# Federated Learning in Automated vehicles

Name:Rohan More
Department: *Mechanical Engineering*
Name of Organization: *Vishwakarma Institute of Information Technology*
Pune,India email:
rohan.22110931@viit.ac.in

Name: Arijit Mondal
Department: *Mechanical Engineering*
Name of Organization: *Vishwakarma Institute of Information Technology*
Pune, India email:
arijit.2110467@viit.ac.in

Guided by: Dr. Sonal Shamkuwar
Department: *Mechanical Engineering*
Name of Organization: *Vishwakarma Institute of Information Technology*
Pune, India email:
sonal.shamkuwar@viit.ac.in

Name: Smita Bodare
Department: *Mechanical Engineering*
Name of Organization: *Vishwakarma Institute of Information Technology*
Pune, India email:
smita..22110091@viit.ac.in

Name: Aditya Pendalwar
Department: *Mechanical Engineering*
Name of Organization: *Vishwakarma Institute of Information Technology*
Pune, India email:
aditya.22110029@viit.ac.in

***Abstract*—The landscape of automated vehicles and the broader automation industry is set to undergo a significant transformation with the advent of 6G connectivity. Addressing concerns surrounding privacy and security, Federated Learning (FL) plays a crucial role in this evolution. By harnessing the power of data-driven machine learning solutions enabled by 6G, FL enables local model training on devices, ensuring the protection of sensitive information within automated vehicles. This collaborative learning approach not only enhances the capabilities of individual vehicles but also contributes to the collective intelligence of the entire fleet. The integration of FL with 6G offers a seamless solution for optimizing operations in automated manufacturing processes and connected devices, creating a robust and scalable system. However, the widespread implementation of FL across diverse devices presents challenges that require standardization and interoperability to ensure a cohesive and efficient integration into the 6G ecosystem. Ultimately, the convergence of 6G and FL ushers in a new era of secure, efficient, and collaborative machine learning solutions for automated vehicles and the broader automation industry.**

***keywords- 6G, Artificial Intelligence, Machine learning, Federated Learning,Automated vehicles ,V2X,V2C.***

## 1. INTRODUCTION

Every day, the realm of communication expands. From 1G to 5G and now to 6G Technology, we have come a very long way. Over the last few decades, technology has advanced significantly thanks to numerous upgrades and additions over earlier generations. With an increase in data speed and data transfer, the 3G network introduced us to video call features. The major goal of 4G was to offer quick speeds. Any type of content could be viewed in real time. Capacity, coverage, and signal quality all improved. Due to affordability, a large number of internet consumers increased. The speed increased nearly ten fold after the introduction of 5G. 5G is based on OWA i.e Open Wireless Technology. It advances a true Wireless-World Wide Web (WWWW). Numerous applications that affect people's daily lives have already shown AI to be indispensable.Today, AI is almost used everywhere. From the Face Recognition feature in phones to sending an email , to tools like Siri and Google Assistant and various smart home appliances, AI has evolved and helped people.It is becoming clear that AI has the ability to optimize and enhance wireless networking infrastructures. Machine Learning has played an important part in the progress of sixth generation (6G) communication, taking into account the considerable expansion of data traffic.

In the evolution of the sixth generation (6G) , Training samples must be gathered at the server for centralized machine learning algorithms. Thus, sending huge numbers of data samples may result in a noticeable transmission delay. User privacy, meanwhile, is not that fantastic. Therefore, privacy restrictions and minimal latency are key factors to take into account. Unmanned aerial vehicles, extended reality, and many other new uses will be among its numerous emerging applications.

The implementation of a federated learning approach will enhance user-device model training and automatically reduce network traffic volume and transmission delay.

In this essay, from the viewpoint of FL, we outline the essential conditions and emerging patterns that will propel widespread AI for 6G.

## 2. KEY 6G REQUIREMENT & EXPECTATIONS

Here are some requirements for 6G and expectations from 6G connectionSystem:

1)Ultra-Reliable, Low-Latency Communication:
To enable real-time decision-making for automated vehicles, 6G needs to provide communication that is both ultra-reliable and low-latency. The ability to quickly exchange information between vehicles and infrastructure is crucial for the success of autonomous driving.

