5G Radio Network Dimensioning and Millimetric Wave Propagation Modeling: The Case of Kirkos Subcity, Addis Ababa

By: Eshetu Tessema Ware

A Thesis Submitted to

The Department of Electronic and Communication Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Master of Science Degree in Electronic and Communication Engineering

Office of Graduate Studies

Adama Science and Technology University

September, 2020

Adama, Ethiopia

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Advisor: Dr. Feyisa Debo

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We, the undersigned, members of the Board of Examiners of the final open defense by Eshetu Tessema Ware have read and evaluated his thesis entitled "5G Radio Network Dimensioning and Millimetric Wave Propagation Modeling: For the Case of Kirkos Subcity (Addis Ababa)" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Masters in Communication Engineering.

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I hereby declare that this MSc thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been properly acknowledged.

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

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To: Department of Electronics and Communication Engineering (ECE)

This is to certify that the thesis entitled "5G Radio Network Dimensioning and Millimetric Wave Propagation Modeling. For the Case of Kirkos Subcity (Addis Ababa)" submitted in partial fulfillment of the requirements of the Master of Science Degree in Electronic and Communication Engineering, postgraduate in Communication Engineering, and has been carried out by Eshetu Tessema Ware. Id No. PGR/18072/11 under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hereby he can submit the thesis to the department.

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Name of Advisor	Signature	Date
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Name of Co-advisor	Signature	Date

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ABSTRACT

The ongoing progress in request for improved mobile quality, higher data rates, and lower latencies are motivating the development of the network to 5G. The advancement of wireless communication technologies and the increasing scope of radio network make the tasks of radio network planning more challenging and attention has to be given for nominal and the desired requirements after deployment. The nominal and detailed 5G radio network dimensioning involves consideration of basic network requirements in terms of coverage prediction, capacity and Quality of Service (QoS). In this thesis, the significance of such basic requirements has been demonstrated using mathematical analysis and Radio network planning and optimization (RNPO) software i.e Winprop tool in order to disclose 5G's radio network planning strategies to the operator and local practicing engineering in the target area. This thesis considers Kirkos sub city in Addis Ababa, with the area of 14.91 km^2. *The simulation result output contains coverage prediction by pathloss, Signal strength (Reference signal received power(RSRP), Reference signal received quality(RSRQ)), Capacity analysis by throughput and SINR (Signal to interference plus noise ratio) and Quality of services that validate the deployed radio network that can handle the cellular traffic of Kirkos sub city in Addis Ababa. Since the real Addis Ababa digital map is used, from which Kirkos Subcity is cut out of this city by using Winprop(Wallman) software. From the coverage and capacity planning perspective of the 5G New radio 57gNodeB's (from Coverage planning) and 44gNodeB's (from Capacity planning) are obtained respectively for Kirkos Subcity, from which the maximum of the two is deployed.*

Key Words: *5G New Radio, Link Budget, Nominal Planning, Detailed Planning, Winprop, and Millimetric wave propagation modeling*

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LIST OF ACRONYMS

1G	1st Generation
2G	2nd Generation
3G	3rd Generation
4G	4th Generation
5G NR	5th Generation New Radio
3GPP	3rd Generation Partnership Project
AMF	Access and Mobility Management Function
AUSF	Authentication Server Function
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BPSK	Binary Phase Shift Key
CA	Carrier Aggregation
CDMA	Code Division Multiple Access
CP-OFDM	Cyclic Prefix Orthogonal Frequency Division Multiplexing
CSI-RS	Channel State Information Reference Signal
DFT-s-OFDM	Direct Fourier Transform Spread Orthogonal Frequency Division Multiplexing
DM-RS	Demodulation Reference Signal
ECA	Economic Commission for Africa
EDGE	Enhanced Data for Global Evolution
eMBB	Enhanced Mobile Broadband
EPC	Evolved Packet Core
E-UTRAN	Evolved Universal Mobile Telecommunications System Terrestrial RAN
FDMA	Frequency Division Multiple Access
f-OFDM	Filter-OFDM
gNodeB	Next-generation NodeB
GPRS	General Packet Radio Services
GSM	Global System for Mobile Communication
HSPA	High Speed Packet Access
IEEE	Institute of Electrical and Electronics Engineers

IMT	Information Management Technology
INI	Inter-Numerology Interference
IP	Internet Protocol
IS-95	Interim Standard 95
ITU	International Telecommunication Union
LMDS	Local Multipoint Distribution Service
MAC	Medium Access control
MAPL	Maximum Allowable Pathloss
METIS	Mobile and Wireless Communications Enablers for the Twenty-Twenty Information Society
mmMAGIC	Millimetre-Wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications
MMTC	Massive Machine Type Communication
NAS	Non-Access Stratum
NEF	Network Exposure Function
NFR	Network Function Repository
NOMA	Non-Orthogonal Multiple Access
OFDM	Orthogonal Frequency Division Multiplexing
OTP	Open Transport Protocol
PBCH	Physical Broadcast Channel
PCF	Policy Control Function
PDCP	Packet Data Convergence Protocol
PDSCH	Physical Downlink Shared Channel
PUSCH	Physical Uplink Shared Channel
PSS	Primary Synchronization Signal
PT-RS	Phase Tracking Reference Signal (PT-RS)
QoS	Quality of Service
QPSK	Quadrature Phase Shift Key
RAN	Radio Access Network
RAT	Radio Access Technology
RLC	Radio Link Control
RRC	Radio Resource Control

SC-OFDM	Single Carrier OFDM
SCS	Subcarrier Spacing
SDAP	Service Data Adaptation Protocol
SINR	Signal to Interference Plus Noise Ratio
SMS	Short Message Service
SNR	Signal Interference to Noise Ratio
SRS	Sounding Reference Signal (SRS)
SSS	Secondary Synchronization Signal
TD-SCDMA	Time Division Synchronous CDMA
TR-RS	Phase Tracking Reference Signal
TTI	Transmission Time Interval
UE	User Equipment
UPF	User Plane function
WIMAX	World Wide Interoperability for Microwave Access

CHAPTER-1

1. INTRODUCTION

1.1 Overview of the Study

Cellular network technologies have been growing for many years. These advanced technologies are named and distinguished from one another using the term Generation. This naming is applicable since these technologies have a very quiet improvement gap among each other. The initial cellular networks are called **First Generation (1G).** 1st Generation Mobile Network were developed in 1980s and completed by early 1990s. It was based on analogue system. It used analogue radio signals with frequency 150MHz and voice call modulation was done with the help of Frequency Division Multiple Access (FDMA). Its speed was up to 2.4 kbps. Its main feature was it allows user to make voice calls within a country. They were designed based on transmission technologies to offer speech services only and they were incompatible to each other [1]. Due to the inconsistency and limited services, the second evolution came into picture.

Second Generation (2G): cellular network technologies are the first step to move onward to digital wireless communication era. It was launched in 1991. It was based on digital system. It can give you speed up to 64 kbps. Main services provided are digital voices and SMS facility with more clarity, using the bandwidth of 30 KHz to 200 KHz. It gave semi global facility. Vital eminent technologies were GSM and Code Division Multiple Access (CDMA).2G cellular networks are widely adopted globally and they provide voice services Short Message Service (SMS) and Packet Data Service with low data rate (kbps). The need for high speed data rate and multimedia connectivity among subscribers brought an evolution of the cellular network technologies into third generation.

The Third Generation (3G): cellular network standards are defined by the International Telecommunication (ITU) by initiative called International Mobile Telecommunications (IMT) -2000.They have been designed being capable on providing high speed packet data services in the ranges of 144 kbps up to larger than 2Mbps [2]. It developed between late 1990s and early 2000s. Its transmission speed lies between 125kbps to 2 Mbps. Data are sent through Packet switching technology and circuit switching was used for interpretation of voice calls. It delivers superior voice quality. It also provides the facility of Video Conferencing, E-mailing, Online banking-billing, Global Roaming, mobile TV etc. The requirements of higher data rate and low latency system with all IP (Internet Protocol) network architecture evolve the third generation mobile communication towards the 4^{th} Generation.

Fourth Generation (4G): It was advanced in 2010. It is faster and more reliable compared to earlier networks. Its speed is up to 100Mbps. It provides improved communication network based on IP. It provides high performance in low cost. Long Term Evolution (LTE) is considered as main technology for 4G. Multimedia Messaging Service (MMS), digital video broadcasting, High Definition (HD) TV, Video chat are the services provided by 4G in addition to features of 3G. Diverse steps of the dimensioning process are itemized and defined for coverage and capacity planning are advanced for dimensioning of LTE radio access networks and special significance is arranged on radio link budget laterally through comprehensive coverage and capacity [3].

Fifth Generation (5G): It is next coming phase of wireless networks. A notion shift to 5G is built on present drifts. It is generally expected that 5G cellular networks must address six challenges that are not efficiently addressed by 4G. These challenges are. higher capacity, higher data rate, lower end to end latency, massive device connectivity, reduced cost and consistent quality of experience provisioning. It conveys 10 times more capacity than other existing systems. It expected speed will be up to 1Gbps. It is completely wireless communication with almost no limits supporting Wireless World Wide Web (WWWW). It provides high capacity, large phone memory, faster data transmission, supports interactive multimedia, etc.

The 5G networks are considered for a completely new era with noticeably increased data rates, number of simultaneously connected Internet of things devices, low latency, and a variety of use cases. Future wireless systems are predictable to use more bandwidth by manipulating spatial diversity techniques with massive MIMO and beamforming. Higher consumer throughput will be attained mostly through carrier aggregation and the use of new frequency bands. The general cell density is therefore projected to increase, while more devices with lower transmission power, transmission or reception gains are expected to be supported by 5G networks. The key benefit points are better or more effective techniques to deliver better network capacity, latency, mobility and transmission speeds.

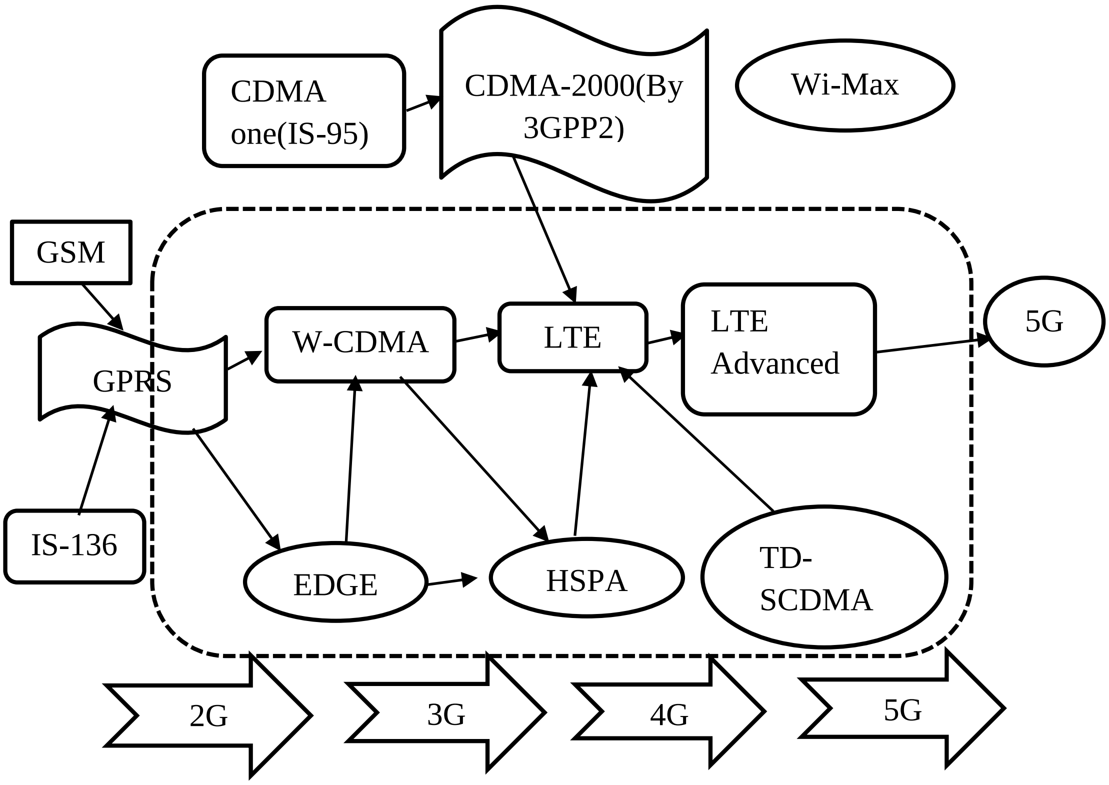


Figure 1.1 Evolution Phases of Mobile Network Technology

The comparison between the 4G and 5G networks are shown in Table 1.1

Table-1.1: The improvements involved in 5G is compared with 4G in the following

Parameter	4G	5G
Maximum data rate	1Gbps	20Gbps
Customer experienced data rate	10Mbps	100Mbps
Spectrum efficiency	-	x 3
Area traffic capacity	0.1Mbps/m^2	10Mbps/m^2
Latency	10ms	1ms
Connection density	100,000/km^2	1,000,000/km^2
Network energy efficiency	-	x 100
Mobility	350km/hr	500km/hr

1.2. Statement of the Problem

In Ethiopia extensive telecom expansion projects are experiencing all over the country. These kinds of projects need qualified and dynamic professionals in the field of network dimensioning and design areas. There will always be an expansion projects to satisfy an ever increasing user demand for various kind of services and mobile applications. Since, the system to be deployed is a new technology, the nominal planning phase has been considered as important point. Because, it provides the first rough estimation to coverage and capacity. In this thesis Kirkos Subcity has been considered as a case study. Because this Subcity contains different hot spot areas including: International Hotels, Government Offices, Different Banks and the Economic Commission for Africa(ECA). Users in this area would require considerable internet speed and connectivity. During problem identification thing that has been obviously seen is that, demand on higher capacity, higher data rate, lower end to end latency, massive device connectivity, and multimedia services. This is due to Coverage and Capacity limitation in existing networks. Considering this fact, in this thesis, a comprehensive investigation for 5G radio network dimensioning has been conducted to enhance Coverage, Capacity and QoS and as well as to address challenges in cellular networks that are not effectively addressed by 4G. Thus, the choice of 5G network for this Sub city is the right decision.

1.3. Objectives of the Thesis

1.3.1. General Objective

The general objective of this thesis is to come up with 5G radio network dimensioning and millimetric wave propagation modeling for the case of Kirkos Sub City (Addis Ababa).

1.3.2. Specific Objectives

This study is carried out specifically to accomplish the followings specific objectives:

- To dimensioning 5G new radio in terms of radio coverage and capacity;
- To calculate the number of sites based on coverage for target area;
- To dimensioning network capacity and capacity based sites count;
- To simulate the planned network with the help of Winprop network planning tool;
- To model propagation channel for millimeter wave.

1.4. Scope and Limitation of the Thesis

1.4.1. Scope of the Thesis

This thesis is limited to the 5G radio network dimensioning for the case of Kirkos Subcity (Addis Ababa). Coverage prediction and Capacity evaluation is performed for only this Subcity.

1.4.2. Limitations of the Thesis

Subsequently, the Winprop simulation software is essentially used for planning of radio network, flexibility of simulation work has been limited. Which means, there is a delay while running the simulation with the increase number of sites(gNodeB). Furthermore, uniform traffic and static simulation assumption are considered and thus the evaluation and optimization does not include impacts of traffic non-uniformity and network dynamism.

1.5. Contributions

As mentioned in previous sections, this thesis work studies 5G radio network dimensioning interms of coverage, Capacity and Quality of services. Cellular radio network planning is one of the challenging tasks in telecommunication industry due to technologies progression as well as the increasing network size arising from wireless communication service demand from the public at large. Therefore, special consideration has to be given for nominal and detailed radio network planning. To attain the desire target network requirements after deployment, this study contributes on how to perform 5G radio network planning for target area to help operators and local practicing engineers. It gives detail considerations about coverage prediction and capacity evaluations by using radio network planning tool. i.e Winprop software which gives clear prediction for the target area with proper propagation modeling (Dominant pathloss model). Also, this thesis studies about propagation channel modeling for millimeter wave. This portion discusses about some of organization which contributes channel models for millimeter wave. So, this is very useful to categorize which channel models are used for millimetric wave frequency.

1.6. Thesis Organization

This thesis document is comprising of 5 Chapters. first Chapter presents the introduction, statement of problem, objectives of the thesis, Scope and Limitations of the thesis and

Contributions of the thesis. The second Chapter presents Literature review and Fundamentals concepts of 5G New radio.

Chapter three presents the methodology, mathematical analysis and the theoretical result from input data and throughput formula. It is the central part of this thesis. This Chapter also contains radio link budget calculation, coverage and capacity planning, selection of propagation models and calculation of site numbers based on capacity and coverage. Chapter four presents Simulation, result analysis and discussion of the of the deployed network and finally Chapter five presents conclusion by summarizing the total this research contents and discourses opportunities of recommendation for coming thesis.

CHAPTER 2

2. LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.1 Overview of the Chapter

This chapter delivers an overview of the 5G system. This chapter covers: Related works, 5G architecture, 5G New Radio requirements and targets, 5G New Radio frequency bands, Technologies used in 5G New Radio, radio interface novelties, 5G network layers and finally wave forms, numerology and frame structure are presented.

2.2 Related Works

This section addresses the work studied by other authors similar to the dimensioning of coverage and Capacity of 5G networks. For each project one explains their methodologies, conclusions and results realized with their respective simulations. Research is deliberated mainly from three sources, academic works, IEEE based literature and institutional research from entities such as METIS, 5G Americas, 3GPP or 5GPPP. In terms of frequency band studies for cellular network design, literature research has been noted to consist essentially of three elements, the first on previous cellular network design studies for LTE networks from the 0.8 to the 2.6 GHz bands, the second on proposals for developing networks based on the mm-wave spectrum band where additional propagation effects may provide usefulness when analyzing the impact of 5G's 3.5 GHz band, and the third on early proposals for dealing with frequency band elements in 5G NR such as numerology and propagation effects.

The coordination of air interfaces for radio network access in 5G Networks presented in [4]. This group develops the general 5G radio access network strategy and provides the practical enablers desired for well-organized arrangement and use of the different 5G technologies and constituents presently advanced. In addition, 5G cooperation structure contained by 5GPPP (5^{th} Generation partnership project) for a common evaluation of 5G radio access network concepts have been delivered by this group. To this end, they made a simulation to evaluate the impact of different waveforms and other parameters to offer multiple services.

These multiple services vary between the key ones studied in the 5G deployment, like mMTC and eMBB. The result of this project is a simulation for different scenarios using macro and micro cells to deliver the 5G services in an urban environment. This study is made mostly to evaluate 5G wave forms and multiple access rather than focused on coverage and capacity dimensioning by using radio network planning and optimization tool.

The use of millimeter waves for implementation on communication networks has been examined in [5]. In this studies important features about the feasibility and technical implementation for the frequency band 6-100 GHz has been analyzed. This project also affords major improvements, e.g. regarding ground reflection and blockage effects, spatial consistency and outside to inside penetration loss modeling. They made simulations and outdoor experiences (28 GHz, 500MHz bandwidth, Cyclic prefix orthogonal frequency division multiple access and Direct Fourier orthogonal division multiple access to prove the concept besides what aspects should be worked on. This study is mainly focused on the use of millimeter waves implementation on communication networks. They made simulation on 28GHz outdoors only (Indoors are not considered) and target area is not deliberated. And also the study is not specific.

In [6], 5G test network has been taken to experiment for different services that is meant to be used on the next generation telecommunication network. To this purpose, they afford state of the art equipment to test 5G services mainly on the IoT (internet of things). This study mainly focus on the use of millimetre waves to cover a certain area, implementing micro cells. Testing multiple radio access techniques to measure the quality of services for several facilities that 5G networks will provide also considered in this studies. They also offer data analytics infrastructure to best analyse results. This study is targeted on testing 5G multiple access techniques and internet of things(IoT). Also, in this study target area and radio network planning and optimization(RNPO) tool is not deliberated.

The use of millimeter waves in Radio access network, Fronthaul and Backhaul studied in [7]. This studies have made tests in order to implement millimeter waves in different scenarios. The use of micro cells to implement the radio access at dense areas being indoors or outdoors has been analyzed in this study. This study is mainly targeted to analyze the use of millimeter waves in Radio access network, Fronthaul and Backhaul (this is between core network and transceiver(gNodeB's)). Radio network planning between transceiver and user equipment is not presented in this study.

In [8], flexible air interface for scalable service delivery within wireless communication networks of 5G has been reviewed. They made simulations to subsidize to the standardization of 5G requirements, providing results of the Key Indicators that need to be achieved to improve capacity, reliability, latency and efficiency of the new network. This studies is only for the spectrum below 6 GHz and uses as reference the E-UTRAN of the LTE network for the general simulations, e.g. the study of interference, capacity and coverage.

The evaluation of the capacity and coverage of millimetre waves at 27 GHz spectrum has been presented in [9]. They did simulation in the language of C++ to made a model for the system capacity and coverage. In this study, the results from simulations impact mainly on the antenna structure level, contributing with information concerning the architecture and structure of the antennas for the 5G network on high frequency bands. Although, target area is not considered.

In [10], the implementation of millimeter waves at 28 GHz in the 5G network has been done. The results allow to compare the quality of the signal in LoS and in NLoS comparing the intensity of the SINR and the value of throughput. This study summarized all about the implementations of millimeter waves at 28GHz. It is not about 5G coverage and capacity dimensioning. The results from simulation is illustrates about the comparison of signal quality in LoS and NLoS and the study is not on the target area.

Dimensioning of wireless-optical hybrid of 5G networks have been studied in [11]. In this study, expressions to estimate the network parameters of the constituent elements of the network in terms of node and link parameters has been presented. And also the expressions for coverage and capacity estimation for the frequency band of 3.5 GHz have been analyzed. This study is not considering target area or specific area. And also RNP (Radio network planning) tool is not considered. In this study capacity is simply estimated, means capacity analysis by using traffic engineering is not presented.

2.2 Fundamental Concepts of 5G New Radio (5G NR)

2.2.1 5G New Radio Network Architecture Overview

The fifth generation of the wireless access technology is known as 5G New Radio (5G NR) and it has been advanced by the Third-Generation Partnership Project (3GPP) over the past years with the goal to address a variety of scenarios to be permitted by future improved mobile technologies. Compared to LTE, the preceding 4G radio access technology, 5G NR offerings many benefits, such as:

- Manipulation of higher frequency bands in order to support very wide transmission bandwidths and very high data rates;
- Ultra-lean design to enhance network energy performance and reduce interfering; avoiding the always-on transmissions;
- Sustenance of multiple subcarriers spacing, Low latency to improve performance.
- Onward compatibility for the future, enabling new services yet unknown;
- Beam-centric design permitting extensive usage of beamforming and massive number of antenna elements.

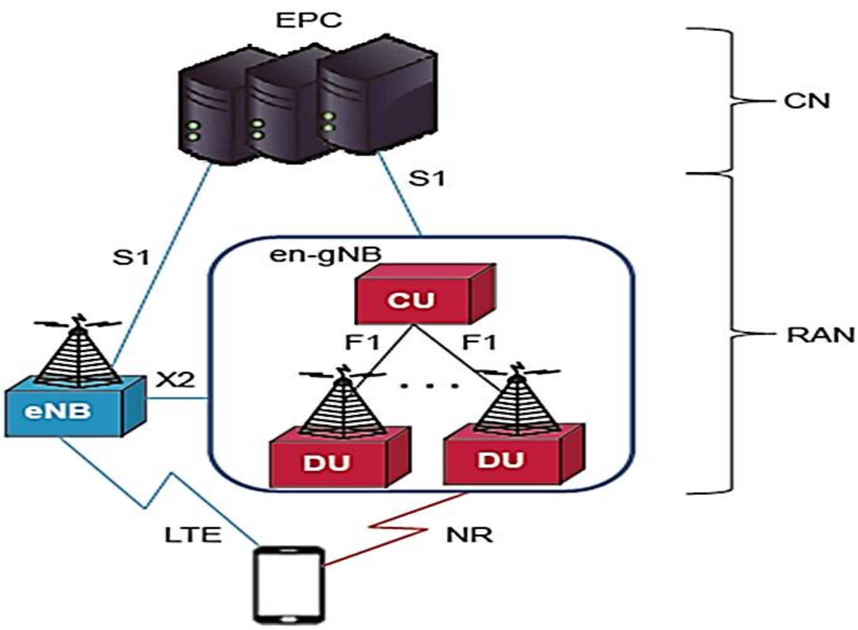


Figure 2.1: Radio access network for Non-standalone operation [32]

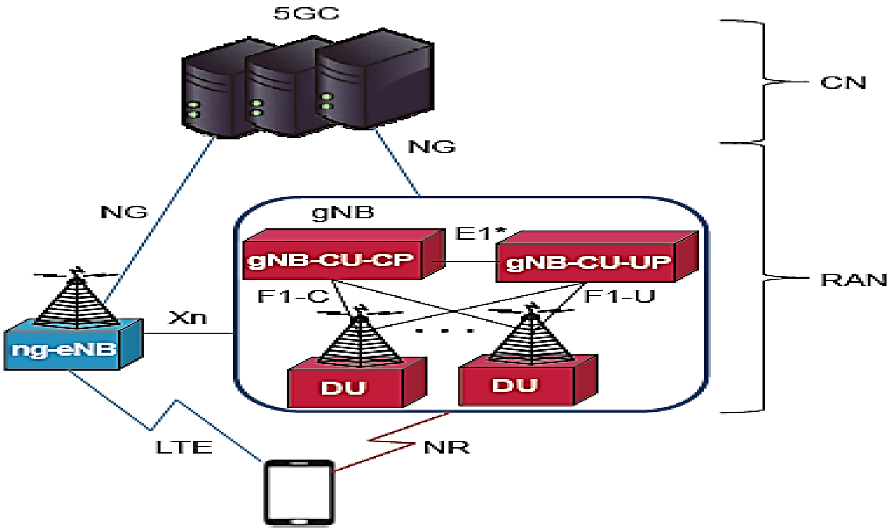


Figure 2.2: Radio access network for Stand-alone operation [32]

3GPP Release 15 delivers specification for both non-standalone operation and stand-alone operation. **Non-standalone** operation is where facilities are delivered in combination with existing LTE/LTE-advanced networks. In contrast **Stand-alone** operation is where New Radio (NR) facilities can be operated alone. In the central network the Evolved Packet Core (EPC) which was conventionally used for LTE, is used for non-standalone operation. While a new 5G Core (5GC) is used for stand-alone operation. The 5G network is still being advanced so there is no final consensus of its standardization yet, though there are proposals for its implementation. Figure 2.1 and Figure 2.2 shows the operations of Standalone and Non-Standalone respectively.

The main functions of the components from above figure is as follows:

RAN(Radio Access Network): A network involving of radio base stations and radio circuit control apparatus positioned between the core and mobile terminals.

CN(Core Network): A network consist of switching equipment,subscriber information, managing equipment,etc. a mobile terminal joins by the core network through a radio access network.

EPC (Evolved Packet Core): A core network that can build different radio access systems including Long term evolution.

gNB (Next-generation NodeB): Node providing NR user plane and control plane protocol terminations towards the UE, and connected via the NG Interface to the 5GC.

Ng-eNB (Next generation enhanced NodeB): Node providing E-UTRA user plane and control plane protocol terminations towards the UE, and connected via the NG interface to the 5G. The gNBs and ng-eNBs are connected to each other by means of the Xn interface. The gNBs and ng-eNBs are also joined via the NG interfaces to the 5GC, more explicitly to the AMF (Access and Mobility Management Function) through the NG-C interface and to the UPF (User Plane Function) by means of the NG-U interface.

NG-C (Next Generation Control plane): Control plane line between NG-RAN and 5GC.

NG-U (Next-Generation User plane): User plane crossing point between NG-RAN and 5GC.
Xn: Network interface between NG-RAN nodes.

The 5G network is still being progressive so there is no final consensus of its calibration yet, though there are proposals for its implementation. Nevertheless, the specification of the general architecture of this new network is getting a final shape and has some similarity with the LTE one. Figure 2.3 illustrates an overview of the architecture proposed where the NG-RAN represents the New Generation Radio-Access Network and 5G Core. To interconnect the system there are the NG and Xn interfaces, where Xn is used to connect the base stations between each other while NG connects the NG-RAN to the 5GC.

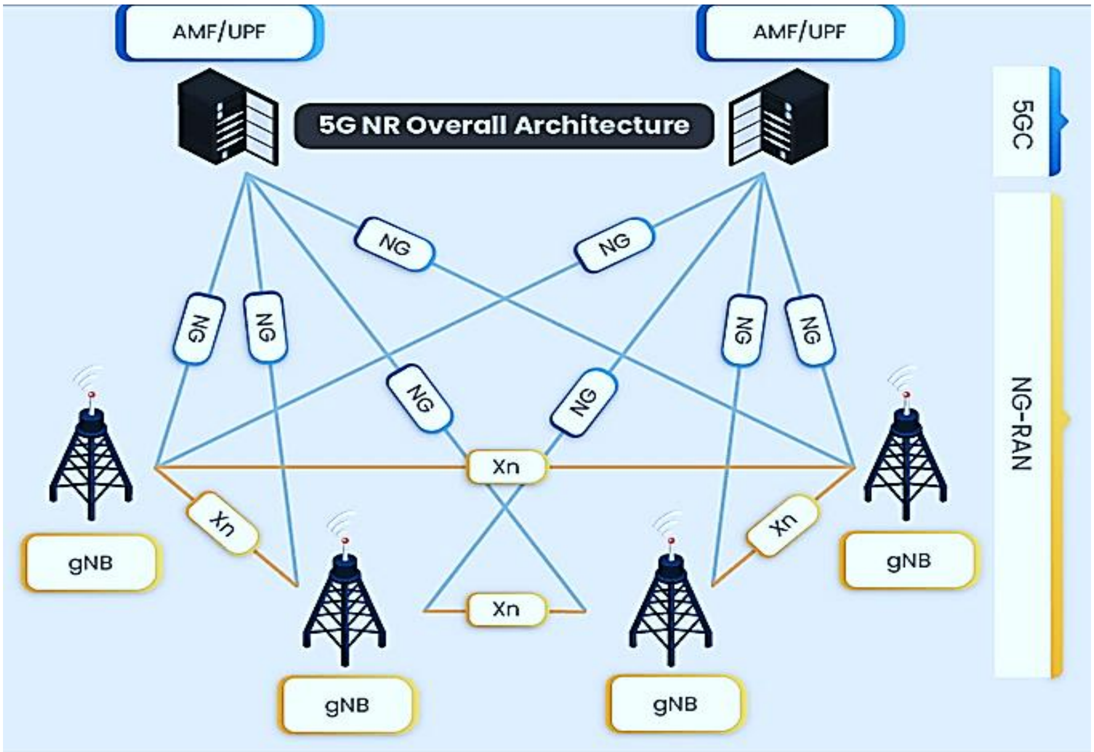


Figure 2.3: General 5G system architecture [12]

This architecture is being updated as 3GPP makes a new release of the development of the 5G network. Currently Release 15 states a more complex and complete architecture presented in Figure 2.2. The modules that are important for this thesis are the User Equipment (UE), RAN, UPF, AMF, SMF and DN. The other ones have functions related to management and policies of the network. These modules can be designated as:

- The Consumer Equipment, UE, is the physical device that can be associated to a person or a network of devices and is connected to the RAN module.
- The Radio Access Network, RAN, is composed of the gNodeBs (NG-RAN). This module passes the connection to the AMF or to the UPF. The AMF is where the termination of the RAN and UE interface ends, N2 and N1 respectively.
- This module is responsible for the access authentication and authorisation process. It comprises the NAS Security and the Idle State Mobility Handling.
- The UPF is responsible for the anchor point for Intra/Inter Radio Access Technology (RAT) mobility, when applicable.
- The SMF, Session Management Function allocates the IP address for the UE and controls the packet data unit session.

- The Data Network, DN, represents the core of the internet that the 5G network is connected.

Functions of each term from above General 5G system architecture and others:

gNodeB and ng-eNB: For Radio Resource Management, Radio Bearer Control, Radio Admission Control, Connection mobility Control, Dynamic allocation of resources to UEs in both uplink and downlink (scheduling) and etc.

Next Generation-Control plane interface (NG-C): is established among the Subsequent Generation radio access network node and the access and mobility management function NG interface management, User (User equipment) setting management, UE flexibility supervision, Transport of Non-access stratum communications, Calling, Protocol data unit Assembly Management, Arrangement Transfer;

Xn-User Plane: Provides non-guaranteed delivery of user plane PDUs and supports the following functions, data forwarding and flow control.

Xn Control Plane: crossing point the following functions; Xn line controlling, User equipmet movement managing, including: setting transfer and Radio access network contacting.

Access and Mobility Management Function (AMF): including the termination of RAN CP interface (N2) and of the NAS interface (N1), NAS ciphering and integrity protection, mobility management, lawful interception, access authentication and authorization, security anchoring, and security context management.

Session Management Function (SMF): including session management, UE IP address allocation and management, UP functions selection and control, termination of interfaces towards PCF, policy enforcement and QoS, and roaming functionality. The SMF is connected to the UPF via the N4 interface.

Authentication Server Function (AUSF): providing authentication and authorization functionalities;

Network Exposure Function (NEF): providing means to collect, store and securely expose the services and capabilities provided by 3GPP.

Network Function Repository (NFR): maintaining and providing the deployed NF instances information when deploying, updating or removing NF instances, and supporting the service discovery function.

Policy Control Function (PCF): supporting a unified policy framework to govern network behaviours, providing policy rules to control plane function(s) to enforce them.

Unified Data Management (UDM): supporting the Authentication Credential Repository and Processing Function, storing the long-term security credentials and subscription information; Application Function (AF), representing any additional CP function which might be required by specific network slices, and is potentially provided by third parties.

User Plane Function (UPF): anchor point for intra-and inter-RAT mobility, external PDU session point of interconnection, packet routing and forwarding, UP QoS handling, packet inspection and policy rule enforcement, traffic accounting, and reporting.

NG-RAN (Next-Generation Radio Access Network): comprises of a set of 5G base stations, termed as gNBs, which are linked to the 5GC over a set of logical crossing point. As per in LTE, gNBs and management purposes (inter-cell interference coordination) [13]. Therefore, the resulting architecture is shaped by a central unit (gNB-CU) that controls one or more distributed units (gNB-DU) over the F1 interface. A distributed unit is allied to a remote radio head (RRH), i.e., the actual radio transceiver. The central unit is once more split in two parts, one for control plane functions (gNB-CU-CP) and another for user plane functions (gNB-CU-UP).

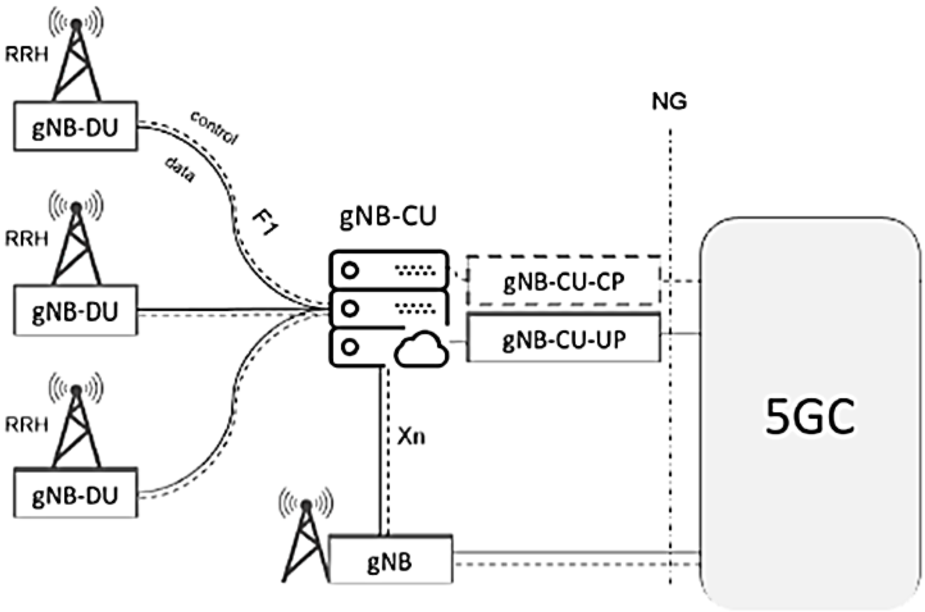


Figure 2.4: Overall NG-RAN Architecture [14]

The main functionalities of the different layers of NG-RAN protocol stack from Figure 2.5 below are as follows:

Physical layer (PHY): Covers the digital and analogue signal processing roles that the mobile and base station uses to send and receive information. It is built on OFDMA, with adaptive carrier arrangement (15,30,60,120,240 kHz) and an adaptive modulation/coding system (e.g., from $\pi/2$ BPSK to 256 QAM).

Medium access control (MAC): protocol delivers low-level control of the physical layer mainly by scheduling data transmissions among the mobile and the gNB.

Radio link control (RLC): protocol confirms consistent delivery of data streams that essential to attain intact (HARQ). It also grips segmentation.

Packet data convergence protocol (PDCP): Conveys out higher-level transport functions connected to header compression and security.

Service data adaptation protocol (SDAP): Maps the interface among the packet of a QoS drift and a data radio bearer (caused by the new QoS framework) by marking the consumer data packets suitably.

