A Hybrid Architecture of 5G Private Network Solution for Urban Rail Transportation Systems

Jianming Zhou[1], Haoxian Jing[2(✉)], Lei Ning[2], and Kailei Pang[1]

[1] China United Network Communications Corporation ShenZhen Branch, Shenzhen, China

[2] College of Big Data and Internet, Shenzhen Technology University, Shenzhen, China

201902010223@stumail.sztu.edu.cn

Abstract. Recently, urban rail transportation is constantly developing to intelligent urban rail based on the Internet of Things, artificial intelligence, and high-speed communication. Long Term Evolution for Urban Rail Transportation System (LTE-URTS) is a communication system for urban transportation service, which carries the essential services by urban rail with 4G LTE. However, with the continuous increase of new demands, LTE also faces the shortcomings of insufficient bandwidth and high construction costs. As an advanced solution, networking through 5G can bring better performance to satisfy multiple demands of the modern Urban Rail Transportation System (URTS) than LTE-URTS. This article provides an overview of the characteristics of 5G and LTE-URTS. In addition, we propose a new network architecture solution based on 5G for the URTS with field test results, which have better performance compared to LTE-URTS.

Keywords: 5G · Urban Rail Transportation System (URTS) · Long Term Evolution (LTE) · Multi-access Edge Computing (MEC) · Network Slice (NS)

1 Introduction

Urban rail transportation plays a significant role in modern society as one of the fundamental choices for people to travel and goods to transport. More and more countries would like to develop more intelligent rail transportation to satisfy multiple needs nowadays. Communication-Based Train Control (CBTC) is the most widely used train control system, but it has many problems [1]. It is necessary not only to solve the existing problems but also to empower some new directions

This work was sponsored by Scientific Research Capacity Improvement Project From Guangdong Province (No.2021ZDJS109) , and SZTU Experimental Equipmental Equipment Development Foundation (No.JSZZ202102007).

Q. Liang et al. (Eds.): CSPS 2022, LNEE 873, pp. 85–94, 2023.
https://doi.org/10.1007/978-981-99-1260-5_11

of rail transportation technologies like the train autonomous circumambulate system (TACS). As a novel generation of mobile communication technology, 5G has provided several outstanding enhancements. With these high-performance enhancements, 5G has lower transmission delay, higher average network throughput rate, and more application scenarios [2,3]. 3GPP has defined three typical application scenarios of 5G:

- eMBB (enhanced Mobile BroadBand): 5G will provide users with better Internet services with its high rate and other characteristics. The mobile network will have a better rate and a more stable transmission capacity. It is suitable for real-time video surveillance systems and mobile live streaming platforms [4].
- mMTC (massive Machine Type of Communication): With the continuous increase of devices on the network, people are no longer satisfied with human-to-human or human-to-machine communication. The Internet of Things(IoT) is an information carrier based on generalized networks, which provides a method for all independently addressed devices to communicate. Low Power Wide Area Networks(LPWAN) is a transmission network for IoT applications with wide coverage and low-power Dissipation. As a representative of LPWAN, Narrow Band Internet of Things(NB-IoT) is a low-power solution in this scenario [5]. 5G enables many IoT devices to access the network with a very low-power dissipation [6,7].
- uRLLC (ultra-Reliable Low-Latency Communications): Nowadays, many scenarios such as driverless driving, industrial robots, and telemedicine require extremely low latency and high reliability. 5G uses network slice, edge computing, and other modes to ensure the rate and quality of communication [8–11].

eMBB can provide low latency and HD video services, such as real-time video surveillance and onboard equipment live broadcast for the URT. mMTC enables rail transportation to perform better by deploying more Rail IoT (RIoT) along the train line. uRLLC allows trains to realize services like autonomous driving. In addition, in order to better support eMBB and uRLLC, 5G introduces New Radio (NR) air interface. It drastically increases the wireless network capacity of 5G and brings new opportunities to URTS [12].

