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An Overview of Wireless Communication Technology Applications for Smart Roads

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Abstract: At present, the application of intelligent highway communication technology involves fiber optic network transmission technology supporting highway backbone transmission network, and various wireless communication technologies supporting vehicle-road cooperation, wireless sensors and other applications. This paper takes functional scenarios as the entry point and analyzes the technical characteristics of various wireless communication technologies and their matching with the demand of application scenarios, which can provide reference for the construction of multi-network convergence communication system.

1. Overview of Communication Technologies

The smart highway adopts multi-network convergence communication technology to support the transmission of information such as highway infrastructure status, traffic operation status, travel services, vehicle behavior sensing and control, specifically involving fiber optic network wired transmission technology that supports the highway backbone transmission network, and various wireless communication technologies that support vehicle-road cooperation, wireless sensors and other applications, in order to achieve comprehensive coverage of traffic information and accurate delivery of information[1] .

After more than 140 years of development, wired communication technology has become quite mature and complete. At present, the most common application in the transportation industry is fiber optic communication technology. Fiber optic communication is a communication method for digital signal transmission using optical waves as the information carrier and optical fiber as the transmission medium[2] . Fiber optic communication system has been put into commercial use communication capacity up to 400Gbps, no relay transmission distance up to hundreds of kilometers, completely free from electromagnetic interference, can completely shield radiation eavesdropping. Because of its large communication capacity, long communication distance, good anti-interference and high confidentiality, fiber optic communication is now widely used for mass data transmission between fixed facilities. The principle of fiber optic communication technology is shown in Figure 1.

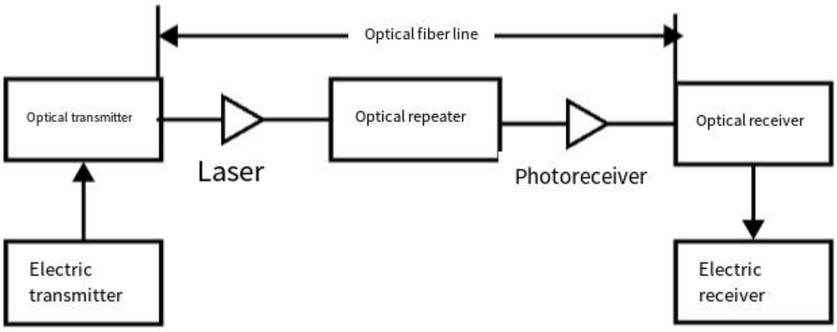

Figure 1: Principle of fiber optic communication technology

There are many types of wireless communication technologies that can be applied to the transportation field, and they differ greatly in terms of communication distance, communication capacity, communication delay and other key indicators. Mobile communication technology with cellular structure has high communication capacity and large communication distance, which is suitable for data transmission applications with low requirements on transmission delay, such as the connection between monitoring center and roadside fixed facilities. The new vehicle-road communication technology introduces a low latency direct connection communication technology, which is suitable for communication applications with high latency requirements, such as communication between vehicles and between vehicles and roadside facilities. Satellite communication is a more special kind of wireless communication system with very limited information transmission channel resources, which is only suitable for emergency critical data transmission applications under special circumstances.

2. Cellular Communication Technology

Cellular mobile communication technology can provide long-distance data transmission channels, including various types of monitoring sensing data, vehicle location data, traffic control and service information data, in areas that cannot be covered by the wired network of the dedicated highway network.

2.1 Fourth Generation Cellular Mobile Communication Technology

The fourth generation cellular mobile communications (4G) system is the largest cellular mobile communications system in China today in terms of coverage. It improves wireless transmission speed by about 50 times compared to 3G networks through the introduction of new carrier aggregation and multiple-input multiple-output technologies.[3] 4G uses the Long Term Evolution (LTE) technology standard for mobile communications and can achieve user data download transmission rates of more than 10 Mbps in commercial systems with a cellular network architecture. 4G cellular mobile communications. The commercialization of the 4G cellular mobile communications system began at the end of 2013 and now has a network coverage of over 95% in China, carrying the majority of cellular communications services.

Since the operation of 2G and 3G cellular communication system requires the support of core network, the transmitted data needs to be forwarded through "base station-core network-base station" series, and the communication delay is large, which cannot meet the demand of vehicle-road cooperation application. LTE-V is a set of technical protocols developed by LTE specifically for Telematics applications and is dedicated to the information interaction between vehicles and other facilities. The schematic of LTE-V technology is shown in Figure 2.

