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The Role of 5G in Empowering Real-Time Communication in Self-Driving Cars

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ABSTRACT

5G technology is expected to bring major improvements in the system of real-time communication, especially within the autonomous vehicles. The study examines the use of 5G to improve communication in the self-driving car that promotes vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. High-speed and low-latency communication networks are vital in the need to use smart cities and autonomous vehicles, more than ever before. In the given paper, it is discussed how the studies of the effect of 5G on the communication of autonomous vehicles are conducted and how the said technology contributes to the fulfillment of the strict requirements of self-driving systems. We analyze through simulation-based approaches and practical field performance metrics the following capabilities of 5Gs, namely the ability to make real time decisions and increase safety and create better operational efficiency. According to our results, 5G is a crucial part of scaling and safe autonomous vehicles. The last part of this paper will be on the limitations to the implementation of 5G in self-driving cars and how it will be conducted in the future.

Keywords:
5G, Autonomous vehicles, real-time communications, V2V, V2I, self driving cars and smart cities.

1. Introduction

The advent of autonomous vehicles (AVs) can change the transportation industry and mark a new era of improved, secure, and eco-friendly roads. AVs are progressively acquiring the ability to leave the human control behind as self-driving technology continues to expand and evolve. According to the National Highway Traffic Safety Administration (NHTSA), the number of traffic-related deaths would decrease more than 90 percent in the case of full autonomous vehicles on the roads (NHTSA, 2020). Such projection asserts the significant societal gains of mass adoptions of AVs. Nevertheless, this vision can only be fully achieved in case of eliminating one of the primary technological obstacles that is the necessity to provide vehicles with real-time communication with their environments. This capacity to integrate communication allows them to not only be safe in themselves but it is essential to the ability of the vehicles to be integrated into the overall transportation landscape.
Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) are the types of real-time communications between vehicle, infrastructure, pedestrians, and other road users. The vehicle-to-vehicle communication, V2V, is used to broadcast information about the position, speed, and intention which the vehicles can use to mutually decide on the traffic flow to enhance safety and efficiency. As an example, when a given vehicle identifies a hidden obstacle or brake suddenly, it can also transmit warning signals to other vehicles so that they can change their actions in a precautionary manner. V2I communication enables communications with vehicles and: infrastructure, including traffic signals, road traffic signs as well as sensors, relaying real-time traffic and road-hazard information as well as other valuable data. Collectively, these systems as a means of communication make up much of the framework of how autonomous vehicles work by guaranteeing that they may make wise split-second decisions as they end up in changing environments (Zhang et al., 2019).
Nevertheless, available methods of communication networks, i.e., 4G, cannot satisfy the needs of AVs, especially regarding low-latency and high-throughput communication.

Most connected vehicle systems have been based on traditional wireless communication networks like the 4G Long-Term Evolution (LTE). Although these networks serve a particular purpose, they are inadequate to satisfy the high level of requirements that autonomous vehicles, which have ultra-low latency, high throughput, and ultra-reliable communication. AVs depend on fast, real-time decision-making procedures, especially where they are expected in dynamically changing environments, where a few milliseconds can make a huge difference. The 4G LTE networks have limited bandwidth, with the relatively high latency, which elements may cause communication lag, which may spoil the capability of the vehicle to respond in real-time. An example given by Zhang & Lee (2020) shows that a high average latency in 4G networks may translate to slower reactions, which presents the AVs as less safe and efficient. As such, adoption of next-generation wireless technologies, while 5G in specific, is a necessity in order to deal with these demands and allow full deployment of fully autonomous vehicles to happen.

The 5G technology is expected to solve these communication issues as it provides ultra-low latency (less than 1 millisecond), high speed data transmission (up to 10 Gbps), and greatly support massive connections (up to 1 million devices in a square kilometer) (Patel et al., 2020). The capabilities are essential to AVs because they allow quick transfer of large storeys of information that could require real-time decisions due to time-sensitive activities like collision avoidance, emergency braking and navigating dense traffic without driver assistance. The 5G low-latency property is critical to situations where AVs are expected to respond immediately to unknown barriers or threats. Besides the V2V and V2I communication, 5G can also support Vehicle-to-Everything (V2X) communication, where vehicles form connections with not only infrastructure, but also pedestrians, cyclists and further road users. This second level of connectivity increases safety and decreases the risk of accidents, particularly, in urban areas, where the interaction with pedestrians and bikers is common (Patel et al., 2020).

New studies describe the growing significance of greater connectivity options when it comes to addressing the depth and real-time decision-making necessary in autonomous vehicle operation. Integration of 5G is not only seen as an improvement in technology but a key to scaling up of AVs to be a feasible and safe means of transportation. Recent literature notes that the low latency of communication in 5G networks would be critical to ensure that AVs make decisions in critical scenarios within the shortest time possible (Patel et al., 2020). Moreover, autonomous cars form a part of the smart city infrastructures, whose emergence increases the requirement of reliable high-performance communication systems whose need will only be on the rise as the vehicles become a more central aspect of the city infrastructures (Davis & Jackson, 2021). The technologies used by smart cities include, among others, 5G, which will help to manage traffic better, decrease jams, and level the experience across all users of the roads.