In this paper, we briefly describe some key technologies in 5G in Sect. 2. Then, We highlight wireless communication solution with 4G LTE and list its advantages and disadvantages, we also propose a solution with 5G in Sect. 3.

2 The Key Characteristics of 5G

In this section, we briefly list some critical technologies of 5G

2.1 Massive MIMO

Multiple-Input-Multiple-Output (MIMO) is a multi-antenna technology in which both the transmitter and receiver have an antenna group composed of multiple antenna elements. A communication system can use MIMO to achieve space diversity and space multiplexing. Space diversity uses multiple antennas to transmit or receive a data stream to enhance communication quality. Space multiplexing is the simultaneous transfer of multiple data streams to the terminal to improve data rate. It is beneficial for a system to increase the whole network throughput, quality, and capacity. Many wireless communication technologies apply MIMO, and MIMO was also evolving to form what is now called massive MIMO [13]. Combining with beamforming, massive MIMO can enhance the overall performance of 5G systems [14].

2.2 Network Slice

5G Network Slice (NS) [15] is an idea for catering to three significant scenarios in 5G: eMBB, mMTC, and uRLLC with just building one 5G network in an area. NS divides a physical 5G network into several end-to-end logic networks. A 5G network NS is a collection of service networks with their resources and functions. 5G NS enables operators to configure the relevant information of the service by slicing, which realizes the effective utilization and management of 5G network resources and isolates critical services to reduce data delay and jitter.

3 5G and Transportation

As a typical public URTS, subways and trains have a lower price and larger transportation volume. However, due to construction costs, road planning, and other factors, the coverage of the railway station is not sufficient in some districts in most cases. Many commuters must take a relatively long walk to reach the station they want and even need to transfer by other traffic tools to arrive at the final destination from the station [16]. In this section, we will introduce an innovative small volumes URTS with 5G.

3.1 Small Volumes URTS

The system uses guideway rubber-tired trams that are suitable for building the extension of metropolitan subways, trunk lines for small-medium cities, travel lines, and airport express. The system has excellent environmental adaptability, a small footprint, a small turning radius, and is suitable for collaborative construction with buildings (Fig. 1). The advantages are as follows:

- As the capillaries of the city: connect to main stations and get through to the last mile.
- A relatively low construction costs with a small transportation volume.
- High security, high intelligence, low energy consumption.

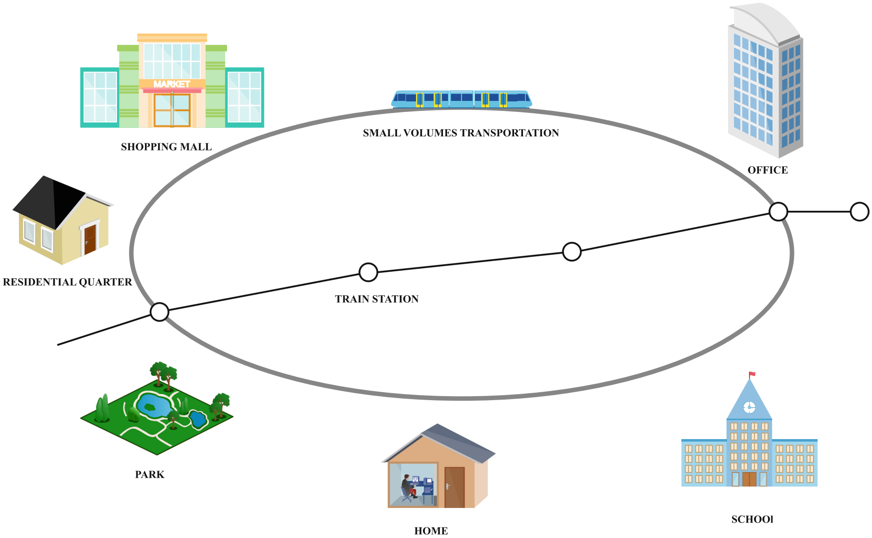

Fig. 1. The applicaiton scenario of small volumes URTS.

