



ANALYSIS AND MODELING OF 5G NETWORK PERFORMANCE BASED ON  
RESPONSE TIME REDUCTION

BY

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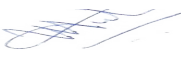
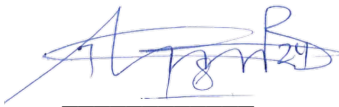
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APPROVAL SHEET

We, the undersigned, members of the Board of Examiners of the final open defense by Mekasha Mekuria have read and evaluated his thesis entitled “Analysis And Modeling of 5G Network Performance Based on Response Time Reduction”, and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Computer Science.

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## DEDICATION



I would like to dedicate this Thesis to my beloved sweetheart Dr. Alemnesh. The completion of this work would not have been possible without her encouragement, support, understanding, patient, and most of all love.

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*Mekasha Mekuria*

## STATEMENT OF THE AUTHOUR

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

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## Abstract

Despite the fact that 5G technology has the benefits of meeting all of the key requirements for a 5G system and understanding the secrets for attaining a reduced response time, which was the most dominating component in 5G, the globe had adequate bandwidth in earlier generations for daily usage. However, response time was not a major concern, but for today's applications such as VANET and ongoing online gaming, as well as for vertical industries accessibilities such as SDN (software-defined network), NFV (network function virtualization), URLLC (ultra-reliable low latency communication), backhaul connection, and control or location update information, response time is more crucial than output. To address the aforementioned challenges and gaps, the study have analyzed the numerologies to 5G NR(radio network) recognizing KPI for cellular system analysis based on human demands and technological efforts to fulfil purpose, and address the aforementioned challenges by using the 5G toolbox for techniques of simulating hidden 5G numerologies. The simulation results show that our proposed approach outperforms state-of-the-art techniques because it yields the highest probability in regarding the requirements from the access network in response time reduction. As a practical implication of the study, the researcher have realized that the adaptable subframe structure leads to a very low symbol duration, which enables low response time, as time critical applications increased, and that wider subcarrier spacing could be used for users to provide them with very low response time symbol duration. In the future work, the study planned to incorporate the channel modeling of the mmwave band was relatively complex; which does not have any perfect channel model, high-capacity backhaul connectivity, for its challenging for the exponentially growing data demands of 5G and would be required more additional exploration in depth and spectrum and interference management due to the scarcity of the spectrum resources and interference issues, thus needs efficiently manage the 5G spectrum, hence should be to conduct comparative performance analysis.

**Keywords:** 5G novel protocols, massive multiple-input multiple-output (MIMO), non-orthogonal multiple access (NOMA), Key Performance Indicator (KPI), software defined network (SDN), network function virtualization (NFV), 5G, response time, frame structure, 5G NR

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## Chapter One: Introduction

### 1 Background of the Study

Certain applications demand exceptionally quick response times as communication capabilities progress, and a telecom system must fulfil the three standards of availability, integrity, and secrecy. As a result, the ultimate relevance of telecom power is usually emphasised; as a proverb goes, a country's might is measured by two factors: its army and its communication infrastructure. Because telecom infrastructure offers a wide range of uses, from everyday use to industrial applications, it has improved our quality of life. We can access our internet services from anywhere on the planet; we can communicate with our family, friends, and coworkers without boundaries; and in an industrial setting, we can monitor and collect data from equipment in the field and perform different operations on this data.

Mobile or cellular network is the most telecom application that plays a significant role in our lives, basically, glad to the mobility that it provides us, however, this did not end here, starting from analogue phone or the 1G which was not so popular, the 2G provided us with the mobility and many voice services which were the critical requirement of the cellular network back then, such as texting, call on-hold, MMS ... ,the human lives isn't only based on talking all the time ,especially after the big evolution of the internet, the realises of the 2G didn't fulfil the requirements and that can be to the old access technology which was TDMA, the throughput provided wasn't sufficient for a user to watch videos or to browse with ease, the 3G came up with a solution for giving the accessibility to the web ,which was the next goal for the cellular communication system, glad to the CDMA technology and separation of packet switching from the voice, the 3G system had a long journey since everyone could access internet with reasonable throughput, many people were fine with the service provided by this generation, but the world of technology isn't only for telecom, the revolution in other technologies made 3G embarrassed, such as HD videos, continues online gaming; the big war is telecom and informatics already settled, we no longer depend on the circuit switching in the voice communication, the packet switching is doing the job.

This made the 4G the first full IP-based system, with a sufficient throughput and response time for the evolution of digitalization, by the introduction of the OFDM approach which played the hero role in 4G systems, but the war of technology did not end here, the world is growing fast and one year of human lives equals four years of technology, a new concept of other technologies was introduced and forced the 4G system to seem old, but rather than throughput problem which was the big concern in the previous generations, now the response time has climbed the stairs and forced itself to be the most critical aspect, which was the primary focus of the 5G, achieving a 1ms response time in our communication system rather than 25ms in 4G, with a reliable link, it is the hardest challenge that the telecom infrastructure has ever seen, the VANET, D2D, tactile internet, telemedicine, internet of things, and etc. And all the promised fictional applications are becoming real in the 5G cellular communication system. The concept of response time reduction is divided into many sections, and every optimization in each section is essential. The evolution of networking made it even easier by introducing SDN and NFV in the core, as well as the variable numerologies in the new mmwave spectrum.

In the case of security and privacy, the 5G network system has big issues maintaining itself, and the 5G mobile networks is a system with many new service capabilities. As technology advances, so do insecurity and privacy, new protections are needed to survive in security and privacy. Hence, it should study threats and safety concerns. Even though, improvements in 5G mobile broadband, mission-critical communications, IoT, automated vehicle communication, big data, Radio Access Networks (RAN), smart cities, industrial automation, and much more. More future services of 5G are unknown today (*Fallgren, M., Dillinger, M., Mahmoodi, T., Svensson, T., & Wiley, J. (Eds.). (2021)*). 5G's modern technology, modern architecture, modern applications, and modern security problems, and solutions are needed. New penetration detection techniques are needed for 5G because the 5G structure of a combination of different networks. The existing 4G, 3G, and 2G, security systems will not be very useful for 5G. It is possible but difficult to provide data protection to users on existing networks, largely due to low bandwidth, and broadcasting issues. Attacks on the OSI model's physical layer and media access control level tend to be more prevalent on existing networks (*Ghosh, T. C., & Jabiullah, M. I. (2021)*).

Our current network does not provide end-to-end security in cryptography. Traffic between phones and base stations is simply encrypted, but there is no encryption when transmitting data

over a wired network (*Wilson, J., Wahby, R. S., Corrigan-Gibbs, H., Boneh, D., Levis, P., & Winstein, K. (2017)*). Our current network security is limited to users and devices only. Future wireless networks will require new technologies, such as low-response-time communication and high energy efficiency (EE). 5G will not only provide us with an advanced wireless network but also solve our new security problems. High-end devices will not always work on the same protocol. Cloud computing, smart apps, and the Internet of Things (IoT) will all require separate protocols. Cryptographic systems depend on the complexity of the algorithm; SDN (software-defined network) and NFV (network function virtualization) are incompatible with traditional networks (*Tschofenig, H., & Baccelli, E. (2019)*). For SDN, data transmission is separate from data management; unified software centralises network management; and physical network resources are virtualized. Physical level protection (PLP) can play a key role in protecting 5G wireless networks. Thus, low-response-time communication was one of the techniques used to maintain security and privacy in the 5G network. Due to this, the study mainly focused on response time reduction in the 5G network.

In this thesis, the study was carried out to address the response time issues of the 5G system and focus on the RAN (radio access network). To address backhaul network issues, the 5G network must handle the huge volume of data for connecting between the access networks and the core network to support high-data-rate services at the user level; otherwise, a bottleneck will be created.

## 1.1 Motivation

The rapid evolutions of LTE technology have inspired the researcher to investigate performance issues and interpret existing 5G models in consideration of response time reduction, as well as modelling that helps reduce response time in 5G networks, as well as to address common understanding constraints of 5G network performances abroad. Performance and throughput support massive connectivity in 5G and its legacy LTE networks. For spectrum sharing, fair and effective existential techniques are required. On the other hand, to support response-time-critical services, response-time reduction approaches need to be developed.

Hence; I felt inspired. To truly engage in the objective of reasoned decision-making, it is crucial that the subject inspire me to discuss it with passionate challenges. It pushes me to think

critically about my beliefs about education, learning, literacy, and change; in other words, it challenges me to grow. Encourage a variety of viewpoints. The issue has to be stated in a way that discourages dichotomies and instead encourages the development and examination of other viewpoints. A good problem is one that would elicit a range of opinions from a large audience, according to the general rule of thumb. Everyone may relate to my research and give suggestions that could influence the analysis and conclusions of my study.

## 1.2 Problem of Statement

In terms of infrastructure, telecom firms are increasing the number of antennas installed to enable short response times on networks to deal with the expanding user population. Another area where 5G might help lessens the environmental impact of high-speed networks in transportation. Whereas a 4G network requires four antennas to accomplish one gigabit, a 5G network just requires one antenna to achieve the same result, consuming less power and materials (*Ebner, W., Leimeister, J. M., & Krcmar, H. (2009)*).

Apart from the difficulties associated with 5G network installation, mmWave communications have been considered a key component of the 5G mobile network for offering eMBB services such as VR (virtual reality), AR (automation reality), and ultra-high definition video (UHDV). It is capable of meeting the needs of the rapid growth in mobile traffic demand while lowering the bottleneck effects of wireless bandwidth, which is a critical challenge for 5G networks. However, electromagnetic signal blockage and the architecture of integrated circuits are the problems of mmWave communications. These waves in the 60 GHz range are prone to blockage by obstacles (e.g., persons and furniture), resulting in a 20–30 dB penalty for blocking by a person. An mmWave emission statement that takes human activities into account has been published in this respect, and it has been proven that a channel may be blocked by 1 to 2 percent on average by 1 to 5 persons. Furthermore, when the user device approaches the edge of the service cell, the chance of blocking grows linearly (*Lien, S. Y., Hung, S. C., Deng, D. J., & Wang, Y. J. (2017)*).

The primary problem of an SDN (software-defined network) or NFV (network function virtualization)-based core network architecture is the management and organization of these

diverse resources. Effective resource allocation and function implementation in this diverse context while retaining a short response times is an up-and-coming research requirement.

The majority of the basic restrictions for obtaining short response times necessitate changes to the physical and Mac layers, which are at the RAN (radio access network) level. An mmWave is a potential technology that delivers significant additional spectrum for communications in the 3-300 GHz region for attaining low response time in 5G networks. However, mmWave is reliant on a variety of factors, including transmitter/receiver position and ambient topology. Furthermore, channel modeling with delay spread, path loss, and NLOS (Non-Line-of-Sight) components in the radio propagation environment can severely degrade the performance of Ultra-Dense Networks (UDNs), beam forming, and angular spread need to be investigated in indoor and outdoor environments that are still evolving (*Celidonio, M., Fionda, E., Vaser, M., & Restuccia, E. (2018)*).

Furthermore, because of the huge size of the packet, distortion and thermal noise caused by the propagation channel are averaged in traditional packet transmission. However, in the case of tiny package sizes, such averaging is not achievable. As a result, thorough channel modelling followed by simulations for tiny packets in various carrier bands must be examined (*Durisi, G., Koch, T., & Popovski, P. (2016)*).

The backhaul network connects the access network (e.g., eNB) to the core network and is made up of fiber, copper, microwaves, and occasionally satellites. Deploying backhaul networks for small cells to enable high data rates and short response times is one of the primary issues for operators in this environment due to a lack of suitable fiber networks in many different places (*Jaber, M., Imran, M. A., Tafazolli, R., & Tukmanov, A. (2016)*). Instead, it requires backhaul and fronthaul to transport high-density cell traffic with capacity limits such as high response time and delay.

According to the caching issues, edge caching can be a critical tool for response time reduction along with spectral and energy efficiency improvements. Recently, this issue has attracted a lot of attention from researchers in both academia and industry, resulting in a lot of different

approaches. However, the researcher believes that there are still a lot of research problems that need to be solved.

To deliver services and use cases, the 5G network leverages new infrastructure technologies such as virtualization, software-defined networking (SDN), and network function virtualization (NFV). Traditional networks separate elements, while with 5G, services and infrastructure are spread as virtualized resources. Different virtual network slices are defined in this heterogeneous environment, each with its own set of virtual network security needs. 5G is compatible with a wide range of services, including mMTC (multiple machine type communication), URLLC (ultra-reliable low latency communication), and eMBB (evolved multicast broadband). Each service must have its own set of security needs, and a multi-level virtual slicing architectural security framework should be necessary to enable policy and threat detection and mitigation in real time.

Due to a lack of technological maturity, operators are releasing 5G services with eMBB (evolved multicast broadband) applications, and other service types, such as URLLC (ultra-reliable low latency communication), will not be accessible anytime soon. This is because 5G network enablers such as SDN (software-defined network), NFV (network function virtualization), and RAN (radio access network) are being developed. Technology maturity necessitates narrowing one's focus and minimizing fragmentation. Instead, each vendor works independently, which may delay the maturity of NFV (network function virtualization) deployment, restricting the potential to deliver diverse service types (e.g., URLLC) in the 5G network domain.

Thus, the researcher has gone to drive different model prototypes concerning the challenge to investigate the way to address those problems and to recommend else more to study the low response time of the 5G network system and focus on the RAN (radio access network), particularly in how the frame structure of 5G plays a big role in reaching an ultra-reliable low response time system using numerologies, investigate critical manipulators, and 5G network novel protocols, as well as through the 5G Toolbox in 5G networks, Channel Coding, Massive MIMO (multiple input, multiple outputs), Multiple Access, Resource Allocation, and Network Security, which are used to reduce response time in 5G networks.

### 1.3 Research Questions

To address the aforementioned research gaps, the study intends to answer the following core research questions:

Q1. What are the challenges identified in the existing 5G wireless mobile network system?

Q2. What are the thorough 5G Toolbox and 5G protocol architectures applied for solving problems in 5G mobile networks?

Q3. How is low response time impacted by cache size, cache location, and wireless channel parameters?

### 1.4 Objectives of the study

#### 1.4.1 General objectives of the Study

The purpose of this thesis is to analyze the performance of a 5G network based on response time reduction and different model interpretations. It also aims to design model prototypes and address the more challenging issues in emerging 5G network technologies, providing a common understanding of response time constraints and analyzing the performance of 5G via simulation, 5G novel protocols, self-generating numerologies through the 5G Toolbox in the Matlab.

#### 1.4.2 Specific objectives of the Study

- To analyze the 5G network's performance from a response time perspective.
- To analyze the main requirements that are needed to achieve a lower and more acceptable 5G network response time.
- To simulate the burst time of the most significant waveform.
- To investigate radio access networks for reduction of response time using their different numerologies.
- To design prototypes that are achievable for low response time communication in a 5G network
- To analyze the efficient algorithms with 5G novel protocols that are used for the reduction of response time in 5G networks.

## 1.5 Scope of the study

5G networks are now a popular research area that encompasses a wide variety of challenges, such as implementation issues, device-to-device communication issues, and so on. MmWave communication problems include issues with building backhaul networks for small cells to handle high data rates, a lack of appropriate fiber networks in many different places, electromagnetic signal blockage owing to small cells with unimproved backhaul networks, and radio access networks (RAN). This research, on the other hand, focuses on the examination of efficient algorithms, protocols, and caching concerns in 5G networks, as well as the performance analysis and modelling of 5G networks based on response time reduction in radio access networks.

## 1.6 Limitations of the study

The one major limitation of this thesis would have to be faced, and as 5G is still an evolving technology, the datasets availability for experimentation were limited. However, most of the data used in the literature surveyed were self-generated numerologies through experimental derivation using the 5G Toolbox. 5G technology is expected to increase the density of mobile communication devices, such as wearable devices, integrated headsets, and implantable sensors. However, providing seamless, high-quality communication everywhere with existing generations may not be possible due to problems such as high mobility, Doppler shift, frequent hand-over, and a lack of coverage in some areas. 5G technologies must participate in Industry 4.0 in building and factory automation, production, e-health, transportation, agriculture, surveillance, and smart networks. However, analyzing its performance globally is too challenging, and a dataset investigation will be impossible to find. The thesis work has been depended solely on the simulation demonstration of its performance analysis of the real-time scenario through 5G Toolbox's experimental derivation of its self-generating numerologies.

## 1.7 Significance of the Study

This thesis would meet the most significant goal of the 5G network with reduced response time, allowing it to create mobile networks that will enable users to do new things in addition to improving what they already do. Each radio access technology has its own radio resource management system, which is well-designed to maximize available resources. Since then, the

possibilities have grown to include multiplayer mobile gaming, factory robots, self-driving cars, and other jobs that require quick reaction in regions where today's 4G networks struggle to fail.

And

- In the 5G network, the LSTM assigns optimal bandwidth and power to the UEs, while the Generic Segmentation Offload (GSO) discovers appropriate hyperparameters.
- By analyzing all of the UEs' request queues, an allocation of resources to the unwanted UE is avoided. Additionally, the LSTM-based RRM reduces network traffic.
- Furthermore, guard-level data insertion is used to reduce ISI (intersymbol interference (ISI) in the network.

5G and IoT are a great combination, with the potential to completely transform how wireless networks and the internet are utilized. With the ability to effortlessly connect hundreds or thousands of devices, new applications and use cases for cities, factories, farms, schools, and households will bloom. Low response time technology, as well as an overabundance of appliances, gadgets, and components that rely on sensors and network connections, will significantly increase industrial automation.

Agriculture, industry, and logistics, as well as gaming, are likely to profit from 5G deployment. As connections improve, virtual reality (VR) and augmented reality (AR) applications are projected to gain prominence. The Internet of Things (IoT) is quickly expanding throughout the world, and businesses and organizations are building complicated solutions to assist people suffering from chronic diseases. Additional benefits of this sort of health IT communication include reduced response time and improved patient care. As:

- A privately secured cloud can store medical data.
- Patients can be empowered to manage and understand long-term health conditions.
- Doctors and other health professionals can track patient health statuses and promptly intervene when observing negative trends or abnormal measurements.

#### 1.7.1 Organization of Thesis

The complete prearrangement of this thesis possibly encompassment the following consistent and coherent chronological fellow:

Chapter one: include the introduction or the background of the study, in chapter two: the majority of the literature review concerning the 5G networks and the techniques that drives the reduction of response time, in chapter three: the techniques that enable in the reduction of response time in 5G, and modeling derivation for proposed problem and its manifestation, chapter four: the simulation that driving mechanisms to the conclusion of the study, and chapter five: the conclusion of the study, and recommending for the future work are the possible inclusive topic contents in this thesis paper will be incorporate.

## Chapter Two

### Literature Review

To understand the problem domain of the proposed solution from the literature background and to identify the clear boundary of this research work from the current state-of-the-art, various books, journals, and research works related to the 5G of mobile technology network considering their performance within the reduction of response time will be reviewed.

The goal of next-generation mobile communication is to offer seamless connections for machines and devices creating the Internet of Things (IoT) as well as personal communication. New applications such as tactile Internet, high-resolution video streaming, telemedicine, telesurgery, smart transportation, and real-time control necessitate new standards for throughput, dependability, end-to-end (E2E) response time, and network resiliency (*Parvez, I., Rahmati, A., Guvenc, I., Sarwat, A. I., & Dai, H. (2018)*). In addition, intermittent or always-on connectivity is necessary for machine-type communication (MTC). Emerging technologies such as wearable appliances, virtual and augmented reality, and fully immersive settings are influencing the demeanour of human end users and have unique user satisfaction criteria. These 5G use cases push the standards of the next-generation network in numerous ways, including data rate, short response time, dependability, device/network energy efficiency, traffic volume density, mobility, and connection density.

The fifth-generation (5G) cellular network is the wireless access solution for meeting 2020 and beyond wireless broadband communication criteria. The 5G ITUR working group at ITU is working on 5G development within the IMT-2020 timeframe. The goal of this endeavor is to achieve a thousand-fold increase in throughput, 100 billion connections, and near-zero response

time. 5G will provide improved mobile broadband (MBB) with 100 Mbps end-user data rates in a uniform geographic distribution and peak data speeds of 10–20 Gbps. Response time and reliability difficulties must be addressed in mission-critical communication (MCC) ( *Wu, C. K., Tsang, K. F., Liu, Y., Zhu, H., Wang, H., & Wei, Y. (2020)*).

To obtain a short response time for MCC, significant changes in network design must be made. A new network design integrating software-defined networking (SDN), network virtualized functions (NFV), and mobile edge computing (MEC)/caching can be used to drastically improve response time.

Thanks to 5G mobile technology, the whole mobile business will benefit from innovation (*Smail, G., & Weijia, J. (2017)*). It aspires to have massive connections and the ability to support a diverse set of users, services, and applications with vastly differing requirements. It seeks to make effective and adaptable use of the available radio resources. Future mobile networks will allow both LTE and air interface evolution by using new frameworks for solutions such as cloud, software-defined networks (SDN), and network function virtualization (NFV). Operators place a high value on both time and money. A reasonable choice must be made in order to keep up with the evolution of the mobile industry. Because earnings are not expanding at the same rate as traffic, new revenue streams and cost-cutting methods are also necessary. RAN (Radio Access Network) sharing is a logical technique that may help reduce costs, increase efficiency and competitiveness, and improve customer satisfaction. The active sharing of RAN (Radio Access Network) between two or more operators is required to reciprocally grant access to each other's resources. This inter-operator agreement provides various benefits to operators, including cheaper operating and capital expenditures (CAPEX), more income, and reduced energy usage. Furthermore, it promotes innovation because operator rivalry is based on features and services supplied (*Ebner, W., Leimeister, J. M., & Krcmar, H. (2009)*).

Current 3GPP standards, such as Multi-Operator Core Networks (MOCN) and Gateway Core Networks (GWCN), fully support network sharing across operators in a range of scenarios. Separating the functionality of physical objects from their hardware via virtualization is a critical step towards infrastructure sharing these days. Furthermore, virtualization enables network densification and small cell deployment; femtocells and picocells are produced by Radio Remote

Heads (RRHs) rather than low-power base stations (BSs) and access points, and infrastructure workload is computed at Base Band Processing Units (BBU), which can be shared among multiple operators in the cloud (*Zhu, Z., Gupta, P., Wang, Q., Kalyanaraman, S., Lin, Y., Franke, H., & Sarangi, S. (2011).*

When we pose a question, we must wait for an answer, which may take many seconds, before we can begin a conversation. The response time is the amount of time that passes between an action and the following response. The rapid response times of 5G networks are critical for improving the user experience and increasing the number of available services. Some applications demand a highly crucial response time in other hands, and a telecom system should meet the three standards of availability, integrity, and secrecy. Today, response time is one of the most crucial features of telecommunications. In contrast to previous network generations, which were designed as general-purpose connectivity platforms with limited differentiation capabilities across use cases (*Vannithamby, R., & Soong, A. (Eds.). (2020) and Attaran, M. (2021)*), 5G aims to create an ecosystem capable of meeting the technical needs of so-called vertical industries such as healthcare, energy, or automotive. Thus, the relevance of telecom is frequently emphasized.

