

5G ENHANCEMENT OF FEMTOCELL FROM NSA TO SA

A Project Report Phase – II

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering degree in Electronics and Communication Engineering

by

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SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

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BONAFIDE CERTIFICATE

This is to certify that this Project Phase-II Report is the bonafide work of **KARANAM SUDHA SAGARI (Reg.no:39130209)** and **A KHATEJATHULL KUBRA (Reg.no:39130224)** who carried out the project entitled "**5G ENHANCEMENT OF FEMTOCELL FROM NSA TOSA**" under my supervision from November 2022 to April 2023.

Internal Guide & Head of the Department

Dr.T.RAVI, M.E., Ph.D.,

25.04.2023

Submitted for Viva voce Examination held on _____

**Internal Examiner
Examiner**

External

DECLARATION

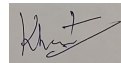
We, **KARANAM SUDHA SAGARI (39130209)** and **A. KHATEJATHULL KUBRA (39130224)** hereby declare that the Project Report entitled “**5G ENHANCEMENT OF FEMTOCELL FROM NSA TO SA**” done by us under the guidance of **Dr. T. RAVI, M.E., Ph.D.** is submitted in the partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Electronics & Communication Engineering.

DATE: 25.04.2023

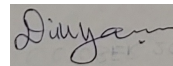
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SIGNATURE OF CANDIDATES

1.



2.



ACKNOWLEDGEMENT

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We express our gratitude to our parents for their constant encouragement and support for the completion of the project.

ABSTRACT

A Femtocell is a Wireless Access Point (WAP) used to enhance indoor Connectivity. Unlike other connectivity options, femtocells connect back through the internet to provide in-home or office cellular connectivity.

Femtocells look and operate like routers, and users can place femtocells near their current hardware setups. Anyone can purchase a femtocell for their home or small business to boost up the cellular connectivity. Multi-Standard (UMTS & LTE) Femto Access Point (MS FAP) wireless base station.

MS FAP is a Multi Standard Base Station which can host both UMTS and LTE cell that is 3GPP compliant. MS FAP is primarily targeted for Indoor (Residential and Small & Medium Enterprise) market segments and is deployed in various markets world-wide. MS FAP is in enhancements from LTE to 5G NSA and 5G SA.

MS FAPs are constantly being upgraded to keep up with the latest advancements. For instance, MS FAPs are now being enhanced to support LTE to 5G NSA (Non-Standalone) and 5G SA (Standalone), enabling them to seamlessly transition to the next generation of wireless connectivity. This makes MS FAPs a future-proof option for users looking to improve their indoor cellular coverage in a rapidly changing technological landscape.



Ref ID : HR/2023/7973/0603

Date : 24 March 2023

Name : A Khatejathull Kubra

Employee Id : 62367973

Subject : Relieving and Experience Letter

Dear A Khatejathull Kubra,

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Nehru Place, New Delhi-110019,
India

This is to certify that you were employed with Nokia from **06 June 2022** to **06 March 2023**. You were designated as **Student Trainee** at the time of leaving the organization.

You stand relieved from the services on the closing hours of **06 March 2023**.

We would like to reiterate your continuing obligation to confidentiality with respect to any proprietary and confidential information that you may have had access to during the course of your employment.

Please feel free to contact us via email at hrservices.imea@nokia.com for any further correspondence.

We wish you all the best in your future endeavors

Yours Sincerely,

For Nokia Solutions and Networks India Private Limited

Vandana Saluja
People Experience IMEA Care

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Ref ID : HR/2023/7973/0603
Date : 14 April 2023
Name : Karanam Sudha Sagari
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Subject : Relieving and Experience Letter

Dear Karanam Sudha Sagari,

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This is to certify that you are currently employed with Nokia Solutions and Networks India Private Limited from **June 6, 2022**, to **May 5, 2023**. Your designation is Student Trainee as of your departure from the organization.

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We would like to reiterate your continuing obligation to maintain confidentiality with respect to any proprietary and confidential information that you may have access to during the course of your employment.

Regd. Address:
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Nehru Place, New Delhi-110019,
India

Please feel free to contact us via email at hrservices.imea@nokia.com for any further correspondence.

We wish you all the best in your future endeavors.

Yours sincerely,
For Nokia Solutions and Networks India Private Limited

Vandana Saluja
People Experience IMEA Care

This is a system generated letter and does not require physical signature

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LIST OF ACRONYMS

Sl.No	ACRONYM	DESCRIPTION
1.	5G	Fifth generation of mobile telecommunications
2.	RAN	Radio Access Network
3.	CU	Control Unit
4.	DU	Distributed Unit
5.	MAC	Medium Access Control
6.	RLC	Radio Link Control
7.	PDCP	Packet Data Convergence Protocol
8.	RRC	Radio Resource Control
9.	NAS	Non-Access Stratum
10.	EPC	Evolved Packet Core
11.	RRM	Radio Resource Management
12.	SDAP	Service Data Adaption Protocol
13.	SDN	Software defined Network
14.	MNO	Mobile Network Operator
15.	NSA	Non-Standalone Architecture
16.	SA	Standalone Architecture
17.	UE	User Equipment
18.	TC	Test Case
19.	UT	Unit Test

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CHAPTER 1

INTRODUCTION

This chapter covers a quick overview of the field of study, its relevance in the modern world, and what motivates people to work on projects, including the flaws of comparable earlier work, the significance of the current effort, and the significance of the results produced. This chapter also covers the creation of objectives in light of motivation. The project report is organized chapter by chapter in this chapter as well.

1.1 MOBILE COMMUNICATION

By turning your speech and data into digital signals that are sent as radio waves, cell phones use radio waves to communicate. Your mobile phone must first establish a connection to a radio access network (RAN) in order to connect to the internet or another network. Radio transceivers are used by RANs to provide cloud connectivity. Base stations, often referred to as transceivers, are typically connected to the mobile core network through fiber backhaul.

A RAN offers radio access and helps wireless devices coordinate network resources. LTE or 5G NR connections are the main ways that devices connect to cellular networks. The user equipment (such your phone or laptop) and the core network's silicon chips both contribute to the RAN's operation.

As cell technology has advanced to 5G, radio access networks have evolved over time. Today's RANs are capable of supporting a wide range of data, multiple-input multiple-output (MIMO) receiving wires, fast transmission rates, multi-band transporter collecting, and that's only the beginning.

This advancement of RAN for 5G will enormously affect remote advances, including empowering Mobile Edge Computing (MEC) and organization cutting.

These RANs of the future will also contribute to the remarkable decreased idleness that characterizes 5G.

1.1.1 Area of Computer Science

The area of the Computer Science for this Project includes Testing. Testing is the process to compare whether the actual product matches the expected result. The purpose of testing is to check whether any errors, gaps, or missing requirements. Testing can be divided into various types. In this project we are following Unit testing. In Unit testing we are checking each individual function, procedure, or interface.

1.1.2 Area of Electronics & Communication

The area of the Electronics & Communication for this project includes the 5G NR architecture and the Base Stations. A Femtocell is a tiny modern-sized low in power station, ideally constructed for use at home or small enterprise. Depending on the serial number, the base station is normally built to accommodate a few people using active mobile devices at once, while quite a few users using active mobile devices in business settings.

1.2 MOTIVATION

The 5G Base Station, referred to as gNB, comprises two distinct components known as CU (Centralized Unit) and DU (Distributed Unit) (Distributed Unit), which are divided into two separate entities. The macro cellular station cannot provide the coverage indoors using a Femto cell which is a smaller cell inside a building communicates with a cellular network over a broadband connection.

Every time the feature enhancement and testing of hardware on the physical setup is difficult and time consuming. So, by Network Virtual Function the test frameworks are developed which function like that of the hardware. The features can be implemented on the framework developed and if it works well in the software then it is integrated to the hardware.

DU helps with the lower levels of the convention stack, such RLC, MAC, and Physical layer, while CU helps with the higher layers, like SDAP, PDCP, and RRC. Additionally, the SDAP layer won't be accessible if the CU is linked to a 4G Core network since SDAP requires a 5G center organization.

However, one CU can control many DUs; for example, one CU can control over 100 DUs. Unlike the 4G BTS, each DU can support at least one cell, Consequently, a single gNB may manage several cells. Additionally, the F1 interface—also known as The CU and DU interface should be an open interface. enabling you to link one CU from seller X with another DU from merchant Y.