3.1.1 LTE-URTS

LTE-URTS is a system, especially for general operations of urban rail transportation, which undertakes many missions, such as CBTC, Passenger Information System (PIS), Video Surveillance System, and Cluster scheduling [17]. Figure 2 illustrates the LTE-URTS demand standards for rail transportation.

3.1.2 Network Solution for LTE-URTS

The original solution is to use LTE to build a private network to carry network services. However, resources in the conventional licensed spectrum are increasingly scarce, which is hard to apply for industry-specific spectrum in 1.4 and 1.8 GHz. In addition, the cost of constructing multiple private networks is high, and the maintenance of wireless networks is complex due to the different systems in different countries. It is necessary to put some data streams into the unlicensed spectrum. Operators can deploy LTE under both licensed and unlicensed spectrum using LTE-U and do not need to change any network structure, enhancing the network capacity and bringing a better experience to users [18]. The solution uses LTE-U to support operations like CBTC, PIS, and Video Surveillance System:

- Service Carrying (two separate networks A and B): Net A is responsible for communicating, and net B undertakes the missions like communication, PIS, Video Surveillance System, and cluster administrating.
- Redundant Coverage: The two-layer network covers the same district simultaneously.
- Redundant Device: Provide core services with board-level redundancy and end-to-end master-slave configuration.

Service Type	Uplink Bandwidth	Downlink Bandwidth	Delay	Packet Loss Probability	Service Statement
GOA3/4 CBTC	0.5Mbps	0.5Mbps	≤150ms	≤1%	Driverless
PIS emergency text	0	0.01Mbps	≤150ms	≤1%	OCC(operation control center) send emergency text to the train
Video Surveillance System	1-6Mbps	0	≤500ms	≤1%	OCC obtains the video of the passenger compartment in the vehicle, according to the two-way 2048K.
Center Video for PIS	0	2-6Mbps	≤500ms	≤1%	OCC transmits live video programs to the train, according to the line 6144K.
Cluster Scheduling(Audio)	0.1Mbps	0.1Mbps	≤150ms	≤1%	Staff for voice transmission
Cluster Scheduling(Video)	1Mbps	1Mbps	≤500ms	≤1%	Staff for video transmission
General	2.6-7.6Mbps	3.61-7.61Mbps			

Fig. 2. The standard of traffic demand for LTE-URTS.

- Unlicensed: Free to apply.
- Wide spectrum: Rich spectrum resources.
- High Landscape Integration: Compared with WLAN, the number of trackside device is reduced by 2/3.

Nevertheless, due to deployment in the unlicensed spectrum, LTE-U will likely interfere with other unlicensed spectrum technologies, such as Wi-Fi. It still needs to use some solutions to avoid the landscape.

3.2 5G Solution

Nowadays, passengers have higher requirements for the train ride experience. PIS is no longer just showing passengers simple information like the arrival time of the vehicle but also provides more information with high real-time demand, such as live broadcasts of events, train status, and even alarm information under emergency conditions. In modern society, surfing the Internet is the primary demand for people, and the train needs to provide a high-speed Internet environment for passengers [19]. In addition, it is necessary to monitor the vehicle's state through the real-time video monitoring system to ensure the safety of passengers. These requirements require ample bandwidth, low latency, and stability, which is difficult to achieve under the LTE scheme, while 5G is a better solution. Figure 3 illustrates the requirements analysis of Rail Transportation in the wireless application scenario with 5G.

Service Type	Priority	Uplink Bandwidth	Downlink Bandwidth	Delay	Packet Loss Probability	Concurrent terminals
Control System	Foremost	1Mbps	1Mbps	≤25ms	≤1%	2
Cluster Scheduling(audio)	Foremost	1Mbps	1Mbps	≤150ms	≤1%	7
Emergency video	High	2-6Mbps	2-6Mbps	≤150ms	≤1%	1
Video Surveillance System	Medium	16—60Mbps		≤500ms	≤1%	4
PIS	High		8—10Mbps	≤500ms	≤1%	1
Wi-Fi for passengers	Low					2
Cluster Scheduling(video)	High	6—12Mbps	6—12Mbps	≤500ms	≤1%	5
General		26-80Mbps	18-30Mbps			

