END TO END PERFORMANCE EVALUATION OF 5G RADIO ACCESS NETWORK

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

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I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with Honours.

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DEDICATION

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ABSTRACT

The fifth generation or 5G network technology improves the user experience and creates new possibilities for a variety of applications including transportation, agriculture, and manufacturing that require ultra-low latency for maximum performance. The 5G also will be far superior to the current networks in terms of speed. This study aims to address the demand for high data rates and low latency that will influence the development of wireless access technologies. To explore the full potential of these studies, it is mandatory to understand the communication along with the 5G network, Radio Access Network (RAN) and Cloud Radio Access Network (CRAN). Hence, there is a need to modify the radio access network (RAN) for the 5G system. This study investigates the 5G RAN architectures in terms of Cloud RAN (CRAN). In addition, to ensure the service quality of 5G network users, the 5G RAN model simulation is designed in OMNeT++ software. Therefore, from the simulation result, a single graph can be generated based on the parameters selected which are delay, throughput, packet sent and packet received, and total packet loss.

ABSTRAK

Teknologi rangkaian generasi kelima atau 5G meningkatkan pengalaman pengguna dan mencipta kemungkinan baharu untuk pelbagai aplikasi termasuk pengangkutan, pertanian dan pembuatan yang memerlukan kependaman ultra rendah untuk prestasi maksimum. 5G juga akan jauh lebih baik daripada rangkaian semasa dari segi kelajuan. Kajian ini bertujuan untuk menangani permintaan untuk kadar data yang tinggi dan kependaman rendah yang akan mempengaruhi perkembangan teknologi capaian tanpa wayar. Untuk meneroka potensi penuh kajian ini, adalah wajib untuk memahami komunikasi bersama rangkaian 5G, Rangkaian Akses Radio (RAN) dan Rangkaian Akses Radio Awan (CRAN). Oleh itu, terdapat keperluan untuk mengubah suai rangkaian capaian radio (RAN) untuk sistem 5G. Kajian ini menyiasat seni bina 5G RAN dari segi Cloud RAN (CRAN). Selain itu, untuk memastikan kualiti perkhidmatan pengguna rangkaian 5G, simulasi model RAN 5G direka dalam perisian OMNeT++. Oleh itu, daripada hasil simulasi, satu graf boleh dijana berdasarkan parameter yang dipilih iaitu kelewatan, pemprosesan, paket dihantar dan paket diterima, dan jumlah kehilangan paket.

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LIST OF SYMBOLS AND ABBREVIATIONS

4G	:	Fourth Generation
5G	:	Fifth Generation
AR	:	Augmented Reality
BBU	:	Baseband Unit
BS	:	Base Station
CN	:	Core Network
CP	:	Central Processor
CRAN	:	Cloud Radio Access Network
CoMP	:	Coordinate Multipoint
CAPEX	:	Capital Expenses
CoIMP	:	Coordinated Multipoint Transmission
DU	:	Distributed Unit
EN-DC	:	Evolved-Universal Terrestrial Radio Access
eMBB	:	Extreme Mobile Broadband
eMTC	:	Enhanced Machine Type Communication
eNB	:	Evolved Node B
gNB	:	Next Generation Node B
eICIC	:	Enhanced Inter-Cell Interference Coordination

Gbps	:	Giga bits per second
GHz	:	Giga Hertz
H2H	:	Human to Human
HARQ	:	Hybrid Automatic Repeat Request
IP	:	Internet Protocol
IoT	:	Internet of Things
IIoT	:	Industrial Internet of Things
LTE	:	Long Term Evolution
LTE A	:	Long Term Evolution Advance
Mbps	:	Megabits per second
M2M	:	Machine to Machine
MIMO	:	Multiple Input Multiple Output
ms	:	Millisecond
mmWave	:	Millimeter Wave
MNO	:	Mobile Network Operators
NR	:	New Radio
NED	:	Network Description
OPEX	:	Operating capital Expenses
PDCP	:	Packet Data Convergence Protocol
PU	:	Processing Unit
QoS	:	Quality of Service
QoE	:	Quality of Experience
RAN	:	Radio Access Network
RAT	:	Radio Access Technologies
RU	:	Radio Unit

RRU	:	Remote Radio Unit
RRH	:	Remote Radio Head
SINR	:	Signal to Interference plus Noise Ratio
UE	:	User Equipment
URLLC	:	Ultra-Reliable Low Latency Communication
Ultra HD	:	Ultra-High Definition
IMT-2020	:	International Mobile Telecommunications-2020
VAR	:	Virtual Augmented Reality
VR	:	Virtual Reality
V2X	:	Vehicle to anything
VoIP	:	Voice over Internet Protocol
Wi-Fi	:	Wireless Fidelity
WLAN	:	Wireless Local Area Network

CHAPTER 1

INTRODUCTION

1.1 Introduction on 5G

The fifth generation of network or also known as 5G technology enables high speed transmission and provides low-latency transmission of large amounts of data. With its reduced latency, 5G has the potential to revolutionize factory communication platforms. It provides greater data volumes, higher data rates, lower power consumption and lower end-to-end latency [1]. In comparison to the present 4G, 5G delivers higher frequency system efficiency, resulting in more data volume per unit area, more devices supported, less power consumption and more simultaneous and rapid connections between devices [2]. Besides, 5G Millimeter Wave (mmWave) communications increasing bandwidth is a successful way to meet the rapid increase in data rates up to 10 of Giga bits per second (Gbps), especially for 5G devices. Most of today's fully utilized mobile networks operate below 3 Giga Hertz (GHz) [3]. In addition, 5G is highly integrated, merging the 5G spectrum and air interfaces with Wireless Fidelity (Wi-Fi) and Long-Term Evolution (LTE) to provide a seamless user experience. With a high coverage in a cost-effective, readily available, scalable and reliable mobile network to achieve a high global connectivity solution [4]. Besides, 5G is modeled entirely of the Internet Protocol (IP). The IP of 5G technology is designed to ensure sufficient control data to route IP packets related to end-to-end connections according to user policy. Therefore, this architecture will make 5G a unified global standard and making the network available anytime and anywhere [5].

1.2 Problem Statement

The first network of 5G employs frequencies that range from 24 to 86 Gigahertz (GHz) for the telecommunication standards. New generations such as 5G have various advantages over the previous generations from 1G to 4G [6]. Due to the requirement to upgrade software and hardware on towers, operators may choose for expenditures, causing LTE penetration in the country to be delayed [7]. With an increase in the number of end users using internet services, the average data rate of 4G will not be in a position to accommodate the future mobile technology [8].

Today's wireless communication infrastructures are overloaded due to rising demand for wireless applications and an exponential increase in the number of connected users. Researchers and network designers are attempting to solve these fundamental issues by ensuring ultra-fast data rates and a large number of connected devices with high efficiency and low latency [9].

This research, therefore, aims to address the demand for throughput and delay that will influence the development of wireless access technologies. In order to ensure the service quality of 5G network users, the 5G RAN model simulation is designed in OMNeT++ software to test and analyze 5G network optimization.

1.3 Objective

The specific objectives of this study:

1. To design a simulation model of 5G RAN using OMNeT++ software.
2. To analyze the throughput, delay, total packet loss, packet sent and packet received parameters in 5G RAN using simulation OMNeT++.

1.4 Scope of Work

Table 1.1 Description Scope of Work

Configuration in Single Cell Standalone	**Input Application**
- Downlink Data Transmission - Uplink Data Transmission	- Voice over Internet Protocol (VoIP)
Software	**Output Parameters**
- OMNeT++ Software	- Delay - Throughput - Packet sent and Packet Received - Total Packet Loss

1.4.1 Explanation about Scope of Work

i) Configuration Single Cell Standalone

This single-cell architecture has two scenarios which are Scenario 1 data transmission for downlink from the base station (gnb) to user equipment (ue) and Scenario 2 data transmission for uplink from user equipment (ue) to a base station (gnb).

ii) Input application

In this 5G RAN, the single cell design is focus on VoIP application for 5G network.

iii) Software

A 5G RAN modelling is create using OMNeT++ software based on four parameters which are delay, throughput, total packet loss, packet sent and packet received.

iv) Output Parameters

Based on the simulation results, a single graph that represents the parameters delay, throughput, total packet loss, packet sent, and packet received can be generated. This explains how the analysis is carried out and the results are compared to the research mentioned in the background study.

1.5 Thesis Outline

The structure of this work is as follows. The work is split into five sections. Chapter 1 presents an overview of the project. The problem statement, objective and scope of work were also covered in this chapter.

Furthermore, Chapter 2 provides a literature study background on 5G. This section discusses the design, characteristics, and benefits of 5G. It also discusses the RAN overview and architecture. This chapter also covered CRAN's introduction, architecture and benefits.

In Chapter 3, the research technique of this project will be outlined. This section will begin with an introduction to the flow chart and the OMNeT++ model structure. Then, each stage of the project's development will be thoroughly explored.

Chapter 4 presents the results and analysis, including all the discussion mentioned in Chapter 3. In addition, this chapter describes the results of 5G RAN based on selected parameters throughput, delay, total packet loss, packet sent and packet received. Comparisons are then made based on the results and theory.

Chapter 5 covers the completion of the entire project, including ongoing discussion, commercialization, and future work on each project.

CHAPTER 2

BACKGROUND STUDY

2.1 Background of 5G

5G networks are already being deployed over the world, leading in a considerable increase in high-density smartphone applications. The solution smartphone usage is predicted to skyrocket over the next decade. Future wireless communication networks' capacity will need to expand by a factor of a thousand to manage the predicted increase in traffic [10]. Early-generation mobile communication networks were designed primarily to support human-to-human (H2H) communications and are said to have been extremely successful in meeting data rate and latency requirements. However, the rise of more innovative products and services today leveraging more advanced communication technology will cause major changes in practically every aspect of global economic development [10].

Furthermore, future smartphone applications will require improved Quality of Service (QoS), Quality of Experience (QoE), greater traffic volumes and much-reduced costs without sacrificing the required level of security. The International Mobile Telecommunications-2020 (IMT-2020) family comprises 5G technology, which provides exceptional services such as high data speeds, fast convergence, great spectrum efficiency, flexibility, and uncompromising security [10]. The 5G standard attempts to upgrade existing mobile communication technologies such as IMT-Advanced (4G) by providing more advanced features. 5G will provide three new services to clients, which are Extreme Mobile Broadband (eMBB) refers to advanced mobile broadband that can offer users increased system capacity and faster wireless access speeds. As a result, consumers can enjoy an improved and ultra-clear experience [11]. Enhanced Machine-Type Communication (eMTC) and Ultra Reliable Low Latency Communication (URLLC) refers to high reliability and low latency [12][13]. 5G eMBB offers users quicker internet, more bandwidth, lower latency, Ultra High Definition (UltraHD) streaming movies and Virtual and Augmented Reality (VAR) media [10].

In addition, the 5G mobile communication system has the potential to radically alter the role of communication technology in advancing communication technology and a ubiquitously connected society. Unlike earlier generations, the transition to 5G systems will require significant further development of radio and overall system design, going far beyond the enhancements of standard LTE or LTE Advanced networks [14]. As a result, 5G could be utilized for a difference of applications that demand ultra-low latency for maximum performance, such as automotive, healthcare, entertainment, the Internet of Things (IoT) [15] and the Industrial Internet of Things [16].

2.2 Features of 5G

The word 5G refers to the fifth generation of wireless communication technology, that will transform many aspects of daily life. Mobile network traffic is increasing rapidly due to new mobile technologies such as virtual reality applications, high definition video streaming, and cloud gaming. 5G networks will also be far faster than present networks [17]. As a result, 5G will offer data transmission rates of up to 10 gigabits per second (Gbps) [10]. This outperforms 4G data transmission rates of over 100 Megabits per second (Mbps) [11] and 4G-LTE [18].

Furthermore, 5G is predicted to go beyond ultra-broadband networks by combining existing technologies like the Internet of Things (IoT), cloud, big data, artificial intelligence, and blockchain to enable the development of creative services. In addition to increasing speed, 5G offers decreased latency. In fact, the latency in the 5G era is less than one millisecond (ms), which is roughly the same as the zero data response time in the actual world [18].

Moreover, unlike current Internet of Things (IoT) services, 5G is predicted to unlock a large portion of the Internet of Things. Furthermore, it is referred on 5G ultra-bandwidth per unit area, connection per unit, near-complete coverage and device connectivity capabilities. As a result, it develops "Smart networks" that may be employed in massive medical devices to create ecosystems that allow real-time engagement [18].

2.3 Bandwidth of 5G

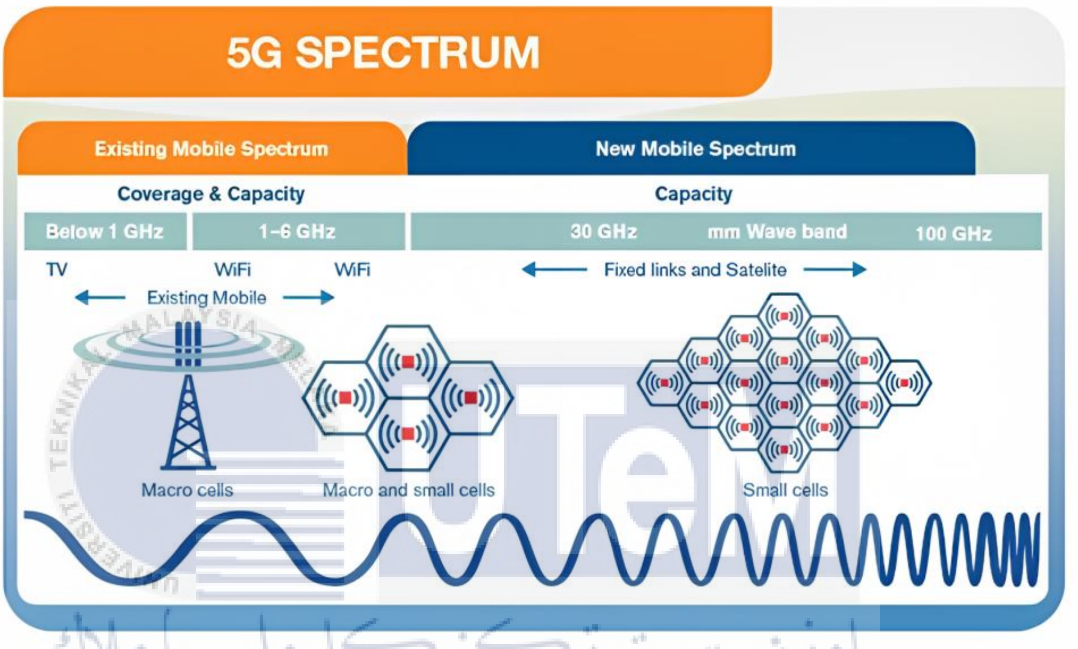

Figure 2.1 5G Spectrum of Frequency Range [19]

5G will expand the use of spectrum resources which means more bandwidth is required. Figure 2.1 shows the radio frequency range from 3GHz to 100 GHz, including the new 5G spectrum above 6 GHz. For reference, there are other wireless services such as Wireless Local Area Network (WLAN), satellite, TV and fixed connection. Furthermore, one of the most critical things to grasp about 5G, especially if upgrading from the previous generation, is bandwidth [20]. 5G will give large data bandwidth and unlimited network capabilities, which will lead to greater data rates, higher capacity, faster speeds, huge connection, spectral efficiency, better QoS, broader signal coverage, and providing users with a higher quality service [20].

