ADAMA SCIEENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF ELECTRICAL ENGINEERING AND COMPUTING

Long Term Evolution (LTE) Radio Network Coverage and Capacity Planning for Dire Dawa City

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A Thesis Submitted to the Adama Science and Technology University, School of Electrical Engineering and Computing, in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Communication Engineering

September, 2017

Adama, Ethiopia

Long Term Evolution (LTE) Radio Network Coverage and Capacity Planning for Dire Dawa City

(A CASE STUDY)

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Declaration

I hereby declare that the work which is being presented in the thesis entitled, Long Term Evolution (LTE) Radio Network Coverage and Capacity Planning for Dire Dawa City (A Case Study), submitted to Adama Science and Technology University (ASTU) in partial fulfillment of the requirements for the degree Master of Science in Communication Engineering, is the result of my own research carried out under the supervision of Dr. Krishnamurthy Ramanujam and all sources of materials used for the thesis have been fully acknowledged.

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Acknowledgments

First and foremost let me grateful to almighty God for his blessings in my life. I would like to express my sincere appreciation and gratitude to Dr. Krishnamurthy Ramanujam for being my advisor and for his valuable guidance and help during the process of this thesis. His continuous interest was a constant source of motivation for me throughout the work.

It is a pleasure to pay tribute to Ethio telecom and Central Statistical Agency staffs for providing me with important data that are relevant to this study. I am also so grateful to my families, friends and classmates, who always motivate and support me to complete this thesis. I am thankful for those who stood with me throughout my work, giving me encouragements as well as valuable helps all the way through.

Abstract

In this thesis, the LTE system capacity and coverage are investigated taking Dire Dawa City as a case study. The main aim of this thesis is to propose number of eNB required for the LTE radio network planning based on coverage and capacity planning. The required number of eNB should be incorporate the coverage area of the target environment as well as capacity evaluation to accommodate the ever increasing subscriber growth. The simulation result of propagation model comparison shows that COST 231 HATA model is suitable for urban environment. According to the numerical result obtained from the coverage planning analysis, 43 (frothy three) eNBs are required to meet the coverage requirement and 47 (forth seven) eNBs are required to meet the capacity requirement from capacity planning analysis. Hence comparing the number of sites from capacity and coverage planning, the total number of eNB that will be used for LTE radio network planning becomes 47(forth seven) eNBs. The simulation was performed using ATOLL planning tool to evaluate number of eNB required that satisfy both coverage and capacity requirement. From simulation output, we verifies that we can cover a 68.62 Km^2 of Dire Dawa urban area using 47 eNodeBs of 4G radio network system.

Keywords: coverage planning, capacity planning, propagation model, ATOLL, eNB, LTE

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List of Acronyms

2G	Second Generation
3G	Third Generation
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
AMC	Adaptive Modulation & Coding
ATDI	Advanced Topographic Development & Images
BPSK	Binary Phase Shift Keying
BER	Blok Error Rate
BH	Busy Hour
CP	Cyclic prefix
CSA	Central Statistical Agency
dB	Decibel
DL	Downlink
DTM	Digital Terrain Model
EIRP	Equivalent Isotropic Radiated Power
eNB	Evolved Node B (interchangeably used as Base station)
EPC	Evolved Packet Core
EPS	Evolved Packet System
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FDD	Frequency Division Duplex
FFT	Fast Fourier Transform
GTP-2	Second Growth and Transformation Plan
LTE	Long Term Evolution
MAPL	Maximum Allowable Path Loss
MCS	Modulation and Coding Scheme
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
NBR	Number of Resource blocks

NGN	Next Generation Network
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Domain Multiple Access
PAPR	Peak to Average Power Ration
PL	Path Loss PRB Physical Resource Block
PS	Packet-Switched
PRB	physical resource block
QAM	Quadrate Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RB	Resource Blocks
RE	Resource Element
RF	Radio Frequency
RLB	Radio Link Budget
SAE	System Architecture Evolution
SC-FDMA	Single-Carrier Frequency Domain Multiple Access
S-GW	Serving Gateway
SINR	Signal to Interference plus Noise Ration
SNR	Signal to Noise Ratio
SUI	Stanford University Interim
TDD	Time Division Duplex
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
WLAN	Wireless Local Area Networks

Chapter - 1 Introduction

1.1 Introduction

The need for high speed data and voice are now starting to rise. One of the technologies that can meet the demands of data and voice communications is the Long Term Evolution (LTE). LTE is a technology that is standardized by 3rd Generation Partnership Project (3GPP). LTE has a great advantage over the other competitive systems. This is due to the reliability of varying the modulation schemes according to the environmental and coverage distance between the base stations and the receiver subscriber station. LTE is designed to have wider channels up to 20MHz, with low latency and packet optimized radio access technology. The peak data rate of LTE is 100 Mbps in downlink and 50 Mbps in the uplink. With its diversity of addressable band for deployment, LTE provides exceptional means for a profitable provisioning of large area coverage and scalable capacity. It is well prepared for coping with the massive growth in traffic being experienced today. LTE with its improved spectrum efficiency, tight interworking with the 2G/3G legacy systems and evolution, exist RF band support of heterogeneous networks has become the preferred technology these days. Moreover, LTE is uniquely identified by its characteristics that it is completely interoperable with the existing cellular infrastructures, like 2G and 3G. LTE is a packet switched (PS) system, which is the domain optimized core network designed to provide a reduced latency and enhanced quality of service [1, 2].

The rapid growth in 4G network deployments and connections, alongside expanding coverage reach, has made the move to 4G one of the fastest network technology migrations ever seen. The 4th generation is a new wireless internet access technology that transforms the existing internet speed to a superfast connection capability. Users of the 4G networks get the advantage of superior and uninterrupted connectivity which enables them to live stream videos and movies at a much faster rate than ever before and can also easily share information online. It provides faster sharing of large files and streaming media and improved performance for latency sensitive applications. In terms of the number of connections, 2G will still account for the majority of connections by 2016 (55 percent) but the number of 2G connections is expected to decline over the next four years as users continue to migrate to 3G and 4G technologies. In spite of the decline of 2G, this generation will still account for a significant share of global connections in 2017 (47 percent) taking into account the slow cycle of renewal of terminals in the developing countries, like Ethiopia, besides its significant satisfaction of needs in terms of voice only [3].

This thesis work focuses on dimensioning the radio access of LTE network so as to make it suitable for deployment in the city of Dire Dawa. Dimensioning refers to the process of analyzing capacity and coverage requirements and accordingly deciding upon operating parameters in the radio access. It is basically capacity and coverage planning rolled into one. This thesis work also analyzes propagation models to determine more accurately estimates path loss given the operating parameters chosen during the planning phase. This propagation model will then be used in a radio network planning tool that can operates on a digital terrain model database and can accurately plot coverage areas for different parts of Dire Dawa.

1.2 Statement of the problem

In Ethiopia massive telecom expansion projects are undergoing all over the country. Telecommunication sub-sector development part of the Second Growth and Transformation Plan (GTP-2) of Ethiopia launched in 2016 demands embracing the latest information technologies and by 2020 the number of mobile subscribers is expected to reach 103.7 million and internet subscribers 56 million in the Second Growth and Transformation Plan period. In 2015, Ethio telecom deployed 4G network in Addis Ababa and the northern part of the country is expected to do so the rest of the region of the country . The main reason for 2G / 3G to 4G is to meet users' needs as regards the expected improvement it offers since Service coverage and capacity is not met customers requirement by existing technology. LTE radio network planning is done basically using link budget calculation to estimate the cell size and theoretical traffic and throughput calculation for capacity estimation. In most cases, since the simplicity of this stage is needed the coverage estimation is done with a general propagation model which doesn't incorporate the actual geographical information (terrain model) and most of the time network planning and design works are done by estimation of vendors. This might be causes the improper radio network planning. To properly resolve this problem and perform the LTE radio network capacity and coverage planning, a consideration of certain site is important where in this thesis Dire Dawa is considered.

1.3 Objectives

1.3.1 General Objectives

The main objective of this thesis is to carryout LTE network coverage and capacity planning taking Dire Dawa City as a case study.

1.3.2 Specific Objectives

- Study of LTE radio Network Planning
- Selection of suitable propagation models for LTE radio Network Planning
- Coverage Planning
- Capacity Planning
- Site Count
- Simulating the model with ATOLL planning software

1.4 Scope

The capacity and coverage will be based on simulation of the proposed techniques using ATOLL tools and for this thesis, LTE radio network capacity and coverage planning for Dire Dawa City will be studied.

1.5 Significance

This thesis can be used by network planners as a design document and guideline for future network expansion projects and even for optimization activities of the existing network. This study will be very useful for the current operators to upgrade for the 4G network.

1.6 Methodology

The process of designing the radio network is considered as one of the most important and crucial issue in the wireless design since it depends on many variables related to the land terrain, population density and the target itself. The below flow chart shows the methodology followed during this thesis. The work started with the literature review and theoretical background study of the LTE. This is followed by shifting the focus on the study of LTE Network coverage and capacity planning. Preliminary work on the LTE Network coverage and capacity planning is then started, along with the theoretical work on the radio link budget, cell radius, number subscriber per site and site count. After integration of a total number of eNB obtained from the coverage and capacity planning into the planning tools, analyzing the calculated value of eNB with respect to simulation result.

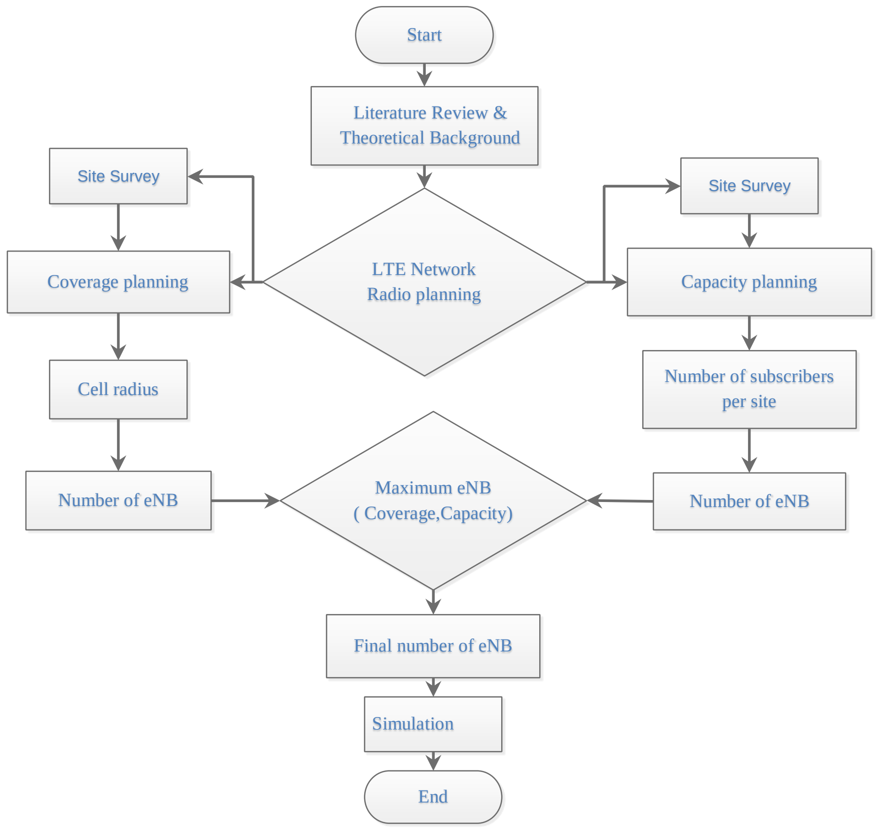

Figure 1.1: LTE Network coverage and capacity planning Process

1.7 Thesis Layout

The thesis work is done in such a way that it gives a clear flow and understanding regarding LTE coverage and capacity planning. Chapter one presents the objectives, scope, methodology and a short introduction with problem explanation. Chapter two presents literature review and theoretical background of LTE for the study. Chapters three focuses on LTE Radio Network Planning Process starting from site survey to site count. Chapter four is all about Radio Planning Analysis and Results for Dire Dawa City. Finally, conclusions are given followed by points of future work in Chapter five.

Chapter - 2 Literature Review and Theoretical Background

2.1 Literature Survey

This section surveys previous work in LTE Radio access network. There have been several works done on the area of LTE dimensioning and planning. Some of the recently published articles related to this work are reviewed as follows.

2.1.1 Literature Review of Different Authors

1) **LTE Radio Network Planning in the Case of Addis Ababa City**
   by Bethelhem Seifu

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 and capacity evaluation 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 planning 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 radio planning tools like ATOLL. Moreover, the study does not show the capability of target network against the expansion of the city and the subscriber's future growth.

2) **Coverage Analysis of 4G LTE Radio Network in a Case of Bahir Dar City**
   by Bekele M.Zerihun and *Solomon H.Gebreyohannes*

LTE radio network coverage analysis has been performed by considering possible network implementation in Bahir Dar City. This study focused only on coverage planning without consideration of the subscriber's future growth. Moreover, study does not incorporate the city expansion as well as capacity evaluation to accommodate the ever increasing subscriber growth. As a result, the calculated eNodeB's capabilities in terms of capacity planning were not performed.

3) Coverage Analysis of LTE Radio Network Planning Considering Khartoum City

by Marwa Elbagir Mohammed, Khalid Hamid Bilal

The main purpose of this paper was to attempt to study coverage planning analysis of Khartoum city. The dimensioning stage coverage analysis was performed. This study focused only on coverage planning without consideration of the subscriber's future growth. However, the study does not integrate the coverage prediction as well as capacity evaluation in consideration of future subscriber growth.

4) Long Term Evolution Capacity Planning using MATLAB

by Jacqueline J.George1, Sheemaa Ali Mohamed Hashim

This paper focuses on capacity planning phase in the dimensioning stage of LTE network. Its main objective is to provide the number of sites (cells) needed in order to support a certain subscriber population with a given capacity. Capacity planning phase has been simulated using a MATLAB software programming. The capacity planning phase was investigated using different factors; Subscriber geographical spread, traffic forecast, over booking factor and the Cell throughput. Due to the limitation of Matlab, in this study, the network prediction and coverage evaluations were not performed as it is done these days by using radio planning tools. Moreover, the study does not show the capability of target network against the geographical area of the target environment.

5) Capacity Dimensioning of LTE Urban Network

by Awais Saeed, Adnan A. Khan, Syed Ismail Shah, Shariq Yasin

Capacity dimensioning is performed before launching a cellular network, which includes forecast of throughput. This paper includes a thorough analysis of factors that affect capacity of 4G networks, including radio propagation models. The performance analysis of this study is done using Matlab and results are verified field measurements. Based on analysis of these results capacity dimensioning, in terms of number of sites is carried out for an urban network of Islamabad. Due to the limitation of Matlab, in this study, the network prediction and coverage evaluations were not performed as it is done these days by using radio planning tools. More over the study does not show the capability of target network against the geographical area of the target environment.

6) LTE Performance and Analysis using Atoll Simulation

by Mohammed Elhadi Abdelgalil, Dr. Amin Babiker A/Nabi

Long Term Evolution is the last step to reach the complete the 4th generation of cellular networks**.** This paper represents some of the LTE parameters, including downlink average throughput and uplink average throughput, data rate, bandwidth, coverage, LTE operates in both paired and unpaired spectrum by supporting both frequency division duplex and time division duplex. In this studies a tool simulator was used and many parameter were compared to get to know the LTE network performance with various method form different view and finally it was concluded that the network has many advantages over the previous networks form coverage by throughput in uplink and downlink, coverage by signal level, coverage by signal to interference ratio in uplink and downlink and overlapping zone. However, 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.

In general, over a recent year's different Authors tried to describe the LTE radio network planning through the analysis of coverage and capacity for different environment. Hence, different environment has different factor which can affect the LTE radio network planning. For my case, the thesis proposes the way to incorporate the coverage prediction as well as capacity evaluation to accommodate the ever increasing subscriber growth by considering Dire Dawa city as case study. In this study, the coverage of the LTE system also calculated based on link budget calculation and selection of suitable propagation model for Dire Dawa environment. Similarly, capacity planning will be investigated which include forecasted subscriber of Dire Dawa city.

2.2 LTE Architecture

LTE is the evolution of the radio access Universal Mobile Telecommunications System (UMTS) known as Evolved Universal Terrestrial Access Network (E-UTRAN), whereas the evolution of the non-radio part including the Evolved Packet Core (EPC) network is referred to as the System Architecture Evolution (SAE). Both the LTE and SAE form what we call the Evolved Packet

System (EPS). Figure 2.1 shows the overall network architecture with the basic EPS entities, different types of interfaces and the type of traffic carried on each link [4, 5].

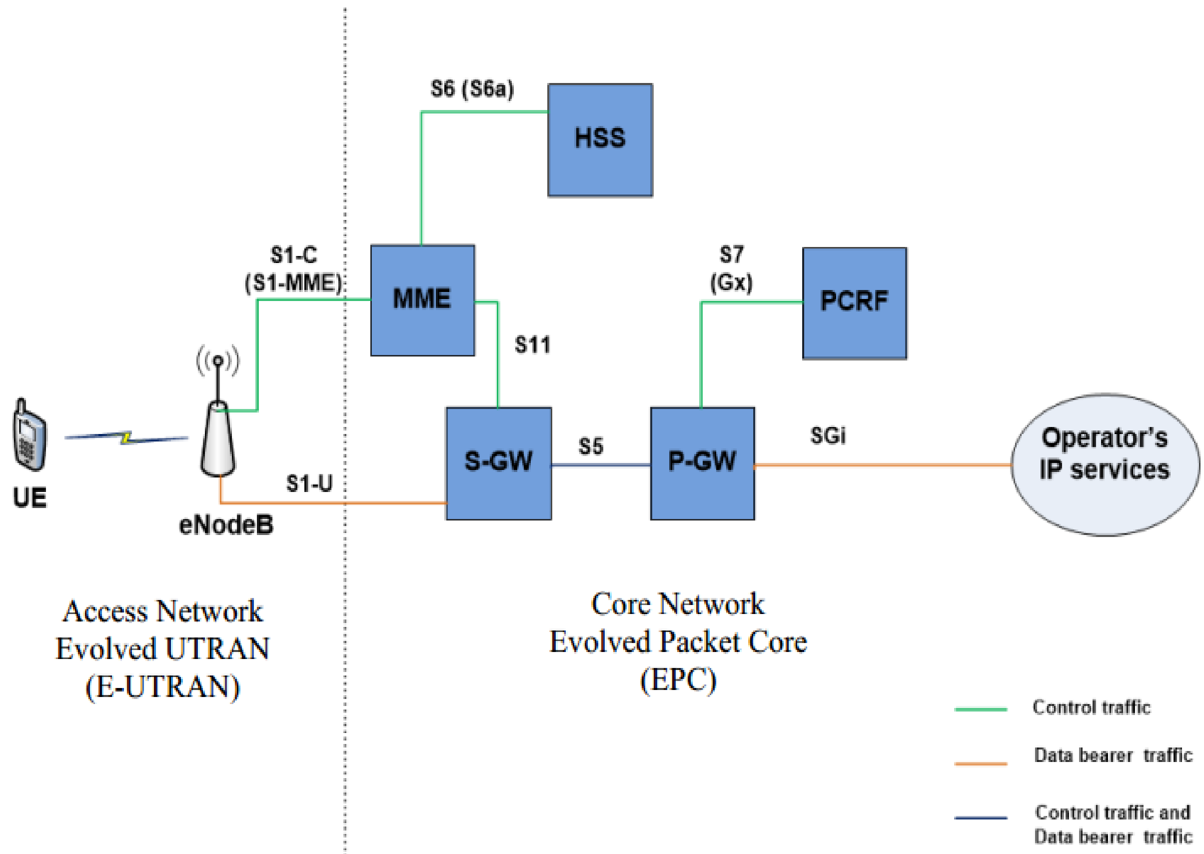

Figure 2.1: Typical architecture for LTE networks [5]

In the following, Table 2.1 show the functions of the EPS core and access networks.