2)Massive Device Connectivity:
Seamless communication among automated vehicles, infrastructure, and other connected devices should be made possible by 6G. This extensive connectivity creates an intelligent ecosystem that promotes efficient collaboration and data exchange.

3)Advanced Data Processing Capabilities:
The enhancement of data processing capabilities in 6G will facilitate on-device artificial intelligence (AI) and machine learning for automated vehicles. By enabling localized decision-making, the reliance on centralized processing is reduced, addressing concerns related to privacy and security.

## 3.CHALLENGES & CONTRIBUTIONS OF FEDERATIVE LEARNING

As per various beliefs, 6G is built upon a groundbreaking concept of revolutionary AI, an exceedingly adaptable structure that incorporates human-like intelligence into every element of networking systems. Despite its immense potential, the integration of ubiquitous AI in 6G is expected to encounter a range of fresh challenges. One significant hurdle lies in the implementation of distributed AI across multiple devices. A promising solution known as federated learning (FL) enables data-driven AI solutions to span diverse and potentially extensive networks. The FL-inspired architecture has been recognized as a highly promising approach to achieving AI in 6G, despite being in the nascent stages of research.

- Federated learning plays a crucial role in addressing the challenges of 6G, which can be outlined as follows.

Enhancing AI Communication in Automated Vehicles:
FL plays a crucial role in promoting efficient AI communication within the realm of automated vehicles. By eliminating the need to upload data from each vehicle to a central server, FL effectively minimizes network congestion. It achieves this by reducing the frequency of model updates and compressing on-device data, thereby overcoming communication obstacles and facilitating seamless data flow for real-time decision-making in automated driving scenarios.

Managing Diverse Data Sources in Automation:
Automated vehicles and various automation systems generate diverse datasets owing to their distinct functionalities and user preferences. FL caters to this diversity by enabling devices to be trained using their unique datasets. Whether it is navigation patterns, performance metrics, or user preferences, FL facilitates the training of models on this heterogeneous data. Consequently, it produces AI solutions that are more adaptable and specialized for automation.

Effective Deployment in Large-scale Automation Networks:
FL proves to be highly advantageous in meeting the scalability requirements of automation networks. As the number of connected devices in automated environments grows, FL ensures that the training process remains unaffected, consistently delivering reliable outcomes. This scalability feature is of utmost importance when deploying FL in extensive automated vehicle fleets and industrial automation setups.

In the realm of automated vehicles and industrial automation, cutting-edge AI technologies such as deep learning, reinforcement learning, transfer learning, and generative learning play a crucial role. By incorporating these advanced AI techniques, FL contributes to the creation of a flexible networking architecture. This flexibility guarantees that FL maintains its position as a leader in delivering dependable, context-aware, and pertinent solutions that align with the continuous progress in AI within the automation industry.

Here are some ways in which federated learning can contribute towards ubiquitous AI in 6G:

*Enhancing Model Performance through Decentralized Data Collection:*
In the world of automated vehicles and automation, federated learning enables the gathering of data from different devices, including images, audio, and text, without compromising sensitive information. By adopting this decentralized method, devices work together to provide their expertise to a central server. This approach guarantees a strong dataset, resulting in AI models that are more accurate, efficient, and specifically designed for the *requirements of automated systems.*

*Enhanced Data Privacy*: Automated systems benefit greatly from enhanced data privacy and security, thanks to the significant role played by federated learning. This approach effectively tackles privacy concerns in areas such as automated vehicles and industrial automation. By decentralizing and securing data, it guarantees the confidentiality of critical information, eliminating the risk of exposure to a centralized server. This commitment to data privacy perfectly aligns with the increased focus on security and privacy in the era of 6G.

*Enhancing Performance Efficiency through Collaborative Learning:*
In the realm of automated vehicles and automation, federated learning promotes collaborative learning among different devices and organizations. Each entity gains knowledge from its own localized data, ensuring privacy and accuracy. By sharing their insights with a central AI model while safeguarding sensitive information, collaborative learning boosts the overall efficiency and performance of AI models, empowering them to thrive in dynamic and evolving situations.

