5G Radio Network Coverage and Capacity Planning: The Case of Adama City

Sara Yohannes Mesfin

A Thesis submitted to the Department of Electronics and Communication Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Electronics and Communication Engineering
(Communication Engineering)

Office of Graduate Studies
Adama Science and Technology University

June, 2022

Adama, Ethiopia

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Approval Sheet

I/we, the advisors of the thesis "**5G Radio Network Coverage and Capacity Planning: The Case of Adama City"** and developed by **Sara Yohannes** hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by **Sara Yohannes** have read and evaluated the thesis entitled "**5G Radio Network Coverage and Capacity Planning: The Case of Adama City** "and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Communication Engineering.

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Declaration

I hereby declare that this Master Thesis entitled "**5G Radio Network Coverage and Capacity Planning: The Case of Adama City**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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Recommendation

I/we, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled "**5G Radio Network Coverage and Capacity Planning: The Case of Adama City**" prepared under my/our guidance by **Sara Yohannes** submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Communication Engineering Therefore, I/we recommend the submission of revised version of the thesis to the department following the applicable procedures.

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ACRONYMS

1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
3GPP	Third Generation Partnership Project
ACI	Adjacent Channel Interference
AF	Application Function
AMF	Access and Mobility Management Function
BCH	Broadcast Channel
CCCH	Common Control Channel
DCCH	Dedicated Control Channel
DFT-s-OFDM	Direct Fourier Transform Spread Orthogonal Frequency Division Multiplexing
DL	Downlink
DN	Data Network
DTCH	Dedicated Traffic Channel
EPC	Evolved Packet Core
FDD	Frequency Division Duplex
FFT	Fast Fourier Transform
gNodeB	Next Generation NodeB
GPRS	General Packet Radio Service
IFFT	Inverse Fast Fourier Transform
IMT	Information Management Technology
LOS	Line of Sight
LTE	Long Term Evolution
MAC	Medium Access Control
MAPL	Maximum Allowable Path loss
MIB	Master Information Block
mm Wave	Millimeter Wave

mMTC	Massive machine type communication
NEF	Network Exposure Function
NFR	Network Function Repository
NLOS	Non-Line of Sight
OTP	Open Transport Protocol
PBCH	Physical Broadcast Channel
PCCH	Paging Control Channel
PCF	Policy Control Function
PCH	Paging Channel
PDCCH	Physical Downlink Control Channel
PDSCH	Physical Downlink Shared Channel
PDSCH	Physical Downlink Shared Channel
PRACH	Physical Random-Access Channel
PRBs	Physical Resource Blocks
PUSCH	Physical Uplink Shared Channel
PUSCH	Physical Uplink Shared Channel
QoS	Quality of Service
QPSK	Quadrature Phase Shift Key
RACH	Random-Access Channel
RAN	Radio Access Network
RLC	Radio Link Control
SCMA	Sparse Code Multiple Access
SCS	Subcarrier Spacing
SINR	Signal to Interference plus Noise Ratio
SMF	Session Management Function
SMS	Short Message Service
TDD	Time Division Duplex
UDM	Unified Data Management Function
UL	Uplink
UPF	User Plane Function
URLLC	Ultra-Reliable and Low Latency Communications

ABSTRACT

One of the most important stages in constructing a wireless network that meets coverage, capacity, and quality of service requirements is radio network planning. In this thesis, the 5G radio network coverage and capacity are investigated taking Adama city as case study. The required number of gNodeB in the target environment's coverage region, as well as capacity evaluation, supported the ever-increasing subscriber growth is calculated in this thesis. For theoretical analysis and simulations, possible parameters for link budget, coverage, frequency, and capacity were gathered from standards and existing networks. The urban macro propagation model is used to model the propagation. The Link Budget and path loss computations are performed using MATLAB 2015 to evaluate the number of gNodeB required to satisfy the coverage and capacity requirements. And the simulation is performed using ATOLL 3.4 version Software to predict the coverage and capacity. For Adama city coverage and capacity planning, 5G New Radio provided 76 gNodeBs (coverage planning) and 60gNodeBs (capacity planning). From which the maximum of the two is (76gNodeB'S) deployed. The simulation output result contains coverage prediction by signal level, RSRP, transmitter overlapping zones. More than 98.1 percent of the target area is covered by the strong signal between -70dBm and -65dBm.From the propagation model comparisons as frequency increases Rural Macro Propagation model has high path-loss compared with Urban Macro and Indoor Hotspot Office The capacity analysis by throughput and SINR is performed. The peak Radio Link Control throughput for uplink is 248.1 Mbps and 185.2 for Mbps for downlink.

Key words: *5G NR, gNodeB, Coverage Planning, Capacity Planning, Radio Link Budget*

CHAPTER ONE

1. INTRODUCTION

This chapter delivers the generations of wireless communication, statement of the problem, objectives, scope, significance of the study and thesis organization.

1.1 Back Ground

Mobile Wireless Communication technology has moved dramatically during the previous few decades. The cellular wire Generation (G) indicates a development in the system's nature, speed, technology, and frequency. Each generation has its own set of standards, capabilities methodologies, and unique characteristics that set it apart from the previous one. Data rate demands have risen dramatically over time, and the exponential growth in traffic necessities the usage of higher frequency bands in addition to the sub 6GHz bands.(Umer et al., 2017). North America, Europe, Oceania, and portions of Asia begun to deploy fifth generation (5G) NR systems in 2019.Initial deployments of 5G systems are for the eMBB use case, inspired by exponentially increasing data rate demands as well as a significant increase in the number of user equipment per square kilometer. The goal of 5G-NR systems is to improve system throughput and coverage reliability because of an order of magnitude over current LTE-A systems. Because of the larger effective area of antenna arrays and higher diffraction efficiency, C-band has a coverage advantage over the mm Wave bands, which has been proven by measurements. Non-standalone (NSA), and stand-alone (SA) are the two most common deployment modes for eMBB systems. Third generation partnership project (3GPP) Release 15 freezes the technical requirements for NSA and SA architecture. Cellular planning's major goal is to reduce network costs, increase coverage, increase capacity, reduce power consumption, and optimize handover zones.

First Generation (1G): The first generation of wireless mobile communication systems has been developed in the 1980s using analog technology. It was used for voice services based on technology called as Advanced Mobile phone system (AMPS), uses Frequency Division Multiple Access (FDMA) with channel capacity of 30 kHz and frequency band of 824-894 MHz. (Farooq et al., 2015).

Second Generation (2G): 2G are digital cellular systems. In comparison to the first-generation wireless system, the second-generation wireless system featured digital modulation schemes such as Time Division Multiplexing Access (TDMA) and Code Division Multiplexing Access (CDMA). The most extensively used 2G standard is GSM. The General Packet Radio Service (GPRS) was a GSM packet overlay network that provided data services. GPRS used the same frame structure as GSM and could send data at maximum rate of 21.4 kbps(Li et al., 2009).

Third Generation: The objective of 3G wireless system was to deliver data services at 14kbps to 384kbps in wide coverage regions and 2Mbps in narrow coverage areas. Wireless web access, email, video teleconferencing, and multimedia services including voice and data streams are all possible applications. The major feature of 3G technology is that it allows for improved voice and data capacity as well as low-cost data transmission.

Fourth generation: provide access to various ranges of telecommunication services including advanced mobile services, supported by increasingly packet-based mobile and fixed networks, as well as support for low to high mobility applications and a wide range of data rates, in accordance with services demands in a multiuser environment. For low mobility, such as nomadic/local wireless access, 4G wireless communication can support data speeds of up to 1Gb/s, and up to 100 Mb/s for high mobility, such as mobile access.(Farooq et al., 2015; Flfg et al., 2012).The technologies orthogonal frequency division multiplexing (OFDM),multiple –input multiple-output (MIMO),and link adaptability technologies are used to provide an improved radio interface.

Fifth generation: Due to the need for large data services, the Third Generation Partnership Project (3GPP) is working on developing 5G New Radio technology. 5G NR uses millimeter wave (mmWave) frequency as a spectrum addition form to achieve multi-Gigabit-per-second (Gbps) data rates for each user. It is forecasted to operate at frequencies between 1GHz and 100GHz.As a result of this high frequency,5G technology requires more base stations to achieve a specific level of coverage than 3G and 4G technologies.(Esa, 2021)

1.2 Statement of Problem

In recent years, Ethiopia's government has been extending communication infrastructure across the country. The number of users and demand for high-speed multimedia services and the city is growing at faster rate. The key advantages for considering 5G are its reduced latency, increased capacity, and faster speeds. It also connects and shares data in real time, has the capacity to handle millions of devices at high speeds, and has the ability to change people's lives all around the world. Network Operators may experience considerable losses as a result of improper path loss prediction and link budget computation. Thus, the impact of neighboring base stations on signal intensity, exact path loss calculations, and the usage of propagation models should all be considered when locating base station transmitters. Coverage estimation with general propagation model which doesn't incorporate the actual geographical information leads to improper radio network planning, choosing certain site is important where in this thesis Adama city is considered.

1.3 Objectives

1.3.1 General Objective

The main objective of this thesis is to carryout 5G network coverage and capacity planning taking Adama city as case study.

1.3.2 Specific Objectives

The Specific Objectives are to:

- Calculate the Link budget.
- Analyze the path loss.
- Find out the maximum subscriber number per site.
- Plan the number of gNodeB's required to provide sufficient coverage to the given total number of subscribers.

1.4 Significance of the Study

This thesis investigates 5G NR cellular network coverage and capacity planning. It considers coverage prediction and capacity evaluations in depth with the ATOLL radio network planning software, which provides a clear prediction for the target area with suitable propagation modeling, which is the Urban Macro Propagation model. Network planners can use this thesis as design document and guide line for future network expansion. This research will be extremely beneficial to current network operators who are looking forward upgrade to a 5G network.

1.5 Scope of the Study

The Scope of this thesis is to study 5G radio Network coverage and capacity planning for Adama City. It addresses about 5G network architectures, Radio wave propagation models in outdoor environments for 5G networks taking in to account the actual morphology and topology details of Adama city for future deployment.

1.6 Thesis Organization

The work on the thesis is organized in such a way that it provides a clear flow and explanation of 5G NR coverage and capacity planning. Chapter 1 contains the introduction, problem statement, thesis objective, the specific objectives thesis scope and limitations, and thesis contributions. The chapter 2 contains a study of the literature and a technical overview of the 5G New radio. The thesis' chapter is the main part. It describes Radio Network Design process of coverage and capacity planning in the 5G NR system, which includes radio link budget calculation, propagation model selection, and site number calculation based on coverage and capacity. Radio Planning Analysis and Results for Adama City are discussed in Chapter 4. Lastly, in Chapter 5, conclusions are presented, followed by points of recommendation.

CHAPTER TWO

2. LITERATURE REVIEW

This chapter includes details on related works, 5G architecture, 5G New Radio frequency bands,5G New Radio requirements and targets, 5G New Radio technologies, 5G network layers, and frame structure.

2.1 Related Works

(Shafi et al., 2020)The deployment options for the C-band and millimeter-wave bands are compared in this study. They concentrated on predicting the two bands operating in the same deployment region. They studied at the two bands' network performance, coverage reliability, and channel rank. According to their measurements, the mm Wave band has a smaller coverage area than the C-band due to higher path loss and smaller antenna array sizes. For the same band width, the C-band has a larger throughput than the mmWave due to the higher instantaneous rank of the propagation channel. The received power of the reference signal was also compared. The limitation of this thesis is the comparison is taken only single UE. It is better to use more samples for better comparison.

(Curry, 2020)This article focused on the 5G NR link budget for data services and coverage prediction, which was then compared to trial measurements to ensure that the link budget and prediction models for 5G NR non-standalone planning were accurate. They employed the frequency band 3.5 and a bandwidth of 60MHz and they used the RF planning tool ATOLL to make a coverage prediction. They have chosen the Cross-Wave propagation as their propagation model. The limitation is they haven't tested the performance of horizontal handover in mobility of cluster of sites because it influences the density of sites.

(Esa, 2021)This research presented 5G NR planning using Mentum Planet 7.2.1 software. The research performed the coverage planning by taking industrial area in East Jakarta. The Uma and Umi propagation model are used to calculate Maximum Allowable Path loss and radius and then simulated using the software. The number of sites, and SS-RSRP calculated. The limitation of this research is that cellular network planning is done based on coverage only. It is preferable to consider capacity as well.

(Chen, 2020)This study used Mentum Planet 7.2.1 software to present 5GNR planning. The coverage planning was carried out using an industrial area in East Jakarta as a case study. This article developed a 5G and LTE hybrid planning method in a non-standalone mode. To adopt the NSA mode for networking, the existing LTE is used as the 5G overlay layer, while the 5G NR is used as the capacity layer. The link budget of LTE 1.8GHz and 5G NR 3.5GHz were evaluated. Under the assumption of fulfilling capacity and coverage, the coverage performance and interference performance loss of this networking approach are analyzed. This paper made a contribution in the following ways: NSA planning reduces construction costs by providing a baseline for eventual 5G and LTE shared network engineering planning. The network design in this thesis is limited to the planning of urban scene coverage and does not include rural area scenarios.

(Sallent et al., 2015) They recognized network capacity planning as a source of considerable CAPEX savings and network operation approaches as a source of significant OPEX savings. Using an AI-based framework, they identified offloading certain users to other cells/technologies and accessing unlicensed spectrum to increase capacity in some specific cells and at specific times. A framework has been presented that processes input data from a variety of sources. Using machine learning-based classification and prediction models, they extracted relevant knowledge that should drive planning and operation decisions.

(Sukarno et al., 2020)The network planning of mid-band 2GHz and high-band 26GHz was compared in this paper using a case study at the Jababeka Industrial Estate. The link budget is calculated using the Urban Macro (Uma) and Urban Micro (Umi) propagation models. The highest data rate is compared to the SS-SINR and SS-RSRP. Mentum Planet 7.3 is used to run the simulation. The thesis's drawback is that the 5G NR planning for these two bands is solely centered on coverage planning, with no consideration for capacity planning.

(Sukarno et al., 2020)This research makes significant contributions by analyzing the capacity, coverage, and cost of several enhanced Mobile Broadband (eMBB) infrastructure solutions. A case study of the Netherlands is used to conduct both a supply-driven and demand-driven investment analysis. Before network densification via tiny cells, the supply-driven analysis evaluated the capacity that could be given to customers via new spectrum. The demand-driven study compared the performance of several tactics in meeting a range of necessary per-user speeds, such as 30, 100, or 300 Mbps. Estimating the throughput threshold produced per user by integrating 5G frequency bands onto the existing Dutch macro cell network is an important contribution.

(Muñoz & Sallent, 2017)This study presents a revolutionary framework for cell planning. The tenant's contracted capacity is transformed into a set of comprehensive planning specifications throughout time and space domains in order to upgrade the network architecture and configuration efficiently in this framework. Based on this, an algorithm is developed that takes into account various operations such as channel additions and removals, as well as the addition and relocation of small cells. The proposed approach is examined in the context of a new tenant's deployment, with several sets of planning specifications being tried. The research's gap is that it requires more investigation of the planning approach, with an emphasis on planning acts and their triggering conditions. The modifiable parameters in these settings, in particular, can be manipulated to give more reactive or proactive cell planning behavior.

(O'Connell et al., 2020)This paper addresses how 5G will affect manufacturing, the standards and technological requirements needed to satisfy the demands of using 5G, and the security concerns that must be addressed if a 5G deployment is planned. This thesis describes the criteria for a successful 5G implementation in a manufacturing environment. Before deploying 5G, industry must examine the individual requirements for each IoT use case. Industry must get a firm understand of the data types being communicated, their latency sensitivity, and if the data must be processed independently or against past data. The limitation of this thesis the heterogeneous interoperability of 5G and existing communication protocols is not evaluated.

(Liu et al., 2020)This article compares and contrasts the SA NR and NSA NR deployment options in terms of coverage, network functionality, network complexity and cost, and industry development. Based on the comparison conclude that NSA is a compromise between adding extra capacity for eMBB and saving some initial deployment costs for operators who do not want to introduce the 5G core network for first NR deployment. For large-scale deployments, SA is preferable. The limitation of this thesis is the comparison based on data rate and throughput has not been broadly analyzed.

Table 2. 1 Summary of related papers contributions and research gap

Paper reference	Contribution	Research gap
Shafi et al,2020	Compared the network performance, coverage reliability and channel rank of C-band and mmWave.	The comparison is taken only on user equipment.
Curry2020	Checked out the link budget analysis and coverage prediction with trial measurements to ensure accuracy.	Haven't tested the performance of horizontal handover in mobility of sites.
Esa,Rai Nur2021	The Maximum Allowable Path Loss is calculated using Uma and Umi Propagation model.	The limitation is the cellular network planning is done based on coverage only. it is better to consider the capacity also.
Sukarno,et al,2020	The network planning of mid-band 2GHz and high-band 26GHz was computed.	5G NR planning for these two bands is solely centered on coverage planning with no consideration of capacity planning.
Chen,2020	Develop a 5G and LTE hybrid planning method reduces construction costs by providing a baseline for eventual 5G and LTE shared network engineering planning	The network design in this thesis is limited to the planning of urban scene coverage and does not include rural area scenarios.
Liuetal,2020	Compares and contrasts the SA NR and NSA NR deployment options.	The comparison based on data rate and throughput has not been broadly analyzed.

2.2 Basic Concepts of 5G NR

5G stands for the fifth generation of wireless technology, and NR refers to a new radio interface and radio access technology for cellular networks. 5G NR is a new radio access technology (RAT) for the 5G mobile network developed by the 3GPP.

2.2.1 Major Expected Services of 5G

eMBB (enhanced Mobile Broadband), URLLC (Ultra Reliable Low Latency Communications), and mMTC (massive Machine Type Communications) are all part of the 5G system service. The initial phase of 5G non-standalone deployments focuses on eMBB.

Enhanced Mobile Broadband (eMBB): The number of requests for mobile broadband is increasing every day**.** As a result, this vision aims to improve mobile broadband ability to access media, services, and data. Scenarios for mobile broadband customers will provide the most recent application area as well as extra needs for existing mobile broadband applications in order to improve performance.

Ultra-Reliable and Low Latency Communications (URLLC): This vision is required as a strict requirement to meet the requirements for reliable communication capabilities and low latency, such as the existence of good throughput, low latency, and high availability. Wireless control of production or industrial processes, long-distance medical operations, distribution automation in a smart grid, transportation security, and so on are some examples.

Massive Machine Type Communication (mMTC): The devices connected with sensitive data delivery without delay and at a relatively low volume describe this connection capacity. To realize this aim, the terminal device must be low-cost to create and have a long battery life.