Radio resource control (RRC): is the signaling protocol recycled in "access stratum" techniques containing the mobile and the gNB. It consists of connection establishment and release functions; the broadcast of system information; radio bearer establishment, reconfiguration and release; RRC connection mobility processes and power control.

Non-access stratum (NAS): is protocol the signaling protocol charity among the UE and the 5GC for PDU session management, security, mobility management, etc. The 5GC object that receipts care of controlling the UE is the access and mobility management function (AMF), which is alike to the LTE MME.

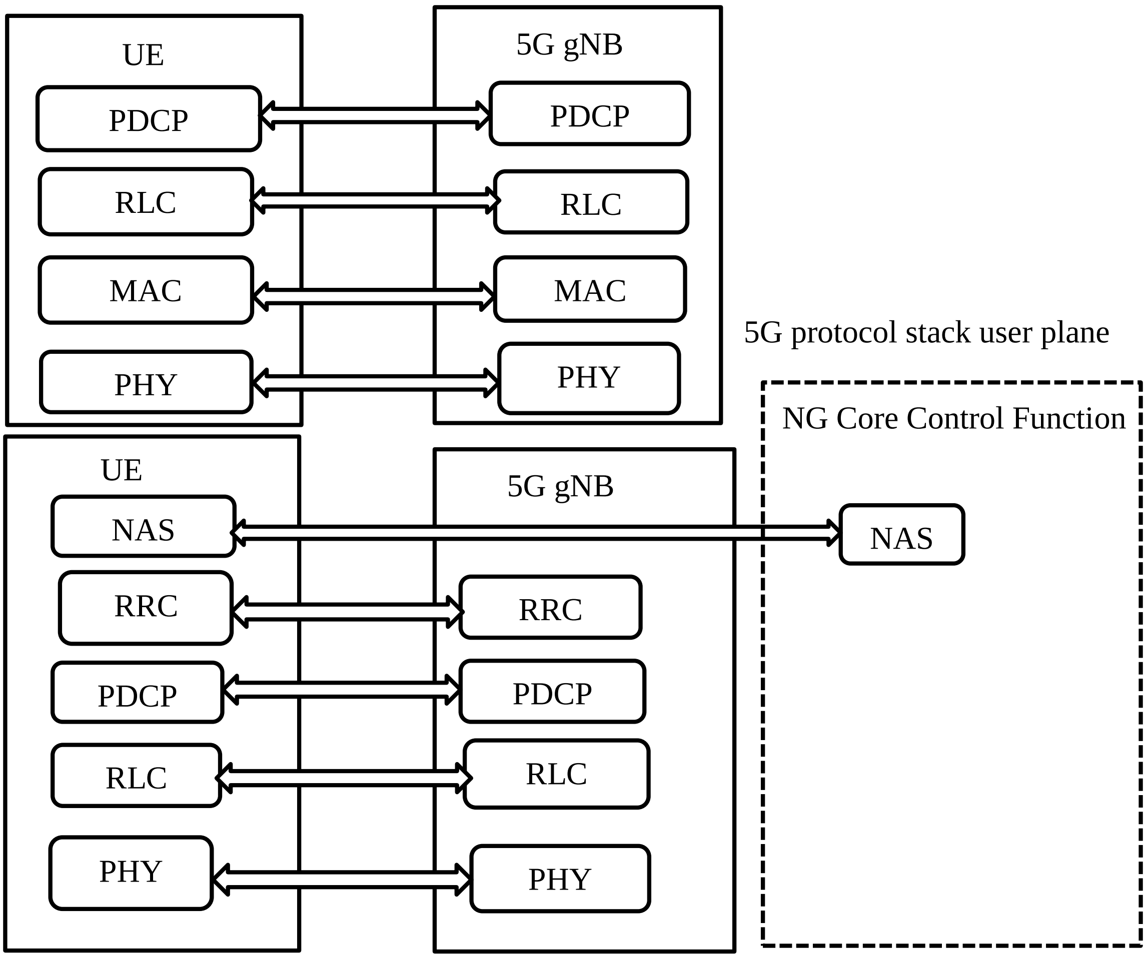


Figure 2.5: NG-RAN Protocol Stack

2.2.2 5G New Radio Technical Requirements and Targets

The following Table summarizes the minimum requirements related to technical performance for IMT-2020 radio interfaces, which are based on a set of capabilities needed to support the 5G use cases and usages scenarios. Table 2.1 describes the technical requirements and targets for 5G New Radio.

2.2.3. Frequency Bands of 5G New Radio

New radio can be deployed in different frequency bands, which were defined by 3GPP on the Release 15 work. Because of different Radiofrequency requirements (e.g. maximum transmission power), these bands were divided into two frequency ranges:

Frequency range 1 (FR1): that contains all existing and new bands below 6 GHz or changed to 7.125 GHz.

Frequency range 2 (FR2): that contains new bands in the range of 24.25 – 52.6 GHz. At the same time, 3GPP defined the operating bands, corresponding to different frequency ranges for downlink and uplink. Table 2.2 and 2.3 describes the summary of key parameters and operating bands for 5G New Radio respectively.

Table 2.1: Technical requirements and targets [15]

Parameter	Minimum technical performance requirement
Maximum data rate	Downlink: 20 Gbps Uplink : 10 Gbps
Maximum spectral efficiency	Downlink: 30 bit/s/Hz Uplink : 15 bit/s/Hz
Customer -experienced data rate	Downlink: 100 Mbps Uplink : 50 Mbps
Area road traffic capability	10 Mbps/m^2 (indoor hotspot for eMBB)
Customer level latency	4 ms for eMBB , 1 ms for URLLC
Control level latency	20 ms
Connecting density	1,000,000 devices per km^2
Vigor efficiency	Effective data broadcast in weighted down case Low energy ingestion when there is no data. High sleep ratio; Long sleep duration.
Consistency	1-10-5 achievement probability of transmitting a layer 2 PDU of 32 bytes within 1 ms, at coverage edge in Urban Macro
Flexibility	1.5 bit/s/Hz at 10 km/h for interior hotspot eMBB ,1.12 bit/s/Hz at 30 km/h for dense urban eMBB, 0.8 bit/s/Hz

	at 120 km/h for pastoral eMBB ,0.45 bit/s/Hz at 500 km/h for rural eMBB.
Movement break time	0 ms
Bandwidth	As a minimum 100 MHz and up to 1 GHz in higher frequency bands. Scalable bandwidth shall be supported.

Table 2.2. Summary of key parameters for 5G New Radio [16]

Parameter	FR1(450-6GHz / 7.125GHz	FR2(24.25 – 52.6 GHz)
Carrier aggregation	Up to 16 carriers	
Bandwidth per carrier	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 90, 100MHz	50, 100, 200, 400 MHz Subcarrier
Subcarrier spacing	15, 30, 60 kHz	60, 120, 240 (not for data) kHz
Max.number of subcarrier	3300 (FFT4096 mandatory)	
Modulation scheme	QPSK, 16QAM, 64QAM, 256QAM; uplink also supports π/2-BPSK (only DFT-s-OFDM)	
Radio frame length	10ms	
Subframe duration	1 ms (alignment at symbol boundaries every 1 ms)	
MIMO scheme	Max. 2 code words mapped to max.8 layers in downlink and to max 4 layers in uplink	
Duplex mode	TDD, FDD	TDD
Access scheme	DL: CP-OFDM; UL: CP-OFDM, DFT-s-OFDM	DL: CP-OFDM; UL: CP-OFDM, DFT-s-OFDM

Table 2.3. NR (New Radio) Operating Bands [3]

NR Operating Band	Uplink Range(MHz)	Downlink Range (MHz)	Duplex Mode
Frequency Range 1 (FR1)			
n1	1920 – 1980	2110 – 2170	FDD
n2	1850 – 1910	1930 – 1990	FDD
n3	1710 – 1785	1805 – 1880	FDD

n5	824 – 849	869 – 894	FDD
n7	2500 – 2570	2620 – 2690	FDD
n8	880 – 915	925 – 960	FDD
n12	699 – 716	729 – 746	FDD
n20	832 – 862	791 – 821	FDD
n25	1850 – 1915	1930 – 1995	FDD
n28	703 – 748	758 – 803	FDD
n34	2010 – 2025	2010 – 2025	TDD
n38	2570 – 2620	2570 – 2620	TDD
n39	1880 – 1920	1880 – 1920	TDD
n40	2300 – 2400	2300 – 2400	TDD
n41	2496 – 2690	2496 – 2690	TDD
n48	3550 – 3700		TDD
n50	1432 – 1517	1432 – 1517	TDD
n51	1427 – 1432	1427 – 1432	TDD
n66	1710 – 1780	2110 – 2200	FDD
n70	1695 – 1710	1995 – 2020	FDD
n71	617 – 652	617 – 652	FDD
n74	1427 – 1470	1475 – 1518	FDD
n75	N/A	1432 – 1517	SDL
n76	N/A	1427 – 1432	SDL
n77	3300 – 4200	3300 – 4200	TDD
n78	3300 – 3800	3300 – 3800	TDD
n79	4400 – 5000	4400 – 5000	TDD
n80	1710 – 1785	N/A	SUL
n81	880 – 915	N/A	SUL
n82	832 – 862	N/A	SUL
n83	703 – 748	N/A	SUL
n84	1920 – 1980	N/A	SUL
n86	1710 – 1780	N/A	SUL

Frequency Range2 (FR2)				
Band	Common name	Uplink Range(MHz)	Downlink Range (MHz)	Duplex mode
n257	LMDS	26500 – 29500	26500 – 29500	TDD
n258	K-band	24250 – 27500	24250 – 27500	TDD
n260	Ka-band	37000 – 40000	37000 – 40000	TDD
n261	Ka-band	27500 – 28350	27500 – 28350	TDD

2.2.4 Core Specifications

2.2.4.1 Operating Bands and Channel Arrangements

As renowned earlier, 3GPP defines only 4 bands for FR2. In general, there is less option for FR2- two Numerologies, no support for UL 256QAM, only four channel bandwidths.

Table 2.5 FR1/FR2 operating bands and channel arrangements

Parameter	FR1	FR2
Numerologies (SCS)	3 (15, 30, 60 kHz)	2 (60, 120 kHz) (Also, 240 kHz for SS/PBCH block)
UL Modulations	Pi/2 BPSK, QPSK, 16 QAM, 64 QAM, 256 QAM	Pi/2 BPSK, QPSK, 16 QAM, 64 QAM
Number of Bands	32 (as of Dec 2018)	4 (3 @ ~28 GHz, 1 @ 39 GHz)
Channel Bandwidth	12 different CBWs	4 (50, 100, 200, 400 MHz)
Intra-Band Carrier Aggregation	12 Classes (up to 8 CCs, and up to 400 MHz aggregate BW) Contiguous and Non-Contiguous	15 Classes (up to 8 CCs, and up to 1.2 GHz aggregate BW) Contiguous and Non-Contiguous
Inter-Band Carrier Aggregation (within FR)	Many defined	None defined
	5 defined:	

Inter-Band Carrier Aggregation (across FRs)	▪ 3 combining n257 (28 GHz) with various 3.5-5.0 GHz bands ▪ CA_n71-n257 (600 MHz + 28 GHz) ▪ CA_n8-n258. (800 MHz + 24 GHz)
NR-DC(New Radio Dual Connectivity)	3 combinations of n257 (28 GHz) with various 3.5-5.0 GHz bands (same combos as with CA).
EN-DC(LTE-New radio Dual Connectivity)	Many combinations, including with NR in FR1, FR2, and both FR1 and FR2.

Here are 15 classes of intra-band CA defined (more than for FR1). But there are only 5 inter-band NR CA arrangements demarcated, and they all chain an FR2 band (24 GHz or 28 GHz) with and FR1 band (600 MHz, 800 MHz, 3.5 GHz, or 5.0 GHz). Three of the CA (Carrier aggregation) combos (28 GHz with 3.5 or 5.0 GHz) are also defined as NR. Table 2.5 explains FR1/FR2 operating bands and channel schedules.

2.2.4. Technologies Used in 5G New Radio

5G New radio consist of different technologies, to deliver the very high levels of recital required of it. Technologies used with 5G New radio mobile communications comprise:

2.2.4.1 Waveforms and Modulation

5G technology has been preferred the waveform and modulation types provisions with to afford spectral efficiency, data throughput and flexibility required for the new mobile communications structure. In the conclusion the system was constructed nearby OFDM, with actual modulation set-ups dependent on the relationship and these include QPSK, 16QAM, 64QAM, 256QAM and on behalf of the uplink once DFT-OFDM is recycled, π/2-BPSK can be functioned.

5G New radio waveform arrangement is based on OFDM, CP-OFDM and DFT-s-OFDM by adaptive modulation together with QPSK and 16QAM, 64QAM, 256QAM [24].

Orthogonal Frequency Division Multiplexing (OFDM): Orthogonal frequency division multiplexing has been an excellent waveform and although providing flexibility to selective fading and it also allows multiple access competence to be carry out using OFDMA. Block diagram of OFDM is shown in Figure 2.6.

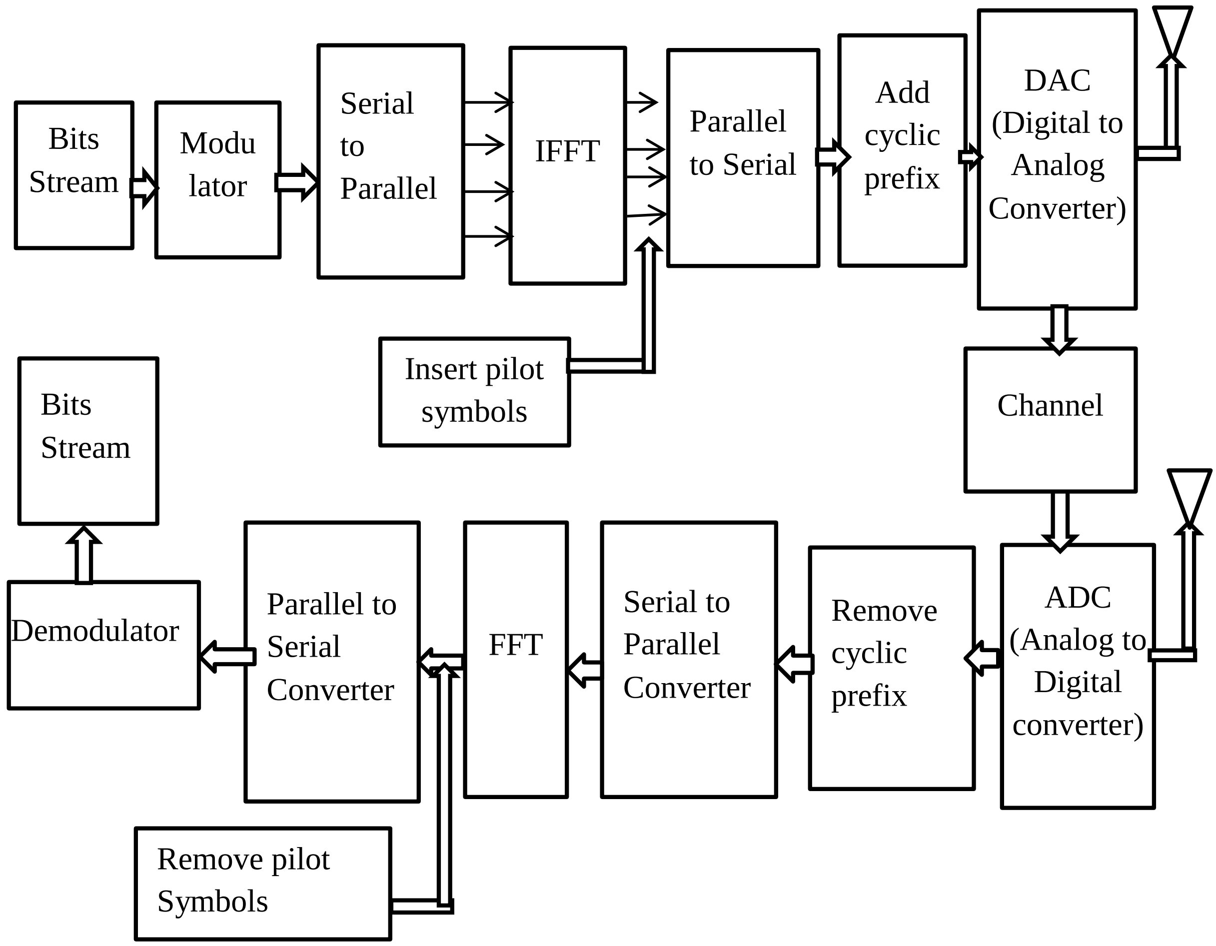


Figure 2. 6: Block diagram of OFDM

There are numerous benefits to the use of new waveforms for 5G technology. OFDM requires the use of a cyclic prefix and this occupies space within the data streams. There are also other advantages that can be introduced by using one of a variety of new waveforms for 5G. Some of the main requirements that need to be supported by the modulation scheme and overall waveform include:

- Capable of handling high data rate wide bandwidth signals;
- Able to deliver low latency transmissions for long and short data bursts;
- Adept of fast switching among uplink and downlink for TDD systems that are likely to be recycled;
- Allow the opportunity of energy efficient communications.

The modulation on the subcarriers can be QPSK, 16QAM or 64QAM. The 5G New Radio (NR) ordinary uses OFDM on both the uplink and downlink. The NR specification is deliberate with a high degree of flexibility to cover a diverse set of applications. The carrier spacing is flexible (15 kHz, 30 kHz, 60 kHz, 120 kHz, 240 kHz, 480 kHz) with up to 3300 subcarriers. The subcarrier modulation can be QPSK, 16QAM, 64QAM or 256QAM.

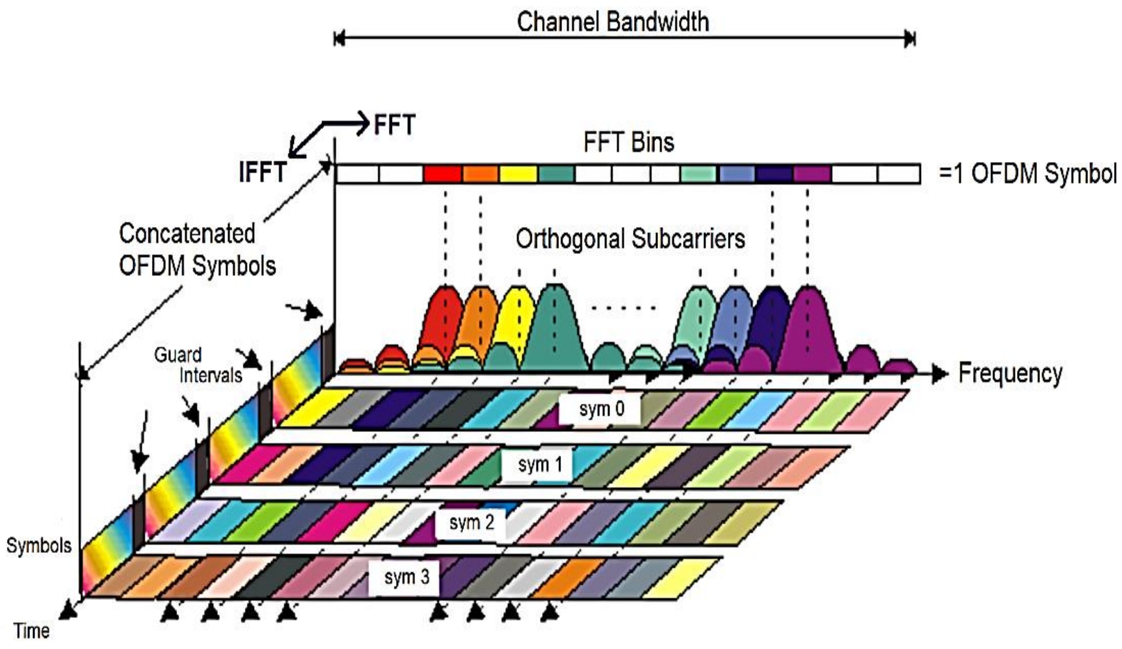


Figure 2.7: Frequency plus time representative of an OFDM signal [30]

Advantages of orthogonal frequency division multiplexing:

Immunity to selective fading: One of the principal advantages of OFDM is that is more resilient to frequency selective fading than single carrier systems because it divides the overall channel into multiple narrowband signals that are affected individually as flat fading sub-channels.

Resilience to interference: Interference give the impression on a channel may be bandwidth restricted and in this manner will not disturb all the sub-channels. This means that not all the data is lost.

Spectrum efficiency*:* Using close-spaced overlapping sub-carriers, an important OFDM advantage is that it makes capable use of the accessible spectrum.

Resilient to Inter Symbol Interference: An additional advantage of OFDM is that it is very resilient to inter-symbol and inter-frame interference. This results from the low data rate on each of the sub-channels.

Resilient to narrow-band effects: By means of adequate channel coding and interleaving it is conceivable to recover symbols lost due to the frequency selectivity of the channel and narrow band interference.

Simpler channel equalization: One of the problems using CDMA systems was the complexity of the channel equalization which had to be applied across the whole channel. An advantage of OFDM is that using multiple sub-channels, the channel equalization becomes much simpler. Whilst OFDM has been widely used, there are still a few drawbacks to its use which need to be addressed when considering its use.

High peak to average power ratio: OFDM signal has a noise like amplitude difference and has a comparatively high large vigorous range, or peak to average power ratio. This impacts the radio frequency amplifier efficiency as the amplifiers need to be linear and accommodate the large amplitude deviations and these factors mean the amplifier cannot operate with a high efficiency level.

Sensitive to carrier offset and drift*:* One more demerits of OFDM is that is sensitive to carrier frequency offset and drift. Single carrier systems are less sensitive.

Cyclic Prefix-OFDM (CP-OFDM): The explicit type of OFDM charity in 5G New radio downlink is cyclic prefix OFDM (CP-OFDM). In cyclic prefix OFDM the preceding part of data of OFDM frame is added at the start of the OFDM frame and length of cyclic prefix is selected to be greater than channel interruption. 5G New radio uplink has castoff a various format to 4G LTE. CP-OFDM- and DFT-S-OFDM-centered waveforms are recycled in the uplink. Furthermore, 5G NR offers for the use of flexible subcarrier spacing. Block diagram of OFDM with Cyclic prefix is shown in Figure 2.8.

Direct Fourier Transform spread OFDM (DFT-s-OFDM): Direct Fourier Transform spread OFDM, usually abbreviated to DFT-s-OFDM is an SC or single carrier-like transmission system that can be joined with OFDM that gives substantial flexibility for a mobile communications system like 5G. It is also normally known as SC-FDMA.The transmission progression of SC-FDMA is very alike to that of OFDMA. On behalf of each consumer, the arrangement of bits transmitted is mapped to a complex constellation of symbols (BPSK, QPSK or M-Quadrature amplitude modulation). Block diagram of DFT-s-OFDM is presented in Figure 2.9.

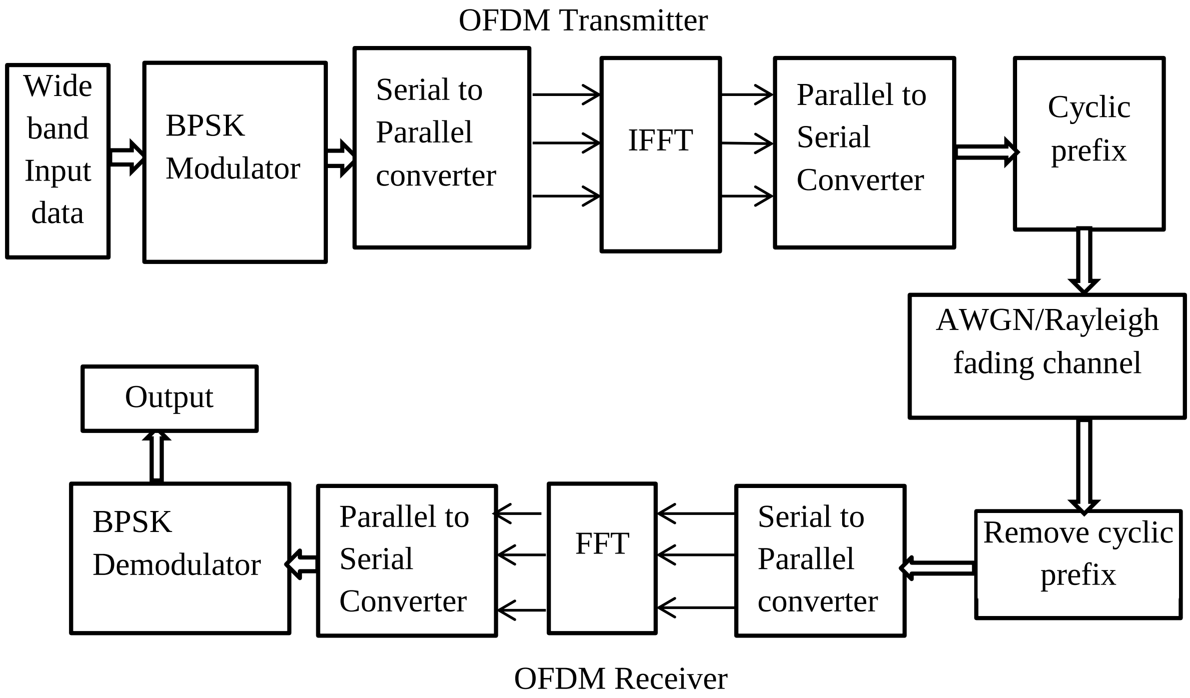


Figure 2.8: Block diagram of OFDM system with cyclic prefix

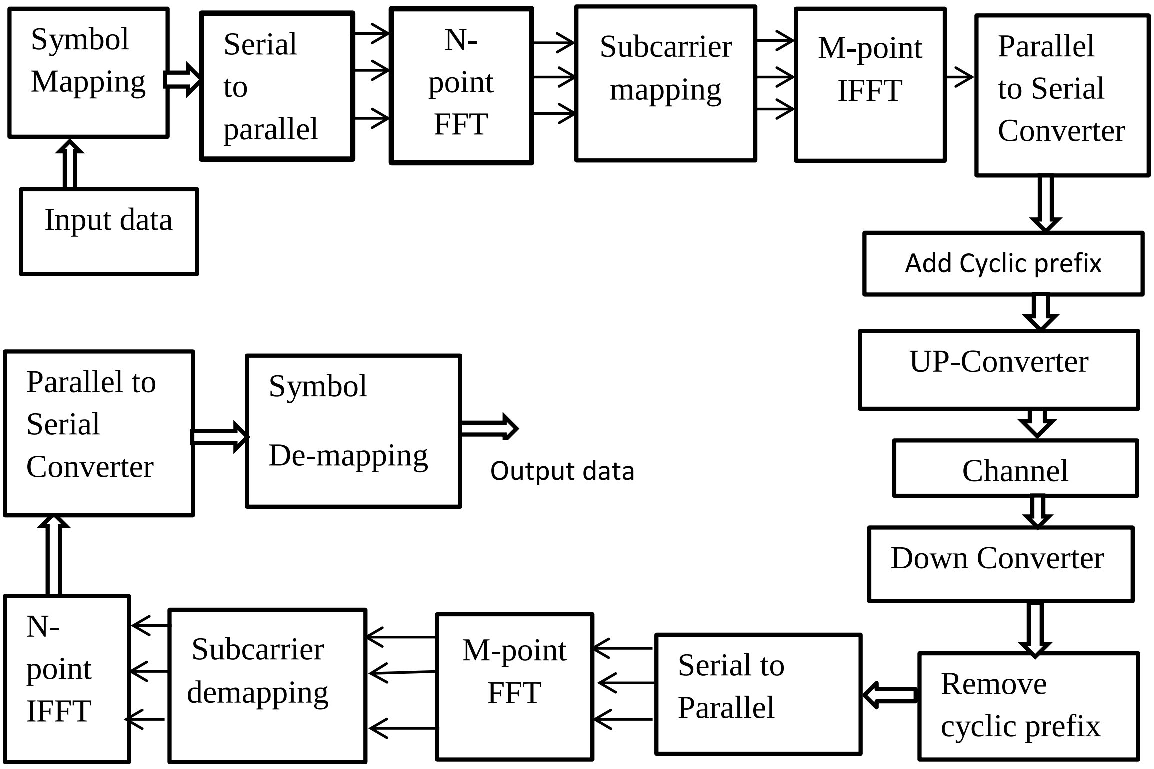


Figure 2.9: Block diagram of direct Fourier transform spread OFDM (DFT-s-OFDM)

2.2.4.2 5G New Radio Modulations

Contained by the general waveform format, diverse categories of carrier modulation can be used. The numerous considerations when using the different modulation formats:

Peak to average power ratio (PAPR): The maximum to average ratio has a direct impact on the efficiency of the power amplifiers. This means that the final Radio frequency amplifiers cannot be run in compression and as the PAPR has increased, so the efficiency of the radio frequency amplifiers has fallen and that has shortened battery life.

Spectral efficiency: The main concerns using any form of 5G modulation system is the spectral competence. Through spectrum existence at a premium, mainly in frequencies below 3 GHz, it is crucial that any modulation pattern accepted for 5G is capable of delivering a high level of spectral competence.

2.2.4.3 5G Multiple Access Schemes

There are numerous candidates that are being deliberated as the 5G multiple access schemes. **Orthogonal Frequency Division Multiple Access**: OFDMA uses the Inverse Fast Fourier Transform (IFFT) to capably create the time domain waveform from the array of modulated subcarriers. The resulting OFDMA signal is in digital form which ambitions the Digital-to-Analog Converter (DAC) which converts it to an analog signal.

At the receiver, the process is reversed. An analog downconverter (DN) shifts the OFDMA signal back to baseband. The Analog-to-Digital Converter (ADC) converts the signal to digital form and passes it on to the FFT block. The FFT block transforms the time domain signal back to the array of subcarriers carrying QAM modulation, in the frequency domain. Figure 2.10 displays block diagram of orthogonal division multiple access (OFDM).

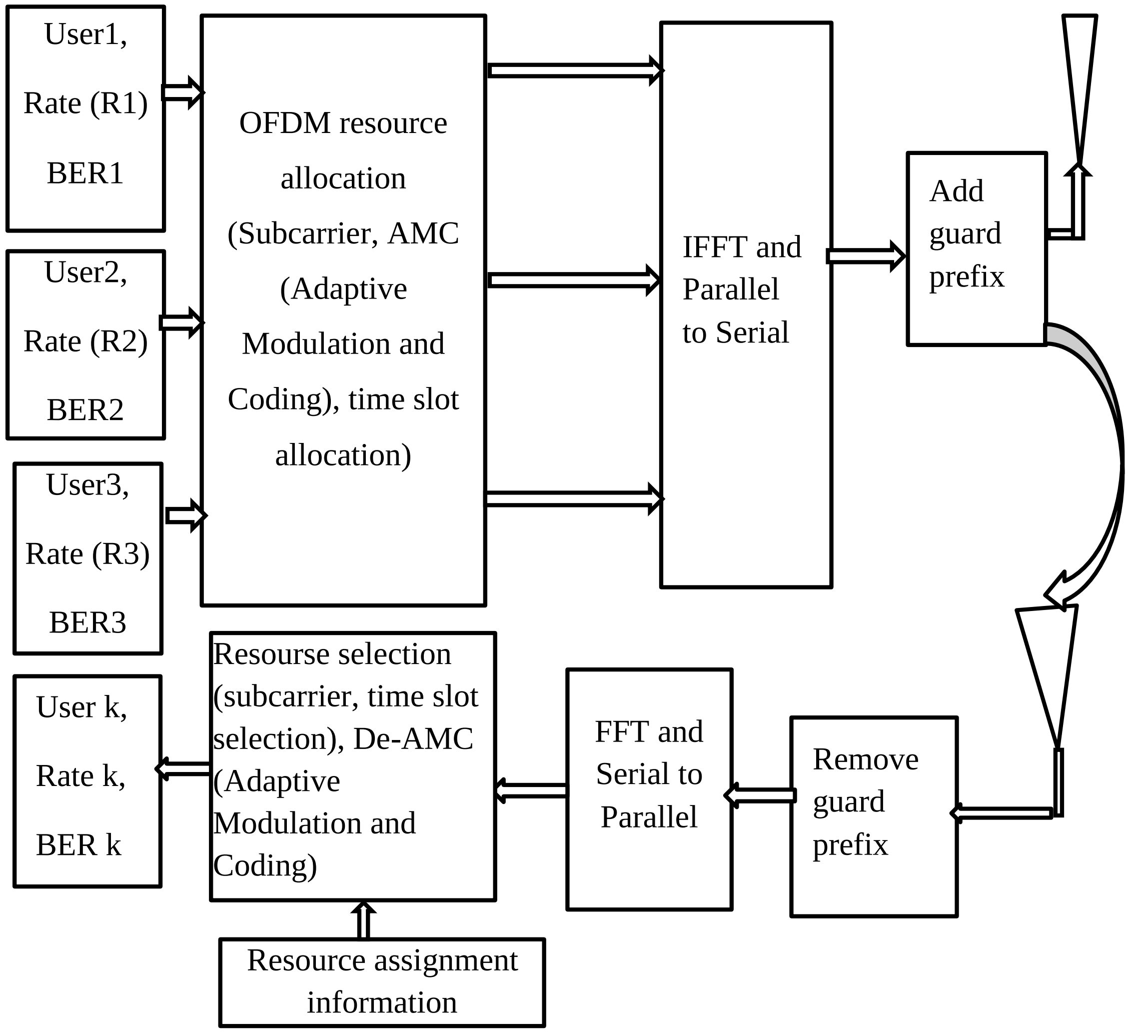


Figure 2.10: Block diagram of OFDMA

Single Carrier Frequency Division Multiple Access(SC-FDMA): It is impossible to use OFDM in the uplink link since, as expressed before, it offerings a high peak to average ratio. SC-FDMA (Singe Carrier FDMA) presents the advantages of a single carrier multiplexing of having a lower peak-to-average power ratio. In the case of SC-FDMA before applying the IFFT the symbols are pre coded by a DFT (Discrete Fourier Transform).

Sparse Code Multiple Access (SCMA): Sparse code multiple access (SCMA) is another clue which is deliberated as a 5G multiple access system and it is efficiently an assortment of OFDMA and CDMA. Ordinarily, in the case of OFDMA a carrier is assigned to a given user. Sparse code multiple access transceiver is presented in Figure 2.11**.**

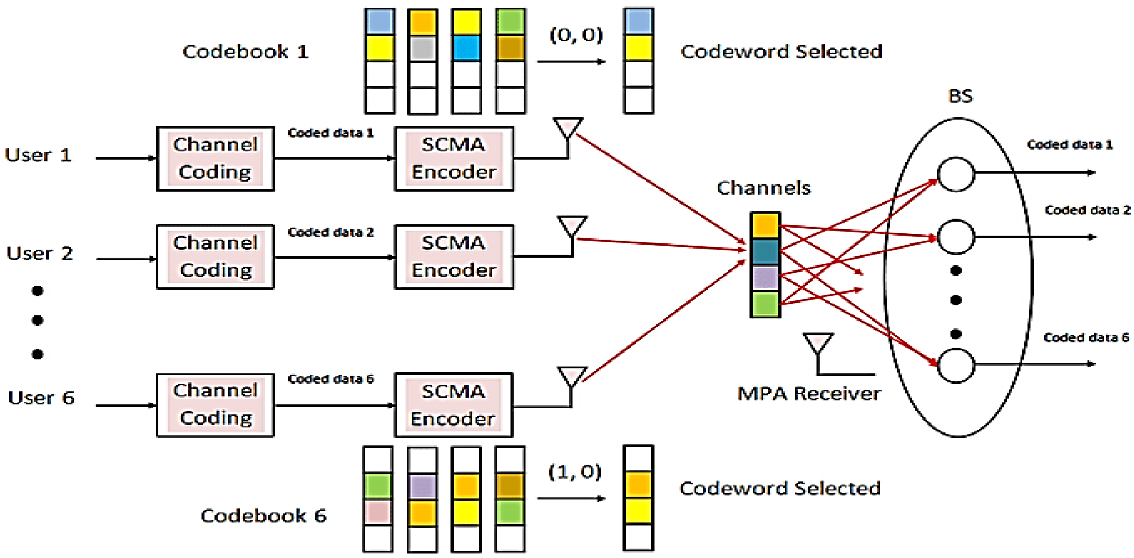


Figure 2.11: Sparse Code Multiple Access Transceiver [31

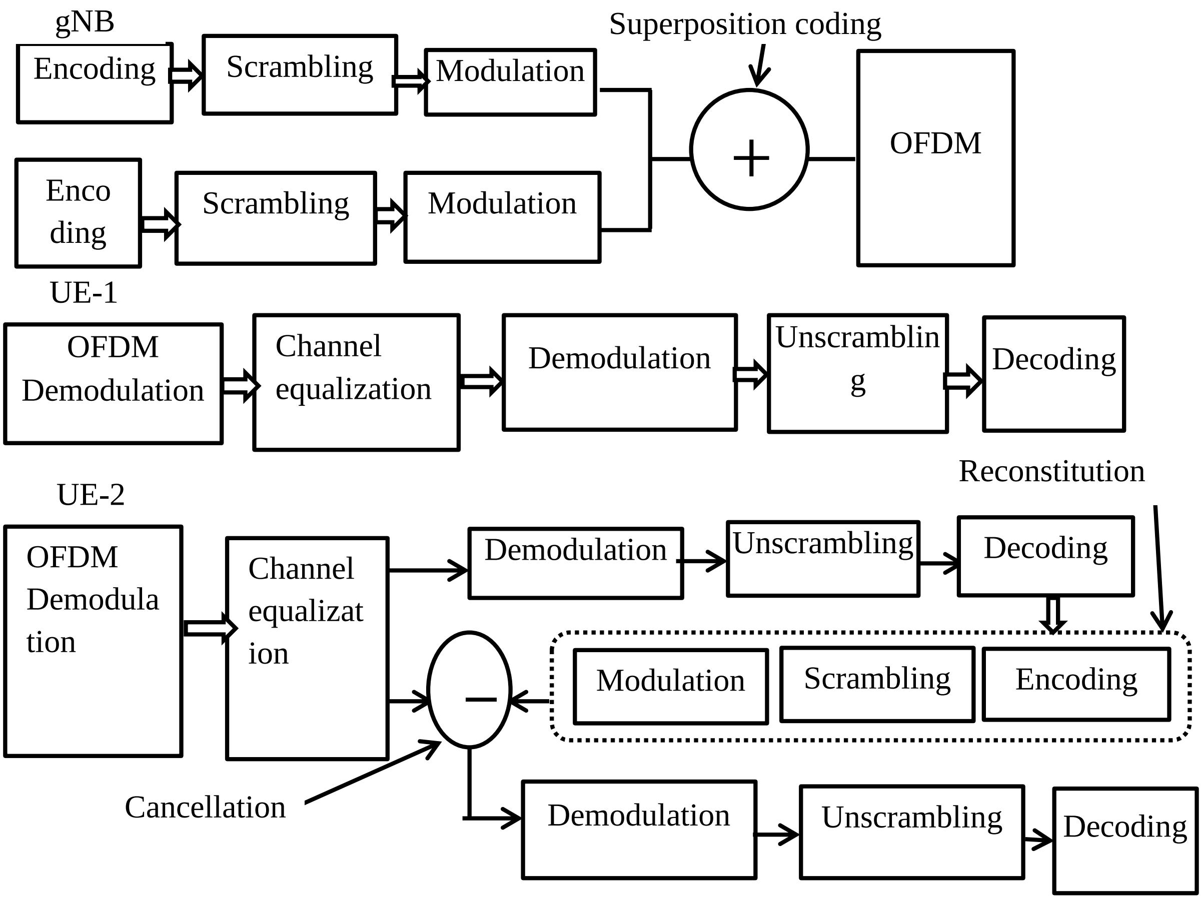


Figure 2.12: Implementation of NOMA Transceiver

Non-Orthogonal Multiple Access (NOMA): Non-orthogonal multiple accesses (NOMA) is one of the methods being deliberated as per 5G multiple access schemes. NOMA might use orthogonal frequency division multiple access, OFDMA or the discrete Fourier transform, DFT-spread OFDM. Non-orthogonal multiple access (NOMA) is the technique proposed for multiple access in the fifth generation (5G) cellular network. In NOMA, different users are allocated different power levels and are served using the same time/frequency resource blocks (RBs). Implementation of NOMA transceiver is shown in Figure 2.12.

