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Quality of Service Performance of Cellular Vehicle-To-Everything Communication in the 5G Network

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ABSTRACT

Cellular Vehicle-to-Everything (C-V2X) using Fifth Generation (5G) networks is a huge step forward in vehicle communication. It improves how cars, infrastructure, pedestrians, and networks all talk to each other, making the transportation system smarter and more efficient. This technology takes advantage of 5G's ultra-reliable low-latency communication (URLLC) and enhanced mobile broadband (eMBB) to allow real-time data sharing, which is crucial for self-driving cars and advanced driver assistance systems (ADAS). C-V2X lets vehicles share specific information about their speed, location, and direction. This makes it much less likely that two vehicles will collide and make traffic flow more smoothly overall. Communication between vehicles and infrastructure (V2I) improves traffic flow by talking to traffic lights and signs, which cuts down on traffic jams and uses less gas. Vehicle-to-pedestrian (V2P) communication keeps pedestrians safe by alerting both drivers and walkers at the right time. 5G's fast data rates and low delay make it possible for high-definition maps and real-time video files to be sent without any problems. These are necessary for accurate navigation and knowing what's going on around you. Technology also improves emergency response coordination by letting vehicles send real-time information to emergency services about where accidents are happening and how bad they are. This cuts down on reaction times and could save lives. By connecting 5G to C-V2X, not only does it make driving better, but it also helps society as a whole by reducing traffic, cutting down on pollution, and making roads safer. This makes the transportation environment smarter, safer, and more efficient.

Index terms- Cellular Vehicle-to-Everything, 5G, Vehicle-to-pedestrian, Ultra-reliable low-latency communication, Vehicles and Infrastructure.

INTRODUCTION

The fifth-generation cellular wireless network represents a major leap in connectivity, promising to revolutionize industries by enabling faster data speeds, ultra-low latency, and greater reliability. One significant application of 5G is in the realm of vehicular communication through Cellular-Vehicle-to-Everything (C-V2X) technology [1][2]. This advancement in modern transportation allows vehicles to communicate seamlessly with each other (V2V), with infrastructure (V2I), and with pedestrians (V2P), thereby improving road safety, optimizing traffic flow, and enhancing the overall driving experience. By leveraging the high throughput, low delay, and superior connectivity of 5G networks, C-V2X stands to greatly benefit from these capabilities, ensuring robust and efficient communication among vehicles and road users [3]. For this research, C-V2X technology will be connected via a 5G network, providing promising Quality of Service (QoS) essential for modern transportation needs [4]. The research will utilize the OMNeT++ simulation platform, chosen for its flexibility and compatibility with the SIMU5G framework. This combination of advanced simulation tools and cutting-edge communication technology positions the project to make significant strides in improving transportation safety and efficiency [5].

The integration of Cellular Vehicle-to-Everything (C-V2X) technology with Fifth Generation (5G) networks as in Fig. 1 represents a significant advancement in the field of intelligent transportation systems. Extensive research has been conducted to explore the potential benefits and challenges associated with this integration. Several studies have demonstrated the capabilities of C-V2X to achieve high reliability and ultra-low latency, essential for safety-critical applications [6][7]. For example, system-level simulations have highlighted the effectiveness of C-V2X in supporting collision avoidance systems and cooperative driving scenarios. These simulations have shown that C-V2X can provide robust communication channels, significantly enhancing road safety and traffic management [8].

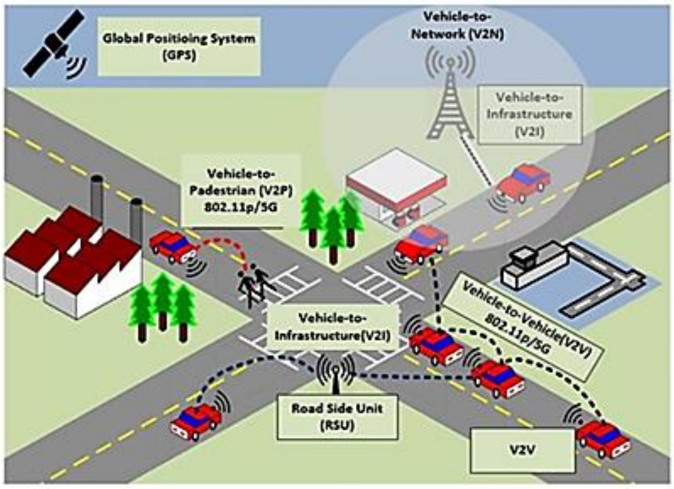

Fig.1 V2X Communication types [9]

