International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Ingénierie des Systèmes d'Information
Vol. 29, No. 3, June, 2024, pp. 1195-1208
Journal homepage: http://iieta.org/journals/isi

Enabling Technologies for Ultra-Low Latency and High-Reliability Communication in 6G Networks

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https://doi.org/10.18280/isi.290336

Received: 21 December 2023
Revised: 20 May 2024
Accepted: 2 June 2024
Available online: 20 June 2024

Keywords:
6G networks, ultra-low latency, high-reliability communication, MEC integration, self-driving cars, edge computing technology

ABSTRACT

The need for faster and more dependable wireless communication networks has encouraged the development of 6G networks. This article explores the integration of Mobile Edge Computing (MEC) cloud architectures and the potential of self-driving Vehicle-to-Everything (V2X) communication to achieve ultra-low latency and high dependability in 6G networks. By integrating MEC into the 6G network fabric, latency is reduced by bringing data processing closer to end-users, particularly vehicles, thus enhancing computational capabilities at the network's edge. The fusion of MEC with self-driving V2X communication holds the key to realizing the potential of 6G networks, enabling seamless communication among vehicles, roadside infrastructure, and individuals. Extensive testing and simulations predict that the 6G network's latency for User Equipments (UEs) will fall within an impressive range of 4ms to 10ms, unlocking new opportunities for mission-critical services, augmented reality, and real-time applications. The paper substantiates the dependability of 6G networks under various scenarios, ensuring a stable and reliable communication infrastructure. The objectives of the study are twofold: firstly, to evaluate the potential of MEC integration in 6G networks and its impact on reducing latency for end-users, particularly in the context of self-driving V2X communication; and secondly, to predict and verify the ultra-low latency capabilities of 6G networks for UEs through extensive testing and simulations, thereby enabling new opportunities for mission-critical services, augmented reality, and real-time applications. The real network simulation carried in the MATLAB environment shows that for UEs in the 6G network, the predicted latency will be approximately 4ms to 10ms, which showcasing unprecedented opportunity of possibilities in communication and services.

1. INTRODUCTION

The features of high-reliability communication and ultra-low latency in 6G networks are being pushed by a number of modern strategies. Another key strategy that has been suggested is the combination of the MEC cloud structures which is a model for minimizing latency by changing the processing of data closer to the end users particularly the vehicles through the arrangement of computational capabilities at the network edge. MEC is crucial to attaining ultra-low latency and high-reliability communication in the 6G network. MEC uses its proximity to the end-users to decrease the time it takes to transfer data, which improves the efficiency of essential applications such as real-time gaming and autonomous vehicles. 6G networks accomplish the demands of future generation strategies by improving reliability and reducing latency by employing the edge computing resources. With this integration, novel features are enabled, and uninterrupted connectivity is supported, bringing in a new era of reactive and efficient communication in the setting of 6G. Furthermore, the revolutionary potential of autonomous V2X communication is crucial for attaining ultra-low latency and high reliability in 6G networks, facilitating seamless connections between vehicles, roadside infrastructure, and individuals. As key technologies for intelligent transport, autonomous vehicles, and network control, V2X technologies are valuable for 6G networks due to their ultra-low latency and high reliability. V2X data interchange enhances traffic efficiency, ecological health, safety, and security through communication of vehicles with individuals, roads, and other vehicles. As a technology that allows for the smooth integration of cars into smart cities and instant decision making, this has revolutionized the way cities are designed and how transport is done. Furthermore, the evolution of packet scheduling techniques for Ultra-Reliable Low Latency Communication (URLLC) services is critical for satisfying the challenges of both ultra-low latency and high reliability in the 6G network, mainly in applications such as self-governed vehicles, industrial control, and other critical applications. These technologies in combination enable the implementation of high reliability and ultra-low latency communication in the framework of the 6G networks. MEC is one of the most important technologies that enhance the low latency in the 6G network by shifting the computation power close to the end user especially vehicles. By moving processing resources closer to the edge of the network, MEC minimizes the physical distance that data must travel, and by extension, the delay it experiences. This reduction in latency is crucial for real-time applications like self-driving cars, which require ultra-low latency and high reliability communication. The integration of MEC with self-driving V2X communication holds the potential to unlock unprecedented opportunities in communication and services. V2X communication enables cars to communicate not only with each other but also with roadside infrastructure and people [1]. Rapid and safer communication is made possible by bringing the network's computational power closer to the cars through the incorporation of MEC with V2X communication. This combination can improve the communication between self-driving cars and other framework components, enabling novel chance for critical services, augmented reality, and real-time usage. The combination of MEC with self-driving V2X communication holds the key to accomplish the potential of 6G networks, enabling seamless communication among vehicles, roadside infrastructure, and individuals. The anticipated latency capabilities for UEs in 6G networks are within an impressive range of 4ms to 10ms, as demonstrated by extensive testing and simulations conducted on the MATLAB platform. These ultra-low latency advances lead to a new form of communication and services in various settings. Low latency is an exceptional feature of 6G networks through which necessary services, actuality services, incorporated reality, and real-time applications can be incorporated. For instance, it offers secure, dependable, and real-time wireless communication beyond enormous momentary latency, which will prove favourable in fields like healthcare, industry, arts, academics, and many others [2]. Furthermore, the integration of MEC with self-driving V2X communication, promoted by the low-latency capabilities, paves the way for transformative improvement in the transportation and automotive industries. In addition, the given latency features of UEs in 6G networks allow for the improvement of haptic communications for VAR applications that are crucial in areas like smart services, production, education, health, and gaming. These abilities also enable the industrial robotic applications such as warehousing transport, extended reality, and the large-scale integration of robots and automation networks. The ultra-low latency characteristics of 6G networks can open a new dimension for a large number of applications and services ranging from the necessary services that demand low latency to the revolutionary innovations in different sectors where the low latency of the UEs in 6G networks is expected to be ensured [3].

6G is expected to revolutionize wireless communication technology, providing unprecedented levels of connectivity and automation. Its comprehensive approach to connectivity and incorporation of cutting-edge technologies make it the next frontier in meeting the needs of a data-driven, fully connected global network. The ultimate goal of 6G is to create a seamless network that can connect any device, anywhere, anytime, incorporating functions such as positioning, automation, navigation, control, computing, imaging, and sensing. 6G addresses the shortcomings of 5G by introducing new capabilities such as ultra-low latency, high data rates, connectivity for an extremely high density of devices, and high throughput. The evolution of 6G networks will be linked to the progress of mobile Internet and the IoE, which will use holographic communications to permit haptic interactions, providing a more natural and satisfying experience in digital worlds. The evolution of 6G networks will be intrinsically linked to the progress of two important IoT offshoots: mobile internet and the IoE as stated by Saad et al. [4]. These enhancements will use holographic communications to permit haptic interactions, making it possible for users to have a more natural and satisfying experience in digital worlds according to the study by Han and Huang [5]. For these developments to succeed, the underlying communication technologies used in 6G networks will need to feature extremely high throughput and ultra-low end-to-end latencies as compared to the current 5G network. The comparison between the current 5G network with the potential 6G network is given by Table 1.

Using trust, low-latency, and high-bandwidth, millions of linked devices and apps are described as being able to function flawlessly in a 6G network, as described in the articles [6, 7]. The article goes on to say that the most difficult challenge is likely to be achieving ultra-reliable and low-latency communications, which has stringent requirements for both low latency and ultra-high reliability [8]. The foundation of a 6G network is automation. Early adopters that have integrated it into Long-Term Evolution (LTE) networks have confirmed that 6G's self-organizing networks can significantly reduce infrastructure lifetime costs, building on the successes of 5G. In order to successfully coordinate and maintain the network infrastructure, the next generation of mobile networks will require the deployment of sophisticated agents in key locations. Experts have stressed [9] the significance of AI and ML in improving vehicle and agent connectivity and guaranteeing high quality service. The most important source of motivation for these developments will be state-of-the-art AI algorithms [10]. However, artificial intelligence algorithms require large datasets for efficient training, which in turn allows systems to make accurate conclusions. This system relies on the accurate flow tracking and other key parameters provided by the 6G core network. While 6G is an evolution of prior systems, it also marks a revolutionary technological change that has the potential to completely transform the foundations upon which today's mobile networks are based according to the study by Kazi and Wainer [11].