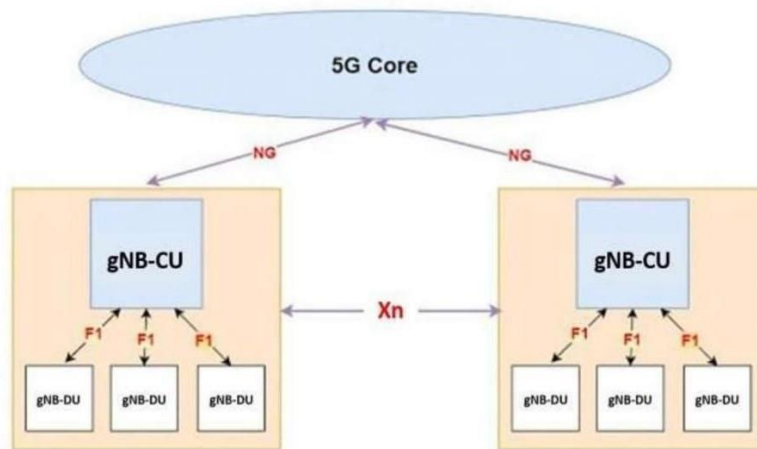


Fig 1.1-5G RAN CU- DU split.

1.3 OVERVIEW OF TESTING

A testing framework is a place where automated tests can be run. It is the entire system that will automate the tests. Single units or pieces of a product are tested in programming testing.

The objective is to make sure that every portion of the product code functions correctly. Complete unit testing was performed by the designer throughout the course of the application's activities. A part of code is isolated and its accuracy is checked via unit tests. A unit might be an individual capability, plan, technique, module, or item. In the Software Development Life Cycle (SDLC), Software Testing Life Cycle (STLC), and V Model, unit testing comes before integration testing as the first stage of testing. A sort of Whitebox testing called unit testing is often carried out by the designer.

By running each test on a different article, the Google C++ Testing Framework detaches the tests. The Google C++ Testing Framework enables you to execute a failed test in isolation for speedy troubleshooting. The design of the code being tested should be reflected in the tests, which should be rapid and effective. Because of this, the Google C++ Testing Framework maintains a list of all characterized tests and doesn't require the client to specify them in order to execute them.

Tests have to be finished fast. You may avoid tests becoming dependent on one another by using Google C++ Testing Framework, which allows you to reuse common assets across tests and only charge once for setup and disassembly.

1.4 WORK SCHEDULE

The below table shows the work schedule which was performed in the internship duration.

Sl. No.	Period	Description
1.	June 2022	Learning about different Platforms and understanding the basics of telecommunication.
2.	July 2022	Familiarizing about the various workloads and went through training on the various language, tools, and protocols.
3.	August 2022 - September2022	Performing the Unit testing on CU Test framework for different modules and owning up the build and execution procedure.
4.	October 2022 – December 2022.	NSA Unit testing on CU Test framework for cell attach and detach.
5.	Jan 2023 – March 2023	Enhancement of the existing framework forSA Unit testing on CU Test framework for cell attach and detach.

Table 1.1 Work Schedule

1.5 ORGANIZATION OF REPORT

The report is divided into chapters, each dealing with different stages of the project starting from the objective formulation to the results and conclusions and the improvements to be done in the future. Each chapter has a short introduction, explaining the subject and contents of each chapter in brief. Chapters or modules have an elaborated description of the subject. Provided below is a brief synopsis of each chapter.

Chapter 1: This Chapter provides the introduction to the 5G. The overview on the TestFramework and the necessity of the testing.

Chapter 2: Outlines the project background and the research made on the project in the initial stage. Background of the project is explained briefly and present developments in the work area is identified, if any. Research gap, if any, are identified because of this step and an analysis is made.

Chapter 3: This chapter gives an overview about the existing methodology and the proposed methodology. The existing methodology is represented in terms of block diagram. The drawback of the existing work is also highlighted.

Chapter 4: This chapter gives an overview about the adapted methodology. The methodology is represented in terms of block diagrams and the call flow of the process is shown. Also, the implementation details about the project are highlighted explaining significance about the implementation done, tools and protocols used.

Chapter 5: The hardware findings and performance evaluation of the suggested approaches and techniques are provided in this chapter. The performances of proposed mechanism have been discussed.

Chapter 6: This chapter altogether concludes the project. It also gives the scheme of the future work that is how the project could be enhanced further. Finally, the references referred to precede the project are given in brief.

CHAPTER 2

LITERATURE SURVEY

This chapter gives a description of the project and its importance. The discussion regarding the background of the project is done here. Any present or recent developments in the work area is addressed. Theoretical discussions are done and a general analysis regarding the theory is made with the appropriate conclusion.

V. Chandrasekhar, J. Andrews, A. Gatherer (2008) presented a paper in IEEE Communications Magazine, vol.46, September 2008 about the Femtocell Networks. The survey's general finding was that consumer-installed wireless data access points are now commonplace inside houses, backhauling data from the Internet to the cellular operator network via a broadband gateway (DSL, cable, Ethernet, or WiMAX). The advantages of wireless access points include lower costs, improved coverage, and longer battery life for mobile devices due to smaller cell sizes [1].

The demand for high-speed data services is consistently increasing, according to **A. Brydon and M. Heath (2008)**. Based on estimates, amount of data traffic on mobile phones would rise 10 to 30 times between 2010 and 2013 [2].

H. Claussen and L.T.W.Ho, L.G released Samuel Self-Optimization of Coverage and Another Architectural Fact in 2009 [3], which modified traditional cellular deployment and used an IP-like architecture.

D.Knisely, T.Yoshizava, F.Favichia (2009) presented the different deployment models of femtocells in microcell. The standardization of femtocells in 3GPP2 Moreover, a legacy network's CDMA2000 femtocell architecture is shown [4].

A neighboring list construction technique for femto-femto handover in a dense femtocell network was put out by **M.Z. Chowdhury and B.T. Minh, J.Y. (2011)**. The list of neighboring femtocells only contains a small selection of adjacent femtocells. The selection of these nearby femtocells is based on factors such as signal level, frequency, and location information [5].

S.A. Rubaye and A.A.Dulaimi, J.Cosmos (2011) published about cognitive femtocell sub-network (CFS) provides services like profile management, user rights and services provision. CFBS controls interface between macro cell and femtocell [6] .

J. Zhang, G.D.L. Roche (2011), it was proposed that the management of Closed Subscriber Group (CSG) lists can be delegated to femtocell owners via a secure webpage. Owners can log in to the webpage and add or remove users by inputting their mobile numbers [7].

Evans J.B (2008) published in IEEE Communications Magazine, vol.46, October 2008 about the WIMAX Femto cells : A perspective on Network Architecture, Capacity and Coverage. Security and performance wise more sophisticated registration and authentication. Femtocell AP shall be a plug and play device in the network without the intervention of the user [8].

- ***NEED FOR RAN DEPLOYMENT***

5G is primarily about providing speedy availability to customers via devices that support fifth-generation network administrations. MNOs have two options for efficiently transitioning from their current inheritance center to 5G: Non-Standalone (NSA) or Standalone (SA) engineering. And even though they are two paths to the same goal, NSA and SA are fundamentally and practically different.

Instead of bringing a new center for 5G, NSA allows administrators to use their current organization's interests in correspondences and portable center. The existing Evolved Packet Core (EPC) can transmit and maintain a 5G Radio Access Network (RAN), lowering CAPEX and OPEX. Administrators can use virtualization of Control and User Plane Separation (CUPS) in conjunction with programming-defined organization to further reduce network operating costs (SDN). These underlying advancements will help to quickly unlock new 5G revenue streams and provide faster data rates.

5G SA is a completely new center engineering standard defined by 3GPP, which includes substantial improvements such as a Service-Based Architecture (SBA) and the practical separation of various organizational functions. Its architecture has the clear benefit of high speed from start to finish and administration confirmation, which is very useful for MNOs who are about to launch new 5G ventures such as smart cities, smart manufacturing lines, or other upward incorporated market arrangements. The sending approach allows for a quick introduction of new administrations as well as a quick opportunity to advertise. However, it entails more assumptions and complexities in managing the organization's several centers.