2.2.4.4 MIMO (Multiple Input-Multiple Output)

MIMO is an antenna technology that increases the radio link by using the multiple paths over which signals travel from the transmitter to the receiver. 5G will proceeds full benefit of Multi-User- MIMO. Multi-user MIMO where it will deliver multiple access competences to MIMO by using the dispersed and uncorrelated spatial location of the different users. Figure 2.13 shows block diagram of MIMO system.

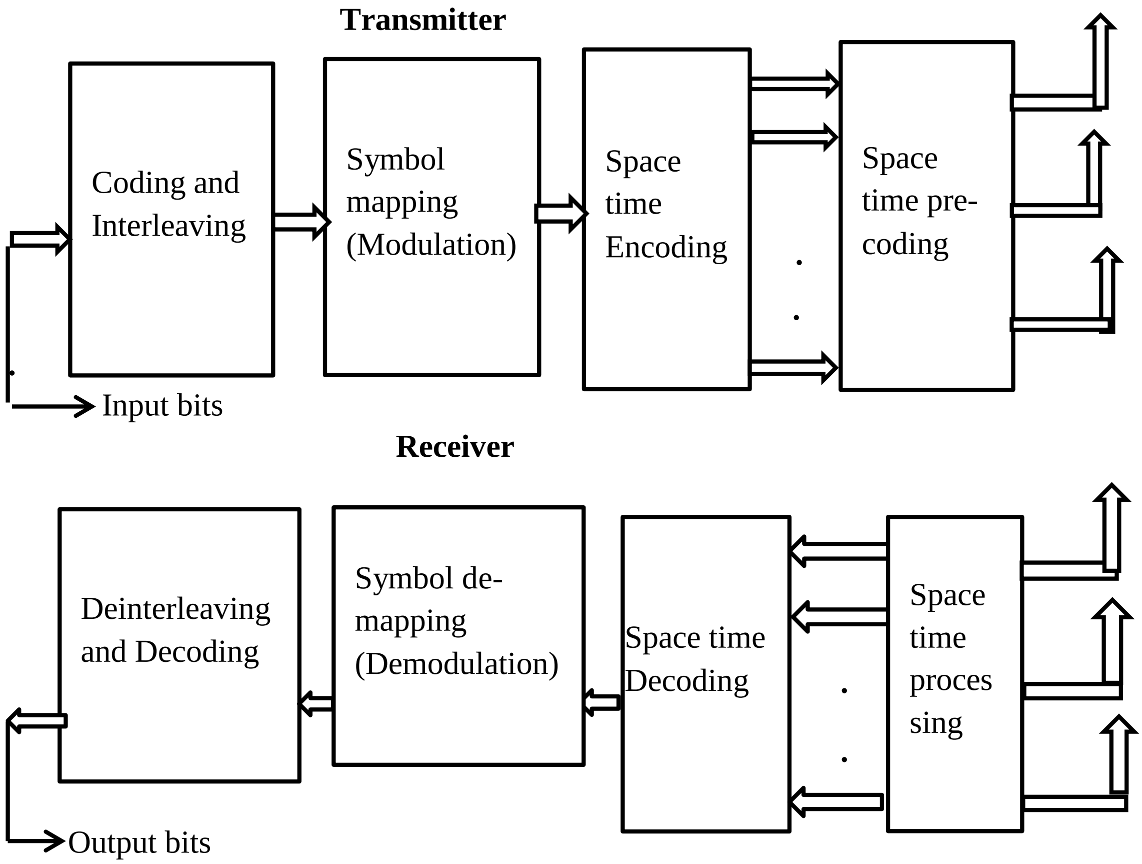


Figure 2.13: Block diagram of MIMO System

2.2.4.5 Millimeter Wave Communications

Millimetre wave mobile infrastructures is not carry out for the preliminary placements of the 5G mobile communications system. 5G with millimeter wave will need a large number of base stations to give the essential coverage. 5G propagation characteristics of millimetre wave bands are very diverse to those below 4GHz. normally distances that can be attained are very greatly less and the signals do not pass over walls and other objects in buildings. Usually, millimetre wave communication is expected to be recycled for outdoor coverage for dense networks.

2.2.4.6 Beamforming

Beamforming is a technology that has turn into reliability in recent years and it delivers some substantial advantages to 5G. It permits the beam from the base station to be concentrating towards the mobile. In this manner the optimum signal can be transmitted to the mobile and received from it, despite the fact that also cutting interference to other mobiles.

2.2.4.7 Small Cells

A small cell network is a collection of low power transmitting base stations which uses millimetre waves to increases the total network capacity. 5G small cell network functions by organizing an assembly of small cells to share the load and reduce the difficulties of physical obstructions which become more important at millimetre waves.

2.2.4.8. Duplex Schemes

5G New radio provisions both frequency-division duplex (FDD) for subordinate frequency bands and time-division duplex (TDD) for upper frequency bands, subject to either half-duplex or full duplex. For TDD operation, a lone carrier frequency is recycled for detached downlink and uplink transmissions. New radio practices vigorous TDD where a slot can be animatedly assigned to either uplink or downlink following of the scheduler decision. TDD permits switching the transmission path and to escape interference at the base station [17]. 5G New radio duplex schemes shown in Figure 2.14.

Conversely, in the case of FDD operation, uplink and downlink transmissions take place concurrently but use diverse carrier frequencies. Here is also conceivable a half-duplex mode, where transmissions are detached in frequency and in time.

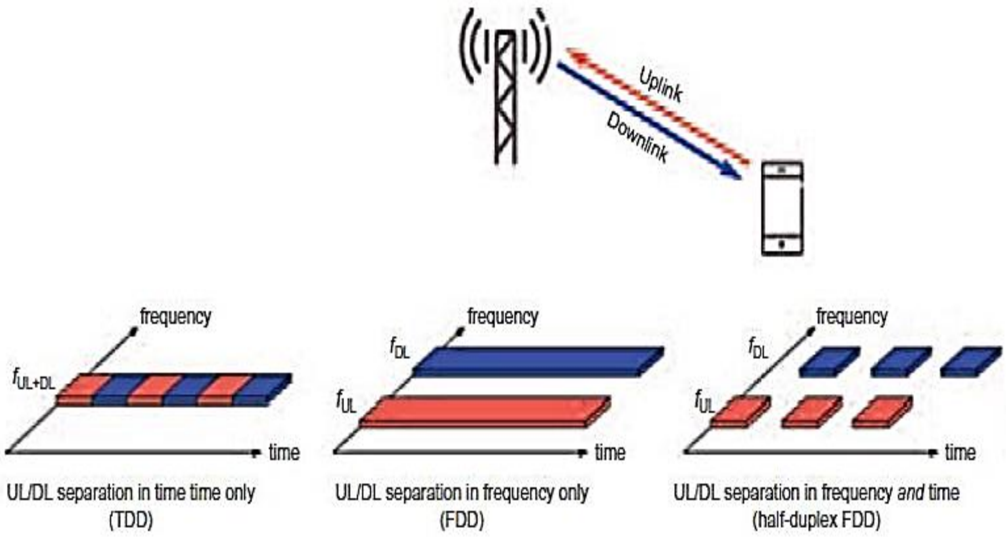


Figure 2.14: 5G New radio duplex schemes [17]

2.2.5. Radio Interface Novelties

This section deliberates the related areas of the air interface needed to this thesis, which are: spectrum, multiple access, frame structure, coding and modulation.

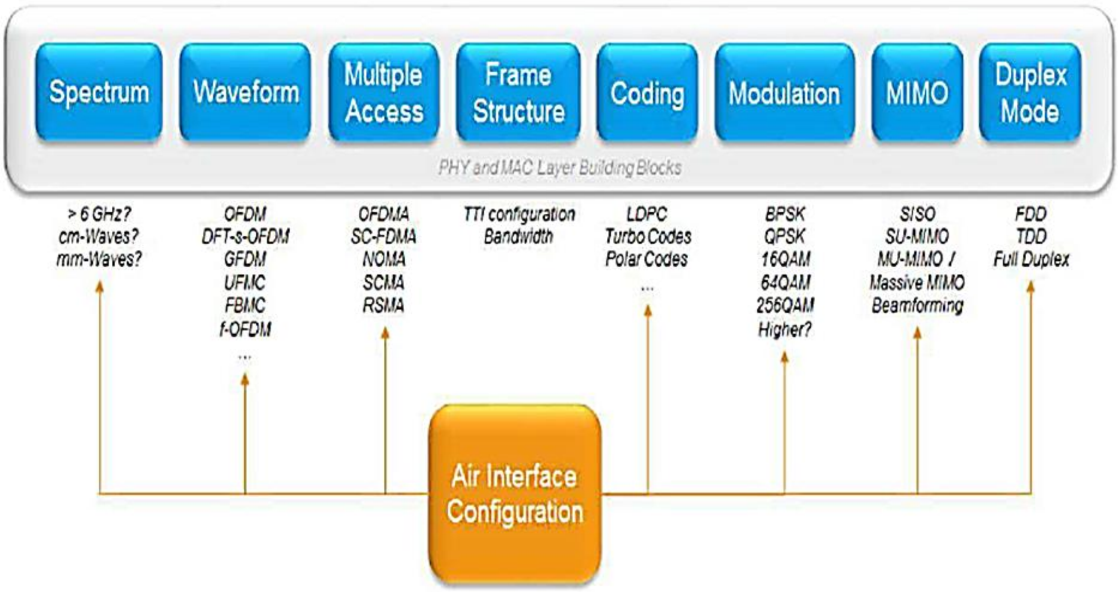


Figure 2.15: 5G Physical and MAC layer building blocks [24]

To use the high frequencies spectrum, millimetre waves are used, which have more attenuation thus less range than the lower frequencies [28]. So, the new radio access network is divided between macro and micro cells that handle low and high frequencies respectively.

Since higher frequencies have a higher attenuation than lower ones, there are more micro cells than macro ones. Figure 2.15 presents 5G physical and MAC layer building blocks.

2.2.6. 5G New Radio Network Layers

The main emphasis of 5G technologies is consumer flexibility as the mobile terminals have access to diverse wireless technologies at the same time & can syndicate some features of other networks also and so finally decide on the strongest wireless network. The thought behind the working of the 5G Network layers' technology is described as follows from Table 2.6.

Physical/Data link Layer: The first two layers of the OSI model for the 5G technology are based on Open Wireless Architecture.

Network Layer: The Network Layer is an Internet Protocol (IP). IPV4 (Internet Protocol Version 4) is spread worldwide with some restrictions. Then Mobile IP came into presence and 5G technology will practice mobile internet protocol. Consequently, mobile can be devoted to numerous wireless networks at the same time. 5G mobile network shall preserve virtual multi-wireless networks.

Table 2.6: 5G network layers [14]

OSI Network Model	Model of 5G Technology
Application layer	Application (Services)
Presentation layer	
Session layer	Open Transport Protocol(OTP)
Transport Layer	
Network layer	Upper Network Layer
	Lower Network Layer
Data link layer (MAC)	Open Wireless Architecture
Physical layer	

Open Transport Protocol (OTA) Layer: This plays a significant role as it meets with high installed speed and higher download. These mobiles can reasonably download updated version which is directed to specific wireless technologies from the base station. This is termed as Open Transport Protocol (OTA).

Application Layer: 5G provide an intelligent behavior capability of choosing best wireless link out of diverse networks. Terminals have access to quality testing and information stowing in this layer. A large number of algorithms are recycled for generous the intelligent behavior to the 5G technology.

2.2.7 Data Channels Hierarchy in 5G New Radio

Three key types of data channels that are recycled within mobile communications systems in 5G. These are:

Logical channel: Can be one of two groups: control channels and traffic channels.

- **Control channels**: are recycled for the transferring of data from the control plane.
- **Traffic channels**: are offerings to transfer of user plane data.

Transport channel: is multiplexing of the consistent data to be conveyed by the physical layer and its channels ended the radio interface.

Physical channel: are contiguous to the actual transmission of the data over the radio access network / 5G RF signal. They are used to transmit the data ended the radio interface.

2.2.7.1. 5G New Radio Logical Channels

Broadcast Control Channel, BCCH: is rummage-sale for transfer of broadcast elegance information to the consumer equipments within that cell in the downlink.

Paging Control Channel, PCCH: is charity to contact the use equipment whose position at cell level is not recognized to the network. As a result, the paging message desires to be transmitted in multiple cells. The PCCH is mapped to the PCH transport channel and at that moment to the PDSCH physical channel.

Common Control Channel, CCCH: This 5G channel is recycled on both the downlink and uplink for conveying control information to and from the consumer equipments or mobiles.

Dedicated Control Channel, DCCH: is contained by the uplink and downlink to carry dedicated control information among the UE or mobile and the network. It is castoff by the UE and the network next a radio resource control, RRC connection has been renowned.

Dedicated Traffic Channel, DTCH: It is existing in both the uplink and downlink. It is devoted to one user equipment and is recycled for carrying user information to and from a specific UE and the network.

The downlink and uplink broadcast among gNB and the UE (User Equipment) work as follows. [25] In the downlink, the UE monitors the PDCCH, typically once per slot. After detecting a valid PDCCH, the UE receives one unit of data (transport block) on the PDSCH following the scheduling decision of the gNB.

In the uplink, the UE requests the gNB for physical time-frequency resources to transmit data (scheduling request) and this request is sent over the PUCCH. In response, the gNB sends a scheduling gift over the PDCCH, which offers permission to a UE to use certain resources for broadcast. These signals are reference signals recycled for purposes such as demodulation, channel estimation, synchronization and channel-state information. [26]. In the Figures 2.16, the mapping among logical, transport channels and physical channels is illustrated.

The downlink physical signals are:

- Demodulation Reference Signal (DM-RS)
- Phase Tracking Reference Signal (PT-RS)
- Channel State Information Reference Signal (CSI-RS)
- Primary Synchronization Signal (PSS)
- Secondary Synchronization Signal (SSS)

Furthermore, the uplink physical signals are:

- Demodulation Reference Signal (DM-RS)
- Phase Tracking Reference Signal (PT-RS)
- Sounding Reference Signal (SRS)

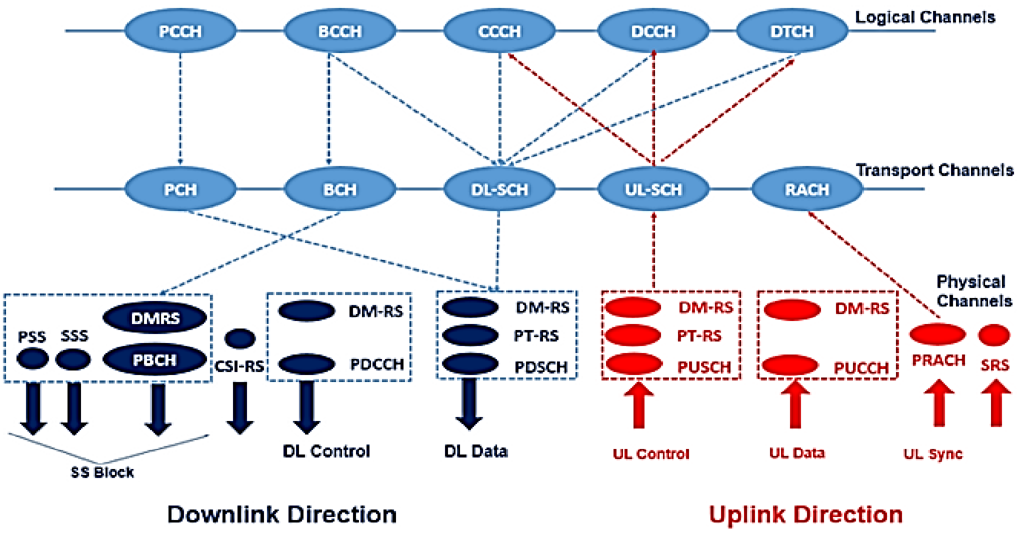


Figure 2. 16: Mapping between logical, transport channels and physical channels [26]

2.2.8. Waveform, Numerology and Frame Structure

An important feature of the 5G technology is the New Radio (NR) that introduces a new concept for the air interface harmonisation. The NR allows multiple numerologies' in the same bandwidth applying multiple subcarrier spaces (SCS). This way, in the same bandwidth one can use different carrier frequencies (Δf) to provide multiple services. The NR supports the multiple OFDM (Orthogonal Frequency Division Multiplexer) numerologies presented in Table 2.7 that can have 5 configurations, and all of them as a normal cyclic prefix (CP), expect configuration 2 that can also handle extend CP. The numerologies follow the reference of Δf_{ref} = 15 kHz multiplied by a factor of 2^{μ}, with μ being an integer. The sampling time is:

$$T_{s[s]} = \frac{1}{\Delta fmax[Hz].Nf} \qquad (2.1)$$

$$\Delta f = 2^{\mu} \cdot 15[\text{kHz}]$$

Where:

- Δf_{max} is the maximum subcarrier frequency 480 kHz;
- N_{f} is the maximum number of carrier frequencies which is 4096.
- μ = (0, 1, 2, 3, 4)

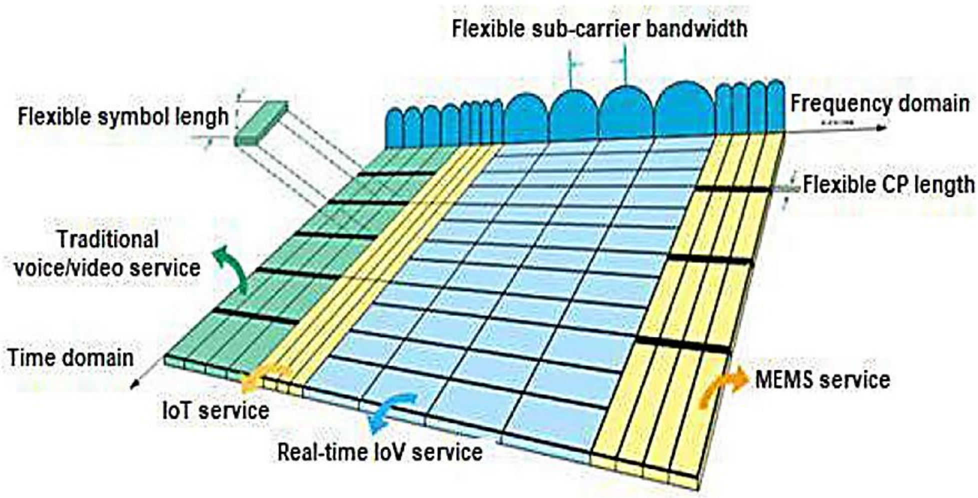


Figure 2.17: Multiple Services with different numerologies [18]

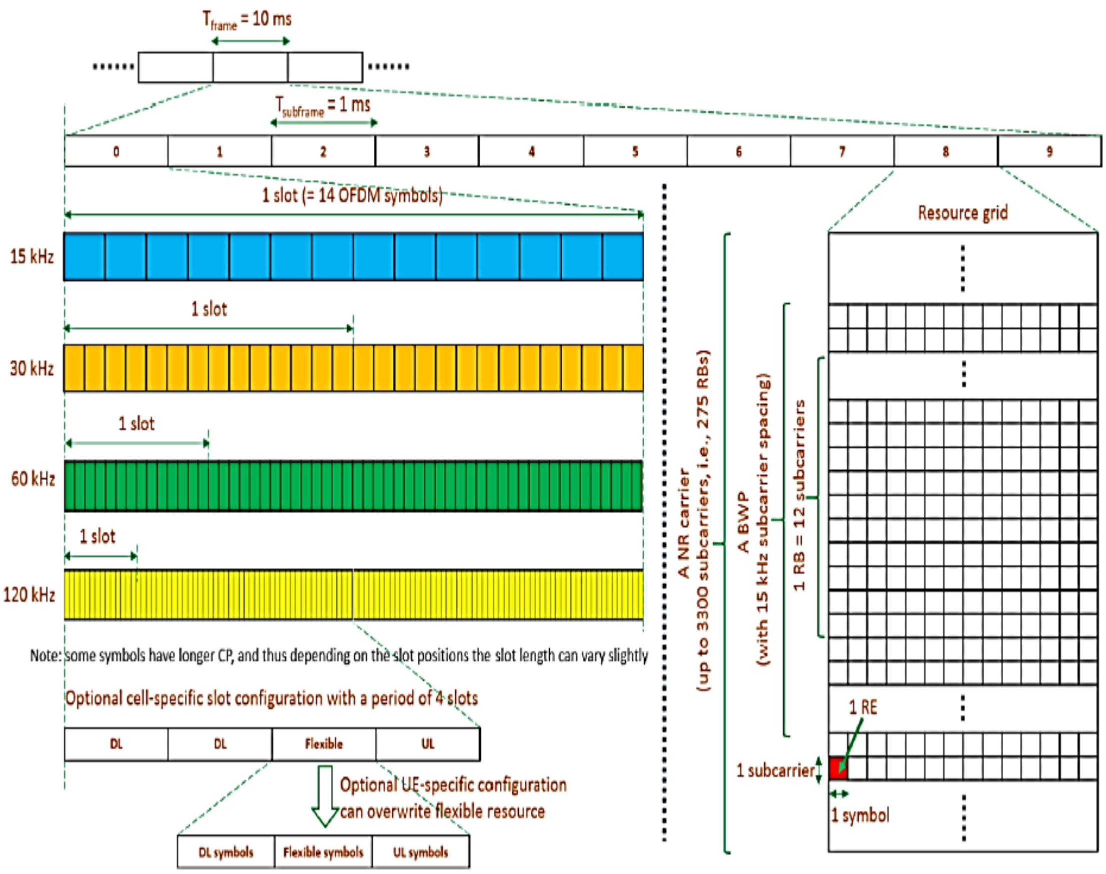


Figure 2.18: 5G New Radio frame structure [19]

Table 2.7 Supported transmission numerologies [20]

μ	$\Delta f = 2^{\mu} \cdot 15$[kHz]	Cyclic Prefix
0	15	Normal
1	30	Normal
2	60	Normal, Extended
3	120	Normal
4	240	Normal

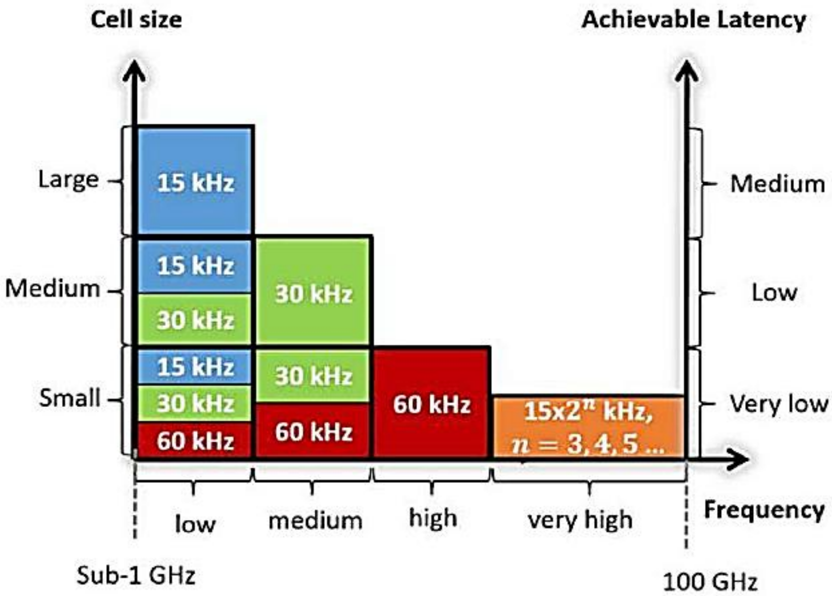


Figure 2.19: Usage of multiple numerologies [5]

The latency intended to be achieved is in a straight line to the size of the cell, so to achieve very low latencies the connection between user and base station should be with micro ones. As it can be observed in Figure 2.19 at lower bandwidths one used 3 different SCSs, 15, 30 and 60 kHz that should be used depending on the service provided to the user. For users at high speed, higher SCSs are used, because of the Doppler Effect. For very low latencies connections, the Transmission Time Interval (TTI) needs to be low, thus, higher SCSs are used. To sustenance multiple numerologies contained by the same bandwidth of the carrier, there are two approaches that can be considered: Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD). The FDD allows more flexibility in scheduling UEs with different numerologies. Though when different ones are used in adjacent frequency resources at the same time, mutual Inter-Numerology Interference (INI) is introduced between them, due to the violation of orthogonality in adjacent subcarriers of different numerologies.

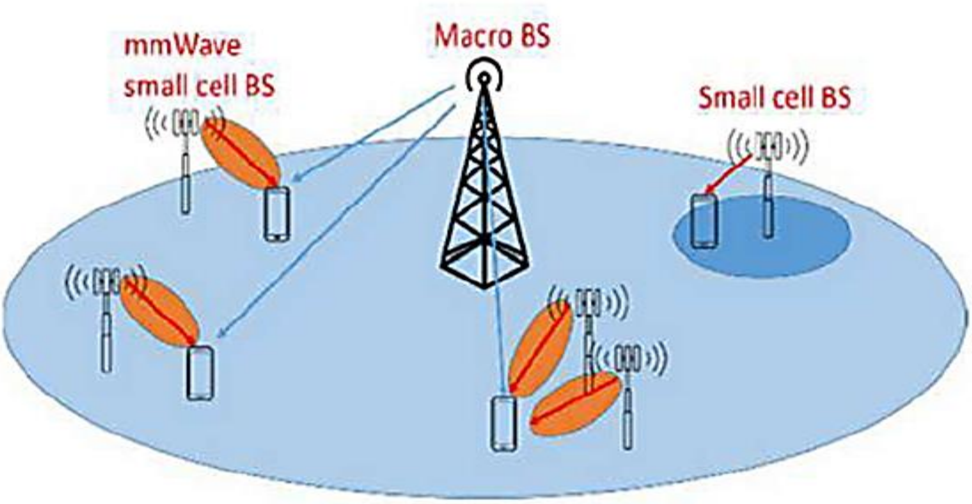


Figure 2.20: Macro and micro cells [5]

On the other hand, in TDD there is no INI since each Transmission Time Interval (TTI) has a single numerology.

Therefore, only filtering and/or windowing are required for this approach. The down side of using TDD is that it would restrict the scheduling flexibility of the UEs to the time unit of a TTI, which impacts on the latency of the system. To overcome the INI problem and respect the resource grid, an offset of $2^{\mu}.\Delta f_0$ is applied to certain n numerology. This way the orthogonally is sustained within the same bandwidth. For instance, the frame structure is shown in Figure 2.18 where the agreed specifications state that the Radio Frame keeps being 10 ms so that some services can be compatible with LTE and 5G. It consists of 10 sub frames, each one with a duration of 1ms, but for different numerologies the number of slots inside this is one can vary (Tables). Figure 2.21 shows an example for the numerology with SCS of 15 KHz.

For a certain numerology it is specified Table 2.8 and Table 2.9 the numeral of OFDM symbols for each slot ($N_{Symbols}^{Slot}$), slots for each frame ($N_{slot}^{frame,\ \mu}$) and slots for each subframe for a certain cyclic prefix ($N_{slot}^{subframe,\mu}$). The allocation of the resource grid to the NR is similar to the LTE one, but their physical dimension varies depending on the numerology used. The numeral of subcarriers per Physical Resource Block (PRB) is always the same despite the numerology used and it is equal to 12. Consequently, for individual numerology there is a resource grid of $N^{\mu}_{RB,x} \cdot N^{RB}_{SC}$ subcarriers and $N^{subframe,\ \mu}_{symbol}$ Symbols for OFDM. The maximum number of resource blocks, $N^{max,\ \mu}_{RB,\ x}$, for a certain numerology for a given link, x, Downlink or Uplink is shown in Table 2.10. Regarding the bandwidths available to transmit information from the BS to the UE, they vary for different numerologies and the allocation of PRB is done by following Table 2.11, where the minimum guard band between each user is given in Table 2.12.

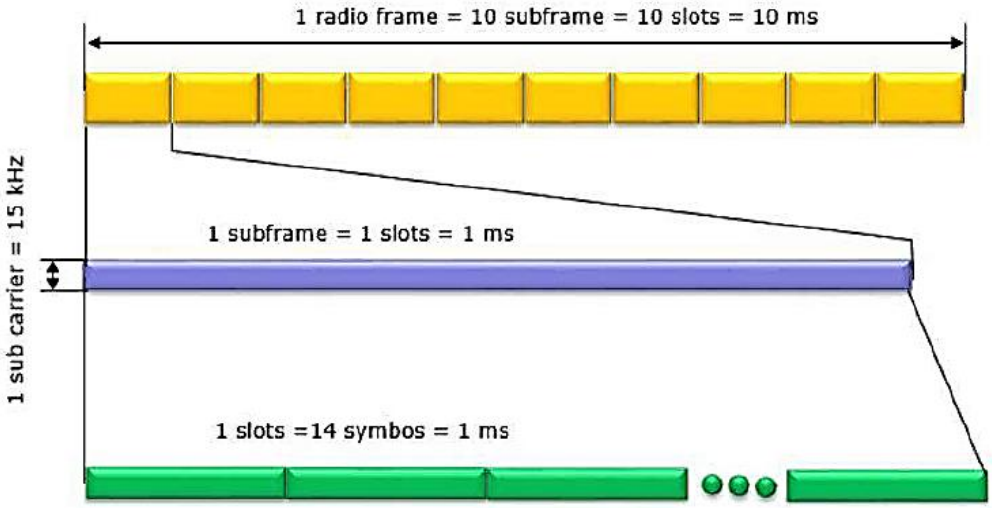


Figure 2.21: Frame Structure of New radio [21]

The channel bandwidths are at least 100 MHz wide and can go till 500MHz. To deliver better spectrum efficiency, filtering/windowing techniques are used.

Table 2.8. Number of OFDM symbols per slot, slots per frame and slots per Subframe for normal cyclic prefix [20]

μ	N^{Slot}_{Symbol}	$N^{frame,\ \mu}_{slot}$	$N^{subframe,\mu}_{slot}$
0	14	10	1
1	14	20	2
2	14	40	4
3	14	80	8
4	14	160	16

5	14	320	32

Table 2.9. Number of OFDM symbols per slot, slots per frame, and slots per subframe for extended cyclic prefix [20]

μ	N_{Symbol}^{Slot}	$N_{slot}^{frame,\mu}$	$N_{slot}^{subframe,\mu}$
2	12	40	4

The modulation schemes that are going to be sustained are QPSK, 16QAM, 64QAM and 256QAM, with code rates that can range between 1/3 to 8/9. At least a code rate of 8/9 is supported for the 20Gbps decoder information throughput.

Table 2.10. Minimum and maximum number of resource blocks [20]

μ	$N_{RB,DL}^{min,\mu}$	$N_{RB,DL}^{max,\mu}$	$N_{RB,UL}^{min,\mu}$	$N_{RB,UL}^{max,\mu}$
0	20	275	20	275
1	20	275	20	275
2	20	275	20	275
3	20	275	20	275
4	20	275	20	275

Table 2.11: Maximum transmission bandwidth configuration N_{RB} [22]

SCS (kHz)	20MHz	50MHz	100MHz
	N_{RB}	N_{RB}	N_{RB}
15	106	270	N/A
30	51	133	273
60	24	65	135

Table 2.12. Minimum guard band in kHz for each UE channel bandwidth and SCS [22]

SCS (kHz)	20MHz	50MHz	100MHz
15	452.5	692.5	N/A
30	805	1045	845
60	1330	1570	1370

CHAPTER 3

3. METHODOLOGY

3.1 Introduction

This Chapter discusses all about the collection and analysis of data, 5G coverage and capacity dimensioning, coverage and capacity based site counts and millimetric wave propagation modeling.

3.2 Required Materials

The software used in this researches are: Winprop (Radio network planning) tool, Matlab/2017a, Microsoft office 2016 and Microsoft excel.

3.3 Radio Network Planning Phases/Methods

The central objective of radio network planning is to deliver a cost effective solution for the radio network in terms of coverage, capacity and quality. In order to dimension a viable 5G network for new deployment scenario, the fundamental radio network planning is divided into preparation phase, nominal planning phase, detailed planning phase, network rollout and network optimizations phases as shown in Figure 3.1 and the first three phases will be discussed briefly as in the below subsections. But, network rollout and network optimizations phase are not considered in this research thesis.

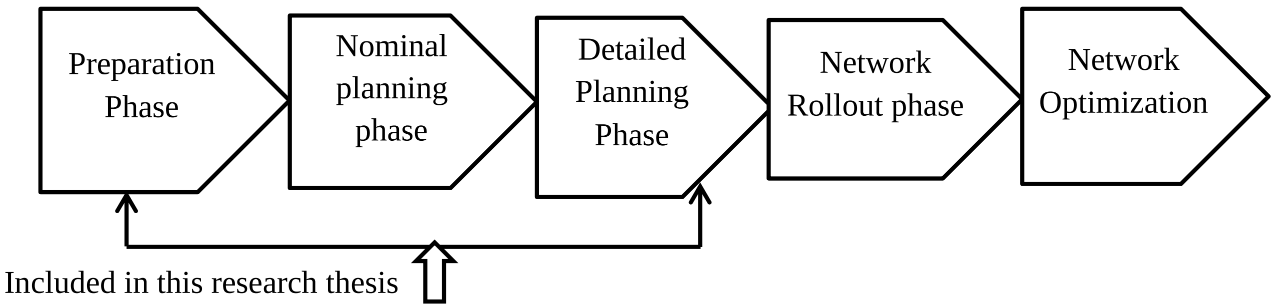


Figure 3.1: Radio network planning process

3.3.1 Preparation Phase

This phase starts with formulating the requirements of coverage and capacity. Coverage requirement contain outlining the coverage areas, the service probability, and related signal strength such as Reference Signal Received Power (RSRP). On the other hand, the capacity requirements comprise traffic forecast (total number of subscriber supported by the network) and the traffic profile in the selected area. The convenience of frequency bands, data collection, the selection of terrain morphology (Dense Urban (DU), Urban (U), Sub Urban (SU), or Rural (RU)), and propagation model selection are also done at this phase.

3.3.2 Nominal Planning Phase

In this phase, the definition of Radio Link Budget (RLB) parameters and determination of their optimum values based on the selected area properties and other factors will be done.

