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LONG TERM EVOLUTION (LTE) COVERAGE AND CAPACITY PLANNING FOR THE CASE OF GONDAR CITY

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BAHIR DAR UNIVERSITY

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DEPARTEMNT OF INFORMATION TECHNOLOGY

MSC Thesis on:

LONG TERM EVOLUTION (LTE) COVERAGE AND CAPACITY PLANNING FOR THE CASE OF GONDAR CITY

BY

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Bahir Dar, Ethiopia

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BY

ABATNEH SHIFERAW

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Information Technology

Advisor

Dr. Tesfa Tegegne

DECLARATION

I, the undersigned, declare that the thesis comprises my own work. In compliance with internationally accepted practices, I have dually acknowledged and refereed all materials used in this work. I understand that non-adherence to the principles of academic honesty and integrity, misrepresentation/ fabrication of any idea/data/fact/source will constitute sufficient ground for disciplinary action by the university and can also evoke penal action from the sources which have not been properly cited or acknowledged.

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Approval of thesis for defense result

I hereby confirm that the changes required by the examiners have been carried out and incorporated in the final thesis.

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Abstract

Extreme data speed is the LTE standard's primary focus, but it is also a very complicated system that uses modern technology. Starting with optical technology for the backbone network and progressing to sophisticated electronics for signal processing and control. Planning a wireless network typically comprises several steps that are vital for a fruitful network design. The performance (capacity and coverage) of the 4G/3G network in Gondar city is poor due to the number of problems and it is not affordable for the city.

The simulation at the end of this paper attempts to illustrate the key planning concepts using the atoll planning tool, which is utilized in this research to plan the capacity and coverage of LTE. Capacity and coverage analysis was performed to prepare a radio planning guideline considering possible network implementation in Gondar city. The outcome demonstrates that greater network coverage and optimal network capacity were achieved by taking into account network factors from the first nominal planning stage through the detailed planning phases in combination with pre-optimization requirements. As the simulation shows Stanford University Interim model becomes the better propagation model for the hilly morphology of Gondar City by 1800MHz.

Keywords: LTE, capacity planning, coverage Planning

Contents

ABBREVIATION

LTE	Long term evolution
SUI	Stanford university interim
SMS	Short Message System
QOS	Quality of Service
MHZ	Mega Hertz
3G	Third generation
4G	Fourth generation
DL	Downlink
UL	Uplink
SNIR	Signal Noise Interference Ratio
UMTS	Universal Mobile Telecommunication System
IP	Internet Protocol
MBPS	Mega bit per second
UE	User Equipment
MME	Mobility Management Entity
HSS	Home Subscriber Server
EPC	Evolved Packet Core
MIMO	Multiple Input Multiple Output
RAN	Radio Access Network
TDD	Time Division Duplex
OFDMA	Orthogonal Frequency Division Multiple Access
SIMO	Single Input Multiple Output
SINR	signal to interference plus noise ratio
3GPP	3rd Generation Partnership Project
KPI	Key Performance Indicators
MAPL	Maximum Allowable Path Loss
EIRP	Equivalent Isotropic Radiated Power
ECP	Cell Edge Coverage Probability
FM	Fading Margin
STDSF	Standard Deviation of Slow Fading

FDD	Frequency Division Duplex
KBPS	Kilo bite per second
RNPO	Radio Network Planning and optimization
RSRQ	Reference Signal Received Quality
BLER	Block Error Rat
RSRP	Reference Signal Received Power
PRB	Physical Resource Blocks
PDSCH	Physical Downlink Shared Channel
QPSK	Quadrature Phase Shift Keying
QAM	Quadrature Amplitude Modulation
PUSCH	Physical Uplink Shared Channel
C/(I+N)	Carrier-to-Noise-plus-Interference-Ratio
RLC	Radio Link Control
VOIP	Voice Over Internet Protocol
RLB	Radio Link Budget
MME	Mobility management entity
SGW	Serving getaway
HSS	Home Subscriber Server
PCRF	Policy and Charging Rules Function
PDN-GW/PGW	Packet data network gateway
PUCCH	physical uplink control channel
PUSCH	Physical uplink shared channel

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Chapter one

1. Introduction

1.1 Background

In 1894, Emperor Menelik II began deploying telephone lines from Harar to Addis Ababa, which marked the introduction of telecom service in Ethiopia. The inter-urban network was also extended from the city's center in all other directions. With the aid of intermediary operators acting as verbal human repeaters, many significant locations throughout the Empire were linked by landlines to facilitate long-distance communications [1]. However, their data transmission speeds are lower than those of its successors. 2G was the first to deploy digital encryption for calls, data services, and SMS text messaging. The necessity for high-speed data rates and interactive program connectivity among subscribers brought an evolution of cellular network technologies into the third generation. Faster data transfer speeds and the principal technology for video conversations are provided by 3G. Because modern smartphones need a consistent high-speed internet connection for many of its applications, this makes 3G particularly suitable for usage in those devices.

LTE technology is implemented and functioning in the capital city of Ethiopia, whereas, other parts of the country are still covered by 2G and 3G cellular technologies but few cities have LTE technologies. However, as the data traffic grows and demand increases, Ethio Telecom will rollout network capacity in other regions by improving network coverage and capacity. One of the regions with big cities available is the Amhara region and among the cities, Gondar is a well-known one. The ancient city in Ethiopia, Gondar is now growing with a number of facilities such as hotels, trade centers, and other private and governmental offices. The other growth in Gondar city is having a high flow of tourists [2]. This is because, Gondar has many attractive natural parks like Semen Park also known as Semen mountains, and historical museums like Fasil Ghebbi, Debre Berhan Selassie, Epiphany ceremony, etc. Gondar is one of the major cities of the top seven cities of Ethiopia ranked 2nd [3]. The citizen and all coming visitors are staying in Gondar. There is also interaction between tourism and tour guides, which need faster and more reliable communication with their visitors. The 4th generation of mobile communications standards is called LTE. Larger bandwidths (up to 20 MHz), reduced latency, and packet-optimized radio access technology are all features of the LTE system, which can reach peak data rates of 100 Mbps in the downlink and 50 Mbps in the uplink [4]. This paper focuses on Gondar city to deploy LTE cellular network coverage and capacity planning. In this work, a detailed radio network planning i.e., capacity and coverage analysis has been performed to prepare a radio planning guideline considering possible network implementation by Using Atoll Radio Planning and Optimization Software.

1.2 Statement of the Problem

The performance (capacity and coverage) of the 4G/3G network in Gondar city is poor due to a number of problems and it is not affordable for the city since Gondar is the center of tourists. The problem with existing cellular technology 4G/3G networks in Gondar city:

- There is demand for high-speed data connection but difficult to access the internet sufficiently
- Due to poor coverage an able to get the needed service every where
- The network is busy due to the increased subscriber numbers the network can't carry the traffic
- Blocking of signal due to natural topography and buildings

Ethiopia financed millions of dollars in the telecommunication sectors to introduce different technologies, and services at different times to move the country onward with cellular technology, which is one part of the long-term growth and transformation plan of the country [5]. To satisfy the customer needs to be required upgrade and expanding of the existing telecom networks. Ethio telecom deployed LTE full coverage in Addis Ababa and introduces advanced service in some parts of Addis [6]. However, due to the rapidly increasing population, usage of smart devices, and demand for high data rates for multimedia services in urban areas needs to address available internet access. Therefore, deploying full LTE technologies is necessary to satisfy visitors and to improve the socio-economic of the Gondar City population.

To address the above-mentioned problems, there should be an action plan that considers LTE deployment programs in Gondar city. Till this time no LTE plan is studied and implemented in the city. So, the main focus of this study is to come up with a well-studied LTE implementation strategy that addresses the above-mentioned problems by considering the current situations and future customer growth by answering the following research questions.

- What kind of design or deployment is appropriate for Gondar city LTE?
- In what extent the proposed design is effective with different parameters?

1.3 Objective of the study

1.3.1 General Objective

The general objective of the study is to planning the coverage and capacity of the LTE cellular network for Gondar city by considering the current demand and future needs of the customers by considering coverage and capacity.

1.3.2 Specific Objectives

To achieve the general objectives, the following specific objectives are drawn.

- To read and review related literature for LTE architecture and deployment issues.
- To collect data on planning coverage and capacity.
- To design or plan an LTE deployment model for Gondar city.
- Evaluate the designed model with different parameters.
- Select appropriate path loss model

1.4 Scope of the study

In this study, the detailed LTE radio network coverage and capacity planning by using a simulation environment of the proposed techniques using ATOLL tools, and post-launch optimization is not performed. Although the Frequency Division Duplex (FDD) and Time Division Duplex (TDD) radio access modes are supported by the LTE system, this study primarily focuses on FDD mode. Also, even though physical site surveys are necessary to complete LTE network planning, in this study the thorough radio network planning is only done using the RNPO tool.

1.5 Significance of the study

Radio network planning for cellular networks plays a key role in reducing capital expenditure and operational expenditure in deploying and expanding cellular systems. Therefore, this study will be used by the telecom operator to use as a guideline to identify the engineering aspects regarding radio network dimensioning and planning. Besides fulfilling the initial requirements such as coverage and capacity, radio resource has to be acquired in a way that the cost is minimized. Cellular network planning is one of the challenging tasks in the telecom industry due to technological advancement. This research work contributes to how to perform LTE radio network planning for new build scenarios to assist the operators and local practicing engineers in the area of LTE network planning. This study contributes to the deployment of LTE to reduce the extra effort the network becomes on air for commercial use.

1.6 Methodology

The latest deployment of LTE cellular technology and the fundamentals of radio network planning in particular have been examined in this study using linked secondary sources of data from books, 3GPP standardized documents, prior researcher's studies, articles, and journals. Data density requirements of the customers and expected traffic in the radio access interfaces are also evaluated in the capacity analysis. Radio Network Planning involves several stages or steps: -

- The initial phase entails gathering data for pre-planning and commencing network dimensioning, or capacity projection using simulations.
- Dimensioning and thorough planning, including the choice and application of a radio planning tool.
- Utilizing the ATOLL radio network planning tool for radio network planning simulation, approaches and models for capacity planning are taken into consideration for this thesis' design of the cellular network.

1.7 Organization of Thesis

The reminder of this thesis is organized as follows. A thorough literature is reviewed on the coverage and capacity of fourth-generation cellular networks in the chapter two. Chapter three presents the methodology of the research used. In chapter four, simulations of the thesis are simulated by the proposed methodology software, and finally the results of the simulations are discussed and analyzed. At the end, in chapter five the conclusion and future works are presented.

Chapter Two

2. Literature Review

2.1 Basics of Long-Term Evaluation

A conceptual analysis of cellular networks in general and a related work in 4G, in particular, are covered in this chapter's extensive literature study. In order to comprehend coverage and capacity planning of LTE cellular networks and the results of the technology, related books, journals, articles, and papers from the Internet have been read.

"The radio network planning process and design criteria vary from place to place depending on the dominating factor, which could be capacity or coverage." Planning a wireless network typically comprises several steps that are vital for a fruitful network design, first step is to state the geographic part where the service is estimated to be launched. Second demographics data include population thickness and population progress in a certain area. Total resources have to use with extreme efficiency, the area must be wisely studied [4] [7]. Extreme data speed is the LTE standard's primary focus. But it is also a very complicated system that uses modern technology. Starting with optical technology for the backbone network and progressing to sophisticated electronics for signal processing and control. LTE is entirely IP-based, focuses on distributing multimedia content, and enhances QoS [7].

Dimensioning is the primary phase of network planning and it has two phases coverage planning phase and capacity planning phase, this paper focuses on the coverage and capacity planning phase. The Atoll Planning tool is used in this research; it is an open, scalable, and flexible multi-technology network design and optimization platform that supports, wireless operators throughout the network lifecycle [8].

An Ericsson mobility investigation found that between 2010 and 2015, mobile data traffic grew globally by a factor of 14. The main objectives of the long-term assessment are maximum data throughput, efficient frequency-band use, and minimal latency. This complex system uses advanced technologies from a variety of industries, beginning with fiber optics for the main backbone network and advanced electronics for signal processing and control. The 3G networks of the universal mobile telecommunications system gave rise to a wireless technology standard known as LTE. As a result, a fourth-generation cellular network is considered for long-term evaluation. LTE is entirely internet protocol based and concentrated on providing multimedia material while enhancing service quality. The LTE network supports older technologies and permits inter-system handover in both directions [7].

2.2 LTE system architecture

The user equipment (UE), the evolved UMTS terrestrial radio access network (E-UTRAN), and the evolved packet core are the three primary parts EPS. The developed packet core then interacts with packet data networks outside of the system, such as the internet, private corporate networks, or the IP multimedia subsystem. The interfaces between the various components of the system are identified by the letters Uu, S1, and SGi [9].

The 4G of mobile communication, or 4G, is an enhanced technology that offers better security, bandwidth, and voice to video multimedia applications. The 4G LTE network uses a TCP/IP architecture, and for better performance, only packet switched communication is practical. Additionally, IP serves as the foundation for all network signaling and control protocols [10].

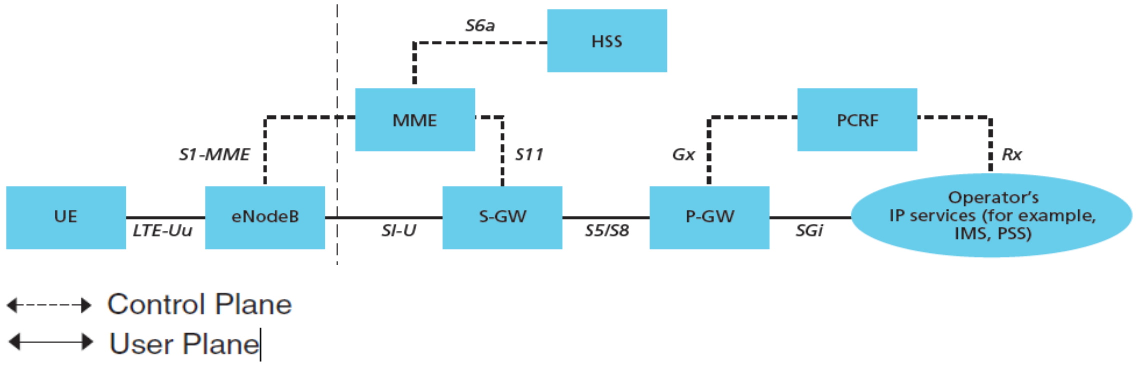


Figure 2.1 LTE architecture *[10]*

To do this, several network elements of the developing packet system are utilized, each with a different aim. The entire network design, together with the network elements and standardized interfaces, are shown in Figure 2.1.

2.2.1 Evolved Packet Core (EPC)

For voice and data, the two separate sub-domains of circuit switched and packet switched have been employed in previous mobile generations to realize the basic functionality of mobile devices. The 3G Partnership Project decided to avoid the circuit-switched domain and use the internet protocol as the principal protocol to convey all services while fostering the expansion of the core network. After careful consideration, these two different mobile core sub-domains are combined into one internet protocol domain called evolving packet core. The evolved packet core, a new, all-IP mobile core network that permits packet data connectivity with the outside world in Release 8 of 3GPP. Release 8 has continued to increase system effectiveness and data rates on the high-speed download/upload packet access side by providing [11]:

- **Multiple input multiple outputs with 64 quadrature amplitude modulation** – It provides for the theoretical rate of 42 Mbps when 64 quadrature amplitude modulation and multiple input multiple outputs are combined.
- **Dual cell operation** – Releases 9 and 10 improve a capability known as dual cell high-speed downlink packet access. As a result, a mobile device may utilize two 5MHz UMTSS channels effectively.

Theoretically, both could transmit data at 42Mbps if they were both employing 64 quadrature amplitude modulation (21.6Mbps). Over other Release 8 capabilities, dual cell high-speed down link packet access has drawn the greatest attention; most networks either support it or are in the implementation phase right now.

- **Further power and battery enhancements** – Installs enhanced radio resource control state evolutions and increased quick dormancy as features. The initial standardization of the long-term evaluation standards is outlined in 3G Partnership Project Release 8. The essential characteristics and components of both the terrestrial radio access network and the core network are required for the evolved packet system. The capacity of the air interface to enable multi-layer data streams when MIMO antenna systems are used to boost spectral efficiency is known as orthogonal frequency division multiplexing [11].

An all-internet protocol network architecture that differs from the traditional circuit switch domain is referred to as long-term evaluation. However, the Release 8 standard uses the circuit switch domain to keep the voice calls circuit switch fallback mechanism compatible with the second and third-generation systems using any of those systems. Theoretically, Release 8's long-term assessment can handle 300 Mbps of data. The most typical deployment is between 100 and 150 Mbps with a 20MHz bandwidth utilization. Numerous more variations are also implemented with less capacity, resulting in slower transmission speeds. The bandwidth allocation is tied to the amount of spectrum acquired by the Long-term evaluation network operators in every country [11].

- **Policy and charging rules function-** It is in charge of administering the flow-based pricing features in the Policy Control Enforcement Function, which is located in the packet data network gateway, as well as policy control decision-making. The QoS permission that determines how a certain data flow is handled in the policy control enforcement function is provided by the policy and charging rules function. It ensures that the user's subscription profile.
- **Home Subscriber Server** – It contains details about users' subscriptions to the System Architecture Evolution, such as QoS profiles for subscribed evolved packet systems and any restrictions on roaming access. It also includes information about the user's access to open data networks. An access point name, which is a label that specifies the access point to the public data network following domain name system naming criteria, may be used in place of a public data network address. The home subscriber server also keeps dynamic information, such as the user's current connection or registration information with the mobility management entity. Alternately, the home subscriber server might be linked with the authentication center, which generates the authentication vectors and security keys.
- **Packet Data Network Gateway** – IP address assignment for the terminal, quality of service enforcement, and flow-based billing following the policies and charging rules function are all handled by the public data network Gateway. It is responsible for sorting user IP packets sent via the downlink into the various quality of service-based bearers. This is performed based on Traffic Flow Templates. The packet data network gateway performs quality service enforcement for guaranteed bit rate bearers.
- **Signaling gateway-** When the terminals transition between eNodeBs, all user IP packets are routed through the Serving Gateway, which also serves as the local mobility anchor for the data carriers. While the mobility management entity begins paging the terminals to restore the bearers, the idle terminal also saves information about the carriers and temporarily buffers downlink data. On the network being accessed, the signaling gateway also completes many administrative responsibilities, such as collecting information for billing and legal interceptions. It also serves as the mobility anchor for integrating with other 3GPP technologies including the general packet radio service and the universal mobile communications system.

- **Mobility Management Entity**: -The control node manages the signaling process between the terminal and the core network. The protocols used between the terminals and the main network are known as non-access stratum protocols. The key objectives that the mobility management system provides are classified into the following categories:
- **Functions related to connection management**: The connection or mobility management layer of the Non-Access Stratum protocol layer handling this, which comprises the establishment of the connection and security between the network and user equipment.
- **Functions related to bearer management** – This is managed by the session management layer of the Non-Access Stratum protocol and covers the establishment, maintenance, and release of the bearers [12].

2.2.2 Evolved UMTS Terrestrial Radio Access Network (E-UTRAN)

The access network of long-term evaluation, Evolved UMTS Terrestrial Radio Access Network, simply contains a network of eNodeBs, as illustrated in Figure 2.2. There is one type of node in the Evolved UMTS Terrestrial Radio Access Network, the eNB, which provides the air interface to the user equipment. The X2 interface allows eNBs to connect, and the S1 interface enables communication with mobile management entities and signaling gateways. Multiple mobile management entities and signaling gateways can connect to a single eNB.

The radio access component of the long-term evaluation network is called the Evolved UMTS Terrestrial Radio Access Network [13]. The long-term evaluation base station known as eNodeB is part of the evolved UMTS Terrestrial Radio Access Network. eNB joins with the user equipment on the long-term evaluation Uu interface, Uu as the air interface, is based on orthogonal frequency division multiple access. Control and user planes are provided by the evolved universal mobile communications system terrestrial radio access network for the user equipment. Each is responsible for tasks relating to call setup or data transmission. The information is exchanged over a protocol stack defined in user equipment and eNB. The protocol stack is divided into the access stratum and the non-access stratum over the interface between the user equipment and the evolving packet system.

