throughput (DL)

Effective RLC Aggregate Throughput

Effective RLC Aggregate throughput is the net RLC layer throughput that can be achieved at a given location using the highest LTE bearer available computed by taking into account the reduction of throughput due to retransmission & errors. Accordingly, Figure 4.28 & Figure 4.29 shows the effective RLC aggregate throughput for both uplink and downlink respectively. The result shows each eNodeB's are well performing to accommodate the given traffic.

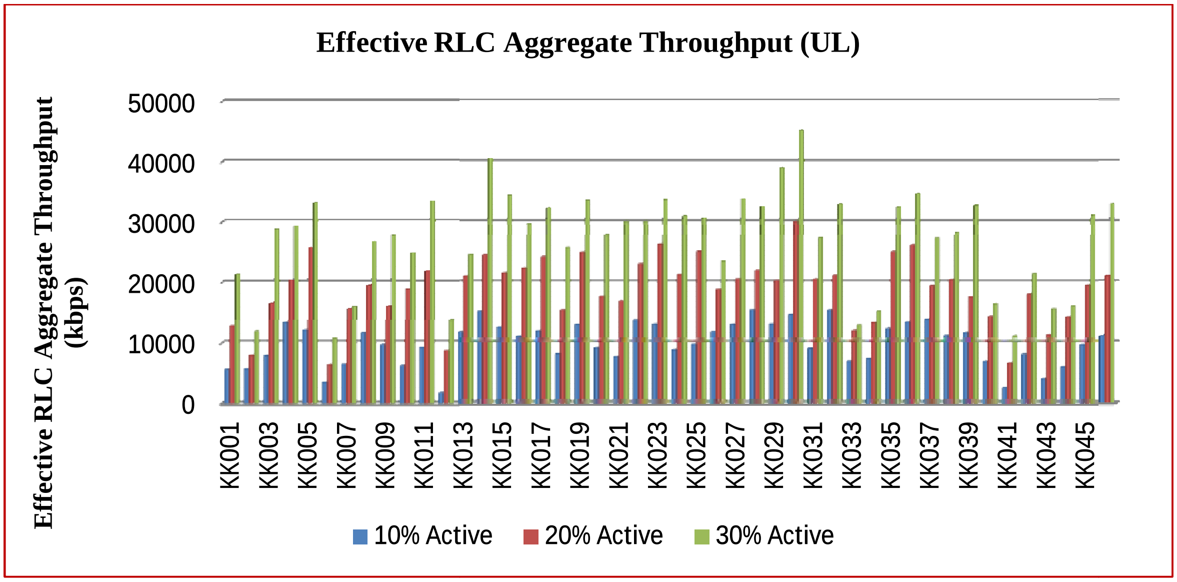


Figure 4. 28: Effective RLC Aggregate Throughput (UL).