Table 2.1: EPS elements and functions [4, 5]

EPS element	Element	Description
E-UTRAN	eNB (*evolved Node B*)	An eNB provides users with the radio interface and performs radio management (RRM) function such as dynamic resource allocation, eNB measurement configuration and provision,

		radio admission control, connection mobility control and radio bearer (RB) control and inter-cell interference coordination.
EPC	MME (*Mobility Management Entity*)	A MME is the main control entity for the E-UTRAN. It communicates with an HSS for user authentication and user profile download, and provides UEs with EPS mobility management (EMM) and EPS session management (ESM) function using NAS signaling. The main functions supported by a MME area as follows: • Signaling and security control • Tracking area management • Inter core network signaling for mobility between 3GPP access networks • EPS bearer management • Roaming and authentication
	S-GW (*Serving Gateway*)	An S-GW terminates the interface towards the E-UTRAN. It serves like packet routing and forwarding, transport level quality of service mapping
	P-GW (*packet data network* (*PDN*) *gateway*)	P-GW is the interconnection point between the EPC and the external IP networks and it is mainly in charge of assigning and distributing the IP addresses for the UE. The main functions supported by a P-GW are as follows: • IP routing and forwarding • per user based packet filtering • mobility anchoring between 3GPP and non-3GPP • Charging per user.
	HSS (Home Subscriber Server)	HSS is the central database where the user profile s are stored. It holds dynamic information to keep track of the MME

		identities to which users are connected. HSS also includes data for the user's System Architecture Evolution (SAE) subscription such as the Qos profile and any roaming access restrictions.
	PCRF (Policy Control and Charging Rules Function)	One of its tasks is to control the Policy Control and Charging Enforcement Function (PCEF) functionalities that are flowbased and residing in the P-GW. The QoS authorization, which is consisting of the QoS Class Identifiers (QCI) and bit rates, defines the PCEF treatment for certain data flows in harmony and agreement with the user's subscription profile.

As shown in Figure 2.1, the names of the interfaces are standardized. The S1-U interface connects the eNB and the S-GW for user plane traffic (i.e. bearers' tunneling, inter-eNB handover), alsothe S1-C (currently referred to as S1-MME) connects the eNB with the MME for control processes and signaling messages between the eNB and the MME. S11 connects the MME to the S-GW, S6 (currently referred to as S6a) connects the MME and the HSS, and S5 connects the S-GW to the P-GW. In addition to that, the S7 (currently referred to as Gx) connects the P-GW (PCEF) to the PCRF, and the SGi is the interface between the P-GW and the packet data network such as Internet or IMS (IP Multimedia Subsystem).

2.3 LTE Air Interface

The air interface is the radio based communication link between the mobile station and the active base station. LTE air interface supports high data rates. LTE uses Orthogonal Frequency Division Multiple Access (OFDMA) for downlink transmission to achieve high peak data rates in high spectrum bandwidth. LTE uses Single Carrier Frequency Division Multiple Access (SC-FDMA) for uplink transmission, a technology that provides advantages in power efficiency [6].

Figure 2.2: LTE air interface [7]

2.3.1 Orthogonal Frequency Division Multiple Access (OFDMA)

OFDMA is a multiple access scheme on the base of the Orthogonal Frequency-Division Multiplexing (OFDM) modulation technique. The OFDM signal can be generated by using the Fast Fourier Transform (FFT). In an OFDM system, the available spectrum is divided into multiple, mutually orthogonal subcarriers. Each of these subcarriers are independently modulated by a low rate data stream and can carry independent information streams. Figure 2.3 shows how the OFDM technique is applied for a signal with 5 MHz bandwidth [7].

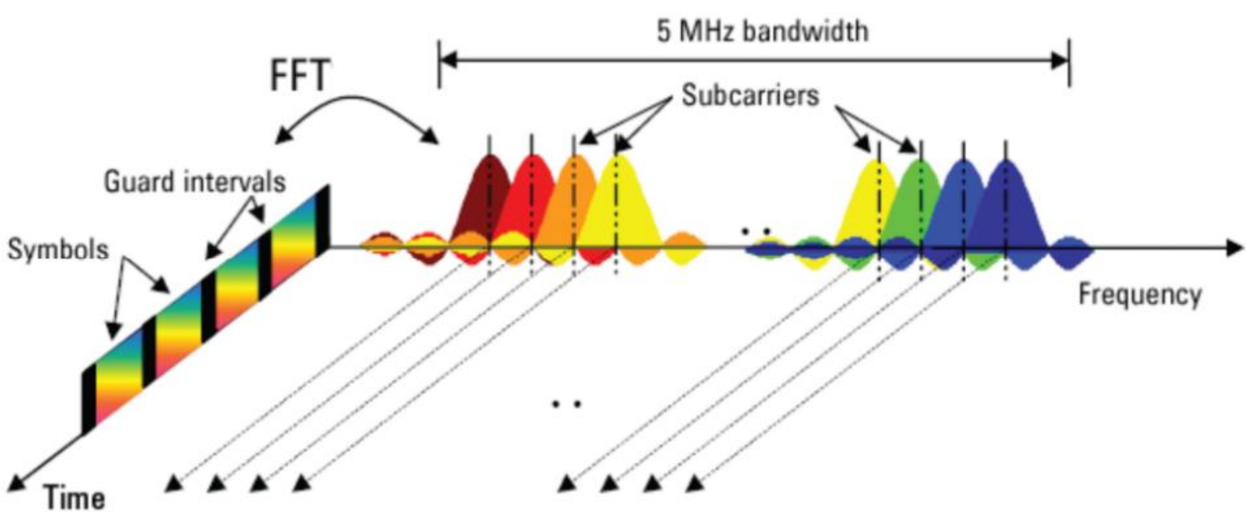

Figure 2.3: Frequency-time representation of an OFDM Signal [7]

In the frequency domain, the 5 MHz bandwidth is divided into a high number of closely spaced orthogonal subcarriers. The subcarriers in LTE have a constant spacing of 15 kHz. In E-UTRA, the downlink modulation schemes can be QPSK, 16QAM and 64QAM. In the time domain, a guard interval is added to each symbol to combat inter OFDM symbol interference due to channel delay spread. In E-UTRA, the guard interval is a cyclic prefix (CP) which is inserted prior to each OFDM symbol. A group of subcarriers is called a sub-channel. Each of the 15 kHz LTE air interface subcarriers are orthogonal to each other giving rise to the OFDM which is employed in the downlink. The process of modulating data symbols and combining them is equivalent to an Inverse Fourier Transform operation (IFFT). The reverse operation is applied to the OFDM symbol to retrieve the data stream which is equivalent to a Fast Fourier Transform operation (FFT).

There are many advantages to using OFDM in a mobile access system [8]:

- Long symbol time and guard interval increases robustness to multipath and limits inter symbol interference.
- Eliminates the need for intra-cell interference cancellation.
- Allows flexible utilization of frequency spectrum.
- Increases spectral efficiency due to orthogonality between sub-carriers.
- Allows optimization of data rates for all users in a cell by transmitting on the best sub-carriers for each user.

2.3.2 Single Carrier Frequency Division Multiple Access (SC-FDMA)

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. 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. Hence, LTE uses Single Carrier FDMA (SC-FDMA) with cyclic prefix on the uplink, which reduces PAPR. SC-FDMA is well suited to the LTE uplink requirements because the data transmitted is consecutive [7, 8].

2.4 Adaptive Modulation and Coding (AMC)

In cellular communication systems, the quality of the signal received by a UE depends on the channel quality from the serving cell, the level of interference from other cells, and the noise level. To optimize system capacity and coverage for a given transmission power, the transmitter should try to match the information data rate for each user to the variations in the received signal. This is commonly referred to as link adaptation and is typically based on Adaptive Modulation and Coding (AMC). The AMC consists of the modulation Scheme and code rate [9].

2.4.1 Modulation Scheme

Low-order modulation (like QPSK) is more robust and can tolerate higher levels of interference but provides a lower transmission bitrate. High-order modulation (like 64QAM) offers a higher bit rate but is more prone to errors due to its higher sensitivity to interference, noise and channel estimation errors; it is therefore useful only when the Signal to Interference and Noise Ratio (SINR) is sufficiently high.

2.4.2 Code Rate

For a given modulation, the code rate can be chosen depending on the radio link conditions: a lower code rate can be used in poor channel conditions and a higher code rate in the case of high SINR [10]. The type of modulation used in LTE depends on the radio environment. The uplink reference signals that are embedded into the uplink transmission are used by the eNodeB to estimate the quality in the uplink. The eNodeB decides which modulation technique should be used based on the quality of the downlink and uplink radio environment.

LTE supports the following modulation techniques in the downlink and uplink [11]:

- 64 Quadrature Amplitude Modulation (64 QAM) which uses 64 different quadrature and amplitude combinations to carry 6 bits per symbol.
- 16 Quadrature Amplitude Modulation (16 QAM) which uses 16 different quadrature and amplitude combinations to carry 4 bits per symbol.
- Quadrature Phase Shift Keying (QPSK) which used 4 different quadrature’s to send 2 bits per symbol.

2.5 LTE Frame Structure

To support transmission in both paired and unpaired spectrum in LTE, two duplexing modes are used. Thus, Frequency Division Duplex (FDD) and Time Division Duplex (TDD).

FDD enables a device to transmit and receive data at the same time by allocating separate uplink and downlink channels. 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 [12]. As shown in Figure 2.4a, the spacing between these two channels is called the duplex spacing.

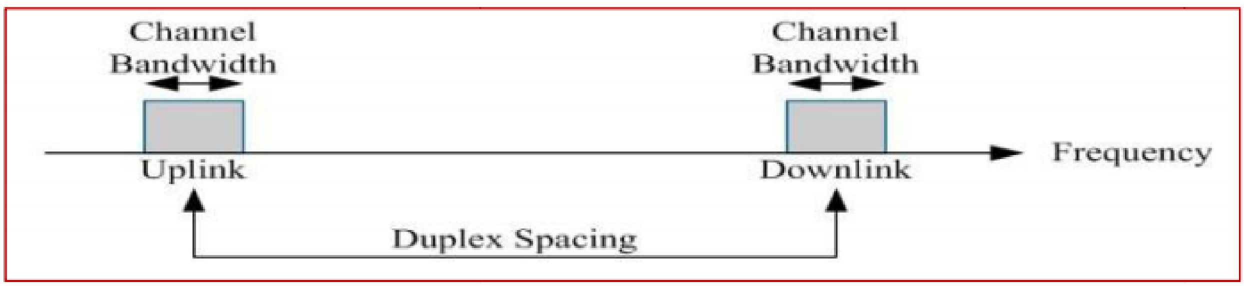

Figure 2.4a: Radio Access Technology, FDD [12]

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 2.4b shows this asymmetrical uplink and downlink allocation.

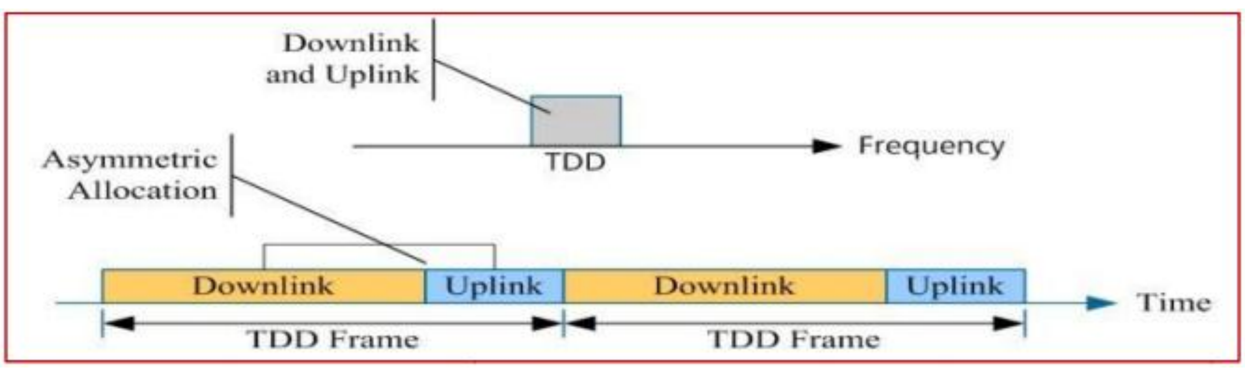

Figure 2.4b: Radio Access Technology, TDD [12]

The LTE FDD frame structure is demonstrated in Figure 2.5 for normal cyclic prefix (CP). Each LTE FDD radio frame is Tf = 307200×Ts = 10 ms long and consists of 20 slots of length Tslot = 15360×Ts = 0.5 ms, numbered from 0 to 19. For LTE FDD, 10 sub-frames are available for downlink transmission and 10 for uplink transmissions in each 10 ms interval. UL and DL transmissions are separated in the frequency domain [13].

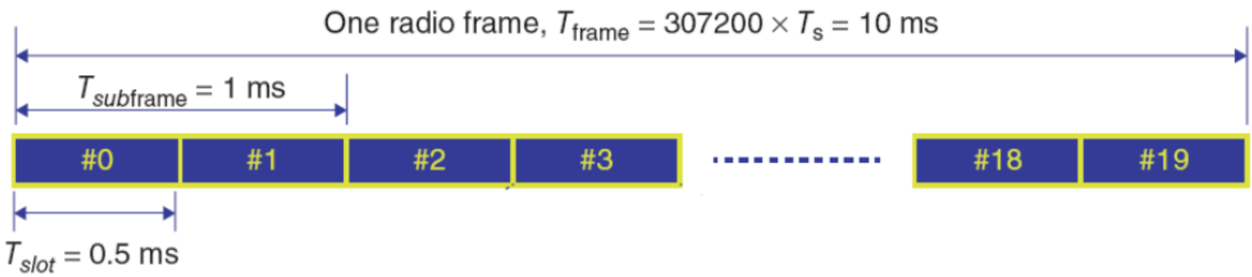

Figure 2.5: LTE FDD frame and slot structure [13]

2.5.1 Resource Blocks (RB)

A physical resource block (PRB) is used in LTE to describe the physical resource in the time/frequency grid. The Resource Element (RE) is used to describe one subcarrier by one symbol in the time-frequency grid. Figure 2.6 illustrates the LTE time/frequency grid definitions. A PRB consists of 12 consecutive subcarriers and lasts for one slot, 0.5 ms. Each subcarrier is spaced by 15 kHz. The NRB DL parameter is used to define the number of RB (resource blocks) used in the downlink. This is dependent on the channel bandwidth. In contrast, NRB UL is used to identify the number of resource blocks in the uplink. Each resource block consists of NSCRB subcarriers, which for standard operation is set to 12 or a total of 180 kHz lasting in a 0.5ms slot. The resource element (RE) is the smallest defined unit, which consists of one OFDM subcarrier during one OFDM symbol interval. Each RB consists of 12 × 7 = 84 REs in the case of normal CP and 72 REs for extended CP. The maximum RB is 100. The 100 RB corresponds to the transmission bandwidth while 20MHz is the channel bandwidth. The number of subcarriers depends on the system BW. The transmission can be scheduled by RB, each of which consists of 12 consecutive subcarriers, or 180 kHz, for the duration of one slot (0.5 ms) [14, 15].

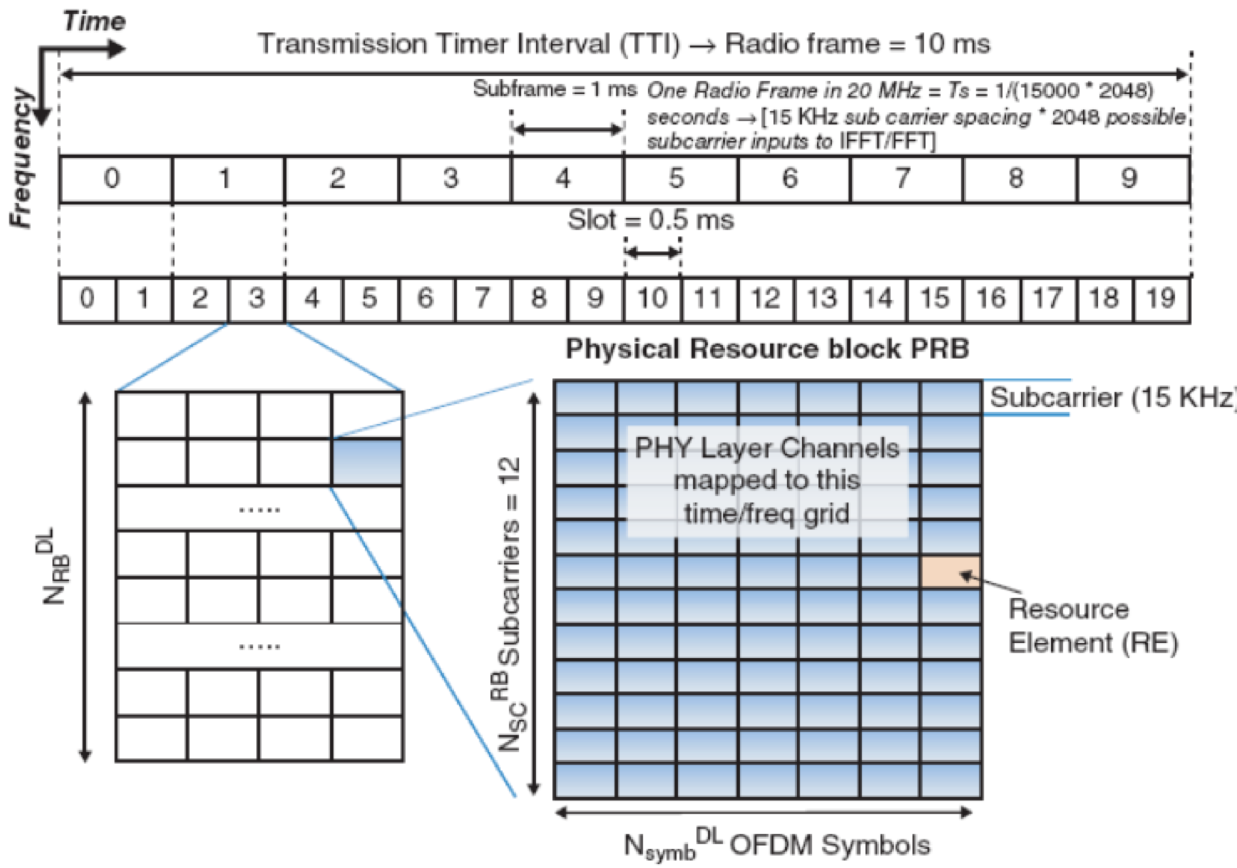

Figure 2.6: Physical resource block and resource element [14]

As there are various channel bandwidths considered in LTE deployment, the illustrated time-frequency grids in Figure 2.6 summarized in the shown below Table 2.2 shown below.

Table 2.2: LTE Frequency Domain Configuration [15]

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

2.6 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.

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 [16].

2.7 The Ethiopian Telecommunication Service System Overview

The Ethiopian government decided to transform the telecommunication infrastructure and services to world class standard, considering them as a key lever in the development of Ethiopia. Thus, Ethio telecom is born from this ambition in order to bring about a paradigm shift in the development of the telecom sector to support the steady growth of country. The mobile communication services were introduced in the year 2000 using second-generation (2G) Global System for Mobile Communications (GSM) standard and network equipment were supplied by Ericsson and Nokia Siemens and initial deployment done for the city of Addis Ababa and by 2005, the network was expanded to all the regional state of the country.

In 2007, as part of the Ethiopia Millennium Project, the next generation network (NGN) was launched to expand and upgrade Ethiopia’s network, which also includes the associated rollout of mobile coverage in rural areas and was deployed by ZTE Company. The NGN project introduces new technology, system application and services such as third generation (3G) WCDMA and CDMA 2000 mobile network infrastructures, call center, billing system and value added services. As a result of these expansions, the number of mobile subscribers has exponentially increased and the prevailing data indicates over 20 million subscribers.

It is well recognized that due to the lower income level of developing countries, like Ethiopia the usage of new technologies has been very low [17]. Because of this, the demand of data service of Ethiopia has been quite less than the African and World demand average for some ten years ago. However, in the last ten years, the Ethiopian Telecommunication system has shown a remarkable development, especial in infrastructure development. Ethio telecom has been investing a huge amount of money for expansion existing network. With the network expansion program, the operator has also laid the fiber optics network to more than 14,000 km to all over the country. This backbone infrastructure is expected to support the new technologies from 3G to 4G technologies [18].