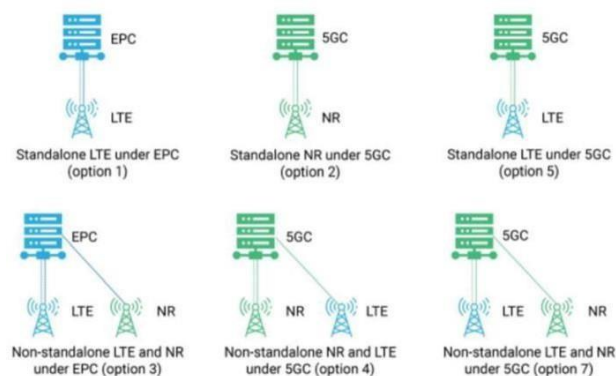


Fig 2.1 5G Deployment Option

THE CU AND DU SPLIT OPTION

3GPP began researching different functional splits between central and distributed units as part of a study item for New Radio (NR). Until RAN2 defines and freezes the protocol stack for New Radio, 3GPP has used the LTE protocol stack as a starting point for debate (NR). They are roughly eight different options, as indicated in the diagram below.

- **Option 1 (RRC/PDCP, 1A-like split)**, the central unit is responsible for RRC, while the distributed unit includes PDCP, RLC, MAC, physical layer, and RF. As a result, the distributed unit contains the complete user plane.
- **Option 2 (PDCP/RLC split)**: Option 2 may serve as a foundation for an X2-like architecture due to similarities in the U-plane, although other functions, such as C-plane, may change due to the requirement for new procedures. This option has two possible variations.
- **Option 2-1**: Only split U-plane. RRC and PDCP are in the central unit in this split option. The distributed unit contains the RLC, MAC, physical layer, and RF.
- **Option 2-2**: RRC and PDCP are in the central unit in this split option. The distributed unit contains the RLC, MAC, physical layer, and RF. The splitting of RRC and PDCP for the CP (Control Plane) stack and PDCP for the UP (User Plane) stack can also be employed to achieve this option.
- **Option 3 (High RLC/Low RLC Split)**: Two ways based on the Real time / non-Real time functions split are used in this option:
- **Option 3-1** Split based on ARQ
It's possible that low RLC is made up of segmentation functions. ARQ and other RLC functions may make up a high RLC. This option divides the RLC sublayer into High RLC and Low RLC sublayers, allowing all RLC functions to be done on the

High RLC sublayer in the central unit while segmentation is conducted on the Low RLC sublayer in the dispersed unit for RLC Acknowledge Mode operation.

- **Option 3-2 Split** that is determined by TX RLC (Radio Link Control) and RX RLC (Radio Link Control). A transmitting TM RLC entity, a transmitting UM RLC entity, a transmitting side of AM, and the routing function of a receiving side of AM, all of which are connected to downlink transmission, may make up low RLC. Except for the routing function and reception of RLC status reports, which are connected to uplink transmission, high RLC may be made up of receiving TM RLC entity, receiving UM RLC entity, and a receiving side of AM.
- **Option 4 (RLC-MAC split):** In this split, the central unit contains the RRC, PDCP, and RLC. The distributed unit contains the MAC, physical layer, and RF.
- **Option 5 (Intra MAC split):** Option 5 is based on the following probability distribution: The Distributed Unit contains the RF, physical layer, and lower part of the MAC layer (Low-MAC). The Central Unit contains the higher MAC layer (High-MAC), RLC, and PDCP. As a result of separating the MAC layer into two entities (for example, High-MAC and Low- MAC), the MAC layer's services and functions will be in the Central Unit (CU), the Distributed Unit (DU), or both.
- **Option 6 (MAC-PHY split):** In the Central Unit, the MAC and higher layers are located (CU). The DU contains the PHY layer and the RF. Data, configuration, and scheduling- related information (e.g., MCS, Layer Mapping, Beamforming, Antenna Configuration, resource block allocation, etc.) and measurements are sent between the CU and the DUs via the interface.
- **Option 7 (Intra PHY split):** This option can be realized in a variety of ways, including asymmetrical alternatives that allow UL and DL to benefit from distinct sub-options independently.

- **Option 8 (PHY-RF split):** This option allows the RF and PHY layers to be separated. This separation allows for the concentration of processes at all protocol layer levels, resulting in extremely tight RAN coordination. This enables CoMP, MIMO, load balancing, and mobility to be supported effectively.

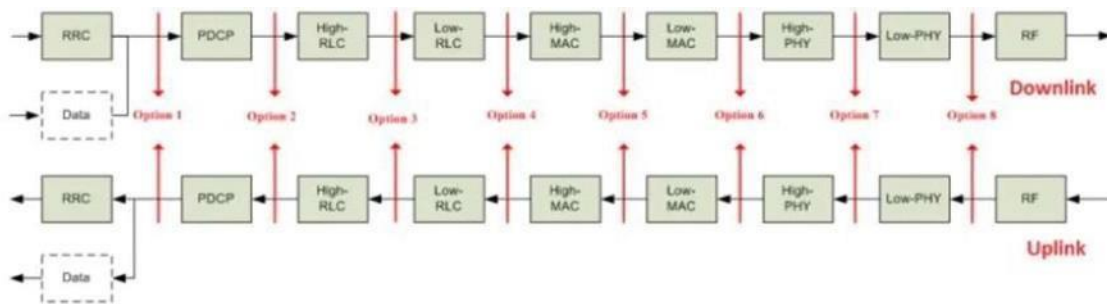


Fig 2.2 CU-DU split option

.1 LITERATURE SUMMARY

Based on the survey that we have mentioned above there are existing system that supports the Femtocell in UMTS and the architecture, handover of the Femtocell. There are many journals and papers published for the enhancements and the features that need to be added to develop a femtocell for 5G.

.2 PROBLEM DEFINITION

- To develop a Standalone Femtocell by fulfilling the standards of 3GPP and enhancements to the existing Non-Standalone Femtocell. Building a Unit Test Framework for the Centralized Unit (CU) for both NSA & SA.

.3 OBJECTIVES OF THE PROJECT

- To design energy-efficient protocols that consider the nodes' power usage and apply optimization techniques to discover the best power allocation to meet the QoS requirements.
- HW implementations that are flexible allow for scalable.
- To develop a Unit Test Framework for the Centralized Unit of the 5G RAN.
- These advancements aim to improve the efficiency, sustainability, and reliability of wireless networks, enabling them to meet the evolving demands of modern communication systems.

CHAPTER 3

AIM AND SCOPE OF THE PRESENT INVESTIGATION

This chapter gives an overview about the existing methodology and the proposed methodology. The existing methodology is represented in terms of block diagram. The drawback of the existing work is also highlighted.

3.1 PROPOSED METHODOLOGY

- The Proposed Methodology compensates the drawbacks of the NSA mode of 5G.
- The enhanced Framework works for the Standalone mode.

3.2 AREA OF PROJECT & APPLICATIONS

Femtocells serve as a solution for extending network coverage to areas where the signal strength of the main network cells may be inadequate. Additionally, femtocells help alleviate congestion on the main network cells by establishing a direct connection from end users, through an internet connection, to the operator's private network infrastructure located elsewhere.

Consumers can conveniently access a wide array of services from home or office networks, mobile operators, and the web, thus simplifying their everyday lives through the utilization of femtocell applications. The first application of femtocells is phone calls, which will be free or at a low price. The new services can be divided into two kinds of application Femtozone Services and Connected Home Services:

Femtozone Service

These services are web/voice services that are activated when the phone comes to the range of the FAP. Some examples include:

- Receive an SMS to indicate when someone enters or leaves the home.
- A virtual number to reach all the people currently in the home.

Connected Home Services

In these kinds of service, the phone accesses the LAN via the femtocell, in order to control a range of networked services, for example:

- Automatically downloads multimedia content from mobile to Home Server and from Home Server to Mobile use the mobile phone to control other devices (TV, Hi)
- Home Security: the femtocell could be programmed to detect unrecognized handsets and active a high-definition security camera and alert the homeowner via SMS should an unrecognized handset be picked up within the property.
- Video Door Bell

3.3 EXISTING METHODOLOGY

In the NSA model of 5G deployment, User End (UE) equipment utilizes the 5G radio infrastructure while the control functions such as signaling use the existing 4GLTE core network.