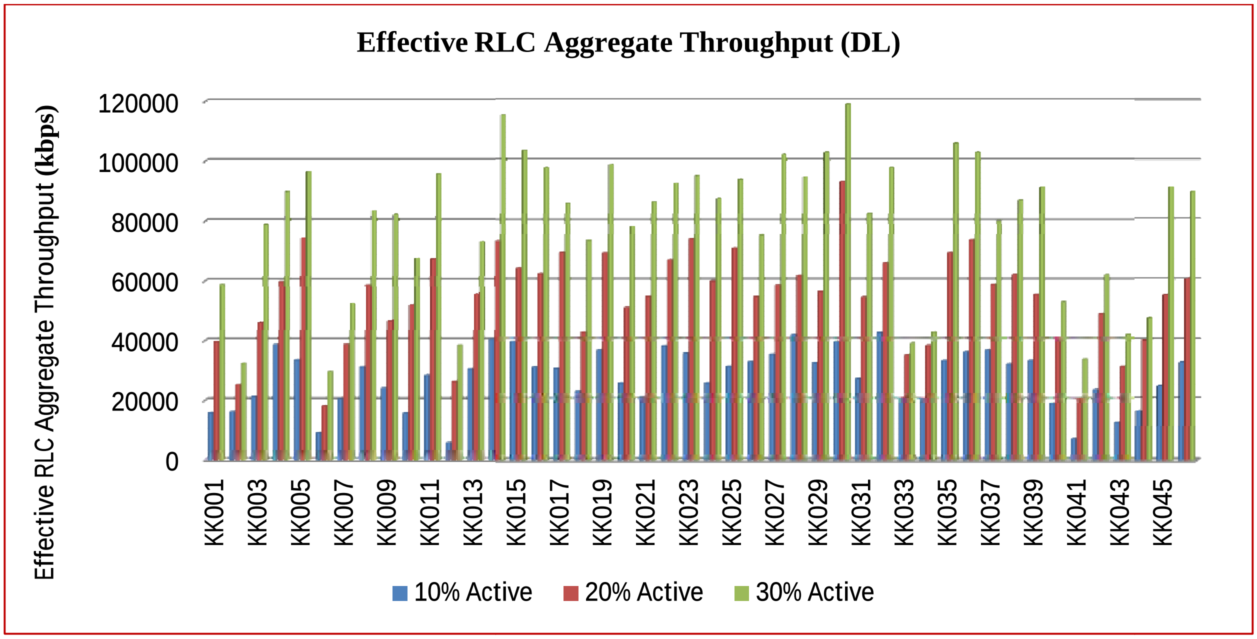


Figure 4. 29: Effective RLC Aggregate Throughput (DL).

Chapter 5: Conclusion and Future Works

5.1. Conclusion

According to the latest technological breakthrough, in cellular network industry radio network planning shall compromise the important factors such as network coverage, capacity, and QoS. Telecom operators similarly approach the radio network planning from the basic point of view of their target network requirements. However, they differently set up network parameters due to the differences in their customer demographic factors. Some of them usually base their existing network data to setup their target network requirements while some others are entirely dependent up on their vendors' solutions.

In the context of Ethiopia, the state owned telecom operator, ethio telecom, has undergone several telecom expansion projects to meet the ever increasing service demand from the public at large. Currently, it became one of the operators in Africa that joined the upgrading path towards the latest 4G cellular network technology by deploying LTE in its capital, Addis Ababa. This can be considered as one of the remarkable achievement in the history of telecom service in the country. However, considering LTE as the latest technology, the radio network planning used for the implementation of LTE network in Addis Ababa was basically vendor dependent. Thus, the study strives to demonstrate the possibility of LTE radio network planning by operators own work force with a combination of inward looking as well as basic radio network parameters.

In this study nominal and detailed LTE radio network planning has been illustrated using mathematical models and computer aided simulations taking Kirkos sub city as a typical case. Special focus has been made on SINR and shadow fading margin in the RLB from the coverage point of view; subscriber data volume per month and average cell throughput in terms of capacity. Besides, the target network performances evaluation has been made against the requirements defined with previously established coverage and capacity using RNPO tool. Therefore, from the result of this study, it can be concluded that:

- Optimum signal coverage and area coverage probability can be achieved when basic RLB parameters are considered in the nominal planning stage in line with target area terrain conditions.
- Optimum cell edge coverage probability, which helps to determine the optimum number of sites for the given target area, can be also achieved when the shadow fading margin consider from the target area perspective. This, in turn, helps operators to reduce their Capital Expenditure (CAPEX) and Operational Expenditure (OPEX).
- Network pre-deployment optimization shall be considered at the initial detail planning stage in order to avoid extra effort that might be necessitated by unforeseen issues after network deployment.
- Network capacity has to be evaluated from the perspective of simultaneous active user's distribution so as to understand how the planned target network accommodates the potential subscriber growth in the future. This help to address the impact of potential network performance related problems at time when there is subscriber growth after the network is commercially deployed.

5.2. Future Works

A great effort has been made in order to achieve the objectives of this study. However, as there is always a need to see a certain research topics using different approaches and methods, the following issues are recommended as future works:

- This study has been approached based on 3GPP's standard, LTE Release 8. The nominal and detailed radio network planning can further be seen from the perspective other 4G Releases.
- In this study, propagation model comparison has been used to select the worst case scenario to determine the cell range of the target network eNodeB's. Due to lack of the CW and drive test data, the selected propagation model parameters tuning were not performed. Hence, further study can be made by incorporating the propagation model comparison after tuning each model parameters using the target deployment area CW and drive test data.