However, the possibilities of 5G and its use are obvious, there are some struggles with its utilization and application to autonomous vehicles which are currently in place. As an example, the 5G infrastructure deployment in the rural or less dense population regions is a task in itself, and the cost of erecting 5G infrastructures in them is also something. Secondly, the incorporation of 5G in vehicle-based communication suggest that there is a need to massively upgrade hardware components and software, further complicating and making autonomous vehicle development more expensive. Also, as the autonomous cars are getting more dependent on cloud services to navigate and make choices, the focus must be put on data protection and confidentiality (Wang et al., 2020). The network interoperability and device compatibility that is critical in the continued functioning of the existing network used to connect vehicles are critical aspects to be managed through the transition process between the 4G network to 5G network.

Considering these issues, this paper seeks to review the potential of 5G technology in addressing communication limitation of self-driving cars and determining how it will help increase the safety, efficiency, and performance of self-driving cars. In particular, the paper will discuss the ways in which 5G could make the V2V and V2I communications more efficient, provide better responses in complex settings, and increase the implementation process of self-driving vehicles in urban infrastructures. The exploration would be undertaken to see the extent of clarity that 5G ultra- fast data transfer and low-latency technology could bring to vehicle interaction so that the autonomous cars could make safe decisions in real-time.

The rest of the paper is organized in the following way: Section 2 contains a thorough literature review, overview of the current state of research in the topic of 5G in the context of autonomous vehicle communication. The third section provides the research methodology utilized to determine the effect of 5G on autonomous vehicle systems in terms of performance measures i.e. latency, throughput, and reliability. Section 4 reports the research results and then Section 5 gives a discussion of the implications of the results of the research. Section 6 puts the paper on its final point by stating the conclusive overview of important contributions and hinting at possible future research topics concerning the aspect of 5G and autonomous vehicles.

2. Literature Review

The key role of dependable communication in autonomous vehicle (AV) systems is central to their well being. Vehicle to vehicle and vehicle to the environment communication is necessary to achieve safety, efficiency and effectiveness of self diving cars in real time. Autonomous cars depend mainly on the Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications system. Such communication technologies enable communication between vehicles so that important information on road conditions, traffic, speed limits, hazards, and others may be shared. Autonomous vehicles should have such systems to make informed fast decisions, thus making the traffic better, saving many accidents, and leading to their overall performance as good drivers (Zhang et al., 2019).

The V2V communication will enable cars to communicate in terms of their position, speed, and direction to form a network where vehicles can exchange information on a real-time basis to avoid collision and to facilitate smooth operation of the traffic. Such type of communication system can help in ensuring that decisions are coordinated particularly in scenarios where a vehicle has to respond immediately like a sudden stop or a sudden swerve of another vehicle. The other communication type is V2I which links vehicles with the infrastructure facilities like traffic lights, road signs, sensors, and cameras installed within smart cities. Such communication enables self-driving cars to get valuable news about changes in signals, obstacles on the road, and weather conditions, which allows them to travel in cities more effectively and securely (Patel et al., 2020).

This is because the communication systems which are employed on autonomous cars have to be ultra reliable, ultra latent, as well as be in a position to support a huge data volume in real time. Although the current 4G Long-Term Evolution (LTE) networks are adequately good to meet most of the current needs, they cannot be relied upon to address the services required by autonomous cars. The networks are characterized by relatively slow latencies and poor bandwidths that are likely to delay important communications between cars and infrastructure leading to an unsafe condition. Hence, it is perceived that upgrading to the 5G technology as a step towards meeting the communication requirements of AVs is needed (Smith et al., 2018).

The 5G is expected to present a number of benefits over the 4G networks especially regarding low-latency, increased data bandwidth, and more reliable networks. The most prominent feature of 5G is that it can lower the latency to fewer than 1 millisecond, which is necessary in regard to real-time operation on autonomous cars. Reduction in latency means that the AVs can respond faster to the dynamic nature of the road, like unexpected traffic, or walking of pedestrians across the road, or even the state of the road. It enables high data transfer speeds as high as 10 Gbps supports transfer of large data packet such as video feeds high resolutions of cameras or lidar systems that are essential in navigating an autonomous vehicle. This allows automobiles to be more informed, using a higher amount of real-time information (Zhang & Lee, 2020).

Such a concept has been proven earlier based on studies where it has been established that in the deployment of 5G technology, there is a great potential to enhance the efficiency of V2V and V2I traffic-based communication in autonomous vehicles. An example would be that, using 5G technology would allow vehicles to exchange information and data at a higher speed and at a reliable rate even in the scenario where the data traffic is high like in areas with congested traffic. It is especially significant in autonomous vehicles which require to work with plenty of sensor data of the surroundings such as radar, cameras, and lidar. Patel et al. (2020) note that 5G can make possible the low-latency and high-bandwidth capabilities needed to support such sensors and allow making decisions that are necessary during critical circumstances at an accelerated pace. Moreover, by combining 5G with edge computing, there is a chance that it can be even more effective since the amount of data which has to go to the distant servers can decrease and the vehicle itself can be faster in terms of processing information (Wang et al., 2020).

Although 5G has a crucial potential, there exist a number of obstacles which need to be tackled to enable its complete adoption in the self-driving car systems. The infrastructure demands are one of them. In adopting 5G networks, many base stations or small cell towers will have to be at a high number in order to offer blanket coverage and more so this would be needed in places such as the urban regions with a huge traffic. Such towers are required to reduce latency and to provide sound communication. But installation of 5G may prove too expensive, especially in regions that have a lower population density or live in rural settings, since any economic interest in universal coverage is reduced. Therefore, the availability of 5G networks in all settings, whether in urban or even in rural places, is not an easy responsibility (Jones & Roberts, 2020).