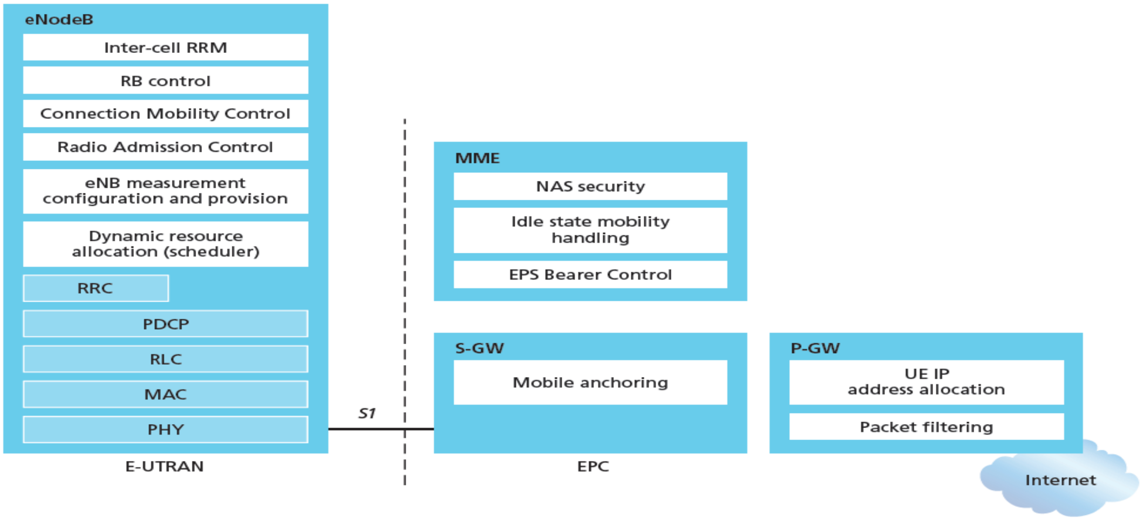


Figure 2.2. Functional splits between Evolved UMTS Terrestrial RAN and evolved packet network *[14]*

The Evolved UMTS Terrestrial RAN design is referred to as flat since there is no centralized organizer for typical user traffic. The eNodeBs are often connected over an interface called "X2," to the evolved packet network through the S1 interface, especially the S1-MME interface, to the mobile management entity through the S1-MME interface, and the signaling gateway through the S1-U interface. The "AS protocols" are the communication protocols used between eNodeBs and user devices. All radio-related tasks are carried out by the Evolved UMTS Terrestrial RAN, which may be summed up as follows:

- Radio resource management-It carries out tasks connected to radio bearers, such as radio bearer control, radio admission control, and radio mobility control, as well as dynamic resource allocation to the user equipment in both uplink and downlink.
- Header Compression – It ensures efficient use of the radio interface by compressing the internet protocol packet headers, which may otherwise be a significant load, especially for short packets like voice-over internet protocol.
- Security – The radio interface encrypts all data before it is sent.
- Connectivity to the evolved packet core: This consists of the signaling toward the mobility management entity and the bearer route toward the signaling gateway [14].

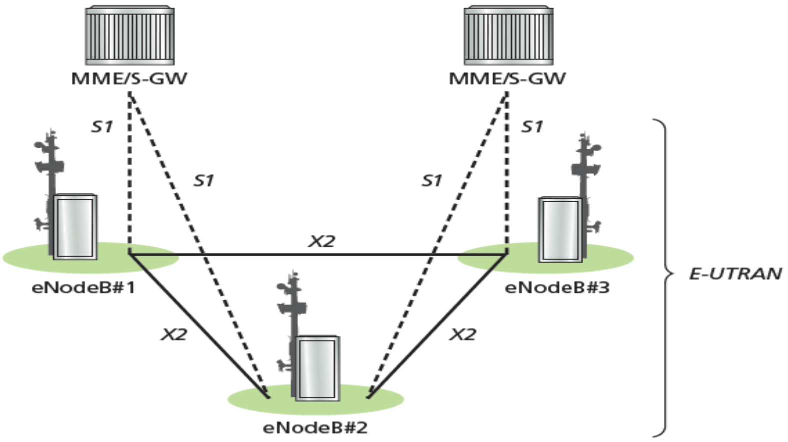


Figure 2.3. Evolved UMTS RAN network architecture *[14]*

The S1 interface that links the access network and the core network is referred to as "S1-flex". Numerous core network nodes (MME/S-GW) may serve a single topographical area, connected through a mesh network to the group of eNodeBs in that area. An area covered by a pool of mobility management entity/signaling gateway nodes is known as a pool area, as is the case for eNodeB #2 in Figure 2.3. A mobility management entity/signaling gateway pool is a collection of mobility management entity/signaling gateway nodes that serve a common region. This idea allows user equipment in the cell controlled by one eNodeB to be shared between multiple core network nodes, thereby providing a possibility for load sharing and also eliminating single points of failure for the core network nodes. The user equipment context usually remains with a similar mobility management entity as long as the user equipment is located within the pool area. The X2 interface is used to interconnect eNodeBs.

2.2.3 LTE User Equipment

The device may be small enough to fit in the palm of your hand, like a data card or a smart phone, or it may be built inside a laptop or tablet. A piece of the user equipment is the USIM, an application that is placed on the Universal Integrated Circuit Card, a removable smart card. The Universal Subscriber Identity Module derives a security key to protect, identify, and authenticating users when radio interface communication is occurring [15] [16].

- **User plane**

An internet protocol packet is tunneled between the packet data gateway and the eNodeB for transmission to a user device in an evolved packet core-specific protocol. Various tunneling protocols are applied to various interfaces.

- **Control plane**

It is a protocol stack between the user device and the mobility management entity. The mobile equipment supports many functional entities and protocols some of which are:

- Radio resource – Both the control plane and the user plane are supported. It is in charge of all low-level protocols, such as physical layers, packet data convergence protocol, radio resource control, and radio link control.
- Evolved packet system mobility management– The long-term evaluation detached, long-term evaluation active, and long-term evaluation idle states of the user equipment are all regulated by this part of the control plane. These states' transactions include procedures like monitoring area updates and handovers.
- Evolved packet system session management-It is a control plane activity that controls the activation, modification, and deactivation of bearer contexts in the evolving packet system. Bearer contexts for evolved packet systems can either be default or dedicated [15] [16].

2.3 LTE Requirements

- Mobility
    - Mobility up to 350 km/h
    - Roaming with 2G/3G networks
- Throughput
    - theoretical downlink100Mbs
    - theoretical uplink 50Mbs
    - Different multiple input multiple output configuration support
- Enhanced Multimedia Broadcast Multicast Service
    - Capability to deliver broadcast and multicast to user equipment
    - The enhanced bit rate for multimedia broadcast multicast service
    - Application registration directly by the user equipment to the application Server

- All internet protocol Architecture
    - Any to any connectivity –layer three virtual private network, layer two virtual private network
    - Standard-based interfaces
    - SP security framework

The name long-term evolution indicates requirements and targets showing an improved long-term higher data rates usage, improved system capacity, and coverage of the operators [17].

2.4 Spectrum Allocation in LTE

Time division duplex and frequency division duplex have separate frequency band allocations for long-term evaluation because they have different spectrum requirements. Pair bands are needed for the frequency division duplex spectrum, one for the uplink and one for the downlink. It is also essential that there be a suitable distance between the top of the lower band and the bottom of the higher band to permit adequate filtering. The uplink-to-downlink channel separation must be adequate to prevent the transmitted signal from entering the receiver and desensitizing it. Time division duplex transmissions only need one band; the paired spectrum is not necessary. The different long-term evaluation frequency bands are assigned numbers. Bands between 1 and 22 are for paired spectrum, or frequency division duplex, while bands between 33 and 41 are for unpaired spectrum, or time division duplex [18].

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

Table 2.1. long-term evaluation system unpaired spectrums *[18]*

Operating Band	3GPP Name	Total Spectrum	Uplink Range (MHZ)	Downlink Range
Band 1	2100	2X60MHZ	1920-1980	2110-2170
Band 2	1900	2X60MHZ	1850-1910	1930-1990
Band 3	1800	2X75MH2	1710-1785	1805-1880
Band 4	1700/2100	2X45 MHz	1710-1755	2110-2155
Band 5	850	2X25 MIZ	821-819	869-894
Band 6	800	2x10 MHZ	830-810	875-885
Band 7	2600	2X70 MHZ	2500-2570	2620-2690
Band 8	900	2X35 MHZ	880-915	925-960
Band 9	1700	2X35 MHZ	1750-1785	1845-1880
Band 10	1700/2100	2X60MHZ	1710-1770	2110-2170
Band 11	1500	2X25MHZ	1427.9-1452.9	1475.9-1500.9
Band 12	US700	2X18 MHZ	698-716	728-746
Band 13	US700	2X10 MHZ	777-787	746-756
Band 14	US700	2X10 MHZ	788-798	758-76S
Band 17	US700	2x10 MHZ	704-716	734-746
Band 18	Japan800	2X30 MHZ	815-830	860-875
Band 19	Japan800	2X30 MHZ	830-845	875-890

Table 2.2. LTE system paired spectrums *[18]*

2.5 Technologies used in LTE

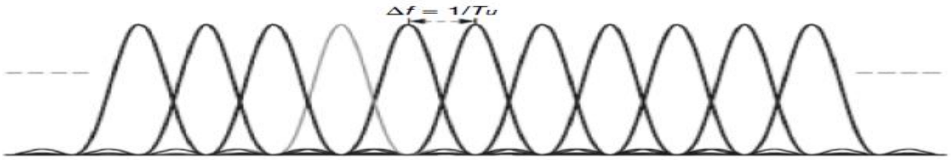
The most crucial technologies for long-term assessment that can provide high data rates across air interfaces in a constrained band are:

- Orthogonal Frequency Division Multiple Access
- Multiple-Input Multiple-Output
- Adaptive Modulation and Coding

2.5.1 Orthogonal Frequency Division Multiplexing (OFDM)

The reason orthogonal frequency division multiple access is a multi-access technology with a high efficiency of spectrum utilization is because orthogonal subcarriers do not need to protect bandwidth, support frequency link auto adaptation and scheduling, and are simple to combine with multiple input multiple outputs. It has a high peak-to-average power ratios and strict time-frequency domain synchronization requirements, though. At the transmitter, the coded and modulated data stream is split up into various sub-streams. There can be up to 1200 sub-streams, with the average being 12 (one resource block) (100 resource blocks at 20MHz bandwidth). Each stream is analyzed and transformed into the appropriate sub carrier by the inverse fast Fourier transform block 15 kHz is used for each sub-carrier in orthogonal frequency division multiplexing. The symbol time is 66.7 s, which should be significantly longer than the delay spread to prevent inter-symbol interference. One orthogonal frequency division multiplexing symbol is carried by one subcarrier. This decision is based on the average radio channel delay spread and the coherence time.

The cyclic prefix should also be longer than the anticipated delay spread to eliminate inter-symbol interference. If the symbol duration is very longer than the coherence time, the radio channel changes a lot during one symbol (Figure 2.4). The main disadvantage of orthogonal frequency division multiple access is that it has a high peak-to-average power ratio. To prevent clipping of the transmitted signal, a larger output power back-off is required the higher the peak-to-average power ratio, which in turn results in a higher adjacent carrier leakage ratio and increased error vector magnitude. The transmitter's power efficiency is decreased by high output power backoff. The single carrier orthogonal frequency division multiple access subcarrier spacing equals Δf=15 kHz and resource blocks, consisting of 12 subcarriers in the frequency domain, are defined also for the uplink [19].



OFDM subcarrier spacing.

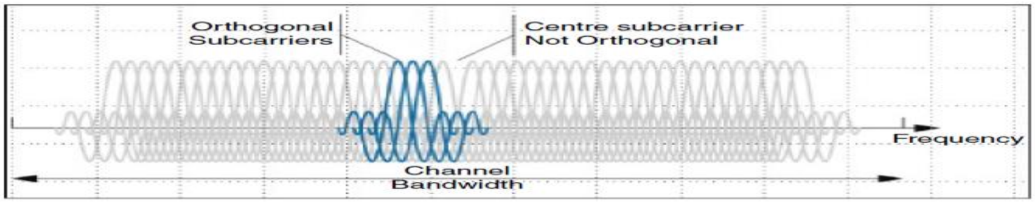


Figure 2.4. Orthogonal frequency duplex modulation *[18]*

For the downlink, orthogonal frequency division multiplexing was used since it can

- Enhanced spectral effectiveness
- Reduce inter-symbol interference effect by multipath
- Improve protection against frequency selective fading

Because it offers good multipath resistance, it is currently accepted as the preferred method for broadband wireless multipath mitigation. It is readily extended to the multiple-access strategy known as orthogonal frequency division multiple access, in which each user is provided with a particular set of sub carriers. Single carrier-frequency division multiple access, a recently created single carrier multiple access technologies, is similar to frequency division multiple access in both structure and performance. Single carrier-frequency division multiple access, which can be thought of as a specific orthogonal frequency division multiple access systems, pre-encodes the user's signal using a discrete Fourier transform. The lower peak-to-average power ratio of the transmit waveform for low-order modulations like quadrature phase-shift keying and binary phase-shift keying, which benefits mobile users in terms of battery life and power efficiency, is a definite advantage of Single Carrier- Frequency Division Multiple Access over Orthogonal Frequency Division Multiple Access. Orthogonal frequency division multiplexing signals have a higher peak-to-average ratio than single-carrier signals. This is because a multicarrier signal is the accumulation of several narrowband signals in the time domain. When this sum fluctuates between being large and little, it indicates that the peak value of the signal is significantly higher than the average value. This high positive acknowledgment with re-transmission is one of the most significant implementations challenges that orthogonal frequency division multiplex faces because it reduces the efficiency and raises the cost of the radio frequency power amplifier, one of the most expensive components of the radio. Each subcarrier in the uplink carries data about every modulation symbol broadcast, whereas each subcarrier in the downlink only carries data about one modulation symbol, this is the primary difference between the uplink and downlink transmission schemes. Finally, the uplink power level due to Single Carrier-frequency division multiple access also needs to be increased by 2-3dB to compensate for the additional noise brought on by wider dispersion [20].

2.5.2 Multiple input multiple outputs (MIMO)

It is a common feature of long-term evaluation networks and a key component of their promise to significantly increase data rates and system capacity. Numerous transmit antennas are used in systems with multiple inputs and outputs in order to send a signal on the same frequency to numerous receive antennas. In a system with multiple inputs and multiple outputs, signals from different transmit travel over a variety of pathways and arrive at the terminals at different times. Long-term evaluation systems require operators to tune their networks' multipath conditions for numerous inputs and outputs while aiming for both rich scattering circumstances and high signal-to-noise ratios for each multipath signal to achieve guaranteed throughputs. Multiple input multiple outputs build on Single Input Multiple Output (SIMO) and Multiple Input Single Output (MISO) also called receive diversity, and transmit diversity respectively. Both SIMO and Multiple input multiple output (MIMO) techniques aim to increase the signal-to-noise ratio to compensate for signal degradation.

The MIMO technology combines SIMO and MIMO techniques, improving the signal-to-noise ratio and boosting coverage and data rates. It uses well-known transmit diversity and spatial multiplexing techniques. The second method in long-term assessment of multiple input multiple outputs is beam forming. In contrast to multiple input multiple output activities, where all the transmission pathways are strongly correlated and each signal is similarly impacted by the transmission medium, beam formation typically necessitates a separate antenna layout. In this situation, the various antennas might perform as though they were a single, powerful antenna with a focused primary lobe lighting up a particular area. By attempting to concentrate the available bandwidth in the desired area, beam formation improves the signal-to-interference plus noise ratio or the transmission quality. Time Division given that the uplink and downlink are time-domain duplexed and transmitted and received signals are at the same frequency, Long Term Evolution can make excellent use of beam-forming antennas [19].

2.5.3 Adaptive Modulation and Coding (AMC)

It tries to choose the modulation and coding scheme to maximize throughput for the intended user's current radio frequency state, which is impacted by both signal fading and interference fluctuations. Fresh transmissions use modulation coding schemes based on channel quality indicator reports from user equipment, while retransmissions use the same modulation coding schemes as the initial transmission. In a specific physical resource block, eNB determines the modulation coding schemes. The third-generation partnership project protocol states that the terabyte size is determined by the modulation coding techniques and the quantity of assigned physical resource blocks [19].

Adaptive modulation and coding enable the use of various modulation schemes and channel coding rates depending on the channel conditions. For LTE, the third-generation partnership project standard has defined several Modulation Coding Schemes that provide, besides differences in the modulation patterns (quadrature phase-shift keying, 16 quadrature amplitude modulation, 64 quadrature amplitude modulation) also differences in the coding rate. The more complex symbols are supported (4 for quadrature phase-shift keying, 64 for 64 quadrature amplitude modulation, etc.) and the smaller the ratio of the coding portion, the higher the throughput per symbol but the lower the robustness of the modulation coding schemes against bad signal-to-interference-plus-noise ratio conditions. The closer to the serving base station, the higher modulation coding schemes may be used. Conversely, when the use equipment moves further away from the base station, the signal-to-interference-plus-noise ratio decreases due to increased signal attenuation and increased interference coming from neighboring cells [13].

2.6 Long-Term Evaluation Frame Structure

The following graph explains the frame structure for long-term evaluation under Time division mode Type 2 and Frequency Division mode Type 1. The main differences between the two modes are:

- Frame 0 and frame 5 (always downlink in time division duplex)
- Frame 1 and frame 6 are always used for synchronization in time division duplex
- Frame allocation for Uplink and Downlink is settable in the time division duplex

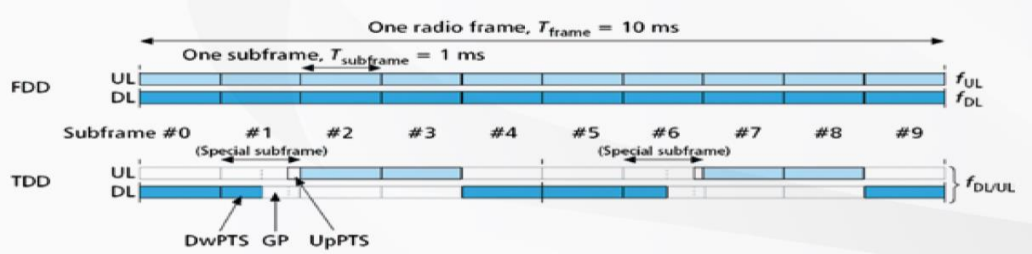


Figure 2.5 LTE Frame Structure *[20]*

The sampling rate in both frequency division duplex and time division duplex is the same and both technologies operate under a 1-ms sub-frame Transmission Time Interval and 0.5us time slot definition. The first 3 configurations (0-2) for time division duplex can also be viewed as 5ms allocation due to repetition [20].

2.7 Related work

Numerous research have been conducted on capacity planning because to its major influence on LTE coverage. Bevek Subba [21] consider the demand for a good network and data traffic is still quite high due to the steadily rising number of mobile cellular subscriptions. To do that, a dependable mobile network and optimization must be improved through efficient network planning. The early feasibility studies for the appropriate deployment of telecommunications heavily on path loss modeling. Authors focused on propagation model comparison by Math lab only they did not address by radio planning tool simulation result.

Marwa Elbagir Mohammed [8] the capacity and coverage analysis of the provided LTE radio network design was done in order to create radio planning guidelines taking into account potential network deployment in Khartoum city's density. They were used Okumura-Hata as a propagation model for the capacity and coverage planning for Khartoum city but they did not consider the other path loss models effect on the targeted area.

I. EL-FEGHI [22] in order to create a radio planning guideline taking into account potential network implementation in the city of Tripoli/Libya, a complete LTE radio network dimensioning technique, including frequency, coverage, and capacity analysis, has been carried out in this study. The authors were better to make comparison different propagation models. These studies gave this research a solid foundation, however they did not compare LTE planning between propagation models based on the intended area, where topography has a significant impact on the plan.

Chapter Three

3. Methodology

3.1. Methodology

The latest deployment of LTE cellular technology and the fundamentals of radio network planning in particular have been examined in this study using linked secondary sources of data from books, 3GPP standardized documents, prior researcher's studies, articles, and journals. Data density requirements of the customers and expected traffic in the radio access interfaces are also evaluated in the capacity analysis.

Radio Network Planning involves several stages or steps: -

- The initial phase entails gathering data for pre-planning and commencing network dimensioning, or capacity projection using simulations.
- Dimensioning and thorough planning, including the choice and application of a radio planning tool.
- Utilizing the ATOLL radio network planning tool for radio network planning simulation, approaches and models for capacity planning are taken into consideration for this thesis' design of the cellular network.