Table 1. Comparison of the current 5G network with anticipated upgrades and advancements of the next 6G network

Feature	Current 5G Network	Potential 6G Network
Network latency	Moderate latency (1-10 milliseconds)	Extremely low latency (10-100 microseconds)
Data rate	High data rates (up to 10 Gbps)	Very high data rates (nearly 1 Tbps)
Device density	Supports moderate device density	Supports massive device density (120 devices/km^2)
Mobile traffic	High mobile traffic capability	Increased mobile traffic capability
IoT connectivity	Provides IoT connectivity	Ultra-densification of IoT networks
Key extensions	Mobile Internet and IoT	Mobile Internet and Internet of Everything (IoE)
Impact	Revolutionizing mobile communications	Transformation of multiple industries

The development of 5G networks was driven by the need to solve problems caused by 4G networks, such as the need for more bandwidth, lower latency, faster data rates, wider device connectivity, and more consistent quality of experience provisioning [12]. This was made possible by the convergence of cutting-edge technologies used in 5G networks, including Massive MIMO, Cognitive Radio, and Mobile and Static Cell Networks. Conventional performance measurements, such as network bandwidth and spectral quality, must continue to adapt in response to the continued progress in 5G technology, enabling a wide variety of connectivity modes to improve the user experience [13]. Emerging as a key 6G use case, URLLC promises to support networking for new technologies like driverless vehicles and smart industries. Because of the strong latency limits imposed by URLLC, its traffic is typically preferred over ongoing enhanced Mobile Broadband (eMBB) transmissions. Beyond 5G networks (B5G) or 6G systems have received considerable attention since the introduction of multiservice networking. It is important to note that 6G reliability and latency factors can be adapted to individual use cases. 6G is also predicted to provide the benefit of extremely extended battery life, which could eliminate the need to charge devices as often as stated in the study by Hakeem et al. [14]. To lessen the effects of rising network complexity, experts predict that integrating multiservice technologies will boost network intelligence.

1.1 Contributions of study

These are some of the primary takeaways from the paper:

- A thorough literature assessment of previous efforts on topics such as autonomous vehicles, 6G-based URLLC networks, Virtualized Radio Access Network (vRAN), and MEC services should be the first step. Find the major problems and restrictions in the current research. Problems with latency, safety, scalability, and MEC integration are all possibilities.
- Comprehensive Analysis of URLLC Packet Scheduling Methods: This study offers a full analysis of the available packet scheduling methods for URLLC services, which are characterized by their extreme reliability and low latency. Applications like autonomous vehicles, industrial automation, and mission-critical communications necessitate ultra-reliable and low-latency connectivity, and URLLC is a crucial part of 6G networks that can provide it. Understanding how effectively URLLC requirements can be met in the context of 6G networks is improved thanks to the paper's thorough discussion of the relevant algorithms.
- Scheduling Algorithms Classification: The study classifies scheduling methods as either decentralized, centralized, or joint to help readers gain a more holistic and organized understanding of packet scheduling in 6G networks. This classification allows researchers and practitioners examine a range of ways for improving resource allocation and traffic prioritization, taking into consideration the different needs of applications in 6G systems.

The study does more than only summarize prior work; it also explores unknown ground in terms of future research possibilities and problems related to scheduling algorithms for URLLC services in the context of forthcoming 6G wireless systems. Coexistence of different services, integration of cutting-edge technologies, and security in a highly linked environment are all problems and opportunities that will emerge as 6G technology develops further. The document helps researchers and industry professionals focus their efforts on the most pressing issues and promising avenues for furthering 6G networks.

2. BACKGROUND

With the advent of 6G, improvements in communication technology are anticipated to usher in revolutionary shifts across many industries, but none more so than remote control and the IIoT. Ultra reliable Low Latency Communication (6G) will rely heavily on this technology. URLLC is a crucial part of 6G communication systems due to its potential to provide extremely low latency with sub-millisecond cycle rates and extremely high transmission efficiency over large areas as mentioned in the study by Vista et al. [15]. Enhanced Mobile Broadband (eMBB), similar to its role in 5G, will continue to enable high-speed data transfer, approaching Gigabit-per-second (Gbps) ranges. This technology is ideal for processing video information and other applications that generate a lot of network traffic. In order to keep up with the ever-increasing volume of video data, eMBB in 6G will likely take advantage of high-bandwidth channels to provide even greater usable bitrates according to the study by Nakamura et al. [16].

Another technology from 5G that will be used in 6G networks to help spread IoT is Massive Machine Type Communication (mMTC). With mMTC, we hope to link a wide variety of gadgets over great distances with concise communications as per article [17]. mMTC is anticipated to play a key role in the 6G era by facilitating the networking of varied devices, supporting applications like sensor readings and small intermittent data transmissions, and ultimately fostering the growth of the Internet of Things.

For applications requiring remote control, such as driverless vehicles, it is imperative to integrate these technologies into 6G [18]. The capabilities of 6G networks for supporting advanced functions like autonomous driving and other remote operations will be shaped by requirements for accurate monitoring, low latency from URLLC, high-speed data transmission from eMBB, and connectivity for numerous devices from mMTC. Due to the demanding requirements for low latency and high precision in the field of autonomous cars, it is expected that 6G will deliver high-precision positioning solutions [19]. To ensure stability and privacy, it was expected that the network architecture for CAVs would be built on a combination of several radio access techniques and cloud-based services. It was anticipated that 6G-based systems for positioning would be able to get around problems with Line of Sight (LOS) and give autonomous cars precise and trustworthy location data. Furthermore, 6G networks should be able to address issues with wireless video streaming [20]. The 6G ecosystem will be built to support a wide range of use cases, with an emphasis on a flexible and smart network architecture, and Quality of Experience (QoE) metrics will continue to play a pivotal role [21]. The 6G architecture uses innovations like network functions virtualization (NFV) and Software Defined Networks (SDN) to improve network uptime, reduce wasted resources, and fix problems autonomously.

Many new types of services are anticipated to leverage the superior capabilities of 6G technology, representing the next generation of wireless communication. These services span a wide range of application areas and promise game-changing capabilities facilitated by 6G technology [22] (see Figure 1).

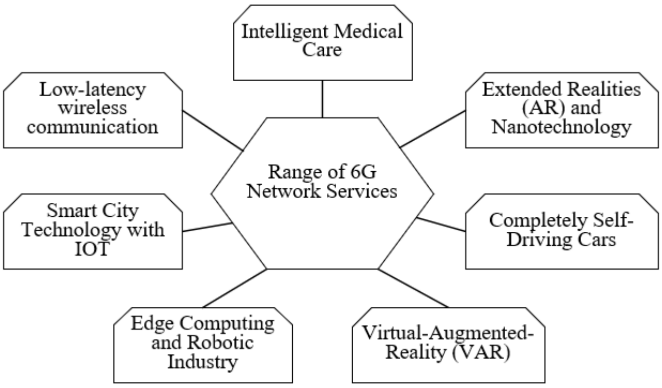

Figure 1. Range of applications compatible with 6G network with advanced coverage on network speed and efficiency

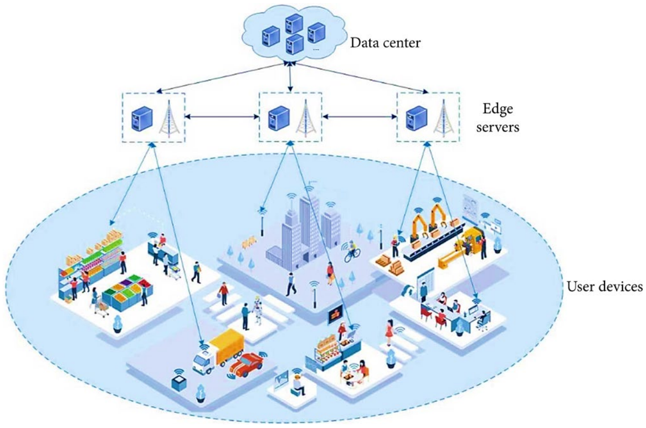

Figure 2. The edge computing architecture of compute offloading for 6G wireless networks