Remote working involves increasing the number of potential users on a network and achieving efficiency. This has been done before with IP addresses and the transition from IPV4 to IPV6, which opened up an enormous number of connections. The move from 4G to 5G on radio networks allowed for a limitless number of new users, and the main advantage of 5G is its ability to speed up network response times (*Attaran, M. (2021)*).

Many advances and standardisations have occurred in the fifth generation of wireless networking, such as in long-distance medical care, online university courses, and commercial meetings. Mobile broadband (MBB) and low response time communication (LRTC) services are utilised for applications requiring high reactivity and dependable data transfer, such as civil security for vital missions. These services need more coverage, consistent response times, and lower energy consumption than high data rates. These services need more coverage, consistent response times, and lower energy consumption than high data rates (*Gupta, R., Kumari, A., & Tanwar, S. (2021)*).

Due to its mobility, the mobile, or cellular, network is the most essential telecom application in our lives. With optimizations in each part of the response time concept, 5G wireless connection technologies makes all previously anticipated uses a reality. Networking has advanced with the advent of SDN and NFV, as well as variable numerologies in the new mmwave spectrum, making it even easier (*Gupta, R., Kumari, A., & Tanwar, S. (2021)*).

Traditional cellular networks (including large-scale 5G networks) feature the idea of deep coverage, which is primarily used to optimise the deep coverage of indoor access requirements. 4G network versions of cellular network systems are geared towards people-centred communication demands, and deep coverage is optimised for typical indoor human activity scenarios (*Cui, H., Zhang, J., Geng, Y., Xiao, Z., Sun, T., Zhang, N., & Cao, X. (2022)*). Starting with 5G networks, the object of communication has expanded from human-centred communication to the simultaneous communication of things, so the design and deployment of 5G and future wireless communication networks must take into account both the deep coverage requirements of people and objects, but the backhaul of 5G networks has been in deep connectivity to no standalone 5G network, particularly the deep coverage and its lack of maturity (*Holma, H., Toskala, A., & Nakamura, T. (Eds.). (2020)*).

Beyond 2020, the fifth-generation (5G) cellular network will be the communication solution to address wireless communication demands. In comparison to the present 4G LTE networks, it will reach 1000 times the throughput, 100 billion connections, and near-zero latency. 5G network needs are divided into three categories: Enhanced Mobile Broadband (eMBB), Massive Machine Type Communication (MTC), and Ultra Reliable Low Response Time Communication (uRLLC) (*Zhang, S., Xu, X., Wu, Y., & Lu, L. (2014)*). The peak data rate of eMBB is 10–20 Gbps, with spatially uniform data rates at end users of 100 Mbps. For irregular short packet transfer, a large number of smart devices in mMTC require a low data rate uplink-oriented connection.

In uRLLC, end-to-end low response time, along with reliability on the order of low response time, is to be fulfilled. 5G is an evolution of LTE, providing high-speed mobile Internet and ubiquitous/omnipresent connectivity for sensors, devices, and machines. It will play a critical role in the modern economy, affecting consumers, transportation, health, the power system, education, logistics, and other major industries (*Valihrach, L., Androvic, P., & Kubista, M.*

(2018)). Services are foreseen to have intermittent as well as always-on hyperconnections in machine-type communications (MTC). Emerging technologies, such as augmented reality, wearable devices, and full immersive (3D) experiences, are affecting the lives of human end users and placing new requirements on the next generation of networks. These use cases drive the 5G specifications on different dimensions, such as throughput, low response time, network and device energy efficiency, reliability, connection density, mobility, and traffic volume density (Parvez, I., Rahmati, A., Guvenc, I., Sarwat, A. I., & Dai, H. (2018)).

The study investigated the critical analysis of the performance of the 5G network, with a focus on the radio access network (RAN). The frame structure of 5G plays a significant role in achieving an ultra-reliable low-response timed system using numerologies, modelling the low-response timed system prototype in 5G networks, analyzing the performance of 5G networks through the 5G Toolbox, channel coding, MIMO, multiple access, resource allocation, and critical manipulation of efficient algorithms and protocols. The study presented the sources and fundamental constraints for achieving low response time in a cellular network, exemplary 5G network architecture compliant with the IMT-2000 vision, and proposed solutions for achieving low response time in 5G.

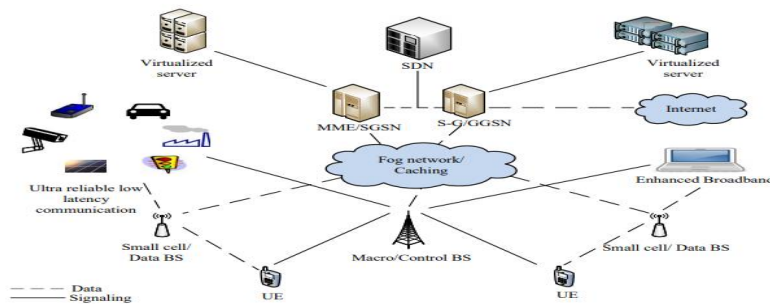


Figure 1: 5G network supporting enhanced mobile broadband, massive machine type communication, and ultra-reliable low response time communication (Lien, S. Y., Hung, S. C., Deng, D. J., & Wang, Y. J. (2017)).

## 2.1 5G network Release phase one: Release 15

The development of a new 5G standard is a major undertaking. The 3GPP has split versions 15 and 16 of the 5G standard into two versions. LTE and network release Phase 1 share features

such as the use of orthogonal frequency division multiplexing (OFDM). A large amount of new hardware must be deployed to properly implement network releases. To maintain the present hardware, a tiered technique has been proposed. There are two versions: one that is self-contained and independent of the LTE core network, and one that is not.

New terminology has been created to make it clear which devices can communicate with one another:

- eLTE eNB (evolved network backbone) is an evolution of the LTE eNB that can connect to the EPC (enhanced public connection) and NextGen cores. gNB (NextGen network backbone) is the 5G network release counterpart of the LTE eNB (evolved network backbone). LTE eNB is a device that can connect to the EPC or the existing LTE core network.
- Network release 1: Interface between the gNB and the NextGen core.
- Network release 2: The core network and RAN's control plane interface (S1-C in LTE);  
Network release 3:
- The core network and RAN's user plane interface (S1-U in LTE)

The differences in frequency ranges are particularly noticeable for network release, as both devices are necessary for network release to function in the new mm-wave bands above 24 GHz. Base stations will be created using largely unique technology, and huge MIMO, beam shaping, and highly integrated antenna systems will be employed more frequently. This has resulted in differences in how frequency range requirements are specified, how they are evaluated in terms of performance, and how the requirements' upper and lower limits are calculated. As a result, the frequency bands covered by the present 3GPP Release 15 work are divided into two frequency ranges:

- Frequency Range 1 (FR1) includes all existing and new bands below 6 GHz.
- The second frequency range (FR2) introduces new bands between 24.25 and 52.6 GHz.

Because the frequency channels in which network release will function contain both paired and unpaired spectra, flexibility in the duplex arrangement is essential. As a result, network releases

support both FDD (frequency division duplex) and TDD (time division duplex) operations (Wu, C. K., Tsang, K. F., Liu, Y., Zhu, H., Wang, H., & Wei, Y. (2020)).

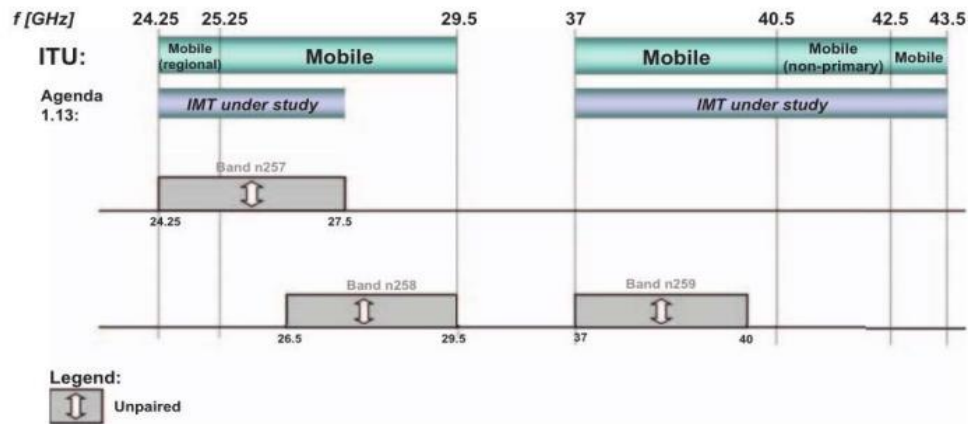


Figure 2: Operating bands specified in 3GPP release 15 for mmwaves (Holma, H., Toskala, A., & Nakamura, T. (Eds.). (2020)).

Release 15 is slated for completion in the middle of 2018. This update includes improvements, including aerial communication and a substantially quicker response time owing to the TTI capability. The benefits of 15th-generation releases over LTE are considerable. Some of the most significant are as follows:

- In Release 15, the novel idea of eMBB is presented as one of the essential conditions for 5G.
- A new frame construction and spectrum are being introduced.
- ultra-lean design to improve network energy performance and prevent interference;
- The use of considerably higher-frequency bands to get more spectrum to accommodate very wide transmission bandwidths and the related high data speeds;
- low response time to boost performance and enable new use cases;
- forward compatibility to prepare for technologies and use cases that are yet to be developed.
- a beam-centric design that permits significant beamforming and a large number of antenna elements for control-plane operations like initial access in addition to data transmission, which is somewhat doable with LTE (Zhang, S., Xu, X., Wu, Y., & Lu, L. (2014)).

The first three would be discussed as design principles (or design requirements) and would be followed by a discussion of the major technology aspects utilized in the network release.

### 2.1.1 5G network release phase two: Release 16 and beyond

Release 16 is scheduled to have specs available around the middle of 2020. By the end of 2019, radio protocols would be finalized, followed by physical layer specifications in March 2020 and an ASN.1 freeze in June 2020. However, due to the efforts necessary for Release 15 finalization and the purpose of ensuring early enough stability for the L1 parameters, the work was significantly delayed from its anticipated timeline, making it difficult to use a version earlier than December 2018 for commercial implementations. The most significant improvements to present features in Release 16 include developments in multiple-input, multiple-output (MIMO) and beamforming, dynamic spectrum sharing (DSS), dual connection (DC), and carrier aggregation (CA), and user equipment (UE) power saving (*Zhang, S., Xu, X., Wu, Y., & Lu, L. (2014)*).



Figure 3: Network release time plan (*Parvez, I., Rahmati, A., Guvenc, I., Sarwat, A. I., & Dai, H. (2018)*).

The researcher will have to sum up release 16's objectives in the following ways:

- Enhanced beam handling, channel-state information (CSI) feedback, support for transmission to a single UE (use equipment) from multiple transmission points, and full power transmission from multiple UE (use equipment) antennas in the uplink are all introduced in release 16.
- Reduced changeover durations are made possible by additional mobility improvements, especially when they are utilized with beam management systems deployed in millimeter (mm) wave bands.
- Release 16 has expanded the number of rate-matching patterns that are available in network releases to enable spectrum sharing when carrier aggregation is utilized for LTE.

- Ultra-reliable, low-reaction-time connectivity capabilities and the Industrial Internet of Things (IIoT) feature ultra-reliable, low-response-time communication (URLLC).
- Vehicle-to-everything (V2X) communications and intelligent transportation systems (ITS) (3GPP versions 16 and 17 overview: the 5G network release progression)
- Because eMTC (evolved machine type communication) uses a DC subcarrier, the PRB (packet resource block) cannot be fully aligned for eMTC and 5G. To support eMTC, an additional 5G PRB will be required for 15 kHz subcarrier spacing (SCSs).

As one example of various potential enhancements, the last subcarrier in the eMTC can be pierced with only six 5G PRBs. Notably, this may be achieved by implementing it while considering the influence on eMTC performance. 3GPP stakeholders have already agreed on the specifics of Rel-17 in 2019. The Rel-17 standards are expected to be finished and issued by June 2021. The following points serve as an overview of the release's 17 primary objectives:

- More use cases for mobile communication will be possible with 3GPP Release 17.
- NR (network release) operation at high frequencies (NR > 52.6 GHz): Using NR at frequencies higher than 52.6 GHz gives operators a lot of capacity for use cases like indoor mobile broadband and crowded urban environments.

The next phase of 5G-U (NR-U) will see the start of work on frequency bands greater than 52.6 GHz. Channel modelling for frequencies up to 114 GHz has begun. The study phase for higher frequency operation, covering waveform and other concerns, is planned to be covered in Release 17. If the Release 17 phases changes, the normative work would be left to alter the Release 17 or Release 18 phase.

Furthermore, 3GPP is working on further use cases from a requirements viewpoint, with areas such as public safety scheduled to be focused after Release 16 (*Ghosh, A., Maeder, A., Baker, M., & Chandramouli, D. (2019)*).

- 5G Low Power Wide Area (LPWA) IoT communications in 3GPP are based on the LTE Massive MTC (mMTC) technologies: LTE-M and NB-IoT.

- Integrated Access and Backhauling (IAB) enhancements: it will be anticipated that the IAB solution, which was introduced in Rel-16, will be further evolved to provide increased efficiency and support for additional use cases.
- Side link improvements: Rel-17 is expected to support more 3GPP-based mobile communication use cases.

### 2.1.2 QoS Parameters

The quality of many service metrics is crucial when designing next-generation networks. These applications are data-hungry, and guaranteeing QoS parameters is a crucial priority to support all of these high-density services (*Bogale, T. E., Wang, X., & Le, L. B. (2018)*). It is vital to provide QoS assurances for various data-hungry applications in next-generation wireless networks in order to fulfil their requirements.

#### 2.1.2.1 Bandwidth

One of the most crucial QoS elements for addressing the expectations of next-generation apps is bandwidth. Bandwidth in bits per second is proportional to the quantity of data sent or the channel capacity (i.e., Radio Access Network capacity).

#### 2.1.2.2 Throughput

The network's success is determined by its throughput. A greater throughput signifies the highest number of bits successfully transferred per unit of time out of the total possible number of bits in the message. Throughput is determined by hardware devices, bandwidth, signal-to-noise ratio (SNR), and other factors (*Bogale, T. E., Wang, X., & Le, L. B. (2018)*). Throughput is an essential aspect of establishing the actual rate of transmission. Higher throughput is required for a variety of applications.

#### 2.1.2.3 Jitter

Everyone desires uninterrupted packet delivery with no delays; however, jitter is one element that hinders overall communication by creating a delay between packets. It's also known as packet delay variation (PDV) because smooth packet transmission relies on a minimal delay

between packets. This is an important QoS performance characteristic that must be within acceptable limits, especially for next-generation video and audio streaming.

#### 2.1.2.4 Bit Error Rate

The bit error rate is a metric that indicates errors in the number of bits transported out of the total possible number of bits. It is also known as the bit error ratio. It is defined as the ratio of bit errors to total transmitted bits. To meet the requirements of next-generation data applications, the bit error rate (BER) must be minimised.

#### 2.1.2.5 Packet Delivery Ratio (PDR)

This is the ratio of delivered packets to total packets transmitted over the network, as the name implies. PDR determines the efficiency of the next-generation network; therefore, it must be extremely high.

#### 2.1.2.6 Route Discovery Time

Route discovery time is the time it takes to determine a route from source to destination. Because of node mobility, the network of a mobile ad hoc network changes regularly. The routing algorithm chooses the optimum path before sending. The route discovery time should be kept to a minimum while connecting various nodes. To achieve the lowest route discovery times for next-generation applications, smart routing algorithms are necessary (*Agiwal, M., Roy, A., & Saxena, N. (2016)*).

#### 2.1.2.7 Response Time

Response time refers to how long it takes a communication network to reply. There are two kinds of delays: low and high. The length of time it takes to transit from one place to another, from source to destination, is referred to as end-to-end delay (EED) (*Kumar, R., Hasan, M., Padhy, S., Evchenko, K., Piramanayagam, L., Mohan, S., & Bobba, R. B. (2017)*).

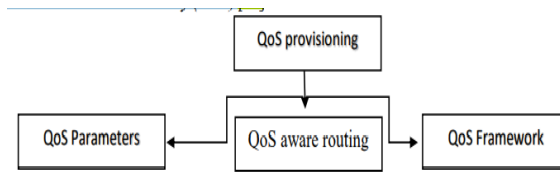


Figure 4 QoS provisioning (Kumar, R., Hasan, M., Padhy, S., Evchenko, K., Piramanayagam, L., Mohan, S., & Bobba, R. B. (2017)).

The following mathematical equation explains how response time is determined by four factors:

$$\text{Response time} = P.T + T.T + Q.T + P.D. \quad \dots\dots\dots \text{Equation 1}$$

Where:

- P.T. is the propagation time
- T.T. is the transmission time
- Q.T. is queuing time
- P.D. is processing delay

The researcher is interested in the parameter of response time reduction in the 5G network-generating network. To enable some demonstration Internet services, high dependability and response time are essential. To achieve the tough response time requirements, improvements are being made, and wireless transmission must be greatly reduced. It is recommended that the LTE transmission time interval be decreased and that the waveform accommodate small packets and a low response time. The majority of today's broadband communication systems are based on orthogonal frequency division multiplexing (OFDM), which is popular owing to its resilience to multi-path channels (Abid, M., Ali, F., Armghan, A., Alenezi, F., Khan, S., Muhammad, F., & Qamar, M. S. (2022)).

To achieve millisecond response time transmissions, the physical layer must contain very tiny packets, requiring a one-way physical layer transfer of many microseconds. To circumvent these constraints, an orthogonal frequency division multiplexing (OFDM)-based system with modified OFDM numerology can achieve a rapid response time (Abid, M., Ali, F., Armghan, A., Alenezi, F., Khan, S., Muhammad, F., & Qamar, M. S. (2022)). A flexible frame structure is desirable to facilitate vertical application cohabitation while attaining a response time of less than one

second, and one way is to dynamically modify the gearbox time interval (TTI) according to service needs.

### 2.1.3 Technical Performance Requirements for 5G Network

The International Telecommunication Union Report (ITU-R) M.2410 specifies the technical performance standards for the ITU's radio communication sector. The 3GPP examined deployment scenarios and related needs for the three usage scenarios (technical performance requirements, uplink, and downlink) to accomplish the 5G network vision. These standards are typically more stringent than the ITU's technical performance requirements, reflecting the 3GPP's intention to provide greater capabilities than the ITU mandates (Reddy, A. P. K., Kumari, M. S., Dhanwani, V., Bachkaniwala, A. K., Kumar, N., Vasudevan, K., ... & James, V. B. (2021)).

### 2.1.4 Sources of High Response Time in a Cellular Network

High user plane (U-plane) and control plane (C-plane) response time; the user-plane response time is measured by the one-way transmit time of a packet in the IP layer between an advanced Universal Mobile Technology System (UMTS) terrestrial radio access network edge. The time it takes for UE (user equipment) to switch from idle to active mode is defined as the control plane response time. Because application performance is mostly determined by the U-plane's response time, it is the major focus of attention for low response-time communication (Parvez, I., Rahmati, A., Guvenc, I., Sarwat, A. I., & Dai, H. (2018)). Combining the radio access network (RAN), backhaul (core network), and data centre/Internet in a cellular network helps minimise packet transmission latency. As seen in the diagram below,

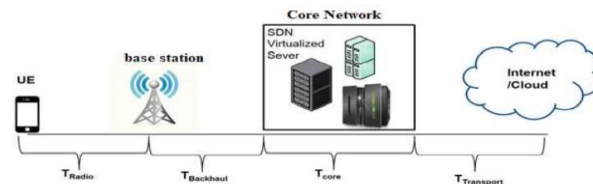


Figure 5: High Response Time/DeLay in end to end delay of packet transmission (Parvez, I., Rahmati, A., Guvenc, I., Sarwat, A. I., & Dai, H. (2018)).

After analysing the graph, the present cellular system's entire one-way transmission time may be expressed as:

$$T = T_{radio} + T_{backhaul} + T_{core} + T_{transport} \dots\dots\dots \text{Equation} \dots\dots\dots 2$$

Where:

- **Tradio:** the amount of time it takes to transmit a packet between an eNB or gNB and a UE (user equipment), owing mostly to physical layer communication between evolved network bones (eNBs) or generated network bones (gNBs), UEs (user equipment), and the environment. Transmit time, evolved network bone (eNB)/UE (user equipment) processing time, retransmissions, and propagation delay are all part of it. Processing delay at the eNB (evolutionary network bone) is caused by channel coding, rate matching, scrambling, cyclic redundancy check (CRC) attachment, precoding, modulation mapper, layer mapper, resource element mapper, and orthogonal frequency division multiplexing (OFDM) signal creation.
- TBackhaul: the time spent connecting an eNB or gNB to the main network (i.e., EPC or CN). Copper cables, microwaves, or optical fibers are commonly used to connect the core network to the eNB (evolved network bone) or gNB (generated network node). Microwaves, in general, have a faster response time than optic fibers. Spectrum constraints, on the other hand, may limit microwave capacity (*Parvez, I., Rahmati, A., Guvenc, I., Sarwat, A. I., & Dai, H. (2018)*).
- Tcore: the time it takes for the core network to process data. Among the core network processing steps are mobility management entities (MME), serving general packet radio services (GPRS) support nodes, servicing GPRS support nodes (SGSN), software-defined network (SDN), network function virtualization (NFV), NAS (network access servicing) security, EPS bearer control, mobility anchoring, UE IP address allocation, idle state mobility handling, and packet filtering.
- The time it takes for data to transit from the core network to the Internet or cloud is referred to as transport. The distance between the core network and the server, bandwidth, and communication protocol all have an impact on response time. As a result, the end-to-end (E2E) delay, TE2E, is approximated by  $2 \times T$ . Tradio is the total transmit time, propagation response time, the channel estimate of the processing time, encoding and decoding time (for the first time), and retransmission time (due to packet loss); Tradio for a scheduled user, in particular, may be stated as:

$$T_{radio} = TQ + TFA + Ttx + Tbsp + Tmpt \dots\dots\dots\text{Equation}\dots\dots\dots 3$$

Where:

- **TQ** is the queuing delay that depends on the multiplexed number of users on the same resources.
- **TFA** is the delay for the alignment of the frame that depends on Its structure and duplexing modes (FDD mode, TDD mode)
- **Ttx** transmission processing time, and payload transmission which uses at least one transmission interval (TTI) depending on radio channel condition, payload size, available resources, transmission errors, and retransmission;
- **Tbsp** is the processing delay at the base station;
- **Tmpt** User terminal processing delay of both the BS (base station) and UE (user equipment) delay depends on the capabilities of BS (base station) and the user respectively.