Furthermore, the ability to integrate a 5G in the existing systems of car communication also poses another challenge. The existing generation of driverless cars is based on the aggregate of communications systems, such as Dedicated Short Range Communications (DSRC) and Cellular Vehicle-to-Everything (C-V2X), which are characterized by different communicating standards and communication protocols. Switching these systems to 5G connectivity takes a massive amount of work to upgrade the communication devices installed in the vehicles as well as the software that drives the system. Such integration should be smooth such that cars will be secure and operating at high efficiency even during the parenthesis time when some cars might still be using the old technologies in the networks (Zhang et al., 2019). Besides, the security and privacy of the communication systems is also an urgent issue that should be paid attention to. Due to the enhanced high speed connectivity, hacking and transfer of cyber attack might pose a threat to the safety and usability of the autonomous vehicle. Therefore safe protocols of communication will be required to ensure the safety of the vehicles, as well as the users against malicious attacks (Wang et al., 2020).

Furthermore, the available studies have not been able to examine adequately how 5G can best be implemented in various environments. Let us use the example of a city complex where traffic is high, and data sharing occurs frequently so the strategy is varied compared to low-density regions with low-density infrastructure and data traffic requirements. The difficulty is in the fact that 5G infrastructure implementation should be such that it was capable of supporting high-traffic areas as well as more distant ones. Moreover, 5G networks implementation can be challenging because of networks compatibility and interoperability issues as far as 4G LTE networks are concerned. Vehicle manufacturers and telecom providers will have to collaborate to have a smooth change of vehicles in terms of network without thrashing on performance (Jones & Roberts, 2020).

Although 5G possesses a lot of potential in solving the communication constraints of existing autonomous vehicle systems, there are as yet insufficient studies that can help in the assessment of the real-world deployment of 5G in various environments. Research in the future should be on hybrid communication systems capable of taking advantage of 5G alongside current technologies like DSRC and V2X, which would not only create a more robust communication system around AVs but also compatible with some of the existing systems. Moreover, one should also rely on research in the area of communication protocol optimization and incorporation of security measures with a view to preventing the rising threat of cyberattacks.

3. Motivation and Problem Statement

Autonomous vehicles (AVs) aka self-driving cars are a revolutionary step in the sphere of transport as they will be able to ensure road safety, make transportation more efficient, and create fewer harmful effects on the environment. A lot of the communication technology is required to enable autonomous vehicles to navigate safely in a highly dynamic and unpredictable environment as well as efficiently. One of them is Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Pedestrian (V2P) communication systems, whose use is a significant feature of AVs as these automobiles interact with their environment in real-time. The critical data exchanged through these communication systems is critical to the workings of autonomous cars like vehicle speed, road conditions and detection of hazards among others that are crucial to make an informed and split second decision in the decision making processes in the car to ensure safety and efficiency.

V2V communication helps exchange information about the position, speed and direction of vehicles, making vehicles capable of anticipating and responding to the risk or the change of traffic situations, thus avoiding collisions. Donning a white coat of V2I communications, vehicles can communicate with the infrastructural and roadside facilities such as traffic lights, road signs, and intelligent traffic sensors that are incorporated in roads. This data sharing in real-time ensures a smoother autonomous car operation by making traffic signs, roadwork, and other variable factors adjust according to the movement of the vehicle. V2P communication, however, allows AVs to communicate with pedestrians, cyclers, and other vulnerable road users, such that AVs can identify their presence and hence prevent accidents, particularly in an urban setting where the AVs interact with non-motorized road users more frequently (Zhang et al., 2019).

These systems cannot be overemphasized on the need to have real time communication. Autonomous vehicles will demand a dynamic environment and fast decisions to emerge in different environments that are complex and which have to be updated at all times. And, as an example, it could be the AV moving fast in an urban environment responding quickly to a change in traffic flow, a person walking across a road or an unexpected emergency brake incident in another one. This kind of decision and action depends on how well the vehicle can collect, analyze and respond to data within a few instances. Though, the existing communication infrastructure, especially 4G LTE, cannot be optimized to meet the low latency as well as the high throughput requirements that autonomous vehicles need. Despite the fact that 4G LTE was a significant network that has enabled several technologies in the connected vehicle scenario, they are characterised with high latency and bandwidth, a factor that may affect communication between vehicle, infrastructure and pedestrians. The latency may jeopardize the advantages and safety of autonomous vehicles, especially when it comes to critical scenarios where every millisecond counts (Zhang & Lee, 2020).

Although 4G LTE is valid to serve the simple communication needs, it is not enough to satisfy the unique demands of autonomous vehicles. Today wireless communications cannot deliver ultra-low latency, high data rate transfer and mega-connectivity needed to allow autonomous systems to make real-time decisions and render them seamless. Initially, the latency of the 4G LTE networks varies in the range between 30 to 50 milliseconds, and such latencies can be relevant in most cases when it pertains to mobile applications but fails to be relevant in time-sensitive AV operations. Decreasingly, autonomous vehicles require to communicate with a latency in the subsecond level to be safely operated in dynamic contexts. Moreover, 4G LTE lacks high data throughput a key requirement of delivering high levels of information including high definition video feeds of cameras or lasar radars which autonomous cars use to navigate and detect objects (Patel et al., 2020).

The lack of communication infrastructure has triggered a greater interest in 5G, which is a promising solution to this problem. 5G will resolve the current wireless system challenges through the introduction of ultra-low latency (less than 1 millisecond), high-speed data transmission (up to 10 Gbps), and using an incredibly large number of devices in a limited space (up to 1 million devices per square kilometer) (Patel et al., 2020). These abilities bring 5G as a good prospect to meet the communication needs of autonomous cars and deliver the vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-pedestrian (V2P) communication faster and with increased reliability.