2.4 Data Rate in 5G

For the data rate in 5G New Radio (NR) aims for 20 Gbit/s on the downlink. The peak data rate is the theoretically highest data rate under faultless conditions when all available radio resources in each connection direction are exclusively allocated to a mobile station. Analytical evaluation involves multiplying maximal spectral efficiency (η_{peak}) by available bandwidth. Integrating a 5G cell with an LTE evolved Node B (eNB) at the radio access level allows for the addition of both peak data rates, resulting in a higher value than a 5G standalone [14].

Multilink aggregation can increase peak data rate and spectrum area efficiency. This is critical in the early stages of the 5G deployment because more throughput may be obtained despite the lower bandwidth. Data transmission can be divided at the Packet Data Convergence Protocol (PDCP) layer of the transmitter and then re-aggregated at the PDCP layer of the receiver over two radio paths. This improves end-user throughput. Besides, it is noted that a healthy environment is taken into account when defining the peak data rate. However, 5G-NR mmWave links are subject to impediments such as significant path loss, big shadows, link limits due to cell height and location, and loss of line of sight [14]. If the signal-to-interference-plus-noise ratio (SINR) deteriorates, the UE's data rates will decrease. The simulation findings demonstrate that the throughput is very poor when the path between the UE and mmWave Next Generation Node B (gNB) is not in the line of sight.

As a result, it can be anticipated that dual connections not only allow enhanced throughput with good SINR, but also aid to maintain tolerable data rates when the gNB connection is of relatively poor quality.

Table 2.1 Data rate description [14]

Option	Key points	Peak data rate
LTE	Bandwidth = 20 MHz Spectral Efficiency = 15 bits/s/Hz	300 Mbps
5G	Bandwidth = 100 MHz Spectral Efficiency = 30 bits/s/Hz	3 Gbps
3	Supports throughput from both eNB and gNB Reasonable data rate when poor link from gNB	3.3 Gbps
3a	Supports throughput from both gNB only Low data rate when gNB path becomes NLOS	3 Gbps
3x	Supports throughput from both eNB and gNB Reasonable data rate even with a weak link from gNB.	3.3 Gbps

Table 2.1 shows throughput estimates for various Evolved-Universal Terrestrial Radio Access New Radio (EN-DC) deployment scenarios. Options 3 and 3x combine data rates from both gNB and eNB. As a result, these alternatives can achieve a peak data rate of 3.3 Gbps (20MHz x 15bps/Hz + 100MHz x 30bps/Hz). However, option 3a does not provide data rate aggregation. Because it is only supported by gNB and has a peak data rate of 3 Gbit/s (100 MHz x 30 bit/s/Hz). Furthermore, Option 3 and 3x, 4G-5G interactions can correct the loss of mmWave connectivity from the gNB by allowing speedy switchover to easily available eNBs [14].

2.5 Advantages of 5G in Industries

5G will accelerate applications that require significant bandwidth such as Augmented Reality (AR) and Virtual Reality (VR), enabling large-scale Internet of Things (IoT) devices, which have enabled education, entertainment, healthcare services, smart cities and manufacturing.

Furthermore, 5G networks offer high capacity, low latency, and strong processing capability. Currently, the most exciting industries in the telecommunications sector are 4G and 5G. Where, 5G is currently in the development stage [11].

Furthermore, 5G also has better support for heavy-consuming services where self-driving cars would also benefit greatly if could communicate with each other almost instantly. IoT and machine-to-machine (M2M) infrastructure have long been hampered by 4G's unexpectedly long latency and limited download speed.

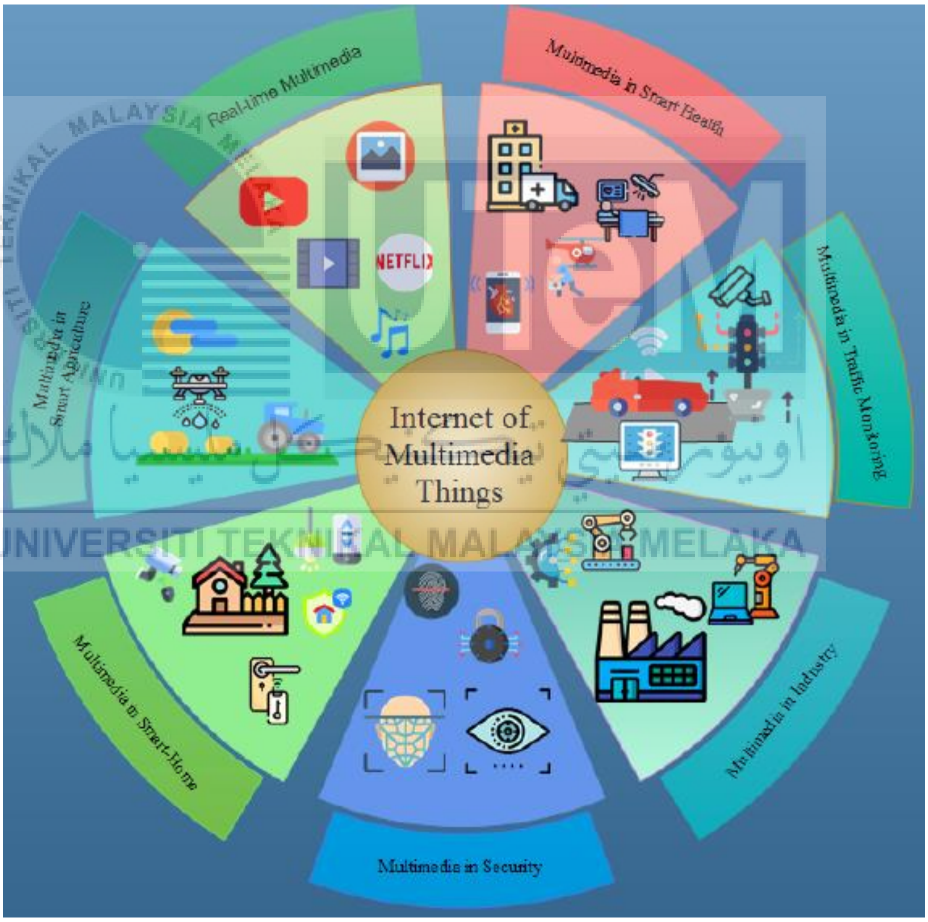

Figure 2.2 Interconnectivity of devices in Industries [21]

Figure 2.2 shows that the businesses that will profit from 5G include smart health, industry, smart agriculture, security, telecommunications and multimedia [22]. 5G is revolutionizing healthcare, with the rise of telemedicine employing smart devices in underserved areas, real-time patient monitoring via wearable technologies and data analytics.

5G will alter one of the most important aspects of transportation and logistics, vehicle-to-vehicle connectivity. Real-time data gathering, analysis and transmission, shorten transportation and delivery times, improve vehicle fuel efficiency and lower pollution. Manufacturing is likely to profit the most from 5G. With lower latency and higher bandwidth, factories may improve production standards, stay in touch with remote personnel, and do real-time analytics on machines [22].

Furthermore, 5G will enable intelligent farming, prevent climate change, and improve agriculture through increased yields. 5G will considerably benefit the financial services industry by improving back-end procedures, delivering services faster, enabling mobile payment applications and improving consumer comprehension. Therefore, 5G is projected to change the public sector by making everything smarter, connecting the public 24 hours and equipping government workers with the latest technology [22].

2.6 5G Mobile Network Architecture

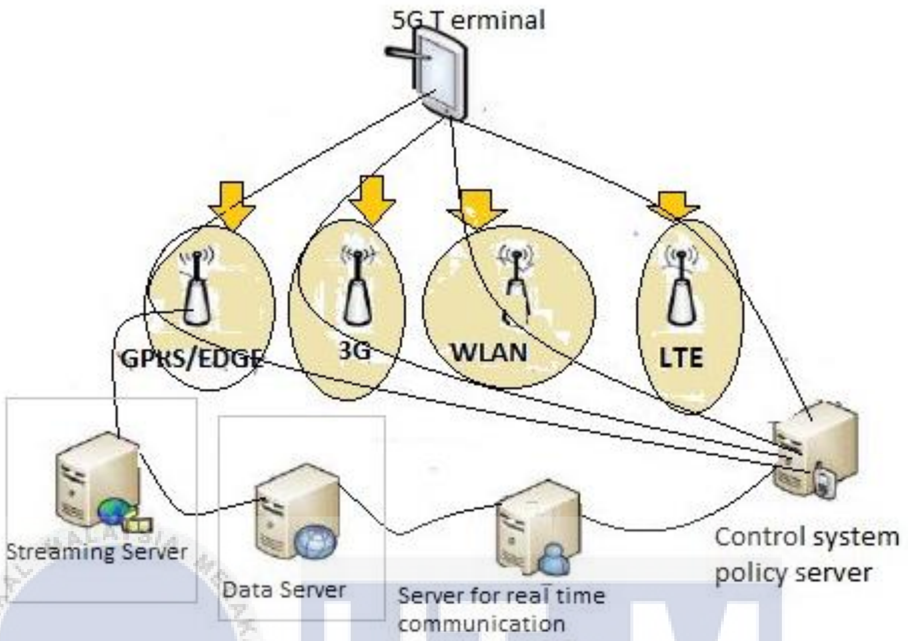

Figure 2.3 Functional Architecture of 5G [23]

Figure 2.3 depicts the system architecture, which incorporates the network infrastructure design for the 5G cellular network as well as a tried-and-true all-IP model for interoperability across wireless and cellular networks. This architecture comprises a computer terminal, which is an important component of the existing structure, as well as a variety of autonomous standalone radio systems. Each wireless approach technology is visible to each terminal via an IP connection to the external environment of the internet [18]. However, mobile end devices require a separate network interface through the Radio Access Technologies (RAT). For example, if the architecture needs to reach 4 separate RATs to work properly, propose four distinct techniques for similar interfaces on mobile devices to have all of these interfaces active simultaneously [18].

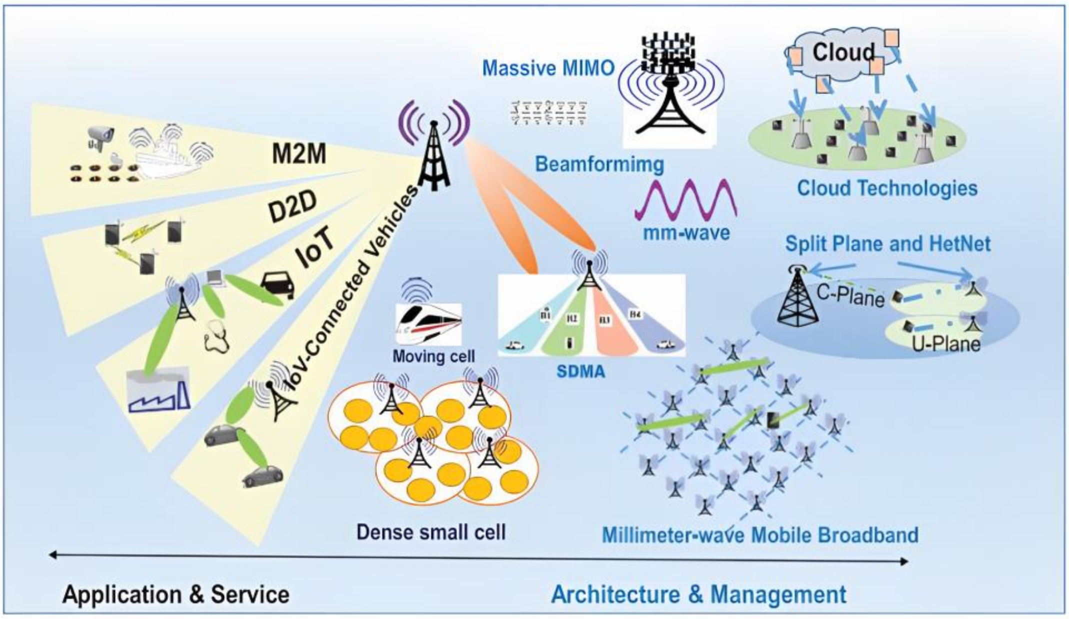

Figure 2.4 5G Wireless networks [3]

The 5G network design uses centralized and local server operations to provide consumers with high-speed content and low-latency apps. A mobile radio network is made up of two major components, the "Radio Access Network" and the "Core Network." A radio access network is made up of a variety components, such as small cells, antennas, towers, and specific building networks and residential systems that connect smartphone users and cellular devices to the core network [3], as illustrated in Figure 2.4. Small cells are an essential component of 5G networks, particularly at the latest millimeter wave (mmWave) frequencies, when coverage is extremely limited. Small cells are arranged in clusters to provide continuous connectivity based on where consumers require connectivity, complementing huge macro networks.