Fig. 3. The requirement analysis of URTS in the wireless application scenario with 5G

3.2.1 Overall Architecture

The system achieves full coverage through 5G, with a 5G base station every 1.2 km along the track. In addition, there is going to deploy 5G room sub-equipment to satisfy the demand for 5G of the station. All the base stations are in charge of transmitting data to the carrier transmission network and bringing public data onto the Internet. MEC nodes in the operator center use User Plane Function (UPF) to offload the data and connect PIS, Video Surveillance System, and cluster data to the private cloud to ensure data security. There are three major parts to the operator transmission network: access, transmission, and MEC. The access network is responsible for establishing the wireless link. The network transmission completes the wired connection part of the access network to the core network and the cloud rail data center. MEC realizes data offload to ensure the security of operation-related data of tracks.

3.2.2 Network Architecture

Customer premises equipment (CPE) and the base station mainly constitute the Communication System Between Train And Ground. All data pass through the vehicular network and access the CPE, CPE will establish a link with the base station to satisfy the wireless communication between train and ground. The vehicular network is built using a vehicular ring network, which deploys a CPE active and standby redundancy in the front and rear of the vehicle. It makes a strategy on the vehicle server to ensure that the backup CPE can communicate with the ground when the communication of the primary CPE is abnormal. The vehicular AP, camera and PIS are connected to the CPE through the vehicular ring network to complete communication with the ground. Due to the occlusion of the platform area, it is necessary to add an additional 5G room sub-equipment to complete the platform's coverage, and the platform's passengers can access the Internet through the 5G network.

3.2.3 System Functions

- 5G back transmission for PIS: With the help of 5G and the system's specific network architecture, the train can provide users with 4K video services and real-time train information to improve their travel experience further.
- Real-time Video Surveillance System: It is necessary to build a real-time Video Surveillance System to monitor the state of trains, which can drastically enhance the quality of train management and the safety of the train and passengers. The traditional practice of onboard Video Surveillance System systems uses Wi-Fi for wireless transmission or a hard disk for data copy while the train arrives at the station. This method does not have real-time performance, which leaves security risks for the operation of the train. However, using 5G makes it easy for a monitoring system to transmit real-time video with low latency because of the characteristic of large bandwidth.
- 5G for onboard networking: Because of the development of mobile phones, passengers now have more demands while traveling onboard, such as watching high-quality videos online and playing games. However, the traditional Communication System Between Train And Ground can not provide a wireless network to meet the needs of passengers for a high-speed network limited by bandwidth performance. Passengers can use 5G for high-speed networking through the network architecture in this new system.
- 5G public network cluster: It is common to use the wireless cluster for train scheduling. However, the traditional narrowband group needs an independent network with a small bandwidth and can not fully meet the scenario for train scheduling and personal communication. Using 5G can provide a new clustering idea for rail transportation.

Figure 4 is the schematic of the overall architecture (HQVSS: HD Video Surveillance System, 5G NSS: 5G Network Scheduling System, 5G HSSS: 5G High-Speed Storage System). Figure 5 illustrates the 5G network slice solution for URTS.

4 Field Test Results

In order to test the performance of the transportation system, we use 5G mobile phones to do 5G SA upload with the system deployed by a dual-operator networking in different frequencies. The band of 5G is 3.5 GHz, and the center frequency point is 3509.76 MHz, which is different from other public networks in the testing district. Table 1 and Table 2 illustrates the statistic of the test.

The field test result proves that the proposed 5G network solutions of the transportation line can reduce interference while guaranteeing a smooth handover sequence and a stable service rate.