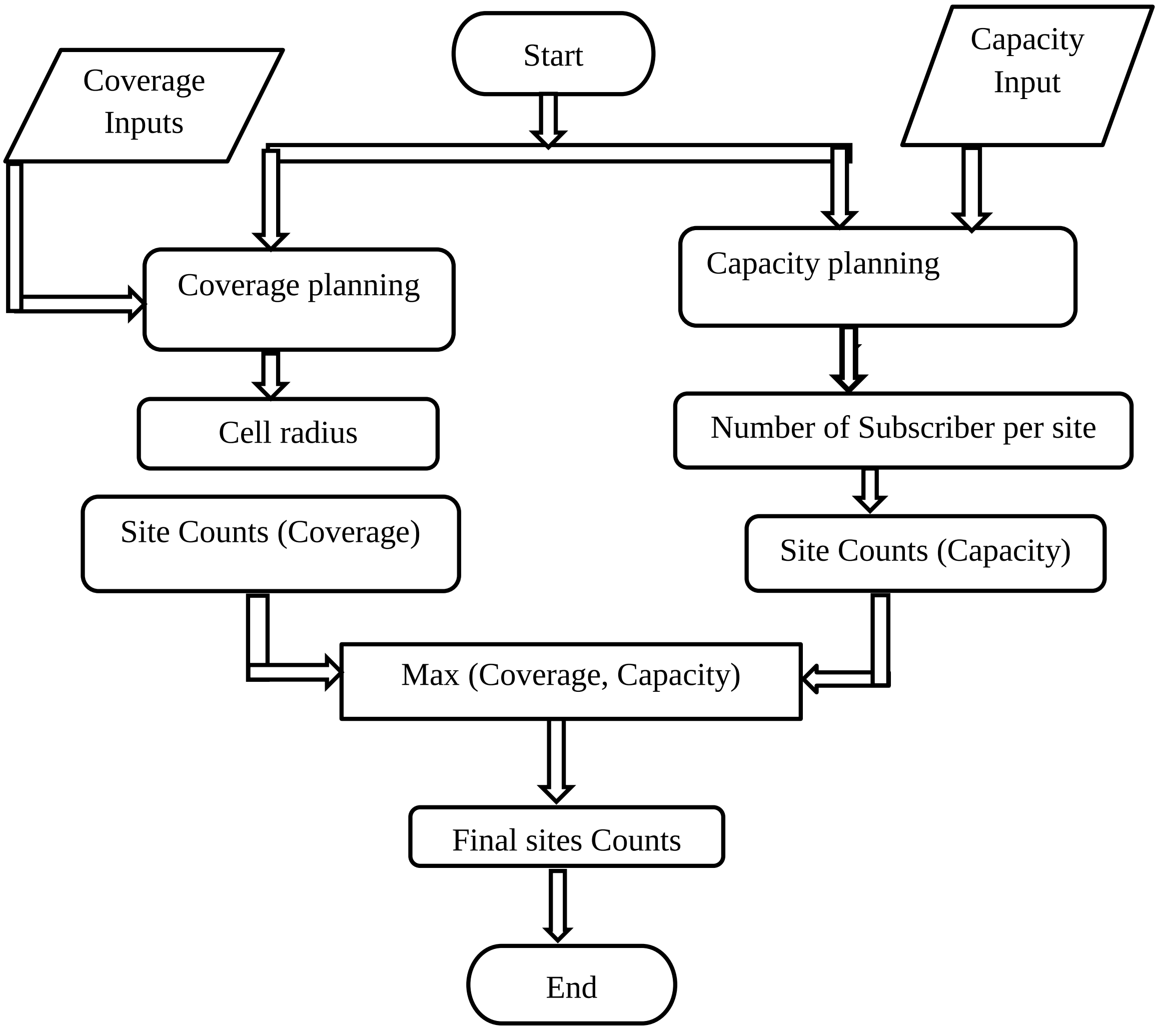


Figure 3.2: Nominal planning overall processes

From the Radio link budget, the **MAPL** and **cell range** can be assessed and becomes an input for the detail planning phase to conduct the radio frequency prediction using radio network planning and optimization (RNPO) tools. The outcomes of this phase is the cell radius of subscribers per site, there by determines coverage and capacity requirements defined in the pre-planning phase as shown in the Figure 3.2.

3.3.3 Detailed Planning Phase

Methods used in thesis to accomplish the required task is shown in figure 3.3.

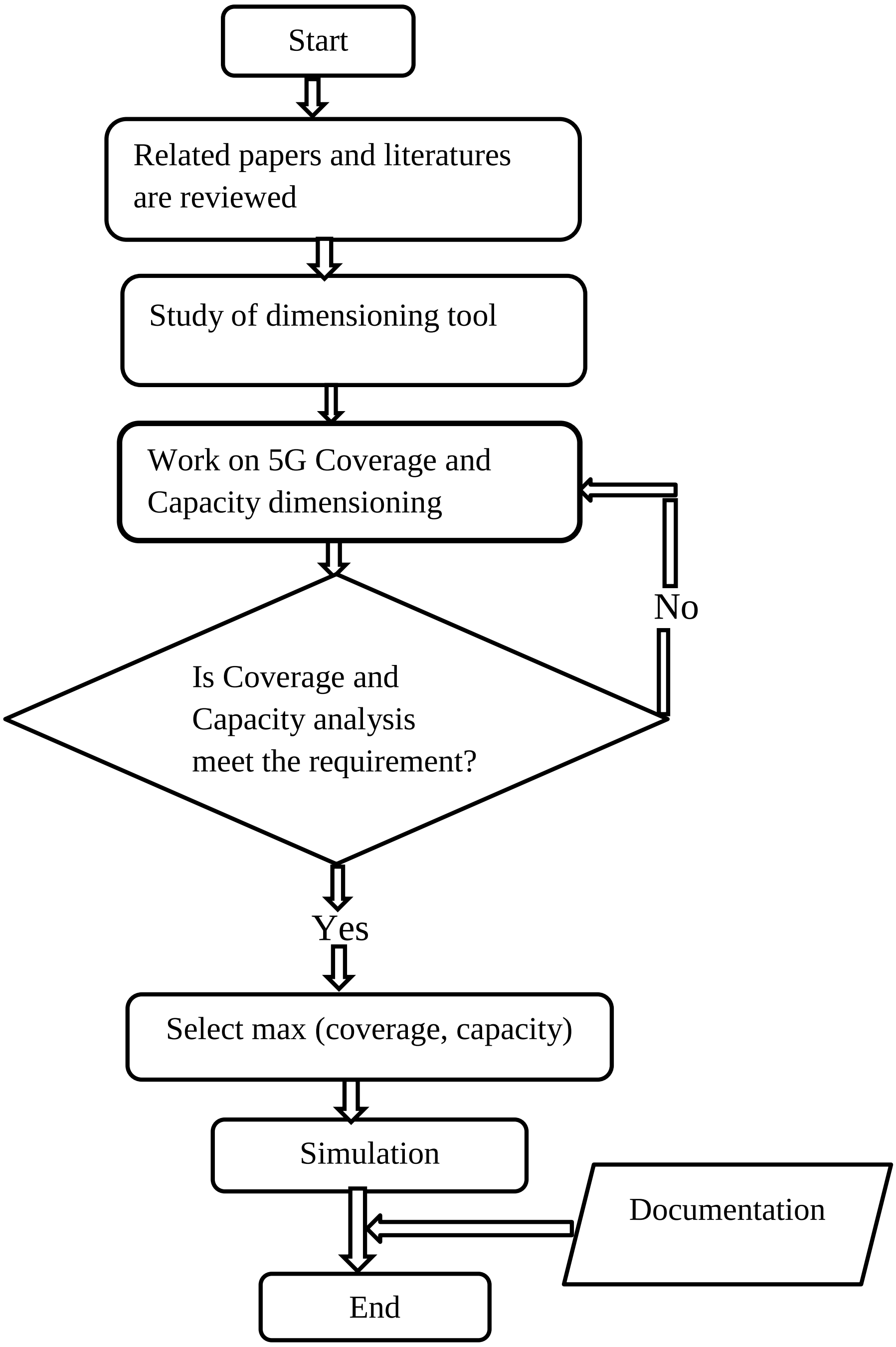


Figure 3.3: System block diagram

On the basis of nominal planning phase, in detailed planning phase: site placement, antenna type selection containing azimuth, mechanical tilt, and electrical tilt are defined. Here after, the radio network prediction will be accompanied by using radio network planning and optimization (RNPO) tool by incorporating the selected propagation model and RLB parameters found in nominal planning phase.

3.4 Dimensioning Process

Dimensioning is the preliminary phase of radio network planning. It offers the first assessment of the network component count as well as the capacity of those elements. The persistence of dimensioning is educated guess for the requisite number of radio base stations required to support an identified traffic capacity in an area. The network dimensioning process comprises of analyzing the necessary resources to fulfill the minimum requirements of the services that are planned to be provided in a certain area [33]. The execution of the main phases of the network dimensioning can be divided into two planes: coverage and capacity-planning. Before these planning is performed, the necessary inputs are obtained for the dimensioning and then these two planning process are sequentially executed, obtaining at last the desired outputs.

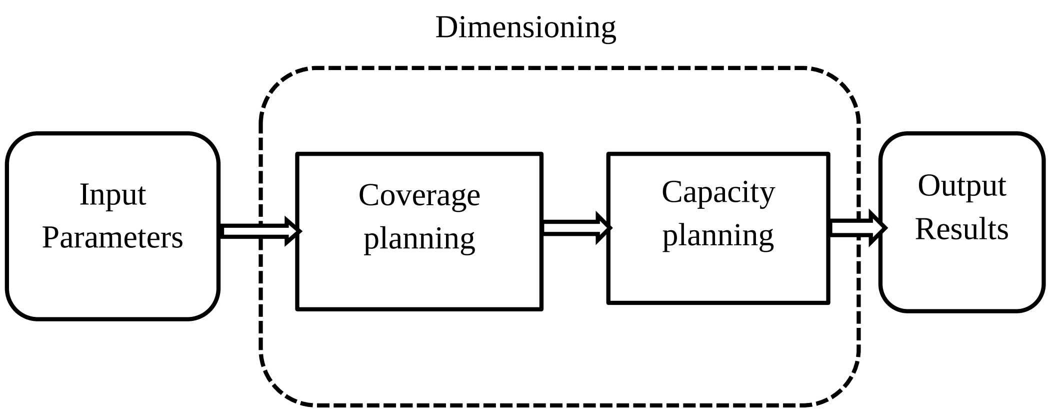


Figure 3.4: Generic network dimensioning

As far the dimensioning process, the first method is to determine the coverage planning limit, i.e. to calculate the maximum radius that the cell can accomplish in a given scenario to attain a link among the BS and the UE, even if the minimum service requirements are not meet. Thus, the site coverage area is determined, which is used in the next phase, in the capacity plan, which begins by the population density calculation. Thus, this model analyses the use of the FR1 frequency bands (2.6GHz).

3.4.1 Inputs and Outputs of 5G New Radio Dimensioning

The input parameters of the dimensioning process of a 5G network are set by the user, scenario and network. In network dimensioning there are many parameters that can be grouped into groups that affect the quality, coverage, and capacity of the cell. However, these groups are correlated with each other, and thus, one parameter can have impact on more than one group in an indirect way. In quality, the lowest throughput achieved at cell edge in DL and UL is the parameter that defines the minimum quality level. With this parameter the required SINR is computed, which in turn affects the coverage of the cell and it is also the reference of the investment by an operator to offer a minimum service.

For coverage, Radio Link Budget parameters play a vital role such as transmitter power, number/type of antennas and numerology used. In the LTE network, a single numerology is available, while in the 5G network there is the possibility of using others [33].

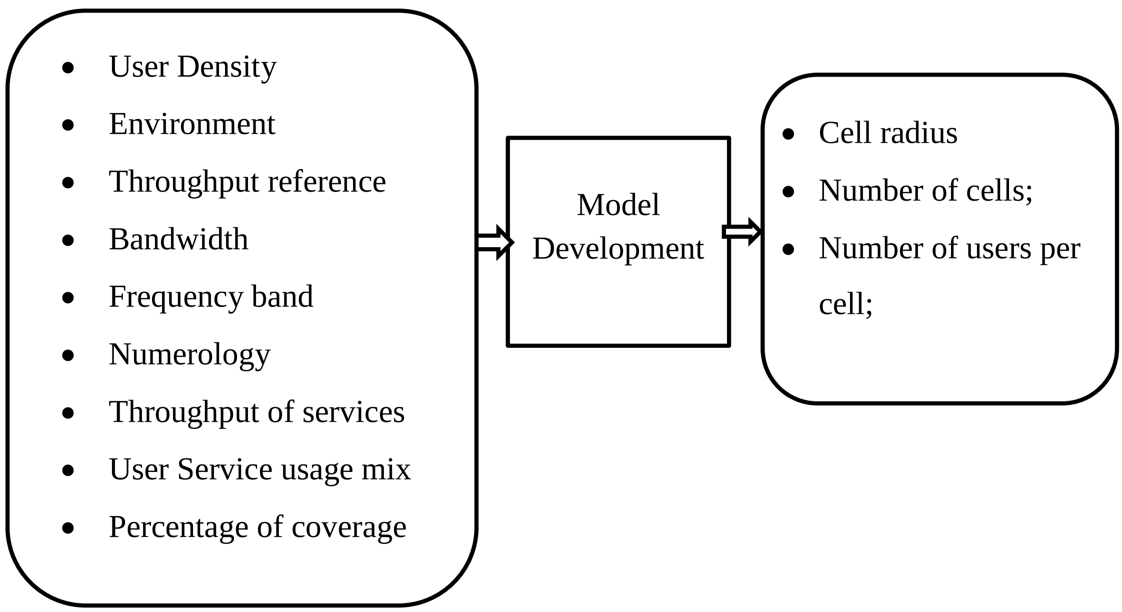


Figure 3.5: Model development input/output dimensioning

Some margins considered in the system also impact the coverage of a site, such as the handover margin and the probability of a user being indoor or outdoor. In capacity, the inputs are the number of subscribers, the services provided, the amount of use by each user and the amount of available bandwidth. The main dimension output parameter is the radius of the cell in which the input parameters are satisfied. The fundamental model inputs and outputs are defined in Figure 3.5. Besides these, there are others specifically applicable to 5G-NR network deployments, such as the numerology configuration and the maximum supported MIMO order.

3.5 Coverage Planning

Coverage area of each base station is determined by coverage planning. It provides the maximum area that can be concealed by a base station. Coverage dimensioning comprises radio link budget and coverage analysis.

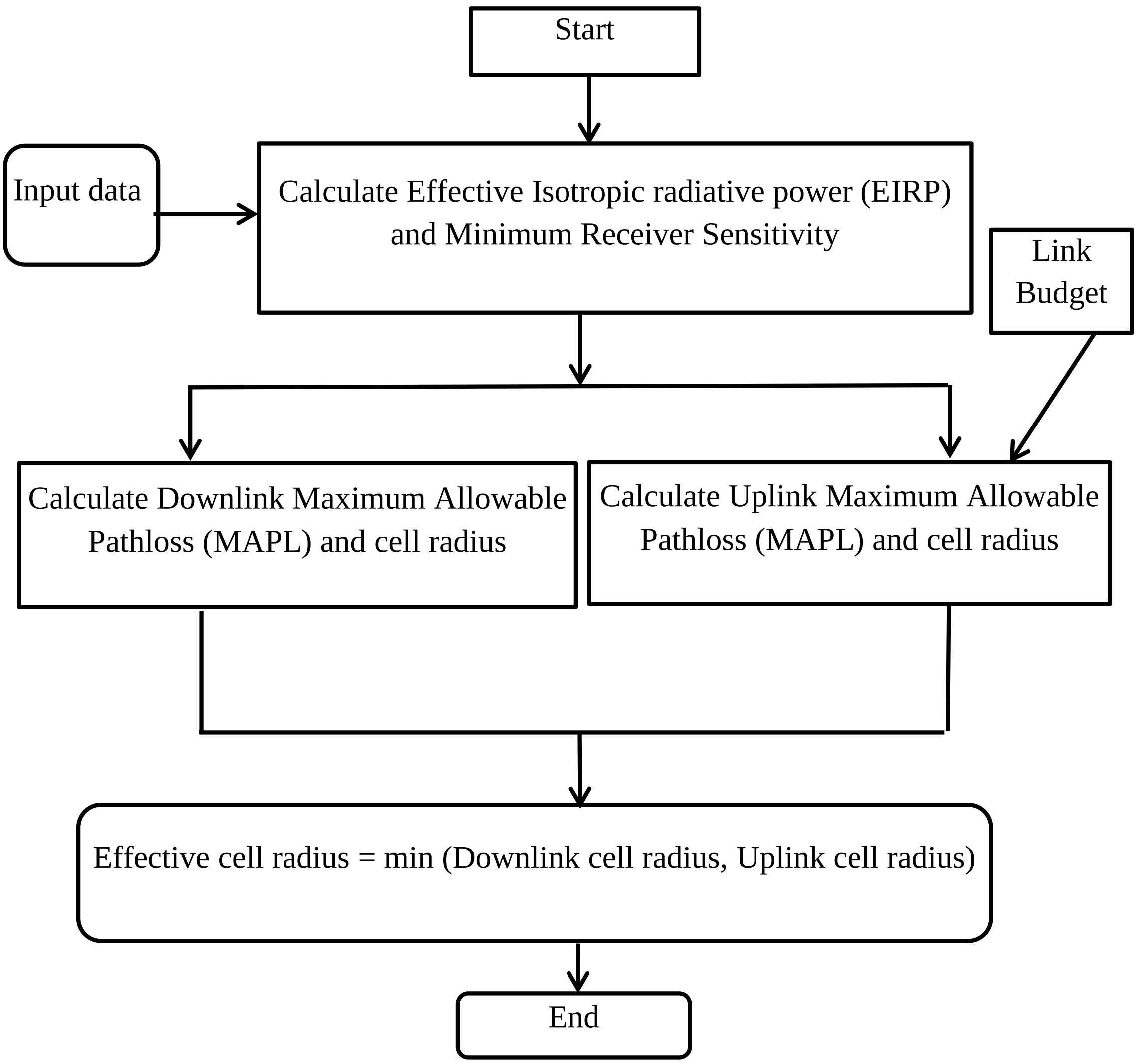


Figure 3.6: Coverage planning work flow

Radio link budget contains all the gains and losses in the route of signal from transmitter to the receiver. Coverage planning is defined by the radio link budget calculation for both channels, DL and UL, with no specific concern on the capacity or quality of service [33]. From the link budget evaluation, the maximum allowed path loss (MAPL) can be computed based on the required SNR. With the appropriate propagation model, it is formerly possible to compute the cell radius and area, then, the total number of cells is calculated and computed for the required geographical target area. In the link budget, the essential parameters are related to power (transmission), gains (transmission, reception) and other elements, such as cable or user losses. In the outdoors propagation models the core parameters are the frequency band 2.6GHz, the propagation scenario Dense Urban. The Coverage planning work flow is shown in Figure 3.6.

3.5.1. Radio link budget

Radio link budget is supportive for assessing the realizable path loss values for each intended target area, among the transmitter and receiver in uplink (UL) and downlink (DL). The link budget calculation provides us the maximum allowable propagation loss (MAPL) value. The MAPL allows the maximum cell range to be estimated with a right propagation model.

3.5.1.1. Radio Link Budget Parameters

Effective Isotropic Radiated Power (EIRP): Stands for effective isotropic radiated power; the term is used to define how much transmitted power is radiated in the preferred direction. It takes into account the losses in transmission cables and connectors and includes the gain of the transmitter antenna as:

$$\text{EIRP} = P_{Tx} + G_{Tx} - \sum Total\ T_{x\,\text{losses}} \quad (3.1)$$

Where;

- $P_{Tx:}$ is the transmitter power (dBm)
- G_{Tx} : is the transmitter antenna gain (dBi)

gNB output Power: In the link budget, output powers is 46dBm per each branch of the MIMO 2×2 which means 2×40 watt is deliberated.

UE Maximum Total Transmitter Power: denotes to the UE transmit power which be contingent on the power class of the UE. Presently merely one power class is demarcated in 3GPP TS 36.101; class 3 with highest transmitter power of 23dBm.

gNB Antenna Gain: The antenna gain is proportional to the antenna size, and beam width of the antenna patterns (horizontal and vertical). A large antenna with narrow beam width provides a high gain while a short antenna with wider beam width provides less gain. The selection of antenna gains and beam width depends on the clutter type and coverage requirement. The low gain antenna (15–17dBi) can be used in dense urban and urban clutters while a high gain antenna (18–20dBi) can be used in rural areas and highways to extend the RF coverage [34].

UE Antenna Gain: Depend on the stipulations of 3GPP, UE(s) are expected to have an essential antenna merely with a gain of 0 dBi for apiece of antenna ports [34].

Signal to interference noise ratio (SINR): SINR values are attained from the system level simulation outcome and it be contingent on the receiver design. Accordingly, SINR is a vendor specific parameter.

Noise Figure: It is a main factor used to measure the receiver recital. The noise figure be contingent on the bandwidth and the gNB competence. A distinctive value for the noise figure is among 6 to 8 dB.

Thermal Noise: The thermal noise is a loss due to heat and can be formulated as:

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

Where:

- K indicates the Boltzmann constant (1.38 x 10^{-23}J/K) ;
- T specifies absolute temperature at a value of 290K;
- B indicates channel bandwidth which is 20MHz.

Receiver Sensitivity ($P_{Rx,\min[dB]}$): Shows the lowest signal strength requisite to allow deciphering by the gNodeB or User equipment receiver's if there is no interference and formulated as:

$$\text{Receiver Sensitivity} = Noise\ figure + SINR + Thermal\ Noise$$
$$P_{\mathrm{Rx,min[dB]}} = -174 + 10.\log_{10}(B_{\mathrm{RB[Hz]}}) + F_{\mathrm{N[dB]}} + \rho_{\mathrm{[dB]}} \tag{3.3}$$

Where:

- B_{RB} **:** Bandwidth per RB, which depends on the SCS;
- F_N **:** Noise figure of gNB receiver;
- $\rho_{[dB]}$ **:** SINR requirement for the UL or DL traffic channel.

Minimum signal reception strength: It used to articulate the receiver side losses and margin such as body loss, cable loss and marginal gain to receiver sensitivity and calculated as:

$$\text{Minimum Signal Receiption Strength} = RS + IM + LR + RAG \quad (3.4)$$

Where:

- RS is receiver sensitivity
- IM is interference Marginal
- LR is receiver body loss + Cable loss
- RAG is receiver antenna gain

Maximum allowable path loss (MAPL): It permits the maximum cell range to be valued with suitable propagation models which offer number of base station sites requisite to concealment the target environment. The maximum allowable path loss expressed as:

$$MAPL = EIRP - MSRS - \text{Penetration loss} - \text{Slow Fading Margin} \quad (3.5)$$

Body loss: Shows the loss produced due to signal delaying and immersion when a terminal antenna is near to the body.

Transmitter Power: It includes the base station affecting downlink budget and terminal sides which affects the uplink budget.

Penetration loss: is declining of signals from an interior terminal to a base station as a result of obstacle by a building and vice versa.

Feeder loss: Loss produced by different devices that are situated on the path of the antenna to the receiver.

Table 3.1: Penetration losses based on clutter type [34]

Clutter type	Penetration loss (dB)	Typical values	Standard deviation of slow fading (dB)
Dense urban	19-25	19	10
Urban	15-18	15	8
Suburban	10-14	11	6
Rural	5-8	8	6

Interference Margin: Accounts for the rise of noise level in the terminal initiated by the interference from neighboring consumers. In this thesis typical value for interference margin is 3-8dBm.

Table 3.2: displays the typical value of standard deviations depend on the clutter type [34]

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

Slow/shadow Fading Margin: is the fading that is carried by obstruction of natural feature. Fading affected by position primarily from obstacle way surpasses attenuation triggered by time. Therefore, the foremost concern for shadow fading is those caused by location changes. The slow fading standard deviation of varies from 5 dB to 12 dB based on the nature of clutter. Table 3.2 describes the representative values of standard deviations depending on the nature of clutter.

User Throughput at Cell Edge: The lowest net single user equipment target throughput prerequisite to be attained at the cell edge. It defines the service that can be delivered at the cell edge; consequently, it can bound the least possible Modulation and Coding Scheme (MCS) to be used. This parameter ordinarily supplied by the network operator depending on the requisite services at cell edge. A usual value for UL can be 512 kbps to 1 Mbps where as in the DL it can be 1 Mbps up to 4 Mbps.

3.5.2 Propagation Model Selection

An accurate propagation model is vital to predict coverage and interference of a cellular network that can illustrate the performance of the real network. In this thesis the Urban Dominant Path (UDP) model in Winprop is used for modeling the propagation. WinProp has Ray-optical propagation models and empirical propagations models for received power and pathloss prediction. Ray-optical propagation models while giving accurate predictions are very time-consuming.

Urban Dominant Path (UDP) model is carefully chosen because it collects the exactness of the ray optical propagation models and the rapidity of empirical models together [35]. In addition, the prediction is less reliant on the vector database compared to the Ray Optical model. UDP works by determining the dominant path between the transmitter and a receiver. The empirical propagation model COST 231(Walfisch-Ikegami) on the other hand, uses parameters outside the vector database and require short computational time. But the accuracy is lower than the Ray-Optical models.

3.5.2.1 Empirical COST 231 Model (Walfisch-Ikegami)

This Empirical model determines the path loss (in dB) using an equation given as:

$$PL = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(ht) - \alpha\ (hr) + (44.9 - 6.55\log_{10}(ht))\log_{10}(d) + Cm \quad (3.6)$$

Where, f is frequency in MHz, d is distance between transmitter and receiver in kilometer (km), ht and hr are transmitter and receiver antenna height in meter (m), $\alpha\ (hr)$ is set according to environment and is given as:

$\alpha\ (hr) = 3.2(\log_{10}(11.75\mathrm{hr}))^2 - 4.97$, in urban environment ; f >400MHz,
$\alpha\ (hr) = (1.1\log_{10}(\mathrm{f} - 0.7))\mathrm{hr} - (2.56\log_{10}(\mathrm{f} - 0.8))$, for suburban, Cm is depends on type of environment and is 3dB in urban area.

3.5.2.2 Urban Dominant Path (UDP) model

The Dominant Path Model (DPM) determines accurately the dominant path between the transmitter and each receiver pixel. So the computation time compared to ray tracing is significantly reduced and the accuracy is nearly identical to ray tracing [35]. Dominant path model (UDP) is given by equation:

$$\mathrm{PL} = 20*\log_{10}\left(\frac{4\pi}{\lambda}\right) + 10*p*\log_{10}(d) + \sum_{i}^{n} f(\varphi, i)ni + \Omega + \mathrm{gt} \quad (3.7)$$

$$\lambda = c / f$$

Where;

- c: speed of light
- f: frequency in MHz
- PL: path loss
- d: is the Distance between the transmitter and the receiver,

- p is the Path loss exponent and is equal to 2.4 in dense urban areas and where as in open areas p = 2.0
- λ: is the Wave length,
- f (φ, i): is diffraction loss, (changing the direction of propagation)
- i: is number of changes in direction
- φ: is the angle between previous direction and new direction
- Ω: is empirical determined wave guiding for reflections and scattering. In typical scenarios the wave guiding effects can be turned off, this reduces the prediction time.
- gt: is transmitter antenna gain.

Table 3.3: Selected Propagation models and Frequency bands for this research

Propagation Scenario	Frequency band(MHz)	Propagation model
Dense Urban	2600	Dominant Path Model(DPM)

Table 3.4: The principle of 5G new radio Downlink radio link budget [34]

General Parameters		
Morphology	Dense Urban	
Data channel type	PDSCH	
Duplex mode	TDD	
User environment	Indoor, Outdoor	
System bandwidth (MHz)	100	
Cell edge rate (kbps)	512/1024	
Transmitter, gNB terminal	Formula	Value
Tx output power (dBm)	A	43
Tx antenna gain (dBi)	B	18
TX cable and connector loss (dB)	C	2
EIPR per sub carrier (dBm)	d = a + b – c	59
Receiver(UE)	Formula	Value
Temperature (K)	E	290
Bandwidth (MHz)	F	10
Thermal noise (dBm)	g = KTB	-174
Rx noise figure (dB)	H	7.0

SNR (dB)	I	-10.0
Receiver sensitivity (dBm)	j= h+i -174+10*$\log_{10}$(30KHz)	-132.2
Interference margin (dB)	k	3.0
Rx antenna gain (dBi)	L	0.0
Rx body loss (dB)	M	5.0
TMA gain (dB)	N	2.5
Minimum received power level of the UE (dBm)	o = j +k - l+m + n	-120.7
Clutter Link Budget Parameters		
Indoor penetration loss(dB)	P	22
Cell edge coverage probability (%)	Q	85
Standard deviation of slow fading (dB)	R	10
Shadow fading margin (dB)	S	9.4
MAPL (dB) = MAPL(dB)$_{\textbf{Downlink}}$	t = d − o − p − s	148.3
Frequency band (MHz)	2600	
Cell radius(Km)	0.654	
Cell radius output(Km)	0.834	

Table 3.5: The principle of 5G new radio Uplink radio link budget [34]

General Parameters		
Morphology	Dense Urban	
Data channel type	PUSCH	
Duplex mode	FDD,TDD	
User environment	Indoor, Outdoor	
System bandwidth (MHz)	10	
Cell Edge Rate (kbps)	948/1024	
Transmitter, Terminal	Formula	Value
Transmitter power	A	24
Cable and connector loss (dB)	B	0.0
Antenna gain (dBi)	C	0.0
Radiating power (EIRP) (dBm)	d = a + b – c	24.0
Receiver, gNodeB	Formula	Value

Temperature (K)	E	290.0
Bandwidth (MHz)	F	
Thermal noise (dBm)	g= KTB	-174
Noise figure (dB)	H	2.0
SINR(dB)	J	− 8.0
Receiver sensibility (dBm)	k = h + j – 174 +10*$\log_{10}(30\text{KHz})$	-135.23
Interference margin(dB)	l	2.0
Antenna gain (dBi)	M	11
Mast head amplifier (dB)	N	2.0
Cable loss(dB)	O	3.0
Minimum received power(dB)	p = k + l – m +n + o	-139.23
Clutter Link Budget Parameters		
Indoor penetration loss(dB)	Q	15
Cell edge coverage probability (%)	R	85
Standard deviation of slow fading (dB)	S	10
Shadow fading margin (dB)	T	8
MAPL (dB) = MAPL(dB)$Uplink$	u = d − p −q − t	140.23
Frequency band (MHz)	2600	
Cell radius(km)	0.365	
Cell radius output(km)	0.26	

3.5.3 Cellular Planning

The main aim of this section is to discuss higher level features within the scope of cellular planning, in order to measure and corroborate the approach taken at this level. To start, a key assumption is that within the coverage area with a specific parameter configuration the cell size is the same, that is to say, it does not take into account two frequencies in use at the same BS site, which could yield different cell radii, nor the occurrence of other types of antennas other than macro-cells, which could yield additional coverage area in some specific scenarios, such as pico-cells in shopping malls.

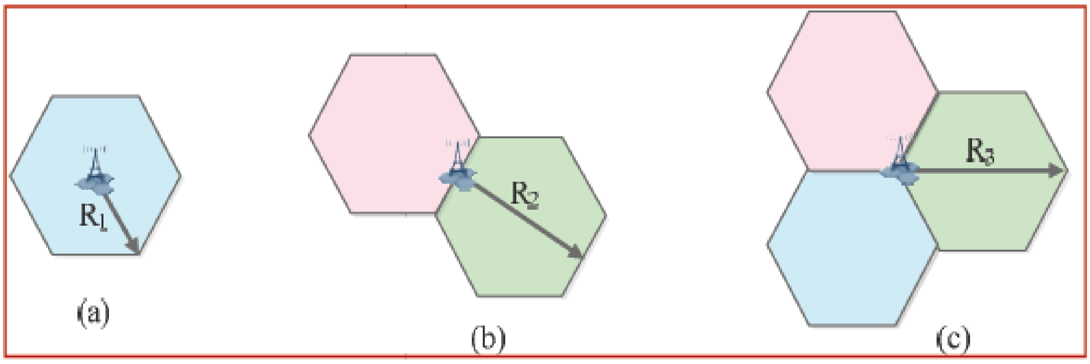


Figure 3. 7: Type of site configurations, a) Omni-directional, b)2- Sector, and c) 3- Sector [39]

The cell structure is anticipated to be hexagonal following the concept of tri-sectorisation in BSs in use in real-life network cell configuration. This is the optimal geometrical shape, since it reduces any overlap or gap given, and on top of this assumption a generic value for handover ratio is defined for any cell size, which finds its limitations if the cell size is too large. Cell area depends on site configuration. It can be Omni-directional, 2-sector or 3-sector and cell radius is calculated for each site configuration.

For each variety of site configurations shown in figure above, the site area is calculated as:

- For Omni-directional:

$$\text{SA } (A_{cell}[km^2]) = \frac{3}{2}.\sqrt{3}\,.\,[R_1]^2{}_{[\text{km}]} \quad (3.8)$$

- For 2-Sector:

$$\text{SA } (A_{cell[km]^2}\ ) = \sqrt{3}\ [R_2]^2\ {}_{[\text{km}]} \quad (3.9)$$

- For 3- Sector:

$$\text{SA } (A_{cell}[km]^2) = \frac{9}{8}.\sqrt{3}[R_3]^2\ {}_{[\text{km}]} \quad (3.10)$$

Where; SA is denoting Site area.

Finally, the site count based on Coverage is calculated as:

$$\text{T}_{\text{NS}} = \frac{\text{T}_{\text{CA}}}{\text{SA}} \quad (3.11)$$

Where; T_{NS} is Total number of sites and T_{CA} is Target coverage area.

3.5.4 Coverage Requirements

- **Frequency Band**

Band 41 (**2600** MHz) is carefully chosen to use in this study. Band 41 spans 2500 – 2690 MHz, which is relatively large amount of bandwidth, capable of handling a large amount of data at high speeds. There are three significant 3GPP-defined LTE spectrum bands in this frequency range. Band 7 is an FDD band with distinct DL and UL spectrum blocks at 2500–2570 MHz and 2620–2690MHz3. Band 38 is a TDD band ranging from 2570 to 2620 MHz.

This frequency range is preferred because this band by means of its unpaired (TDD) configuration brings important advantages over employing the hybrid LTE Bands 7/38 configuration:

- Advantages in dealing with traffic asymmetry
- Provides more capacity and increased spectrum efficiency
- Comparable network coverage
- Avoids inter-band interference
- Simplified network operation
- Key global roaming band
- Normally, lower spectrum cost for TDD spectrum
- Easier to transition LTE Band 41 to 5G New Radio.

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

One of the measurements that UE's achieve for the duration of handover, cell selection or re-selection is the RSRP. It delivers information about signal strength. According to the 3GPP requirement the commentary range of RSRP is defined from -140dBm to -44 dBm.

- **Reference Signal Received Quality(RSRQ)**

RSRQ is a channel per interference type of measurement and shows the quality of the received reference signal. The RSRQ measurement offers extra information when RSRP is not enough to make a consistent handover or cell reselection decision. RSRQ measurements are moreover used for Cell selection, Cell reselection, Handover and Mobility measurement. The measurement of RSRQ is defined from -3 to -19.5 dB.

- **Reference Signal Strength Indicator (RSSI)**

Signifies the whole received power containing the desired power from the serving cell as well as all co-channel power and other sources of noise The RSSI is deliberated as a linear average of the total power measured across OFDMA symbols which comprise Reference Symbols transmitted from the first antenna port (if MIMO is not functioned).

- **Cell-edge Coverage Probability**

All radio coverage is depending on probability concept. Since radio coverage cannot be certain 100%; radio coverage at a certain location, some distance away from a transmitter can be identified as 50%, 90% or more. The cell edge coverage probabilities be contingent on the fading margin; it is the safety factor recycled to define the level of probability of effective radio communication. Accordingly, in this thesis, it is supposed to have a cell-edge coverage probability of 90%, and hence a fading margin of 9dB is used during radio link budget calculation.

- **Area Coverage Probability**

Area coverage probability tells how much extant of the target area will be covered by the intentional network. In this study, the coverage probability is expected to cover 97% of the target area.

Table 3.6: Summary of Coverage requirements and Standard Signal Strength indicators

<table>
<tr><td colspan="6">Parameters</td></tr>
<tr><td colspan="2" rowspan="5">Signal strength indicators</td><td>Radio frequency Conditions</td><td>RSRP(dBm)</td><td>RSRQ(dB)</td><td>SINR(dB)</td></tr>
<tr><td>Excellent</td><td>≥-80</td><td>≥ -10</td><td>≥ 20</td></tr>
<tr><td>Good</td><td>-80 to-90</td><td>-10 to -15</td><td>13 to 20</td></tr>
<tr><td>Midcell</td><td>-90 to -100</td><td>-15 to -20</td><td>0 to 13</td></tr>
<tr><td>Cell edge</td><td>≤ -100</td><td>< -20</td><td>≤ 0</td></tr>
<tr><td rowspan="4">Fading margin over minimum</td><td>Values</td><td colspan="2">Coverage probability at the cell-edge (%)</td><td colspan="2">Coverage probability over the entire cell (%)</td></tr>
<tr><td>0</td><td colspan="2">50</td><td colspan="2">77</td></tr>
<tr><td>5</td><td colspan="2">75</td><td colspan="2">90</td></tr>
<tr><td>7</td><td colspan="2">84</td><td colspan="2">96</td></tr>
</table>

received level (dB)	9	90	97
	12	95	99

3.5.5 Coverage Based Site Counts

Using the selected propagation model and the UL and DL MAPL, it is possible to compute the cell radius directed by both the UL and DL path. As it existed said earlier in Chapter 3 the effective radius will be the lowest of the radiuses found in the UL and DL path.