2.7.1 Mobile Phone and Internet subscription

The number of subscribers in mobile phone and internet has been very low before ten years, and within recent years, especially the last five years, the subscription rate in mobile is almost three times in 2016 compared with the 2012 data. The subscription of internet users before five years also very low. This due to infrastructure and low awareness of the users. However, in the last three years, the increase of subscription has highly increased. The deployment of 3G in country and 4G systems in the capital city Addis Ababa has contributed for the rise of subscribers as all mobile users can access internet.

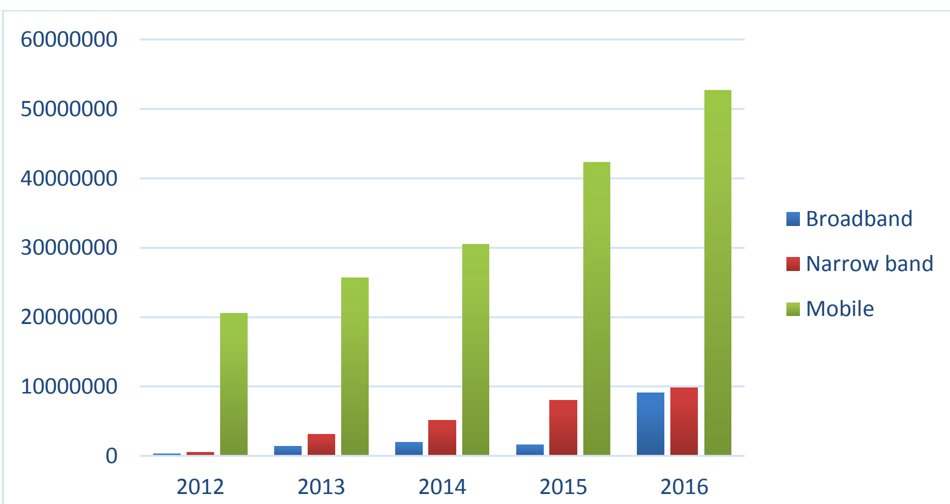

Figure 2.7: Ethiopian mobile phone and Internet subscription [19]

2.7.2 Mobile phone network coverage

Ethiopia's mobile coverage has seen strong growth in recent years. The voice service coverage of the country is covered by the 2G & 3G technology. The 2G mainly covers the rural area of the country. The existing technology network voice covers about 90% and this is mainly in the urban areas. According to the second Growth and Transformation Plan (GTP -2), it is expected that existing and new deployed technology will cover about 100% of the country in 2020.

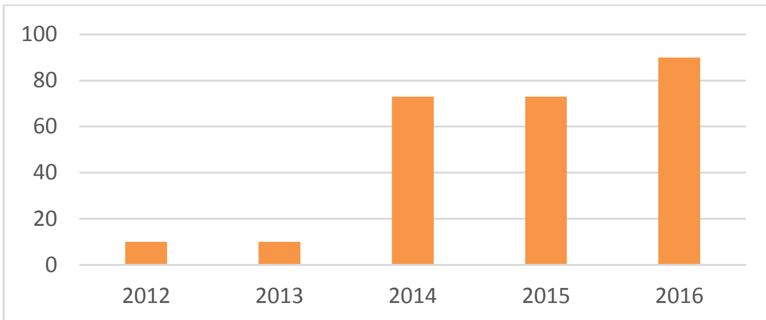

Figure 2.8: Ethiopian mobile network coverage (in percent) [19].

Chapter - 3 LTE Radio Network Planning Process

Radio Network Planning is the process of assigning frequencies, transmitter locations and parameters of a wireless communications system to provide sufficient coverage and capacity. It remains an essential process for network operators. 4G also known as beyond 3G refers to the fourth generation of wireless communications. Network operators are deploying 4G wireless networks to effectively deliver next generation broadband services to an expanding base of consumers eager to experience media rich applications. Still operators are quite aware of the fact that effective 4G radio planning indeed is a challenging issue. While 4G LTE promises to increase network capacity, improve quality of service and significantly enhance data rates brings new design challenges.

The target radio network planning should be a compromise between coverage, capacity and quality of services. The network designer should consider these factors during the planning phase of the network. On the other side, the network should be dimensioned properly to meet current and future capacity requirement without underestimation or overestimation of the traffic growth. The network planning process and design criteria vary from region to region depending upon the dominating factor, which could be capacity or coverage. Environmental factors also greatly affect network planning. The network design can be an extension of the existing LTE network or a new network to be launched. Figure 3.1 demonstrates the radio network planning process of LTE network. The LTE radio network planning process is divided into different steps.

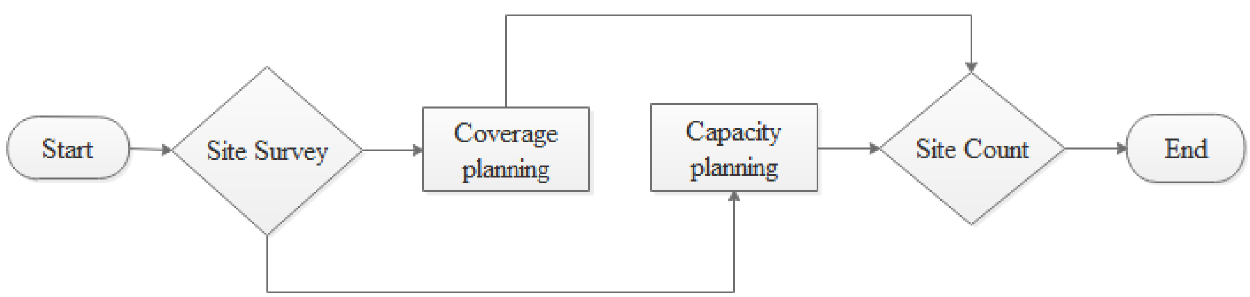

Figure 3.1: LTE radio network planning steps for Dire Dawa City

3.1 Site Survey

The city of Dire Dawa is over a hundred years old. Dire Dawa is located in the eastern part of the country enclosed by the State of Somalia and the State of Oromia. It is found at a distance of 515 Kilometers from Addis Ababa. Dire Dawa is a city established at an average elevation of about 1276 m meters above sea level.

Dire Dawa city is structured in 9 Kebeles and the central statistical agency (CSA) conducted census per five year basis. I took the data from ethio telecom, Dire Dawa city Municipality and CSA. Both CSA and Dire Dawa Municipality data include urban, sub-urban and rural region population as part of Dire Dawa. Dire Dawa is assumed to have urban, sub-urban and rural region and according to Dire Dawa Municipality office. My thesis focusses on the Dire Dawa urban City. The urban City covers a total area of about 68.62 km^2. Therefore, I figure out the population inside the urban city only. Table 3.1 presents the CSA data and existing ethio telecom network users to define the demographics of Dire Dawa city. CSA conducted census in the year 2006/2007 and 2011/2012 and its result and the growth rate of population and current mobile network user are all shown.

Table 3.1**:** Dire Dawa city CSA demographic & Mobile Network Subscriber data

Demographics Dire Dawa City	Value	Remark
2006/2007 population	233224	a
2011/2012 population	257566	b
Population growth rate	0.02	$c = \sqrt[5]{(b/a)} - 1$
2016/2017 population	284449	$d = a(1+c)^n, \quad n = 10$
2016/2017 current Subscribers	184159	e
Expected population of 2021/2022	314054	$f = d(1+c)^m, m=5$
Expected market penetration (*by the 5^{th} year of operation*)	Increases by 10%	g
2021 /2022 Forecasted Subscribers	296496	$h = e\,(1+g)^k, k=5$
Area of Urban Dire Dawa	68.62 km^2	

3.2 Coverage Planning

Coverage Planning is the main step in the process of dimensioning. It gives an estimate of the eNodeB number needed to provide service in the deployment area with the given system parameters, without any capacity concern. Radio network planning mainly depends on geographical and morphological data. Thus, a basic coverage may be calculated with propagation models using digital maps of the respective area during simulation.

Network coverage is calculated based on the path loss data between the base stations and users as well as using antenna configuration parameters such as antenna height, power, radiation characteristics, tilt and azimuth. Figure 3.2 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

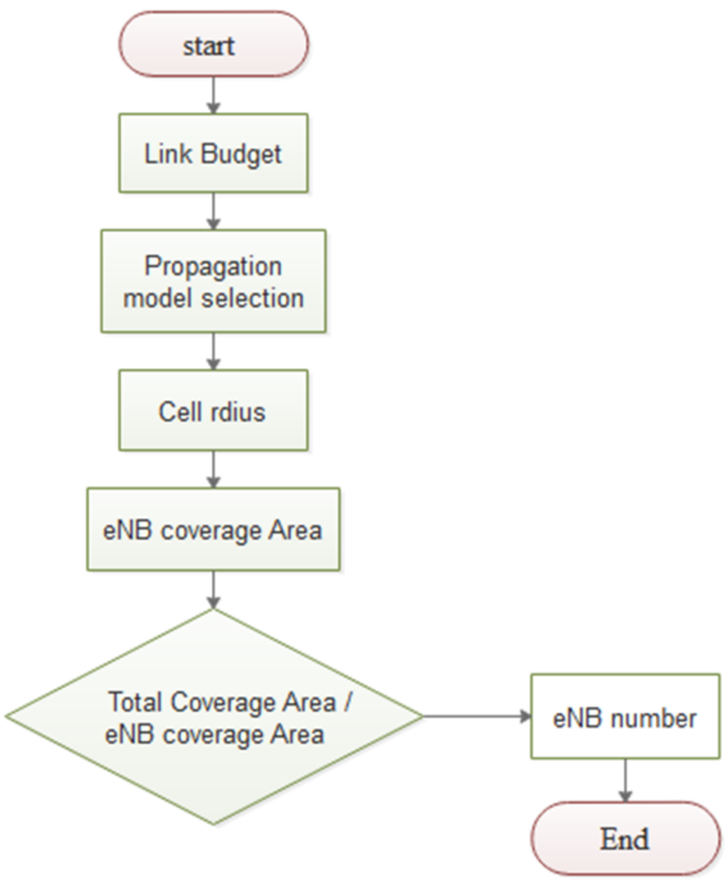

Figure 3.2: Summarized LTE coverage planning

3.2.1 Radio Link Budget (RLB)

A link budget is the sum and total of all gains and losses in the radio connection between two parties from end to end; including antennas, feed lines and the path between the antennas, but also the relevant portions of the transmitter and the receiver. Link budget calculation is used to determine the maximum allowable path loss (MAPL). MAPL is the link margin we get when we subtract all the loss parameters from the sum of our gain parameters. The path loss at any given point in our intended coverage area needs to be less than or equal to this link margin.

The purpose of link budget is to analyze the power balance between downlink and uplink through the given system parameters and design parameters. The links are calculated separately and are different from the transmission powers. The BTS transmission power is higher than the MS transmission power and therefore the reception of the BTS needs to have high sensitivity. One of the required parameters is radio wave propagation to estimate the propagation loss between the transmitter and the receiver. By comparing the MAPL with the PL of the appropriate propagation model, the cell radius can be calculated for different terrain morphologies.

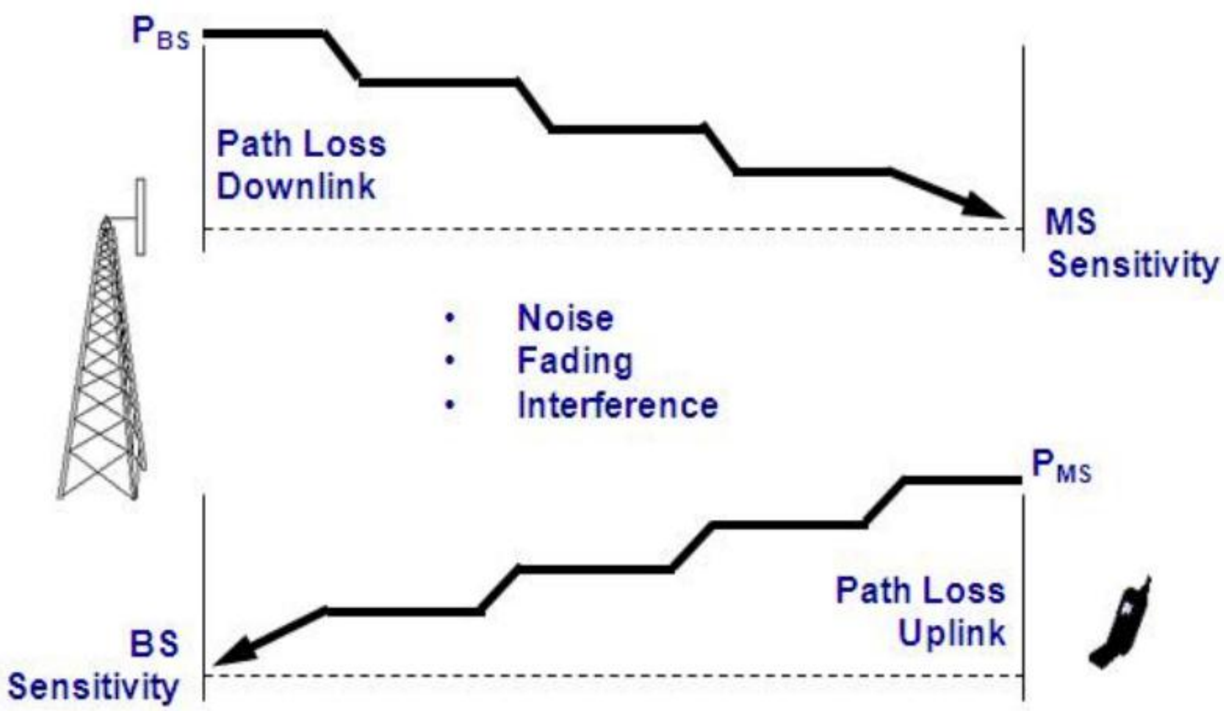

Figure 3.3: A simplified block diagram of link budget Estimation [20]

3.2.1.1 Link Budget Parameters

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, 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 [1, 21, 22, 23].

- ***eNB Antenna Gain***: The selection of antenna gain and beam width depends on the clutter type and coverage requirement. The antenna gain is proportional to the antenna size. The low gain antenna (15 to 17 dB) can be used in dense urban and urban clutters while a high gain antenna (18 to 20 dB) can be used in rural areas.
- ***eNB Maximum Total Transmitter Power***: This is one of the main factors that impact the link budget. Refers to the transmit power value per transmitting (TX) path. Typical value is 46dBm.
- ***UE Maximum Total Transmitter Power***: It refers to the UE transmit power which depends on the power class of the UE. Typical value is 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 dB for each antenna port(s).
- ***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, 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. Typical value 0dB.
- ***Equivalent Isotropic Radiated Power (EIRP)***: The 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. The power radiated by a directional antenna is transposed into the radiated power of an isotropic antenna by consideration of antenna gain and power at the antenna input. The EIRP in the UL and DL is calculated as follows.

$$EIRP_{UL} = \text{UE Transmitter power} + \text{UE Antenna gain} - \text{UE Body Loss} \quad (3.1\ a)$$

$$EIRP_{DL} = \text{eNB Transmitter power} + \text{eNB Antenna gain} - \text{Cable Loss} - \text{connector Loss} \quad (3.1\ a)$$

- ***Noise spectral density (N_P)***: N_P is the density of the thermal white noise power which is −174dBm/Hz in room temperature (290K).
- ***Thermal Noise***: The thermal noise is a loss due to heat and thermal noise is calculated as

$$N = KBT \tag{3.2}$$

Where,

K is the Boltzmann constant (1.38 x 10^{-23} J/K).

T is absolute temperature at a value of 290K

B is channel bandwidth which is 15MHz

- ***Noise figure***: In link budget of mobile telecommunications, noise figure includes the noise figure of base station receiver and the noise figure of MS receiver. When signals pass a receiver, noise is added to the signal and thus the noise figure is a method to measure the noise addition. 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.
- ***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. In telecommunications system, receiver sensitivity is given by:

$$Receiver\ Sensitivity = Noise\ figure + SINR + Thermal\ Noise + 10\log(\mathrm{B}) \tag{3.3}$$

Where,

SINR is the Signal to interference noise ratio

B is bandwidth in KHz

- ***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.

Table 3.2: Penetration losses range based on clutter type [23]

Clutter type	Penetration loss range (dB)	Typical values (dB)
Dense urban	19 - 25	19
Urban	15 - 18	15

Sub- urban	10 - 14	11
Rural	5 – 8	8

- ***Slow fading margin / Shadow fading margin***: Shadow fade is also named slow attenuation. It follows a lognormal distribution in the calculation of radio coverage. To reach the specified coverage probability, during network planning, certain power margin must be reserved for BS or MS receivers to reduce the attenuation effect. Shadow fading standard deviation is related to electromagnetic wave propagation environment. In urban areas, the shadow fading standard deviation is about 8 to 10 dB. In suburban and rural areas, the value range is 6 to 8 dB.
  For outdoor environment, the standard deviation of propagation loss random variable is always 8dB.

  Table 3.3: Common edge coverage probability and shadow fading margin [23]

Coverage Probability (%)	*70*	*75*	*80*	*85*	*90*	*95*
Shadow fading margin (dB)	0.53σ	0.68σ	0.85σ	1.04σ	1.29σ	1.65σ

  Where σ is the standard deviation of slow fading. In our LTE network planning, we take 10.32 dB margin is reserved to ensure a 90% edge coverage probability for $\sigma=8$.
- ***Minimum signal reception strength***: It used to formulate the receiver side losses and margin such as body loss, cable loss and marginal gain to receiver sensitivity and calculated as:

  $$Minimum\ Signal\ Receiption\ Strength\ (MSR) = RS + IM + L_R - RA_G \qquad (3.4)$$

  Where,

  RS is receiver sensitivity

  IM is interference Marginal

  L_R is receiver body loss + Cable loss

  RA_G is receiver antenna gain
- **Fast fading margin:** Fast fading refers to the attenuation of the signals due to multipath reflections and diffractions. The short term average of fast fading can typically be represented by a Rayleigh distribution. In slow moving environments, the UE’s closed-loop fast power control can effectively compensate for fast fading. This would require appropriate headroom in the UE transmission power. The value range is 2 to 3 dB is used [24].

- ***Maximum allowable path loss (MAPL)***: It allows the maximum cell range to be estimated with suitable propagation models which provide number of base station sites required to cover the target geographical area. The maximum allowable path loss expressed as:

  $MAPL = EIRP - \text{MSR} - Penetration\ loss\text{-}- shadow\ fading\ margin$ (3.5)

  Where,

  MSR is $Minimum\ Signal\ Receiption\ Strength$

3.2.2 Propagation Models

In a wireless cellular communications system, the information is transferred by using electromagnetic waves between transmit and receive antennas. The electromagnetic waves signal strength becomes weak during its propagation through the environment [24]. The signal strengths difference from the transmitter antenna to the receiver antenna is called Path Loss (PL). Path loss models play a significant role in planning of wireless cellular systems. They represent a set of mathematical equations and algorithms that are used for radio signal propagation prediction in certain areas. Propagation path loss models are used for calculation of electromagnetic field strength for the purpose of wireless network planning during preliminary deployment. Path loss model describes the signal attenuation from transmitter to receiver antenna as a function of distance, carrier frequency, antenna heights and other significant parameters like terrain profile (urban, suburban and rural).

In order to determine the PL, a radio wave propagation model used. Propagation models are mainly classified in two major categories, i.e. empirical models and Theoretical models. Empirical models are based on measurement data to define a model path loss and consider all environment factors, whereas the theoretical models are based on theoretical analysis and they do not use information about any specific environment, although the assumptions may be based on measurement data [25]. Theoretical models are useful for analytical studies of the behavior of communication systems under a wide variety of channel response circumstances, but because they do not deal with any specific propagation information, they are not suitable for planning communication systems to serve a particular area. 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.

3.2.2.1 Free Space Path loss Model (FSPL)

In telecommunication, free space path loss (FSPL) is the loss in signal strength of an electromagnetic wave that would result from a line of sight path through free space, with no obstacles nearby to cause reflection or diffraction.

