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Microsoft applications of 6G in V2X

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Abstract. With the rapid advancement of intelligent transportation systems and autonomous driving technologies, 6G networks, as a key technology for future communications, are set to bring trans-formative changes to V2X (Vehicle-to-Everything) communication. This paper explores the application prospects of 6G in V2X, with a focus on the critical technological support 6G provides to vehicular networks. The high transmission rates and ultra-low latency of 6G will significantly enhance real-time interactions between vehicles and between vehicles and infrastructure, improving traffic safety and efficiency. Additionally, 6G's broad connectivity and flexible network architecture will support a greater number of simultaneous device connections, facilitating the widespread adoption of intelligent transportation systems. However, 6G faces challenges in V2X applications, including security issues, privacy protection, and internet power supply concerns. The paper analyzes these challenges, proposes corresponding solutions, and envisions the future development of 6G technology in the V2X domain.

Keywords: 6G, v2x, MiMo.

1. Introduction

Vehicle-to-everything is a communication technology aimed at enabling vehicles to communicate with other vehicles, traffic infrastructure, and other devices. It encompasses Vehicle-to-Vehicle (V2V), Vehicle-to-Pedestrian (V2P), and Vehicle-to-Infrastructure (V2I) communications, allowing vehicles to transmit real-time traffic information such as speed, location, and traffic conditions to each other and to infrastructure nodes. The rapid development of wireless communication technologies represented by 6G is expected to bring trans-formative capabilities to V2X networks. These networks play a crucial role in modern transportation systems, where timely and reliable information exchange is essential for ensuring safety and efficiency.

6G represents a new era of mobile communication technology beyond 5G systems, aiming to provide faster speeds, lower latency, and higher capacity. 6G networks are anticipated to make available performance better than current 5G networks.[1] It is projected that Green 6G will be deployed by early 2030, offering capacity improvements of up to 1000 times compared to 5G networks. [2]

Global demand for data traffic continues to grow, driving an urgent need for 6G to support explosive growth in communication devices and digital applications, making the concept of smart autonomous vehicles feasible. Concurrently, the demand for autonomous vehicles is increasing for numerous emerging services, ranging from enhanced viewing experiences and free-floating 3D displays to holographic control systems and immersive entertainment, all of which pose new communication challenges for V2X networks. These advancements are set to significantly surpass the capacity limits of

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existing wireless networks, presenting new scientific and technological challenges in data rates, latency, coverage, spectrum/energy/cost efficiency, intelligence, network, and security. Incorporating 6G with V2X promises enhanced performance and potentially novel solutions.

The convergence of human-machine-network in the context of 6G-enabled V2X communication is poised to significantly facilitate the widespread deployment and application of autonomous/self-driving vehicles. The architecture of the V2X system under 6G environment integrates human-machine-network, as depicted in Figure 1. At the lowest level is the Intelligent Connected Vehicle layer, supporting basic transportation functions and advanced services like autonomous driving and platooning. The middle layer consists of Intelligent Edge Nodes comprising roadside units and edge servers connected via wired backhaul, providing network coverage and handling real-time computing tasks such as vehicle control decisions, route planning and navigation, and local traffic network optimization. The top layer is the Cloud Transport and Computing layer, facilitating core network data exchange, traffic data storage and maintenance, and global traffic network optimization, e.g. traffic signal timing and flow distribution. This paper proposes a novel architecture of human-machine-network integrated V2X system, exploring tightly coupled networking models and new network service paradigms including remote driving, vehicle-mounted holographic communication, and customized public transportation services. It further investigates key technologies in the human-machine-network integrated V2X system architecture [3].