2.2.2 5G NR Basic Architecture

The networking modes of 5G are primarily separated into NSA and SA. The NSA networking design is based on a 4G and 5G collaboration model, which can help the old EPC. The SA networking architecture is a new 5G organization that requires the building of a new 5G core network. The NSA network is the first choice because of its one-step planning, distributed execution and manageable investment features (Chen, 2020).

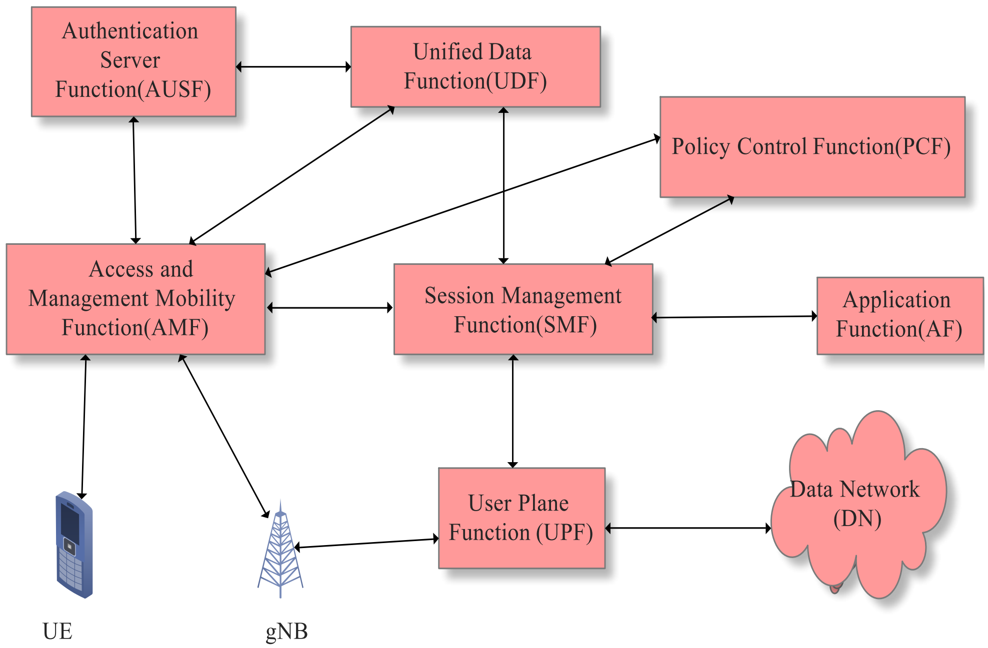

Figure 2. 1 Basic Architecture of 5G NR (Guidotti et al., 2019)

5G Core Network: The mobile exchange and data network, often known as the core network, is responsible for managing mobile voice, data, and Internet connections. The core network for 5G is being upgraded to better interface with the Internet and cloud-based applications, and distributed servers are being deployed across the network to improve response times.

User Equipment (UE): 5G smart phones and other cellular devices connect to the 5G core and then to Data Networks (DN), such as the Internet, via the 5G New Radio Access Network.

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

Access and Mobility Management Function (AMF): functions as the UE connection's sole point of entry. Based on the service requested by the UE, the AMF selects the appropriate Session Management Function (SMF) for managing the user session.

User Plane Function (UPF): transmits IP data traffic (user plane) from the User Equipment (UE) to the external networks.

Authentication Server Function (AUSF): enables the AMF to authenticate the UE and access services to 5G core services.

Network Function Repository (NFR): When deploying, upgrading, or removing NF instances, and supporting service discovery, keep track of and provide information about the deployed NF instances.

Session Management Function (SMF): The SMF is responsible for interfacing with the decoupled data plane and creating, updating, and removing Protocol Data Unit (PDU) sessions.

Data Network (DN): Internet access, operator services, and other services are provided by Data Network.

Policy Control Function (PCF): provides a consistent policy framework for governing network behavior, as well as policy rules for the Control Plane function to enforce them.

Unified Data Management Function (UDM): UDM supports subscription management, user identification, subscription-based access authorization and SMS management.

Application Function (AF): Designers can use the 5G Application Function to interface with the 3GPP 5G system and influence the routing of edge application traffic as well as receive subscription notifications.

2.2.3 5G NR Frequency Bands

The telecommunication infrastructure relies heavily on limited frequency spectrum, especially when deploying data intensive services. Varied frequency spectrums with different characteristics are required for eMBB, URLLC, and mMTC usage situations. The spectrum bands set aside for 5G deployment can be classified into three categories.(Sukarno et al., 2020).The reason for using low-band for mobile broadband and the Internet of Things (IoT) is that wireless signals can penetrate barriers such as buildings, have extreme coverage and minimum data rates. Because it can provide a good network in terms of coverage and capacity, the mid-band is a suitable frequency for 5G NR.

Millimeter Wave (mmWave) is a very high frequency with a significant quantity of spectrum capable of delivering Gbps data rates, high capacity, and low latency (1 ms). Because the mmWave signal can be interfered with by rain or ice, and it is easily blocked not only by building materials, but also by foliage and human bodies, mm Wave normally requires a line of sight due to its wavelength.

For 5G deployment, 3GPP specifications for the 5G initial bands and accompanying band-combinations were finalized in June 2018. The new 5G-NR frequency bands established by 3GPP are shown in the table 2.2.

Table 2. 2 5G NR Operating Bands(Position, 2020)

NR Operating Band	Uplink Range (MHz)	Down link Range (MHz)	Duplex Mode
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
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
n257	26500-29500	26500-29500	TDD
n258	24250-27500	24250-27500	TDD
n260	37000-40000	37000-40000	TDD
n261	27500-28350	27500-28350	TDD

The Special 5G band-n78: Right in the middle of this mid band is a band which is being used by most European and Asian countries and spans 3.3 GHz to 3.8 GHz. The n78 band which is also referred to as 3.5 GHz band is the most popular 5G band. This popularity stems from the fact that:

- Most commonly available.
- It offers good speed.
- Great coverage and to top that.
- Most commercial 5G networks are majorly relying on the 3.3-3.8 GHz range.

2.2.4 5G NR Duplex Scheme

Half Duplex: Within a cell, simultaneous transmission and reception in both UL and DL is not possible for a certain frequency range. Due to the relaxed or no-duplex filters, it provides for a simpler device implementation.

Full Duplex: Within a cell, it is feasible to have simultaneous transmission and reception in both UL and DL for a specific frequency range. One disadvantage of this approach is that the band definition necessitates the use of a guard band between UL and DL, and the receiver must be fitted with a duplex filter to eliminate transmitter interference.

Frequency Division Duplex (FDD): In FDD, the carrier is paired spectrum, indicating that it has both an uplink and downlink carrier. Because the carrier frequencies for the two directions are different, data can be transmitted both ways at the same time. Furthermore, the resource allocation can be handled dynamically and assigned in either the UL or DL direction. Each frame has a full set of slots in both UL and DL transmissions with in a cell. To distinguish between UL and DL transmissions, duplex filters are utilized.

Time Division Duplex (TDD): TDD employs a single carrier frequency. The UL and DL use the same frequency but have different time slots for transmission and reception. The UL or the DL can be assigned time slots. TDD uses unpaired bands, in which the UL and DL transmissions are non-overlapping in time from the device's and cell's perspectives. In this situation, the receiver complexity is minimized because the duplex filter is not required. UL and DL time intervals are typically used to divide a time interval such as frame structure or slot structure. It has a lot of advantages, especially when it comes to beam forming techniques. The benefit of TDD in high-frequency bands is that the UL/DL capacity can be adapted to the cell's traffic pattern. The cell capacity can be changed to the demands of the cell by giving more or less time for DL. One of the scheme's disadvantages is the sort of synchronization required to correct for propagation delay due to inter-cell interference and the need for a guard time between transitions from receiver to transmitter.

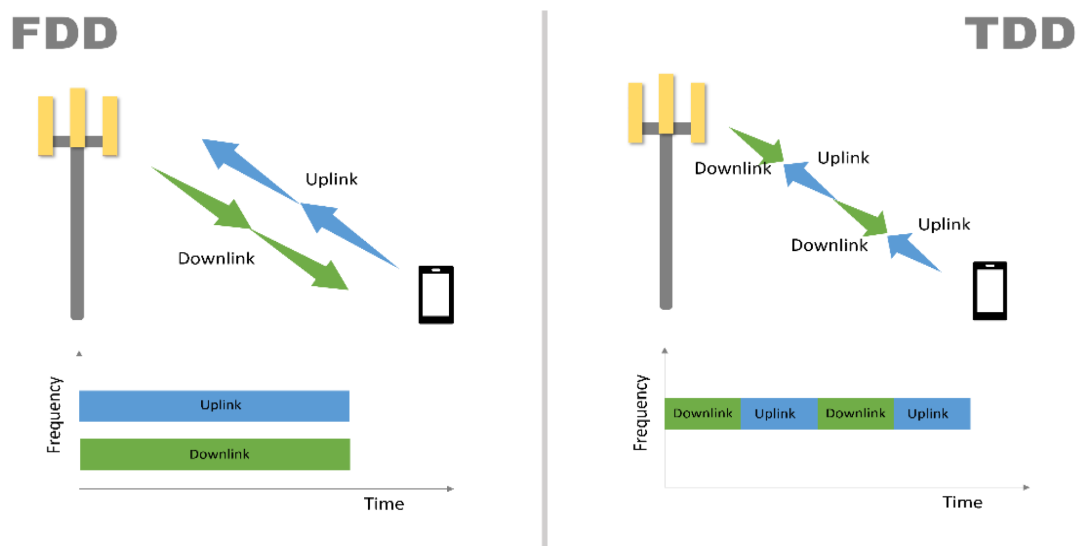

Figure 2. 2 TDD and FDD Duplex Scheme(Askar et al., 2021)

As Shown in figure 2.2 in FDD scenario the frequency of uplink and downlink is different. But in TDD they have the same frequency for both uplink and downlink.

2.2.5 Waveforms and Modulation

The waveform is the actual structure of the signal that transmits modulated data through a channel. In a communications system, the information is mapped from the message space to the signal space at the transmitter, and the message is recovered at the receiver via a reverse operation.(Demir et al., 2018).

OFDM (Orthogonal Frequency Division Multiplexing): It's a high-efficiency modulation format utilized in 5G wireless communication systems. OFDM is a frequency-domain technique for communications that offers significant benefits when dealing with the frequency-selective nature of high-speed communication networks. OFDM systems have evolved as the requirement for operating at larger data rates has increased. Using OFDM, an array of subcarriers may be created that operate together to transport data over a wide range of frequencies. The functions of these Subcarriers must be orthogonal. The use of the IFFT (Inverse Fast Fourier Transform) to efficiently produce the time domain waveform from an array of modulated subcarriers is a fundamental enabler for OFDM. Both the uplink and downlink of the 5G NR standard employ OFDM. The New Radio Specification is built with a lot of flexibility in mind to support a wide range of applications. Carrier spacing is variable (15 kHz, 30 kHz, 60 kHz, 120 kHz, 240 kHz, and 480 kHz) with up to 3300 subcarriers. QPSK, 16 QAM, 64QAM, or 256 QAM can all be utilized as subcarrier modulation.

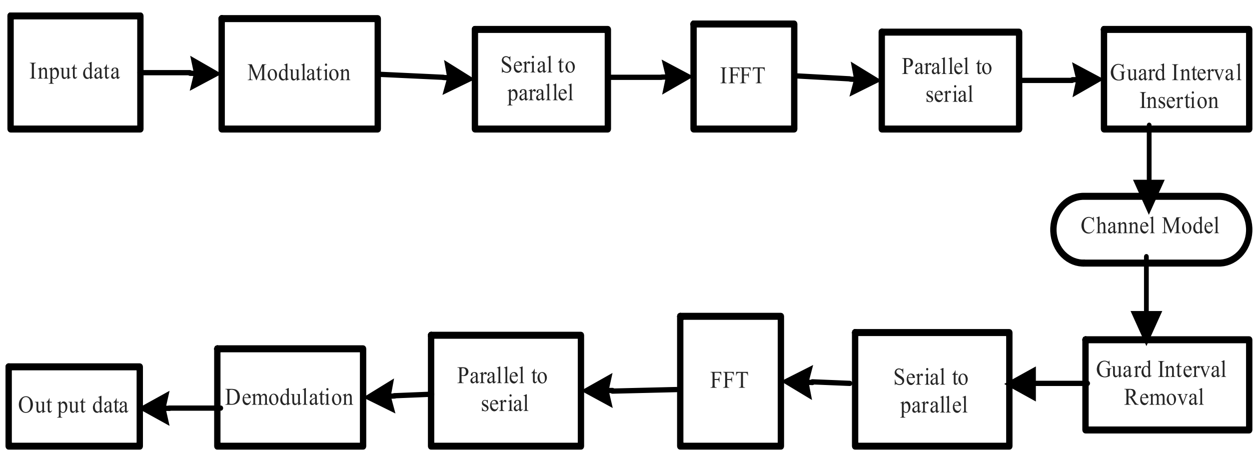

Figure 2. 3 OFDM transceiver (Karimian, 2011)

CP-OFDM (Cyclic Prefix OFDM): Numerology is a feature of CP-OFDM that allows for changeable subcarrier spacing. The cyclic prefix duration per symbol changes when the SC spacing is changed. In the case of SC-OFDM, at the start of the OFDM frame, the preceding part of the OFDM frame's data is added, and the length of the cyclic prefix is chosen to be longer than the channel interruption. The cyclic prefix is used in OFDM and other orthogonal frequency division multiplexing schemes as a guard band between successive symbols to prevent inter-symbol interference. The advantages of SC-OFDM are:

- Prevent Inter-Symbol Interference

- With the use of retransmitted data, it provides robustness to OFDM signals.
- CP-OFDM provides better flexibility and time–frequency localization using various filtering/windowing methodologies and precoding strategies
- It supports in packet time synchronization at the receiver through the use of a correlation method.
- To suppress ACI (adjacent channel interference) and maintain OFDM subcarrier orthogonally, a cyclic prefix is placed in the guard interval.

Disadvantage of CP-OFDM:

- Due to the use of redundant data, it decreases the system capacity and data rate of the system.
- Due to the increase in overall bandwidth, more power is required to transmit.
- It takes longer for the data to be transmitted. As a result, the overall latency of meaningful payload transfer via OFDM subcarriers increases.

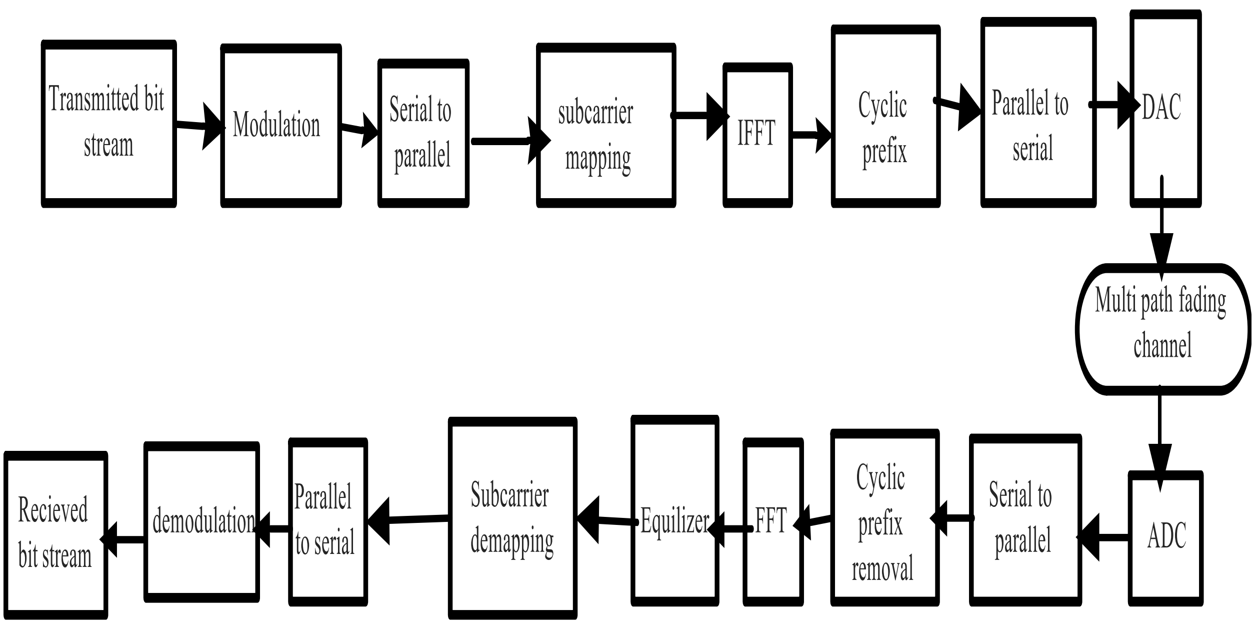

Figure 2. 4 Block diagram of SC-FDMA

DFT-s-OFDM (Discrete Fourier Transform spread OFDM): Waveforms based on the discrete Fourier transform spread OFDM (DFT-s-OFDM) are presented to address the high PAPR problem in CP-OFDM while retaining its useful qualities. CP-DFTs-OFDM is a promising candidate for 5G, similar to CP-OFDM, because of its low complexity, support for dynamic spectrum access, and MIMO compatibility. However, because of the discontinuity between adjacent symbols, the spectral efficiency of this waveform is comparable to CP-OFDM, and it has a high OOBE.

2.2.6 5G multiple access techniques

Orthogonal Multiple Access (OMA) has been used in previous generations of communication systems. To avoid inter-user interference, each time/frequency resource block is allocated to only one of users. For both DL and UL transmissions, synchronous-based OMA continues to play a key role in NR. OMA can only support limited numbers of users due to limitations in the numbers of orthogonal resources blocks, which limits the SE and the capacity of current networks.(Cai et al., 2018).

OFDMA: OFDMA has been widely and successfully used for 4G and could be used as a 5G multiple access system. It does, however, necessitate the use of OFDM, as well as orthogonally between carriers and the use of a cyclic prefix, which has several downsides. As a result, different multiple access techniques are under consideration.

SC-FDMA: It is concerned with the assignment of a shared communication resource to a large number of users. Because it includes an additional DFT processing step before the standard OFDMA processing, it can be regarded of as a linearly pre-coded OFDMA scheme. SC-FDMA has gained popularity as a viable alternative to OFDMA, especially for uplink communications.

Non-orthogonal multiple access (NOMA): NOMA was recently proposed to increase system capacity and support huge connectivity by allowing multiple users to use the same time or frequency resource. Different power allocation coefficients or signatures like code word, sequence, interleave, and preamble are used to multiplex the signals of numerous NOMA users. Improvements in UE spectral efficiency and connection number can be achieved in NOMA by sharing the same radio resources across multiple UEs and allocating more radio resource per UE.