Table 1. The statistics of the uplink performance

Index	Max	Min	Average
`RSRP (dBm)`	−44.00	−103.69	−72.91
`SINR (dB)`	37.25	−8.31	16.65
`RSRQ (dB)`	−9.19	−20.63	−10.72
`UL Throughput (Mbps)`	291.58	5.9	153.35

Table 2. The statistics of the field networking results

Index	Value
`Total Distance (km)`	4.86
`Total Duration (s)`	1643.25
`NR Access Delay (ms)`	152.859
`NR Switching Success Rate (%)`	100.00
`NR Handoff Control Layer Delay (ms)`	19.448
`Failure Probability (%)`	0.00
`Total Uploaded Data (MB)`	30298.36
`Total Uploaded Time Cost (s)`	1635.50

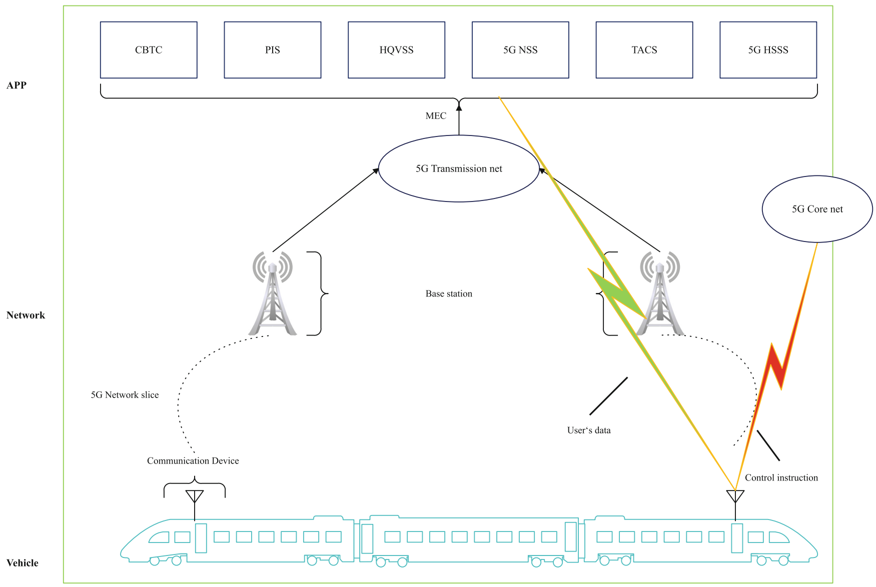

Fig. 4. The overall architecture of the small volumes URTS.

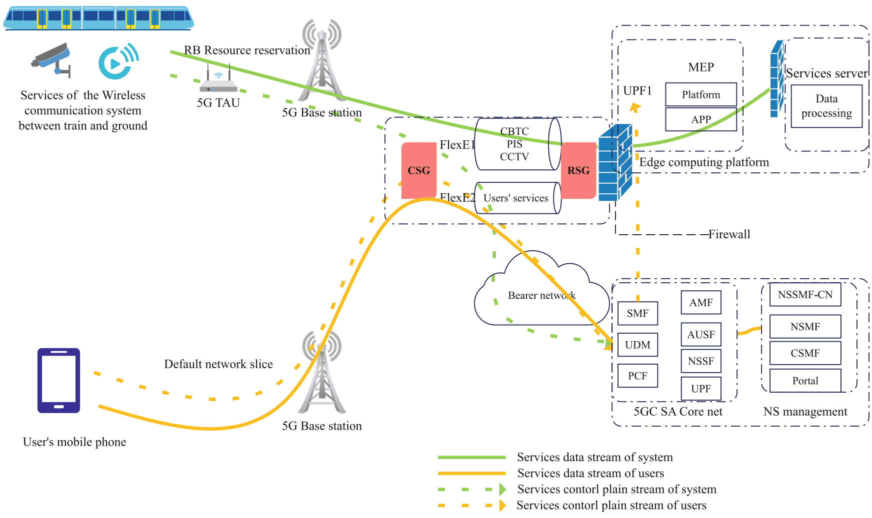

Fig. 5. The diagram of the 5G network slice solution for URTS.

5 Conclusion

It is necessary to develop intelligent URTS which can significantly improve the passenger travel experience. In the early stages of commercial applications of 5G, scenarios like uRLLC and mMTC are not mature, and 5G complements LTE-URTS as an additional technology, such as eMBB. It is believed that with the constant maturity of 5G in commercial scenarios, 5G can bring more vitality to the URTS in the future.