Videos in Extreme HD (EHD) quality will benefit from increased bandwidth and decreased latency in the wireless network, enabling the use of 16 GB and 32 GB patterns of EHD videos to meet network communication's significant need for video file processing. 6G introduces transceiver devices with separate antennas, allowing for automatic software updates and protection against hacking and signal interference to provide safe, efficient data transfer. Secure, dependable, low-latency wireless communication enables real-time service engagements, benefiting fields such as healthcare, industry, the arts, and academia. Haptic communications' support for Virtual-Augmented-Reality (VAR) through the use of sensory-based signals will have applications in industry, smart services, manufacturing, education, healthcare, and gaming. These programs require extremely fast data transmission in real time, and the availability of 1 Tbps bandwidth paves the way for genuine face-to-face communication utilizing several digital patterns from disparate origins or real-time immersion models. Low-latency network connectivity and precise interior positioning will be beneficial for applications in the robotic industry, including warehouse transportation, extended reality, large integration of robotics, and automation. 6G technology's high bandwidth, reliability, and low latencies pave the way for V2X connection, profoundly affecting the transportation and auto industries. Applications in healthcare, smart cities, the military, etc., will benefit from the "Internet of Bodies" and "Internet of Nano-Things" ideas by making use of low-power and implantable sensors, smart wearable devices, etc. Accessible around-the-clock, HD video conferencing solutions that are both secure and reliable are key to the concept of a future-proof healthcare system, paving the way for remote disease diagnosis and continuous health monitoring. High-stakes data management in fields like parking, traffic control, public transit, healthcare, utilities, and more will be essential to the development of smart cities in the future. Multiple access edge computing shortens the delay of communications by removing unnecessary service transmission paths. Extended Reality in the 6G context provides users with an interactive environment that incorporates data from a wide variety of sources, including audio, video, and GPS, combining AR, VR, and MR.

The integration of reconfigurable intelligent surfaces, terahertz communications, and artificial intelligence (AI) in the realm of 6G exploration is particularly compelling [22]. These cutting-edge technologies are poised to revolutionize wireless communications, offering a paradigm shift in how we conceptualize and implement connectivity. A comprehensive investigation into 6G with a focus on terahertz communications is detailed by De Alwis et al.[23], providing insights into various technological advancements, the intricacies of transmitter-receiver design, and diverse use cases. The incorporation of AI in 6G is anticipated to bring forth a host of advanced functionalities, encompassing self-aggregation, context awareness, auto-configuration, and opportunistic set-up, as highlighted by Merluzzi et al. [24]. Furthermore, AI-driven 6G is expected to delve into the untapped potentials of radio signals, enabling the transition from cognitive radio to intelligent radio [25]. Notably, machine learning (ML) plays a pivotal role in understanding the algorithmic nuances of AI-enabled 6G. Reconfigurable intelligent surfaces take center stage as the envisioned Massive MIMO 2.0 in 6G, as discussed by Khan et al. [26]. These surfaces, when coupled with index modulation, are poised to significantly enhance 6G spectral efficiency. Beyond individual initiatives, numerous global projects are underway, each aiming to spearhead the specification and establishment of 6G, reshaping frameworks and business models in wireless communication as shown in Figure 2. Initiation was recognized by the 6Genesis Flagship Program, and in 2019, the Terabit Bidirectional Multiuser Optical Wireless System for 6G became operational. In March 2019, the first 6G summit took place in Levi, Finland. Since then, there has been a flurry of academic research on 6G, with events like Huawei 6G Workshops, Wi-UAV Globecom 2018, and Carleton 6G adding to the conversation about the potential and progress of 6G.

The primary goal of 6G is to address the evolving demands of the information society by 2030, envisioning a future where 5G's limitations are surpassed and unmet service needs are addressed. The four main components of 6G's vision are "Intelligent Connectivity," "Deep Connectivity," "Holographic Connectivity," and "Ubiquitous Connectivity," shaping the overall 6G vision [27]. In contrast, the 5G network is confined to a communication range of just 10 kilometers above the Earth's surface and is primarily focused on data interchange and the Internet of Things. Although 5G's efforts to standardize NTN characteristics, the technical structures, and standards of satellite and cellular networks within the NTN architecture remain distinct, requiring specific gateway equipment for connection and interaction [28]. The efficacy and communication capabilities of 5G fall short of meeting the future demands of ubiquitous connectivity. To address these shortcomings, 6G must support the integration of space, air, ground, and sea (SAGS) networks. For true ubiquitous connectivity in the SAGS arena, this integration requires a unified technological system and common protocol architecture. Unlike 5G, 6G places more emphasis on the number of communication links in massive Machine Type Communications (mMTC) and URLLC, prioritizing real-time performance and reliability over throughput and connection count [29]. Consistent, extensive, high-throughput, and real-time performance are the pillars upon which the 6G vision rests. While some fundamental ideas in the 6G vision are rooted in 5G, the 6G vision advances these concepts to meet the demands and challenges of emerging scenarios in the future, as compared in Table 2.

Table 2. Comparison between 5G and 6G networks

Parameter	5G Network	6G Network (Speculative)
Frequency Bands	Sub-6 GHz and mmWave (24-100 GHz)	mmWave and Terahertz bands (100 GHz and above)
Cells	Small cells, macro cells, and pico cells	Highly dense small cells, potentially incorporating aerial and space cells
MIMO (Multiple Input, Multiple Output)	Up to Massive MIMO (32×32, 64×64)	Advanced Massive MIMO, Intelligent Reflecting Surfaces (IRS)
Duplex Nature	Full Duplex (Simultaneous transmission and reception)	Enhanced Full Duplex, Improved spectral efficiency
Latency	Sub-10 milliseconds (Goal: 1 millisecond)	Ultra-low latency, potentially sub-millisecond
Data Rate	Peak data rates up to 20 Gbps (in ideal conditions)	Enhanced peak data rates, potentially exceeding 100 Gbps
Energy Efficiency	Improved energy efficiency compared to 4G	Further improvements in energy efficiency, sustainable technology than 5G
Security	Enhanced security features compared to 4G	Improved security protocols, potentially quantum-resistant algorithms
Connection Density	Up to 1 million devices per square kilometer	Increased connection density, supporting the Internet of Everything (IoX)
Use Cases	Improved mobile broadband, massive Internet of Things (IoT), and URLLC	Transforming Internet of Things (IoT) applications, holographic communication, and cutting-edge augmented reality (AR) and virtual reality (VR) are undergoing continuous evolution.

3. NETWORK ANALYSIS

3.1 6G and self-driving cars usage case scenario

6G technology holds the promise of delivering advanced capabilities in terms of low latency, data rates, and connectivity. However, the practical implementation of these features in the context of self-driving cars will be contingent upon the development of standards, infrastructure deployment, and the resolution of various technical and regulatory challenges. To comprehend the potential impact of 6G technology on self-driving cars as it matures, it is essential to stay updated on its ongoing developments.One key aspect of 6G is its capacity to provide significantly higher data rates compared to its predecessors. This will help in enhancing the level of networking within self-driving cars and other related uses. There is an urgent need to build on this potential to mean that URLLC is an important innovation of 6G to solve the challenges relating to standards, policies, and regulations. This is especially important in applications such as self-driving cars where communication must be reliable and not delayed at all. URLLC will provide very low latency, high reliability, and availability which is crucial for the autonomous vehicle to operate in a highly dynamic environment. The massive device connectivity feature of 6G is poised to support the proliferation of connected devices in smart city environments, including self-driving cars. This capability is crucial for handling the increasing complexity and interconnectedness of devices within urban landscapes, contributing to the efficiency and reliability of self-driving car operations. Additionally, 6G could bring improvements in positioning technology, for global navigation satellite system (GNSS) and other capabilities that provide more accurate and reliable This Revolution could provide automobiles self-driving species have better understood their surroundings and environment to improve their steering or speed. In the future, as 6G continues to be developed and more research is done, it will go a long way towards automous vehicles technology.