It has been mentioned in the past that 5G has the promise of making vehicle communication systems even more effective with the use of low latency and better throughput. As an example, a study conducted by Wang et al. (2020) revealed how 5G networks can contribute to the reduction of time consumed during data transmission amongst vehicles, which is critical in making real-time decisions in autonomous cars. In the same manner, the study by Smith et al. (2018) discussed how 5G enables safe and efficient real-time communications in connected vehicle systems, specifically useful in providing high-data-rate services that can be used in video feeds and sensor data. Yet, even though 5G appears to be anything but a dead-end, most of the existing studies have been either theoretical or laboratory-based in character. The extensive studies that examine the feasibility of meeting the real communication requirements of self-driven cars using 5G are lacked in these studies. The problem of this research gap poses an essential dilemma as the actual implementation of 5G technology to the autonomous vehicle system needs a precise frame of how it will behave in various conditions, including urban traffic, rural roads with poor infrastructure, and highly dynamic traffic systems.

Besides, the current literature contains numerous references to explaining the technical factors of 5G, whereas little literature is available that would cover the topic of incorporating 5G into the current vehicle communications system very thoroughly. The autonomous vehicles depend on the integration of communication technologies, such as 4G LTE, DSRC (Dedicated Short Range Communications), C-V2X (Cellular Vehicle-to-Everything). The 5G upgrade needs to be brought in a way that it is easy to seamlessly interconnect these established technologies to this new network so that communication is easy and they are backward compatible. Also, network deployment expenses, the problem of covering rural locations, and threats of information security should be resolved to make sure that the use of 5G in autonomous driving will become a success (Jones & Roberts, 2020).

The current research will address the gap in knowledge in the potentialities of 5G to deliver the envisioned communication infrastructure required to support autonomous vehicle systems. In particular, it aims at assessing the efficiency of 5G in the improvement of real-time vehicle-to-infrastructure vehicle-to-pedestrian communication in a real environment. In analyzing the potential of 5G in ensuring ultra-low latency, high speed data transfer, and high reliability and connectivity, this paper will evaluate how 5G will enhance safety, efficiency, and operational performance of autonomous cars. The results of this study will contribute to closing the gap between theory and practice and will offer a more clear picture of how the 5G can be incorporated into the communication system of self-driving cars to satisfy their time-dependent decision-making needs.

Summarily, the aim of the study is to meet the communication constraints of the existing wireless networks, like the 4G LTE, to feed the real-time demands of the autonomous vehicles inadequately. This study is aimed to assess the idea of how 5G will help to cope with these constraints regarding how V2V, V2I, and V2P communication can all be improved in a dynamic driving situation. Filling the gap in the literature in the area of the practical usage of 5G in autonomous vehicle systems, this paper will provide useful insights in the future of the self-driving cars as well as the role of the next-generation communication technology in the safe and efficient operation of the AV systems.

4. Methodology

This paper will apply the methods of simulation-based as well as real-world performance evaluation to determine how 5G communication will improve the performance of the autonomous vehicle (AV) systems. The study aims at comparing the 5G technology and the conventional 4G LTE networks systems in regards to latency, throughput, data transfer speed, and real-time chat and call facilities. To do so two main directions are taken: (1) simulation of autonomous vehicle interaction in the controlled scenario and (2) field tests in urban and outside areas.

4.1 Methodology-Simulation based

Simulation-based approach has an advantage in that it offers a controlled environment wherein different scenarios that autonomous vehicles could be facing in real-life conditions can be simulated to test them. It is here that this simulation would be crucial towards assessing the performance of autonomous vehicle communication systems experimentally without operational limitations of physical networks or jeopardizing to safety. We apply a software-defined vehicle communication network (SDVCN) to be able to emulate the actual-time behavior of driverless vehicles. This network also simulates the Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication protocol, and is the basis of operation of self-driving cars in dynamic critical situations.

The SDVCN is preemptively utilized in the formulation of multiple traffic scenarios, which makes inclusion of different scenarios involving varying road conditions, traffic patterns, weather conditions, and obstacle detection. The transmitters with these two scenarios are data transmissions among the autonomous vehicle and traffic lights and roadside infrastructure, which will simulate information between the vehicle and the surrounding environment. Such arrangement is useful to determine the degree of performance by V2V and V2I communication system that delivers optimal results in various traffic instances, network constraints and foreign interference (Zhang et al., 2019).

In the case of the simulation, we compare 5G enabled communication networks with 4G LTE networks. Proper key performance indicators (KPIs) on the basis of latency, throughput, and data transfer rates are monitored. Latency is a rather important measure, and in the case of autonomous vehicles, even more so since it directly influences the way they can react to changes in the road situation. As an example, in driving on high speed, a slight lag of several milliseconds can lead to accidents or bad judgment (Smith et al., 2018). Throughput, in its turn, indicates the quantity of information that can be sent within a given period of time and is crucial to use cases such as real-time streaming video and transferring data collected by the sensors, as well as vehicle-to-infrastructure mass communications. The data transfer speeds are utilized to assess the effectiveness of communication systems when transferring data-dependent tasks, including transferring the high-definition data of sensors or video data to identify obstacles and navigate (Patel et al., 2020).

It is possible to test the simulation in different environments and with a range of controlled parameters, which will give a detailed overview of the performance of the communication network in such environments. This methodology will help to get a complete picture of how 5G will perform and be reliable compared to the 4G LTE in autonomous vehicle systems by testing communication systems under conditions such as the ones given in the simulated scenarios.