Field measurements across multiple Mobile Network Operators (MNOs) have provided empirical insights into the performance of Long-Term Evolution (LTE) networks in supporting C-V2X applications [10-12]. Introducing Multi-access Edge Computing (MEC) architectures has proven effective in addressing these challenges, significantly reducing end-to-end delays, and improving overall Quality of Service (QoS) for critical applications [13-15]. Comparative analysis between LTE and 5G Test Networks (5GTN) has highlighted 5G's superiority in terms of throughput, delay, and network bandwidth. Field measurements in Arctic Finland have shown that 5GTN performs better than LTE, particularly for applications requiring high-speed data transmission and quick responses [16]. This performance advantage positions 5G networks as the future backbone for advanced C-V2X applications, capable of delivering enhanced functionalities crucial for next-generation vehicular communication systems [17-20].

Additionally, research has focused on the use of simulation platforms such as OMNeT++ to evaluate the performance of C-V2X within 5G network environments. These simulations consider various scenarios and network configurations to assess crucial performance metrics, including delay, throughput, and packet loss [21-24]. The findings from these simulations have provided valuable insights into the feasibility and effectiveness of integrating C-V2X with 5G networks to achieve optimal QoS parameters for intelligent transport systems [25-27].

In conclusion, the merging of C-V2X technology with 5G networks holds immense promise for advancing transportation safety and efficiency. The combination of C-V2X and 5G enables vehicles to exchange critical information swiftly and accurately, enhancing proactive responses to road conditions and potential hazards [28-30]. As research continues to push the boundaries of intelligent transport systems, the synergy between C-V2X and 5G networks exemplifies a transformative paradigm shift towards a connected and sustainable future for mobility. By leveraging advanced simulation tools and empirical studies, researchers

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can further explore and enhance the possibilities of C-V2X in 5G environments, leading to smarter, safer, and more efficient transportation systems [31-33].

RESEARCH METHOD

A discrete event simulation framework called Objective Modular Network Testbed in C++ (OMNeT++) primarily used for simulating communication networks and complex systems. It is open-source and component-based, making it easy to integrate simulations into various applications using a high-level language (NED). There are four tools involved in this OMNeT++ in this simulation including INET, SIMU5G, Veins and SUMO. Fig.2 explains the flow of designing the research in detail.

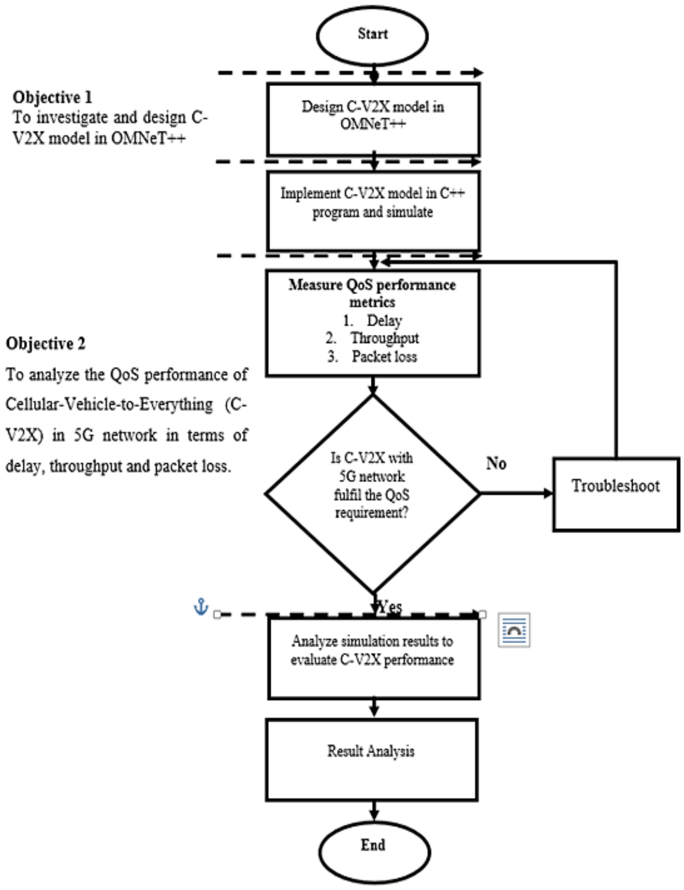

Fig 2 Flowchart in designing C-V2X

RESULTS AND DISCUSSION

Fig.3 shows that a network design labelled as “Highway” which describe a communication network setup. Several key components, including gNodeBs, are the base stations for 5G. It is responsible for communicating with mobile devices such as User Plan Function (UPF). The UPF is to handle data traffic between the gNodeBs and the core network. Another key component is a router which is for directing data packets within the networks and a server which provides various network services and applications. Additionally, there are also configuration icons such as Channel Control, which is for managing radio channels, Timing Order which is related to timing, Configurator for network configuration and Binder for managing bindings between network elements.