*Adaptive and Dynamic Models*: Federated learning plays a vital role in creating automation systems in the 6G era. It allows for the creation of AI models that are both adaptive and dynamic. By continuously updating the models based on real-time data from connected devices, AI systems can be trained and adjusted to changing data patterns and environments. This adaptability ensures that the models remain resilient and robust, even in the face of complex scenarios encountered in automated vehicles and industrial automation processes.

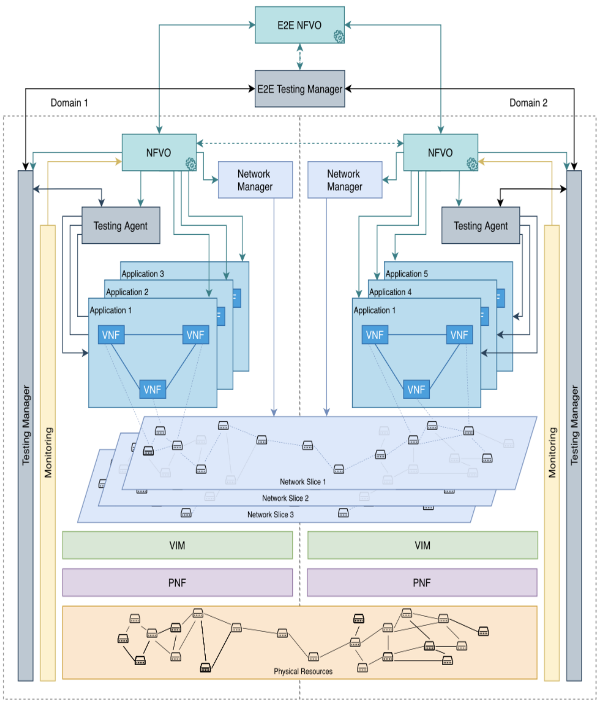



FIG 1: 6G application management architecture.

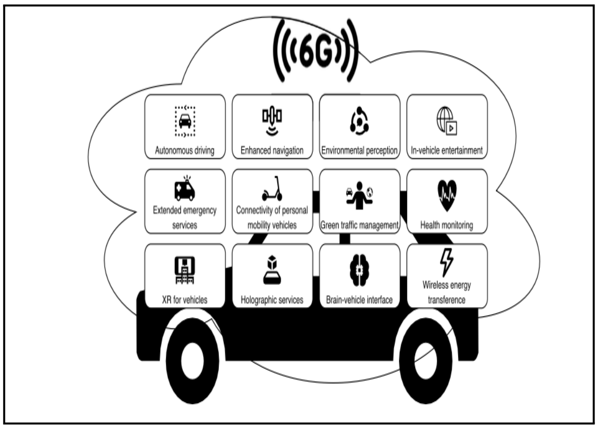



FIG 2 :Evolutionary 6G vehicular applications.

## 3.APPLICATIONS FOR FEDERATED LEARNING FOR AUTOMATED VEHICLES & AUTOMATION

The future development of 6G designs encompasses more than just ground network deployments. It involves integrated architectures that connect space, air, ground, and sea. This comprehensive approach ensures coverage in three dimensions - space, time, and frequency - by leveraging advancements in various technologies including tactile communications, quantum computing, Distributed Ledger Technology (DLT), THz communications, Machine Learning (ML)-based network resiliency and slicing, multiple radio access technologies, intelligent reflecting surfaces, and the integration of cloud–edge–fog. By adopting this integrated approach, we have the potential to revolutionize the Vehicle-to-Everything (V2X) ecosystem, which includes vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P), and communication with remote entities like cloud servers. The envisioned applications of 6G, building upon the use cases of Cellular V2X (C-V2X) in previous generations, are extensive. They include remote driving, advanced driving, vehicle platooning, extended sensors, and improved vehicle Quality of Service (QoS) support. These advancements pave the way for more sophisticated features within each group, opening up possibilities for revolutionary applications and an expanding range of potential V2X services that will benefit from the expected performance improvements of 6G. In our recent paper, we highlight the evolution of 6G applications, starting from the services envisioned with 5G, as shown in Figure 1. We also emphasize the continuous growth in potential V2X services made possible by the advancements of 6G.