Let us contemplate the gNodeB and UE antenna height to be 30m and 1.5m respectively. The cell radius in the Downlink path , d_{DL} can be calculated by using Dominant path model (DPM) formula in Equation (3.7) and **MAPL** from Downlink radio link budget as follows:

$$d_{DL} = 10^{\frac{(PL - 20*\log_{10}\left(\frac{4\pi f}{c}\right) + g_t}{10*\rho}}$$

$$d_{DL} = 0.654 \text{ km}$$

The cell radius in the Uplink path , d_{UL} can be calculated by using Dominant path model (DPM) formula in Equation (3.7) and MAPL from Uplink radio link budget) as follows:

$$d_{UL} = 10^{\frac{(PL - 20*\log_{10}\left(\frac{4\pi f}{c}\right) + g_t}{10*\rho}}$$

$$d_{UL} = 0.365 \text{ km}$$

Thus, the effective radius, $R_{effective}$= min (d_{DL}, d_{UL}) which is 0.365 km. Here, the reason behind selecting minimum cell radius is that, as we move away from cell or node, there is probability of outage and also as distance increases, the loss is also increases.

Table 3.7: Indicates the summery of the cell radius and effective cell radius

Parameter	DL	UL
gNodeB Antenna Height (m)	30	
UE Antenna Height (m)	1.5	
Frequency in MHz	2600	
MAPL (dB)	148.3	140.24
Cell radius(Km)	0.654	0.365
Effective cell radius($R_{eff)}$ (Km)	0.365	

Now Suppose that all gNodeB's are a three sectored sites (Tri-sector), the site area and the total number of coverage based sites count are calculated by using Equations (3.10) and (3.11) respectively as follows:

$$SA = \frac{9}{8}\sqrt{3} * (R_{eff})^2 = 1.95 * (0.365)^2 = 0.26 \text{ Km}^2$$

The Coverage area of the Kirkos Sub City (which is one sub City of Addis Ababa) is 14.91Km^2. Thus, the total number of sites for the target area is:

$$T_{NS} = \frac{T_{CA}}{SA} = \frac{14.91}{0.26} = 57 \text{ gNodeBs}$$

Hence, a total of 57(Fifty-Seven) Coverage based gNodeB's are required to deliver the radio coverage for 14.91 Km^2 area of Kirkos Sub City.

3.6 5G New Radio Capacity Planning

Speculative capacity of the network is restricted by the number of gNBs set up in the network. The main indicator of capacity, in capacity planning is the SINR delivery in the cell. The SINR distribution may be directly mapped to the system capacity (data rate). A summarized 5G new radio capacity planning process is shown in the Figure 3.9.

3.6.1 Network Capacity Evaluation and Performance Analysis

Network performance is usually measured by throughput and SINR metrices. SINR is metrics used in telecommunications to measure quality of a network. SINR is delineated as the power of a certain signal of interest divided by the sum of the interference power (from all the other interfering signals) and the power of some background noise. SINR is given by the following formula.

$$SINR = \frac{P_{r\ signal}}{\text{Interference Signal} + \text{Noise Power}} \quad (3.12)$$

Where P_r is received power which is desired signal. Changing antenna parameters such as tilt and azimuth can increase P_r and reduce Interference power + Noise power so that SINR can be improved. From radio link budget(RLB) received power (P_r) is given by:

$$P_r = \frac{P_t \times G_t \times G_r}{\text{Pathloss}} \quad (3.13)$$

Where;

- P_t : is the transmitter power;
- G_t : is the transmitter antenna gain;
- G_r : is the receiver antenna gain.

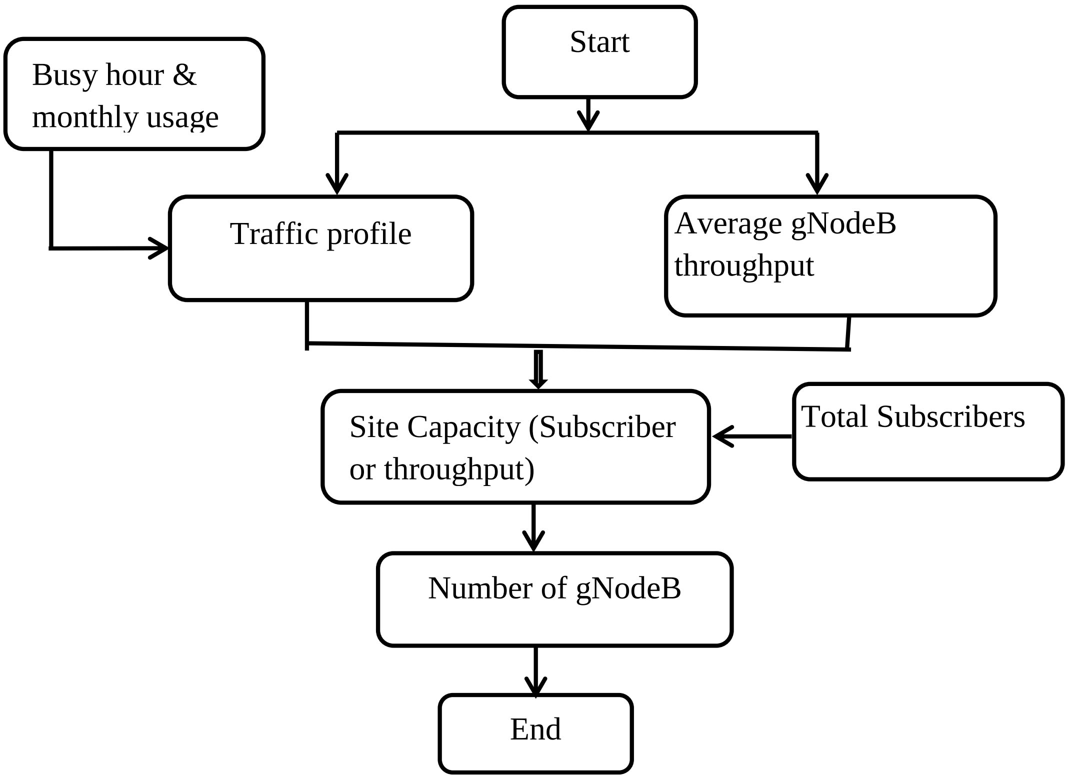


Figure 3.8: Summarized capacity planning process

Throughput by definition is the maximum data rate transmitted by the communication system. It is also defined as the measure of quality expressed as the data transfer rate of usual and non-redundant information. In the theoretical limit it is equal to the Shannon channel capacity. The throughput can be calculated from Shannon capacity formula. The Shannon capacity formula is meant to account for the system bandwidth efficiency and the SINR efficiency of radio network. Shannon capacity formula is given by [17]:

$$C\ (\text{bps}) = BW \times \log_2(1 + SINR) \qquad (3.14)$$

Where;

- C : is channel capacity(bps);
- BW: is the Channel bandwidth in Hz;
- SINR: is Signal interference plus noise ratio.

3.6.2 Capacity Requirements

- **Throughput at cell-edge in downlink (DL) and uplink (UL)**

Throughput at cell-edge design target in the downlink and uplink are assumed to be 1024 kbps & 512kbps respectively.

- **Total number of subscribers**

Number of subscribers is very significant input for capacity planning in determining the sites count based on capacity. In order to have a network capable enough to accommodate the upcoming subscriber's growth, subscriber forecasting is a very important task to be completed before starting network planning. Thus understanding which social and economic factors affects the number of subscribers for the given market and predicting how the subscriber number will evolve within the upcoming years are extremely important. In order to demonstrate the involvement of all the features for effective network capacity planning, the following assumptions are made in this study.

Assumptions:

- Total 5G New Radio subscribers in Addis Ababa is expected to 1000,000 in the year 2025; Age group of promising 5G New Radio subscribers is supposed to be above 20 years old;
- Population census data per sub city taken on 1st July 2007 and 2010 [37], [38]is deliberated to assume population growth per sub city in the year 2025;

Table 3.8: 5G new radio subscriber number distribution assumption per sub cities [37]

Geographical area or Sub City of Addis Ababa	Population 2007/2014 /2015	Population 2010/2017 /18	Population growth rate	Projected Population 2024/2025	Total Projected Subscriber	Subscriber (%)
Akaki Kaliti-Sub City	216,538	227,182	0.9531	443720	129214	12.92
Nefas Silk-Lafto-Sub City	377,892	396,486	0.9531	774378	225503	22.55
Kolfe Keraniyo-Sub City	512,369	537,561	0.9531	1049930	305745	30.57

Gulele-Sub City	319,712	335,434	0.9531	655146	190782	19.078
Lideta-Sub City	240,989	252,842	0.9531	493831	143806	14.38
Kirkos-Sub City	264,337	277,346	0.9530	541683	157741	15.77
Arada-Sub City	252,705	265,141	0.9530	517846	150800	15.07
Addis Ketema-Sub City	305,058	320,053	0.9531	625111	182036	18.20
Yeka-Sub City	414,212	434,599	0.9530	848811	247179	24.71
Bole-Sub City	369,189	387,355	0.9531	756544	220310	22.03
Total	3,273,000	3,434,000	0.9531	6,707,000	1000,000	100%

Following the total population of Addis Ababa and total assumed 5G new radio subscribers, the number of 5G New Radio subscriber per sub city is determined based on the following formula:

$$T_{SS} = \left(\frac{T_{SA}}{T_{PA}}\right) \times T_{PS} \tag{3.15}$$

Where:

- T_{SS} : The total 5G new radio subscriber per sub city
- T_{SA} : The assumed total 5G new radio subscribers in Addis Ababa
- T_{PA} : The total population in Addis Ababa
- T_{PS} : The projected population of a sub city

Consequently, the projected population growth of Addis Ababa City in the year 2025 is considered and distributed per sub city using population ratio as showed in Table 3.8. Thus, the inclusive number of 5G new radio subscriber for Kirkos sub city is found to be 157,741 as shown Table 3.8. This means the sub city will have 15.77% share from the total 5G new radio subscribers assumed in the capital Addis Ababa.

- **Data volume per month**

Data volume per month is an accounting solution by which a user can buy a certain amount of data service. In the capacity estimation, the data service is expressed by a certain amount of data volume per month per subscriber. The capacity planning can be ongoing by estimating the daily traffic of the busy hour traffic as a percentage. In this study 5G new radio users are considered to be users that are using smart phones, dongles, and other kind of terminals (fixed or portable), the busy hour assumed to be in different three-time segment within the 24 hours of a day. The first fragment is from 10:00 AM to 11:00 AM in the morning, the second fragment is from 3:00 PM to 4:00 PM in the afternoon and the third fragment is assumed to be from 08:00PM to 09:00PM in the evening. Thus, a total of 3 hours are consider to be the busy hours within 24 hours of a day, which makes the busy hour traffic to be 12.5% of the daily traffic.

The daily traffic in this thesis design is assumed 12.5% of the busy hour traffic. Generally, the main persistence of traffic model is to describe the average subscriber activities during the most loaded day period (Busy Hour) and the capacity of site should be based on busy hour as the traffic is not equally distributed during 24 hours [39].

Table 3.9: Users service category[39]

Types of customer	Traffic Usage in GB/Month/User	Usage ratio of the services (%)	Traffic ratio of busy hour to whole day (%)
Gold	20	60	12.5
Silver	15	30	
Bronze	10	10	

Three classes of delivery packages are offered, golden service package, silver service package, and bronze service package. Every delivery has its own quality, the month service package, the DL and UL peak data rates, and the package percentage. In general, the traffic model of the above types of service is based on the LTE current usage of Ethio-telecom data usage is listed in Table 3.9 [39].

First step: Calculate the average total throughput per subscriber@ Busy Hour (BH):

Average throughput per

$$\text{subscriber@Busy Hour (Kbps)} = \frac{\text{Monthly service package} \times 8 \text{ bit/byte}}{\text{Number of days} \times \text{Time in seconds}} \times \text{BH ratio} \qquad (3.16)$$

- Gold customer Average throughput (DL + UL):

$$\text{Av.throughput per Subscriber@BH (Kbps)} = \frac{20\times10^9 \times \frac{8\,bit}{byte} \times 12.5\%}{30\times3600} = 185.185$$

- Silver customer Average throughput (DL + UL):

Av.throughput per Subscriber@BH (Kbps) = $\frac{15 \times 10^9 \times \frac{8\text{ bit}}{\text{byte}} \times 12.5\%}{30 \times 3600}$ = 138.888

- Bronze customer Average throughput (DL + UL):

Av.throughput per Subscriber@BH (Kbps) = $\frac{10 \times 10^9 \times \frac{8\text{ bit}}{\text{byte}} \times 12.5\%}{30 \times 3600}$ = 92.592

Then, the average total throughput per subscriber in busy hour is given by:

Total Av.throughput per Subscriber@BH = $\sum($ Av.throughput per Subscriber@BH (Kbps) $\times$ usage ratio of the servicpackages)

= $(185.185 \times 0.6) + (138.888 \times 0.3) + (92.592 \times 0.1)$

= $111.111 + 41.666 + 9.259$

= 162 Kbps

Second step: Calculate 5G new radio aggregate throughput or data rate

5G New radio throughput or data rate (in Mbps) =

$$10^{-6} . \sum_{j=1}^{J} (V_{Layers}^{(j)} . Q_M^{(j)} . f^{(j)} . R_{max} . \frac{N_{PRB}^{BW(j),\mu}}{T_s^{\mu}} . 12(1 - OH^{(j)})) \quad (3.17)$$

Where:

- J: number of aggregated component carriers in a band or band combination
- $R_{max:}$ 948/1024
- For the j-th CC (component carrier), $V_{layers(j)}$ is the maximum number of layers
- $Q_{m(j):}$ Maximum modulation order, Q_m is 2 for QPSK, 4 for 16-QAM, 6 for 32-QAM, 8 for 256-QAM
- f(j): Scaling factor, can take any value from 1/0.8/0.75/0.4;
- μ: 5G New radio numerology can take any value from 0 to 5;
- T_s^{μ}: Average OFDM symbol duration in a subframe for μ value,
- $N_{PRB}^{BW(j),\mu}$: Maximum RB Allocation in bandwidth, BW (j) with numerology (μ), BW (j) is UE supported maximum Bandwidth in given band or in band combinations. Table 3.10 shows subcarrier spacing with maximum resource block allocation in bandwidth.

Table 3.10: Subcarrier spacing with maximum resource block allocation in bandwidth

Bandwidth in MHz	Maximum RB Allocation	Frequency band(FR1)	Frequency band(Fr2)	Subcarrier Spacing(SCS)

	in bandwidth			
50	270	✓		15 kHz
100	273	✓		30 kHz
100	135	✓		60 kHz
200	264		✓	60 kHz
400	264		✓	120 KHz

- RE (Resource elements) are come together into PRBs (Physical Resource Blocks). Each PRB consists of 12 Subcarriers.
- OH (j): Overhead which takes any of the following values in the Table 3.11

Table 3.11: Overhead values for FR1 and FR2

Overhead(OH)	Frequency range FR1 for DL	Frequency range FR1 for UL	Frequency range FR2 for DL	Frequency range FR2 for UL
0.14	✓			
0.18			✓	
0.08		✓		
0.10				✓

Now, calculate the peak 5G new radio capacity throughputs or data rate by using equation (3.17). Accordingly; in this thesis design; consider the following values in the Table 3.12

Table 3.12: Parameters used in this thesis to calculate the throughputs for 5G New radio

Parameters	Values
Frequency range	FR1
Bandwidth(MHz)	100
Number carriers(J)	1
Number of Layers (V)	2
Bits per Symbol from modulation scheme(Q_M)	8
Scaling factor/ signaled per band (f)	0.5
Max. code rate(R_{max})	948/1024
Max. number of Resource block	273

Sub-carrier per Resource block	12
Sub-carrier spacing	30kHz
Numerology(μ)	1
Average OFDM symbol duration (Ts)	$T_s^{\mu} = \frac{10^{-3}}{14 * 2^{\mu}}$ =3.577$* 10^{-5}$
Overhead (OH)	0.14(DL) and 0.08(UL)

Hence, the aggregate capacity throughput per site or data rate from Equation (3.17) and Table 3.12 can be calculated as:

Downlink Data rate (in Mbps)

$$= 10^{-6} . \sum_{j=1}^{J} (V_{Layers}^{(j)} . Q_M^{(j)} . f^{(j)} . R_{max} . \frac{N_{PRB}^{BW(j),\mu}}{T_s^{\mu}} .12(1 - OH^{(j)}))$$

$$= 10^{-6} * 1 * 2 * 8 * 0.5 * (\frac{948}{1024}) * (273 * 12) * (14 * 2^1)/10^{-3}(1 - 0.14))$$

Thus, Aggregate capacity throughput per site or data rate (DL) = 584.25 Mbps

Uplink Data rate (in Mbps)

$$= 10^{-6} . \sum_{j=1}^{J} (V_{Layers}^{(j)} . Q_M^{(j)} . f^{(j)} . R_{max} . \frac{N_{PRB}^{BW(j),\mu}}{T_s^{\mu}} .12(1 - OH^{(j)}))$$

$$= 10^{-6} * 1 * 2 * 8 * 0.5 * (\frac{948}{1024}) * (273 * 12) * (14 * 2^1)/10^{-3}(1 - 0.08))$$

Thus, Aggregate capacity throughput per site or data rate (UL) = 625.01 Mbps

The maximum subscriber's number per site is now calculated as:

$$\text{Max. no of Subs per Site}_{(DL)} = \frac{\text{Aggregate capacity throughput per site or data rate (DL)}}{\text{Total Av. throughput per Subscriber@BH}}$$

$$= \frac{584.25\text{Mbps}}{162 \text{ Kbps}}$$

$$= 3606$$

$$\text{Max. no of Subs per Site}_{(UL)} = \frac{\text{Aggregate capacity throughput per site or data rate (UL)}}{\text{Total Av.throughput per Subscriber@BH}}$$

$$= \frac{625.01\text{Mbps}}{162 \text{ Kbps}}$$

$$= 3858$$

Hence, the numeral of gNodeBs required to accommodate the given total number of subscriber (157,741**)** can be calculated by using Equation (3.15)

Capacity based Sites count ($_{DL)}$ $= \frac{\text{Total Subscriber number of the required area}}{\text{Max.no of Subs per Site}_{(DL)}}$

$$= \frac{157{,}741}{3606}$$

$= 44$ gNodeBs

Capacity based Sites count ($_{UL)}$ $= \frac{\text{Total Subscriber number of the required area}}{\text{Max.no of Subs per Site}_{(UL)}}$

$$= \frac{157741}{3858}$$

$= 41$ gNodeBs

From the above capacity based sites count (DL and UL) perspective we have to select the maximum number of sites.

Table 3.13: Best Selected from Capacity based Sites count (DL and UL)

Capacity based sites count	# of gNodeBs calculated	Best selected
Downlink	44	44
Uplink	41	

Thus, a total of 44 (Forty-four) gNodeBs are requisite to meet the capacity request. In the nominal planning phase, it is exposed that a total of 57 (Fifty-Seven) gNodeBs are required to meet the coverage condition and on the other hand a total of 44 (Forty-four**)** gNodeBs are essential to meet the capacity necessity. Since the target network should satisfy both the requirements of coverage & capacity, the total number of gNodeBs that will be used in order to analyze the target network further in the detail planning stage becomes 57 (Fifty-Seven) gNodeBs. That is Sites Count or number of gNodeBs is the maximum of the Coverage based sites count and Capacity based sites count. From Figure 3.3;

Sites count = Max (Coverage, Capacity) = Max (57 gNodeBs, 44 gNodeBs)

= 57gNodeBs

From the coverage and capacity dimensioning perspective we have to select the maximum number of sites.

Table 3.14: Selected number of 5G New radio sites for Kirkos Sub city

Dimensioning	# of gNodeBs calculated	Best selected
Coverage	57	

Capacity	44	57

3.7 Millimetric Wave Propagation Modeling

This section discusses about some of propagation models that are used in millimetric wave and their technical challenges. And also, mathematical modeling for large scale pathloss of urban macro and urban micro are illustrates and summarized mathematical model for pathloss are given the Table 3.15-3.19.

Common wireless propagation model parameters include: carrier frequency, bandwidth, 2-D or 3-D distance between transmitter (TX) and receiver (RX) and environmental effects. The conclusive challenge for a 5G channel model is to deliver a fundamental physical basis, while being flexible and precise, especially through a wide frequency range such as 0.5 GHz to 100GHz.

Groups and projects with channel models are:

3rd Generation Partnership Project (3GPP TR 38.901): This effort to offer channel models from 0.5-100 GHz depend on an adjustment of 3GPP's extensive exertion to improve replicas from 6 to 100 GHz in TR 38.900.

METIS Channel Models: has **r**ecognize 5G necessities (e.g., extensive frequency range, high bandwidth, massive MIMO, 3-D and correct polarization modelling)**,** Performed channel measurements at different bands between 2GHz and 60 GHz**,** Delivered various channel model methodologies (map-based model, stochastic model or hybrid model). Intended for stochastic model, the projected channel is dedicated on outdoor square, Indoor cafeteria and indoor shopping mall scenarios.

MiWEBA Channel Models: This model presents many contests: shadowing, spatial consistency, environment dynamics, spherical wave, modelling, dual mobility Doppler model, ratio among diffuse and specular reflections, polarization, Proposed Quasi-deterministic channel model, implemented channel measurements at 60 GHz and Dedicated on university campus, street canyon, hotel lobby, backhaul, and D2D scenarios.

ITU-R M Channel Models: This model addressed the propagation loss and atmospheric loss on millimeter wave, presented permitting antenna array technology and semiconductor technology, planned deployment scenarios, concentrated on dense urban environment for high data rate service: indoor shopping mall, indoor enterprise, in home, urban hotspot in a square/street, mobility in city.

NYU WIRELESS Channel Models: In this model many urban propagation measurements on 28,38,60,73 GHz bands for both outdoor and indoor channels are conducted.

802.11 ad/ay Channel Models: This model combined ray-tracing methodology on 60 GHz band indoor channels, containing conference room, cubicle, living room scenarios, Intra cluster parameters were proposed in terms of ray excess delay and ray power distribution, Human blockage models were recommended in terms of blockage probability and blockage attenuation

mmMAGIC: In this model major infrastructure vendors, European operators, leading research institutes and universities and measurement equipment vendors are bringing together. This model carries out wide radio channel measurements on the 6 -100 GHz range

2.7.1. Technical Challenges with Millimetric Wave Channel Modeling

Despite of many interesting technique, benefits and potentials for 5G millimeter wave communications, there still have several challenges and limitations that we should try to overcome for mobilizing millimeter wave [40]. The following are some characteristics which are considered in basic propagation modeling.

Free space path loss: The free space path loss is the loss in signal strength of a signal in terms of radio energy when it travels between the feed points of two antennas through free space (i.e., unobstructed LOS channels in the air). In [41] The signal strength of a signal can be measured as the transmitter power output received by a receiving antenna at a transmission distance from the transmitting antenna.

Atmospheric attenuation: When millimeter wave frequencies are used the atmosphere found to be more attenuating and absorbing for the received signal following exponential relationship with d from transmitter to receiver. The coefficient of attenuations shown dependency upon the atmospheric conditions such as rain and fog etc. and sometimes upon frequency too [42], [43]. Under millimeter wave conditions, attenuation constant does not affect the path loss more than few decibels even in the situations when there are heavy rain storms.

Vegetation attenuation: Foliage always plays a significant role at millimeter wave frequencies, it is generally found that the path length travelled during foliage, always increases the attenuation coefficient travelled through foliage, whenever path containing canopies comes into picture attenuation gets saturated [44].

Channel sparsity: It is generally considered that millimeter-wave channels are “sparse”. Because there is less resolution of horn antennas, engaged generally in experimental setups, it is a challenging problem to determine actual number of multipath coefficients. Sometimes it is possible to found a lowest possible value of channel sparsity with the help of these experiments, but this cannot go lower than cm wave frequencies [45].

Blockage effect: Although, millimeter wave communications own the ability to deliver ultra-high-speed, indoor wireless transmission, wireless backhaul, small cell access, cellular access, etc,millimeter wave bands are not robust enough and the system performance degrades significantly due to the sensitivity of millimeter wave links to blockages, e.g., static, dynamic, and self-blockage [46].Typically, the propagation of millimeter wave signals is rather disposed to blockage effect due to severe penetration loss and higher reflection/diffraction loss [46] and [47].

Beam misalignment: The narrow beams of millimeter wave signals permit the ability to accomplish highly directional beams and greater resolutions along the preferred directions. We can utilize the highly directional antennas to focus their power of steerable narrow beams on the intended users. With the large-scale antenna arrays, highly directional beamforming can be leveraged to compensate for stronger atmospheric attenuation and higher free space path loss at millimeter wave frequencies.

3.7.2 Large-Scale Path Loss Models

Three main categories of large-scale path loss models to forecast millimeter wave signal strength [48]. These include: Close-in (CI) free space reference distance model (with a 1 m reference distance), CI model with a frequency-weighted or height weighted path loss exponent (CIF and CIH models) and Floating intercept (FI) path loss model also recognized as the ABG model for the reason that of it uses of three parameters alpha, beta and gamma.

3.7.2.1. Close-in (CI) free space reference distance model

The **CI** path loss model versions for the frequency dependency of path loss by means of a close-in reference distance based on Friis'Law as given by [49]:

$$PL^{CI}\ (fc,\ d3D)\ [dB] = FSPL\ (fc,\ 1\ m) + 10n\ \log10\ (d_{3D}) + \delta^{CI} \tag{3.18}$$

Where δ^{CI} is the shadow fading (SF) that is displayed as a zero-mean Gaussian random variable with a standard deviation in dB, n is the path loss exponent (PLE) recognized by diminishing the fault of the measured data to d_{3D} > 1m, FSPL (f, 1 m) is the free space path loss (FSPL) at frequency f_c in GHz at 1 m and is calculated by:

$$FSPL\ (fc,\ 1m) = 20\ .\log_{10}(4\pi f_c \times 10^9/c) = 32.4 + 20.\ \log_{10}(f_c)\ [dB]$$

$$PL^{CI}\ (fc,\ d3D)\ [dB] = 32.4 + 20.\ \log_{10}(f_c)\ [dB] + 10n\ .\log10\ (d_{3D}) + \delta^{CI} \tag{3.19}$$

Where c is the speed of light, 3×10^8m/s.

3.7.2.2. Close-in model with a frequency weighted or height weighted path loss exponent

Two parameters are Used in this model to calculate average path loss ended distance, and return to the single parameter CI model when b = 0 for multiple frequencies, or when a single frequency $f = f_0$ is modeled as [50]:

$$PL^{CIF}(f_c,\ d)[dB] = 32.4+20.\log_{10} f_c+10n(1+b(\frac{f-f_0}{f_0}))\log_{10}(d) + \delta^{CIF} \tag{3.20}$$

Where n represents the distance dependence of path loss, b is an optimization parameter that refer to the linear dependence of path loss around the weighted average of frequencies f_0 (in GHz), from the data recycled to optimize the model.

3.7.2.3.FI (Floating intercept) or ABG (Alpha, Beta and Gamma) path loss model

This model has three parameters that differ enthusiastically through various scenarios and frequency ranges, and the ABG model parameters vary extensively across frequencies and distances, while reducing the standard deviation by simply a fraction of a dB related to the simpler, physically-based CI model. The enhancement in error with the additional complex three-parameter ABG model is unimportant ordinarily well below an order of magnitude of the actual standard deviation value of all models considered here [51].

Close-in and Alpha, beta, and gamma models deliver very similar modeling performance by using actual data, with the Close-in model affording simplicity and a physical basis with one parameter, and delivering a very conservative NLOS path loss estimation at large distances, while [55] Alpha, beta, and gamma model needs three parameters that are not physically founded, despite the fact predicting less path loss close to the transmitter and more loss at greater distances.

ABG model is given by:

$$PL^{ABG}(fc, d)\,[dB] = 10\,\alpha\log_{10}(d) + \beta + 10\,\gamma\log_{10}(fc) + \delta^{ABG} \qquad (3.21)$$

Where α, β and γ are determined by finding the best fit values to diminish the error among the model and the measured data.

- α: shows the slope of path loss;
- β: indicates floating offset value in dB;
- γ: indicates models the frequency dependence of path loss;
- f_c: is frequency in GHz.

3.7.3. Large-Scale Path Loss Model: Urban-Micro(Umi)

5G Channel Modeling(5GCM): Close-in model is chosen for modeling UMi LOS path loss, subsequently in the ABG model is very nearly identical to the PLE of the CI model [52]. Both the CI and ABG models were accepted for UMi NLOS in 5GCM.

3GPP TR 38.901(the 3rd Generation Partnership Project): Path loss models use 3D TR departure distances d3D that account for the base station height (hBS) and UE height (hUE). The delivery of the shadow fading is log-normal, and the standard deviation for LOS is δ^{SF} = 4.0 db. The LOS breakpoint distance d'_{BP} is a function of the carrier frequency, BS height, and the UE height [53].

$$d'BP = 4h'_{BS.}\,h'_{UE}\,f_c \times 10^9/c$$
$$h'_{BS} = h_{BS} - 1m; \qquad (3.22)$$
$$h'_{UE} = h_{UE} - 1m.$$

Where h'BS and h'UE are the operative antenna heights at the BS and the UE, and hBS and hUE are the actual antenna heights, respectively. The breakpoint distance in an urban environment is where the PLE transitions from free space (n = 2) to the Asymptotic two-ray ground bounce model of n = 4.

In the case of NLOS scenarios, the UMi-NLOS model practices the ABG model form, with a frequency-dependent term that illustrates path loss increases with frequency and also has an extra height improvement term for the UE.

METIS: In METIS the path loss model for UMi is an improved version of the ITU-R UMi path loss model and is demanded to be legal for frequencies from 0.8 to 60 GHz. Some METIS models contain breakpoints based on sub-6 GHz work [53]. For LOS scenarios, a scaling factor is used, consequently the breakpoint distance dBP (in meters) becomes:

$$d_{BP} = 0.87\exp\left(-\frac{\log_{10} fc}{0.65}\right) 4\left(\frac{hBS-1m(hUE-1m)}{}\right) \tag{3.23}$$

Then formula for LOS pathloss is written as:

$$PL_{LOS}(d_1)\,[dB] = 10n_1\log_{10}(d1) + 28.0 + 20\log_{10}(fc) + PL_0 \tag{3.24}$$

For 10 m < d ≤ 6 d_{BP} , where PL0 is a path loss offset calculated by:

$$P_{L0[dB]} = -1.38.\log_{10}(f_c) + 3.34 \tag{3.25}$$

After the breakpoint distance pathloss is:

$$PL_{LOS}(d1)\,[dB] = 10n_2\log_{10}\left(\frac{d1}{dBP}\right) + PL_{LOS}(d_{BP}) \tag{3.26}$$

For dBP < d1 < 500m where (h) and (i) represent path loss before and after the breakpoint, respectively.

mmMAGIC: The mmMAGIC project approved the ABG path loss model for UMi, similar to that from 5GCM (i) but using different parameter values (54).

3.7.3. Large-Scale Path Loss Model: Urban Macro (Uma)

3GPP TR 38.901(the 3rd Generation Partnership Project): In this model 3GPP TR 38.901 UMa LOS path loss model is permitted from 3GPP TR 36.873 (below 6 GHz Release 12 for LTE) and TR 38.900. For UMa NLOS scenario, ABG model and an optional CI model are delivered.

5GCM (5G Channel Modeling): In this model three UMa path loss models are used. CI, CIF, and ABG. The PLEs of the CI/CIF models for UMa are to some extent lower than for the UMi models displaying less loss ended distance.

METIS: This model recognized the sub-6 GHz 3GPP TR 36.873 3D UMa model that was published in 2014 for LTE. Generally, models for path loss in the Urban micro and Urban macro scenario are summarized as follow in the Table (3.15 - 3.18).

Table 3.15, part(1a): Summarized Path loss models in the Urban- Micro scenario

	PL[dB], f is in GHz and distance in meters	Shadow fading std(dB) δ^{SF}	Applicability range and parameters
	5GCM		
5GCM UMi-street canyon LOS	**CI model** with 1m reference distance $PL=32.4 + 21\log_{10} d + 20\log_{10}(fc)$ … (1a)	3.76	6 < f < 100 GHz
5GCM UMi-street canyon NLOS	**CI model** with 1m reference distance $PL = 32.4 + 31.7\log_{10} d + 20\log_{10}(f\ c)$ … (2b) **ABG model** $PL= 35.3\log_{10}(d) + 22.4 + 21.3.\log_{10}(fc)$ … (3c)	8.09 7.82	6 < f < 100 GHz
5GCM UMi-open street square LOS	**CI model** with 1m reference distance $PL=32.4+18.5\log_{10} d + 20\log_{10}(f\ c)$ … (4d)	4.2	6 < f < 100 GHz
5GCM UMi-open square NLOS	**CI model** with 1m reference distance $PL= 32.4+28.9\log_{10} d + 20\log_{10}(f\ c)$… (5e) **ABG model** $PL= 41.4\log_{10} d + 3.66 + 24.3\log_{10}(f\ c)$ … (6f)	7.1 7.0	6 < f < 100 GHz

Table 3.16, part(2a): Summarized path loss models in the urban- micro scenario

mmMAGIC			
mm MAGIC UMi-street canyon LOS	PL = 19.2 $\log_{10} d$ + 32.9 +20.8$\log_{10}(fc)$ … (7g)	2.0	6 < f < 100 GHz
mm MAGIC UMi-street canyon NLOS	PL = 45$\log_{10} d$ + 31.0 + 20$\log_{10}(f\ c)$… (8h)	7.82	6 < f < 100 GHz
3GPP TR 38.901 V14.0.0			
3GPP UMi-Street Canyon LOS	PLUMi-LOS = $\begin{cases} PL1, & 10m \le d2D \le d'BP \\ PL2, & d'BP \le d3D \le 5km \end{cases}$ PL1= 32.4 + 21$\log_{10}(d3D)$ + 20$\log_{10}(fc)$ PL2 = 32.4 + 40$\log_{10}(d3D)$ + 20$\log_{10}(fc)$ – 9.5$\log_{10}((d'BP)^2 + (hBS - hUE)^2)$ … (9i) Where d’$_{BP}$ is specified in (i)	4.0	0.5 < fc < 100 GHz 1.5m ≤ hUE ≤ 22.5 m hBS = 10 m
3GPP UMi-Street Canyon NLOS	PL = max(PLUMi-LOS(d3D); PLUMi-NLOS(d3D)) PLUMi-NLOS = 35.3 $\log_{10}(d3D)$+ 22.4 + 21.3$\log_{10}(fc)$ - 0.3(hUE - 1.5) **Option: CI model** with 1 m reference distance PL = 32.4 + 20$\log_{10}(fc)$ + 31.9 $\log_{10}(d3D)$ (10j)	7.82 8.2	0.5 < fc < 100 GHz 10 m < d2D < 5000m,1.5 m ≤ hUE ≤ 22.5 m hBS = 10 m

Table 3.17, part-3a, Summarized path loss models in the urban- micro scenario

METIS			
METIS Umi-Street Canyon LOS	PLUMi-LOS = $\begin{cases} PL1;\ 10\,m \leq\ d3D \leq\ d'BP \\ PL2;\ d'BP \leq\ d3D \leq 500\,m \end{cases}$ PL1 = 22 $\log_{10}(d3D)$ + 28.0 + 20$\log_{10}(fc\ )$ + PL0 PL2 = 40 $\log_{10}(\ d3D)$ + 7.8 - 18 $\log_{10}(hBS.hUE)$ +2 $\log_{10}(\ fc)$ + PL1(dBP) (11k) d'BP and PL0 are specified in [f] and [g]	3.1	0.8≤ fc ≤ 60 GHz
METIS UMi-Street Canyon NLOS	PL = max (PLUMi-LOS(d3D); PLUMi-NLOS(d3D)) PLUMi-NLOS = 36.7 $\log_{10}(\ d3D)$ + 23.15 + 26 $\log_{10}(\ fc)$ - 0.3(hUE) … (12m)	4.0	0.45 ≤ fc ≤ 6 GHz 10 m < d2D < 2000 m hBS = 10 m 1.5m≤hUE≤22.5 m

Table 3.18, part-1b: Summarized path loss models in the urban- macro scenario

Urban-Macro scenario			
5GCM			
5GCM UMa-LOS	**CI model** with 1 m reference distance: PL = 32.4 + $20\log_{10}(d3D)$ + 20 $\log_{10}(fc)$	2.0	6 < fc < 100 GHz
5GCM UMa-NLOS	**CI model** with 1 m reference distance: PL = 32.4 + 30 $\log_{10}(d3D)$ + 20 $\log_{10}(fc)$ **ABG model**: PL =$34\log_{10}(d3D)$ +19.2 +23 $\log_{10}(fc)$ (13n)	7.82	6 < fc < 100 GHz
3GPP TR 38.901			
3GPP TR38.901 UMa –LOS	PLUMa-LOS = $\begin{cases} PL1, 10m \leq d2D \leq d'BP \\ PL2,\ d'BP \leq d2D \leq 5km \end{cases}$ PL1 = 28.0 + 22 $\log_{10}(d3D)$ + 20 $\log_{10}(fc)$ PL2 = 28.0 + $40\log_{10}(d3D)$ + 20 $\log_{10}(fc)$ - $9\log_{10}((d'BP)^2$ + $(hBS - hUE)^2)$ where; d'BP= $4h'_{BS}\, h'_{UE} f_c \times 10^9\ /c$ … (14o)	4.0	0.5 < fc < 100 GHz 1.5 m ≤ hUE ≤ 22.5 m hBS = 25 m
3GPP TR38.901 UMa - NLOS	PL = max (PLUMa-LOS(d3D); PLUMa-NLOS(d3D)) PLUMa-NLOS = 13.54 + 39.08 $\log_{10}(d3D)$ +$20\log_{10}(fc)$ - 0.6(hUE -1.5) **Option: CI model** with 1 m reference distance	6.0	0.5 < fc < 100 GHz 10 m < d2D < 5000 m,1.5 m ≤ hUE ≤22:5 hBS = 25 m

	PL = 32.4+20 $\log_{10}(fc)$ + 30 $\log_{10}(d3D)$ (15p)	7.8	

Table 3.19, part-2b: Summarized path loss models in the urban- macro scenario

METIS			
METIS UMa-LOS	PLUMa-LOS $=\begin{cases} PL1, 10m \leq d2D \leq d'BP \\ PL2, d'BP \leq d2D \leq 5km \end{cases}$ PL1 = 28.0 + 22 $\log_{10}(d3D)$ + 20 $\log_{10}(fc)$ PL2 = 28 .0 + 40 $\log_{10}(d3D)$ + 20 $\log_{10}(fc)$ -9 $\log_{10}((d'BP)^2 + (hBS - hUE)^2)$ (16 q) where; d'BP = 4(hBS - 1)(hUE - 1)$f_c \times 10^9$ /c	4.0	0.45 < fc < 6 GHz 10 m < d2D < 5000 m 1.5 m ≤ hUE ≤ 22.5 m,hBS = 25 m
METIS UMa-NLOS	PL = max (PLUMa-LOS(d3D); PLUMa-NLOS(d3D)) PLUMa-NLOS = 161.94 - 7.1 $\log_{10}(w)$ + 7.5 $\log_{10}(h)$ – (24.7-3.7$(\frac{h}{hBS})^2$) $\log_{10}(hBS) + (43.42 - 3.1\log_{10}(hBS))(\log_{10}(d3D) - 3) + 20\log_{10}(fc) - 0.6(hUE)$ … (17r)	6.0	0.45 < fc < 6 GHz 10 m < d2D < 5000 m 1.5 m ≤hUE ≤ 22.5 m hBS = 25 m, w=20 m, h = 20 m

CHAPTER 4

4. SIMULATION AND RESULTS ANALYSIS

4.1 Overview

Simulation is a realistic and systematic method to examine a complex system. In this research, simulation is used to examine the radio network planning nominal planning of 5G networks as it is done using Winprop tool. The 5G radio network planning simulation is projected to carry out the link budget calculation, propagation modeling using the terrain model, coverage prediction and capacity estimation. This chapter discusses the detailed planning phase of radio network dimensioning, the parameters finally, the planned network result will be evaluated.