### 2.1.5 URLLC Physical Layer in 5G Network Release

In contrast to 4G LTE systems, the 5G Network Release should evaluate response time, dependability, and throughput needs concurrently, resulting in a fundamental shift in the physical layer architecture (packet, slot, and frame). Furthermore, when the URLLC (ultra-reliable low-latency communication) service is launched, a scheduling strategy that assists in minimising the URLLC packet transmit response time is required. This necessitates a scheduling scheme that significantly reduces re-transmission response time, including the packet and frame structure to minimise response time, multiplexing schemes to overlay the URLLC service into enhanced mobile broadband and mMTC services, and air-handling approaches. However, the network release standard conference of the third generation project partnership (3GPP) decided that response time is a priority (Ji, H., Park, S., Yeo, J., Kim, Y., Lee, J., & Shim, B. (2018)).

#### 2.1.5.1 Packet Structure

The goal of URLLC packet design is to reduce processing response time (Tproc) and time-to-transmit response time (Titt). To minimise Tproc response time, the three components of a packet (data portion, pilot, and control) should be brought together and pipelined. In the 5G

Network Release, low-density parity checks (LDPC) and polar codes are utilised to enhance data and control channels, respectively. Many efforts have been undertaken to increase the decoding performance and computational complexity of these codes, as well as their processing response time (*Chang, G. K., Xu, M., & Lu, F. (2020)*).

#### 2.1.5.2 Response time-sensitive Scheduling and Frame Structure

One of the key aims of the 5G network rollout is to provide a single frame structure that can span a wide range of frequency bands and service categories; to that end, flexible frame scheduling techniques have been implemented.

##### 2.1.5.2.1 Flexible Frame for URLLC

Shortening the symbol period is an easy way to lower the time-to-transmit or response time. Because of route loss, when the frequency range crosses 6 GHz, the cell radius and channel delay spread are substantially less than in traditional cellular systems. When employing a frequency range less than 6 GHz, this option may not be acceptable. Mini slot frame level (3–4 symbols) or slot level (7 symbols) transmission can be utilised to reduce packet TTIs (transmission time intervals). However, to enable this variable frame structure, a sophisticated receiver is required (*Chang, G. K., Xu, M., & Lu, F. (2020)*).

##### 2.1.5.2.2 Instant scheduling scheme

By stopping the ongoing data transfer, the URLLC packet is initiated. This technique is effective for reducing URLLC time access; however, it may cause a considerable performance reduction. As a result, it must use an ongoing service strategy to reduce performance deterioration.

##### 2.1.5.2.3 Reservation-based scheduling scheme

There are two kinds of reservation strategies in the URLLC resource reserve: semi-static and dynamic. The base station broadcasts the frame structure configuration only occasionally in the semi-static reservation method, but information on the URLLC resource is often changed via a scheduled user's control channel in the dynamic reservation system. However, if no URLLC transfer happens during the allocated time frame, the reserved resources will be squandered. To

convey reservation information and assure the dependability of control signalling, dynamic reservations necessitate an extra control overhead (*Ji, H., Park, S., Yeo, J., Kim, Y., Lee, J., & Shim, B. (2018)*).

#### 2.1.6 Massive MIMO

Massive MIMO, a MIMO extension, increases the number of antennas at the base station. MIMO was employed in 4G wireless communication, but enormous MIMO will arise with the massive growth in data demand that 5G network communication will bring. It aids in the emphasis on energy, resulting in significant gains in throughput and efficiency. It also improves the resilience of 5G network communication against interference and jamming (*Zou, Y., Zhu, J., Wu, T., Guo, H., & Wei, H. (2021)*). In power control, it is used to solve the non-convex optimisation issue and to use channel state information (CSI) feedback for accurate channel and direction of arrival estimates.

Both 2D and 3D were employed, but for distinct purposes: 2D for single-user settings and 3D for multi-user scenarios. The data was compressed using the 2D and 3D Max pooling networks to make the original data and reshaped into a one-dimensional vector after it was filtered and feature vectors were retrieved.

#### 2.1.7 Multiple Access /Non-Orthogonal Multiple Access (NOMA)

In cellular communication, a method that delivers communication services to several users at the same time is necessary. Various multiple access techniques, such as frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA), and orthogonal frequency division multiple access (OFDMA), have been utilised over the years. In the downlink and uplink of 4G wireless communication, OFDMA and single-carrier FDMA (SC-FDMA) were excellent for high-speed data transfer. Non-orthogonal multiple access (NOMA) can leverage existing resources more efficiently than traditional multiple access approaches in 5G network communication, successfully supporting data traffic and user congestion (*Bawazir, S. S., Sofotasios, P. C., Muhaidat, S., Al-Hammadi, Y., & Karagiannidis, G. K. (2018)*). A multiuser signal is multiplexed in the transmitter using superposition coding and then transmitted to the users at varied power levels in NOMA.

When a signal is received, the user with the greater channel gain instantly retrieves it, but the user with the lower channel gain recognises other signals as interference and executes successive interference cancellation (SIC) to retrieve its original signal. (*Bawazir, S. S., Sofotasios, P. C., Muhaidat, S., Al-Hammadi, Y., & Karagiannidis, G. K. (2018)*) NOMA is an orthogonal multiple access system that operates on the premise of distributing time-frequency resources among users by splitting them into two regimes: code-based and power-based. NOMA delivers huge connections by serving more users concurrently, which is made feasible through sequential interference cancellation.

#### 2.1.8 Resource Allocation

The practise of managing and allocating resources in order to obtain the best strategic solution is known as resource allocation. The purpose triangle of 5G network communication comprises capacity expansion, enormous connectivity, and a short response time with ultra-high dependability. It has outperformed standard resource optimisation strategies in terms of flexibility and computation speed (*Popovski, P., Nielsen, J. J., Stefanovic, C., De Carvalho, E., Strom, E., Trillingsgaard, K. F., & Sorensen, R. B. (2018)*). QoS requirements are technical specifications that describe the quality of a system in areas such as performance, scalability, serviceability, and availability. 5G QoS standards are predicted to have 10–20 Gbps throughput, reduced end-to-end response time, 100% network availability and dependability, and bandwidth ranging from 100 Kbps to several hundred megabits per second (*Kumar, R. (2020)*).

#### 2.1.9 Security

Cybersecurity has grown increasingly crucial in recent years, and the growing use of technology has resulted in a rise in criminality and cyberattacks. Malware, phishing, data leakage, hacking, SQL injection, denial-of-service attacks, and DNS tunnelling are all instances of cybersecurity concerns. The next-generation technology, 5G, is designed to deliver faster speeds, shorter response times, and more resilience than earlier 3G and 4G communications (*Kumar, A., & Gupta, M. (2018)*). Thus, 5G helps to preserve safety and security by providing communication with the quickest response time for those who have more devices, more mobile data, and thus more network traffic with a fast response time.

### 2.1.10 LSTM (long short-term memory)-RRM (radio resource management) Method

Radio resource management (RRM) based on LSTM is used in the 5G context to distribute bandwidth and power to the user equipment. GSO is employed for hyperparameter tuning, frequency interleaving is being developed to decrease network burst faults, and guard level insertion is enabled prior to data transmission (Balmuri, K. R., Konda, S., Lai, W. C., Divakarachari, P. B., Gowda, K. M. V., & Kivudujogappa Lingappa, H. (2022)). The block diagram of the LSTM-RRM approach is illustrated in the picture below.

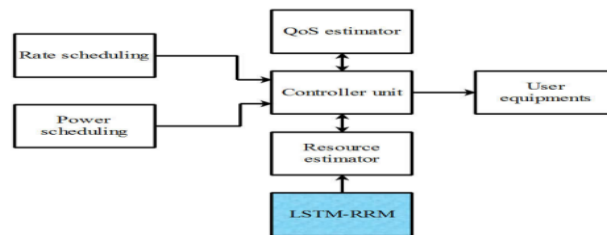


Figure 6: Block diagram of LSTM-RRM method (Balmuri, K. R., Konda, S., Lai, W. C., Divakarachari, P. B., Gowda, K. M. V., & Kivudujogappa Lingappa, H. (2022)).

### 2.1.11 System Model for LSTM-RRM method

Radio access in a conventional LTE network is generally based on single-carrier frequency division multiple access (SC-FDMA) and orthogonal frequency division multiple access (OFDMA) in the uplink and downlink, respectively. OFDMA and SC-FDMA share the same radio frame structure, which benefits channel subdivision. The frequency domain channel bandwidth spans from 1 to 20 MHz, which is split into sub-channels of 12 sub-carriers of 15 kHz, totaling 180 kHz. A resource block is the radio resource's smallest allocation unit (RB), with a time domain of low response time and a frequency domain of 180 kHz. Transmission time intervals (TTI) are used to split radio resources over time. Machine-to-machine (M-M) and human-to-human (H-H) user traffic is supported by the 5G LTE-A network. The eNB transmits the RBS-specified number of resource blocks between M-M and H-H users (Saddoud, A., Doghri, W., Charfi, E., & Fourati, L. C. (2020)).

### 2.1.12 Interleaving Frequency and Guard Interval Insertion for Minimizing the Losses through the 5G Network

Frequency interleaving is being developed in the 5G context to offset/counterbalance the impacts of a burst fault. After frequency interleaving, the inverse fast Fourier transform is used on the transmitter side. Data is transferred in time rather than frequency, and symbol collision is prevented by introducing guard intervals into the parallel-to-serial data. To accomplish frequency division multiplexing, non-orthogonal multiple access (NOMA) protocols are utilised. When the network must send data to two distinct user devices in a single time slot, RRM is employed. The LSTM is employed in 5G RRM to perform efficient RRM (Balmuri, K. R., Konda, S., Lai, W. C., Divakarachari, P. B., Gowda, K. M. V., & Kivudujogappa Lingappa, H. (2022)).

### 2.1.13 Process of Radio Resource Management (RRM)

In LSTM-based RRM, the priority for providing resources to the intended user equipment is decided by analysing the request queue. A collection of queues is utilised to identify which user equipment sends the most request queues to the BS. Previous values of bandwidth, power, and data rate are utilised as matrices by the LSTM, and Generic Segmentation Offload (GSO) is used to control the LSTM's hyperparameters. RRM divides resources into two categories depending on data rate elements such as bandwidth and power (Thantharate, A. (2022)). This minimises the number of request queues sent across the network and, as a result, traffic in the 5G environment. The block diagram of the LSTM-based RRM is shown below.

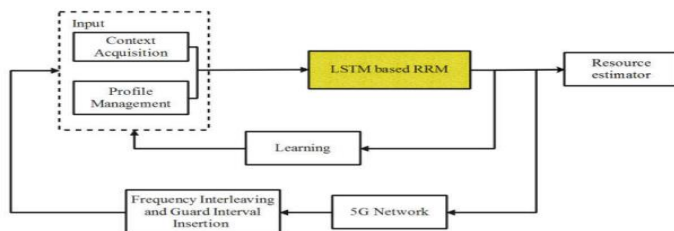


Figure 7: LSTM-based Model RRM (Thantharate, A. (2022)).

After receiving input from two modules (context acquisition and profile maintenance), this RRM system employs the LSTM to produce the output. The RRM is connected to the 5G network in this location, and the resource management input modules and LSTM are as follows:

- Context Acquisition: Context acquisition is first used to obtain information about network components and the UE. Each component of the 5G network uses the monitoring technique to gather information. The monitoring technique gives information for each component, a certain period, request queues, and QoS levels. This context information is utilised to solve UE difficulties in the 5G network.
- Profile management: The capacity of segment terminals and elements is determined by profile management. This profile management component also gives information about the UE's preferences (queues), behaviour, limitations, and needs. This component defines the operational parameter settings for network elements and terminals that will be checked. This information is essential in order for the UE to do appropriate resource management using LSTM.
- Learning: The LSTM's learning component comprises information on context acquisition and profile maintenance, as well as the LSTM's learning rate as received through Generic Segmentation Offload (GSO). This data helps the LSTM-based RRM system discover and resolve problems.
- RRM based on LSTM: The major purpose of the LSTM is to maximise bit rates while retaining the best feasible degree of QoS. The LSTM is utilised to determine the appropriate resource management for providing greater QoS levels to UEs.

#### 2.1.14 RAN (radio access network) solutions for achieving low response time in 5G network

Frame and packet structure, enhanced multiple access methods, energy-aware response time reduction, and carrier aggregation in mmWave are among the RAN (radio access network) advances. These issues give a thorough overview of each remedy (*Yli-Kaakinen, J., Levanen, T., Palin, A., Renfors, M., & Valkama, M. (2022)*).

Table 1: RAN (radio access network) solutions for low response time in 5G network

Approaches	Summary
Frame/Package structure	Flexible OFDMA (orthogonal frequency division multiplexing)-based TDD (time division multiplexing) subframe: TDD numerology is optimised for dense deployment with smaller cell sizes and wider bandwidth on higher carrier frequencies. Numerology, flexible subframes, and resource allocation Numerology and subframe structure are established in order to visualise 5G with a short response time. The cyclic prefix, FFT(fast Fourier transform) size, subcarrier spacing, and sampling frequency were all

	stated as functions of carrier frequency ( <i>Yli-Kaakinen, J., Levanen, T., Palin, A., Renfors, M., &amp; Valkama, M. (2022)</i> ).
Advanced multiple access/Waveform	Filtered CP-OFDM, UFMC (Universal Filtered Multi-Carrier), and FBMC (Filter-Bank Based Multicarrier): UFMC beats OFDM by roughly 10% in both big and small packets. FBMC performs well while broadcasting large sequences, but it struggles when transmitting small bursts or frames ( <i>Parvez, I., Rahmati, A., Guvenc, I., Sarwat, A. I., &amp; Dai, H. (2018)</i> ).
Modulation and coding	A dynamic shrunk square searching (DSSS) technique is developed, which eliminates needless communication control port (CCP) calculations while using both the noise characteristic and state space structure. A response time reduction strategy is offered by implementing TDM (time division multiplexing) of higher priority ultra-low response time data over other less time-essential services, which maps higher priority user data at the beginning of a subframe followed by regular data ( <i>Parvez, I., Rahmati, A., Guvenc, I., Sarwat, A. I., &amp; Dai, H. (2018)</i> ).
mmWave	The use of mmWave aggregation is proposed for the physical layer air interface. Large bandwidth, along with technologies like compact frame construction, mmWave backhaul, and beamforming, can aid in achieving a short response time ( <i>Agiwal, M., Roy, A., &amp; Saxena, N. (2016)</i> ).
Location-aware communication	Location information: 5G issues and research hurdles are explored, followed by the conclusion that 5G networks may use location information to achieve performance benefits in terms of throughput and response time ( <i>Agiwal, M., Roy, A., &amp; Saxena, N. (2016)</i> ).
QoS/QoE Differentiation	Constraint differentiation on QoS and QoE helps keep response time low in 5G applications such as ultrahigh resolution and 3D video content, real-time gaming, and neurosurgery ( <i>Parvez, I., Rahmati, A., Guvenc, I., Sarwat, A. I., &amp; Dai, H. (2018)</i> ).

- **Frame/packet structure:** As appealing options for RAN solutions, the physical air interface and medium access control layers have been proposed. A radio frame in LTE is 10 ms long and is divided into 10 subframes of 1 ms and 0.5 ms; these are known as resource blocks (RBs).
- **Advanced Multiple Access Techniques/Waveform:** MA (multiple access) methods and waveforms, such as orthogonal, non-orthogonal, and asynchronous access, have been proposed for short response time communication. Because OFDM is hampered by synchronization and orthogonality, synchronized none-orthogonal multiple-access approaches have been considered.
- **Modulation and Channel Coding:** Small packets can be used to achieve a short response time, but proper modulation and coding are necessary. In terms of tiny packets, LDPC, and polar codes surpass turbo codes. Other criteria like implementation complexity,

technological performance, and adaptability are also taken into account (*Indoonundon, M., & Pawan Fowdur, T. (2021)*).

- ***MmWave Communications***: Carrier aggregation over the mmWave spectrum is a possible candidate technique for 5G, capable of offering large bandwidth and ultrafast response times. It's especially important for VR and AR applications that demand high throughput and fast response times. A novel frame design for the mmWave MAC layer has been presented, with advantages such as flexible transmission intervals, dynamic control signal placements, and directional control signal multiplexing (*Ford, R., Zhang, M., Mezzavilla, M., Dutta, S., Rangan, S., & Zorzi, M. (2017)*).

#### 2.1.15 Core Network Solutions for Low Response time in 5G network

The core network is proposed in order to satisfy the 5G objective of ultra-low response times. SDN, MEC, and NFV are new entities, as a new backhaul approaches. These modifications seek to shorten processing time, avoid many protocol layers, and assure smooth operation (*Parvez, I., Rahmati, A., Guvenc, I., Sarwat, A. I., & Dai, H. (2018)*). The rest of this section delves deeper into the key network solutions for short response times.

- ***Core Network Entities***: To minimise response times in 5G core networks, SDN (software-defined network) and NFV (network function virtualization) technologies are being deployed. The EPC (evolved packet core) of the 3GPP has constraints, such as a level of connection between the serving gateway and the packet data network gateway. SDN and NFV may be used in EPC (evolved packet core) architectures to decouple the data plane and control plane to minimise response time. An SDN controller can serve as a bridge between disconnected planes. User-plane and control-plane separation based on SDN (software-defined network) and NFV (network function virtualization) can significantly reduce response time (*Sun, S., Kadoch, M., Gong, L., & Rong, B. (2015)*).

There is, however, a compromise between controller scalability and increased response time. Furthermore, the data plane of the LTE EPC (evolved packet core) is implemented centrally, resulting in suboptimal system performance and long response time. To reduce capital expenditures (funds used by a company to acquire, upgrade, and maintain physical assets)

and operating expenses (costs incurred by a company for running its day-to-day operations), new technologies such as cloud computing, fog networks, mobile edge computing, SDN (software-defined network), and NFV (network function virtualization) can be used (*Sun, S., Kadoch, M., Gong, L., & Rong, B. (2015)*).

➤ **Backhaul Solutions:** Backhaul transports signalling and data from the core network and the Internet between base stations and the core network. 5G backhaul necessitates more capacity, decreased response time, synchronisation, security, and resilience. Backhaul systems now available include microwave, copper, and optical fiber lines. 5G backhaul necessitates more capacity, decreased response time, synchronisation, security, and resilience (*Sharma, T., Chehri, A., & Fortier, P. (2021)*). There are two types of current backhaul solutions: general backhaul and mmWave backhaul.

Table 2: Backhaul Solutions to Achieve Low Response Time

Approaches	Summary
General backhaul	<p>A dynamic GTP(general transfer protocol) termination technique that combines cloud-based GTP with a fast GTP(general transfer protocol) tunnel using specialised hardware Fog networks, MEC (mobile edge computing), and SDN (software-defined network) are new components of 5G-compliant networks that optimise GTP(general transfer protocol) tunnels.</p> <p>Modified VLC technology was used to establish an OW link for low-cost tiny cell backhauling. PON-based design with a customised dynamic bandwidth allocation mechanism Unified packet-based transport network based on MAC-in-MAC Ethernet.</p> <p>The first is based on an overprovisioned transport network, whereas the second is based on dynamic sharing, SDN (software-defined network), and NFV (network function virtualization) controllers. SDN and cache provide a restricted backhaul design (<i>Ejaz, S., Iqbal, Z., Shah, P. A., Bukhari, B. H., Ali, A., &amp; Aadil, F. (2019)</i>).</p>
mmWave backhaul	<p>A hybrid precoding and combining system for mmWave huge MIMO (multiple inputs, multiple outputs) based on a digitally controlled phase-shifter network. A framework that allows for in-band, point-to-point, non-line-of-sight, and mmWave backhaul.</p> <p>Backhaul frame construction is based on mmWave carrier frequencies ranging from 3 to 10 GHz. Backhaul solutions for mmWave networks are based on ultra-</p>

	dense wavelength division multiplexing (UDWDM) passive optical networks (PONs) (Konstantinou, D., Bressner, T. A., Rommel, S., Johannsen, U., Johansson, M. N., Ivashina, M. V., & Monroy, I. T. (2020)).
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### 2.1.16 Caching Solutions for Low Response time

In 5G networks, the limited capacity of backhaul cables is a hurdle for low-reaction-time communication. Caching and information-centric networking are prospective entrant technologies for designing a paradigm shift for response time reduction in next-generation communication systems. Following an introduction of caching principles for cellular networks, basic restrictions and available response time solutions are presented as follows:

Table 3: Overview of Caching In 5G Network.

Approaches	Summary
Content caching	Filling of appropriate data is investigated by diverse techniques employing time intervals in which the network is not congested.
Content delivery	Content delivery to requested users is presented by different approaches for reduction of response time.
Centralized caching	Various centralized caching is investigated with assumption that a coordinator with access to almost all the information about the storage capacities of different BSs, the connectivity of the users and BS (base station), and etc.
Distributed caching	Various aspects of distributed caching has been investigated in order to minimize the communication overhead among SBSs and the central schedule
Local caching	When a UE wants to access content, it first checks in itself. Once the content is confirmed in the local caching storage, it is accessed by the UE without any delay
D2D caching	If the requested content is not found locally, user will seek it within the range of its D2D communication. If it is found in nearby devices, it is delivered to the requester UE by D2D communication
MBS (mobile broadband system) caching	If the content is not found in local caching storage, nearby devices or SBS caching, the content is delivered by MBS caching

➤ **Existing Caching Solutions for 5G:**

File delivery services on mobile networks might include cache placement and content delivery. Cache placement can be centralised or distributed, and in some cases, a distributed cache

placement strategy is offered to minimise the average download delay. A decentralised content placement caching method is given that can achieve rates comparable to the best centralised scheme. Two caching and delivery strategies are investigated, with the code length reflecting the trade-off between coded multicasting and spatial reuse. The most relevant aspects that recommended cooperative content caching and content delivery systems to accommodate the increasing growth in demand for mobile network applications (*Sai, Y., Fan, D. Z., & Fan, M. Y. (2020)*).

A weighted optimisation problem is developed to minimise backhaul and downlink traffic while keeping cache memory capacity and bandwidth limitations for D2D communication in mind. In a cache-enabled network, joint response time awareness and forwarding are researched to enhance end-to-end experienced response time by user equipment when there is no coordination among them. In a cache-enabled multi-cell network, a cooperative content caching technique between base stations is studied to minimise average latency while meeting a finite cache capacity limitation for base stations (*Zaidi, A. A., Baldemair, R., Tullberg, H., Bjorkegren, H., Sundstrom, L., Medbo, J., & Da Silva, I. (2016)*).

As a result, cooperative caching architecture proposes a content distribution approach to minimise the mean total content delivery delay for all users in the proposed system. End-to-end packet transmission in a cache-enabled network is modelled, taking into account both the wired backhaul and the radio access network. The average packet response time is found to be lower in comparison to the system without caching capability owing to the traffic unloading of the wired backhaul via caching.