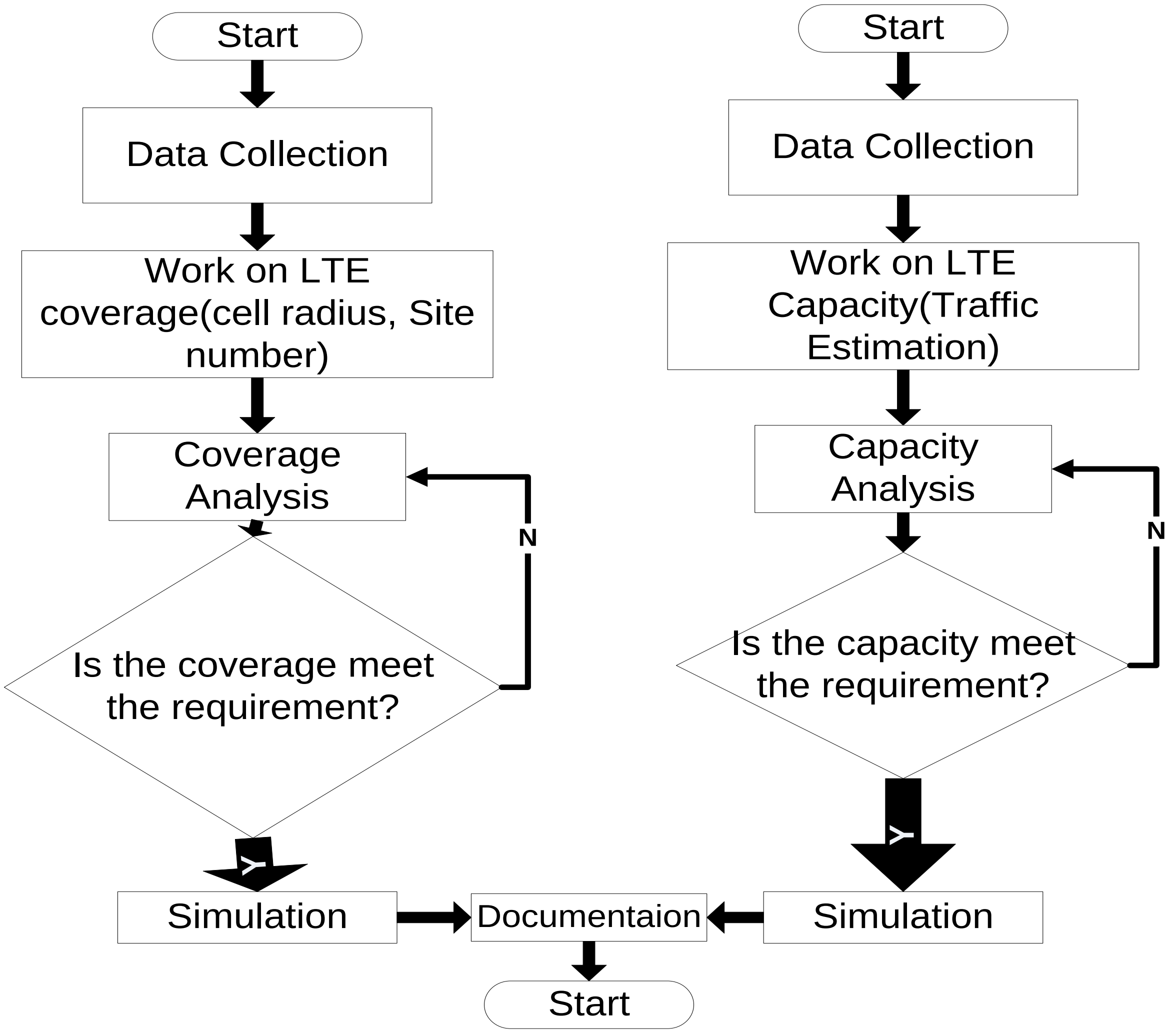


Figure 3.1. research methodology and process

3.2. Overview

The eNodeB, UE, and the interface between them are all part of the LTE radio network. Since this portion of the network is directly connected to the user equipment (UE), it would be able to communicate with the UE within a specific coverage area with a respectable level of service. Radio Frequency Planning, as it relates to cellular radio communication systems, is the process of selecting appropriate transmitter locations, allocating frequencies, and setting radio parameters for wire-free communications systems in order to provide effective coverage and capacity to meet the necessary services. While capacity refers to the network's ability to support a specific number of subscribers, coverage planning refers to the geographic footprint inside the network that delivers sufficient radio frequency signal strength to enable voice or data services [23].

Cellular radio network preparation involves a number of necessary phases, ranging from straightforward analysis to computer-aided mathematical computation and simulation, or from nominal planning to detail planning and ongoing optimization. The radio network planning process is not the only process in the overall network planning and design process; it must closely coordinate with the planning processes of the core network and the transmission network in order to install a new cellular network or expand an existing network. However, the practical issues of coverage and capacity planning in the LTE network for Gondar city are explored in this study together with the nominal and comprehensive radio network planning.

3.3. Radio Network Planning Process

The basic goal of radio network planning is to deliver a high-quality, cost-effective radio network in terms of coverage and capacity. The planning and design criteria for radio networks differ from location to location based on the dominant factor, which may be capacity or coverage [4].

The topographical coverage limit of the network will frequently be determined by one of the following factors:

- The desired availability of the network will be affected by minimum signal level and topographical noise.
- Interference is limited, in which to achieve the necessary level of performance, an increase in the level of signal is required.

For some reason, the network configuration can be determined by capacity limitations that affect the cell size and cluster size in systems with frequency reuse [13].

3.3.1. Preparation Phase

Coverage and capacity requirements have been established at this point. Some of these are the traffic profile, cell-edge throughput (CET), required QoS (quality of service), and so forth. Along with any applicable indoor penetration loss, the clutter kinds must be taken into consideration. At this point, the propagation model selection and tweaking for link budget computation are examined. The following points should be done at this phase [24].

- Coverage environment (Dense urban, Urban, Suburban, Rural)
- Capacity requirement (total number of subscribers, traffic model)

- Link budget parameters (Maximum Allowable Path Loss, Propagation model)
- Coverage requirement (defining the coverage areas and related signal strength such as Reference Signal Received Power)
- Capacity dimensioning
- Site numbers/configuration
- Cell radius

3.3.2. Nominal Planning phase

Link budget, capacity dimensioning, and radio frequency forecasting are focused on at this stage. The outcomes of these tests include coverage maps for the desired locations, supported subscriber numbers, necessary sites per clutter, and cell radius for various clutters. The reference signal received power, received signal strength indication, signal-to-interference-noise ratio, and medium access control throughput are all included in the converge maps.

The following points should be done at this phase.

- Naming sites
- Current sites information
- Allocate site/ radio frequency parameters configurations
- Forecast & Simulation [24]

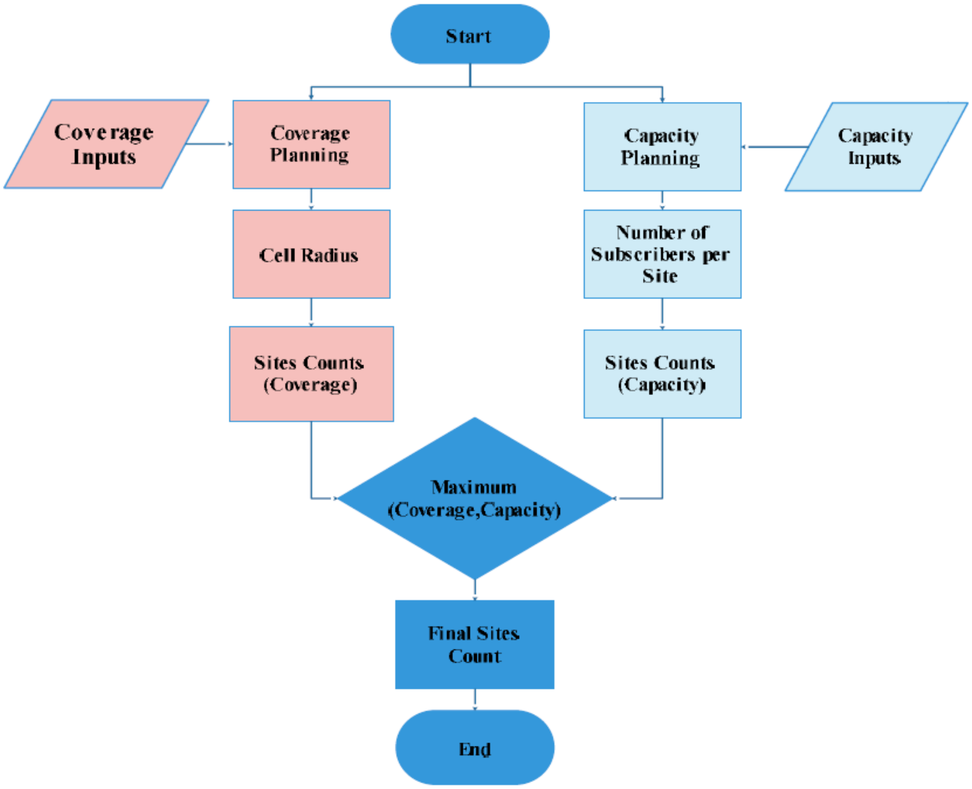


Figure 3.2. Nominal detail planning process *[17]*

3.3.3. Detailed planning process

At this stage, it is necessary to demonstrate that the planning was nominal by establishing the site coordinates, conducting site surveys, and choosing the appropriate candidates to achieve the coverage goals. In this phase, the vendor's recommendations are used to specify the neighbor list preparation and cell parameters. Finalizing azimuth, the chosen antenna type, tilt, and antenna height at this step is necessary to achieve the requisite convergence and reduce interference. There is no potential inter-carrier interference since orthogonal frequency division multiplexing is based on overlapped orthogonal carriers, unlike historical frequency division multiplexing systems. Having said that, intra-cell interference can be disregarded, unlike the universal mobile telecommunications system. The primary goal that must be achieved to increase the throughput at the cell edge is inter-cell interference. To decrease inter-cell interference, antenna tilt, height, azimuth, and inter-site remoteness must all be kept to a minimum. To achieve the convergence objective and clutter type, the antenna type must also be chosen. [24].

3.3.4. Network rollout phase

Based on the detailed planning phases, the network rollout and site-building are completed in this stage. The network acceptance should be carried out in a cluster or an entire city depending on the rollout plan.

3.3.5. Network optimizations

In this step, the network is validating the cell parameters, coverage objective, and throughput in preparation for the optimization process. Before the commercial promotion, the detailed and nominal planning results must be compared to the actual network performance. The network parameters must then be adjusted to satisfy the agreed-upon key performance indicators. The network is currently in the possession of the supplier till the operator admits the network. Modifications made during pre-launch optimization are primarily physical (e.g., antenna tilts and azimuths), however, they may also involve a few parameter changes to enhance network coverage and quality. The best network optimization may significantly reduce network interference, improve network performance and call success rates, reduce service interruption, improve data throughput, improve network capacity, and optimize network handover success rates. The final stage before the full commercial promotion is a soft launch if the operator is happy with the network quality [25] [24].

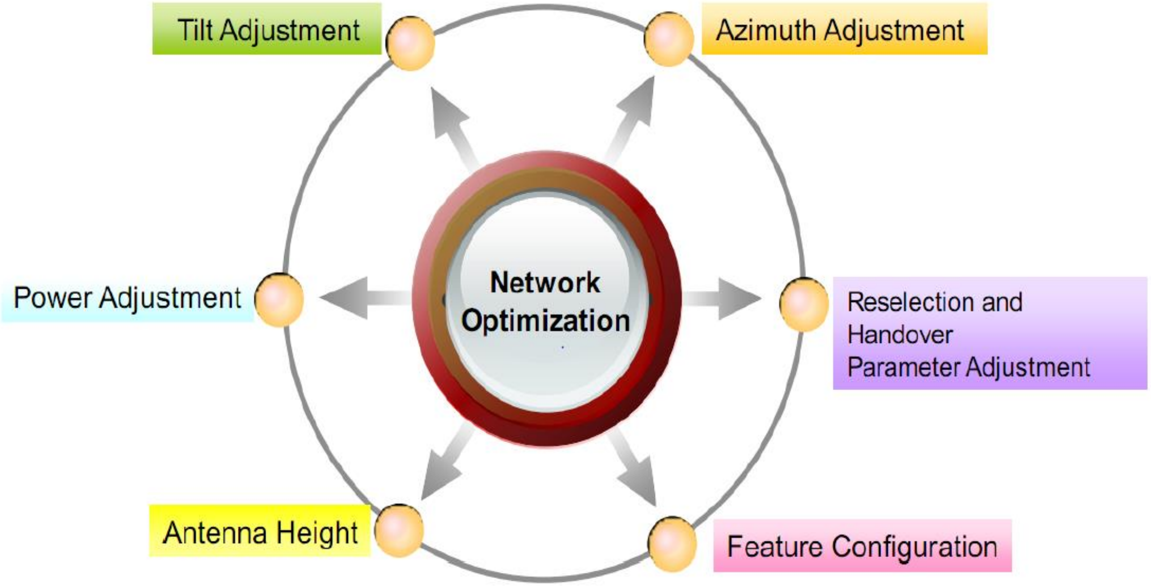


Figure 3.3. Overview of network optimization *[26]*

3.3.6. Soft launch

The network has agreed to the necessary KPIs and the service level agreement at this point in the process. Finally, it can be made available for friendly user testing or in soft launch mode. Only a select few customers are allowed to utilize the network. To validate the network, KPIs provided by the supplier's network management system, and the responses and comments from the customers are gathered. The operator will approve the network for commercial launch when network performance matches expectations and agreed-upon key performance indicators [24].

3.4. LTE coverage planning

The purpose of the planning objective is to create a network environment blueprint that will allow users at the cell edge to receive strong enough radio frequency signals. To calculate the Maximum Allowable Path Loss based on the needed Signal-to-Interference-Noise Ratio level at the receiver and take interference into account, the uplink and downlink radio link budgets are evaluated. Based on the proper propagation model for the deployment location, the cell radius for various terrain morphologies is calculated using both the downlink and the uplink Maximum Allowable Path Loss. The effective cell radius must be taken into consideration because the downlink and uplink capabilities differ to calculate the cell area and, consequently, the total number of sites from a coverage perspective. The overall procedure for planning LTE coverage is shown in Figure 3.4. The selection of suitable path loss prediction models is necessary for better coverage planning.

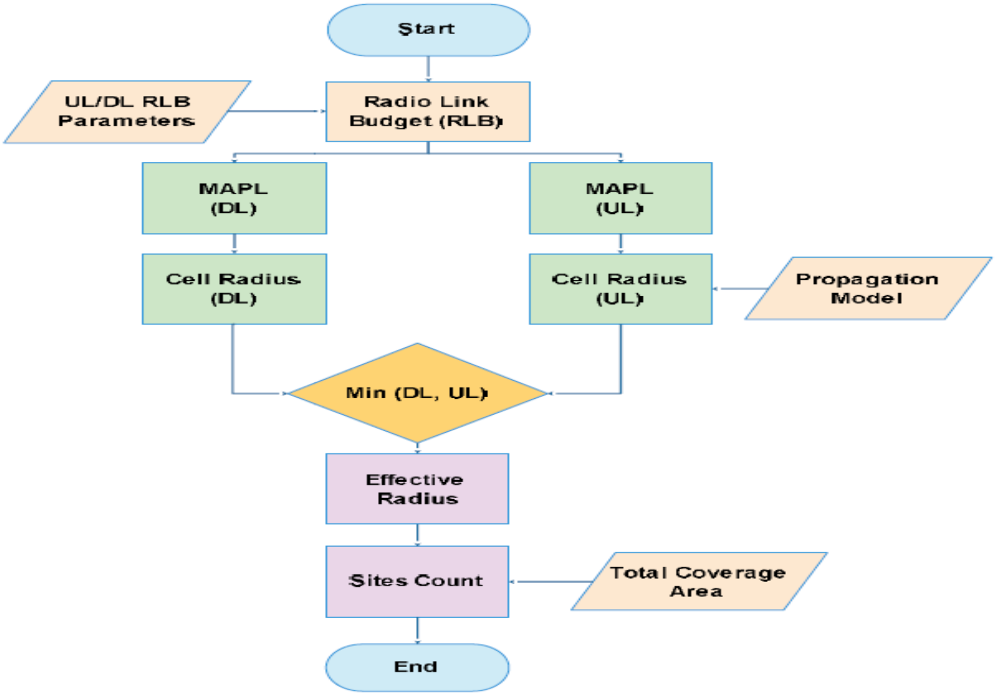


Figure 3.4. Summarized LTE coverage planning process

3.4.1. Propagation models

Propagation models have been created to anticipate path loss and communication performance. The simplest models, referred to as empirical models, are created by adjusting actual measurements to various topographies. The median path loss at a given distance in topographies distinct from the topography in which they were produced can be predicted using empirical models. Since they will predict the path loss from a single point to a distance, spanning a specific area, empirical models are known as "point-to-area models" [26]. Path loss models are essential instruments for estimating signal strength and a vital performance indicator for installing radio systems inside a wireless communication topography. Due to the signal path distance and the dynamic terrain features, the signal strength decreases as electromagnetic waves radiate through space. Signal scattering, absorption, and reflection are some of the effects of this. It is important to remember that these models are site-specific and were created using the propagation land of the relevant topography [27]. This thesis is focused on the empirical model the main empirical radio frequency propagation models that are currently used with LTE path loss prediction are briefly discussed here.

3.4.1.1. Okumura Hata model

Field strength curves were created from measurements under various system parameters early in the communications planning process. Engineers were given a tool to forecast the signal strength at a specific distance in specific terrain and clutter groups using the curves produced by Okumura in the 1960s. These graphical methods may have been straightforward to use for spot measurement in the field, but when computers' capacity for computing increased, employing them for numerous different places was no longer as effective. Hata developed an empirical formulation of Okumura's graphical methods [26].

$PL_{HATA} = A+B\log(f_c)-13.82\log(h_b)-a(h_m)+[44.9-6.55\log(h_b)]\log(R)$………………..(3.1)

Where: -

- h_b is the base station height from 30-200 m
- R is the receiver distance from 1-20km,
- f_c is the operating frequency valid in the band of 150-1500 MHz, extension 1500–2000 MHz
- h_m is the receiver height and $a(h_m)$ is the correction factor for the receiver height in different environments.

For a medium to the small city:

$a(hm) = (1.1\log(f_c)-0.7)h_m - (1.56\log(f_c)-0.8)$………………………………………(3.1a)

For a large city:

$$\alpha(h_m) = \begin{cases} 3.2(\log(11.75hm))^2 - 4.97\ if\ f_c \geq 400\ MHZ \\ 8.29(\log(1.54hm))^2 - 1.1\ if\ f_c \leq 200\ \ MHZ \end{cases}$$ …………….(3.1b)

The parameters A and B are dependent on the frequency as follows

$$A = \begin{cases} 69.55, \mathrm{f} = 150 - 1500\mathrm{MHz} \\ 46.30, \mathrm{f} = 1500 - 2000\mathrm{MHz} \end{cases}$$

$$B = \begin{cases} 26.16, \mathrm{f} = 150 - 1500\mathrm{MHz} \\ 33.90, \mathrm{f} = 1500 - 2000\mathrm{MHz} \end{cases}$$

Correction factors are also involved in suburban and rural areas. These areas are categorized as having quasi-smooth terrain and minimal clutter compared to the urban areas. This gives a reduced loss from the urban environment and should be considered. These terms given in (3.1a) and (3.1b) are subtracted from the loss in (3.1).

For a suburban area

$\mathrm{Kr}=2(\log\left(\frac{fc}{28}\right))^{2} + 5.4$ ……………………………….………..…….(3.1c)

For a rural area

$K_r = 4.78(\log(f_c))^2 – 18.33 \log(f_c) + 40.94$………………………(3.1d) [26], [28]

$PL_{HATA} = A+B \log(f_c)-13.82\log(h_b)-a(h_m)+(44.9-6.55\log(h_b)\log(R)$

3.4.1.2. COST231-Hata model

The COST-231 Hata model, an expansion of the Hata-Okumura model, is primarily used for forecasting route loss in mobile wireless systems. It is intended for usage in the 500 MHz to 2000 MHz frequency band. Corrections for urban, suburban, and rural environments are also included. Although the COST-231 Hata frequency band is outside the range of the measurements, it is extensively used for path loss prediction at this frequency band due to its simplicity and the availability of correction factors [29].

$PL=46.3+33.9\log(f) - 13.82\log(h_{Bs}) + \lfloor 44.9 - 6.55\log(h_{Bs})\rfloor \log(d) - \alpha(h_{UE}) - C_m$……… (3.2)

Where: -

- f is the frequency in MHz
- d is the distance between transmitting and receiving antennas in km
- h_{BS} is the transmitting antenna height above ground level in meters (m)
- h_{UE} is UE antenna height (m)
- C_m is parameter zero for suburban and rural environments 3dB for urban.