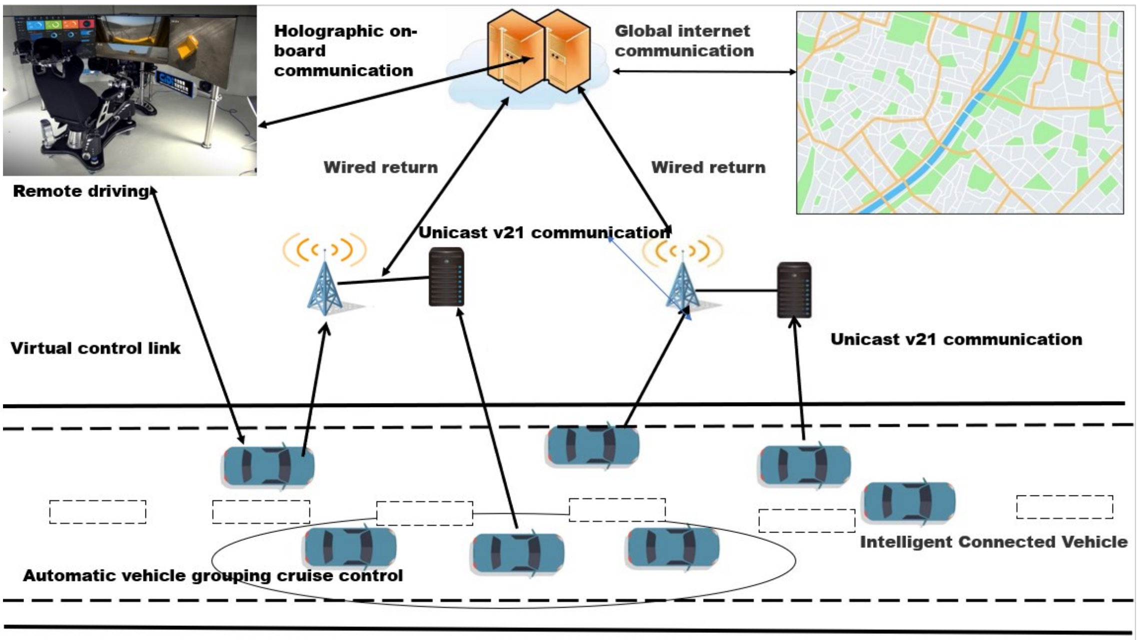

Figure 1. Internet of Vehicles architecture of human-machine-network fusion in 6G environment

This article introduces the key technical support for 6G and vehicular networking, followed by applications of 6G with AI, discussion of existing issues, exploration of future developments, and concluding remarks. The accompanying image illustrates the architecture of vehicular networking under the 6G environment, depicting a layered structure of human-machine-network integration: bottom layer, middle layer, and top layer. The subsequent sections of this article are structured as follows:

2. Key technologies

2.1. Integrated Sensing and Computing

In the domain of edge computing resource management for vehicular networks, optimizing the joint allocation of communication and computing resources is essential to address task offloading challenges. Reference [4] establishes a mathematical model for task prioritization, designs task offloading

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algorithms based on reinforcement learning, and optimizes energy consumption and latency. Reference [5] proposes a distributed offloading strategy for V2X scenarios, optimizing system latency with multiple collaborative nodes using serial and parallel computing modes. Reference [6] introduces a spectrum and power resource management mechanism for vehicular networks based on deep reinforcement learning, effectively enhancing user channel capacity.

Satellite Role in Integrated Sensing and Computing: In integrated sensing technology, a network node can support multiple communication scenarios simultaneously, such as 5G, satellite communication, and WiFi. Introducing satellite communication improves coverage and reliability, especially in areas where ground communication facilities are insufficient. Satellite communication provides broad coverage and high reliability due to redundant designs like dual-satellite, multi-satellite, and backup communication links. Incorporating satellite communication enhances the reliability, continuity, and stability of integrated sensing technology. Satellite computing, employed primarily in satellite communication, remote sensing, and control fields, embeds computing capabilities within satellites for functions such as on-orbit data processing, transmission, and storage. Satellite computing offers higher parallelism, stronger real-time capabilities, and a more stable environment compared to ground computing.

2.2. Integration of 6G with Artificial Intelligence

AI tasks are computationally intensive, mostly conducted in data centers with customized servers. Given the rapid growth of intelligent mobile devices, numerous smart applications are expected to deploy on wireless network edges. Thus, 6G wireless networks will be designed to support AI applications on various edge mobile devices using advanced wireless communication and mobile computing technologies.

Achieving 6G Privacy with Artificial Intelligence: 6G's small-cell multi-connected mesh networks enable devices to communicate simultaneously through multiple base stations. Edge-based machine learning models can dynamically detect and rank privacy-protected routes, allowing devices to transmit data via privacy-protected routes based on rankings. Federated learning keeps data near users, enhancing data and location privacy compared to cloud-based centralized learning. Subnet-level AI in 6G enables privacy protection within subnets, sharing learned intelligence externally to minimize privacy risks. Data confinement within networks is applicable for applications like intranet networks. Given the large number of applications in 6G and the extensive data collection required to provide information for intelligent models, users are likely to prefer different privacy levels across different applications. AI-based service-oriented privacy protection policy updates are a potential solution to support fully automated 6G networks while protecting privacy.

Intelligent Switching: Efficient mobility management is critical for meeting the high-speed mobility and low-latency requirements of large-scale vehicular networks in 6G networks. Predictive mobility management based on deep learning (e.g., RNN, ANN) and optimization of switching parameters based on fuzzy Q learning can learn the mobility patterns of high-speed vehicle users, effectively avoiding frequent switching, switching failures, or connection failures [7]. Additionally, LSTM is a powerful AI tool for addressing switching issues as it uses the vehicle's previous and future mobility contexts to learn a series of future time-related movement states, ultimately predicting vehicle trajectories to optimize switching parameters and avoid frequent switching [8]. Furthermore, machine learning is also used in vehicular networks for traffic flow prediction, local data storage, and congestion management.

Annu has proposed a resource-efficient congestion estimation algorithm to address congestion management challenges in 6G V2X side-chain networks.

2.3. MIMO Large-scale Communication Network Technology

MIMO technology is a multi-antenna technology that improves system capacity by receiving and transmitting signals through multiple antennas at the transmitter and receiver ends, gaining array gains, selective diversity gains, reuse gains, and interference mitigation. The MIMO technology is critical to

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improving the peak rate and reliability of data transmission, extending coverage, suppressing interference, increasing system capacity, and enhancing system throughput.

