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Key Technology for Autonomous Driving in Connected Vehicles Based on 5G Communications

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Abstract: With the rapid development of intelligent transportation, significant progress has been made in the development of autonomous driving technology and the Internet of Vehicles. Autonomous driving technology has transitioned from a concept stage to practical application. The rise of 5G communication technology provides an important technical guarantee for the wide application of the Internet of Vehicles and autonomous driving. However, in the current practical application of the Internet of Vehicles and autonomous driving, challenges such as communication delays, network stability and data security persist in real-world applications. Based on existing literature and data research, this study focuses on the key technologies of 5G-based connected vehicle autonomous driving, aiming to explore how 5G communication technology can improve the performance and reliability of autonomous driving systems. The findings indicate that edge computing can significantly reduce communication delays and improve real-time performance; network slicing technology can meet the quality of service requirements of different scenarios through dynamic resource allocation; and ultra-reliable low-latency communications ensure the reliability and stability of emergency tasks. Despite current technological advancements, achieving large-scale deployment of autonomous driving in complex environments remains a critical research challenge.

Keywords: 5G, Internet of Vehicles, Autonomous Driving, Communication Technology, Network Slicing Technology

1. Introduction

With the development of intelligent transportation, vehicle networking and autonomous driving have become important components for the realisation of smart cities. Through information exchange and collaborative decision-making, vehicle networking can significantly improve traffic efficiency, reduce traffic accidents, and provide passengers with more convenient travel services. However, the massive amounts of data generated by vehicles, roadside equipment and infrastructure need to be processed and transmitted over low-latency, highly reliable networks. Traditional architectures of separating communication and computing are gradually unable to meet the needs of complex traffic scenarios [1]. Additionally, the complex and ever-changing network environment in traffic scenarios places higher demands on communication technology. The rise of 5G communication technology provides a solution to these problems.

This study focuses on the key technologies of 5G-based vehicle networking and autonomous driving, and aims to explore how to use the advantages of 5G communication to improve the

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performance and reliability of the autonomous driving system in vehicle networking. Specific research issues include the following: the application of edge computing in vehicle networking, the optimisation and application of network slicing technology, and the guarantee of ultra-reliable low-latency communication (URLLC) for the communication terminal of autonomous driving. This paper mainly adopts the method of literature analysis to systematically sort out the relevant research results of 5G communication in the field of autonomous driving in the Internet of Vehicles at home and abroad. It focuses on analysing the advantages and disadvantages of these technologies in terms of reducing communication latency, improving resource allocation efficiency and ensuring system reliability. In addition, the research discusses the technical challenges in practical applications, offering theoretical insights and practical recommendations for future research in 5G-based autonomous driving. This research has important theoretical and practical significance. This research enriches the relevant research content in the field of connected vehicles and autonomous driving. By systematically sorting out the current status and development trends of edge computing, network slicing and ultra-reliable low-latency communication technologies, the role and limitations of these key technologies in improving the performance of autonomous driving systems are clarified, providing theoretical guidance for future research directions. From a practical perspective, this research provides a practical reference for the implementation of 5G-based connected vehicle autonomous driving technology.

2. Autonomous Driving Technology

With the development of intelligent transportation systems, autonomous driving technology has gradually transformed from the early experimental stage to practical application. In particular, autonomous driving testing and trial operations have made significant progress in some cities and regions. Autonomous vehicles rely on the highly integrated technologies of perception, decision-making algorithms, control systems, and vehicle-to-everything (V2X) technology. In the early days of autonomous driving, technological advancements primarily focused on vehicle intelligence. However, with the popularization of V2X and the continuous development of 5G communication technology, 5G communication technology in the field of autonomous driving will improve the energy efficiency and transmission efficiency of data processing systems, connect to receive high-precision maps and traffic information for real-time transmission, enable driverless vehicles to respond quickly to real-time traffic changes, and improve the accuracy and response speed of the autonomous driving system [2]. The high bandwidth and low latency of 5G communication technology ensure the rapid transmission and real-time processing of massive amounts of data, providing the necessary information foundation for autonomous vehicles [3]. As a result, autonomous driving technology has entered a new stage of development—the intelligent era of multi-party collaboration between vehicles, roads, and the cloud-based systems.