The parameter a(h) is mobile station antenna height correction factors it is defined for different areas as follows:

Urban areas: $a(h_{UE}) = 3.2[\log 11.75\times h_{UE})]^2 - 4.79$ ……………………………3.2a

Suburban: $a(h_{UE}) = [1.11\log(f) -0.7]h_{UE} –[1.5\log(f) -0.8]$………………….3.2b [25]

3.4.1.3. Stanford University Interim (SUI) Model

In 2007, the IEEE802.16 wireless access committee established the Stanford University Interim (SUI) concept. The model had access to the correction factors. The SUI Model is adopted on path loss predictions for frequencies below 11 GHz. Also known as IEEE 802.16, model, its propagation characteristics due to the environment are represented by the following equations. SUI has three distinct area kinds. Terrain A, B, and C. The urban area depicted in Terrain A is the area with the greatest path loss, In Terrain B, a sub-urban area is depicted as having the medium path loss. The least path loss is shown in Terrain C. The terrains and features used in the SUI model are displayed in Table 3.1. The Path Loss is calculated using:

$\boldsymbol{PL_{(SUI)}}$=**A+10ylog**$_{\mathbf{10}}(\frac{d}{d_0})$**+Xf+ Xh +S……………………………….** (3.4)

Where: -

- $PL_{(SUI)}$=$Path\ Loss, measured\ in\ dB$
- A=$Free\ Space\ Loss, measured\ in\ dB$
- d=$Transmitter\ to\ Receiver\ separation\ (km)$
- d_0=100$m\ Used\ as\ a\ Reference$
- X_f= $Correction\ factor\ for\ frequency$
- X_h= $Correction\ factor\ for\ BS$ height
- S= is the correction for shadowing in dB and its value is between 8.2 and 10.6 dB at the presence of trees and other clutter on the propagation path
- γ= $Path\ loss\ component$

Parameters	Definition
A	$20log(\frac{4\pi do}{\lambda})$
λ	wavelength in m
ϒ	a-$b * h_b$+ $\frac{c}{h_b}$ ((the path loss exponent))
S	$s = 10x\sigma_\gamma \log\left(\frac{d}{d_0}\right) + y\mu_\sigma + yz\sigma_\sigma$

Table 3.1Variables used in the SUI Model *[26]*

Where: -

h_b= $Height\ of\ Base\ Station\ (BS)$

Where a, b, and c describe the terrain, and their values are stated in the bellow table

Parameters	Terrain A	Terrain B	Terrain C
A	4.6	4	3.6
B	0.0075	0.0065	0.005
C	12.6	17.1	20

Table 3.2. Different Terrains and Parameters for SUI Model *[30]*

Where: -

Terrain A- hilly topography with moderate-to-heavy tree densities, has high path loss (urban area).

Terrain B- hilly topography with vegetation or high vegetation but flat terrain, minimum path loss (sub-urban area).

Terrain C- primarily level ground, few trees, and minimal path loss (rural area).

The typical scenario is as follows for the three prior groups: Cells are < 10 km in radius.

- Receiver antenna height in the range of 2 to 10 m.
- Base station antenna height between 15 to 40m.
- High cell coverage requirement (80-90%)

The frequency correction factor is given as:

$$X_f = 6.0 \log_{10}\left(\frac{f}{2000}\right) \ldots\ldots(3.5)$$

For terrain A and B, the correction factor of BS height is explained in the following expression

$$X_h = 10.8 \log_{10}\left(\frac{hr}{2}\right) \ldots\ldots(3.6)$$

For terrain C, the correction factor for BS height is given by the following expression:

$$X_h = 20 \log_{10}\left(\frac{hr}{2}\right) \ldots\ldots(3.7)$$

The shadowing factor is given by:

$$S = 0.65(\log_{10} f)^2 - 1.3 \log_{10} f + \alpha \ldots\ldots(3.8)$$

Where: -

$\alpha = 5.2\ dB\ for\ Terrain\ A\ and\ B\ and\ 6.6\ dB\ for\ (Terrain\ C)$

$h_r = Height\ of\ Receiver\ Antenna$ the range 1 to 10m [31] [32] [33] [34] .

3.4.2. Radio link budget parameters and formulas

The radio link budget aims to clarify the maximum allowable path loss between the transmitter and receiver for both the uplink and downlink directions. The cell radius can be estimated for various terrain topologies by comparing the maximum permissible path loss with the path loss of the relevant propagation model. The final cell overage is one of many parameters taken into account by the radio link budget. To compute all gains and losses, these variables include building penetration loss, feeder loss, antenna gain, and the margin of radio link interference. The radio link budget parameters can be divided into three categories: equipment-related, propagation-related, and parameters particular to long-term evaluation. The penetration loss, body loss, feeder loss, and background noise are propagation-related characteristics.

The manufacturer's specifications, such as those on transmitter power, receiver sensitivity, and antenna gain, serve as the equipment-related parameters. The edge coverage rate, rapid fading margin, interference margin, and type of multiple input multiple outputs employed are among the LTE-specific factors.

The key parameters are covered here.

- **ENodeB Antenna Gain**: - The clutter category and required coverage determine the best antenna gain. A high-gain antenna (18-20dBi) can be used in rural areas and on high-speed roadways to increase radio frequency coverage, whereas a low-gain antenna (15-17dBi) can be used in dense metropolitan areas and urban clutter [35].
- **eNodeB Total Transmit Power**: Customer configuration specific, referring to per TX path transmit power value. The typical value is either 43dBm (20W) or 46 dBm (40W).
- **User equipment Transmit Power**: Typical value is 23dBm +/- 2dB for a Class 3 unit. The minimum transmits power by this UE is -40dBm according to 3rd generation partnership project TS 36.101. Actual UE power can be reduced by the modulation used.
- **UE Antenna Gain**: Typical value is 0dB in the absence of any external antenna.
- **Body loss**: It shows the loss produced when a UE antenna is close to the body due to signal blockage and absorption. This has an impact on handsets specifically, depending on where the UE is located. A body loss can be neglected for UE such as a USB dongle, a mobile WiFi device, and a long-term evaluation fixed router because they are placed distant from the user's body. When an eNodeB antenna is deployed at a height of several tens of meters, body loss is unimportant because it is 0dB. For voice services, body loss is roughly 3dB, however, it is not taken into account for data services [20].
- **Feeder loss**: - It is the transmission losses brought on by radio frequency feeders, jumpers, and connectors in the line of sight between the antenna and the eNB. The feeder loss is determined by the kind, material, length, and diameter of the feeder. All losses from the feeders, jumpers and combiners will occur if the eNB is located inside the shelter and a feeder system is utilized to connect the antenna and the eNB. A typical figure for the jumper loss between the remote radio device and the antenna is 0.5dB loss. Depending on the features of the feeder and its connectors, feeder losses may be 3dB or more.

- **Equivalent isotropic radiated power**: - The equivalent isotropic radiated power, or the power that would be radiated by the idealized isotropic antenna to achieve this peak power density, is used to indicate the peak power density that is seen in the direction of the highest antenna gain. The power radiated by a directional antenna is transformed into the radiated power of an isotropic antenna by accounting for antenna gain and power at the antenna input. The equivalent isotropic radiated power per subcarrier in the downlink and uplink is determined, respectively, for the long-term assessment system as follows:

  $\mathrm{EIRP}_{DL}^{SC} = P_{eNB(SC)} + AG_{eNB} - \mathrm{FL} + \mathrm{MG}$……………….……………….(3.9)

Where: -

- $P_{eNB(sc)}$ is the power per subcarrier in the downlink
- AG_{eNB} is the antenna gain of the eNB
- FL is the feeder loss
- MG is the multiple input multiple output gain

  $\mathrm{EIRP}_{UL}^{SC} = P_{U(SC)} + AG_{UL} - \mathrm{BL}$……..………………………….(3.10)

Where: -

  - $P_{U(sc)}$ is the power per subcarrier in the UL
  - AG_{UL} is the antenna gain of the UE
  - BL is body loss [35]

- **Cell Edge User Throughput**: - The minimum net throughput requirement for single-user equipment in both uplink and downlink is known as the "Cell Edge Throughput," which is the target throughput that must be attained at the cell edge. The service that can be offered at the cell edge depends on the carrier's internet transit. It can therefore restrict the minimal Modulation and Coding Scheme that can be employed. According to the services needed at the cell edge, the network operator often provides this parameter. A common uplink speed ranges from 512 kbps to 1 Mbps, whereas DL speeds range from 1 Mbps to 4 Mbps [35].
- **Signal-to-Interference Noise Ratio**: - The threshold of the receiver's ability to demodulate the uplink signal is connected to the downlink's modulation and coding scheme. The results of the system-level simulation are used to calculate the Signal to Interference Noise Ratio values, which are then dependent on the receiver design. As a result, the parameter known as Signal to Interference Noise Ratio is vendor-specific.

- **Noise Figure**: The noise figure in dB is the ratio of the input Signal to Interference Noise Ratio at the input end to the output Signal Interference Noise Ratio at the output end of the receiver. It is a key factor to measure the receiver's performance. Therefore, the receiver sensitivity together with the noise figure should be considered to benchmark the eNB receiver performance. The noise figure depends on the bandwidth and the eNB capability. For long-term evaluation UE, the noise figure is between 6 and 8 dB [35].
- **Receiver Sensitivity**: - The signal level or threshold at which the radio frequency signal may be recognized with a particular level of quality is known as the eNodeB receiver sensitivity. This signal level, which applies to the antenna connector, must account for additional demodulation and the needed output signal quality. The following formula can be used to determine each subcarrier's receiver sensitivity.

$R_{XS(SC=}$Signal to interference plus noise ratio + NF + 10log(sc) + NP………(3.11)

Where: -

- Signal to interference plus noise ratio is the threshold of the receiver that can demodulate the signal
- NP is the density of the thermal white noise power, which is -174 dBm/Hz
- SC is the subcarrier and it is 15 KHz in LTE
- NF is the noise figure in dB [24] [16]

- **Penetration Loss**: - According to the penetration loss, radio signals that are obstructed by a building from an interior terminal to a base station and vice versa would fade with time. The type of clutter and the type of structures in the desired coverage region determine the penetration loss.

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

Table 3.3. Penetration loss range for different clutters *[35]*

- **Shadow Fading Margin**: Indicates the fading due to obstruction-like building. To minimize the effect of shadow fading and ensure a certain probability of edge coverage needs some allowance. This allowance is called the slow fading margin or shadow fading margin.

Standard slow fading deviation is used to calculate the slow fading difference and indicates the radio signal intensity distribution at different test points at the same distance from the transmitter. The standard deviation of slowly fading varies from 5dB to 12dB depending on the clutter type [20].

Clutter Type	The standard deviation of slow fading (dB)
Dense urban	10
Urban	8
Suburban	6
Rural	6

Table 3.4. Typical example of standard deviations in slow fading *[20]*

The slow fading margin can be obtained based on the cell edge coverage probability and standard deviation of slow fading.

The formula for calculating the edge coverage probability is as follows:

$$E_{cp}=1-Q\left(\frac{F_M}{std_{sf}}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.12)$$

$$F_M=\lfloor Q^{-1}(1-E_{cp})\rfloor \times std_{sf}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.13)$$

Where: -

- Ecp =cell Edge coverage probability
- Fm =fading margin,
- STDsf =Standard deviation of slow fading

Based on the above-explained main link budget parameters and the common parameters, the maximum allowable path loss will be calculated as the difference between the equivalent isotropic radiated power and the overall loss. Table 3.4 demonstrates the link parameters and the formulas used for both uplink and downlink link budget calculation by categorizing parameters as general parameters, transmitter side parameters, receiver side parameters, and clutter parameters. In the simulation and discussion part, this table use calculates the cell radius and then the number of eNodeBs for coverage analysis.

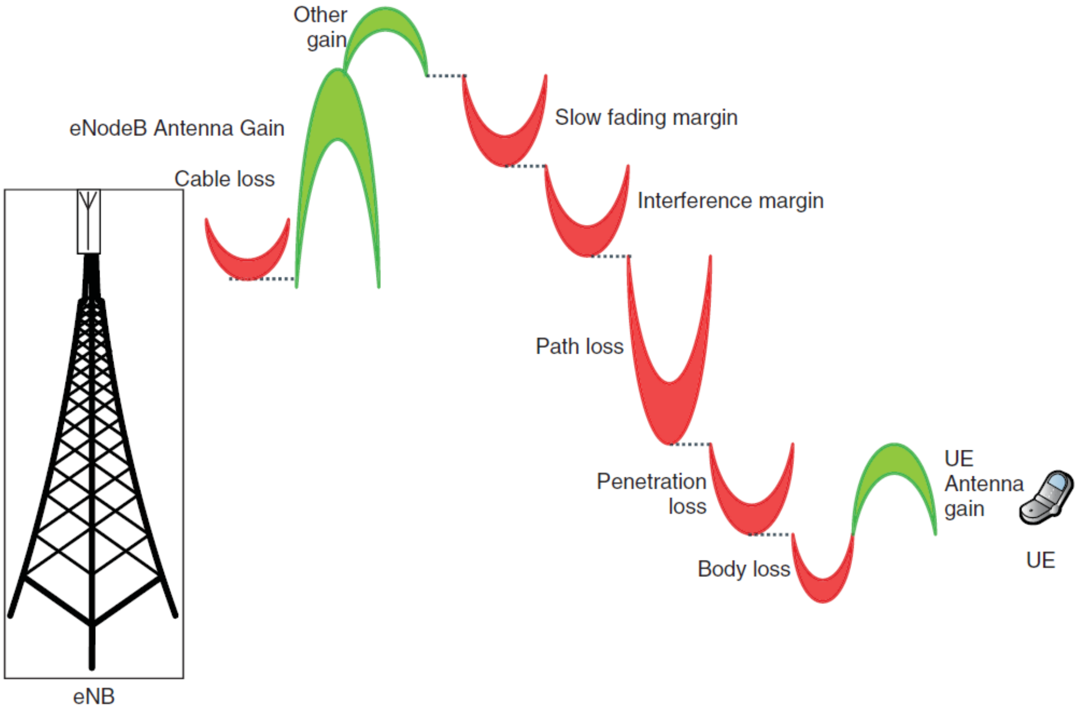


Figure 3.5. Downlink budget estimation *[36]*

LTE Radio Link Budget	
Parameters	Downlink/Uplink Budget Variable
General Parameters	
Morphology	DU, U, SU, RU
Data Channel Type	PDSCH/PUSCH
Duplex Mode	FDD
User Environment	Indoor, Outdoor
System Bandwidth (MHz)	LTE Bandwidths
MIMO scheme	2x2/ 1x2
Cell Edge Rate (kbps)	1024/512
Transmitter(eNB/UE) Side Link Budget Parameters	
Max Total Tx Power (dBm)	A
Allocated RB (Radio Resource)	B
RB to Distribute Power	C
Subcarriers to Distribute Power	D=12*C

Subcarrier Power (dBm)	E=A-10*Log10(D)
Transmitter Antenna Gain (dBi)	G
Transmitter Cable Loss (dB)	H
Transmitter Body loss (dB)	I
EIRP per Subcarrier (dBm	J=E+G-H-I
Receiver (UE/eNB) Side Link Budget Parameters	
Signal to interference plus noise ratio(dB)	K
Receiver Noise Figure (dB)	L
Receiver Sensitivity (dBm)	M=K+L-174+10*Log10(15KHz)
Receiver Antenna Gain (dBi)	N
Receiver Cable Loss (dB)	O
Receiver Body loss (dB)	P
Interference Margin(dB)	Q
Minimum Signal Reception Strength(dBm)	R=M-N+O+P+Q
Clutter Link Budget Parameters	
Indoor Penetration Loss (dB)	S
Shadow Fading Margin (dB)	T
Maximum Allowable Path Loss (MAPL)	
MAPL (dB)	U=J-R-S-T

Table 3.5. LTE Radio Link Budget DL/UL Parameters [30] [16]

3.4.3. Cell area and site count

Once the maximum allowable path loss value is calculated for both uplink and downlink, the next step in the coverage planning is to determine the cell radius by using the appropriate propagation model. After deciding the cell radius, sites number and sites coverage areas are calculated based on-site configuration by the equation below. Cell radius (R) the distance between transmitter and receiver in kilometers.

$R=10^{\gamma}$……………………………………………………………………(3.14)

$\Upsilon=\frac{MAPL-46.3-33.9\log(f)+13.82\log(hBS)+\alpha(hUE)+c_m}{44.9-6.55\log(hBS)}$…………..(3.15)

Where :-

- $a(hUE)=3.2[\log(11.75*hUE)]^2-4.79$
- Cm = constant parameter
- $a(h_{BS})$ antenna correction factor
- h_{BS} is eNodeB height and UE is user equipment

Coverage based site count

For 3 sector configuration sites

Site coverage area $=\frac{9}{8}\times\sqrt{3}\ \times R^2$…………………………..(3.16a)

Inter-site distance $d=\frac{3}{2}\times R$ …..……………………………..(3.16b)

Cell area= $\frac{site\ coverage}{3}$…..…………………………………(3.16c)

For 2 Sectors configuration site

Site Area $(A_{S2})=\sqrt{3}\ [R_2]^2$…………………………………………(3.17)

For Omni-directional configuration site

Site coverage area= $\frac{3}{2}\times\sqrt{3}\ \times R^2$ ……………………...……(3.18a)

Cell area= site coverage area……………………..…………………..…….(3.18b)

Inter-site distance $d=\sqrt{3}\times R$…………………………….…..……..…(3.18c)

Required sites number= $\frac{Area\ to\ be\ covered}{Single\ site\ coverage\ area}$……..…………(3.19) [4] [25]

capacity based sites count can be calculated as follows:-

capacity based site count= $\frac{\text{total subscriber supported in the network}}{\text{subscriber supported per site}}$ ………..(3.20)

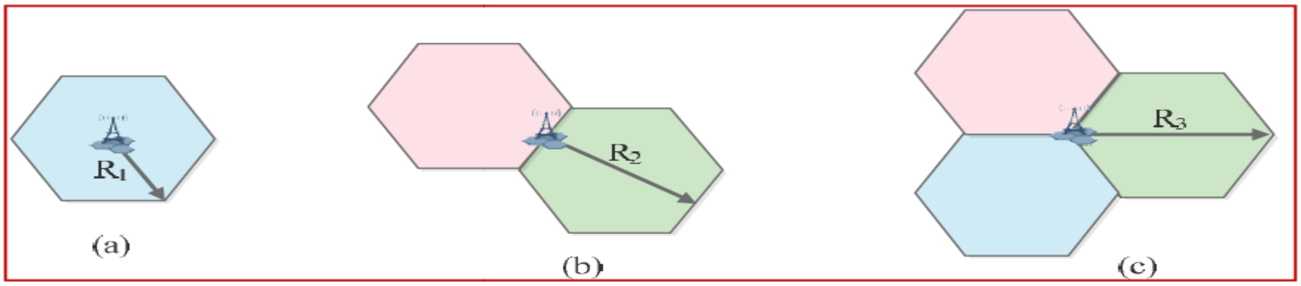


Figure 3.6 (a) omnidirectional, (b) 2-sector, (c) 3-sector *[17]*

3.5. LTE capacity planning

It is determined whether the given sites count can support the projected user's capacity after the cell size and sites count from the coverage forecast have been evaluated. The definition of capacity given by Shannon, which reads as follows: "Capacity is the greatest feasible set of rates in multiple access channels with an arbitrarily small likelihood of mistake," is one that is frequently used. In reality, the aggregated data rate or total of transmitted data rates is used because this statistic serves as a performance bound. The maximum aggregated data rate subject to the requirement that the average experienced quality of all system flows should be met in accordance with a specified target could be referred to as the system capacity [20].

3.5.1. Capacity dimensioning process

The goal of LTE capacity dimensioning is to determine the network's capacity for packet switch throughput depending on each user's available bandwidth and channel conditions. The long-term evaluation capacity dimensioning process consists of the following steps [25] [35] [22]:

1. To determine the intended capacity, use the traffic profile, the following inputs make up the traffic profile:
    a) Number of LTE subscribers
    b) Type of services
    c) Traffic usage per subscriber(kbps)
    d) Activity factor for the services

The average throughput per subscriber based on traffic usage in the month ρ (Gigabytes) is calculated using:

$$\Omega(\text{Kbps})=\rho\times\alpha\times K\left(\frac{8bit\times 10^{6}}{30\ day\times 24\times 60\times 60}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\quad(3.21)$$

Where: -

- Ω(Kbps) is average throughput per subscriber in busy hour (uplink + downlink)
- α is traffic ratio of busy hour to the traffic of the whole day
- k is busy hour convergence ratio
- ρ is the Traffic Usage in Month per User

The total average throughput per subscriber during busy hour is calculated by manipulating the average throughput per subscriber for each service type specified by the operator, as follows:

$\Phi(Kbps)$= Σ(Ω(Kbps) × Usage ratio of the services…………………………..…… (3.22)

Where: -

- $\Phi(Kbps)$ is the total throughput per subscriber in a busy hour (uplink + downlink) in Kbps
- Usage ratio of each service/package to the total services/package.