*An important area of focus in the field of autonomous driving is reaching level 5, where vehicles can operate without any human intervention. This is particularly crucial for last-mile transportation, which refers to domestic travel.*

**Current status** :
There have been significant advancements in integrating 5G communications and related technologies to enable cooperative perception in autonomous vehicles. Recent studies have demonstrated the practicality of this integration. While widespread implementation is still pending, various research projects have successfully tested the potential of base 5G-NR on real roads. These initiatives highlight the vital role that communication plays in complementing the data gathered from on-board sensors such as cameras, laser systems, and ultrasound radars. The continuous developments in this area emphasize the critical significance of communication technologies in advancing the capabilities of autonomous driving.
*Enhanced Navigation* :
The integration of drone and satellite support, along with anticipated advancements in radio access, is set to revolutionize navigation capabilities. The aim is to achieve sub-meter positioning accuracy, while also improving bandwidth and network availability to enable the use of digital maps and real-time traffic information.
**current status** :
Extensive research in the field has established the importance of accurate 5G positioning, which surpasses the capabilities of traditional GPS. Recent studies have shown significant progress, with performance metrics reaching centimeter-level precision. This increased accuracy allows for real-time identification of vehicle paths within specific lanes, offering the potential for substantial enhancements in perception, decision-making, and control within the realm of transportation. The current trajectory of research and development suggests a clear shift towards achieving unparalleled levels of navigation precision in the 5G era

*Connectivity of personal mobility vehicles :*

The connectivity of personal mobility vehicles, such as bicycles or scooters, is on the verge of a breakthrough. By utilizing 3GPP technologies, the energy impact per transmitted bit is being dramatically reduced. This opens up new possibilities for these vehicles to connect and communicate. In the past, the technologies used for this purpose required a higher amount of power compared to their LPWAN counterparts.

**current status:**Currently, there is a great deal of interest within the research community regarding the integration of eco-efficient personal vehicles into the Cooperative Intelligent Transport Systems (C-ITS) ecosystem. Researchers are actively working on developing On-Board Units (OBUs) that are both efficient and lightweight. These OBUs will be capable of providing additional services to riders. To achieve this, key enabling technologies are being explored from both communication and computation perspectives When it comes to communication technologies, Low Power Wide Area Network (LPWAN) solutions like LoRaWAN, Sigfox, and NB-IoT are being considered as viable alternatives. This is because they offer long transmission distances and consume limited amounts of energy. However, there is great anticipation for the development of efficient 6G transmission schemes. These schemes are expected to further enhance the long-term connectivity of Internet of Things (IoT) devices.On the computation front, algorithms based on the TinyML paradigm are gaining traction. These algorithms provide intelligent data processing and decision-making capabilities with low computational overhead. This development is particularly exciting as it opens up new possibilities for efficient and intelligent data processing in the context of personal mobility vehicles.a comprehensive method for enhancing the connectivity and computational effectiveness of individual transportation devices

