QATAR UNIVERSITY

COLLEGE OF ENGINEERING

MULTI-CONNECTIVITY MANAGEMENT AND ORCHESTRATION ARCHITECTURE INTEGRATED WITH 5G MULTI RADIO ACCESS TECHNOLOGY NETWORK

BY

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ABSTRACT

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The significant growth in the number of devices and the tremendous boost in network/user traffic types and volume as well as the efficiency constraints of 4G innovations have encouraged industry efforts and also financial investments towards defining, developing, and releasing systems for the fifth generation. The 5G of mobile broadband wireless networks with multiple Radio Access Technologies (Multi-RATs) have actually been designed to satisfy the system and service requirements of the existing as well as the coming applications. The multi-RAT access network is considered the key enabling technology to satisfy these requirements based on low latency, high throughput. To utilize all available network resources efficiently, research activities have been proposed on multi-connectivity to connect, split, steer, switch, and orchestrate across multiple RATs. Recently, multi-connectivity management and orchestration architecture standardization has just started; therefore, further study and research is needed. This project proposed a multi-connectivity management and orchestration architecture integrated with 5G, Long-Term Evolution (LTE), and Wireless LANs (WLAN) technologies. The simulations experiments conducted to measure the Quality of Experience (QoE) by provisioning network resources efficiently, which are: data rate, latency, bit error rate. The results show that the 5G requirements have been achieved with latency and throughput around 1ms and 200 Mbps, respectively.

DEDICATION

Dedicated to

My beloved family

&

Prof. Amr Mohamed

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CHAPTER 1: INTRODUCTION

Every new Generation of wireless networks delivers high speeds with low latency, and it becomes more functional to our devices and smartphones. The first analog cell phones were brought in First Generation (1G). Second Generation (2G) let us text for the first time. Then, the subscribers started using online in Third Generation (3G). Fourth Generation (4G) delivered the speeds that the users enjoy today. However, as more applications started to emerge, such as interactive gaming, virtual reality, in addition to 4K video on demand, etc., broadband service providers started to appreciate the need for upgrading network resources to cope with the increasing demands from users. Today, the evolution is heading toward Fifth Generation (5G), which is the next generation of mobile broadband in wireless; it will be able to handle way more traffic compared to the previous generation. 5G will be the foundation for all heavy application like Internet of Things (IoT), virtual reality, autonomous driving, and not only people to people connections, also people to machine and machine to machine and other stuff that the users cannot imagine even yet. So what exactly is a 5G network?

1.1 Introduction to 5G

The 5G Generation of mobile broadband wireless networks comes by such a design that keeps pace with significant growth in a broad range of existing and new applications and use cases, and network and traffic density. To satisfy the demand for better network capacity, lower latency, higher throughput, full bandwidth, more reliability, higher mobility, and lower power consumption, the performance of the wireless systems should be pushed to a new limit to fulfill the requirements. To accommodate various use cases smartly and cost-effectively, modular network functions in 5G network architecture need to be released, configured, and scaled on demand. Three main usage models, namely, enhanced Mobile Broadband (eMBB), ultra-Reliable Low-Latency Communication (uRLLC), and massive Machine Type Communications (mMTC), are targeted by this megatrend (see Fig.1) and its need to be examined to understand the scope of 5G. As in [2,3], transport delay along with average and peak data rates are the leading performance indicators of a very high throughput and low latency mobile broadband scenario. For example, virtual reality, interactive gaming, and immersive entertainment are notable services consumed, which hold the significant promise of user experience. The downlink peak data rates delivered by eMBB is reaching up to 20 Gbps with 100 Mbps expected user experienced data rates anytime, anywhere. To clarify more, user experienced data rate is dependent on the application used. As shown in Fig. 1, smart grid, automotive, IoT, and traffic safety are some of the examples of uRLLC type communication. mMTC and the mission-critical machine-type communication applications are revolutionary. Therefore, mMTC use cases are expected to be used in the new band above 6 GHz to improve the performance metrics, for instant, throughput, and latency.

The key challenge of designing and deploying the 5G system is not about new radio interfaces deployment, but also how the cooperation in a heterogeneous environment considered by the existence of Multi-RAT, multi-layer networks, and diverse user interactions, would really be possible. Under these circumferences, there is an essential need for the concept of 5G to fulfill consistent user experience and seamless mobility across space and time. Furthermore, 5G is going to include several emerging applications with widely diverse service and requirements attributes, from stationary scenarios in office or home, to high-speed scenarios in airplanes/trains, from delay-tolerant use cases, to ultra-low latency use cases, and from best effort use cases to more reliable use cases, to support the evolution of the established mobile broadband usage models. Besides, the data or the information will be delivered through Multi-RATs with various range of devices such as wearables and smartphones. It will require an increasing number of base stations or access nodes across the network to deal with these types of applications. In other words, these requirements can be realized with high capacity virtual Radio Access Network (RAN) or cloud-RAN and small cells [45].

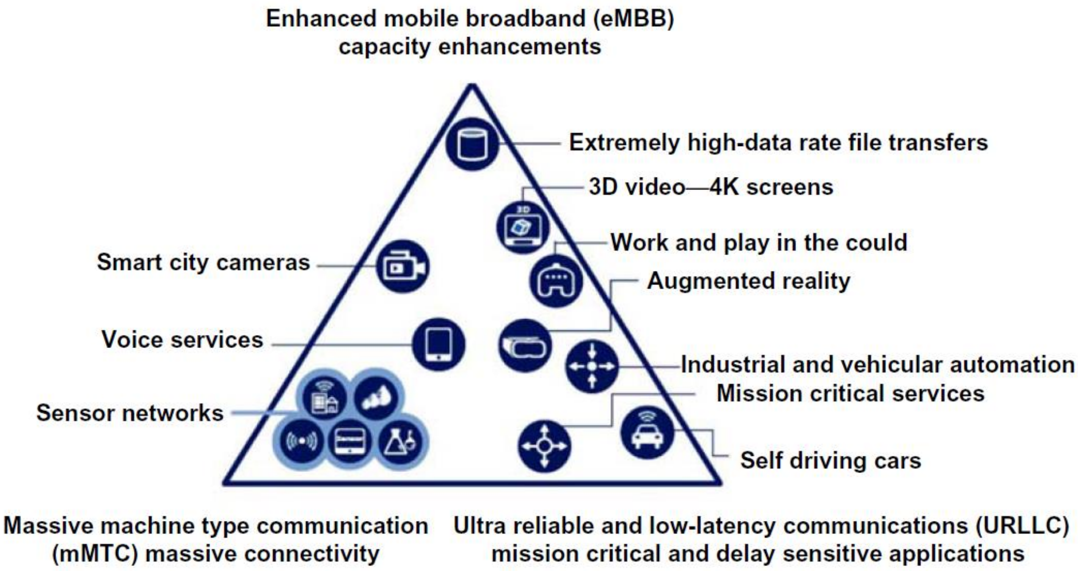

Figure 1: 5G Use Cases Categories [1]

In the past few years, research and studies are still ongoing regarding 5G, and the efforts of the standards development are revealing several candidate technologies, which in turn will contribute to achieving the service requirements. These technologies are shown in Fig. 2, and are summarized as follows:

- New waveform and multiple access schemes: LTE air-interface is OFDM-based, and this may not be suitable for some applications. Thus, several numbers of new waveform and modulation schemes have been proposed, but due to their practical limitations and complexity, convinced the 3GPP community to accept OFDM modulation with some adaptation that change the frame structure and radio resource allocations depend on the application, bandwidth, and available spectrum.

- New spectrum: use of a large number of blocks of spectrum in higher frequency, above 6 GHz, and reach up to 100 GHz, as well as the unlicensed spectrum, this will lead to higher network capacity.

- The massive Multiple Input Multiple Output (MIMO): To handle all cellular traffic in LTE, antennas in base stations have about a several ports for that, but in case of massive MIMO it can support about hundred ports; this leads on increase the capacity of the network. Massive MIMO comes with its complications. Today’s cellular antenna, usually using omni directional or sector antennas to broadcasts information in every direction at once, and this could cause dangerous interference. Therefore, beamforming technology comes to solve this issue. To understand the concept of Beamforming, it acts as a traffic signaling system for cellular signals; rather than broadcasting in every direction, it would enable a base station to send out a concentrated stream of data to a certain subscriber. This precision prevents interference and also it means a lot more effective. That indicates stations might manage extra incoming and outgoing data streams simultaneously.

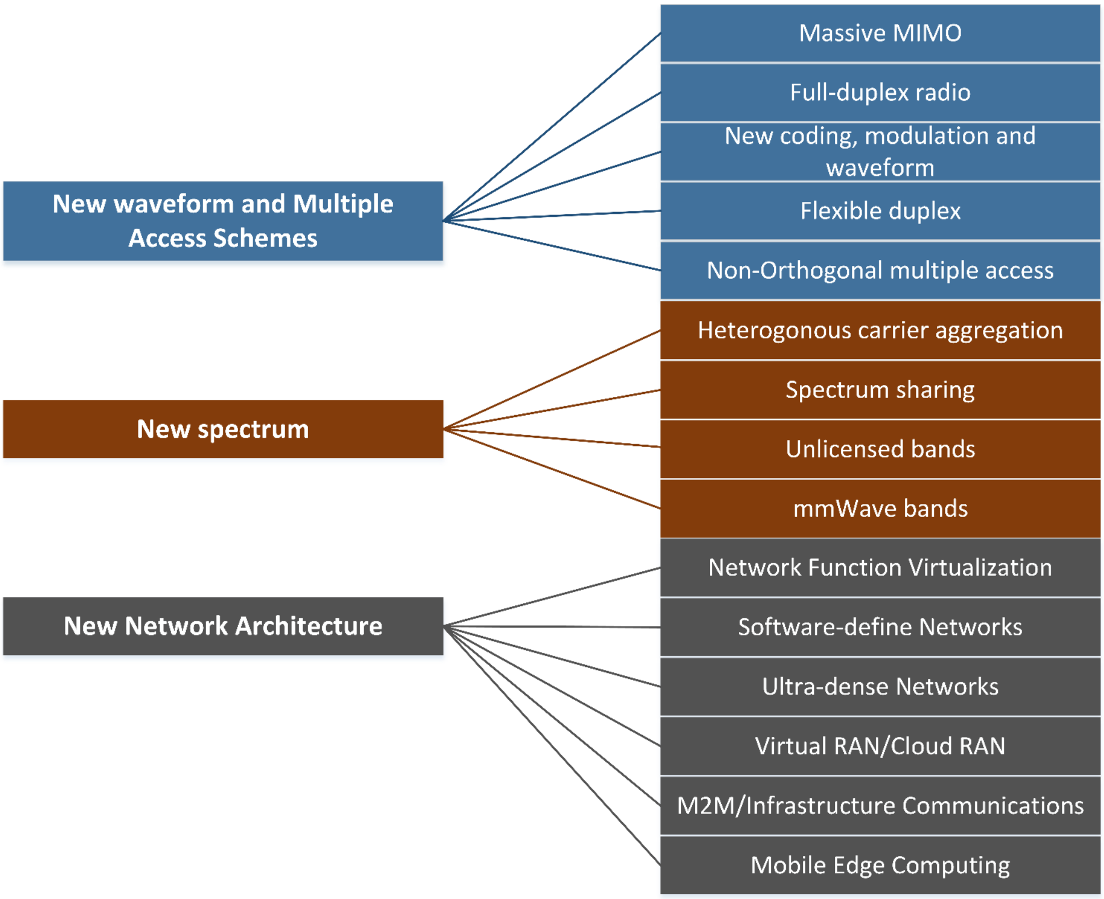

Figure 2: 5G Technologies Mapped with KPIs [4].