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

$\Gamma(Kbps)$ = $\Phi(Kbps)$× $UL\ traffic\ ratio$…………………………………… (3.23)

η $(Kbps)$ = $\Phi(Kbps)$× $DL\ traffic\ ratio$…………….……………………….(3.24)

Where: -

- Γ $(Kbps)$ is the average throughput per subscriber for uplink
- η $(Kbps)$ is the average throughput per subscriber for downlink
- Φ $(Kbps)$ is the total throughput per subscriber in a busy hour (uplink + downlink) in Kbps

Average site throughput is an important factor in LTE dimensioning. In this section, we use the vendor approach to get the average throughput per site. Then the peak and average throughputs per site for both UL and DL is be calculated as follows.

δ $(Mbps)$ = (DRE/sec × BPRE × MIMO × coding rate) ………………………..……..(3.25)

Where: -

- δ $(Mbps)$ is the peak throughput per site per modulation
- BPRE is bit per resource element
- DRE/sec 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 QUADRATURE PHASE-SHIFT KEYING1/2 is 1/2, and the volume-coding rate of 16QAM3/4 is 3/4

The average throughput per site for uplink and downlink formulated as:

λ $(Mbps)$ = Σδ(Mbps) × Traffic ratio of UL……………………….………(3.26)

μ $(Mbps)$ =Σδ (Mbps) ×Traffic ratio of DL………..………………..………..(3.27)

Where:

- λ $(Mbps)$ is the average throughput per site for uplink
- μ $(Mbps)$ is the average throughput per site for downlink

2.Calculate the number of eNB/sectors needed to cater for the total traffic demand. From equation 3.23 to 3.27, maximum subscriber number per site is calculated as follows:

Max sub No. per site= $\frac{Average\ throuput\ per\ site}{Average\ throuput\ per\ subsriber}$

Max subscriber no. per site UL=$\frac{\lambda(Mbps)}{r(Mbps)}$……………………..…..(3.28)

Max subscriber no. per site DL=$\frac{\mu(Mbps)}{\eta(Mbps)}$……….………………(3.29)

Where: -

Max Sub.No.per site = maximum number of subscribers per site.

3.Estimate the average sector throughput. This can be obtained via simulation or based on field measurement. Finally, the total site based on the capacity required, taking the minimum number of subscribers from uplink and downlink or from equation 3.28 and 3.29 is calculated as:

Total site number=$\frac{total\ sub\ the\ area}{No\ sub\ per\ site}$………………………………..………….(3.30)

3.6. Pre deployment optimization

The pre-optimization and ongoing optimization of the LTE network occur both before and after the network is launched. Results of network optimization efforts and their intensity have a direct impact on the capacity and stability of the network in the future. In order for the network performance to meet predetermined thresholds or targets for key performance indicators (KPIs) set in advance with the operator, optimization is required. During pre-launch optimization, it is usual practice to organize sites into clusters and then optimize those clusters to meet agreed-upon KPIs. Improved network performance, call success rates, reduced service interruptions, increased data throughput, improved handover success rates across the board, and increased network capacity can all be attributed to effective network optimization. Pre-launch optimization, in general, concentrates on "course" network tuning, whereas counter-based optimization concentrates on "fine" network tuning i.e., parameter based [19].

3.6.1. Optimization Target

The following performance must be taken into account when performing optimization.

- **Coverage**: - Cell range, overlapping, overshooting, RSRP and signal to interference plus noise ratio distribution, downlink/uplink loading, and downlink/uplink cell edge bit rate are all examples of coverage optimization items.

- **Interference**: - To deliver a high-quality air interface, interference must be kept to an acceptable degree in the cell's service area. The performance of the same frequency network benefits greatly from the improvement of the power control parameters. Various circumstances include adjusting the power control parameters, such as the control channel power control and traffic channel power control, to lessen system interference.
- **Mobility**: The air interface in a cell is of good quality when it comes to handover behavior, and no needless handovers occur. By changing the handover parameter, mobility optimization seeks to make handover areas more fair. In the control handover area, excessive reference signal levels may interfere more with neighboring cells and excessively low levels will likely result in session loss and access failure.
- **Capacity**: PRB (control channels included) use, power and spectrum consumption, number of concurrent EPS bearers, UL RSSI, PDCCH format and S1 utilization, traffic distribution, and intra- and inter-LTE load balancing are all items that can be optimized for capacity.
- **Quality**: Quality optimization items include channel quality indicator MODULATION CODING SCHEMES, RSRQ, BLER, MIMO, Tx diversity, UE Rx diversity, eNB power, UE power, packet loss, jitter, and so on [19].

3.6.2. Site’s location rearrangements

Radio network planning and optimization (RNPO) technologies are used to position the initial sites in green field scenarios (new deployment) in order to determine the initial sites footprint. These early sites' footprints could be placed in inappropriate locations, including next to rivers, roadways, or other off-limits locales. These problematic site locations should be changed as part of the first optimization, if not to practical locations, then at least to positions that can be confirmed during the site survey.

3.6.3. Initial antenna parameters adjustment

Antenna characteristics like azimuth and tilt are applied consistently across all of the sites in the target area during the first green-filed planning. These parameters must be modified based on the geography of the target network where the RNPO tool's coverage study was performed. The RNPO tool can be used to make these adjustments for the entire network or manually, treating each site separately. The highest of the two will be used for further analysis and prediction, taking into account the clutter circumstances in the chosen area. To do this, the parameters are simulated using a network-planning tool to get the ideal value. Due to the chosen area's terrain, we may encounter holes during forecast because the sites count is based only on mathematical calculations that assume the area to be geographically flat. Thus, until the best forecast result is attained, per-deployment optimization, such as changing the antenna's height, azimuth, or tilt, moving the site's beginning location, or adding more sites, will be taken into consideration. The necessary criteria are established for both coverage and capacity in the following chapter, Chapter 4. Utilizing the RNPO tool, coverage prediction and capacity evaluation are performed based on the maximum sites count. Additionally, the analysis and interpretation of simulation findings are covered in order to assess the outcome in light of the prerequisites.

Chapter Four

4. Simulation, Results Analysis, and Discussions

4.1 Overview

Network simulation is a practical and scientific recent method used to analyze a complex system by understanding the character of the network. Network simulator software forecasts the behavior of a network. It permits the designer to assess new networking protocols and modify the existing protocol. It controls the behavior of the network by calculating the interactions of different network entities using several mathematical formulas. Under different situations, the features of the environment can be altered in a controlled manner to evaluate how the network would behave. In simulators, the computer network is typically modeled with devices, links, applications, etc. and the performance is then analyzed [36].

In this thesis, simulation is used to examine the radio frequency planning of long-term evaluation networks for the target area (Gondar city) by using ATOLL Planning Tool. In addition, the investigation/analysis and interpretation of simulation outcomes are discussed to evaluate the result based on the given requirements. The long-term evaluation radio network planning simulation is intended to carry out propagation modeling, link budget calculation, capacity estimation, and coverage evaluation. To this end, the simulation result of actual planning and prelaunch optimization is performed using ATOLL software.

4.2 Target Network Requirements

In this study one of the main cities in the Amhara region city, Gondar is selected to study the coverage and capacity characteristics of the long-term evaluation network. The morphology of the city is urban and has a total area of 22.46 km2 with mountainous topography. In this city, there are different hotspot areas including hotels, government offices, universities, and different historical museums like Fasil Ghebbi, Debre Berhan Selassie, etc. Thus, the choice of a long-term evaluation network for this city is the right decision as users in this area would require considerable Internet speed and connectivity. In long-term evaluation network planning, the target radio network should compromise between capacity and coverage. The coverage aim should achieve the business requirements of the operator by reducing the expenses; on the other hand, the target network should also be assessed to know how the network is capable to meet the present and future capacity requirements.

4.2.1 Coverage Requirements

- **Frequency Band**

Band three (1800 MHz) is chosen to use in this research. This band is the most preferable LTE band as it can be used for nationwide coverage with dense urban, urban, and suburban convergence. Some of the main merits of this choice are: -

- The coverage area is about 2x larger than LTE 2.6 GHz with better indoor coverage;
- 35% improvement in cell edge throughput compared to LTE 2.6 GHz;
- Availability of LTE terminals in this band
- Have a wide spectrum (2x75MHz for FDD), offering the potential to support a very high-performance LTE service. Capacity can be particularly useful because LTE1800 can reuse existing infrastructure and can increase capacity without requiring new cell sites.
- Enhanced user experience by providing a strong signal that travels well over distance and in buildings, improving indoor data rates and battery life of LTE-connected devices [25] [37].

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

Over the cell-specific Reference Signals within the measurement bandwidth and during the measurement period, the UE measures RSRP. A measurement of signal strength that reflects cell coverage is the RSRP. It is described as the linear average of the power contributions made by the resource element that transmits cell-specific Reference Signals inside the bandwidth of the measured frequency. The Reference Signals transmitted on the second antenna port may also be utilized for RSRP determination if the UE can reliably identify them as being transmitted. Normally, the Reference Signals transmitted on the first antenna port are used for RSRP determination. The total RSRP must be at least as big as the RSRP of any one of the individual diversity branches if the UE is using receive diversity. The average received power of one reference received resource element is known as the RSRP. The power of several resource elements utilized to transmit the reference signal is measured by UE, but an average is calculated instead of a total. A range of -44 to -140 dBm is reported [38].

In this thesis, the RSRP is assumed to be greater than or equal to -133 dBm in order to have a stronger signal over the selected area.

- **Area Coverage Probability**

This value is used to calculate the intended network's percentage coverage of the target area. In this analysis, it is expected that 90% (my assumption) of the target area will be covered. For the aforementioned value of RSRP, the target network would thus cover 90% of the chosen area.

4.2.2 Capacity Requirements

Cell-edge throughput in downlink and uplink design targets for cell-edge throughput in the downlink and uplink are 1024 kbps and 512 kbps, respectively. The target network offers 1 Mbps wherever, at any time in the target deployment area, from the downlink perspective.

- **Total number of subscribers**

The number of subscribers is highly relevant input for capacity planning in determining the sites count, in gondar have 94013 LTE subscriber customers as of Jan 2023. In addition, to accommodate additional subscribers, the growth rate of the subscriber number should be forecasted before starting the actual network planning. In order to show the contribution of all such factors to successful network capacity planning, the total population of Gondar city should be explained. According to Amhara Region Plan commission.

Age Group	Total population of Gondar city in the year 2022	Total population of Gondar city in the year 2025
0-19	203428	253572
20-60	205404	245804
60-80+	23358	54384

Table 4.1. Assumption number of subscriber

4.3 Coverage Planning

The coverage planning, as it was said in Chapter 3, evaluates the downlink and uplink radio link budget to obtain the maximum allowable path loss to determine the cell radius. Setting the radio link budget parameters value is the first step in coverage planning, which is a part of nominal planning. The cell radius is determined using the radio link budget parameters and the appropriate propagation model.

4.3.1 Radio Link Budget

Link budget is utilized to determine the maximum signal attenuation that can occur between the mobile antenna and the base station antenna for both uplink and downlink .With an appropriate propagation model, the maximum path loss enables the estimation of the maximum cell range [39].The RLB parameters for the DL and UL are dealt with individually in this section. Tables 4.2 and 4.3 illustrate the assumed and computed values for DL and UL, respectively, based on the definitions and formulas in Chapter 3. However, SINR and Shadow fading margin has received special attention because they play an important role in achieving cell edge throughput and cell edge coverage probability requirements, respectively.

4.3.1.1 Signal to Interference Noise Ratio calculation

SINR values are derived from the system and link-level simulation results, as explained in Chapter 3. SINR values are vendor specific because they are reliant on receiver design. However, in this study, the SINR values for both UL and DL are calculated using a modified Shannon capacity model using the following assumptions and formula. Assumptions:

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

Formula:

$$\text{TP}=\text{BW}\times\text{M}\times\text{A}\times\log_2\left(1+\frac{SINR}{B}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.1)$$

$$\text{TP}=N_{PRB}\times BW_{PRB}\times\text{SE}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.2)$$

Where:

- TP: - Cell edge throughput
- BW: -Bandwidth in terms of PRBs
- M: Number of data streams
- A and B: Constant factors that are proportional to the number of antennas and the physical layer performance.

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

Table 4.2. SINR calculation constant factors A, B, & M *[40]*

The SINR values for UL and DL were found to be -1.83 dB and -3.06 dB, respectively, based on the formula in equation 4.2 and the assumptions provided above, as shown in Table 4.2:

Parameters Descriptions	Variable	DL	UL
Allocated RB (10% Radio Resource)	B	10	10
Factor A	From table 4.2 FA=M*A FA(DL)=2*0.42, FA(UL)=1*0.62	0.84	0.62
Factor B	From table 4.2 FB==M*B	0.84	1.80
PRB bandwidth (MHz)	PRB	0.18	0.18
Rate per PRB (Mbit/s)	RpP=CER/B	0.1	0.05
Required spectral efficiency (bit/s/Hz)	SE=RpP/PRB	0.56	0.28
SINR (linear)	SL=FB*(2^(SE/FA)-1)	0.49	0.66
SINR (dB)	K	-3.06	-1.83

Table 4.3. SINR to achieve cell edge throughput *[40]*

4.3.1.2 Shadow fading margin Calculation

As illustrated in Chapter 3, Equation 3.13, the slow fading margin can be calculated using a Q function derived from the cell edge coverage probability and slow fading standard deviation. Because the chosen location is urban, the standard deviation of slow fading will be 8 dB in this study, as shown in table 3.4, and the shadow fading margin will be 8 dB under the assumption of 90% cell edge coverage probabilities.

LTE Down Link Radio Budget		
Parameters	Variable	Values
General Parameters		
Morphology	Urban	
Data Channel Type	PDSCH	
Duplex Mode	FDD	
System Bandwidth (MHz)	20	
MIMO Scheme (MS)	2x2	
Cell Edge Rate (kbps)	1024	
Transmitter Side Link Budget: eNodeB		
Max Total Tx Power (dBm)	A	46
RB (10% Radio Resource)	B	10
RB to Distribute Power	C	100
Subcarriers to Distribute Power	D=12*C	1200
Subcarrier Power (dBm)	E=A-10*Log(D)	15.2
Transmitter Antenna Gain (dBi)	G	17
Transmitter Cable Loss (dB)	H	0.5
Transmitter Body loss (dB)	I	0
EIRP per Subcarrier (dBm)	J=E+G-H-I	31.7
Receiver Side Link Budget: UE		
SINR (dB)	K	-3.06
Receiver Noise Figure (dB)	L	8
Receiver Sensitivity (dBm)	M=K+L-174+10*Log(15KHz)	127.30
Receiver Antenna Gain (dBi)	N	0
Receiver Cable Loss (dB)	O	0
Receiver Body loss (dB)	P	0

Interference Margin(dB)	Q	3
Minimum Signal Reception Strength(dBm)	R=M-N+O+P+Q	-124.3
Clutter Link Budget Parameters		
Indoor Penetration Loss (dB)	S	15
Shadow Fading Margin (dB)	T	8
Maximum Allowable Path Loss (MAPL)		
MAPL (dB)=	U=J-R-S-T	133

Table 4.4. LTE Downlink radio link budget

LTE Uplink Radio Budget		
Parameters	Variable	Values
General Parameters		
Morphology	Urban	
Data Channel Type	PUSCH	
Duplex Mode	FDD	
System Bandwidth (MHz)	20	
MIMO Scheme (MS)	1x2	
Cell Edge Rate (kbps)	512	
Transmitter Side Link Budget: eNodeB		
Max Total Tx Power (dBm)	A	23
RB (10% Radio Resource)	B	10
RB to Distribute Power	C	3
Subcarriers to Distribute Power	D=12*C	36
Subcarrier Power (dBm)	E=A-10*Log(D)	7.44
Transmitter Antenna Gain (dBi)	G	0
Transmitter Cable Loss (dB)	H	0
Transmitter Body loss (dB)	I	0
EIRP per Subcarrier (dBm)	J=E+G-H-I	7.44
Receiver Side Link Budget: UE		

SINR (dB)	K	-1.83
Receiver Noise Figure (dB)	L	8
Receiver Sensitivity (dBm)	M=K+L-174+10*Log(15KHz)	-126.13
Receiver Antenna Gain (dBi)	N	18
Receiver Cable Loss (dB)	O	0.5
Receiver Body loss (dB)	P	0
Interference Margin(dB)	Q	3
Minimum Signal Reception Strength(dBm)	R=M-N+O+P+Q	-140.63
Clutter Link Budget Parameters		
Indoor Penetration Loss (dB)	S	15
Shadow Fading Margin (dB)	T	8
Maximum Allowable Path Loss (MAPL)		
MAPL (dB)=	U=J-R-S-T	125

Table 4.5. LTE Uplink radio link budget

The MAPL in the UL path is 125dB, whereas the MAPL in the DL path is 133dB, according to the two tables above. We can see that the downlink path loss is more than the uplink path, indicating that the region covered by the eNodeB antenna radiation is greater than the area covered by the UE antenna, implying that the downlink direction can provide more coverage.

4.3.1.3 Propagation Model Selection

As a result of numerous studies and comparisons of various propagation models in LTE network systems, several software tools have been used to measure and simulate various propagation models. The behavior of a signal as it is transmitted from the transmitter to the receiver is described by radio propagation models. Depending on the operating frequency and the local climatic and environmental factors, it often correlates the path loss to the distance between the transmitter and receiver [39].

Two propagation models COST 231-Hata and SUI, were chosen for comparison in this work. Atoll and MATLAB is used to compare propagation models based on path loss, antenna height, and transmission frequency. In comparison to the two models, the SUI has shown better results than COST 231 Hata.

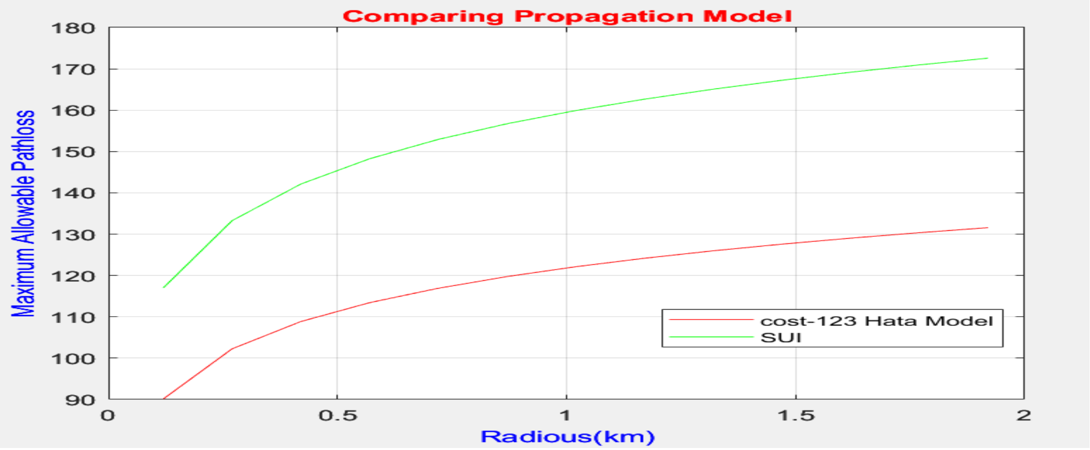


Figure 4.1 Propagation model comparison by MATLAB

4.3.1.4 Coverage Based Sites Count

We can determine the cell radius dictated by both the UL and DL path using the specified propagation model and the UL and DL MAPL the effective radius will be the minimum of the radiuses discovered in the UL and DL paths, as stated previously in Chapter 3. Assume that the eNodeB and UE antenna heights are 40 and 2 meters, respectively. As per the COST 231 Hata model path loss formula in Equation (3.2) be used to compute the cell radius in the UL and DL.

$R=10^{\gamma}$

$d_{UL}=10^{[PL_{UL}-46.3-3-33.9*\log(f)+13.82*\log(h_{BS})+3.2*((\log(11.75*\log(h_{UE})))^2+4.97)/(44.9-6.55*\log(h_{BS}))]}$

$d_{UL}=10^{[123.71-46.3-3-33.9*\log(f)+13.82*\log(h_{BS})+3.2*((\log(11.75*\log(h_{UE})))^2+4.97)/(44.9-6.55*\log(h_{BS}))]}$

$d_{UL=}0.7$km

$d_{DL}=10^{[PL_{DL}-46.3-3-33.9*\log(f)+13.82*\log(h_{BS})+3.2*((\log(11.75*\log(h_{UE})))^2+4.97)/(44.9-6.55*\log(h_{BS}))]}$

$d_{UL}=10^{[129.9-46.3-3-33.9*\log(f)+13.82*\log(h_{BS})+3.2*((\log(11.75*\log(h_{UE})))^2+4.97)/(44.9-6.55*\log(h_{BS}))]}$

$d_{DL=}1.1$km

As a result, the effective radius (R_{ef}=Min (d_{UL}, d_{DL})) becomes 0.7 Km. Table 4.6 summarizes the cell radius for the UL and DL paths, as well as the effective cell radius for computing the coverage-based sites count.