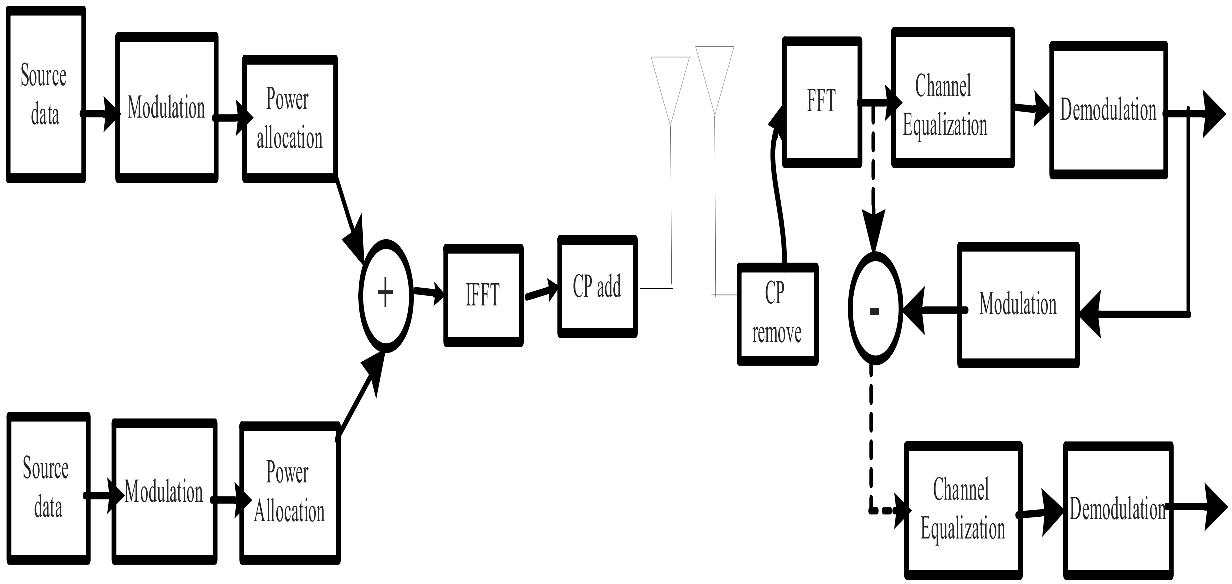

Figure 2. 5 Block diagram of NOMA (Kim et al., 2019)

Sparse Code Multiple Access (SCMA): is a Code Division Multiple Access method that is distinguished by its sparse codebooks. Codebooks are created using multi-dimensional constellations. In terms of sum throughput, SCMA outperforms OFDMA and the other suggested non-orthogonal MA schemes, making it a promising candidate multiple access scheme for 5G.

Advantages of SCMA:

- It offers low-complexity iterative message passing multi-user identification when there are fewer users.
- Users are clustered together in low-density resource blocks.
- Low multi-user joint detection complexity
- Even with a huge number of concurrent users, there are less collisions.
- As a result of the spreading gain, there is more coverage.

2.2.7 5G NR Data channels

The 5G communications system is able to manage data transfers in an orderly manner by organizing data into various channels, and the system is able to recognize what data is arriving and hence process it in the needed manner. The main types of data channels that are used within mobile communications systems are logical channels, transport channels, and physical channels.

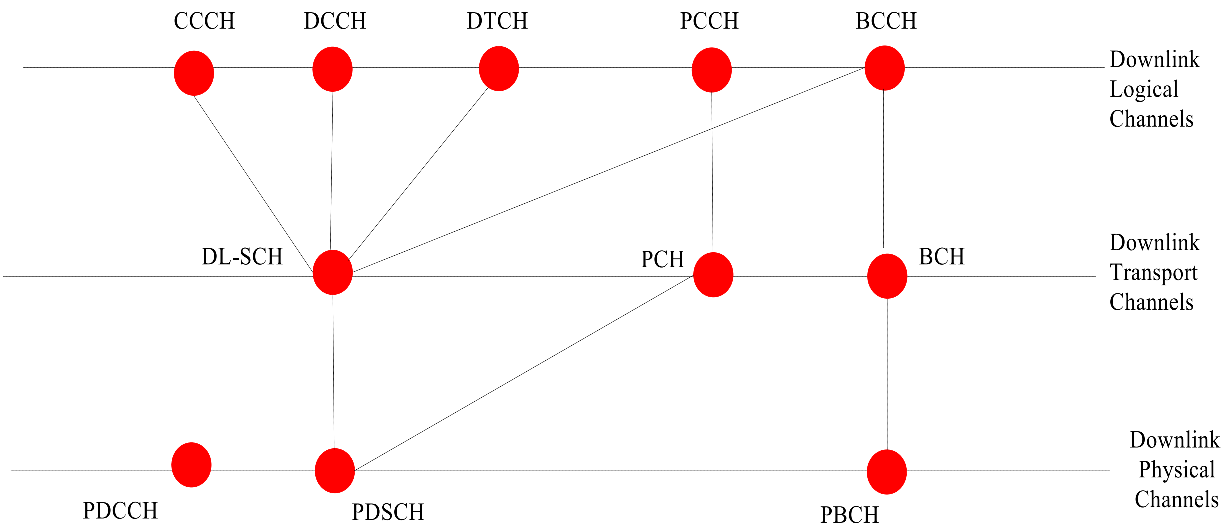

Figure 2. 6 5G NR Downlink logical, transport and physical channels (Devopedia,2021)

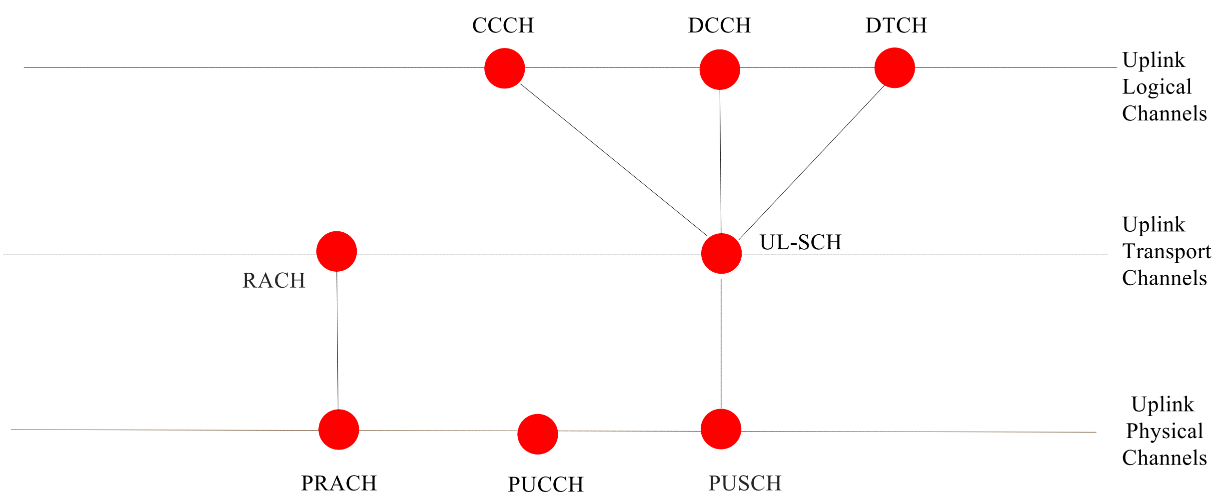

Figure 2. 7 5G NR Uplink logical, transport and physical channels (Devopedia.2021)

2.2.7.1 5G NR Logical Channels

Within the 5G NR radio access, numerous different logical channels are used.

Broadcast Control Channel: The BCCH is used in the downlink to send broadcast-style information to the cell's user equipment. The 5G NR BCCH transmits system data in many blocks.

Master Information Block: It is mapped to the BCH transport channel before being sent to the PBCH physical channel.

System Information Block: System Information Block are assigned to the DL-SCH transport channel then allocated to the PDSCH physical channel.

Paging Control Channel (PCCH): PCCH is a downlink channel. It's used to page UEs whose network doesn't know where they are at the cell level. The paging message must be delivered to multiple cells. The PCCH is associated with the PCH transport channel, which in turn is associated with the PDSCH physical channel.

Common Control Channel (CCCH): On the downlink and uplink, it's utilized to send and receive control information from user equipment.

Dedicated Control Channel (DCCH): DCCH carries dedicated control information between the UE and the network for both uplink and downlink. Following the formation of a radio resource control (RRC) link, it is used by the UE and the network.

Dedicated Traffic Channel (DTCH): DTCH is used to transfer data between a UE and the network.

2.2.7.2 5G NR Transport Channels

On the uplink, downlink, or both, there are five different transport channels that can be used.

Broadcast Channel (BCH): The BCH 5G channel is only used in the downlink to carry BCCH system data, particularly MIB data. The data is formatted precisely in order to be utilized.

Paging Channel (PCH): Paging data from the PCCH logical channel can be transported through the PCH. The PCH is compatible with discontinuous reception in order to help the UE save battery life.

Downlink Shared Channel (DL-SCH): It provides all of the key 5G NR features like dynamic rate adaptation, spatial multiplexing and channel aware scheduling**.**

Uplink Shared Channel (UL-SCH): The UL-SCH is the transport channel for uplink data transmission (a transport block).

Random-Access Channel (RACH): It is used to prevent message collisions when many users access the system at the same time by carrying a random-access preamble.

2.2.7.3 5G NR Physical Layer data channels

The radio communications link between the UE and the base station requires physical layer data to maintain and optimize it. There are uplink and downlink physical channels.

Physical Downlink Shared Channel (PDSCH): The PDSCH protocol is used to transmit DL user data, system information, UE-specific higher layer information, and paging. The PDSCH uses an adaptive modulation format that is dependent on link conditions and incorporates a variable coding method.

Physical Downlink Control Channel (PDCCH): It transports downlink control data. Its major job is to schedule downlink and uplink data transmissions on the PDSCH and PUSCH, respectively. The PDCCH uses QPSK for modulation and polar coding for coding.

Physical Broadcast Channel (PBCH): PBCH provide the Master Information Block (MIB) to UEs and supports time and frequency synchronization. This makes cell capture, selection, and re-selection much easier. The PBCH uses QPSK modulation to transmit a cell-specific demodulation reference signal.

Physical Random-Access Channel (PRACH): It sends out an initial random-access pre-amble consisting of two different length sequences.

- The long sequence is applied to 1.25 kHz and 5 kHz subcarrier spacing.
- Subcarrier spacing of 15 kHz and 30 kHz (FR1 bands), as well as 60 kHz and 120 kHz (FR2), are used with short sequence durations of 139.

Physical Uplink Shared Channel (PUSCH): utilized to transfer data on a frequency and time-shared basis from the UL-SCH and its higher mapped channels. Frequency resources are allocated using resource blocks and a flexible modulation and coding method based on the signal to noise ratio of the link. The PUSCH comprises DMRS signals to aid in channel link estimation and demodulation.

Physical Uplink Control Channel (PUCCH): used to transfer data on a frequency and time-shared basis from the UL-SCH and its higher mapped channels Frequency resources are allocated using resource blocks and a flexible modulation and coding method based on the signal to noise ratio of the link. The PUSCH comprises DMRS signals to aid in channel link estimation and demodulation.

2.2.8 5G NR Frame Structure

To handle the various use cases of 5G, various numerologies are used. The frame structure is similar to LTE in terms of time and frequency grid, but with more configurable parameters. A frame is 10 milliseconds long, containing 10 millisecond sub frames. For a particular carrier frequency, it will be able to multiplex several numerologies, but the entire communication must be synchronized on a sub frame basis. Each slot has 14 OFDM symbols. The supported subcarrier spacing in FR1 are 15, 30, 60 kHz, while the supported subcarrier spacing in FR2 are 60, 120 kHz.

Table 2. 3 5G NR supported transmission numerology(Lien et al., 2017)

μ(numerology)	Subcarrier spacing (2^{μ}×15KHz)	Resource block bandwidth (2^{μ}×12 subcarriers)	Number of slots per sub frame (2^{μ})	OFDM symbol per slot	Cyclic prefix
0	15KHz	180KHz	1	14	Normal
1	30KHz	360KHz	2	14	Normal
2	60KHz	720KHz	4	14	Normal, Extended
3	120KHz	1.44MHz	8	14	Normal
4	240KHz	2.88MHz	16	14	Normal

In 5G, each NR Resource Block (RB) has 12 frequency-domain sub-carriers, similar to LTE. The resource block bandwidth in LTE is set at 180 kHz. In 5G NR, resource block bandwidth is dependent on sub-carrier spacing. NR is predicted to work with 100 MHz channel bandwidth for lower bands under 6 GHz and 400 MHz channel bandwidth for higher bands. In comparison to LTE, NR is designed to give improved bandwidth efficiency, reaching 99 percent. The resource grid has a frequency axis with the number of subcarriers and a time axis with the number of OFDM symbols. According to the subcarrier spacing configuration, a set of resource grids is assigned per transmission direction (uplink and downlink) and for each of the antenna ports. In a resource grid, there are multiple RBs. Physical Resource Blocks (PRBs) are groups of resource elements. The resources in the 5G NR are mapped across time and frequency grids, as illustrated in the figure 2.8.

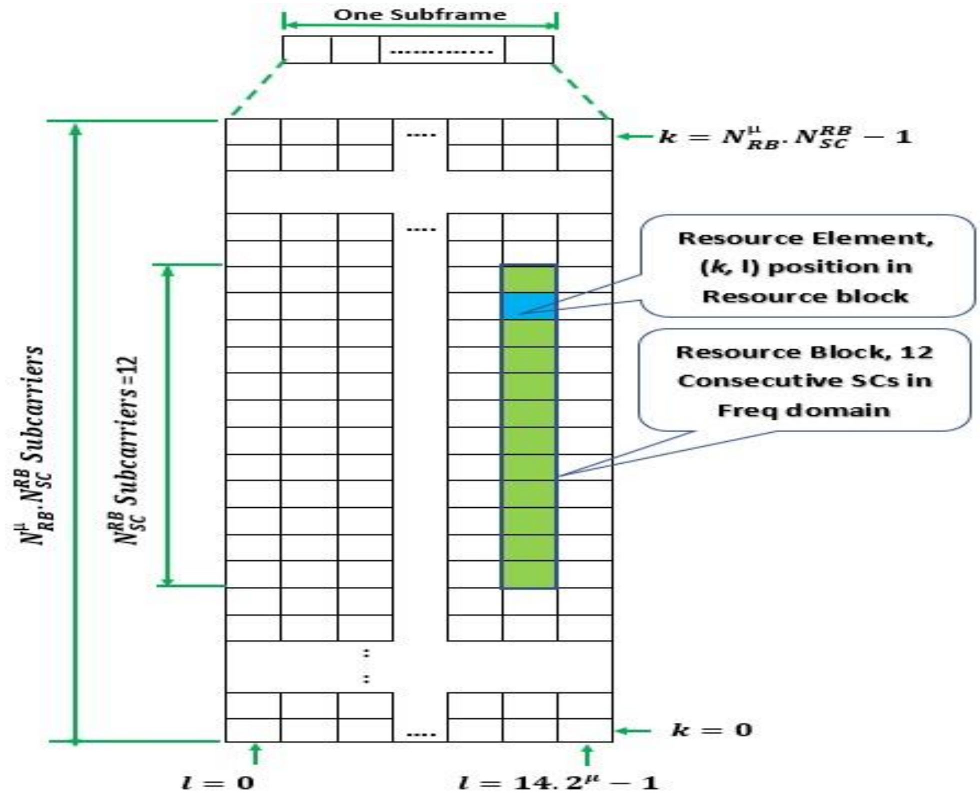

Figure 2. 8 5G NR resource block mapping(Lien et al., 2017)

2.2.9 5G NR Network Layers

The main focus of 5G technology is consumer versatility. Mobile terminals have simultaneous access to many wireless technologies and can aggregate some features from other networks, allowing them to choose the strongest wireless network.

Table 2. 4 5G NR Network Layer

OSI Network Model	5G Technology Model
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	Open Wireless Architecture
Physical Layer	

Application Layer: 5G enables intelligent behavior by selecting the optimum wireless connectivity from a variety of networks. This layer provides access to quality testing and information storage for terminals.

Open Transport Layer: It incorporates both transport and session layer functions. The OTP Layer is important since it works with high installed speeds and download speeds. Mobiles can download an updated version from the base station that is targeted at specific wireless technologies.

Open Wireless Architecture: The main function of OWA is to send data across a medium, to provide mechanical and electrical standards, to group items into frames, and to provide a hop-by-hop delivery service.

CHAPTER THREE

3. MATERIALS AND METHODS

Radio Network Planning is the process of assigning frequencies, transmitter locations and parameters of a wireless communications system to provide sufficient coverage and capacity. It remains an essential process for network operators. The cell planning consists of three phases: pre planning (dimensioning) detailed planning (coverage and capacity planning) and post planning (optimization). This thesis focuses on detailed planning.

3.1 Cell Coverage Area

Consider a base station inside a circular cell of radius R. The cell coverage area in a cellular system is defined as the predicted percentage of locations within a cell where the received power at these locations is over a predefined minimum. Cellular networks divide their coverage area into cells, each with its own antenna for sending signals. The frequencies of each cell are unique. The base station transmitter, receiver, and control unit serve data communication in cellular networks.

3.1.1 Geometry of Cells

When modeling a cellular communication system, the geometry of the cells is a crucial issue to consider. In real life, topographical elements and man-made buildings influence the irregular and complex shapes of cells. However, for the sake of conceptual and computational simplicity, we frequently adopt approximate approaches for their design and simulation. Area without overlap, geometric shape, and cell area are the three criteria for cell shape. Hexagons and circles are the most popular shapes for cells.

3.1.2 Circular Coverage Area under Path loss and Shadowing

If you use a circle to cover it, all of the sections will be covered, but the circles will overlap at the edges, causing interference. Shadowing causes some areas inside the cell to have received power that is lower or higher than the constant received power. As a result, the base station must transmit more power to ensure that users who are affected by shadowing, which leads to excessive interference in neighboring cells.

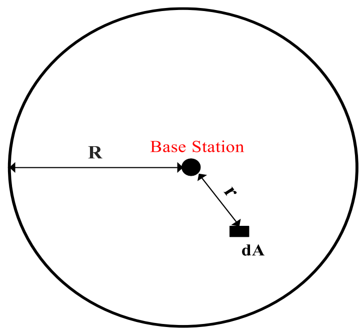

Figure3. 1 Circular cell

$$C = \frac{1}{\pi R^2} \int P_A dA \tag{3.1}$$

$$C = \frac{1}{\pi R^2} \int_0^{2\pi} \int_0^{R} P_A r dr d\theta \tag{3.2}$$

$$P_A = P\left(P_r(r) \geq P_{\min}\right) = Q\left(\frac{P_{\min} - (P_t + 10\log K - 10\gamma \log(\frac{r}{d_0})}{\sigma_{dB}}\right) \tag{3.3}$$

Where: $P_A = 1 - P_{out}(P_{\min}, r)$ $K = \left(\frac{\lambda}{4\pi}\right)^2$

The total area of circular cell is πR^2.