Path loss in free space defines how much strength of the signal is lost during propagation from transmitter to receiver without any obstruction in free space. Free space path loss is proportion to the square of the distance between the transmitter and receiver, and also proportional to the square of the frequency of the radio signal. The equation for FSPL in decibels is [26].

$$PL(dB)= 32.45 + 20\log_{10}(d) + 20\log_{10}(f) \qquad (3.6)$$

Where,

f is the signal frequency (MHz)

d is the distance between transmitter and receiver (Km)

3.2.2.2 Okumura HATA Model

The Okumura Hata model is a propagation model, which can be applied for a macro cell environment to predict median radio signal attenuation. This model applies for macro cell coverage planning where the configuration of the base station antenna height is usually higher than the surrounding obstacles. Therefore, this model is the most widely used one in wireless communications for predicting the behavior of electromagnetic waves in built up areas. The main propagation loss for this model is the diffraction and scattering over rooftops near the mobile station.

Okumura Hata model defines the path loss as follows [25, 26]:

$$PL(dB) = A_{fs} + A_{bm} - G_b - G_r \qquad (3.7)$$

Where,

A_{fs} is Free space attenuation

A_{bm} is basic media path loss

G_b is transmitter antenna height gain factor and

G_r is receiver antenna height gain factor

These factors can be separately described and given by as:

$$A_{fs} = 32.45 + 20 \log_{10}(d) + 20 \log_{10}(f) \tag{3.7a}$$

$$A_{bm} = 20.41 + 9.83 \log_{10}(d) + 7.89 \log_{10}(f) + 9.56[\log_{10}(f)]^2 \tag{3.7b}$$

$$G_b = \log_{10}(h_b/200)\{13.958+5.8[\log_{10}(d)]^2\} \tag{3.7c}$$

When dealing with gain for medium cities, the *Gr* will be expressed in:

$$G_r = [42.57 + 13.7 \log_{10}(f)]\,[\log_{10}(h_r) - 0.585] \tag{3.7d}$$

For large city

$$G_r = 0.759h_r - 1.862 \tag{3.8e}$$

Where,

f is the signal frequency (MHz)
d is the distance between transmitter and receiver (Km)
h_b is transmitter antenna height (m)and
h_r is receiver antenna height in (m)

3.2.2.3 COST 231 Hata Model

The Hata model is introduced as a mathematical expression to mitigate the best fit of the graphical data provided by the classical Okumura model [26]. Hata model is used for the frequency range of 150 MHz to 1500 MHz to predict the median path loss for the distance d from transmitter to receiver antenna up to 20 km, and transmitter antenna height is considered 30 m to 200 m and receiver antenna height up to 10 m. To predict the path loss in the frequency range 1500 MHz to 2000 MHz. It is used to calculate path loss in three different environments like urban, suburban and rural (flat). This model provides simple and easy ways to calculate the path loss. The basic path loss equation for this COST 231 Hata Model can be expressed as [26, 27]:

$$PL(dB) = 46.3+33.9 \log_{10}(f)- 13.82 \log_{10}(h_b)- ah_m +(44.9- 6.55\log_{10}(h_b)) \log_{10}(d) +c_m \tag{3.9}$$

The parameter c_m has different values for different environments like 0 dB for suburban and 3 dB for urban areas and the remaining parameter ah_m is defined in urban areas as:

$$ah_m = 3.20(\log_{10}(11.75h_r))^2 - 4.79\,, \qquad \text{for } f > 400\text{MHz} \tag{3.9a}$$

The value for ah_m in suburban and rural (flat) areas is given as:

$$ah_m = (1.11\log_{10}(f\text{-}0.7)h_r - (1.5\log_{10} f - 0.8) \tag{3.9b}$$

Where,

f is the signal frequency (MHz)

d is the distance between transmitter and receiver (Km)

h_b is transmitter antenna height (m)and h_r is receiver antenna height in (m)

3.2.2.4 Ericsson Model

To predict the path loss, the network planning engineers are used a software provided by Ericsson company is called Ericsson model. This model also stands on the modified Okumura Hata model to allow room for changing in parameters according to the propagation environment. Path loss according to this model is given by [25, 27]:

$$\text{PL}(dB) = a_0 + a_1\log_{10}(d) + (a_2 + a_3\log_{10}(d))\log_{10}(\text{h}_\text{b}) - 3.2\,(\log_{10}(11.75h_r)^2) + g(f) \tag{3.10}$$

Where,

$g(f)$ is defined by

$$g(f) = 44.49\log_{10}(f) - 4.78(\log_{10}(f))^2 \tag{3.10a}$$

and parameters

f is the signal frequency (MHz)

d is the distance between transmitter and receiver (Km)

h_b is transmitter antenna height (m)and

h_r is receiver antenna height in (m)

Where a_0 , a_1 , a_2 and a_3 are values, which are changed according to the environments (i.e. areas). For different areas, the parameters are described in following Table 4.2.

Table 3.4: Parameters and Terrains for Ericsson Model [26]

Parameters	Rural Area	Sub-Urban Area	Urban Area
a_0	45.95	43.20	36.2
a_1	100.6	68.93	30.2
a_2	12.0	12.0	12.0
a_3	0.1	0.1	0.1

3.2.2.5 Stanford University Interim (SUI) Model

The Stanford University Interim (SUI) Path Loss model [26] has been developed by IEEE for IEEE 802.16. This model is used for frequencies above 1900 MHz. As LTE will be using frequency band of 2100 MHz and 2600 MHz, so it is a suitable solution for LTE network. In this propagation model, we have three different types of areas. These are called as terrain A, B and C. Terrain A represents an area with highest path loss which describes an urban area. Terrain B represents an area with moderate path loss which describes a sub-urban area. Terrain C represents the least path loss.

The basic path loss expression of The SUI model with correction factors is presented as [26, 28]

$$PL = A + 10\,\gamma \log_{10}(d/d_0) + X_f + X_h + S, \qquad \text{for } d > d_0 \tag{3.11}$$

The parameter A is defined as

$$A = 20 \log_{10}(4\pi d_0 / \lambda) \tag{3.11a}$$

and the path loss exponent γ is given by

$$\gamma = a - b h_b + (c/h_b) \tag{3.11b}$$

Where,

d is Distance between BS and receiving antenna (m)

d_0 is100 m

λ is Wavelength (m)

X_f is Correction for frequency above 2 GHz (MHz)

X_h is Correction for receiving antenna height (m)

s is Correction for shadowing (dB)

γ is Path loss exponent

h_b is the base station antenna height in meters

The constants a, b, and c depend upon the types of terrain, that are given in Table 3.3. The value of parameter $\gamma = 2$ for free space propagation in an urban area, $3 < \gamma < 5$ for urban NLOS environment, and $\gamma > 5$ for indoor propagation.

The frequency correction factor X_f and the correction for receiver antenna height X_h for the model are expressed in:

$$X_f = 6.0 \log_{10}(f/2000) \tag{3.11c}$$

$$X_h = \{-10.8 \log_{10}(h_r/2000)\} \quad \text{for terrain type A\& B} \tag{3.11d}$$

$$X_h = \{-20.0 \log_{10}(h_r/2000)\} \quad \text{for terrain type C} \tag{3.11e}$$

Table 3.5: The parameter values of different terrain for SUI model [28]

Model parameter	Terrain A ($Urban\ Area$)	Terrain B (Sub-$Urban\ Area$)	Terrain C ($Rural\ Area$)
a	4.6	4.0	3.6
b(m^{-1})	0.0075	0.0065	0.005
c(m)	12.6	17.1	20

3.3 Capacity Planning

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 general overview Capacity planning process is shown in Figure 3.4.

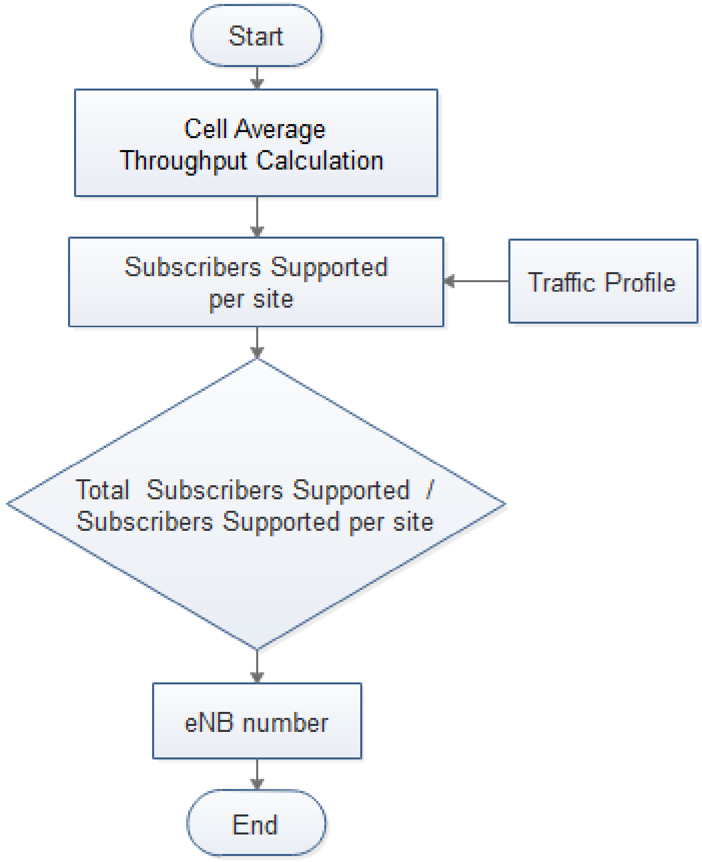

Figure 3.4: Capacity planning process

3.3.1 Traffic Model Approach for Capacity Dimensioning

The traffic model defines an application services such as VoIP, Video, Streaming, Web browsing & FTP provided by network based on the service providers. The main purpose of traffic model is to describe the average subscriber behavior during the most loaded day period (the Busy Hour) and the capacity of site should be based on busy hour as the traffic is not equality distributed during 24 hour [29]. In network dimensioning the busy hour needs to be reserved in order to guarantee low delays and reasonably good data rates. The traffic volume based approach estimates the maximum traffic volume in megabytes that can be carried by LTE site.

The total average throughput per subscriber shall be calculated in order to estimate the average throughput per site

$$\textit{Avg. throughput per sub @BH per month} = \frac{monthly\ service\ packet\ x\ 8\,\frac{bit}{byte}\,x\ BH\ ratio}{30\ days\ x\ time\ in\ second} \qquad (3.12)$$

After manipulating the average throughput per subscriber for each service type defined by operator, the total average throughput per subscriber in busy hour is given by:

$$\textit{Total Avg. throughput per sub @BH} = \Sigma\ \textit{Avg. throughput per sub x packet percentage} \qquad (3.13)$$

Finally based on the traffic of services, the average throughput per subscriber for uplink and downlink written as:

$$\textit{Avg. throughput per sub @BH}_{UL} = \textit{Total Avg. throughput per sub @BH x UL traffic ratio} \qquad (3.14a)$$

$$\textit{Avg. throughput per sub @BH}_{DL} = \textit{Total Avg. throughput per sub @BH x DL traffic ratio} \qquad (3.14b)$$

As per 3GPP release 10, LTE support modulation QPSK, 16QAM and 64QAM for downlink and QPSK and 16QAM for uplink. Each of Modulation has its bits carrying capacity per symbol. One QPSK symbol can carry 2bits, one 16QAM symbol can carry 4bits and 64 QAM symbol can carry 6 bits.

Based on the frame structure and coding rate the peak throughput per site is given by:

$$\textit{Peak throughput per site = Data RE/sec x bit/RE x MIMO effect x data rate} \qquad (3.15)$$

Where,

The data RE/s is the data in resource element per second

Coding rate indicates the volume coding rate of the channel code. For example, the volume coding rate of QPSK is 1/2, and the volume coding rate of 16QAM is 3/4.

The number maximum subscriber number per site is calculated for both uplink and downlink from equations 3.14 to 3.15 as follow:

$$\textit{Max sub No per site}_{UL} = \frac{Total\ avg.throughput\ per\ site\ \ for\ \ uplink}{Total\ avg.throughput\ per\ subscriber\ for\ uplink} \qquad (3.16a)$$

$$\textit{Max sub No per site}_{DL} = \frac{Total\ avg.throughput\ per\ site\ \ for\ \ downlink}{Total\ avg.throughput\ per\ subscriber\ for\ downlink} \qquad (3.16b)$$

After the maximum subscriber's number per site is calculated for UL and DL and taking the minimum number of subscriber from uplink and downlink or from equation 3.16*a* and 3.16b. Finally the total site based on the capacity required is calculated as:

$$Total\ Site\ required = \frac{Total\ \ subscriber\ number\ for\ required\ Area}{Maximum\ subscriber\ number\ \ per\ site} \tag{3.17}$$

3.4 Site Count

In the LTE network planning the required sites number for a specific area should be chosen to be the maximum number of sites obtained from coverage and capacity planning to obtain the demand traffic requirements. Hence by comparing the number of sites from capacity and coverage planning and we choose the maximum eNodeB number to satisfy both coverage and capacity requirement. Figure 3.5 summarizes the steps to estimate the number of eNodeB needed to provide service in the deployment area.

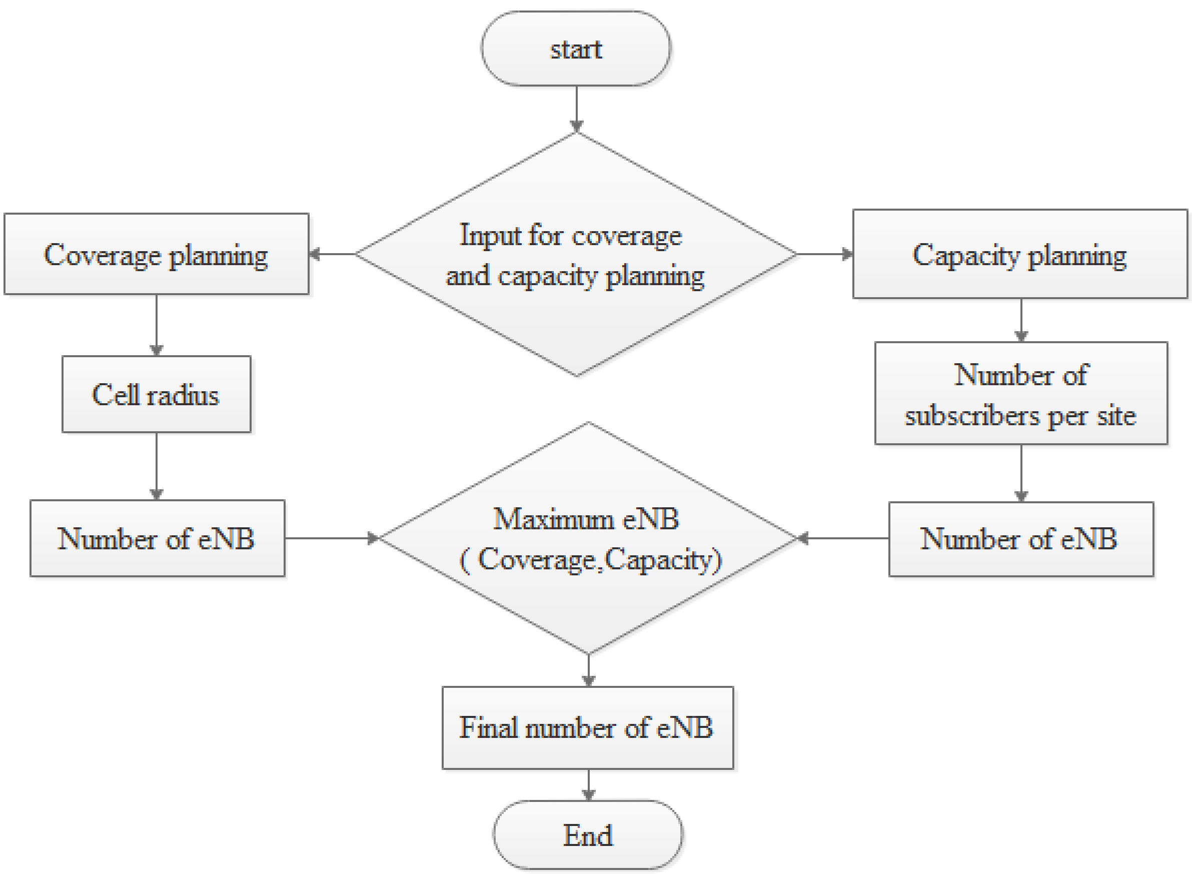

Figure 3.5: Selection of the number of eNB between coverage and capacity planning

3.4.1 Coverage based Sites Count

Once the link budget is calculated for both UL and DL, the next step in the coverage planning is to determine the cell radius by using the appropriate propagation model. After determining the cell radius, sites number and sites coverage areas are calculated based on site configuration by the equations below:

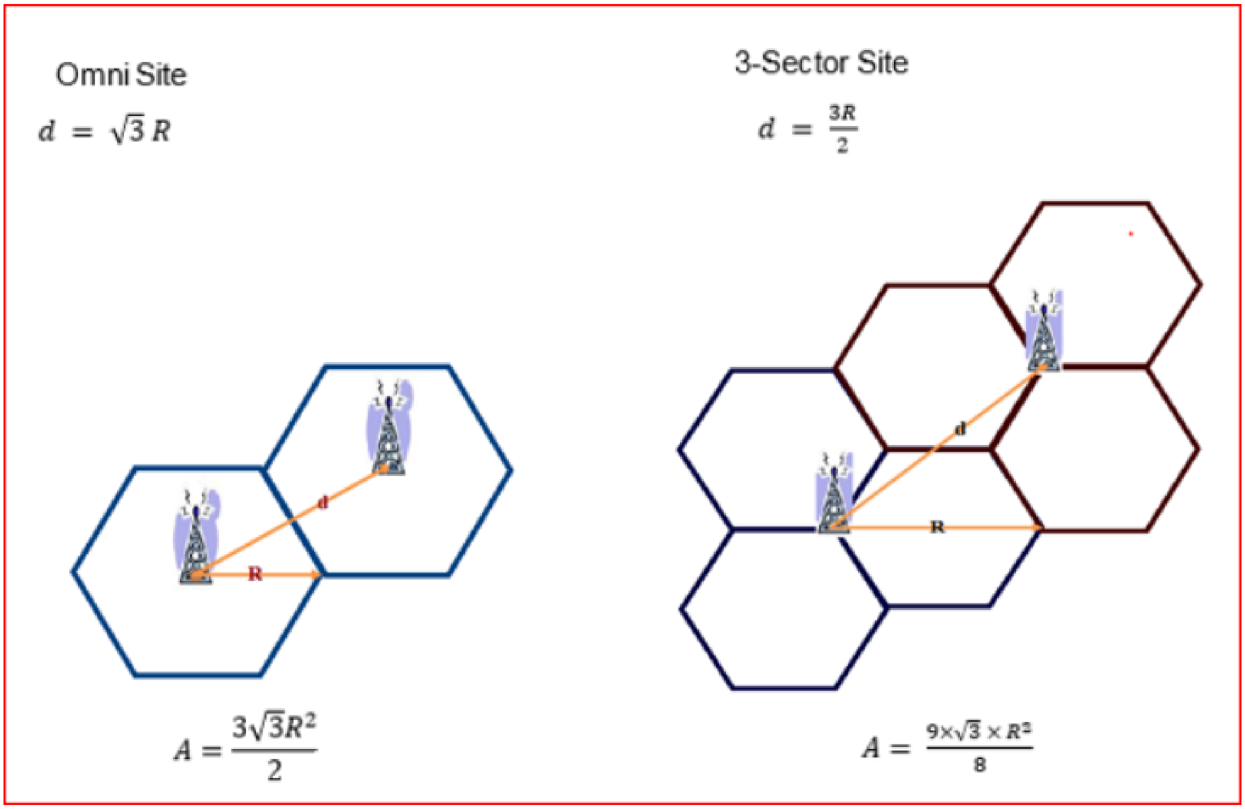

Figure 3.6: Site configuration and coverage area calculation [30].

- Site coverage Area for Omni Site:

$$A = \frac{3\sqrt{3}\,R^2}{2} \tag{3.18a}$$

- Site coverage Area for three sector Site:

$$A = \frac{9\sqrt{3}\,R^2}{8} \tag{3.18b}$$

- Required Sites number: The number of sites needed to meet coverage requirements can be calculated by dividing the site are to be covered, i.e.

$$Site\ Number = \frac{\text{Area to be covered}}{\text{Site coverage Area}} \qquad (3.18c)$$

3.4.2 Capacity based Sites Count

First we get the subscriber number supported per site and then the capacity based site count is calculated as:

$$\text{Site Number} = \frac{\text{Total subscriber supported in the netework}}{\text{subscriber supported per site}} \qquad (3.19)$$

Chapter - 4 Radio Planning Analysis and Results

Dire Dawa is the second largest city of Ethiopia and it is considered an overpopulated city compared to the rest of most of the country. In this city, there are different hotspot areas including hotels, government offices, different banks and industries. Thus the choice of LTE network for this city is the right decision as users in this area would require substantial Internet speed. In this part of the work, coverage analysis along with link budget preparation and capacity analysis, and the simulations with an Atoll planning tool have been performed.