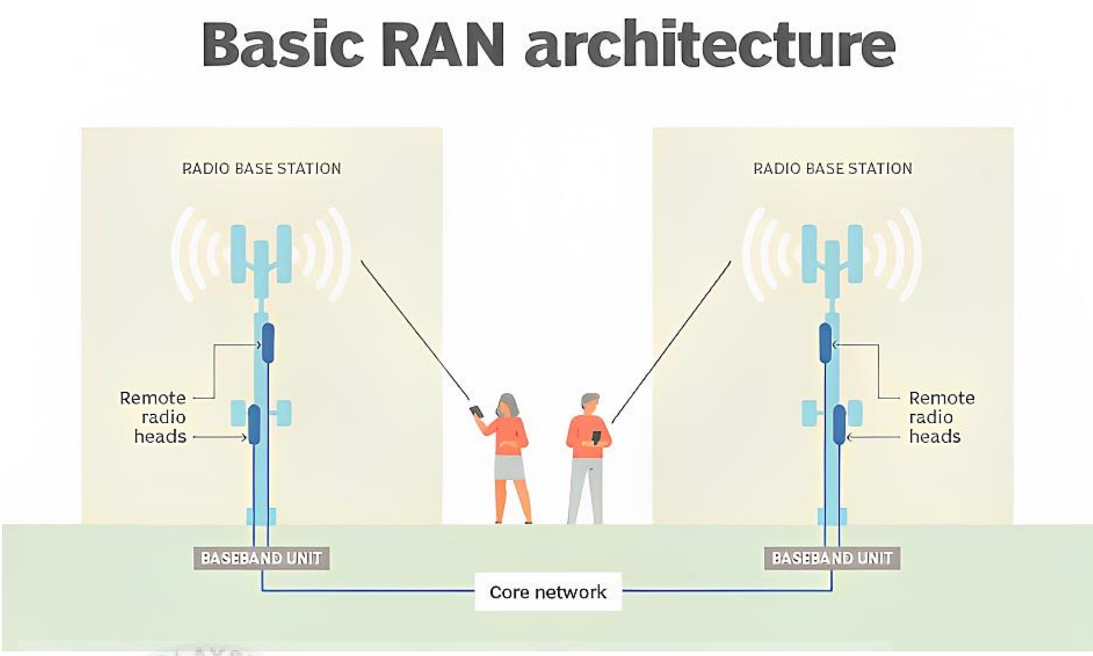

Figure 2.5 Basic RAN Architecture [24]

Moreover, 5G Macro Cells use many Input Multiple Output (MIMO) antennas with many elements or connections to send and receive more data at the same time. Consumers gain from the ability to connect to network simultaneously while maintain the excellent performance. MIMO use a huge number of antenna components, sometimes referred to as "mega-MIMO," yet the spatial dimensions of the antennas in the 3G base station and this 4G base station are identical. A core network is a mobile network that exchanges and manages voice, data and internet access data via phone as shown in Figure 2.5. The "Heart Network" has been redesigned for 5G to improve connectivity to the Internet and cloud-based networks, including servers distributed throughout the network to improve responsiveness to reduce the latency [3].

In addition, many of 5G's innovative technologies such as network functions and network slicing can be centrally managed by various software and services. An example a local cloud server that enables faster movie streaming for customers and a low-latency car collision avoidance system.

Table 2.2 Description features of 5G mmWave technology [3][25]

Features	Description
Data rate	More than 10 Gbps
Frequency bands	Bands range from 30 GHz to 40 GHz to 100 GHz
Bandwidths	Instead of aggregation at 40 GHz and 500 MHz to 2 GHz bandwidth, 10 subcarriers of 100 MHz each will have 1 GHz bandwidth and zero bandwidth at 40 GHz.
Distance coverage	Two indoor meters to 300 outdoor meters
Modulation types	CP-OFDMA < 40 GHz SC < 40 GHz
Frame topology	Duplex of Time Division

2.7 Security in 5G

The upcoming wireless 5G networks should provide wider coverage, greatly better Quality of Service (QoS), very low latency, and very fast data speeds. 5G will also deliver the Internet of Things (IoT), widespread Machine-to-Machine (M2M) communications, reliable and affordable mobile broadband connectivity and a variety of new cyber-physical system gadgets. These attributes imply that 5G is not merely an incremental increase from 4G, but a new breakthrough cable technology to handle the ever-increasing demands of user traffic, new services and the future of IoT devices [18].

Furthermore, it demonstrates that it is a combination of meeting gadgets. 5G security is much more crucial given its predicted function and impact on our lives. Furthermore, significant effort is required to secure the safety of 5G network equipment, users and the 5G network itself. The advancement of LTE is an important aspect of 5G. As a result, 5G will encompass the growth of all network components, including core and management systems, as well as all protocol layers from radio to application [18].

2.8 Overview and evolution of RAN

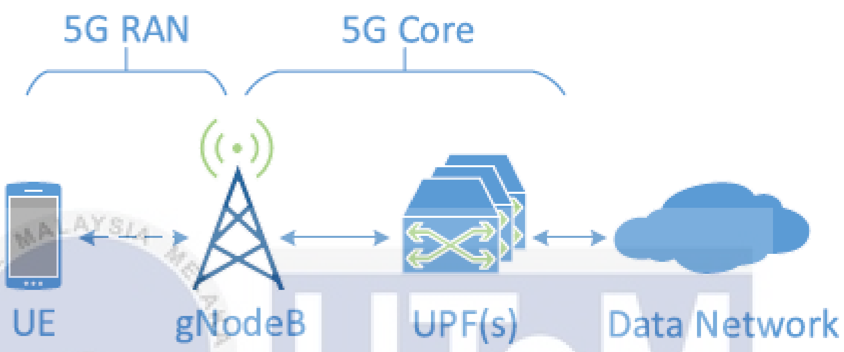

Figure 2.6 Architecture of data plane in 5G network [26]

The Radio Access Network (RAN) is the primary component of the radio communication system, connecting UE to the Core, as seen in Figure 2.6. A major role of RAN is the management of radio resources, and a typical RAN consists of two primary units, the Radio Unit (RU) and the Processing Unit (PU). The RU has a transceiver antenna that is responsible for sending and receiving. The processing units of the RAN are in charge of radio management, resource use and other processes including precoding and encryption [27]. Besides, 5G base stations are known as gNodeB (gNB), which are an evolution of 4G base stations known as eNodeB (eNB). Furthermore, in RAN, communication between BS and UE occurs in OSI reference model at Layer 2. Both Layer 1 and 2 are implemented using four protocol stacks on both the BS and the UE [26].

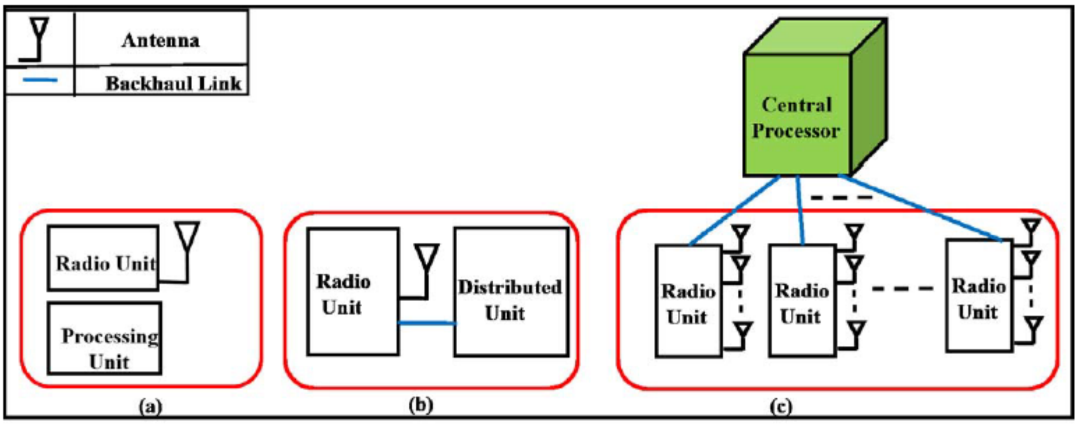

Figure 2.7 Different generation of RAN condition [27]

Figure 2.7 depicts the evolution of RAN over time. Initially, the number of users and data rate needs were extremely low. Because some data-limited cellular services for voice calls and text messaging were available, only a modest number of Base Stations (BS) were required to achieve this criterion. Figure 2.7 (a) depicts a traditional RAN with integrated RU and PU components. Each BS was sufficient to cover a broad area [27]. Since the implementation of the frequency reuse architecture, little computation is necessary to avoid interference. Following that, the radio unit and distributed unit were split, that illustrated in Figure 2.7 (b). The antenna of radio unit was set high, typically at the top of the tower, to cover a vast area, and the DU was pre-installed in the space beneath the BS. A fiber optic connection was utilized to connect both devices [27].

Furthermore, the introduction of data-intensive apps and the growing number of UE have increased demand for even higher densities. However, compression alone cannot meet the rising demand for data rates. As a result, the framework proceeded to Spectrum Reuse Scenario 1. Also, demand for millimeter waves (mmWaves) began, followed by an increase in demand for connection frames, as illustrated in Figure 2.7 (c). Figure 2.7 (c) depicts the Cloud Radio Access Network (CRAN) scenario, in which all base station PUs are organized into standalone CPs, formally known as Central Processors [27].

2.8.1 Advancements in RAN

The evolution of RAN from BS centric to UE centric is that conventional RAN used to associate BS to UE based on received signal intensity from different BS, selecting the most dominant BS. Part of the reason for this form of BS selection is that the interference power received from cell-edge users is usually comparable to the power of the serving BS. On the other hand, the UE-centric strategy allows each UE to select numerous BS based on received signal intensity, and all of these BS work together to avoid signals from surrounding BS [27]. Thus, the UE-centric strategy offers an interference-free environment independent of the user's location.

Besides, traditional networks connected each user using a BS-centric strategy for single point-to-multipoint transmission. As a result, edge users experienced severe inter-cell interference. CRAN has adopted a UE-centric approach with several BS to reduce interference from neighboring cells. As a result, each UE is served by a group of BS or radio heads overseen by the Central Processor (CP). Furthermore, for coordinated frequency, various frequency bands are used to orthogonalize users in nearby cells. As a result, resource utilization technology was incredibly terrible. CRAN serves each user through a network of several transmission sites. This sort of transmission is known as Coordinated Multipoint (CoMP) transmission. The CoMP algorithm operates at the center of CP and coordinates the cluster's BS. Coordinated beamforming, distributed transmission and shared transmission are examples of prominent CoMP approaches [27].

2.8.2 RAN Architecture

5G multicast solutions should be more flexible than existing multicast services and cover different deployment possibilities. The suggested 5G multicast system should be capable of enabling conventional multicast or broadcast services for downloads, streaming, group communications, and TV while also including new vertical applications such as vehicle-to-anything (V2X), interactive media and entertainment with personalized content. These services are available in regions where popular events, such as stadiums, have huge numbers of users, and the distribution of people inside the multicast area changes over time.

In addition, in the multicast environment, the RAN is aware of the UE's interest in receiving data from IP multicast groups as well as the interested UEs' radio channel conditions. When the number of UEs is modest, RAN employs link adaptation, beamforming, and other techniques to improve signal quality and throughput. As the number of users increases, link adaptation and other approaches become less effective [27].

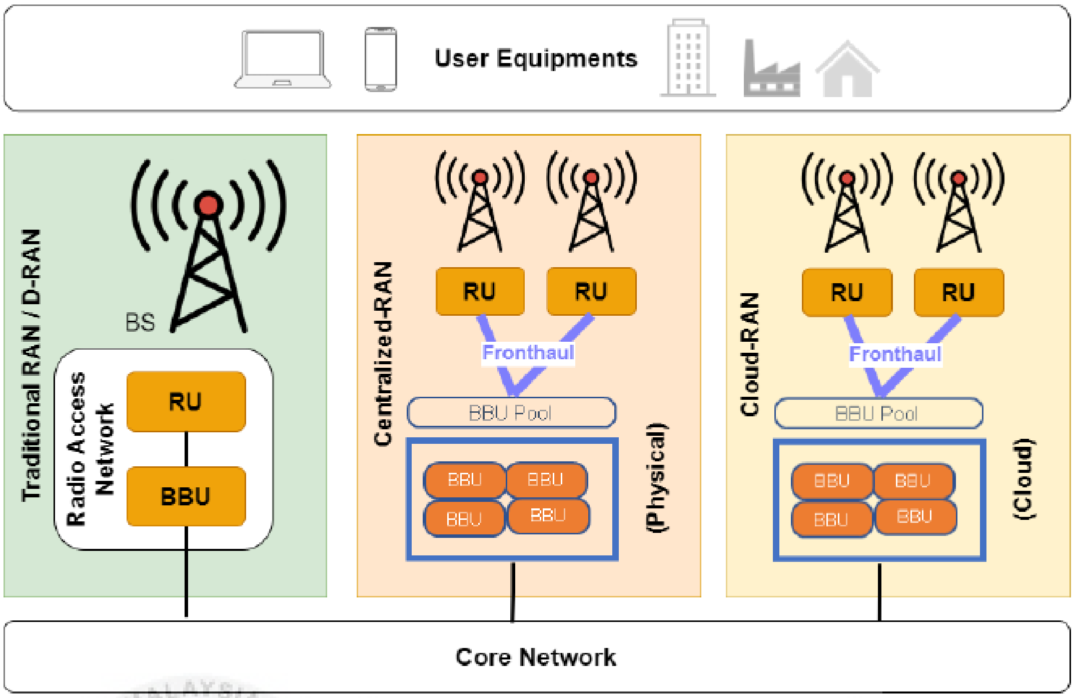

Figure 2.8 RAN Architecture per generation [28]

The actual implementation of RAN is known as a base station (BS). As illustrated in Figure 2.8, BS consists of two primary units, the Radio Unit (RU) and the Baseband Unit (BBU). RU is in charge of sending and receiving. BBU, on the other hand, is accountable for radio management, resource usage, and other activities [28].

The BBU was normally found in the room directly below the BS. The RU can be put in space or on top of a tower, allowing it to provide connectivity across a wide area. In this context, RU is also known as the Remote Radio Unit (RRU). In any event, the distance between RU or RRU and BBU is small. Each RAN functions separately [27]. As the number of UE increases, the network becomes denser and more BS are added.