P_{out} is the outage probability of the cell. The outage probability of the cell is defined as the percentage of area within the cell that does not meet its minimum requirement P_{min}, given the log-normal distribution.

Let $a = \dfrac{P\min - \Pr(R)}{\sigma_{dB}}$ and $b = \dfrac{10\gamma \log_{10}(e)}{\sigma_{dB}}$

The received power at cell boundary is due to path loss alone is calculated as:

$$\mathrm{P}_R = P_t + 10\log_{10} K - 10\gamma \log_{10}(R/d_0) \tag{3.4}$$

$$C = \frac{2}{R^2}\int_0^R rQ\left(a + b\ln\frac{r}{R}\right)dr \tag{3.5}$$

Larger frequencies have higher path-loss exponents, whereas higher antenna heights have lower path-loss exponents. The attenuation produced by flooring, objects, and barriers could explain the wide range of empirical path-loss exponents for indoor propagation. Values of path loss exponent for various environments are summarized in table 3.1.

Table3. 1 Path loss exponent ranges for different environment

Environment	Path loss exponent range(γ)
Urban macro cells	3.7-6.5
Urban micro cells	2.7-3.5
Office building (same floor)	1.6-3.5
Office building (multiple floor)	2-6
Store	1.8-2.2
Factory	1.6-3.3
Home	3

3.1.3 Hexagonal Coverage Area

Hexagons are commonly used to represent cell shapes in macro cellular networks with base stations on the roofs of buildings. A hexagonal cell is widely suggested because of its ease of coverage and calculations. Some the advantages of hexagonal cell are:

- The length of a side is equal to the distance between its center and its vertex.
- Deployed equally spaced antennas.

- ❖ Without overlapping, cells can be positioned adjacent to each other.
- ❖ There are no gaps in the coverage of the entire geographical region.

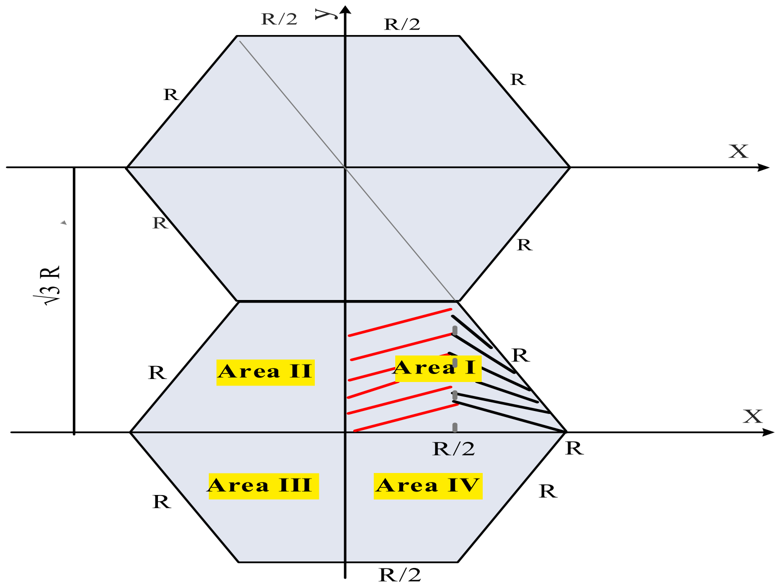

Figure3. 2 Hexagonal cell

The area of shaded region (Area I) is the sum of area of rectangular and triangle.

$$Area(I) = \int_{x=0}^{R/2} \int_{y=o}^{\frac{\sqrt{3}}{2}R} dxdy + \int_{R/2}^{R} \left(\sqrt{3}R - \sqrt{3}x\right)dx \tag{3.6}$$

$$= \frac{\sqrt{3}R}{2} \times \frac{R}{2} + \sqrt{3}R\left(R - \frac{R}{2}\right) - \sqrt{3}\left(\frac{R^2}{2} - \frac{R^2}{8}\right) \tag{3.7}$$

$$Area(I) = \frac{\sqrt{3}}{4}R^2 + \frac{\sqrt{3}}{8}R^2 = \frac{3\sqrt{3}}{8}R^2 \tag{3.8}$$

The total area of hexagonal cell is calculated as

$$\text{Total area}_{Hexagon} = AreaI + AreaII + AreaIII + AreaIV \tag{3.9}$$

$$\text{Total area}_{Hexagon} = 4 \times \frac{3\sqrt{3}R^2}{8} = \frac{3\sqrt{3}R^2}{2} \tag{3.10}$$

$$Coverage\ \text{area (Hexagon)} = \frac{4 \times \int_x \int_y P_A \times Area(I)}{Total\ \text{Area Hexagon}} \tag{3.11}$$

3.2 Site Survey

Adama is a city in Ethiopia's central Oromia Region. Adama is part of Oromia's Special Zone and is surrounded by the East Shewa Zone. It is 99 kilometers southeast of Addis Ababa, at 8.54°N 39.27°E at an elevation of 1712 meters. The city is located between the Great Rift Valley to the east and the base of an escarpment to the west. The city of Adama is divided into 18 kebeles, and the Central Statistical Agency (CSA) conducts a census every five years. In this thesis the data from ethio telecom and the CSA are used to define the demographics of Adama city. This thesis covers the total area of 55 km^2 of adama city. The CSA data and existing Ethio telecom network customers were used to establish the demographics of Adama city. The CSA conducted censuses in 2011/2012 and 2016/2017, and the results, as well as the population growth rate and current mobile network users, are all presented in table 3.2.

Table3. 2 Adama city CSA and subscriber data

Demographics of Adama city	symbol	Unit	Formula
2011/2012 population	A	180,710	
2016/2017 population	B	290,468	
Population growth rate	C	0.09	$C = \sqrt[5]{\frac{B}{A}}$ -1
2021/2022 population	D	427,794	$D=A(1+C)^n$ n=10
2021/2022 current subscriber	E	247,810	
Expected population of 2026/2027	F	658,214	$F=D(1+C)^P$ P=5
Expected market penetration (by 5 year of operation)	G	10%	
2026/2027 Forecasted subscriber	H	396496	$H=E(1+G)^K$ K=5
Area to be covered (Adama city)	I	$55km^2$	

3.3 Coverage Planning

Coverage analysis gives an estimation of the resources needed to provide service in the deployment area with the given system parameters i.e., it estimates the number of gNodeB required to cover the specified area with good signal strength. Figure 3.3 shows the coverage planning flow chart.

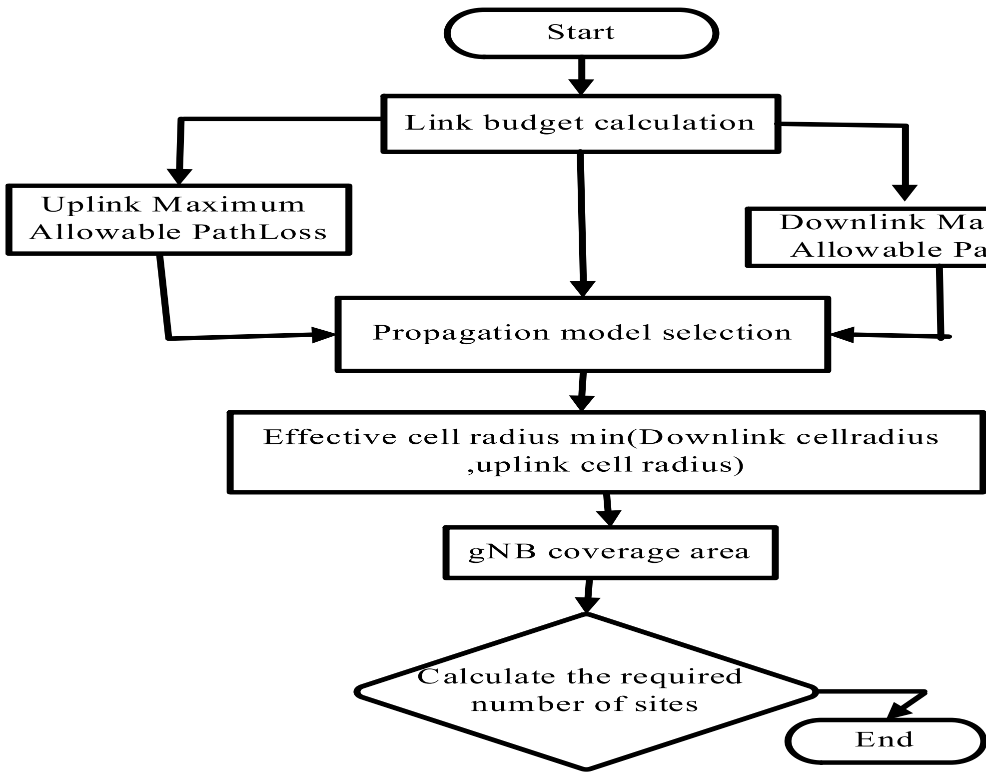

Figure3. 3 Coverage planning flow chart

3.3.1 5G Radio Link Budget

Cell planning best practices begin with selecting a suitable receive level at the UE. The cell edge will be determined using receiving level in conjunction with coverage prediction techniques. A link budget outlines the gains and losses in the mobile communications channel and serves as the foundation for what service level the network is designed for. With this information, a final received power level that matches to the intended service level can be computed..(Curry, 2020; Patra, 2020). The purpose of link budget computation is to determine the maximum value of Allowable Path Loss (MAPL), or the weakening signal received between the mobile antenna and the mobile station antenna on the downlink and uplink sides, respectively.

3.3.2 Parameters of Link Budget Calculation

gNB Maximum Total Transmitter Power: This is one of the main factors that impact the link budget. Refers to the transmit power value per transmitting (TX) path.

UE maximum Transmitter Power: This refers to the UE's transmit power, which is determined by the UE's power class.

gNB Antenna gain: The clutter type and coverage requirement influence antenna gains and beam width selection. To extend RF coverage, a low gain antenna (15–17dBi) can be used in dense cities and urban clutters, whereas a high gain antenna (18–20dBi) can be used in rural areas and roads.

Body Loss: It is a loss generated due to signal blocking and absorption, when UE antenna is close to the body of the user.

Penetration Loss: The penetration loss indicates the fading of radio signals due to building obstruction from an indoor terminal to the gNB and vice versa. It depends on the nature of the buildings and the clutter type of the targeted coverage area.

Effective Isotropic Radiated Power (EIRP): is defined as a power that would have to be radiated by a hypothetical isotropic antenna to achieve identical level in the direction of maximum radiation of a specific antenna.

$$EIRP_{dBm} = P_{TX\,(dBm)} + G_{TX\,(dB)} - \sum \text{Total transmitter losses}(dB) \tag{3.12}$$

Where:

P_{TX}: Transmit Power

G_{TX}: Transmit Gain

Total transmitter loss includes transmission cable and connector losses.

Thermal Noise: Thermal noise is the loss due to heat.

$$N = KBT \tag{3.13}$$

Where:

K is Boltzmann constant $\left(1.38\times10^{-23}\,\frac{J}{{}^{0}K}\right)$

T is absolute temperature at value of 290^{0}K

B is channel bandwidth which is 100 MHZ

Noise Figure: When signals flow through a receiver, noise is added to the signal, and the noise figure is a technique of determining how much noise is added. The amount of noise is determined by the bandwidth and gNodeB abilities. The noise figure has a value of 6 to 8 dB.

SINR: SINR values are derived from the results of system-level simulations and are dependent on the receiver design. SINR is thus a vendor-specific parameter.

Receiver Sensitivity: The signal level (threshold) at which an RF signal can be received with a given level of quality is determined by receiver sensitivity.

$$\mathrm{RS}_{(dBm)} = \mathrm{SINR}_{(dB)} + \text{Noise figure}_{(dB)} + \text{Thermal Noise power}_{(dBm)} + 10\log(\text{subcarrier frequency})_{dB} \quad (3.14)$$

Interference Margin: The term "interference margin" refers to the rise in terminal noise produced by interference from other users, as well as the loss in system receives performance caused by internal system interference caused by system traffic.

Minimum Signal Reception Strength (MSRS): It is used to compute the receiver side losses and margins, such as body loss, cable loss, and marginal gain.

$$MSRS_{(dBm)} = RS_{(dBm)} + IM_{(dB)} + LR_{(dB)} + R_{AG(dB)} \quad (3.15)$$

Where:

RS is receiver sensitivity

IM is interference marginal

LR is body loss+ Cable loss

R_{AG} is receiver antenna gain

Feeder loss: Feeder loss is the signal loss generated by various equipment on the antenna's path to the receiver.

Shadow fading (Slow fading): The fading caused by an interruption such as a building or a natural feature is referred to as shadow fading**.** The fading produced by location, which is primarily due to blockage, significantly surpasses the fading caused by time. As a result, location changes are the most common source of shadow fading**.**

Shadow Fading Margin: Shadow fading margin is the allowances made to reduce the effect of shadow fading while also ensuring a certain probability of edge coverage. To achieve the stated coverage probability, a sufficient power margin must be reserved for BS or MS receivers during network planning to reduce the attenuation effect. The shadow fading standard deviation in urban environments is around 8 to 10 dB. The value range is 6 to 8 dB in suburban and rural locations.

Penetration loss: The penetration loss represents the fading of radio signals from an inside terminal to the gNodeB and vice versa caused by building obstacles. It relies on the type of clutter in the targeted coverage area and the nature of the buildings.

Table3. 3 Penetration loss based on clutter type

Clutter type	Penetration loss(dB)	Typical value
Dense Urban	19-25	19
Urban	15-18	15
Sub urban	10-14	11
Rural	5-8	8

Maximum Allowable Path Loss (MAPL): It enables the maximum cell range to be valued using appropriate propagation models that provide the required number of base station sites to cover the target environment.

$$\mathrm{MAPL}_{(dB)} = \mathrm{EIRP}_{(dBm)} - \mathrm{MSRS}_{(dBm)} - Penetration\ loss_{(dB)} - Shadow\ fading\ margin_{(dB)} \qquad (3.16)$$

3.3.3 Propagation model selection

Path loss models play an important part in wireless cellular system planning. They are a series of mathematical equations and techniques used to predict the propagation of radio signals in specific locations. For wireless network design during preliminary deployment, propagation path loss models are employed to calculate electromagnetic field strength. In this thesis Urban Macro Propagation model (UMa) in ATOLL Software is used for modelling the propagation. Uma gives better coverage and speed for urban cities.

3.3.4 Coverage Based Site Counts

The cell radius is computed using the link budget calculation and propagation model results. The number of sites and their coverage zones are computed depending on site configuration after the cell radius has been determined. The lowest of the radiuses identified in the UL and DL path will be the effective radius. The coverage area of the cells is determined by the layout of the site. It might be omnidirectional, two-sector, or three-sector in nature.

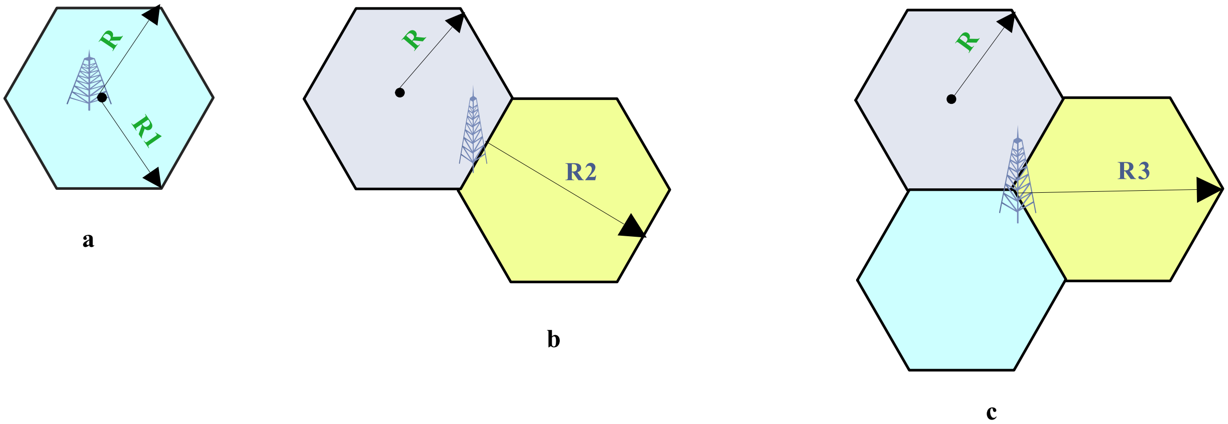

Figure3. 4 Types of site configurations: a) Omnidirectional b)2 sector c)3sector

All gNodeBs are assumed to be three-sector cells for this thesis work. The lowest of the radius identified in the UL and DL path will be the effective radius. The site area of omni -directional, 2 sector and 3-sector site configuration and number of sites are calculated as:

$$Area_{cell}(km^2) = \frac{3}{2} * \sqrt{3} * \left(R_1\right)^2 \text{.......for omni-directional} \qquad R_1 = R \tag{3.17}$$

$$Area_{cell}(km^2) = \sqrt{3}\left(R_2\right)^2 \text{.........2-sector} \qquad R_2 = \sqrt{3}R \tag{3.18}$$

$$Area_{cell}(km^2) = \frac{9}{8} * \sqrt{3} * \left(R_3\right)^2 \text{...........3 sector cells} \qquad R_3 = 2R \tag{3.19}$$

For this thesis 3 sector site configuration is chosen:

$$\text{Number of sites} = \frac{\text{Area to be covered}}{\text{Area of cell}} \tag{3.20}$$

3.4 Propagation Model Comparison

LOS: when the transmitter and receiver antennas are pointed at each other, aligned on bore sight, with no obstructions between them.

NLOS: when the transmitter and receiver antennas are separated by obstructions and there is no clear optical path between the antennas. This scenario also includes the case where the transmitter receiver antennas have a clear line of sight path to one another, but the antennas are not aligned on boresight.

Information is exchanged between transmit and receive antennas in a wireless cellular communications system utilizing electromagnetic waves. The signal intensity of electromagnetic waves degrades as they travel through the environment. Path Loss is the difference in signal strength between the transmitter and reception antennas. Common wireless propagation model parameters include:

- Carrier frequency, bandwidth, antenna heights.
- 2-D or 3-D distance between transmitter (TX) and receiver (RX).
- Terrain profile like urban, suburban and rural.