4.1 Coverage Planning Analysis

Coverage planning is performed with a link budget calculation and propagation model as mentioned in chapter 3.

4.1.1 Link Budget Calculation

The aim of the link budget is to identify the maximum allowable path loss (MAPL) between the transmitter and receiver for the UL and DL. MAPL has different values for different environment. MAPL for DL and UL are calculated using equations (3.1), (3.2), (3.3), (3.4) and (3.5). So the calculation must be done and from these results the cell radius can be calculated. The basic input parameters are as shown in Table 4.1.

Table 4.1: UL and DL LTE 1800 link budgets for urban clutters

Parameters	Unit	Value		*Formula*
Channel type		UL	DL	
Transmitter Side				
Tx power	dBm	23	46	a
Resource to distribute power		3	100	b
Subcarriers to Distribute Power		36	1200	$c = 12 \times b$
Subcarrier Power	dBm	7.44	15.21	$d = a - 10\log_{10}c$
Tx Antenna Gain	dBi	0	18	e
Tx Cable Loss dB	dB	0	0.5	f

TX Body Loss	dB	0	0	*g*
EIRP	dBm	7.44	32.71	$h = d + e - f - g$
Receiver Side				
RX Antenna gain	dBm	18	0	*i*
RX Cable loss+ connector loss	dB	3	0	*j*
RX Body Loss	dB	0	2	*k*
Noise Spectral Density, Ni	dBm/Hz	-174	-174	$l = 10log_{10}(KxT)$
Bandwidth	dBHz	41.76	41.76	$m = 10log_{10}(1500)$
Noise Power per subcarrier	dBm/Hz	- 132.24	- 132.24	$n = l + m$
Noise Figure	dB	6	7	*o*
SINR	dB	-4.2	-5.4	*p*
Receiver Sensitivity	dBm	-130.44	-130.64	$q = n + o + P$
Slow Fading Standard Deviation	dB	8	8	*r*
Slow Fading Margin	dB	10.3	10.3	*s*
Interference Margin	dB	2	3	*t*
Indoor Penetration Loss	dB	3	5	*u*
Sum of Margins	dB	15.3	18.3	$v = s + t + u$
Maximum Allowed Path Loss	dB	137.58	143.05	$w = h + i - j - k - q - v$

4.1.2 Propagation Model Selection

The selection of a suitable radio propagation model for LTE is of great importance. A radio propagation model describes the behavior of the signal while it is transmitted from the transmitter towards the receiver. It is good practices to make a comparison between different propagation models in order to find out the model which is suitable for selected environment (urban, sub-urban and rural). It gives a relation between the distance of transmitter and receiver, and the path loss. From this relation, one can get an idea about the allowed path loss and the maximum cell range.

In this study the five propagation models; Free space, Okumar HATA, COST 231 Hata, Ericsson and SUI are chosen for the comparison. In simulation, we use different parameters such as carrier frequencies, speed of electromagnetic wave, distance between transmitter and receiver, receiver height and base station height which is suitable for Dire Dawa environment. The simulation parameters for the propagation models selection are given in the Table 4.2

Table 4.2: Simulation Parameters of models

Parameters	Values
Base station power	46 dBm
Mobile power	23 dBm
Transmitter antenna height	30 m
Receiver antenna height	1.5m
Distance between transmitter and receiver	5 Km
Carrier frequency	1800 MHz
fading standard deviation	8 dB
speed of electromagnetic wave	3×10^8 m/s

Here the selection is based on which propagation model reads maximum path loss at a certain calculated radius for urban, sub-urban and rural area. And this is because to minimize signal degradation at the edge of the cell and to get better signal coverage. Figure 4.1(a, b & c) is a matlab simulation to compare and contrast among deterministic propagation models which is important to select proper propagation model for coverage planning.

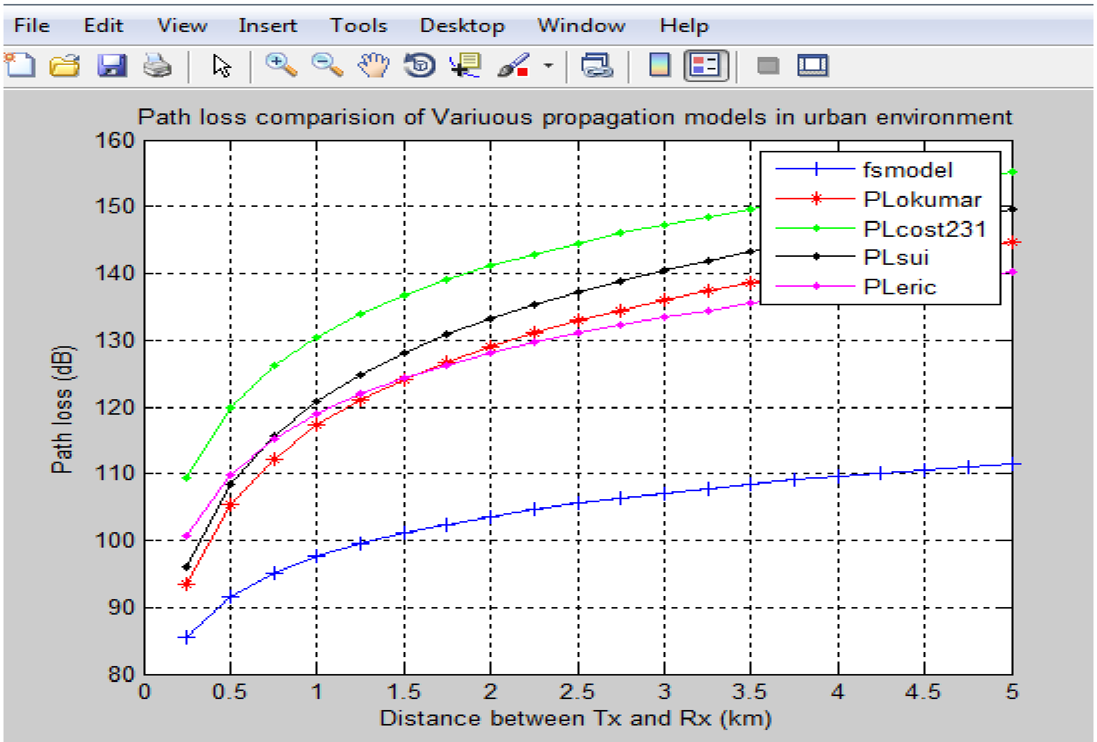

Figure 4.1a: path loss in urban environment

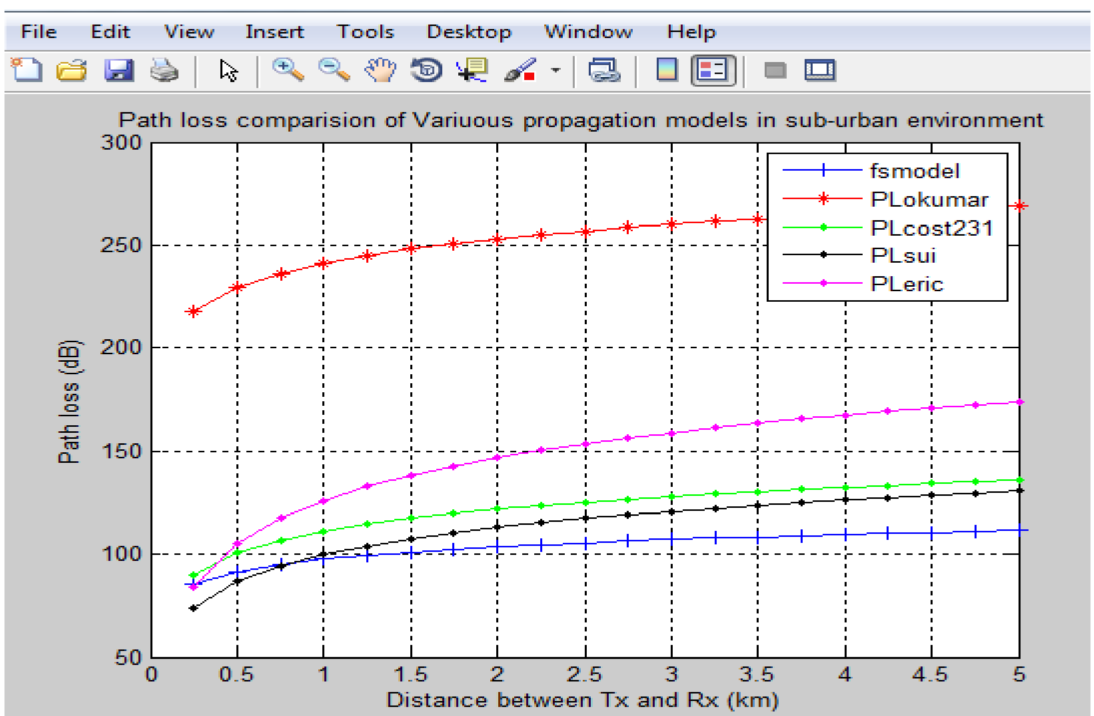

Figure 4.1b: path loss Path loss in sub-urban environment

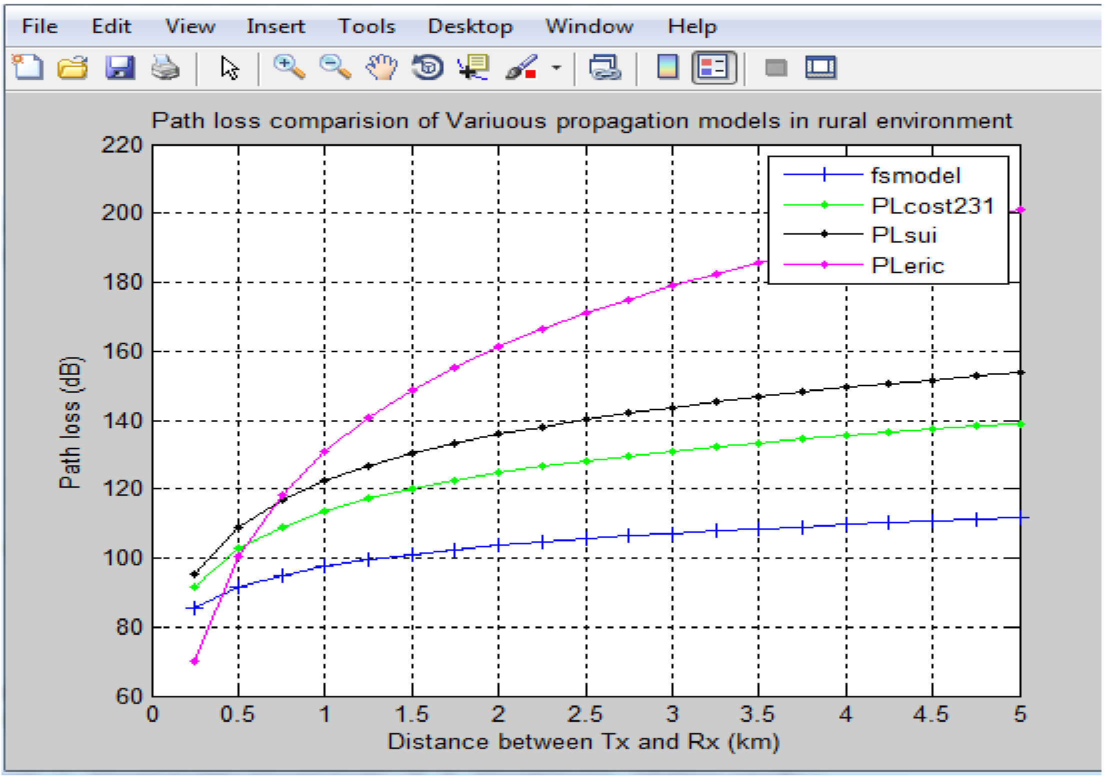

Figure 4.1c: path loss in rural environment

The simulation results for urban environment are shown in Figure 4.1a. It shows that the COST 231 HATA model propagation model gives the highest value of path loss among all models and FSPL gives the lowest value of path loss among all models. This is due to the fact that FSPL assumes ideal conditions with no effect of reflection or diffraction. Similarly for suburban environment are shown in Figure 4.1b. It showed that the Okumar HATA model predict the highest path loss in suburban. In rural area shown in Figure 4.1c, Ericsson model showed the highest path loss prediction for rural environment.

Based on the simulation result of propagation model comparison in Figure 4.1a for urban environment COST 231 HATA model is selected by comparing with other propagation model. Accordingly, COST 231 HATA model shows the maximum path loss as compared to the other models for urban environment. Therefore, COST 231 HATA propagation model is selected by considering the worst case scenario for better radio network planning. Thus, in this study COST 231 HATA model is the best suited model among all propagation models for LTE network operating in 1800 MHz.

4.1.3 Coverage Based Sites Count

For the second requirement of the coverage planning is to find number of eNB for LTE radio network planning. In this case different basic parameters (the radius of the cell, site area and site count) have been calculated. Using the selected propagation model and the UL and DL MAPL, we can calculate the cell radius governed by both the UL and DL link budget. The effective radius will be the minimum of the radiuses found in the UL and DL link budget.

The cell radius in the UL, and the cell radius in the DL can be calculated by using COST231- Hata path loss formula in Equation (3.9) as follows:

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

Let us consider the eNodeB and UE antenna height to be 30m and 1.5m respectively for dire Dawa environment. As well as f = 1800MHz.

$$PL(dB) = A + B - C - D + E + c_m$$

Where

- $A = 46.3$
- $B = 33.9 \log_{10}(f) = 33.9\log_{10}(1800) = 33.9 * 3.26 = 110.514$
- $C = 13.82 \log_{10}(h_b) = 13.82 \log_{10}(30) = 13.82*1.48 = 20.45$
- $D = ah_m = ((1.11\log_{10}(f) - 0.7)h_r - ((1.5 \log_{10} f) - 0.8)$

  $= (1.11*(3.26) - 0.7)*1.5 - ((1.5*3.26)-0.8)$

  $= (3.62 - 0.7)*1.5 - (4.89 - 0.8)$

  $= 4.34 - 4.09 = 0.25$
- $E = (44.9 - 6.55\log_{10}(h_b)) \log_{10}(d) = (44.9 - 6.55*1.48)\log_{10}(d) = 35.2 \log_{10}(d)$
- $c_m = 3$ for urban, hence

$$PL(dB) = 46.3+110.514 - 20.45 - 0.25+35.2 \log_{10}(d)+3$$

$$= 139.114 + 35.2 \log_{10}(d)$$

$$\log_{10}(d) = \frac{PL(dB) - 139.114}{35.2}$$

$$d = 10^{\frac{(PL(dB) - 139.114)}{35.2}}$$

Hence PL(*dB*) is 137.58 for uplink and 143.05 for downlink.

Then

$$d_{UL} = 10^{\frac{(137.58-139.114)}{35.2}} = 10^{-0.0436} = 0.9045 \text{ Km and}$$

$$d_{DL} = 10^{\frac{(143.05-139.114)}{35.2}} = 10^{\frac{(143.05-139.114)}{35.2}} = 1.3 \text{ Km}$$

Thus, the effective radius (r_{ef} = min (d_{UL}, d_{DL})) becomes 0.9045 Km. Table 4.3 shows the summary of the cell radius for UL and DL MAPL as well as the effective cell radius that we can use to calculate the coverage based sites count.

Table 4.3: Cell radius summary (UL & DL)

Parameter	UL	DL
eNodeB Antenna Height (m)	30	
UE Antenna Height (m)	1.5	
Frequency (MHz)	1800	
MAPL (dB)	137.58	143.05
Cell Radius (Km)	0.9045	1.3
Effective Cell Radius (Km)	0.9045	

For this thesis work, we assume that all eNodeB's are tri-sector cells, then the site area and the total number of coverage based sites count are determined by equation (3.18*b*). From LTE link budget calculation cell radius is 0.9045 km.

$$\text{Site coverage Area, A} = \frac{9\sqrt{3}\,R^2}{8} = = \frac{9\sqrt{3}\,(0.9045)^2}{8} = 1.9486*0.818 = 1.594 \text{ km}^2$$

$$Site\ Number = \frac{\text{Area to be covered}}{\text{Site coverage Area}} = \frac{68.62}{1.594} = 43 \text{ eNB.}$$

Hence, from the coverage dimensioning perspective, we need 43 eNodeB sites to provide LTE service throughout the entire 68.62 km^2 area of Dire Dawa urban area.

4.2 Capacity Planning Analysis

The capacity analysis should produce information about the subscriber numbers and the expected capacity or traffic demand [29]. Capacity planning inputs gives the number of subscribers in the system, their demanded services and subscriber usage level in the busy hour. The daily traffic can be estimated as a percentage of the busy hour traffic. In this thesis, we assume that the busy hour assumed to be in different three time segment within the 24 hours of a day. The first segment is from 9:00 AM to 10:00 AM in the morning, the second segment is from 4:00 PM to 5:00 PM in the afternoon and the third segment is assumed to be from 8:00 PM to 9:00 PM 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.

Three types of service packages are provided; golden service package, silver service package and bronze service package. Each service has its own quality, the month service package, the DL and UL peak data rates, and the package percentage. All of these characteristics are shown in table 4.4. Thus service usage, distribution is required and assumed to be 10%, 40% and 50% for Gold, Silver, and Bronze users respectively. The traffic ratio of the UL and DL in terms of the total traffic is chosen to be 20% for UL and 80% for DL. The number of subscribers must be specified in order to continue the analysis and from Table 3.1, Dire Dawa City LTE network subscribers for the next five years forecasted as 296496.

Table 4.4: LTE Users Category

Types of customer	Data Volume per Month per User(GB)	Service usage (%)	Traffic ratio (%)	
			UL	DL
Gold	20	10	20	80
Silver	15	40	20	80
Bronze	10	50	20	80

The total average throughput per subscriber are determined by equation (3.12) and (3.12) as follows:

Avg. throughput per sub @BH (Kbps) = $\dfrac{montly\ service\ packet\ x\ 8\ \frac{bit}{byte} x\ BH\ ratio}{number\ of\ days\ x\ time\ in\ second}$

Gold customer Average throughput (DL + UL):

Avg. throughput per sub @BH (Kbps) = $\dfrac{20x10^9\ x\ 8\ \frac{bit}{byte} x\ 12.5\%}{30\ x\ 3600\ second} = \dfrac{20x10^9}{30\ x\ 3600}$ = 185.185

Silver customer Average throughput (DL + UL):

Avg. throughput per sub @BH (Kbps) = $\dfrac{15x10^9\ x\ 8\ \frac{bit}{byte} x\ 12.5\%}{30\ x\ 3600\ second} = \dfrac{15x10^9}{30\ x\ 3600}$ = 138.889

Bronze customer Average throughput (DL + UL):

Avg. throughput per sub @BH (Kbps) = $\dfrac{10x10^9\ x\ 8\ \frac{bit}{byte} x\ 12.5\%}{30\ x\ 3600\ second} = \dfrac{10x10^9}{30\ x\ 3600}$ = 92.593

Then,

Total Avg. throughput per sub @BH (Kbps) = Σ *Avg. throughput per sub x packet percentage*

= 185.185 *x* 10% +138.889 *x* 40% + 92.593 *x* 50%

= 18.518 +55.556 + 46.296

= 120.370

Table 4.5 shows Average Throughput per subscriber at BH, Uplink and downlink average throughput per subscriber result.

Table 4.5: Total Average Throughput per subscriber for UL & DL

Parameters		User Service Category		
		Gold	Silver	Bronze
Data Volume per Month per Subscriber (GB)		20	15	10
Days per Month		30		
Traffic Ratio of Busy Hour to Whole Day (%)		12.5		
Avg. throughput per sub @BH (Kbps)		185.185	138.889	92.593
Service Usage (%)		10	40	50
Total Avg. throughput per sub @BH(Kbps)		120.370		
	UL	20		

Traffic ratio (%)	DL	80
Total Avg. throughput per sub @BH(Kbps)	UL	24.074
	DL	96.296

The peak average throughput per sector and per site for both UL and DL can be calculated as follows. To calculate the peak capacity throughput per sector, first we consider a 2×20 MHz LTE system with 2×2 MIMO configuration, 64QAM (6 bit per 64QAM symbol) .

