QUALITY OF SERVICE (QOS) PERFORMANCE OF CELLULAR-VEHICLE-TO-EVERYTHING (C-V2X) COMMUNICATION IN THE 5G NETWORK

NURUL KHAIRUNNISA' WAHYUNI BINTI BAHARUDDIN

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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NURUL KHAIRUNNISA' WAHYUNI BINTI BAHARUDDIN

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

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DR. JUWITA BT MOHD SULTAN
Pensyarah Kanan
Fakulti Kejuruteraan Elektronik Dan Kejuruteraan Komputer
Universiti Teknikal Malaysia Melaka (UTeM)
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DEDICATION

This thesis is dedicated to the cherished individuals who have supported and encouraged me along my academic journey. My dear parents, Nor Aini binti Husain and Baharuddin bin Mohamad Suhaimin your unwavering encouragement and faith in my abilities have guided me on this challenging but worthwhile journey. Your support and selflessness have motivated me to accomplish my goal.

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To my lecturers, for imparting knowledge, guidance, and invaluable insights that have shaped my intellectual growth. is as much yours as it is mine.

To my younger self, who faced uncertainty with resilience and determination, this accomplishment is a tribute to your tenacity. Your passion for knowledge and the curiosity that fuelled your early academic pursuits have paved the way for this moment. Thank you all for being a part of this journey and for contributing to the realization of this milestone.

ABSTRACT

The fifth generation of networks, or 5G, aims to accommodate new services while also delivering increased capacity and cutting-edge user experiences. The advantages and promises of 5G technology are highlighted in this abstract, including its high data speeds, reduced latency, improved dependability, increased network capacity, and higher availability. Instead of concentrating on faster mobile internet like its predecessor, 4G LTE, 5G promises to be a unified platform that supports various services, including mission-critical communications. Even with limited network capacity, Quality of Service (QoS) is essential for maintaining the performance of vital applications. QoS enhances the performance of various applications by considering parameters such as bit rate, latency, jitter, and packet rate by prioritising high-performance apps and regulating network traffic. This study is focused on Cellular-Vehicle-to-Everything (C-V2X) communication, which includes communication between vehicles and pedestrians, infrastructure, and other vehicles. The advantages of C-V2X include better traffic flow management, increased GPS performance, and direct communication over greater distances. In order to analyse throughput, delay, and latency indicators for quality of service across multiple 5G service flow types, the research makes use of the simulation programme OMNeT++.

ABSTRAK

Generasi kelima rangkaian, atau 5G, bertujuan untuk memenuhi keperluan perkhidmatan baru sambil memberikan kapasiti yang lebih baik dan pengalaman pengguna yang canggih. Kelebihan dan janji teknologi 5G ditekankan dalam abstrak ini, termasuk kelajuan data yang tinggi, pengurangan latensi, peningkatan kebolehpercayaan, peningkatan kapasiti rangkaian, dan ketersediaan yang lebih tinggi. Berbeza dengan penumpuan pada internet mudah alih yang lebih pantas seperti pendahulunya, 4G LTE, 5G berjanji sebagai platform yang bersatu untuk menyokong pelbagai perkhidmatan, termasuk komunikasi yang penting untuk misi. Walaupun dengan kapasiti rangkaian terhad, Kualiti Perkhidmatan (QoS) adalah penting untuk mengekalkan prestasi aplikasi. QoS meningkatkan prestasi pelbagai aplikasi dengan mempertimbangkan parameter seperti kadar bit, latensi, jitter, dan kadar pakej dengan mengutamakan aplikasi berkualiti tinggi dan mengawal lalu lintas rangkaian. Kajian ini memberi tumpuan kepada komunikasi Kenderaan ke Segalanya (C-V2X), yang merangkumi komunikasi antara kenderaan dan pejalan kaki, infrastruktur, dan kenderaan lain. Kelebihan C-V2X termasuk pengurusan aliran trafik yang lebih baik, peningkatan prestasi GPS, dan komunikasi secara langsung dalam jarak yang lebih jauh. Bagi menganalisis penunjuk kelajuan aliran, lewat, dan laten untuk kualiti perkhidmatan melalui pelbagai jenis aliran perkhidmatan 5G, penyelidikan ini menggunakan program simulasi OMNeT++.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

C-V2X	:	Cellular-Vehicle-to-Everything
QoS	:	Quality of Service
V2V	:	Vehicle to Vehicle
V2I	:	Vehicle to Infrastructure
V2P	:	Vehicle to Pedestrian
OMNeT+	:	Objective Modular Network Testbed in C++
IoT	:	Internet of Things
eMBB	:	Extreme Mobile Broadband
AR	:	Virtual reality
VR	:	Augmented reality
eMTC	:	Enormous Machine-Type Communication
URLLC	:	Ultra-reliable Low-Latency Communications
ITU	:	International Telecommunication Union
MIMO	:	Multiple-Input Multiple-Output
UMTS	:	Universal mobile telecommunication system
NLOS	:	non-line-of-sight
PC5	:	Direct Communication
Uu	:	Network Communication

RLC	:	Radio Link Control
PDSCP	:	Packet Data Convergence Protocol
RRC	:	Radio Resource Control
SDAP	:	service data adaptation protocol
DSMP	:	Dedicated Short Message Protocol
DME	:	Dedicated Management Entity
QoE	:	Quality of Experience
WRED	:	Weighted random early detection
RED	:	random early detection
GUI	:	Graphical User Interface

CHAPTER 1

INTRODUCTION

1.1 Introduction

To meet the escalating demands of our connected society, the fifth generation of networks, or 5G, has been painstakingly engineered and developed. 5G intends to support new deployment patterns, enable next-generation user experiences, and deliver cutting-edge services thanks to its significantly increased capacity and improved capabilities [1]. In contrast to its forerunners, 5G envisions a network that links not only individuals but also devices, objects, and other objects, ushering in an era of pervasive connectivity [2].

While the primary goal of fourth generation (4G) LTE was to offer mobile broadband services quicker than its predecessor, third generation (3G), fifth generation (5G) aims to be a unified, robust platform that goes beyond conventional communication barriers [3]. It also provides quicker speeds and introduces ground-breaking features like mission-critical communications. 5G networks are built to guarantee the quality of service (QoS) for essential applications even when the network's capacity is limited by utilizing cutting-edge technologies and novel strategies. To provide the best performance and user experience using QoS, QoS techniques priorities high-performance applications, dynamically control network traffic, and optimize resource allocation [4].

This research study primarily examines the Cellular-Vehicle-to-Everything (C-V2X) technology within the context of 5G, an essential component of the broader 5G ecosystem. Communication between vehicles (V2V), between vehicles and infrastructure (V2I), and even between vehicles and pedestrians (V2P) is made possible by C-V2X. C-V2X, which uses a specific spectrum for direct communications, enables vehicle interaction and information sharing inside and beyond the range of cellular service [5]. This broadens the network's coverage area and enables cutting-edge capabilities in fields like intelligent transportation systems, improved road safety, and effective traffic management. Informed decisions and appropriate actions are enabled, enhancing safety and the transit experience.

This research project conducts a thorough assessment of the quality of service (QoS) characteristics, such as throughput, delay, and latency, across various 5G service flow types [6]. The research team carefully examines and evaluates the performance traits of various applications in the context of the 5G network using the OMNeT++ simulation platform. This analysis sheds light on potential opportunities and problems in realizing the full potential of 5G technology for various applications and use cases while offering priceless insights into the network's capabilities.

1.2 Problem Statement

Due to the rapid advancement and escalating needs in traffic management and communication, technology is witnessing a substantial transition towards 5G. The earlier benefits that 4G networks provided have gradually changed into drawbacks as they struggle to keep up with the increasing demands of contemporary applications. Since 4G's access speed has declined, connectivity has decreased, and data transfer rates have slowed [7]. Furthermore, a fundamental disadvantage of 4G networks is the problem of high latency and large delays, which impede responsiveness and real-time communication.

The ability of 4G networks to effectively manage several connected devices near is another issue they face. As smartphones, tablets, Internet of Things (IoT) devices, and other connected technologies proliferate, 4G networks frequently experience congestion and need help allocating resources to meet the demands of several devices running in the same area [8]. As a result, this congestion may result in poor network performance and a bad user experience.

The necessity for a more sophisticated solution and the limits of 4G networks led to the introduction of LTE-V2X, an intermediate technology. LTE-V2X, however, was still dependent on the underlying 4G infrastructure, which limited its capabilities and made it difficult to fulfil the needs of upcoming applications. The idea of (C-V2X), which intended to link cellular networks with vehicle communication systems to produce a more effective and future-proof solution, emerged when the limits of LTE-V2X became evident [9].

A 5G QoS model simulation is developed to confirm that the 5G network can offer the required quality of service (QoS) for C-V2X communication. This simulation's main goal is to extensively test and analyse the optimal speed and performance of the 5G network, ensuring that users using C-V2X applications would have a high-quality communication experience. Researchers and engineers can evaluate the network's ability to properly handle the demands of C-V2X applications by simulating various scenarios and assessing crucial performance indicators, including speed, latency, reliability, and coverage.

The simulation is useful for seeing potential problems and enhancing network settings. It helps researchers improve protocols and algorithms to guarantee the maximum QoS for C-V2X consumers by providing insights into the network's performance under various scenarios. Researchers can use the simulation to create a reliable and effective 5G network infrastructure that can accommodate the changing needs of C-V2X communication.

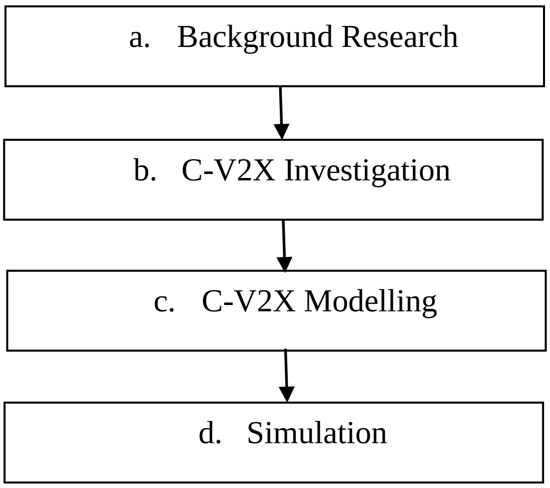
The goal is to develop an accurate and high-performing 5G network that enables seamless communication and interaction between cars, infrastructure, and other components of the transportation ecosystem through extensive simulations and assessments. The simulation ultimately significantly impacts the creation and implementation of a cutting-edge 5G network that ensures improved quality of service for C-V2X applications, paving the way for more secure, effective, and linked transportation systems.

1.3 Objective

The specific objectives of this study:

1. To investigate and determine the Quality of Service (QoS) in 5G Network.
2. To analyze the QoS performance of Cellular-Vehicle-to-Everything (C-V2X) in 5G Network in terms of throughput, packet sent and packet received, latency and packet loss.

1.4 Scope of Work



a. Background Research:

To create a simulation model using OMNET++, it is necessary to comprehend the overview of C-V2X in the 5G network.

b. QoS Investigation:

Understanding the idea of Quality of Service (QoS), which is used in C-V2X 5G to deliver quality services to a network to reduce packet loss and delays to ensure the traffic on their network and modify how packets are routed to the internet or other networks to prevent transmission delays.

c. QoS modeling:

Using the OMNETT++ program, a QoS model is developed based on latency and throughput.

d. Simulation:

In OMNETT++, a simulation model of the QoS C-V2X utilized in 5G will be run with all the parameters considered. After the simulation, keep troubleshooting until the desired outcome is obtained.

e. Result and Analysis:

A graph can be produced using the simulation results based on the latency and throughput parameters used. As a result, an analysis will be done, and the results will be compared to the research.

CHAPTER 2

BACKGROUND STUDY

2.1 Overview of 5G

Over time, the telecommunications industry has made incredible strides, revolutionizing how to connect with the rest of the world. The imminent arrival of fifth-generation wireless technology, commonly called 5G, marks a significant advancement in telecommunications. 5G, a paradigm shift, can revolutionize how individuals work, reside, and interact with technology. 5G, with its exceptional speed, capacity, and capabilities, is expected to create opportunities in diverse areas such as healthcare, transportation, entertainment, and intelligent cities. Understanding the importance of 5G in the context of the telecoms industry is essential in this age of hyperconnectivity and digital transformation [10].

The creators of the next generation of wireless network technology coined the term 5G Technology to broaden mobile technology's possibilities beyond LTE. It is the most modern iteration of cellular technology. It uses the most up-to-date cellular technology. Everybody always has access to high-speed internet and locations because of 5G. 5G stands out due to its unique features, which include the ability to connect individuals and manage devices and items.

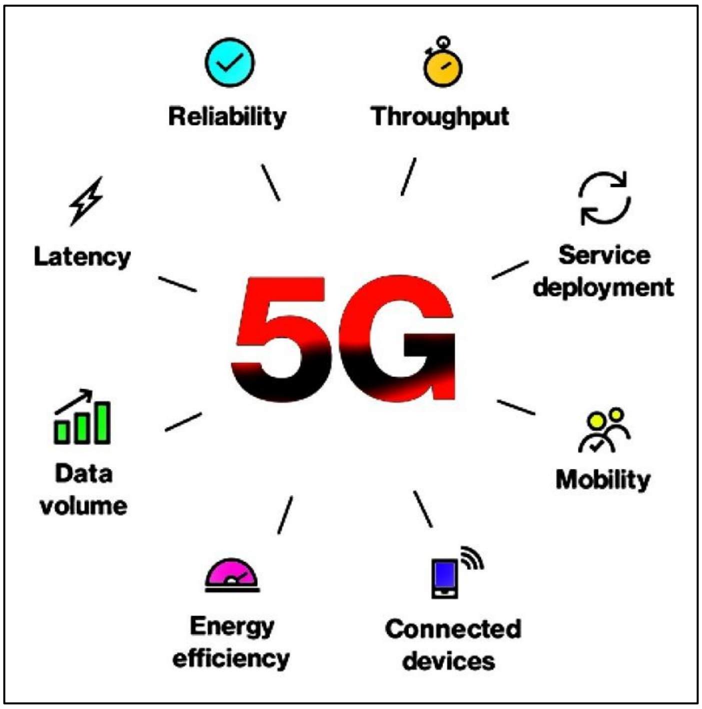


Figure 2.1: Overview of 5G [11]

5G provides three services: eMBB stands for Extreme Mobile Broadband, and it is the initial or primary kind of mobile broadband. This non-standalone design offers several advantages, such as high-speed internet connectivity, expanded bandwidth, average latency, Ultra HD streaming videos, and virtual reality and augmented reality (AR/VR) media. (2) The 13th specification from the 3GPP introduces a technology called enormous machine-type communication (eMTC). It provides cost-effective, high-capacity communication for machine-type devices while consuming minimal power, even across long distances. eMTC provides a high-speed data connection, low battery consumption, and wider coverage for IoT applications using simplified devices through mobile carriers. (3) URLLC, in contrast to traditional mobile network architecture, provides minimal latency, exceptional reliability, and high-quality service [12]. The designers have specifically built URLLC to facilitate immediate and real-time interactions for a range of applications, such as Industry 4.0, smart grids, intelligent transportation systems, remote surgery, and vehicle-to-vehicle communication (V2V).

2.1.1 The Evolution of 5G.

The user experience with communication systems has substantially enhanced as mobile generational advancements from 1G to 5G have occurred. The trip started in the early 1980s with the introduction of 1G based on analog systems and circuit-switched networks. However, 1G had drawbacks such as limited capacity, subpar reception, and interference with background noise. It had a straightforward infrastructure and needed fewer network components despite these shortcomings [12].

The second generation (2G) signified a substantial advancement in wireless cellular technology with the introduction of digital systems. GSM, the original 2G network, offered voice and data services. Improvements like GPRS (2.5G) and EDGE (2.75G), which raised data speeds to 384 Kbps, came after it. Circuit-switched networks are utilized in 2G for voice traffic and packet-switched networks for data traffic. For the purpose of protecting data transfer, 2G also included digital encryption [13].

To improve voice services, data throughput, and quality of service (QoS), the third generation (3G) was created. IMT-2000 was first presented by the International Telecommunication Union (ITU) in 2000. For voice and data transmission over packet switching, 3G reached data rates of up to 2 Mbps for users inside. It introduced features including SMS, MMS, video, high-speed data, and video conferencing while also greatly enhancing data speed and voice quality. HSDPA (3.5G) and HSUPA (3.75G), two 3G variants, greatly accelerated data rates and decreased latency.

The fourth generation (4G) was introduced in 2010, bringing with it a number of significant improvements over its forerunners. During the handoff stages, the peak performance requirements for 4G's internet-based core networks were established at 100 Mbps. 4G also adopted an all-IP network. Global mobility, MIMO (Multiple-Input Multiple-Output) technology, and high-speed handoff were all introduced. Data rates offered by 4G's ultra-broadband internet services ranged from 100 Mbps to 1.0 Gbps. Users could use features like high-definition voice, SMS, MMS, mobile TV, wearable technology, HD streaming, international roaming, and gaming.

The fifth generation (5G), which aims to meet present and future wireless communication needs, will debut in 2020. By enabling extreme mobile broadband, enormous machine-type communication, and ultra-reliable low-latency communication, 5G is predicted to revolutionize mobile networks. It provides high-speed connectivity, low latency, and rich QoS for applications like augmented reality, the Internet of Things, and real-time interactions. 5G claims to offer seamless and high-performance mobile communication technology with downlink rates of up to 20 Gbps, support for the IPv6 protocol, and infinite energy-efficient connectivity [13].

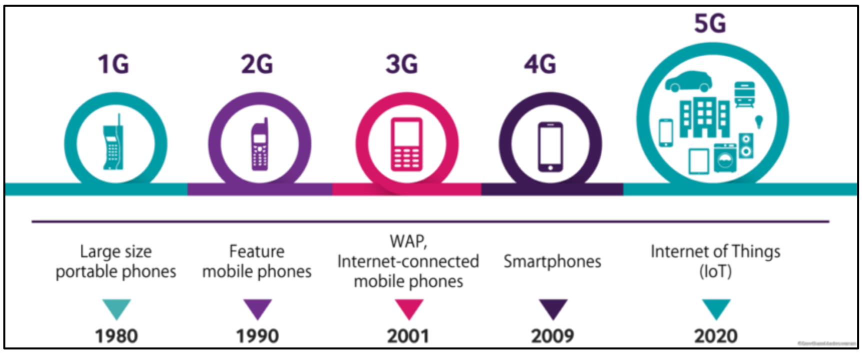


Figure 2.2: Evolution from 1G to 5G [13]

2.1.2 Benefits of 5G

1. **Fast mobile network:** 5G is better than all older mobile network systems and allows superfast download speeds of about 10-20 Gbps. Like fibre optic internet, the 5G wireless network also works similarly. Unlike all past ways of sending messages on phones, 5G strongly gives quick voice and data access. 5G is perfect for essential tasks and self-driving cars because it has a short delay of less than one-tenth of a second.5G will use millimetre waves to send data. These give more space and a faster speed than the lower LTE bands. Because 5G is a fast phone network tech, it will give safe and secure use to cloud services on mobiles plus apps for work. It also lets us access big computer power online virtually without any problem. One great part of 5G is the small cell. It has many good points such as wide reach, fast internet speed, saving power, and quick access to clouds [12][14].

2. **Entertainment and multimedia:** According to a 2015 analysis, downloading videos accounted for more than 50% of all mobile internet traffic. Future developments will undoubtedly see a rise in this tendency, which will spread video streaming more widely. High-speed 4K video streaming with crystal-clear audio will be available with 5G, creating a high-definition virtual environment on mobile devices. The entertainment sector will profit from 5G's 120 frames per second, better quality, higher dynamic range video streaming, and uninterrupted access to HD TV channels on mobile devices. In the future, augmented reality (AR) and virtual reality (VR) will be straightforward to deploy because of 5G's low latency and high-definition transmission. Games that use virtual reality are popular right now, and plenty of corporations are investing in HD versions of these games. The 5G network will provide high-speed internet connectivity and an improved gaming experience [12].
3. **The Internet of Things (IoT):** It connects everything that is being developed primarily thanks to the 5G mobile network. IoT will link various things, including devices, sensors, appliances, objects, and applications, to the internet. These applications will gather data points from several gadgets and sensors. For data collection, transfer, control, and processing, 5G will offer extremely fast internet connectivity. The most effective technology for IoT is 5G since it is a flexible network with unused spectrum available and allows very low-cost deployment. The following are some of the benefits that 5G brings to IoT [15]:

a. **Smart homes:** Demand is high for smart home devices and appliances. The 5G network enables high-speed connectivity and intelligent appliance monitoring, which brings the concept of smart homes closer to reality. By using the 5G network, innovative home products may be readily accessible and set up from distant locations since it provides a high-speed, low-latency connection.

b. **Smart cities:** The 5G wireless network helps build apps for smart cities. These include controlling traffic without drivers, getting weather updates quickly, and easily broadcasting local news in our area. It also saves energy by giving out power more efficiently than before while using systems that do not use much electricity to control how lights are turned on or off at different times. This technology can manage water resources better.

c. **Industrial Internet of Things:** 5G wireless technology will give many tasks to future businesses. These include safety, tracking deliveries, innovative packaging, and shipping stuff more efficiently than before. It also saves energy while making machines do jobs themselves without human help if needed. It can lead to predicting what might break down or need maintenance and working smarter with organizing goods delivery logistics, too! Furthermore, 5G smart sensor tech makes industrial IoT operations safer and more cost-effective. It is also better at saving energy.

d. **Satellite Internet:** Since few ground-based base stations exist in remote locations, 5G will be essential for connecting these places. The 5G network will use satellite systems to provide connectivity, and the satellite system uses a constellation of numerous tiny satellites to provide connectivity in both urban and rural locations worldwide.