Free space path loss: Free space path loss is the reduction in signal strength of an electromagnetic wave caused by line-of-sight travel across free space with no impediments to induce reflection or diffraction. Path loss in free space indicates how much signal intensity is degraded during transmission from transmitter to receiver in the absence of any obstruction in free space.

$$PL(dB) = 32.45 + 20\ log10(d) + 20\ log10(f) \tag{3.21}$$

Where:

d: the distance between transmitter and receiver(km)

f: signal frequency(MHz)

Okumura HATA model: The Okumura Hata model is a propagation model that can be used to forecast median radio signal attenuation in a macro cell environment. This model is used to plan macro cell coverage when the antenna height of the base station is typically higher than the surrounding obstacles. Diffraction and scattering over rooftops near the mobile station are the main propagation losses for this model.

Cost HATA model: The Cost 231 Hata model predicts path loss in the frequency range of 1500 MHz to 2000 MHz, and path loss is calculated in three different environments: urban, suburban, and rural (flat). This model makes calculating the path loss simple and straightforward. This COST 231 Hata Model's basic path loss equation is as follows.

$$PL(dB) = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - a(h_r) + \left(44.9 - 6.55\log_{10}(h_b)\right)\log_{10}(d) + c \qquad (3.22)$$

Here, f is the frequency in MHz, d is the distance between the transmitter and receiver, and h_b and h_r are the base station and receiver height correction factors, respectively. For suburban and rural surroundings, the parameter c is 0, while for urban areas, it is 3. The urban, suburban and rural area function $a(h_r)$is defined as follows:

$$a(h_r) = 3.2\left(\log_{10}(11.75h_r)\right)^2 - 4.79 \qquad \text{For urban areas} \qquad (3.23a)$$

$$a(h_r) = \left(1.1\log(f)\right) - 0.7h_r - \left(1.58f - 0.8\right) \qquad \text{For suburban and rural areas} \qquad (3.24b)$$

Standard Propagation model: The standard propagation model is derived from the Hata formula and is well suited to GSM900/1800, UMTS, CDMA2000, WiMAX, and LTE technologies. It is particularly good for prediction in the 150MHz-3500MHz band across long distances (1 to 20Km). In order to determine path loss, this model uses the terrain profile, diffraction processes, clutter classifications, and effective antenna heights.

$$PL = C_1 + C_2\log(d) + C_3\log\left(H_{Teff}\right) + C_4\text{Diffraction loss} + C_5\log(d)\log\left(H_{Teff}\right) + C_6 H_{Reff} + C_{Clutter} f(clutter) \qquad (3.25)$$

Where:

C_1 is constant offset (dB)

C_2 is distance attenuation constant

d is distance between transmitter and receiver(km)

C_3 and C_4 are correction coefficient of height of mobile station antenna

H_{Teff} is effective height of transmitter antenna (m)

C_5 is multiplying factor of log(d)log(H_{Teff})

C_6 is multiplying factor of H_{Reff}

H_{Reff} is effective height of receiver antenna (m)

$C_{clutter}$ is multiplying factor of f (clutter)

f(clutter) is average of weighted losses due to clutter

3D propagation model

The 3D propagation model defined in 3GPP 36.873 is used by 5G New Radio. In 3GPP 38.901, the Urban Macrocell (UMa), Urban Microcell (UMi), Indoor Hotspot (InH), and Rural Macrocell (RMa) models are applied to frequency ranges of 2 to 6 GHz and later expanded to 0.5 to 100 GHz.(Suryanegara & Rohman, 2021).

Propagation model for urban micro cell

$$PL_{LOS} = 40\log_{10}(d_{3D}) + 28 + 20\log_{10}(f_c) - 9\log_{10}\left((d'BP)^2 + \left(h_{BS} - h_{UT}\right)^2\right) \tag{3.26}$$

$$h'_{UT} = h_{UT} - hE \tag{3.26a}$$

Where:

fc is the center frequency in Hz

c: propagation velocity in free space

h_{BS}: height of base station

h_{UT}: height of user terminal

d_{3D}: resultant of the distance between h_{BS} and h_{UT} (m)

d_{BP}: breakpoint distance (m)

d: distance between BS and user terminal(m)

hE: Environmental height

Propagation Model for InH office

Indoor propagation is required in places where outdoor propagation is ineffective, such as houses, buildings, and sports arenas. When different materials are employed in various types of structures, the signal does not propagate with the same strength. The path loss of Indoor hotspot office for LOS and NLOS is calculated as:

$$PL_{LOS} = 32.4 + 17.3\log_{10}(d_{3D}) + 20\log_{10}(f_c) \tag{3.27}$$

$$PL_{NLOS} = 38.3\log_{10}\left(d_{3D}\right) + 17.3 + 24.9\log_{10}\left(f_c\right) \tag{3.28}$$

Where:

fc is the center frequency in Hz

d_{3D}: resultant of the distance between h_{BS} and h_{UT} (m)

Rural Macro Propagation Model

RMa path loss models are commonly employed for tall transmitter heights greater than 35 meters. They are useful for estimating the numerical behavior of received signal intensity and interference in rural areas. When there is a clean, unobstructed path between the transmitter and receiver, the existing 3GPP/ITU-R RMa LOS path loss model is employed to offer statistical modeling of path loss over distance (RX). The 3GPP RMa LOS path loss model is divided into two portions separated by a breakpoint distance, beyond which the slope attenuation rises.(MacCartney & Rappaport, 2017).

$$PL_1 = 20\log_{10}\left(\left(40\pi \times d_3D\right)\times\frac{f_c}{3}\right)+\min\left(0.03h^{1.72},10\right)\log_{10}(d_3D)-\min\left(0.044h^{1.72},14.77\right)+0.002\log_{10}\left(h\right)d_3D \quad (3.29)$$

$$PL_2\left[dB\right] = PL_1\left(d_{Bp}\right)+40\log_{10}\left(\frac{d_3D}{d_{Bp}}\right) \quad (3.30)$$

Where:

d_{Bp}: Breakpoint distance

d_{3D}: resultant of the distance between h_{BS} and h_{UT} (m)

Urban Macro Propagation Model

In most channel models, two sets of channel parameters are used. These include large-scale factors like shadow fading and path loss, as well as small-scale parameters like Angle of Arrival (AoA) and Angle of Departure (AoD), or ray delay. The majority of the signal reaches subscribers through diffraction in an urban macro-cell environment, and the primary propagation path is above buildings. Uma gives better coverage and speed for urban cities.

$$PL = 28+40\log_{10} d+20\log fc-9\log_{10}\left((d_{Bp})^2+(h_{BS}{'}-h'_{UT})^2\right) \quad (3.31)$$

$$h'_{BS} = h_{BS} - hE$$

$$h'_{UT} = h_{UT} - hE$$

Where:

d: distance between h_{BS} and h_{UT}

d'_{Bp}: break point distance

fc: frequency (GHz)

h_{BS}: height from gNB

h_{UT}: height from user terminal

hE: Environmental height

3.5 Capacity Based Planning

The capacity analysis should yield data on subscriber numbers as well as forecasted capacity or traffic demand. Figure 3.5 shows the flow chart of capacity planning

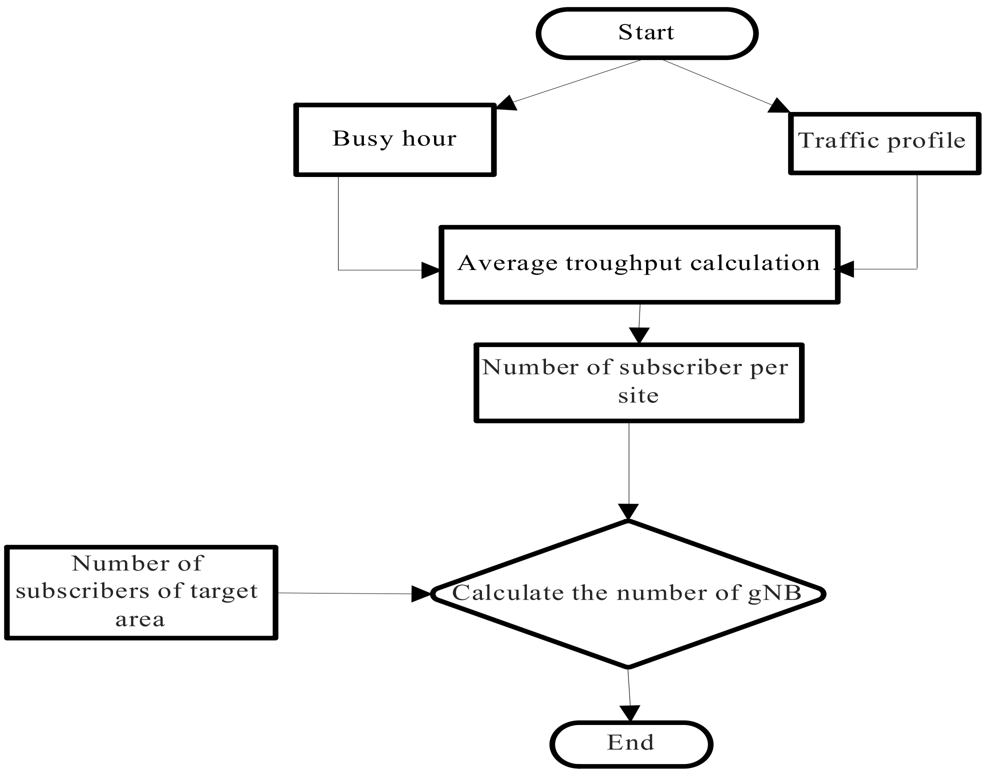

Figure3. 5 Capacity planning flow chart

Traffic Model: The major goal of a traffic model is to represent average subscriber behavior at the busiest time of day (the "busy hour"). The capacity of a site should be based on the busy hour because traffic is not evenly dispersed throughout the day.

Data volume per month: The data service is measured in terms of data volume per subscriber per month. Capacity planning can be done in real time by estimating daily traffic during peak hours as a percentage**.**

Step1: Total average throughput per subscriber

To estimate the average throughput per site, the total average throughput per subscriber must be estimated**.**

$$\Psi = \frac{\mathrm{M} \times {}^{8bit}\!/_{byte} \times \mathrm{H}}{30days \times \text{time in second}} \tag{3.32}$$

Where:

Ψ : Average throughput per subcarrier at busy hour per month (UL+DL)

M : Monthly service packet

H : Busy Hour ratio

There are 3 different types of service packages available: golden service, silver service, and bronze service. The monthly service package, the DL and UL peak data rates, and the package % are all unique to each service. The data volume per month per user, service usage, and traffic ratio is illustrated in table 3.3.

Table3. 4 User category

Types of customers	Volume of data per month per user (GB)	Service Usage (%)	Traffic ratio (%)	
			UL	DL
Gold	20	65	20	80
Silver	15	35	20	80
Bronze	10	10	20	80

The busy hour is supposed to be in three separate time segments throughout the 24 hours of a day in this thesis. The first session takes place between 8:00 AM to 11:00 AM in the morning, the second between 2:00 PM to 4:00PM in the afternoon, and the third between 7:00 PM to 9:00 PM in the evening. Thus, within the 24 hours of a day, a total of 7 hours is considered busy hours, making busy hour traffic 29.2 percent of daily traffic.

Step 2: Total average throughput:

Following the operator's manipulation of the average throughput per subscriber for each service type defined, the total average throughput per subscriber at busy hour for uplink and down link is calculated as:

$$\mathrm{T}_{UL} = \left[\Sigma\left(\Psi \times \text{Service usage ratio}\right)\right] \times v_{UL} \tag{3.33}$$

Where:

T_{UL} : Total average throughput per subscriber at busy hour

Ψ : Average throughput per subcarrier at busy hour per month

v_{UL} : Uplink traffic ratio

$$T_{DL} = \left[\sum\left(\Psi \times \text{Service usage ratio}\right)\right] \times v_{DL} \tag{3.34}$$

Where:

T_{DL} : Average throughput per subscriber at busy hour for down link

Ψ : Average throughput per subcarrier at busy hour per month

v_{DL} : Down link traffic ratio

Step 3: Peak throughput per site

$$\text{Data rate in subframe(bit)=OFDM symbol per subframe} \times \text{bit per QAM} \tag{3.35}$$

For this thesis we use 256 QAM modulation, the number of bits per QAM is 8bit.

$$\text{Data rate per subcarrier(kbps)} = \frac{\text{Data rate in subframe}}{m_{\sec}} \tag{3.36}$$

$$\text{Data rate per resource block=Data rate per subcarrier} \times S\text{ubcarrier per resource block} \tag{3.37}$$

$$\text{Peak throughput per site =resource block} \times \text{Data rate per resource block} \tag{3.38}$$

Step 4: Calculate site number

$$\text{Site number} = \frac{\text{Total subscriber suppoted in the area}}{\text{Maximum number of subscribers per site}} \tag{3.39}$$

3.6 Simulation

The ability to build wireless access networks is aided by radio network planning tools. It's used to forecast radio coverage, handle subscriber data for mobile and fixed subscribers, and assess network capacity. Based on the numerical findings obtained from coverage and capacity estimation the simulation results of 5G NR coverage and capacity planning using radio network planning tools is analyzed in this section. Figure 3.6 depicts the radio planning tool's simulation workflow for designing and evaluating a 5G NR network in this study. ATOLL 3.4 version was the planning tool used in this investigation.

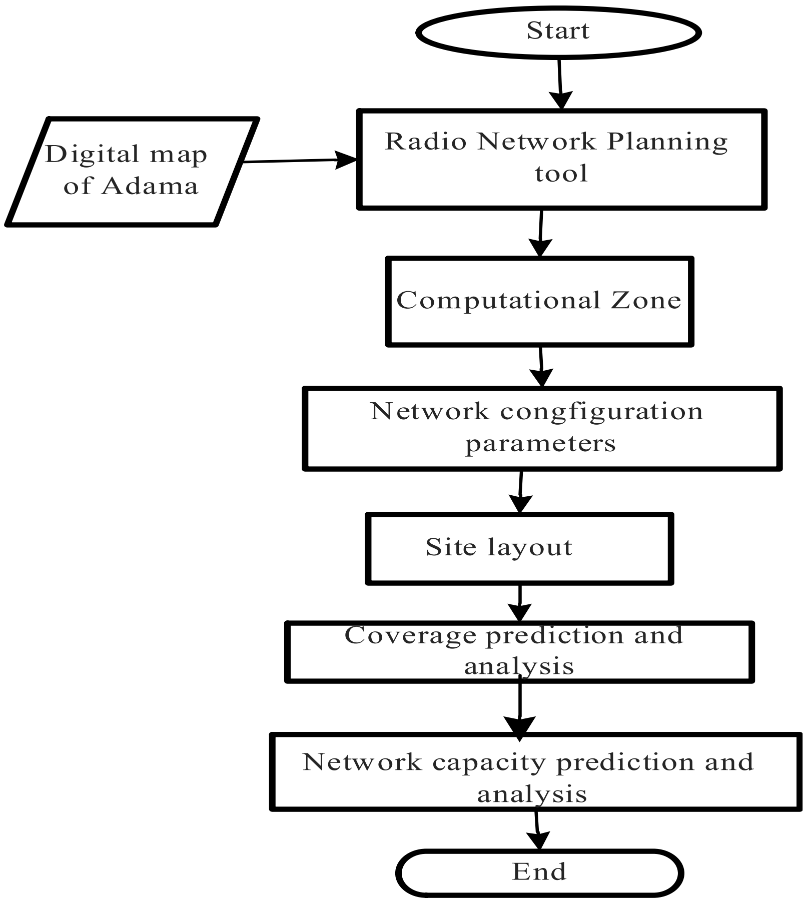

Figure3. 6 5G NR network simulation flow chart

3.6.1 Digital map of Adama city

A digital map is an electronic database that contains geographic data like as land use (clutter information), height data, and vector data (streets, main roads, secondary roads, highways, and railways). Figure 3.7 shows the digital map of adama city.

Figure3. 7 Digital map of Adama city

3.6.2 Network configuration parameters:

To simulate the desired radio network planning of the target location, ATOLL simulation software needs input parameters. They're utilized to set network parameters like the site, the transmitter, and the cells.

Table3. 5 Network configuration input parameters

Network parameters	**Uplink**	**Downlink**
Frequency (MHz)	3500 (TDD**)**	
Transmit power(dBm)	23	43
Antenna height(m)	36.5	
Propagation model	Urban macro propagation model	
Antenna configuration	65deg18dBi 3500MHz	
Traffic Load	20	80
Modulation QAM	256 QAM	

3.6.3 Site Layout

In the ATOLL a total of 76 gNodeB's are constructed depending on the nominal planning phase. The coordinate of the site given, the longitude, and latitude is listed in table3.6.