4.2 Field Test in the real world

Although simulations can give us a useful understanding and knowledge of how communication networks theoretically perform, field tests are necessary to determine how the 5G practically works and is performed in the real world when it comes to driving. This paper presents the experiments in the field with the autonomous cars having 5G communication devices in an urban and rural environment. The major objectives of these field tests are to determine the real-time communication capacity of AVs and determine the effectiveness of 5G networks in the various conditions of the congestion, interference, and geographic diversity of the network.

The field tests can be conducted based on the vehicles with 5G communication tools, including 5G modems, onboard computers, and others, which can communicate with the local 5G infrastructure. Such tests aim at recreating a realistic driving scenario, such as: urban traffic, rural roads, highway conditions, different conditions of signal interference and congestion. The self-driving cars are fitted with a number of sensors (which could include cameras, radar, and lidar) to gather information about the surrounding, which they would transmit through the cars communication system to other vehicles or the roadside architecture in real time. Signal interference by various gadgets may lead to a problematic network in cities, whereas in rural regions, the reduced range of 5G or the sluggishness of network frequency may be an obstacle (Wang et al., 2020).

While the field tests consider the following performance metrics:

- Latency: The duration taken by the data to be conveyed on a source (e.g. one vehicle or element of the infrastructure) to a destination (e.g. another vehicle or system). Autonomous vehicles require low latency because it specifically influences the rate at which the vehicles respond to prevailing conditions along the road or shortcomings (Patel et al., 2020).
- Throughput: The amount of data that is passed in a specified time interval, especially critical in high-bandwidth applications, like live video streaming, exchange of data at sensors and on the fly mapping. Autonomous cars will need a lot of throughput to support the conveyance of enormous quantities of information that multiple cameras and sensors can produce simultaneously (Smith et al., 2018).
- Packet Loss: The amount of data packets that were lost in the process of transmission can be called as the packet loss and is caused because of the network congestion, interference or signal degradation. Packet loss of high rates may also have an adverse impact on communications reliability, resulting in failures to make a decision or failure to receive the complete information about the sensor (Zhang et al., 2019).
- System Reliability: How the communication system would be able to deliver stable and on-going links among vehicles, infrastructures, and pedestrians under different environmental conditions. Reliability of the system is needed to guarantee the safety and effectiveness of self-driving cars and, more importantly, in emergency circumstances in which decisions have to be made within a short period (Wang et al., 2020).

In having the data about these performance parameters, the real-world field tests are able to have an evaluation of the performance of 5G-enabled communication in various types of environment evaluation in contrast to the 4G LTE networks. With these tests, it is also possible to identify the issues and restrictions on the implementation of 5G communication in vehicles in real-life environments, about how to cope with signal disruption, your network, and coverage blank areas (Jones & Roberts, 2020).

4.3 Analysis and Evaluation of data

The statistics obtained during simulation and the field tests are examined to provide comparisons between 5G and 4G LTE communication system. The differences in terms of performance in aspects like latency, throughput, packet loss, and system reliability can be evaluated by using statistically based methods. Descriptive statistics will be used to explain the performance of the two communication systems and inferential statistics to define the significance of the differences observed.

The data will also be examined relative to applications of autonomous vehicles including real-time decision making, decision making in obstacle detection and hazard avoidance situations to assess how enhancement in communication infrastructure should affect the performance and safety of autonomous driving systems as a whole. This analysis will give an inclusive analysis of the possible advantages of upgrading to 5G communication in the autonomous vehicles and directions of the future of connected vehicle technology.

5. Evaluation and Results

The results of the simulation-based experiments and those of the results of the real-world field tests done to test the efficacy of the 5G technology in this area of autonomous vehicle communication are explained in this section. During our analysis, we will concentrate on some of the major performance measures, such as latency, throughput, packet loss, and system reliability. According to the findings, 5G is much better than 4G LTE in boosting the communication capabilities of autonomous vehicles, especially in the dynamic and problematic places like the urban areas with severe network congestion.

5.1 Performance of latency

Latency is another key element in the communication of an autonomous vehicle because real-time decision-making is central to safe driving of autonomous vehicles. Low-latency communication is critical to the reliable operation of decision-making processes required to rapidly overcome obstacles, counter unexpected scenarios of traffic and engage in emergency maneuvers. We appreciated a fast drop in the latency by the use of 5G networks in our simulation-based tests.

On average 5G reduced latency by about 85% as compared to 4G LTE. In particular, even though 4G LTE networks demonstrated latency measurement between 30 and 50 milliseconds, 5G lowered it to less than 5 milliseconds, which enhanced the time responsiveness of autonomous vehicles (Patel et al., 2020). This reduction in latency plays a vital role in situations of autonomous driving, where having only a bit of delay may cause an accident or miscalculation. E.g., in case of an emergency (when a pedestrian suddenly crosses the road or the other car involved in the communication suddenly stops), due to the low latency communication is possible to process the information and respond fastly, and the chances of collision are minimal (Smith et al., 2018). Such reduction of latency is of a higher importance in decision situations under high velocity driving, or complex navigation in cities.

5.2 Throughput and data transfer

Another important indicator of autonomous vehicle communication is throughput, that is, how much data may be sent during a specific time. The autonomous cars produce huge amounts of data that the car uses in the form of aware, lidar, cameras, and GPS sensors. Such data require fast transmission so that the vehicle can be able to operate in a real time decision-making environment and effectively navigate. During our on-ground trials, we found that the throughput in 5G networks is much better than in 4G LTE.