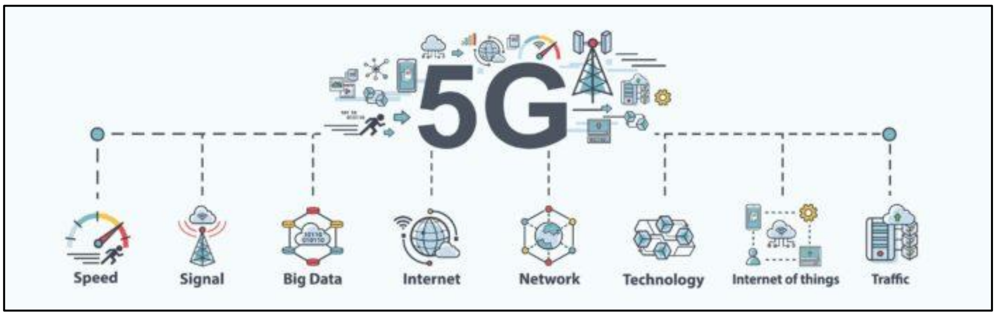


Figure 2.3: Benefits of 5G [15]

2.1.3 Features of 5G

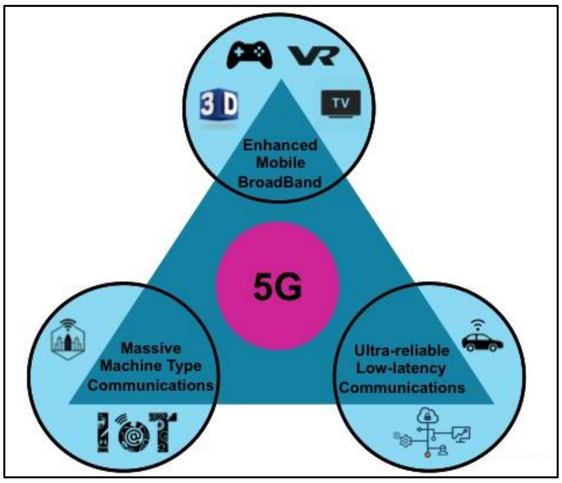


Figure 2.4: Features of 5G [12]

Globally, 5G offers extremely fast, incredibly low latency, and highly marketable connections for IoT. A very adaptable framework for creating a new generation of applications and industry objectives will be made available by 5G. The following list of services provided by the 5G network architecture:

a. **Massive machine-to-machine communications:** 5G facilitates the Internet of Things (IoT), sometimes referred to as the IoT, which allows for machine-to-machine interaction without human involvement. This service enhances the functionality of 5G applications and facilitates communication across the construction, agriculture, and industrial sectors [12].

b. **Ultra-reliable low latency communications (URLLC):** This service offers various independent operations, extremely secure transportation systems, fast vehicle-to-vehicle communication, industrial networking, and real-time machine management. Low-latency communications create opportunities for remote medical treatment, surgeries, and procedures [12].

c. **Enhanced mobile broadband:** The 5G system, which employs large MIMO antenna, mmWave, and beamforming techniques to provide high-speed connectivity across various areas, is a significant use case for enhancing mobile broadband [12].

2.2 Overview of C-V2X

The advanced wireless communication technology known as C-V2X (Cellular Vehicle-to-Everything) enables smooth communication between vehicles and numerous entities in their surroundings. In real-time, it permits communication between moving objects on the road, including infrastructure, pedestrians, other vehicles, and anything else. This extensive connectedness has enormous effects on transportation systems and has the potential to revolutionize driving conditions, traffic flow, and road safety.

C-V2X, which offers real-time, highly reliable, and actionable information flows, aims to change transportation by facilitating more informed choices. Vehicles are given the ability to recognize and respond to possible risks, thereby lowering the likelihood of accidents. The platform for V2X, C-V2X, will offer 360° non-line-of-sight awareness and a greater degree of predictability for improved traffic safety and autonomous driving. Potentially, C-V2X technology holds the key to realizing the potential of intelligent transportation systems. On the widely used 3GPP LTE cellular specifications, C-V2X systems rely. Newer 5G technology will be utilized in future communication models to enhance features, boost data rates, and reduce latency [16].

C-V2X utilizes 3GPP, 4G, LTE, or 5G NR connectivity for signal transmission and receiving. Two complementary gearbox modes are utilized. The first method entails establishing direct connections with infrastructures, vehicles, and pedestrians that traverse highways. In this mode, C-V2X functions autonomously without relying on cellular networks. It transmits data using a PC5 interface. C-V2X utilizes cellular network connections as a secondary method of connection, enabling cars to obtain local traffic and route information. Communication uses the Universal mobile telecommunication system (UMTS) interface. Unfortunately, incidents caused by human mistakes, poor road conditions, and severe traffic delays brought on by accidents or special occasions will no longer be an issue thanks to the development and application of C-V2X technology. Soon, C-V2X, V2V, and V2P will be able to identify risks before they pose a problem and traffic congestion before even seeing them. C-V2X, Intelligent Transport Systems, and 5G can work together to make this vision of safer roads and more effective travel a reality [17].

In terms of transport systems, C-V2X is incredibly important. It improves situational awareness by enabling vehicles to communicate with their surroundings, giving drivers essential information about their surroundings. Cooperative driving, sophisticated driver assistance systems, and overall intelligent transportation management are made possible by this real-time data sharing.

The impact of C-V2X on driving safety is one of its main advantages. The ability to transmit location, speed, and direction data between vehicles, or C-V2X, improves the ability to avoid collisions. Vehicles are given the ability to recognize and respond to possible risks, thereby lowering the likelihood of accidents. Additionally, C-V2X enables information sharing between vehicles and infrastructure, enabling improved traffic control and synchronization, further enhancing road safety [18].

Vehicles have the potential to establish communication with other vehicles (V2V), pedestrians (V2P), roadside infrastructure (V2I), and networks (V2N) with C-V2X technology. This communication can occur with or without a cellular network and offers both low latency and high dependability. The purpose of this communication is to enhance traffic efficiency and safety. By utilizing C-V2X, it is possible to detect potential hazards and traffic conditions at greater distances, even when things are not directly visible to a fully driverless vehicle. C-V2X may address non-line-of-sight (NLOS) challenges by employing PC5 interface sideline communication or cellular network as supplementary safety measures. The sensors in the automobile are crucial for enabling autonomous driving and will remain unchanged in the future. They play a vital role in ensuring security. Nevertheless, the automotive industry has recognized the crucial importance of connectivity in ensuring both safety and comfort [17].

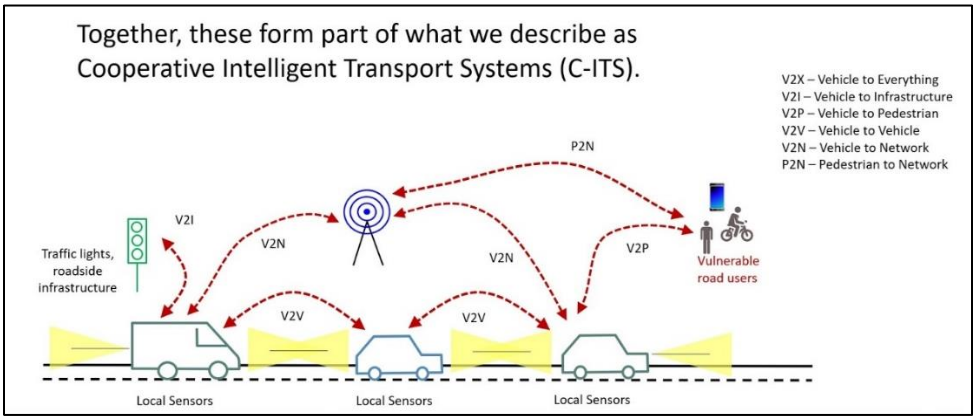


Figure 2.5: C-V2X Concept [17]

Additionally, C-V2X helps to increase traffic efficiency. It lets drivers make wise decisions by giving vehicles real-time information on traffic conditions, road work, and congestion. As a result, routes are better chosen, traffic flows more smoothly, there is very little congestion, and transportation is generally more efficient. Additionally, CV2X can help with adaptive traffic management, dynamic rerouting, and traffic signal coordination, all of which improve traffic efficiency.

To update the map with precise information on the road layout and send the localized HD (High Definition) map to cars based on their locations, C-V2X may aggregate data from the collective perception. These improved and sophisticated services include platooning, remote driving, long-range vision, and blind spot detection. Road capacity, driver safety, and comfort can all be improved using C-V2X [17].

C-V2X improves driving experiences beyond safety and efficiency by providing cutting-edge technologies and services. It makes it possible to integrate automated driving functions, connected car apps, and intelligent transportation systems. This connectivity allows vehicles to offer individualized services like real-time navigation help, auto diagnostics, infotainment, and emergency services. Additionally, C-V2X creates possibilities for the creation of innovative city initiatives because automobiles become a crucial component of the more significant urban infrastructure [20].

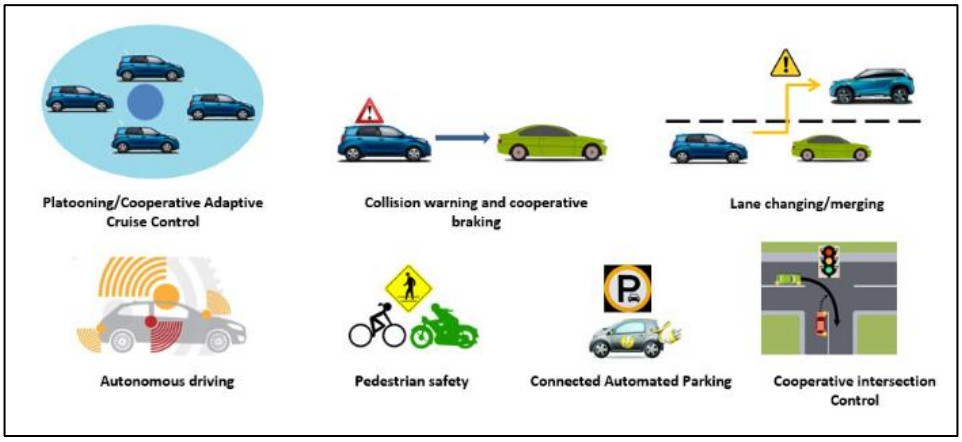


Figure 2.6: Cases Facilitated by C-V2X [21].

In conclusion, C-V2X technology will fundamentally change the design of transport networks. It has enormous potential for facilitating communication among vehicles, infrastructure, pedestrians, and other road users. In the age of connected and autonomous vehicles, improved mobility solutions will be possible because of C-V2X's revolutionary improvements in traffic efficiency, road safety, and driving experiences.

2.2.1 The evolution of C-V2X

A wireless communication system called C-V2X allows communication between automobiles and other environmental entities. It aims to improve road safety, increase traffic efficiency, and open new connected automobile applications. When Vehicle-to-Vehicle (V2V) communication initially gained popularity in the early 2000s, CV2X was developed. The objective was to enable real-time vehicle communication regarding the position, speed, and other vital data. Thanks to this communication, vehicles could coordinate maneuvers, alert other motorists of possible collisions, and avoid them [17].

Long-Term Evolution Vehicle-to-Everything, or LTE-V2X, is a study item that the 3GPP, a global telecommunications-standard organization, established in its Release 14 specifications in 2014. Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication is made possible by LTE-V2X, which was created to take advantage of the cellular network infrastructure [17].

Major telecom and automotive industry firms began to support the technology as it developed over the ensuing years. The first set of LTE-V2X specifications was published by the 3GPP in its Release 14 specification in 2017, and it includes two transmission modes: direct communication (PC5) and network communication (Uu). Through cellular networks, these modes allowed cars to communicate directly with one another (V2V) and with infrastructure (V2I) [17].

However, in 2019, the 3GPP improved the technology and unveiled the idea of C-V2X, broadening its application beyond LTE networks. Compared to earlier incarnations, C-V2X has more outstanding capabilities and improved performance and is designed to operate on LTE and 5G networks. Depending on the application's needs, it contains both direct communication (PC5) and network communication (Uu) modes, allowing vehicles to communicate using either mode [17].

Since then, the telecom and automobile industries have continued to support CV2X and give it impetus. Numerous field tests and pilots have been carried out to evaluate and confirm the technology's capabilities. The objective is to broadly implement CV2X and enable various applications, such as traffic efficiency applications like optimized traffic signal control and traffic flow optimization, as well as safety-related features like collision warnings, intersection assistance, and cooperative driving [17].

Overall, the growth and evolution of wireless communication technologies for connected vehicles are demonstrated by the history of CV2X to enhance traffic efficiency and road safety and enable new vehicle applications in the future [17].

2.3 Significance of C-V2X

In the context of 5G networks, C-V2X is crucial because it uses 5G's capabilities to enable cutting-edge applications and services in the transportation sector. With the help of 5G's dependable, fast, and high-speed connectivity, CV2X provides many advantages and creates new opportunities for transportation needs in the future [17].

For C-V2X applications, the low latency of 5G networks is essential. It ensures that communication between cars and their surroundings happens quickly, enabling swift responses and decisions. Low latency is crucial for guaranteeing the effectiveness and dependability of C-V2X communication in time-critical circumstances, such as preventing collisions or reacting to abrupt changes in traffic conditions [22].

Furthermore, for C-V2X applications to run well, the dependable connectivity of 5G networks is essential. C-V2X calls for a strong and reliable link between vehicles, infrastructure, and other road users to facilitate the prompt and correct transmission of information. With 5G's dependable connectivity, C-V2X may function well even in densely populated areas or places with many vehicles [20].

The combination of C-V2X and 5G networks has enormous promise for addressing future transport demands. It is crucial in enabling connected and automated vehicles to work together and communicate effectively, which creates the groundwork for autonomous driving that is both safe and successful. By giving real-time data to traffic management systems, C-V2X supports smart city projects by enabling improved traffic flow, decreased congestion, and increased transportation efficiency.

Additionally, the integration of C-V2X with 5G can promote breakthroughs in applications and services for transportation. Personalized infotainment services, preventive maintenance, remote diagnosis, and intelligent transportation systems are now possible. By combining the capabilities of C-V2X with the high-speed and low-latency connection provided by 5G networks, innovative transport solutions that improve the overall mobility experience may be developed and deployed [20].

In conclusion, C-V2X's importance in the context of 5G networks rests in its capacity to take advantage of the fast, dependable, and low-latency connectivity offered by 5G. It makes cutting-edge transportation applications and services possible, supporting connected and automated cars, smart city initiatives, and increased transportation effectiveness. A future with safer, more effective, and seamlessly connected transport systems is made possible by the union of C-V2X with 5G.

2.3.1 Features of C-V2X

The term "Cellular Vehicle-to-Everything" refers to some communication channels that let vehicles communicate with numerous objects in their surroundings. These modalities of communication include vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P), and vehicle-to-network (V2N) [26]. Each mode has a specific function and helps achieve the overall objectives of increasing traffic management efficiency, strengthening road safety, and enabling cutting-edge applications in connected and automated cars.

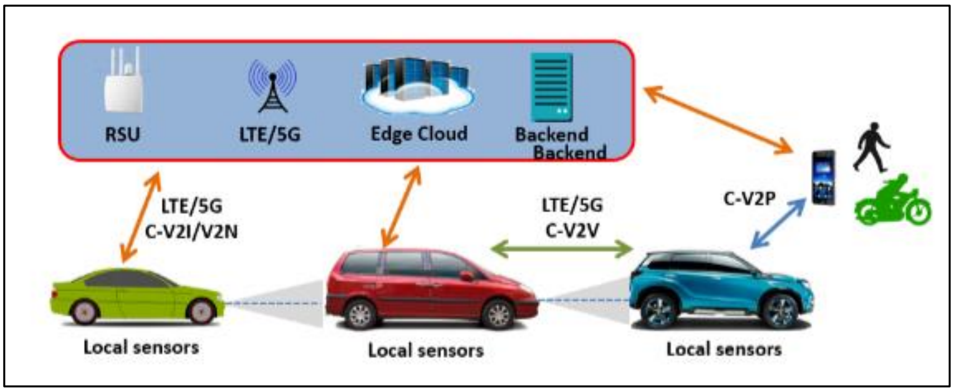


Figure 2.7: Envisioned cellular-based vehicle-to-everything (C-V2X) communication system. [21]

Direct communication between cars is the primary goal of V2V communication. It lets cars communicate their position, speed, and direction in real time. This mode is crucial for following safe distances, organizing group driving maneuvers, and enabling features like adaptive cruise control, collision avoidance, and lane change. Vehicle-to-vehicle communication (V2V) is crucial in improving overall road safety by allowing vehicles to share information and work together in real-time actively.

The communication between automobiles and the road infrastructure is known as V2I. By signing this mode, automobiles may communicate with traffic signals, toll gantries, road signs, and other infrastructure features. Vehicles can make wise decisions and adjust their behavior by getting real-time data from the infrastructure. Optimize traffic flow, lessen congestion, and improve overall traffic management; V2I communication supports applications, including traffic signal optimization, intelligent transportation systems, and intersection management [23].

Vehicles and the network infrastructure can communicate via V2N communication. Vehicles can connect to the internet using this mode and access various services and data. It enables real-time traffic updates, weather reports, entertainment services, and vehicle software updates. The transmission of vehicle data, including mechanical performance, to the automaker or pertinent service providers for remote diagnostics, maintenance monitoring, and performance optimization is also made easier by a V2N connection.

Vehicles can create thorough connectivity with their surroundings thanks to integrating several communication mechanisms under the C-V2X architecture. By enabling direct communication between cars, infrastructure, pedestrians, and the network, C-V2X increases traffic management, encourages cooperative driving, and creates new opportunities for cutting-edge transportation applications and services. It is a crucial enabler for developing automated and connected cars, innovative city programs, and improved transportation efficiency.

2.3.2 Modes of C-V2X

C-V2X manifests in two ways: (1) device-to-device mode, which is direct communication between devices, and (2) device-to-network mode, which is indirect communication between devices over an underlying network. These two distinct modes introduce the communication types V2V, V2P, V2I, and V2N. The two C-V2X technology modes are briefly described in the paragraphs that follow [24]:

a. **Device-to-Device Mode:** This C-V2X communication mode focuses on enabling the bit-pipes for communication between infrastructures (V2I), pedestrians (V2P), and vehicles (V2V). Since cars, pedestrians, and infrastructure are all considered devices, the vehicular communication types, or V2V, V2P, and V2I, are thus realized through device-to-device mode [24].

b. **Device-to-Network Mode:** The bit-pipe communication between devices and network elements/entities is made possible by C-V2X communication—this method of C-V2X implementation results in V2N. As a result, the end-user (driver) can benefit from network and cloud services. The V2N is crucial in completing the picture of an end-to-end solution based on C-V2X communications for many verticals. [24]

2.3.3 Transmission of C-V2X

Transmission modes known as C-V2X enable sidelink channel-based direct V2X connections via the PC5 interface. The vehicular nodes communicate with other nodes directly over the same channel at the PC5, which is the point of contact when connectivity to the base station is not necessary. The 3GPP announced C-V2X technology based on Rel.14 [13] and Rel.15 standard. To support low latency V2X connections, Rel.14 added two further transmission sidelink modes. Figure 3 depicts the two gearbox modes, which are mode 3 and mode 4. The C-V2X can function both inside and outside of service areas, i.e., it can use the sidelink as well as the standard LTE air interface.

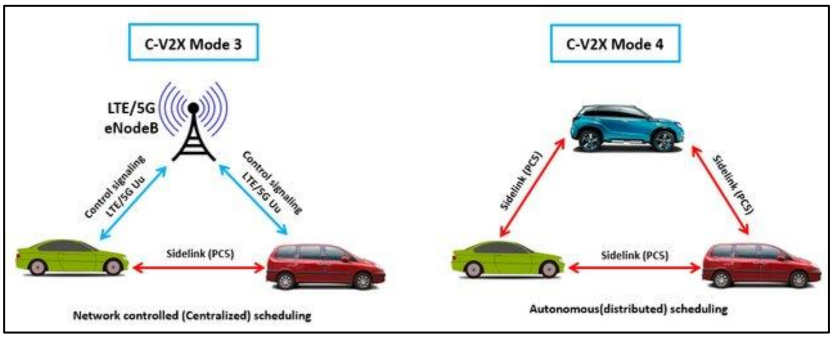


Figure 2.8: Transmission modes 3 and 4 of Cellular V2X (C-V2X) communications [21].

1. V2X based on LTE-Uu Air Interface: The common air interface for establishing a connection between User Equipment (UE) and an eNodeB is LTE-Uu. Each LTE-Uu-capable UE transmits its signal to the eNB on the uplink, and the eNB then sends the signal to the destination UE on the downlink. Semi-persistent scheduling will be used by the eNB to reduce the scheduling burden associated with V2X uplink transmission. Due to

the majority of traffic being periodic and having comparable packet sizes, the eNB assigns resources to a user over a number of successive transmissions when using semi-persistent scheduling [25].

2. V2X based on PC5 Air Interface: The device-to-device connection mode, or PC-5, must be activated in C-V2X for direct safety message transfer that ensures privacy, according to the 5G Automotive Association (5GAA). This mode offers privacy and performs well in the ITS 5.9 GHz band without a paid membership. Additionally, C-V2X can employ V2N mode based on already licenced cellular networks for commercial purposes like voice or data access. Direct UE connections are possible thanks to the PC5 air interface, which eliminates the need for every packet to pass through an eNodeB. When eNodeB is available or not, the user nodes can take advantage of the PC5 interface [25].

    - **C-V2X sidelink mode 3**: In this mode, an eNodeB or a base station is required for the scheduled mode to operate. The cellular network centrally oversees the distribution of resources. Mode 3 approaches include semi-persistent scheduling, UE reports-based scheduling, and cross-carrier scheduling. This model has a challenge in high-mobility highway scenarios, where cars must establish a connection with the eNodeB [25].
    - **C-V2X sidelink mode 4**: The C-V2X side-link mode 4 functions autonomously without relying on eNodeB assistance, utilizing a 5.9 GHz frequency band that is equivalent to the DSRC. The PC5 side-

link radio interface is utilized. Autonomous mode is a synonymous term for it. It can communicate directly with other nearby vehicles without depending on a centralized cellular network. During an initial comparison, Mode 4 in C-V2X outperformed the IEEE 802.11p protocol in a number of scenarios [17]. Additionally, it offers great security for various operation modes [25].