Table3. 6 Site placement

Site name	Longitude	Latitude
Site0	39°16'28.49"E	8°32'32.6"N
Site1	39°17'6.4"E	8°33'45.07"N
Site2	39°15'12.24"E	8°31'28.2"N
Site3	39°16'6.31"E	8°33'38.56"N
Site4	39°15'51.7"E	8°32'51.29"N
Site5	39°16'41.52"E	8°31'25.93"N
Site6	39°15'23.04"E	8°32'31.06"N
Site7	9°16'26.65"E	8°32'31.06"N
Site8	39°17'16.55"E	8°30'3.91"N
Site9	39°17'42.65"E	8°34'9.26"N
Site10	39°16'15.67"E	8°34'31.8"N
Site11	39°16'2.34"E	8°31'13.23"N
Site12	39°17'8.63"E	8°34'45.55"N
Site13	39°15'55.01"E	8°31'39.07"N
Site14	39°17'14.1"E	8°34'6.17"N
Site15	39°16'11.24"E	8°33'8.68"N
Site16	39°15'45.07"E	8°33'46.44"N
Site17	39°15'37.71"E	8°30'18.61"N
Site18	39°17'50.06"E	8°31'3.68"N
Site19	39°16'35.18"E	8°32'6.76"N
Site20	39°17'59.99"E	8°32'10.61"N
Site21	39°14'3.05"E	8°31'15.02"N
Site22	39°16'20.78"E	8°32'16.26"N
Site23	39°16'19.52"E	8°30'44.42"N
Site24	39°15'6.83"E	8°31'48.91"N
Site25	39°17'9.6"E	8°32'48.48"N
Site26	39°15'54.12"E	8°32'0.02"N
Site27	39°17'44.77"E	8°29'58.02"N
Site28	39°16'10.24"E	8°32'39.12"N
Site29	39°16'21.59"E	8°31'58.17"N
Site30	39°17'1.14"E	8°32'9.13"N
Site31	39°17'9.85"E	8°32'29.98"N
Site32	39°14'58.96"E	8°32'29.29"N
Site33	39°16'34.32"E	8°32'46.46"N

Site34	39°15'16.16"E	8°32'19.03"N
Site35	39°15'48.24"E	8°32'26.27"N
Site36	39°16'52.56"E	8°32'42.27"N
Site37	39°14'40.52"E	8°30'45.68"N
Site38	39°15'49.25"E	8°30'54.32"N
Site39	39°16'46.27"E	8°31'12.54"N
Site40	39°16'56.13"E	8°31'45.16"N
Site41	39°16'16.74"E	8°31'41.99"N
Site42	39°15'40.93"E	8°32'0.46"N
Site43	39°14'20.18"E	8°32'2.8"N
Site44	39°17'27.54"E	8°32'6.48"N
Site45	39°15'7.19"E	8°32'8.88"N
Site46	39°18'22.68"E	8°32'27.6"N
Site47	39°16'2.28"E	8°32'29.4"N
Site48	39°17'28.54"E	8°32'55.18"N
Site49	39°16'19.2"E	8°32'54.96"N
Site50	39°17'4.13"E	8°33'15.88"N
Site51	39°15'41.54"E	8°33'21.74"N
Site52	39°17'28.36"E	8°33'27.4"N
Site53	39°15'59.26"E	8°34'3.68"N
Site54	39°16'45.48"E	8°34'7.07"N
Site55	39°17'31.74"E	8°34'33.1"N
Site56	39°16'33.17"E	8°30'13.91"N
Site57	39°14'40.83"E	8°31'22.76"N
Site58	39°15'11.85"E	8°30'53.21"N
Site59	39°17'5.7"E	8°30'42.89"N
Site60	39°17'19.82"E	8°31'17.82"N
Site61	39°15'14.61"E	8°33'5.29"N
Site62	39°17'47.31"E	8°33'47"N
Site63	39°18'8.96"E	8°34'37.48"N
Site64	39°16'37.35"E	8°34'57.13"N
Site65	39°16'24.01"E	8°33'58.62"N
Site66	39°15'42.2"E	8°34'29.3"N
Site67	39°16'43.61"E	8°33'43.91"N
Site68	39°16'42.78"E	8°33'13.03"N
Site69	39°17'57.68"E	8°33'16.28"N
Site70	39°18'37.6"E	8°32'56.72"N
Site71	39°17'43.6"E	8°32'38.35"N
Site72	39°14'43.54"E	8°32'11.67"N
Site73	39°16'51.08"E	8°34'31.61"N

Site74	39°17'48.33"E	8°31'40.97"N
Site75	39°15'36.34"E	8°31'26.15"N

Figure 3.8 shows the site placement of 76 gNodeBs in the targeted deployment region using atoll software.

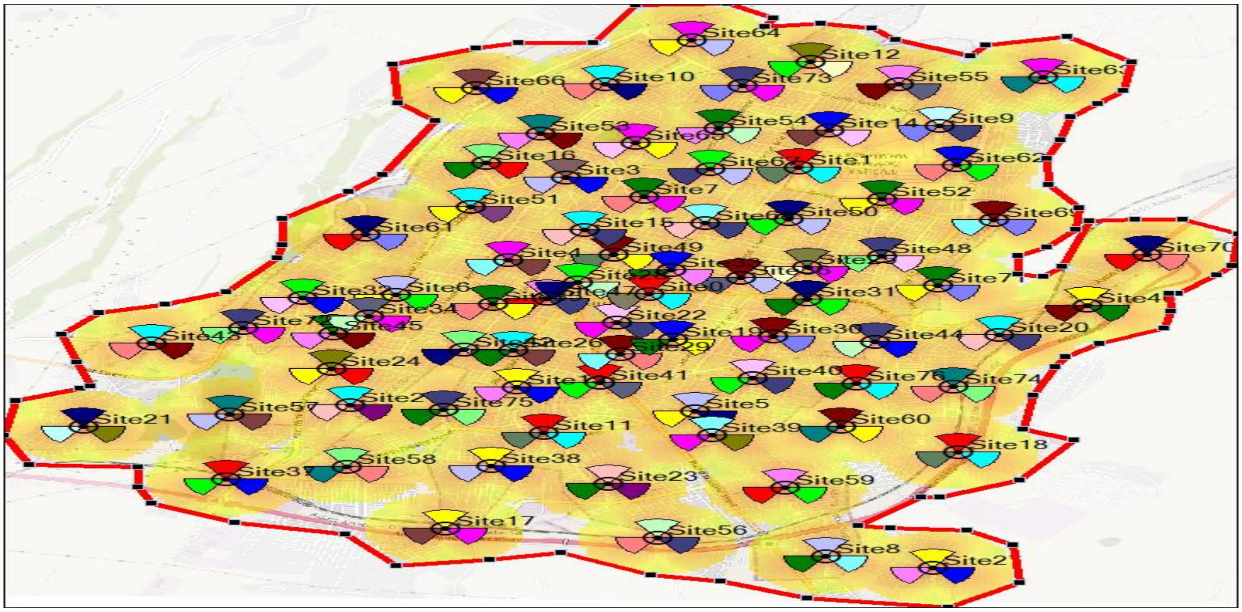

Figure3. 8 Site placement

3.6.4 Coverage Requirements

Before conducting each of these simulations, automatic frequency and cell planning were performed. The detailed simulation results were acquired, and the associated legends color-coded each of them. To validate the target network requirement, the target network prediction result will be examined.

Table3. 7 Coverage area requirements

Criteria		Target
Best signal level	Good	above -95 dBm
	Medium	-95 to -116 dBm
	Poor	below -116dBm
Overlapping zone	Area with ≥ 4 servers	≤2%
	Area with ≥ 2 servers	<35%
Coverage probability at cell edge		97%

CHAPTER FOUR

4. RESULTS and DISCUSSIONS

Coverage analysis along with link budget calculation, capacity analysis, coverage analysis under path loss and shadowing, comparison of propagation models, and simulations using an Atoll planning tool were all performed in this section.

4.1 Coverage Area Analysis

The coverage area analysis under path loss and shadowing for circular cell, hexagonal cell (at edge and vertex) and square is illustrated based on mathematical analysis.

4.1.1 Circular Coverage Area Analysis under Path loss and Shadowing

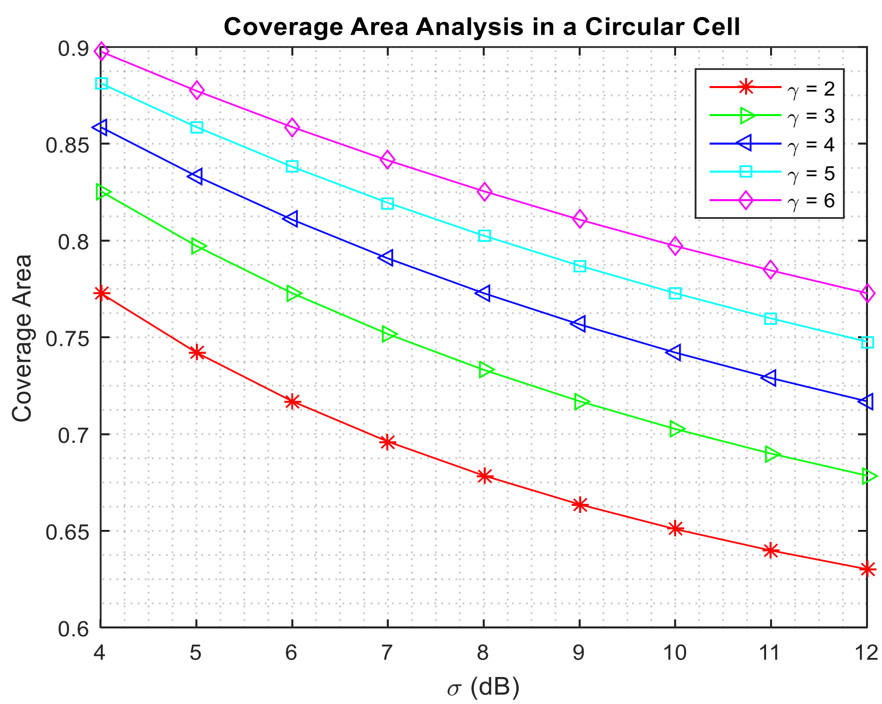

Figure 4. 1 coverage area analysis in circular cell

Result and discussion: As we observed in the above figure, shadowing affects cell coverage area. The probability of coverage area decreases as the value of the shadowing effect increases.

Coverage area of Urban macro cell environment (γ=6) is high, whereas coverage area in free space (γ=2) is low.

4.1.2 Hexagonal Cell Coverage Area Analysis Under Pathloss and Shadowing

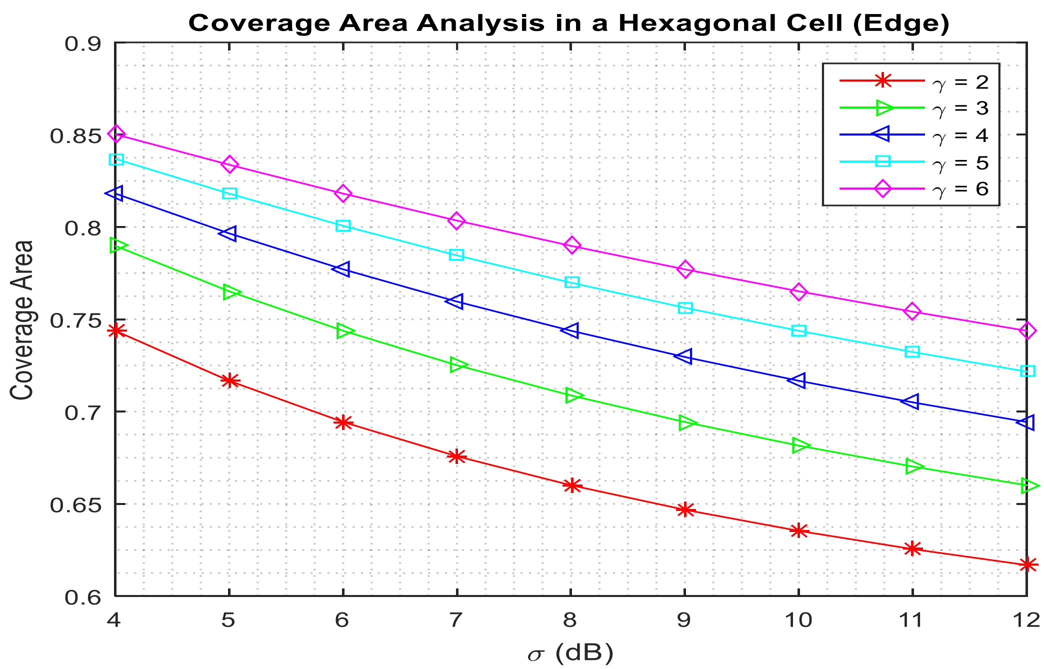

Figure 4. 2 Coverage area analysis in a hexagonal cell at edge

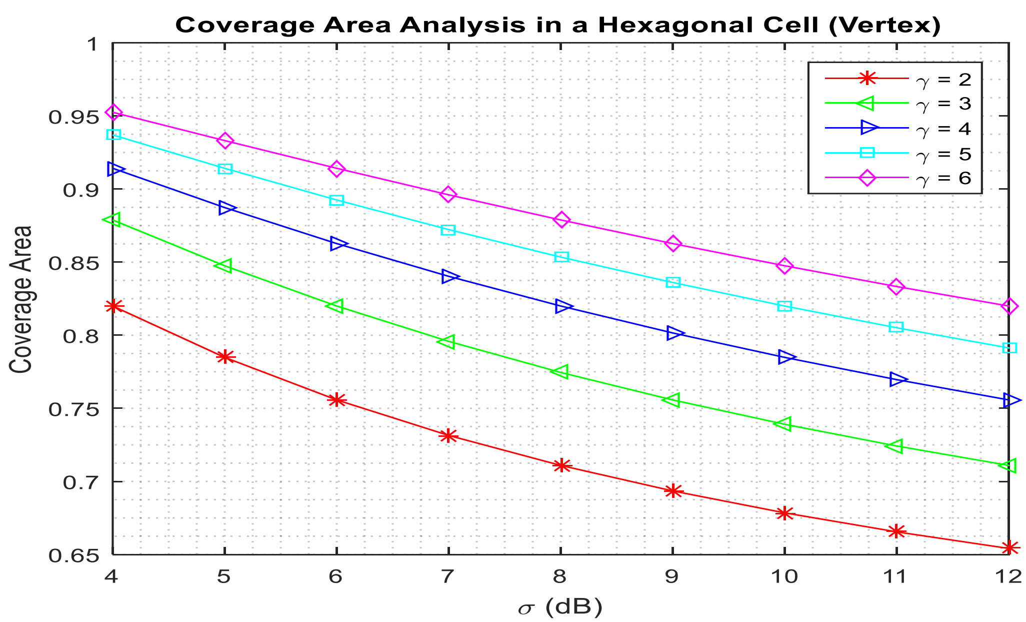

Figure 4. 3 Coverage area analysis in a hexagonal cell at vertex

Result and discussion: Similar to circular cell the probability of coverage area in hexagonal cell at cell edge and vertex decreases as the value of the shadowing effect increases. The path loss exponent for different environments (Free space, at home, Office building, Factory) has a different value. As a result, the coverage area differs. Urban macro cell environment (γ=6) is high, whereas coverage area in free space (γ=2) is low. Hexagonal cell is preferred compared to circular cell for coverage analysis.

4.2 Coverage Planning Analysis

As discussed in chapter 3, coverage planning is done using link budget computation and propagation model.

4.2.1 Radio Link Budget Analysis for Uplink and Downlink

The link budget's objective is to determine the UL and DL's maximum allowable path loss (MAPL) between the transmitter and receiver. Equations (3.12), (3.13), (3.14), (3.15), and (3.16) are used to calculate MAPL for DL and UL.

Table 4. 1 Radio Link Budget calculation for uplink and down link.

Parameters	Symbol	Formula	Uplink value	Downlink value
Transmit Power(dBm)	A		24	43
Transmit antenna Gain(dBi)	B		0	18
Transmitter Cable loss	C		0	2
EIRP(dBm)	D	D=A+B-C	24	59
Thermal Noise(dBm)	E		-193.93	-183.9
Noise Figure(dB)	F		2	7
SINR (dB)	G		-8	-10
Bandwidth per resource block(dB)	H		41.8	44.77
Rs(dBm)	I	H=E+F+G+H	-158.17	-142.2
IM (dB)	J		2	3

Body loss(dB)	K		0	5
Receiver cable loss(dB)	L		3	2
Receiver antenna gain(dBi)	M		11	0
Mast head amplifier(dB)	N		2	2.5
MSRS (dBm)	O	O=J+K+L-M+N	-162.17	-131.7
Fade margin(dB)	P		8	9.4
Penetration loss(dB)	Q		15	22
MAPL (dB)	R	R=D-O-Q-P	163.17	159.3

4.2.2 Coverage Based Site Counts

As discussed in Chapter 3, coverage planning is done using a link budget computation and propagation model. For estimating cell range, the propagation model is crucial, and there are numerous of them with varied qualities. For this thesis Urban Macro Propagation model is selected. The cell radius influenced by both the UL and DL link budgets can be calculated by using the chosen propagation model and the UL and DL MAPL.

$$d = 10 \wedge \frac{\left(MAPL - 28 - 20\log(fc)\right) + 9\log(d_{Bp})^2 + \left(h_{BS} - h_{UT}\right)^2}{40} \tag{4.1}$$

Table4. 2 Cell radius summary for uplink and downlink

Parameters	Uplink	Downlink
Frequency (MHz)	3500 MHz	
gNodeB Antenna height(m)	30	
UE antenna height(m)	1.5	
MAPL (dB)	163.17	159.3
Propagation model	Urban Macro propagation model	
Cell Radius (Km)	0.7605	0.6072
Effective cell radius (Km)	0.6072	

$$Area_{cell}(km^2) = \frac{9}{8} * \sqrt{3} * \left(R_3\right)^2 \text{.......3 sector cells} \tag{4.2}$$

$$Area_{cell}(km^2) = \frac{9}{8} * \sqrt{3} * (0.6072)^2 = 0.7198km^2 \tag{4.3}$$

$$\text{Total number of sites} = \left(\frac{\text{Target coverage area}}{Area_{cell}}\right) = \frac{55km^2}{0.7198km^2} = 76 \tag{4.4}$$

As a result, in terms of coverage dimensioning, we require 76 sites to provide 5G NR service across Adama's entire 55 km^2 region.

4.3 Path loss comparison of different propagation models

The behaviour of a signal as it travels from the transmitter to the receiver is described by a radio propagation model. In this thesis, the Rural Macro Propagation model, the Urban Macro Propagation model, and the Indoor Hotspot Propagation model are compared. The LOS and NLOS for these propagation models are also analysed.

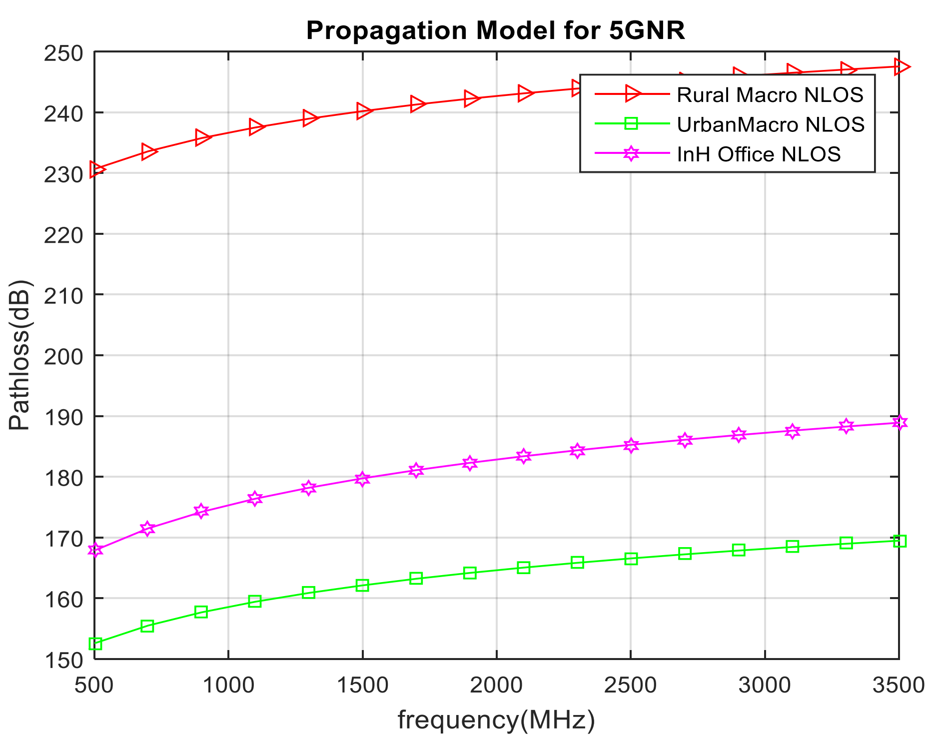

Figure 4. 4 path loss comparison under frequency

Result and Discussion: The above figure describes the overall result comparison of propagation models. Path loss of signal increases as the frequency value increase. The result indicates that the Rural macro propagation model has high path loss compared with Urban macro and In H office propagation model in NLOS communication.