We first calculate the number of data in sub-frame (a sub-frame is 1 msec) using equation (4.15) as follows:

Data in sub-frame (bits) = 6 bit per 64QAM symbol x 14 OFDM symbols per sub-frame

= 84

Data rate per sub-carrier (Kbps) = Data rate per sub-frame (bits)/1msec

= 84bits/1msec = 84

Data rate per Resource Block (Mbps) = Data rate per sub-carrier x sub-carrier per resource block

= 84 Kbps x 12

=1.008

Since there are 100 Resource Block corresponds to the transmission bandwidth while 20MHz is the channel bandwidth, Peak Throughput (Mbps) per antenna becomes;

Peak Throughput (Mbps) per antenna = 100 x 1.008 = 100.8

Peak Throughput per sector for UL communication is 100.8 Mbps since there is one TX antenna i.e. no MIMO.

Peak Throughput per sector for 2 x 2 MIMO DL communication is 2 x 100.8 Mbps = 201.6 Mbps. Therefore, for a three sector with 20 MHz channel bandwidth, the average throughput per site can be found by multiplying the peak throughput per sector by three.

Peak Throughput per site for UL = 3 x 100.8 Mbps = 302.4 Mbps

Peak Throughput per site for DL = 3 x 200.8 Mbps = 604.8 Mbps

Table 4.6: Total Average Throughput per site

Peak Throughput per site (Mbps)	UL	DL
	302.4	604.8

Now, the number maximum subscriber number per site is calculated for both uplink and downlink using equations (3.16*a*) and (3.16*b*) as follow:

$$Max\ subscriber\ N\underline{o}\ per\ site_{\ UL} = \frac{Total\ avg.throughput\ per\ site\ \ for\ \ UL}{Total\ avg.throughput\ per\ subscriber\ for\ UL}$$

$$Max\ subscriber\ N\underline{o}\ per\ site_{\ UL} = \frac{302.4\ Mbps}{24.074\ Kbps} = 12561$$

$$Max\ subscriber\ N\underline{o}\ per\ site_{\ DL} = \frac{Total\ avg.throughput\ per\ site\ \ for\ \ DL}{Total\ avg.throughput\ per\ subscriber\ for\ DL}$$

$$Max\ subscriber\ N\underline{o}\ per\ site_{\ DL} = \frac{604.8\ \text{Mbps}}{96.296\ \text{Kbps}} = 6281$$

Table 4.7: Maximum subscriber number per site

Max subscriber number per site	UL	DL
	12561	6281

4.2.1 Capacity Based Sites Count

By taking the values of Dire Dawa City LTE network subscribers for the next 5 years forecasted as 296496 from Table 3.1 of chapter 3 and the maximum number of subscriber per site for both UL and DL from Table 4.6(the lowest is chosen), the number of eNB can be calculated using formula given in equation (3.18) and (3.20) as follows:

$$Total\ Site\ required = \frac{Total\ \ subscriber\ number\ for\ required\ Area}{Maximum\ subscriber\ number\ \ per\ site}$$

$$Total\ Site\ required = \frac{296496}{6281} = 47\ \text{eNB}$$

4.3 Site count Analysis

In this LTE network planning, the required sites number for Dire Dawa City urban area should be chosen to be the maximum number of sites obtained from coverage and capacity planning calculations to satisfy the traffic requirements of both coverage and capacity. According to the results obtained from the coverage analysis, 43 (frothy three) eNBs are required to meet the coverage requirement and 47 (forth seven) eNBs are required to meet the capacity requirement from capacity planning analysis. Hence comparing the number of sites from capacity and coverage planning, the total number of eNB that will be used for LTE radio network planning becomes 47 (forth seven) eNBs.

4.4 Simulation

In this part we discuss the simulation results LTE coverage and capacity planning using radio network planning tools based on the numerical results obtained from coverage and capacity estimation. Figure 4.2 shows a simulation workflow used in this study to plan and evaluate an LTE network using the radio planning tool. The planning tool used in this study is ATOLL. It is an open, scalable, and flexible multi technology network design and optimization platform that supports the LTE radio network planning.

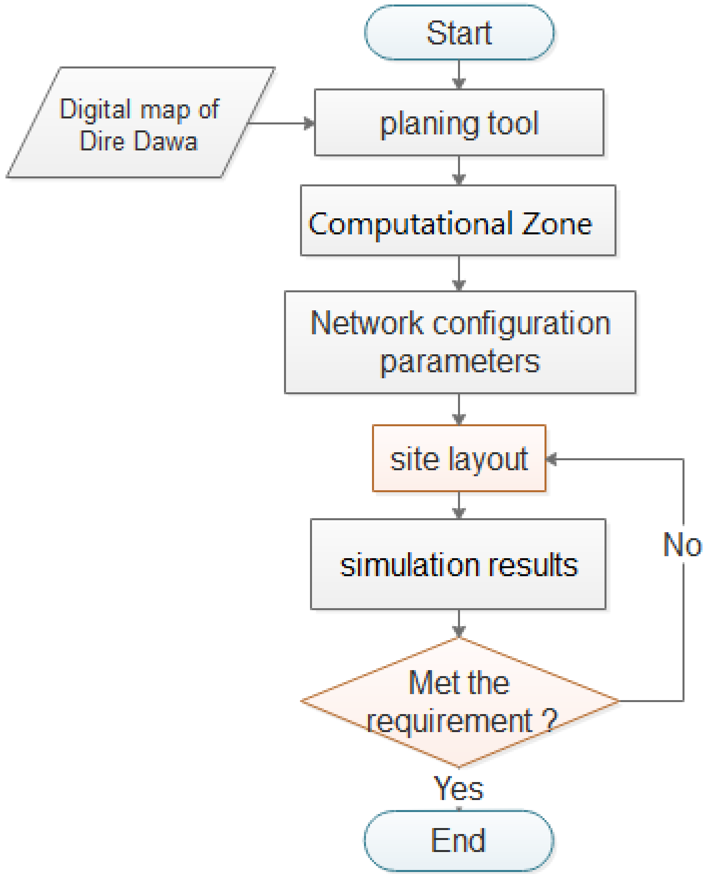

Figure 4.2: LTE network simulation workflow

4.4.1 Digital Map of Dire Dawa City

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 water). It is first input to radio planning tool.

Geographic data used in propagation calculation

- Digital Terrain Model: describes the elevation of the ground over sea level
- Clutter classes: geo data file describes land cover or land use
- Clutter heights: describe the altitude of clutter over the DTM with one altitude defined per pixel

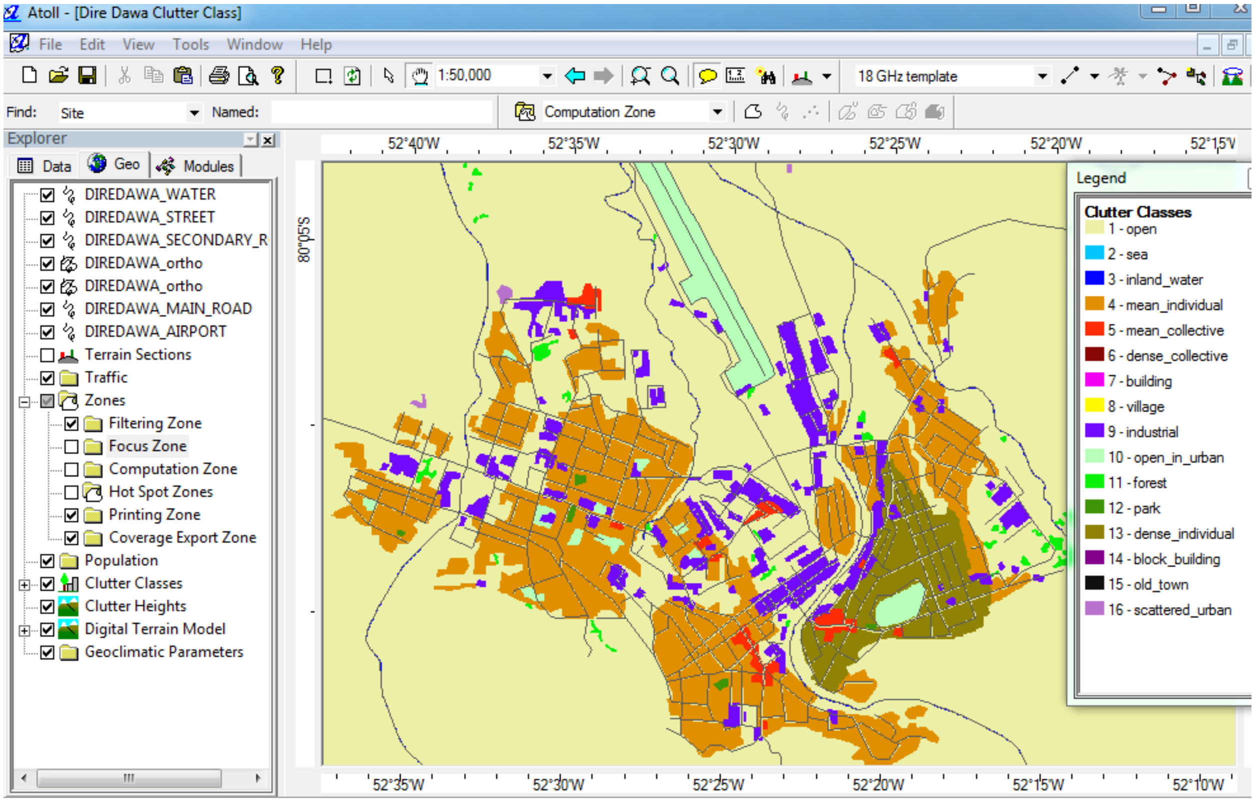

Figure 4.3: Digital maps of Dire Dawa City

4.4.2 Computational Zone

The computation zone is used to define the area where Atoll carries out calculations. When we create a computation zone, Atoll carries out the calculation for all base stations. Area is an important input for coverage and capacity planning, hence the computation zone defines the area in which the coverage prediction results will be displayed. Thus the computation zone that shows in Figure 4.4 allows us to restrict our coverage prediction result to the part of the network we are currently working on. If there is no defined computation zone, Atoll makes its calculations on all base stations that are active and filtered for the entire extent of the geographical data available.

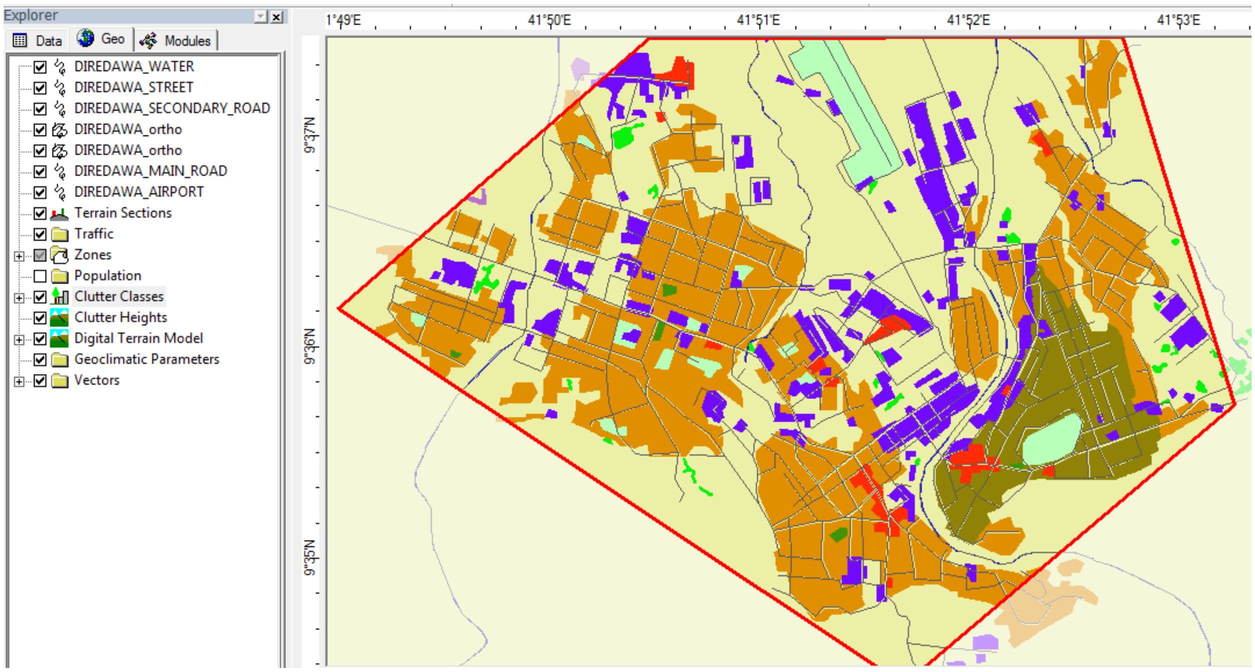

Figure 4.4: Dire Dawa city computational zone

4.4.3 Network Configuration parameters

ATOLL simulation software required input parameters to simulate the desired radio network planning of target place. They are used to configure network parameters such as site, transmitter and cells. Table 4.8 shows some of the input parameters used to configure the target network in ATOLL planning tool.

Table 4.8: The input parameters

Parameter	value
Frequency	1800 MHz
Propagation Model	Cost 231 HATA
Transmit Power	46 dBm
Antenna Height	30 m
Antenna Configuration	65deg 17 dBi1800MHz
MIMO Configuration	2x2

4.4.4 Site Layout

Based on the capacity and coverage planning, it requires deploying a total of 47 eNodeB's all over the selected area. Therefore, a total of 47 eNodeB's are created in the Atoll planning tool. Once the coordinate of the site given, the longitude, latitude and altitude i.e. geographic point where the site will be located, will be automatically displayed base on the digital terrain model. Table 4.9 shows the list of the sites with their longitude, latitude and altitude.

Table 4.9: Summarized sites with their Longitude, Latitude and Altitude

Name of sites	Longitude	Latitude	Altitude (m)
DD00	41°50'25.25"E	9°37'18.31"N	[1,142]
DD01	41°50'2.81"E	9°36'55.43"N	[1,157]
DD02	41°49'36"E	9°36'34"N	[1,171]
DD03	41°49'12.62"E	9°36'10.02"N	[1,187]
DD04	41°49'50"E	9°35'45"N	[1,199]
DD05	41°50'4"E	9°36'30"N	[1,166]
DD06	41°49'35.09"E	9°35'56.99"N	[1,190]
DD07	41°49'46.22"E	9°36'15.34"N	[1,181]
DD08	41°50'55.94"E	9°36'17.4"N	[1,182]
DD09	41°50'59.81"E	9°36'41.44"N	[1,163]
DD10	41°50'17"E	9°36'10"N	[1,190]
DD11	41°51'22.93"E	9°36'27.75"N	[1,171]
DD12	41°50'22.87"E	9°35'53.31"N	[1,198]
DD13	41°50'46"E	9°35'52"N	[1,185]
DD14	41°50'17.4"E	9°35'33.58"N	[1,203]
DD15	41°50'40.62"E	9°35'32.71"N	[1,195]
DD16	41°50'36"E	9°37'4"N	[1,149]
DD17	41°50'33"E	9°36'45"N	[1,159]
DD18	41°51'6"E	9°35'52"N	[1,191]
DD19	41°51'4"E	9°35'18"N	[1,204]
DD20	41°51'32.08"E	9°35'29.65"N	[1,213]
DD21	41°51'11"E	9°37'4"N	[1,154]
DD22	41°52'39"E	9°37'20"N	[1,171]
DD23	41°50'36"E	9°36'28"N	[1,176]
DD24	41°51'11.14"E	9°34'46.99"N	[1,223]
DD25	41°51'39"E	9°34'54"N	[1,231]
DD26	41°52'4"E	9°34'49"N	[1,247]
DD27	41°51'55"E	9°35'14"N	[1,224]
DD28	41°52'1"E	9°35'36"N	[1,206]
DD29	41°52'32"E	9°35'26"N	[1,221]
DD30	41°52'5"E	9°35'4"N	[1,273]
DD31	41°52'23"E	9°36'3"N	[1,191]

DD32	41°52'31"E	9°36'19"N	[1,180]
DD33	41°52'24"E	9°36'46"N	[1,166]
DD34	41°51'45"E	9°37'4"N	[1,151]
DD35	41°51'51"E	9°36'35"N	[1,173]
DD36	41°51'46"E	9°36'9"N	[1,191]
DD37	41°52'49.35"E	9°36'35.58"N	[1,176]
DD38	41°51'43.86"E	9°35'47.02"N	[1,204]
DD39	41°51'20.58"E	9°35'7.01"N	[1,223]
DD40	41°51'25"E	9°36'11"N	[1,183]
DD41	41°52'10"E	9°36'17"N	[1,180]
DD42	41°52'13.42"E	9°37'9.19"N	[1,154]
DD43	41°52'56"E	9°35'38"N	[1,218]
DD44	41°52'59"E	9°36'8"N	[1,203]
DD45	41°52'0"E	9°36'1"N	[1,192]
DD46	41°52'33"E	9°35'47"N	[1,204]

The sites placement of the 47 eNodeB's on the target deployment area are shown below in Figure 4.5.

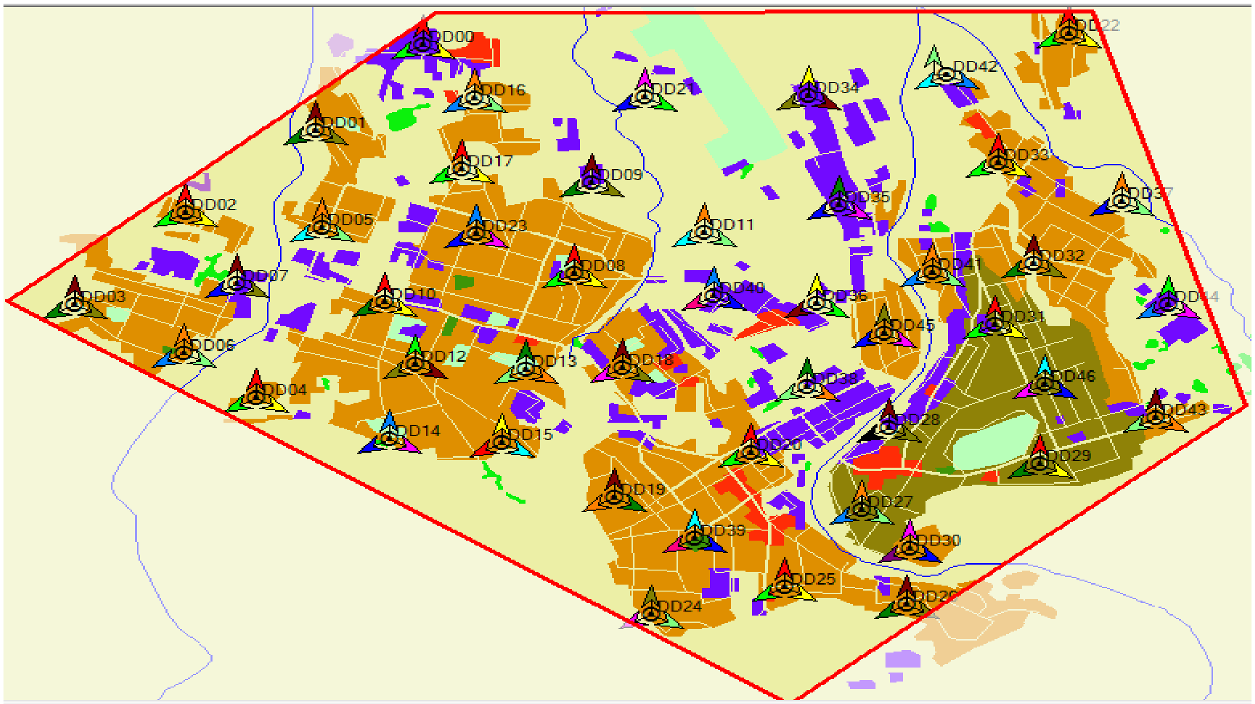

Figure 4.5: Sites placement

4.4.5 Validation criteria of radio coverage

To validate the radio coverage of a network, a set of indicators and levels that need to be achieved were defined. Automatic frequency planning and cell planning were performed before running each of these simulations. In detail simulation results were obtained and the corresponding legends show each of them with different color. The target network prediction result will be evaluated to validate the target network requirement. Table 4.10 provides typical design targets for the LTE 1800 MHz.