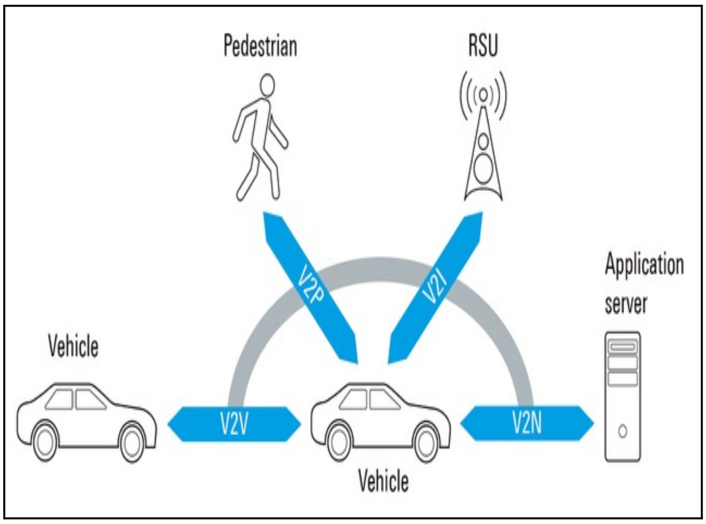



FIG: some types of v2c

## 5.TYPES OF FEDERATED LEARNING

*Decentralized Model Training*:
Explanation: In this method, individual autonomous vehicles independently train their machine learning models using their own data. These models are then regularly combined to form a global model that incorporates insights from all participating vehicles.
Utilization: Decentralized model training is particularly suitable for situations where vehicles operate in diverse environments, allowing the global model to encompass a comprehensive understanding of various driving conditions.

*Privacy-Preserving Federated Learning:*
Explanation: With a focus on safeguarding data privacy, this form of federated learning utilizes encryption and secure aggregation techniques to ensure that raw data never leaves the individual vehicles. Only encrypted model updates are shared for global model aggregation.
Utilization: Privacy-preserving federated learning is essential for addressing concerns regarding sensitive information in autonomous vehicles, making it ideal for applications where data security is of utmost importance.

*Edge Federated Learning*:
Explanation: This approach involves training machine learning models directly on the edge devices, such as the onboard processors in autonomous vehicles. Model updates are locally aggregated on the edge, reducing the reliance on centralized processing.
Utilization: Edge federated learning is advantageous in scenarios where real-time decision-making is crucial, as it minimizes latency by keeping model updates close to the data source.

Transfer learning federated frameworks are a type of federated learning that enables the fine-tuning of models trained on one set of vehicles for another set. This allows for the transfer of knowledge between fleets with different characteristics, promoting efficient knowledge reuse in situations where certain vehicles share similarities in their operational environments.

Dynamic federated learning, on the other hand, is a form of federated learning that adjusts the model aggregation process based on the real-time performance of individual vehicles. In this approach, vehicles with higher accuracy or relevance have a stronger influence on the global model. This adaptive learning strategy is particularly useful in scenarios where the relevance and reliability of different vehicles' data may vary over time.

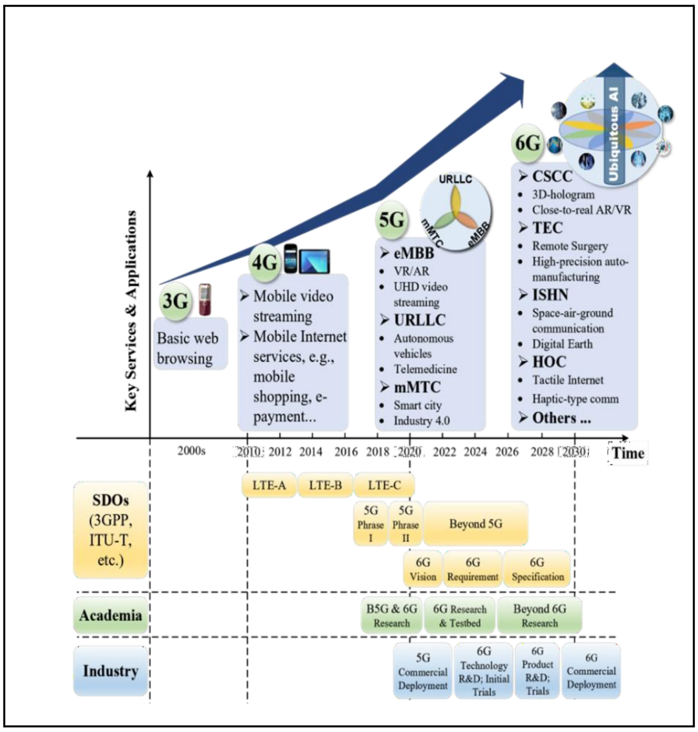
For ensuring the reliability of federated learning systems in environments where compromised or faulty vehicles may be present, robust federated learning incorporates mechanisms to handle adversarial or outlier vehicles. This involves the implementation of techniques to detect and mitigate the impact of poorly behaving or maliciously intended participants. This approach is especially relevant in environments where the presence of compromised or faulty vehicles is a potential concern.