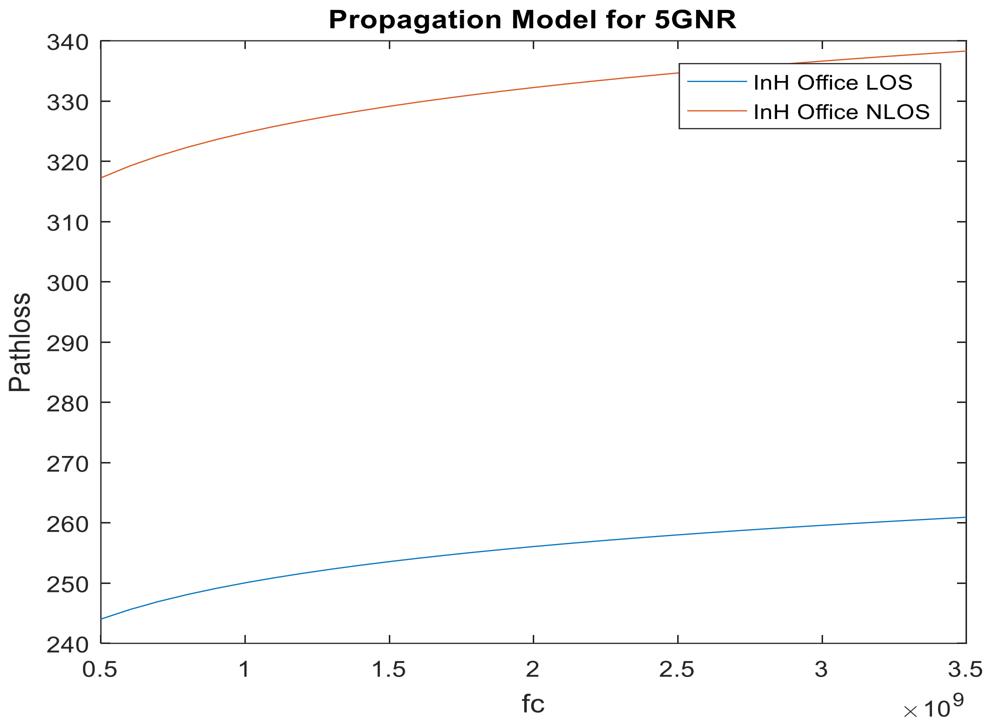

Figure 4. 5 InH office propagation model for LOS and NLOS

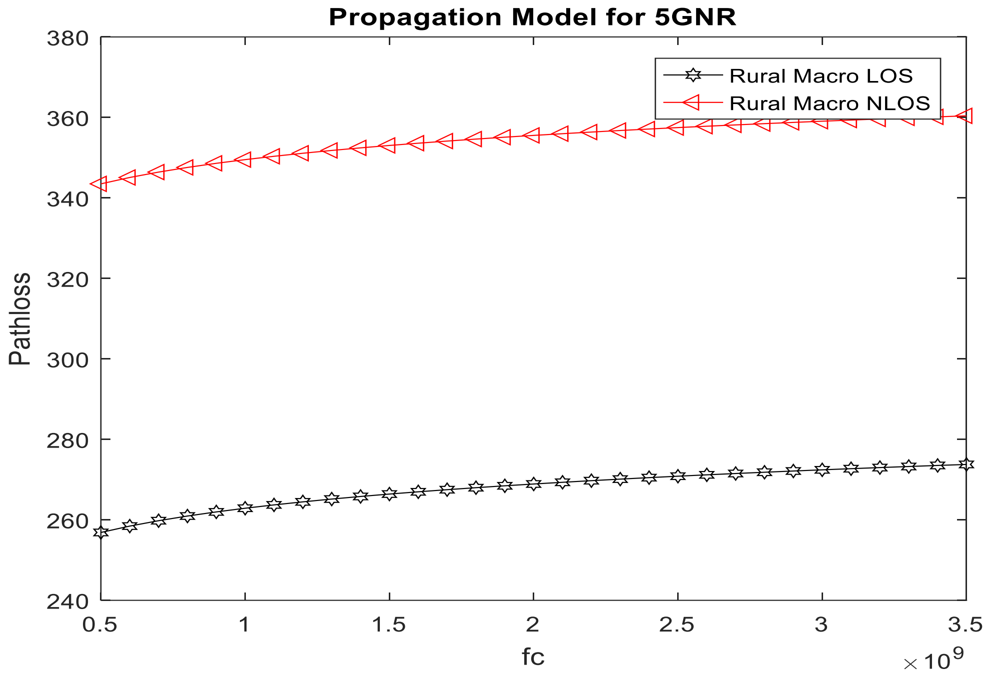

Figure 4. 6 Rural Macro LOS and NLOS

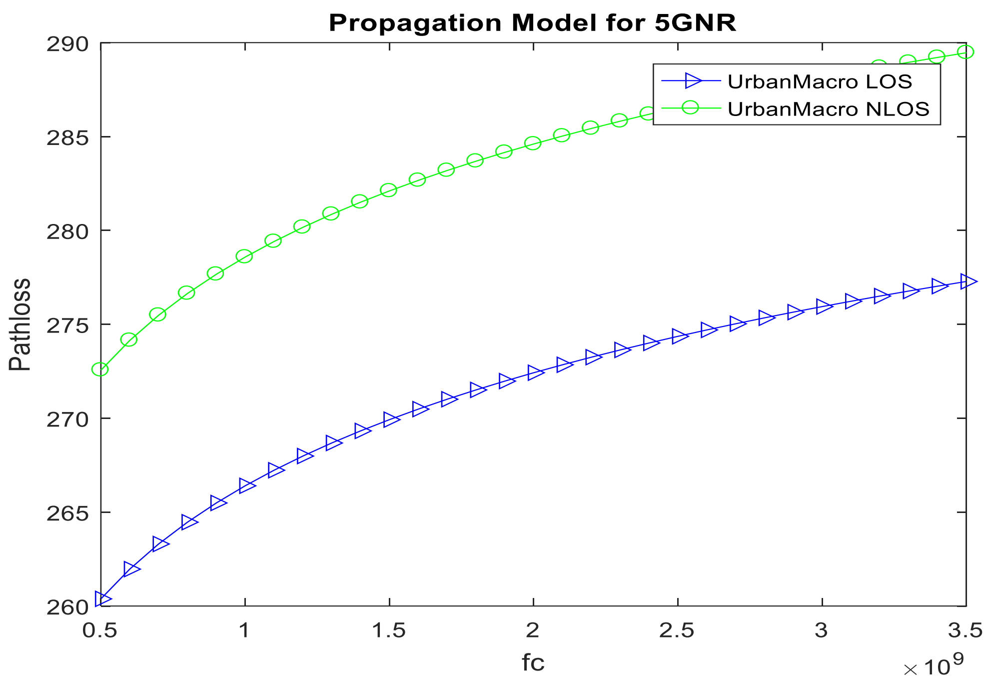

Figure 4. 7 Urban Macro LOS and NLOS

Result and Discussion: As shown in these above three figures (Figure 4.5, 4.6and 4.7), the path loss increases with frequency for both LOS and NLOS. In outdoor scenarios, the considerable path loss grows with frequency. There is energy absorption when buildings and other things are in the way. They absorb more energy as the frequency rises, and the path loss rises with it. The NLOS has high path loss compared to LOS for Urban, Rural and Indoor Hotspot office scenarios.

4.4 Capacity Planning Analysis:

The number of subscribers in the system, their requested services, and the subscriber usage level during peak hours are all inputs into capacity planning. The traffic model in table 4.5 is based on Ethio Telecom's current data use. The following is a summary of the input parameters and the output result.

Step 1: The average uplink and downlink throughput per subscriber is calculated using equations (3.32, 3.33, 3.34,) and table 3.4.

Table 4. 3 Average throughput per subscriber for uplink and downlink

Types of customers	Traffic Usage in GB/Month	Service usage ratio	Traffic ratio		Busy hour ratio	Average throughput per subscriber(kbps)
			DL	UL		
Gold	20	65	80%	20%	29.16%	432.1
Silver	15	25				324.07
Bronze	10	10				216.05
Total average throughput per subscriber(kbps)					383.49	
DL total average throughput per subscriber (kbps)					306.79	
UL average throughput per subscriber (kbps)					76.698	

Step 2: Calculate average throughput per site for uplink and downlink (using equation (3.31), (3.32), (3.33), (3.34) and table 4.5).

Table 4. 4 Input parameters for average throughput per site analysis

Parameters	Value
Data rate in sub frame(bit)	112
Data rate per subcarrier(kbps)	112
Number of resource block	250
Subcarrier per resource block	12
Data rate per resource block (Mbps)	1.344

Since there are 250 resource blocks corresponds to while 100 MHz is channel bandwidth, peak throughput per sector (Mbps) becomes,

$$\text{Peak Throughput per sector(Mbps)} = 250 \times 1.344 = 336 Mbps \tag{4.5}$$

Peak throughput for uplink communication with 2×2 transmission antenna is 672 Mbps and for Downlink communication is with 2×2 transmission antenna is 672 Mbps.

Then for 3-sector with 100MHz channel bandwidth peak through per site for uplink and downlink is

$$\text{Peak throughput per site for UL(Mbps)} = 3 \times 672 = 2016 Mbps \tag{4.6}$$

$$\text{Peak throughput per site for DL(Mbps)} = 3 \times 672 = 2016 Mbps \tag{4.7}$$

Now the number of subscribers per site for both uplink and downlink are calculated.

$$\text{Muximum subscriber number per site(UL)=} \frac{\text{average throughput per site for uplink}}{\text{average throughput persubscriber for uplink}} \tag{4.8}$$

$$= \frac{2016 Mbps}{76.698 kbps} = 26285$$

$$\text{Maximum subscriber number per site (DL)=} \frac{\text{average throughput per site for DL}}{\text{average throughput per subscriber for DL}} \tag{4.9}$$

$$= \frac{2016 Mbps}{306.79 kbps} = 6571$$

Table 4. 5 Maximum subscriber number per site

Maximum subscriber number per site	UL	DL
	26285	6571

4.5 Capacity Based Site Count

The number of gNB can be calculated using the maximum number of subscribers per site calculated for both UL and DL from Table 4.7 (the lowest is chosen) by taking the values of Adama City 5G network subscribers for the next 5 years, forecasted as 396496 (Table 3.2).

$$\text{Site number} = \frac{\text{Total subscriber suppoted in the area}}{\text{Maximum number of subscribers per site}} \tag{4.10}$$

$$= \frac{396496}{6571} = 60$$

The number of gNB required based on capacity is 60 gNBs.

4.6 Site Count Analysis

The required sites number for the Adama City urban area should be determined as the maximum number of sites obtained from coverage and capacity planning calculations to satisfy both coverage and capacity traffic needs. According to the coverage analysis results, 76 gNBs are required to meet the coverage requirement, while 60 gNBs are required to meet the capacity requirement based on the capacity planning study. By comparing the number of sites from capacity and coverage planning, the total number of gNB that will be used for 5G network planning is becomes 76 gNBs.

4.7 Coverage Prediction Analysis

Coverage is defined as the ability to obtain a service that meets a set of network requirements for signal quality Coverage prediction is analysed by signal level, transmitter, RSRP, and overlapping zones.

4.7.1 Coverage Prediction by Signal Level

Coverage zones can be predicted based on the transmitter signal intensity within the computation zone using a coverage prediction by signal level.

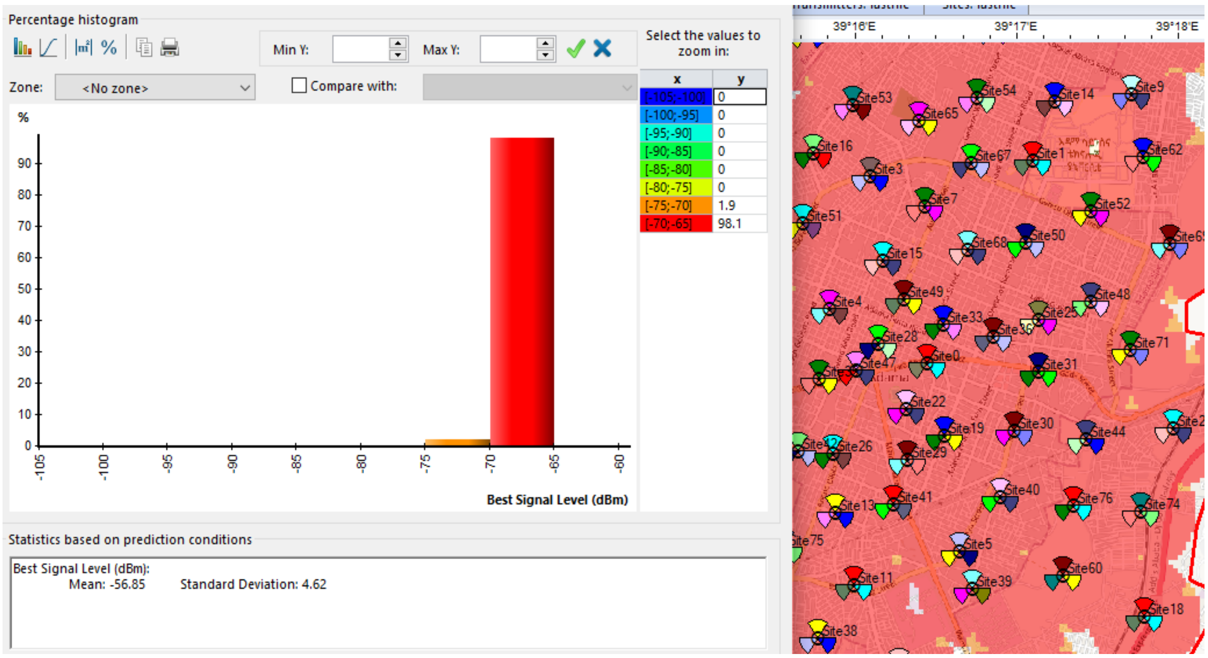

Figure 4. 8 Best signal level versus coverage area in percent

Result and discussion: The wireless signal strength is the amount of power received by the network device. More stable connections and faster speeds are the outcomes of strong signal strength. Signal strength is expressed in decibels (dBm). The statistical result shown in the above figure is that more areas within the computation area are covered by strong signal level.98.1% of the target area is covered with strong signal level between -70dBm and -65 dBm.

4.7.2 Coverage Prediction by Reference Signal Received Power

Reference Signal Received Power (RSRP) is the most important indicator of signal strength and quality. When a mobile device moves from cell to cell and performs cell selection, cell reselection, and handover, it measures signal strength.

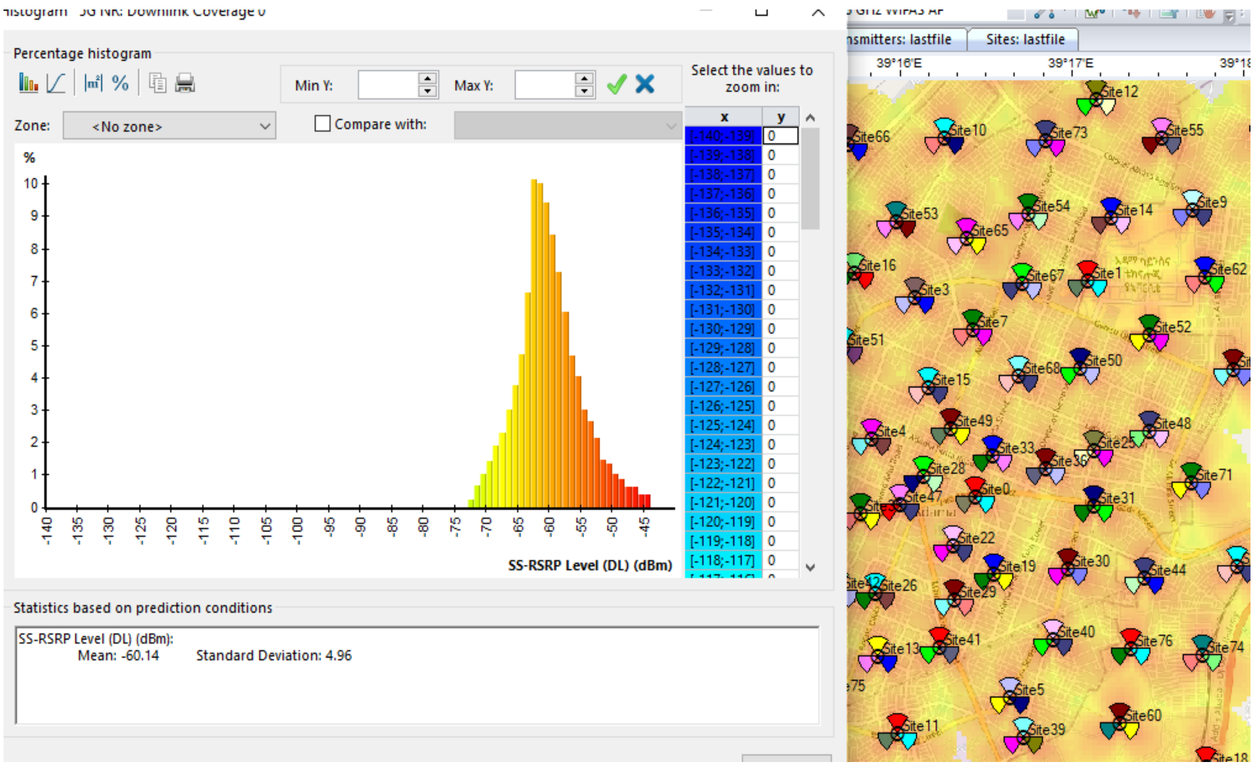

Figure 4. 9 coverage prediction by RSRP

Result and Discussion: The mean value of RSRP is -60dBm.This indicates that UEs can receive a stronger signal than the radio link budget's projected minimum signal reception strength (which is -131.7dBm).