References

1. Zhao, J., Liu, J., Yang, L., Ai, B., Ni, S.: Future 5G-oriented system for urban rail transit: opportunities and challenges. China Commun. **18**(2), 1–12 (2021)
2. Navarro-Ortiz, J., et al.: A survey on 5G usage scenarios and traffic models. IEEE Commun. Surv. Tutorials **22**(2), 905–929 (2020)
3. Pisarov, J., Mester, G.: The impact of 5G technology on life in 21st century. IPSI BgD Trans. Adv. Res. (TAR) **16**(2), 11–14 (2020)
4. Abdullah, D.M., Ameen, S.Y.: Enhanced mobile broadband (embb): a review. J. Inf. Technol. Informat. **1**(1), 13–19 (2021)
5. Gbadamosi, S.A., Hancke, G.P., Abu-Mahfouz, A.M.: Building upon NB-IoT networks: a roadmap towards 5G new radio networks. IEEE Access **8**, 188641–188672 (2020)
6. Chettri, L., Bera, R.: A comprehensive survey on internet of things (IoT) toward 5G wireless systems. IEEE Internet Things J. **7**(1), 16–32 (2019)
7. Wijethilaka, S., Liyanage, M.: Survey on network slicing for internet of things realization in 5G networks. IEEE Commun. Surv. Tutorials **23**(2), 957–994 (2021)

8. Addad, R.A., Taleb, T., Flinck, H., Bagaa, M., Dutra, D.: Network slice mobility in next generation mobile systems: challenges and potential solutions. IEEE Network **34**(1), 84–93 (2020)
9. Kekki, S., et al.: Mec in 5G networks. ETSI White Paper **28**(28), 1–28 (2018)
10. Hassan, N., Alvin Yau, K.-L., Wu, C.: Edge computing in 5G: a review. IEEE Access **7**, 127276–127289 (2019)
11. Pham, Q.-V., et al.: A survey of multi-access edge computing in 5G and beyond: fundamentals, technology integration, and state-of-the-art. IEEE Access **8**, 116974–117017 (2020)
12. Fodor, G., et al.: 5G new radio for automotive, rail, and air transport. IEEE Commun. Mag. **59**(7), 22–28 (2021)
13. Lu, L., Li, G.Y., Swindlehurst, A.L., Ashikhmin, A., Zhang, R.: An overview of massive MIMO: benefits and challenges. IEEE J. Selected Topics Signal Process. **8**(5), 742–758 (2014)
14. Rao, L., Pant, M., Malviya, L., Parmar, A., Charhate, S.V.: 5G beamforming techniques for the coverage of intended directions in modern wireless communication: in-depth review. Int. J. Microwave Wireless Technol. **13**(10), 1039–1062 (2021)
15. Zhang, S.: An overview of network slicing for 5G. IEEE Wireless Commun. **26**(3), 111–117 (2019)
16. Lunke, E.B.: Commuters satisfaction with public transport. J. Transp. Health **16**, 100842 (2020)
17. Tang, T., Dai, K., Zhang, Y., Zhao, H., Jiang, H.: Field test results analysis in urban rail transit train ground communication systems of integrated service using LTE-M. In: 2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC), pp. 2017–2021. IEEE (2016)
18. Zhang, R., Wang, M., Cai, L.X., Zheng, Z., Shen, X., Xie, L.-L.: LTE-unlicensed: the future of spectrum aggregation for cellular networks. IEEE Wireless Commun. **22**(3), 150–159 (2015)
19. Yuan, T., ZhiWei, H.: Research and application of 5G collaborate carrying for metro passenger information system. In: Proceedings of the 5th International Conference on Electrical Engineering and Information Technologies for Rail Transportation (EITRT) 2021: Rail Transportation Information Processing and Operational Management Technologies, vol. 867, p. 316. Springer, Singapore (2022). https://doi.org/10.1007/978-981-16-9909-2_35