- New network architecture: the objective is to run today's network functions, which are Network Function Virtualization (NFV), core network architecture, and cloud-based radio access, in virtual machines, hardware accelerators, and storage instead of implementing them on dedicated hardware. A further approach is to split the radio network into two: baseband processing and remote radio units and virtualized the baseband functions to serve many remote radio units and to be able to perform different network slices in the core network.

- Multi-connectivity: This technology applied in a heterogeneous network where decoupling the uplink and downlink control and data paths. It will allow to control the signaling of users' devices on a macro-cell and send/receive data via several small cells or several technologies.

1.2 Problem Description

The existing mobile specification designed to satisfy requirements for voice and standard mobile Broadband services. However, the International Telecommunication Union (ITU) has proven the complexity to support diversified 5G services due to many Network Elements, multiple upgrades of 3GPP versions. [5]. The following aspects are the reasons behind the transformation of network architecture:

Complex networks including numerous services, standards, as well as site types. 5G networks must be able to give diversified solutions of various KPIs, sustain co-existent gain access to 5G, LTE, and Wi-Fi of several requirements, and also coordinate various cell types: Pico, Micro, and Macro base stations. The challenge is to develop a network design capable of sustaining such flexibility, while meeting users demands and provide guaranteed quality of service.

Coordination of multi-connectivity, and the co-existence of 5G with LTE and Wi-Fi is expected for an extended period of time, incorporating multi-connectivity technologies as part of the new 5G air interface. Multi-connectivity technology must coordinate, and support traffic and mobility requirements of the user equipment to produce high data rates on the go.

On-demand deployment of service anchors as part of the 5G network is needed to provide dynamic network slicing. In line with different service requirements, network resource allocations, real-time and non-real time RAN resources may be deployed on demand, based on the location and real-time user demands. For that, service gateway location is required to be deployed on the access cloud or the core network side.

Also, service demands vary with varying the functions of the network, which highlights the need for Flexible Management and Orchestration (MANO) of the network functions. uRLLC needs ultra-low latency and high dependability. Enhanced Mobile Broadband calls for a vast throughput for scheduling. Networks must flexibly coordinate network abilities considering solution characteristics, which substantially simplify network features and boost network effectiveness.

As discussed previously, the available network resources need to be used effectively, so a multi-connectivity technology has been suggested to all at once link, steer, as well as manage across multiple RATs. The significant benefit of the multi-connectivity approach fosters the possibility of sending the individual traffic in different RATs that satisfy user needs and service requirements. The implementation of multi-connectivity is an essential part of 5G network architecture from different perspectives:

- It improves the overall throughput to the users.
- It improves the optimal utilization of network resources to meet the 5G KPIs.
- It can guarantee the service continuity to the users, even during mobility.

However, these points of views do not drop merely without initiatives of appropriate Management and Orchestration (MANO) of Multi-RATs environment. The main challenge is the complete lifecycle management of resources associated with the multi-connectivity settings, such as resource status monitoring, analytics, decision, as well as execution. Observation of accurate resource status of different RATs (5G, LTE, and Wi-Fi) requires new capabilities across Radio Access Network (RAN) and User Equipment (UE). Analytics play a role in the accurate diagnosis of resource usage optimization in the multi connectivity scenario. Based on the results of the analytics, intelligent choice-making for the optimization of resource usage can carry out by using some load-balancing techniques or algorithms. Lastly, the traffic steering and load-balancing results will be a trigger in the execution process. This complete lifecycle management must consider the challenges facing network operators, which are:

- Flawlessly integrate the heterogeneous RATs.
- Efficiently utilize radio resources.
- Successfully functioning RATs as a single node.
- Delivering better Quality-of-Service (QoS) service to the clients.

1.3 Scope

The scope of this project focuses on two main concerns related to 1) the multi-connectivity functions and 2) how it will map onto the 5G network architecture. The project will report relevant state-of-the-art related to the 5G multi-connectivity architectures and the techniques used to control the traffic flow. Then, it would proceed to propose a MANO architecture used for the multi-connectivity environment in a 5G network, including 5G, LTE, and Wi-Fi technologies with a proposed control technique.

1.4 Objectives

The objectives of the project are: 1) Study the characteristics of wireless links. 2) Model a 5G radio access network with different types of RATs, which are 5G, LTE, and Wi-Fi transceivers. 3) Propose a MANO architecture with centralized control technique to maximize throughout and Quality-of-Service (QoS), and minimize the latency. 4) Evaluate and test the proposed architecture performance using different practical scenarios.

1.5 Outline

This project started with an introduction that briefly highlighted the need of 5G Network and the enabling technologies that comes with 5G network. This is followed by the main problems of achieving these requirements then the scope, objectives as well as the outline of the project. In chapter 2, a literature survey that views the state-of-the-art related to the 5G multi-connectivity architectures and the techniques used for controlling the traffic steer. The proposed method will be explained, implemented, discussed in chapter 3. Finally, chapter 4 draws the conclusions of this work and the further improvements for future works.

CHAPTER 2: 5G NETWORK ARCHITECTURE

This chapter provides state-of-the-art related to the 5G multi-connectivity architectures and the techniques used to control the traffic flow. The multi-connectivity architectures come with three main issues:

- What is the type of integration method used for the architecture?
- What method to use to manage the architecture?
- What protocol stack split used in the architecture?

2.1 5G Multi Connectivity architectures

This section divided into three main parts: integration method, management method, protocol stack split techniques. In [6], three Multi-RATs integration methods are presented:

First, higher-layer integration: It includes an application-layer interface, supplying information exchange between the client and the server over Multi-RATs. This approach can be easy to apply, yet it is application dependent. It may not adequately consider the network state, which results in suboptimal exploitation of resources, mainly if the state of the network observed a non-stable status. Second, Core-Network based integration: In this situation, the RAT choice made considering the policy of the operator for network selection, but the UE will continually control the overall network selection decision. The UE is then able to make its choices, taking into consideration operator policies, customer preferences, and radio links performances. Third, RAN-based integration: this service is recommended by 3GPP in NR/LTE dual-connectivity and enables coordination between the RATs utilizing dedicated interfaces. The backhaul links constrain the cooperation level between the various RATs. With capabilities of backhaul link, it allows full participation in between Multi-RATs, enabling even more dynamic Radio Resource Management (RRM) system and boosting the overall system and user efficiencies.

Three types of RAN-Based options presented in [7]: First, Hard Handover (HH): allows users with inadequate coverage to switch to another RAT, which can give better coverage. The HH calls for considerable Radio Resource Control (RRC) and CN signaling, in addition to cell search and synchronization, which results in relatively long interruption delays. One more disadvantage is the low reliability since the UE can link to just one RAT at the time. Second, Fast Switch (FS) assumes to have a typical Control

Plane between various technologies. In FS, no signaling required for User Plane switch, and it can respond instantly when the channel quality variants occur. One more benefit brought using FS consists of the increased reliability, considering that the users can link to multiple RATs at each time. Indeed, even FS has some disadvantages; these are because of the visibility of more significant overhead for the increased control signaling. Third, User Plane Aggregation: assumes to have both User Plane (UP) and Control Plane (CP) attached to all the RATs, and that the UP data aggregated. The benefits, in this case, are raised throughput, resource pooling, and the support for reliable, smooth mobility. However, these benefits may limit, due to different throughput and latency of the involved RATs. Typically, the UP Aggregation can consider as the most effective option to increase throughput and reliability, while reducing signaling and switching time. The adoption of UP Aggregation or Fast Switch enforces the architectural constraints that have discussed over, e.g., they require typical entities to accommodate the regular performances.

The next step is to choose the way of managing the architecture. There are different approaches presented in [6], which are: First, User-Centric approach: the UE is continually keeping track of the channel conditions and considering thresholds-based performance parameters (for example Signal to Noise Ratio (SNR)), the RAT selection can perform. Second, the RAN-Assisted approach: The User-Centric technique restricted to the regional UE understanding. As an example, the UE does RAT selection based, usually, on the SNR, and in a very dense atmosphere, the choice decision usually does not continue to be efficient for long, because of the varying load of Multi-RATs. The Radio Access Network Assisted approach, in this approach, the choice decisions are done in the network. For the instant of useful criterion can be RAT utilization and expected resource allocation. Third, Radio Access Network-Controlled approach: in this method, the RAN can designate the UEs to individual radio technologies. Such a solution might use a central unit or distributed units across the network that manages radio resources across different radio technologies. The user equipment, in this solution, is arranged to report radio measurements on the nearest local base station. This approach is taken on by 3GPP for attending to dual connectivity issues.

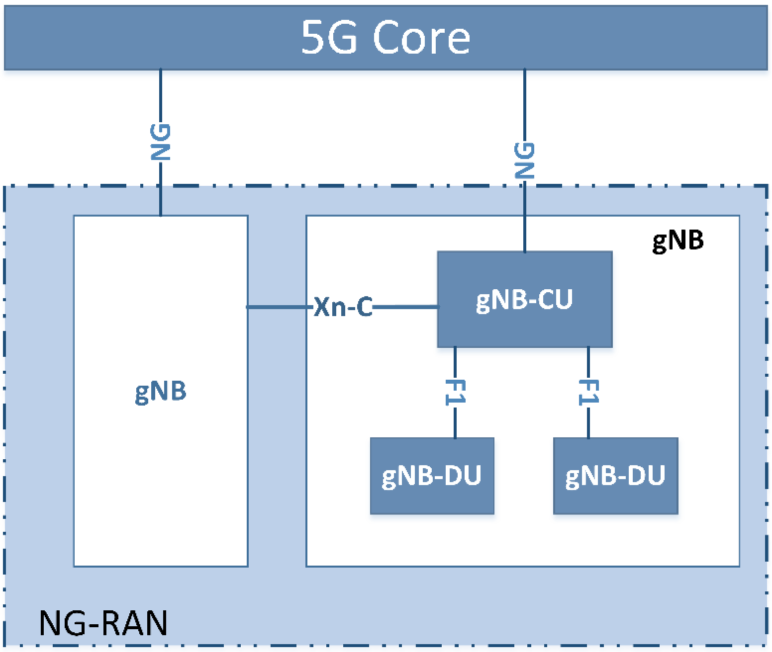

Figure 3: Overall RAN Architecture [8]

Several works have actually addressed the challenges of Multi-Connectivity from architectural [9], [10], [11]- [18], [19]- [21], and algorithmic [22], [23], [24], [25]-[31] perspectives. The major topic of discussion is the practical split amongst RAN components. Following the 3GPP design in Fig. 3, the gNB, which the next generation base station replaces the eNB in LTE, is composed of a Central Unit (CU), additionally called either Central-RAN or Cloud-RAN, and of several Distributed Units (DUs). This useful split between the Central and Distributed unit has the purpose of putting the sharing, and technology independent, RAN functionalities in a central node, to ensure that they can take advantage of centralization, permitting flexible RATs selection, such as Fast Switch approach.