3.2 Ultra low latency with 6G (Usage case: Self driving cars)

The ultra-low latency in the context of 6G networks and self-driving cars involves minimizing the time delay between sending a command and receiving a response. This delay consists of several components, and each can be mathematically represented. Here are the numerical representation of latency functions in network.

Having ultra-low latency is essential for self-driving cars to acquire and react to real-time information quickly. This is anticipated to be revolutionized by 6G technologies, which will reduce transmission latency to milliseconds or less. Self-driving cars can instantly communicate essential data with other vehicles, traffic facilities, and centralized networks due to this extremely quick connection. This allows for safer and more effective navigation through difficult conditions, which ultimately improves road security and transportation.

(1) Handling latency (H)

Depicts the amount of time needed for transmitting data between two points. The method for determining handling latency involves dividing the transferred data size by the transmission rate. This process requires an understanding of the duration it takes to send a particular amount of data at a certain speed. For example, higher handling latency is the effect of transferring more information at slower speeds.

$$H = \frac{Size\ of\ Data}{Transmission\ Rate}$$

where, transmission rate is the speed at which data is transmitted, while size of data is the total amount of data being transmitted.

(2) Propagation latency (P)

Stands for time a signal needs to go from its origin to its final destination. Propagation latency can be computed as the ratio of the distance between source and destination to the propagation speed. Employing fundamental physics, one can compute the time it requires for a signal to move across a medium by dividing the distance by the speed.

$$P = \frac{Distance}{Propagation\ Speed}$$

where, distance is the physical distance between the source and destination. The speed of a signal is its propagation through a certain medium.

(3) Processing delay (Pr)

Depicts the amount of time required for receiving data processing. The receiving device's processing capacity and the data's complexity determine the duration of this delay. The complex nature of the data and the processing power of the receiving device determine the processing latency. Determining the time it requires for various data types and devices to analyze incoming information is necessary for analysis.

(4) Queuing delay (Q)

Shows how much time is spent waiting in queues at different nodes in the network. The data transmission priority and network congestion determine the queuing latency. Network congestion and priority of data transmission are the causes of queuing delay. Using queuing theory, it attempts to clarify the impact of many parameters on the amount of time that users spend waiting in queues at various network nodes.

When added together, these factors make up total delay (T):

$$T = H + P + Pr + Q$$

Minimizing each of these components is the main goal when it comes to ultra-low latency for self-driving cars. As an example, 6G technologies strive to offer quicker processing capabilities, fewer propagation delays, and higher transmission rates. Additionally, efficient network management can help minimize queuing delays (Q) which will also indirectly affect the reliability of the 6G communication network.

3.3 Reliability with 6G (usage case: self driving cars)

Reliability in the context of 6G networks and self-driving cars is often associated with ensuring that communication is highly dependable, with a minimal risk of failure or disruption. While reliability is a complex concept and depends on various factors, including network architecture and protocols, here are some general components that contribute to reliability, along with their mathematical representations.

In 6G networks, high reliability is essential for self-driving cars because safety can be determined in ms. The reliable infrastructure of 6G provides constant communication, which is necessary for real-time data sharing between cars and their environment. Self-driving cars have ultra-low latency and little downtime, which allow them to react quickly to changing road conditions and improve effectiveness and security for passengers. 6G's advanced communication standards reduce the possibility of network traffic, enabling uninterrupted service even in densely populated urban areas. Furthermore, failover systems and duplication techniques improve reliability by lowering the possibility of transmission failures. In the end, 6G's consistent dependability paves the way for autonomous car use on a large scale, completely changing transportation systems worldwide.

(1) Packet error rate (PER)

Represents the probability of errors occurring in transmitted data packets. The ratio of defective packets to the total packets transferred is used to calculate the PER. This method computes the risk that errors may occur during transfer, which affects the distribution efficiency of data.

$$PER = \frac{Number\ of\ Erroneous\ Packets}{Total\ Number\ of\ Packets\ Transmitted}$$

where, number of erroneous packets - total number of packets that were corrupted or received with faults during transfer. Total number of packets transmitted - total number of packets transmitted over the communication channel in a certain amount of time.

(2) Bit error rate (BER)

Indicates the probability of errors in individual bits within a transmitted signal. BER is calculated similarly to PER, except it concentrates on the chance of errors within each bit of the delivered signal. Determining the possibility of bit errors developing during transmission is critical for determining the credibility of data at the bit stage.

$$BER = \frac{Number\ of\ Erroneous\ Bits}{Total\ Number\ of\ Bits\ Transmitted}$$

where, number of erroneous bits - total number of bits that were corrupted or erroneously received during transmission. Total number of bits transmitted - total number of bits delivered over the communication channel, comprising both the correct and incorrect bits.

(3) Availability (A)

Represents the proportion of time a system is operational and available for use. The percentage of a system's operation is expressed by availability. When determining how frequently a system could be used, it includes calculating the entire operating time and dividing it by its total duration.

$$A = \frac{Total\ Operational\ Time}{TimeTotal}$$

where, total operational time - amount of time that the system is completely operational and functional, without any downtime or faults. TimeTotal is a representation of the whole amount of time that is being considered, which may be a more general timeframe or a particular duration.

(4) Reliability (R)

Represents the probability that a system will perform its intended function without failure over a specified period. The system reliability is the probability that the system will perform as required in the intended time frame and is expressed as the failure possibility complement. This computation is especially important to determine the reliability of a system.

$$R = 1 - failure\ probability$$

where, failure probability is the probability of the system not meeting its reliability requirements.

(5) Mean time between failures ($MTBF$)

Represents the average time between consecutive failures in a system. These systems include the ability to calculate the MTBF which is the average time between two consecutive system failures is calculated from the total time of operation by the total failure rate. This measure is instrumental in assessing the dependability of the system and in identifying the actions and processes to be carried out.

$$MTBF = \frac{Total\ Operational\ Time}{Number\ of\ Failures}$$

where, number of failures - the overall number of failures encountered by the system during its operational period. Total operational time - total amount of time the system is operational, functioning well, and without failure.

This equation provides the basis for speculative measuring reliability in 6G communication systems. High levels of reliability are essential for self-driving cars that rely on 6G networks to ensure that connections between cars, services and other devices are reliable and robust.

It is important to note that achieving high reliability involves implementing error detection and correction mechanisms, redundancy, and other techniques to mitigate the impact of potential failures. The specific reliability requirements for self-driving cars in a 6G context would depend on safety-critical considerations and industry standards.

Table 3. Industry standards requirement for 6G network

Requirement	6G Support for V2X
Low latency	Ultra-low latency (<5 ms)
Reliability	High reliability (>99.9%)
Data rates	High data throughput (>20 Gbps)
Signal interference and fading resistance	Strong resistance to interference
Signal coverage	Wide coverage range (up to 500 meters)
Mobility support	High-speed data transmission support (up to 500 km/h)

With the evolution of wireless communication and the IoT, there is a potential for significantly enhanced and efficient transportation systems. In the realm of 6G networks, V2X emerges as a pivotal application, mirroring the role of 5G URLLC in fostering automated, accident-free, and collaborative driving as the requirement are given in Table 3. V2X imposes specific requirements on the wireless communication network [30]:

Low latency: Autonomous vehicles necessitate extremely low latency in COMMUNICATION between each other, surpassing the capabilities of the current 5G.

Reliability: Given that transmission errors, such as packet loss, can lead to serious incidents in autonomous vehicle scenarios, the reliability of these communication systems must be exceptionally high in case of 6G.