2.3.4 C-V2X Stack Architecture

The OSI model, which comprises an access layer, a network layer, and an application layer, is also used by the C-V2X protocol stack. WAVE and C-V2X's LTE-V2X and NR-V2X are primarily reflected in the wireless access technology, which is the difference in the access layer in the V2X protocol architecture.

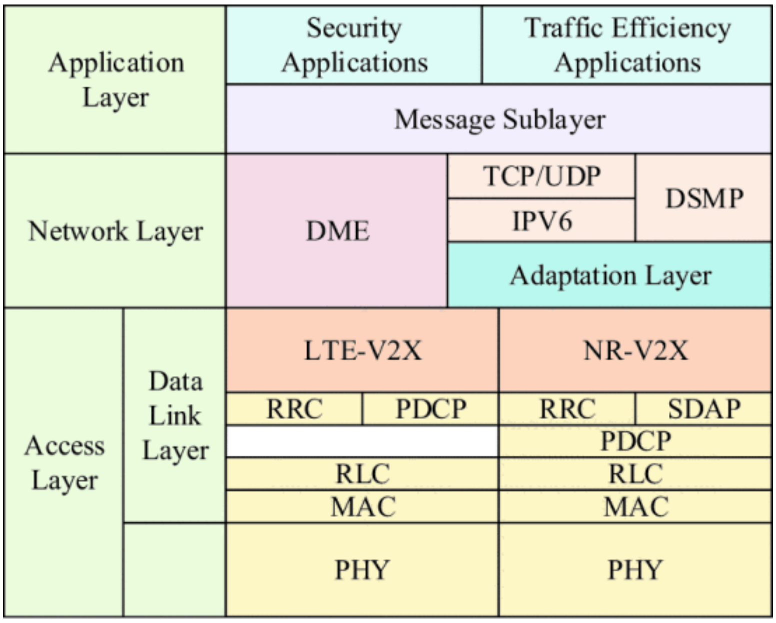


Figure 2.9: C-V2X Architecture [26]

The access layer supports two of these: the UU interface and the PC5 interface. The Uu interface employs the LTE access network interface between the terminal and the access layer protocol stack, while the PC5 interface is built on multiplexing the LTE protocol stack's features. Form the functions of each layer supporting LTE-V2X using the features appropriate for V2X communication. The Physical, data link, and network layers are all access layer components. [29] The radio link control (RLC), packet data convergence protocol (PDCP), radio resource control (RRC), service data adaptation protocol (SDAP), and various sub-layers make up the data link layer. Data and management sublayers are part of the network layer. The administration sublayer primarily completes tasks like system configuration and upkeep. The data sublayer is made up of IPv6, TCP/UDP, and DSMP (Dedicated Short Message Protocol). As the central component of the management sublayer, the DME (Dedicated Management Entity) unifies standard management services, offers management interfaces for all entities that make up the sublayer, and uses the services offered to transport management data streams across various devices [26]

The packetization and analysis of various application messages are completed at the application layer. The message sublayer defines fundamental message bodies and gives the application layer an interactive interface.

2.3.5 Differences between LTE-V2X and NR-V2X:

LTE-V2X Phase 1 of 3GPP Rel-14, completed in March 2017, gave the foundational specifications for V2V services and further V2X services utilizing cellular infrastructure. Under 3GPP Rel-14, the major safety features of C-V2X were supplied using cellular networks or sidelink communications through the PC5 interface. To accommodate C-V2X using unlicensed 5.9 GHz airwaves, a new LTE (Long-Term Evolution)-V2X band 47 (with 10 and 20 MHz bandwidth) was introduced.[20]

The completion of 3GPP Rel-15 occurred in June 2018. As phase 2 of 3GPP V2X, the release included improved V2X services such as platooning, extended sensors, advanced driving, and remote driving, which has created a stable and resilient ecosystem around LTE-V2X [17]:

• **Platooning**: A platoon of vehicles dynamically forms when moving together. The platoon's cars communicated with one another to maintain a short distance safely.

• **Extended Sensors**: Extending the capabilities of sensors by exchanging raw or processed sensor data across automobiles, roadside equipment, pedestrian devices, and V2X application servers (for example, by exchanging real-time video).

• **Advanced Driving**: Make driving partially or entirely automated. Synchronize and coordinate, driving intention is shared with nearby vehicles, and perception data is collected from nearby sensors.

• **Remote Driving**: A remote driver or a V2X application drives a remote vehicle (for example, a vehicle carrying a disabled passenger, a vehicle in a hazardous environment, or a vehicle on a predetermined route).

NRV2X: 5G NR (New Radio)-V2X is backward compatible with LTE-V2X at higher layers as phase 3 of 3GPP V2X. The developers made NR-V2X to support these applications and satisfy the low latency and reliability criteria for advanced V2X services. 5G URLLC (Ultra-Reliable Low-Latency Communication) network slicing can offer advanced functionalities for autonomous driving as a V2N-type application.

Table 1: Differences between LTE-V2X and NR-V2X [17]

Items	**LTE-V2X**	**NR-V2X**
Specification	**3GPP Rel-14/Rel-15**	**3GPP Rel-16/Rel-17**
Latency	Low Latency 10 ~ 100ms	Ultra-low latency: 1 ms
PC5 Message Type	Broadcast	Broadcast, Unicast and Groupcast
Application Scenario	Safety related/Enhanced	Advanced Application
Cellular Network Coverage	Uu and PD5 Mode3	Uu and PC5 Mode1
Out of Cellular Network Coverage	PC5 Mode4	PC5 Mode2

2.4 Overview of Quality of Services (QoS)

Telecommunications networks provide the foundation for communication services in today's globally connected society. Users expect dependable and smooth connectivity for everything from voice calls to video streaming, online games, and data transfers. In order to satisfy these customer expectations and guarantee optimum network performance, it is essential to be able to provide high-quality service.[27]

Quality of Service (QoS) is a key idea in telecommunications networks that deal with the problem of delivering dependable and positive customer experiences. QoS plays a critical role in meeting user expectations by guaranteeing that the network can supply particular performance characteristics to support various applications and services.

Intending to lower packet loss, latency, and jitters for a particular type of network traffic or protocol, QoS is a technique that controls and prioritizes certain types of data traffic on a network. By establishing priority for types of network traffic, Quality of Service (QoS) regulates and maintains network resources. By controlling bandwidth and giving priority to apps that use more resources than others, QoS optimizes the network [27].

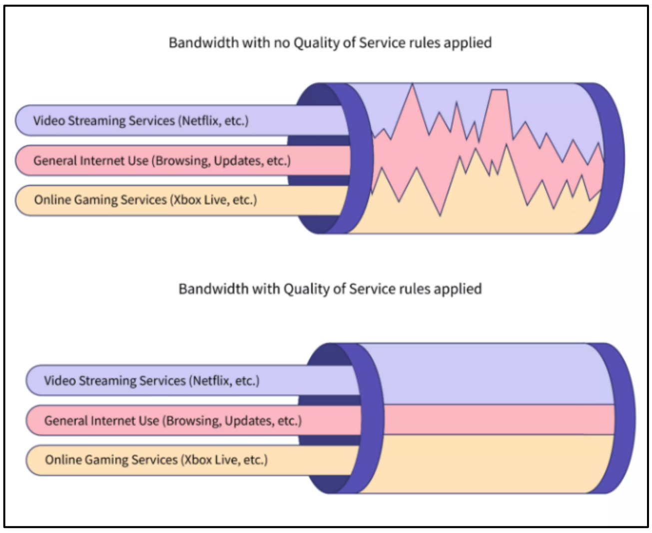


Figure 2.10: Differentiation between Bandwidth without QoS and Bandwidth with QoS [27]

2.4.1 Parameters of Quality of Services (QoS)

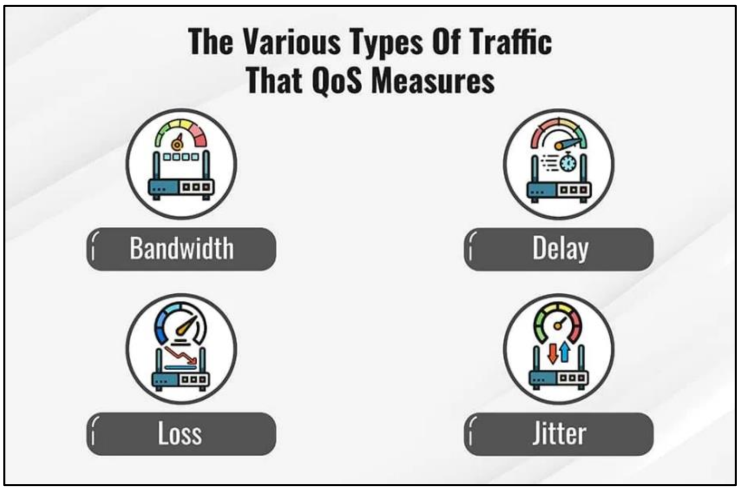


Figure 2.11: Parameters of Quality of Services (QoS) [30]

- **Loss of packets:** Network congestion leads to packet loss when routers and switches become overwhelmed and begin discarding packets. Real-time communication sessions, such as audio or video chats, may experience disruptions in the form of jitter and speech gaps caused by missed packets. If a queue, which is a queue of packets waiting to be sent, becomes excessively full, packets may be discarded.

- **Jitter:** The sources of this issue are network congestion, time drift, and route alterations. Excessive jitter can diminish the quality of both verbal and visual communication [30].

- **Latency:** Transit time refers to the duration required for a package to travel from its origin to its destination. The goal is to minimize delay as much as feasible. If the latency is excessively high, users may experience echo and overlapping audio during a voice-over IP call [30].

• **Bandwidth:** Bandwidth refers to the capacity of a network communications link to efficiently transport the maximum amount of data between two specific places within a set timeframe. Enhancing network performance is achieved by managing bandwidth and delivering additional resources to high-priority applications that have greater performance requirements compared to other applications through the implementation of Quality of Service (QoS) [30].

In the absence of Quality of Service (QoS), network data may become disordered, leading to a decrease in performance or, in some cases, a complete network shutdown. The importance of service quality lies in the necessity for organizations to provide reliable services to both their customers and staff. Service quality has a direct impact on the Quality of Experience (QoE). The reliability of a company's services could harm the relationships between customers and employees.

Moreover, a firm that has a below-average Quality of Service (QoS) is at a higher risk of experiencing breaches in data security and integrity. Effective communication services are vital for both customers and staff to fulfill their responsibilities. Diminishing service quality leads to a reduction in both work and experience quality. Organizations employ packetization to shape data or information when transferring it between network endpoints. Computers employ the process of organizing data into discrete "packets" that may be transmitted across a network, analogous to how physical goods are packaged for delivery through postal services.

By the utilization of the limited bandwidth available on the network, quality-of-service solutions assume the responsibility of prioritizing packets. However, the network has a limited capacity to send a certain amount of data within a set timeframe. Optimize bandwidth use and provide the highest quality internet service within the given time constraints; QoS solutions prioritize packets.

For example, packets pertaining to a video call would be prioritized over ones related to an email download. The reason for this is that a video conference is a more synchronous mode of communication compared to an email, as it necessitates immediate and real-time interaction during a video chat. Nevertheless, sending emails can be something other than time-critical. If a packet is dropped or delayed during a video chat, the end user may experience jitter or lag. The end user will not experience any service disruption if email packets are dropped or delayed during the sending process. Although an individual observing a live transmission can perceive the packets as they are received, they will receive the email only after all the fragments have been assembled.

2.4.2 Mechanism of Quality of Services (QoS)

• **Marking and classifying**: these technologies classify packets into multiple traffic classifications and differentiate between applications. Every packet is labeled with a distinct network class identifier, allowing network devices to recognize the packet's class. Networking hardware uses classification and marking, including routers, switches, and access points [31].

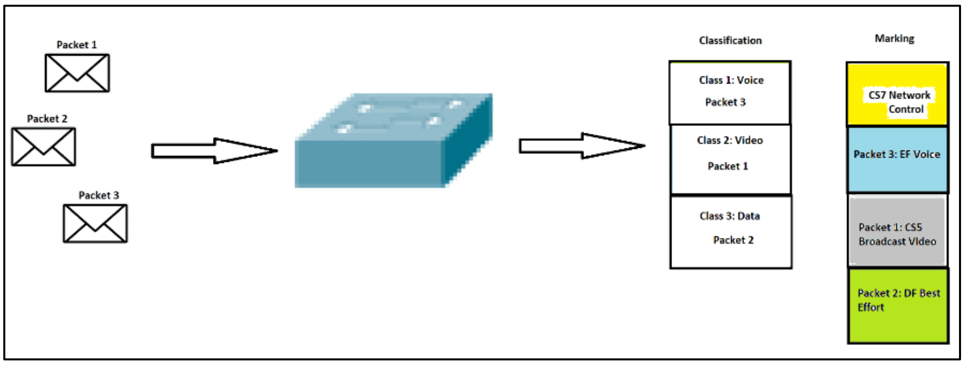


Figure 2.12: Marking and Classification [32].

• **Controlling traffic:** These tools categorize and label each packet to determine the appropriate queue for packet placement. Priority queuing, first-in, first-out, and low-latency queuing are tools used to handle areas with high congestion [31].

• **Preventing traffic jams**: When there is congestion, these tools drop low-priority packets from the network traffic they monitor. Weighted random early detection (WRED) and random early detection (RED) are techniques used to prevent network congestion. The user's text is incomplete and does not provide any information [31].

• **Shaping:** These technologies control the network's traffic flow and give real-time apps precedence over less urgent applications like email and messaging. Buffers, Generic Traffic Shaping, and Frame-Relay Traffic Shaping are examples of traffic shaping tools [31].

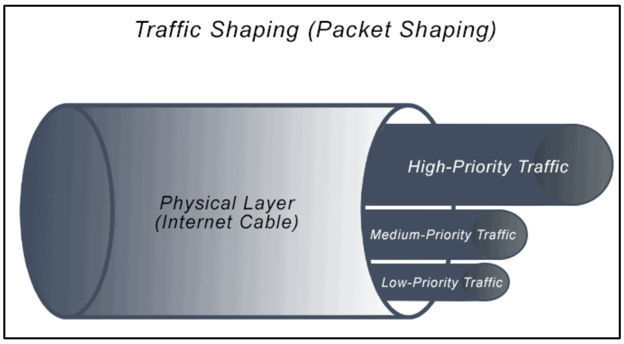


Figure 2.13: Traffic Shaping [31]

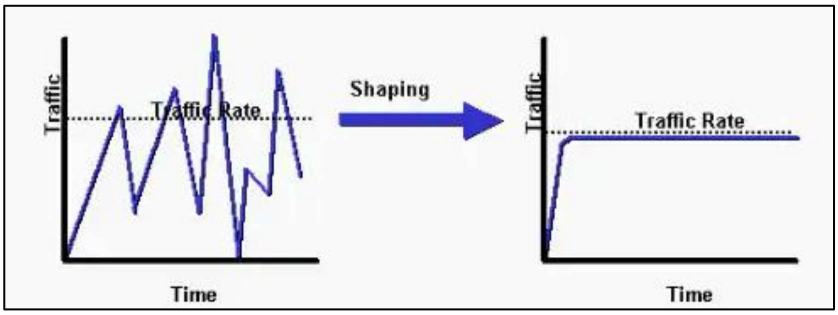


Figure 2.14: Graph for Traffic Shaping.[31]

In conclusion, QoS is essential for telecommunications networks since it makes it possible to give high-quality service. Offering particular performance characteristics like bandwidth, latency, packet loss, and jitter ensures that customer expectations are satisfied. By using efficient QoS algorithms, network operators can optimise network performance, improve user experiences, and uphold customer satisfaction.

CHAPTER 3

METHODOLOGY

The study approach is paramount in the project, particularly in Chapter 3. Ensuring the completion of the project necessitates meticulous arrangement and strategic planning. Utilizing this technique in the project is vital as it ensures the systematic completion of the project to achieve the intended outcomes. Furthermore, to attain optimal outcomes in this chapter, it is necessary to follow each step systematically. The project comprises two distinct components: theoretical comprehension and simulation modeling.

3.1 Omnett++ Model Software

A discrete event simulation framework called OMNeT++ (Objective Modular Network Testbed in C++) is primarily used for modeling and simulating communication networks and other complicated systems. This open-source, component-based simulation platform offers comprehensive modeling and simulation capabilities. OMNeT++ offers a component architecture for models. A high-level language (NED) builds smaller (called modules) into more significant components and models. Model reuse is entirely free. Because of its modular architecture and strong GUI support, OMNeT++ makes it simple to integrate the simulation kernel (and models) into your applications. Figure 3.1 depicts the OMNeT++ Version 5 open simulator used in this research.

Figure 3.1: OMNeT++ IDE

Over the years, researchers from various fields have developed numerous simulation models and model frameworks for OMNeT++. These fields include queuing, resource modeling, internet protocols, wireless networks, switched LANs, peer-to-peer networks, media streaming, mobile ad-hoc networks, mesh networks, wireless sensor networks, vehicular networks, NoCs, optical networks, HPC systems, cloud computing, SANs, and more. Most of these model frameworks were developed as autonomous endeavors, are publicly available, and adhere to their release timelines. Researchers and professionals in computer networks, telecommunications, distributed systems, and other related fields frequently use it. By mixing pre-built components, the framework's versatile and extendable architecture enables users to build sophisticated simulation models [30].

Critical features of OMNETT++ include:

1. Modular Component Architecture: OMNeT++ enables users to construct simulation models using interchangeable and reusable software components. These parts, called modules, can be created separately and combined to create the required system [30].

2. Discrete Event Simulation: OMNeT++ uses the discrete event simulation paradigm, in which events occur at particular times and are handled sequentially. This method makes it possible to accurately simulate dynamic systems where external factors affect the system's state [30].

3. Extensibility: An extensive collection of libraries, protocols, and models are provided by the framework, enabling users to increase the capability of their simulations. C++ is one of the many programming languages that OMNeT++ offers for creating unique models and algorithms [30].

4. Graphical User Interface (GUI): The Simulation IDE (Integrated Development Environment) by OMNeT++ is a graphical environment that makes creating, setting up, and visualizing simulation models more accessible. It has attributes like a network editor, tools for result analysis, and debugging capability [30].

5. Scalability: With the help of OMNeT++, distributed and parallel simulation may be used to run extensive simulations over numerous computing resources. When modelling complex network scenarios with several entities, this functionality is beneficial [30].

For modelling and simulating communication networks and other systems, OMNeT++ is a potent tool. It is a popular option among academics and developers in network modelling due to its modular and extendable architecture and broad collection of capabilities.

Figure 3.2 shows the general OMNeT++ Framework while Figure 3.3 shows the general OMNeT++ Module.

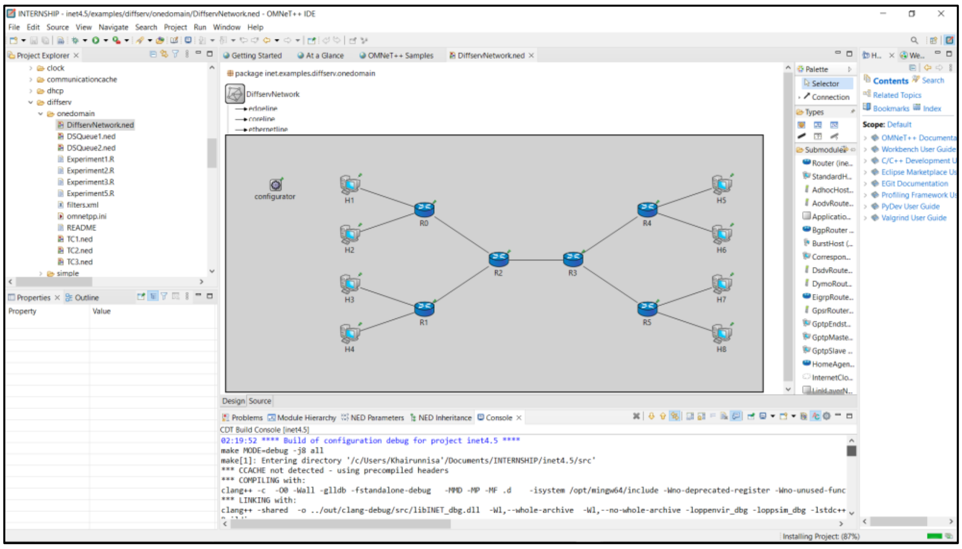


Figure 3.2: OMNeT++ Framework

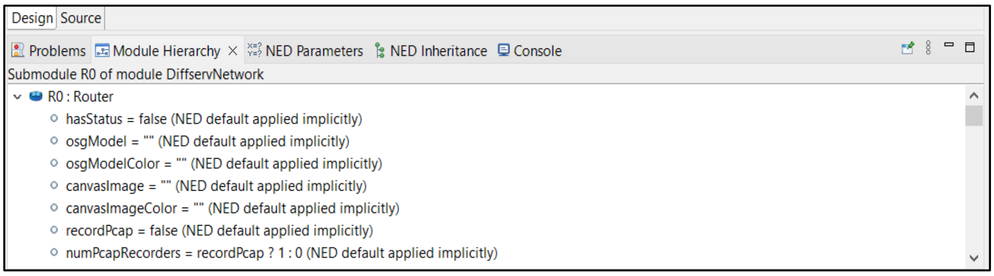


Figure 3.3: OMNeT++ Module

Figure 3.4 shows the general OMNeT++ Implementation.

```
            @display("p=1000,200");
        }
        H7: StandardHost {
            @display("p=1000,300");
        }
        H8: StandardHost {
            @display("p=1000,400");
        }
        H3: StandardHost {
            @display("p=250,300");
        }
        H4: StandardHost {
            @display("p=250,400");
        }
        configurator: Ipv4NetworkConfigurator {
            @display("p=100,100;is=s");
        }
    connections:
        H1.ethg++ <--> ethernetline <--> R0.ethg++;
        H2.ethg++ <--> ethernetline <--> R0.ethg++;
        H3.ethg++ <--> ethernetline <--> R1.ethg++;
        H4.ethg++ <--> ethernetline <--> R1.ethg++;
        H5.ethg++ <--> ethernetline <--> R4.ethg++;
        H6.ethg++ <--> ethernetline <--> R4.ethg++;
        H7.ethg++ <--> ethernetline <--> R5.ethg++;
        H8.ethg++ <--> ethernetline <--> R5.ethg++;
        R0.pppg++ <--> edgeline <--> R2.pppg++;
        R1.pppg++ <--> edgeline <--> R2.pppg++;
        R2.pppg++ <--> coreline <--> R3.pppg++;
        R4.pppg++ <--> coreline <--> R3.pppg++;
        R5.pppg++ <--> coreline <--> R3.pppg++;
}
```

Figure 3.4: OMNeT++ Implementation

Figure 3.5 shows the general OMNeT++ Network Description (NED)

Design | Source

Problems | Module Hierarchy | NED Parameters | NED Inheritance | Console

Submodule R0: Router, all parameters

Parameter	Value	Remark
R0.hasStatus	false	NED default applied implicitly
R0.osgModel	""	NED default applied implicitly
R0.osgModelColor	""	NED default applied implicitly
R0.canvasImage	""	NED default applied implicitly
R0.canvasImageColor	""	NED default applied implicitly
R0.recordPcap	false	NED default applied implicitly
R0.numPcapRecorders	recordPcap...	NED default applied implicitly

Figure 3.5: OMNeT++ Network Description (NED)

This research focuses on C-V2X in 5G networks where C-V2X can only be done with 5G networks. The concept of C-V2X is to make cars communicate with everything in their surroundings, like infrastructure, pedestrians, vehicles, and networks. In this research, two base stations are used, which are gNodeB1 and gNodeB2. Each base station in a traditional cellular network would be responsible for just serving consumers. In a 5G CV2X network, base stations and vehicles will communicate with each other to give customers the maximum experience. This research focuses on communication between the base station and vehicle and the vehicle with the vehicle.