Parameter	UL	DL
eNodeB Antenna Height (m)	40	
UE Antenna Height (m)	2	
Frequency (MHz)	1800	
MAPL (dB)	125	133

Cell Radius (Km)	0.7	1.1
Effective Cell Radius ($R_{ef)}$ (Km)	0.7	

Table 4.6. Cell radius summary (Uplink & Downlink) by Cost 231 Hata Model

Now by assuming that all eNodeBs are three sectored sites, the site area and the total number of eNodeB are calculated by using equations (3.16a) and (3.19) respectively as follows.

Site coverage area=$\frac{9}{8} \times \sqrt{3} \times R^2$ =$\frac{9}{8} \times \sqrt{3} \times (0.7)^2$ =0.95km^2

Required site number=$\frac{eare\ to\ be\ covered}{single\ site\ coverage\ area}$= $\frac{22.458}{0.95}$ =24 coverage-based eNodeBs are required to provide the radio coverage for the 22.458 km^2 area of Gondar city.

As per the SUI path loss formula in Equation (3.4-3.8) be used to compute the cell radius in the UL and DL since Gondar morphology is hilly Terrain A category used to calculate the radius.

R=10 $^{\gamma}$

Y=$\left(\frac{A+xf+xh+s-pl}{-10y}\right) - logd0$

$d_{UL=}$0.635km

$d_{DL=}$0.950km

As a result, the effective radius (R_{ef}=Min (d_{UL}, d_{DL})) becomes 0.635 Km. Table 4.6 summarizes the cell radius for the UL and DL paths, as well as the effective cell radius for computing the coverage-based sites count.

Parameter	UL	DL
eNodeB Antenna Height (m)	40	
UE Antenna Height (m)	2	
Frequency (MHz)	1800	
MAPL (dB)	125	133
Cell Radius (Km)	0.635	0.950
Effective Cell Radius ($R_{ef)}$ (Km)	0.635	

Table 4.7 Cell radius summary (Uplink & Downlink) by SUI model

Now by assuming that all eNodeBs are three sectored sites, the site area and the total number of eNodeB are calculated by using equations (3.16a) and (3.19) respectively as follows.

Site coverage area=$\frac{9}{8} \times \sqrt{3} \times R^2$ =$\frac{9}{8} \times \sqrt{3} \times (0.635)^2$ =0.784km^2

Required site number=$\frac{eare\ to\ be\ covered}{single\ site\ coverage\ area}$= $\frac{22.458}{0.784}$ =29 coverage-based eNodeBs are required to provide the radio coverage for the 22.458 km^2 area of Gondar city.

4.4 Capacity Planning

For a particular cell range, capacity dimensioning calculates the average site throughput and the average number of subscribers that can be accommodated. The vendor technique is used to do capacity dimensioning. This method was chosen for its simplicity and because it is used by several commercially launched networks in various countries. Because the goal of this study isn't to represent any vendor's value, a change was made to collect average sector/cell throughput to calculate site count. For LTE capacity planning, the available spectrum and channel BW utilized by the LTE system are also critical. A total of 3 hours is considered 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. From a practical point of view, a category couldn’t utilize all the 100% service throughout all the time, thus service usage distribution is required and assumed to be 10%, 40%, and 50% for gold, silver, and bronze users respectively as shown in Table 4.7

User service category	Traffic usage in GB/Month/user	Traffic ratio of Busy hours to the whole day (%)	User ratio of service (%)	Traffic ratio	
				DL	UL
Gold	20	12.5	10	80%	20%
Silver	15	12.5	40	80%	20%
Bronze	10	12.5	50	80%	20%

Table 4.8. Users' service usage category

- **<u>Step 1:</u>** Calculate the average throughput per subscriber using input parameters of table 4.7 and equations 3.21, 3.22, 3.23,3.24.

User category	Average throughput per user in busy hour (Kbps) (DL and UL)	Assigned	Remark
Gold	185.19	A	A=(20×0.125×8×10^6)/30×3600

Silver	138.89	B	B=(15×0.125×8×10^6)/30×3600
Bronze	92.59	C	C=(10×0.125×8×10^6)/30×3600
Average throughput per subscriber (UL and DL)			
Total average throughput per subscriber in busy hours (Kbps)	120.37	D	D= A×10% + B×40% +C×50%
DL Average throughput per subscriber (Kbps)	96.3	E	E=D×DL Traffic ratio (80%)
UL Average throughput per subscriber (Kbps)	24.1	F	F=D×UL Traffic ratio (20%)

Table 4.9. Average throughput per subscriber result

Table 4.8 shows that for DL and UL, respectively, the average throughput per subscriber was found to be 96.3 Kbps and 24.1 Kbps. Due to the downlink antenna's 2x2 MIMO configuration, which makes it more efficient than UE antennas that employ 1x2 MIMO, the downlink average throughput is higher than the uplink throughput.

- **Step 2:** Determine peak throughput per site and average throughput per site for DL and UL by using equations 3.25, 3.26, 3.27, table 4.7, and 4.8 for the input parameter.
- **Step 3:** Determine capacity based required site number. This is done by using the results obtained in Tables 4.9, and 4.10 and equations 3.28, 3.29, and 3.30.

Description	Value	Assigned	Remark
User bandwidth (MHz)	20	a	-
Assumed 10% of the bandwidth used for the guard (Cyclic Prefix) (MHz)	2	b	10%*a
Effective bandwidth (MHz)	18	c	a-b
The bandwidth of one subscriber (KHz)	15	d	-
Total subcarrier	1200	e	
Symbols per 1ms for resource block	16800		12*7*2
Symbols per 1ms for RB (Mbps)	16.8		16800/1000
MIMO	2Tx2R for downlink		
Bits capacity per symbol (bit)	2		QPSK

	4		16QAM
	6		64QAM
Coding rate	0.667		QPSK
	0.793		16QAM
	0.8		64QAM

Table 4.10. Average throughput per subscriber result

Parameters	QPSK	16QAM	64QAM	Assigned	Remark
Data rate	2	4	6	a	
Code rate	0.3	0.38	0.45	b	
MIMO effect	2	2	2	c	
Data resource/sec (Mbps)	16.8	16.8	16.8	d	
Average throughput per site					
Total Peak Throughput per site (Mbps)			162	e	e =Σ a×b×c×d
Average throughput per site for downlink (Mbps)			129.6	f	f = e × DL traffic ratio
Average throughput per site for uplink (Mbps)			32.4	j	j = e× UL traffic ratio

Table 4.11. Average throughput per site for uplink and downlink result

Parameters	Calculated value	assigned	Remark
Total number of populations 20-59 age	245804	p	Recent population
Estimated total number of subscribers	90,000	a	37% * p
Avg. throughput per subscriber UL (Kbps)	24.1	b	Result From table 4.8
Avg. throughput per subscriber DL(Kbps)	96.3	c	Result From table 4.8
Average throughput per site UL (Mbps)	32.4	d	Result From table 4.10

Average throughput per site DL(Mbps)	129.6	e	Result From table 4.10
Maximum subscriber per site UL	1359	f	f = d/b
Maximum subscriber per site DL	1378	g	g = e/c
Effective subscriber number per site	1359	h	h = min (f, g)
Total number of sites	67	s	S=a/h

Table 4.12. Result of capacity-based number of sites

The minimum number of subscribers per site is selected from UL and DL to determine the total number of eNodeBs needed for the region, as shown in table 4.11 above. Thus, as indicated in the table, a total of 67 sites were discovered. It is demonstrated in this nominal planning stage that a total of 29 eNodeBs are needed to satisfy the coverage requirement, and a total of 67 eNodeBs are needed to satisfy the capacity requirement. To meet both coverage and capacity, we then compare the number of sites from capacity and coverage planning and select the greatest site.

Capacity-based site number	Coverage-based site number	Clutter Type	Propagation model
67	29	Urban	Cost-hata231 and SUI
Effective number sites 67			

Table 4.13. Summary of dimensioning result

4.5 Simulation: Designing an LTE Network

4.5.1 Overview of ATOLL

Through flexible scripting and methods, ATOLL's integration and automation features enable operators to quickly automate planning and optimization activities. For the development and optimization of radio networks, ATOLL has emerged as an industry standard. It's crucial to construct the zones before running the forecasts. Based on the ATOLL User Manual, a description of these zones is provided below.

- **Filtering Zone**: A graphical filter called the filtering zone limits the objects displayed on the map. Additionally, it restricts the kind of inputs that are utilized in the calculations, such as estimates for coverage, etc.

- **Computation Zone**: The term "computation zone" refers to the region where ATOLL computes route loss matrices and coverage studies as well as the base stations that should be taken into account while performing computations.
- **Focus Zone**: We may choose the regions of coverage estimation or other calculations on which we wish to create reports and results using the focus zone.

4.5.2 Simulation Workflow

The network planner may design wireless access networks using the RNPO tool. It is used to assess network capacity, manages mobile and fixed subscriber data, and forecast radio coverage. The simulation approach is shown in Figure 4.2.

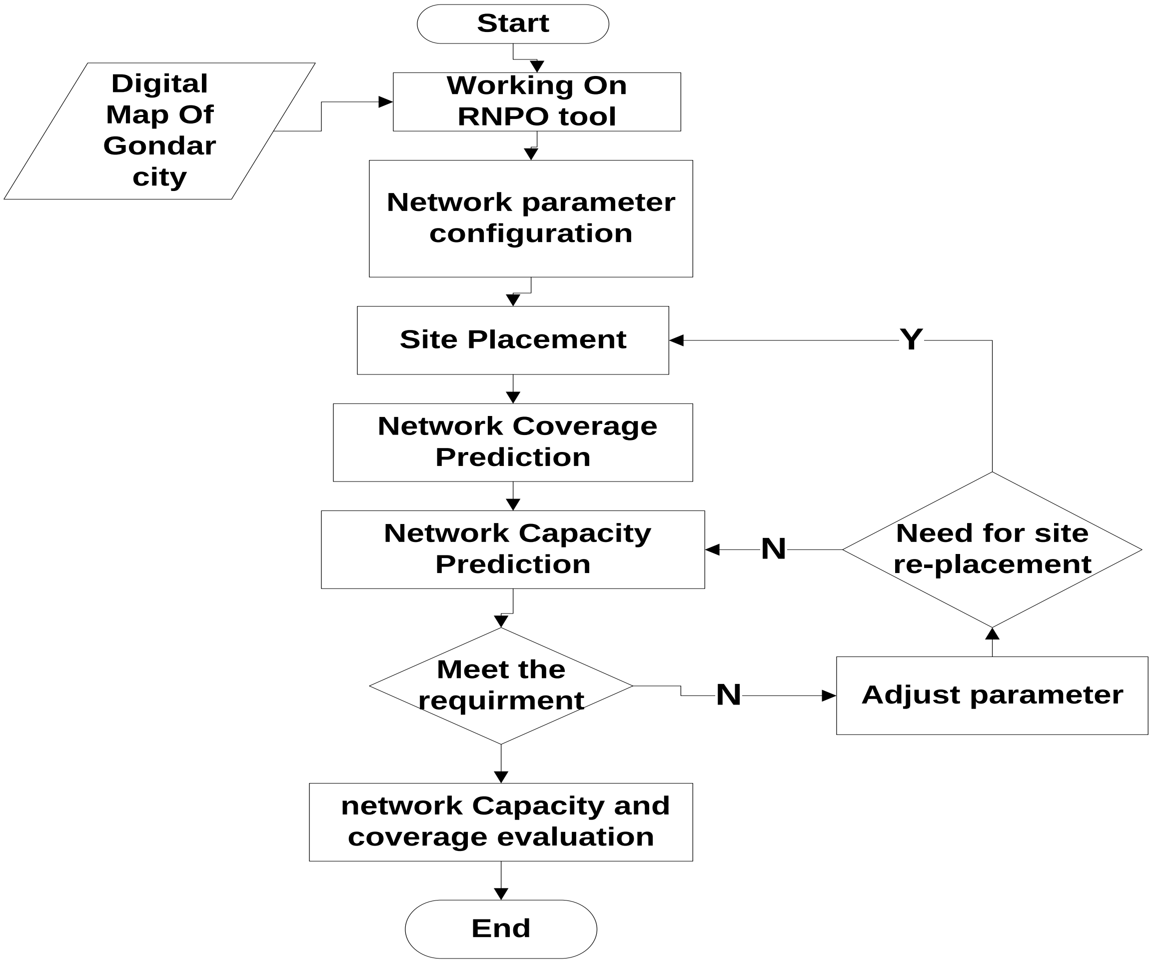


Figure 4.2. Workflow for LTE network simulation

The procedure needs two inputs, as indicated in the workflow above. A digital map is an initial input needed to set up the RNPO tool's operating environments. In Figure 4.3, the chosen location

(Gondar city) is circled in black to represent it in the simulation. A digital map is an electronic database including geographic data, such as height information, vector data, and land usage (clutter information) (streets, main roads, secondary roads, highways, and railways).

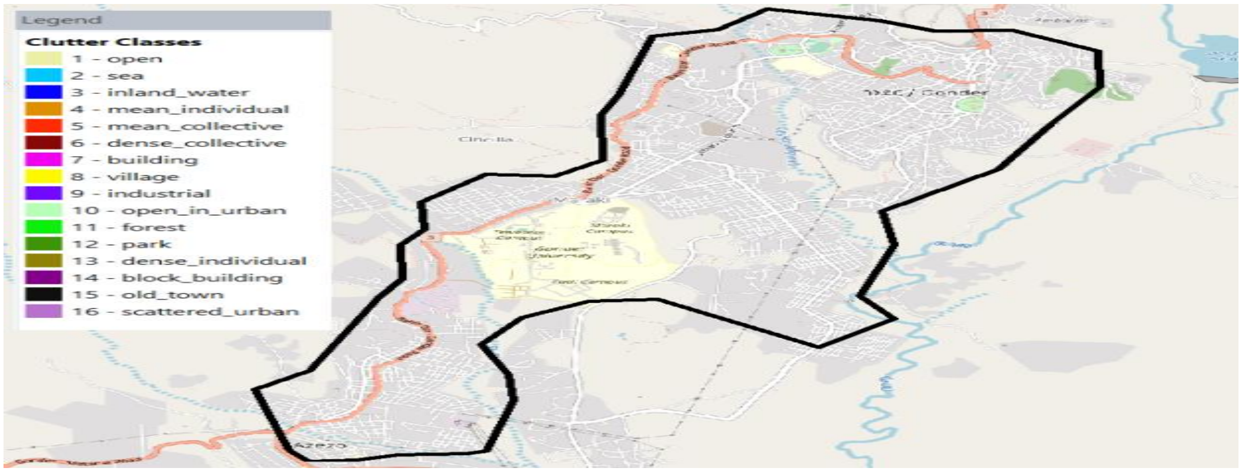


Figure 4.3. Digital Map of Gondar city

The parameters identified during the nominal planning stage make up the second input. They are used to set up global parameters as well as site, transmitter, and cell settings for networks. Some of the key settings for configuring the target network in the RNPO tool are shown in Table 4.14.

Parameters	DL	UL
Frequency	1800 MHz	
Bandwidth	20 MHz	
Duplex Mode	FDD	
Propagation Model	Cost 231 Hata and SUI	
Frequency Reuse	1	
Scheduling	Proportional Fair	
MIMO Configuration	2x2	1x2
Transmit Power	46 dBm	23dBm

Table 4.14. Sample parameters for network configuration

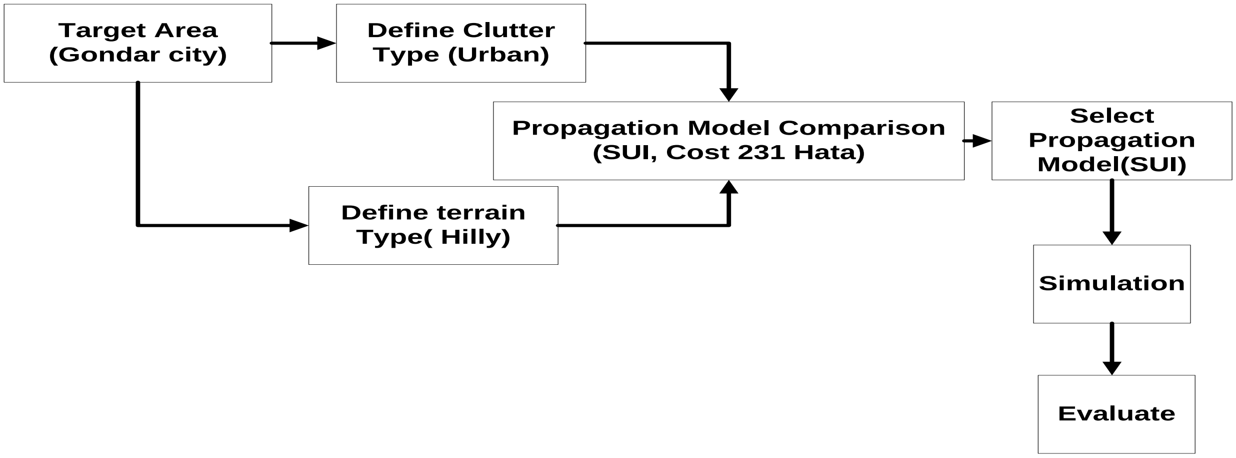


Figure 4.4 Propose Network framework for Gondar City

4.5.3 Sites Placement

The RNPO tool generates a total of 67 eNodeBs based on the nominal planning phase. The parameters shown in Table 4.14 are used to initially establish these sites. We may change the initial assumptions of these parameters for better outcomes based on the results of the coverage forecast. The locations of this 67 eNodeBs on the intended deployment region are shown in Figure 4.5.