- Subscriber forecasting is one of the input to estimate the number of eNodeB’s in terms of capacity. The subscriber forecasting used in this study is based on the population projection from census data. However, it can be further studied considering data users penetration for both 2G and 3G data service usage from the live network.
- There are three approaches which can be used to get the average sector throughputs in LTE; vendor’s approaches, simulation-based approach, and based on the available traffic channel RB. In this study the vendor’s approaches has been used and further study can be done by using the other approaches as well.
- This study focused on the network planning of the radio access part. One can further study the transport system capacity as well as the core network part that accommodate the radio access part design target.

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Annex A

Initial Sites Placement Geographical Information

Name	Longitude	Latitude	Altitude (m)
KK001	38°44'23.21"E	8°59'47.65"N	[2,308]
KK002	38°44'40.66"E	8°59'17.64"N	[2,278]
KK003	38°44'40.65"E	8°59'37.66"N	[2,285]
KK004	38°44'40.63"E	8°59'57.66"N	[2,308]
KK005	38°44'40.62"E	9°0'17.68"N	[2,331]
KK006	38°44'40.6"E	9°0'37.71"N	[2,356]
KK007	38°44'58.12"E	8°59'7.62"N	[2,293]
KK008	38°44'58.11"E	8°59'27.65"N	[2,302]
KK009	38°44'58.1"E	8°59'47.67"N	[2,318]
KK010	38°44'58.08"E	9°0'7.7"N	[2,319]
KK011	38°44'58.07"E	9°0'27.72"N	[2,353]
KK012	38°44'58.05"E	9°0'47.75"N	[2,362]
KK013	38°45'15.54"E	8°59'17.66"N	[2,299]
KK014	38°45'15.53"E	8°59'37.69"N	[2,321]
KK015	38°45'15.51"E	8°59'57.71"N	[2,336]
KK016	38°45'15.5"E	9°0'17.71"N	[2,348]
KK017	38°45'15.49"E	9°0'37.73"N	[2,362]
KK018	38°45'15.47"E	9°0'57.76"N	[2,351]
KK019	38°45'33"E	8°59'7.64"N	[2,309]
KK020	38°45'32.99"E	8°59'27.67"N	[2,303]
KK021	38°45'32.98"E	8°59'47.7"N	[2,314]
KK022	38°45'32.96"E	9°0'7.72"N	[2,343]
KK023	38°45'32.95"E	9°0'27.75"N	[2,348]
KK024	38°45'32.94"E	9°0'47.77"N	[2,346]
KK025	38°45'32.92"E	9°1'7.8"N	[2,361]
KK026	38°45'50.47"E	8°58'57.66"N	[2,308]
KK027	38°45'50.45"E	8°59'17.68"N	[2,319]
KK028	38°45'50.44"E	8°59'37.71"N	[2,329]
KK029	38°45'50.43"E	8°59'57.74"N	[2,342]
KK030	38°45'50.41"E	9°0'17.73"N	[2,356]
KK031	38°45'50.4"E	9°0'37.75"N	[2,344]
KK032	38°45'50.39"E	9°0'57.78"N	[2,363]
KK033	38°45'50.37"E	9°1'17.81"N	[2,402]
KK034	38°46'7.88"E	8°59'7.67"N	[2,306]
KK035	38°46'7.87"E	8°59'27.69"N	[2,330]

Name	Longitude	Latitude	Altitude (m)
KK036	38°46'7.86"E	8°59'47.72"N	[2,344]
KK037	38°46'7.84"E	9°0'7.74"N	[2,341]
KK038	38°46'7.83"E	9°0'27.77"N	[2,345]
KK039	38°46'7.82"E	9°0'47.79"N	[2,350]
KK040	38°46'7.81"E	9°1'7.82"N	[2,380]
KK041	38°46'25.33"E	8°59'17.71"N	[2,286]
KK042	38°46'25.32"E	8°59'37.73"N	[2,329]
KK043	38°46'25.31"E	8°59'57.76"N	[2,325]
KK044	38°46'25.3"E	9°0'17.78"N	[2,330]
KK045	38°46'25.28"E	9°0'37.78"N	[2,349]
KK046	38°46'25.27"E	9°0'57.8"N	[2,363]