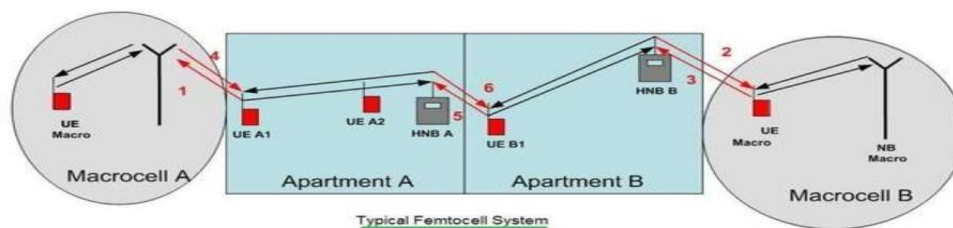


Fig 3.1 Typical Femtocell

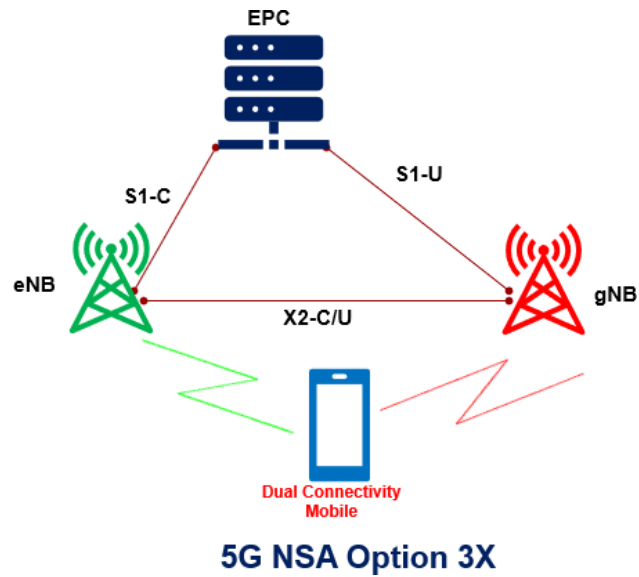


Fig 3.2 NSA Mode of Deployment

- As per NSA 3.x deployment architecture we will have following available interfaces.
 - S1-U: Provides user plane connectivity to EPC for eNB and gNB.
 - S1-C: Provides control plane (signaling) connectivity to EPC for eNB and gNB.
 - X2-U: Provide user plane connectivity between eNB and gNB
 - X2-C: Provides control plane between eNB and gNB.

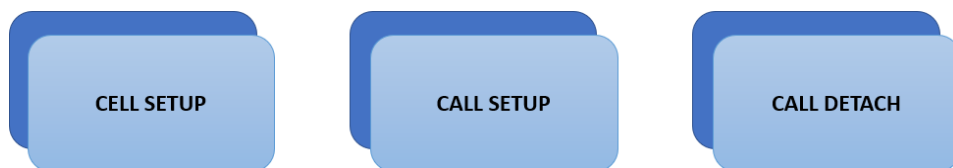


Fig 3.3 Block Diagram of Existing Non-Standalone

3.2.1 Drawbacks of Existing Work:

- Limitations arise from the absence of a complete end-to-end 5G network.
- In scenarios where numerous nodes need to be interconnected on a network with ultra-low latency, such as in smart factories, the Non-Standalone (NSA) deployment mode may not be the optimal choice.

3.3 PROPOSED STANDALONE DEPLOYMENT

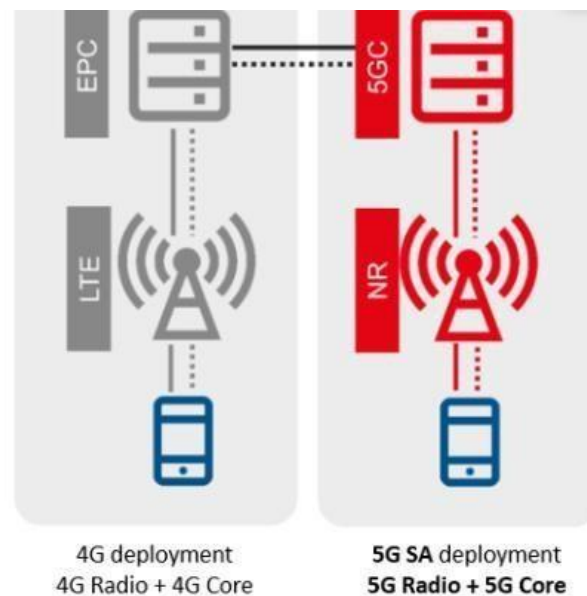


Fig 3.4 Block diagram of Proposed Standalone Mode

Enhanced Mobile Broadband (eMBB), Massive Machine Type Communication (mMTC), and Ultra-Reliable Low Latency Communication (uRLLC) are key features of 5G NR. Among these, eMBB, also known as Extreme Mobile Broadband, is a prominent use case for 5G due to the high-speed mobile broadband standard established by 4G LTE networks.

Standalone 5G, also known as 5G SA, is a deployment model that encompasses an end-to-end 5G network, including a 5G radio network and Next Generation Radio Access Network (NG-RAN), and a 5G Cloud-Native core network (5GCN) to deliver basic and advanced 5G cellular services.

Standalone 5G is a self-sufficient network deployment model that empowers mobile operators to deploy a comprehensive end-to-end 5G New Radio (NR) network. 5G Standalone (SA) technology enables the realization of futuristic 5G use cases that demand flexibility, availability, lower latencies, and high-speed data.

Standalone 5G NR leverages mid and high frequency bands for advanced use cases that demand ultra-low latencies, as well as higher frequency bands (above 6 GHz) for lower latencies and higher data rates. 5G SA also supports lower frequency bands, such as 600 MHz and 700 MHz, to enable IoT (Internet of Things) use cases that require connectivity for billions of low-powered devices with low bit-rate needs, such as smart meters.

CHAPTER 4

PROTOCOLS AND TOOLS USED

This chapter gives an overview about the adapted methodology. The methodology is represented in terms of block diagrams and the call flow of the process is shown. Also, the implementation details about the project are highlighted explaining significance about the implementation done, tools and protocols used here.

4.1 5G NR CU DU PROTOCOLS

A protocol stack is a collection of protocols that are used to construct a network protocol suite and are all executing at the same time. The interconnectivity rules for a layered network architecture, such as the OSI or TCP/IP models, are determined by the protocols in a stack. To become a stack, protocols must be interoperable, with the ability to link both vertically between network layers and horizontally between transmission segment endpoints. The convention stack is used to allow the mixing of different conventions that each set the stopping points for different organizational activities.

The organization and the client gear trade client information on the client plane. The application and IP layers are the most notable layers, and they refer to the general web and the various programs that operate on it. The information then passes through the SDAP (Support Data Variation Convention), another convention layer for the board's nature of administration (QoS).

LTE is required for the upper convention levels. At the bundle information assembly convention (PDCP) layer, the IP header is replaced with a 5G identical. The radio connection control (RLC) layer assembles the data and, if necessary, retransmits it. At the media access control (MAC) layer, prioritization and cross

breed automated retransmission demands take place. The real layer is the last layer in the convention structure (PHY). Angles relevant for the correspondence station between the client gear and the center organization, as well as other perspectives such as balance and beamforming, are included in this layer.

The PHY layer is where the best changes for the convention structure in 5G may be seen. There are a few notable alterations on layer 2 as well, including.

Another SDAP layer in the client plane for QoS executives that provides planning between QoS stream and information radio carriers, as well as checking for QoS stream IDs in downlink and uplink bundles all the way to the 5G center.

Preparation bundle information units to more than one coherent channel and transmitting them through several segment transporters is another feature that enables PDCP duplication. Shaft the techniques and transmission modes that use various numerologies and transmission time lengths have RLC/MAC layer support. Preparing inactivity reduces it as well. The MAC layer in LTE had a massive header that tinted the unique PDUs. In 5G, the header is placed ahead of the bundle, greatly reducing idle time. Information glides effortlessly through the intricate pathways of channels, seamlessly bridging the RLC, MAC, and PHY layers of the technology stack. Between the RLC and the MAC layers are the coherent channels. These channels define the types of data that can be transmitted.

Data is sent from the MAC layer to the PHY layer via the vehicle channels. These channels define how data will be delivered to the real layer and the information's quality.

Finally, the actual layer communicates directly with the client hardware via the actual channels. Planning, access conventions, and information rates are all actual channel properties.