The choice regarding which function needs to place in either the central or the distributed units, is a crucial point that specifies the entire traffic flow control system. From the control plane perspective, the suitable situation would certainly be to place the entire set of functionalities that are technology independent along with Non-Real-Time and reduced low bit rate, (e.g., spectrum sharing, traffic steering) in the central unit in order to have a complete view of the system, allowing optimal decision making. In this instance, the distributed units have technology-dependent, Real-Time, and high bit rate functionalities in order to meet their needs.

The choice regarding which function demands to put in either the central or the distributed units, is a critical point that specifies the entire traffic control system. From the control plane point of view, a complete view of the system will be the appropriate scenario and this system will contain technology independent, non-real time, as well as reduced low data rate functionalities. In this instant, the distributed units have technology dependent among real time, as well as high data rate performances in order to fulfill their demands. Accordingly, three solutions have been proposed, as shown in Fig. 4, which are:

- Intra-PHY split: in this instance, the dealing is with the demands of high throughput and low latency, but the distributed units do not consume high power.
- PHY-MAC split: comparing with the previous opting the throughput is lowered, but the same latency restraints exist. In this case, the power

consumption in the distributed units is more than the first solution.

- Packet Data Convergence Protocol (PDCP) split: this solution having the highest latency comparing with others and for that reason there will be a substantial demand in distributed units for more power consumption.

A common PDCP is a suitable choice for the user plane, and the Control Plane is a common RRC. Regarding the synchronization with lower layers, the PDCP functions do not have strenuous restraints. Additionally, the traffic load management, in this solution, can enable the traffic aggregation. This split has currently been standard for LTE Dual Connectivity [33]. But project will not deal with this kind of splitting, and further explanation will be in the coming chapter.

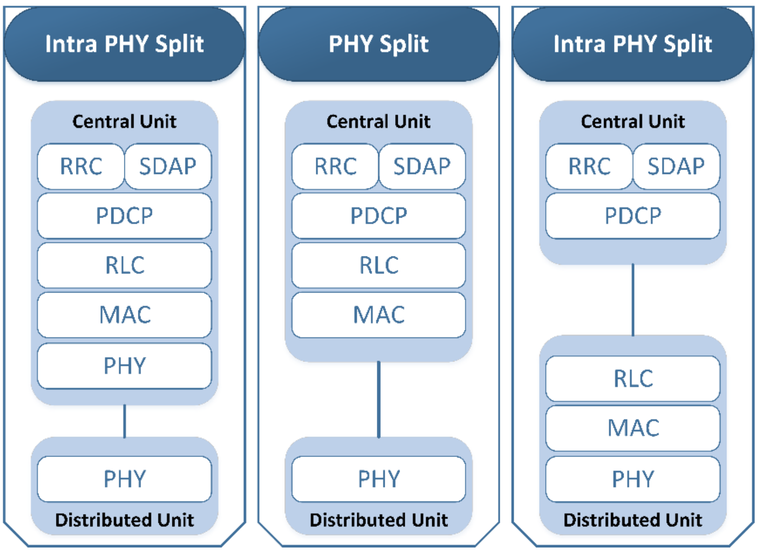

Figure 4: Functional Splits [34]

2.2 Traffic Steering

The most current discussions about Multi-Connectivity concern the option of suitable technologies thinking about user requirements and services. In [34], [35], the traffic steering issue is investigated, where the traffic steering is defined as the function of distributing the traffic load optimally across different network entities as well as spectrum bands, taking into consideration customer and operator preferences. Moreover, the traffic steering problem requires considering the characteristics of the various RATs, such as insurance data rate, latency, and the different traffic characteristics, specified by the QoS requirement. The objective of the traffic steering is to effectively provide the ability to the UEs pleasing the QoS/QoE needs, considering the network management operation, such as load optimization, congestion management. Traffic steering can perform in a central or distributed fashion. In both cases, it allows the traffic steering algorithms to accessibility details relating to serving and load capacity of all the RATs. Central synchronization can achieve ideal performances, yet this option might present problems in the real-time control of the RATs. On the other hand, a distributed implementation can only do traffic steering based upon local information accomplishing suboptimal services.

The main decision for traffic steering in multi-connectivity scenarios represent by the RAT selection problem [36]-[38]. The problem is how to satisfy the 5G KPIs by choosing the most suitable access technology. These selections can perform by considering various network features, for example: the QoS attributes, the channel performance. The algorithms qualified to carry out the RAT selection are reviewed by taking into consideration the characteristics of the algorithms. RAT choice methods, already explored in the literary works, concern the use mathematical algorithms with the attributes described in Table 1. In this project, we will not go at that level a simple algorithm will be used to make a decision.

Table 2.1: RAT Selection Based on Mathematical Algorithms

	Utility Functions [36]	**Fuzzy Logic [37]**	**Game Theory [36]**	**Combinatorial Optimization [36]**	**Markov Chain [36]**
Objective	Utility evaluation	Imprecision handling	Equilibrium between multiple entities	Allocation of applications to networks	Consecutive decision/ rank aggregation/ priority evaluation
Decision Speed	Fast	Fast	Middle	Slow	Middle
Implementation Complexity	Simple	Simple	Complex	Complex	Complex
Middle	Middle	Middle	High	High	High
Model-Based/ Data Driven	Model-Based	Model-Based	Model-Based	Model-Based	Model-Based or Data Driven
Open/ Closed loop	Open loop	Open loop or Close loop	Open loop or Close loop	Open loop or Close loop	Open loop or Close loop
Centralized/Distributed	Centralized	Centralized	Centralized or Distributed	Centralized or Distributed	Centralized or Distributed

CHAPTER 3: PROPOSED METHOD IMPLEMENTATION, RESULTS AND DISCUSSIONS

The Multi-Connectivity, as currently presented, is done to configure a UE to be connected to Multi-RATs. In a Multi-Connectivity scenario, the UE can transmit and receive traffic through radio bearers established with different RATs, performing traffic switch, and split functions. In switch scenario, the traffic sent or received through a radio bearer can change in one or more radio bearers. In a split scenario, the traffic is split and sent at the same time to different radio bearers. Multi-Connectivity utilized to be more reliable and increase the throughput connections by utilizing those two functions; such functions allow to adopt the "always-best connected" method with a dynamic selection of the best technologies to fulfill user and network requirements. As mentioned previously, this project deals with:

- RAN-Integration approach.
- RAN-Controlled approach.

3.1 Proposed Method

The proposed multi-connectivity architecture, shown in Fig. 5, has been developed to be according to the existing vision of distributed resource control and to maximize the entire user's experience by optimizing the performance of the radio. In this regard, this project aims to enrich the current entities, i.e., Cloud and Distributed radio access network, 5G, LTE and WLAN technologies, with proposed functionalities by controlling adapting the QoS from the network’s perspective to guarantee certain Quality of Experience (QoE) from the user’s perspective.

As shown in Fig. 5, the radio access network has been splitting into two; cloud radio access network and distributed access network. The Distributed Radio Access

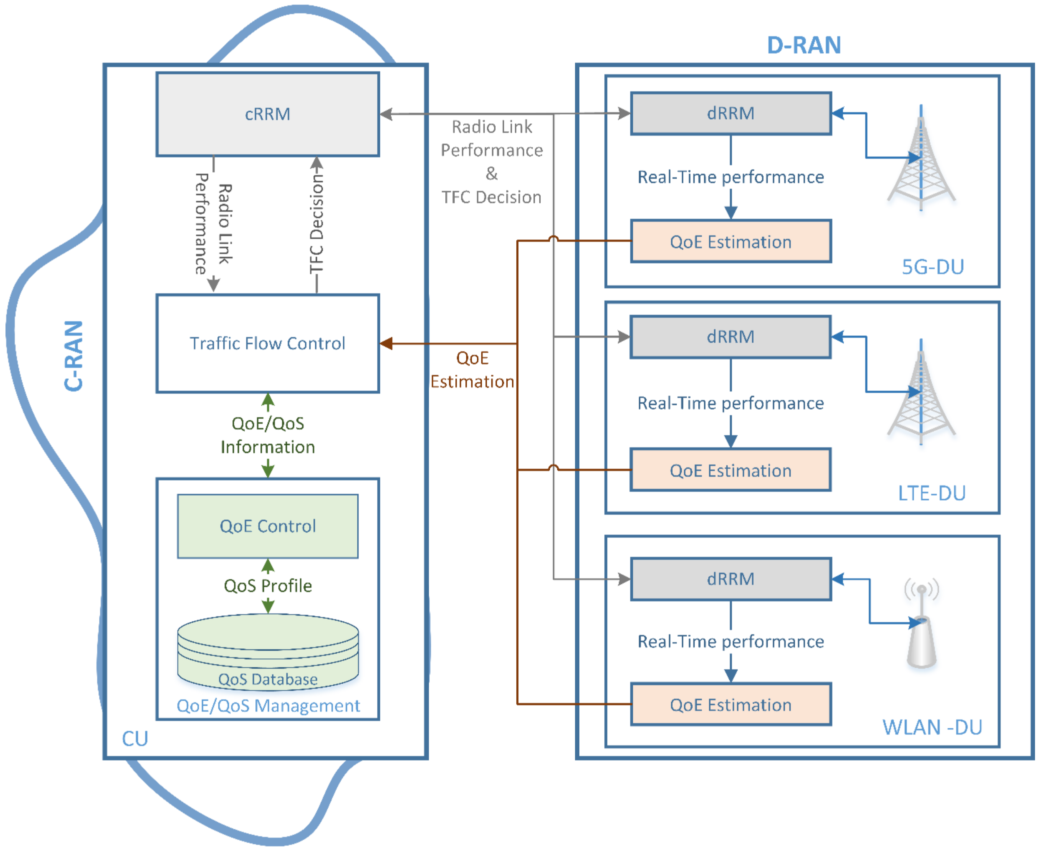

Figure 5:Proposed Multi-Connectivity Functional Architecture

Network (D-RAN) designed with two main features able to capture real-time information from the users. These features are dRRM and QoE Estimation. The distributed Radio Resource Management designed, allocated in each RAT, to estimate the cell performance as closest as possible to the user in real-time. Then, it reports this result to both cRRM and QoE estimation. QoE estimation module implemented in each RAT measures the experience from UE's perspective instead of measuring the QoS from network parameters [39]. Several works have been done to express the QoS measures into QoE, the two most useful approaches based on the exponential and logarithmic conversion of QoS in QoE. Based on the performance comparison in [40], this project will choose the exponential conversion approach because the logarithmic conversion approach shows the sensitivity of QoE as a function of reciprocal QoS only, where the exponential conversion approach formulates the sensitivity of QoE as a function of QoE itself, and it shows superior convergence as the QoS parameters having extreme values. If the QoE is extremely high, a tiny disturbance will highly reduce the QoE. On the other hand, if the QoE is already low, an additional disturbance is not perceived dramatically. The authors in [40], from that concept, assumed that the adjustment of QoE depends upon the present degree of QoE, given the same quantity of change of the QoS worth, yet with a different sign. Assuming a linear dependence on QoE level, authors arrived at the differential equation:

$$\frac{\partial QoE}{\partial QoS} = -\beta(QoE - \gamma) \approx -QoE \tag{1}$$