Data rates: V2X applications, particularly those relying on high-resolution images and videos to perceive their environment, demand substantial data throughput.

Signal interference and fading resistance: Vehicles contend with significant signal interference from other wireless communication systems, especially in urban settings. Additionally, structures and large objects may scatter or reflect signals, requiring resistance to interference and fading.

Signal coverage: V2X transmissions must consistently reach the nearest base station, even when it is located hundreds of meters away.

Mobility support: V2X applications should seamlessly transmit and receive data at very high speeds, accommodating scenarios such as communication with high-speed trains.

3.4 System model

This speculative model represents the deployment of 6G network on the MEC Cloud with the potential effects of geography and the environment on signal propagation as shown in Figure 3. This also illustrate the effect of latency on creating radio frequency (RF) simulations for the potential 6G network, covering the signal density and latency of network. It proposes a structure for examining how the next-generation networks, 6G, could be developed and utilized within the MEC Cloud context, taking into account elements such as terrain, climate, and networking node distance. Through the integration of these variables into the model, researchers can more accurately predict obstacles and enhance network efficiency for upcoming 6G deployments.

3.4.1 Determine the best assets for a 6G network

The first step in deploying 6G is to locate and assess potential spectrum bands, such as terahertz frequencies. The potential usage of terahertz frequencies, which can transport massive amounts of data at extremely fast speeds and fall between hundreds of gigahertz and several terahertz, is being evaluated for use in 6G.

Determine whether cutting-edge methods, such as massive MIMO and beamforming, are practically feasible. While beamforming concentrates radio frequencies into narrow beams directed at certain users or places, massive MIMO utilizes an extensive number of antennas at the receiver and transmitter to serve numerous users concurrently.

Look into possible 6G infrastructure solutions that are energy efficient. The need to use less energy to save operating costs and the environment is becoming more and more significant as technology grows.

3.4.2 Counter for iterations

Create a procedure for optimizing the system through iterative processes. Establishing an average efficiency utilizing initial configurations is the first step in iteratively optimizing a system. Operating the system under typical conditions and logging performance indicators are part of this process. The optimization process requires making small, controlled alterations to the configuration or architecture of the system, which are then evaluated in terms of performance to determine their effects.

Establish throughput, dependability, and latency as key performance indicators (KPIs). The rate at which the network produces data or transactions is referred to as throughput, and it is usually expressed in units per second. Availability and dependability are related terms that describe the degree to which a system operates as intended and how often it remains functional throughout a specific time frame. The time lag between providing an input and getting the intended result is measured as latency, and it's frequently important in real-time applications. These KPIs offer a quantitative structure for assessing the effectiveness of the system.

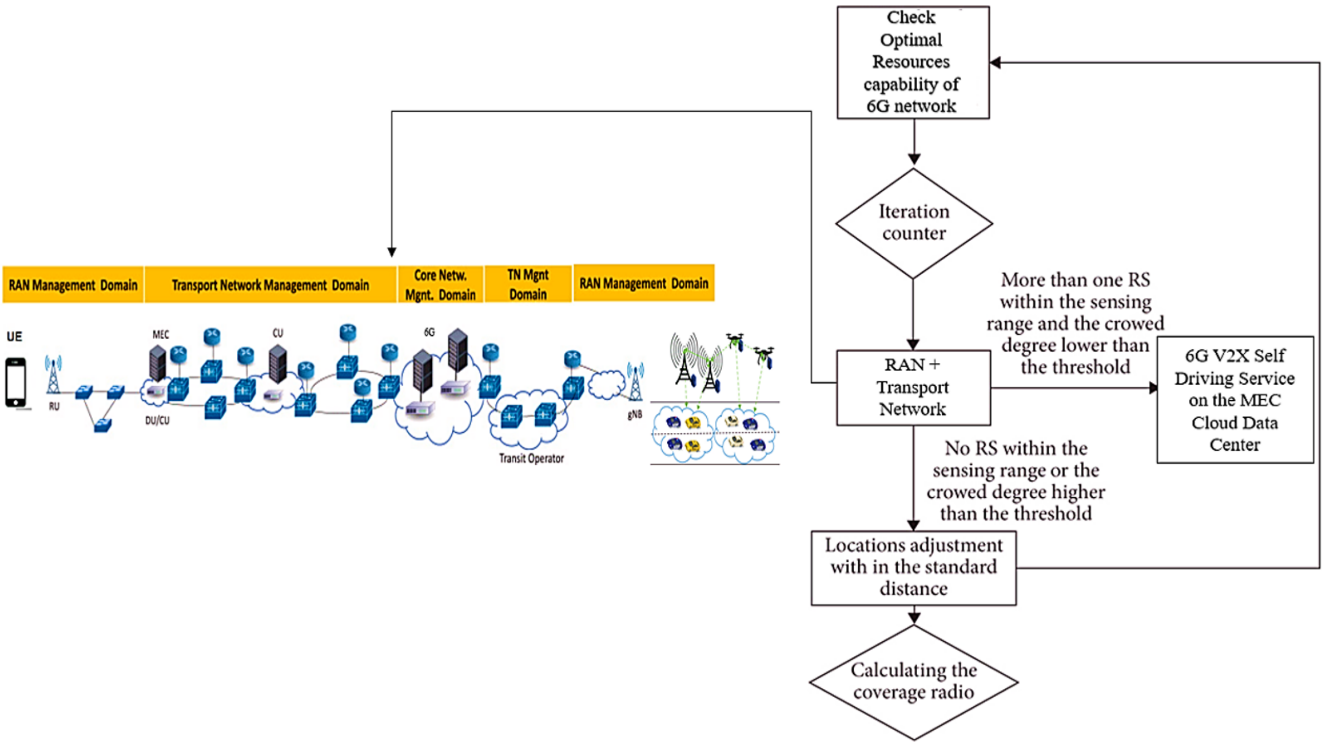

Figure 3. Speculative model of the potential 6G network with the V2X self-driving cars on the MEC cloud

Adjust the system's settings using an adaptive algorithm that takes user input into account. Initially, user preferences and data are gathered. The adaptive algorithm then processes this information to find trends and patterns. The system can adjust to evolving user preferences and behaviors since the algorithm constantly enhances its forecasts by integrating new user data. Employing an adaptive algorithm has the main benefit of personalizing the system's effectiveness, which increases user responsiveness and efficiency.

Network access network plus for 6G vehicle-to-everything self-driving service on the MEC cloud. For real-time V2X relationships, 6G technology offers incredibly rapid and low-latency communication features. Reducing delay and improving system adaptability, the MEC cloud shifts processing and storage capabilities closer to the vehicles. Reliable data transfer and continuous connectivity throughout the network is provided by the Network access network plus module.

3.4.3 Reducing latency: Integrating RAN with the transport network

Set up MEC, or multi-access edge computing, to handle data near its origin. As a result of this proximity, delay is decreased because less data can travel. For latency-sensitive uses like self-driving cars and V2X interactions, MEC is especially useful since it allows for real-time evaluation and decision-making by analyzing information locally at the edge.

Measure the effect of cloud-native designs on 6G V2X (vehicle-to-everything) data transmission. Microservices and containerization are used in cloud-native systems to improve the expansion and adaptability of networks. Network designers may improve V2X communication networks for dependable and effective data delivery by evaluating their impact on latency. The latency of MEC with the car can be find out by:

$$MEC\ latency =* \frac{Local\ Processing\ Time * Edge - to - Edge\ Communication\ Delay}{ELocal\ Processing\ Time + Edge - to - Edge\ Communication\ Delay} + \sin(Edge - to - Edge\ Communication\ Delay) + MEC\ Latency = \frac{LPT * E2ED}{LPT + E2ED} + \sin(E2ED)$$

Shake up the transportation system so it can meet the needs of autonomous vehicles for low-latency, high-throughput service. Enhancing the network's structure is required for this adaption to facilitate efficient interaction between vehicles and infrastructure. Improving bandwidth, spreading out MEC nodes across the transportation system, and broadening the coverage of networks are some approaches.