However, autonomous driving technology still faces many challenges. First, most existing autonomous driving systems rely on high-precision sensors, such as lidar, cameras, and radars, which are expensive and not well-suited to harsh weather conditions. Second, persistent issues such as communication delays, network stability, and real-time data processing are still key factors affecting the performance and safety of autonomous driving. Addressing these challenges and achieving efficient and safe autonomous driving in complex traffic environments has become a critical focus of ongoing research.

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3. G Communication Technology

3.1. Edge Computing Technology

Edge computing is a computing paradigm that shifts data processing and computing power from the traditional centralised cloud to the edge of the network, close to the source of data, to improve processing efficiency and response speed. As an important part of 5G communication technology, edge computing plays a vital role in autonomous driving systems. Combined with edge computing technology, data processing is pushed to the edge of the network, close to the source of data, thereby reducing the distance data needs to travel across the network and significantly shortening response times [4]. Compared to the 50-100 millisecond latency that may be caused by the traditional cloud computing model, edge computing can reduce the data processing latency to 1-10 milliseconds, which is crucial for autonomous driving systems that require real-time decision-making and helps improve driving safety and reliability.

Autonomous vehicles demand extremely low latency and high real-time responsiveness, particularly in scenarios such as collision warnings and emergency braking, where even minor delays can lead to catastrophic consequences. By deploying data processing and decision-making capabilities closer to the vehicle, edge computing enhances system responsiveness and stability.

In a connected vehicle environment, edge computing can not only process perception data locally in the vehicle, but also collaborate with other vehicles and the traffic infrastructure to make smarter and more efficient decisions. The application of edge computing technology enables the in-vehicle computing platform to handle more complex tasks, such as dynamic path planning and real-time traffic information analysis, while compensating for the shortcomings of cloud computing technology in offloading real-time tasks [5], further improving the performance and safety of the autonomous driving system.

3.2. Network Slicing Technology

Network slicing technology is an important innovation in 5G communications. In 4G networks, all services converge within a single network. As the volume of services gradually increases, the network configuration becomes increasingly difficult, making it inconvenient to expand and reduce the capacity of services. To overcome these issues, 3GPP first proposed the services and operations of the 5G open network architecture, i.e., network slicing.

Network slicing is not only a technical advantage of 5G networks but also an important element of business model innovation. Slicing can be carried out according to network needs in the face of vertical industries, providing a 5G network customisation platform for various business needs [6]. In autonomous driving scenarios, network slicing can flexibly provide customised network services for vehicles according to different needs. For example, on the highway, autonomous vehicles may require lower latency and higher data transmission rates, while in the complex urban traffic environment, vehicles may require higher network reliability and security. Through network slicing, the 5G network can dynamically adjust to different scenarios and needs to ensure the efficient operation of the autonomous driving system.

5G network slicing technology has huge application potential. Through virtualization technology, physical resources can be divided into multiple logical networks to meet the needs of different services [7]. More customized services can be provided to enhance the connectivity and performance of IoT devices. For example, enhanced mobile broadband (eMBB) slicing supports ultra-high-speed data transmission, suitable for applications such as augmented reality, virtual reality, and high-definition video streaming. Meanwhile, massive machine-type communication (mMTC) slicing enables large-scale IoT deployments, supporting up to one million devices per square

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kilometer—ideal for smart cities and IoT ecosystems. Additionally, ultra-reliable low-latency communication (URLLC) slicing provides millisecond-level end-to-end latency with over 99.999% reliability, making it particularly suitable for autonomous driving applications [8].