The QoE is then computed, by solving the differential equation, as:

$$QoE = \alpha\, e^{-\beta\, QoS} + \gamma \tag{2}$$

Constant values $\alpha, \beta, and\ \gamma$ are assigned depending on the user's preferences. The QoE estimation, as mentioned previously, will be implemented to compute the actual QoE as a function of QoS_m, which is the QoS measured at any UE level, as it is shown in Eq.3. Then, the target QoE measured, and it defined in Eq. 4. Finally, both $QoE_{estimate}$ and QoE_{target} will be used to compute the QoE error QoE_{error}, and it defined in Eq. 5.

$$QoE_{estimate} = \alpha\, e^{-\beta\, QoS_m} + \gamma \tag{3}$$

$$QoE_{target} = \alpha\, e^{-\beta\, QoS_{target}} + \gamma \tag{4}$$

$$QoE_{error} = \left| QoE_{estimate} - QoE_{target} \right| \tag{5}$$

QoE_{error} is a fundamental input to Traffic Flow Control module, will be discussed later, which should be computed in real-time in each Distributed Unit (DU). Based on the value of QoE error, Traffic Flow Control will update the previous decision trying to decrease the error to meet the requirement of the user. Notice that, in this project, three QoS parameters are being used, which are latency, data rate, and bit error rate. So, in total, three QoE errors need to be computed for each QoS parameter.

In the cloud access radio network, or call it a centralized unit, it will manage all the distributed units in the distributed radio access network using a centralized control functionality. Notice that each distributed unit represents a RAT. The implemented control functionalities in a centralized unit are:

QoE/QoS Management: there are two main functions in this element; mapping data packets to QoS flows and arrange the packets based on the priority level of each packet. First, the data packets stream enters the module. A given ID can identify the service type or the application, since this project does not deal with upper layers, e.g., IP address, Protocol type. QoE control will access the QoS database to get the QoS profile for each service type to map with all received IDs. Based on this mapping, QoS parameters for each service type will be used by both QoE control and traffic flow control in the next step. The QoS database is containing QoS parameters introduced in 3GPP [41], as shown in Table 2. Table 2 shows the standardized 5G Quality Indicator (5QI) to QoS requirement mapping. Once the mapping is done, QoE control will perform priority queuing method (without discarding any packets) to rearrange the data packets based on the Default Priority Level (mentioned in Table 2), as shown in Fig. 6. Then it will pass to the Traffic Flow Control module.

The centralized Radio Resource Management (cRRM): The primary function of this element is to manage all the decentralized Radio Resource Management (dRRM) modules and report the radio links QoS performance to Traffic Flow Control. The QoS parameters reported are latency, data rate, and bit error rate. Each parameter is computed as the weighted mean of the performance experienced by all the connections served. In addition, the cRRM will receive the decision made by Traffic Flow Control, and based on this decision, and it will select the appropriate radio bearers/technology/DU dynamically.

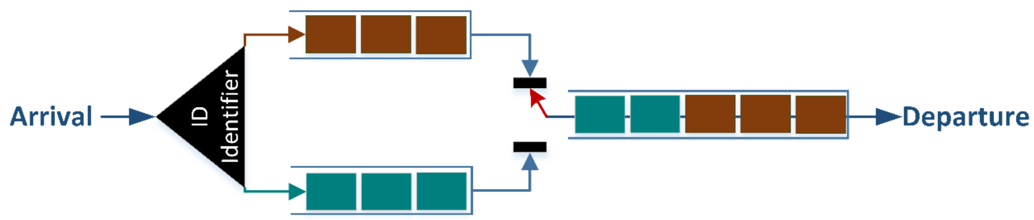

Figure 6: Packets Rearrangement in QoE Control

Traffic Flow Control (TFC): this element plays a significant role in the entire architecture, where the proposed solution aims at implementing a multi-connectivity mechanism to boost the data rate and guarantee the continuity of the service (minimizing delay and packet loss). TFC is responsible for ensuring the 5G KPIs by considering the Traffic QoS requirements, Radio Link performance, and QoE. Based on that, TFC will have the ability to associate the traffic for the user dynamically to the individual Multi-RATs. The traffic requirements should be considered based on some QoS parameters, received from QoE/QoS management, which are: resource type, priority level, maximum packet error rate, and maximum packet delay budget. The performance of the radio link updated every transmission time, and it contains the data rate, latency, bit error rate for each technology. The QoE estimation is a mathematical module used to estimate the QoE using the QoS served to the UE, and it keeps changing in a real-time manner. Figure 7 shows the high-level design for TFC.

First, the radio links performance will be reported to TFC. Based on this performance, which indicates the QoS parameters, the QoE estimation will be calculated. At the same time, the data traffic comes from the QoE control module in an arranged manner based on the priority level.

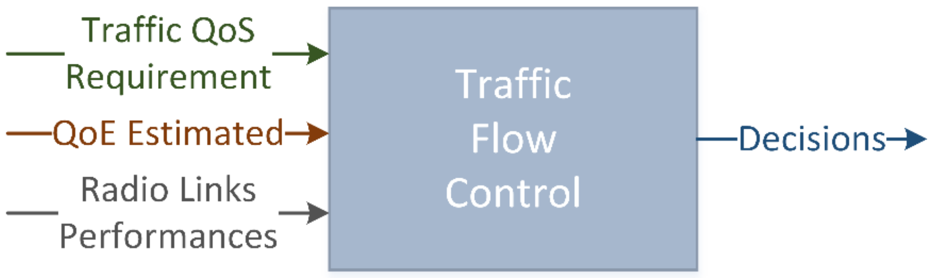

Figure 7: TFC High-Level Design

Now, the first step is to check the resource type of the received data packets by doing the following:

- If the resource type is Delay Critical Guaranteed Bit Rate, TFC will sort the QoE error concerning the latency. Then, it will start filling the buffer for each RAT starting from lowest error QoE.
- If the resource type is Guaranteed Bit Rate, TFC will sort the QoE error concerning the data rate. Then, it will start filling the buffer for each RAT starting from lowest error QoE.
- If the resource type is Non- Guaranteed Bit Rate, TFC will sort the QoE error concerning the bit error rate. Then it will start filling the buffer for each RAT starting from lowest error QoE.

Once all the buffer filled, the decision, which is the buffer, should pass to cRRM to distribute it to all RATs.

Table 3.1: Standardized 5QI to QoS requirements mapping [42]

5QI Value	Resource Type	Default Priority Level	Packet Delay Budget (ms)	Packet Error Rate	Default Maximum Data Burst Volume (Bytes)	Default Averaging Window (ms)	Example Services
1	GBR	20	100	10^{-2}	N/A	2000	Conversational Voice
2		40	150	10^{-3}	N/A	2000	Conversational Video (Live Streaming)
3		30	50	10^{-3}	N/A	2000	Real-time Gaming, V2X Messages, Electricity Distribution, Process Automation
4		50	300	10^{-6}	N/A	2000	Non-Conversational Video (Buffered Streaming)
65		7	75	10^{-2}	N/A	2000	Mission-critical User-plane Push-to-Talk Voice
66		20	100	10^{-2}	N/A	2000	Non-mission-critical User-plane Push-to-Talk Voice
67		15	100	10^{-3}	N/A	2000	Mission-critical Video
75		–	–	–	–	–	–
5	Non-GBR	10	100	10^{-6}	N/A	N/A	IMS Signaling
6		60	300	10^{-6}	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		70	100	10^{-3}	N/A	N/A	Voice, Video (Live Streaming) Interactive Gaming
8		80	300	10^{-6}	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
9		90					
69		5	60	10^{-6}	N/A	N/A	Mission-critical Delay Sensitive Signaling
70		55	200	10^{-6}	N/A	N/A	Mission-critical Data
79		65	50	10^{-2}	N/A	N/A	V2X Messages
80		68	10	10^{-6}	N/A	N/A	Low-latency eMBB Applications, Augmented Reality
82	Delay Critical GBR	19	10	10^{-4}	255	2000	Discrete Automation
83		22	10	10^{-4}	1354	2000	Discrete Automation
84		24	30	10^{-5}	1354	2000	Intelligent Transport Systems
85		21	5	10^{-5}	255	2000	Electricity Distribution

3.2 Simulation Model

Towards testing the proposed method, a simulated setup was built using MATLAB. The core setup of this simulation consists of three transceivers for three different access technologies; 5G, LTE, and IEEE 802.11n with a channel added to it

Additive Gaussian Noise and multipath fading as it is shown in Fig. 8.

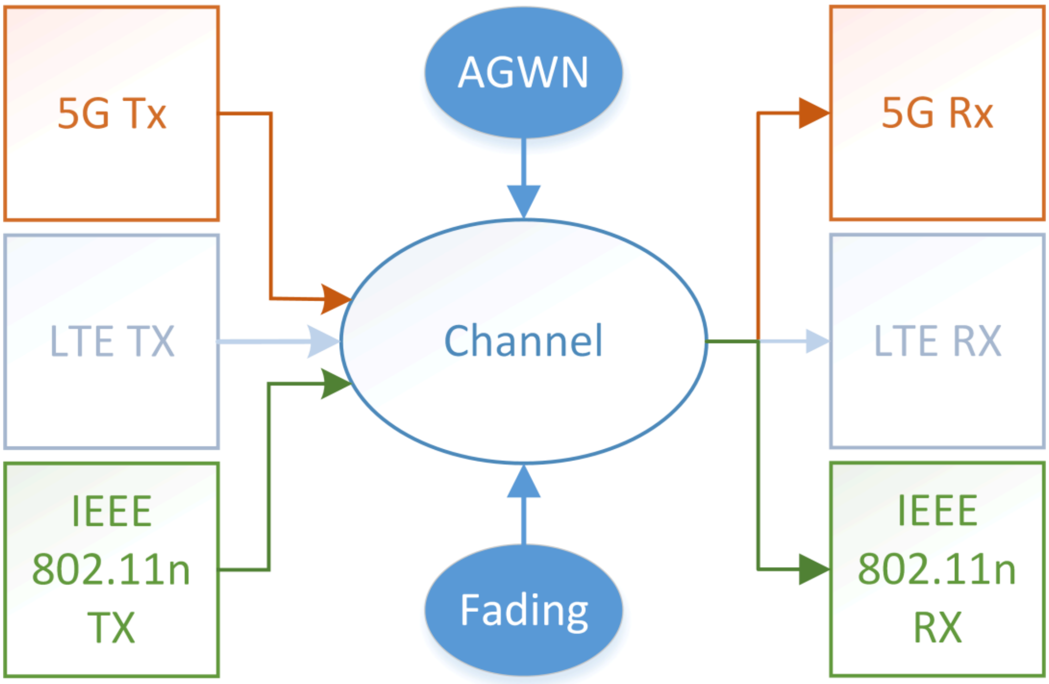

Figure 8: Core Simulation Network

3.2.1 Simulated Scenario

This project aimed to prove that by using the enabling keys, which are multi-connectivity architecture, its management and orchestration will play an essential role in maximizing the whole user's experience and utilize all the resources in the network. Also, it aimed to evaluate and test the proposed architecture performance using different practical scenarios. From that concept, three simulated scenarios were implemented. The first scenario will evaluate the performance without utilizing the entire network resource means that the user will send only through one RAT Also, no classification or mapping of the uplink packets will be done. The second scenario will evaluate the performance by mapping the uplink packets with no knowledge of the network resources means that only one RAT will be used. The third scenario will evaluate the performance by analysis of the uplink packets and map it to the appropriate RAT.