## 2.2 Methodology

The study's goal is to develop a model and undertake a performance analysis of 5G networks based on response time reduction in consideration of radio access network and frame structure factors. To attain success, the researcher will employ the following methodology:

### **Literature review:**

- Investigate the existing LTE system for challenging issues in the reduction of response time.
- Reviewing different works of literature related to the topic issue
- Examine the existing approaches and understand the mechanisms for achieving the proposed objectives.

### **Modelling prototypes and performance analysis:**

Critical analysis of the performance and model of the LTE to 5G systems helps to address the issues of the length of response time in consideration of radio access networks. Here the researchers gone to addressed the constraints and approaches for achieving low response time in consideration of critical analysis.

### **Mechanism of Driving Conclusion:**

The researcher has used the simulation method to test and evaluate the performance of the 5G frame structure's ability to enable URLLC. This is due to several modifications in the physical layer, one of which is the frame structure's flexibility. The researcher has used the NS2, MATLAB, NetSIM, Network Simulator-3, or CMX 500 network simulators as possibilities for studying signal processing, its library for 5G, and its response time. In the first step, the researcher would have simulated the burst time of the most significant waveforms and see how it affects the response time. In the second part, the researcher focused on simulating the numerologies of 5G and how to manage high-bandwidth decoding for small devices using the bandwidth-part technique. Finally, the researcher would analyse the 5G Toolbox in a 5G network via channel coding, massive MIMO, multiple access, resource allocation, and network security.

**Tools:** The 5G Toolbox provides standard-compliant functions and references for the modelling, simulation, and verification of 5G New Radio communications systems. It supports link-level simulation, golden reference verification, conformance testing, and test waveform generation. The researcher could modify or customise the toolbox functions and use them as reference models for implementing 5G systems and devices. The toolbox provides functions and references to help characterise uplink and downlink baseband specifications and simulate the

effects of RF (radio frequency) designs and interference sources on system performance. The researcher could generate waveforms and customises them, either programmatically or interactively, using the Wireless Waveform Generator application. With these waveforms, the researcher could simulate, prototype, and implement those that comply with the 3GPP 5G new radio specifications.

Table 4: Summary of Literatures Analysis

<b>Study1:</b> Authors & year	Agiwal, M., Maheshwari, M. K., & Toor, W. T. (2020)
Research title and journal name	Two step random access latency improvement in congested beyond 5G networks. <i>Electronics</i>
Core Contributions of the study	The study examined a two-step random access procedure for reducing latency and response time in a densely congested network.
Techniques used	The study included innovative 5G algorithms for analysis, including the sequential algorithm (SeA), the preceding algorithm (PrA), and the reasserting algorithm (ReA), with simulations carried out in the Matlab environment.
Results obtained	To address the issues of mmWaves and congestion, the 2s-random access technique will coexist alongside the old 4s-random access procedure. In the most recent 3GPP proposal, the user equipment has no flexibility to modify its initial choice of 2s- random access method or 4s- random access procedure in the event of a reattempt after a failure.
Comments/Critical remarks	The studies solely argue for the decrease in control plane delay caused by random access to establish a radio resource communication link.
<b>Study2:</b> Authors & year	Cao, L., Kiani, A., Xiang, A., John, K., & Saboorian, T. (2022).
Research title and journal name	Latency Aware Multi-Path Data Transmission for URLLC Services. <i>arXiv preprint</i>
Core Contributions of the study	According to the findings, path loss has a significant influence on response time performance when comparing multi-path and single-path solutions.
Techniques used	The proposed solution optimization framework techniques aim to minimize user equipment end-to-end latency in a time-slotted system while taking into account specific network conditions, traffic characteristics, and latency requirements of each time interval and average latency under different scenarios. In addition, simulation approaches were applied in the Matlab environment.
Results obtained	The study found that the multi-path solution performs best when the user equipment is constantly moving between two base stations so that the path loss effects of two paths are approximate and that increasing the bandwidth causes the multi-path solution to gain more than the single-path solution when the user equipment is constantly moving around one BS.
Comments/Critical remarks	In the study, no analogous optimization for downlink (DL) latency was taken into account. The queuing time may be short in such a circumstance.

<b>Study3:</b> Authors & year.	Lähetkangas, E., Pajukoski, K., Vihriälä, J., Berardinelli, G., Lauridsen, M., Tirola, E., & Mogensen, P. (2014, June)
Research title and journal name	Achieving low latency and energy consumption by 5G TDD mode optimization. <i>IEEE International Conference on Communications Workshops (ICC)</i>
Core Contributions of the study	According to the study, in order to obtain exceedingly small frame lengths with reasonable overhead control, somewhat significant subcarrier spacing should be employed.
Techniques used	Based on channel simulations in both an indoor and outdoor setting, the research was carried out as an approach to the newly proposed TDD (time division duplex) and OFDM (orthogonal frequency division multiplex)-based 5G physical air interface frame structure.
Results obtained	The proposed 5G frame structure with a very short frame length achieves extremely low TDD latency, allowing for extremely short user equipment-initiated data transmission and reception times of 1.5 ms, encompassing synchronization, scheduling signaling, and actual data transfer with acknowledgment. As a result, it is a considerable improvement over LTE and allows devices to be in energy-efficient sleep mode for the bulk of the time, resulting in decreased energy usage.
Comments/Critical remarks	There have been several alternatives investigated for decreasing the consequently increasing cyclic prefix and guard period overhead, such as the use of different subcarrier spacing and receivers for control and data parts of the frame, the use of time advance, or the use of adaptive cyclic prefix length, but none of these have been addressed in the study.
<b>Study4:</b> Authors & year.	Lee, S., & An, D. (2022)
Research title and journal name	Enhanced Flow Control for Low Latency in QUIC (Quick UDP Internet Connection). <i>Energies</i>
Core Contributions of the study	The study discovered a quick autotuning technique to enable low-latency communication in the Quick UDP Internet Connection (QUIC) protocol, which is most important in tiny buffer caching networks in the event of 5G backhaul difficulties in order to avoid buffer overflow.
Techniques used	The study used three flow control algorithms for implementation: static, autotuning, and fast autotuning allowances; analyzed the ns-3 simulator with QUIC (Quick UDP Internet Connection); and then modified four protocols as QuicL5Protocol, QuicSocketBase, QuicStreamBase, and QuicStreamRxBuffer classes.
Results obtained	According to the simulation findings, if the buffer has a large empty space, the receive window is immediately extended to enhance the transmission rate and lower the transmission delay, and so fast autotuning efficiently reduces transmission latency and boosts throughput. As a result, the suggested technique may improve network performance.

Comments/Critical remarks	In the study, there have not included settings for factors such as buffer occupancy or possession and the increase factor. Thus, in rapid autotuning, the increase factor is shown to be inversely related to the received buffer occupancy. The increase factor is raised when the buffer occupancy is low.
<b>Study5:</b> Authors & year	Jain, V., Chu, H. T., Qi, S., Lee, C. A., Chang, H. C., Hsieh, C. Y., ... & Chen, J. C. (2022)
Research title and journal name	A low latency 5G core network based on high-performance NFV platforms. In Proceedings of the ACM SIGCOMM 2022 Conference
Core Contributions of the study	They studied contributed as: <ul style="list-style-type: none"> <li>✓ Consolidation on the same node helps reduce inter-network function communication overheads, so they used the flexibility and scalability of network function virtualization platforms to consolidate the control and data plane network functions on the same node while retaining the flexibility to implement each network function separately.</li> <li>✓ Implementation of smart buffering, which is utilized both for the optimized changeover method and to buffer packets to idle user equipment, optimizing the handover procedure to eliminate additional hairpin and daisy chain routing without modifying the 3GPP protocol.</li> </ul>
Techniques used	The study implemented and compared multiple approaches, including linear search, Tuple Space Search (TSS), and a partition sort classifier, through a simulation environment as a UE and RAN simulator for generating user events based on the New Generation Application Protocol (NGAP) specified by 3GP.
Results obtained	The results reveal a considerable performance boost over non-NFV-based 5G connectivity. The reduction in total event completion time and an improvement in individual message exchange latency. Importantly, lowering control plane latency improves data plane performance. Data packet delay (as a result of the better control plane) during paging and handover occurrences makes scalability and high data-plane throughput feasible.
Comments/Critical remarks	During the changeover, all inbound download link packets are delayed at the 5G core network and face an extra queuing delay. As a result, the RTT (retransmission time) increases. However, in the case of a 5G core network, TCP senders incorrectly interpret this delay as growing congestion, resulting in the expiration of the retransmission timeout (RTO).
<b>Study6:</b> Authors & year	Fan, X., & Huo, Y. (2021).
Research title and journal name	An overview of low latency for wireless communications: an evolutionary perspective. <i>arXiv preprint</i>

Core Contributions of the study	The study comprehended the reduction of latency by changing the network structure, including the radio access network (RAN), core network, and bearer network (backhaul network or transport network), for each generation of network structure changes from 2G to 5G mobile communication systems and presented the communication technologies involved in each generation of mobile communication systems for attaining low latency, including packet size, frame structure, and minimum transmissibility.
Techniques used	The study used approaches to achieve low latency since it is important to update not only the network architecture but also the wireless air interface technology. Thus, the study was primarily focused on the growth of physical layer technologies to lower response times, including frame structure, scheduling, multiple access, modulation, channel coding, and signal carrier.
Results obtained	The transmission time interval is constantly decreasing to achieve low latency in a smaller packet transmission mode; the scheduling mechanism is becoming faster and faster, even allowing for dispatch-free transmission; and the coding style is becoming more flexible and customizable, no more one-size-fits-all. Multiple access methods and modulation techniques offer greater latitude and higher orders for establishing massive connections, resulting in decreased queue latency. Carrier frequency rises as cell size falls.
Comments/Critical remarks	Other performances may suffer as a result of lowering latency. Low latency, for example, is associated with control overhead (including cycle prefix and pilot). Short transmission time intervals increase the fraction of control overhead, resulting in radio frequency resource waste. As a result, numerous trades-offs such as spectrum efficiency, energy efficiency, and throughput must be addressed.
<b>Study7:</b> Authors & year	Chen, J. I. Z. (2020).
Research title and journal name	5G systems with low density parity check based channel coding for enhanced mobile broadband scheme. IRO Journal on Sustainable Wireless Systems.
Core Contributions of the study	The fair comparison research is accomplished by investigating block lengths and achieving acceptable rates through correct design, and the performance of BLER / BER (block error rate/bit error rate) is achieved for various block lengths and coding rates based on analysis.
Techniques used	As study carried the candidate schemes considered for this purpose are polar codes, low density parity check (LDPC) and turbo codes, and the Quadrature amplitude modulation (QAM) is used for simulation of the candidate coding schemes.
Results obtained	Despite the superior performance of polar codes at small block lengths, simulation findings reveal that LDPC (low density parity check) is comparably efficient for varied code rates and block lengths. As an added benefit, LDPC (low density parity check) codes are quite simple to implement.

Comments/ critical remarks	The properties of polar codes are not adaptable in the study because channel-based code design is required to optimize the performance of polar codes.
<b>Study8:</b> Authors & year	Abdullah, D. M., & Ameen, S. Y. (2021).
Research title and journal name	Enhanced mobile broadband (EMBB): A review. Journal of Information Technology and Informatics
Core Contributions of the study	As study contributed via using the antenna technique proposed, the planned high-gain array antenna has a low profile, low cost, and low weight, which is desirable for 5G commercial applications. It also has a broad bandwidth, horizontal omnidirectional plane pattern, and low side lobes in 5G network communication.
Techniques used	The research was carried out using techniques such as eMBB-based Antenna Techniques, Diversity Techniques, Channel Coding Techniques, and Modulation Techniques, after which the technical challenges of broadband systems were proposed, and workable solutions for achieving cost-effective solutions were provided, as well as a discussion of the best technologies used to improve mobile broadband.
Results obtained	Using the proposed antenna technique, the planned high-gain array antenna has a low profile, low cost, and low weight, which is desirable for 5G commercial applications. It also has a broad bandwidth, horizontal omnidirectional plane pattern, and low side lobes. Channel Coding Strategies: In the instance of mMTC, channel coding was successful, resulting in high efficiency, low latency, and low energy consumption. As the block length increases, the $E_b/N_0$ value decreases, resulting in lower power consumption while using the lower code rate.
Comments/ critical remarks	Several other factors, such as implementation difficulty, latency, and stability, should be considered when choosing a 5G URLLC coding scheme. The study employed implementable encoding methods for turbo, LDPC, and convolutional codes, and additional research on latency-restricted efficiency is needed before agreeing on the coding arrangement. However, due to concerns about list decoding design and the sequential existence of Successive cancellation decoding algorithms, the use of URLLC polar codes at this stage is rather ambiguous.
<b>Study9:</b> Authors & year	Benzaghta, M., & Rabie, K. M. (2021).
Research title and journal name	Massive MIMO systems for 5G: A systematic mapping study on antenna design challenges and channel estimation open issues. IET Communications.
Core Contributions of the study	The strategy was assessed utilizing zero-forcing precoding maximum ratio transmission approaches, as the study contributed; interfering users in neighboring cells are recognized based on an assessment of large-scale fading. As a result, interfering users are included in the shared channel processing. The channel quality of users is improved by assigning orthogonal pilot reuse sequences to the centre and edge users based on their amounts of pilot contamination.

Techniques used	The study offered a clear categorization framework on the suggested solution strategies based on literature analysis, with a special focus on the problems of mutual coupling, antenna selection, pilot contamination, and feedback overhead.
Results obtained	The simulation results shown that overcoming pilot contamination improves channel estimation; the system performance is improved in terms of Bit Error Rate (BER), and the proposed algorithm can mitigate pilot contamination impact and accurately obtain channel state information with low computational complexity as well as exploiting spatial correlation using factor analysis, the proposed channel estimation scheme can mitigate the impact of both pilot contamination and as a result, channel approximation and system performance in the downlink are increased, as is the possible data rate.
Comments/critical remarks	Overcoming mutual coupling issues in huge antenna array design is mostly designed for sub-6 GHz applications with a limited number of antenna components employed. As a result, further work is required to examine the viability of using such approaches for higher frequency bands as well as their validity for larger numbers of antennas ranging from tens to hundreds.

## Chapter Three

### Modeling, and the Techniques that Enables the Reduction of Response Time

#### 3. Algorithms and 5G network Protocols for the Next Generation network

The architectures of upcoming 5G mobile networks must incorporate protocols and algorithms. The suggested paradigm is built on a mobile environment that is user-centric and made up of a number of wireless and mobile technologies. The service band should be used for all solutions for next-generation mobile and wireless networks, whereas the transport stratum is for radio access technologies. A transparent switch in RATs by the mobile terminal would be possible thanks to the inclusion of the so-called Policy Router as a node in the core network, which creates IP tunnels to the mobile terminal via several available RATs. The basic premise of this strategy is that the user will be able to access many RATs simultaneously from a single mobile device (*Le, L. B., Lau, V., Jorswieck, E., Dao, N. D., Haghighat, A., Kim, D. I., & Le-Ngoc, T. (2015)*). The planned 5G network design would have to address a number of issues in order to be functional.

#### 3.1 Radio Access Technology Selector

The four parts of a unique 5G network protocol for radio network selection in heterogeneous situations are the most crucial information in this paper. A group of concurrent fuzzy logic (FL) controllers that receive measurement data for various selection criteria, including user requirements, QoS requirements, service regulations, and radio link conditions, make up the first part of the system (*Ahuja, K., Singh, B., & Khanna, R. (2018)*). The outputs from the FL controller in the first module are used as inputs in the second module, which is a multi-criteria decision mechanism algorithm. The final module, the Genetic Algorithm, maximises the weighting coefficients of various input criteria. Particle Swarm Optimisation (PSO), the fourth module, dynamically changes the first module's fuzzy logic controllers' capabilities.

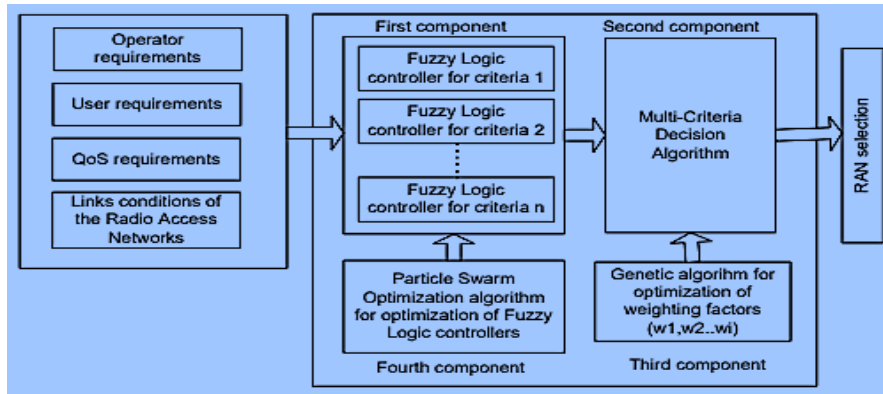


Figure 8: Design screenshot of Radio Access Network selection model scenario; April, 2023.

The technique for choosing wireless networks in diverse contexts is suggested in this thesis. The best wireless network is chosen or all current radio access networks are ranked in a given order using measurements of the radio access network's (RAN) characteristics. The suggested approach makes the assumption that mobile terminals have sufficient processing power, memory, and battery support to perform functional tasks. Given Moore's law for computers, it is reasonable to predict that by the year 2020, mobile phones would have computing capability comparable to that of powerful computers today. The suggested plan makes the assumption that mobile terminals can manage a database and perform processing at predetermined intervals using measurement data from a predetermined period of time in the past.

#### Particle Swarm Optimization (PSO) algorithm

Optimisation is the process of determining the best values for a set of particular system parameters to satisfy all design criteria while taking into account the lowest cost. An effective meta-heuristic optimisation technique called particle swarm optimisation (PSO) was developed in response to the swarm behaviour seen in nature, such as fish and bird schools. A simpler social system is simulated by PSO. A bird flock's elegant yet erratic dance was intended to be graphically simulated using the PSO algorithm.

**Step1:** Randomly initialize Swarm population of N particles  $X_i$  ( $i=1, 2, \dots, n$ )

**Step2:** Select hyperparameter values  
 $w, c_1$  and  $c_2$

**Step 3:** For Iter in range(max\_iter): # loop max\_iter times  
 For i in range(N): # for each particle:

```

    a. Compute new velocity of ith particle
       swarm[i].velocity = w*swarm[i].velocity +
r1*c1*(swarm[i].bestPos -swarm[i].position) + r2*c2*( best_pos_swarm
- swarm[i].position)
    b. If velocity is not in range [minx, maxx] then clip it
       if swarm[i].velocity < minx:
           swarm[i].velocity = minx
       elif swarm[i].velocity[k] > maxx:
           swarm[i].velocity[k] = maxx
    c. Compute new position of ith particle using its new velocity
       swarm[i].position += swarm[i].velocity
    d. Update new best of this particle and new best of Swarm
       if swaInsensitive to scaling of design
variables.rm[i].fitness < swarm[i].bestFitness:
           swarm[i].bestFitness = swarm[i].fitness
           swarm[i].bestPos = swarm[i].position
       if swarm[i].fitness < best_fitness_swarm
           best_fitness_swarm = swarm[i].fitness
           best_pos_swarm = swarm[i].position
    End-for
End -for

```

**Step 4:** Return best particle of Swarm

## Genetic Algorithm

Genetic algorithms (GAs) are adaptive heuristic search techniques that make up the majority of evolutionary algorithms. These are sophisticated random search applications backed by past data to concentrate the search on regions with the best performance in the solution space. They are typically used to provide exceptional solutions to problems relating to search and optimisation. In GAs, a population of people is updated iteratively. The people are judged using a fitness function after each repetition. Probabilistically, picking fitter people from the current generation produces a new generation of the population. The following generation accepts some of these people in the same condition. Other individuals are subjected to genetic processes like crossover and mutation to produce new children.

### Algorithm 1. Genetic Algorithm

```

//Initialization
generate  $\alpha\alpha$  feasible solutions randomly;
save them in the population  $PPPPPP$ ;
Loop until the terminal condition
for  $ii = 1$  to  $\delta\delta$  do

```

Elitism based selection

```
number of elitism  $nnnn = \alpha \cdot \beta$ ;
select the best  $nnnn$  solutions in  $PPPPPP$  and save them in  $PPPPPP1$ ;
Crossover number of crossover  $nnnn = (\alpha - nnnn)/2$  ;
for  $jj = 1$  to  $nnnn$  do
randomly select two solutions  $XXAA$  and  $XXBB$  from  $PPPPPP$  ;
generate  $XXCC$  and  $XXDD$  by one-point crossover to  $XXAA$  and  $XXBB$ ;
save  $XXCC$  and  $XXDD$  to  $PPPPPP2$  ;
end for
Mutation
for  $jj = 1$  to  $nnnn$  do
select a solution  $XXjj$  from  $PPPPPP2$ ;
mutate each bit of  $XXjj$  under the rate  $\gamma$  and generate a new solution  $XXjj'$  ;
if  $XXjj'$  is unfeasible
update  $XXjj$ 
' with a feasible solution by repairing  $XXjj'$  ;
End if
update  $XXjj$  with  $XXjj'$  in  $PPPPPP2$ ;
end for
Updating
update  $PPPPPP = PPPPPP1 + PPPPPP2$  ;
end for
Returning the best solution
return the best solution  $XX$  in  $PPPPPP$  ;
```

## Fuzzy Logic

Anything that is hazy or unclear is regarded as fuzzy. Their fuzzy logic offers highly useful flexibility for thinking since, in the actual world, we frequently run into situations where we are unable to discern whether the state is true or false. The ambiguities and errors of any scenario can be taken into account in this way. The foundation of fuzzy logic is the premise that there are often numerous shades of grey between true and false, making it too limiting to use. As opposed to being completely true or untrue, it permits partial truths, where a statement might be either partially true or wrong.

### 3.2 Prototype of performance analysis for the next generation 5G networks

Data transfer, control transport, service support, and application support are all features of next-generation networks (NGNs). A key control activity in delivering quality service is traffic analysis. (*Modarressi, A. R., & Mohan, S. (2000)*) As a result, performance analysis is a fundamental part of next-generation networks (NGNs), and it is often carried out at network nodes in access, core, and transit networks as well as at network edges (borders). In a wireless environment, it will also be carried out by mobile terminals, and its development will be essential for mobile user-assisted probing of RAT performances in this setting (*Modarressi, A. R., & Mohan, S. (2000)*). Its design must take into account the whole next-generation network architecture for management for performance measurement (MPM) as well as extra features on the mobile terminal side of CPE (customer premises equipment).

The network architecture consists of three entities:

- Performance Measurement Execution Functional Entity (PME-FE) is responsible for three groups of functionalities: performance measurements, process measurements, and a single configuration entity conducting the measurements;
- PMP-FE is responsible for two groups of functions: processing of measurements and configuration of measurement tests across the network architecture; and
- PMR-FE is an entity reporting the performance measurements performed.