Annex B

Sites Transmitters Final Parameters

Site	Transmitter	Azimuth (°)		Mechanical Downtilt (°)		Electrical Downtilt (°)	
		Before	After	Before	After	Before	After
KK001	KK001_1	0	0	0	2	0	6
KK001	KK001_2	120	120	0	5	0	6
KK001	KK001_3	240	240	0	0	0	0
KK002	KK002_1	0	345	0	0	0	6
KK002	KK002_2	120	120	0	2	0	6
KK002	KK002_3	240	220	0	0	0	6
KK003	KK003_1	0	0	0	3	0	6
KK003	KK003_2	120	120	0	3	0	6
KK003	KK003_3	240	240	0	0	0	0
KK004	KK004_1	0	0	0	0	0	6
KK004	KK004_2	120	120	0	3	0	6
KK004	KK004_3	240	240	0	5	0	6
KK005	KK005_1	0	0	0	0	0	6
KK005	KK005_2	120	120	0	4	0	6
KK005	KK005_3	240	250	0	5	0	0
KK006	KK006_1	0	340	0	0	0	0
KK006	KK006_2	120	120	0	5	0	6
KK006	KK006_3	240	260	0	0	0	0
KK007	KK007_1	0	0	0	5	0	6
KK007	KK007_2	120	120	0	4	0	6
KK007	KK007_3	240	240	0	0	0	0
KK008	KK008_1	0	0	0	0	0	6
KK008	KK008_2	120	120	0	4	0	6
KK008	KK008_3	240	225	0	0	0	0
KK009	KK009_1	0	0	0	5	0	6
KK009	KK009_2	120	120	0	4	0	6
KK009	KK009_3	240	240	0	0	0	0
KK010	KK010_1	0	0	0	2	0	6
KK010	KK010_2	120	120	0	2	0	6
KK010	KK010_3	240	240	0	5	0	6
KK011	KK011_1	0	0	0	3	0	6
KK011	KK011_2	120	120	0	5	0	6
KK011	KK011_3	240	240	0	5	0	6

Site	Transmitter	Azimuth (°)		Mechanical Downtilt (°)		Electrical Downtilt (°)	
		Before	After	Before	After	Before	After
KK012	KK012_1	0	340	0	0	0	0
KK012	KK012_2	120	120	0	2	0	6
KK012	KK012_3	240	240	0	0	0	6
KK013	KK013_1	0	0	0	3	0	6
KK013	KK013_2	120	120	0	5	0	6
KK013	KK013_3	240	240	0	5	0	6
KK014	KK014_1	0	0	0	3	0	6
KK014	KK014_2	120	120	0	5	0	6
KK014	KK014_3	240	240	0	5	0	6
KK015	KK015_1	0	0	0	5	0	6
KK015	KK015_2	120	120	0	5	0	6
KK015	KK015_3	240	240	0	5	0	6
KK016	KK016_1	0	0	0	3	0	6
KK016	KK016_2	120	120	0	5	0	6
KK016	KK016_3	240	240	0	5	0	6
KK017	KK017_1	0	0	0	0	0	0
KK017	KK017_2	120	120	0	4	0	6
KK017	KK017_3	240	240	0	5	0	6
KK018	KK018_1	0	0	0	5	0	0
KK018	KK018_2	120	120	0	5	0	6
KK018	KK018_3	240	240	0	0	0	6
KK019	KK019_1	0	0	0	5	0	6
KK019	KK019_2	120	120	0	5	0	6
KK019	KK019_3	240	240	0	0	0	6
KK020	KK020_1	0	0	0	2	0	6
KK020	KK020_2	120	120	0	4	0	6
KK020	KK020_3	240	240	0	5	0	6
KK021	KK021_1	0	0	0	0	0	6
KK021	KK021_2	120	120	0	2	0	6
KK021	KK021_3	240	240	0	3	0	6
KK022	KK022_1	0	0	0	4	0	6
KK022	KK022_2	120	120	0	4	0	6
KK022	KK022_3	240	240	0	5	0	6
KK023	KK023_1	0	0	0	5	0	6
KK023	KK023_2	120	120	0	2	0	6
KK023	KK023_3	240	240	0	4	0	6
KK024	KK024_1	0	0	0	3	0	6
KK024	KK024_2	120	120	0	4	0	6