3.2.2 Setup and Configuration

As mentioned before, MATLAB is used to implement the proposed solution. The simulation setup should be more reliable to get more practical results. Three steps to configure the proposed method. First, the transceivers for each RAT with help from MATLAB toolboxes. Notice that, as mentioned before, this project will deal only with the physical layer. It assumes that the packet received from the upper layer does not contain any headers. Table 3 shows the cell configurations for each technology.

Table 3.2: Cells Configurations

	5G	LTE	IEEE 802.1n
Scenario	Single cell with 3.4 GHz	Single cell with 2.4 GHz	Single cell with 5 GHz
Antenna	DL: 1x4 UL: 1x8	DL: 2x2 UL: 1x2	DL: 2x2 UL: 1x2
Modulation	16 QAM	16 QAM	64 QAM
Sampling rate	30720000	15360000	20000000
Bandwidth (MHz)	200	20	20

For QoE equations, three equations should be derived for each QoS parameter. According to ITU-T Recommendation ITU-T P.862.1 [43], QoE represented by Mean Opinion Score (MOS), taking on the value excellent = 5, good = 4, fair = 3, poor = 2, and bad = 1, and. Now, the value of the unknown parameters, which are $\alpha, \beta, and\ \gamma$ in Eq. 2, is the main target to find an optimal fitting function with output ranges from 1 to 5. The three parameters need to be measured: latency, bit error rate, and data rate in the first place. The unknown values will be found using a trial and error method. First, the values $\alpha, \beta, and\ \gamma$ in [44] will be used. After many trials, the optimal values $\alpha, \beta, and\ \gamma$ have been found. Notice that each QoS parameter should have a unique model function, as it is shown in Fig. 9, 10, and 11 for latency, bit error rate, and throughput, respectively

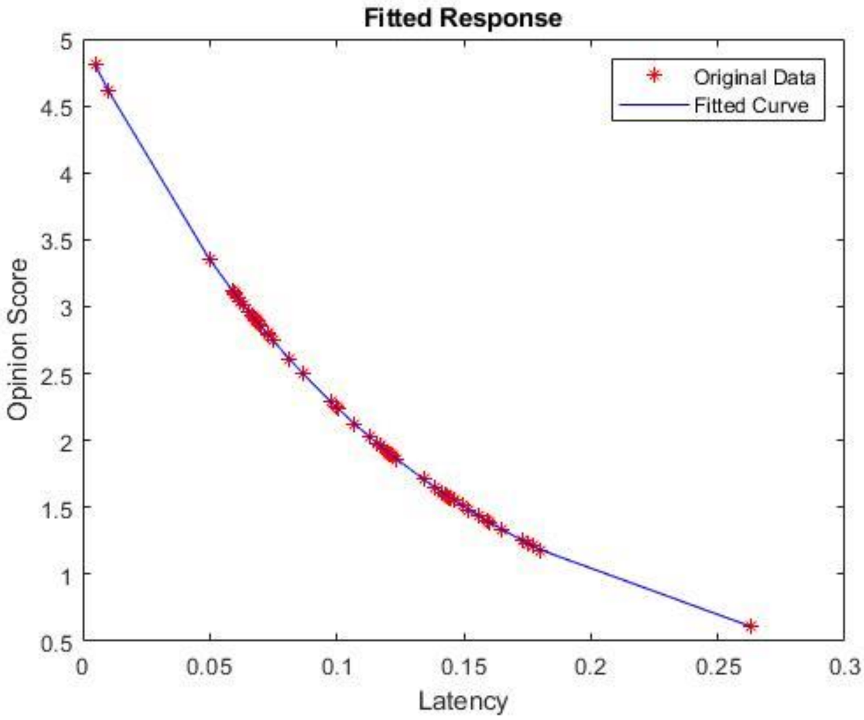

Figure 9: Best Fitting Curve for Latency

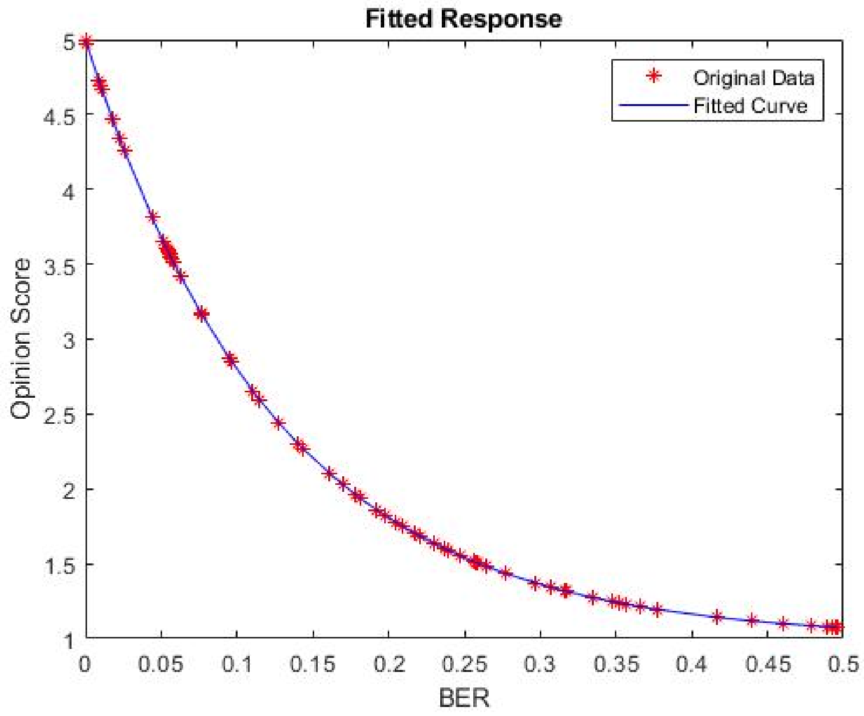

Figure 10: Best Fitting Curve for BER

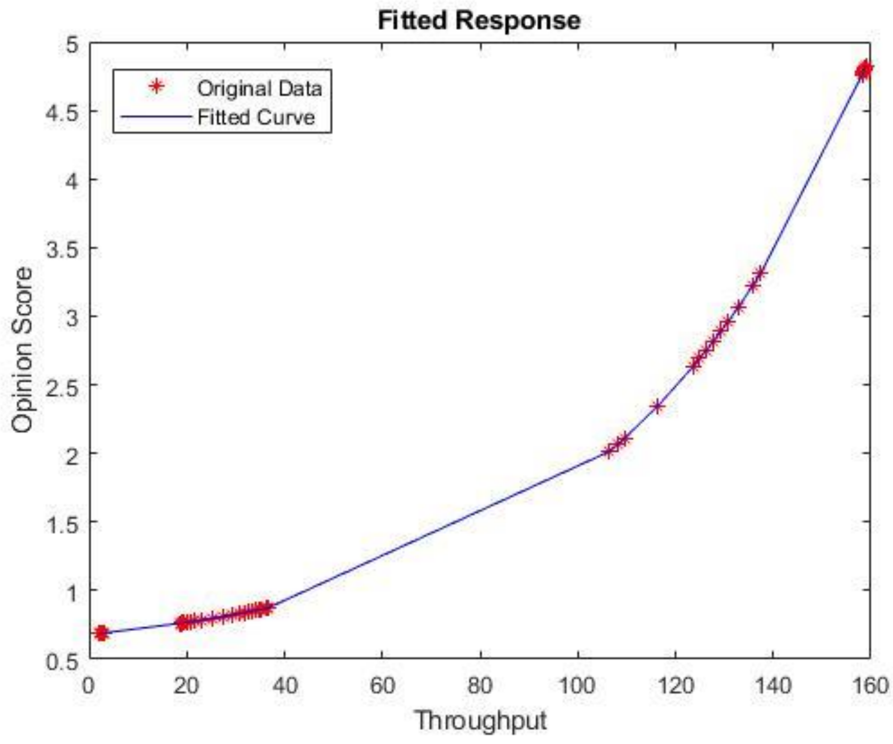

Figure 11: Best Fitting Curve for Throughput

3.3 Results and Discussion

3.3.1 Characteristics of wireless links

Study the characteristics of the implemented models is an essential step. The key variable used to see the behavior of implemented transceivers is the Signal-to-Noise Ratio (SNR). The SNR used to add noise in the channel to see how the RAT will act. In this simulation, the Bit Error Rate, throughput, is calculated to measure the performance. Figure 12, 13, and 14 is the responses for 5G, LTE, and IEEE 802.11n, respectively.