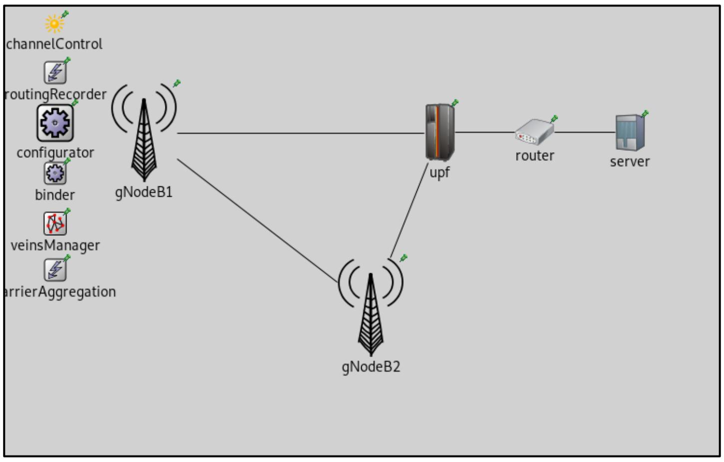


Figure 3.6: Network Connection for C-V2X

In designing the multicell network, a few settings need to be considered. Table 3.1 explains the function of each setting in Simu5G OMNeT++ simulation.

Table 3.1: Function of Component in Simu5G OMNET++

SETTING COMPONENT	FUNCTION
Highway	The network scenario or environment for 5G Cellular Vehicle-to-Everything (CV2X) simulations is represented by the "Highway" component in Simu5G OMNeT++. Its main purpose is to specify the proportions and physical configuration of the simulated region, including the locations of roads, crosswalks, and vehicle movement patterns. It provides the foundation for

	vehicle-to-vehicle communication, enabling practical evaluation of 5G CV2X applications and protocols under various traffic conditions
Channel Control	A 5G CV2X network's radio channels are largely managed and controlled by the "Channel Control" module. It controls things like resource scheduling, interference control, and channel allocation. This module aids in assessing radio communication performance in intricate vehicular environments, guaranteeing that cars can consistently exchange data over the 5G network in various scenarios.
Configurator	The "Configurator" in Simu5G OMNeT++ configures the network, specifically assigning IP addresses and other crucial settings to network nodes and interfaces. By specifying the network layout and connections, this configuration ensures that the simulated network closely resembles a 5G CV2X environment in the actual world. The Configurator is essential to create precise simulations and efficient data transmission between cars, infrastructure components, and network nodes.
Binder	Binder: In the context of 5G CV2X, the "Binder" module is the binding agent, tying together various network components. It facilitates communication and data transmission by managing connections between different network components. The Binder is essential to vehicular communication because it allows many network components to work together seamlessly, simulating real-life interactions between base stations, automobiles, and other infrastructure components

Veins Manager	Realistic vehicular network simulations are made possible by the "Veins Manager" module, which combines Simu5G OMNeT++ with the Veins framework. To facilitate mobility data sharing and interactions between 5G network components and vehicle components, it manages the connection between the OMNeT++ environment and external tools such as SUMO for traffic simulation. Vehicular mobility patterns and 5G network behaviour must be coordinated for realistic and thorough CV2X simulations, which can only be achieved using the Veins Manager.
Carrier Aggregation	Carrier Aggregation is essential for maximizing network performance in a 5G CV2X simulation. It controls combining various frequency bands or carriers to increase network capacity and data speeds. The ability to simulate sophisticated 5G capabilities, such as multi-connectivity, is made possible by this module. This is crucial for guaranteeing smooth connectivity in car contexts with high mobility and fluctuating network circumstances. It is feasible to evaluate the reliability and effectiveness of 5G CV2X communication in practical situations by simulating carrier aggregation.

Table 3.2 delineates the purpose of each component chosen for the CV2X design. Each of these components has a specific function in networking, enabling the smooth transmission of data, device connectivity, and access to resources and services.

Table 3.2: Function of Component in C-V2X Design

COMPONENT	FUNCTION
SERVER	The Server module symbolises a typical host that hosts services and programs. In your scenario, it serves as a VoIP application receiver. The VoIP traffic from cars is received and processed by the server, which typically offers services other devices can access.
ROUTER	The Router module acts as a network router and is in charge of routing data packets among the many nodes in your simulated network. Routers play a crucial part in controlling data traffic by deciding how to deliver packets to their destinations and ensuring effective communication within the network.
UPF	In a 5G network, the Upf module simulates the User Plane Function. It manages and routes user data traffic within the network, ensuring information is properly sent between gNodeBs and cars. In your simulation, the UPF is essential for managing user data.
GNODEB1	The base stations in a 5G network, known as gNodeBs, are emulated by the "gNodeB1" and "gNodeB2" modules. Within their coverage areas, these base stations give mobile devices (represented by cars) wireless connectivity. The cars and the rest of the network manage connections, process signals, and route data. In your simulation, "gNodeB1" and "gNodeB2" are crucial for enabling car-to-car communication and giving them access to radio resources.

CARS	The Cars modules in the simulated network represent moving nodes or automobiles. They have models and applications for mobility. Cars drive around the simulated area and interact with servers and other network elements using VoIP and D2D communication, simulating how mobile devices might behave in a real-world network.

3.2 Research Methodology

It is essential to perform in-depth research on advancing cellular vehicle-to-everything (C-V2X) communication in 5G networks to sustain the Quality of Service (QoS) in communication networks. Road safety and productivity are improved through C-V2X, which provides seamless communication between cars, infrastructure, pedestrians, and other entities.

Simulations and QoS modelling are crucial to examine the effectiveness of C-V2X communication and determine how it affects QoS. OMNeT++, a robust simulation framework, is frequently used for these objectives. Researchers can use OMNeT++ to build precise and thorough simulation models of 5G networks that include numerous C-V2X communication-specific elements and protocols.

The end-to-end packet delay and jitter should be measured and analysed for a project focusing on C-V2X communication. These metrics highlight the fluctuation and time delay data packets encounter while moving through the network. Researchers can better understand the performance characteristics of the C-V2X system by measuring latency and jitter with OMNeT++.

Two crucial parameters—latency and throughput—will be considered in the simulation tests run in OMNeT++. Throughput is the quantity of data successfully communicated in each amount of time. In contrast, latency is the time it takes for a data packet to travel from its source to its destination. These measures will aid in determining how effectively and dependably C-V2X communication delivers data packets.

The simulation findings will be compared to well-known theoretical models and computations to confirm accuracy. This verification procedure ensures the simulation appropriately depicts the C-V2X system's anticipated behavior. Researchers' confidence in the dependability of their simulation models can increase if the simulation outcomes match the theoretical predictions.

The simulation is ultimately expected to produce measured latency and throughput figures within a tolerable range and satisfy the intended QoS requirements for the C-V2X connection. Researchers can carry out in-depth analysis and make relevant deductions regarding the performance and behaviour of the C-V2X system by creating graphs and visual representations based on the simulation findings.

In conclusion, employing OMNeT++ to research C-V2X communication in 5G networks enables researchers to mimic and predict the system's behaviour precisely. Researchers can get critical insights into the performance and quality of C-V2X communication by measuring variables like latency and throughput, contrasting simulation results with theory, and analysing generated graphs. This information will help in the development and optimisation of this technology.

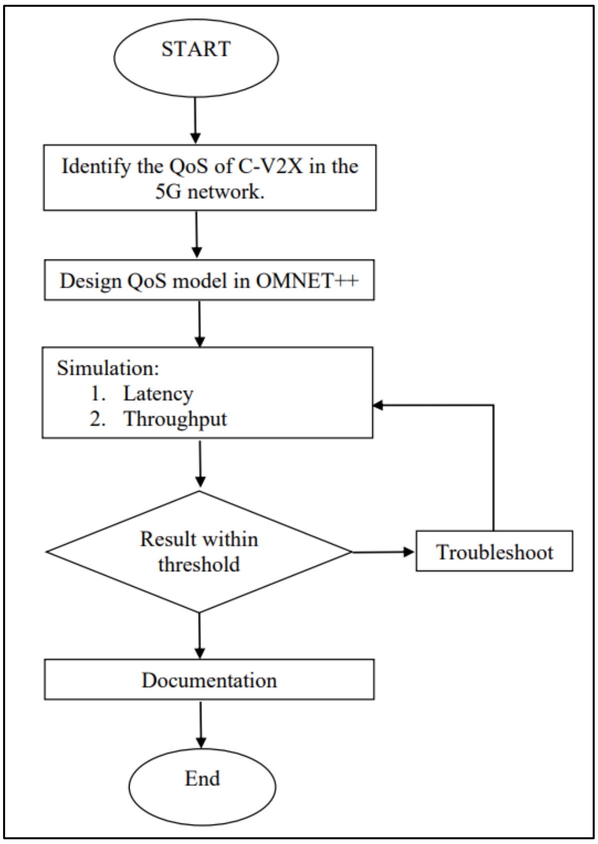


Figure 3.7: Methodology Flowchart

CHAPTER 4

RESULTS

4.1 Introduction

This chapter will discuss the simulation tools employed in this research, such as the libraries. The following data analyzes parameters: throughput, latency, and packet loss in C-V2X. The analysis incorporates the parameters measured during the simulation. The simulation data will be graphed and shown. The graphs will be used to evaluate the performance of the C-V2X network. This research will inform future recommendations and strategies for improving the C-V2X network.

4.2 Simulation Environment

Simulation tools are commonly used across various domains to study and assess system performance. Simulation can enhance time efficiency. Engaging in real-world trials or implementing improvements can be lengthy and may necessitate significant periods of inactivity. Simulation tools are employed to simulate and evaluate various scenarios in a significantly shorter time frame than conducting actual experiments. Simulation techniques can be applied to compare against real-time network data if feasible. The simulation can be streamlined without compromising the accuracy of the outcomes by employing the same parameters as in the actual system. This approach can provide valuable insights into the performance of the system and allow for predictions to be made about its performance in the future. Simulation tools can also be used to identify potential areas of improvement, as well as to test the robustness of a system.

4.3 OMNeT++ Simulation Tools

The research integrates the INET, Simu5G, veins and SUMO libraries as extension libraries in OMNeT++ to enhance the capabilities of network simulation and communication systems. The extension library utilized in this project is succinctly elucidated in Table 4.1.

Table 4.1: Description of Extension Library

LIBRARY	EXPLAINATION
INET Framework	An open-source simulation tool for modelling and simulating communication networks is called the INET (Inter-networking Simulation Environment) Framework. INET provides a full range of network modules and models to simulate different network protocols and technologies on top of the OMNeT++ simulation framework. TCP/IP, HTTP, and Ethernet are among the internet-related protocols and technologies that are given particular attention. Researchers, network engineers, and developers frequently use this framework to build and review network protocols, examine network performance in various scenarios, and evaluate the behavior of wired and wireless networks.

Simu5G	A specialized simulation framework known as SIMU5G was created exclusively for modelling and simulating 5G wireless networks. It incorporates OMNeT++ and the INET Framework and offers a variety of tools, modules, and components made specifically for the demands of simulating 5G networks. To conduct experiments, test and improve 5G technologies and protocols, and evaluate the performance of 5G networks in various scenarios, such as those requiring millimeter-wave communication, massive MIMO, and network slicing, researchers and engineers employ SIMU5G. Understanding the complexities of 5G networks and optimizing their rollout rely heavily on this paradigm.
Veins	Veins is an open-source framework for designing and simulating vehicular communication networks. It easily integrates the OMNeT++ network simulator with the SUMO (Simulation of Urban MObility) traffic simulator. Its main emphasis is vehicular ad hoc networks (VANETs), where cars can connect with equipment like traffic lights and devices. For researchers and developers working on connected and autonomous vehicles, vehicle-to-vehicle (V2V), and vehicle-to-infrastructure (V2I) communication, Veins is a crucial resource. Modelling the interactions of cars in an urban or suburban context enables the investigation of various transportation and traffic management situations.
SUMO	SUMO is an open-source traffic simulation tool that models urban mobility and road traffic. It enables users to simulate

	intricate road networks, automobiles, pedestrians, traffic signals, and other urban features, resulting in a realistic depiction of traffic behaviors and flow. Researchers, city planners, and transportation specialists frequently use SUMO to assess and improve transportation systems, examine the effects of various traffic management techniques, and assess the effects of cutting-edge technologies like intelligent transportation systems (ITS) on mobility and traffic congestion. The software is a priceless tool for evaluating the effectiveness of urban transport infrastructure and enhancing traffic control procedures.

By integrating the Inet, Simu5G, veins, and SUMO libraries into the OMNeT++ framework, users can utilize a diverse range of pre-existing models, protocols, and simulation components as foundational elements in network simulations. These libraries offer a time-saving and efficient solution for constructing complex network features from scratch. They also served as a solid foundation for modeling various network scenarios, including traditional wired networks and advanced 5G communication systems.

OMNeT++ is widely recognized as one of the most exceptional networking simulation tools, chosen for multiple compelling reasons:

a) The software supports a variety of wireless network extensions and libraries, such as INET, Veins, and SUMO. These tools enable users to replicate realistic Quality of Service (QoS) scenarios.

b) Establish a structure for constructing and merging network models using components that can be used again.

c) OMNeT++ can manage simulations of wireless ad hoc networks that are both large-scale and complex.

d) User-friendly interface and access to a supportive learning community. Despite its modest community, OMNeT++ continues to expand. The software comprises a graphical user interface (GUI) and a network description language (NED) to facilitate the design and visualization of simulations.

4.4 Overview of OMNeT++ Simulation

The procedure to create a network model and run simulations is depicted in Figure 4.2 below:

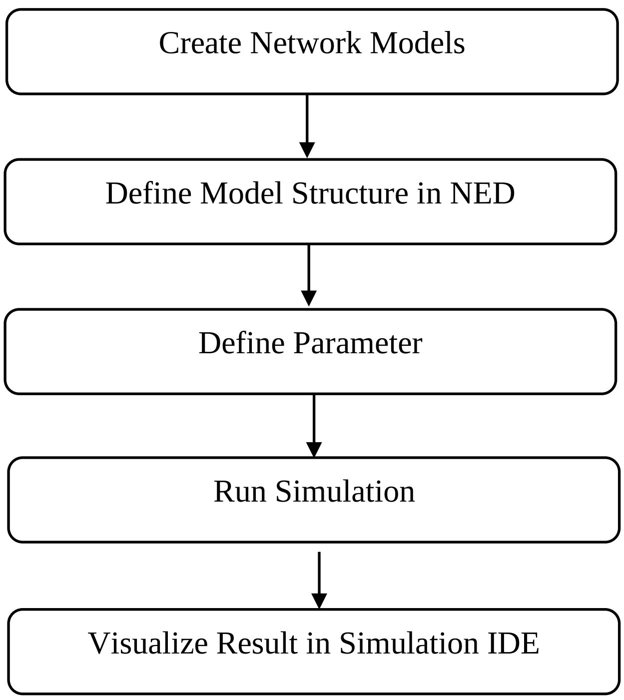


Figure 4.1: OMNeT++ Simulation Workflow

To run and execute a design in OMNeT++, the code is required to implement the simulation model's behavior and logic. This project required two different codes to build the simulation: highway coding and general setting coding. Highway coding starts with Figure 4.2, which shows the package for the code.

```
package simu5g.simulations.NR.cars;
```

Figure 4.2: Package for Code

Next is code imports different OMNeT++ modules and classes from the INET framework and other libraries utilised in the simulation as shown in Figure 4.3.

```
import inet.networklayer.configurator.ipv4.Ipv4NetworkConfigurator;
import inet.networklayer.ipv4.RoutingTableRecorder;
import inet.node.inet.AdhocHost;
import inet.node.inet.Router;
import inet.node.inet.StandardHost;
import inet.node.ethernet.Eth10G;
```

Figure 4.3: OMNeT++ modules and classes from the INET framework

Figure 4.4 shows the line of code includes import statements for modules and classes from the simu5G package, which is an extension or complement to the INET framework for simulating 5G and NR communication scenarios.

```
import simu5g.world.radio.LteChannelControl;
import simu5g.common.carrierAggregation.CarrierAggregation;
import simu5g.nodes.Upf;
import simu5g.common.binder.Binder;
import simu5g.nodes.NR.gNodeB;
import simu5g.nodes.cars.Car;
```

Figure 4.4: Extension to the INET framework for simulating 5G and NR communication

The simu5G package, which is an enhancement to the INET framework for simulating 5G and NR communication scenarios, is imported in these lines along with modules and classes as shown in Figure 4.5.

```
import org.car2x.veins.subprojects.veins_inet.VeinsInetManager;
```

Figure 4.5: Simu5G Package

Then, Figure 4.66 shows the parameters specify the size of the simulation area in meters in three dimensions (X, Y, and Z).

```
network Highway
{
    parameters:
        double playgroundSizeX @unit(m); // x size of the area the nodes are in (in meters)
        double playgroundSizeY @unit(m); // y size of the area the nodes are in (in meters)
        double playgroundSizeZ @unit(m); // z size of the area the nodes are in (in meters)
        @display("bgb=732,483");
```

Figure 4.6: Simulation Area

Next, Figure 4.7 shows defines submodules and connections with the network. Submodules are fundamental elements or units within the network, and connections determine the way they are linked together.