## 6.WHAT IS V2X & V2C

Vehicles communicating with various elements in their environment is known as Vehicle-to-Everything (V2X) technology. This includes Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Pedestrian (V2P), and more. V2X uses wireless communication protocols to facilitate information exchange between vehicles, roadside infrastructure, pedestrians, and cloud servers. The goal is to improve road safety, traffic efficiency, and transportation effectiveness. By sharing real-time data about location, speed, and other relevant information, V2X enables dynamic decision-making to enhance traffic flow and minimize accidents. This technology is essential for the advancement of smart and connected transportation systems, paving the way for autonomous driving and intelligent traffic management.

Within the V2X framework, Vehicle-to-Cloud (V2C) communication focuses specifically on the interaction between vehicles and cloud-based services. Through V2C, vehicles communicate with remote cloud servers to exchange data, access services, and utilize computational resources. This communication allows vehicles to delegate certain tasks, such as data storage, processing, and analysis, to cloud servers, thereby enhancing the capabilities of the connected vehicle ecosystem.

V2C enhances the journey behind the wheel with its array of features, including up-to-the-minute traffic updates, guidance with navigation, and the ability to remotely diagnose your vehicle. By harnessing the capabilities of cloud computing, it adds a touch of intelligence, efficiency, and personalization to your driving experience. Furthermore, it paves the way for connected and autonomous vehicles by offering a flexible and centralized platform to process and analyze real-time data generated by vehicles.



## 7. APPLICATION

*Green traffic managment* :

The advancement of connected devices will greatly enhance the number of On-Board Units (OBUs) available, thus enabling the implementation of real-time traffic management. This will allow for the introduction of various scenarios, such as optimized platooning, adaptive traffic lights, pollution reduction measures, flexible and fast routes, as well as emergency response tracks.

*Health Monitoring*:

In the realm of automobiles, our research highlights the vital importance of health monitoring. With the rise of extensive connectivity and rapid data processing, it becomes possible to establish comprehensive systems for monitoring both drivers and passengers. This involves making use of wearable devices that are connected to the vehicle, as well as real-time video analysis within the vehicle itself, in order to gather essential health-related information. These monitoring systems hold the potential to keep track of various health indicators, such as heart rate, fatigue levels, and stress markers, thus contributing to a comprehensive understanding of the well-being of the vehicle occupants throughout their journey. By seamlessly integrating wearable technologies and in-vehicle analytics, we are able to provide continuous health assessments, which in turn enable timely interventions and personalized support. This aspect of our study delves into the transformative effects of health monitoring, as it enhances overall safety and well-being within the vehicle environment.

*Augmented/Mixed/Virtual Reality (XR) for Ground and Flying Vehicles:*

Our research focuses on the incorporation of Extended Reality (XR), which encompasses Augmented Reality (AR), Mixed Reality (MR), and Virtual Reality (VR), in ground and flying vehicles. This cutting-edge feature requires real-time processing of 8K videos, quick response times, and rapid updates of virtual environments. The impact of XR extends to practical uses like remote driving, providing operators with an immersive experience as they navigate and control vehicles from a remote location. Furthermore, the integration of transparent or on-board panels presents tangible scenarios where these XR advancements are crucial. Our study examines the technical complexities and potential applications of XR technologies in the automotive and aerospace industries, highlighting their significance in transforming the user experience, enhancing safety, and improving operational efficiency in ground and flying vehicles.

*Holographic services:*

Examining the potential of holographic services is the focus of our research, with a particular emphasis on the impact of Massive Ultra-Reliable and Low Latency communications (mURLL) and Terahertz (THz) connectivity. This advanced technology has the potential to revolutionize vehicle control by allowing remote driving through the use of holograms and 3D environments. By integrating mURLL and THz connectivity, we can pave the way for the development of holographic-powered applications within vehicles, creating a whole new level of user interface and experience. This aspect of our study dives into the technical capabilities and practical applications of holographic services in the automotive industry, highlighting their ability to redefine how vehicles are controlled, operated, and experienced through immersive holographic technologies.