Table 4.10: Typical design targets for the LTE

Criteria		Target
Best Signal Level	Good	Above -95dBm
	Medium	-95 to -116 dBm
	Poor	Below -116 dBm
Area coverage probability		90 %
SINR	Good	Above -7dB
	Medium	-7 to -10 dB
	Poor	Below -10 dB
Overlapping Zone	Area with ≥ 2 servers	Below 35%
	Area with ≥ 4 servers	Below or 2%
Cell edge throughput (kbps)	DL	Above or 1025
	UL	Above or 512

4.4.6 Simulation Results & Analysis

Radio network planning process are used different techniques for analysis of LTE mobile networks. To analysis the predictions obtained using the planning tool, and in order to validate coverage, the results must be in agreement with values presented in Table 4.9. In the following sections, different techniques and methods through information provided by the planning tool allows detection of faults and the improvement of radio planning. Any coverage prediction made on a base station uses the propagation model to calculate its results.

4.4.6.1 LTE Coverage Prediction by Signal level

Coverage is defined as the possibility to get a service with a defined network requirement in terms of signal quality. A coverage prediction by signal level allows us to predict coverage zones by the transmitter signal strength within the computation zone. Signal level in a cell addresses the highest signal strength of the best server of the studied area.

Accordingly, the coverage prediction results are shown in Figure 4.6a and the target area is covered by strong signal i.e. -85 dBm. This signal prediction result have acceptable coverage as we observe from the simulation result below. The coverage of each site is indicated by different colors according to the received signal level measured in dBm.

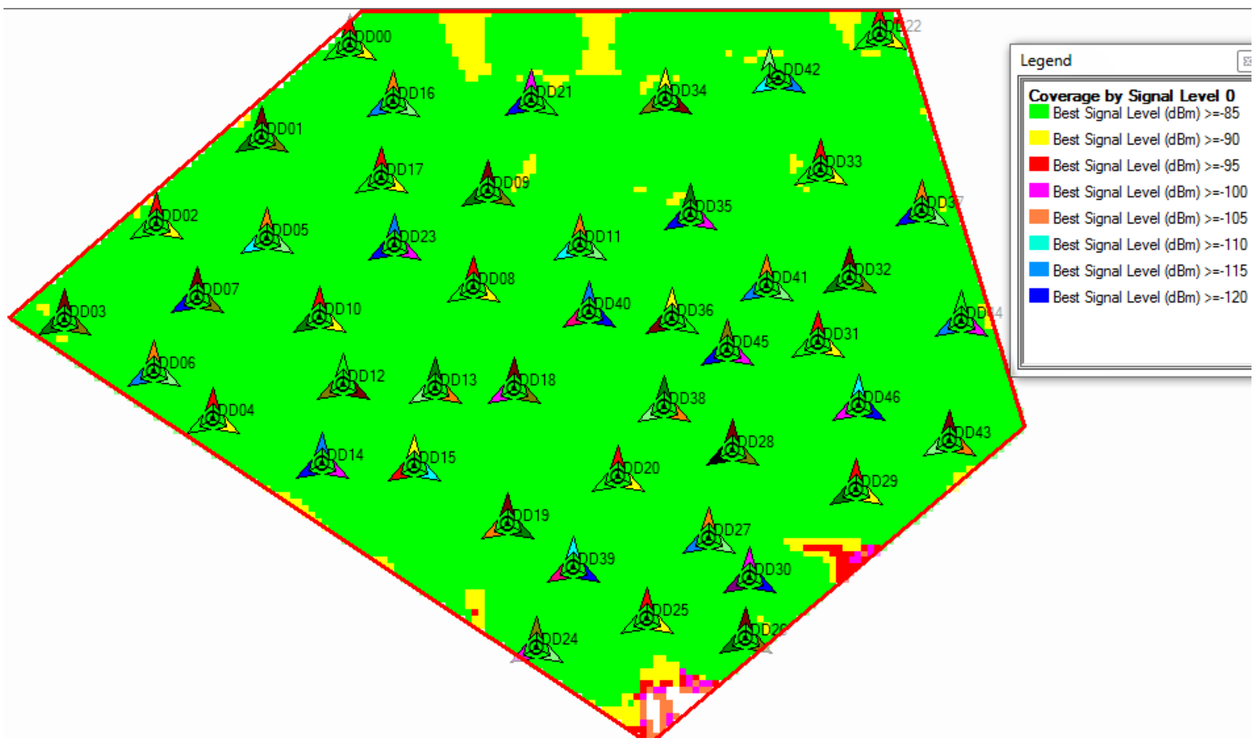

Figure 4.6a: Coverage Prediction by Signal Level

Figure 4.6b illustrate the relation between best signal levels (in dBm) versus coverage area in (%). The threshold value used for simulation purposes was -95dBm. From the coverage by signal level results, the signal levels in the focus zone were above the threshold with the signal level within the focus zone being - 85dBm. The statistical result shown in the histogram is that more areas within the computation area are covered by strong signal level. That means for the strong signal -85 dBm more than 97% of the target area is covered.

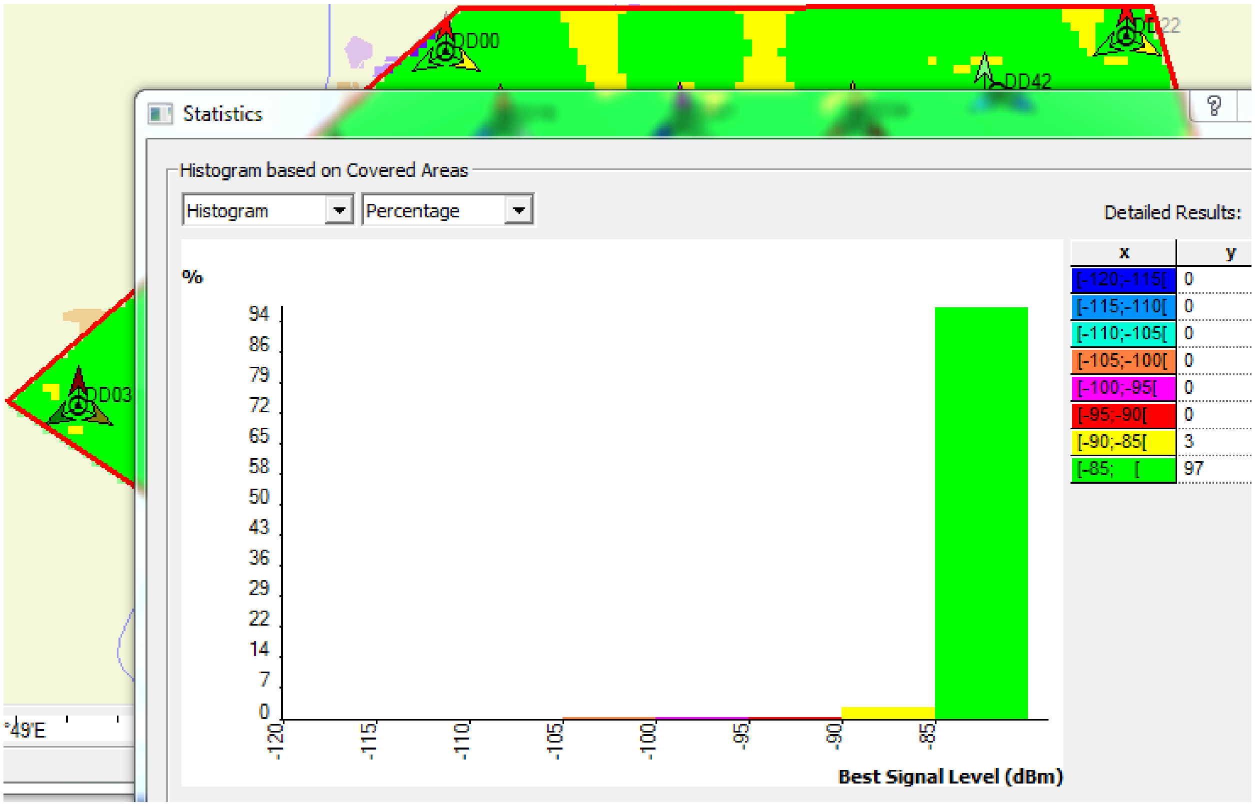

Figure 4.6b: Signal Level versus Coverage Area in Percent

4.4.6.2 LTE Coverage Prediction by Transmitter

A coverage prediction by transmitter allows predicting coverage zones by transmitter at each pixel. It predicts the maximum area that can be covered by a base station. How far the placed transmitters have covered is shown in coverage by transmitter map in Figure 4.7. When we create a transmitter, ATOLL automatically creates a cell for the transmitter using the configuration parameters. For a transmitter with more than one cell, the coverage is calculated for the cell with the highest power. For a coverage prediction by transmitter once you have created the coverage prediction, you can calculate it to save the defined coverage prediction. Once Atoll has finished calculating the coverage prediction, the results are displayed in the map window which shown in Figure 4.7

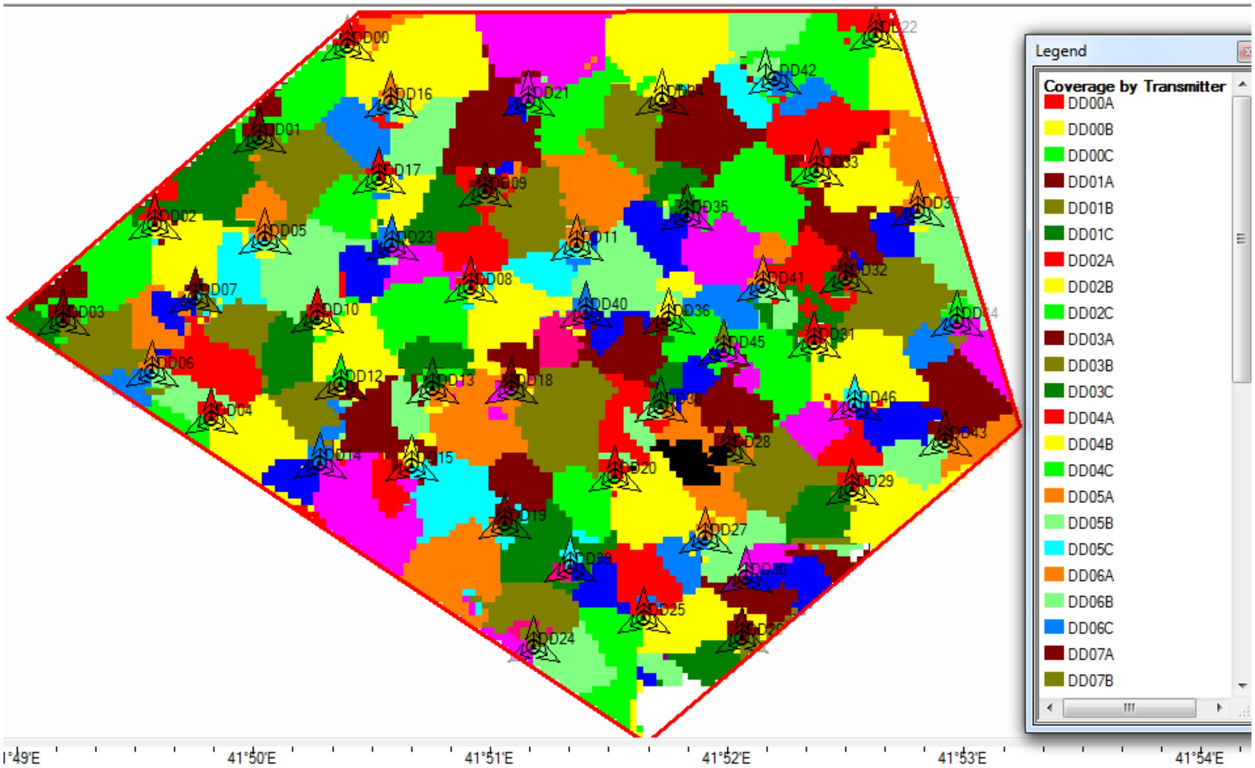

Figure 4.7: Coverage Prediction by Transmitter

4.4.6.3 LTE Path loss with Distance

Atoll is a tool for the design and simulation of wireless systems. It predicts the performance of a radio link by using information from the designed network and a digital map of the area. During the simulation, it checks the line of sight and calculates the path loss.

The simulation result in Figure 4.8a below justifies that at our designed cell radius we can get an acceptable signal level which is better than our receiver sensitivity signal level, it implies the signal can fully serve a user at this particular point. According to the coverage planning results based on the link budget calculations and the COST 231 Hata propagation model suggests that we should expect a cell radius of around 1.3 km for downlink. The result of the developed radio network planning tool is also more in line with our planning result at 1.4 km.

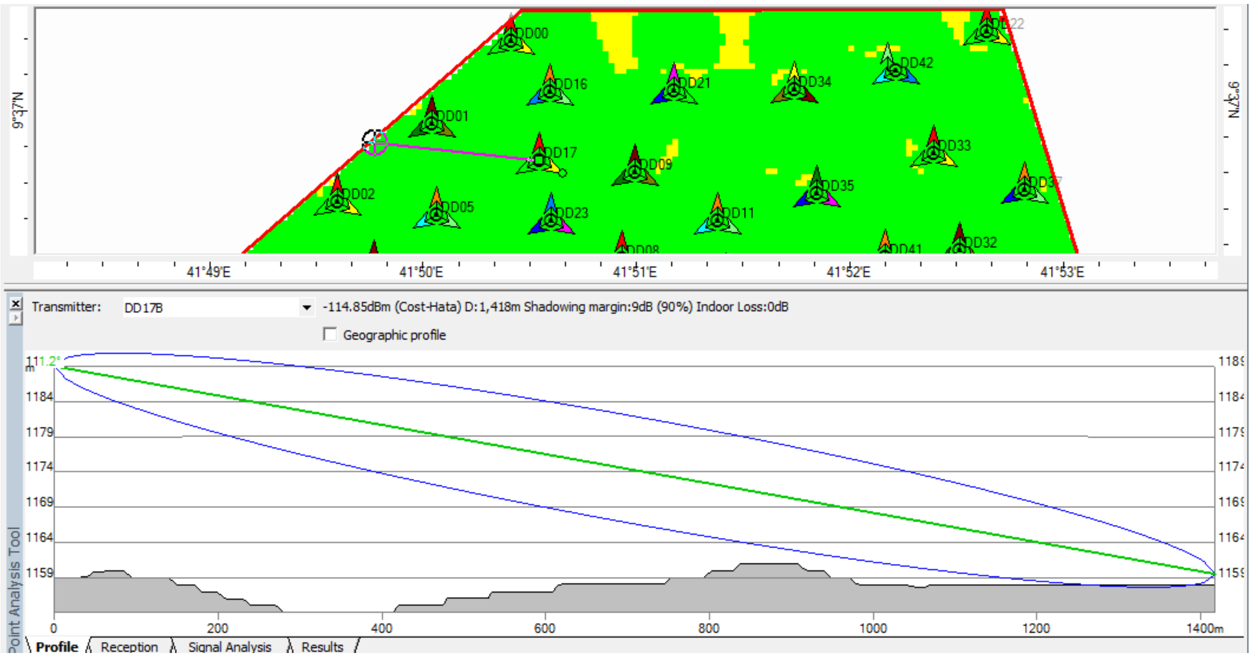

Figure 4.8: LTE Path loss with Distance

4.4.6.4 LTE Coverage Prediction on Overlapping Zones

The other coverage prediction that has been done on the selected area is by the overlapping zones meanwhile cells are considered to overlap. The overlapping zone occurs very often in mobile networks and can reduce the quality of a network, in particular the area where it occurs. The overlapping zone is the existence of several zones in which a cell is dominant (best server), but that is outside the normal coverage area. It is mainly caused by antennas located at higher and lower areas, but also due to reflections in the environment. Hence large areas overlapping reduce the performance. The best server prediction of LTE are shown in Figure 4.9. As requirement for this indicator of Figure 4.9, it was determined that the area percentage of 4 or more servers must be less than 2%, and the area with 2 or more servers must be less than 35% which is 24%.

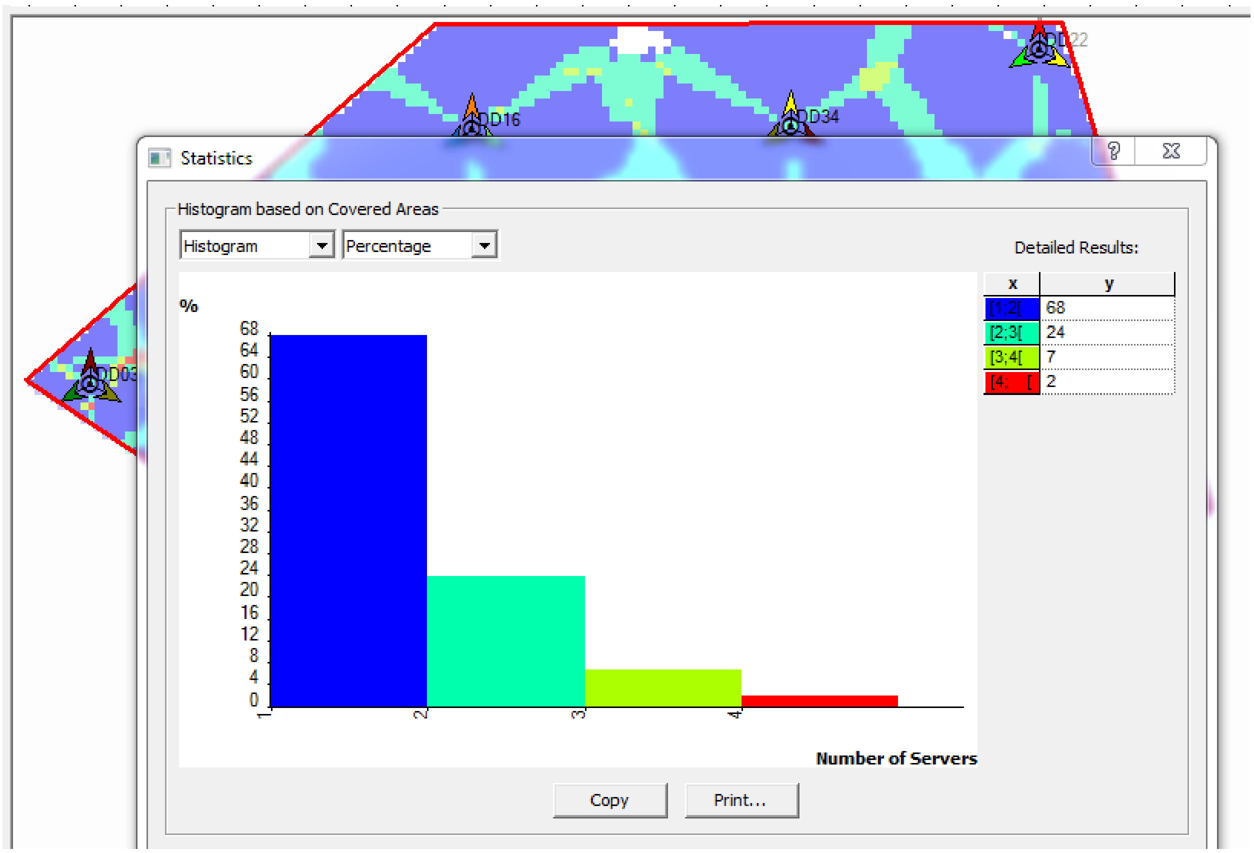

Figure 4.9: overlapping zone of transmitter using histogram

4.4.6.5 LTE Coverage predictions by SINR

Coverage predictions by SINR level evaluates the interference levels and the signal-to-interference levels of the target network being studied. This indicator allows analyzing the signal quality, by the calculation of ratio between received power and the interference and noise. Figure 4.10 shows coverage prediction by the SINR value from the simulation result obtained by ATOLL when the transmitter power is 46dB. The value carrier to noise ratio obtained is -5 db which greater than or equal to -7 dB threshold value.