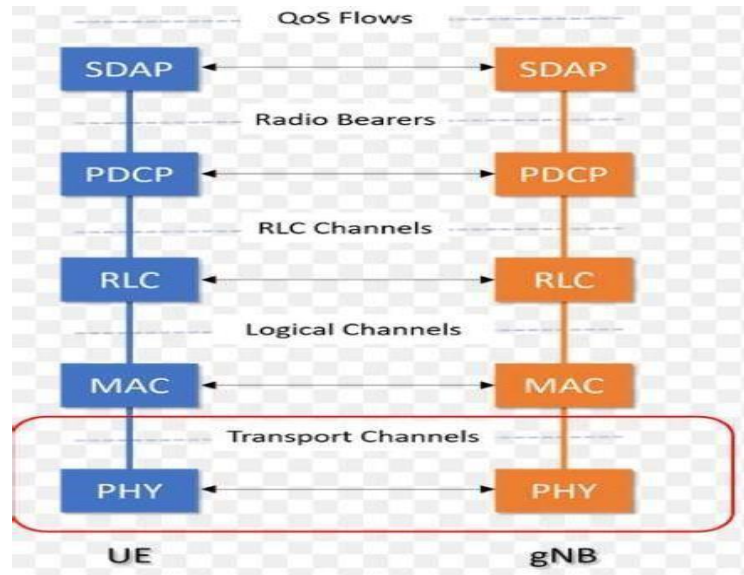


Fig 4.1 5G NR Protocol Stack Layers

- **The Medium Access Control (MAC):** A Media Access Control or MAC address serves as a unique identifier for each piece of equipment in a LAN (Local Area Network) or other type of organization, such as the internet. The MAC convention provides a channel of access and a monitoring instrument, allowing each accessible hub on the organization to communicate with other accessible hubs either on the same organization or on others. Macintosh addresses, also known as actual addresses or equipment addresses, are assigned by equipment manufacturers to distinguish their products. A traditional MAC address is a twelve-digit hexadecimal number, 48 bits or six bytes long ago, written in one of the following styles:

MM: MM: MM: SS: SS: SS

MM-MM-MM-SS-SS-SS MMM.MMM.SSS.SSS

A prefix is a line of "M"s on the left (six numbers, or 24 pieces) that refers to the device producer. Every seller that registers with the IEEE standards authority is assigned a set of MAC prefixes. These could be restricted to the several items that make up their equipment scope. The "S" digits on the correct correspond to an

identifiable proof number associated with a certain device. Each piece of equipment made by a certain vendor.

- **The Radio Link Control (RLC):** The RLC convention is responsible for dividing RLC SDUs from the PDCP into RLC PDUs with reasonable measurements. It also manages the retransmission of PDUs that were received in error, as well as the deletion of copied PDUs. The RLC can be configured in one of three modes Transparent mode, unacknowledged mode, or acknowledged mode to perform some or all these functions, depending on the type of administration.
- **Transparent Mode:** The Transparent Mode is a pass-through mode that maps RLC SDUs to RLC PDUs and vice versa without any overhead or packet alteration. Only some control signaling, such as broadcast system information and paging messages, is done with it.
- **Unacknowledged Mode:** This mode is used for traffic that has a long delay, such as VoIP. This mode is also used by point-to-multipoint communications like the Multimedia Broadcast/Multicast Service (MBMS). The layer performs RLC SDU segmentation and concatenation, RLC PDU reordering and duplicate detection, and RLC SDU reassembly in this mode
- **Acknowledge Mode:** This mode is used to accommodate communication that is delay tolerant but error prone (non-real time applications such as web browsing). It enables bidirectional data transfer, allowing the RLC to send and receive data. It has an Automatic Repeat reQuest (ARQ) feature that corrects erroneous packets by retransmitting data (Note: Hybrid ARQ applies to a MAC transport block while ARQ applies to an RLC SDU.) This mode is also used by some control plane data (for example, RRC messages). The RLC AM mode conducts retransmission of RLC data plane PDUs, re-segmentation of retransmitted RLC data PDUs, and other activities such as polling and status reporting, in addition to the UM mode's duties.

- **The Packet Data Convergence Protocol (PDCP):** The PDCP layer runs on top of the RLC layer (radio asset control). A PDCP element that is used to carry out the PDCP capabilities can be set up with both sending and receiving sides (for a bidirectional radio carrier) or just one of them (for a single-sided radio carrier) (for a unidirectional radio conveyor). SRB, AMDRB, and UM DRB are three types of radio conveyors that use PDCP elements.

The PDCP control unit oversees the PDCP substance's control data. Control data is classified into two types: PDCP status report and ROHC input. All user plane data packets' headers are compressed and decompressed. This is based on the ROHC protocol, which keeps static elements of the header and only updates them when they change. By communicating the difference from the reference, the dynamic components are compressed. The IP/UDP/RTP header makes up a considerable portion of the actual packet size in voice services, hence RoHC is very crucial.

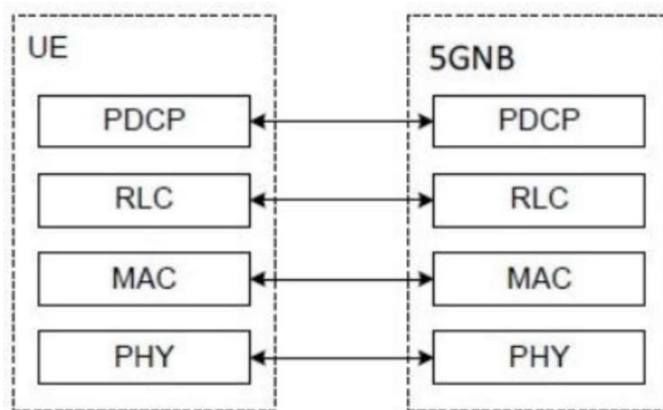


Fig 4.2 User Plane Protocol stack

In the user plane, the application generates data packets that undergo processing by protocols such as TCP, UDP, and IP. On the other hand, in the control plane, the radio resource control (RRC) protocol facilitates the creation and exchange of signaling messages between the base station and the mobile device.

- **Radio Resource Control (RRC):** On the Air Interface, the Radio Resource Control (RRC) protocol is employed. Connection establishment and release functions, transmission of system information, radio bearer establishment, reconfiguration, and release, RRC connection mobility processes, paging notification and release, and outer loop power control are all significant functions of the RRC protocol. The RRC configures the user and control planes based on network state and allows Radio Resource Management techniques to be performed using signaling functions.
- **Non-Access Stratum (NAS):** At the radio interface, the non-access layer (NAS) is the most notable layer of the control plane among UE and MME. The assistance of flexibility of the client equipment (UE) and the assistance of meeting the executives approaches to set up and maintain IP availability between the UE and a bundle information network entrance are vital aspects of the conventions for the NAS (PDN GW).

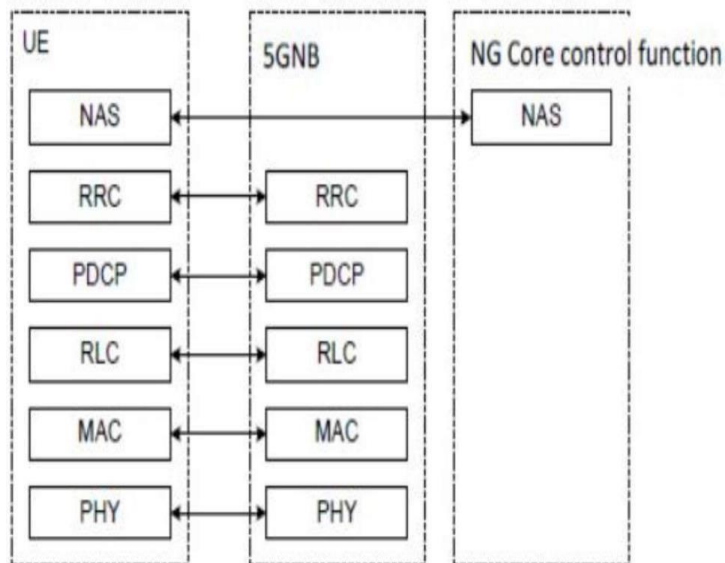


Fig 4.3 Control Plane Protocol stack

Control-applicable data is sent between the organization and the client hardware in the control plane. The foundation and executives of meetings take place at the non-access layer, which is the highest layer on the control plane (NAS). The next layer, radio access control (RAC), exchanges control data with the gadget to establish significant meeting boundaries.

4.2 TOOLS USED:

- **Google Test framework:** Google Test is a unit testing library based on the xUnit architecture for the C++ programming language. It may be compiled for a wide range of POSIX and Windows platforms, allowing unit testing of C and C++ sources with minimal source changes. The tests themselves might be called to run one at a time or all at once. As a result, the debugging procedure is somewhat particular. You must include the gtest / gtest.h file to use the Google Testing Framework.