The advantages of large-scale MIMO systems mainly manifest in several aspects:Significantly Enhancing Total System Capacity,Improves channel interference and spatial resolution effectively reduces power consumption at the transmitter end.

3. Existing Issues

The While 6G plays a crucial role in V2X, this combination still faces several challenges that need to be addressed. Issues such as IoT power supply problems, high-precision positioning technology issues, and congestion estimation problems.

3.1. IoT Power Supply Problems

Energy consumption in mobile communication networks accounts for a significant portion of global energy consumption, increasing carbon emissions and costs. Future 6G networks with ultra-massive wireless nodes and sensors will bring challenges of ultra-high energy consumption. Additionally, the widespread application of artificial intelligence in 6G networks will involve handling massive amounts of data with high computational complexity and bit volume, resulting in significant energy consumption. Therefore, addressing the large-scale energy consumption of 6G is one of the future's important challenges to achieve green and energy-efficient communication [9].

3.2. Security issues

The integration of diversified connections in 6G-V2X and strict data service provisioning exacerbates security challenges. While 6G-V2X aims to provide seamless connectivity between infrastructure nodes and vehicles, the broadcast nature of vehicle communication makes it susceptible to malicious attacks. Various types of malicious attacks (e.g., authentication and authorization attacks, data forgery, and distribution) may target vehicle networks, impacting communication security [10].

3.3. Congestion Estimation Issues

Congestion poses significant risks to security and efficiency in 6G vehicular networks (V2X) side-chain networks. Due to dynamic network changes, traditional methods are inadequate, necessitating efficient and adaptive congestion estimation methods to achieve resource optimization and timely information exchange. The challenge lies in the lack of transparent and efficient 6G V2X Sidelink network congestion estimation, as inaccurate methods can affect resource allocation and security.

4. Future Developments

4.1. Cloud based vehicular networking

In recent years, with the widespread adoption of cloud computing technology, significant changes have occurred. More companies from various industries are starting to offer their own cloud computing services to their customers. The automotive industry is one such industry, thus the V2C model has garnered widespread attention. Given the immense potential of vehicle services, automotive manufacturers have altered their sales strategies by selling services to customers rather than just vehicles. Unlike general internet services, such vehicle services are closely related to vehicles, necessitating proprietary vehicle cloud platforms to support them. Considerations include full coverage sensing, seamless computing, reliable caching, and persistent consensus and security integration into future 6G systems. Not only OEMs but also CT/IT companies are targeting this vast market. To profit from cloud-based vehicle services, OEMs are willing to equip their vehicles with more advanced wireless access capabilities. Therefore, it can be said that V2C/CIoV is the ultimate path to achieving vehicular networking and will reshape the automotive industry and human travel methods [11].

4.2. Quantum Computing-assisted V2X

Quantum computing is considered one of the revolutionary technologies for universal 6G wireless communications, significantly enhancing communication security. Quantum computing possesses inherent security features such as quantum entanglement, which cannot be cloned or accessed without tampering, making it a suitable technology for enhancing 6G-V2X communication security. Furthermore, quantum domain security is based on the quantum key distribution (QKD) framework, allowing detection of any malicious eavesdropping attempts. For example, using quantum federated learning to securely perform learning tasks among vehicles may be a crucial use case. Besides enhanced security features, the advent of quantum computing is expected to fundamentally enhance computing capabilities by rapidly executing extremely complex and currently time-consuming optimization algorithms, significantly improving and optimizing 6G-V2X services. Although quantum computing is seen as a promising technology, further research is needed to fully harness its potential for widespread use [12].

5. Conclusion

As an integral part of intelligent transportation systems, V2X technology has significantly improved road safety, optimized traffic flow, and enhanced driving experiences through integration with 6G. Analyzing existing research and implementation cases reveals that V2X can be combined with 6G in multiple ways:

The integration of V2X technology with 6G communication greatly enhances the performance and efficiency of intelligent transportation systems. The ultra-high data rates, ultra-low latency, and massive connectivity capabilities of 6G provide robust data transmission support for V2X technology, making the acquisition, processing, and transmission of traffic information faster and more reliable.

V2X combined with satellite communication technology achieves broader coverage and more stable communication links. This is crucial for achieving efficient communication between vehicles and between vehicles and infrastructure in complex urban environments and on highways, enhancing communication accuracy and coverage effectiveness.

The integration of edge computing and artificial intelligence technologies of 6G with V2X enables more intelligent traffic management and decision support while protecting user privacy. By distributing intelligent perception and decision-making capabilities between vehicles and infrastructure, traffic events can be more accurately predicted and responded to, enhancing driving experience and road safety.

However, to effectively integrate V2X technology with 6G communication, challenges such as IoT power supply, congestion estimation, and security must be addressed. Future research and development should focus on these aspects to drive the coordinated development of intelligent transportation systems and 6G communication technology.

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