The usage of RTP and RTCP to do continuous performance measurements by customer premises equipment (CPE) without adding extra probing systems is the most crucial information in this work. This has a direct impact on the provision of the necessary QoS for each of the realised services that consumers use and helps with decision-making about resource allocation in next-generation networks. The software module for controlling handovers between wireless technologies (ITHC) and the QoS/QoE control measurement software module is where measurement data is interfaced. The QoS/QoE CM software module and the software module for inter-tunnel handover control (ITHC), which controls handovers across wireless technologies, serve as the interface for measurement data.

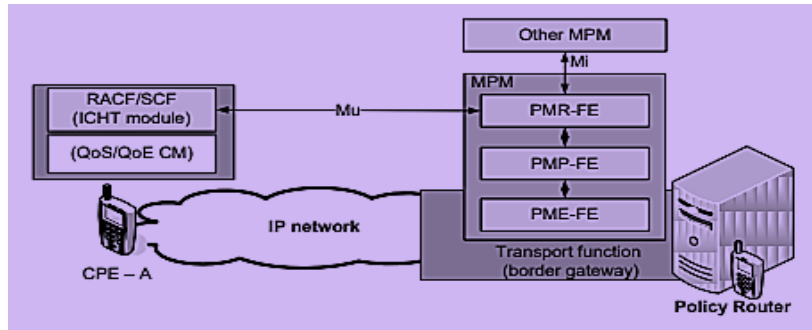


Figure 9: Design screenshot of Performance measurements Network using RTP / RTCP and RTCP extension; (Clark, A., & Wu, Q. (2012)).

The process for notifications based on qualitative performance measures derived by an RTP- or RTCP-based method is depicted in Figure below. The policy client and router sides of the network architecture must communicate via a new protocol.

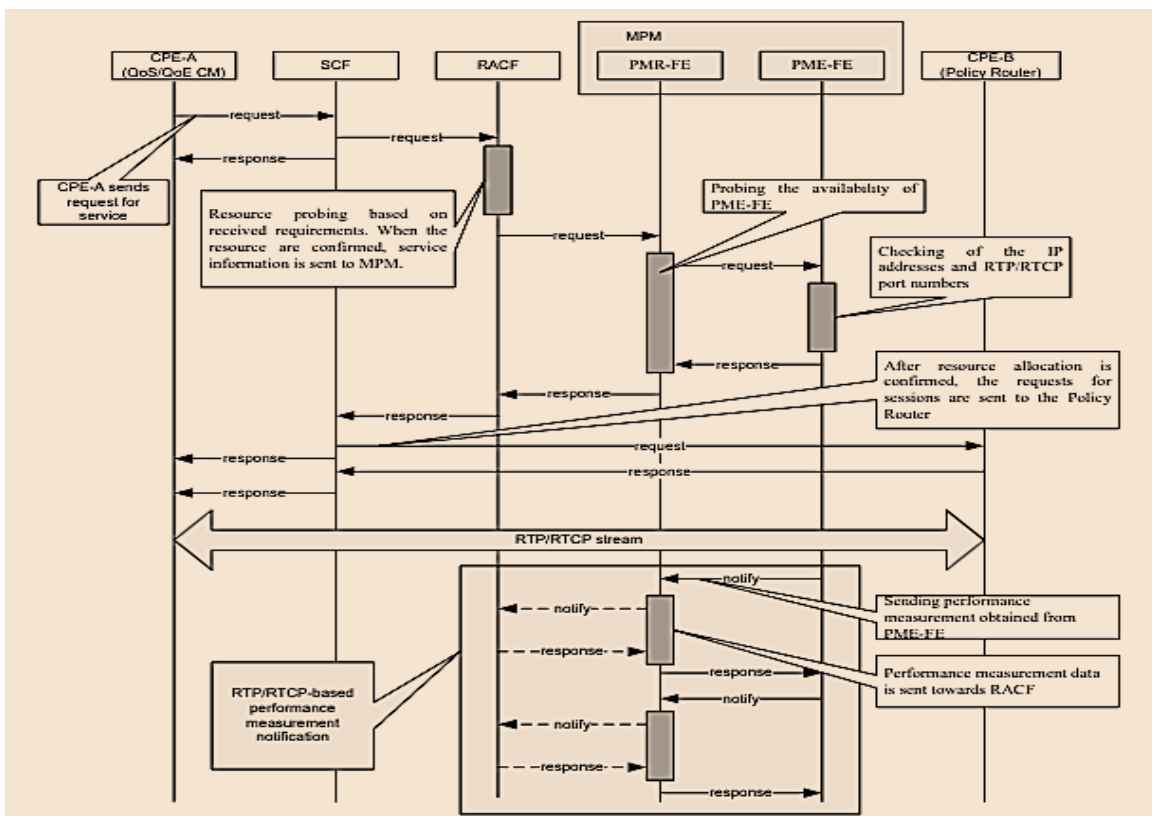


Figure 10: Design screenshot of RTCP / RTP-based diagram for performance measurements NGN; (Huntgeburth, B., Maruschke, M., & Schumann, S. (2011)).

Four essential features are needed for the control and packet-routing processes:

- exchange of initial policies for technologies and user requirements;
- exchange of the application characteristics for separation of the packets;
- continuous periodic exchange of measurement information of the QoS parameters of each radio access technology, which is achieved through connection to the client with the IP world; and
- Exchange of information on a selected set of routes for given applications (periodic exchange triggered by the ITHC module)

A protocol called QoSPRO (Quality of Service Policy Based Routing) provides communication between control and measurement entities, specifically between the software modules MQPBR (Measurement of Quality Policy Base Routing) and CQPBR (Control Quality Policy Based Routing). On the mobile terminal (client) side, decisions about a change in radio access technology are carried out using the M-RATS algorithm, which was designed and employs important performance indicators as input parameters for the right decision regarding RAT choice (Krishna, M. B., & Mauri, J. L. (2016)).

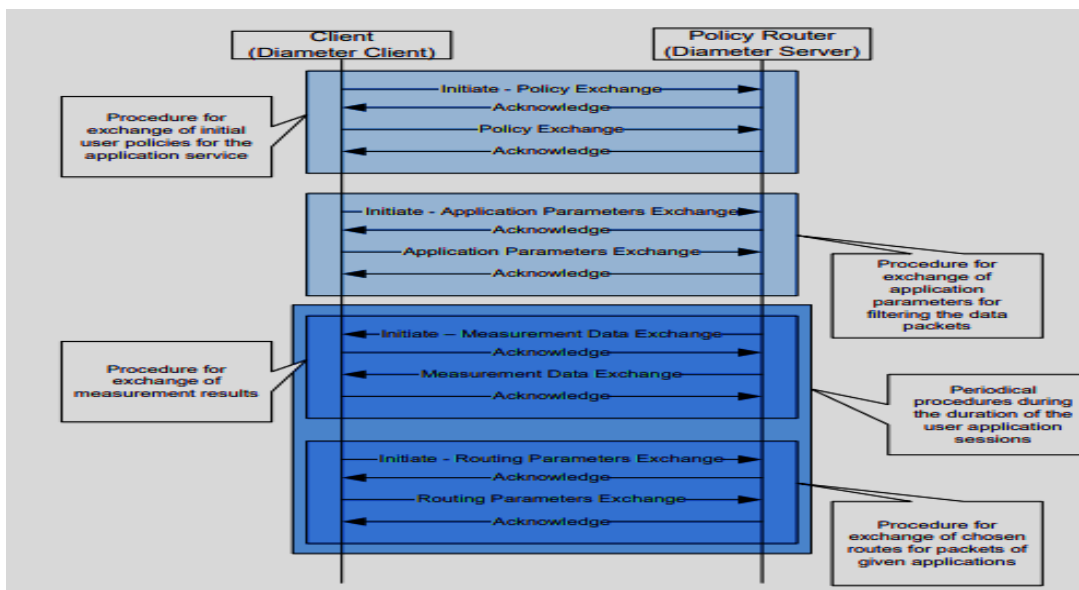


Figure 11: Design screenshot of QoSPRO procedure for the information exchange in the proposed architecture; (Tudzarov, A., & Janevski, T. (2011)).

In order to prevent the effect of Ping-Pong switching between the RATs, it is crucial to include hysteresis in periodic reviews of their condition. Distance as the foundation of this protocol offers tremendous flexibility and simplicity, as well as being strong and scalable enough to satisfy future requirements of the suggested architecture.

Therefore, faster data rates and all-IP concepts are becoming more prevalent in the construction of mobile and wireless networks. There are several radio access technologies available that enable IP-based communication at the network layer. The same programmes are being run on mobile terminals with increased processing power, onboard memory, and battery life. In this thesis, novel network architecture for 5G mobile networks is described. This design includes the introduction of software agents into the mobile terminal that will be used to communicate with newly specified nodes called policy routers. Through each of the possible interfaces to the various RATs, the policy router establishes IP tunnels with the mobile terminal.

As a result, the suggested RAT selection method, which is based on evolutionary algorithms and particle swarm optimisation, offers the maximum possibility that users will be happy with their needs for the access network. The suggested architecture is a particularly attractive option for the upcoming generation of mobile and wireless networks since it can be built using components off-the-shelf (current, standardised Internet technologies) and is transparent to radio access methods.

### 3.3 Key Performance Indicator for 5G Radio Network Waveform

5G networks have many different characteristics, including high data rates, wide channel bandwidths, difficult propagation conditions, URLLC requirements, severe radio frequency impairments, small base stations, numerous antennas, and TDD deployments. The following key performance indicators (KPIs) are listed by the 3GPP for waveform design:

- In order to meet requirements for traffic densities, data rates, and user connections, *spectral efficiency* is of utmost importance. The spectral efficiency KPI often places a lot more weight on lower carrier frequencies than on higher frequencies.
- **MIMO compatibility:** As a result of the increase in carrier frequency, both the base station and the user equipment's number of antenna elements would rise. The researcher

must provide higher coverage with the deployment of various MIMO systems that provide high spectral efficiency.

- **Low PAPR (*Peak-to-Average-Power-Ratio*):** It is crucial for devices, especially on the uplink side (user equipment), to have power-efficient transmissions since they require a low PAPR. An inadequate PAPR becomes much more crucial at very high frequencies. Since low-cost, small-sized base stations are anticipated at high frequencies, low PAPR may also be crucial for downlink transmissions.
- **Robustness to channel time selectivity:** Large cells display the high-speed situations. Large cells may not be a suitable option at very high frequencies due to wave impediments for propagation circumstances, which might result in a coverage constraint. Small cells at extremely high frequencies, where mobility is not a big problem, are likely to be used for the deployments.
- **Transceiver baseband complexity:** Since a base station at high frequencies may be a small access node with limited processing power, low baseband complexity is also important for faster processing and the ability to support low response time applications. Baseband complexity is always very important, especially from the receiver's point of view.
- **Time localization:** One of the criteria is that TDD uses frequent link direction switching for brief burst broadcasts. Additionally required are short transmission time slots, which aid in permitting a low response time; this is one of the important criteria for both the eMBB and the URLLC. For enabling short transmissions, a time-domain-restricted waveform is appropriate.
- **Out-of-band emissions and Frequency localization:** When employing different waveform numerologies at high frequencies in diverse 5G wireless network applications, frequency localization in FDD mode is helpful for possible multiplexing and effective spectrum utilisation. However, frequency localization is not a significant KPI when broad channel bandwidths are available. Both uplink and sidelink applications, as well as asynchronous access, can benefit from frequency localization.
- **Scalability and Flexibility:** Future waveform improvements will require much greater scalability and flexibility.

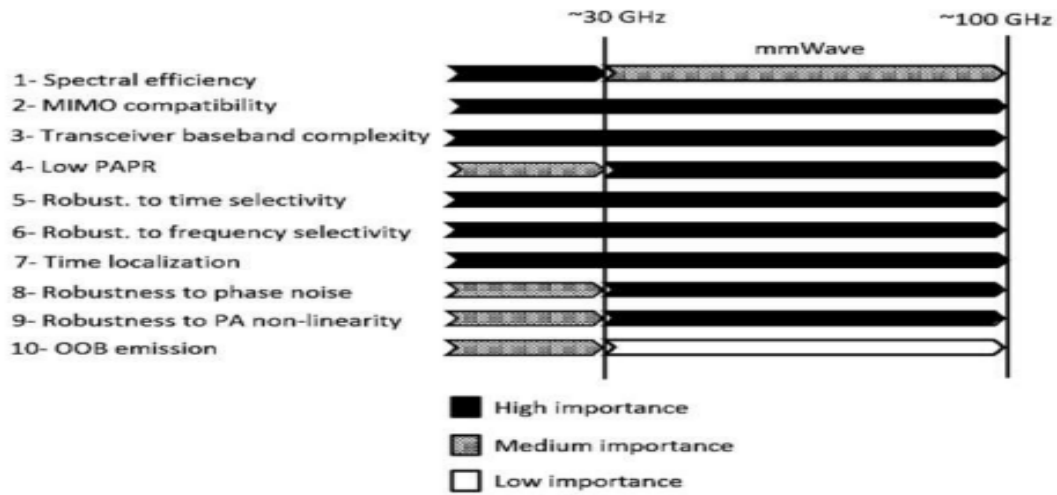


Figure 12: Simulation's screenshot for Importance of waveform performance indicators especially for low response time communication; (Tarboush, S., Sareddeen, H., Alouini, M. S., & Al-Naffouri, T. Y. (2022)).

The graphic illustrates the significance of the waveform KPIs for the radio network across several frequency bands. The researcher should have realised that frequency localization is not very significant in mmwave communication; rather, considerably more hardware flaws and power efficiency need to be taken into consideration. The world's energy usage now cannot be separated from the ultra-large-scale mobile communication network. It accounts for a sizeable portion of the operational expenditures in addition to producing significant amounts of carbon emissions.

### 3.3.1 Power Efficiency

All multicarrier waveforms have a high PAPR, which is frequently an issue (along with low power efficiency). All multicarrier waveforms, with the exception of UF-OFDM, which has a higher PAPR (assuming 16 QAM and 1200 subcarriers), were proved by the researcher to have similar PAPR. The PAPR and power efficiency of OFDM with DFT-based precoding (DFTS-OFDM) are worse than those of OFDM.

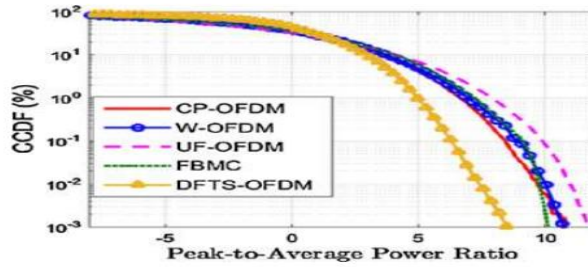


Figure 13: Simulation’s screenshot for PAPR of multicarrier waveforms and single carrier DFTS-OFDM; April, 2023.

Based on simulation studies, 5G networks should have extremely high throughput, extremely huge bandwidth, and extremely large numbers of ubiquitous wireless nodes, which should provide hitherto unheard-of issues for energy usage. Throughput can improve significantly as spectrum efficiency and bandwidth increase, but the energy efficiency issue will become more important. As much as feasible should be done to decrease the energy used for each bit (J/bit).

### 3.3.2 Time-Varying Fading Channel

The graph below shows the symbol error rate for a number of multicarrier waveforms (CP-OFDM, W-OFDM, UF-OFDM, FBMC-OQAM, and FBMC-QAM) over a time-varying fading channel with 60 km/h UE speed at 6 GHz carrier frequency (assumes QuaDRiGa channel model). Assume 16-QAM with 512 subcarriers for all waveforms and a signal bandwidth of 120 MHz. In channels that fade over time, CP-OFDM works better than other waveforms.

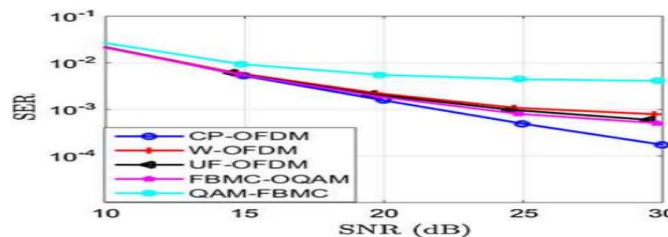


Figure 14: Simulation’s screenshot for Multicarrier waveforms subject to a time-varying fading channel (60 km/h UE speed at 6 GHz carrier frequency); (Keller, T., & Hanzo, L. (2000)).

### 3.3.3 Baseband Complexity

The number of real multiplications required for demodulation and synthesis, omitting the calculations needed for channel estimation, makes the implementation of multicarrier waveforms

challenging. OFDM, W-OFDM, F-OFDM, UF-OFDM, and FBMC were the multicarrier waveforms whose complexity was examined by the researcher. In order to indicate the difficulty of an N-point FFT/IFFT operation using CFFT (N), the researcher must consider the fact that FFT/IFFT operations are much more prevalent in the implementations of all of these suggested waveforms.

### 3.3.4 Suitability of OFDM for 5G Radio Network

Depending on the carrier-frequency band and link type, different radio network waveforms have different design requirements. Following a comparison of cutting-edge waveforms and consideration of the required criteria, the 3GPP investigated a number of multicarrier and single-carrier waveforms and ultimately chose the CP-OFDM waveform for the radio network. The KPIs assessed included spectral efficiency, MIMO compatibility, peak-to-average power ratio (PAPR), robustness against channel time selectivity, time localization OFDM, and robustness to synchronisation problems, flexibility, and scalability (*Somesula, M. K., Rout, R. R., & Somayajulu, D. V. (2022)*).

### 3.3.5 NOMA vs OMA

Multi-access cellular communication systems are necessary. It is a technique for letting several users share a communication channel. Orthogonal signals for various users on the receiver side have been considered while developing a number of access strategies (*Vaezi, M., Ding, Z., & Poor, H. V. (Eds.). (2019)*). For instance, in OFDMA, which is frequently used in 4G networks, the signals from various users are orthogonal in the frequency or time domains. In other words, only one user can get a 180 kHz orthogonal frequency division multiplexing (OFDM) resource block.

Contrarily, non-orthogonal multiple access (NOMA) enables several users to share the same resource elements, regardless of their location in space, time, or frequency. NOMA is now a popular study area in both academia and industry for 5G and beyond (*Nguyen, H. V., Kim, H. M., Kang, G. M., Nguyen, K. H., Bui, V. P., & Shin, O. S. (2020)*).

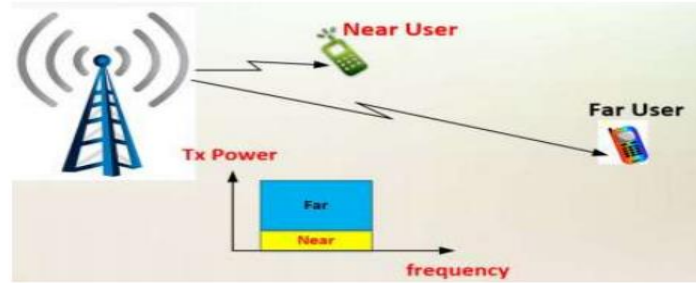


Figure 15: Design screenshot of two users' scenarios for the NOMA model (Nguyen, H. V., Kim, H. M., Kang, G. M., Nguyen, K. H., Bui, V. P., & Shin, O. S. (2020)).

Where the near user (strong channel gain) and the far user (weak channel gain) disagree, the NOMA employing QPSK (QAM-4) modulation technique is distinct from the standard QPSK modulation. The signal of the far user is not significantly hampered by the signal of the near user, and the far user decodes its signal normally. But there is a little more interference (Shankar, R., Beuria, M. K., Kulkarni, G. R., Zamani, A. S., Krishna, P., & Krishnan, V. G. (2022)) that makes it suffer.

- The near-user signal has large interference from the far-user signal; the near-user decodes the far-user signal first.
- Subtracts this interference from the composite NOMA signal.
- User interference is cancelled.
- The Near user decodes its data from the cleaned signal; the Far user is unable to cancel near user interference because it is too weak to be decoded.

Comparing NOMA to OMA, some key benefits at the same time and with the same frequency of resources, serve several users. Regarding;

- Higher spectral efficiency (more data rate per Hz)
- benefit from the geographical distribution of users
- Better serve cell edge users (users far from the base station).
- Some applications need low data rates. It is a waste of resources to allocate dedicated time and frequency.
- Sensor readings
- Inter-vehicle communications

- Machine-to-machine communications
- ***Superposition Coding with Successive Interference Cancellation***: At the transmitter and receiver, NOMA is compared to superposition coding with successive interference cancellation (SC-SIC). Due to the literature examined using the term NOMA and the fact that SC-SIC is the approach used to achieve capacity for the downlink channel in ISO transmission, this is the case (*Nguyen, H. V., Kim, H. M., Kang, G. M., Nguyen, K. H., Bui, V. P., & Shin, O. S. (2020)*).
- ***Overloading***: Separating NOMA from OMA based on system loads is the second crucial viewpoint. Overloaded systems are those that have more users than there are time, frequency, code, or space resources available. This is referred to as NOMA. This viewpoint, which has its origins in CDMA systems, is seen as an OMA scheme if there are more codes than users in the system and as a NOMA scheme if it is overloaded. Low-density spreading (LDS) CDMA and LDS-OFDM are examples of NOMA schemes created with this viewpoint (*Millar, G., Kulhandjian, M., Alaca, A., Alaca, S., D'Amours, C., & Yanikomeroglu, H. (2022)*).
- ***Linear Transform Decoding***: Any scheme that adheres to this specification may be referred to as NOMA. NOMA is a scheme that uses a linear transform to segregate the signals of various users into orthogonal subspaces.

### 3.3.6 Determinations NOMA

The ability for numerous users to share all domains, such as time, frequency, and location, is made possible by effective multiple accesses (NOMA), which is a major enabler in meeting 5G standards. By making use of a downlink capacity-achieving technique and enabling additional connections in the uplink, NOMA may improve spectral efficiency and user fairness. NOMA can increase user bandwidth while decreasing response and dependability times.

## 3.4 Frame Structure of 5G Radio Network

The radio network interface protocol architecture's physical layer, which is the initial layer, offers data transport services to upper levels. Coding, modulation, demodulation, processing using multiple antennas, and mapping of the coded transport channel to the appropriate physical

channels are all included. Orthogonal frequency-division multiplexing (OFDM) is the waveform used by the radio network for both uplink and downlink transmission. By dividing the available bandwidth (BW) into mutually orthogonal subcarriers, OFDM offers a flexible multiple-access strategy that allows users to share bandwidth without experiencing intra-cell interference. Although DFT-pre-coded OFDM is used to increase power amplifier efficiency, it has disadvantages such as making MIMO receivers more complicated and limiting frequency domain scheduling (*Kassir, A., Dziyauddin, R. A., Kaidi, H. M., & Izhar, M. A. M. (2018)*).