The subsequent lines delineate many submodules, including a routing recorder, network configurator, Veins manager, LTE-related modules, standard hosts, routers, UPF (User Plane Function), and gNodeBs (New Radio base stations). The OMNeT++ simulation environment organizes and visually displays these submodules.

```
submodules:

    routingRecorder: RoutingTableRecorder {
        @display("p=50,75;is=s");
    }
    configurator: Ipv4NetworkConfigurator {
        @display("p=50,125");
        config = xmldoc("demo.xml");
    }

    //# Veins manager module
    veinsManager: VeinsInetManager {
        @display("p=50,227;is=s");
    }

    //# LTE modules
    channelControl: LteChannelControl {
        @display("p=50,25;is=s");
    }
    binder: Binder {
        @display("p=50,175;is=s");
    }
    carrierAggregation: CarrierAggregation {
        @display("p=50.993748,258.7;is=s");
    }
    server: StandardHost {
        @display("p=660,136;is=n;i=device/server");
    }
    router: Router {
        @display("p=561,135;i=device/smallrouter");
    }
    upf: Upf {
        @display("p=462,136;is=l");
    }
    gNodeB1: gNodeB {
        @display("p=156,136;is=vl");
    }
    gNodeB2: gNodeB {
        @display("p=391,313;is=vl");
    }
```

Figure 4.7: Submodules and Connection with Work

The Connections section provides links between these submodules. For instance, it establishes a connection between the "Server" and an "Eth10G" node, as well as between the "Router" and an "Eth10G" node. These connections represent the network topology as shown in Figure 4.8.

```
connections allowunconnected:
    server.pppg++ <--> Eth10G <--> router.pppg++;
    router.pppg++ <--> Eth10G <--> upf.filterGate;
    upf.pppg++ <--> Eth10G <--> gNodeB1.ppp;
    upf.pppg++ <--> Eth10G <--> gNodeB2.ppp;

    //# X2 connections
    gNodeB1.x2++ <--> Eth10G <--> gNodeB2.x2++;
```

Figure 4.8: Network Topology

Next, Figure 4.9 shows the general setting for the code. The sim-time limit refers to the duration of simulation time, which is seventy seconds. The second line is to declare the network used, which is C-V2X using Simu5G.

```
############################################################
#              Simulation parameters                        #
############################################################
debug-on-errors = false
print-undisposed = false

sim-time-limit = 100s

**.sctp.**.scalar-recording = false
**.sctp.**.vector-recording = false
**.routingRecorder.enabled = false
```

Figure 4.9: General Setting Code

The next setting is VeinsManager, which manages network nodes. 0.1s is set for the interval for the Veins Manager as shown in Figure 4.10.

```
##########################################################
#             VeinsManager parameters                    #
##########################################################
*.veinsManager.host = "localhost"       # if traci-launchd runs on localhost
*.veinsManager.moduleType = "simu5g.nodes.cars.NRCar"
*.veinsManager.moduleName = "car"
*.veinsManager.launchConfig = xmldoc("heterogeneous.launchd.xml")
*.veinsManager.updateInterval = 0.1s
```

Figure 4.10: Veins Manager

Next, the Figure 11 shows the mobility model for the vehicles in the simulation. It is likely related to vehicle movement and communication in a vehicular network simulation.

```
##############################################################
#                         Mobility                           #
##############################################################
*.car[*].mobilityType = "VeinsInetMobility"
```

Figure 4.11: Model for Vehicle in Simulation

Figure 4.12 depicted the setting for the power transmission used in the design. The number of resource blocks is 25. Its resource blocks are frequency-time slots used for communication. The power transmitted by user equipment is set to be 23 watts, while the power transmission for eNodeB is 46 watts.

```
##############################################################
#                LTE specific parameters                     #
##############################################################

# Number of Resource Blocks
**.numBands = 25

# Transmission Power
**.ueTxPower = 26
**.eNodeBTxPower = 46
```

Figure 4.12: Setting for Power Transmission

Next, Figure 4.13 shows lines controlling the dynamic association of UEs (User Equipment) to cellular base stations. The code enables dynamic association, which allows UEs to connect base stations based on the best Signal-to-Interference-plus-Noise Ratio (SINR).

```
# Enable dynamic association of UEs (based on best SINR)
*.car[*].cellularNic.nrPhy.dynamicCellAssociation = true
*.car[*].masterId = 0     # ignored if dynamic association is disabled
*.car[*].macCellId = 0    # ignored if dynamic association is disabled
*.car[*].nrMasterId = 1     # ignored if dynamic association is disabled
*.car[*].nrMacCellId = 1    # ignored if dynamic association is disabled
```

Figure 4.13: Lines Control for Dynamic Association

Then, Figure 4.14 shows this line handover and configure handover-related parameters in the network. It sets the handover latency to 60 milliseconds for eNodeB. At the same time, 1s is set for the interval at which eNodeB sends broadcast messages.

```
# Enable handover
*.car[*].cellularNic.nrPhy.enableHandover = true
*.gNodeB*.cellularNic.phy.enableHandover = true
*.gNodeB*.cellularNic.phy.handoverLatency = 60ms
*.gNodeB*.cellInfo.broadcastMessageInterval = 1s # eNB will sends broadcast triggers every second
```

Figure 4.14: Handover Parameters

In this Figure 4.15, configurations are related to the X2 interface. The X2 interface is used for communication with eNodeB.

```
# X2 and SCTP configuration
*.gNodeB*.numX2Apps = 1    # one x2App per peering eNodeB
*.gNodeB*.x2App[*].server.localPort = 5000 + ancestorIndex(1) # Server ports (x2App[0]=5000, x2App[1]=5001, ...)
*.gNodeB1.x2App[0].client.connectAddress = "gNodeB2%x2ppp0"
*.gNodeB2.x2App[0].client.connectAddress = "gNodeB1%x2ppp0"
**.sctp.nagleEnabled = false         # if true, transmission of small packets will be delayed on the X2
**.sctp.enableHeartbeats = false
```

Figure 4.15: X2 Interface

Figure 4.16 shows that Setting up VoIP-Uplink for 5G CV2X involves the establishment of numerous settings to govern the manner in which VoIP applications will perform under an uplink situation. The line indicates that 10 instances of VoIPReceiver are on each node in the "server." After that, the line *.server.app[*]. type = " VoIPReceiver" designates all apps on the server node parts as applications belonging to type "VoIPReceiver." To make sure that many different apps on the "server" nodes all have unique local port numbers, a setting of ".server.app[*].localPort = 3000 + ancestorIndex(0)" is used, such that the local port number becomes determined by its place in line (i e. by ancillary index).

As for the "car" nodes, in their configuration file, *.car.numApps is set to 1, meaning that each car node can only acoomodate one application at a time. More information about the first application on "car" nodes follows. The property line, *.car[*].app[0].type = " VoIPSender" indicates that the first application on each car node is a Voipsender app. These lines set the destination address and port for the initial application on each of these "car" nodes: *.car[*].app[0].destAddress = "server";*. car [*] . app [0] . destPort=3000. More precisely, the destination address is set to "server," which specifies that data are being transmitted over to the server. The resulting port value at the other end indicates a different number for every application, though it is dynamically computed. To sum up, these settings define the VoIP-Uplink situation in 5G CV2X simulation. They include, for instance, the number of applications and their types, the local ports on different interfaces (adapter cards), destination addresses(or, as our chapter rules have it: Mail to address), and ports for both ends.

```
# ---------------------------------------------------------------------------- #
# Config "VoIP-Uplink"
#
[Config VoIP-UL]

##########################################################
#                    App Layer                           #
##########################################################
*.server.numApps = 10
*.server.app[*].typename = "VoIPReceiver"
*.server.app[*].localPort = 3000 + ancestorIndex(0)
*.server.app[*].destAddress = "car["+string (ancestorIndex(0)) + "]"
*.server.app[*]startTime =0.05s

*.car[*].numApps = 1
*.car[*].app[0].typename = "VoIPSender"
*.car[*].app[0].destAddress = "server"
*.car[*].app[0].destPort = 3000 + ancestorIndex(1)

#Instrument to measue latency
*.server.app[*].recordLatency = true
```

Figure 4.16: Setting up VoIP-Uplink

Figure 4.17 shows the setting up VoIP-D2D(V2V) For the “VoIP-D2D” scenario in configuring corresponding parameters, it is sought to create a complete setup for communication between User Equipments UEs when communicating with VoIP apps using D2 adaptation links if they are present within one cell. The peculiarities of this configuration include several main components.This strategic outline allows the communication protocols to meet D2D interaction requirements perfectly.

Furthermore, the configuration “.car[*].cellularNic.d2dInitialMode = true” becomes significant to allow D2D initial mode for UEs. This strategic decision enables UEs to establish direct communication links via D2D when their closeness in the same cell implies ideal connectivity.Enabling the reporting of Channel Quality Indicator for D2D links by both eNodeBs and UEs is achieved through this configuration “*.gnodeb* .cellularNic.nrPhy.enableD 2DCqiReporting = true”. This functional feature enables a robust way to measure communication channel quality, which in turn contributes towards effective resource allocation as

In addition, the line “.”usePreconfiguredTxParams = false” is noteworthy since it purposefully switches off pre-defined transmission parameters. Instead, this configuration emphasizes the direction of constant adjustments depending on live conditions in a network that improves adaptability and efficiency for VoIP-D2D.The configuration afterward determines which vehicles are selected to communicate with other cars using D2D for VoIP communication. This fine-grained detailing enhances the practicality of a simulation scenario, making it more realistic and adding to its precision regarding depicting nuance in VoIP-D2D communication.

```
# ----------------------------------------------------------------------------- #
# Config "VoIP-D2D"
#
# In this configuration, UEs run a VoIP application (using UDP as transport layer protocol)
# They communicate using the D2D link, if they are under the same cell
#
[Config VoIP-D2D]

**.amcMode = "D2D"

# D2D-capable flows are started in D2D mode
*.car[*].cellularNic.d2dInitialMode = true

# --- Select CQI for D2D transmissions --- #
#
# To enable the reporting of CQIs for each D2D link, set the parameter *.gNodeB.cellularNic.phy.enableD2DCqiReporting
# To use fixed CQI, set the parameter **.usePreconfiguredTxParams and select the desired CQI using the parameter **.d2dCqi
*.gNodeB*.cellularNic.nrPhy.enableD2DCqiReporting = true
**.usePreconfiguredTxParams = false

# each car transmits using D2D to the following one
*.car[*].numApps = 1
*.car[0].app[0].typename = "VoIPSender"
*.car[0].app[0].destAddress = "car[2]"
*.car[2].app[0].typename = "VoIPReceiver"

*.car[1].app[0].typename = "VoIPSender"
*.car[1].app[0].destAddress = "car[3]"
*.car[3].app[0].typename = "VoIPReceiver"
```

Figure 4.17: Setting up VoIP-D2D(V2V)

4.5 C-V2X for 5G

5G cellular vehicle-at-all (CV2X) technology uses a specially designed network design to improve communication efficiency and facilitate the flow of information in a constantly changing vehicular communication. In this context, the network consists of separate cells, each supported by its dedicated base station. The cell coverage areas are strategically arranged to ensure full territorial coverage. Importantly, the standardized system provides seamless communication as vehicles equipped with C-V2X capabilities traverse coverage areas. Seamless communication is essential for the transmission of critical information immediately, such as traffic updates and safety alerts, thus improving the overall performance of communication systems—top-notch service experience in situations where smooth connectivity and prompt information sharing are of utmost importance. Figure 4.18 illustrates the design for 5G CV2X using OMNeT++ software.

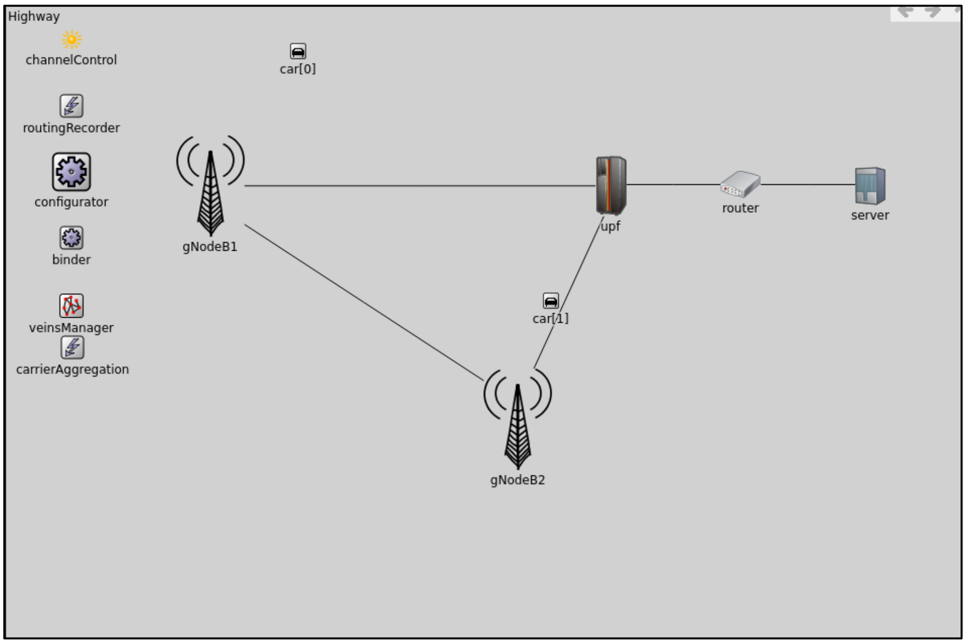


Figure 4.18: C-V2X Design Network

The C-V2X design integrates multiple essential components and functionalities. The INET Framework offers modular and hierarchical architectures by utilising submodules within NED files. It enables the user to arrange and encapsulate efficiently. Integrating functionality into network models simplifies the management and modification of simulations. Figure 4.19 shows the NED file for router used in this project which was obtained from INET library.

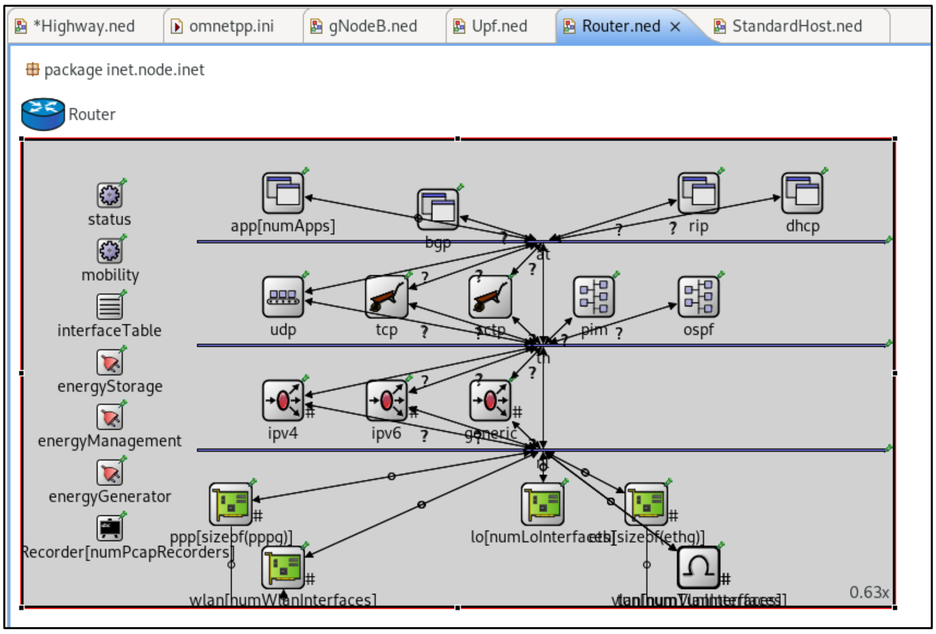


Figure 4.19: The NED Editor in Graphical Editing Mode for Router

Next, in Figure 4.20 shows the NED file for standard host used in this project that available in Inet Library.

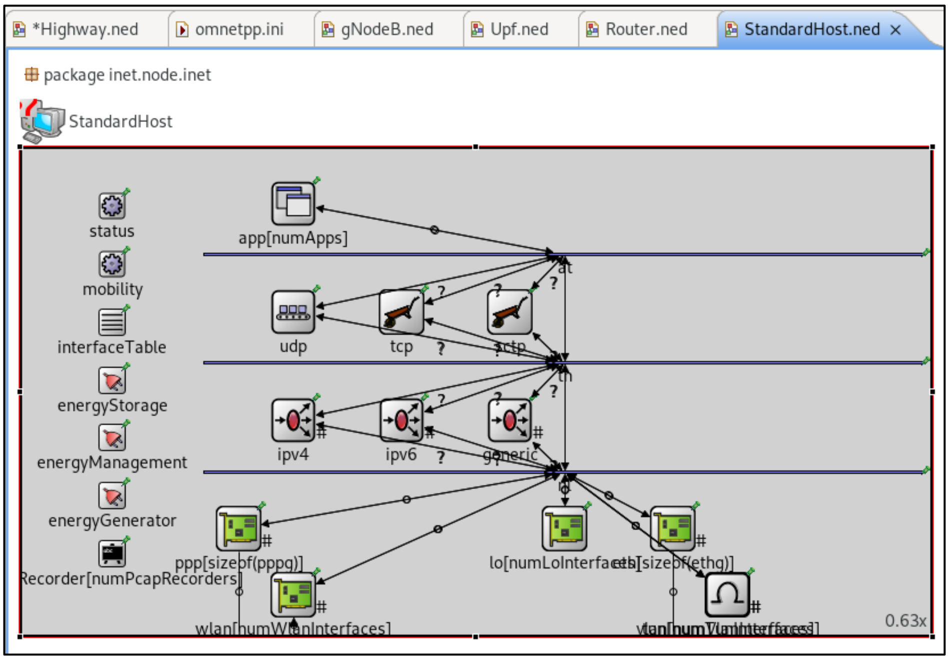


Figure 4.20: The NED editor in Graphical Editing Mode for Standard Host

Simu5G is a library designed specifically for simulating 5G networks within the OMNeT++ simulation environment. The Simu5G library comprises a set of NED files that delineate the architecture and constituents of 5G networks, encompassing base stations, user equipment, core network elements, and several protocols and interfaces employed in 5G communication. The pre-defined NED files serve as the fundamental basis for constructing and tailoring 5G network simulations. Users can focus on establishing connections by utilizing the NED files given by the Simu5G library. Simulation parameters and testing can be conducted without the necessity for manual development or production of NED files for the fundamental components of the 5G network. When implementing simulations, this can result in time and energy savings. Figure 4.21 shows the Ned file for Upf package in Simu5G library.

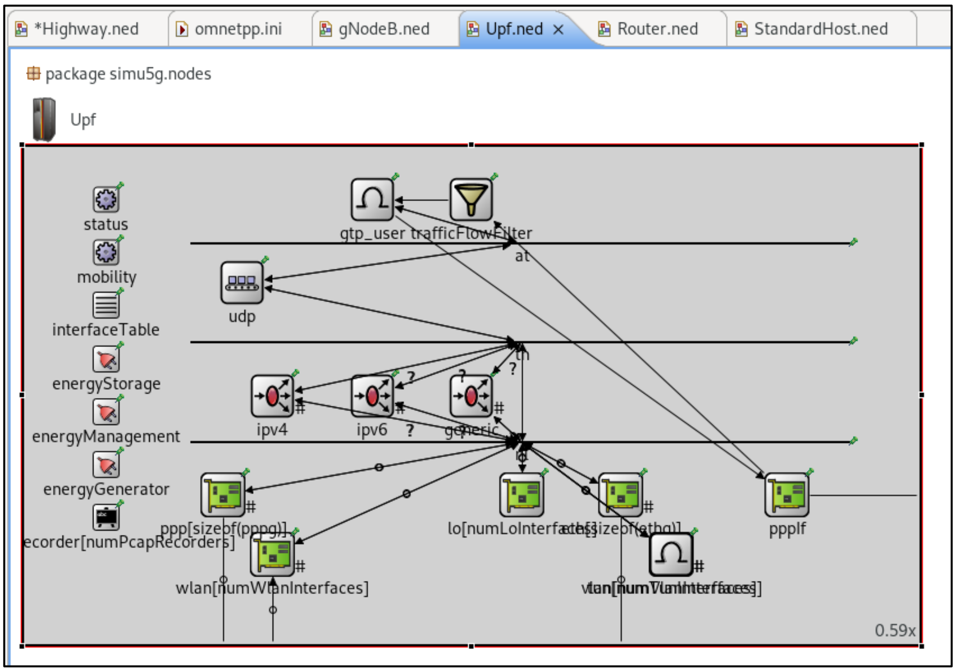


Figure 4.21: The NED editor in Graphical Editing Mode for Upf

Figure 4.22 depicted the gNodeB from Simu5G library used for this project.

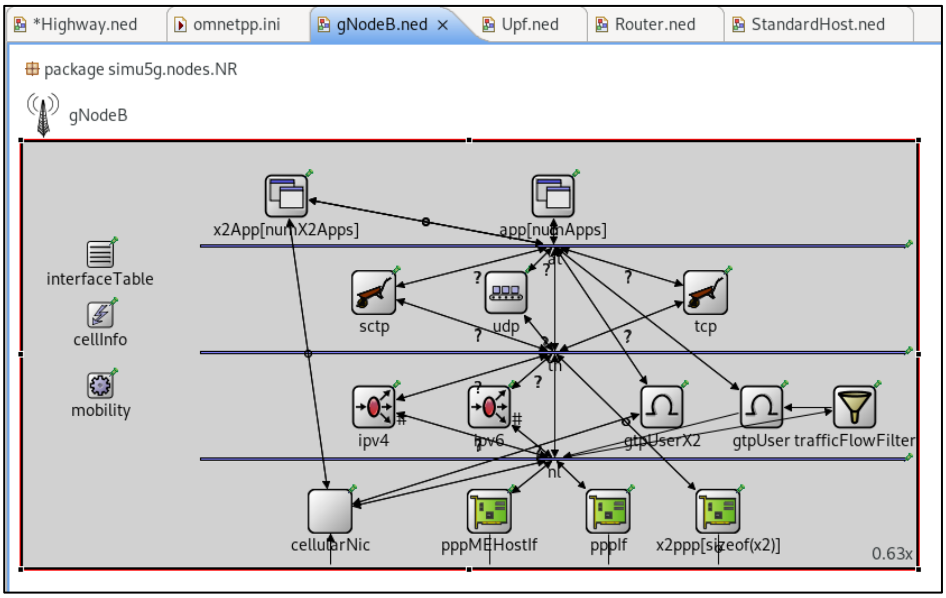


Figure 4.22: The NED editor in Graphical Editing Mode for gNodeB

4.6 Parameter Results

This simulation was to get the findings for a parameter's throughput, latency, and packet loss. There are two scenarios for this research.

a. Scenario 1: Vehicle-To-infrastructure (V2I)

Figure 4.23 shows the first scenario is Vehicles to Infrastructure when Vehicles communicate directly with the base station.

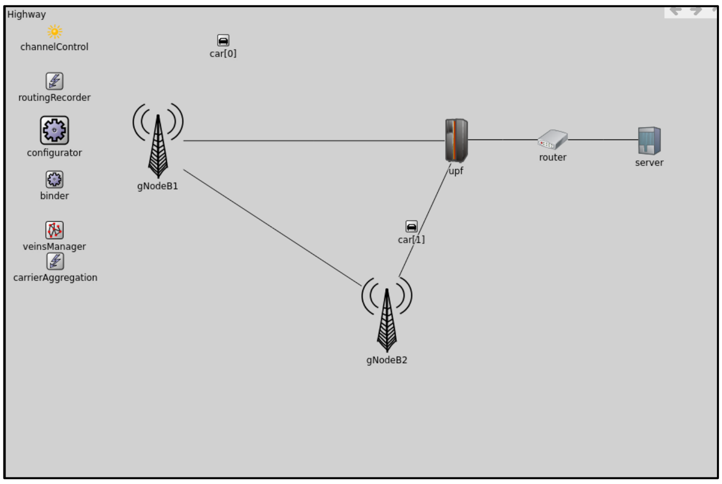


Figure 4.23: Design Simulation for V2I

The 5G C-V2X graph in Figure 4.24 shows that Car 0 has a very clear trend. A signal is transmitted by Car 0 to the base station initiate. It has been noticed that there is a momentary signal drop, then stabilization. The dip of the signal profile means that the vehicle has taken a purposeful stop, during which it ceases to broadcast for some time and waits for the appropriate moment when it will connect to the base station without any interruptions.