Position modification for measured distance. In V2X communications, obtaining accurate position measurements is essential to reducing latency. Accurate measurements can be obtained by modifying location algorithms to consider environmental and real-time changes. These metrics can be improved by combining sensors, which will further reduce latency.

3.4.4 Optimizing base station spacing for coverage and latency

Calculate the potential effects of geography and the environment on signal propagation. This includes taking into consideration variables that could impact signal reception and transmission, including as topography, frameworks, weather, and other geographical characteristics. This is probably achieved by the system using advanced modeling methods that combine topographic, meteorological, and material property data to precisely forecast signal behavior.

Use adaptive algorithms to update locations in real-time according to traffic and usage trends. The system constantly changes the placement of resources, like nodes in the network or service endpoints, in response to variations in user activity and needs. The system's ability to adjust quickly to changing circumstances allows it to effectively handle the network's capacity, improve resource consumption, and respond to changing traffic flows and usage patterns.

3.4.5 Coverage radio signal calculation for 6G networks

Model the properties of signal transmission by creating radio frequency (RF) simulations. This involves demonstrating how radio frequency signals function as they spread through different media. Through the use of these simulations, communication networks can be optimized for enhanced efficiency and a greater knowledge of how various signals relate to the environment.

Find out how interference and obstructions affect the signal's strength and dependability. The intensity and dependability of a signal can be greatly impacted by physical obstacles like buildings or topography as well as interruption from other transmissions. Establishing reliable communication networks that can reduce interruption and adjust to changing circumstances requires knowledge of that data.

Be sure that cell handoffs go off without a hitch by calculating the coverage areas of each base station. The process of determining every base station's coverage area is figuring out the region in which each station can reliably offer an adequate signal strength. Precise calculations of coverage areas guarantee seamless transitions between cells, preventing lost calls or data disruptions while customers cross different coverage zones.

Conduct trials and measurements in the field to validate the coverage model. This includes turning up mobile devices and test instruments in real-world settings and comparing the actual signal quality and strength with the values estimated by the simulation algorithms. These evaluations offer valuable information that can be used to improve network efficiency and modify coverage models [31-41].

4. RESULT

The simulation using the recommended method uses an Intel dual-core i7 CPU with 8 GB of RAM and performs in the MATLAB R2021a environment. Our suggested MEC+ V2X model is evaluated in terms of precision, F1-score, accuracy and recall with the traditional Extreme Gradient Boosting (XGBoost), k-nearest neighbor (KNN), and Random Forest (RF) [42-52]. Table 4 shows the simulation parameters.

Regarding 6G networks and their use in self-driving V2X automobiles [UE], a number of important variables affect communication dependability, latency, and overall performance. The advancements made in these areas are highlighted by the following findings in Table 5:

- Optimization of Channel Dispersion [Q]
- Improvement in reliability function [R].
- Downlink Probability Optimization.

The speculative curve provides a visual representation of how the spreading of signals, or channel dispersion, affect the signal quality in a 6G network. The numerical values and powers of 10 help illustrate the concept that as channel dispersion increases (moving along the X-axis), the quality and integrity of signals decrease (Y-axis values decreasing from 10^0 to 10^{-6}) of reliability is given in Figure 4.

The speculative graph illustrates how the Downlink Probability in a 6G network may influence the UE Timeout durations as shown in Figure 5. As the likelihood of successful downlink communication decreases, the UE Timeout durations may increase. Thus, the values ranging from 10^{-2} to 10^{-4} for the X-axis (Downlink Probability) and from 10^1 to 10^6 for the Y-axis (UE Timeout) to describe a speculative graph between UE Timeout and Downlink Probability in a 6G network.

Now to assess the reliability and latency of autonomous vehicles in the context of a 6G network, Monte carlo simulations were conducted with the following configurations: the weight factor was set to 20, and the RSU covered a road length of 800 meters. Signal density was specified as 0.5 vehicles per minute w.r.t car speed. Key parameters, including the message generation exchange rate at 80 messages per second, average service time for each UE (car) at 10 milliseconds, and vehicle transmission power set to 50 *dBm*, were taken into consideration as shown in Table 6.

In order to account for a multiple-hop scenario, we also set the slot duration at 65 microseconds, the noise power density at -180 dBm/Hz, and the number of resource blocks at 20. Figures 6-8 show the results of the simulations, respectively, illustrating advancements in handling latency, propagation latency and total latency within the 6G network context.

Propagation latency is shown to increase gradually on the graph, as the density of UEs stays constant. This increase suggests that there may be problems with the efficiency of signal transmission if the density of UEs is not changed on the fly to meet the communication demands of the network. The graph also shows an alternative scenario where the propagation latency decreases with a constant and steady density of self-driving cars.

Table 4. Simulation parameters

Simulation Parameters	Values
Number of vehicles	200 Vehicles per square kilometer
Communication range	250 meters for vehicle-to-vehicle communication
Transmission power	10 dbm – 30 dbm
Latency Range	1 – 20 ms
Network frequency	100 GHz – 1THz
Data rate	1 Gbps – 10 Gbps

Table 5. Speculative analysis of the important variables affect communication dependability, latency, and overall performance for V2X

UE	Channel Dispersion [Q]	Reliability Function [R]	Downlink Probability	Total Latency [*ms*]
Car 1	0.015	1.12×10^{-5}	10^{-5}	8
Car 2	0.040	1.15×10^{-3}	10^{-4}	6
Car 3	0.025	1.05×10^{-5}	10^{-3}	4
Car 4	0.032	1.11×10^{-7}	10^{-2}	5
Car 5	0.030	1.09×10^{-4}	10^{-1}	9
Car 6	0.027	1.19×10^{-3}	10^{0}	10
Car 7	0.020	1.04×10^{-6}	10^{1}	3

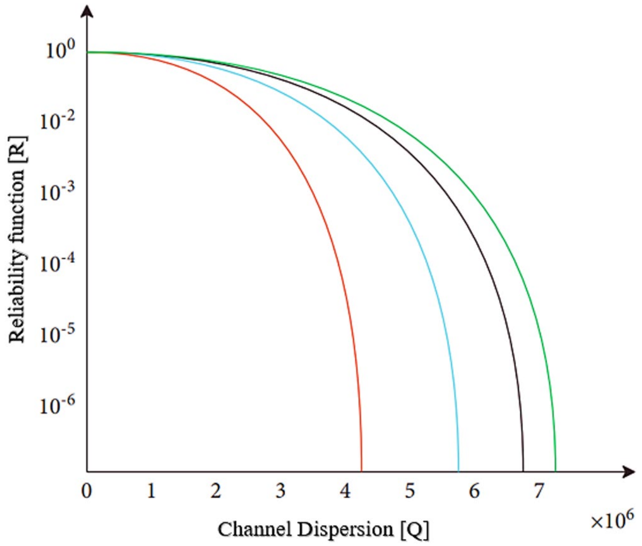

Figure 4. Curve showing the channel dispersion effect on the signals speculated over 6G network

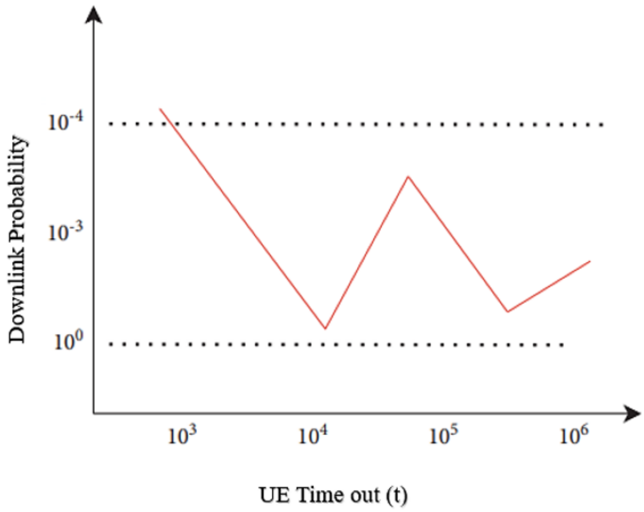

Figure 5. The threshold point representing a critical level of Downlink Probability where UE timeout durations increase more noticeably

The F1-score is a useful metric for assessing how well communication methods achieve low latency and high reliability by balancing precision and recall. Our proposed model, MEC+V2X, has a F1-score of 97.05% when compared to conventional techniques. In comparison, the F1-score of the traditional XGBoost, RF, and KNN approaches are 82.23%, 74.43%, and 70.21%. Output of F1-score is displayed in Figure 9.