There are two scenarios involved in simulation, which are V2V and V2I. For V2V, there are 8 cars involved in this design simulation which are from car 0 to car 7. Each two cars are defined as a pair. Pair 1 is for car 0 and car 2, pair 2 is for car 1 and car 3, pair 3 is for car 4 and car 6 and lastly pair 4 is for car 5 and car 7. In this VoIP-D2D, cars 0, car 1, car 4 and car 5 are configured as the sender while other cars such as car 2, car

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3, car 6 and car 7 are configured as the receiver. Therefore, the sender will transmit the VoIP data packets to the receiver.

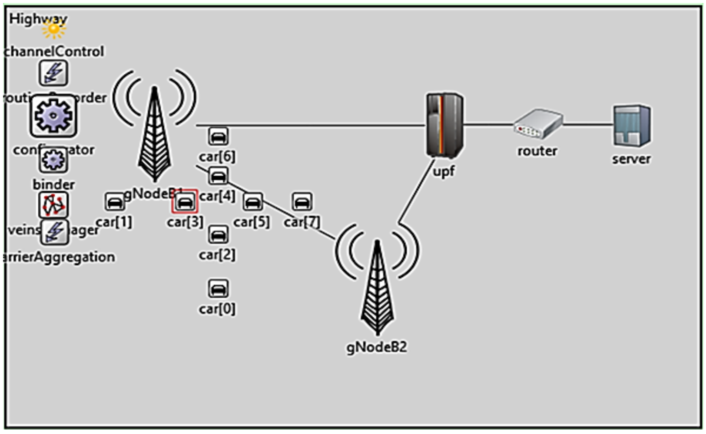

Fig.3 The Simulation Design

Fig.4 shows that comparison of throughput for V2V which is measured in bps over time between all pairs. Each pair represented by different colours. The blue line represents Pair 1, the red line represents Pair 2, the green line represents Pair 3, and the yellow line represents Pair 4. From this graph, Pair 2, the red line achieved the highest among overall throughput reaching at 10000 bps (10 kbps). The higher throughput indicates better performance in terms of data transmission rates and stability. This comparison is relevant for understanding the efficiency and capacity of different pairs in a network scenario.

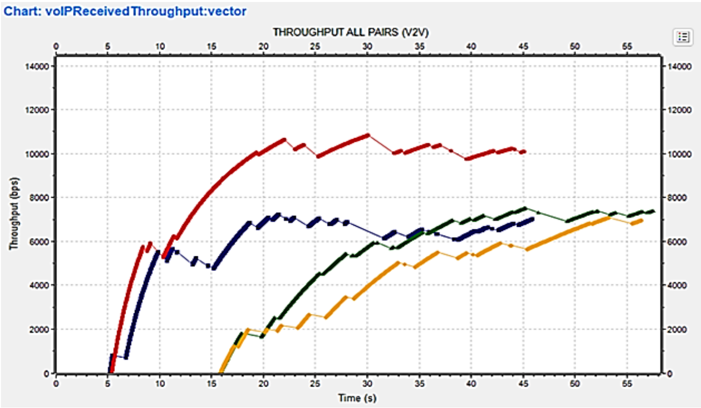

Fig.4 Throughput Comparison for V2V

Fig.5 explains the result of delay comparison for all pairs in graph over time for the V2V scenario. The x-axis represents time in seconds while the y-axis represents delay in seconds. These multiple-coloured lines represent different pairs, which are the blue line is for Pair 1, the red line is for Pair 2, the green line is for Pair 3, and the yellow line is for Pair 4. The chart visualized how delay varies over time for each pair. It provides insights into the performance and reliability of network communication for each pair.