2.9 Introduction of Cloud Radio Access Network (CRAN)

The advent of Industry 4.0 and new technologies such as the Internet of Things (IoT) and artificial intelligence, network performance requirements such as large-scale access and low latency are increasing. The current 4G network can no longer meet these requirements, hence a 5G network is being phased in. The Cloud Radio Access Network (CRAN), which includes the Baseband Unit (BBU) and Remote Radio Head (RRH) devices, is a critical 5G technology. Because of its centralization and cloud features, C-RAN can increase the number of devices using 5G networks and reduce transmission delays [29].

In addition, CRAN is proposed as a promising network architecture to handle various service requests and guarantee good quality of services (QoS) to end users. Unlike traditional cellular networks where the baseband functions are located at the cellular sites along with the antennas, CRAN separates traditional base stations into RRHs and centralized BBUs, which are bundled and used as shared resources, resulting in better utilization of network resources and improved energy efficiency. CRAN is expected to minimize network costs Capital Expenses (CAPEX) and Operating Expenses (OPEX) by reducing the number of base stations required to meet antenna demand [12][30]. On the other hand, CRAN can also improves radio performance by enabling various forms of multi-cell coordination to combat inter-cell interference caused by high cell density [31].

CRAN also provides a new architecture for next-generation wireless cellular systems, which connects a base station (BS) to the cloud central processor (CP) via faultless fronthaul link [32][33]. In this architecture is well regarded as an effective technique of enhancing the spectral efficiency of cellular networks by letting signals received from multiple BS to be jointly processed by the CP and potentially mitigating the effects of interference [34].

2.9.1 Architecture of Cloud Radio Access Network (CRAN)

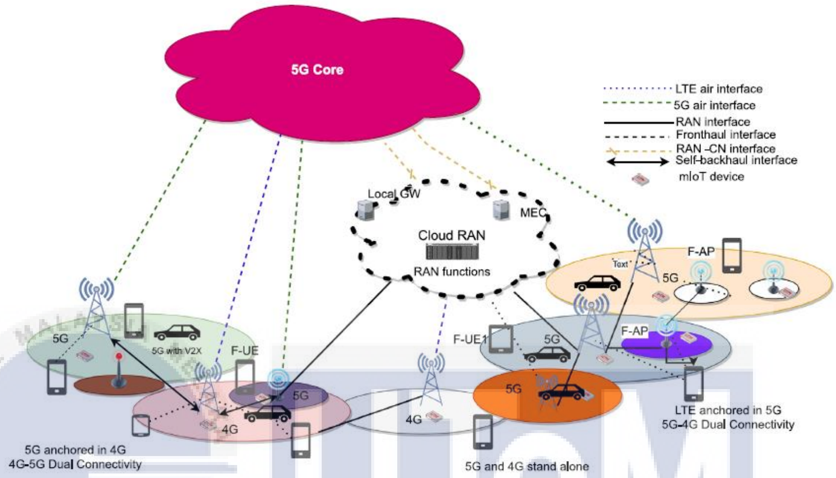

Figure 2.9 5G CRAN Architecture [16]

CRAN is a 5G cellular architecture resulting from existing traffic patterns and technological advancements. CRAN is built on centralized processing, cooperative radio, and real-time cloud architecture, which divides the BBU pool, base station (BS) and Remote Radio Head (RRH) to form a centralized pool, as illustrated in Figure 2.9. Centralized BBUs improved computing with virtualization and cloud computing technology [16]. CRAN's architecture seeks to limit the number of BSs while also reducing network power consumption. Furthermore, CRAN uses cooperation and virtualization technologies to offer dynamic resource allocation, increased spectrum efficiency, high bandwidth utilization, design flexibility and operating efficiency [16].

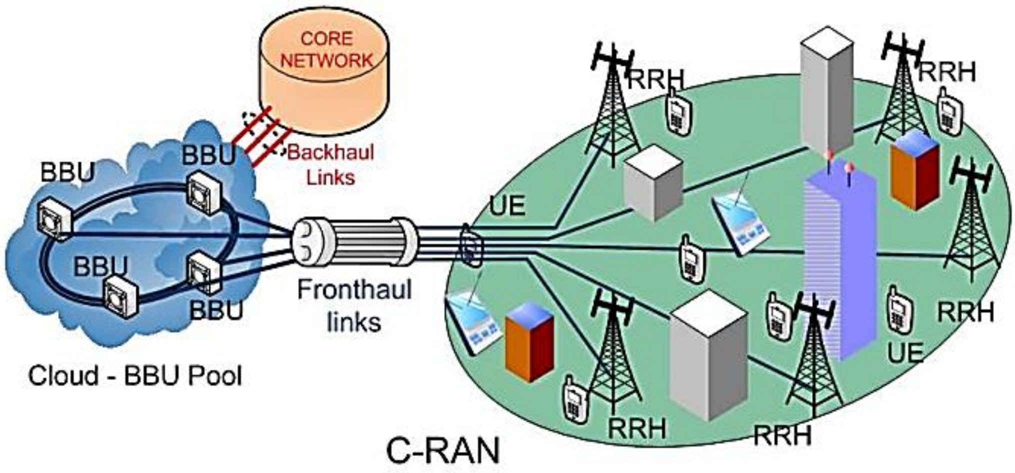

Figure 2.10 CRAN Architecture [35]

In addition, a major concept in CRAN is the separation of BS into BBU and RRH. The BBU is responsible for intense baseband signal processing activities, whereas the RRH is responsible for light computational duties such as signal modulation and amplification [16]. This also breaks the direct connection between BBUs and RRHs, thus each RRH is dynamically assigned to the BBU pool as illustrated in Figure 2.10 [35]. Besides, the RRH uses virtual BBUs to send and receive signals. The virtual assignment increases the processing power of the virtual BS based on the processors assigned to the real-time BBU pool [16].

2.9.2 Benefits of CRAN

Advantages of CRAN in terms of increased power efficiency and spectral efficiency. In contrast to traditional RAN, CRAN uses fewer BBUs, which significantly reduces power consumption. Additionally, the radio module can be naturally cooled by hanging the RRH from a pole or building wall, eliminating the need for many on-site support devices such as air conditioners [16].

In addition, CRAN enables the offload of energy-intensive data calculations from UEs and BSs to adjacent clouds. Therefore, it can conserve energy. Adopting cooperative radio technology will reduce the distance between RRHs and UEs, limit interference between RRHs, and lower energy bills in 5G networks [16]. As part of a related study on increasing spectral efficiency with CRAN usage, the pros and disadvantages of using licensed and unlicensed frequencies with various technologies for 5G CRAN fronthaul were investigated. In addition, cooperative and coordinated transmission approaches for increased SE are being investigated. Enhanced Inter-Cell Interference Coordination (eICIC) and Coordinated Multipoint Transmission (CoIMP) using RRHs linked to the same cloud [16].

Besides, Mobile Network Operators (MNOs) can lower 5G CRAN CAPEX and OPEX by virtualizing baseband activities on cloud platforms. CRAN architecture necessitates low-cost RRH spatiotemporal deployment, installation and maintenance. Multiple geographical processes are used to investigate the costs of deploying BS, transport networks and data centers. According to the analysis, CRAN can lower capital expenditures by up to 15% by combining backhaul options to connect BSs to data centers. Similarly, a two-phase approach to discover the best BS clustering scheme is proposed on CRAN [16]. This framework has proven to reduce deployment costs by 12.88%.

Next, improved mobility management is a key benefit of BBU pooling. The ability to dynamically assign BBU resources to RRHs for load balancing mobile traffic across BBU pools. The distributed BBU pool's load-balancing feature makes CRAN appropriate for dynamically distributed traffic. Serving RRH changes with UE movement, while serving BBU remains in the same pool because BBU has a greater coverage than typical BS. This enables the unevenly distributed traffic generated by UEs to be routed across virtual BSs within the same BBU pool. It helps MNOs with mobility management [16]. A location-based approach for tower clustering and BBU cluster categorization was presented, which used CRAN mobility and traffic pattern predictions.

2.9.3 Challenges of CRAN architecture

Despite all of the advantages that the CRAN architecture provides, numerous problems must be overcome to enable and facilitate CRAN adoption. The first challenge for CRAN concerns the prediction of high delays in the fronthaul network. In CRAN architecture, the fronthaul network connecting RRH to BBU pools needs to handle massive real-time traffic demands with high bandwidth and high latency requirements. In fact, the transmission delay of the link between the RRH and the central data center should be less than 1 millisecond (ms) to meet the Hybrid Automatic Repeat Request (HARQ) [31]. HARQ is the process that imposes the highest latency requirements on cellular networks where the maximum distance between the RRH and the BBU pool should not exceed 20 kilometers to 40 kilometers.

Besides, another key challenge for CRAN is the allocation of shared computing and radio resources among multiple cellular sites. Network operators must consider new approaches to determine the optimal strategy for allocating heterogeneous antenna requirements to available edge data centers while meeting hard latency requirements. The optimal mapping between RRH and BBU enables better resource utilization by reducing the number of edge data centers used to meet antenna requirements. This also minimizes network costs including CAPEX and OPEX [31].

In addition, Centralization of RAN functions in the BBU pool enables the exploitation of computational gains and improved cellular network capabilities for example in scheduling and flow control. Nonetheless, handling RAN functions in a central location increases fronthaul data rate requirements and imposes strict latency requirements [31]. Therefore, it is necessary to address the trade-off between the centralization of RAN functions and transport requirements by finding the optimal placement of baseband functions in CRAN architecture.

CHAPTER 3

METHODOLOGY

The research methodology is the most significant part of the study in Chapter 3. To ensure that the project is finished, a correct sequence and planning are required. The technique used in this project is critical since it aids in the completion of the project in a systematic manner to get the intended objectives. Furthermore, in order to achieve the best results in this chapter, each step must be followed exactly as planned. The research is divided into two sections, theoretical comprehension and simulation model. The first section collects all of the information from the study paper to ensure that the project is fully understood. In the second segment, a simulation model for a 5G network is developed using the modeling software OMNeT++.

3.1 Simulation Tool for OMNeT++ Software

In this study, simulating the 5G new radio requires an additional framework known as Simu5G. Simu5G can also be used as a network emulator, connecting simulated 5G networks to real-world systems. It is designed in C++ and provides a simple flexible interface with unlimited modifications [36]. New modules with other algorithms and protocols can also be created. Simu5G simulates a 5G radio access network (RAN) and core network data plane.

In this study, three tiers of system needs must be considered, the Open System Interconnection (OSI), the OMNeT++ and the frameworks layers. The OSI layer in this project is implemented with Windows 11, OMNeT++ version 6.0.1, Simu5G version 1.2.2, and INET version 4.5.2. Windows 11 offers a variety of advantages. Its user-friendly design improves productivity and usability by allowing users to easily discover and use the application. Furthermore, Windows 11 provides extensive program support, ensuring the compatibility and availability of a large range of software items.

Simu5G is a 5G NR network simulator based on the OMNeT++ framework that utilizes the INET library in this study. It enables a wide range of network configurations and capabilities by replicating the data plane of a 5G RAN or core network. This compatibility is suited for use with the simulation software OMNeT++. Figure 3.1 shows the OMNeT++ version 6 open simulator that was used in this investigation.

Figure 3.1 OMNeT++ IDE

This study focuses on single-cell standalone for VoIP applications in 5G networks, where VoIP applications are regarded as crucial applications for receiving data signals. A single-cell design consists of a base station and one piece of user equipment. The base station for this study is gNodeB. Figure 3.2 illustrates the simulated IDE for a single cell network.

Figure 3.2 Network connection for Single cell Standalone

There are only a few settings to consider in this single cell design. Table 3.1 describes the function of each setting in the Simu5G OMNeT++ simulation.

Table 3.1 Function of Components in Simu5G [37]

Setting component	**Function**
1. Channel control	The Channel Control module manages the network's radio channel allocation and usage. It handles channel assignment, interference control, and dynamic channel selection, among other functions. Channel Control guarantees that available radio resources are utilized properly and that interference between adjoining cells is minimized.
2. Routing recorder	The Routing Recorder module captures and records the routing information that is sent between cells. It gets routing updates and monitors the current network topology. The

	information gathered is used to study routing protocols, evaluate network performance, and assess the efficacy of routing strategies.
3. Configurator	The configuration module allows users to define and configure a wide range of network characteristics and settings. It enables the change of features such as cell architecture, traffic patterns, mobility models, and QoS requirements when developing simulation scenarios. Configuration allows researchers to examine different network configurations and evaluate their effects on system performance.
4. Binder	The Binder module coordinates and manages intercellular communication and synchronization. It allows information to travel between cells, such as handover signaling, resource allocation decisions, and scheduling policy coordination. The Binder ensures that cells in a single cell network communicate and collaborate effectively.
5. Carrier aggregation	Carrier Aggregation is a multicell design feature that combines multiple carriers or frequency bands to increase network bandwidth and capacity. The Carrier Aggregation module manages carrier allocation and aggregation across several cells, ensuring efficient spectrum usage, faster communication rates, and a better user experience.
6. Single cell standalone	A single cell standalone operates independently, making decisions within its own cell without relying on information from neighboring cell.

Table 3.2 describes the purpose of each component chosen for the single-cell standalone VoIP architecture. Each of these components has a specific purpose in networking, allowing for the smooth flow of data, device connection, and access to resources and services [37].

Table 3.2 Function of Component in Single Cell Standalone

Component	Function
1. Server	A server is a computer or device that provides services or resources to other networked devices. Servers run applications or websites, store and process data, and respond to client requests. They are responsible for processing and distributing data to associated clients or devices.
2. Router	A router is a network device that connects and routes data packets between different networks. Routers check network addresses to determine the most efficient data transmission channel. They facilitate communication between networks and ensure that data reaches its intended destination.
3. User Plane Function (UPF)	UPF enforces the QoS policies for user data traffic. It ensures that various types of services, applications and user data streams receive the appropriate level of service quality, including factors such as latency, throughput and reliability.
4. gNodeB base station (gnb)	gNodeB base station is responsible for establishing and maintaining the radio connection with user devices. It handles the transmission and reception of radio signals, including data and control information.
5. User equipment (UE)	End-user devices that connect to a network are referred to as User Equipment (UE), also known

	as terminals or client devices. Smartphones, tablets, laptop computers and other network-capable devices are examples of UEs. UEs send and receive data packets over the network, access server-provided services, and interact with other network components.

3.2 Research Methodology

This research is divided into several stages. The first step is to comprehend project research. This section covers 5G architecture theory, 5G radio access networks, and 5G network parameters. As previously said, this part is critical to the project's success.