With a variety of subcarrier spacings (SCSs), the radio network supports a number of OFDM numerologies. 15, 30, 60, 120, and 240 kHz are among the permitted subcarrier spacings; nevertheless, the synchronisation signal block (SSB) is the only one that supports 240 kHz. In order to effectively cohabit with LTE, the flexible numerology is based on scaling, with 15 kHz as the minimum. The following terms are used to define the scaling of subcarrier spacing from baseline:

$$\Delta f = 2^{\mu} \times 15 \text{ kHz} \dots\dots\dots\text{Equation 4}$$

Where:

$$T_u = \frac{1}{SCS} \dots\dots\dots\text{Equation 5}$$

$$SCS = \Delta f \dots\dots\dots\text{Equation 6}$$

In this case, the higher-layer parameter subcarrier spacing is used to provide the subcarrier spacing configuration, which is an integer with a range of 0 to 4. Subcarrier spacing with cyclic prefix (CP) durations and proportional symbols (*Lipovac, A., Lipovac, V., & Modlic, B. (2021)*).

Table 5: Supported subcarrier spacing with proportional symbol and CP (cyclic prefix) durations.

Sub-carrier spacing configuration ( $\mu$ )	$\Delta f$ [kHz]	Symbol duration [ $\mu$ s]	Cyclic prefix duration [ $\mu$ s]
0	15	66.7	4.7
1	30	33.3	2.3
2	60	16.7	1.2
3	120	8.33	0.59

4	240	4.17	0.29
---	-----	------	------

Transmissions across radio networks are segmented into 10 ms-long frames, 10 subframes, and slots. In the frequency domain, each slot has 12 subcarriers and 14 OFDM symbols in the time domain. The usage of 60 kHz subcarrier spacing with an extended CP, which may be utilised to shorten slot duration and delay while retaining a CP similar to 15 kHz, is an exception to this rule. The slot length in milliseconds in the time domain is defined as:

$$\text{Slot length} = 1 \text{ ms} / 2^\mu \text{ .....Equation 7}$$

The number and length of slots with the supported SCSs are shown in the table below, where the subcarrier spacing configuration depends on slot length. The number of slots inside a subframe is likewise doubled when the subcarrier spacing is increased (*Lipovac, A., Lipovac, V., & Modlic, B. (2021)*).

Table 6: Number, and length of slots with the supported subcarrier spacing

Subcarrier spacing configuration ( $\mu$ )	Number of symbols in a slot	Number of slots in a subframe	Number of slots in a frame	Slot length [ms]
0	14	1	10	1
1	14	2	20	0.5
2	14 (normal CP) 12 (extended CP)	4	40	0.25
3	14	8	80	0.125
4	14	16	160	0.0625

According to the frequency band 5G NR permits transmissions across various system bandwidths. System bandwidths of 5, 10, 15, 20, 25, 40, 50, 60, 80, or 100 MHz are permitted in Frequency Range I (FRI), which covers 450 MHz to 6 GHz. A bandwidth of 50, 100, 200, or 400 MHz is possible with Frequency Range 2 (FR2), which is defined as being between 24.25 GHz and 52.6 GHz. One resource element is defined as the allocation of a single subcarrier in a single OFDM signal. The term resource block in the frequency domain refers to a collection of 12 consecutive subcarriers. The frame structure for numerology  $\mu=0$  is illustrated using the picture below based on all these factors. When compared to TDM in LTE, for instance, the time-division

multiplexing (TDM) method used in NR is more flexible. OFDM symbols inside a slot can be uplinked, downlinked, or flexible.

A mix of uplink and downlink symbols makes up the flexible slot. The UE only transmits in the uplink or flexible symbols because it thinks that the downlink transmission only takes place in the downlink or flexible symbols. The NR also supports mini-slots, which are additional slot types beyond the three specified slot types. Since a mini-slot can be as brief as one OFDM symbol at a time, it can be used to allow shorter transmissions. To provide for a more flexible start position in the time domain, a mini-slot can also start at any moment throughout a slot. The beginning of the slot can also be front-loaded with control and reference signals (RSS) in order to achieve a low response time. They can be employed, for instance, in low-response-time settings where the gearbox must begin right away because to the mini-slots' adaptable time structure.

Each individual element, grouped into one subcarrier of the PRB, is called a resource element (RE). The RE is the smallest unit in the resource grid. It corresponds to a physical resource made up of one OFDM symbol in time and one subcarrier in frequency. A PRB is made up of 12 subcarriers, which have the same subcarrier spacing and CP overhead within a PRB. The bandwidth is doubled, and the slot duration is cut in half when the SCS is increased by two. It is evident that more slots may fit into a subframe when the SCS is higher (*Patriciello, N., Lagen, S., Giupponi, L., & Bojovic, B. (2018)*).

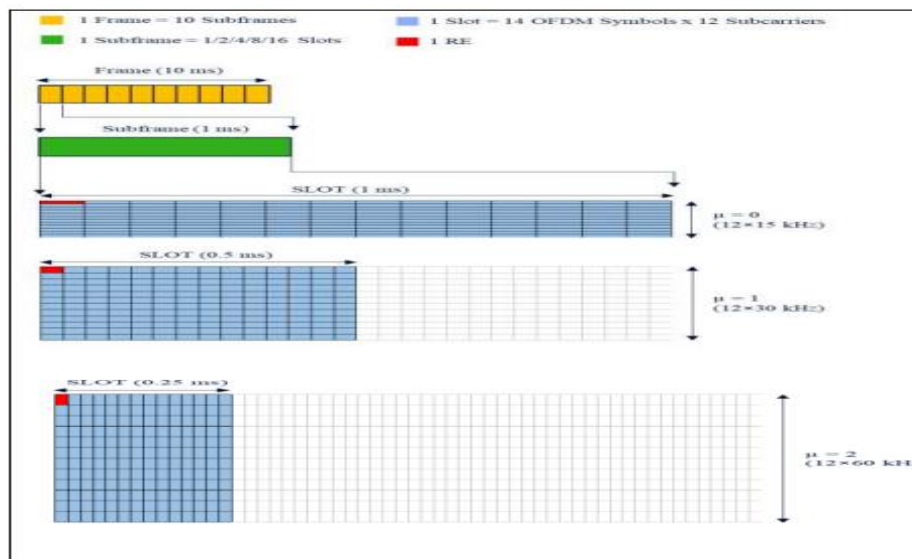


Figure 16: Simulation's screenshot for NR Frame Structure; (Lien, S. Y., Shieh, S. L., Huang, Y., Su, B., Hsu, Y. L., & Wei, H. Y. (2017)).

### 3.5 5G NR Physical Channels and Signals

Control and data content is allocated at the described 5G NR frame structure for downlink and uplink transmissions thanks to the use of physical channels and signals. Since it was mainly focused on the downlink side, only the physical channels and signals transmitted from the base station (NB) to the UE are described in this subsection. The set of downlink physical channels and signals in figure below:

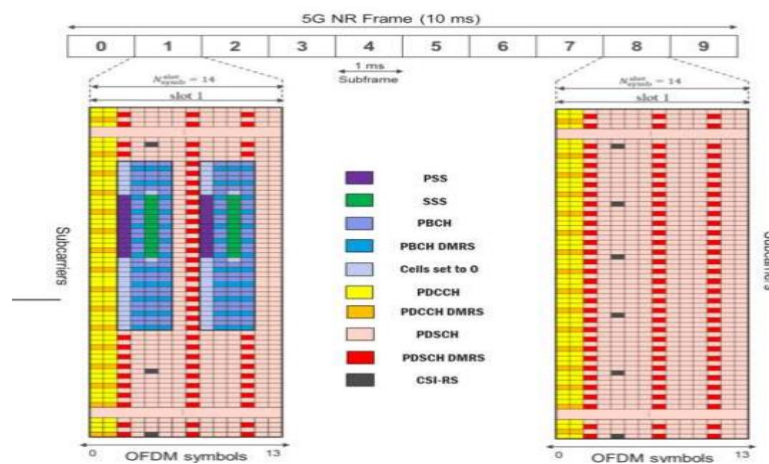


Figure 17: Design screenshot of Frame structure for SFI = 0 (10 subframe, 100% Downlink); April, 2023.

#### 3.5.1 Physical Shared Channels

##### ➤ **Physical Downlink Shared Channel (PDSCH)**

DL user data, upper layer data unique to UEs, system information, and paging are all sent through PDSCH. An LDPC base graph selection is added after a transport block CRC is applied to facilitate error detection. Each code block is encoded, and the LDPC-coded blocks are independently rate-matched, after which the transport block is segmented into code blocks, and code block CRC attachment is carried out. The creation of a code word for transmission on the PDSCH (physical downlink shared channel) is completed by concatenating code blocks. On the PDSCH (physical downlink shared channel to channel), it allows for the simultaneous broadcast of up to two code words.

Each code word's information is modulated and jumbled to create a block of complicated modulation symbols. Up to four MIMO layers can be used to map the symbols. To accommodate up to eight layers of transmission, a PDSCH (physical downlink shared channel) can include two code words. The layers are then explicitly mapped to the antenna port openings in a transparent way (i.e., without using a codebook) before explaining to the user how the beamforming or MIMO precoding operation is carried out depending on the network implementation. The symbols are mapped to resource blocks (RBs) for each of the ports, for example, layers used to transmit the PDSCH (physical downlink shared channel) (Al Azzawi, F. F., Al Azzawi, Z. F., Al Azzawi, S. F., & Abid, F. A. (2020)).

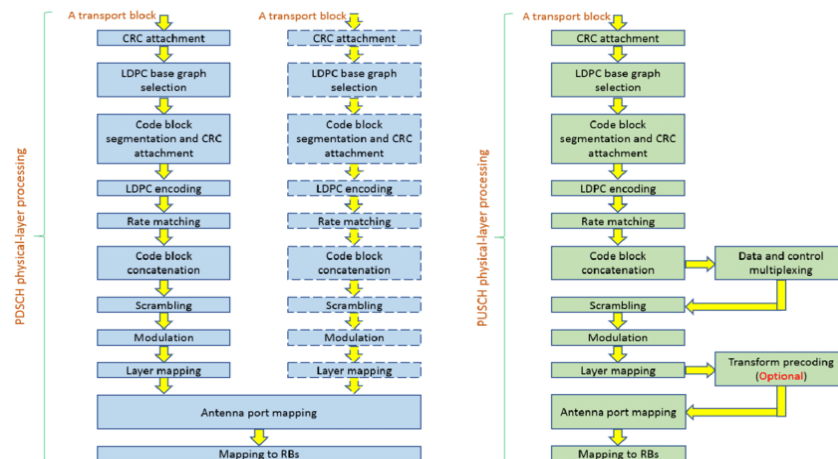


Figure 18: Design screenshot of physical layer processing for 5G NR PDSCH and PUSCH; April, 2023.

➤ **Physical uplink Shared Channel (PUSCH)**

A UL transport block is sent across the UL-SCH transport channel. A UL transport block's physical layer processing resembles that of a DL transport block. In order to create a block of complex-valued modulation symbols, the code word's contents are modulated and scrambled. The symbols are then projected onto one or more layers. One code word can be mapped to up to four levels using PUSCH (Wu, Z., Lu, K., Jiang, C., & Shao, X. (2018)). Both non-codebook-based transmission and codebook-based transmission are supported in the UL for the layers to antenna port mapping. The symbols are assigned to RBs for every transmission antenna port. In contrast to LTE, the mapping is completed in time to allow for early decoding at the receiver.

### 3.5.2 Physical Control Channels

- **Physical Downlink Control Channel (PDCCH):** PDCCH is used to transmit DCI, including uplink and downlink scheduling awards. It is designed specifically for transmission in a CORESET, or customizable control resource set. A PDCCH is limited to a single CORESET and is sent with a unique demodulation reference signal (DMRS). For different DCI payload sizes or different coding rates, it is carried by 1, 2, 4, 8, or 16 control channel elements (CCE) (Lin, X., Li, J., Baldemair, R., Cheng, J. F. T., Parkvall, S., Larsson, D. C., & Werner, K. (2019)). A CORESET's CCE-to-REG mapping can be either interleaved or non-interleaved (for frequency variety and localized beam shaping, respectively). A UE is set up to obviously monitor several PDCCH candidates with various DCI formats and aggregation levels.

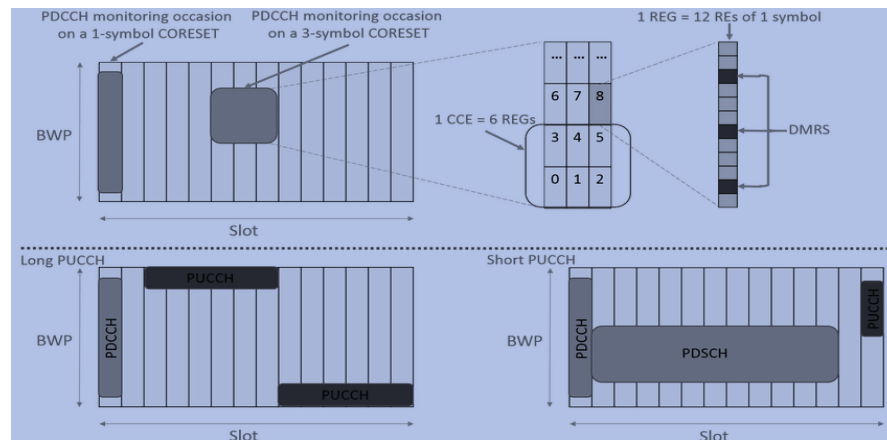


Figure 19: Design screenshot of physical layer processing for 5G NR PDCCH and PUCCH; April, 2023.

- **Physical Uplink Control Channel (PUCCH):** Uplink control information (UCI), such as scheduling requests (SR), channel status information (CSI), and hybrid automated repeat request (HARQ) feedback, is transmitted via PUCCH. In contrast to LTE PUCCH, NR PUCCH has variable time and frequency distribution, enabling users with lower bandwidth capabilities and effective resource utilisation. The NR PUCCH architecture is based on five PUCCH formats, with formats 0 and 1 carrying UCI payloads of one or two bits, while the remaining formats are used to transport UCI payloads greater than two bits. To maintain a low peak-to-average power ratio (PAPR) in PUCCH formats 1, 3, and 4, symbols containing DMRS are time-division multiplexed with UCI symbols (Kundu,

*L., Xiong, G., & Cho, J. (2018)*). In format 2, DMRS is frequency multiplexed with data-carrying subcarriers.

### 3.5.3 Physical Reference Signals

Reference signals are available when needed and may be configured to suit needs with the least amount of overhead, according to lean carrier design principles. The transmission might be very sparse to save power and minimise inter-cell interference. A degree of forward compatibility is also produced via the on-demand approach and great design flexibility. When compared to NR, which uses many users' individually defined reference signals to enable various services, LTE ties numerous functions to the always-on CRS (*Lin, X., Li, J., Baldemair, R., Cheng, J. F. T., Parkvall, S., Larsson, D. C., & Werner, K. (2019)*).

#### ➤ *Downlink and Uplink Demodulation Reference Signals (DMRS)*

The receiver generates channel estimates for the linked physical channel's demodulation using DMRS. The PBCH, PDCCH, PDSCH, PUSCH, and PUCCH cache physical channels are specifically affected. Each UE has a unique DMRS, which is only communicated when necessary (*Rico-Alvariño, A., Bouazizi, I., Griot, M., Kadiri, P., Liu, L., & Stockhammer, T. (2022)*). The use cases, user-end capabilities, and PDSCH/PUSCH DMRS support a broad variety of scenarios. By configuring the amount of DMRS symbols in a PDSCH and PUSCH time, very high UE mobility and reduced DMRS overhead are supported. DMRS's frequency domain and density may be adjusted to have an optimised overhead. The receiver can begin channel estimation sooner and lower the processing response since the first DMRS incident occurs early in the PDSCH or PUSCH broadcast.

#### ➤ *Downlink and Uplink Phase-Tracking Reference Signals (PTRS)*

PTRS is a method used to monitor the local oscillator's phase at the transmitter and receiver. It reduces phase noise and inaccuracy, which are crucial at high carrier frequencies. It may be seen in both the uplink (PUSCH) and the downlink (PDSCH), where a PTRS is only connected to one DMRS port and is limited to the PDSCH's or PUSCH's planned bandwidth and duration if broadcast (*Lin, X., Li, J., Baldemair, R., Cheng, J. F. T., Parkvall, S., Larsson, D. C., & Werner,*

K. (2019)). Scheduled bandwidth and SNR determine the frequency and temporal density of PTRS.

➤ ***Channel-State Information Reference Signals (CSI-RS)***

NR Downlink CSI collection is supported by CSI-RS, which can additionally enable RSRP measurements, frequency and time tracking for demodulation, and UL reciprocity-based precoding for CSI-RS setup (Bertenyi, B., Nagata, S., Kooropaty, H., Zhou, X., Chen, W., Kim, Y., & Xu, X. (2018) Bertenyi, B., Nagata, S., Kooropaty, H., Zhou, X., Chen, W., Kim, Y., & Xu, X. (2018)). The NR offers a lot of versatility because of its customizable density and up to 32 ports. Depending on the number of ports set, a CSI-RS resource in the time domain can start at any OFDM symbol in a slot and span 1, 2, or 4 OFDM symbols. CSI-RS may be regular, irregular, or aperiodic (DCI-triggered).

➤ ***Sounding Reference Signals (SRS):***

In addition to downlink precoder selection and link scheduling, the SRS is employed for uplink channel sounding and reciprocity operations. Contrary to LTE, it makes the system extremely flexible by being user-end-specifically customised.

The frame structure could be used to achieve a low response time communication link end-to-end through several changes, and evaluation mechanisms using 5G key performance indicators are useful to track each waveform's performance and how it adheres to the standards of the new networks. The main waveform for the investigational 5G network has had several runners, but the one that best meets the majority of 5G worldwide applications (eMBB, URLLC, and mMTC) is the best option. Due to its spectrum possibilities, research has recommended a non-orthogonal waveform, but up to now, it hasn't been reliable. The new numerology idea and the adjustable time slot utilised in the scope of 5G put a greater emphasis on scalability.

### 3.6 The Researcher's Model

The lowest TTI in the LTE system has a low response time and a fixed frame structure with very low milliseconds. In order to adjust the transmission rate while maintaining a consistent control overhead, this fixed frame structure depends on modulation and coding techniques. It is not

advisable to take into account a packet with a low radio transmission time because a high response time is connected with control overhead, which takes up a significant amount of a packet's transmission time. As a result, the researcher's packet/frame structure and transmission approach need to be drastically improved (Parvez, I., Rahmati, A., Guvenc, I., Sarwat, A. I., & Dai, H. (2018)). In light of this:

- First, a unique radio frame that is strengthened by less overhead control and shorter transmission times must be devised. User scheduling, resource allocation, and channel training methods can be dropped or combined to reduce control overhead.
- With improved waveforms and transmission techniques that shorten the retransmission delay, the chance of packet errors during the initial transmission should be minimised.
- Third, strategies for giving precedence to data above regular data must be developed since reaction-time-critical data has to be sent out right away.
- Fourth, OFDM's essential components of synchronisation and orthogonality, which pose significant obstacles to obtaining short response times, are essential. Despite having a faster response time than synchronised operations, asynchronous communication still needs more spectrum and power.
- Fifth, caching networks may be used to decrease response time by storing frequently used data at the network edge since the response time for data transmission also depends on the delay between the core network and the BS (base station).

New or modified frame or packet structures, waveform designs, multiple access strategies, modulation and coding schemes, transmission schemes, control channel enhancements, low response time symbol detection, mmWave aggregation, cloud RAN, reinforcing QoS and QoE, energy-aware response time minimization, and location-aware communication techniques are some examples of RAN solutions. For the core network, new entities like SDN, NFV, MEC, and fog networks have also been suggested. Backhaul solutions may be classified into general and mmWave backhaul, while caching solutions can be divided into cache placement, content delivery, centralised caching, and distributed caching.

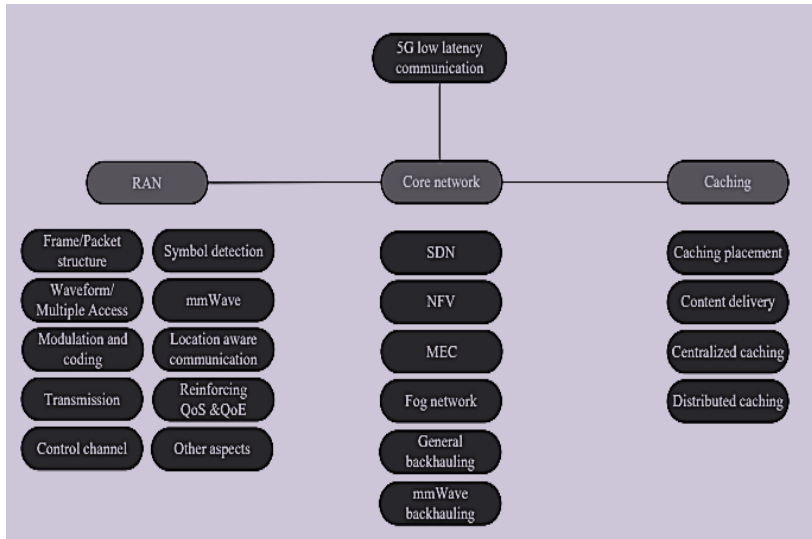


Figure 20: Design screenshot of The HU-IOT-CS-5G model; April, 2023.

## Chapter Four

### Simulations, Results, and Discussion

#### 4 Introduction

Due to a number of changes in the physical layer that were observed in Chapter Three, including the frame structure flexibility, the 5G frame structure can support URLLC. The study employed the MATLAB package's 5G Toolbox to mimic the burst time of the most important waveforms and examine how it impacts response time. First, the researcher used a simulation to determine how to manage high-bandwidth decoding for tiny devices utilising the bandwidth-part approach.

##### 4.1 Activity 1: Simulation of burst duration for 5G candidates parameters

For the most prominent 5G waveform candidates' parameters, the researcher chose CP-OFDM, UFMC (universal filtered multi-carrier), and FBMC (filter bank multi-carrier) to study the spectral efficiency depending on the burst time. The following parameters were available to the researcher:

Table 7: Simulation parameters for the burst time duration

<b>Bits per subcarrier</b>	<b>6</b>
<b>Fast Fourier transform size (FFT)</b>	4096
<b>Number of cyclic prefix</b>	43
<b>Filter length</b>	43

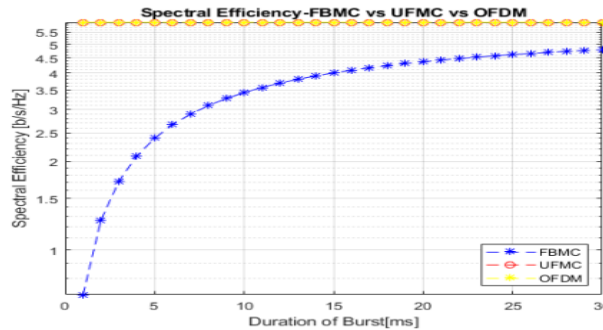


Figure 21: Simulation's screenshot for spectral efficiency CP-OFDM, UFMC, and FBMC; April, 2023.