4.7.3 Coverage Prediction by Transmitter

A coverage prediction by transmitter allows predicting coverage zones by transmitter at each pixel. It predicts the maximum area that can be covered by a base station. How far the placed transmitters have covered is shown in coverage by transmitter map in Figure 4.10

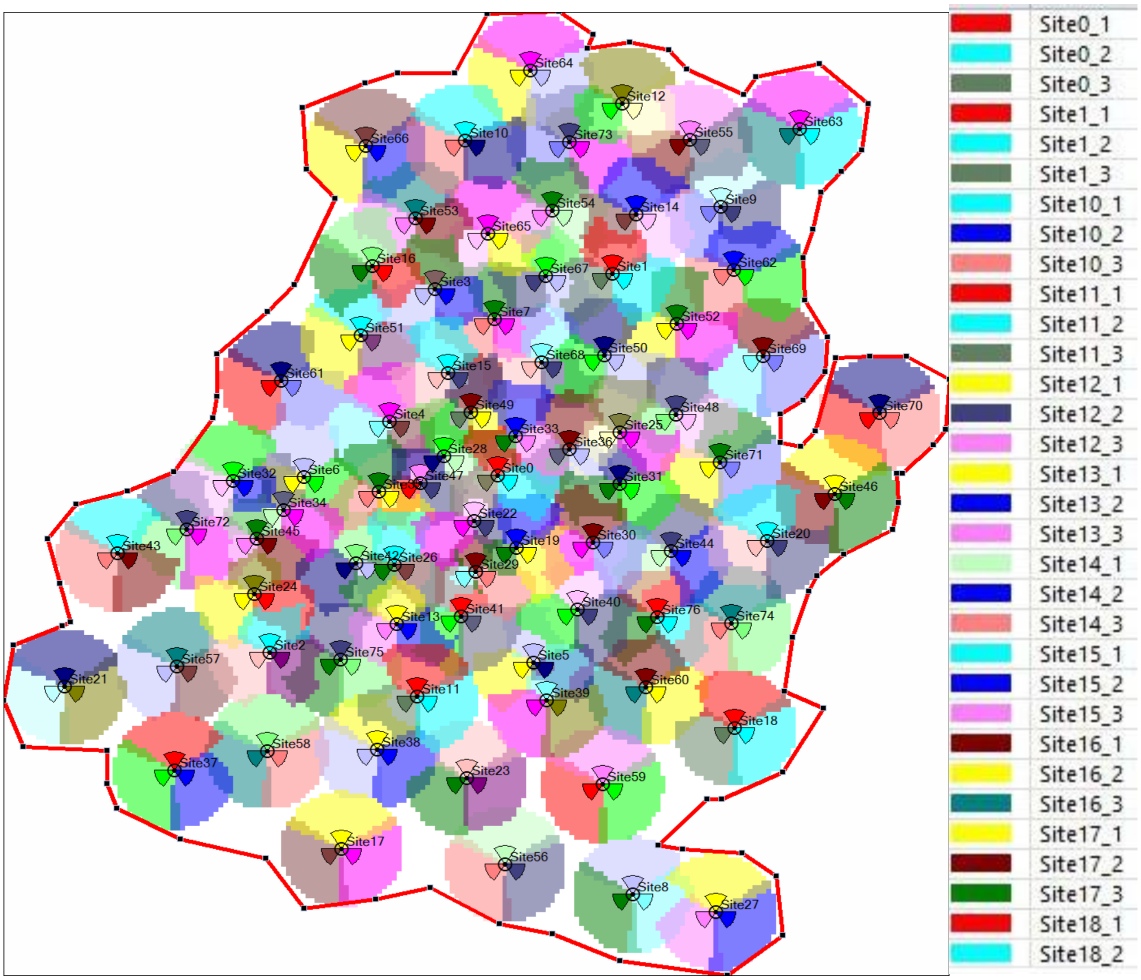

Figure 4. 10 Coverage prediction by transmitter

4.7.4 Coverage prediction on overlapping zones

The existence of many zones in which a cell is dominating (best server) but that are outside the regular coverage region is referred to as an overlapping zone. It is mostly caused by antennas positioned in higher and lower areas. It can also be generated by environmental reflections. In mobile networks, overlapping zones happen frequently and can degrade network quality, particularly in the area where they occur.

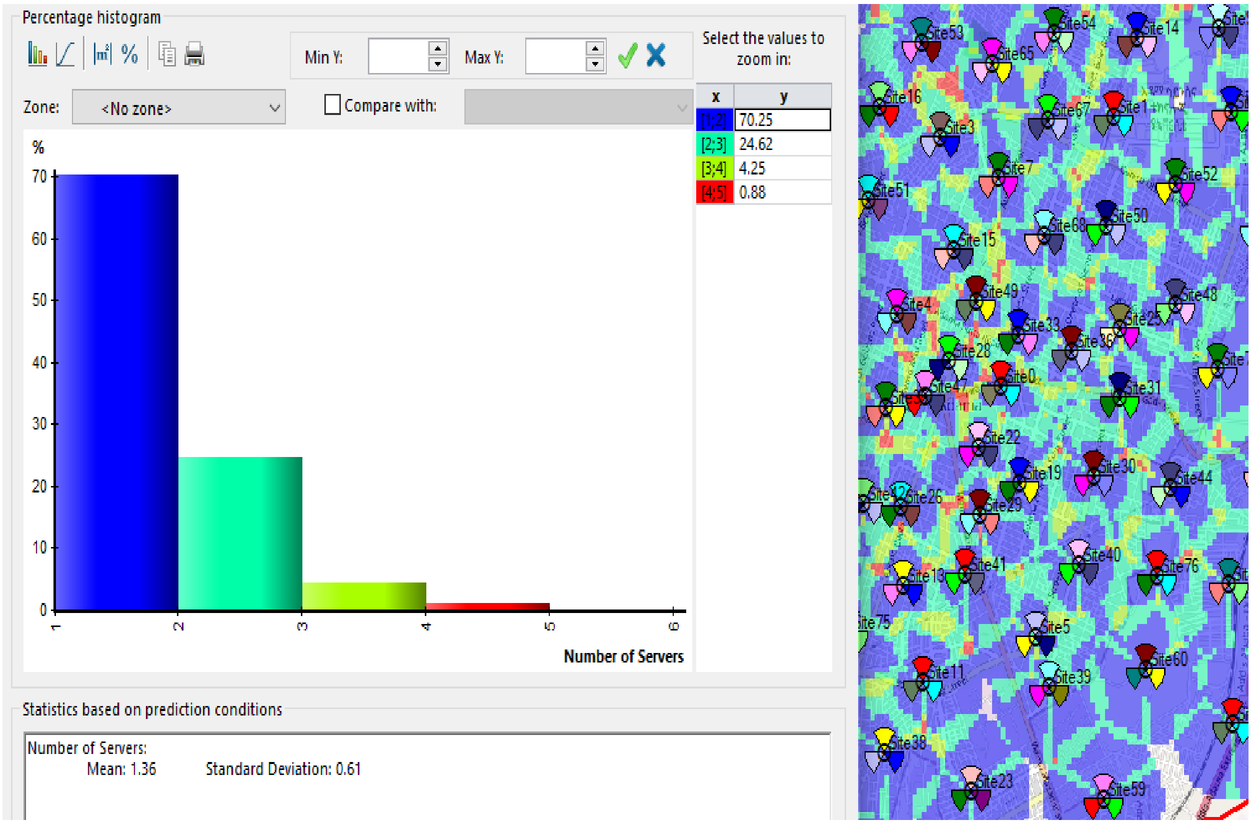

Figure 4. 11 Overlapping zones of transmitter

Result and Discussion: The above figure indicates that 70% of the target area is covered non overlapping zones and percentage of 4 servers or more is 0.88% which is less than 2%.and it fulfills the coverage area overlapping requirements which are explained in table 3.7.

4.7.5 Capacity Analysis by Throughput

The ratio of data transmitted per unit of time is referred to as throughput. Bits per second (bps) is the unit of throughput. Uplink throughput refers to the data rate from UE to 5G-NB data and the downlink refers to the 5G-NB to UE data rate.

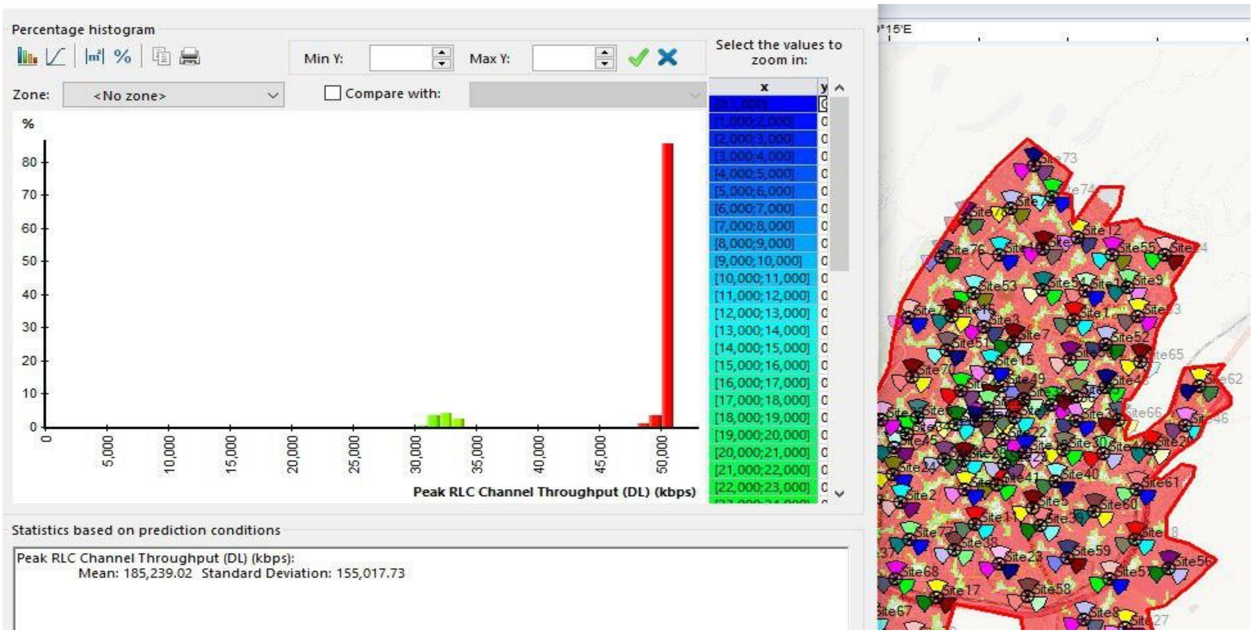

Figure 4. 12 Peak RLC channel throughput

Result and Discussion: ATOLL planning tools calculates the downlink and uplink throughput predictions to display the channel throughputs and cell capacities.as shown in the figure 4.12 the mean of RLC Channel Throughput is 185.239Mbps

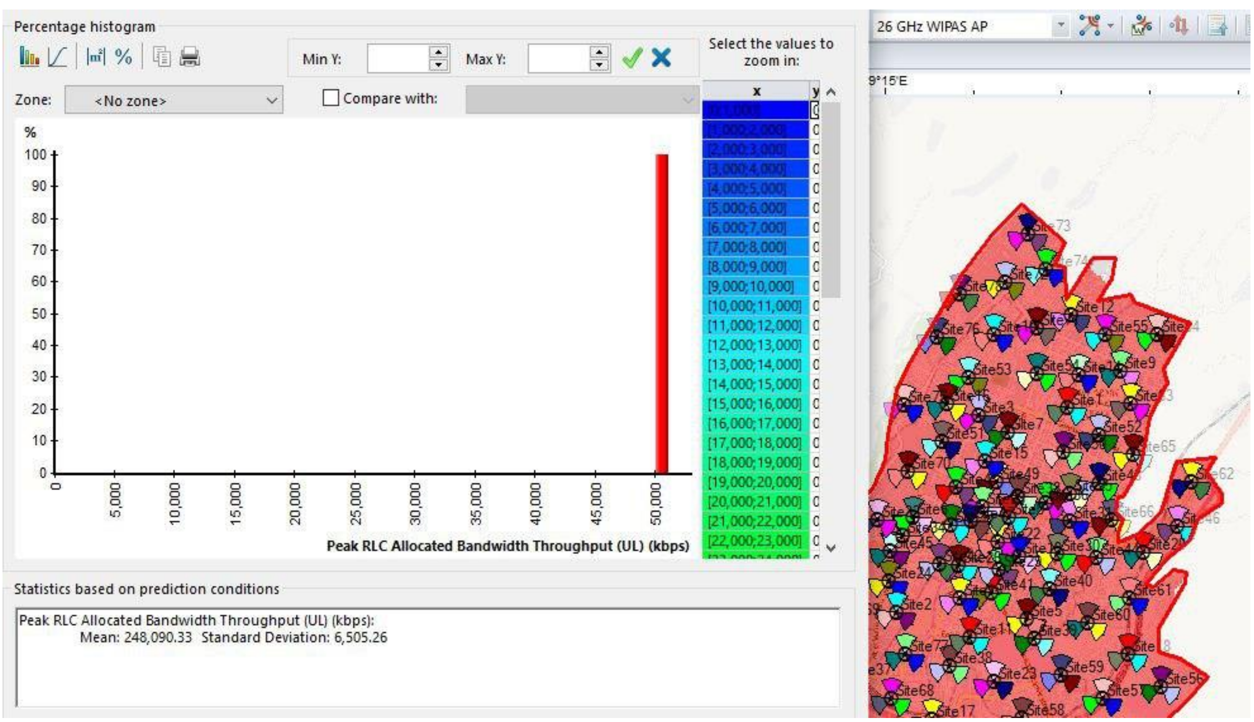

Figure 4. 13 Peak RLC Allocated Bandwidth Throughput (UL)

Result and Discussion: For certain transmissions, the Radio Link Control protocol layer provides a completely reliable transport service. It allows for the transmission of signaling data as well as user data. As shown in figure 4.13 the peak Radio Link Control throughput is 248.1 Mbps.

Capacity Analysis by SINR:

The PDSCH SINR is a component of the 5G SINR. Many mobile phones estimate SINR and then convert it to a Channel Quality Indicator using a combination of channel state information and PDSCH resources. The PDSCH SINR is generally the best SINR because it has no interference other than load-based interference.

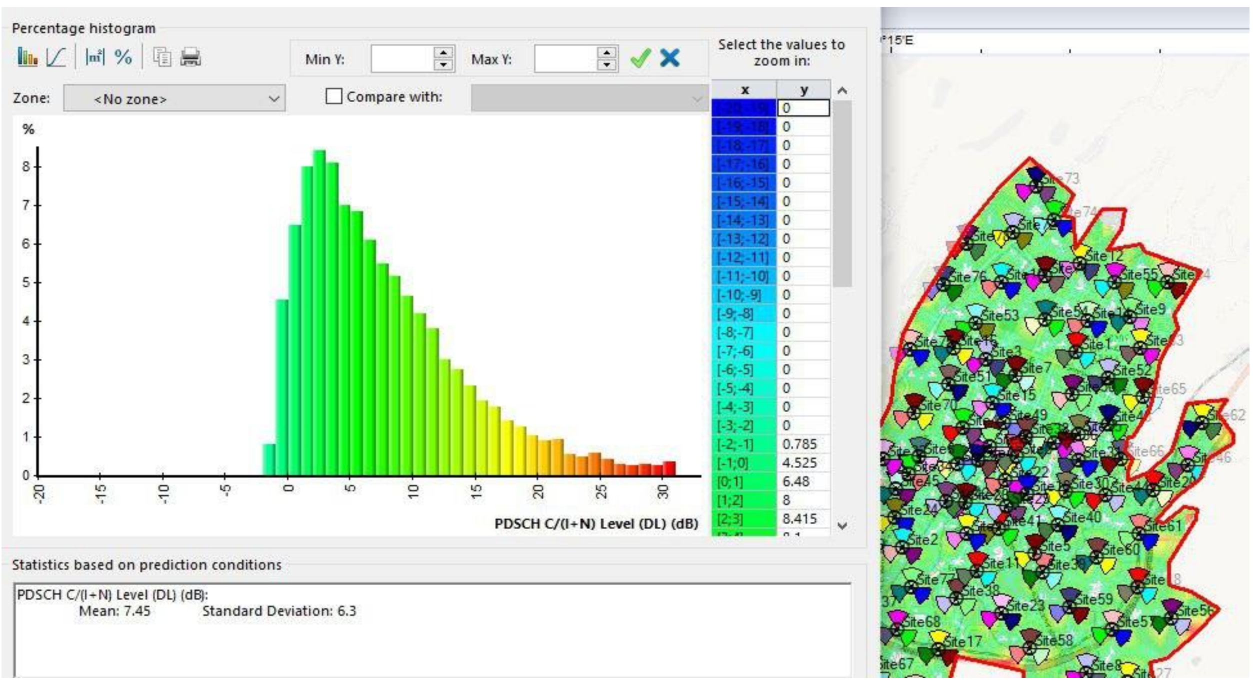

Figure 4. 14 Coverage prediction by SINR

Result and Discussion: The target network signal-to-interference levels are analyzed for coverage prediction using SINR level. ATOLL's simulation, employing a transmit power of 43 dB, yielded the coverage prediction by SINR value. The carrier to noise ratio is -2 dB that is higher than the threshold value of -7 dB, as seen in the figure 4.14. The mean value of SINR is 7.45 dB.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Like any other cellular technology, 5G radio network planning requires an extensive analysis of capacity and coverage requirements. The capacity and coverage estimates should contribute to the technology's deployment and implementation process by giving useful information. The relevant 5G NR features, propagation models, coverage, capacity, and number of gNodeBs for radio planning were discussed during the study of this thesis. The capacity and coverage analysis in this thesis revealed that 76 gNBs are sufficient to cover Adama City's urban clutter. The coverage and capacity planning findings can be verified using simulation as a result of this planning procedure. Strong signal levels cover more locations inside the computation area. More than 98.1 percent of the target area is covered by the strong signal between -70dBm and -65dBm. The maximum area that a base station can cover can be predicted using a transmitter coverage prediction. Non-overlapping zones cover 70% of the target region, and the number of servers with four or more is 0.88 percent, which is less than 2%. It meets the overlapping coverage area requirements. The coverage area analysis under path loss and shadowing for circular cell, hexagonal cell (at edge and vertex) also performed. Coverage area decreases as the shadowing increases. From the propagation model comparisons as frequency increases Rural Macro Propagation model has high path-loss compared with Urban Macro and Indoor Hotspot Office. The NLOS has high path-loss compared to LOS for Urban, Rural and Indoor Hotspot office scenarios.

5.2 RECOMMENDATIONS

There are certain areas where further improvements might be made. This work can be continued in a variety of ways. The study presented in this thesis focuses on 5G network access network planning. This can be broadened to include frequency planning and optimization. It must be designed to efficiently minimize both the initial investment cost and the operational cost of deploying the optimized 5G radio network dimensioning. Radio Network Dimensioning by itself will not satisfy customers; it must also deliver a service at a reasonable cost based on network traffic analysis and dynamic tariff. So, in addition to customer happiness, research into this and other value-added services (VAS) is required in order to manage existing resources and generate extra money.

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