To make a test, define and name a test function with the TEST macro. Each test is a standard C++ function with no return value. The execution of a single unit test is represented by a test. Either the test passes or fails. One or more tests are contained in a test case. The first parameter is a more generic name for the test case. The second parameter is the test name, which is more particular. The test's entire name includes both the test case and the test name.

- **SSH Tools:** SSH tools such as PuTTY is used to connect to the components, test slaves or any CI tool since all of them are deployed on remote labs.
- **WinSCP:** WinSCP (Windows Secure Copy) is a Secure FTP client for Windows that is open source. Secure file transfers between the client's local computer and the remote server are possible. To protect your login details and sensitive information, the WinSCP software incorporates cryptographic methods into SSH.

- **Ubuntu:** Ubuntu is a modern open-source operating system on Linux for the enterprise server.
- **C++:** C++ is a versatile programming language for a wide range of applications. It is utilized in the development of operating systems, browsers, games, and other applications. C++ supports a variety of programming styles, including procedural, object-oriented, and functional programming. As a result, C++ is both powerful and adaptable.
- **Shell Scripting:** A shell script is a set of commands in a computer program that is executed by a command line interpreter such as the Unix shell. The steps in a shell script are frequently described in comments. Shell scripts are used for executing various tasks, including program execution, file manipulation, and text output. In this project shell scripting is used to automate the steps in building and compiling the CU test framework.
- **Wireshark:** Wireshark is the world's foremost and widely - used network protocol analyzer. It lets the user to see what's happening on in the network at a microscopic level.
- **MSC Generator:** MSC-generator is a tiny application that parses Message Sequence Chart descriptions and generates graphics in a variety of file formats or as a Windows OLE embedded object. Here we used MSC.
- **Notepad++:** Notepad++ is a source code editor that is free to use and is available in various languages. The source code editor is also written in C++ and is based on the Scintilla editing component. Notepad++ offers a wide range of features, such as autosaving, line bookmarking, simultaneous editing, tabbed document interface, and many more features. Over 140 plugins are also available to use in the default program.

- **Visual Studio Code** is a free coding editor that enables quick coding in any programming language, eliminating the need to switch editors. Visual Studio Code has support for many languages, including Python, Java, C++, JavaScript, and more.
- **MobaXterm:** MobaXterm is a set of network tools included in a single portable exe file. MobaXterm integrates an X server and multiple network clients accessible through a tab-based terminal, along with a comprehensive set of Unix commands.
- **Marben ASN decoder:** MARBEN ASN.1 Decoders is a set of online decoders for decoding and conversion of ASN.1 encoded data to XML. No application development or installation is required. Simply provide the raw data and select the corresponding ASN.1 syntax, and the decoding result will be returned in XML format.
- **Python:** Python is a high-level, general-purpose programming language. The design philosophy of VirtualBox emphasizes code readability through the use of significant indentation. dynamically typed and garbage-collection.
- **VirtualBox:** VirtualBox is open-source software that virtualizes the x86 computing architecture, acting as a hypervisor to create a virtual machine (VM) where users can run another operating system (OS). The OS running VirtualBox is referred to as the "host" OS, while the OS running in the VM is called the "guest" OS. is open-source software for virtualizing the x86 computing architecture. It acts as a hypervisor, creating a VM (virtual machine) where the user can run another OS (operating system). The operating system where VirtualBox runs is called the "host" OS. The operating system running in the VM is called the "guest" OS.

4.3 HARDWARE & SOFTWARE REQUIREMENTS

Hardware and software requirements encompass a comprehensive list of components, devices, tools, and applications that are essential for project's successful implementation.

COMPONENT	REQUIREMENT
Processor	Intel Core 2
Ram	4GB
CPU	2.54 GHz
Hard Disk	20 GB

Table 4.1 Hardware Requirements

COMPONENT	REQUIREMENT
Operating System	Windows 7 and above
Browser	Firefox, google chrome
Ubuntu	18.04.6

Table 4.2 Software Requirements

4.4 STEPS INVOLVED

- Defining test case class.
- Adding unit test function for public member function of the class.
- Adding unit test function for private/protected member function of the class.
- Implementing unit test functions, using assertions that provided by Gtest.
- Compiling and linking application against Google Test.
- Running the unit test.

4.4.1 DEFINING TEST CASE CLASS

It suggested by Google Test that a specific purpose “test case class” should be

defined to conduct the unit test. The following is a simple test case class that inherits from the `::testing::Test` class provided by Google Test.

```
#include<gtest/gtest.h>
class TestBase : public ::testing::Test
{
public:
    TestBase(void);
    virtual ~TestBase(void);
    static void SetUpTestCase();
    static void TearDownTestCase();
    virtual void SetUp(void);
    virtual void TearDown(void);

public:
    static int mArgc;
    static char** mArgs;

    static SampleClass* pSC;
};
```

Fig 4.4: Test Case Class

SetUpTestCase() is invoked before any test defined in TestBase is taken. It serves as preparation operation.

TearDownTestCase() will be called after all the tests of TestBase are performed.

The TestBase should handle the cleanup of shared resources among the tests.

SetUpTestCase() and **TearDownTestCase()** are static member functions.

SetUp() and **TearDown()** are called before and after each individual test defined in TestBase.

4.4.2 CREATING A TEST:

Define and name a test function using the TEST macro. Each test is an ordinary C++ functions that does not return a value.

Syntax to write the unit test case:

```
TEST (test_case_name, test_name)
{
    ...test body...
}
```

The test's name is made up of two parameters. The following terminology is used by the Google Testing Framework, and it may differ from what you are used with. The execution of a single unit test is represented by a test. Either the test passes or fails. One or more tests are contained in a test case. The first parameter is a more generic name for the test case. The second parameter is the test name, which is more particular. The test's entire name includes both the test case and the test name. `ASSERT_EQ` is used to verify if an expected condition is met. Google Test provides numerous pre-defined assertion routines that are convenient to use.

```
TEST_F(attachNsa, legacyCallSetup)
{
    ASSERT_EQ(UTF_SUCCESS, nsaCellSetup(0,0));
    ASSERT_EQ(UTF_SUCCESS, nsaCallSetup(0,0));
    ASSERT_EQ(UTF_SUCCESS, nsaCallDetach(0,0));
}
```

Fig 4.5: NSA UT

```
TEST_F(attachSaCall, legacyCallSetup)
{
    ASSERT_EQ(UTF_SUCCESS, saCellSetup(0,0));
    ASSERT_EQ(UTF_SUCCESS, saCallSetup(0,0));
    ASSERT_EQ(UTF_SUCCESS, saCallDetach(0,0));
}
```

Fig 4.6: SA UT

UE Attach Procedure & Detach

1. The UE transmits an RRC Connection Request message to the gNB-DU.
2. In the F1AP INITIAL UL RRC MESSAGE TRANSFER message, the gNB-DU sends the gNB-CU an RRC message and, if the UE is permitted, a relevant lower layer configuration for the UE. The first transmission of the UL RRC message contains the C-RNTI assigned by the gNB-DU.
3. In addition to sending the UE an RRC CONNECTION SETUP message, the gNB-CU allocates the UE the gNB-CU UE F1AP ID. The RRC message is contained in the F1AP DL RRC MESSAGE TRANSFER message.
4. The gNB-DU sends the UE an RRC CONNECTION SETUP message.
5. The UE sends the gNB-DU the message RRC CONNECTION SETUP COMPLETE. The RRC message is encapsulated in the F1AP UL RRC MESSAGE TRANSFER message and sent to the gNB-CU by the gNB-DU.
6. The gNB-CU transmits an INITIAL UE MESSAGE message to the AMF.
7. A first UE Context Setup Request message is sent by the AMF to the gNB-CU.
8. The gNB-CU sends a UE Context Setup Request message to the gNB-DU to create a UE context. The RRC SECURITY MODE COMMAND message may also be included in this message.
9. The gNB-DU sends the UE an RRC SECURITY MODE COMMAND message.
10. The UE CONTEXT SETUP RESPONSE message is sent by the gNB-DU to the gNB-CU.
11. The message RRC SECURITY MODE COMPLETE is sent by the UE. The UE transmits the message RRC SECURITY MODE COMPLETE.
12. The F1AP UL RRC MESSAGE TRANSFER message encapsulates the RRC message and transmits it to the gNB-CU through the gNB-DU.
13. An RRC CONNECTION RECONFIGURATION message produced by the gNB-CU contains the F1AP DL RRC MESSAGE TRANSFER message.
14. The gNB-DU sends the UE an RRC CONNECTION RECONFIGURATION message.