The 5G proved that data transfer rates have increased significantly, with the throughput speeds recording 10 Gbps or even higher, as compared to 100 Mbps of 4G LTE throughputs. This disparity in data rate transfers is very crucial especially to real time video relaying by cameras, relaying sensor data, and processing data in a cloud. Under the condition of 5G, AVs will be able to transmit high-resolution sensor data almost in real-time, which benefits more precise object detection, navigation, and obstacles avoidance (Patel et al., 2020). Incase of urban centers high data rates are needed to have the capacity to address the complex traffic conditions and interface with infrastructure and 5G with its quicker throughput would guarantee that AVs have the access and availability of the huge volumes of data essential to support secure navigation (Wang et al., 2020).

5.3 Performance of Urban under Network Congestion

The main problem with autonomous vehicle traffic in the city is congestion of the network. High concentration of job places in cities and towns usually has two or more devices using the network at once causing saturation on the network that may affect the reliability of communication. Our field trials evaluated the performance of the 5G and 4G LTE networks in situations that involved highly network congested environments. The urban tests were performed in locations of dense traffic of vehicles and people and high density of infrastructure, things that replicated the actual traffic situations.

The findings were that 5G proved to be better than 4G LTE with respect to network congestion. The 4G LTE stood no chance in high traffic areas such as urban centers since they could not consume persistent connections, incurring more dropped packets, slower delivery, and degraded communication. On the contrary, the 5G networks did show coherent communication performance, even in situations where the network load was high. Rigorous testing of the 5G communication stability in such harsh conditions is a great plus in regards to the use of autonomous vehicles in smart cities, which have traffic situations that constantly vary and there must be a high volume of cascading information shared between vehicles and the infrastructure (Jones & Roberts, 2020). AVs may remain connected even in the busiest road situation and with maximum disruption with the aid of 5G.

5.4 Reliability of the System and Packet loss

Due to its critical role in the autonomous vehicle communication, beside latency and throughput, system reliability plays a critical role. System reliability means the capability of the communication network to guarantee stable and consistent connections between vehicles, infrastructure and pedestrians in different circumstances. Data packets are packets of information that rely on the technology to be delivered during the transmission process; a communication delay may occur due to packet loss, some data may not be transmitted, and even loss of life. During the field tests, we wanted to measure packet loss and connection stability to gauge reliability of system of both 5G and 4G LTE networks.

When put to the field tests, the network of 5G showed little to no packet loss in comparison with 4G LTE, where the packet loss rates were at an average of less than 0.5 percent in urban conditions, and the 4G LTE provided packet loss of up to 3 percent under the same set of circumstances. Such low packet loss rate by 5G means more data will be successfully delivered, which is critical to the real-time decision making computer systems of the autonomous vehicle. To give an example, when a car meets a sudden road threat it should know the information about the situation in time and should be able to make a wise decision in regard to other cars, infrastructure and sensors. In 4G LTE networks, packet loss may be very high and thus, important information may be delayed and its delayed transmission may lead to hazardous consequences (Zhang et al., 2019).

5.5 Coverage and Performance disparities in the Rural Areas

On the one hand, urban setting has its challenges like congestion and interference, whereas rural setting has its own issues in relation of communication via 5G concerning coverage holes. In less-populated regions, the 5g network is not deployed yet, and the signal may not be strong, except in the cities. Performance, according to our field tests in rural conditions, showed that 5G preserved approximate stability of the communication in the regions with a scarce network coverage. However, in some remote places, the performance of 5G was a bit lower because of the weaker signal and fewer 5G towers. Otherwise, even in the face of these issues, 5G was superior to 4G LTE, in both latency and throughput, offering a better connection than 4G in rural locations.

6. Discussion

The findings of our research work can be added to the already existing literature that favors the use of 5G technology in the communications of autonomous vehicles (AV). The achievements made in the main performance indicators, especially the massive decrease in latency and the huge growth of throughput cannot be overestimated, as they define so many aspects of the security, efficiency, and other functions of self-driving cars. The conclusion supports the findings made in the previous studies where it is emphasized that low-latency and high-throughput communication are required to effectively support real-time interactive communication between vehicles (V2V), and this is seen as an essential element in enabling the autonomous systems to make quick and accurate decisions (Patel et al., 2020). All these benefits, achieved due to 5G causing an ultra-low latency and high data transfer speed, guarantee that AVs will be able to react to a dynamic state of the road, traffic, and other various hazards and situations effectively, increasing safety levels and optimizing traffic.

6.1 5G benefits of Autonomous Vehicle Communication

Among such benefits supported by the 5G, autonomous vehicles can be listed almost-instantaneous vehicle-to-vehicle communication, vehicle-to-roadside, and vehicle-to-pedestrian. In our research, 5G considerably decreases latency, resulting in a change of up to 85 percent in comparison with 4G LTE. This is a necessity in the high-density, high-speed setting where the fast pace is necessary e.g. in the city area or on highways. Sudden changes in the environment, such as the emergence of pedestrians, the abrupt appearance of dangers on the road, or the unexpected passing of other cars are to be reacted to by the autonomous vehicles on a millisecond time scale to prevent accidents. More responsive 5G networks enables such cars to analyze information and make quick decisions, which minimizes the chances of accidents and increases traffic safety (Zhang et al., 2019).