3.3. URLLC

5G ultra-reliable and low-latency communications (URLLC) is a core technology of the 5G network that can meet the needs of mission-critical scenarios for ultra-high reliability and ultra-low latency. Unlike traditional communication technologies, URLLC has greatly improved communication latency, data transmission stability, and end-to-end communication reliability [9]. For example, in a 5G network, the end-to-end delay of URLLC can be reduced to less than 1 millisecond, which is a significant improvement compared to the 20-50 millisecond delay of 4G LTE. In addition, the communication reliability of URLLC can reach 99.999%, which is much higher than the 99.9%-99.99% of traditional communication networks, ensuring high stability of data transmission. This is crucial for real-time decision-making in autonomous driving systems. In critical moments such as emergency braking and collision avoidance in traffic accidents, autonomous vehicles need to communicate and coordinate with their surroundings in near real time, which is ensured by URLLC technology.

With URLLC, autonomous vehicles can exchange real-time information with other vehicles, roadside units, and cloud platforms, ensuring that every second of reaction is timely and accurate, thereby greatly improving traffic safety and road traffic efficiency.

4. Future and Challenges

Although edge computing, network slicing and ultra-reliable low-latency communications (URLLC) provide strong support for the development of autonomous driving technology, there are still some challenges in practical applications. For example, the deployment and maintenance of edge computing are costly, and the differences in network coverage and computing power in different regions may lead to unstable performance. In addition, the management and resource allocation of network slicing need to be more intelligent and flexible to adapt to changes in demand in different scenarios. The implementation of URLLC also faces challenges in terms of communication spectrum resources and network equipment performance.

Therefore, future research should focus on the following directions:

1. Improving the efficiency of edge computing deployment: exploring more efficient and lower-cost edge computing architectures, especially in densely trafficked areas, and how to quickly build and deploy edge computing nodes to improve data processing efficiency. The importance of AI-enabled resource optimisation and allocation in the Internet of Vehicles is becoming increasingly prominent [10].
2. Optimising the resource scheduling strategy for network slicing: researching AI-based dynamic resource scheduling mechanisms to cope with network traffic fluctuations in different traffic scenarios and achieve more flexible and intelligent network management.
3. Ensuring reliability and latency in URLLC: In-depth discussion of the practical application of URLLC in complex traffic environments, optimisation of communication protocols and device performance to ensure consistently stable and reliable communication quality.

Edge computing and network slicing have already been applied in some autonomous driving pilot projects. For example, in an autonomous driving public transport project in a city, the deployment of edge computing nodes and 5G network slicing technology allowed vehicles to receive real-time traffic light information and adjust driving routes accordingly. However, this project also revealed some technical bottlenecks. For example, in high-density urban areas, congestion in the communication network is relatively serious, which leads to unstable response times of the autonomous driving system and affects driving safety.

These challenges illustrate that although the application of 5G communication technology provides a theoretical basis for autonomous driving, continuous optimization and adaptation are required to address the complexities of real-world traffic conditions. Future advancements in AI-driven resource management, network optimization, and communication stability will be critical in overcoming these obstacles and achieving the full potential of autonomous driving.

5. Conclusion

This study explores the key technologies of vehicle networking and autonomous driving based on 5G communication technology, highlighting its role in reducing communication latency, optimizing network resource allocation, and ensuring the stable execution of critical tasks. Although edge computing, network slicing and URLLC provide technical support for autonomous driving, several challenges remain, including high deployment costs, uneven network coverage, complex resource scheduling, and limited communication reliability. Future research should focus on improving the efficiency of edge computing deployment, optimising network slicing resource scheduling, enhancing URLLC stability, and improving system adaptability through AI technology. Practical experiments have shown that 5G technology can help optimise autonomous driving decisions, but further improvements are still needed in high-density urban environments to ensure communication stability and driving safety. Future research should be verified using data from real-world traffic scenarios to explore the application performance of 5G technology in complex environments. Meanwhile, future intelligent vehicle communication systems will continue to evolve towards higher performance, greater safety and greater intelligence to meet the growing demand for intelligent transportation. 6G is expected to achieve even faster data transmission speeds, lower latency and a wider connection range than 5G. These advancements will greatly improve the communication efficiency and reliability of intelligent vehicles, providing powerful communication support for applications such as autonomous driving, remote control and real-time traffic monitoring.

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