Sector Configuration	Antenna Configuration	Antenna Height	Azimuth	Mechanical Down tilt	Electrical Down tilt
Sector 1	65deg 17 dBi 1800MHz	40m	0^0	0^0	0^0
Sector 2	65deg 17 dBi 1800MHz	40m	120^0	0^0	0^0
Sector 3	65deg 17 dBi 1800MHz	40m	240^0	0^0	0^0

Table 4.15. Initial site parameters

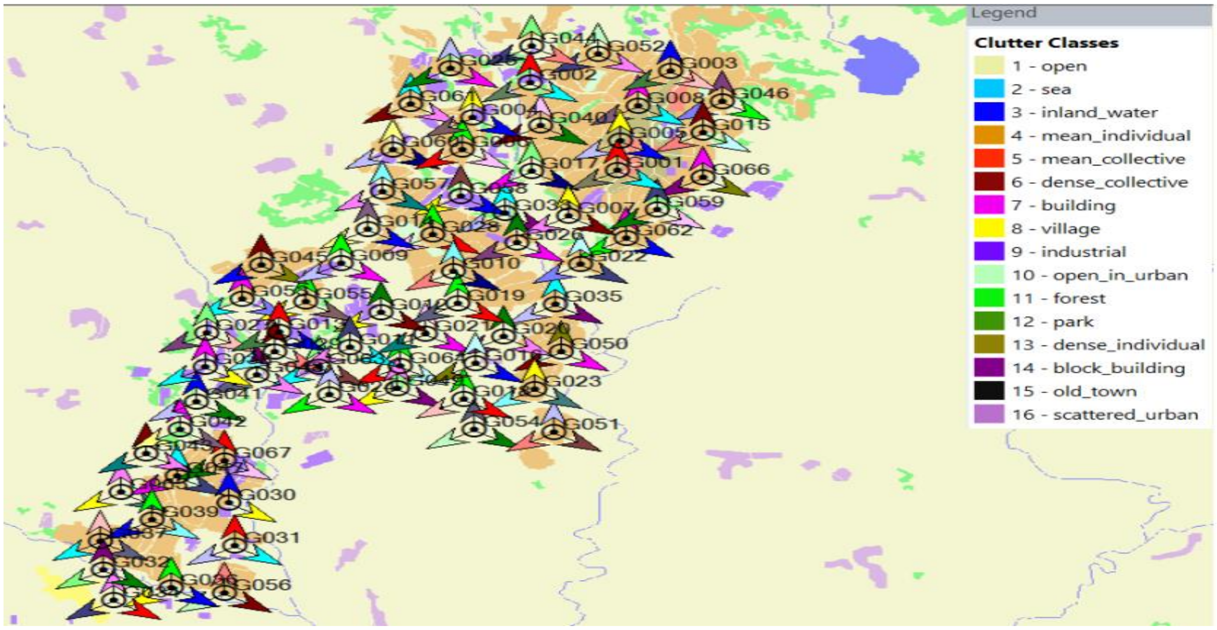


Figure 4.5. Site Placement

4.6 Target Area Coverage Prediction and Analysis

The outcomes of a set of coverage conditions are shown in a coverage prediction. The path loss matrices are used to calculate it depending on the coverage conditions and coverage resolutions. In order to perform the coverage prediction calculations, the RNPO tool used in this study takes into account the geographic profile between the eNodeB and UE, as shown in Figure 4.6. The results are then displayed as a graphical representation of the pixels for which the defined coverage conditions are satisfied. Each pixel is treated as a non-interfering user with a specific service, mobility, and terminal type in this study. The findings of the following coverage predictions will be used to assess the nominal planning phase in accordance with the target network criteria set in Chapter 4 Section 4.2:

- Coverage by Signal Level
- Effective signal analysis
- Coverage by C/(C+N)

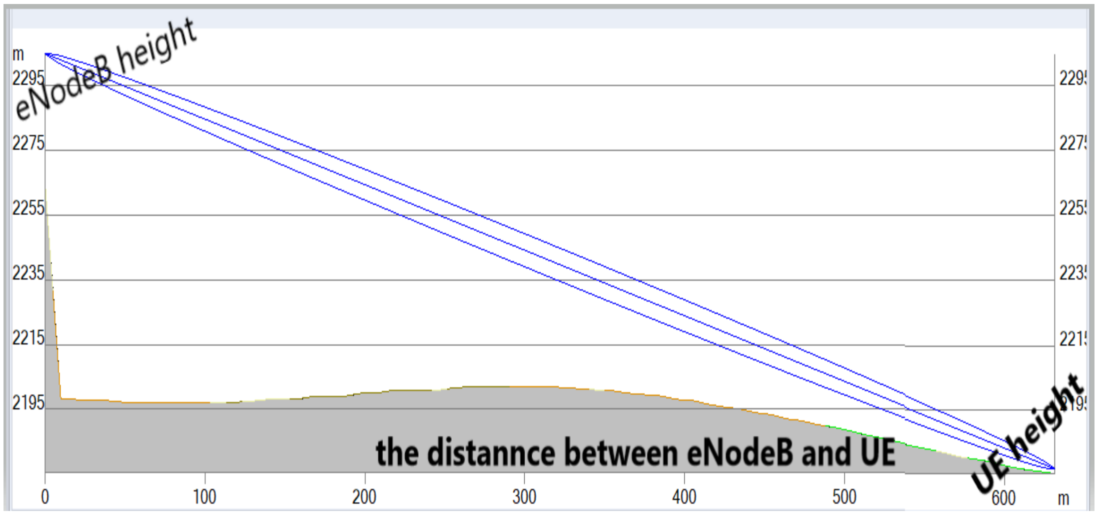


Figure 4.6. The geographical profile between eNodeB and UE

4.6.1 Initial Prediction Results

- Coverage by Signal Level

By taking into account the "Best Signal Level" throughput across the target area coverage condition indicated in Table 4.15, target network signal level coverage prediction is carried out. The outcome of the coverage forecast based on the "Best Signal Level" in the target region is shown in Figure 4.6. In this diagram, the green color plots reflect the best signal level, which is ≥ -85 dBm, while the blue color plots show the worst signal level, which is ≥-133 dBm, and illustrate the target area's poor coverage. In this section the signal level coverage prediction is performed by taking into account the condition;

- Shadowing taken into account
- Indoor coverage considered
- Cell edge coverage probability is 90%

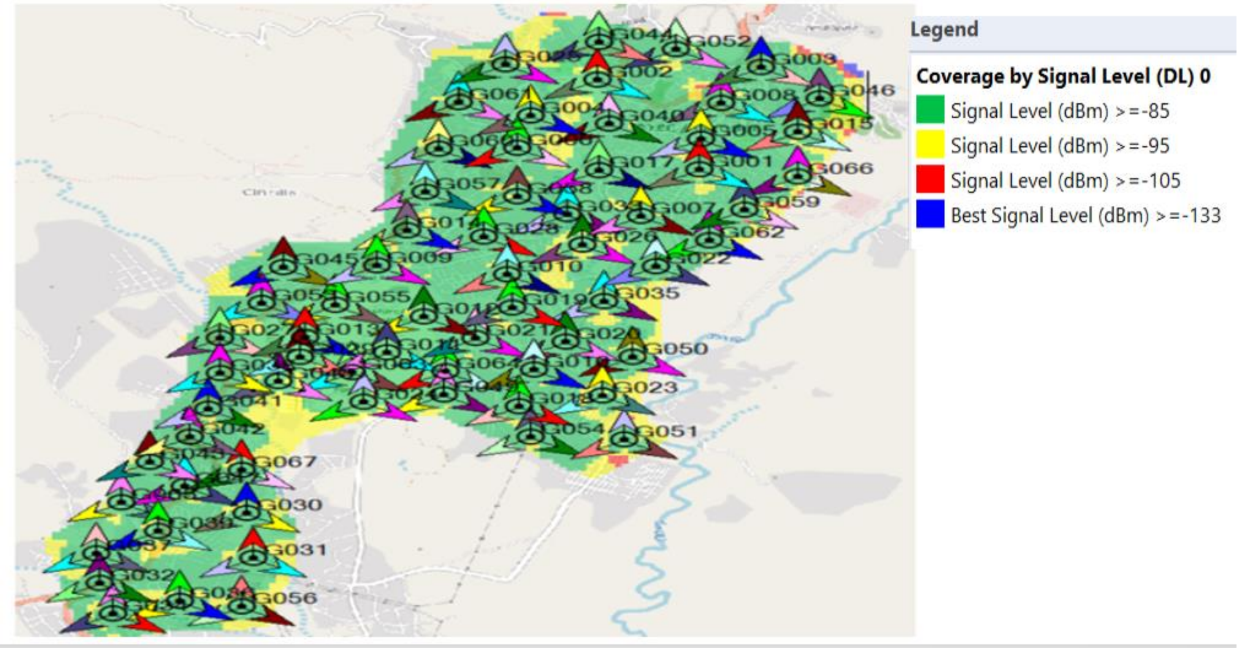
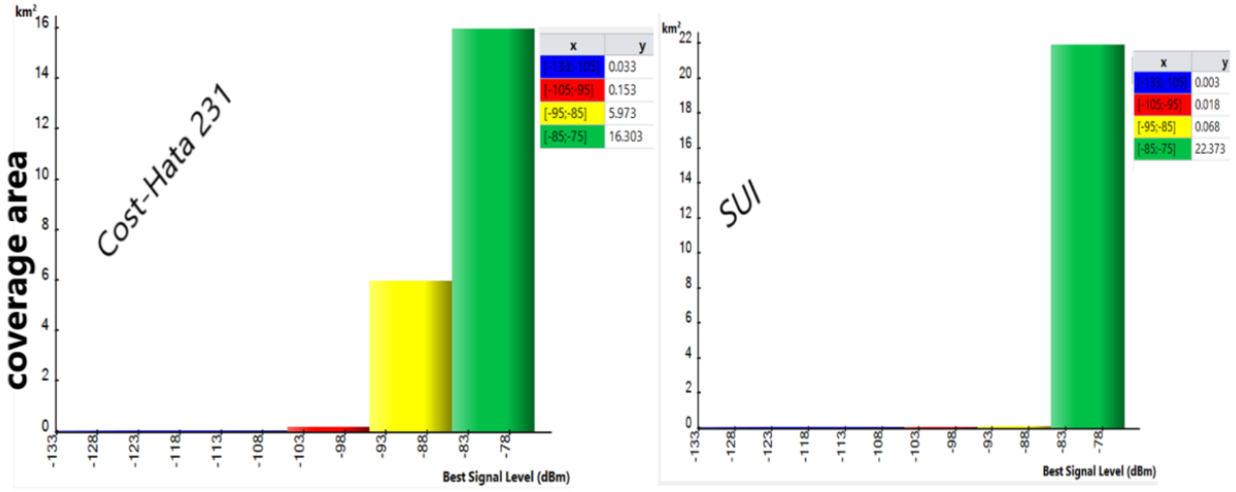


Figure 4.7. Coverage prediction by the signal level

According to Figure 4.8, the green color represents the signal level ≥ -85dBm that accounts for the best signal strength, the signal level between -85 dBm and -95 dBm, which is represented by yellow, while the signal level between -95dBm and -105 dBm is represented by red. The blue and red-colored region in Gondar city represents areas with low signal coverage.



x	y
[-133;-105]	0.033
[-105;-95]	0.153
[-95;-85]	5.973
[-85;-75]	16.303

x	y
[-133;-105]	0.003
[-105;-95]	0.018
[-95;-85]	0.068
[-85;-75]	22.373

Figure 4.8. Coverage prediction by signal level result in histogram form (Cost 231 Hata and SUI)

When analysis is conducted using covered area per square kilometer, As illustrated in Figure 4.7, it is discovered that Cost 231 Hata and SUI covered 22.3km2 and 22.4km2 by the signal intensity of ≥ -95dBm respectively. This demonstrates that the intended network provides excellent signal strength at SUI model rather than Cost 231 Hata Model.

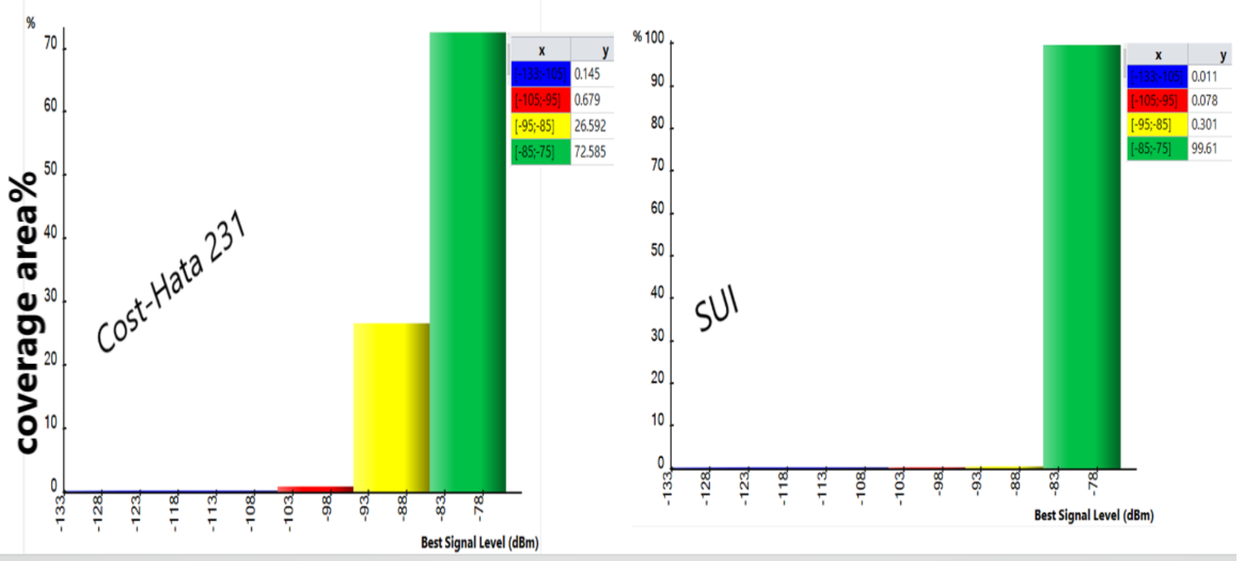


Figure 4.9. Histogram result % coverage prediction by the signal level (Cost 231 Hata and SUI)

The simulation result indicates that Cost 231 Hata model and SUI model covered 99% and 99.9% of the region covered by the signal is -95dBm respectively, as represented by the histogram statistical result in Figure 4.9. This demonstrates that UEs can receive signals better than the link budget's estimated minimum signal reception strength of 133dBm.

This simulation's output makes it evident that the target network requirement's value for the cell edge coverage probability in Section 4.2.1 is exceeded (90%).

Coverage by Signal Level	Covered area (%) Cost 231 Hata model	Covered area (%) SUI
Signal Level (dBm) ≥-85	72.582	99.613
Signal Level (dBm) ≥-95	99.176	99.911
Signal Level (dBm) ≥-105	99.853	99.991
Signal Level (dBm) ≥-133	100	100

Table 4.16. Prediction result for Coverage by Signal Level (Cost 231 Hata and SUI)

- Effective Signal Analysis

For various forms of signals, "effective signal analysis" coverage predictions allow for the prediction of effective signal levels in both the UL and DL directions. The following simulation depicts the outcome of the RSRP and PUSCH signal analysis.

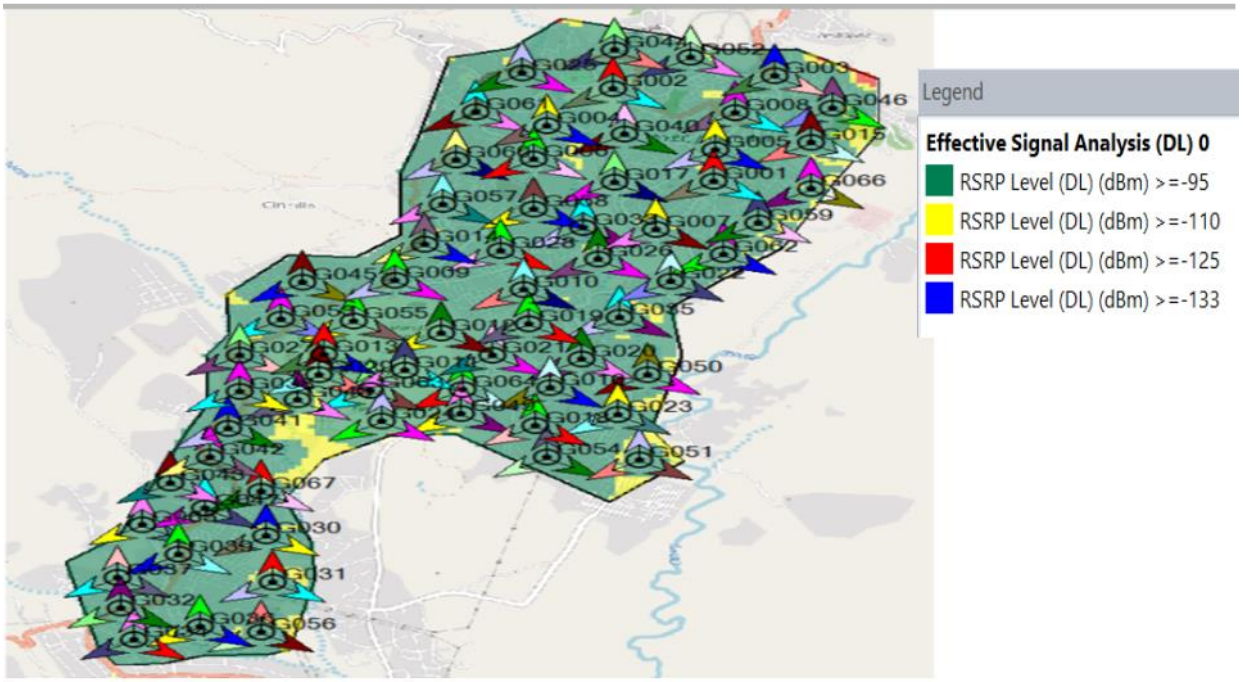
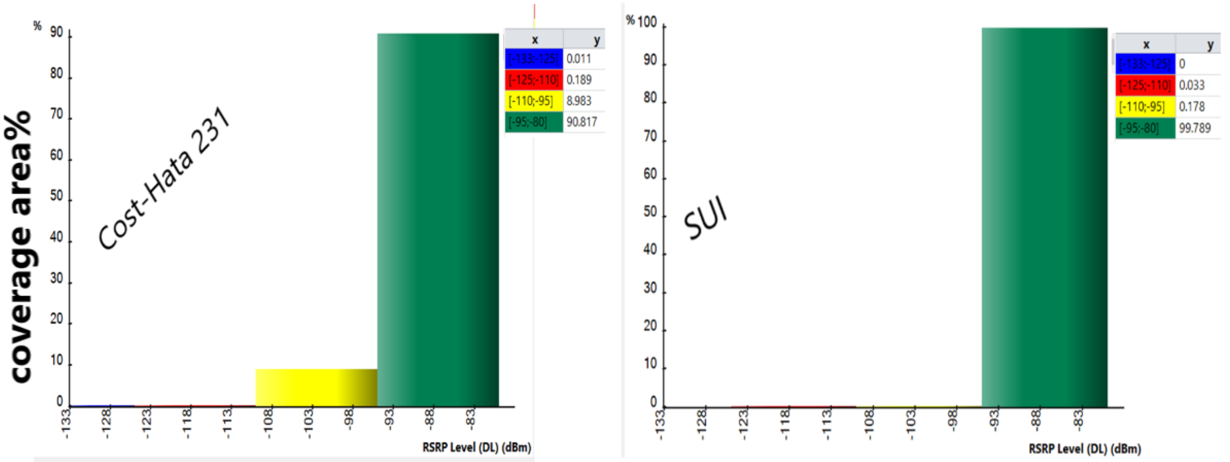


Figure 4.10. Effective signal analysis results DL



x	y
[-133;-125]	0.011
[-125;-110]	0.189
[-110;-95]	8.983
[-95;-80]	90.817

x	y
[-133;-125]	0
[-125;-110]	0.033
[-110;-95]	0.178
[-95;-80]	99.789

Figure 4.11. Histogram DL effective signal analysis, RSRP level (Cost 231 Hata and SUI)

Legend	Covered area(%) Cost 231 Hata	Coverage area (%) SUI
RSRP Level (DL) (dBm) ≥-95	90.819	97.791
RSRP Level (DL) (dBm) ≥-110	99.8	99.969
RSRP Level (DL) (dBm) ≥-125	99.991	100
RSRP Level (DL) (dBm) ≥-133	100	100

Table 4.17 Prediction result for Coverage by effective Signal Level (Cost 231 Hata and SUI)

Based on the result Cost 231 Hata and SUI achieves 90% and 97 % of the area achieves an RSRP ≥ -95 dBm respectively, thus the RSRP target requirement is achieved.

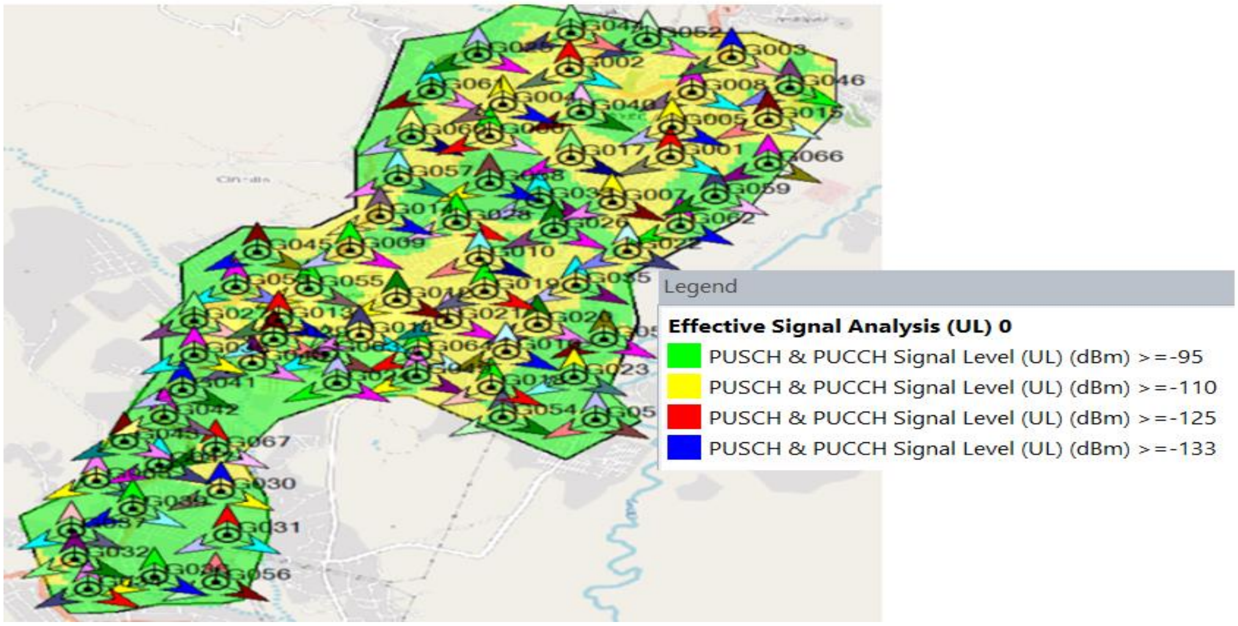


Figure 4.12. Effective signal analysis results in UL

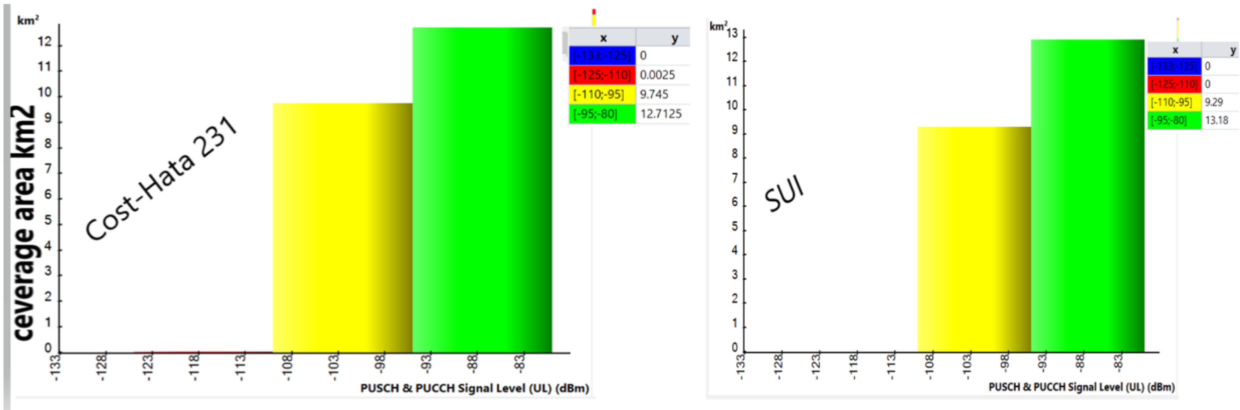


Figure 4.13. Histogram UL effective signal analysis (Cost 231 Hata and SUI)

Legend	Covered area(%) Cost 231 Hata	Coverage area (%) SUI
PUSCH & PUCCH Signal Level (UL) (dBm) ≥-95	56.603	58.66
PUSCH & PUCCH Signal Level (UL) (dBm) ≥-110	99.991	100
PUSCH & PUCCH Signal Level (UL) (dBm) ≥-125	100	100
PUSCH & PUCCH Signal Level (UL) (dBm) ≥-133	100	100

Table 4.18 Prediction result for Coverage by effective Signal Level (Cost 231 Hata and SUI)

Based on the result Cost 231 Hata and SUI, 99.9% and 100% of the area achieves an PUSCH & PUCCH Signal Level ≥ -110 dBm respectively, thus the RSRP target requirement is achieved.