*Brain vehicle interface*:

The concept of a Brain-Vehicle Interface is at the forefront of our investigation, with a specific focus on the advancements expected with 6G technology. This interface envisions a wireless connection between the human brain and vehicle systems, requiring high-speed capabilities of gigabits per second (Gbps). The potential impact of this interface is significant, especially in the realm of driving interfaces for individuals with disabilities. With the improved data transfer speeds and minimal delay offered by 6G, new opportunities arise for seamless and real-time interactions between the human brain and the vehicle's control systems. Our research explores the technological requirements, potential applications, and ethical considerations of the Brain-Vehicle Interface, highlighting its ability to transform accessibility and user experience, particularly for those facing mobility challenges.

*Wireless Energy Transference:*

Our study focuses on the revolutionary concept of wireless energy transference, specifically in relation to the emerging field of electric vehicles. The envisioned scenario involves these vehicles being able to charge their batteries wirelessly through innovative energy transfer methods. This breakthrough has the potential to eliminate the need for physical plugs, revolutionizing the charging infrastructure for electric vehicles. The study also investigates the possibility of on-route charging, either through specialized road infrastructure or through collaborative charging with other vehicles and roadside units. This vision relies on a precise coordination system, made possible by the anticipated capabilities of 6G infrastructure. By enabling wireless energy transfer, this technology not only overcomes the logistical challenges of charging but also supports the idea of vehicles that are always ready to go, minimizing potential disruptions caused by energy-related issues that could affect communication within the vehicular ecosystem.

*Advanced Emergency Services:*

Our investigation delves into the progress of emergency services, specifically focusing on expanding safety measures in driving situations. This improvement involves the integration of cutting-edge communication technologies, including Massive Ultra-Reliable and Low Latency Communications (mURLL) and ultra-massive Machine Type Communications (umMTC). By combining these technologies with Visible Light Communications (VLC) and other transmission methods, our aim is to establish a strong framework for swift and dependable emergency responses. Additionally, our research explores the implementation of solutions designed for Internet of Things (IoT) scenarios, such as Low Power Wide Area Network (LPWAN), which contributes to a comprehensive emergency communication infrastructure. Moreover, the study takes into consideration Distributed Ledger Technology (DLT)-based solutions and quantum security measures to ensure long-term cybersecurity and the trustworthiness of emergency services in the ever-evolving world of vehicular communications.

## 8. CONCLUSION

In the ever-evolving world of 5G technology, the focus has already shifted towards the development of 6G cellular networks. Unlike the approach taken for 5G, the success of 6G relies on understanding and addressing the needs of upcoming applications. Among these applications, vehicular use cases are of utmost importance and will shape the requirements for future 6G deployments. This paper presents a comprehensive overview of current and anticipated vehicular applications, highlighting their primary needs. By identifying these requirements, we can establish measurable Key Performance Indicators (KPIs) that will guide the design of different aspects of 6G. To ensure the success of instantiated applications, this paper also introduces a 6G-focused platform that manages deployment across various domains and monitors the Quality of Service (QoS) performance. Furthermore, this platform enables post-instantiation testing to verify if QoS requirements are being met.

Our future research will focus on thoroughly evaluating this solution in various challenging vehicular scenarios, such as network and computing-intensive situations and autonomous driving conditions. This work marks the next step in our continuous efforts within the 5GASP European project and the national initiatives of R3CAV and Cerberus.

## 9.REFERENCE


[1] W. Saad, M. Bennis, M. Chen, A vision of 6G wireless systems: Applications, trends, technologies, and open research problems, IEEE Netw. 34 (3) (2020) 134–142, http://dx.doi.org/10.1109/MNET.001. 1900287.

[2] Z. Qadir, K.N. Le, N. Saeed, H.S. Munawar, Towards 6G internet of things: Recent advances, use cases, and open challenges, ICT Express (2022) http://dx.doi.org/10.1016/j.icte.2022.06.006.