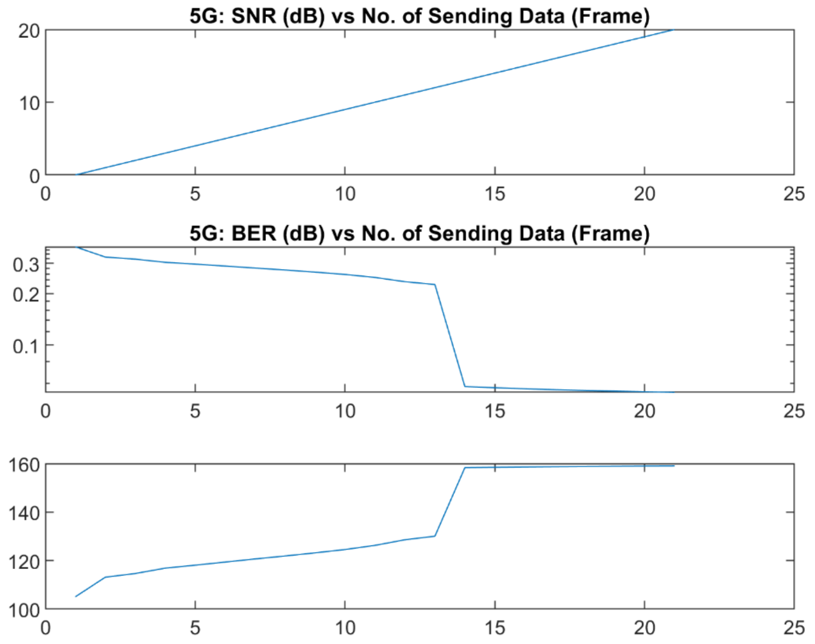

Figure 12: 5G Responses

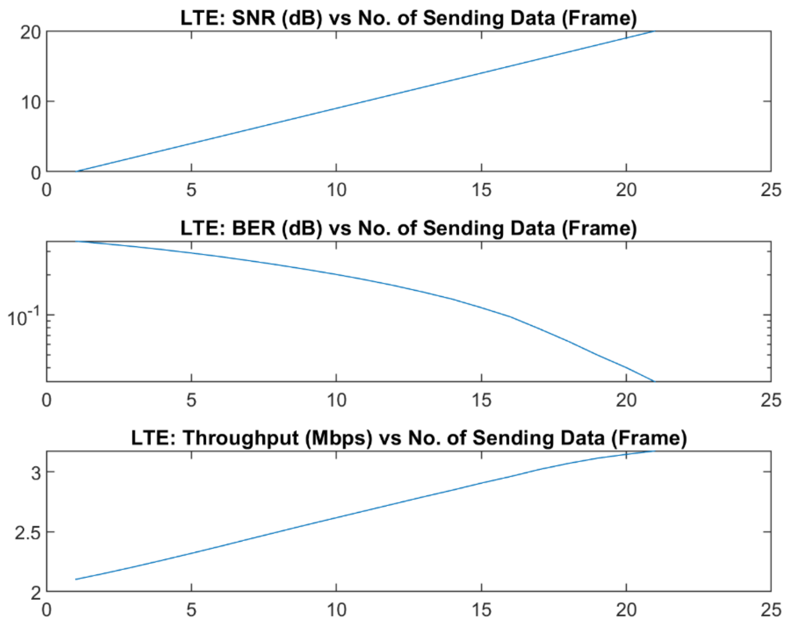

Figure 13: LTE Responses

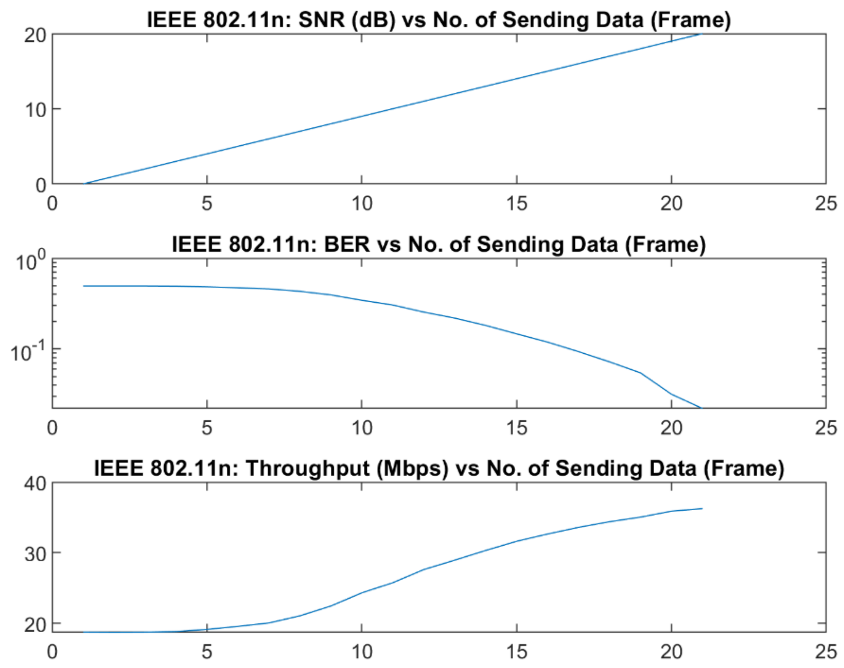

Figure 14: IEEE 802.11n Responses

In all graphs, the x-axis indicates the number of data to be sent, and the y-axis means the SNR, BER, and throughput, respectively. As the SNR becomes decrease, BER increases, thus throughput is increased. This behavior is observed in all 5G, LTE, and WLAN. For example, in Fig, the lowest SNR has been recorded at the point of 5, whereas BER is highest, and throughput is also lowest. Since the SNR is the difference between signal power and noise power, the signal becomes very noisy when the difference gets very small; consequently, throughput becomes lower.

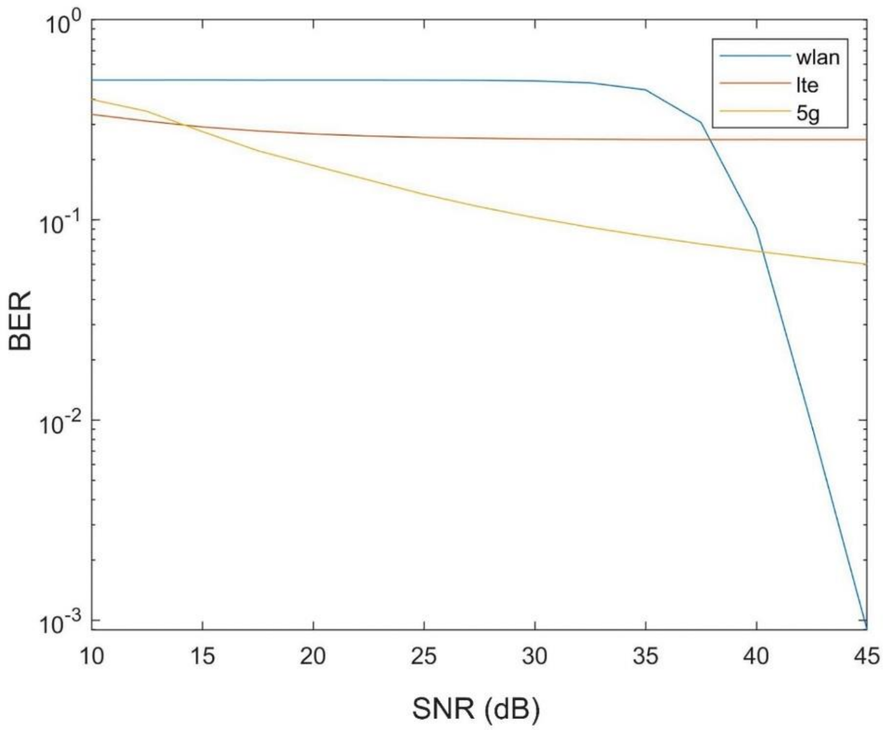

Figure 15: Relationship between BER and SNR (dB)

The relation between BER and SNR is depicted in Fig.15 How BER change with respect to the SNR is the main observation of this graph. As the SNR becomes large, the value of BER is decreases and vice versa. At the first moment, when SNR is small, WLAN BER is higher than 5G, and 5G is higher than LTE. Then, in the end, LTE BER becomes the highest, then 5G then WLAN. The reason is related to many factors. First is the frequency since LTE frequency is the lowest comparing with 5G, and WLAN will respond slower than the other, and it shows clearly in WLAN since it has the highest frequency. Second is the modulation and coding sets (MCS). For example, 256 QAM will respond slower than 16 QAM the same as code rate if the same modulation scheme used with different code rates; the lower code rate will require fast response than the higher code rate. From that explanation, WLAN acts slower than the other since it uses a 64 QAM modulation scheme.

3.3.2 First Scenario

In this scenario, from the user's side only one RAT is available in the network, and from network's side, it will not have any knowledge about the packet type received from the user. The purpose of this scenario is to evaluate the QoE of the user when only one RAT is used exclusively either 5G, LTE, or WLAN as well as when there is no information about the target of QoE need to be provided to the user. The SNR value will change randomly every time the user needs to send, and in each time, the QoE is measured based on the QoS. The target QoE is between fair and good since in this scenario, no information about the packets is known. Figure 16, 17, and 18 show the 5G, LTE, and WLAN QoE measurement in terms of BER, throughput, and latency. As shown in Fig. 16, when the user sends through 5G radio, the QoE the user experienced is above the target, and this means a waste of resources since, in multiple user scenarios, other users will not have the same QoE. In Fig. 17, sending through LTE, the user always experiences bad QoE, since the QoS does not reserve the resources needed, same as in Fig. 18, when the user sends through WLAN. Notice that, in all figures, the

QoE target remains the same since the network does not have any knowledge about the traffic. It deals with all types of packets with the same experience.