A fascinating note on the graph is that Car 0 communicates with a base station for less than a half millisecond. Temporal efficiency is proof that the system has low latencies. The short duration of this communication interval demonstrates the effectiveness of such a system for very rapid, almost instantaneous data transfer.

In addition, it shows that car 0 can achieve even 13 gigabits per second (Gbps). This throughput capability of car 0 underscores the practicality of using 5G C-V2X for high-speed and large-scale data transfer. Therefore, low-latency communication combined with a high data rate makes Car 0 a qualified participant in car communications in the coming era of 5G.

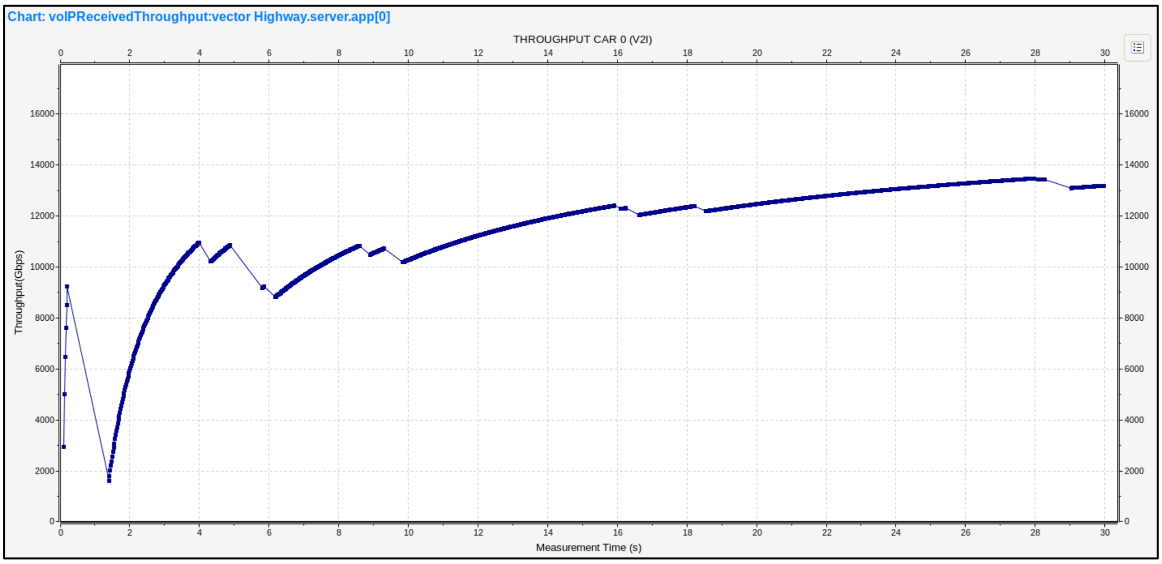


Figure 4.24: Throughput Car 0 (V2I)

In Figure 4.25, the messages exchanged between car 1 and the base station are uninterrupted. A precise intersection occurs exactly at 0.1 milliseconds. Efficient, with little delay, shows immediate connection establishment. Its rapid communication initiation demonstrates that the connection has a low latency feature. This finding enhances effectiveness by significantly reducing the time it takes to generate and establish a signal.

Furthermore, the graph indicates that it has a high data transfer rate. For example, Car 1 reaches data speed of about 12 Gbps. Therefore, this car can quickly transfer data within the 5G C-V2X application systems framework. However, with its outstanding 5G CV2X capabilities, Car 1 can quickly and efficiently transmit large amounts of data. It helps develop latency and high-capacity vehicular communications.

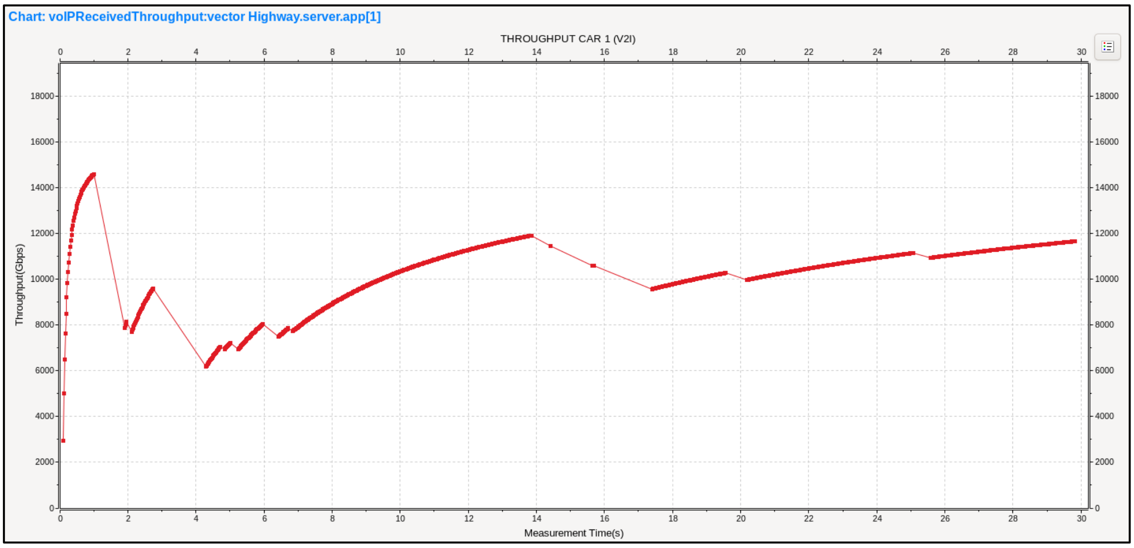


Figure 4.25: Throughput Car 1 (V2I)

Analyzing Figure 4.26 for C-V2X Car 0 and Car 1 communication in terms of effective communication efficiency shows great performance. The graph shows that car 0 communicates with the base station. However, despite this artificial intentional interruption, the temporal efficiency of Car 0 was rather impressive, given that it is under 0.5 milliseconds in terms of time constant. Here, it illustrates the latent low latency of this system, proving that information in it flows like lightning. In addition, Car 0 can achieve a speed of up to 13 Gbps. With a high speed of communication and a large quantity of data, car 0 will be one of the most outstanding practitioners concerning today's technology in mobility integrated into 5G.

However, there are different communication rules for car 1. There is no signal break; Car 1 could precisely connect at the point of 0. It reveals the quickness of connection, Car 1's low-delay characteristic. Because its low latency minimization capability reduces the time for initiating a signal to make actual contact, it shows how efficient it is. Furthermore, the data transmission rate of car 1 reaches up to 12 Gbps. Its transfer speed shows that car one is well equipped to handle fast data transmissions within the scope of its role in applications related to C-V2X technology.

Subtly different communication tactics used by Car 0 and Car 1 are also partially related to their different positions and distances from the base station. It may be closer to the base station, giving Car 1 stronger signals and thereby improving latency. However, Car 0 will experience a temporary reconnection as it searches for reliable connections in a distant location.

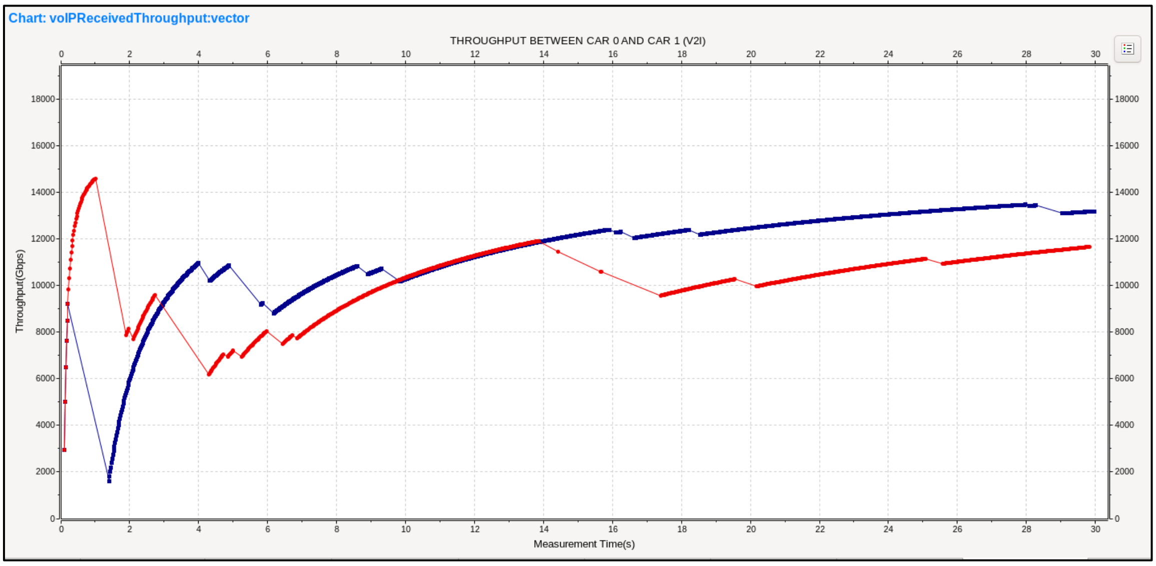
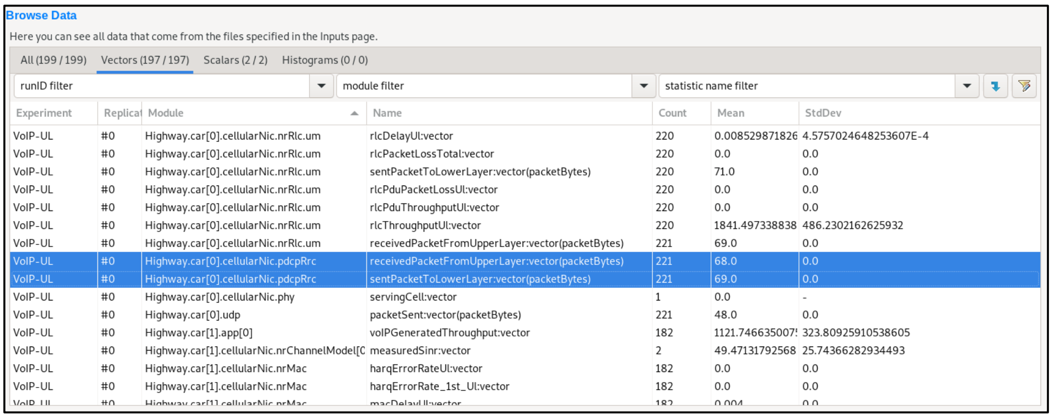


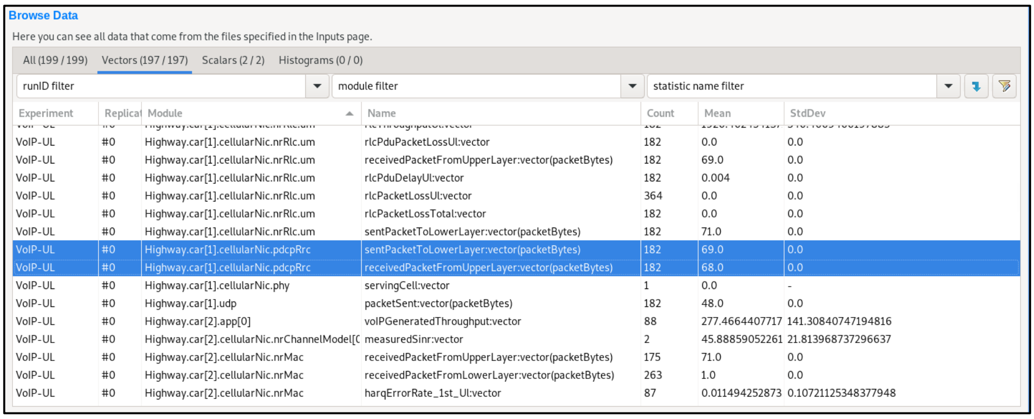
Figure 4.26: Comparison Throughput between Car 0 and Car 1 (V2I)

The 5G performance for all parameters is measured from the Output Vector View as shown in Figures 4.27 and 4.28. The results can be checked in the Output Vector View to look at numerical data. It can output the raw data extracted from a vector file or calculation result. Afterwards, the data can be represented as part of a point on a linear chart or vector in Dataset View by clicking it.



Experiment	Replicat	Module	Name	Count	Mean	StdDev
VoIP-UL	#0	Highway.car[0].cellularNic.nrRlc.um	rlcDelayUl:vector	220	0.008529871826	4.5757024648253607E-4
VoIP-UL	#0	Highway.car[0].cellularNic.nrRlc.um	rlcPacketLossTotal:vector	220	0.0	0.0
VoIP-UL	#0	Highway.car[0].cellularNic.nrRlc.um	sentPacketToLowerLayer:vector(packetBytes)	220	71.0	0.0
VoIP-UL	#0	Highway.car[0].cellularNic.nrRlc.um	rlcPduPacketLossUl:vector	220	0.0	0.0
VoIP-UL	#0	Highway.car[0].cellularNic.nrRlc.um	rlcPduThroughputUl:vector	220	0.0	0.0
VoIP-UL	#0	Highway.car[0].cellularNic.nrRlc.um	rlcThroughputUl:vector	220	1841.497338838	486.2302162625932
VoIP-UL	#0	Highway.car[0].cellularNic.nrRlc.um	receivedPacketFromUpperLayer:vector(packetBytes)	221	69.0	0.0
VoIP-UL	#0	Highway.car[0].cellularNic.pdcpRrc	receivedPacketFromUpperLayer:vector(packetBytes)	221	68.0	0.0
VoIP-UL	#0	Highway.car[0].cellularNic.pdcpRrc	sentPacketToLowerLayer:vector(packetBytes)	221	69.0	0.0
VoIP-UL	#0	Highway.car[0].cellularNic.phy	servingCell:vector	1	0.0	-
VoIP-UL	#0	Highway.car[0].udp	packetSent:vector(packetBytes)	221	48.0	0.0
VoIP-UL	#0	Highway.car[1].app[0]	voIPGeneratedThroughput:vector	182	1121.746635007!	323.80925910538605
VoIP-UL	#0	Highway.car[1].cellularNic.nrChannelModel[C	measuredSinr:vector	2	49.47131792568	25.74366282934493
VoIP-UL	#0	Highway.car[1].cellularNic.nrMac	harqErrorRateUl:vector	182	0.0	0.0
VoIP-UL	#0	Highway.car[1].cellularNic.nrMac	harqErrorRate_1st_Ul:vector	182	0.0	0.0

Figure 4.27: Output Vector View for Sent and Received Packet for Car 0



Browse Data

Here you can see all data that come from the files specified in the Inputs page.

All (199 / 199) Vectors (197 / 197) Scalars (2 / 2) Histograms (0 / 0)

runID filter | module filter | statistic name filter

Experiment	Replicat	Module	Name	Count	Mean	StdDev
VoIP-UL	#0	Highway.car[1].cellularNic.nrRlc.um	rlcPduPacketLossUl:vector	182	0.0	0.0
VoIP-UL	#0	Highway.car[1].cellularNic.nrRlc.um	receivedPacketFromUpperLayer:vector(packetBytes)	182	69.0	0.0
VoIP-UL	#0	Highway.car[1].cellularNic.nrRlc.um	rlcPduDelayUl:vector	182	0.004	0.0
VoIP-UL	#0	Highway.car[1].cellularNic.nrRlc.um	rlcPacketLossUl:vector	364	0.0	0.0
VoIP-UL	#0	Highway.car[1].cellularNic.nrRlc.um	rlcPacketLossTotal:vector	182	0.0	0.0
VoIP-UL	#0	Highway.car[1].cellularNic.nrRlc.um	sentPacketToLowerLayer:vector(packetBytes)	182	71.0	0.0
VoIP-UL	#0	Highway.car[1].cellularNic.pdcpRrc	sentPacketToLowerLayer:vector(packetBytes)	182	69.0	0.0
VoIP-UL	#0	Highway.car[1].cellularNic.pdcpRrc	receivedPacketFromUpperLayer:vector(packetBytes)	182	68.0	0.0
VoIP-UL	#0	Highway.car[1].cellularNic.phy	servingCell:vector	1	0.0	-
VoIP-UL	#0	Highway.car[1].udp	packetSent:vector(packetBytes)	182	48.0	0.0
VoIP-UL	#0	Highway.car[2].app[0]	voIPGeneratedThroughput:vector	88	277.4664407717	141.30840747194816
VoIP-UL	#0	Highway.car[2].cellularNic.nrChannelModel[(	measuredSinr:vector	2	45.88859052261	21.813968737296637
VoIP-UL	#0	Highway.car[2].cellularNic.nrMac	receivedPacketFromUpperLayer:vector(packetBytes)	175	71.0	0.0
VoIP-UL	#0	Highway.car[2].cellularNic.nrMac	receivedPacketFromLowerLayer:vector(packetBytes)	263	1.0	0.0
VoIP-UL	#0	Highway.car[2].cellularNic.nrMac	harqErrorRate_1st_Ul:vector	87	0.011494252873	0.10721125348377948

Figure 4.28: Output Vector View for Sent and Received Packet for Car 1

Examining the graph representing the sent packet and received packet by car 0 is the same in Figure 4.29. It also shows the relationship between the results of the throughput graph, which shows how much data is transferred when communicating between the vehicle and the base station. Significantly, when the throughput graph decreases, the connection is fleetingly severed before being reestablished and returning to a steady state. Thus, the lack of linearity in the findings becomes apparent whenever the throughput decreases.

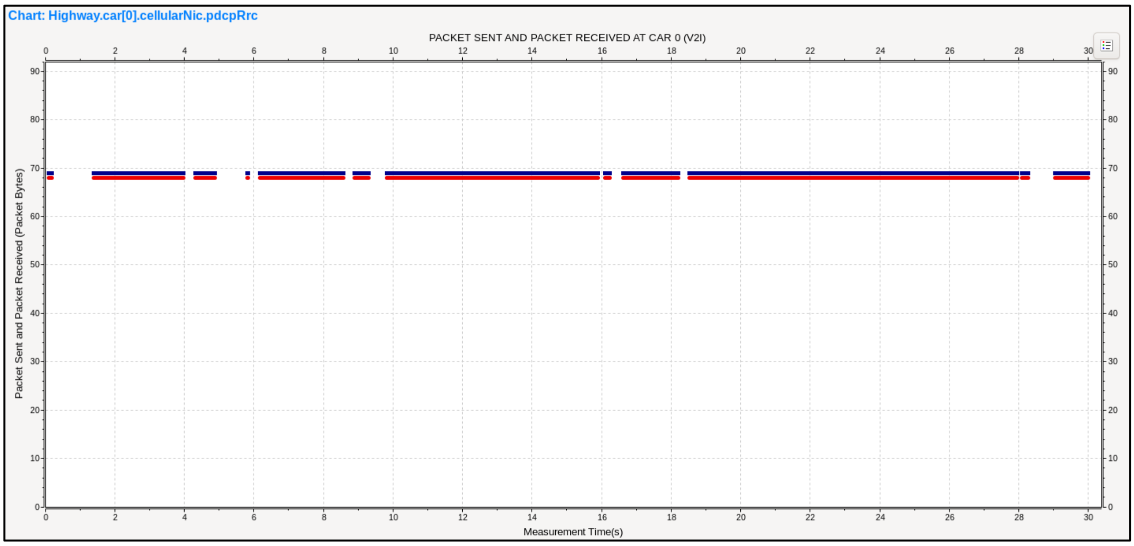


Figure 4.29: Packet Sent and Packet Received at Car 0 (V2I)

The findings indicate that the value of the packets that were transmitted and those that were received is the same as shown in Figure 4.30. It demonstrates the effectiveness of the network, a consistent match telling that the network can handle data traffic reliably; it is evidence that C-V2X can assist in achieving low latency, which is of great significance to customers because it will help reduce disruptions and provide a seamless experience..

Acknowledging that this real-time simulation provides a view from the network provider's perspective is essential. The network provider's connection can detect this transient disturbance, which the end user may ignore. Significantly, this intermittent disruption in the relationship negatively affects the customer's overall experience. The dynamics of the vehicle are a factor in these problems. Vehicle speed introduces dynamic variables that affect the rate of communication.

In summary, interlinked diagrams highlight occasions when a connection experiences temporary interruptions due to changes in data flow. The network provider gains valuable insight into these events and provides a unique background perspective. Reassuringly, though, these occasional glitches have no noticeable impact on the end user. The strategic difference is that the real-time simulation considers some network features that cannot be observed during regular operation of the 5G C-V2X technology, especially when the vehicle is moving.