## Discussion

Due to its superior spectrum efficiency, UFMC (universally filtered multi-carrier) beats OFDM (orthogonal frequency division multiplexing) in the results above. It is superior to FBMC (filter bank multi-carrier) for brief bursts because of its ability to filter the sub-bands, which eliminates the guard bands between the sub-bands and shortens the filter length. Because the CP-number and filter length overlap during the burst, the graph above demonstrates how spectral efficiency is dependent on the burst duration of the highlighted waveform candidates. Because FBMC lengthens bursts to boost spectral efficiency, it is not appropriate for applications requiring quick responses.

Therefore, FBMC (filter bank multi-carrier), UFMC (universal filtered multi-carrier), and GFDM (generalised frequency division multiplexing) are all based on filters and can all increase spectral efficiency and reduce latency primarily by shortening CP and decreasing the dependence on synchronisation. Despite the fact that the CP is reduced, the lengthy transmission impulse response length causes the FBMC frame to be long. Additionally, FBMC is not a good candidate for low-latency communication since its computational cost is substantially higher than that of OFDM. As a result, by filtering through a number of continuous subcarriers, UFMC has

enhanced FBMC. To minimise computational complexity and processing delay, GFDM substitutes cyclic convolution for linear convolution (*Wild, T., Schaich, F., & Chen, Y. (2014).*)

## 4.2 Activity 2: Simulation of frame structure in 5G

Table 8: Simulation parameters for frame structure

Frequency	FR1 < 6 Ghz		FR2 >> 6 Ghz (mmwave)	
<b>Modulation</b>	QAM64	QAM64	QAM64	QAM64
<b>Channel bandwidth</b>	50 MHz	100 MHz	200 MHz	400 MHz
<b>Subcarrier spacing( SCS)</b>	15 KHz	30 KHz	60 KHz	120 KHz
<b>Duplexing mode</b>	TDD/FDD	TDD/FDD	TDD/FDD	TDD/FDD

### Discussion

The simulation's major objective is to demonstrate how 5G provides short response times while maintaining dependability. In order to determine how the frame and bandwidth flexibility may permit a significant portion of the rapid response time, the researcher has simulated 5G frames and BWP (bandwidth part) for various instances. The simulation plan comprises simulating the bandwidth and frame structure for a downlink with symbols distributed according to various numerologies as well as the EVM (error vector magnitude) of the radio network test model for the downlink. The researcher has two frequency ranges, FR1 and FR2 that range from 50 MHz to 100 MHz for frequencies below 6 GHz and from 100 MHz to 400 MHz for mmwave frequencies. The variable subcarrier spacing of CP-OFDM in 5G NR is utilised to lower the symbol rate while gaining the advantages of orthogonality. Two frames are utilised for demodulator synchronisation in TDD, while 10 frames are needed in FDD. Channel simulation is done by the bandwidth part.

#### 4.2.1 Activity 2.1: Channels

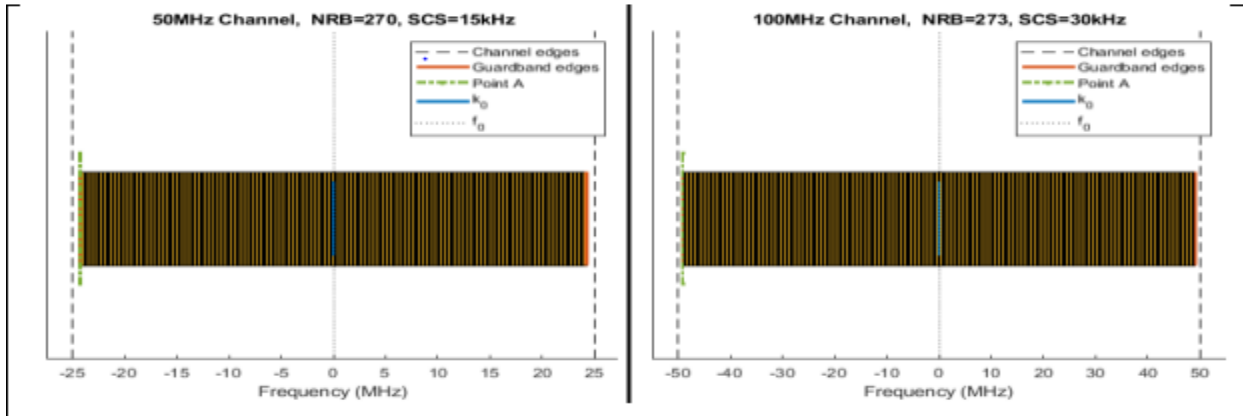


Figure 22: Simulation's screenshot for Downlink CHANNELS for FR1 with TDD/FDD; April, 2023

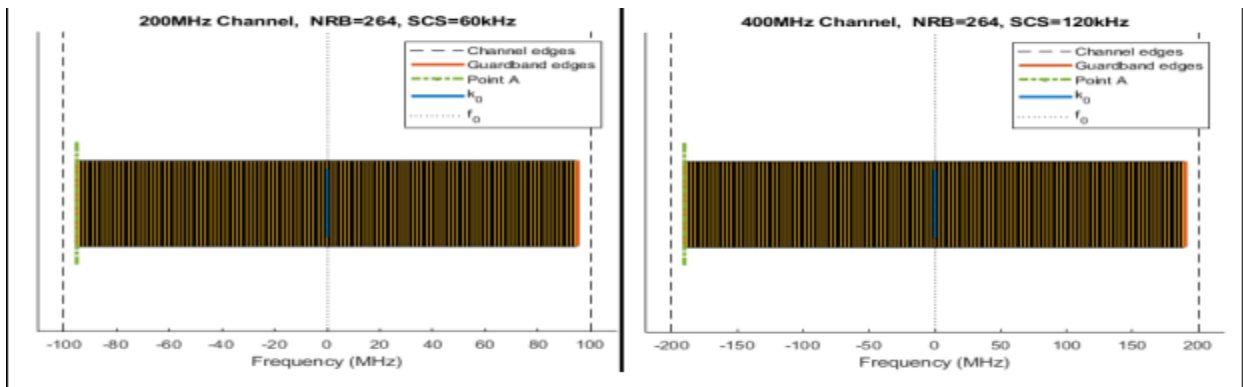


Figure 23: Simulation screenshot for Downlink CHANNELS for FR2 with TDD/FDD; April 2023

## Discussion

The two types of channels FR1 (sub-6 GHz) and FR2 (mmwave) that exist in the result above are the most crucial information in this thesis. Researchers may use up to 400 MHz for FR2, but only 100 MHz is permitted for FR1. The phrase nominal bandwidth, or useful bandwidth for the data, is introduced because a guard band is required to create isolation while channel edges, typically 20 MHz, are utilised to map data and symbols in the channel.

## 4.2.2 Activity 2.2: Time Division Duplex

### Activity 2.2.1: Bandwidth Parts

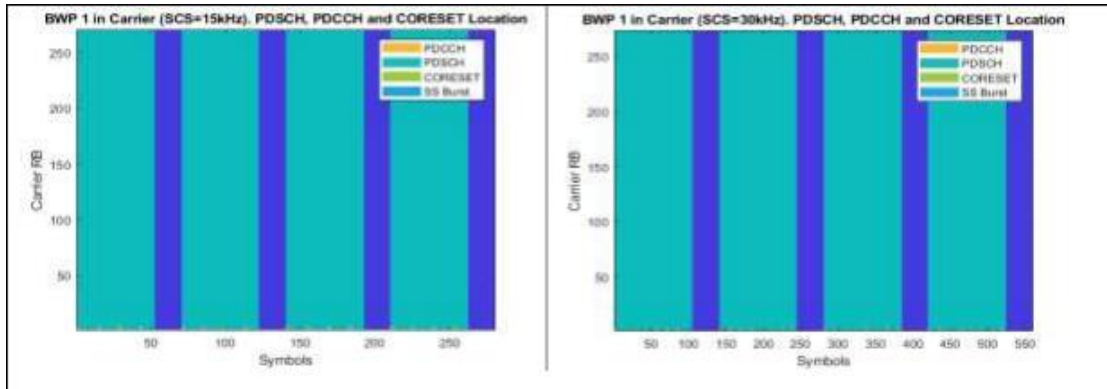


Figure 24: Simulation's screenshot of Bandwidth part FR1 subcarrier spacing TDD; April 2023

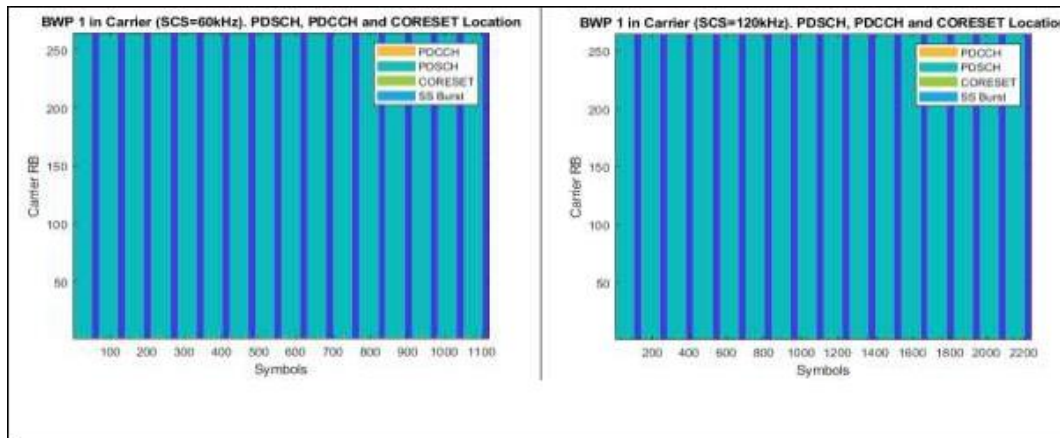


Figure 25: Simulation's screenshot of Bandwidth part FR2 subcarrier spacing TDD; April 2023

## Discussion

As seen in the aforementioned result, FR2 NR-TM is only defined in TS 38.141-2 for TDD, although this example also permits the creation of FDD waveforms. Similar scheduling freedom is available for NR, which allows for transmissions of up to two downlink codewords and one uplink codeword. Because we use a lot more bandwidth in 5G, the UE doesn't have to decode the entire bandwidth as it does in LTE while it is in idle mode. Instead, it may read the information for other bandwidth parts (BWP) that are included in the first bandwidth portion. FDD and TDD are the two most popular duplexing techniques used for both paired and unpaired spectrums. Since TDD uses the entire burst at once, we can dedicate an entire channel for one user, making

it more flexible with mmwave and having a larger bandwidth than FDD. TDD can be configured for both link subframes, but the configuration is somewhat slow because synchronisation is necessary. To solve this issue, we use a synchronisation protocol.

The supported processing durations, the monitoring capacity, and the subcarrier spacing for TDD. In comparison to the traditional TDD configurations supported by LTE, NR TDD with self-contained subframes can offer faster response times. For the high-frequency TDD carrier, the DL/UL time-slot (TS) ratio configuration only needs to take into account the long-term DL/UL traffic statistics to ensure the DL spectrum exploitation efficiency.

### Activity 2.2.2: Frames simulation

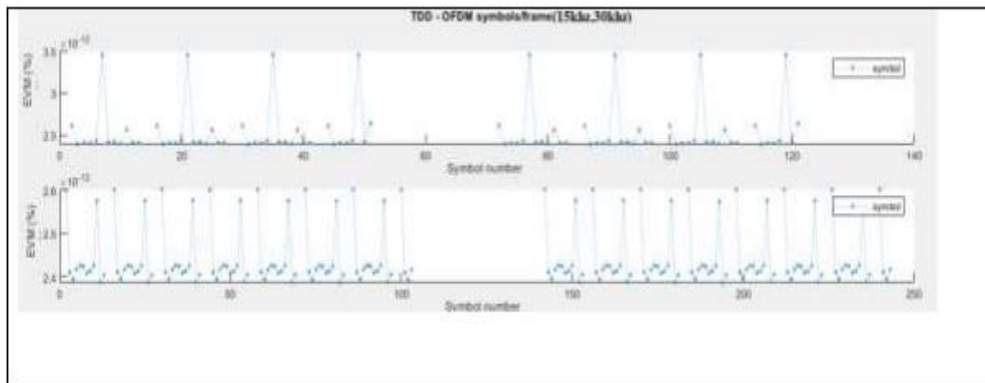


Figure 26: Simulation's screenshot for Frame simulation for FR1 TDD; April 2023

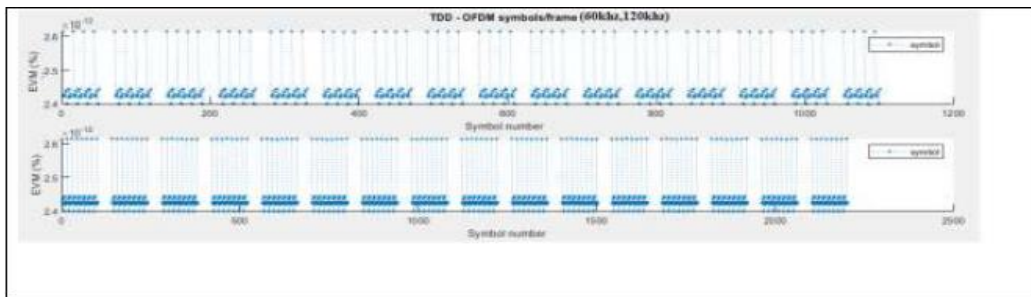


Figure 27: Simulation's screenshot for Frame simulation for FR2 TDD; April 2023

## 4.2.3 Activity 2.3: Frequency Division Duplex (FDD)

### Activity 2.3.1: Bandwidth Part

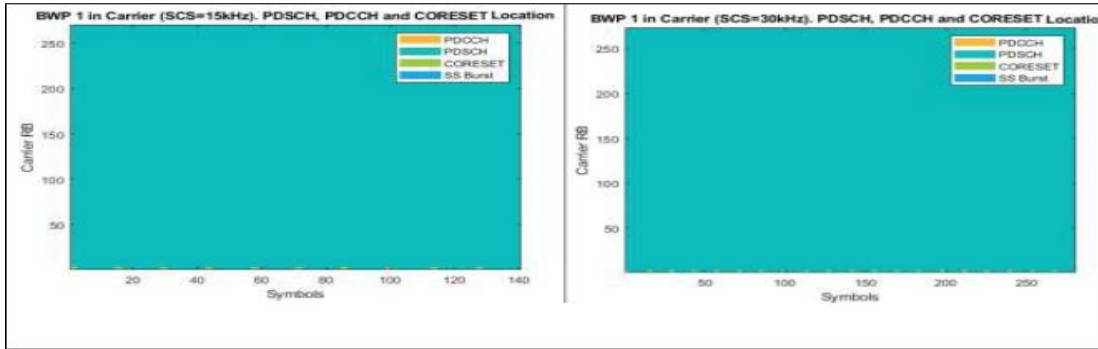


Figure 28: Screenshot simulation for bandwidth part for FR1 subcarrier spacing FDD; April 2023

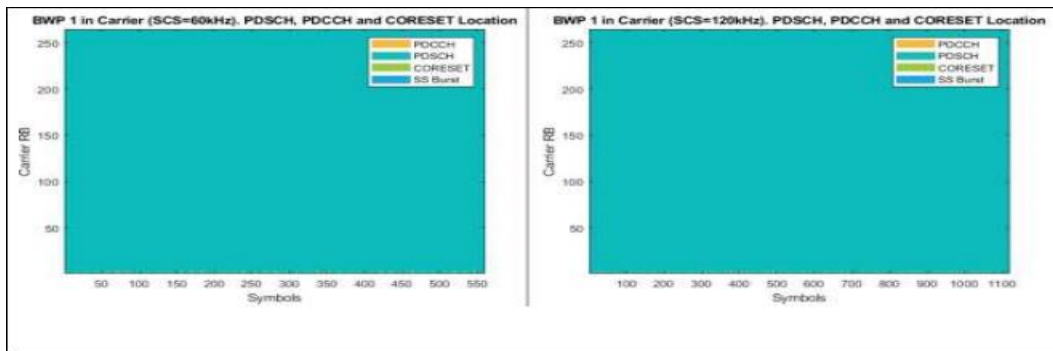


Figure 29: Screenshot simulation for bandwidth part for FR2 subcarrier spacing FDD; April 2023

## Discussion

In the aforementioned result, the downlink channel may handle both FDD and TDD in duplex mode, with FDD being able to use two. The DL/UL symmetric bandwidths in FDD result in an ineffective approach to utilising the UL spectrum since there are greater imbalances between the downlink and uplink loads. As a result of the flexible duplexing, the radio network has an extremely flexible frame structure, and each symbol inside a slot can theoretically be configured to transmit in either the uplink or downlink direction. With more feasible subcarrier spacing, the high response time might have been greatly decreased.

Whether FDD or TDD is utilised, as well as the settings, would have a significant impact on how well the radio network for URLLC performs. One downlink bandwidth part can be active at a time within certain subcarrier spacing when a UE is configured with up to four downlink

bandwidth parts. This configuration's subcarrier spacing and cyclic prefix gave the bandwidth aspect of the concept's execution a lot more simplicity. Supporting lower UE power consumption for intermittent and burst traffic patterns, as well as during the connected mode, was notably useful for devices with constrained radio frequency capacity or those unable to utilise the entire carrier bandwidth. The bandwidth and subcarrier spacing of UE might be separated into many segments. Moreover, DC is modulated in 5G NR because, according to the idea of bandwidth parts, each bandwidth part must be centred inside its carrier frequency.

### Activity 2.3.2: Frames simulation

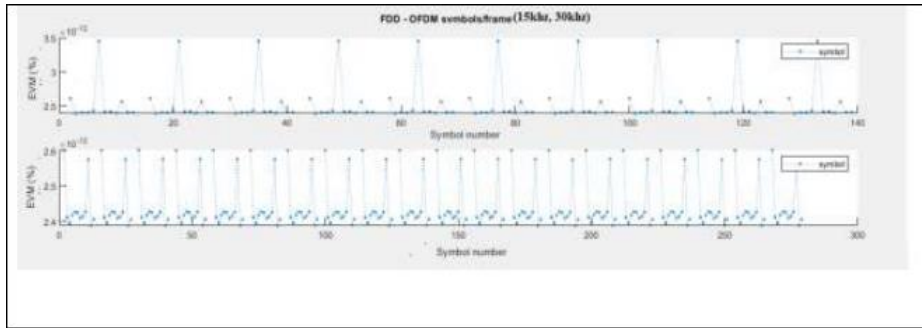


Figure 30: Simulation's screenshot for Frame for FR1 FDD; April, 2023.

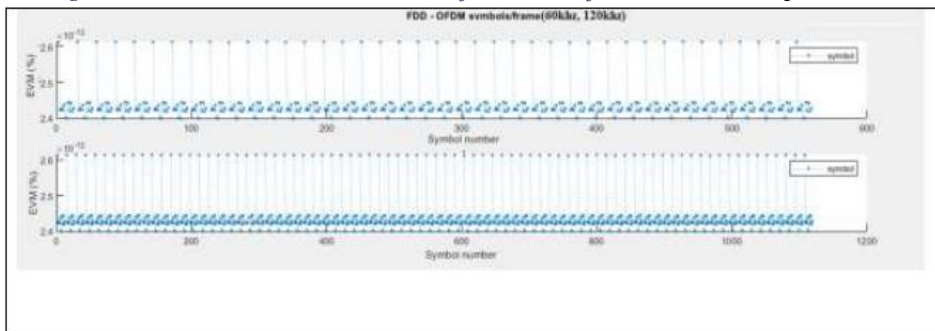


Figure 31: Simulation's screenshot Frame for FR2 FDD; April, 2023.

### Discussion

According to the frame structure of 5G NR, 30 KHz SCS will shorten a symbol's duration by 50%, while 60 KHz SCS can shorten it by 75%. This is because 5G NR supports variable frames, which allow for adjustable symbol duration. Both the user plane response time and the control plane response time would be lowered as a result, which would aid in speeding up air interface transmission stages. To accommodate various usage scenarios, the researcher has several subcarrier spacings. The researcher employed Error Vector Magnitude (EVM) measurement in a

single frame structure without the use of any impediment. EVM may be used as a useful and practical way to assess the radio frequency performance of such digitally modulated communication systems. When the distance between the sent and received symbols, or EVM, is described as a vector, it is measured in length. Understanding which symbol has been conveyed is essential for proper demodulation. Both LTE and 5G NR make the assumption that the transmitted symbol is the one that is immediately after the received one in their EVM measurement methods.

Since each subframe has many slots and the slots in 5G NR are different from those in LTE (where slots are fixed in time to 1 ms), a flexible subframe structure is what causes flexible frame duration. Because of the wider subcarrier spacing, which results in a lower symbol duration, the frame may contain a significantly different number of symbols than it would in an LTE environment. The frame time in 5G NR was 10 ms, each subframe had duration of 1 ms, and each subframe had a variable number of slots, which led to a variable number of symbols, which, as previously indicated, had a variable number of slots. In Figures 31 and 32, as well as Figures 26 and 27, and the 15 KHz SCS, the researcher has one slot per subframe; each slot contains 14 OFDM symbols, and the total time of all 10 slots is 10 ms (each slot lasts 1 ms).

- 30KHz SCS: The researcher has two slots per subframe; each slot contains fourteen OFDM symbols; the total duration of the 20 slots is ten milliseconds; and the slot duration is one millisecond.
- 60KHz SCS: The researcher has two slots per subframe; each slot contains fourteen OFDM symbols; the period of 40 slots is ten milliseconds; and the slot duration is 0.5ms.
- Using a 120 KHz SCS, the researcher has two slots per subframe; each slot has 14 OFDM symbols, and there are 80 slots per subframe. The length of each slot is 0.125 ms.

Following this finding, the researcher could have seen that the flexible subframe format results in a very low symbol duration that enables a low response time. In time-critical applications, this meant that users could use a wider subcarrier spacing to give them a very low response time for symbol duration. Additionally, the researcher noticed that the 60 kHz and mmwave frequencies used in FR2 are somewhat high for users to handle. To address this, 5G NR proposes a bandwidth part, which allows the user to decode only a part of the bandwidth, as mentioned in

Figures 26 and 27, as well as Figures 29 and 30. The difference is that in TDD, the simulator simulates only 8 frames, and the other two are for synchronisation. For shorter transmissions, mini-slots of 2, 4, or 7 symbols can be used; for longer broadcasts, slots can also be aggregated. Because the other two symbols typically the first and last ones are muted for the cyclic prefix, the researcher may have noted that there were only 12 symbols.

### 4.3 Protocol and algorithm simulation

The initial buffer's size has been determined by simulations, and a comparison study has been done. The optimal buffer size, can be seen in the figure below, may be specified as boundaries of 300–400 history intervals. The times between consecutive measurements of the mobile terminals' radio access technology characteristics and the snapshot of user and service network needs during those periods are known as history intervals, as illustrated below. They provide the most recent history of user activity, along with individual and service requests that users have for the network.