Site	Transmitter	Azimuth (°)		Mechanical Downtilt (°)		Electrical Downtilt (°)	
		Before	After	Before	After	Before	After
KK024	KK024_3	240	240	0	0	0	6
KK025	KK025_1	0	0	0	0	0	0
KK025	KK025_2	120	120	0	1	0	6
KK025	KK025_3	240	240	0	5	0	6
KK026	KK026_1	0	0	0	4	0	6
KK026	KK026_2	120	140	0	0	0	0
KK026	KK026_3	240	240	0	0	0	6
KK027	KK027_1	0	0	0	5	0	6
KK027	KK027_2	120	120	0	4	0	6
KK027	KK027_3	240	240	0	5	0	6
KK028	KK028_1	0	0	0	2	0	6
KK028	KK028_2	120	120	0	4	0	6
KK028	KK028_3	240	240	0	5	0	6
KK029	KK029_1	0	0	0	3	0	6
KK029	KK029_2	120	120	0	4	0	6
KK029	KK029_3	240	240	0	5	0	6
KK030	KK030_1	0	0	0	4	0	6
KK030	KK030_2	120	120	0	5	0	6
KK030	KK030_3	240	240	0	4	0	6
KK031	KK031_1	0	0	0	4	0	6
KK031	KK031_2	120	120	0	4	0	6
KK031	KK031_3	240	240	0	2	0	6
KK032	KK032_1	0	0	0	0	0	6
KK032	KK032_2	120	120	0	5	0	6
KK032	KK032_3	240	240	0	5	0	6
KK033	KK033_1	0	340	0	0	0	0
KK033	KK033_2	120	120	0	5	0	6
KK033	KK033_3	240	220	0	0	0	0
KK034	KK034_1	0	0	0	3	0	6
KK034	KK034_2	120	120	0	0	0	0
KK034	KK034_3	240	205	0	0	0	6
KK035	KK035_1	0	0	0	4	0	6
KK035	KK035_2	120	120	0	0	0	6
KK035	KK035_3	240	240	0	5	0	6
KK036	KK036_1	0	0	0	4	0	6
KK036	KK036_2	120	120	0	5	0	6
KK036	KK036_3	240	240	0	5	0	6
KK037	KK037_1	0	0	0	0	0	6

Site	Transmitter	Azimuth (°)		Mechanical Downtilt (°)		Electrical Downtilt (°)	
		Before	After	Before	After	Before	After
KK037	KK037_2	120	120	0	5	0	6
KK037	KK037_3	240	240	0	3	0	6
KK038	KK038_1	0	0	0	5	0	6
KK038	KK038_2	120	100	0	3	0	6
KK038	KK038_3	240	240	0	4	0	6
KK039	KK039_1	0	0	0	0	0	6
KK039	KK039_2	120	120	0	4	0	6
KK039	KK039_3	240	240	0	5	0	6
KK040	KK040_1	0	0	0	2	0	0
KK040	KK040_2	120	120	0	0	0	0
KK040	KK040_3	240	240	0	5	0	6
KK041	KK041_1	0	20	0	0	0	2
KK041	KK041_2	120	120	0	0	0	0
KK041	KK041_3	240	220	0	3	0	6
KK042	KK042_1	0	15	0	5	0	6
KK042	KK042_2	120	120	0	0	0	6
KK042	KK042_3	240	240	0	4	0	6
KK043	KK043_1	0	0	0	5	0	6
KK043	KK043_2	120	120	0	0	0	6
KK043	KK043_3	240	240	0	2	0	6
KK044	KK044_1	0	20	0	0	0	6
KK044	KK044_2	120	120	0	0	0	0
KK044	KK044_3	240	240	0	1	0	6
KK045	KK045_1	0	0	0	5	0	6
KK045	KK045_2	120	100	0	0	0	6
KK045	KK045_3	240	240	0	0	0	0
KK046	KK046_1	0	340	0	5	0	0
KK046	KK046_2	120	120	0	5	0	0
KK046	KK046_3	240	240	0	3	0	6