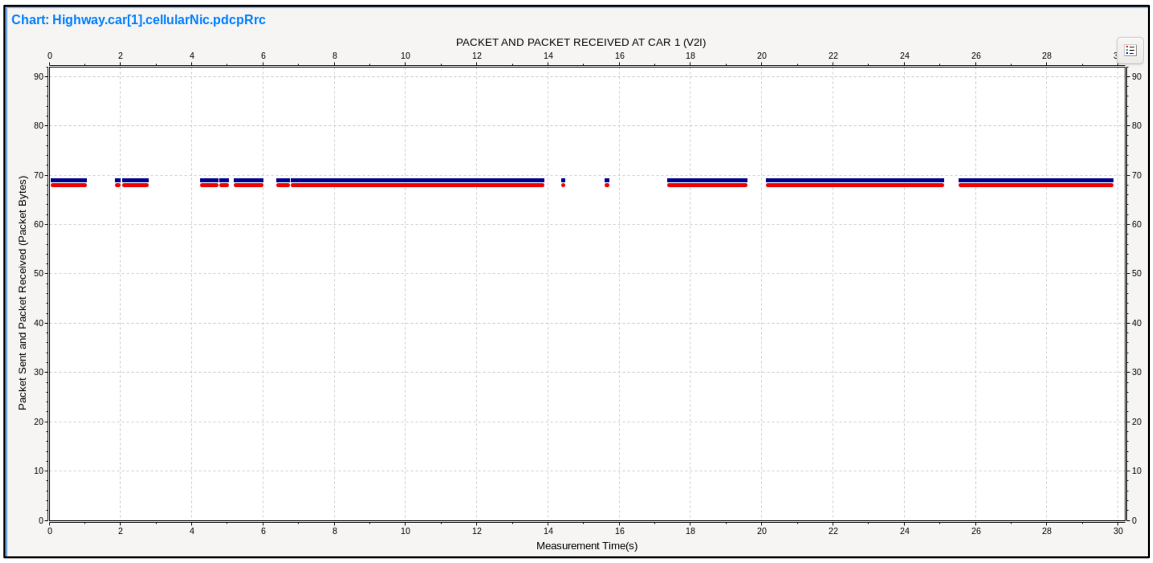


Figure 4.30: Packet Sent and Packet Received at Car 1 (V2I)

Delay refers to the duration required for data to get from a source to a destination across a network. It is a crucial performance measure that affects the responsiveness, efficiency, and user experience of network applications. This simulation result for the average delay measured at car 0 is 0.004 ms, as shown in Figure 4.31.

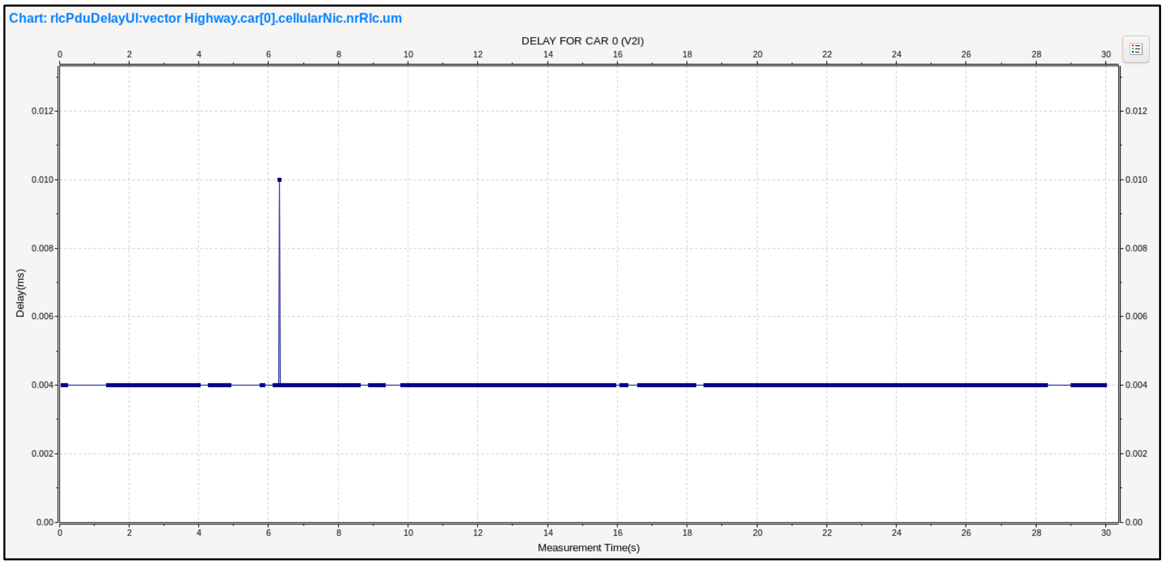


Figure 4.31: Delay for Car 0 (V2I)

Figure 4.32 shows average delay measured at Car 1 is 0.004ms.

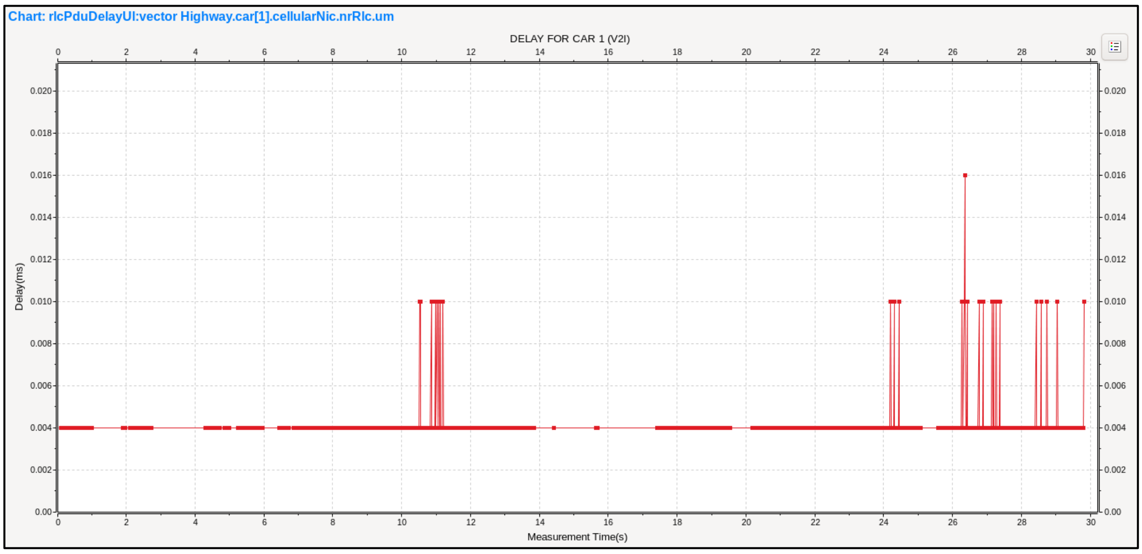


Figure 4.32: Delay for Car 1 (V2I)

As shown in Figure 4.33 average delay value for both Car 0 and Car 1 is 0.0014ms which is smaller than the value specified by 5G, 1ms.

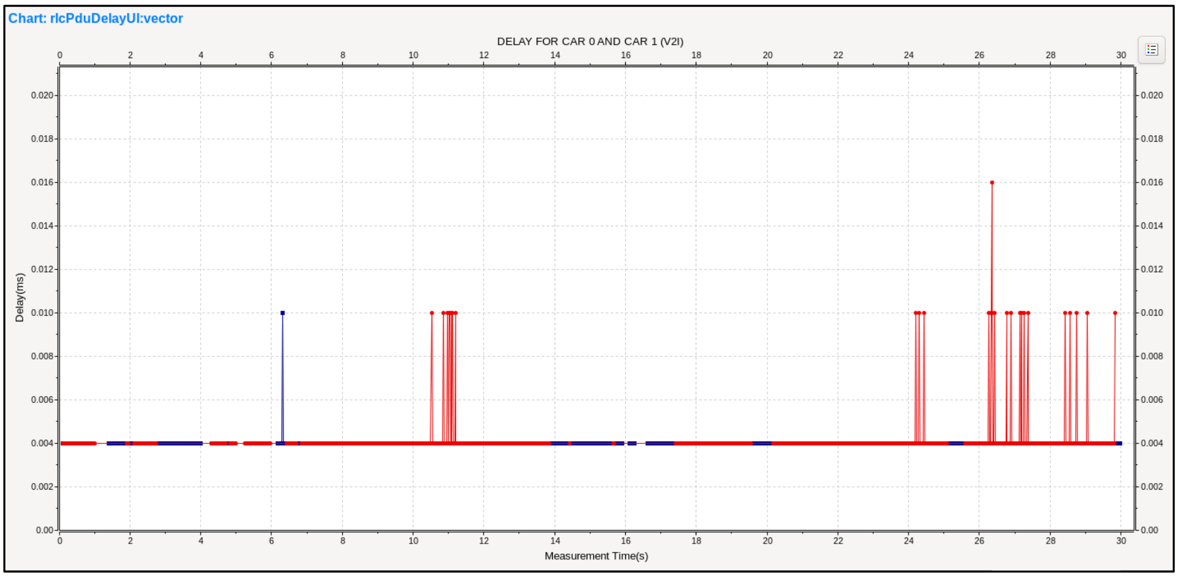


Figure 4.33: Delay for Car 0 and Car 1 (V2I)

Packet loss refers to one or more data packets being lost or failing to be transmitted successfully over a network. Data is frequently divided into packets in network communication to facilitate efficient transfer. Figure 4.34 shows that the graph indicates that both car 0 and car 1 have had no packet loss. However, there is no loss of data throughout the transmission process, which would hinder the transfer of data.

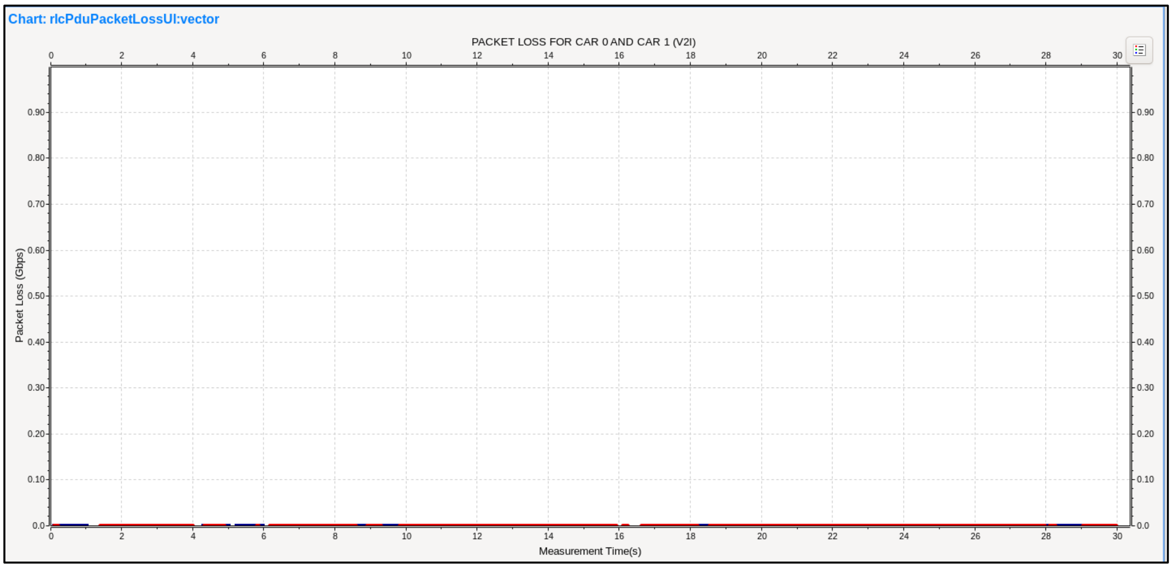


Figure 4.34: Packet Loss for Car 0 and Car 1 (V2I)

b. Vehicle-To-Vehicle(V2V)

Figure 4.35 shows scenario two is Vehicles-to-Vehicles, or in terms of C-V2X, it is called V2V. For this part it has two pairs. Pair 1 is Car 0 and Car 2, while Pair 2 is Car 1 and Car 3.

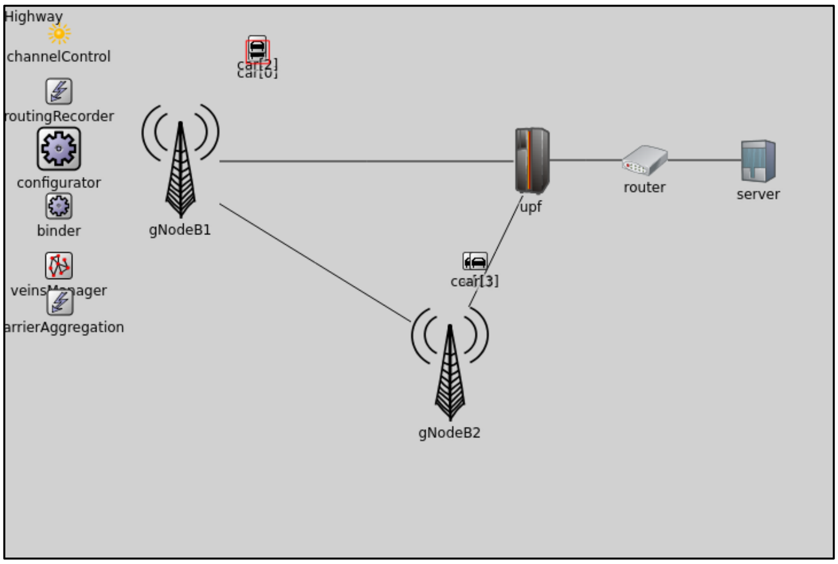


Figure 4.35: Design Simulation for V2V

Figure 4.36 shows the signal transmission between two vehicles, denoted as Pair 1. Notably, the signal reception by Pair 1 initiates precisely at 5.0 s showcasing the temporal synchronization of communication events. The corresponding throughput achieved during this communication exchange is recorded at 7 Gbps.

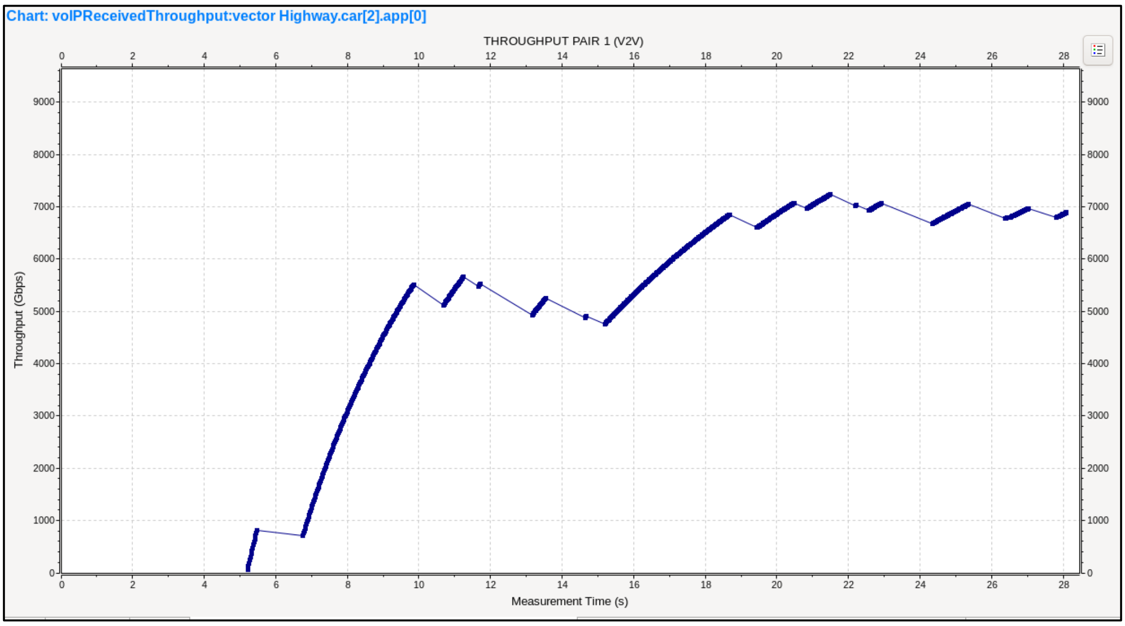


Figure 4.36: Throughput Pair 1 (V2V)

Figure 4.37 explains the signal transmission process of Pair 2. Noteworthy is the temporal alignment of this communication event, with Pair 2 commencing signal reception precisely at 5.2 s. This temporal precision emphasizes the coordinated efficiency of the 5G V2V C-V2X framework. Furthermore, the data throughput in this instance of communication reaches 11Gbps.

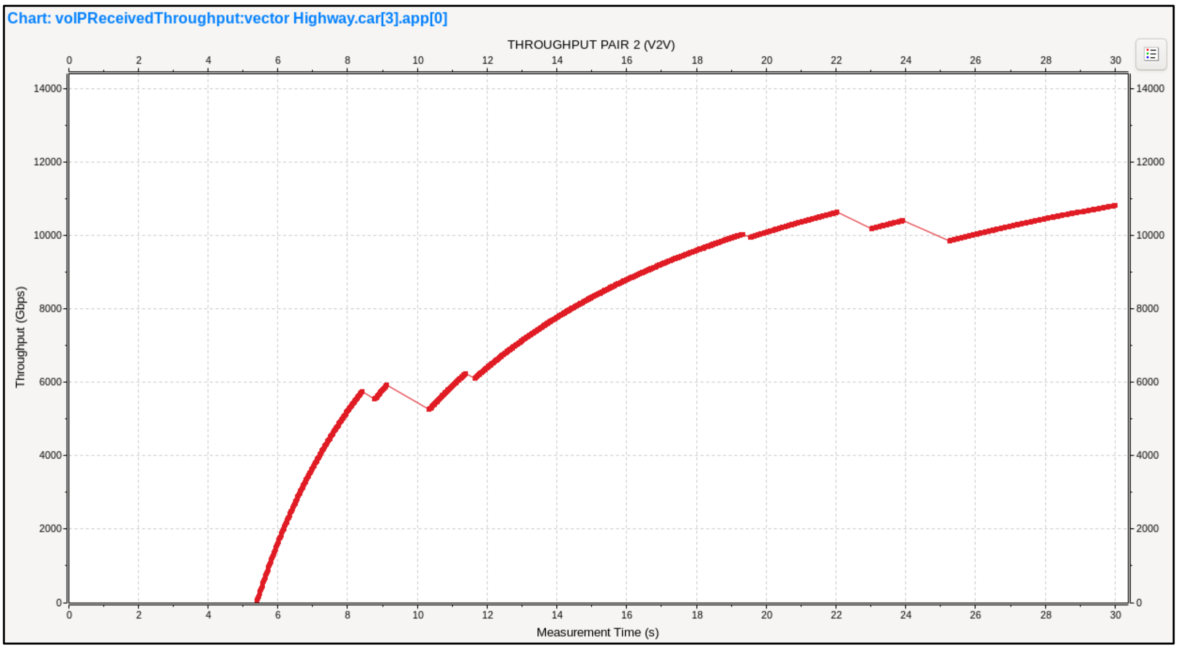


Figure 4.37: Throughput Pair 2 (V2V)

In Figure 4.38, the signal transmission of Pair 1, representing a synchronized communication event where the signal reception initiates precisely at 5.0s. The achieved throughput in this instance is recorded at 7 gigabits per second (Gbps), testifying to good data transmission capabilities inherent in this model of a 5G V2V C-V2X communications network.

However, it depicts a separate communication situation of Pair 2. Noteworthy in this context is the temporal alignment of the communication event, with Pair 2 starting signal reception at 5.2s This temporal precision underscores the coordinated efficiency of the 5G V2V C-V2X framework, although with a slight temporal variation compared to the scenario. Importantly, the data throughput achieved in this specific communication instance is notably higher, reaching 11 gigabits per second (Gbps). This difference in throughput values points to the changing nature of 5G V2V communication. Depending on distance, signal strength and network conditions, different vehicle pairs may have varying amounts capable of data transfer each second.

The above comparison of these figures collectively provides valuable pointers to the finer points of 5G V2V C-V2X communication. The throughput performance and transmission characteristics for different vehicular pairs may differ as well as share common features.

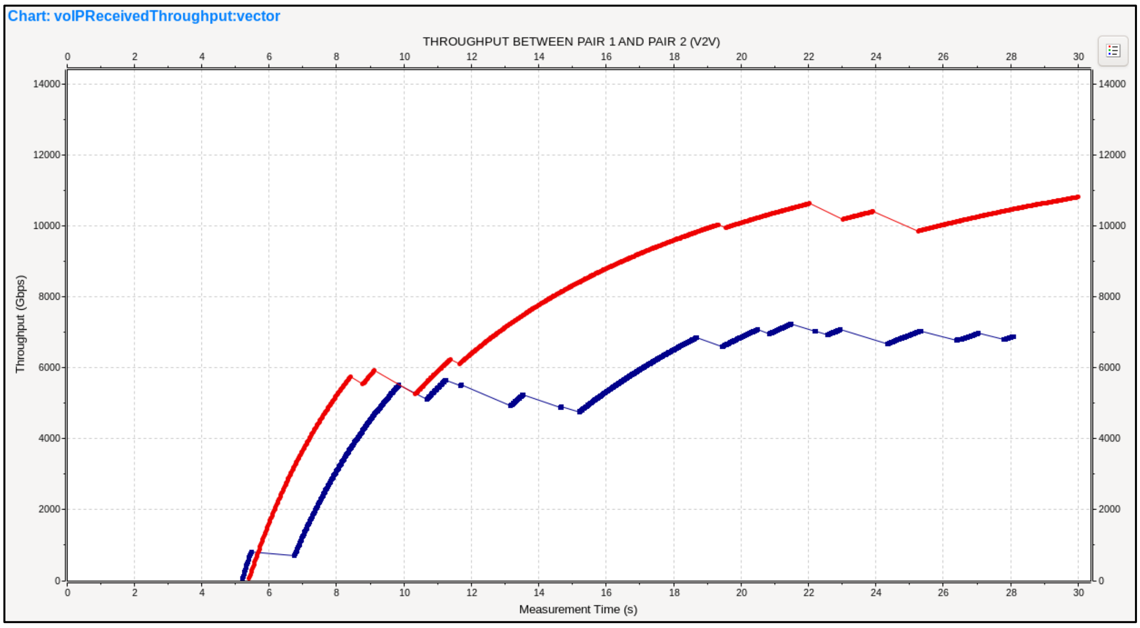


Figure 4.38: Comparison Throughput between Pair 1 and Pair 2 (V2V)

By analyzing the graph depicting the transmitted and received packets Pair 1 in Figure 4.39, one can observe the correlation between the outcomes of the throughput graph. This graph illustrates the amount of data exchanged during communication between vehicles. As the throughput graph declines, the connection is briefly interrupted before being restored and resuming to a stable condition. Therefore, the absence of a linear relationship in the results becomes evident when the throughput declines. The received packets for Pair 1 is equal to the transmitted packets.