For crucial applications, the precision evaluates the system's capacity to reliably provide packets within a set period with the least possible errors, ensuring correct and timely data transfer. Our proposed model, MEC+V2X, has a precision value of 94.78% when compared to the traditional approaches. By comparison, the precision values of the traditional XGBoost, RF, and KNN algorithms are 85.45%, 79.34%, and 71.21%. Figure 10 shows the output of precision.

The accuracy measures how well the network can reliably deliver data with low latency and great reliability, guaranteeing essential services' accessibility in real time. In comparision with the existing methods, our suggested MEC+V2X model has the accuracy of 95.03%. The conventional XGBoost, RF, and KNN methods has the accuracy value of 87.93%, 80.63%, and 72.06%, respectively. Figure 11 displayed the result of accuracy.

Recall assesses the percentage of pertinent communication situations that the network has successfully located, providing low latency and optimal reliability for essential services and real-time data transfer. Compared with the existing methods, our suggested model, MEC+V2X, has a recall rate of 96.12%. In contrast, the recall rates of the conventional XGBoost, RF, and KNN algorithms are 80.32%, 76.21%, and 69.32%. Result of recall is shown in Figure 12.

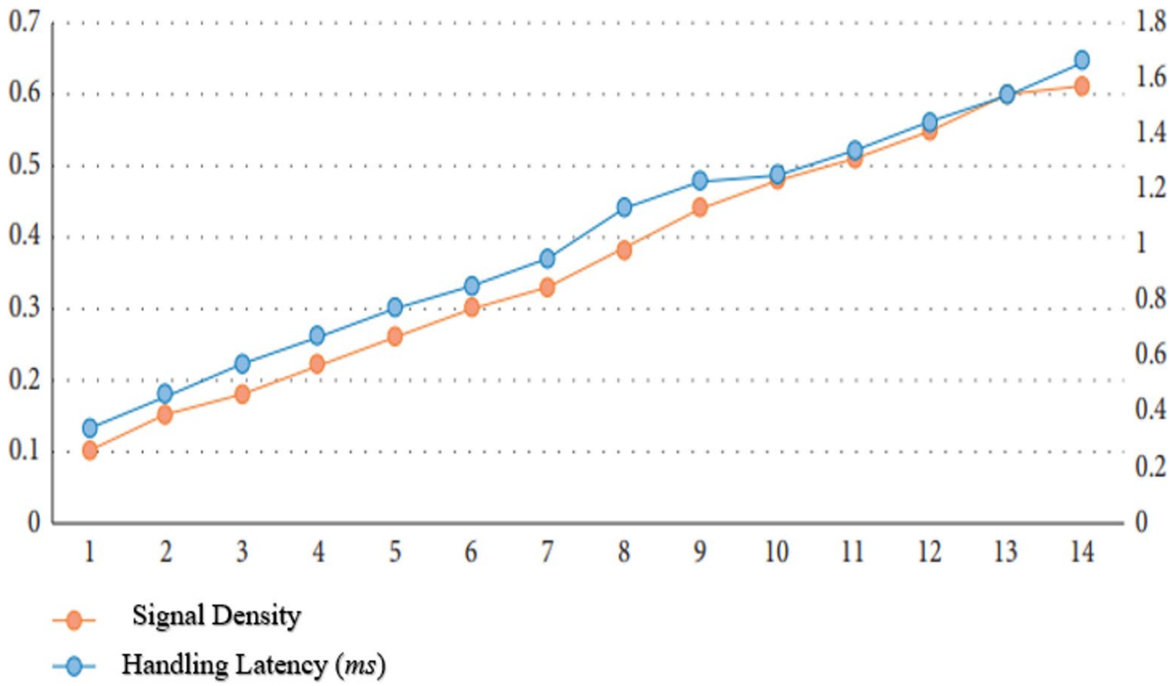

Figure 6. With increase of signal density, reduction in the handling latency of 6g signal

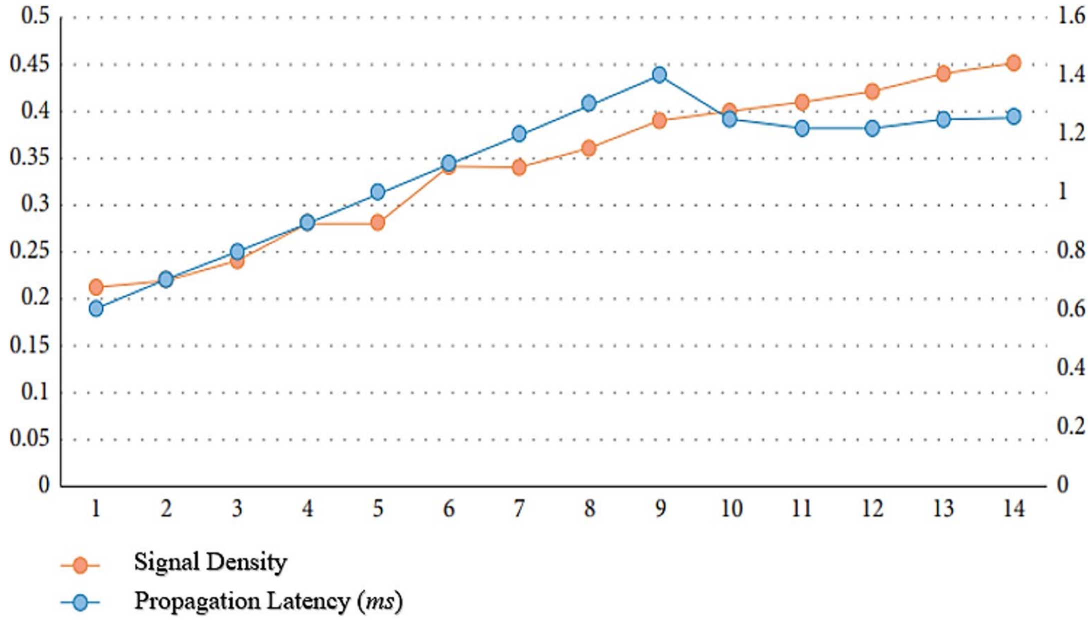

Figure 7. Impact of signal density on propagation latency for UE (car) and self-driving car

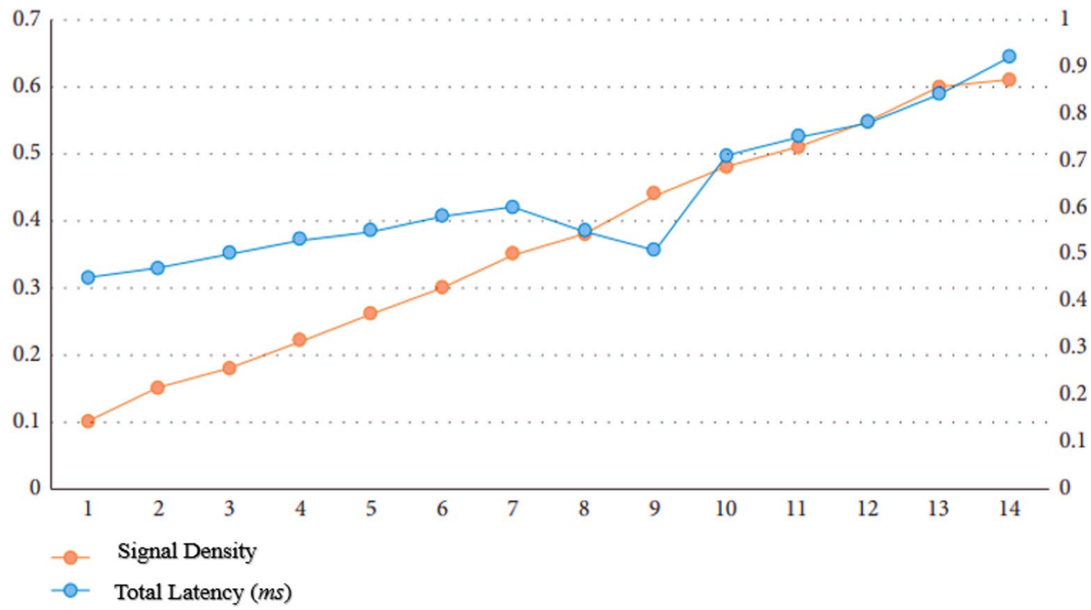

Figure 8. Relationship between signal density and total latency in a network with self-driving cars