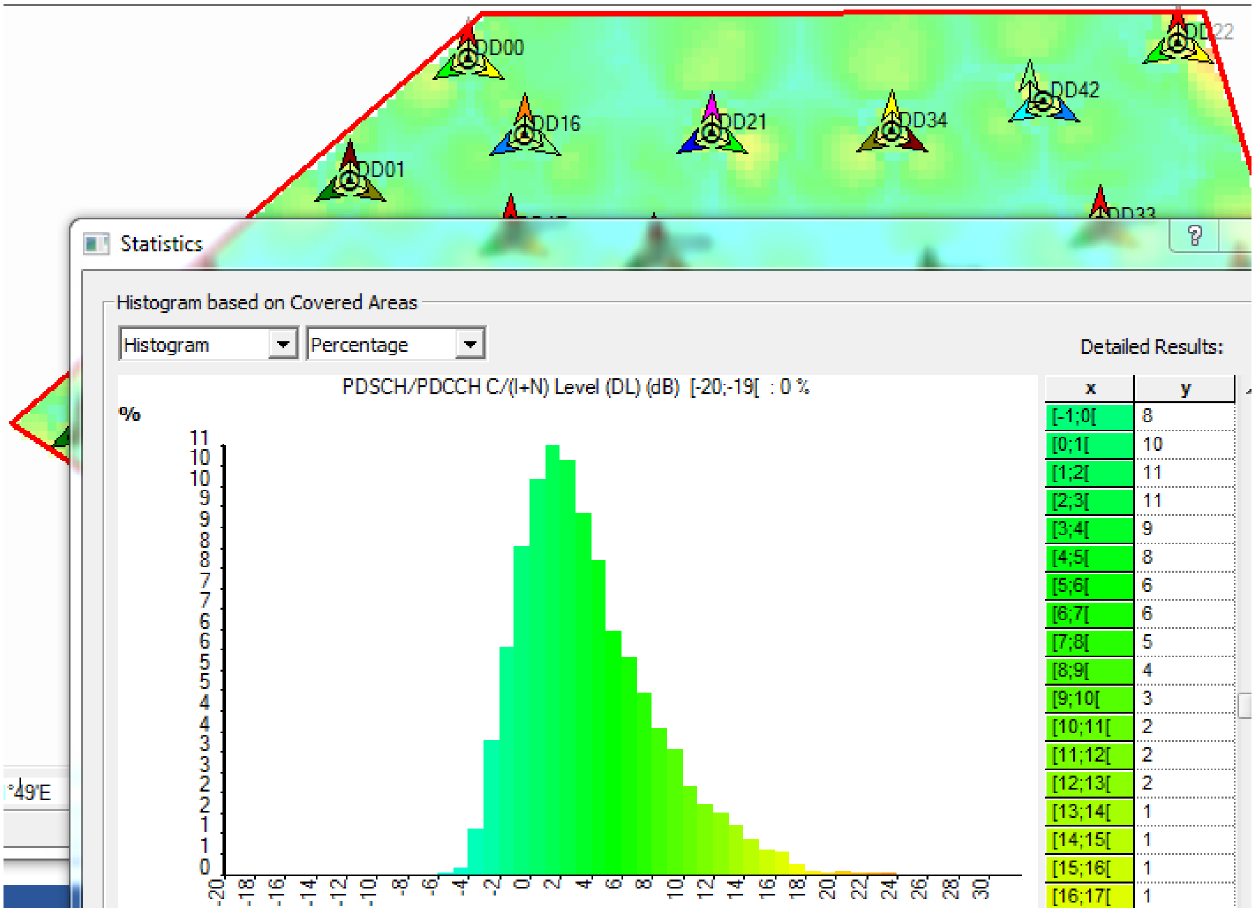

Figure 4.10: LTE coverage prediction by the SINR

4.4.6.6 LTE Coverage Prediction by Throughput

In this study, the ATOLL planning tools calculates the downlink and uplink throughput predictions to display the channel throughputs and cell capacities. Considering the target network requirements, the cell edge coverage probability set to 90% 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 4.11a and b shows the prediction result for uplink and downlink effective Radio Link throughput. The statistics 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.

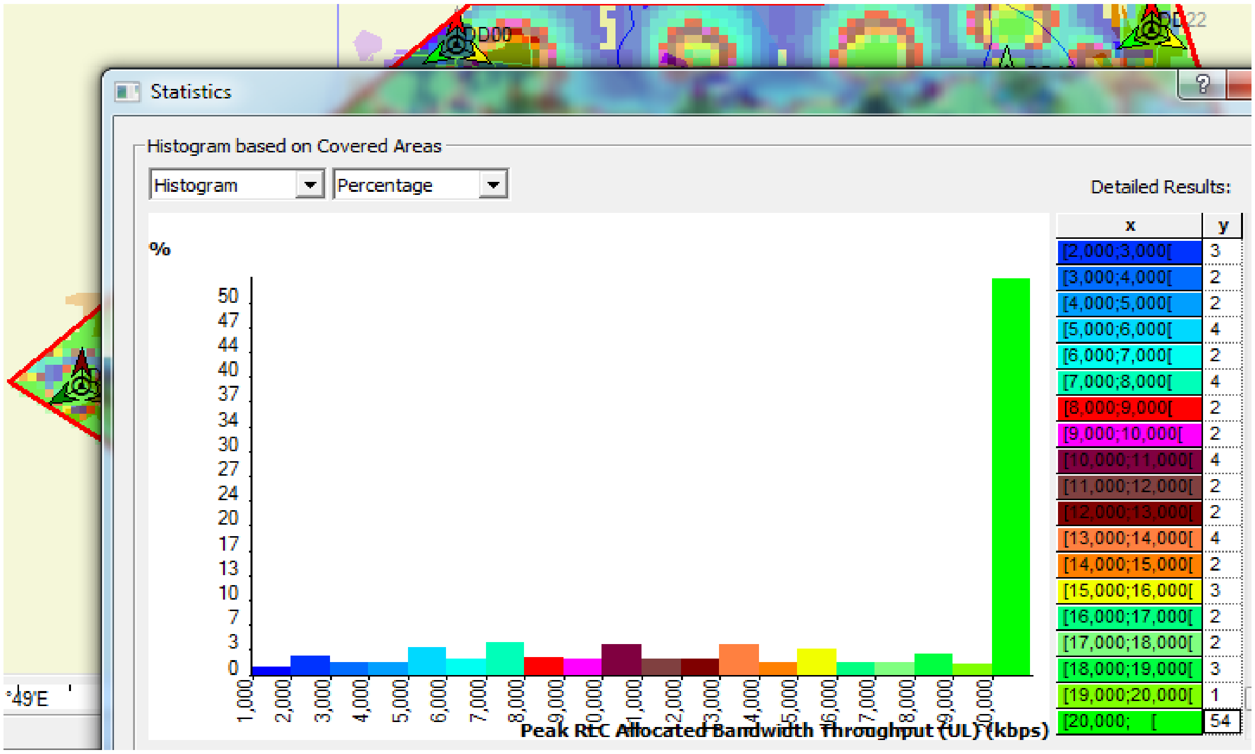

Figure 4. 11*a*: UL effective RLC user throughput

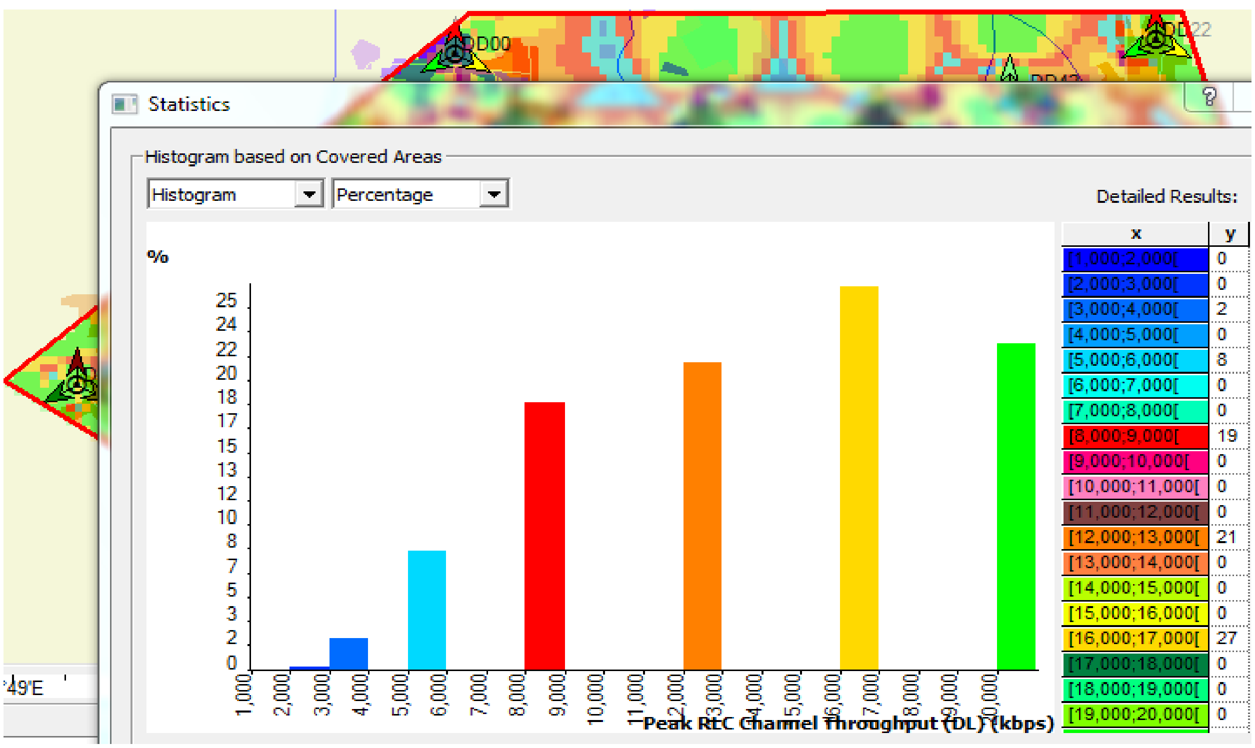

Figure 4. 11b: DL effective RLC user throughput

Chapter - 5 Conclusion and Future Work

This chapter finalizes the present study by summarizing the main conclusions obtained throughout this work and presenting an overall analysis about the main results achieved. Possible future word and improvements are also discussed in this chapter.

5.1 Conclusion

The radio network planning of LTE, like any other cellular technologies, needs extensive assessment in terms of capacity and coverage requirements. The estimations regarding the capacity and coverage should contribute for the deployment and implementation process of the technology by providing substantial data. During the study of this thesis the relevant LTE features, propagation models, coverage, capacity and number of eNBs for radio planning have been discussed. The capacity of the LTE network is depicted with the indicators of average transmission data rate, peak transmission data rate and the subscriber's numbers supported by the LTE system. The coverage of the LTE system is also calculated on the base of Base Station parameters and different propagation models. According to the simulation result of propagation model comparison COST 231 HATA model shows the maximum path loss as compared to the other models for urban environment. Therefore, in this study COST 231 HATA model is the best suited model among all propagation models for LTE network planning. The target LTE network performances evaluation has been made against the requirements defined with coverage area prediction using ATOLL radio planning tool.

In this thesis the result obtained from the capacity and coverage analysis shows that 47 eNBs are enough to cover the urban clutters of Dire Dawa City. The output of this planning process by using simulation can verify the coverage and capacity planning results. In this study coverage prediction was performed. Various graphs are used to provide the information about coverage prediction from simulation results, in terms of coverage by signal level, coverage prediction by transmitter and coverage prediction by overlapping zones. As it is shown in the radio planning simulation, we can cover a 68.62 Km^2 of Dire Dawa urban area using 47 eNodeBs sites. It was analyzed that more than 97% of the target area is covered by strong signal i.e. greater than -85dBm. A coverage prediction by transmitter allows predicting the maximum area that can be covered by a base station.

Analyzing the coverage prediction results with respect to calculated values, it is quite evident that the planned network provides a good coverage.

5.2 Future Work

Based on the studies we have concluded above, there are some discussions which can further enhancements should be done. There are number of ways in which this work can be carried forward. The work done in this thesis covers the access network planning of LTE network. This can be extended to include frequency planning.

In this work, we use propagation model based on simulation results. The selection of this propagation model may be changed depending on simulation results and measurements in reality. Hence, our simulation results show different propagation model gives different performance result in different environment. Therefore more suitable propagation model propagation can be depending on simulation results and measurements in reality as part of future work.

This study on LTE coverage and capacity analysis was done with the test of LTE network performance using ATOLL planning tools in the urban area. Therefore, the LTE radio planning could be expanded to other environments such as sub-urban and rural area of Dire Dawa.

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Appendix

I. Comparisons of various propagation models in urban environment

```
%%%%%%%%%%%%%% models for urban area by Tafari Lemma %%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=5;
d=0.0:0.25:N;
f=1800;  %frequency in MHz
hb=30;   %transmitter antenna heights
hr=1.5;  %receiver antenna heights
%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);
%%%%%%%%%%%%%%%% Okumar Hata Model %%%%%%%%%%%%
y=log10(hr)-0.585;
Afs=92.4+20.*log10(d)+20.*log10(f);
Abm=20.41+9.83.*log10(d)+7.894.*log10(f)+9.56*2.*log10(f);
%in urban environment the parameter a=3.6,b=0.005,c=20 in m
a=(5.8*2*(log10(d)));
b=13.958;
c=log10(hb/200);
Gb=c.*(b+a);
x=42.57+13.7.*log10(f);
Gr=x.*y;
PLokumar=Afs+Abm-Gb-Gr;
%%%%%%%%%%%%%%%%Cost 231 hata Model%%%%%%%%%%%%%%
cm=3;  %3dB in urban area
ahm2=3.20.*(log10(11.75*hr))^2-4.97;
PLcost231=46.3+33.9.*log10(f)-13.82.*log10(hb)-ahm2+(44.9-6.55.*log10(hb))*log10(d)+cm;
%%%%%%%%%%%%%%%SUI model%%%%%%%%%%%
%100 m used as a reference
d1= 0.1;
%receiver hight
lambda=((3*10^8)/( 1800*10^6));
%fading standard deviation s is 8 dB in urban%
s=8.0;
a=3.6;
b=0.005;
c=20;
gamma=a-b*hb+c/hb;
PLsui=20.*log10((4*pi*d1)/lambda)+10*gamma.*log10(d/d1)+6.*log10(f/2000)-20.*log10(hr/2000)+s;
%%%%%%%%%%%%%%%%%% Ericsson Model  %%%%%%%%%%%%%%%%%%%%
g(f)=44.49.*log10(f)-9.56.*log10(f);
PLeric=36.2+30.2.*log10(d)-12.*log10(hb)+0.1.*log10(hb)*log10(d)-6.4.*log10(11.75*hr)+g(f);
%%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%
plot(d,fsmodel,'b+-',d,PLokumar, 'r*-',d,PLcost231,'g.-',d,PLsui,'k.-',d,PLeric,'m.-');
```

```
grid on;
%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('Path loss comparision of Variuous propagation models in urban environment');
legend('fsmodel','PLokumar','PLcost231','PLsui','PLeric',
'Location,NorthEast');
```

II. Comparison of various propagation models in Sub-urban environment

```
%%%%%%%%%%%%% models for suburban area by Tafari Lemma %%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=5;
d=0.0:0.25:N;
f=1800;  %frequency in MHz
hb=30;   %transmitter antenna heights
hr=1.5;  %transmitter antenna heights
%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);
%%%%%%%%%%%%%%%%Okumar Hata Model %%%%%%%%%%%%
y=log10(hr)-0.585;
Afs=92.4+20.*log10(d)+20.*log10(f);
Abm=20.41+9.83.*log10(d)+7.894.*log10(f)+9.56*2.*log10(f);
%in urban environment the parameter a=3.6,b=0.005,c=20 in m
a=(5.8*2*(log10(d)));
b=13.958;
c=log10(hb/200);
Gb=c.*(b+a);
x=42.57+13.7.*log10(f);
Gr=x.*y;
PLokumar=Afs+Abm-Gb-Gr;
%%%%%%%%%%%%%%%%Cost 231 hata Model%%%%%%%%%%%%%%
cm=0; %0dB in suburban area
ahm=(1.11.*log10(f)-0.7)*hr-(1.5.*log10(f)-0.8);
PLcost231=46.3+33.9.*log10(f)-13.82.*log10(hb)-ahm+(44.9-6.55.*log10(hb))*log10(d)+cm;
%%%%%%%%%%%%%%%%SUI model%%%%%%%%%%%
%100 m is used as a reference in SUI model
d1= 0.1;
%receiver hight
lambda=((3*10^8)/( 1800*10^6));
%fading standard deviation s is 8.2 dB in suburban
s=8.2;
% Suburban is consider as a terrain B
a=4;
b=0.0065;
c=17.1;
```

```
gamma=a-b*hb+c/hb;
PLsui=20.*log10((4*pi*d1)/lambda)+10*gamma.*log10(d/d1)+6.*log10(f/2000)-10.8.*log10(hr/2000)+s;
%%%%%%%%%%%%%%%%%% Ericsson Model  %%%%%%%%%%%%%%%%%%%%%
g(f)=44.49.*log10(f)-9.56.*log10(f);
PLeric=43.20+68.93.*log10(d)-12.*log10(hb)+0.1.*log10(hb)*log10(d)-6.4.*log10(11.75*hr)+g(f);
%%%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%
plot( d,fsmodel,'b+-',d,PLokumar, 'r*-',d,PLcost231,'g.-',d,PLsui,'k.-',d,PLeric,'m.-');
grid on;
%%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('Path loss comparision of Variuous propagation models in sub-urban environment');
legend('fsmodel','PLokumar','PLcost231','PLsui','PLeric','Location,NorthEast');
```

III. Comparison of various propagation models in rural environment

```
%%%%%%%%%%%%%% models for rural area by Tafari Lemma %%%%%
close all;
clear all;
clc
%Distance in Kilometer
N=5;
d=0.0:0.25:N;
f=1800; %frequency in MHz
hb=20;  %transmitter antenna heights in rural area
hr=1.5; %receiver antenna heights
%%%%%%%%%%%%%%%%Free Space Loss%%%%%%%%%%%%%%%%%%
fsmodel=32.45+20.*log10(d)+20.*log10(f);
%%%%%%%%%%%%%%%%%Cost 231 hata Model%%%%%%%%%%%%%%%
cm=0;  %0dB in rural area
ahm=(1.11.*log10(f)-0.7)*hr-(1.5.*log10(f)-0.8);
PLcost231=46.3+33.9.*log10(f)-13.82.*log10(hb)-ahm+(44.9-6.55.*log10(hb))*log10(d)+cm;
%%%%%%%%%%%%%%%%SUI model%%%%%%%%%%%
%100 m used as a reference
d1= 0.1;
%receiver hight
lambda=((3*10^8)/( 1800*10^6));
%fading standard deviation s is 8.2 dB in rural
s=8.2;
% Urban is consider as a Terrain A with highest path loss%
a=3.6;
b=0.005;
c=20;
gamma=a-b*hb+c/hb;
```

```
PLsui=20.*log10((4*pi*d1)/lambda)+10*gamma.*log10(d/d1)+6.*log10(f/2000)-20.*log10(hr/2000)+s;
%%%%%%%%%%%%%%%%%% Ericsson Model 9999 %%%%%%%%%%%%%%%%%%%%%
g(f)=44.49.*log10(f)-9.56.*log10(f);
PLeric=45.95+100.6.*log10(d)-12.*log10(hb)+0.1.*log10(hb)*log10(d)-6.4.*log10(11.75*hr)+g(f);
%%%%%%%%%%%%%%%%%Plotting%%%%%%%%%%%%%%%%%%%%%%
plot(d,fsmodel,'b+-',d,PLcost231,'g.-',d,PLsui,'k.-',d,PLeric,'m.-');
grid on;
%%%%%%%%%%%%%%%%%Axis and Title%%%%%%%%%%%%%%%%%%%
xlabel('Distance between Tx and Rx (km)');
ylabel('Path loss (dB)');
title('Path loss comparision of Variuous propagation models in rural environment');
legend('fsmodel','PLcost231','PLsui','PLeric','Location,NorthEast');
```