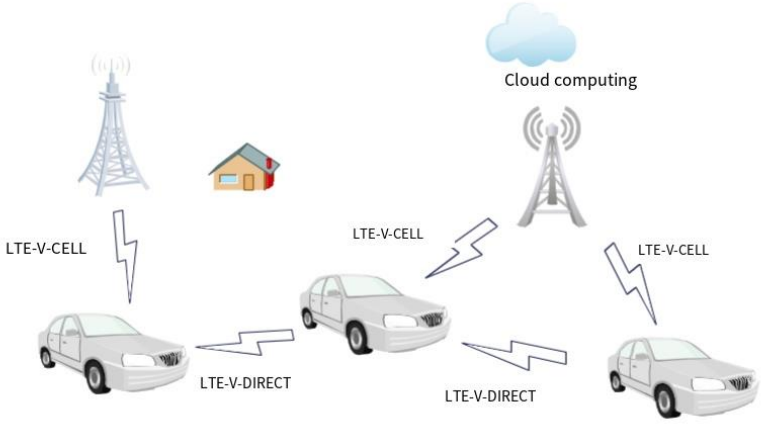

Figure 2: LTE-V schematic architecture diagram

Smart highway should choose to use cellular LTE-V or directly connected LTE-V according to the requirements of specific services on communication capacity and delay. various products based on LTE technology have been more comprehensive and mature, basically meeting the application requirements of vehicle-road cooperation in the field of transportation.

2.2 Fifth Generation Cellular Mobile Communication Technology

The fifth-generation cellular mobile communication (5G) system is the result of the continued evolution of 4G. 5G is a new wireless air interface (New Radio, NR) formed through the evolution of LTE, using a new frequency band, beam assignment and other technologies, with high bandwidth, low latency, large-scale connectivity, etc., in the enhanced mobile broadband (eMBB), ultra-high reliability ultra-low latency communications (ultra-high reliability ultra-low latency communications (URLLC and mMTC to provide higher performance communication services in three application scenarios[4] . The advantages of the communication systems required for these three application scenarios are supported by different technologies to achieve them, so the smart highway should select the appropriate technology for facility deployment according to specific services.

The eMBB and mMTC scenarios are mainly supported by cellular network systems. eMBB scenarios are the fastest to achieve on-the-ground applications and are based on the 5G R15 technology standard, with many applications in remote HD video transmission and various cell phone services. mMTC scenarios are supported by existing IoT technologies, such as Narrow Band Internet of Things (NB-IoT) and LTE enhanced MTO (eMTC). The URLLC scenario is mainly supported by direct connection communication technology. 5G R16 standard will be frozen in July 2020 and 5G R17 standard will be frozen in June 2022. Phase 3 functional freeze will facilitate the deployment of NR-V (or NR-V2X) based vehicle-road collaboration applications. Similar to 4G, NR-V has two modes of operation, cellular NR-V and direct NR-V, inheriting the "cellular" + "direct" approach of LTE-V.

In the construction of intelligent highways, the monitoring of traffic infrastructure status is a typical mMTC application scenario; the transmission of various multimedia, electronic maps and other data belongs to the eMBB application scenario; the transmission of traffic operation status and service information involving safety is a typical URLLC application scenario. The operational architecture for monitoring the condition of the transport infrastructure is shown in Figure 3. Therefore, the 5G commercialization process will have a profound impact on the morphological structure and specific functions of the new road infrastructure.