15. The UE transmits a message to the gNB-DU that reads, "RRC CONNECTION RECONFIGURATION COMPLETE."
16. The gNB-DU sends the F1AP UL RRC MESSAGE TRANSFER message to the gNB-CU, which contains the RRC message.
17. The gNB-CU transmits an INITIAL UE CONTEXT SETUP RESPONSE message to the AMF.

NGAP Signaling for UE Registration

Time	Source	Destination	Protocol	Message
18:13:00.476	gNB	AMF	NGAP	NG Setup Request
18:13:00.476	AMF	gNB	NGAP	NG Setup Response
18:13:00.476	gNB	AMF	NGAP/NAS-5GS	InitialUEMessage, Registration request, Registration request
18:13:00.476	AMF	gNB	NGAP/NAS-5GS	DownlinkNASTransport, Authentication request
18:13:00.684	gNB	AMF	NGAP/NAS-5GS	UplinkNASTransport, Authentication response
18:13:00.684	AMF	gNB	NGAP/NAS-5GS	DownlinkNASTransport, Security mode command
18:13:00.703	gNB	AMF	NGAP/NAS-5GS	UplinkNASTransport, Security mode complete
18:13:00.703	AMF	gNB	NGAP/NAS-5GS	DownlinkNASTransport, Registration accept
18:13:00.722	gNB	AMF	NGAP/NAS-5GS	UplinkNASTransport, Registration complete
18:13:01.011	AMF	gNB	NGAP/NAS-5GS	UplinkNASTransport, UL NAS transport, PDU session establishment request
18:13:01.012	AMF	gNB	NGAP/NAS-5GS	InitialContextSetupRequest, DL NAS transport, PDU session establishment accept
18:13:01.122	gNB	AMF	NGAP	UERadioCapabilityInfoIndication
18:13:01.324	gNB	AMF	NGAP	InitialContextSetupResponse

Fig 4.7 NGAP Signaling for UE Registration

No.	Time	Source	Destination	Protocol	Length	Info
42	2021-04-02 11:10:01.336258	gNB-DU	gNB-DU	F1AP	152	F1SetupRequest
52	2021-04-02 11:10:01.341534	gNB-CU	gNB-DU	F1AP	140	F1SetupResponse S1B2 S1B3
56	2021-04-02 11:10:01.344070	gNB-DU	gNB-CU	F1AP	264	GNBDCConfigurationUpdate, MIB, SIB1[Malformed Packet]
57	2021-04-02 11:10:01.345626	gNB-DU	gNB-CU	F1AP	96	SACK , GNBDCConfigurationUpdateAcknowledgement
60	2021-04-02 11:10:01.345174	gNB-DU	gNB-CU	F1AP	88	Reset
61	2021-04-02 11:10:01.345284	gNB-DU	gNB-CU	F1AP	96	SACK , ResetAcknowledgement
270	2021-04-02 11:10:43.912443	gNB-DU	gNB-CU	F1AP/NR RRC	292	RRC Setup Request
271	2021-04-02 11:10:43.912980	gNB-DU	gNB-CU	F1AP/NR RRC	292	SACK , RRC Setup
272	2021-04-02 11:10:43.970627	gNB-DU	gNB-CU	F1AP/NR RRC/WAS...	200	SACK , RRC Setup Complete, Registration request, Registration request MAC=0x00000000
275	2021-04-02 11:10:43.972571	gNB-DU	gNB-CU	F1AP/NR RRC	120	SACK , Security Mode Command MAC=0x4a36f941
278	2021-04-02 11:10:44.010588	gNB-DU	gNB-CU	F1AP/NR RRC	120	SACK , Security Mode Complete MAC=0x0ce3e1c36
280	2021-04-02 11:10:44.010806	gNB-DU	gNB-CU	F1AP/NR RRC/WAS...	148	SACK , DL Information Transfer MAC=0x1ee5c551
281	2021-04-02 11:10:44.050581	gNB-DU	gNB-CU	F1AP/NR RRC/WAS...	172	SACK , UL Information Transfer MAC=0x949a7664
285	2021-04-02 11:10:44.215951	gNB-DU	gNB-CU	F1AP/NR RRC/WAS...	144	SACK , DL Information Transfer MAC=0x0bde774f
289	2021-04-02 11:10:44.050616	gNB-DU	gNB-CU	F1AP/NR RRC/WAS...	148	UL Information Transfer MAC=0x0640b2d5
292	2021-04-02 11:10:44.061853	gNB-DU	gNB-CU	F1AP	484	SACK , UEContextSetupRequest
293	2021-04-02 11:10:44.063084	gNB-DU	gNB-CU	F1AP	104	SACK , UEContextSetupResponse
294	2021-04-02 11:10:44.064773	gNB-DU	gNB-CU	F1AP/NR RRC/WAS...	316	SACK , RRC Reconfiguration MAC=0xfcf4d66
295	2021-04-02 11:10:44.090596	gNB-DU	gNB-CU	F1AP/NR RRC	120	SACK , RRC Reconfiguration Complete MAC=0x71c0b669
297	2021-04-02 11:10:44.090795	gNB-DU	gNB-CU	F1AP	104	SACK , UEContextModificationRequest
298	2021-04-02 11:10:44.090864	gNB-DU	gNB-CU	F1AP	100	SACK , UEContextModificationResponse
327	2021-04-02 11:10:45.011144	gNB-DU	gNB-CU	F1AP/NR RRC	292	RRC Setup Request
328	2021-04-02 11:10:45.011351	gNB-DU	gNB-CU	F1AP/NR RRC	292	SACK , RRC Setup
329	2021-04-02 11:10:45.053095	gNB-DU	gNB-CU	F1AP/NR RRC/WAS...	204	SACK , RRC Setup Complete, Registration request, Registration request MAC=0x00000000
334	2021-04-02 11:10:45.054563	gNB-DU	gNB-CU	F1AP/NR RRC	124	SACK , RRC Release MAC=0xb25b09c3
336	2021-04-02 11:10:46.054162	gNB-DU	gNB-CU	F1AP/NR RRC	104	Security Mode Command MAC=0xcfc429dd
337	2021-04-02 11:10:46.093096	gNB-DU	gNB-CU	F1AP/NR RRC	120	SACK , Security Mode Complete MAC=0x4d290e58
339	2021-04-02 11:10:46.093285	gNB-DU	gNB-CU	F1AP/NR RRC/WAS...	152	SACK , DL Information Transfer MAC=0x140c6f9d
344	2021-04-02 11:10:46.053093	gNB-DU	gNB-CU	F1AP	94	UEContextReleaseComplete
395	2021-04-02 11:10:55.002623	gNB-DU	gNB-CU	F1AP	88	UEContextReleaseRequest
398	2021-04-02 11:10:55.004068	gNB-DU	gNB-CU	F1AP/NR RRC	124	SACK , RRC Release MAC=0xe7f0220f
400	2021-04-02 11:10:55.900991	gNB-DU	gNB-CU	F1AP/NR RRC	308	SACK , RRC Setup Request
401	2021-04-02 11:10:55.901173	gNB-DU	gNB-CU	F1AP/NR RRC	292	SACK , RRC Setup
402	2021-04-02 11:10:55.935591	gNB-DU	gNB-CU	F1AP/NR RRC/WAS...	160	SACK , RRC Setup Complete, Service request, Service request MAC=0x00000000
407	2021-04-02 11:10:55.936789	gNB-DU	gNB-CU	F1AP/NR RRC	124	SACK , RRC Release MAC=0x6f5c712a
409	2021-04-02 11:10:56.136205	gNB-DU	gNB-CU	F1AP/NR RRC	104	Security Mode Command MAC=0xa5f96f5e
410	2021-04-02 11:10:56.175681	gNB-DU	gNB-CU	F1AP/NR RRC	120	SACK , Security Mode Complete MAC=0x3b9aa3f5

Fig 4.8 SA Call Flow

CHAPTER 5

RESULTS AND DISCUSSION

This chapter shows and describes the results obtained with the use of methodologies adapted in the project. The findings are analyzed, and a suitable conclusion is provided. Any variation in result is noted and further analyzed. We are performing Unit Testing on CU Test framework.