Following the acquisition and comprehension of all theoretical knowledge, the 5G radio access network architecture is created using OMNeT++ software version 6.0.1. This program was chosen since it allows for the simulation of communication networks and the evaluation of performance in real time. To simulate the 5G RAN model, this software requires an additional installation library, Simu5G, as well as the INET Framework. The INET library modules serve as a bridge between the simulation environment and the actual networking devices in the network operating system [38].

The project's final phase involves simulating 5G radio access network parameters such as delay, throughput, packet sent and received, and total packet loss. This step necessitates effort and concentration to secure a successful outcome. As the desired outcome is within the 5G standard, an analysis is conducted using the generated graph. Figure 3.3 depicts the flowchart for this study process.

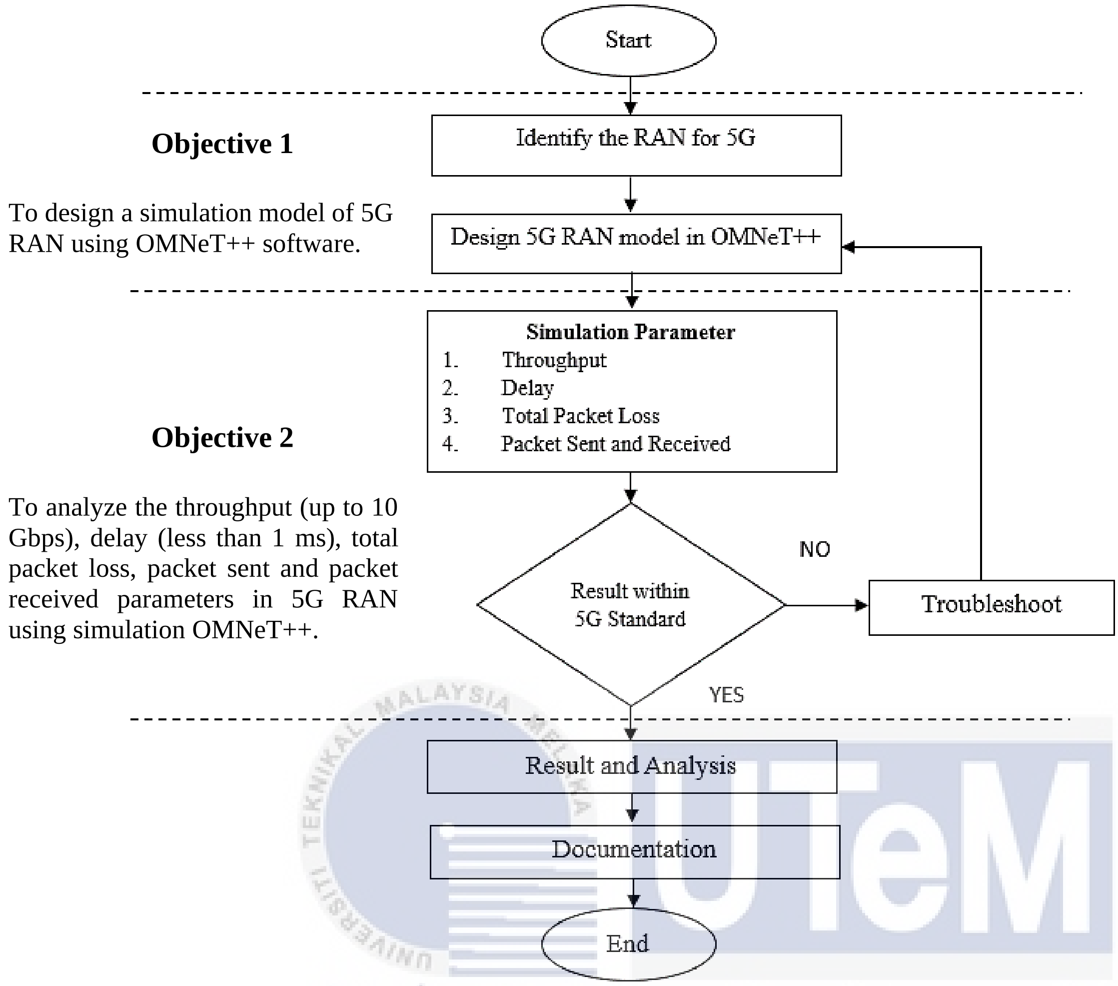

Figure 3.3 Flowchart of Research Methodology

3.3 OMNeT++ Simulation Tools

The OMNeT++ integrated development environment (IDE) is built on the Eclipse platform and includes new editors, wizards and views. The function of the software is to provide the configuring and creating models for the NED files, analysis and batch execution of the simulation results. Several of the libraries can be added to the software according to user preference [37]. Figure 3.4 below shows the IDE's interface, with the libraries used in this project listed on the left.

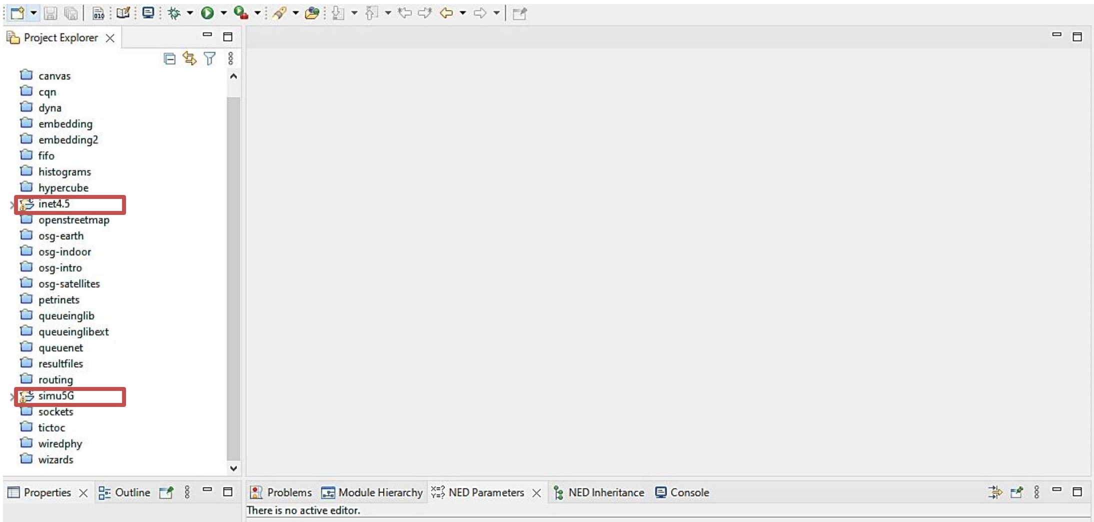

Figure 3.4 Default layout of OMNeT++ IDE

In this study, the Inet 4.5 and Simu5G libraries are included as extension libraries in OMNeT++ to enable network modeling and communication systems. Table 3.3 provides a brief description of the extension libraries utilized in this project.

Table 3.3 Description of Extension Library [37]

Library	**Explanation**
INET 4.5 Framework	The INET 4.5 framework is an open-source OMNeT++ toolkit aimed toward simulation networks. This framework contains protocols, models and tools for modeling and investigating communication networks, such as wired, wireless and mobile networks. Inet4.5 includes routers, switches, hosts and applications, as well as communication algorithms. The users can design several models and simulate the network situations to analyze the performance of the simulation.

Simu5G	The specialized library that is based on the INET framework and the OMNeT++ is the Simu5G. The simulation and research are focused on the 5G (fifth-generation) communication technologies. The features of the 5G networks in the Simu5G are the models, components and simulation. Network slicing, 5G radio access technologies, traffic modeling and mobility management are the capabilities that 5G has. The Simu5G library analyzes the performance of 5G networks, protocols and emerging technologies.

By incorporating the Inet 4.5 and Simu5G libraries into the OMNeT++ framework, users gain access to a collection of prebuilt models, protocols, and simulation components that may be used as building blocks for network simulations. These libraries save time building sophisticated network functions from scratch and are useful to simulate various network circumstances from wired networks to the state of the 5G communication system [39]. OMNeT++ is considered one of the best networking simulation tools and was chosen for numerous reasons:

a) Enable large-scale simulation, simulation models should be layered and composed of reusable components whenever possible.
b) It supports numerous wireless network extensions and libraries, including INET and Veins, allowing users to simulate various realistic scenarios.
c) Ease of use and support for learning communities. The OMNeT++ community is small but constantly growing. It features a graphical user interface (GUI)

and network description language (NED) to facilitate the design and visualization of simulations.

3.4 Overview of OMNeT++ Simulation

Figure 3.5 illustrates the methods for creating a network model and running a simulation.

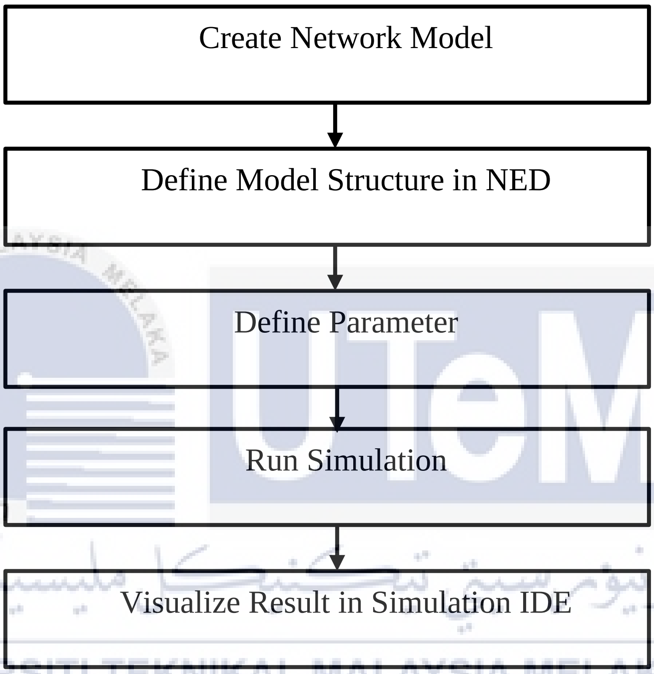

Figure 3.5 OMNeT++ Simulation Flow

To run the design in OMNeT++, the code is needed to implement the behavior and logic of the simulation model. The code used in this single-cell standalone network design is illustrated in the following diagram. Figure 3.6 shows the general setup of the code. The simulation time limit refers to the length of the simulation time and is set to 20 seconds. The third line sets data recording to a vector file. Vector file recording collects and stores simulation data in vector format for further analysis and viewing. It logs the values of numerous variables or statistics at different simulated time steps.

```
sim-time-limit=20s
**.routingRecorder.enabled = false
```

```
**.vector-recording = true
```

Figure 3.6 General code for simulation

The next step is to set the number of resource blocks for the uplink and downlink, as illustrated in Figure 3.7. In a cellular network, the uplink and downlink signals indicate the direction of data transfer. Both uplink and downlink communication occur between user equipment (UE) and network infrastructure. Downlink data transfer from the base station to the user equipment, and uplink data transmission from the user equipment to the base station. These are essential for establishing two-way communication between devices and networks.


```
**.numBands = 50 # this value should be kept equal to the number of RBs
```

Figure 3.7 Setting for Number of Resource Blocks

Figure 3.8 displays the power transmission settings used in the design. The power transferred at the user equipment is set to 26 watts, whereas the eNodeB power transmission is set to 40 watts.

```
**.ueTxPower = 26
**.eNodeBTxPower = 40
```

Figure 3.8 Setting for Power Transmission

Next, Figure 3.9 shows the declaration of the network used in the design which is, a single-cell standalone using Simu5G. In this design, the user equipment used one user and a single server for the data transmission. Each user should have one User Datagram Protocol (UDP) application. The number of UDP apps on the server should be equal to the number of user devices for downlink and uplink data transmission.

```
network = simu5g.simulations.NR.networks.SingleCell_Standalone
sim-time-limit=20s
```

```
*.ue[*].numApps = 1
```

```
*.server.numApps = 1
```

Figure 3.9 Type of Standalone Network

After that, Figure 3.10 shows the setting position for the base station gNodeB and the user equipment based on the x-axis and y-axis. The coordinate for gNodeB is at (450m,300m) while the coordinate for the user equipment is at (450m,400m). The position for this equipment is determined based on the model in this standalone design.

```
*.gnb.mobility.initialX = 450m
*.gnb.mobility.initialY = 300m
```

```
*.ue[0].mobility.initialX = 450m
*.ue[0].mobility.initialY =400m
```

Figure 3.10 Position of UE and Base Station

Figure 3.11 shows the configuration parameters that are related to a Voice over Internet Protocol (VoIP) downlink scenario. The box that indicates number one, shows the receiver configuration on the client side. This sets the application type for all UE instances to "VoIPReceiver." The local port for the first application (index 0) on each UE is set to 3000. Next, the second box that indicates number two shows the sender configuration on the server side. This sets the application type for all server instances to "VoIPSender." This configuration defines a scenario where VoIP data is sent from a server (VoIPSender) to multiple clients (VoIPReceiver) in a simulated network. The client is configured to listen on port 3000 and the server sends a VoIP packet of 40 bytes to the client's address on a dynamically assigned port starting from 3088. The transmission begins at a random time between 0 seconds and 0.02 seconds.


```
*.ue[*].app[*].typename = "VoIPReceiver"
*.ue[*].app[0].localPort = 3000
```
1

```
*.server.app[*].PacketSize = 40
*.server.app[*].destAddress = "ue[0]"
*.server.app[*].localPort = 3088+ancestorIndex(0)
*.server.app[*].typename = "VoIPSender"
*.server.app[*].startTime = uniform(0s,0.02s)
```
2

Figure 3.11 Configuration VoIP Downlink

Following that, Figure 3.12 shows a configuration scenario for VoIP uplink communication in a network simulation environment. The box number one is the receiver configuration on the server side. This sets the application type of all server instances to “VoIPReceiver.” The local port for each application on the server side is set to index 0, which is 3000 plus the index possibly UE or client. Box number two indicates sets of packet sizes for each application on all UE instances to 40. This configuration sets up a scenario where VoIP data is transmitted from multiple clients (VoIPSender) to a server (VoIPReceiver) in a simulated network. The clients are configured to send VoIP packets with a size of 40 bytes to the server's address on dynamically assigned ports starting from 3088. The server listens on port 3000 plus the index of the corresponding client. The transmission starts at a random time between 0s and 0.02s.

```
*.server.app[*].typename = "VoIPReceiver"
*.server.app[*].localPort = 3000+ancestorIndex(0
```
1

```
*.ue[*].app[*].PacketSize = 40
*.ue[*].app[*].destAddress = "server"
*.ue[*].app[*].localPort = 3088+ancestorIndex(0)
*.ue[*].app[*].typename = "VoIPSender"
*.ue[*].app[*].startTime = uniform(0s,0.02s)
```
2

Figure 3.12 Configuration VoIP Uplink

3.5 Summary

In this chapter, a thorough study has been conducted on single-cell standalone networks with an emphasis on VoIP applications for 5G networks. The OMNeT++ software is used to generate a viable design, and the Simu5G and INET libraries are utilized to run the simulation. Simu5G and INET have collaborated to create a comprehensive framework for modeling 5G networks, which contains both specific 5G features and traditional networking capabilities needed for a realistic and detailed simulation. This research technique provides a theoretical understanding of the software and method used. Finally, the parameters chosen in this study, which are delay, throughput, total packet loss, packet transmitted, and packet received, may be measured using the created graph from the simulation.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter provides a detailed description of the simulation tools and libraries utilized. The results for parameters such as transmitted and received data packets, packet loss, throughput, and delay in this solo network are analyzed. The analysis includes parameters that were measured during the simulation. The data from the simulation will be displayed on a graph.