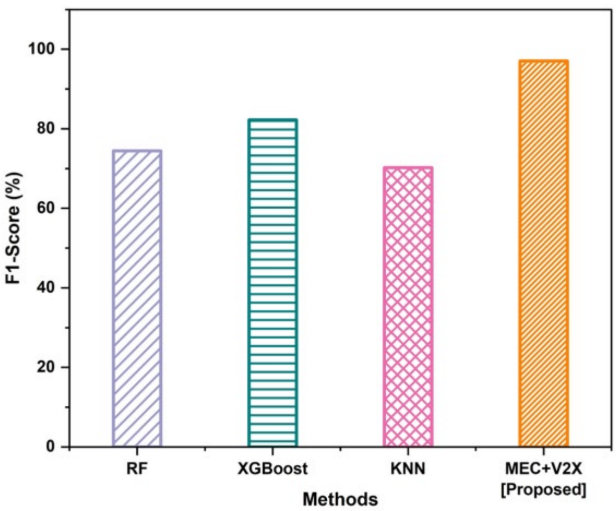

Figure 9. Result of F1-score

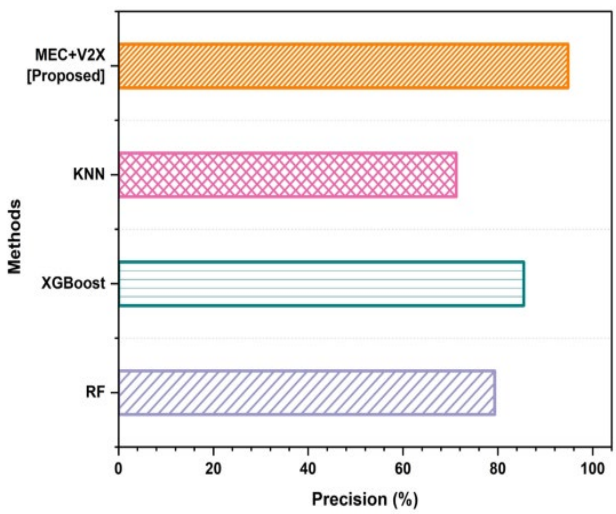

Figure 10. Result of precision

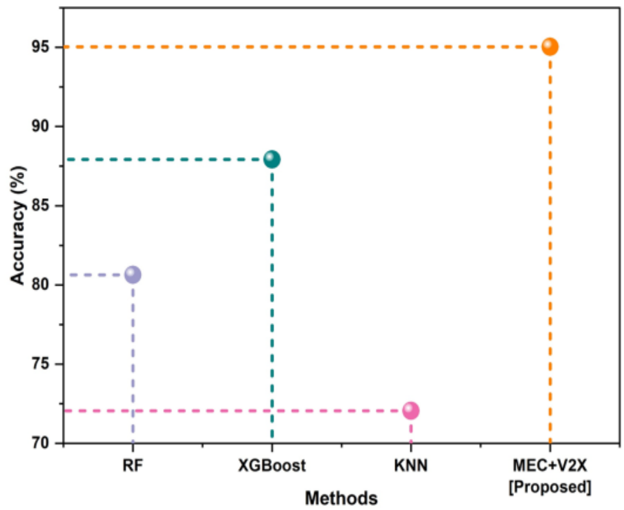

Figure 11. Result of accuracy

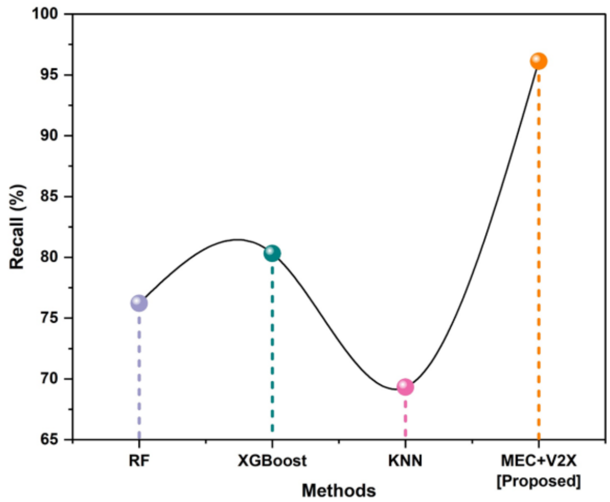

Figure 12. Result of recall

Table 6. Premise the UEs w.r.t to their total latency in network and the signal density

UE	T. Latency (*ms*)	Signal Density
Car1	4.2 *ms*	0.8
Car2	5.6 *ms*	0.6
Car3	9.4 *ms*	0.9
Car4	7.8 *ms*	0.7
Car5	10.1 *ms*	0.85
Car6	5.5 *ms*	0.4
Car7	6.2 *ms*	0.9

5. CONCLUSION

The advancement of 6G networks plays a pivotal role in achieving exceptionally low latency and reliable communication, particularly when integrating MEC with autonomous vehicles and V2X communication. 6G employs cutting-edge technology to achieve extremely low latency, utilizing strategies such as moving processing resources closer to the network edge through MEC to minimize data travel distance and subsequent delays. Predictive analytics and artificial intelligence contribute to proactive network management, addressing potential delay concerns. Additionally, advanced antenna systems like massive MIMO and beamforming maximize signal transmission efficiency.In the pursuit of high reliability within the 6G framework, multiple approaches are employed. Redundancy measures in hardware and software provide backup resources or paths in case of error, minimizing downtime and enhancing system resilience. System reliability is further improved by signal density, efficient error correction codes, self-healing abilities, and factors like channel dispersion and downlink possibility. As we navigate towards achieving ultra-low latency and high reliability, it is imperative to address both technical challenges and legal and ethical considerations. Our suggested MEC+V2X performance is evaluated in terms of precision (%), F1-score (%), accuracy (%), and recall (%). Researchers, the policy makers and industry stakeholders have a critical role for the V2X communications spectrum allocation; setting of rules for communication protocols and development of strong security architecture. These areas of application are crucial in present-day society and require collaboration to overcome challenges and achieve the successful design and deployment of these next-generation 6G networks. However, such important issues as availability of the spectrum for real-world deployment remain to be discussed. To eliminate interference, it is crucial to allocate the correct frequency bands for each transmission. It is necessary to clarify that standardization of protocols is crucial for their stable and identical work in devices and regions. Moreover, one of the main effects that require improvement of the network organization and distribution of resources is the rise in the quantity of devices that are connected. Edge computing poses a serious security risk due to the privacy processes conducted in close proximity to the point of collection. Concerns about protecting data privacy and protecting edge infrastructure from cyber attacks are paramount. V2X communications, in particular, are vulnerable to attackers because they transmit sensitive information, including vehicle status and position information. Future applications include developing more effective security and data privacy standards for edge computing and V2X networks to protect confidential data and provide secure communications from cyberattacks.

ACKNOWLEDGEMENT

The authors would like to thank Al-Bayan University for their support to complete this research paper.

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