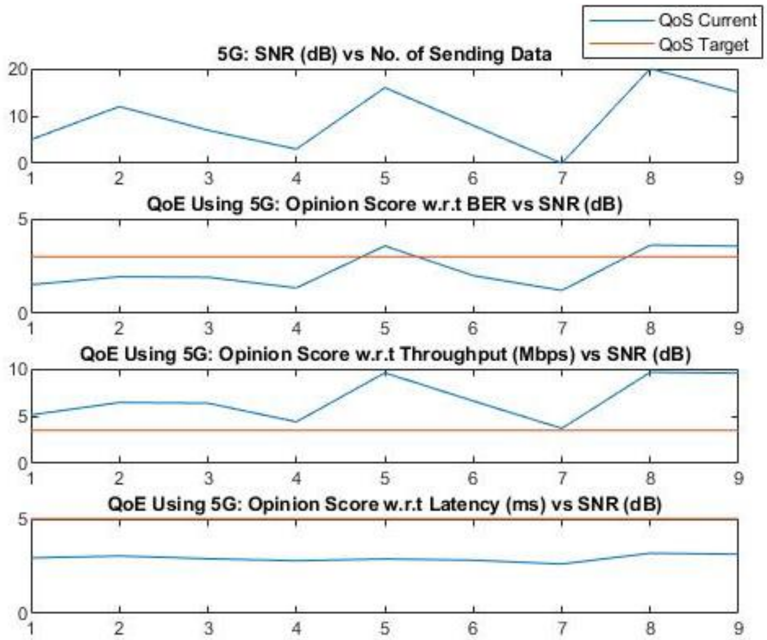

Figure 16: 5G QoE in First Scenario

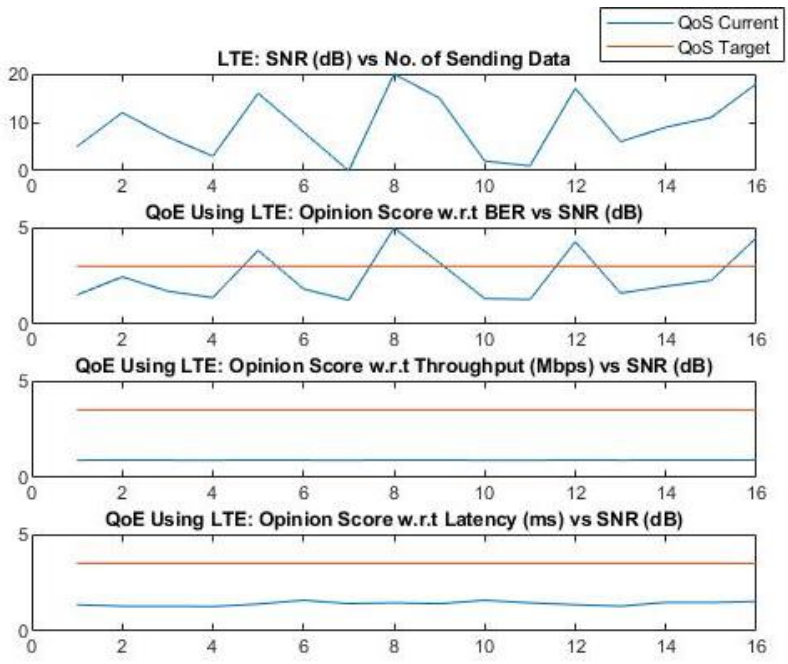

Figure 17: LTE QoE in First Scenario

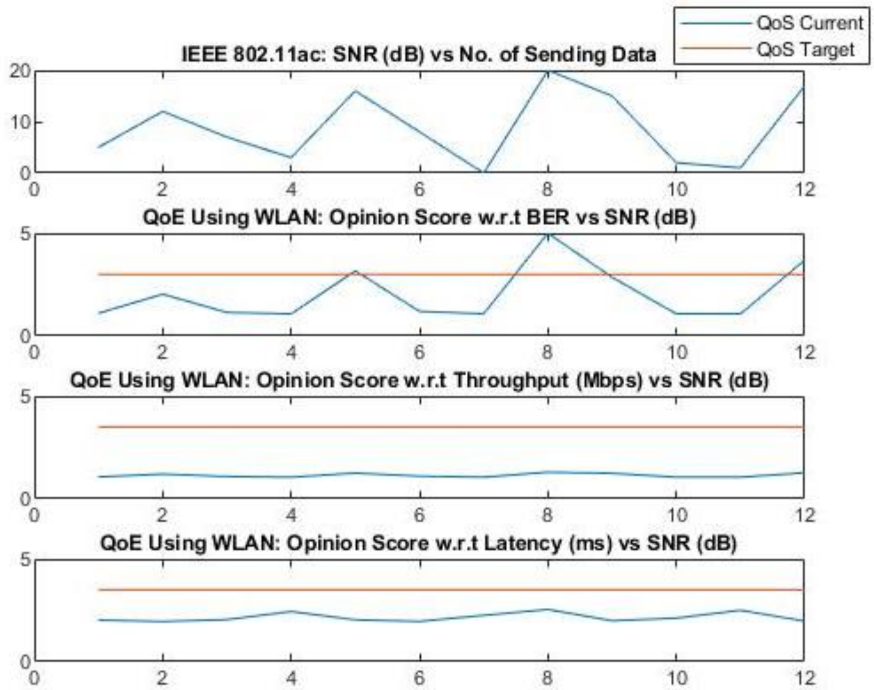

Figure 18: WLAN QoE in First Scenario

3.3.3 Second Scenario

In this scenario, from user's side only one RAT is available in the network, and from network's side, it will have knowledge about the packet type received from the user, meaning that the MANO architecture will be implemented but will be integrated with one RAT. The purpose of this scenario is to evaluate the QoE of the user when only RAT is used either 5G, LTE, or WLAN as well as when there is information about the QoS profile of the transmitted packets. Like the previous scenario, the SNR will be selected randomly, and in each time, the comparison between the target QoE and QoE measured will be made. Figures 19, 20, and 21 show the QoE readings from 5G, LTE, and WLAN technology, respectively. In general, it is notable that the target QoE is to keep change for every iteration since the packet type is change. In Fig. 19, 20, and 21, the QoE, considering throughput, does not improve since the user keeps sending the data through one RAT only. Conversely, the QoE, considering latency, is improved because the network knows the target QoE of each packet type.

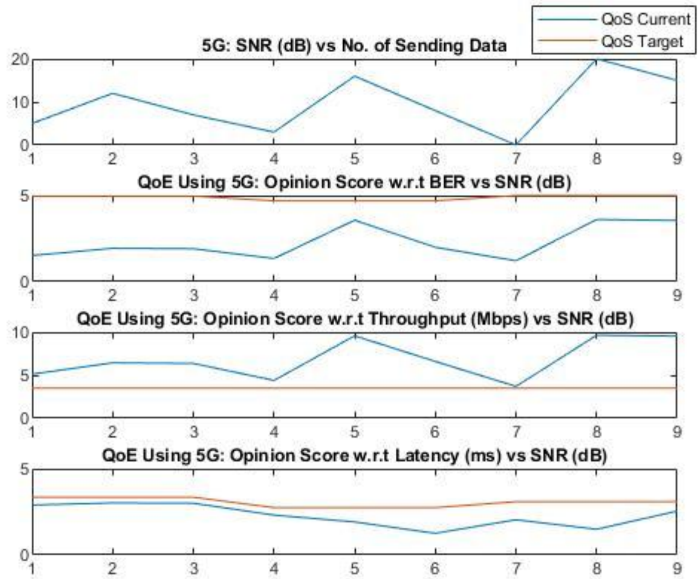

Figure 19: 5G QoE in Second Scenario

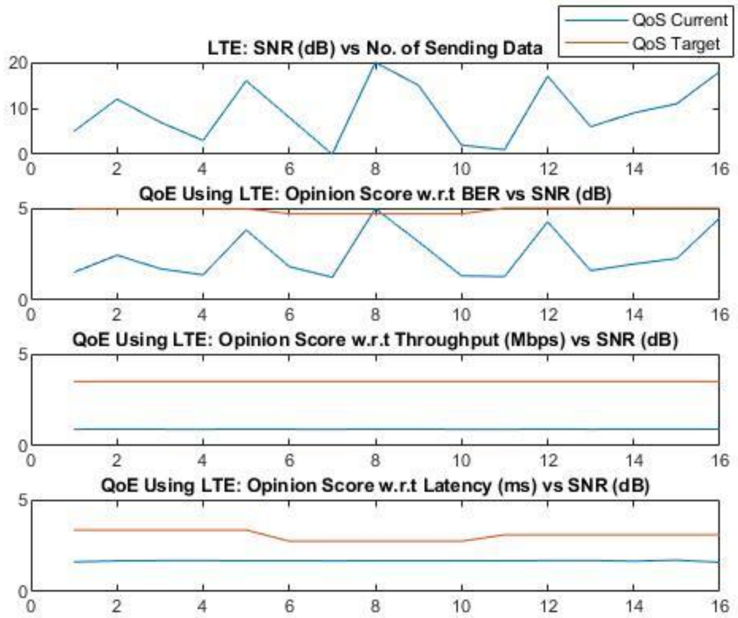

Figure 20: LTE QoE in Second Scenario

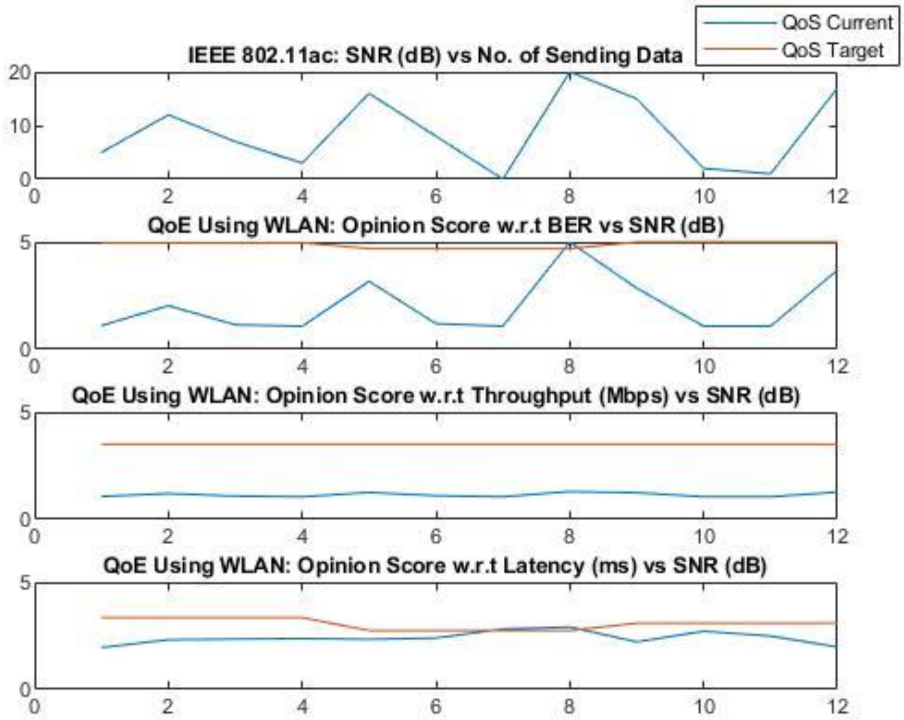

Figure 21: WLAN QoE in Second Scenario

3.3.4 Third Scenario

Testing and evaluating the proposed method will be in this scenario. The user can utilize all the network resources using the proposed multi-connectivity architecture using Multi-RAT. Also, the network will contain the MANO module to deliver the best QoE to the user. Figure 22 shows the average QoE considering all the QoS parameters. It shows apparently, based on the QoE values indicates that the user is receiving a good service comparing with previous scenarios. Figure 23 shows how the proposed method responds when the channel becomes worse or good. When the SNR becomes very low, the network tries to minimize the QoE error even if the condition of the channel is perfect; the network makes the user send his data based on the target QoE.