- Coverage by C/(I+N) or carrier-to-interference-and-noise ratio

Network loads have an impact on the LTE cells' capacity and effective service coverage zones. The region that a cell service downgrades as the network load rises. Because of this, it is necessary to describe network loads in order to compute these coverage projections. Based on the expected signal level from the best server and the predicted signal levels from other cells (interference) for each pixel, or carrier-to-interference-and-noise ratio, or C/(I+N), ATOLL provides a number of coverage projections.

The signal-to-interference ratios and interference levels in the area of the network under study are predicted by the C/(I+N) level. Depending on the downlink reference signal level, ATOLL determines the serving transmitter for each pixel. According to the received reference signal strength from the cell with the greatest power, the serving transmitter is chosen. The cell with the lowest order is chosen as the serving (reference) cell if more than one cell covers the pixel. The carrier to interference plus noise (CINR) ratio measures how well the signal carrier serves the intervention as seen at all other sites and sectors while also taking into account all the noise. When a signal goes below to the level of noise, it is impossible to decode it and no usable information can be extracted from it. For high-data-rate communications, a strong signal is essential.

The C/(I+N) in the downlink calculated for different channels using their respective transmission powers and by calculating the interference received by the resource elements corresponding to these channels from interfering cells. Figure 4.13 shows coverage prediction by the C/(I+N) value for both downlink and uplink signals.

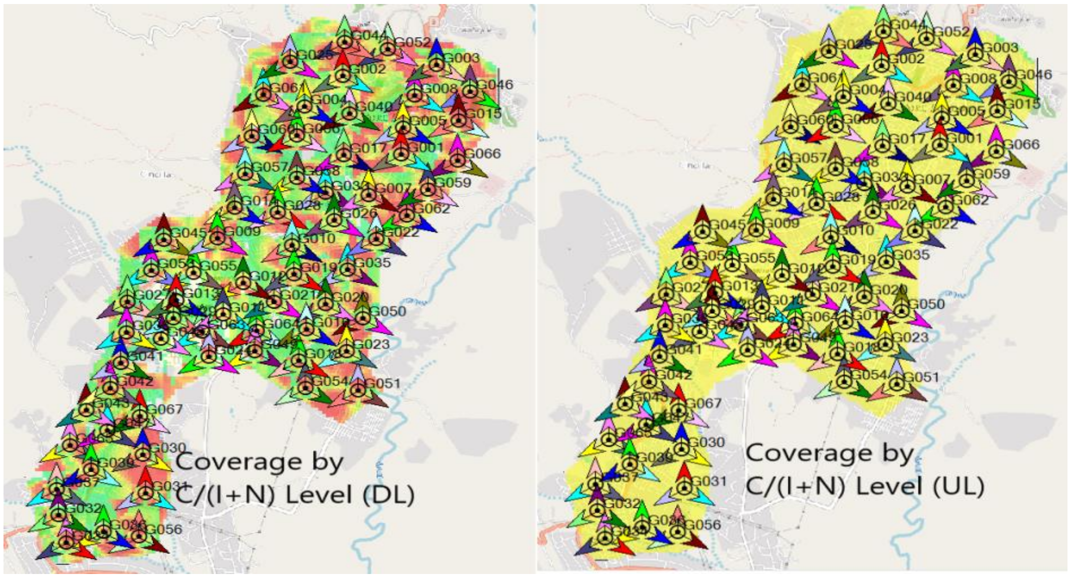


Figure 4.14. Coverage prediction by C/(I+N) level DL & Coverage prediction by C/(I+N) level UL

Legend	Coverage area% Cost 231 Hata	Coverage area% SUI
PDSCH C/(I+N) Level (DL) (dB) >=6	85.374	94.807
PDSCH C/(I+N) Level (DL) (dB) >=5	88.303	95.964
PDSCH C/(I+N) Level (DL) (dB) >=4	91.126	97.027
PDSCH C/(I+N) Level (DL) (dB) >=3	93.376	97.825

Table 4.19 Downlink C/(I+N) level (Cost 231 Hata and SUI)

Legend	Coverage area% Cost 231 Hata	Coverage area% SUI
PUSCH & PUCCH C/(I+N) Level (UL) (dB) >=4	100	100
PUSCH & PUCCH C/(I+N) Level (UL) (dB) >=3	100	100
PUSCH & PUCCH C/(I+N) Level (UL) (dB) >=2	100	100
PUSCH & PUCCH C/(I+N) Level (UL) (dB) >=1	100	100

Table 4.20 Uplink C/(I+N) level (Cost 231 Hata and SUI)

- Pre-Deployment Optimizations Results

Radio engineers can optimize the basic network parameters in terms of network quality and coverage using the RNPO tool. In a scenario for a new deployment, basic characteristics such as antenna types, azimuths, heights, mechanical tilts, and electrical tilts can be adjusted to obtain the best network parameters during the detailed planning stage. In this study, it was found that pre-deployment optimization was necessary to achieve strong network performance in terms of signal level, C/(I+N), and RSRP to avoid having to optimize the network further after deployment, even if the target network requirements for area coverage probability, cell edge coverage probability, and

RSRP value were met. Thus, the transmitter parameters, such as antenna azimuths, antenna mechanical down tilt, and antenna electrical down tilt, are adjusted with the aid of the RNPO tool. Following the completion of the pre-deployment optimization, the target network's performance was assessed using important network performance metrics such as coverage signal level, RSRP effective signal analysis, and C/(I+N). As a result, the network performance is significantly better than it was before pre-deployment optimization as compared to the initial prediction results. The following is an illustration of this notable improvement:

○ **Coverage Signal Level Improvements**

The comparison between the starting signal level and the end signal level following pre-deployment adjustment is shown in Figure 4.16. Signal levels≥-85 dBm indicate an improvement of 11.8 % by Cost 231 Hata and 0.3% bt, while in Table 4.18 also shows other signal level improvements.

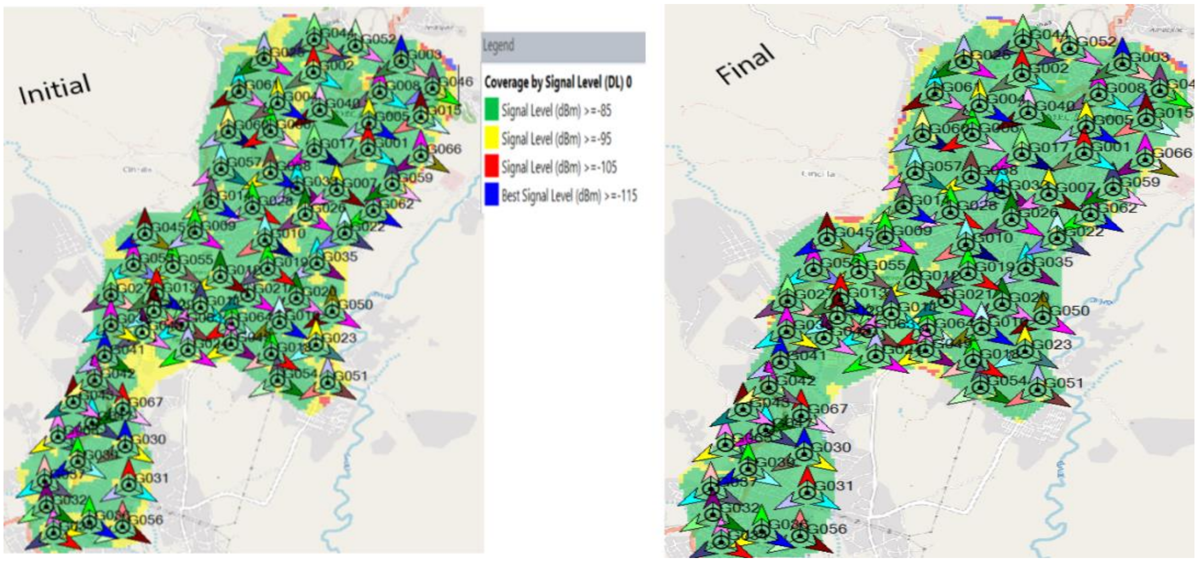


Figure 4.15. Signal level before and after pre-deployment optimizations

Coverage by Signal Level	% Covered Area (Initial) Cost 231 Hata	% Covered Areas (Final) Cost 231 Hata	Improvements by % Cost 231 Hata	% Covered Area (Initial) SUI	% Covered Areas (Final) SUI	Improvements by % SUI

Signal Level (dBm) ≥-85	72.582	84.372	11.8	99.6	99.969	0.3
Signal Level (dBm) ≥-95	98.197	99.176	0.7	99.91	100	0.09
Signal Level (dBm) ≥-105	99.853	99.889	0.2	99.99	100	0.01
Signal Level (dBm) ≥-133	100	100	0.00	100	100	0.00

Table 4.21 Coverage signal level improvements after pre-deployment optimizations

- RSRP Level Improvements

The comparison between the initial RSRP value and the final RSRP level following pre-deployment optimization is shown in Figure 4.16. It indicates a 2% improvement by Cost 231 Hata and 2% improvement by SUI for RSRP levels greater than or equal to -95 dBm. Table 4.16 illustrates improvements.

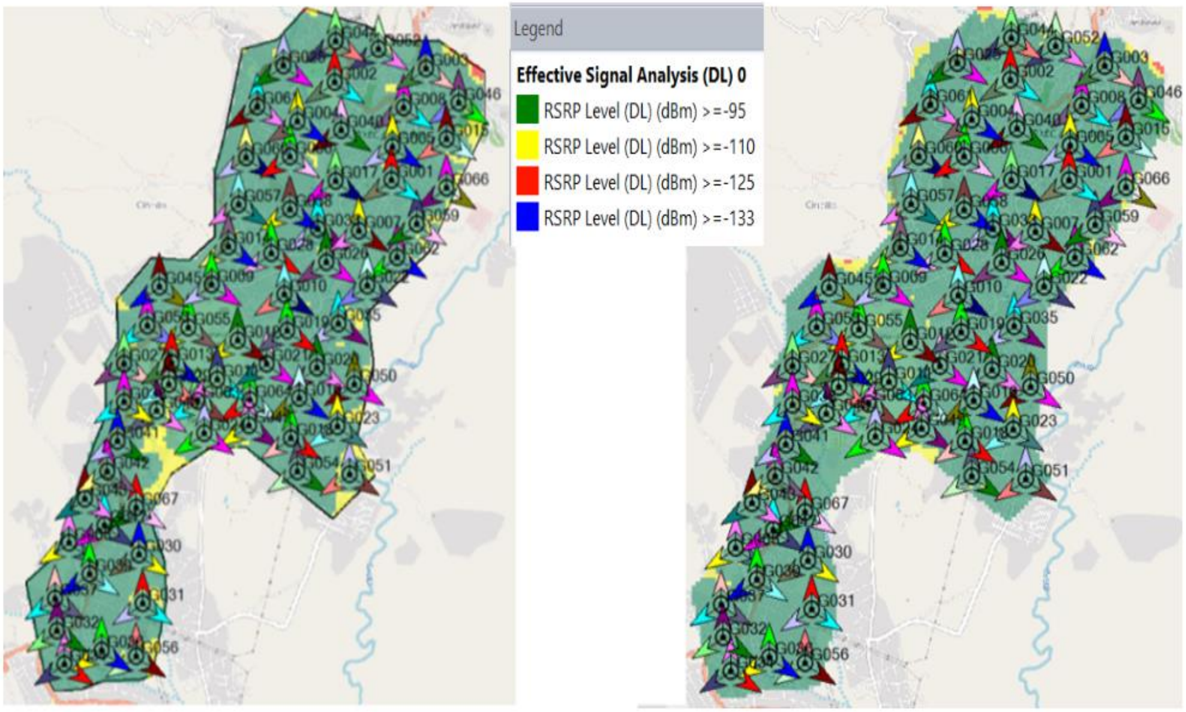


Figure 4.16. RSRP level improvements after pre-deployment optimizations

Coverage by RSRP	% Covered Area (Initial) Cost 231 Hata	% Covered Areas (Final) Cost 231 Hata	Improvements by % Cost 231 Hata	% Covered Area (Initial) SUI	% Covered Areas (Final) SUI	Improvements by % SUI
RSRP Level (DL) (dBm) ≥-95	90.863	92.756	2	97.7	99.791	2
RSRP Level (DL)	99.844	99.9	0.1	99.9	100	0.1

(dBm) ≥-110						
RSRP Level (DL) (dBm) ≥-125	99.9	100	0.01	100	100	0.00
RSRP Level (DL) (dBm) ≥-133	100	100	0.00	100	100	0.00

Table 4.22 RSRP improvements after pre-deployment optimizations (Cost 231 Hata and SUI)

4.7 Network Capacity Evaluation & Analysis

Verifying the network capacity is a crucial stage in the planning of an LTE network. This is accomplished using simulations based on a realistic user distribution at a particular moment and measurements of the downlink and uplink throughput forecasts. The RNPO tool is utilized in this thesis to assess the intended network capacity.

1. Prediction by throughput

To show the channel throughputs and cell capacities using this way, the RNPO tools compute the downlink and uplink throughput forecasts based on C/(I+N) and bearer calculations for each pixel. To assess if the target network meets the requirements of cell edge throughput of 512 kbps and 1024 kbps for uplink and downlink, respectively, the cell edge coverage probability was set at 90%.

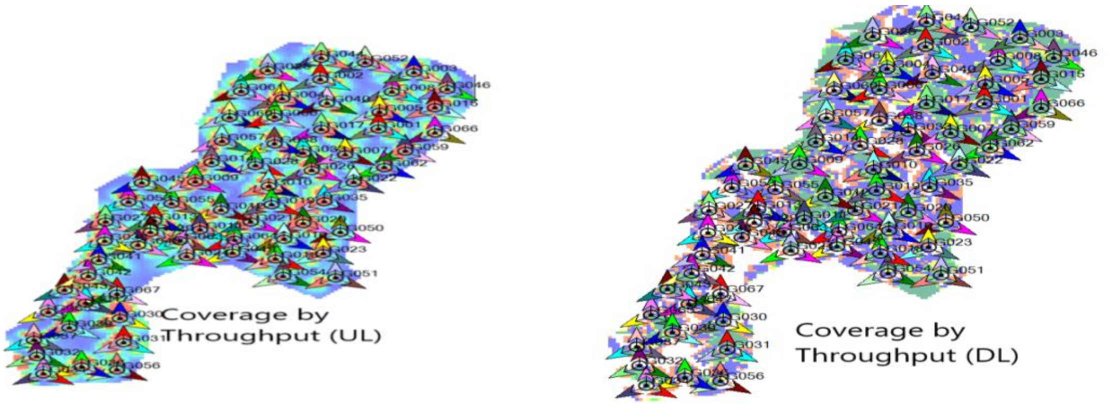


Figure 4.17. Prediction result for uplink and downlink throughput

The statistics of the throughput for both forecasts are displayed in tables 4.23 and 4.24. The outcome shows that the cell edge throughput objectives have been met and illustrates a better performance than the performance specified by the target network requirement for both uplink and downlink.

Legend	%Covered Area Cost 231 Hata	%Covered Area SUI
Peak RLC Channel Throughput (DL) (kbps) ≥102,400	58.325	80.411
Peak RLC Channel Throughput (DL) (kbps) ≥49,000	72.143	91.869
Peak RLC Channel Throughput (DL) (kbps) ≥17,000	99.986	99.471
Peak RLC Channel Throughput (DL) (kbps) ≥16,000	99.986	100
Peak RLC Channel Throughput (DL) (kbps) ≥8,000	100	--

Table 4.23 Prediction result for capacity by throughput (DL) (Cost 231 Hata and SUI)

Legend	%Covered Area Cost 231 Hata	%Covered Area SUI
Peak RLC Allocated Bandwidth Throughput (UL) (kbps) ≥51,200	90.873	99.724
Peak RLC Allocated Bandwidth Throughput (UL) (kbps) ≥1,000	99.835	100

Table 4.24 Prediction result for capacity by throughput (UL) (Cost 231 Hata and SUI)

As we have seen the Peak RLC Allocated Bandwidth Throughput prediction Stanford University Interim shows better throughput in the target area than Cost 231 Hata by 1800Mhz.

Chapter Five

5. Conclusion and Recommendations

5.1 Conclusion

This study aims to illustrate the viability of LTE radio network planning the city of Gondar as a case study. In this study, LTE radio network planning and pre-launch optimization using Gondar city as a representative case have been demonstrated using mathematical models and computer-assisted simulations.

From the result of this study, it can be concluded that:

- RLB characteristics are taken into account in the dimensioning stage following the demographics of the target area terrain conditions, maximum signal coverage and area coverage probability can be attained. The operators and local engineers should refer to this type of analysis for new deployment scenarios when deciding where to deploy.
- Shadow fading margin is taken into account from the perspective of the target area, and the maximum cell edge coverage probability, which aids in determining the ideal number of sites for the specified target area, can also be attained. Operators can then lower their capital expenditures and operational expenditures as a result.
- In order to avoid having to spend additional time and resources fixing unexpected problems after network deployment, network pre-deployment optimization must be taken into account at both the beginning and end of radio network planning.
- To understand how the proposed target network would support prospective subscriber growth in the future, network capacity must be assessed from the perspectives of simultaneous active user distribution and future subscriber number projection. After the network has been commercially launched, this helps to address the effect of potential network performance-related issues at a time when subscriber growth is occurring.

From the simulation we can conclude as:

- 99% and 100% of the area covered by optimum signal strength by Cost 231 Hata model and Stanford University Interim respectively i.e., greater than -95dBm (table 4.21)

- Reference signal receiving power analysis shows 92% and 100% of the area achieves an RSRP ≥ -95 dBm by Cost 231 Hata and Stanford University Interim respectively (table 4.22).
- From the capacity perspective the DL throughput 58% target area is covered by 100Mbps and 8MBbps is 100% the target area, the UL throughput 90% target area is covered by 50Mbps and 1MBbps is 100% the target area by Cost-231 Hata model (table 4.23 and 4.24).
- From the capacity perspective the DL throughput 80% target area is covered by 100Mbps and 16MBbps is 100% the target area, the UL throughput 99% target area is covered by 50Mbps and 1MBbps is 100% the target area by Stanford University Interim model (table 4.23 and 4.24).

So, from the simulation results, it is observed that Stanford University Interim model terrain A shows the better propagation model for the hilly morphology of Gondar City by 1800MHz.

5.2 Recommendation

- As we know there are different public holidays which are celebrated outside home at one place like at stadium/road, high market center so the place which uses for the holiday is so congested therefore dynamic network load balancing at different locations and times of a day should require research to use the resources effectively.
- Using a different tool, LTE network planning for coverage and capacity can be implemented.

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