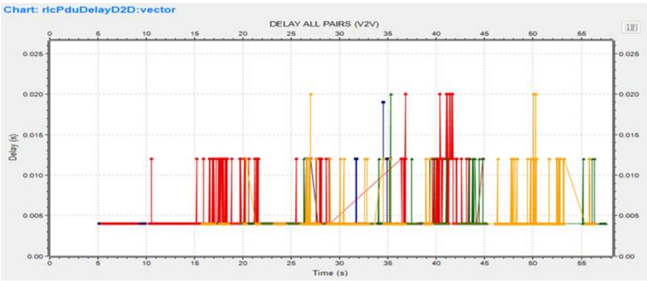

Fig.5 Delay Comparison for V2V

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Fig.6 indicates the parameter for amount of the succesful packet sent and received for four different pairs. Each chart plots the number of packet sent and packet received over time in seconds. Notably, all pairs observed the same number of packet sent and received which means that it is indicating consistent communication performance across the different pairs.

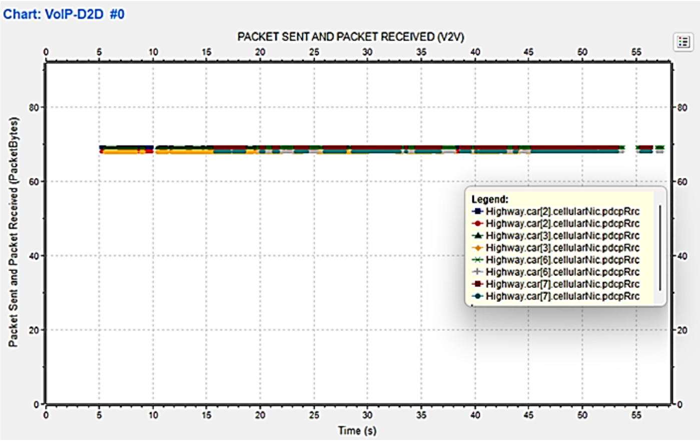

Fig.6 Comparison of Packet Sent and Packet Received for V2V

The next discussion refers to the process transmission of VoIP data from user's device to the wireless communication network infrastructure for V2I scenario. Fig.7 shows that a graph of throughput comparison in bps over time in seconds for different cars which are Car 0 to Car 7. The dark blue line represents Car 0, the red line represents Car 1, the dark green line represents Car 2, the yellow line represents Car 3, the light green line represents Car 4, the grey line represents Car 5, the brown line represents Car 6 and the light blue line represents Car 7. The graphs shows that how the throughput changes over time for each car. From the graph, Car 0 has achieved higher throughput than others with 12000 bps (12 kbps). However, this comparison highlights the performance differences between the cars in terms of data transmission rates. It can be crucial for applications requiring high speed communication.

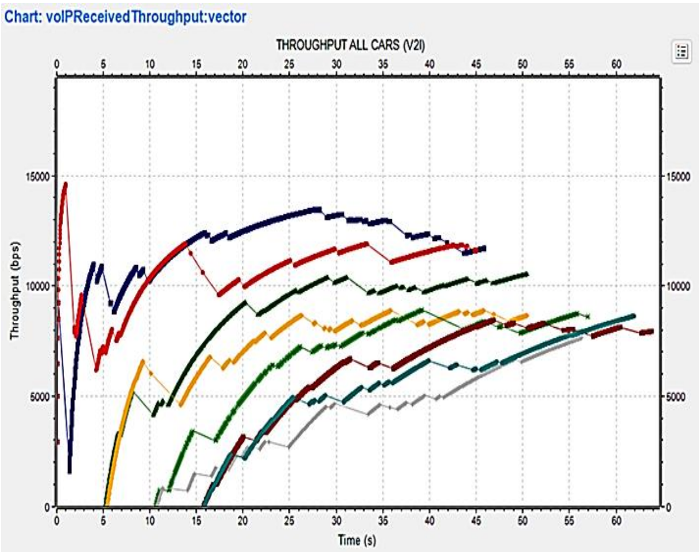

Fig.7 Throughput Comparison between all cars (V2I)

Fig.8 shows that the delay comparison for all cars over time. The x-axis represents time in seconds ranging from 0 to 34 seconds. The y-axis represents delay in seconds (s), ranging from 0 to 0.0020 s. The graph also includes multiple coloured lines indicating delay values at different times. Those colours represents different cars with dark blue line is for Car 0, red line is for Car 1, dark green line is for Car 2, yellow line is for Car 3, light green line is for Car 4, grey line is for Car 5, brown line is for Car 6 and light blue line is for Car 7. From the graph, the delay are mostly clustered around 0.005 s with occasional spikes reaching up to 0.002 s.