4.2 Simulation Environment

Simulation use models to simulate the behavior of a genuine process or system. The model describes the key behaviors and characteristics of the chosen process or system, whereas the simulation depicts how the model changes over time and under various conditions. Simulation is often computer-assisted and use software-generated models to help managers and engineers make decisions or to teach employees. The simulation technique enhances learning and experimenting since the models in the design are visual and interactive [37]. The simulation can be simplified without affecting the results' adjustments by employing the original parameter utilized in the real system.

4.3 Standalone Single Cell for 5G Radio Access Network

5G standalone includes a new 5G packet core architecture and can provide 5G services without any existing 4G LTE devices on the network. In the 5G standalone architecture, a 5G RAN is made up of gNodeB (gNB) macrocell base stations and New Radio (NR) interfaces that link to the 5G packet core network and function as "standalone" entities. Single-cell means that the network is focused on providing coverage and connectivity within a specific area that is served by a single cell or base station [16]. Single-cell design requires the combined Inet 4.5 and Simu5G libraries. Several components used from Inet 4.5 version are server, router and User Plane Function (UPF), while components from Simu5G libraries are the Next Generation Node B (gNodeB) and the user equipment (UE).

Inet 4.5 and Simu5G libraries contain predefined network description (NED) files that can be utilized in simulations without requiring any programming. In OMNeT++, the Inet 4.5 framework includes preloaded NED files that can be utilized in simulation without the need to generate them. The Inet 4.5 library comprises the NED files, which can be described in the structure and components of the network model. It can be used as is or adapted to suit individual simulation requirements. This will allow the users to quickly summarize and organize the functionality into a network model and make it easier to manage and modify the models [37].

Figure 4.1 Standalone Single Cell Design Network

Figure 4.1 illustrates the design for a single-cell standalone of a 5G radio access network using OMNeT++ software. This architecture has two configurations, downlink data transfer and uplink data transmission. The data transfer for the downlink comes from the base station (gnb) to the user equipment devices (UE0). The contents for the downlink transmission include voice call data, information from the internet and other information that will sent to user devices. Meanwhile, for the uplink, the data transmission is from the user equipment (UE0) or end-user device to the base station (gnb) [20]. The contents for uplink include text messages, voice calls and data uploads.

4.4 Parameter Results

The simulation for this standalone design was run to acquire the results for the parameters that have been mentioned in the objective for the throughput, delay and packet ratio. The packet ratio contains sent packet bytes, received packet bytes and total packet loss from the data transmission. The output vector file contains the results of the parameters mentioned above. The selected data can then be displayed as the content of a line chart graph or a vector by selecting the desired parameters.

4.4.1 Result from Downlink Single Cell Standalone

The first scenario in this single-cell design is a downlink data transmission. Data for the downlink is transmitted from the base station (gnb) to the user equipment devices (ue0) that focus on VoIP applications for the 5G network. Figure 4.2 shows the mean value of sent packet bytes and received packet bytes for the upper layer and lower layer at (ue0) and the mean value for throughput, delay and total packet loss obtained from the downlink simulation at (ue0). The data value from the parameters can be read directly from the highlighted part.

Experi...	M...	Re...	Module	Name	Count	Mean
VoIP-DL		#0	SingleCell_Standalone.ue[0].cellularNic.nrMac	sentPacketToLowerLayer:vector(packetBytes)	804	1
VoIP-DL		#0	SingleCell_Standalone.gnb.cellularNic.mac	macDelayDl:vector	804	0.004000 s
VoIP-DL		#0	SingleCell_Standalone.ue[0].cellularNic.nrMac	sentPacketToUpperLayer:vector(packetBytes)	804	71
VoIP-DL		#0	SingleCell_Standalone.ue[0].cellularNic.nrRlc.um	receivedPacketFromLowerLayer:vector(packetE	804	71
VoIP-DL		#0	SingleCell_Standalone.ue[0].cellularNic.nrRlc.um	rlcPduThroughputDl:vector	804	0 Bps
VoIP-DL		#0	SingleCell_Standalone.ue[0].cellularNic.nrRlc.um	rlcPduDelayDl:vector	804	0.004000 s
VoIP-DL		#0	SingleCell_Standalone.ue[0].cellularNic.nrRlc.um	rlcThroughputDl:vector	804	2,697.688823 Bps
VoIP-DL		#0	SingleCell_Standalone.ue[0].cellularNic.nrRlc.um	rlcPacketLossDl:vector	804	0
VoIP-DL		#0	SingleCell_Standalone.ue[0].cellularNic.nrRlc.um	rlcPacketLossTotal:vector	804	0
VoIP-DL		#0	SingleCell_Standalone.ue[0].cellularNic.nrRlc.um	rlcDelayDl:vector	804	0.004634 s
VoIP-DL		#0	SingleCell_Standalone.ue[0].cellularNic.nrRlc.um	sentPacketToUpperLayer:vector(packetBytes)	804	69
VoIP-DL		#0	SingleCell_Standalone.ue[0].cellularNic.nrRlc.um	rlcPduPacketLossDl:vector	804	0
VoIP-DL		#0	SingleCell_Standalone.ue[0].cellularNic.pdcpRrc	receivedPacketFromLowerLayer:vector(packetE	804	69
VoIP-DL		#0	SingleCell_Standalone.ue[0].cellularNic.pdcpRrc	sentPacketToUpperLayer:vector(packetBytes)	804	68
VoIP-DL		#0	SingleCell_Standalone.ue[0].udp	packetReceived:vector(packetBytes)	804	48
VoIP-DL		#0	SingleCell_Standalone.ue[0].app[0]	voIPReceivedThroughput:vector	804	1,563.877579 Bps
VoIP-DL		#0	SingleCell_Standalone.ue[0].cellularNic.nrMac	harqErrorRate_1st_Dl:vector	804	0
VoIP-DL		#0	SingleCell_Standalone.ue[0].cellularNic.nrMac	harqErrorRateDl:vector	804	0
VoIP-DL		#0	SingleCell_Standalone.ue[0].cellularNic.nrMac	harqTxAttemptsDl:vector	804	1

Figure 4.2 Output vector for Packet Sent and Received, Throughput, Delay and Total Packet Loss at Downlink

Next, Figure 4.3 and Figure 4.4 shows the average packet ratio for received packet bytes and sent packet bytes within 20 seconds. The sent packet and received packet both have the same mean value of 71 bytes. The output reading is maintained from 0 seconds to 20 seconds at 71 bytes. However, from 3.5 seconds until 5.6 seconds the data transmission is not available. This condition is called an idle state. This occur due to the no active data transmission to be sent and received during that period. Furthermore, this situation might happen when the users are not actively using the network, or when there is no ongoing communication between devices [13].

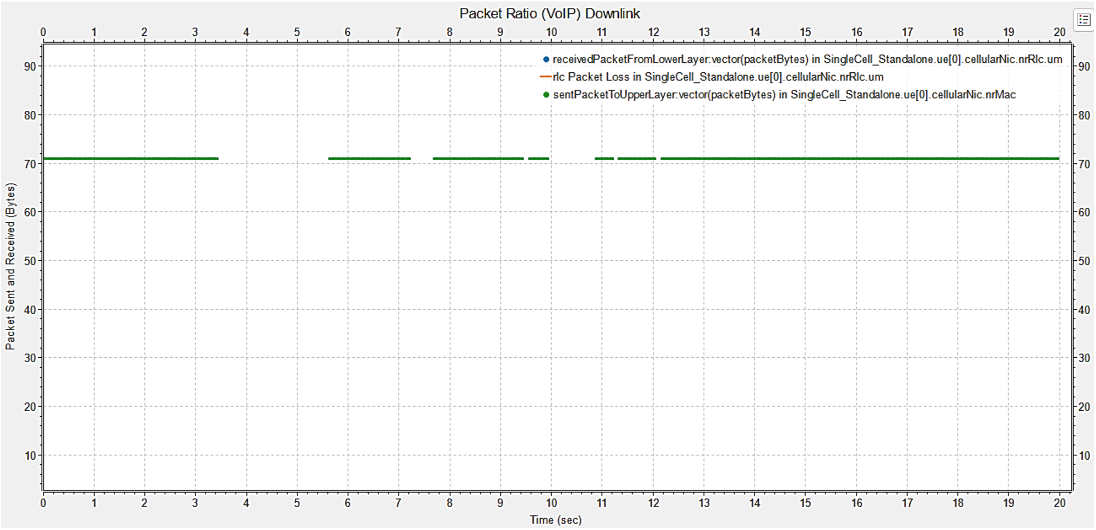

Figure 4.3 Average Sent Packet to Upper Layer

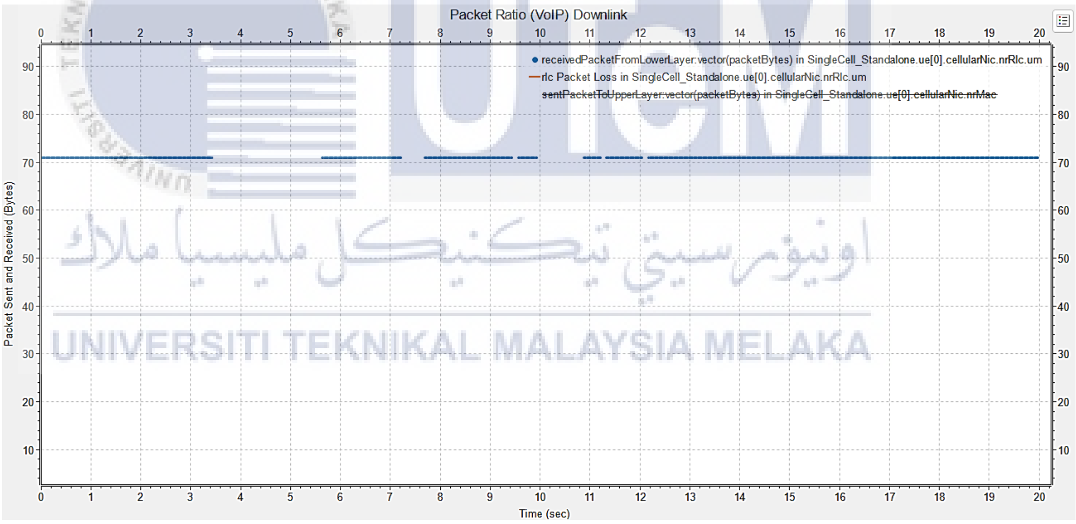

Figure 4.4 Average Received Packet from Lower Layer

Figure 4.5 shows the total packet loss that has been run within 20 seconds. The output value for the total packet loss is zero because there are no losses from the base station to the user equipment in the downlink data transmission.

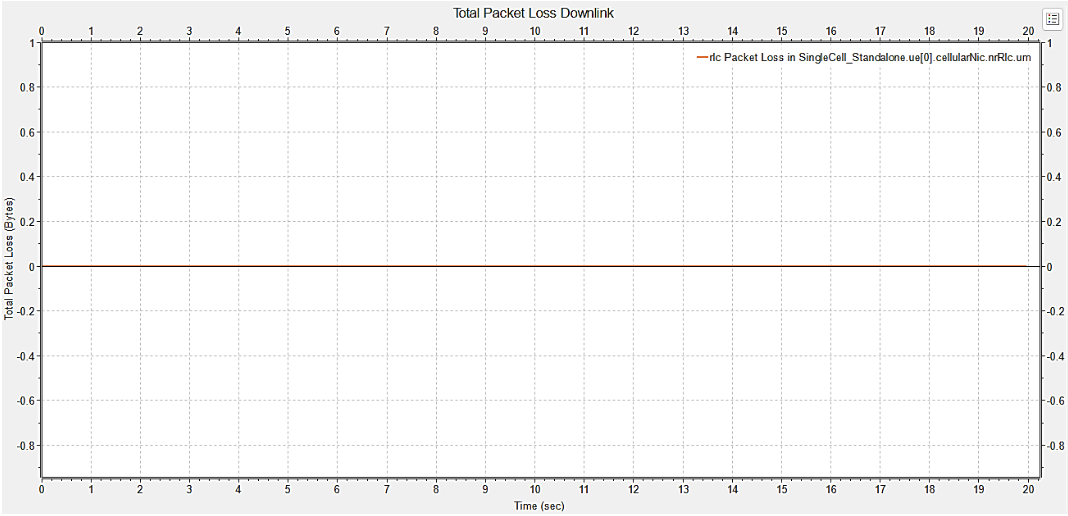

Figure 4.5 Average Total Packet Loss at Downlink

Afterward, Figure 4.6 shows the average delay output at the user equipment. The delay refers to the time taken for the data transmission to go from the base station to the user equipment. The simulation result average for the delay in this single standalone network is maintained at 0.00478 milliseconds from 12.2 to 20 seconds at the end of the simulation time limit. The delay for this simulation is smaller than the value mentioned by the 5G standard which is less than 1 millisecond [18]. This proved that a single cell standalone has achieved less than 1 millisecond for the delay data transmission.