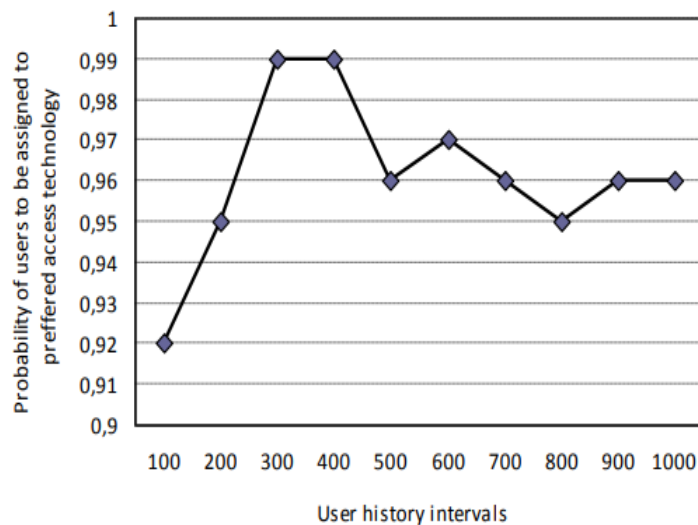


Figure 32: simulation's screenshot of buffer size dependency; (Yang, L., Fu, Y., Li, S., Huang, B., & Tao, P. (2008)).

With each mobile terminal's velocity determined by the mobility model as follows, the mobility model offers unpredictability for user movement.

$$v_i = v_{i-1} * C_v + \sqrt{1 - C_v^2} * v_{mean} * N \dots\dots\dots\text{Equation 8}$$

Where  $v_i$  is the user's speed [m/s]. The velocity correlation between time steps is known as  $C_v$ . It depends on both a mean, which is the average acceleration of the mobile user, and a  $v_{mean}$ , which is the average velocity of the mobile user.  $C_v$  might take the form of:

$$C_v = \left( \frac{-dt * a_{mean}}{v_{mean}} \right) \dots\dots\dots\text{Equation 9}$$

Where  $N$  is a Rayleigh-distributed magnitude with a mean of 1 and an arbitrary direction. The mobile phone's average speed ( $v_{mean}$ ) was set to 10 km/h, and the mean was set to 1 km/h<sup>2</sup>, both of which are normal values for an urban setting. The users are depicted in the designated locations in the virtual world in the image below. Voice calls, high bitrate video, low bitrate real-time video telephony, and non-real-time data traffic were the four types of services that were taken into account in the simulation and were divided evenly among the customers.

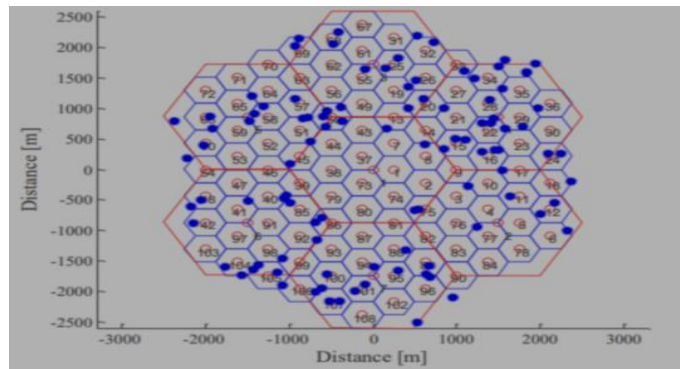


Figure 33: Simulation's screenshot for services selected; April 2023

## Discussion

As a result, the researcher had to model the four categories of services that were employed in the simulation study in the thesis's next section. According to the desired bandwidth (in bps) and response time (in ms), each of the four service categories is explained and defined. Due to the fact that the first service type also contains telephonic services, it is specified with a reduced bandwidth (data rate) and response time. A video conferencing service is the focus of the second service type, which is defined by a higher average data rate and a relatively fast response time. The third service type is video streaming, which takes more data per connection but has a faster

response time than phone calls. Since these services employ TCP (transmission control protocol), which uses all available bandwidth end-to-end, the final service type is specified with somewhat higher data rates and represents non-real-time services, including web and email. For simulation analysis, the following pairs of data (bandwidth and response time) are used to define each of the four service types:

[Service\_response time (ms), service\_bandwidth (kbps)]

{[100, 64]; [200,128]; [400,256]; [800,512]}

Each user is randomly allocated to one of the four types of services that have been specified in the simulation, which has a mean holding time of 50 seconds for a particular number of active users;  $N$ .  $N$  is based on the Poisson process. To meet the FL (fuzzy logic) controller parallel system shown in Figure 9, fuzzy logic controllers were created. The FLC (fuzzy logic controller) was designed using membership functions that were tailored to the observed signal intensities and desired user behaviour, and the Particle Swarm Optimisation (PSO) technique was utilised to optimise the FLC. In the scenario, two outputs from each FL controller and two RAT technologies were examined. The degree of each RAT's membership, scaled to input variables for fuzzy logic, is displayed in the controller's outputs

The maximum number of iterations and swarm size for the PSO method employed in the simulations is 50. The assessment process involved comparing the measured value to the predetermined expectations while attempting to minimise the mean square error (MSE). 300 historical periods make up the initial data buffer used in the simulations. In this situation, this indicates that a 300-time slot (interval) training period is required, and the initial data analysed during that time were saved. The initial set of weights that would be applied to the choice made using the multi-criteria method was therefore acquired using data that was then employed in GA. Following that first period, FIFO data from the buffer was continuously updated with freshly measured data. There was a certain time window for data processing in the mobile terminal collected from various current RATs since the buffer data size remained the same as 300 previous measured values.

When using several criteria for decision-making, the Genetic Algorithm (GA) was an optimisation technique used to establish the right weights for each criterion. Optimising the weights based on user locations and requests on the network, which depended on the type of service requested by each user, was the main objective. Given that most of the time there was little to no progress after 100 sequential generations, the researcher employed 200 iterations in the investigation.

The suggested method is compared to practically all other pertinent algorithms in the comparison in Figure below. Mobility-based Radio Resource Management (RRM) produced the lowest results, whereas our suggested method, which combines FL optimised with PSO and GA for Multi-Criteria Decision Making (MCDM), produced the greatest results.

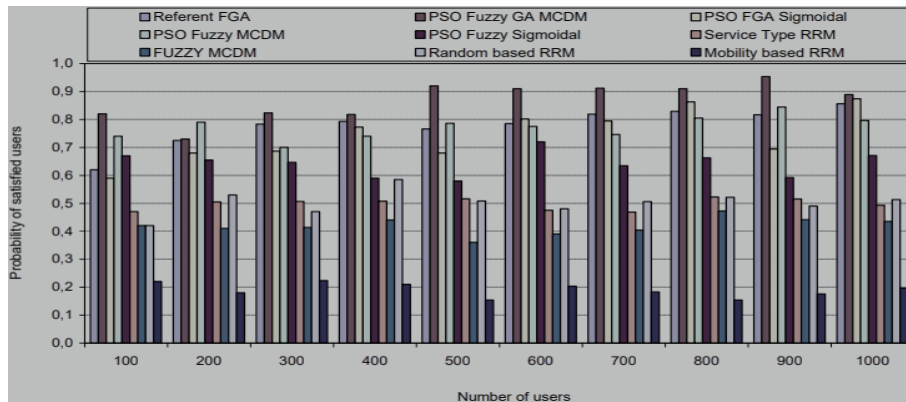


Figure 34: Simulation screenshot of satisfied users; April 2023

## Discussion

Sigmoidal refers to membership functions for FL controllers, which are trapezoidal or triangular in other situations, and FGA stands for fuzzy-logic genetic algorithm in the above figure. A number of simulation runs have been conducted for various user counts in the simulation scenario (ranging from 100 to 1000 users), and the results show the likelihood that a user will be connected to the RAT that offers the highest user satisfaction for the bandwidth and response time requirements for each service type. In this thesis, a wireless access selection algorithm was presented, and it outperformed random and service-based methods. Along with that, it outperforms all other wireless network selection algorithms, something that becomes more

obvious as user density increases. Accordingly, the suggested RAT selection algorithm, which is based on evolutionary algorithms and particle swarm optimisation, offers the maximum likelihood that users would be happy with regard to their needs from the access network.

#### 4.4 Results Analysis

According to the analysis of the top three waveform candidates for 5G, as the researcher has seen thus far throughout the thesis, the frame structure for the downlink has a variety of parameters, ranging from the channel shape to the distribution of the symbols in the frame. The researcher used a fixed slot time and various numbers of symbols depending on the bandwidth (subcarrier spacing). Each of the multiple access approaches has a benefit, but they are not flexible. For example, FBMC is excellent for large packets but not for tiny packets with short response times, whereas NOMA is good for low response times but unreliable. Low response times were also associated with reliability; this term was used to describe situations in which the response time for a single gearbox could be slashed and additional repetitions may potentially be possible while still staying within the response time budget. This might lead to an increase in dependability.

For release 15 and NR's new physical layer, CP-OFDM has been selected as the waveform for both links, with a small modification made to the OFDM by introducing the DFT-S-OFDM in the uplink for its power of coverage and low energy consumption for the end-user devices. The use of a cyclic prefix also enables the user to perform frequency equalisation with one tap.

The 5G spectrum deployment varies from country to country, but the 3GPP standards were able to find a 100 MHz bandwidth easily in the sub-6 GHz frequency, which was a useful bandwidth compared to the 4G, which has a 20 MHz maximum bandwidth. In addition, the use of multiple numerologies enables the deployment of various scenarios and applications, such as URLLC, eMBB, mMTC, SDN, and NFV. A narrow subcarrier assigns the user wider subcarrier spacing and, as a result, a short symbol length. It also allows the user to reduce battery consumption and is good in idle mode (15 kHz) and active mode.

Furthermore, the Policy Router carried out the change in RAT (radio access technology) vertical handover based on the provided policies regarding the quality of service, user preferences, and

performance measurements obtained by the user equipment via the newly defined procedure for that purpose in this thesis, called Quality of Service Policy-based Routing (QoS-PRO). Ultimately, the suggested RAT selection algorithm, which is based on evolutionary algorithms and particle swarm optimisation, offers the maximum likelihood that users will be happy with regard to their needs due to the short response time of the network. Future 5G mobile networks' proposed architecture can be built using off-the-shelf components (current, standardised Internet technologies), and its implementation is transparent to radio access technologies, making it a very appealing option for next-generation wireless and mobile networks.

## Chapter 5

### Conclusions, and Recommendations

#### 5.1 Conclusions

The implementation of 5G as a backhaul and fronthaul was still under investigation throughout the world in 2020, but meeting all the requirements was still a long way off. For example, achieving 1 ms total response time and 10 Gbps required a lot of work.

A small modification or optimisation, whether in response time optimisation, throughput, or any other entity, could make the difference in achieving the theoretical requirements of the 5G system. Meeting the world's needs in telecom in general or in the cellular network in particular was based on appreciating the work and collaboration of each person. The work focused on providing the greatest amount of information about how response time functions and the important parts of it since the researcher thought that the key to the innovation journey begins with knowing the technology.

The majority of technologies are now possible thanks to previous efforts in a variety of industries, such as LDPC coding, which was previously an outdated system but now has features that can be used in 5G. The same is true of beamforming, which was first discovered in analogue and has been used in numerous outdated technologies. Additionally, SDN (software-defined network) and NFV (network function virtualization) are now feasible thanks to the vast capacity

and advancements in hardware. With the use of these numerologies, we no longer need to create application-specific integrated circuits (ASIC) and discard or recycle them after a short period of time. Instead, the software has made it simpler for us to construct any form of network architecture and monitor and manage our system with more accuracy and at a cheaper cost.

The flows made in 4G as well as the new ability to use the resources we have, such as massive bandwidth, brought about the frame structure, which has a significant impact on the response time in 5G. The concept of variable numerologies also left its mark on the response time aspect, as there was a reciprocal relationship between high frequencies, which made the symbol duration shorter. Higher frequencies, however, presented a number of other challenges, most notably the ability of an IoT or low-power device to decode the entire bandwidth. This is where the concept of the bandwidth part comes into play; the UE receives only a portion of the bandwidth and can easily decode it. Another aspect was the mini-slot, which sent 2, 4, or 7 symbols for a user instead of 14 OFDM symbols; this would help applications that depend more on response time than throughput.

Despite the fact that the topic is still being researched and there are numerous suggestions that could be made to improve the overall response time in a 5G system, many different types of research are focusing on scheduling techniques for the frame structure in RAN and the cloud scheduling algorithms in the core network. Caching helps to minimise the route from UE to the cloud, which makes the idea more practical and applicable.

Eventually, throughout in the paper the research questions have been addressed as:

*RQ1: What are the challenges identified in the existing 5G wireless network system?*

While 5G wireless networks offer significant advancements over previous generations, there are still several challenges that have been identified in the existing 5G network system. Some of the key challenges include:

1. Coverage and Infrastructure Deployment: 5G networks require a denser infrastructure with more base stations and small cells compared to previous generations. The deployment of this infrastructure, including the installation of new antennas and backhaul connectivity, can be

complex, costly, and time-consuming. Achieving comprehensive coverage, especially in rural or remote areas, remains a challenge.

2. **Interference and Signal Propagation:** Higher frequency bands used in 5G, such as millimeter wave (mmWave), provide higher data rates but have limited signal propagation characteristics. These signals can be easily obstructed by physical objects, including buildings and trees, leading to signal loss and reduced coverage. Overcoming this challenge requires careful planning of base station locations and the use of advanced technologies like beamforming.
3. **Spectrum Availability and Management:** 5G networks require a significant amount of spectrum to deliver high data rates and low response time. However, the availability of suitable spectrum varies across different regions and countries. Harmonizing and allocating spectrum resources for 5G can be challenging due to existing spectrum allocations and regulatory considerations, including spectrum auctions and licensing.
4. **Energy Efficiency:** 5G networks demand higher energy consumption due to the increased number of base stations and the need for denser infrastructure. This poses challenges in terms of sustainability and cost-effectiveness. Developing energy-efficient solutions, optimizing network elements, and adopting green technologies are crucial for minimizing the environmental impact and operational costs.
5. **Security and Privacy:** As 5G networks connect more devices and enable various critical applications, ensuring robust security and privacy becomes paramount. The increased attack surface, new network elements, and the complexity of 5G architecture introduce new vulnerabilities. Protecting user data, preventing unauthorized access, and addressing potential security threats require ongoing research, development, and collaboration among stakeholders.
6. **Interoperability and Standards:** 5G is a complex ecosystem involving multiple vendors, technologies, and standards. Ensuring interoperability and seamless integration between different components and networks can be challenging. The development and adoption of global standards, such as those defined by 3GPP (Third Generation Partnership Project), are essential for promoting interoperability and enabling a unified 5G experience.  
Addressing these challenges requires continuous research, collaboration between industry stakeholders, regulatory support, and technological advancements. Efforts are underway to overcome these obstacles and further enhance the capabilities and performance of 5G networks.

RQ2: What are the thorough 5G toolbox and 5G protocol architectures applied for solving problems in 5G mobile networks?

The 5G mobile network incorporates a comprehensive toolbox of technologies and protocol architectures to address various challenges and enable advanced capabilities. Here are some of the key components:

1. **New Radio (NR):** The 5G New Radio is the air interface standard for 5G wireless communication. It provides higher data rates, lower latency, improved spectral efficiency, and support for a wide range of frequency bands, including both sub-6 GHz and mmWave bands. NR employs advanced techniques such as Massive MIMO (Multiple-Input Multiple-Output), beamforming, and flexible channel coding to enhance performance.
2. **Network Slicing:** Network slicing allows the creation of multiple virtual networks on a shared physical infrastructure. It enables the customization of network resources and services to meet specific requirements of different applications, industries, or user groups. Network slicing helps optimize network performance and efficiently allocate resources based on diverse use cases.
3. **Software-Defined Networking (SDN):** SDN separates the control plane from the data plane and centralizes network management. It enables dynamic and programmable control of the network infrastructure, allowing for efficient resource allocation, traffic management, and network optimization. SDN facilitates the flexibility and scalability required in 5G networks.
4. **Network Function Virtualization (NFV):** NFV decouples network functions from dedicated hardware appliances and virtualizes them on standard servers. It enables operators to deploy network functions as software instances, making network management more agile and cost-effective. NFV allows for flexible scaling, rapid service deployment, and efficient resource utilization.
5. **Mobile Edge Computing (MEC):** Mobile Edge Computing brings computing and storage resources closer to the network edge, reducing latency and enabling real-time processing of data. MEC allows for localized data processing, content caching, and edge-based applications, enhancing the performance of latency-sensitive and bandwidth-intensive services.
6. **Cloud-RAN (C-RAN):** Cloud-RAN is an architecture that centralizes baseband processing in a cloud-based central unit (CU) while distributing remote radio units (RRUs) at the edge of the network. C-RAN provides better coordination and resource sharing among base stations,

improving spectral efficiency and enabling advanced features such as coordinated multi-point transmission/reception (CoMP) and beamforming.

7. **3GPP Protocol Stack:** The 3GPP (Third Generation Partnership Project) defines the protocol stack for 5G networks. It includes various protocols such as the 5G Core Network (5GC), which facilitates network management and control, and the User Plane Function (UPF), responsible for data forwarding. Other protocols include IP Multimedia Subsystem (IMS) for multimedia services, Diameter for authentication and charging, and others.

These components and protocols work together to provide a robust and flexible architecture for 5G networks. They address the challenges of high data rates, low latency, scalability, efficient resource management, and support for diverse use cases, enabling the realization of the full potential of 5G technology.

*RQ3: How is low response time impacted by cache size, location and wireless channel parameters?*

Low response time can be influenced by cache size, cache location, and wireless channel parameters in the following ways:

1. **Cache Size:** The cache size refers to the amount of data that can be stored in the cache memory. A larger cache size can potentially improve response time by increasing the likelihood of finding requested data in the cache. When a requested item is already present in the cache, it can be retrieved quickly, reducing the need to access the original source, such as a remote server. Therefore, a larger cache size tends to result in lower response times as more data can be readily available.
2. **Cache Location:** The location of the cache can have a significant impact on response time. Placing the cache closer to the end-users or devices can reduce the distance data needs to travel, thereby minimizing latency. Caches deployed at the network edge, such as in a mobile edge computing (MEC) architecture, can provide lower response times as data can be retrieved from nearby cache servers instead of distant data centers. Proximity to the users helps reduce the propagation delay and improves overall response time.
3. **Wireless Channel Parameters:** The wireless channel parameters, such as signal strength, interference, and bandwidth, can affect response time in wireless networks. In scenarios with weak signals or high interference, the quality of the wireless connection may degrade. This can result in increased packet loss, retransmissions, and higher latency, leading to longer response

times. Additionally, limited bandwidth or congestion in the wireless channel can impact the speed at which data can be transmitted, further increasing response time.

It's worth noting that while cache size and location can directly impact response time, wireless channel parameters can indirectly affect response time by influencing the quality and reliability of the wireless communication. Therefore, optimizing cache size, strategic cache placement, and ensuring a robust wireless channel are all important considerations for reducing response time in wireless network environments.

## 5.2 Future Work

Frequency bands, communication topologies, service delivery, and other sorts of communication system constraints would be present in heterogeneous wireless networks. Additionally, there would have been a major difference in the hardware settings between the access points and mobile terminals. With the transition from 4G to 5G, the massive MIMO technology would have been improved even more, necessitating an even more complicated design. The communication protocol as well as the algorithm design would have been more difficult. But communication would have incorporated AI and machine learning. In addition, several communication systems need hardware that is designed differently. The integration of all the communication systems into a single platform would be difficult as a result.

In the case of autonomous wireless systems, the 5G system would offer a limited level of assistance to automation systems like autonomous vehicles, unmanned aerial vehicles (UAVs), and AI-based Industry 4.0. Autonomous computing, interoperable processes, the system of systems, machine learning, autonomous clouds, machines of systems, and heterogeneous wireless systems are just a few of the heterogeneous sub-systems that must come together to form autonomous wireless full systems. As a result, the growth of the entire system is complicated and difficult. For instance, creating a fully autonomous system for a driverless car will be significantly harder since 5G researchers need to create fully automated self-driving cars that are more effective than those that are controlled by humans.

As a result, absorptive and dispersive effects were seen in sub-mmWave (GHz) frequency modelling and the propagation characteristics of the mmWave and sub-mmWave (GHz). The

atmospheric conditions were highly uncertain due to their frequent changeability. As a result, this band's channel modelling was quite complicated, and it lacks a precise channel model.

Access networks in 5G would be extremely dense for high-capacity backhaul connectivity. Additionally, within a given region, these access networks were numerous and varied. These access networks will all allow very high-data-rate connectivity for a variety of user categories. In order to enable high-data-rate services at the user level in 5G, the backhaul networks must be able to handle the enormous volume of data needed to communicate between the access networks and the core network. Otherwise, a bottleneck will be created. Any increase in the capacity of the optical fiber and FSO (free-space optics) networks is challenging for the exponentially expanding data demands of 5G and would require further investigation. These networks are potential solutions for high-capacity backhaul connectivity, which is why it is necessary to further explore these options.

It was crucial to effectively manage the 5G spectrum, including spectrum-sharing plans and cutting-edge spectrum management techniques, in addition to managing the spectrum and interference. This is because spectrum resources are scarce and interference problems are a major concern. To maximise resource use while maximising QoS, effective spectrum management was crucial. The upcoming research in 5G will have to deal with issues like spectrum sharing and managing the mechanisms in heterogeneous networks that synchronise transmission at the same frequency. The typical interference cancellation techniques, such as parallel interference cancellation and successive interference cancellation, need to be studied as potential means of eliminating the interference.

As a result, massive MIMO beamforming systems were a viable technique for providing high-data-rate communications in beam management in GHz communications. Despite this, due to the sub-mm wave's unique propagation properties, beam management in the GHz range, or sub-mm wave, is difficult. It will be difficult for a huge MIMO system to handle beams effectively in the face of unfavourable propagation characteristics. The ability to rapidly select the best beam in high-speed vehicle systems would be crucial for a flawless transfer, though.

To provide flexibility, reconfigurability, and programmability, softwarization and virtualization were two key aspects that served as the foundation for the construction of 5G networks. They would also enable the sharing of billions of gadgets in a common physical infrastructure, making their examination by upcoming researchers entirely feasible.

In the end, the researcher highly advises that the next contribution be made on the fundamental network response time or caching concepts for much better optimisation and comprehension of the response time element.

It is now possible to separate the hardware from the transceiver algorithms should in order recent advancements in circuits and antennas, which enables intelligent radio to function as a single system. Support for intelligent radio should be made feasible by the combination of software-defined radio and networking methods, which should be used to utilise various high-frequency bands and dynamically utilise different frequencies.

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