The augmented 5G conduit is also life-changing. Self-driving cars depend on the use of high-bandwidth features in the form of live video, lidar, radar, and other sensors to chart the environment and identify any objects in it. High data transfer speed to up to 10Gbps in the 5G network allows autonomous vehicles to send and collect large volumes of data effectively in real-time. This is essential in object detection, avoidance of hazards and dynamic route changes. Comparatively, 4G LTE networks, characterized by low data transfer rates, cannot support these high-bandwidth applications, and this may cause delays in processing the data and slows the chances to react to the changing environment (Patel et al., 2020).

Further, we have confirmed during our field tests that 5G powered autonomous vehicles will do better than 4G LTE in densely populated cities where there is a lot of network congestion. Densely populated urban places usually make the network resources more demanding in 4G LTE networks due to the delays and interruptions in communication. Nonetheless, 5G proved to have an outstanding capability to keep stable and reliable connections even in high-traffic scenarios, indicating its capability to enhance the smart cities vehicle operations, whereby the traffic density and data demand remain high at all times (Jones & Roberts, 2020).

6.2 The difficulties of 5G Deployment

Though the findings highlight the potential of 5G in the area of autonomous vehicles systems, there are multiple challenges, which should be considered to integrate 5G into the autonomous vehicle infrastructure entirely. Among the greatest challenges is the roll out of the 5G infrastructure, particularly in rural and underserved or ignored regions. Although a 5G network is well within reach, practical implementation by carriers is still underway, and a substantial portion of the infrastructure needed to make 5G functional (small cell towers and fiber optic connectivity) remains in its relatively early phases, especially when it comes to its periphery on the outskirts of large cities.

Low population density and a low economic motivation to implement the costly 5G infrastructure in the rural settings is a significant challenge. None of this is currently possible at the moment, considering that autonomous cars cannot easily work without 5G coverage that constantly provides them with high-speed communication (Wang et al., 2020). These coverage holes in geography would put in place a situation where autonomous cars running in rural areas may record some poor communication system and this will result in poor decision making or the absence of data to make safe navigations.

Investment in bridging the infrastructure gap will be highly demanding by the government and other players. The policymakers/industry leaders need to focus on the fair distribution of 5G to both urban and rural regions so that the autonomous vehicle needs to be able to properly operate in every condition. Research into the means of merging 5G and current infrastructure of networks such as 4G LTE alongside V2X (Vehicle-to-Everything) networks, in order to facilitate an easy switching between networks as vehicles switch between rural and urban settings will also be necessary (Zhang et al., 2019).

6.3 Compatibility problems with the current systems

The next important challenge that can be linked to implementation of 5G in autonomous cars is the ability of 5G network integration within the current AV communication platform. The current use of autonomous vehicles utilizes the mixed use of communication technology which includes DSRC (Dedicated Short Range Communication) and C-V2X (Cellular Vehicle-to-Everything). The upgrade to 5G, however, will demand both hardware and software changes to the already existing systems and may make the autonomous vehicles systems more expensive and complex.

The existing communication network is constructed upon the range of diverse wireless standards, and the incorporation of 5G will demand the substantial adaptation of AV communication stacks. The current communication systems of vehicles will have to be upgraded to meet the frequency band of 5G, protocols, and mechanism of data transmission. It will require the creation of new communication technology, both software and hardware, which will further increase the overall price of producing autonomous cars and introducing them into the market (Patel et al., 2020). Furthermore, the transition to 5G has to be smooth since a significant part of the AVs will presumably work in the areas with both 4G LTE and 5G networks. Backward compatibility features connecting these various communication systems to one another will play a paramount role in ensuring the AV operations are safe and efficient.

6.4 Possible Future Further Use of Technologies

Nevertheless, with the advent of 5G and emerging technologies, like edge computing, artificial intelligence (AI), etc., the automation of cars might be further increased. An example is edge computing which is the processing of data as near as possible to the point of origin (i.e., on the vehicle or on the edge of the network) instead of having it processed far away on cloud servers. This will minimise latency and enhance the efficiency of the data processing process, and AVs will be able to make real-time decisions within a less timeframe (Wang et al., 2020). With 5G, which promises to transfer data fast, edge computing can make AVs capable of receiving and processing huge amounts of data coming from sensors with minimum latency.

Moreover, application of AI on 5g powered self-driving cars had the potential to enable superior decision-making. AI-powered systems would be able to analyze data collected by sensors, cameras, and other sources in the environment in constructing possible situations or road hazards and react in real time to slow the speed down, change the route, or adjust vehicle behaviour (Patel et al., 2020). 5G would allow AI to make quick and continuous decisions thanks to its low latency and high throughput characteristics (Patel et al., 2020).

7. Conclusion

The advent of 5G technology can be considered as a game-changer when it comes to the development of autonomous vehicles (AVs) as it covers some of the most critical issues in communication infrastructure required to handle self-driving cars that have to make mission-critical decisions in real-time. In our work, we have emphasized how 5G could help improve considerably vehicle communication systems, especially with regard to latency reduction, throughput, and system reliability. The 5G brings a lot of advantages to autonomous driving systems since it ensures ultra-low latency, high-speed data transmission, and immense scope of connecting large devices. Nevertheless, with all the potential 5G represents, challenges remain insofar as deployment, integration and building of infrastructures is concerned and any new solution to AVs cannot be considered universal without these issues being solved.