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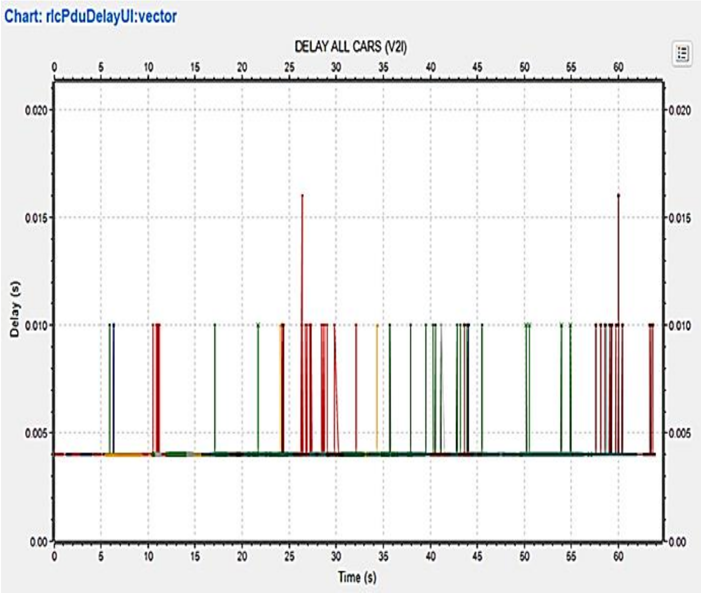

Fig.8 Delay comparison for all cars (V2I)

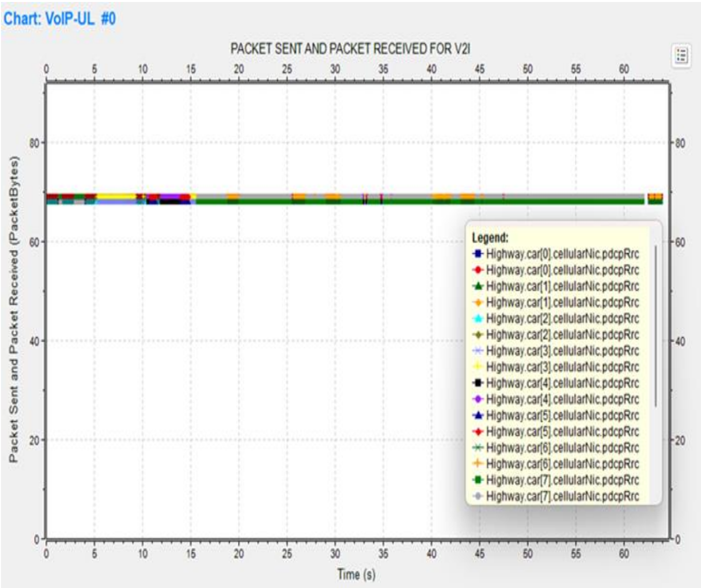

Fig. 9 Comparison of Packet Sent and Packet Received for V2I

CONCLUSION

This project effectively demonstrated the integration of C-V2X communication within a 5G network environment using OMNeT++ and associated frameworks like SIMU5G and Veins. The study primarily focused on evaluating Quality of Service (QoS) parameters such as throughput, delay, and packet loss, which are crucial for reliable communication in intelligent transportation systems. The findings highlighted that 5G-enabled C-V2X significantly enhances vehicular connectivity by achieving high throughput and low delay, particularly in V2V and V2I interactions. High data rates offered by 5G networks support real-time communication requirements in C-V2X applications, and simulations showed delays of nearly to 1 millisecond in most scenarios, validating 5G's suitability for time-sensitive vehicular applications. Low packet loss across all tested scenarios confirmed the reliability of the C-V2X model. The versatility of the simulation framework allowed comprehensive modeling of complex vehicular communication scenarios. The study emphasized the transformative impact of 5G-enabled C-V2X on road safety, traffic management, and its alignment with Sustainable Development Goals, specifically promoting economic growth and climate action by optimizing traffic control and reducing fuel consumption and greenhouse gas emissions.

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The comparison of packet sent and received data for the V2I simulation can be seen in Fig.9. The data observed are being same as the value of 68 packets. The network might be under optimal conditions with minimal interference and congestion. These results also show that all packets sent are successfully received.

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