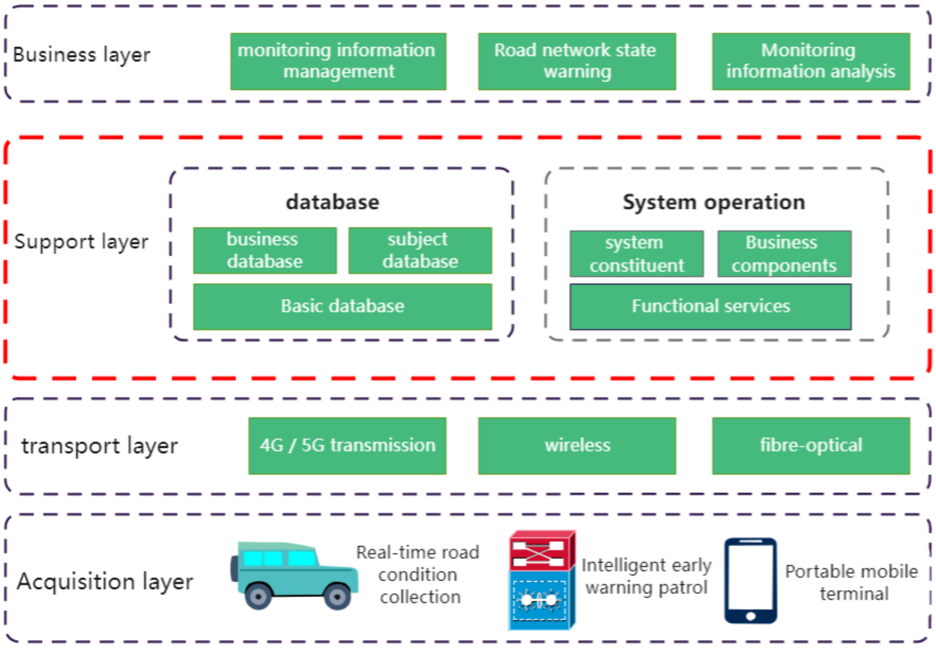

Figure 3: Traffic infrastructure condition monitoring business architecture diagram

3. Wireless Direct Connection Communication Technology

Direct link communication is another type of communication network as opposed to cellular mobile communication. A typical direct-connected communication system consists of a number of subscribers that interact with each other directly through a wireless communication channel. Compared with cellular structure system, the structure of direct link system is simpler and does not need to relay through cellular network, which can be integrated with various upper layer applications, allowing the vehicle to sense and respond to the surrounding environment more quickly and ensure driving safety.[5]

Directly connected wireless communication systems currently in use in the transportation field include: radio frequency identification (RFID) systems for logistics and transportation; dedicated short-range communication (5.8G-DSRC, based on China's DSRC protocol standard implementation) systems for electronic non-stop charging (ETC); dedicated short-range communication (US DSRC, based on IEEE 802.11p protocol) systems for vehicle-vehicle communication applications; and 4G directly connected LTE-V communication systems. 5G direct-connected NR-V related equipment and systems will be considered to support future vehicle-road collaboration applications. All the above-mentioned direct-connected communication systems have their own dedicated radio frequency bands and communication protocol standards, so it is difficult to be compatible at the physical and network layers; however, due to their simple structures and mechanisms, it is easier to achieve low-cost integration at the application level. At present, many information technology systems have multiple direct-connected wireless communication applications at the same time.

RFID systems are widely used in the logistics field with the advantage of low power consumption, but their communication capacity is low and not suitable for vehicle-road cooperation related applications. Other than RFID, other direct link communication systems are suitable for

VRM applications. 5.8G-DSRC, U.S. DSRC, and direct link LTE-V all use 5GHz to 6GHz radio band resources, which can provide large communication capacity, but the communication distance is less than 1km. Since the 5G extension utilizes the wireless band resources from 24250 MHz to 52600 MHz, directly connected NR-V can achieve a significant increase in communication capacity. In terms of the standard-setting body and intellectual property rights, 5.8G-DSRC is China's fully-owned intellectual property rights technology; both direct-connected LTE-V and NR-V are China's partially-owned intellectual property rights technology; and U.S. DSRC is a U.S.-led communication technology.

Among the above technologies, the application of 5.8G-DSRC in ETC has been proven to be mature and reliable after years of use, but has not yet been deployed in scenarios other than ETC. The main problems faced by direct LTE-V applications include high equipment costs, unclear application requirements, and concerns about new technology (such as NR-V) updates and compatibility issues. The differences between LTE-V and DESC technologies are shown in Table 1.

Table 1: Comparison of DESC and LTE-V technologies

	DSRC	**LTE-V**
Formulator	IEEE	3GPP
representative enterprise	NXP	Qualcomm, Huawei
standard conditions	The standardization process began in 2004	The standardization process began in 2014
standard delay	The support speed is 200 km/h, the reaction time is about 100ms, the average data transmission rate is 3Mbps (up to 27 Mpbs), and the transmission range is 1km in the outdoor environment	LTE-V-CELL transmission rate bandwidth can be expanded up to 100 MHz, peak rate of 500Mbps up, 1 Gbps down, and support speed of 500 km/h High (greater than 50ms)
key index	Low (less than 50ms)	High level (greater than 50ms)

4. Typical Application Scenarios

4.1 Vehicle-Road Collaboration Communication

Vehicle-road cooperative autonomous driving is an important direction for future road traffic development, which will comprehensively improve the efficiency, safety and green level of road traffic system and has significant social and economic benefits. Vehicle-road cooperation adopts advanced wireless communication, sensor detection and new generation Internet technologies to implement vehicle-vehicle and vehicle-road real-time dynamic information interaction and sharing, realize intelligent coordination and cooperation between vehicles and roads, and carry out active safety control of vehicles and collaborative road management based on the collection and integration of all-time dynamic traffic information, so as to optimize the use of resources, improve road traffic safety and alleviate The purpose of traffic congestion[6,7] .