4.2 Site Survey

The method of site survey is to categorize the various environmental factors that directly or indirectly affect the radio network planning process and as well to list out them as planning parameters. In this study one of the sub cities of Addis Ababa called Kirkos Sub city is carefully chosen to study the coverage and capacity characteristics of the 5G New radio network. Kirkos Subcity in Addis Ababa is located on longitude line of 38.7630° E and at latitude line of 9.0024° N. The number of subscribers' of Kirkos Subcity is deliberated to be 157741(Table 3.7), from 1,000,000 assumed total number of subscribers in Addis Ababa city by considering feature expansion. The morphology of this Sub city is considered as Dense urban with a requirements of continues coverage area of 14.91 Km^2. In this Subcity there are different hot spot areas including: International Hotels, Government Offices, Different Banks and the Economic Commission for Africa(ECA).Thus, the choice of 5G New radio network for this Sub city is the right decision as users in this area would require substantial internet speed and connectivity.

4.3 Simulation Work Flow

Radio network planning tools empowers the network planners to design wireless access networks. It is used to predict radio coverage, manage mobile and fixed subscriber's data and evaluate the network capacity. Figure 4.1 illustrate simulation workflow used in this study to design and evaluate 5G network using Winprop software.

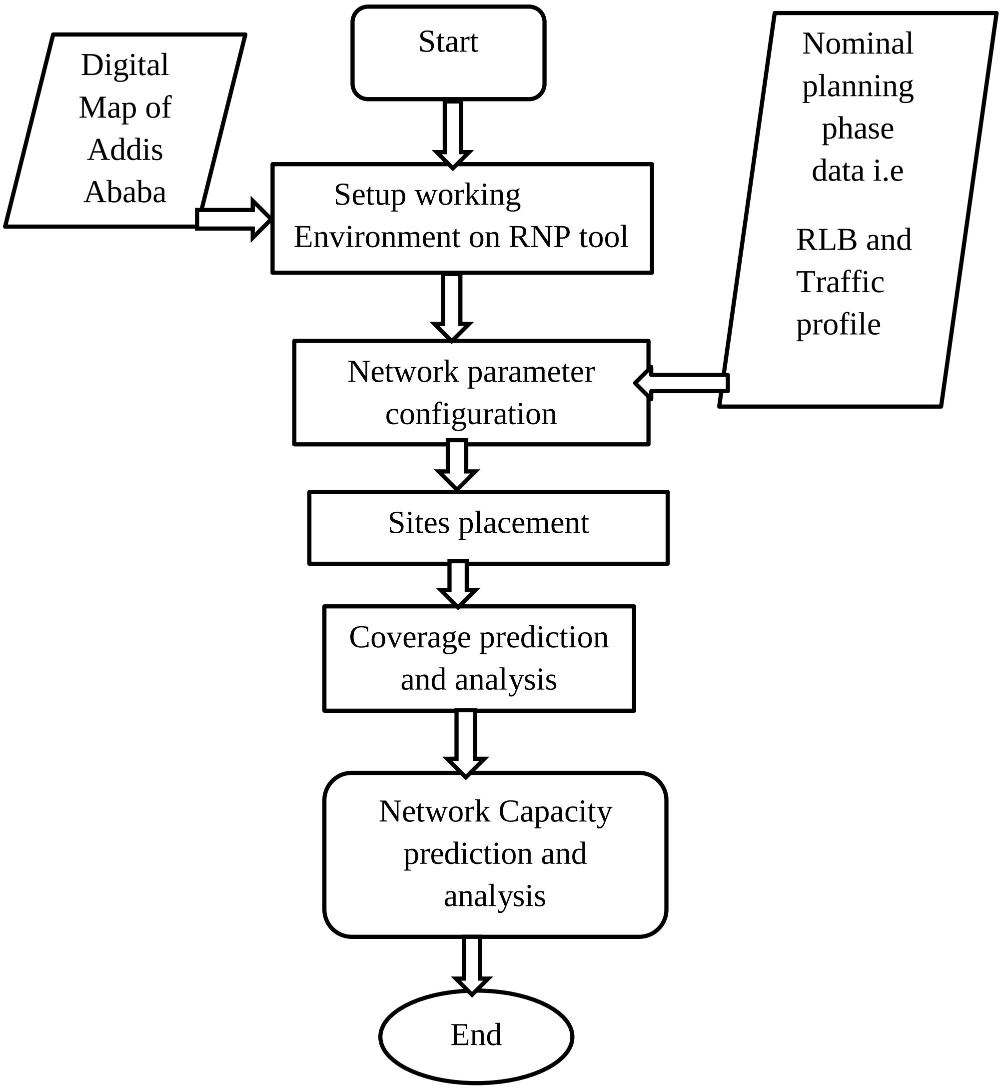


Figure 4.1 5G New Radio Simulation Work Flow

As it is exposed in the work flow above the process requires two inputs . The first input is a digital map,which is used to set up working environments on the Radio network planning tools/software.In this study, digital map of Addis Ababa with a resolution of 5m is used ,in particular the area under Kirkos Sub city is dedicated to accomplish the simulation and the nominated area as shown in Figure 4.2 circled in rectangular red color. A digital map is an electronic database comprising geographical information such as land usage (clutter information), height data, and vector data (streets, main roads, secondary roads, highways, and railways).

Figure 4.2: Digital map of target area from winprop/wallman

The second inputs are the parameters found from the planning phase. They are used to configure network parameters such as site parameters, transmitter, cell parameter and global parameter. Table 4.1 shows some of the key parameters used to configure the target network in the RNP tool.

Table 4.1: Network configuration sample parameters

Parameters	Downlink	Uplink
Data Channel Type	PDSCH	PUSCH
Duplex Mode	TDD	
Frequency(MHz)	2600	
System Bandwidth(MHz)	100	
MIMO Scheme	4×4	2×2
Max Total Tx Power (dBm)	43	24
Tx Antenna Gain (dBi)	18	11
Rx Noise Figure (dB)	7	2
Receiver Sensitivity (dBm	-132.2	-135.2
Propagation Model	Dominant Pathloss Model	

4.4 Sites Placement

Depending on nominal planning phase, a total of 57 gNodeB's are formed in the radio network planning tool/Winprop. These sites are initially configured by the parameters shown in Table 4.2. Figure the sites placement of these 57 gNodeB's on the target deployment area. The list of the sites with their initial geographical coordinate information (Longitude and Latitude) is shown in appendix.

Table 4.2: Initial sites sector parameters

Sector Configuration	Antenna Configuration	Antenna Height	Azimuth	Mechanical down tilt	Electrical down tilt
Sector-1	45deg18dBi 2600MHz	30m	0°	0°	0°
Sector-2	45deg18dBi 2600MHz	30m	120°	0°	0°
Sector-3	45deg18dBi 2600MHz	30m	240°	0°	0°

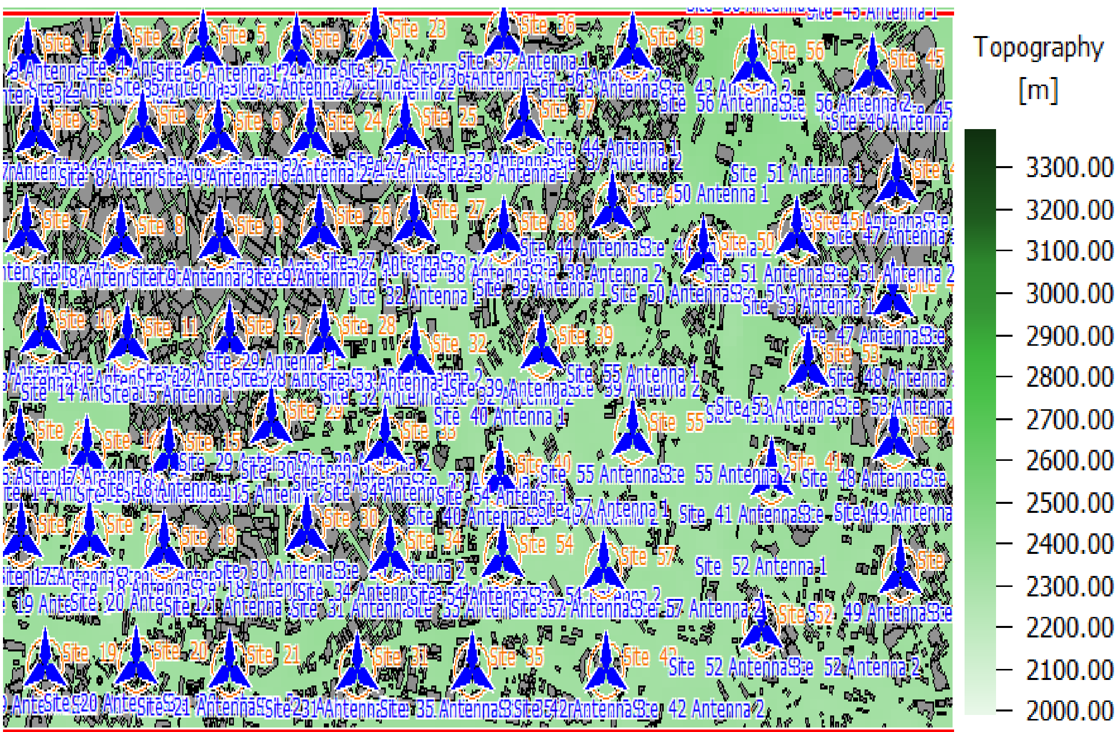


Figure 4.3: Initial Sites Placement (Full number of sites)

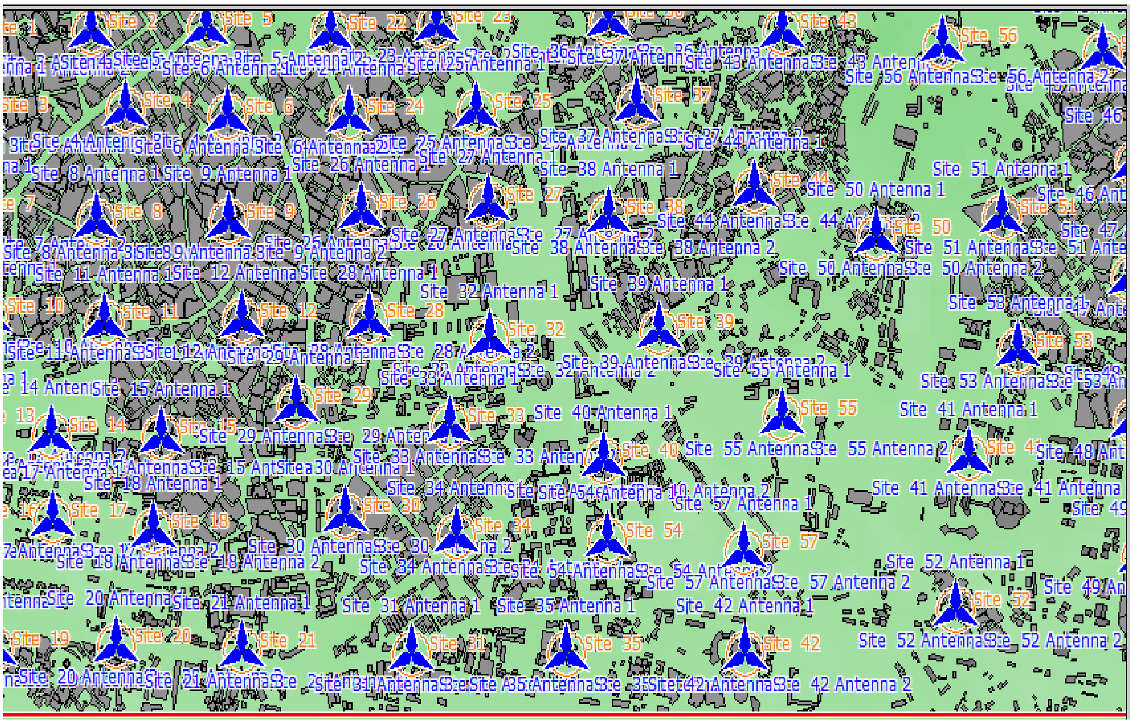


Figure 4.4: Initial Sites Placement(zoom out)

4.5 Target Area Coverage Prediction and Analysis

The prediction of coverage shows the results of a defined coverage conditions. It is calculated based on coverage conditions and coverage resolutions using the pathloss matrices. As per the coverage requirements and Signal strength standards set in section 3.5.3 and Table 3.6, the nominal planning phase will be evaluated by the following Coverage prediction results.

4.5.1 Coverage Predictions by Pathloss

As discussed in chapter 3, path loss is defined by the declining in power density (attenuation) of an electromagnetic wave as it propagates through space. It is a major constituent in the assessment and design of the link budget of a telecommunication system. Path loss may be due to many effects, such as free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption. It is also biased by terrain contours, environment (urban or rural, vegetation and foliage), propagation medium (dry or moist air), the distance between the transmitter and the receiver, and the height and location of antennas. Figure 4.5 illustrates the coverage prediction by pathloss.

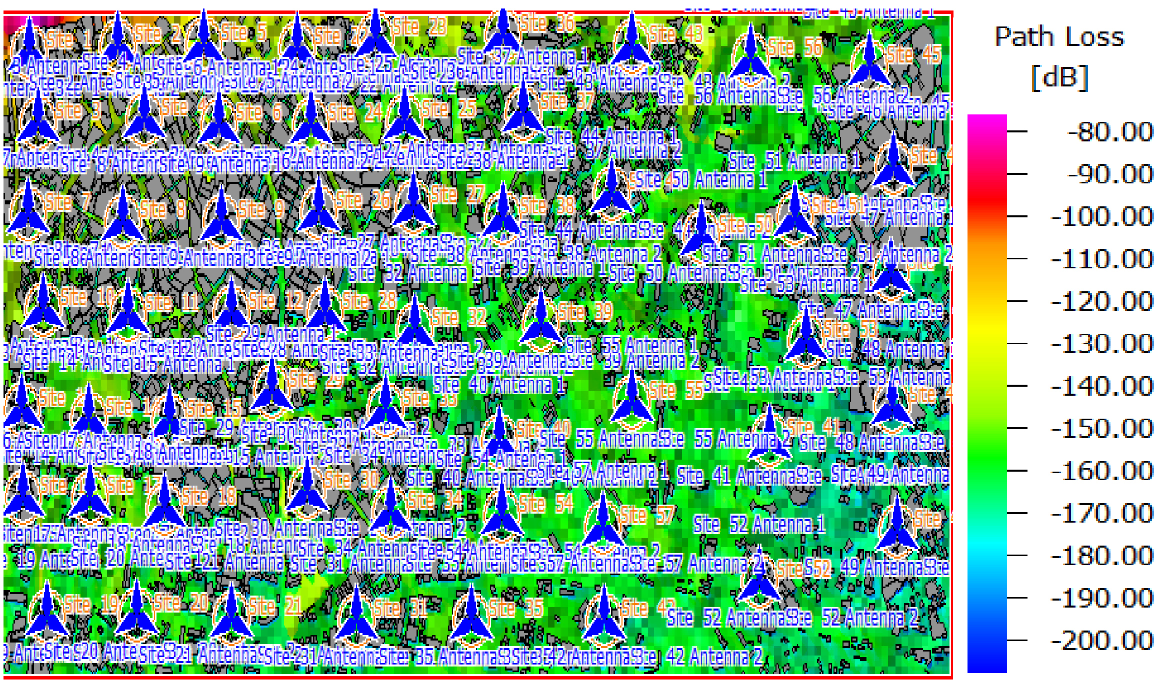


Figure 4.5: Coverage prediction by pathloss

Figure 4.6 shows pathloss in Cumulative density function (total area), which is depending up on coverage prediction based on pathloss, which illustrates in Figure 4.5.

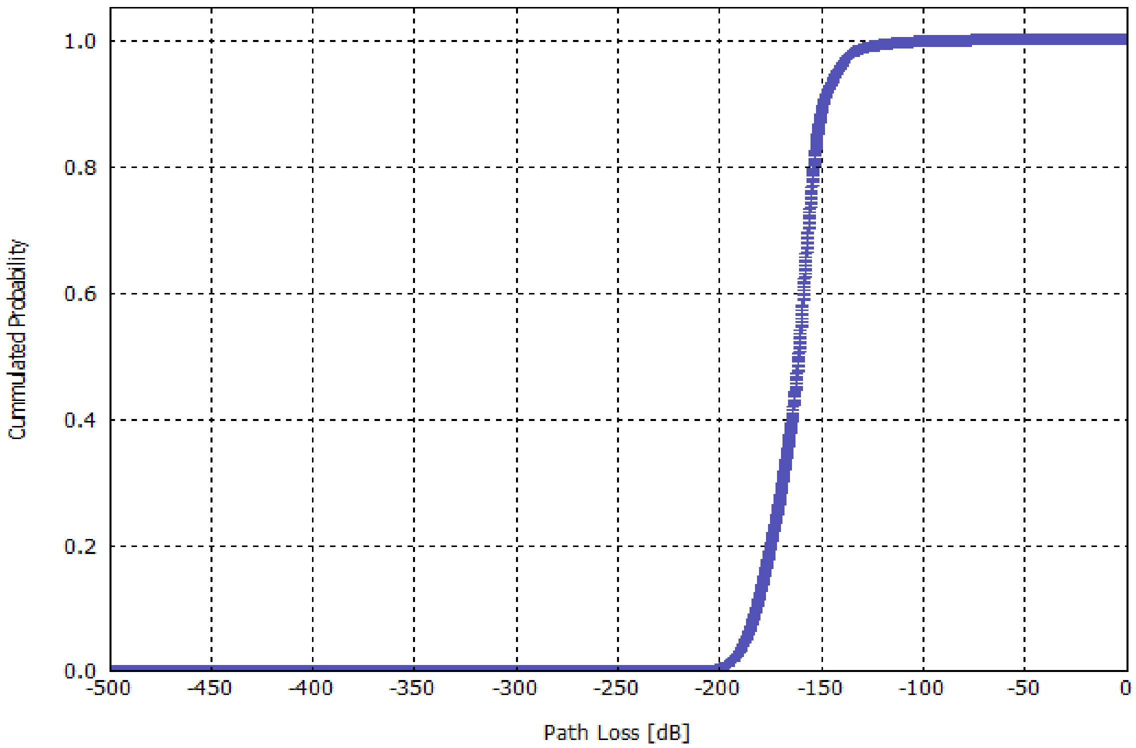


Figure 4.6: Cummulative density function of pathloss

Coverage prediction by pathloss also demonstrates by probability density function (relative to total area) as shown in Figure 4.7,

Result discussion: The simulation result from this Figure 4.6 and 4.7, shows that the range of pathloss is -200dB ≤ -80dB. This pathloss is a loss on carrier frequency 2.6GHz. Pathloss is various depending up on the carrier frequency, i.e as carrier frequency increases, pathloss also increases, due to technical challenges with frequency increases.

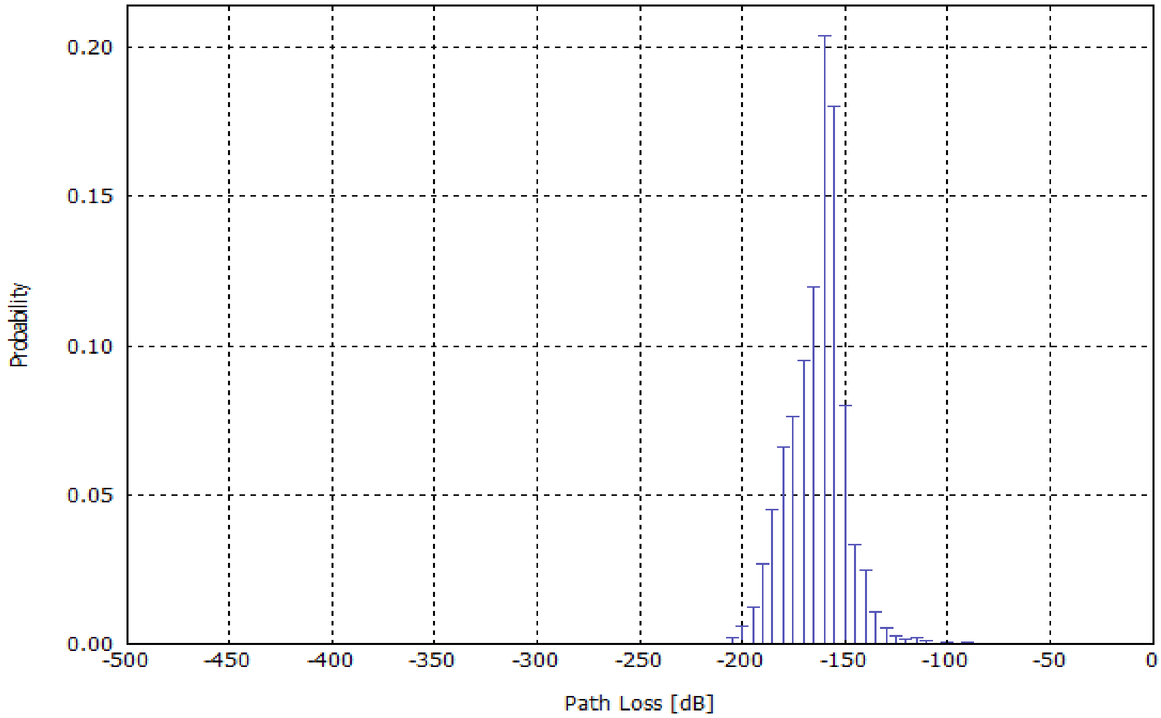


Figure 4.7 Probability density function of pathloss

4.5.2 Coverage Predictions by Signal strength

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

Reference signal received power is the key measures of signal level and quality for recent networks. In cellular networks, when a mobile device moves from cell to cell and performs cell selection/reselection and handover, it has to measure the signal strength/quality of the neighbor cells. Reference signal received power (RSRP) for coverage prediction is performed by comparing the standard RSRP 3GPP specification discussed in Section 3.5.3 with the simulation results. Figure 4.8 shows the coverage prediction by reference signal received power.

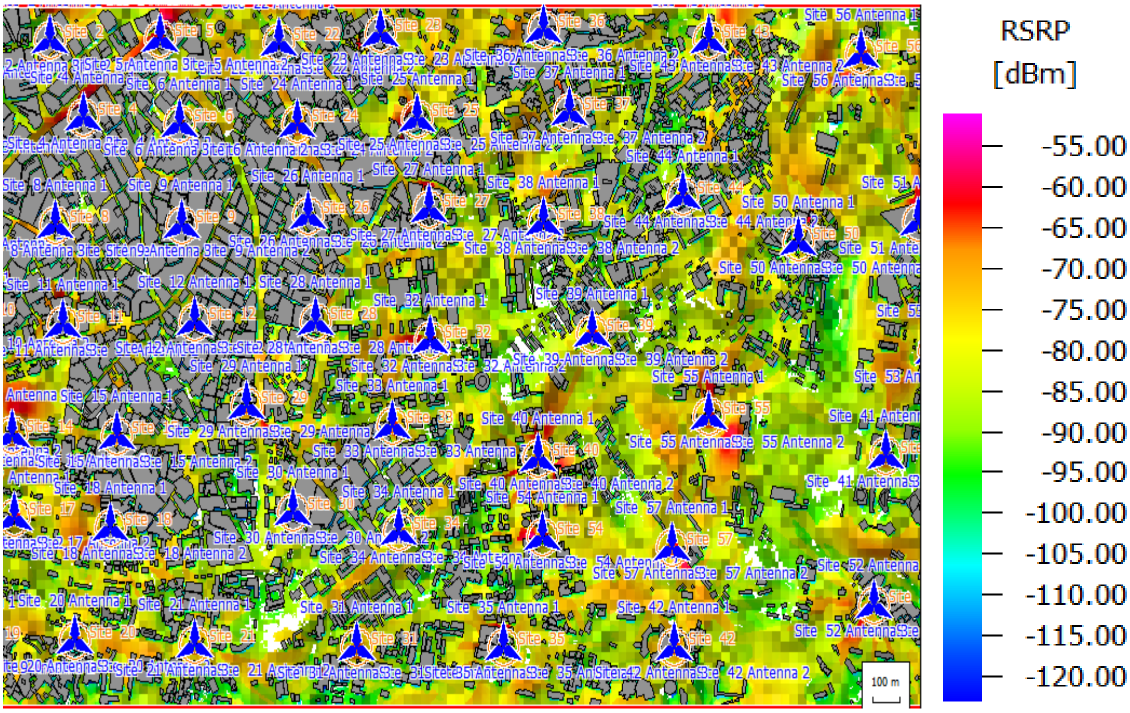


Figure 4. 8: Coverage prediction by reference signal received power(RSRP)

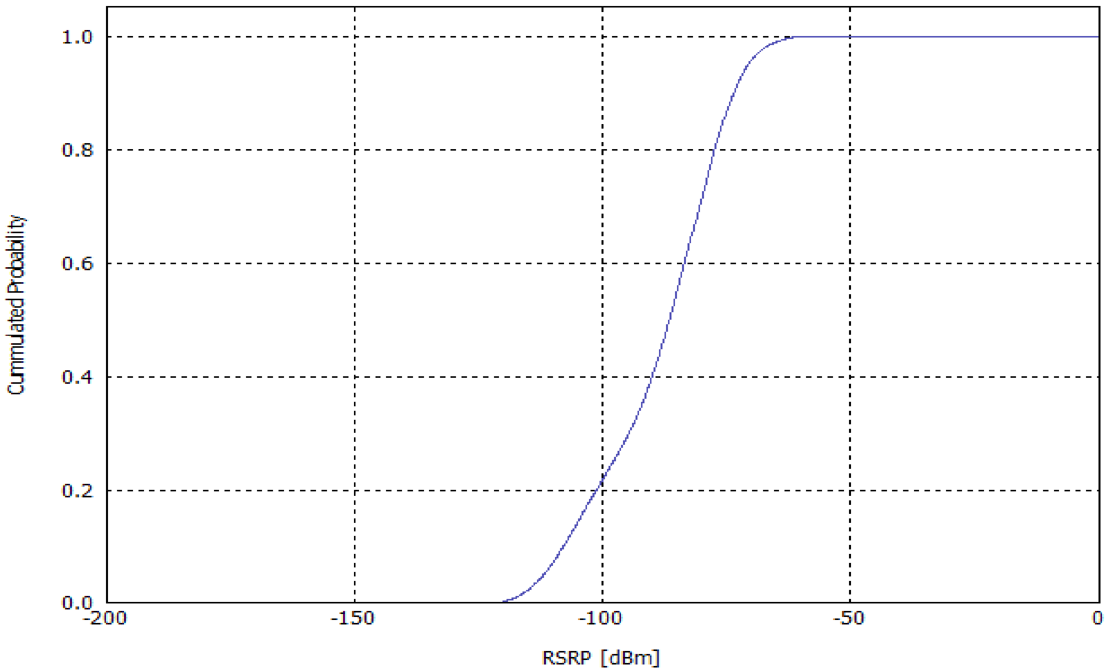


Figure 4.9: Cummulative density function (CDF) of reference signal received power

Result discussion: According to the result shown in Figure 4.8, the simulation result proves that around 85 % of the area is covered by the signal above ≥ -80 dBm and the signal condition is good. This shows a better signal can be received by UE’s as compared to the calculated minimum signal reception strength of -120.7dBm from the radio link budget. This illustrates that the area coverage probability requirement (97%) has been already attained by this RSRP signal value. The Cummulative density function of Reference signal received power is presented in Figure 4.9.

- **Reference Signal Received Quality(RSRQ)**

As discussed in Section 3.5.3, RSRQ is a channel per interference type of measurement and it shows the quality of the received reference signal. Figure 4.10 shows the coverage prediction by reference signal received quality.

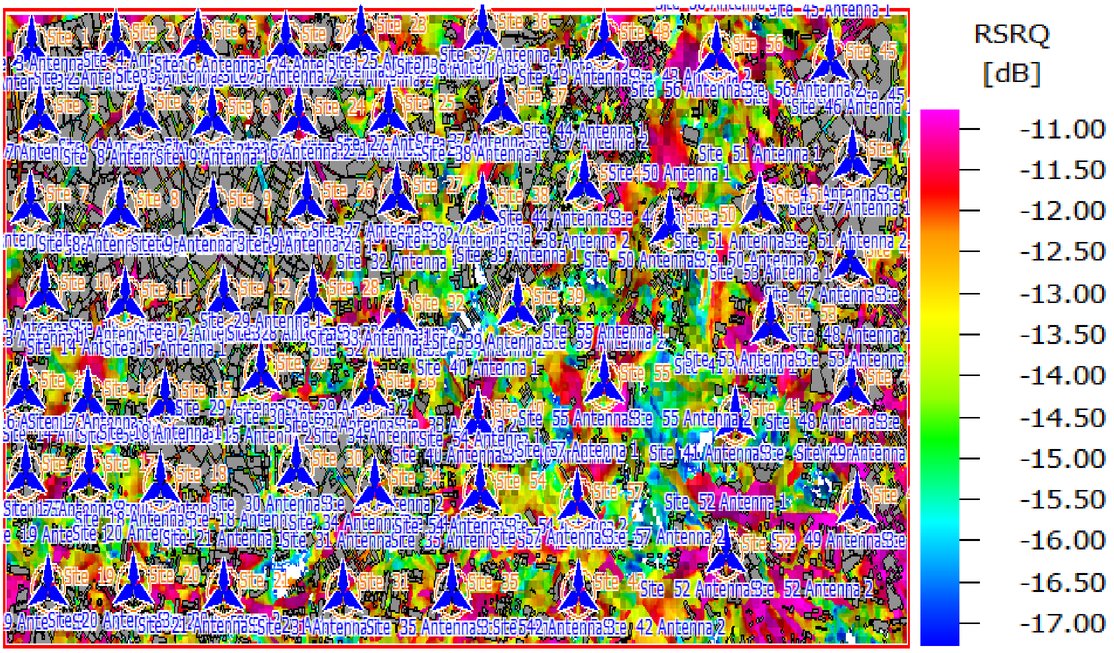


Figure 4.10: Coverage prediction reference signal received quality

Result discussion: Reference signal received Quality (RSRQ) for coverage prediction is performed by comparing the standard RSRQ 3GPP specification set in Table 3.6 with the simulation results.

According to the result shown in Figure 4.10 above, the simulation result value of the RSRQ is between -17 ≤-11dB. Thus, relatively compared this simulation result with standard value around 90% they are similar. This attained good signal conditions. This illustrates that the standard condition of reference signal received quality for coverage prediction has been realized. Figure 4.11 shows the Cummulative density function of reference signal received quality.

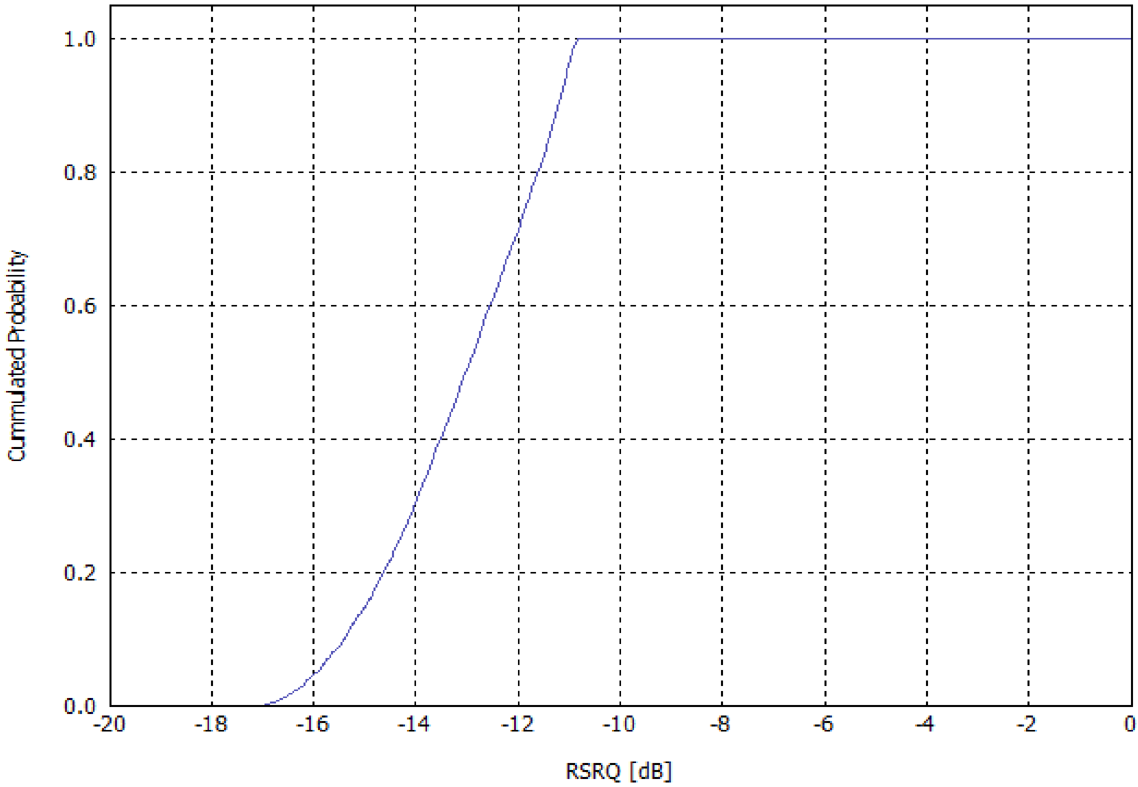


Figure 4.11: Cummulative density function of reference signal received quality

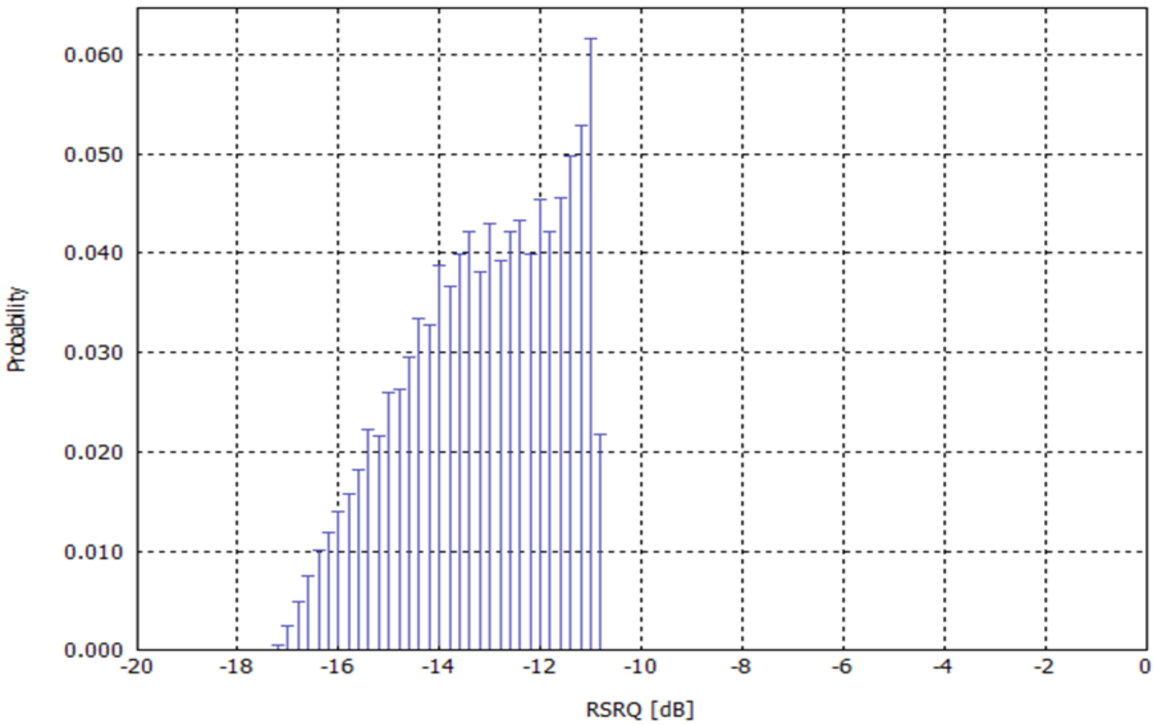


Figure 4.12: Probability of reference signal received quality

Whilst, Reference signal received quality can be also shown by probability density function as illustrates in Figure 4.12. The result is illustrating that the values obtained from simulation is between -17 and -11, which is the same with the value obtained from Cummulative density function of reference signal received quality.