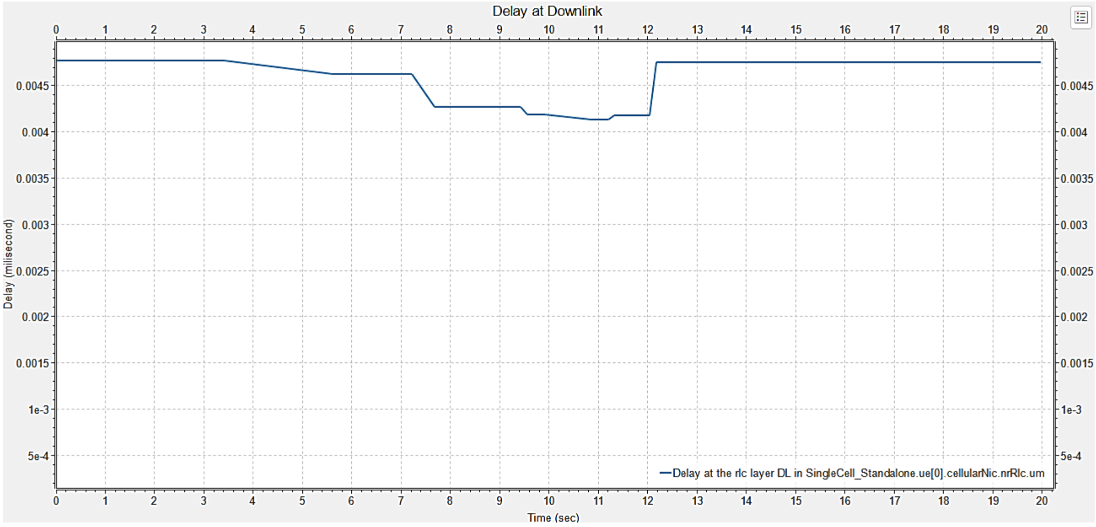

Figure 4.6 Average Delay for Downlink

The amount of data or information that a user receives to communicate across a communication channel or system is known as throughput. Figure 4.7 shows the average throughput at layer downlink in a single-cell network. The throughput reading in this time limit from 0 seconds to 20 seconds is starting from 3400 Gbps to 2800 Gbps. At the range of 2.2 seconds, the throughput drops from 3400 Gbps at 3.4 seconds to 2100 Gbps at 5.6 seconds. This may occur due to network interference, bandwidth limitation or hardware issues [10]. However, the throughput data starts to increase at 5.6 seconds again and shows a stable increasing reading toward the end of the time simulation. In this single-cell standalone design, the amount of throughput value at user equipment is less than 10 Gbps as mentioned in the 5G standard. This simulation results for the downlink show the value of throughput low compared to the 5G standard due to the path between UE and the base station is not in the line of sight [14].

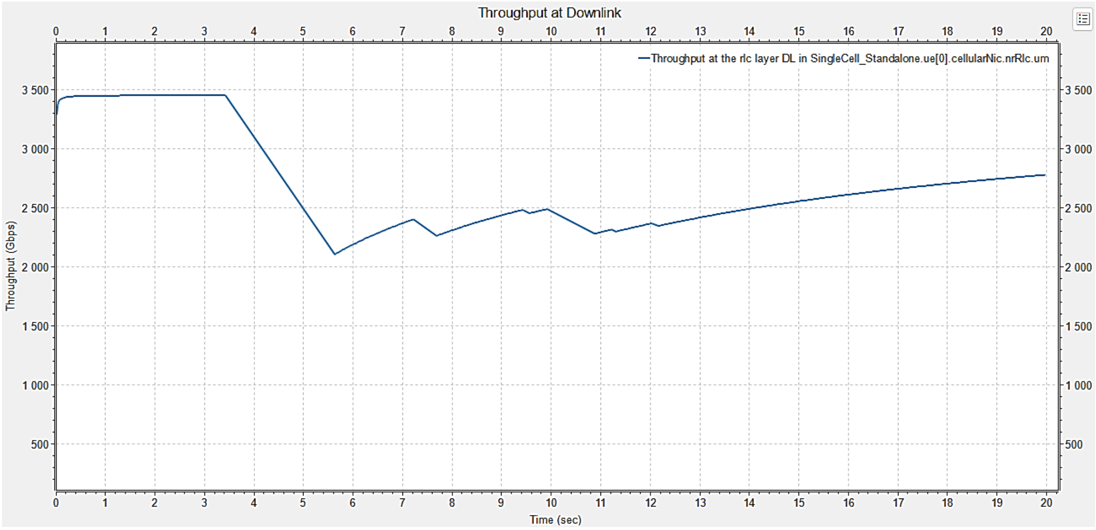

Figure 4.7 Average Throughput for Downlink

4.4.2 Result from Uplink Single Cell Standalone

Furthermore, the second scenario in this single-cell design involves uplink data transmission. The data transmission for the uplink comes from the user equipment (ue0) to the base station (gnb), which concentrates on VoIP applications for the 5G network. Figure 4.8 shows the mean value of sent packet bytes and received packet bytes for the upper layer and lower layer at the (gnb) and the mean value for throughput, delay and total packet loss at (ue0) that obtained from the uplink simulation. The data value from the parameters can be read directly from the highlighted part.

Experi...	M...	Re...	Module	Name	Count	Mean
VoIP-UL		#0	SingleCell_Standalone.ue[0].cellularNic.nrRlc.um	rlcPacketLossUl:vector	1216	0
VoIP-UL		#0	SingleCell_Standalone.ue[0].cellularNic.nrRlc.um	sentPacketToLowerLayer:vector(packetBytes)	608	71
VoIP-UL		#0	SingleCell_Standalone.ue[0].cellularNic.nrPhy	averageCqiUl:vector	608	15 cqi
VoIP-UL		#0	SingleCell_Standalone.ue[0].cellularNic.nrChanne	rcvdSinrUl:vector	608	45.130089 dB
VoIP-UL		#0	SingleCell_Standalone.ue[0].cellularNic.nrMac	macDelayUl:vector	608	0.004000 s
VoIP-UL		#0	SingleCell_Standalone.gnb.cellularNic.mac	sentPacketToUpperLayer:vector(packetBytes)	608	71
VoIP-UL		#0	SingleCell_Standalone.gnb.cellularNic.rlc.um	receivedPacketFromLowerLayer:vector(packetE	608	71
VoIP-UL		#0	SingleCell_Standalone.ue[0].cellularNic.nrRlc.um	rlcPduThroughputUl:vector	608	0 Bps
VoIP-UL		#0	SingleCell_Standalone.ue[0].cellularNic.nrRlc.um	rlcPduDelayUl:vector	608	0.004000 s
VoIP-UL		#0	SingleCell_Standalone.ue[0].cellularNic.nrRlc.um	rlcThroughputUl:vector	608	2,703.378602 Bps
VoIP-UL		#0	SingleCell_Standalone.ue[0].cellularNic.nrRlc.um	rlcPacketLossTotal:vector	608	0
VoIP-UL		#0	SingleCell_Standalone.ue[0].cellularNic.nrRlc.um	rlcDelayUl:vector	608	0.008502 s
VoIP-UL		#0	SingleCell_Standalone.gnb.cellularNic.rlc.um	sentPacketToUpperLayer:vector(packetBytes)	608	69
VoIP-UL		#0	SingleCell_Standalone.ue[0].cellularNic.nrRlc.um	rlcPduPacketLossUl:vector	608	0
VoIP-UL		#0	SingleCell_Standalone.gnb.cellularNic.pdcpRrc	receivedPacketFromLowerLayer:vector(packetE	608	69
VoIP-UL		#0	SingleCell_Standalone.gnb.cellularNic.pdcpRrc	sentPacketToUpperLayer:vector(packetBytes)	608	68
VoIP-UL		#0	SingleCell_Standalone.gnb.udp	packetSent:vector(packetBytes)	608	84
VoIP-UL		#0	SingleCell_Standalone.gnb.pppIf.queue	incomingPacketLengths:vector	608	832 b
VoIP-UL		#0	SingleCell_Standalone.gnb.pppIf.queue	queueingTime:vector	608	0 s
VoIP-UL		#0	SingleCell_Standalone.gnb.pppIf.queue	outgoingPacketLengths:vector	608	832 b
VoIP-UL		#0	SingleCell_Standalone.gnb.pppIf.ppp	rcvdPkFromHl:vector(packetBytes)	608	104

Figure 4.8 Output vector for Sent and Received Packet, Throughput, Total Packet Loss and Delay at Uplink

After that, Figure 4.9 and Figure 4.10 shows the average packet ratio for sent packet bytes and received packet bytes that have been run within 20 seconds. The sent packet and received packet both have the same mean value of 71 bytes. The output reading is maintained from 0 seconds to 20 seconds at 71 bytes. However, from 8 seconds to 10 seconds and from 10 seconds to 14.2 seconds the data transmission is not available. This condition is called an idle state. This occur due to the no active data transmission to be sent and received during that period. Furthermore, this situation might happen when the users are not actively using the network, or when there is no ongoing communication between devices [13].

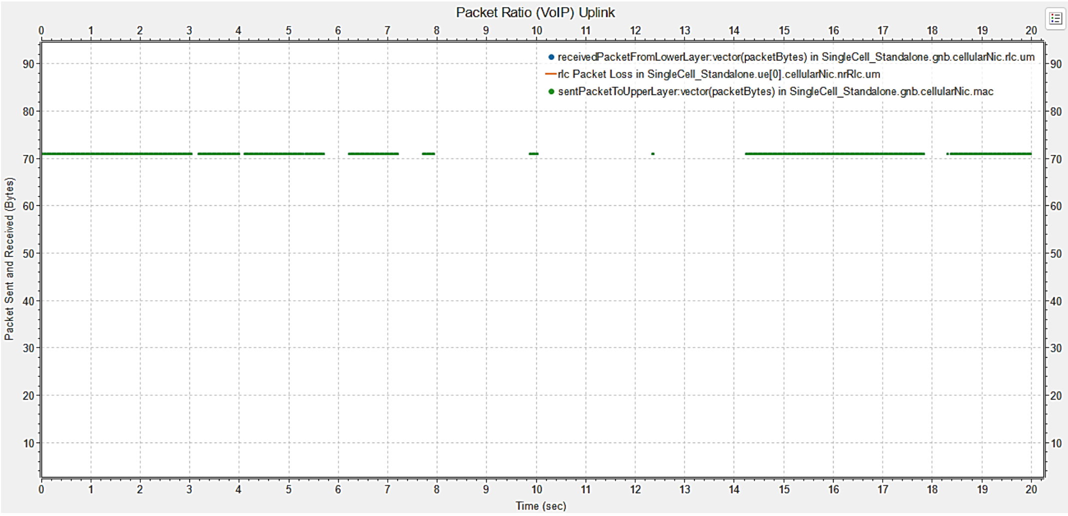

Figure 4.9 Average Sent Packet to Upper Layer

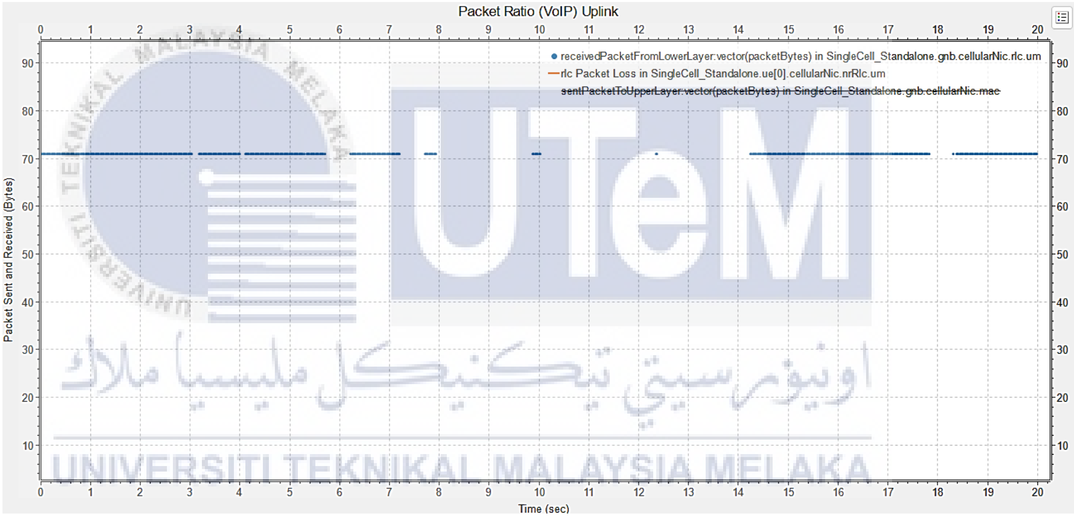

Figure 4.10 Average Received Packet from Lower Layer

Figure 4.11 depicts the total packet loss that occurred within 20 seconds. The total packet loss value is zero since there are no data losses from user equipment to the base station during uplink data transmission.

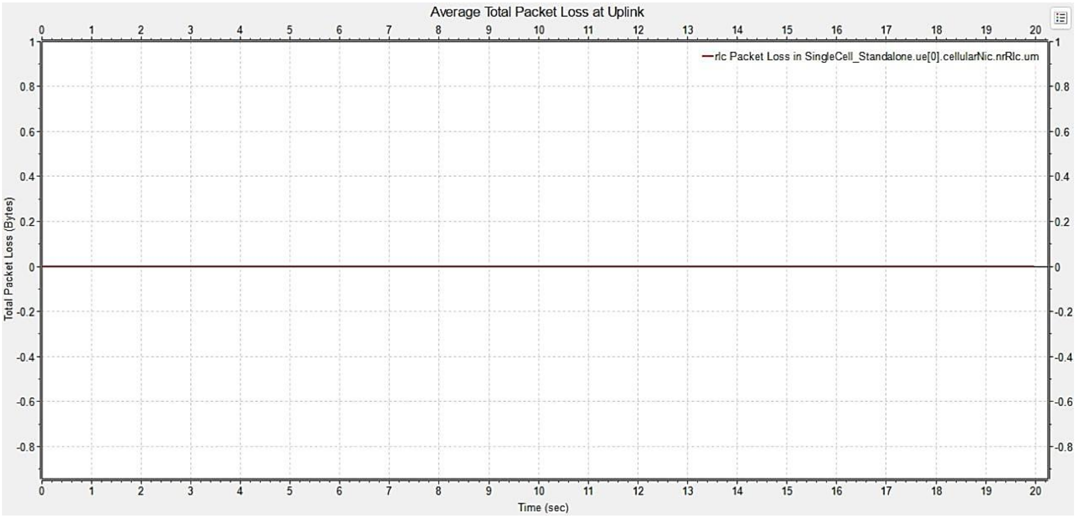

Figure 4.11 Average Total Packet Loss at Uplink

Afterward, Figure 4.12 shows the average delay output at the user equipment. The delay refers to the time it takes for data transmission from the user equipment (ue0) to the base station (gnb) of the design network. The simulation result average for the delay in this single standalone network is measured at 0.0082 milliseconds at the end of the simulation time limit. The delay for this simulation is smaller than the value mentioned by 5G forum which is less than 1 millisecond [18]. This proved that a single cell standalone has achieved less than 1 millisecond for the delay at uplink data transmission.