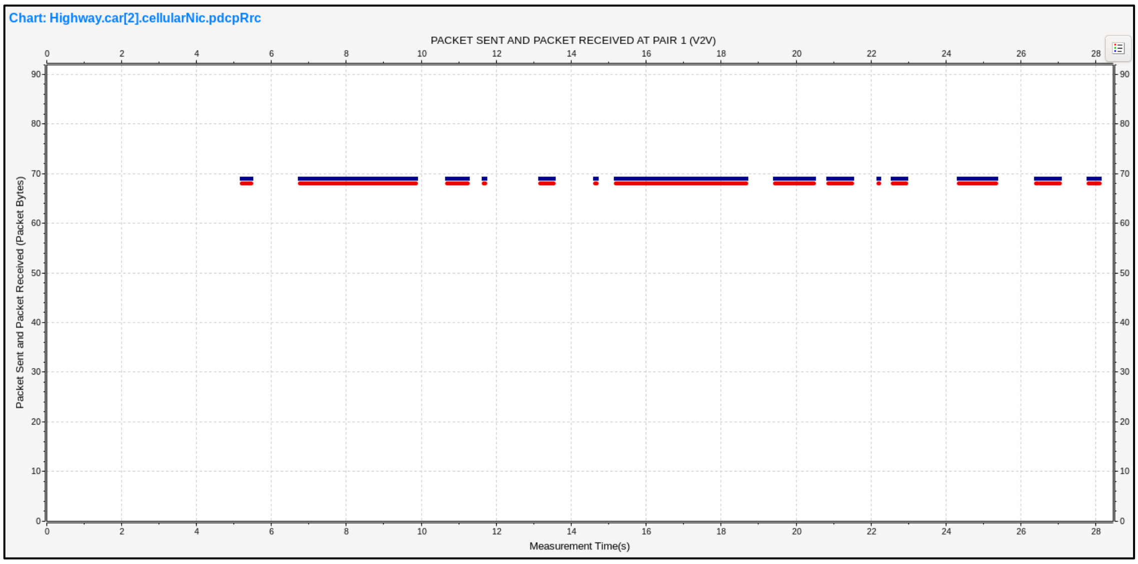


Figure 4.39: Packet Sent and Packet Received at Pair 1 (V2V)

The received packets for Pair 2 are shown in Figure 4.40, respectively. The data shows that the value of the transmitted packets is equal to the value of the received packets.

Both Pair 1 and Pair 2 showcases the network's efficacy, consistently proving its ability to handle data traffic with reliability. It proves that C-V2X can contribute to achieving low latency, which holds immense importance for customers as it aids in minimizing disruptions and ensuring a smooth experience.

It is crucial to recognize that this real-time simulation offers a perspective from the network provider's point of view. The network provider's connection can identify this temporary disruption, which the end user may overlook. The sporadic interruption in the relationship has a detrimental impact on the customer's overall experience. The vehicle's dynamics contribute to these issues. The speed of a vehicle is influenced by dynamic elements that contribute to the occurrence of these issues. The velocity of a vehicle introduces dynamic factors that impact the communication rate.

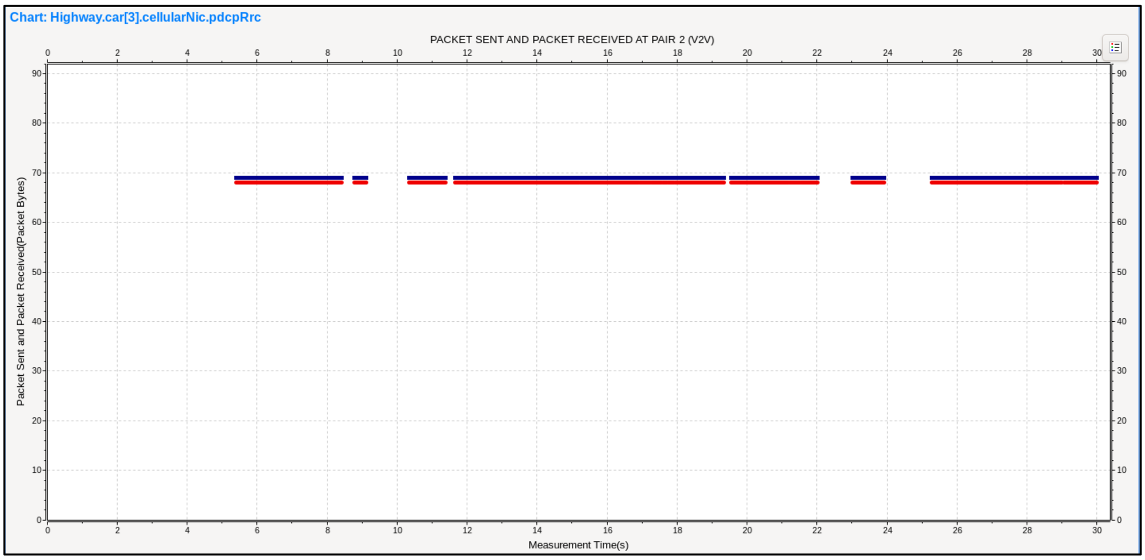


Figure 4.40: Packet Sent and Packet Received at Pair 2 (V2V)

This simulation result for the average delay measured at car 0 and 1 is 0.014 milliseconds, as shown in Figure 4.41.

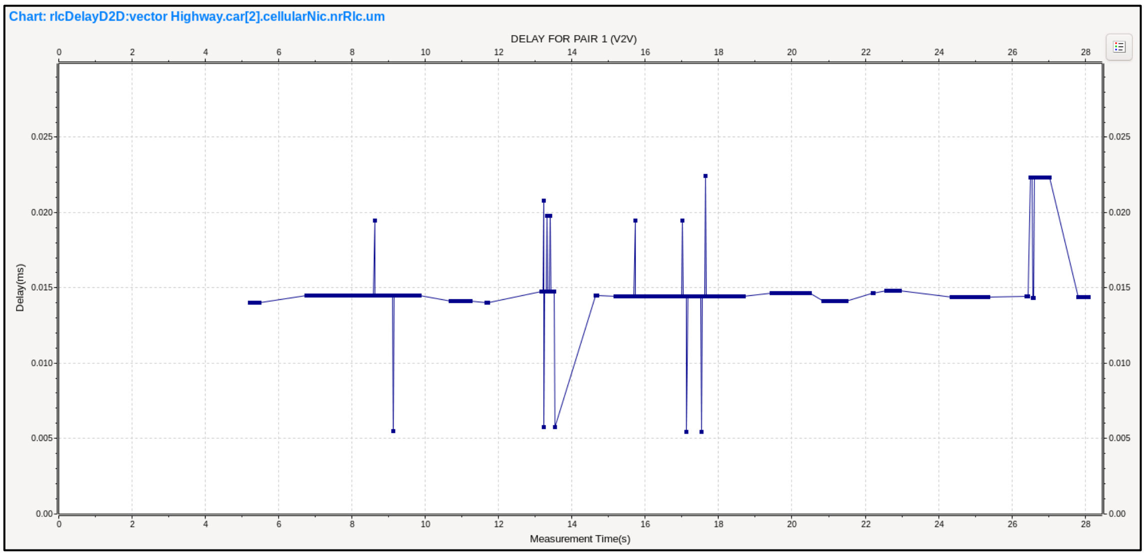


Figure 4.41: Delay for Pair 1 (V2V)

Figure 4.42 shows the average delay measure for Pair 2 is 0.014ms.

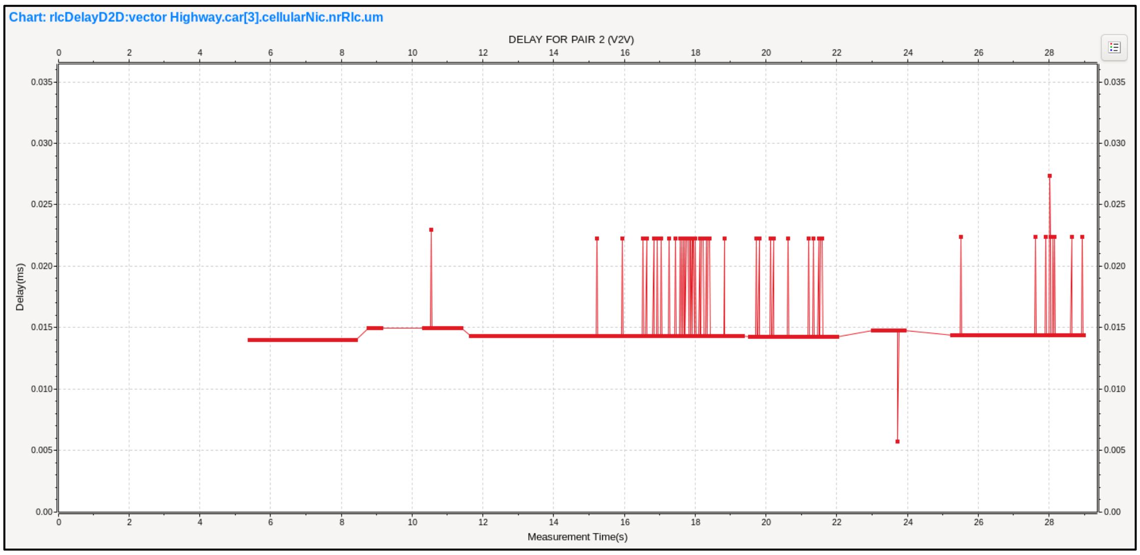


Figure 4.42: Delay for Pair 2 (V2V)

Both Pair 1 and Pair 2 average delay value are 0.0014ms and it is smaller than the value specified by 5G, 1ms. Figure 4.43 shows the increase and decrease quickly; this can occur owing to several factors. Firstly, it is caused by dynamic network conditions, where the vehicle is always in motion, leading to changes in the network conditions. As previously said, it refers to the exchange of information between two vehicles. Signal interference is caused by nearby structures, fluctuating signal intensities owing to distance, and dynamic network congestion.[31] Secondly, this might also occur due to resource allocation difficulties, which may arise from the demand for multiple interconnected vehicles. These modifications can lead to variations in latency as the network adjusts to the changing demands of the communication environment.[31]

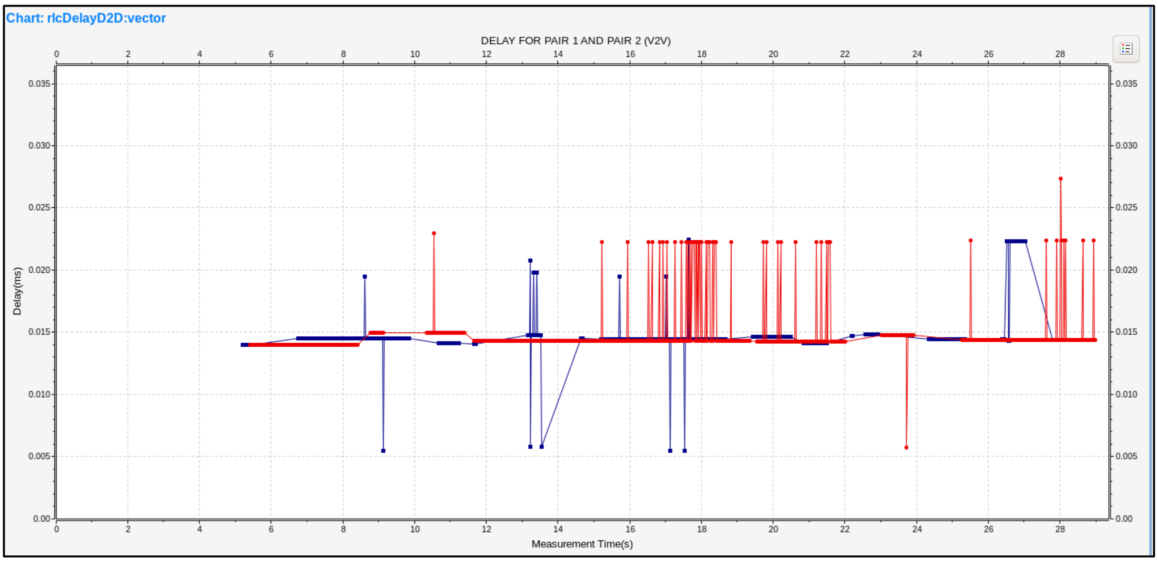


Figure 4.43: Delay for Pair 1 and Pair 2 (V2V)

Data is frequently divided into packets in network communication to facilitate efficient transfer. Figure 4.44 shows that the graph indicates that both car 0 and car 1 have had no packet loss. However, there is no loss of data throughout the transmission process, which would hinder the transfer of data.

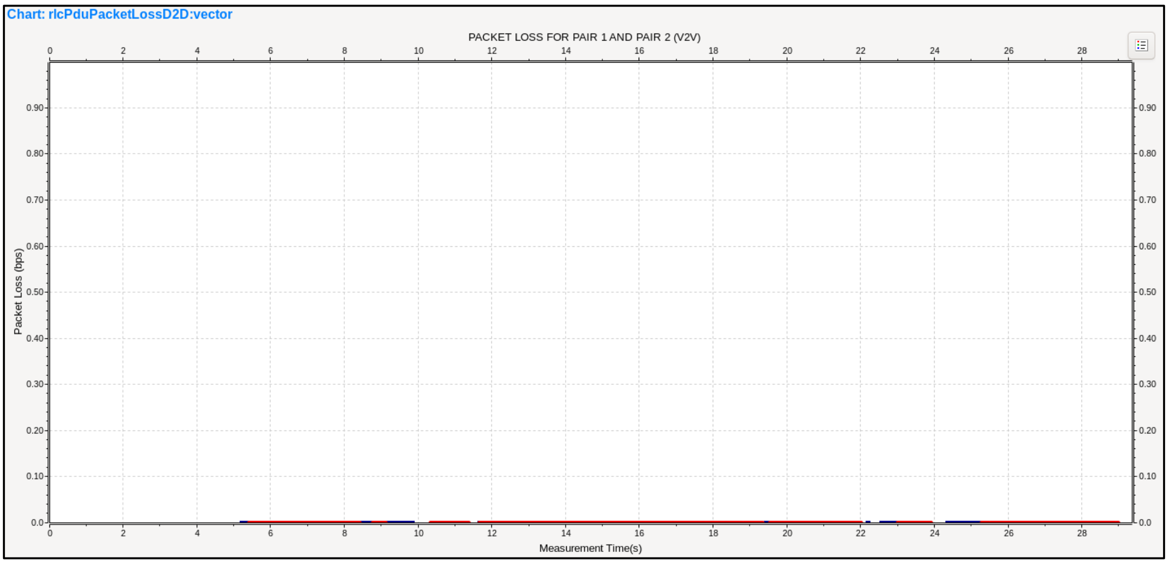


Figure 4.44: Packet Loss for Pair 1 and Pair 2 (V2V)

Therefore, in summary, the investigation focused on two distinct scenarios within the context of 5G Cellular Vehicle-to-Everything (C-V2X) communication: Vehicles to Infrastructure (V2I) and Vehicles to vehicles (V2V). To evaluate the efficiency of these communication methods used metrics such as throughput, latency, packet sent and packet received and packet loss in this examination. In the V2I scenario, Car 0 demonstrated an impressive throughput of 13 Gbps, proving the feasibility and scalability of V2I models over rapidly developed networks with large amounts of data required for real-time transmission. Car 1 exhibited a data speed of 12 Gbps, showing that it can quickly transfer large amounts of data. The latency of both vehicles was quite low, with Car 0 communicating with the base station in less than half a millisecond, emphasizing near-instantaneous data transfer.

Additionally, no packet loss was observed for Car 0 or Car 1. Demonstrating the stability of the network in handling data traffic. A comparison between Car 0 and Car 1 showed markedly different communication strategies, depending upon whether they were closer to or further from the base station.

Shifting focus to the V2V scenario, it showed how the signal transmits between different vehicle pairs. Pair 1 achieved a throughput of 7 Gbps, highlighting high-speed data transfer capabilities, while Pair 2 demonstrated an even higher throughput of 11 Gbps. Precise temporal synchronization in signal reception showcased coordinated efficiency in V2V communication. No packet loss was observed in this scenario, reaffirming the reliability of C-V2X in handling data traffic seamlessly. The average delay measured at Pair 1 and Pair 2 was only 0.014 milliseconds, even less than the one-millisecond threshold for commercial fifth-generation communication standards (5G). Fluctuations in delay were attributed to dynamic network conditions, signal interference, varying signal strengths, and network congestion. The research presented detailed information about 5G C-V2X, focusing on low latency and high throughput without packet loss. These conclusions add to our comprehension of vehicle communications systems and provide insight into how 5G technology can be integrated for better mobile experiences.

CHAPTER 5

CONCLUSION

5.1 Conclusion

This study examines the Quality of Service (QoS) metric in 5G networks. The study successfully simulated four characteristics, namely throughput, latency, packet sent, and packet received and packet loss, using the OMNeT++ program. This research focuses on C-V2X, a novel and advanced application in the context of 5G networks. In order to guarantee the transmission of data at a superior level of excellence, CV2X should prioritize the network by implementing Quality of Service (QoS).

As stated in Chapter 4, the analysis primarily examined two specific scenarios in the framework of 5G Cellular Vehicle-to-Everything (C-V2X) communication: Vehicles to Infrastructure (V2I) and Vehicles to Vehicles (V2V). In this evaluation, the efficiency of these communication techniques is assessed using measures such as throughput, latency, number of packets transmitted and received, and packet loss. Car 0 achieved a remarkable throughput of 13 Gbps in the V2I scenario, which confirms the practicality and expandability of V2I models across rapidly deployed networks that handle substantial volumes of data needed for immediate transmission. Car 1 demonstrated a transmission speed of 12 Gbps, indicating its ability to transfer substantial quantities of data rapidly. Both vehicles exhibited minimal latency, as Car 0 established communication with the base station in just 0.5 milliseconds, highlighting the nearly immediate data flow.

In addition, packet loss was not observed for Car 0 or Car 1. They illustrated the network's capacity to manage data flow without disruptions efficiently. Car 0 and Car 1 exhibited distinct communication techniques, which varied based on their proximity to the base station.

Turning attention to the V2V scenario, it demonstrated the transmission of signals between several pairs of vehicles. Pair 1 attained a data transfer rate of 7 Gbps, showcasing its ability to transfer data at high speeds. In comparison, Pair 2 exhibited a higher throughput of 11 Gbps. Demonstrating precise temporal synchronization in signal reception highlighted the coordinated efficiency in V2V communication. There was no packet loss in this situation, which confirms the dependability of C-V2X in efficiently managing data flow. The average delay recorded at Pair 1 and 2 was a mere 0.014 milliseconds, which falls below the one-millisecond barrier set for commercial 5G communication standards. The variations in latency were ascribed to the dynamic characteristics of the network, signal interference, fluctuating signal intensities, and congestion in the network.

This research provided an in-depth analysis of 5G C-V2X, specifically emphasizing its low latency and high throughput capabilities while ensuring little packet loss. These findings enhance our understanding of vehicle communication systems and offer valuable insights for integrating 5G technology to enhance mobile experiences.

This research is relevant to Sustainable Development Goals (SDG), specifically SDG number 8, which focuses on promoting decent work and economic growth. 5G CV2X technology facilitates improved transportation efficiency by enabling advanced connectivity between vehicles and infrastructure. Enhancing efficiency can result in a more seamless movement of vehicles, decreased traffic congestion, and optimised management of goods and services, enhancing total economic production. The following SDG is number 13, which focuses on climate action. CV2X, enabled by 5G, enables sophisticated communication among vehicles, infrastructure, and other road users. This link improves the ability to control traffic in real-time, enabling the optimisation of routes based on the present traffic conditions. Minimising congestion enhances the operational efficiency of cars, resulting in reduced fuel consumption and decreased greenhouse gas emissions.

5.2 Future Works

This thesis evaluates four crucial characteristics, namely throughput, delay, packet sent and packet received and packet loss, in the context of Vehicle-to-Everything communication, focusing on two scenarios: Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V). The Quality of Service (QoS) in the 5G network, namely within the CV2X architecture, is receiving increasing attention due to the ongoing evolution of communication technology.

While the present research provides valuable insights into V2I and V2V scenarios, including 5G technology, it adds a layer of complexity. Subsequent research can examine the effects of 5G Quality of Service (QoS) characteristics, such as latency, reliability, and bandwidth allocation, on the performance of V2X communication. Therefore, it is critical to comprehend the influence of 5G technology in these vital domains to advance and enhance communication systems for future vehicle connectivity.

In addition, exploring vehicle-to-pedestrian (V2P) and vehicle network-based scenarios could be a promising avenue for future research. Within V2P (Vehicle-to-Pedestrian) scenarios, there would be a heightened emphasis on enhancing safety and coordination in urban settings by examining communication protocols employed between cars and pedestrians. This type of research may involve developing prompt warning systems for drivers regarding the presence of pedestrians and alert systems for pedestrians in the event of an approaching vehicle.

Simultaneously, examining V2N scenarios necessitates analysing the interaction between vehicles and external network infrastructure. Effective communication between vehicles and network components, including roadside units, traffic control systems, and cloud-based services, is crucial for this interaction. Future research in V2N could prioritise enhancing connectivity, guaranteeing dependable data exchange, and addressing challenges such as network latency and resource allotment.

An examination of the quality of service (QoS) of 5G in heterogeneous vehicle-to-person (V2P) and vehicle-to-everything (V2X) scenarios is proposed. This approach addresses these scenarios' increasing issues and opportunities, allowing for a comprehensive knowledge of the intricate dynamics inherent in many V2X settings.

As technology advances, it is important to explore potential future research directions related to 5G Quality of Service (QoS) and other V2X situations. These research directions are critical for developing adaptable and robust V2X communication systems. These systems are necessary to accommodate the enormous variety of components in smart and connected settings, guaranteeing seamless and efficient communication for diverse concerns.

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