4.6. Network Capacity Evaluation and Performance Analysis

4.6.1. Signal to Interference plus Noise Ratio (SINR)

Signal Interference to Noise Ratio also called CINR (Carrier to Interference + Noise Ratio) is the ratio of the signal level to the noise level (or just the signal-to-noise ratio). The SINR value is measured in dB (dB). The higher the value, the better the signal quality.

At SINR values below 0, the connection speed will be very low, since this means that there is more noise in the received signal than the useful part. SINR for coverage prediction is also performed by comparing the standard RSRQ 3GPP specification set in Table 3.6 with the simulation results. Figure 4.13 demonstrates the channel capacity as a function of signal to noise ratio (SNR) from Shannon channel capacity formula through matlab.

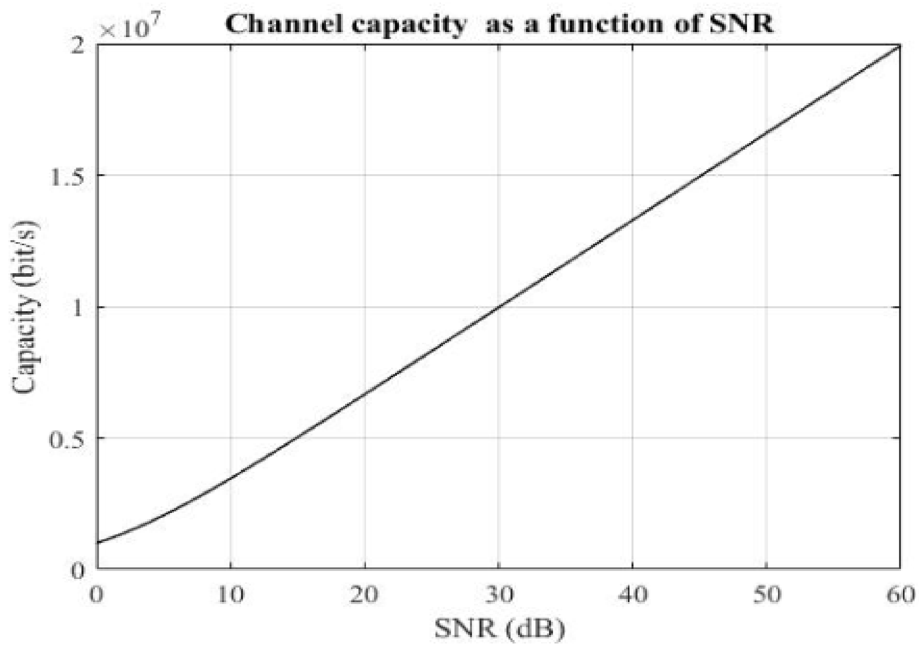


Figure 4.13: Channel capacity versus Signal to Noise Ratio

This Simulation result shows that signal to noise(SNR) has a significant role to increase channel capacity. At the same time channel bandwidth is also very important concept to increase channel capacity.

Table 4.3: Shows summary of channel capacity vs SNR from simulation result

SNR(dB)	Channel Capacity (bit/se)
15	0.5
30	1
45	1.5

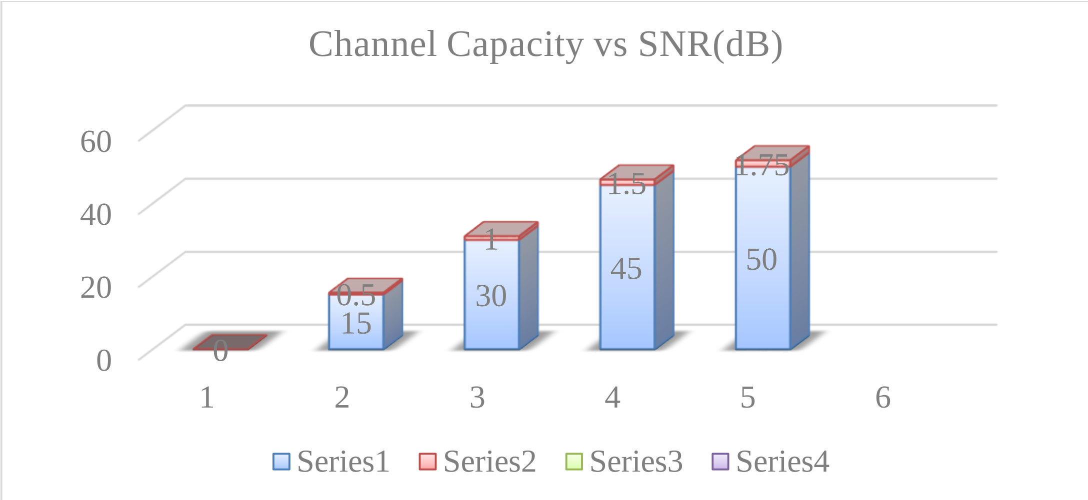


Figure 4.14: Graphical representation of Table 4.1

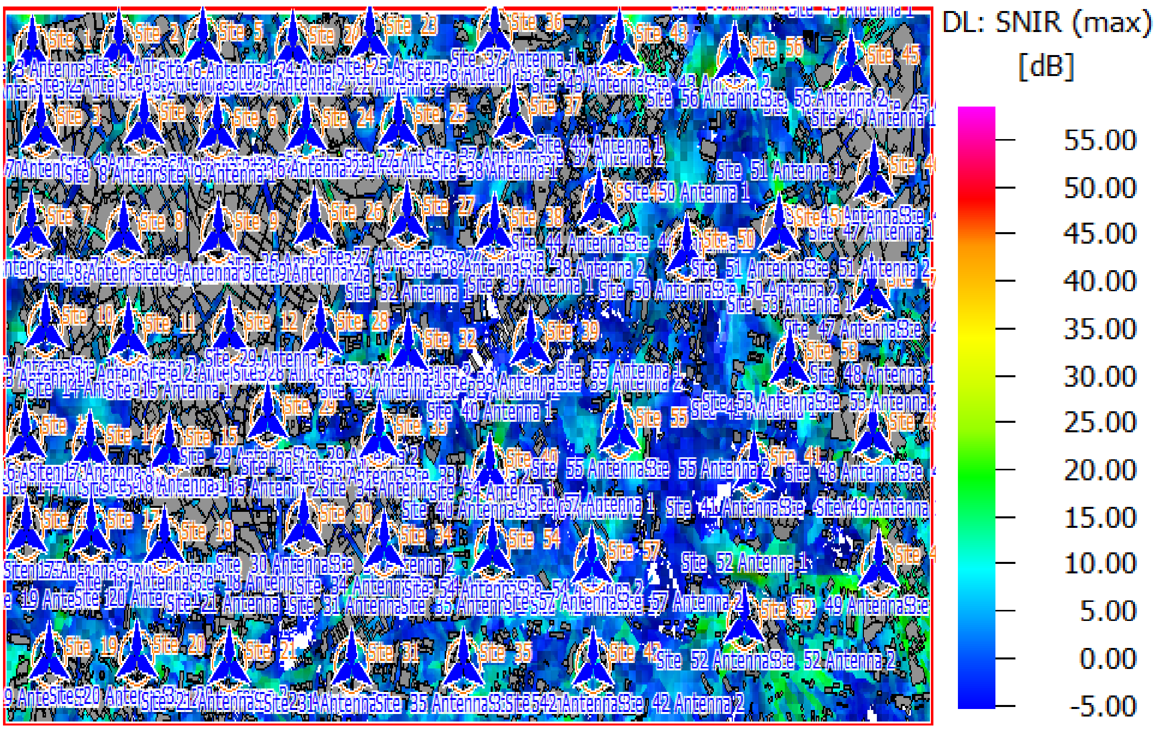


Figure 4.15: Coverage prediction by signal to interference plus noise ratio

Result discussion: Table 4.3 shows summary of Channel Capacity vs SNR by taking some values from Figure 4.13. Graphical representation of Table 4.3 is shown in Figure 4.14. In both cases, channel capacity increases proportional to signal to noise ratio. This means signal to noise ratio has significant impact on channel capacity.

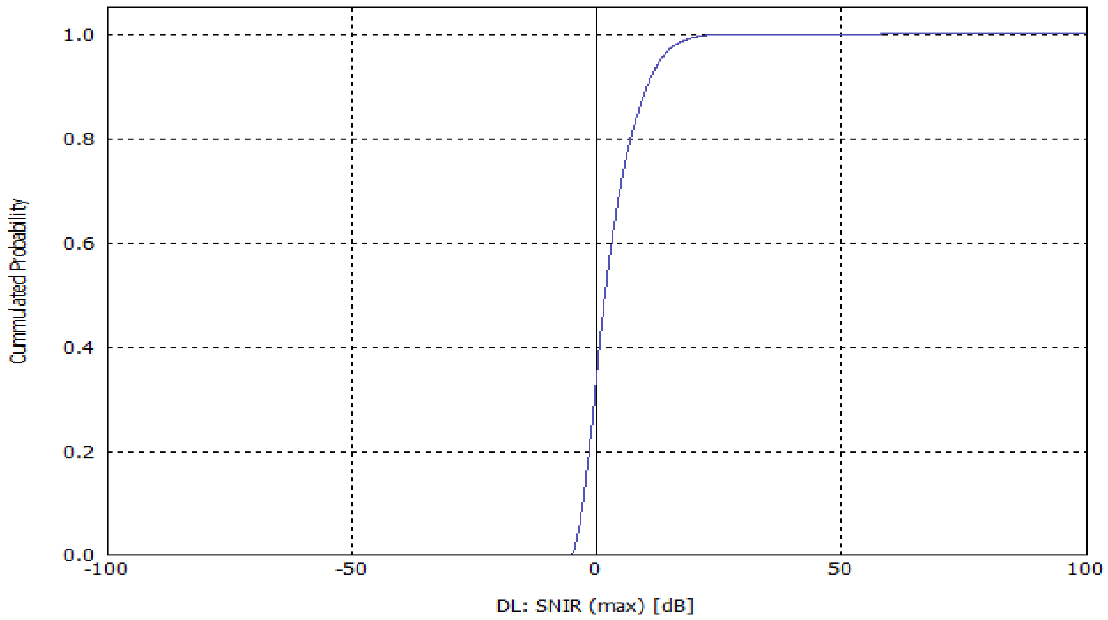


Figure 4.16: Cummulative density function of signal to interference plus Noise Ratio(SINR)

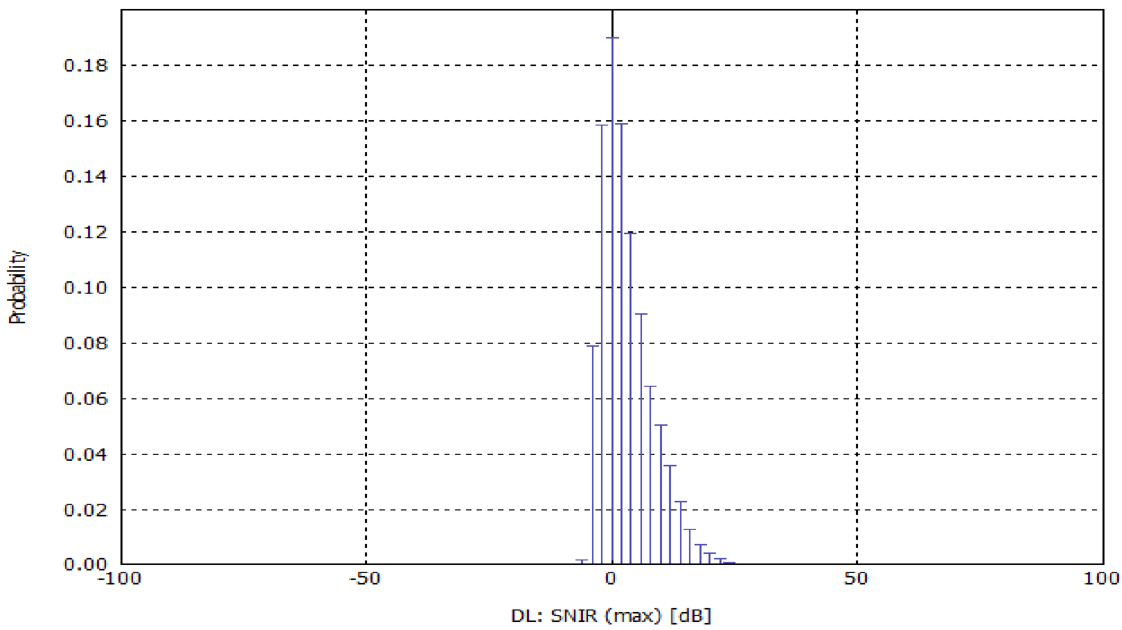


Figure 4.17: Probability density function of signal to interference plus noise ratio

Result discussion: According to the result shown in Figure 4.15 , the simulation result of SINR indicates that above 90 % is ≥ 20dB , which attained Good signal conditions. This demonstrates that the standard condition of SINR for coverage prediction has been approved. The Cummulative density function and Probability density function of signal to interference plus noise ratio is illustrates in Figure 4.16 and Figure 4.17 respectively. In both cases, the result from simulation has been permitted the signal to interference plus noise ratio standard condition that has been described in Table 3.6.

4.6.2 Maximum Downlink Throughput

Agreeing to the result shown in figure 4.18, the simulation result illustrates the maximum downlink throughput with red color, which is 123.7Mbps. This result is low relatively comparing with theoretical result (584.25Mbps) obtained in chapter 3.

This result shows the simulation result is one fourth of theoretical result. This is because, the standard air interface used in this thesis is band41, which is 4G air interfaces. But, the theoretical value is obtained from 5G throughput formula. Since 5G is new technology there is no standard air interface defined for this technology in our country ethiotelecom (Ethiopia).

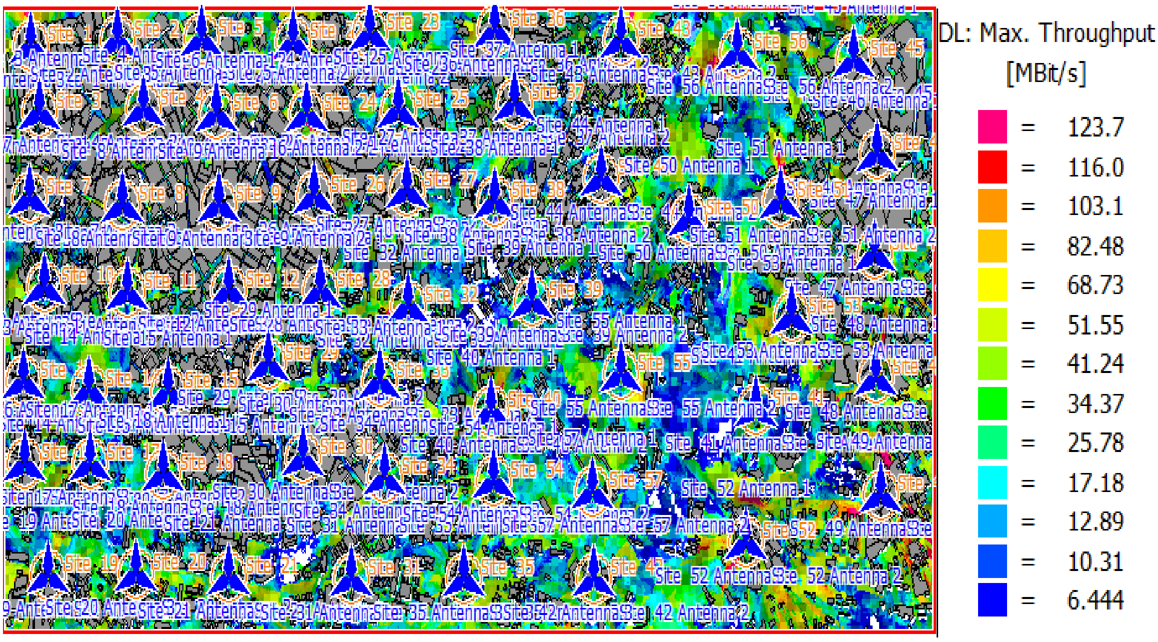


Figure 4.18: Capacity analysis by throughput (Max.DL throughput)

The Cummulative density function of maximum downlink throughput is shown in Figure 4.19. From the result value from simulation is between 100Mbps and 150Mbps.

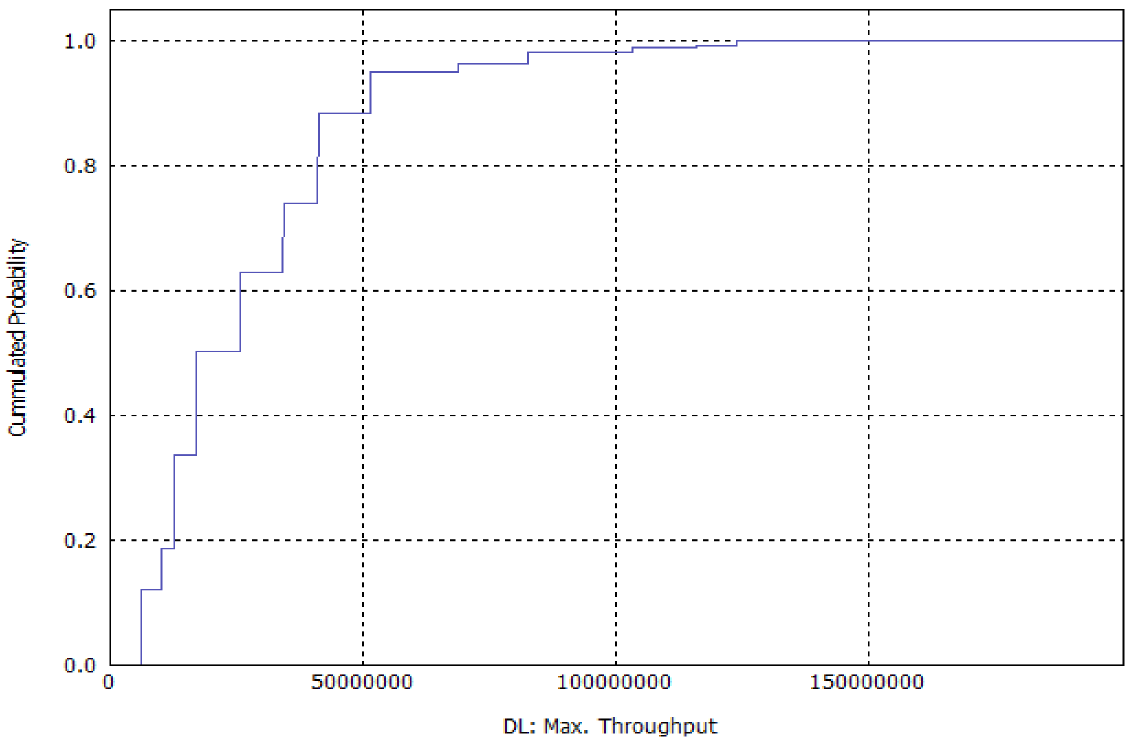
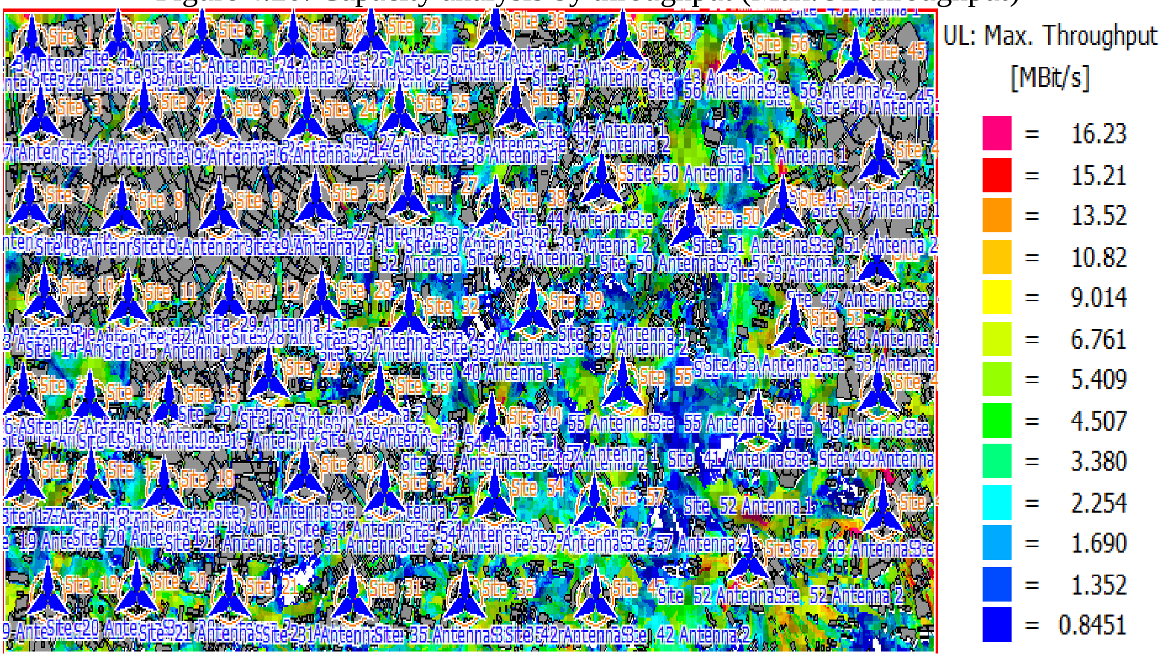


Figure 4.19: Cummulative density function of maximum downlink throughput

4.6.3 Maximum Uplink Throughput

The simulation result describes the maximum Uplink throughput is shown in Figure 4.20.

Figure 4.20: Capacity analysis by throughput (Max.UL throughput)



Result discussion: According to the result shown in Figure 4.20, the simulation result clarifies the maximum Uplink throughput with red color, which is 16.23Mbps. This result is very low relatively comparing with theoretical result (625.01Mbps) achieved in Chapter 3. The reason for this result is clearly discussed in section 4.6.2 above. Figure 4.21, shows that the Cummulative density function of maximum downlink throughput. As shown in the Figure 4.21 the result value from simulation is slightly above 15Mbps.

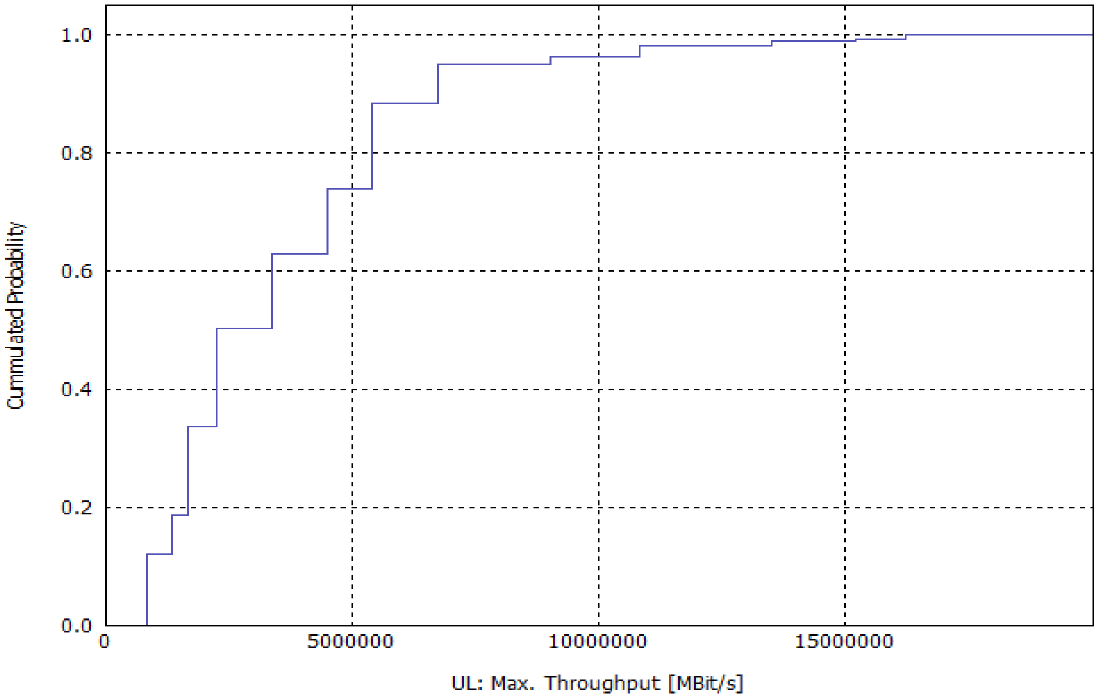


Figure 4.21: Cummulative density function of maximum uplink throughput

4.7. Performance Comparison of Millimetric wave propagation Modeling

In this section, the comparison of millimetric wave propagation modeling are discussed. Pathloss models such as: Free space pathloss model, Close-in pathloss models, Floating intercept or Alpha, Beta and Gamma (ABG) pathloss model and Dominant path loss model are demonstrated and their comparison are analyzed through matlab code as shown in Figures. In all cases, the result is illustrated as pathloss versus frequency at constant distance. This is to show that, as frequency increases which propagation model is best to reduce pathloss. Although, it is possible to analyze pathloss as a function of distance at constant frequency to show the impact of distance on pathloss. Figure 4.22 and 4.23 shows the simulation result for Free space pathloss(dB) and Close-In pathloss models dB) respectively. By taking the same frequency from the Figure, it is possible to compare the pathloss.

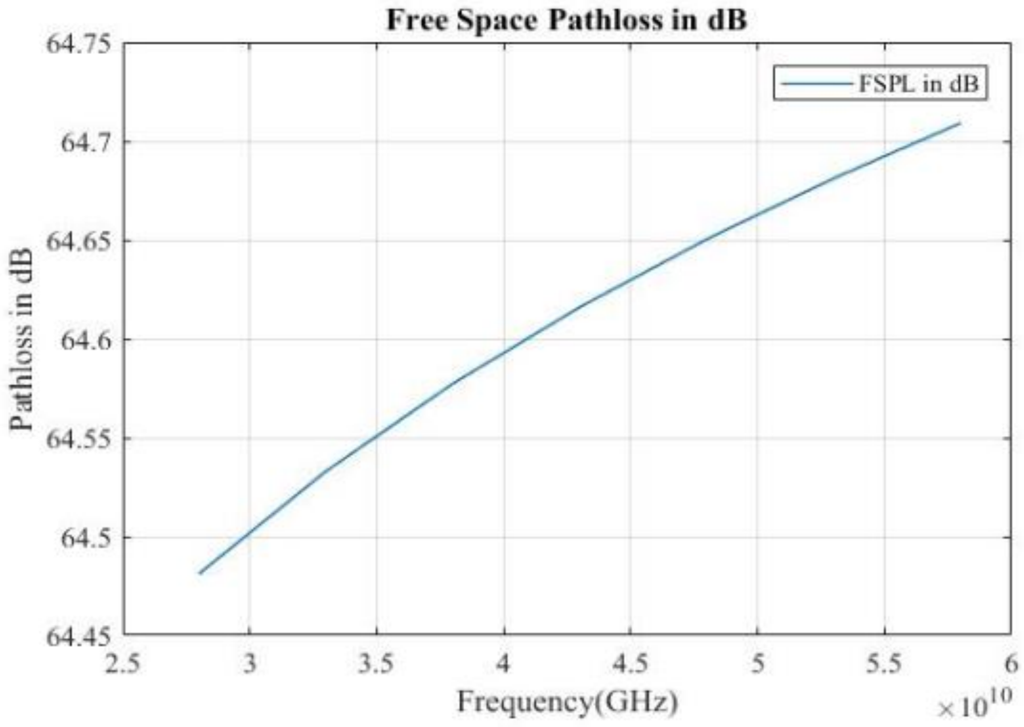


Figure 4.22: Free space pathloss model

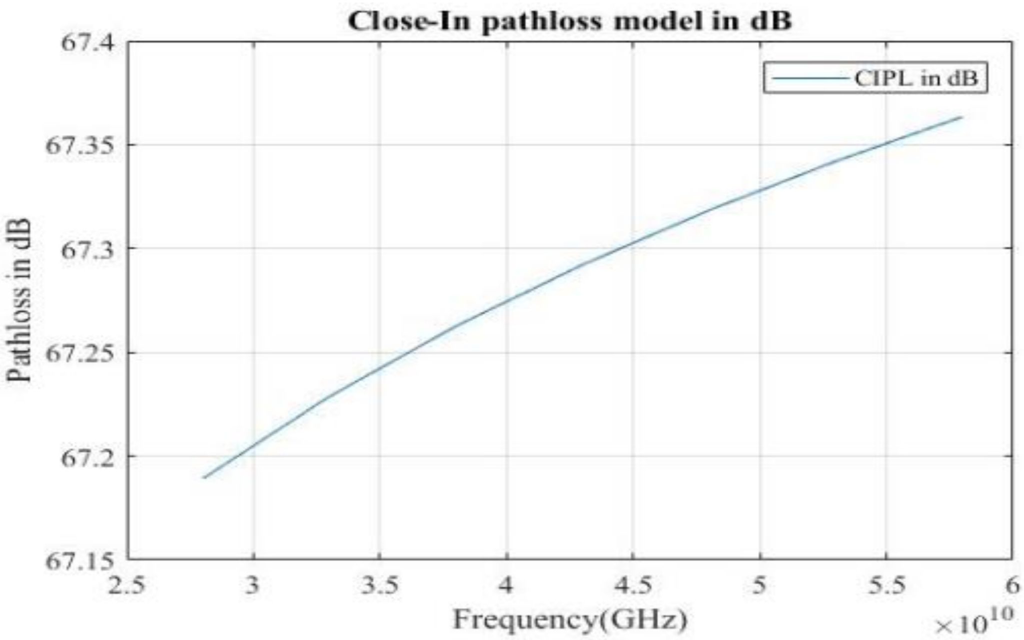


Figure 4.23: Close-in pathloss model

Result Discussion: Table 4.4 shows the result comparison for Figure 4.22 and Figure 4.23 by taking the value of frequency from figure and compare the propagation pathloss at this frequency. The result indicates that the pathloss of Close-in propagation model is slightly high relatively compare with Free space pathloss. The result comparison in Table 4.4 also shown by bar graph in Figure 4.24.

Table 4.4: Result Comparison of Free space pathloss with Close-in pathloss

Frequency (GHz)	Propagation Model Pathloss (dB)	
	Free Space pathloss model(dB)	Close-In pathloss model(dB)
3	64.5	67.2
4.5	64.63	67.3
5.5	64.69	67.35

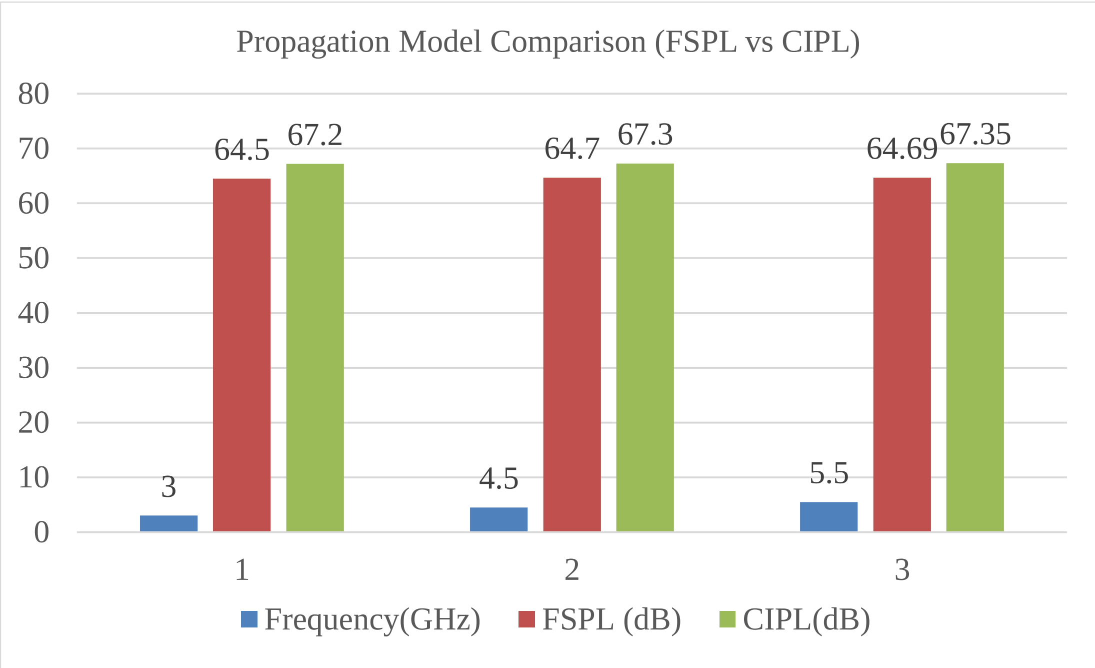


Figure 4.24: Graphical representation of propagation comparison in Table 4.1

Figure 4.25 and 4.26 illustrates the simulation result for Floating intercept or ABG pathloss model and Dominant pathloss model respectively.