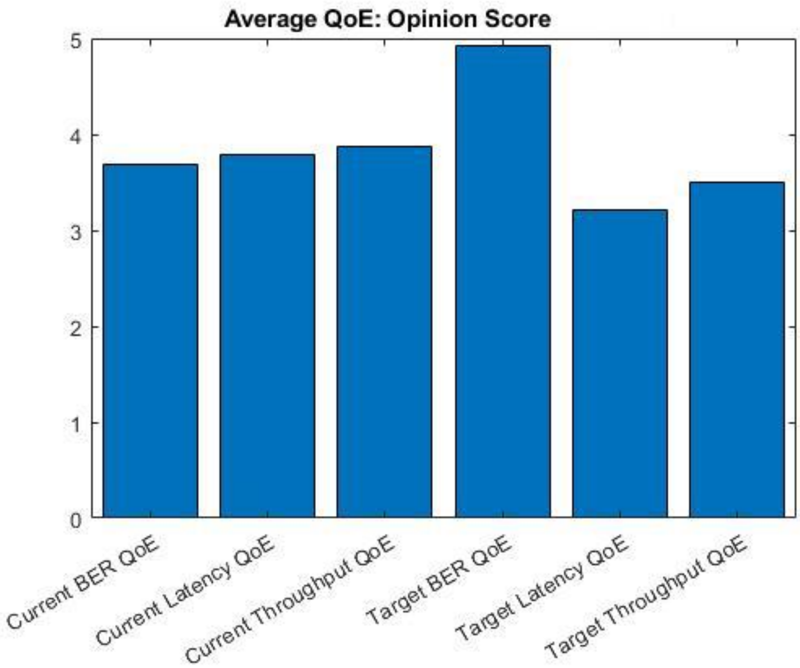

Figure 22: Average QoE in the Third Scenario

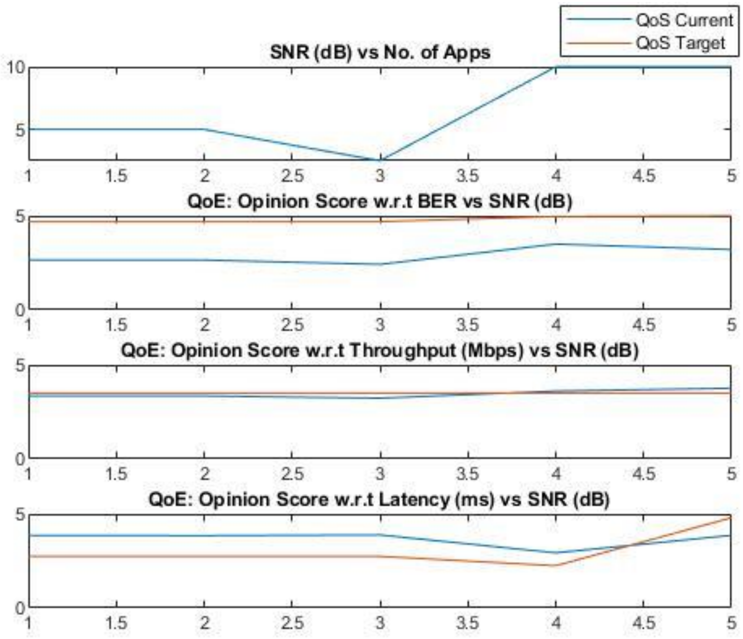

Figure 23: Proposed Method QoE

3.3.5 Comparison Between Three Scenarios

As shown previously, in the third scenario, when the proposed method is applied, the results become more acceptable in both points of view. First, from the network point of view, the network gave the user the exact amount of resources needed. Second, the user's point of view, the QoS delivered from the network, is good and satisfies his requirement. Based on the previous results, the first scenario is the worst scenario comparing with second and third since the network does not utilize the resources well; also, it was so far to satisfy the user requirements. Based on this conclusion, the comparison happened between the second and third scenarios.

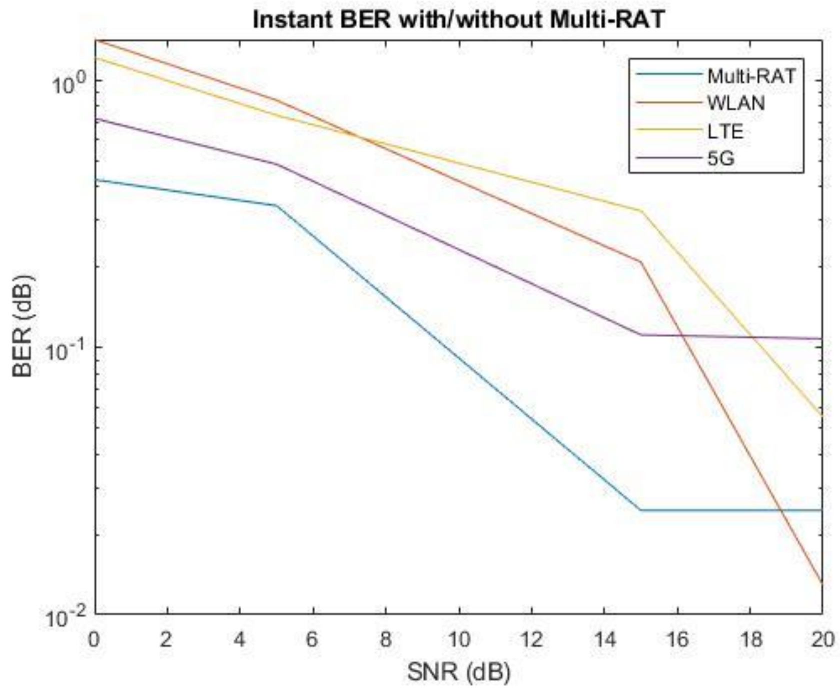

Figure 24: Instant BER with/without Multi-RAT

Figure 24 shows the instant BER with and without using the proposed method. It observed that using Multi-RAT, the BER is always the lowest compared to others, and this due to spreading the packets to have less chance for error.

Similarly, with latency, as shown in Fig. 25, the proposed method achieved the lowest latency, and the reason for that is by sending the packets in parallel through all the available technology.

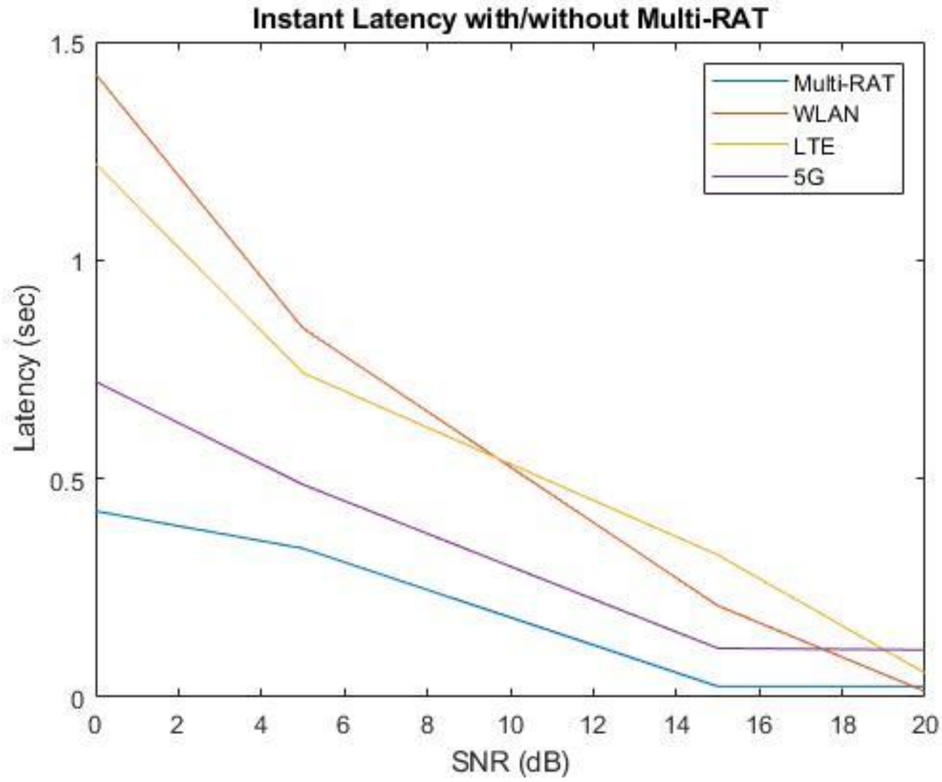

Figure 25: Instant Latency with/without Multi-RAT

Figure 26 shows the instant throughput with and without using the multi-connectivity technique in Multi-RATs. The throughput reaches, in the best channel performance, around 200 Mbps. Comparing with others, using Multi-RAT resulted in getting high throughput. As mentioned in the first chapter that 5G requirements are to reach 100 Mbps as the user experienced data rate with latency around 1ms.

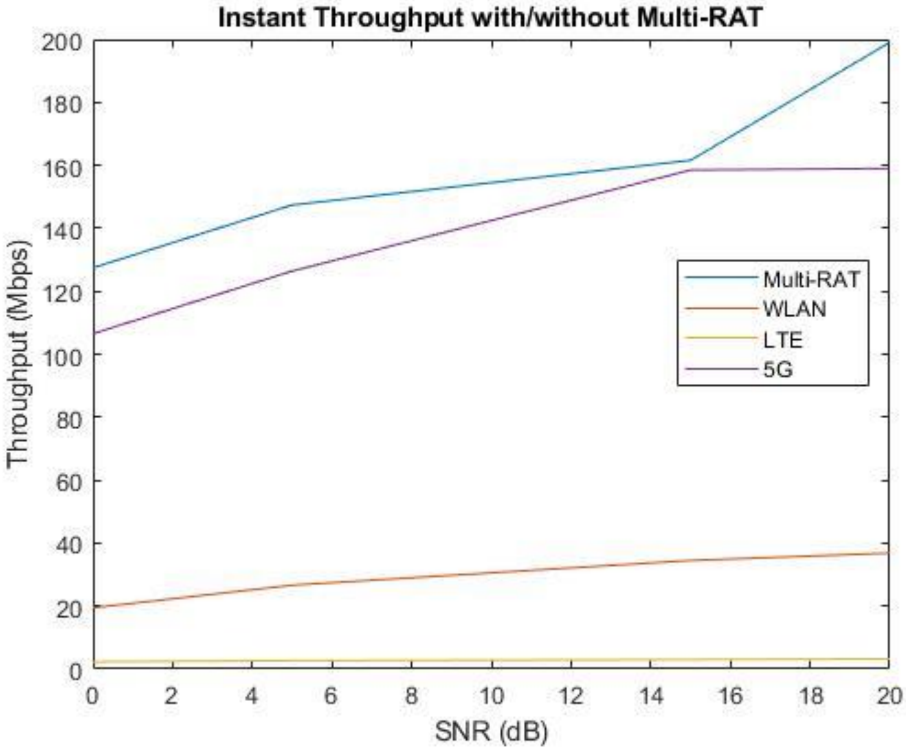

Figure 26: Instant Throughput with/without Multi-RAT

4.1 Conclusions

In conclusion, this project confers the way of multi-connectivity MANO architecture integrated with Multi-RATs, which are 5G, LTE, and WLAN. The RAN-based approach was selected, allowing the coordination between all RATs. For managing the architecture, the RAN-Controlled method was chosen to control the multi-connectivity technique in the radio network. Based on that, we proposed a multi-connectivity MANO architecture that improves the overall throughput to the users, optimal exploitation of 5G network resources to meet the 5G KPIs and guarantee the continuity of the service to the users. Practical simulation experiments confirmed that the proposed method tries to always find the best results that satisfy the user requirements in terms of low latency and high throughput. The 5G specifications have been achieved by having 1ms latency and around 200 Mbps data rate. The limitation of this work is that the mmWave technology is not addressed since it is one of the critical key technologies in 5G.

4.2 Future Work

As it is shown that the packet was predefined in the simulation, an automated solution can be done to classify the incoming data using IP-address, protocol type. Furthermore, this project can be enhanced by using an intelligent load-balancing algorithm, as mentioned in the previous chapter. In terms of simulation experiments, a multiple user scenario can be tested.

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