Unlike the United States and Europe, which mainly adopt DSRC technology to realize Telematics, China directly adopts LTE-V2X in 4G era to C-V2X technology in 5G era, and has conducted a lot of research in vehicle-road coordination, and through the construction of demonstration zones, it has promoted Telematics technology innovation and standards development, promoted industrial integration and innovation, and cultivated the development of new business models, while also actively promoting intelligent highways based on vehicle-road coordination Pilot construction[8] .

At present, domestic and foreign intelligent roadside infrastructure construction and the promotion of vehicle units are in the pilot area and demonstration line construction stage, the lack of large-scale industrial applications.

4.2 Travel Services Communications

Dynamic, real-time and personalized information service for travelers is one of the main applications of smart highway.

Internationally, the Japanese VICS system is considered to be the most successful road traffic information system in the world, built and managed by the Japan Road Traffic Information Center (JRTIC), and is available throughout Japan. construction, speed and lane restriction information, etc. Compared to non-VICS vehicles, VICS vehicles can reduce driving time by 15%, thus improving traffic safety and environmental friendliness[9] .

The current information services for travelers on China's highways mainly include radio broadcasts, road information boards, static traffic signs, LED information release screens, smartphone navigation APP information push, etc. The information release means have not been integrated, the timeliness is low, and it is difficult to meet the needs of safe driving. For example, the front accident cannot systematically notify the subsequent vehicles, easy to produce secondary accidents; vehicles cannot systematically obtain real-time information on road weather and road conditions.

The development trend of information service is mainly reflected in several aspects such as customization of information release content, diversification of information release means, personalization of information release objects and rapid information release. China's road information provision system also needs to be upgraded and transformed using modern information technology, such as convergent communication technology.

4.3 Free Flow Charges Communications

Since the end of the 20th century, China's expressway tolling has gone through the stages of single section tolling, multi-section network tolling and intra-provincial network tolling. With the continuous development of highway tolling technology, the establishment of a full section vehicle-road communication system, and then evolve to a national traffic control network, is the future development trend of toll road network, and the free flow tolling technology provides technical support for the realization of national "one network" tolling[10] .

Based on the technical requirements of national 5.8GHz dedicated short-range communication, the application of tolling technology in path identification and ramp free flow tolling has been promoted and landed in various provinces. With the application of new tolling technology, highway tolling gradually realizes national networking and unified tolling technology, and will develop towards a free-flow tolling system with ETC as the main mode and Beidou and other multi-modes as supplementary modes. In the future, combined with the wireless positioning technology of roadside units, lane level free flow tolling can also be realized. The principle of the satellite free-flow cloud charging system is shown in Figure 4.

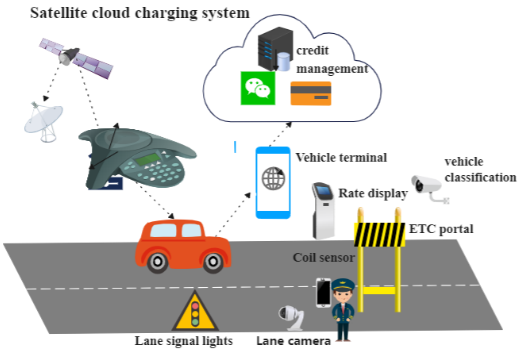

Figure 4: Satellite free-flow charging system

5. Conclusion

Ubiquitous wireless communication network, based on heterogeneous network convergence and spectrum resource sharing, can achieve ubiquitous network coverage and on-demand information acquisition, transmission, storage, cognition, decision-making, use and other comprehensive services, and is an important part of the smart highway heterogeneous communication network[11] . The construction of smart highway needs to consider the different coverage, application area, technical characteristics and access rate of various wireless communication technologies, and accelerate the integration process and diversified integration of multi-mode heterogeneous communication network integrating fiber optic transmission backbone network, mobile communication network, wireless LAN, dedicated short-range communication network, wireless sensor network, broadcasting network, etc., so as to provide strong guarantee for the data, voice and image This provides a strong guarantee for real-time transmission of data, voice and images, and provides the basis for highly intelligent vehicle-road cooperation in the future.

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