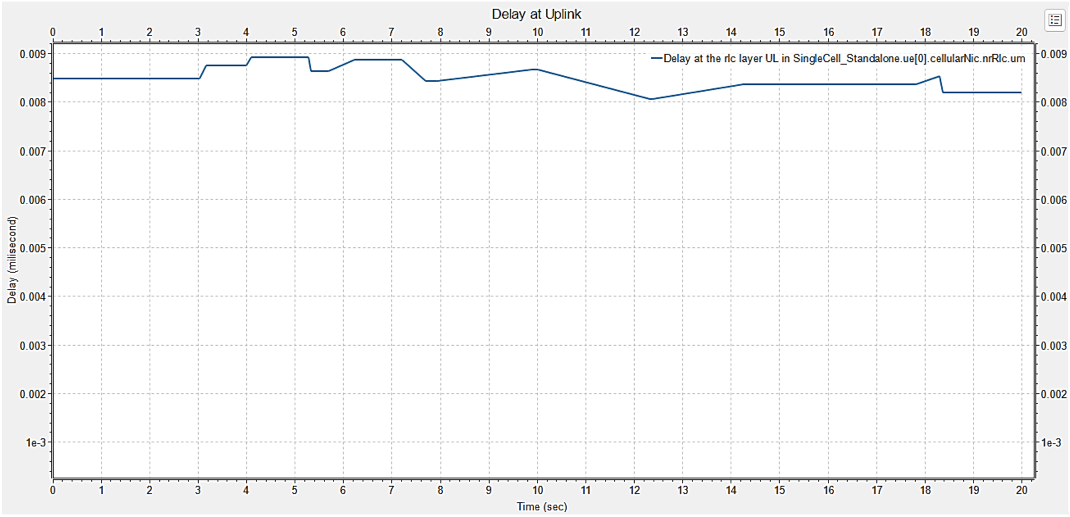

Figure 4.12 Average Delay for Uplink

The amount of data or information that a user receives to communicate across a communication channel or system is known as throughput. Figure 4.13 shows the average throughput at layer uplink in a single-cell network. The throughput reading in this time limit from 0 seconds to 20 seconds is starting from 3800 Gbps to 2100 Gbps. At the range of 6.2 seconds, the throughput drops dramatically from 2900 Gbps at 8 seconds to 1700 Gbps at 14.2 seconds. This may occur due to network interference, bandwidth limitation or hardware issues. However, the throughput data starts to increase at 14.2 seconds and shows a stable increasing reading toward the end of the time simulation. This single-cell uplink throughput in this design has not reached the 5G standard to achieve up to 10 Gbps [10] as shown in the figure below where the throughput for this design network at 2100 Gbps. This simulation results for the uplink show the value of throughput low compared to the 5G standard due to the path between UE and a base station is not in the line of sight [14].

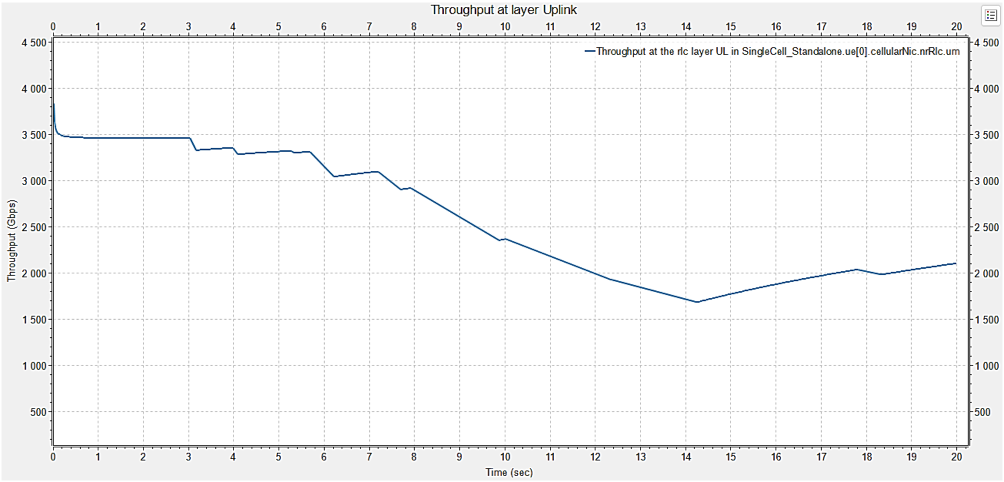

Figure 4.13 Average Throughput for Uplink

4.4.3 Comparison of Downlink and Uplink Data Transmission

Table 4.1 Comparison of Downlink and Uplink [3]

Data transmission / **Characteristics**	**Downlink**	**Uplink**
1. Direction of data transmission	The direction of data transmission from the base station (gNodeB) to the user equipment.	The direction data from user equipment (UE) or end-user devices to the base stations (gNodeB).
2. Contents of information	The data content of the internet, voice calls and other information that sent to the user device.	The data includes voice calls, text messages and data uploads.
3. Latency considerations	Ensures that the user receives the other person's audio and video quickly.	For the video call, low uplink latency ensures the user voice and video transmit with minimal delay.
4. Packet ratio	Sent packet: count 804 Received packet: count 804 Total packet loss: 0	Sent packet: count 608 Received packet: count 608 Total packet loss:0

5. Throughput with a limit of 20 seconds	2800 Gbps	2100 Gbps
6. Delay with a limit time of 20 seconds	0.00478 ms	0.0082 ms

Therefore, Table 4.1 shows the data transmission for downlink throughput is higher compared to the uplink throughput. For the downlink, the delay shows the measured value at 0.00478 ms less than the uplink transmission. This shows user devices at downlink receive the content of audio and radio quickly compared to the uplink to transmit the signal.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1 Conclusion

The primary purpose of this research is to assess the end-to-end performance of 5G in Radio Access Networks (RAN). In this research, end-to-end performance evaluation involves the full 5G networks from the user equipment to the core network, focusing on VoIP applications. There are four parameters selected in this research which are delay, throughput, total packet loss, packet sent and packet received that were successfully simulated using OMNeT++ software. From this single-cell standalone design, there are two configurations which are Scenario 1 downlink data transmission and Scenario 2 uplink data transmission. Scenario 1 is where the data transmission from the base station (gnb) to the user equipment (ue0) while for Scenario 2 the data transmission is from user equipment (ue0) to the base station (gnb).

From the simulation in this single-cell design, Scenario 1 shows the total of packets sent and packets received at 71 Bytes during the 20-second time simulation limit. The total packet loss for this scenario is zero due to the no losses during the data transmission. After that, the simulation results for throughput measured in this scenario is 2800 Gbps which is below the 5G standard that mentioned up to 10 Gbps. This may occur due to the path between the user equipment (ue0) and the base station (gnb) is not in the line of sight. However, the parameters result for the delay in Scenario 1 at 0.00478 ms has achieved the 5G standard which is less than 1 millisecond.

Next, Scenario 2 for the uplink data transmission. The total number of packets transmitted and received in this simulation is the same as Scenario 1, which is 71 bytes throughout the 20-second time simulation limit. The total packet loss in Bytes for Scenario 2 is zero due to no losses during the transmission of the sent packet and received packet. The throughput result measured in this scenario is 2100 Gbps which is below the 5G standard that mentioned up to 10 Gbps. This shows the value throughput for Scenario 1 is higher than Scenario 2. This could occur if the path between the user equipment (ue0) and the base station (gnb) is not in the line of sight. In addition, the data transmission in Scenario 2 includes voice calls, text messages and data uploads. However, the parameters result for the delay in Scenario 2 at 0.0082 ms that achieved the 5G standard which is less than 1 millisecond.

This 5G offers unparalleled speed, minimal latency, and huge connectivity [1]. Higher data rates and lower latency will enable innovative applications and services that include virtual reality (VR) and augmented reality (AR) for the Internet of Things.

In conclusion, the overall findings of this research objective are achieved. The knowledge from this research will have a positive impact on quality education as the 4th Sustainable Development Goal (SDG) where the 5G technology can enhance the access to quality education by enabling virtual classrooms and online learning experiences. Next, another environment and sustainability that 5G facilitates is the development of smart cities with transportation systems and connected infrastructure which refers to SDG 11th [40].

5.2 Future Works

Although this study objective is successful, there are few recommendations to increase the value of throughput up to 10 Gbps. First, during the simulation conducted, the throughput value that can be obtained from the graph is 2800 Gbps at Downlink and 2100 Gbps at Uplink for the 20-second simulation time limit. Therefore, to make this throughput value achieve up to 10 Gbps in a 5G network, there are a few recommendations such as dual connectivity that can be implemented for a device connected to multiple base stations simultaneously to enhance the throughput using multiple network paths. Dual Connectivity considerably increases data throughput by combining the capabilities of both the primary and secondary cells. This is especially useful in situations where the user's data requirements exceed the capacity of a single cell [14]. This can improve coverage and reliability by allowing the UE to stay connected even if one of the cells' signal quality degrades. The secondary cell will serve as a backup, resulting in a more reliable and robust communication relationship.

The next step is to integrate advanced antenna technologies like Massive MIMO (Multiple Input Multiple Output) to expand the coverage and capacity of the network design. Massive MIMO base stations have a large number of antennas, frequently in the hundreds or even thousands. These antennas work together simultaneously to transmit and receive the signals. It improves spectral efficiency by allowing multiple data streams to be sent simultaneously to numerous customers on the same time-frequency resource. This leads to faster data rates and more network capacity [3]. The use of beamforming in Massive MIMO improves coverage and range. The system can deliver reliable communication over great distances by focusing transmission energy to specific locations or user devices.

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APPENDICES

```
image-path=../../../images
output-scalar-file-append = false
sim-time-limit=20s
**.routingRecorder.enabled = false

############### Statistics ##################
output-scalar-file = ${resultdir}/${configname}/${repetition}.sca
output-vector-file = ${resultdir}/${configname}/${repetition}.vec
seed-set = ${repetition}
**.vector-recording = true

################ Mobility parameters #####################
# *

**.mobility.constraintAreaMaxX = 1000m
**.mobility.constraintAreaMaxY = 1000m
**.mobility.constraintAreaMinX = 0m
**.mobility.constraintAreaMinY = 0m
**.mobility.constraintAreaMinZ = 0m
**.mobility.constraintAreaMaxZ = 0m
**.mobility.initFromDisplayString = false

############### Number of Resource Blocks ################
**.numBands = 50 # this value should be kept equal to the number of RBs

############### Transmission Power ##################
**.ueTxPower = 26
**.eNodeBTxPower = 40
**.targetBler = 0.01
**.blerShift = 5

############### IPv4 configurator config #################
*.configurator.config = xmldoc("./demo.xml")


#------------------------------------#
# Config Standalone
#
# Topology configuration for the exemplary scenario for NR Standalone
deployment
#
[Config Standalone]
network = simu5g.simulations.NR.networks.SingleCell_Standalone
sim-time-limit=20s

############### e/gNodeB configuration #################
```

```
*.gnb.mobility.initialX = 450m
*.gnb.mobility.initialY = 300m

############## UE configuration #################
*.numUe = 1

# connect the UE's NIC to the corresponding serving gNB (NR side only)
*.ue[0].macCellId = 0
*.ue[0].masterId = 0
*.ue[0].nrMacCellId = 1
*.ue[0].nrMasterId = 1

# UE position
*.ue[0].mobility.initialX = 450m
*.ue[0].mobility.initialY = 400m
#-----------------------------------#



#-----------------------------------#
# Config VoIP-DL
#
# General configuration for Voice-over-IP DL traffic to the UE
#
[Config VoIP-DL]
extends=Standalone

# one UDP application for each user
*.ue[*].numApps = 1

# the amount of UDP applications on server should be equal to
(numUEs)*(ue[*].numApps)
*.server.numApps = 1

#============ Application Setup ============
*.ue[*].app[*].typename = "VoIPReceiver"
*.ue[*].app[0].localPort = 3000

*.server.app[*].PacketSize = 40
*.server.app[*].destAddress = "ue[0]" # obtain the address of the client
by reading its index in the array of udp Apps
*.server.app[*].localPort = 3088+ancestorIndex(0)
*.server.app[*].typename = "VoIPSender"
*.server.app[*].startTime = uniform(0s,0.02s)
#-----------------------------------#



#-----------------------------------#
# Config VoIP-UL
#
# General configuration for Voice-over-IP UL traffic from the UE
#
[Config VoIP-UL]
extends=Standalone

# one UDP application for each user
*.ue[*].numApps = 1
```

```
# the amount of UDP applications on server should be equal to
(numUEs)*(ue[*].numApps)
*.server.numApps = 1

#============= Application Setup =============
*.server.app[*].typename = "VoIPReceiver"
*.server.app[*].localPort = 3000+ancestorIndex(0)

*.ue[*].app[*].PacketSize = 40
# obtain the address of the client by reading its index in the array of
udp Apps
*.ue[*].app[*].destAddress = "server"
*.ue[*].app[*].localPort = 3088+ancestorIndex(0)
*.ue[*].app[*].typename = "VoIPSender"
*.ue[*].app[*].startTime = uniform(0s,0.02s)
#-----------------------------------#
```