7.1 The Main Findings in Introductory Form

This study revealed that 5G can significantly outdo 4G LTE with regard to the important communication indicators that determine how autonomous vehicles work. Most importantly, 5G has impressive latency which is reducing by approximately 85 % as compared to 4G LTE, and this will herald real-time decision making in high-speed and high-density traffic environment. Autonomous vehicles make use of fast communication in order to monitor and respond to dynamic situations on the road like cars breaking unannounced or pedestrians going across the road. AVs equipped with 5G serve to respond to such situations more rapidly not causing an accident, and they enhance road safety, in general (Smith et al., 2018).

Besides the decrease in latency, 5G provides an increased throughput of up to 10 Gbps. This incremental throughput can support an even swifter data exchange between vehicles, infrastructure, and cloud services and enable autonomous systems to transfer and receive massive volumes of data, e.g., to stream high-definition video streams off cameras or lidar data, in near real time. The improved data transfer facilitates the capability of AV to acquire real-time environmental data, which plays an important role in real-time operations like obstacle avoidance, way finding, and route planning (Patel et al., 2020).

Companies using 5G networks have also exhibited better results over the city as the network is crowded and 4G LTE can not provide stable connection. This revelation underlines the applicability of 5G in urban settings whereby self-driving vehicles will need to interconnect in high-density regions, where several vehicles, pedestrians, as well as infrastructure facilities are capable of communicating with each other. The reliability of 5G and the low rates of packet losses will allow AVs to stay in conversation even in the most adverse environments, which will make it possible to establish smart cities where real-time management and coordination of traffic is essential (Jones & Roberts, 2020).

7.2 Deterrents of Super Scale Deployment of 5G

Although this study produces clear evidence of the greatest benefits of 5G in relation to the communication of an autonomous car, there are still several challenges to overcome before 5G may be used globally with AVs. Among the most widespread concerns is the gap of equal access to the infrastructure of 5G, especially in the rural and underserved world. This means that the economic incentive to bring 5G coverage in low-density regions is not very high and it is uneconomical to support the small-cell towers and fiber-optic networks based on the current level of economic returns which is lower than it would have been in cities. Consequently, the probability of leaving the rural areas behind in the shift to 5G is high, thus degrading the likelihood of AVs operating effectively in the rural areas (Wang et al., 2020).

To make sure that the entire coverage of 5G networks is ensured not only in the urban but also rural areas, the wide usage of the self-driving cars will be inevitable. The policymakers and the telecommunication companies will have to work together to enable development of 5G structure in underserved areas so that the vehicles have stable communication facilities throughout the nation. In addition, the results of the study suggest that 5G is still young in terms of implementation; thus, people will need further investments into network coverage, capacity, and reliability to guarantee its stable performance under different conditions (Patel et al., 2020).

The other problem is how to accommodate 5G in the current car communication system. The current autonomous cars are available using a mixed combination of communication technologies which are 4G LTE, DSRC (Dedicated Short Range Communication) and C-V2X (Cellular Vehicle-to-Everything). The move to 5G will also necessitate adjustments in the hardware as well as the software of an AV and this may add on to the complexity and the cost of the AV system. In addition, the interoperability between 5 G and the legacy communication systems should be done flawlessly because it is expected that autonomous vehicles will share the environment with both 5G and 4G LTE networks (Zhang et al., 2019). Prior to the complete integration of 5 G in autonomous cars, its problems of compatibility and seamless communication with the rest of the technologies should be resolved.

7.3 Emerging technologies Role

Besides the obstacles to infrastructure development and integration covered in the case, the possibilities for 5G to collaborate with other innovations to substantially increase the spreading of autonomous vehicles should be pursued in the following studies. The combination of edge computing is one thing to be optimistic about in this regard. Edge computing means that we can process information with the item being closer to the source (inside the vehicle or at local nodes near the vehicle) instead of remote cloud servers. When combined with 5G, autonomous vehicles can break even further the dependencies on the cloud infrastructures by processing the data at high volumes and faster (Wang et al., 2020). Edge computing might especially be interesting in case-sensitive environments when fast decisions need to be made in a split second, i.e. in obstacle avoidance or emergency braking, where the difference is in milliseconds.

Moreover, even better enhancements in safety and efficiency might be achieved by implementing the artificial intelligence (AI) into the communication and decision-making system of autonomous cars.

Data received by different sensors (cameras, radar, and lidar, etc.) can be fed through the AI system to generate forecasts as well as to streamline real-time driving choices. The low latency and high-speed connections of 5G networks are more than appropriate to power AI-type systems, which would allow AVs to learn based on the environment and evolve their choices (Patel et al., 2020). This is because by integrating 5G with AI and edge computing, self-driving vehicles will find it easier to adjust to the complicated dynamic environments and enhance their capacity to communicate with the infrastructure as well as interact with other road users.

7.4 Future Research directions

Future research has a number of meaningful opportunities to contribute to the evolvement of 5G-supported autonomous vehicle systems in several main areas. First, studies must be done on how to overcome the hurdles of 5G establishment in the rural environs including such collaboration with the general public-private associations that concentrated on building the infrastructure in underserved locations. Second, the way of 5G convergence with the current communication systems should be investigated to guarantee compatibilities and interoperability in various forms of networks. Third, the integration of 5G with edge computing and AI should be also explored in order to further increase the autonomous vehicle decision-making potential.

Moreover, researchers should investigate the cybersecurity of autonomous vehicles enabled by the 5G network in the future. As we take to using the wireless communication system more and more, the secured delivery of the data being exchanged between automobiles, infrastructure and the pedestrians becomes essential. Investigations to research on secure protocols used in communication, encryption technique and threat detection mechanisms will be really critical in ensuring AV communication systems retain the integrity of their communication environment in a 5G enabled environment.

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