5.1 RESULTS:

Upon completion of the project, a thorough evaluation of the hardware and software requirements was conducted, leading to the following findings.

5.1.1 NSA TESTCASE:

The initial 5G deployment was non-Standalone mode and the framework of NSA CU test framework and the message signally between the CU & DU is depicted in the outputs attached.

NSA TC PRE-CONDITIONS:

The Pre-conditions of the NSA TC is to set the random port numbers to the interfaces present in accordance to the standards of the 3GPP. The port randomization is to allow multiple users to run the TC. Before the start of the TC there are few binaries which has to be run.

```
Note: Google Test filter = attachNsa.legacyCallSetup
[=====] Running 1 test from 1 test case.
[-----] Global test environment set-up.
[-----] 1 test from attachNsa
Running Test Suite Precondition here:
```

Fig 5.1 NSA TC Pre-Conditions

CELL SETUP:

There are a few communication sockets generated after the TC's preconditions. F1AP and X2AP are the interfaces. The interface between the gNBCU and gNB-DU is called F1ap. The interface that links one eNB to another eNB is called X2ap. X2AP, or X2 Application Protocol, is the name of the protocol used for communication via the X2 interface.

```
Running gnb_oam_manager gnb_oam_gw and gnb_cu binaries
2022-9-15-5:39:51
gnb_oam_manager started pid :4279
gnb_oam_gw started pid :4344
gnb_cu started pid :4412
    utfMain.cpp:369 ][createSctpsocketForF1ap]      F1AP connect is successfull
RUN      ][attachNsa.legacyCallSetup
In each test case pre condition...
    nsaAttachProc.c:9      ][      nsaCellSetup] Cell Setup Started
    utfMain.cpp:411      ][createSctpsocketForX2ap]      X2AP connect is successfull
    nsaAttachProc.c:20      ][      nsaCellSetup] NSA cell setup is successfull
```

Fig 5.2 NSA Cell Setup

CALL SETUP:

```
[      nsaAttachProc.c:27      ][      nsaCallSetup] NSA Call setup procedure
[      utfUtils.c:172      ][      read_message] ERROR: Msg not found in Local Msg store
[      utfUtils.c:172      ][      read_message] ERROR: Msg not found in Local Msg store
[      utfUtils.c:172      ][      read_message] ERROR: Msg not found in Local Msg store
[      utfUtils.c:172      ][      read_message] ERROR: Msg not found in Local Msg store
RECV E1 prime msg PDCP_RX_SN_STATUS_UPDATE_REQ
[      utfUtils.c:172      ][      read_message] ERROR: Msg not found in Local Msg store
Number of rb are zero
[      nsaAttachProc.c:46      ][      nsaCallSetup] NSA Call setup procedure is successful
```

Fig 5.3 NSA Call Setup

CALL DETACH:

```
nsaAttachProc.c:50 ][ nsaDetachSetup] NSA Detach procedure
:CV E1 prime msg PDCP_RX_RB_MODIFY_REQ
utfUtils.c:172 ][ read_message] ERROR: Msg not found in Local Msg store
number of rb are zero
gnb Release Req Ack is success
nsaAttachProc.c:61 ][ nsaDetachSetup] NSA Call detach procedure is successful
Each test case post condition
```

Fig 5.4 NSA Call Detach

NSA TC POST-CONDITIONS:

In the post condition of the TC the processes running are killed after the TC is completed.

```
Running Test Suite Postcondition here:
Killing gnb cu: pid : 18477
Killing gnb cu: pid : 18478
Killing oam mgr: pid : 18464
Killing oam mgr: pid : 18465
Killing oam gw: pid : 18469
Killing oam gw: pid : 18470
-----] 1 test from attachNsa (7866 ms total)

-----] Global test environment tear-down
=====] 1 test from 1 test case ran. (63222 ms total)
PASSED ] 1 test.
test2oia-testframework-UT516
```

Fig 5.5 NSA TC Post-Conditions

5.1.2 SA TESTCASE:

The other form of 5G deployment Standalone mode is developed using the framework. The CU test framework of Standalone mode is deployed and the output after the Test Case is attached.

SA TC PRE-CONDITIONS:

```
Note: Google Test filter = attachSaCall.legacyCallSetup
[=====] Running 1 test from 1 test case.
[-----] Global test environment set-up.
[-----] 1 test from attachSaCall
Running Test Suite Precondition here:
```

Fig 5.6 SA TC Pre-Conditions

CELL SETUP:

```
[2023-02-22T20:43:47.527Z] [utflog] [createSctpsocket] [ DEBUG] [utfMain.cpp:359]F1AP connect is successfull
[2023-02-22T20:43:47.527Z] [utflog] [makeclient_udp] [ DEBUG] [utfMain.cpp:294]Created FD[5] for E1 prime msg
[2023-02-22T20:43:47.528Z] [utflog] [SetUp] [ DEBUG] [attachSaCall.cpp:31]In each test case pre condition ...
[2023-02-22T20:43:48.528Z] [utflog] [saCellSetup] [ DEBUG] [saAttachProc.c:9]Cell Setup Started
```

Fig 5.7 SA Cell Setup

CALL SETUP:

```
[2023-02-22T20:43:51.751Z] [utflog] [saCellSetup] [ DEBUG] [saAttachProc.c:21]SA cell setup is successfull
[2023-02-22T20:43:51.751Z] [utflog] [saCallSetup] [ DEBUG] [saAttachProc.c:27]SA Call setup procedure
[2023-02-22T20:43:51.751Z] [utflog] [sendMsg] [ DEBUG] [utfMain.cpp:547]SENDING MSG: UTF_RRC_CONNECTION_REQ
[2023-02-22T20:43:51.751Z] [utflog] [sendMsg] [ DEBUG] [utfMain.cpp:550]READ the msg from XML
```

Fig 5.8 SA Call Setup

CALL DETACH:

```
[2023-02-22T20:43:55.459Z] [utflog] [saCallSetup] [  DEBUG] [saAttachProc.c:79]SA Call setup procedure is successful  
[2023-02-22T20:43:55.468Z] [utflog] [saCallDetach] [  DEBUG] [saAttachProc.c:84]SA Call Detach procedure  
[2023-02-22T20:43:55.469Z] [utflog] [sendMsg] [  DEBUG] [utfMain.cpp:547]SENDING MSG: UTF_UL_INFORMATION_TRANSFER
```

```
[2023-02-22T20:43:57.210Z] [utflog] [saCallDetach] [  DEBUG] [saAttachProc.c:100]SA Call Detach procedure is successful  
[2023-02-22T20:43:57.210Z] [utflog] [TearDown] [  DEBUG] [attachSaCall.cpp:37]In each test case post condition ...
```

Fig 5.9 SA Call Detach

SA TC POST-CONDITIONS:

```
[-----] attachSaCallLegacyTestSetup (4362 ms)  
Killing gnb cu: pid : 17699  
Killing gnb cu: pid : 17700  
Killing oam mgr: pid : 17551  
Killing oam mgr: pid : 17552  
Killing oam gw: pid : 17622  
Killing oam gw: pid : 17623  
[-----] 1 test from attachSaCall (4362 ms total)  
  
[-----] Global test environment tear-down  
[=====] 1 test from 1 test case ran. (62770 ms total)  
[ PASSED ] 1 test.
```

Fig 5.10 SA TC Post-Conditions:

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

This chapter summarizes the whole project and its significance. Any future improvisations to the project are also suggested here. Suitable concluding remarks are provided.

6.1 CONCLUSION

Understanding the principles of 5G NR PROTOCOL STACK AND CU DU flow of End-to-End Data Flow, Need of QoS in Networking, and implementing them to achieve various efficiency criteria in numerous testcases were the project's goals. Through this project we were able to explore in the vast area of telecommunication networking and its applications. I was able to understand the data flow from each end.

We were able to identify various features and bugs that could arise in protocol stack. We got a chance to know the various protocols involved in Layer 2 and Layer 3 of 5G NR as well as in the whole System. We were able to understand its mode of working and its applications. Keeping all the above in testcases were written in such a manner to achieve the Quality of Service and ensure Reliability and Durability of the product. All testcases were validated precisely to achieve the customer needs and quality.

6.2 FUTURE SCOPE

The future scope of this framework is to have both the Non-Standalone & Standalone mode in the same test case by using the appropriate flags depending on the necessity.

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