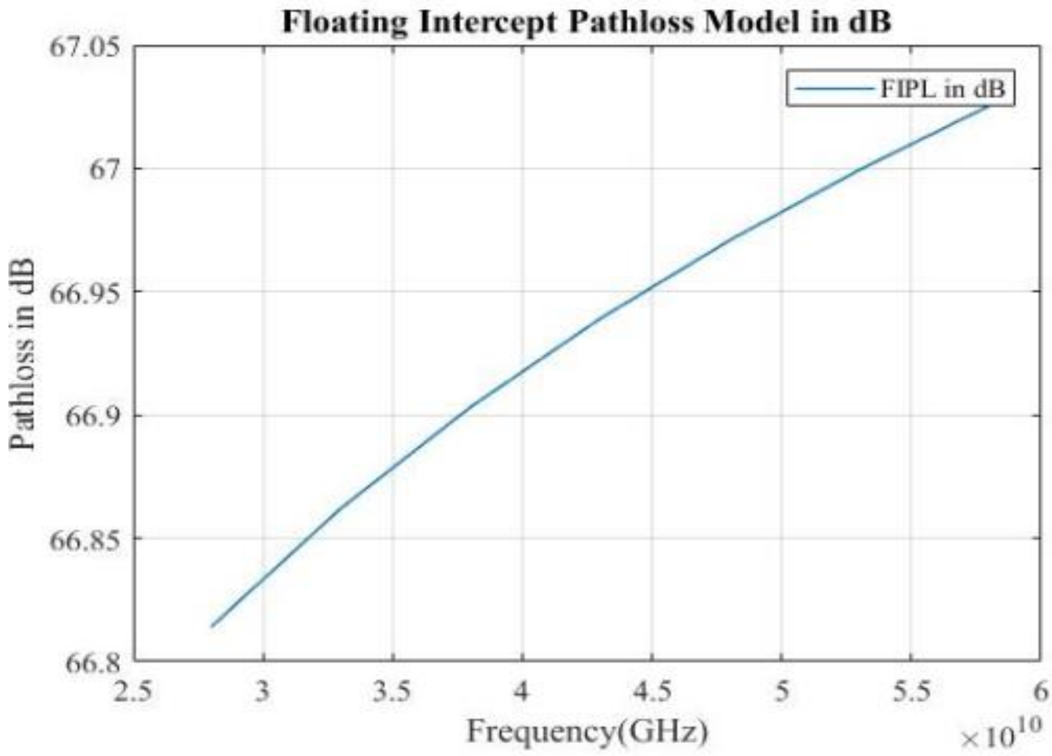


Figure 4.25: Floating intercept pathloss model

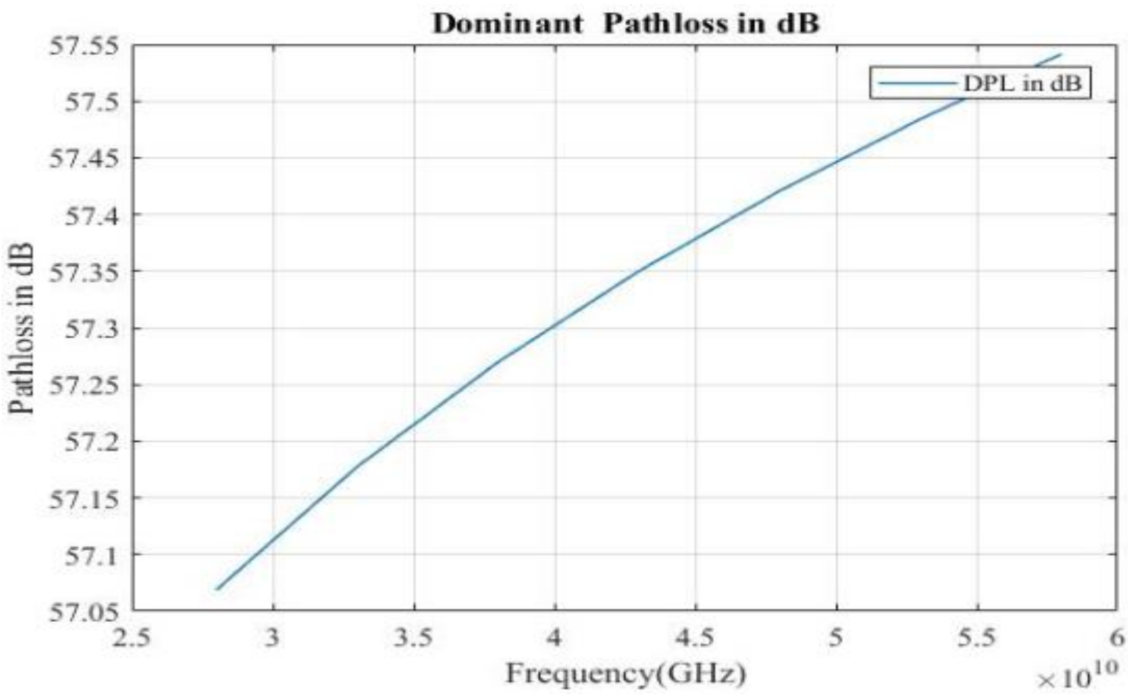


Figure 4.26: Dominant pathloss model

Result Discussion: The result comparison for Figure 4.25 and Figure 4.26 are shown in Table 4.5; by taking the value of frequency from Figure and compare the propagation pathloss at that frequency. The result indicates that the pathloss of floating intercept propagation model is high relatively compare with Dominant pathloss Model. The result comparison in Table 4.5, also shown by bar graph in Figure 4.27.

Table 4.5: Result Comparison of Floating Intercept pathloss with Dominant pathloss

	Propagation Model Pathloss (dB)	
Frequency (GHz)	Floating intercept pathloss model(dB)	Dominant pathloss model(dB)
3	66.82	57.2
4	69.91	57.3
5	66.98	57.45

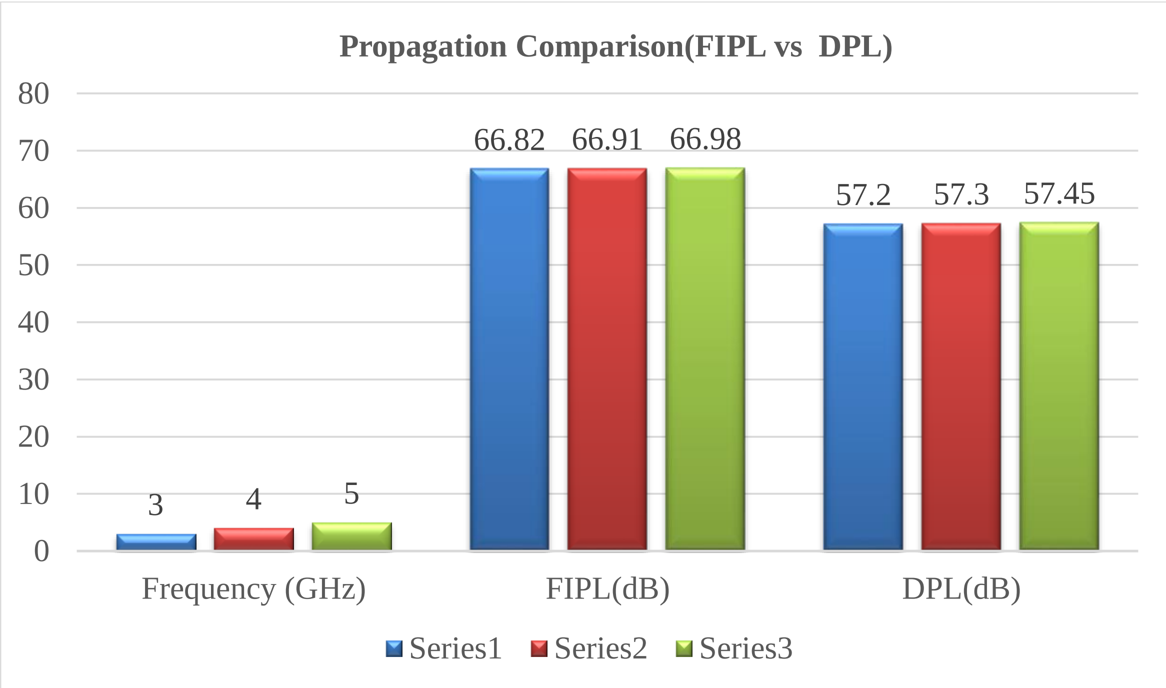


Figure 4.27: Graphical representation of Table 4.2

Figure 4.28 discusses the overall the simulation result comparisons of propagation model path losses. The summary of result discussion is illustrated in Table 4.6 and Figure 4.29.

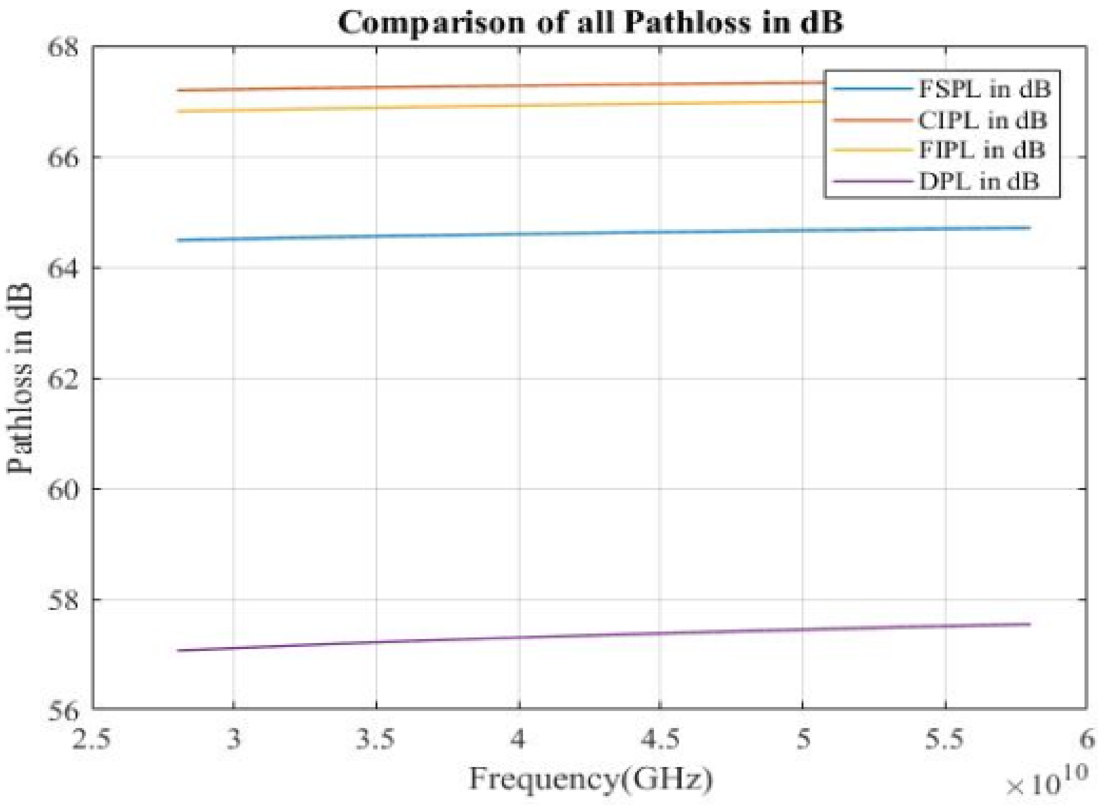


Figure 4.28: Comparison of all propagations model together

Result Discussion: The result comparison in Figure 4.28 is shown in Table 4.6 and Figure 4.29. The analysis is simply by taking the value of frequency from the figure and compare their propagations model path losses at that frequency. The result indicates that the Close-in propagation model has high path losses relatively compare with the left pathloss Model.

Table 4.6: Comparison of all propagation together

Frequency (GHz)	Propagations Model			
	FSPL (dB)	CIPL(dB)	FIPL(dB)	DPL(dB)
3	64.5	67.2	66.82	57.2
4	64.63	67.3	69.91	57.3
5	64.67	67.32	66.98	57.45
5.5	64.69	67.35	67.02	57.5

Whilst, Dominant pathloss model has low path losses relatively compare with the others three. Therefore, using Dominant path loss model in this thesis research is the right choice, because it reduces losses due to path as frequency increases. Figure 2.29 demonstrates graphical representation of Table 4.6.

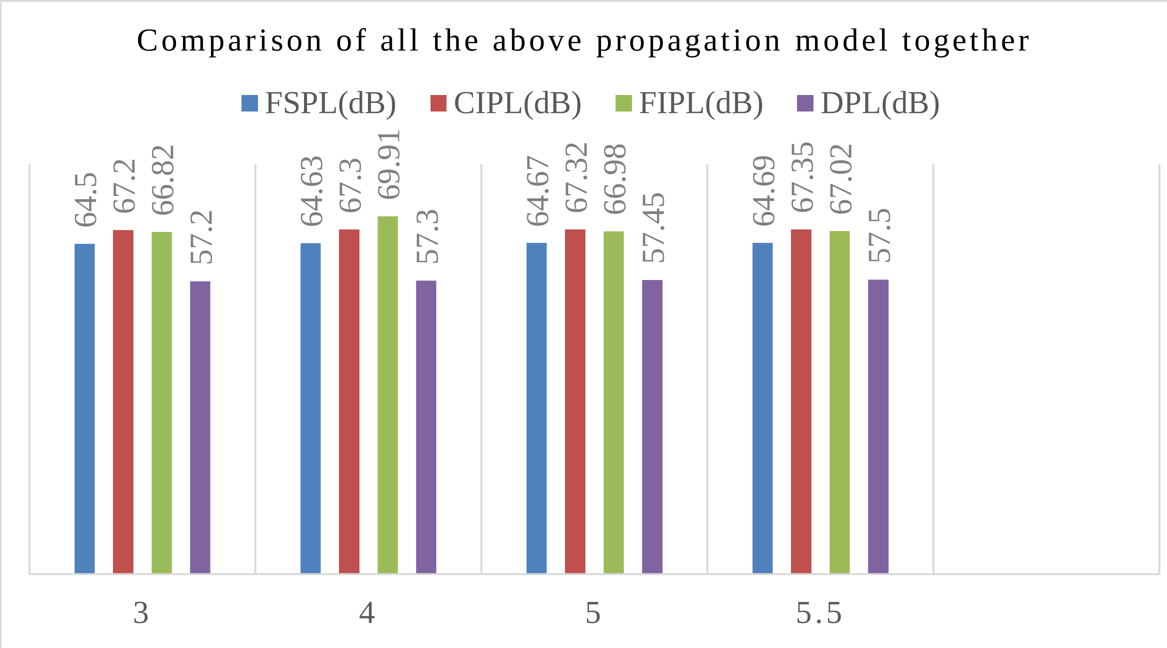


Figure 2.29: Graphical representation of Table 4.6

4.8. Evaluation of the Technical Challenges with Millimetric Wave Propagation Modeling

As mentioned, in Section 3.7.1, the technical challenges with millimetric wave propagation channel modeling can be illustrating in figure below through matlab simulation. Figure 4.30 shows pathloss due to free space pathloss as a function of frequency at different distances. This result indicates that frequency and pathloss are directly proportional. As frequency increases, the pathloss also increases.

At the same time, the pathloss is high as distance between transmitter and receiver increases. Figure 4.31 shows propagation loss due to rain. The simulation result illustrates that as frequency increases, the losses due to rain is also increases upto some critical point(100GHz) and decreases, which has impact on millimetric wave propagation channel modeling. Although, the simulation result for propagation loss due to cloud and fog is shown in Figure 4.32.

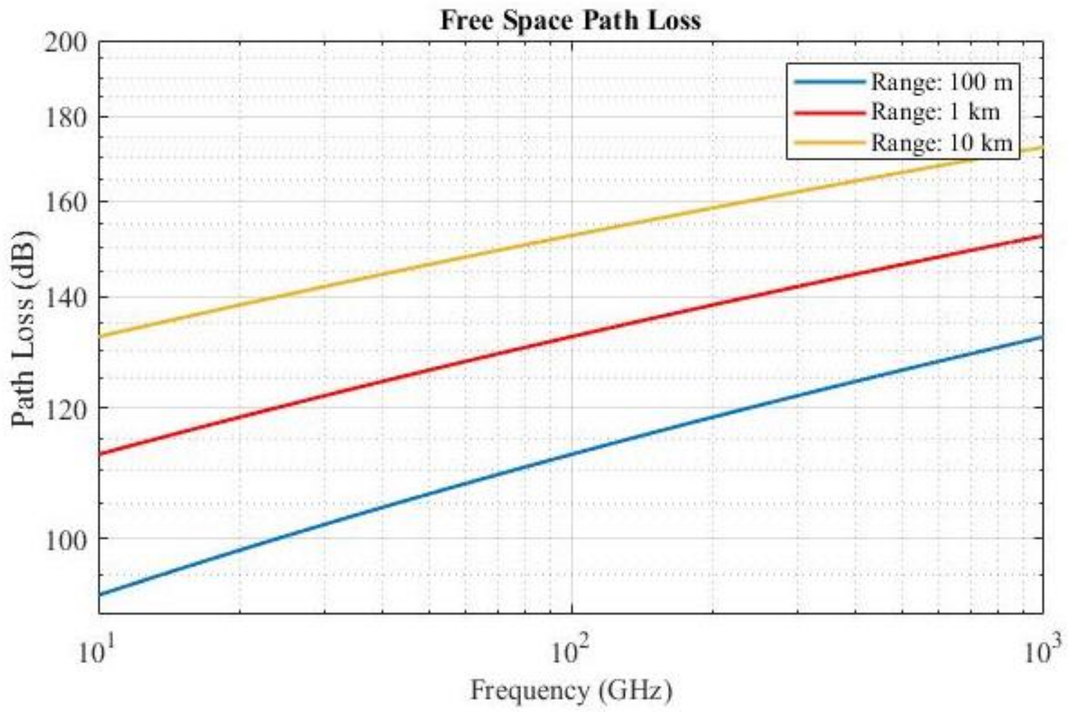


Figure 4.30: Free space pathloss (Frequency vs pathloss)

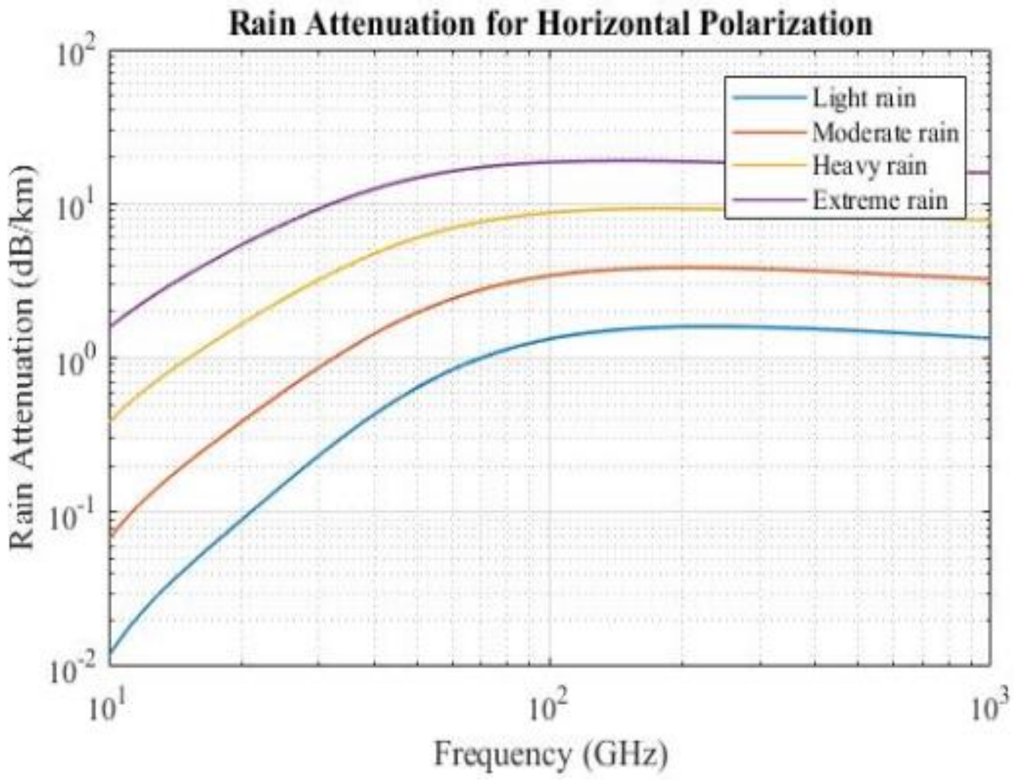


Figure 4.31: Propagation loss due to rain.

This simulation result shows that fog attenuation is heavy as frequency increases. At very high frequency (millimetric wave frequency) the fog attenuation is very heavy. This indicates cloud and fog attenuation has direct impact on millimetric wave propagation channel modeling.

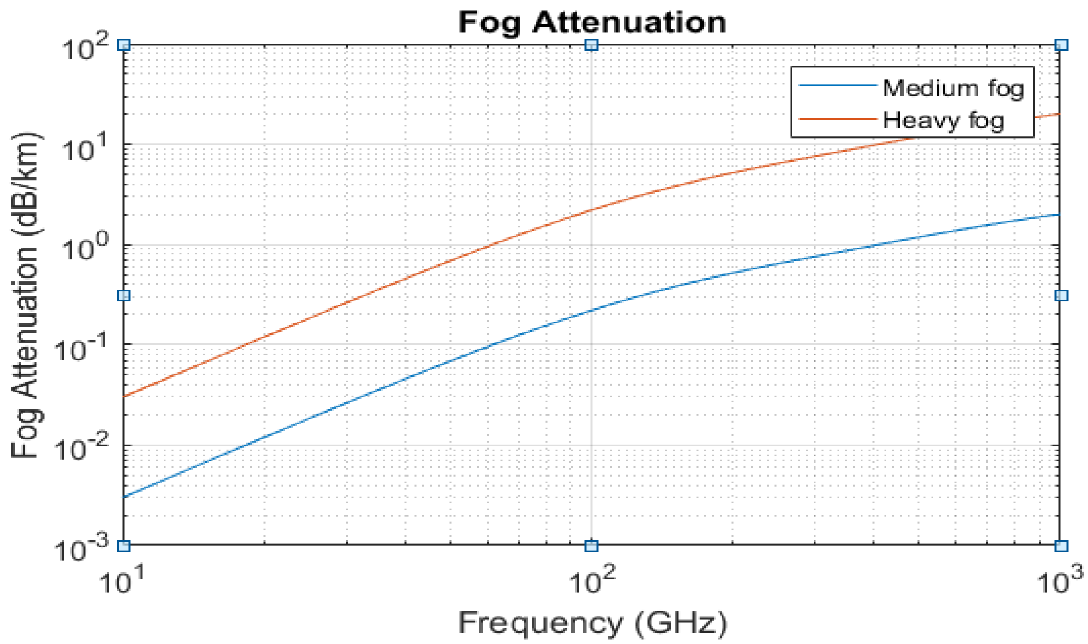


Figure 4.32: Propagation losses due to cloud and fog

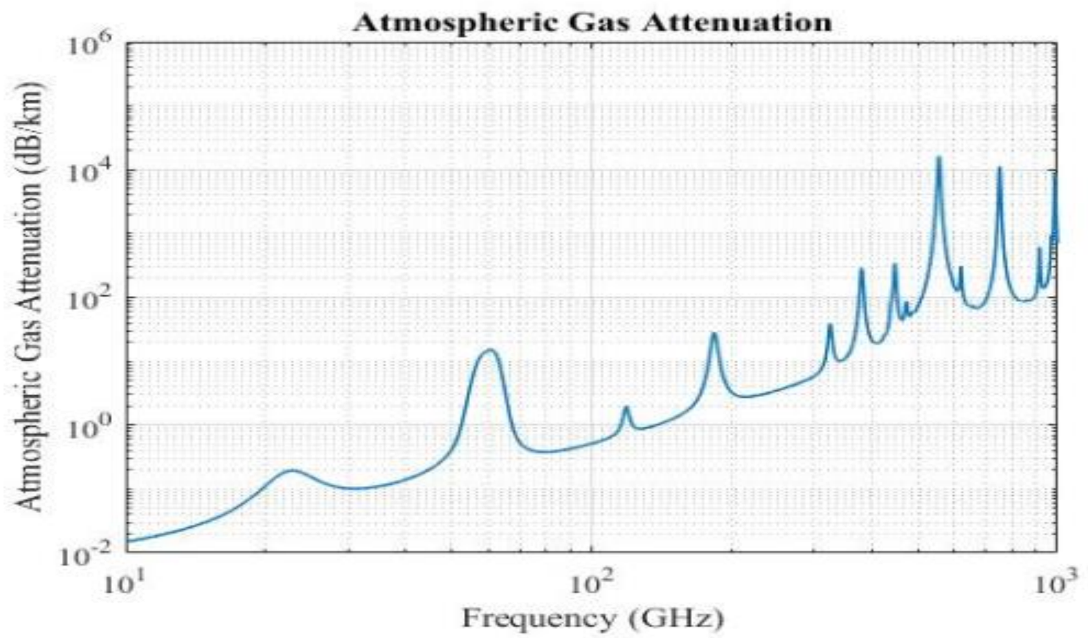


Figure 4.33: Propagation loss due to atmospheric gas.

The simulation result of propagation loss due to atmospheric gases is exposed in Figure 4.33. This simulation result shows that; atmospheric gases are high at high frequency (at millimetric wave frequency).

Result Conclusion: Simulation results in Section 4.8, demonstrates that each technical challenges mentioned in Section 3.71 has significant impact on millimetric wave propagation modeling.

CHAPTER 5

5.CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This chapter accomplishes the present thesis, collecting a discussion and a critical analysis of the results, presenting future advancement opportunities of mobile communications. According to the latest technological advance, in cellular network industry radio network planning shall collaborate the main factors such as network coverage, capacity and QoS for Kirkos Subcity (Addis Ababa) with the area of 14.91 km^2 by considering dense urban clutter. Radio network planning is the basis for mobile communication network and is of significant importance to network quality, so it is essential to make a good planning at prior stage, which is supportive for network expansion and service update in the future.

The main inspiration for this thesis was to generate new tools and methods able to support multi-service radio network dimensioning and planning. Furthermore, understanding the significance of the radio network planning phase to the overall network performance. Radio network prediction and simulation tool i.e Winprop can prove and adjust the coverage and capacity planning results is the output of this planning process. The output such as cell radius of sites and required number of sites are some of the vital important factors for the final simulation results in dimensioning.

The simulation result output contains coverage prediction by pathloss, Signal strength (Reference signal received power(RSRP), Reference signal received quality(RSRQ)), Capacity analysis by throughput and SINR (Signal to interference plus noise ratio) and Quality per each radio access technology that validate the deployed radio network that can handle the cellular traffic of Kirkos sub city in Addis Ababa for the subsequent five and above years. Since the real Addis Ababa digital map is used, from which Kirkos Subcity is cut out of this city by using Winprop/Wallman software. From the coverage and capacity planning perspective of the 5G New radio 57gNodeB's (from Coverage planning) and 44gNodeB's (from Capacity planning) are obtained respectively for Kirkos Subcity, from which the maximum of the two is deployed.

Although, Millimetric wave propagation modeling are mathematically modeled and their performance are evaluated through Matlab. From propagation modeling discussed in Chapter-3, Free space path loss, Close-in path loss, Floating intercept or ABG pathloss model and Dominant path loss models are evaluated/simulated and compared through matlab. From simulation result Close-in propagation models has high path losses relatively compared with the rest. While, Dominant path loss models has low path losses. At the same time, some technical challenges with millimetric wave propagation modeling are mentioned and their impact are evaluated through matlab.

5.2. Recommendations and Future Work

5G radio network planning and deploying has to be done first by performing in-depth assessment of the existing cellular networks. Subsequently, 5G New radio network planning has to be done with proper optimization of the existing topology and the predictable quality using the standard parameters. It has to be planned to efficiently minimize both the initial investment cost and as well as operative cost to the deployment of the optimized 5G radio network dimensioning, but this is prerequisite to conduct study on cost analysis to compare the planned radio network with existing one.

In this study nominal and detailed 5G radio network planning can be further being seen mostly from advanced LTE and 3Gpp perspective. The carrier frequency considered in this thesis is 2.6GHz (band41). It is possible to consider other frequency above 2.6GHz. But, the technical challenge to consider other frequency above 2.6GHz is due to standard air interface. There is no air interface data from ethiotelecom for these frequency. Air interface is the heart of radio network planning; because, it connects user equipment(UE) to the node(gNB). It is recommended to use carrier frequency above 2.6GHz, if air interface data is provided by ethiotelecom. The radio network planning tool used in this thesis is Winprop. WinProp has Ray-optical propagation models and empirical propagations models for received power and pathloss prediction. Furthermore; it is highly recommended to deploy 5G new radio by using Winprop tool, since accurate propagation model (dominant pathloss model) is used in this software for modeling the propagation.

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APPENDIXES

Appendix A1: Geographical Information from Initial Sites Placement (57 Sites) by Universal Transverse Mercator (UTM) for Kirkos Subcity.

Name	Longitude	Latitude
Site 1	470778.40 m	997812.59 m
Site 2	471184.22 m	997831.91 m
Site 3	470817.89 m	997593.08 m
Site 4	471302.52 m	997606.34 m
Site 5	471577.16 m	997838.35 m
Site 6	471647.73 m	997586.44 m
Site 7	470771.41 m	997307.61 m
Site 8	471202.94 m	997287.70 m
Site 9	471654.37 m	997287.70 m
Site 10	470837.80 m	997015.51 m
Site 11	471229.49 m	996995.59 m
Site 12	471700.85 m	997002.23 m
Site 13	470739.75 m	996698.19 m
Site 14	471048.95 m	996672.42 m
Site 15	471422.56 m	996665.98m
Site 16	470746.19 m	996427.64 m
Site 17	471055.39 m	996427.64 m
Site 18	471396.79 m	996395.43 m
Site 19	470857.72 m	996059.52 m
Site 20	471269.32 m	996066.16 m
Site 21	471700.85 m	996052.88 m
Site 22	472002.31 m	997825.47 m
Site 23	472363.04 m	997851.24 m
Site 24	472065.98 m	997586. 44 m

Site 25	472497.50 m	997599.72 m
Site 26	472105.81 m	997314.25 m
Site 27	472537. 33 m	997334.17 m
Site 28	472132.37 m	997002.23 m
Site 29	471886.36 m	996756.16 m
Site 30	472052.70 m	996444.57 m
Site 31	472278.42 m	996046.24 m
Site 32	472543.97 m	996949.12 m
Site 33	472408.13 m	996698.19 m
Site 34	472431.11 m	996384.82 m
Site 35	472802.89 m	996046.24 m
Site 36	472949.22 m	997864.12 m
Site 37	473041.88 m	997619.64 m
Site 38	472949.22 m	997297.26 m
Site 39	473121.55 m	996969.03 m
Site 40	472929.90 m	996601.56 m
Site 41	474173.13 m	996608.00 m
Site 42	473413.65 m	996046. 24 m
Site 43	473539.79 m	997832.08 m
Site 44	473445.23 m	997374.56 m
Site 45	474630.49 m	997767.49 m
Site 46	474739.99 m	997451.86 m
Site 47	474727.11 m	997123.33 m
Site 48	474733.55 m	996711.07 m
Site 49	474759.32 m	996324.57 m
Site 50	473857.49 m	997239.28 m
Site 51	474289.08 m	997297.26 m
Site 52	474128.04 m	996169.97 m
Site 53	474240.61 m	996917.20 m
Site 54	472942.78 m	996369.66 m
Site 55	473539.79 m	996723.40 m

Site 56	474084.17 m	997792.24 m
Site 57	473407.02 m	996338.35 m

Appendix A2: Geographical Information from Initial Sites Placement (57 Sites) in degree for Kirkos Subcity.

Name	Longitude	Latitude
Site 1	38°44’17.21” E	9.02668°1’36.6812”N
Site 2	38°44’16.13”E	9.02618°1’36.6888”N
Site 3	38°44’16.13”E	9.02613°1’36.6888”N
Site 4	38° 44’ 4.13” E	9.02400°1’28.9056”N
Site 5	38°44’20.01”E	9.02401°29.3484”N
Site 6	38°44’ 29.00”E	9.02621°1’36.9084”N
Site 7	38°44’2.623”E	9.02301°1’19.6068”N
Site 8	38°44’16.76”E	9.0170°1’18.9696”N
Site 9	38°44’31.546”E	9.0178°1,18.9804”N
Site 10	38°44’4.80”E	9.02412°1’10.0992”N
Site 11	38°44’17.63”E	9.01131°1’9.4584”N
Site 12	38°44’33.07”E	9.02461°1’9.6852”N
Site 13	38°44’1.60” E	9.0175°0’59.7636”N
Site 14	38°44’11.73”E	9.0171°0’58.9321”N
Site 15	38°44’23.96”E	9.0191°0’58.7304”N
Site 16	38°44’1.82” E	9.0242°0’50.9544”N
Site 17	38°44’11.94”E	9.0112°0’50.9616”N
Site 18	38°44’23.12”E	9.01341°0’49.9212”N
Site 19	38°44’5.48”E	9.02412°0’38.9712”N
Site 20	38°44’18.96”E	9.0189°39.1968”N
Site 21	38°44’3.09” E	9.02245°0’38.772”N
Site 22	38°44’42.92”E	9.02421°1’36.498”N
Site 23	38°44’54.74”E	9.0231°1’37.3476”N
Site 24	38°44’44.98”E	9.02464°1’28.704"N
Site 25	38°44’59.15”E	9.024767°1’29.1612”N

Site 26	38° 44’46.33”E	9.022182°1’19.8552”N
Site 27	38° 45’ 0.45”E	9.022363° 1’20.5068”N
Site 28	38° 44’47.19”E	9.019358°1’9.6888”N
Site 29	38°44’39.15”E	9.017133° 1’1.6788”N
Site 30	38°44’44.61”E	9.014315°0’51.534”N
Site 31	38° 44’52.02”E	9.010714°0’38.5704N
Site 32	38°45’0.69”E	9.018882°1’7.9752”N
Site 33	38°44’56.25”E	9.016612° 0’ 59.8032”N
Site 34	38°44’ 57.01”E	9.01377° 0’49.5972N
Site 35	38°45’ 9.19”E	9.010717°0’38.5812”N
Site 36	38°45’13.95”E	9.027161°1’37.7796”N
Site 37	38°45’16.98”E	9.02495°1’ 29.8212”N
Site 38	38°45’13.95”E	9.022034°1’19.3224”N
Site 39	38°45’19.61”E	9.019066°1’8.6376”N
Site 40	38°45’13.34”E	9.015741°0’56.6676”N
Site 41	38° 45’54.06”E	9.015806°0’56.9016”N
Site 42	38°45’29.18”E	9.015744°0’56.6784”N
Site 43	38°45’ 33.28”E	9.026875°1’36.75”N
Site 44	38°45’30.20”E	9.022736°1’21.8496”N
Site 45	38°46’9.002”E	9.026297°1’ 34.6692”N
Site 46	38°46’12.61”E	9.023442°1’24.3912”N
Site 47	38°46’12.19”E	9.020471°1’13.6956”N
Site 48	38°46’12.41”E	9.016742°1’0.2712”N
Site 49	38°46’13.26”E	9.013246°047.6856”N
Site 50	38°45’43.71”E	9.021515°1’17.454”N
Site 51	38°45’57.84”E	9.022042°1’19.3512”N
Site 52	38°45’52.59”E	9.011844°0’42.6384”N
Site 53	38°45’56.26”E	9.018604°1’6.9744”N
Site 54	38°45’13.76”E	9.013643°0’49.1148”N
Site 55	38°45’33.31”E	9.016847°1’0.6492”N
Site 56	38°45’51.12”E	9.026517°1’35.4612”N
Site 57	38°45’ 28.97”E	9.013363°0’48.1068”N

Appendix B: Appendix related to performance evaluation of propagation modeling through Matlab code.

MATLAB code for Free space pathloss model

```
clear; close all;
d=365;                                  % distance
fc=28*10.^9:5*10.^9:58*10.^9;       % initial carrier frequency
for i=1:1:7;
FSPL(i) = (32.4 +(20*log(d))+(20*log (fc(i))));
end
plot(fc,10*log(FSPL));
legend('FSPL in dB ');
xlabel('Frequency(GHz)');
ylabel('Pathloss in dB');
title('Free Space Pathloss in dB')
grid on
```

MATLAB Code for Close-in pathloss model

```
clear; close all;
d=365;                               %distance
 n=3.19;                             %pathloss exponent
sigma=8.2;
fc=28*10. ^9:5*10. ^9:58*10. ^9;    % initial carrier frequency
for i=1:1:7;
FSPL(i) = (32.4 +(20*log(d))+(20*log (fc(i))));
CIPL(i)=FSPL(i)+10*n*log(d)+sigma;
end
plot(fc,10*log(CIPL));
```

```
legend('CIPL in dB');
xlabel('Frequency(GHz)');
ylabel('Pathloss in dB');
title('Close-In pathloss model in dB')
grid on
```

MATLAB Floating Intercept or Alpha, Beta and Gamma (ABG) pathloss model

```
clear;close all;
d=365;          % distance
sigma=8.2;      %fading margin
alpha=3.48;
beta=21.02;
gamma=2.34;
fc=28*10. ^9:5*10. ^9:58*10. ^9;
for i=1:1:7;
FIPL(i)=10*alpha*log(d)+beta+10*gamma*log(fc(i))+sigma;
end
plot(fc,10*log(FIPL));
legend('FIPL in dB');
xlabel('Frequency(GHz)');
ylabel('Pathloss in dB');
title('Floating Intercept Pathloss Model in dB')
grid on
```

MATLAB Code for Dominant pathloss model

```
Clear all; close all;
d=365;                    % speed of light
p=2.4;                    % path loss exponent for dominant path loss
```

```
gt=18;                    % transmitter antenna gain
c=3*10^8;
fc=28*10. ^9:5*10. ^9:58*10. ^9;
for i=1:1:7;
DPL(i)=20*log(12.56*fc(i)/c) + 10*p*log(d)+gt;
end
plot(fc,10*log(DPL));
legend('DPL in dB');
xlabel('Frequency(GHz)');
ylabel('Pathloss in dB');
title('Dominant  Pathloss in dB')
grid on
```

MATLAB Code for all the above pathloss together

```
clear all; close all;
c=3*10^8;        % speed of light
d=365;           % distance
n=3.19;          % path loss exponent
p=2.4;           % path loss exponent for dominant path loss
gt=18;           % transmitter antenna gain
sigma=8.2;       % fading margin
alpha=3.48;
beta=21.02;
gamma=2.34;
fc=28*10. ^9:5*10. ^9:58*10. ^9;                % carrier frequency
for i=1:1:7;
FSPL(i) = (32.4 +(20*log(d))+(20*log (fc(i))));      % free space path loss
```

```
CIPL(i)=FSPL(i)+10*n*log(d)+sigma;                    % close-in path loss
FIPL(i)=10*alpha*log(d)+beta+10*gamma*log(fc(i))+sigma;%floating intercept
PLDPL(i)=20*log(12.56*fc(i)/c) + 10*p*log(d)+gt;    %dominant pathloss model
end
plot(fc,10*log(FSPL));
hold on
plot(fc,10*log(CIPL));
hold on
plot(fc,10*log(FIPL));
hold on;
plot(fc,10*log(DPL));
grid on
legend('FSPL in dB ','CIPL in dB','FIPL in dB','DPL in dB');
xlabel('Frequency(GHz)');
ylabel('Pathloss in dB');
title('Comparison of all Pathloss in dB')
```