[3] D.C. Nguyen, M. Ding, P.N. Pathirana, A. Seneviratne, J. Li, D. Niyato, O. Dobre, H.V. Poor, 6G internet of things: A comprehensive survey, IEEE Internet Things J. 9 (1) (2022) 359–383, http://dx.doi. org/10.1109/JIOT.2021.3103320.

[4] 3GPP, 3GPP TR 23.287 V17.4.0: Architecture enhancements for 5G System (5GS) to support Vehicle-to-Everything (V2X) services (Release 17), standard, 3rd Generation Partnership Project, 2022.

[5] 3GPP, 3GPP TR 22.501 V17.6.0: System architecture for the 5G Sys- tem (5GS); Stage 2 (Release 17), standard, 3rd Generation Partnership Project, 2022.

[6] 3GPP, 3GPP TR 22.502 V17.6.0: Procedures for the 5G System (5GS); Stage 2 (Release 17), standard, 3rd Generation Partnership Project, 2022.

[7] S.A. Abdel Hakeem, H.H. Hussein, H. Kim, Vision and research directions of 6G technologies and applications, J. King Saud Univ. - Comput. Inform. Sci. 34 (6) (2022) 2419–2442, http://dx.doi.org/10. 1016/j.jksuci.2022.03.019.

[8] S. Dang, O. Amin, B. Shihada, M.-S. Alouini, What should 6G be? Nat. Electron. 3 (1) (2020) 20–29, http://dx.doi.org/10.1038/ s41928- 019- 0355- 6.

[9] D.C. Nguyen, M. Ding, P.N. Pathirana, A. Seneviratne, J. Li, D. Niyato, O. Dobre, H.V. Poor, 6G Internet of Things: A Comprehensive Survey, IEEE Internet Things J. 9 (1) (2022) 359–383, http://dx.doi. org/10.1109/JIOT.2021.3103320.

[10] Y. Lu, X. Zheng, 6G: A survey on technologies, scenarios, challenges, and the related issues, J. Ind. Inform. Integr. 19 (2020) 100158, http://dx.doi.org/10.1016/j.jii.2020.100158.

[11] H.H.H. Mahmoud, A.A. Amer, T. Ismail, 6G: A comprehensive survey on technologies, applications, challenges, and research problems, Trans. Emerg. Telecommun. Technol. 32 (4) (2021) http://dx.doi.org/ 10.1002/ett.4233.

[12] J.R. Bhat, S.A. Alqahtani, 6G Ecosystem: Current Status and Future Perspective, IEEE Access 9 (2021) 43134–43167, http://dx.doi.org/10. 1109/ACCESS.2021.3054833.

[13] B. Ji, Y. Han, S. Liu, F. Tao, G. Zhang, Z. Fu, C. Li, Several Key Technologies for 6G: Challenges and Opportunities, IEEE Commun. Stand. Mag. 5 (2) (2021) 44–51, http://dx.doi.org/10.1109/MCOMSTD. 001.2000038.

[14] A.I. Salameh, M. El Tarhuni, From 5G to 6G—Challenges, Tech- nologies, and Applications, Future Internet 14 (4) (2022) 117, http: //dx.doi.org/10.3390/fi14040117.

[15] E. Yaacoub, M.-S. Alouini, A Key 6G Challenge and Opportunity—Connecting the Base of the Pyramid: A Survey on Rural Connectivity, Proc. IEEE 108 (4) (2020) 533–582, http://dx.doi.org/10.1109/JPROC. 2020.2976703.

[16] M. Vaezi, A. Azari, S.R. Khosravirad, M. Shirvanimoghaddam, M.M. Azari, D. Chasaki, P. Popovski, Cellular, Wide-Area, and Non- Terrestrial IoT: A Survey on 5G Advances and the Road Toward 6G, IEEE Commun. Surv. Tutor. 24 (2) (2022) 1117–1174, http: //dx.doi.org/10.1109/COMST.2022.3151028.