# Scheme of Railway 5G Integrated Innovation Test Platform

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*Abstract: An inevitable trend has already taken shape for the application of the 5th Generation Mobile Communication Technology (5G) in the railway sector. The application scenarios and business types of the railway sector are complex and diverse, so it is indispensable to test and verify the railway 5G before actual deployment. The design and creation of the railway 5G integrated innovation test platform provides engineering design, test and verification conditions for the networking, coverage and business development of 5G public networks and 5G-R in railway scenarios. This paper introduces the design of the overall architecture for the integrated railway 5G innovation test platform according to the railway network requirements, application scenarios and intelligent development trend; respectively elaborates on the design of the 5G-R core network, bearer network and wireless access along loop tracks, in combination with the characteristics of railway scenarios and the requirements of railway dispatching, operation and safety; raises further solutions on the network deployment and coverage schemes of 5G public networks so as to meet the application requirements of 5G public networks. The study results show that the integrated railway 5G innovation test platform scheme contains co-existence of 5G public and private networks, combines the indoor and outdoor scenarios, as well as takes into account of the dynamic and static tests so as to meet the environmental requirements for the integrated railway 5G test and application of all network functions, for which it can provide comprehensive technical support for railway 5G technology research and development, standard formulation, testing, etc.*

Keywords: railway communication; 5G public network; 5G-R; integrated innovation; test platform

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## 1 Introduction

Railway transportation is one of the most important component parts among the traffic and transportation system and is the pillar industry of the national economic development. The Outlines for Building China into a Country with Strong Transportation Network unveiled by the Central Committee of the Communist Party of China and the State Council clearly pointed out that "integrated modern transportation system which is safe, convenient and express, high-effective, green and economical with first-rate facilities, technology, management and services should be built to make China into a country with strong transportation network with satisfaction from the people, powerful guarantee and front-ranking position in the world so as to provide firm supports for building China into a great modern socialist country in all respects and advancing the Chinese dream for the rejuvenation of the Chinese nation". With the advantages of relatively great traffic volumes, low costs and high reliability, the railway transportation will still occupy the important position in the future integrated transportation network of modernization and high quality. The leaping development of the railway sector can by no means be separated from the driving by scientific and technological innovation, for which the frontline technologies such as the new-generation information technology and artificial intelligence can enhance the coordinated operation and service technology of the regional integrated transportation network; the deep convergence of the new technologies such as big data and Internet with the transportation industry can advance the data resources endowing with impetus to the transportation development, accelerate the fusion development of the transportation infrastructure network with the transportation service network, and construct the advanced ubiquitous infrastructure of transportation information. Among them, applications of the 5th Generation Mobile Communication Technology (5G) in the railway sector are the important orientation and opportunity for the railway information technology development. It was made clear by China State Railway Group Co., Ltd. (CHINA RAILWAY) in 2020 that the railway 5G private network (5G-R) should be taken as the development system of next-generation mobile communication for the railway sector.

With the three major features of large bandwidth, multiple accession and low delay, the technical advantages of the core network such as slicing, edge computing and Service-based Architecture (SBA), as well as the capabilities in supporting the high-speed mobile scenarios[1], the 5G communication is the important support for advancing construction of the digital and smart railway transportation. Building the railway applications based on the 5G public network and 5G-R plays the important roles in further consolidating the leading advantage of China's railway development, racing to control a commanding point of the new-round science and technology, and implementing the "going global" strategy of the Chinese railways[2-3]. Applications of the 5G technologies in the railway sector have such significance and benefits as including promoting the development of the 5G-related industrial chains, pushing forward the updating and upgrading of the railway technical equipment, giving an impetus to the development of the relevant industries such as communication network, equipment manufacturing, technology research and development, and operation and maintenance, and likewise deriving the new service products and economic formats to bring along rapid development of 5G in the vertical industries; further uplifting the railway service quality and providing more express, comfortable and individual passenger and freight transport services to the customers of passengers; securing the railway transportation safety and improving the efficiency and benefits; and further consolidating the leading advantages of China's railways in the world[3].

In view of the needs for the safe railway transportation, massive tests and researches must be carried out before the overall application of the 5G technology in the railway sector. As the integrated test platform of railway, the loop railway track test base of National Railway Track Test Center (hereinafter called "loop railway track") bases itself on the existing railway tracks and overhead contact lines as well as the environment for different kinds of laboratories, has the aid of the rich railway test experiences and builds the railway 5G integrated innovation test platform so as to speed up the advancement of the 5G application in the railway sector and provide the continuous railway 5G innovation.

## 2 Overall Scheme

The scheme is based on the loop railway track to provide the environmental supports for scientific research, service innovation, industrial chain development, interoperability, failure diagnosis, technological support, tests, and on-track verification with the aim of building the innovation and demonstration base for the railway 5G application in China. The overall scheme of the railway 5G integrated innovation test platform includes the three-level architecture (refer to Fig. 1) as follows:

(1) 5G network environment. The 5G public network has an overall coverage of the loop railway track and the indoor areas, and the 5G-R covers the radio frequency test areas of the loop railway track and the laboratory, which will provide the railway 5G communication test environment for the combination of interior and exterior fields, concurrent dynamic and static considerations and side-by-side existence of the public and private networks.

(2) Innovation platform. The railway 5G integrated innovation platform is fostered through the 5G network detection and evaluation platform, the 5G intelligent railway service

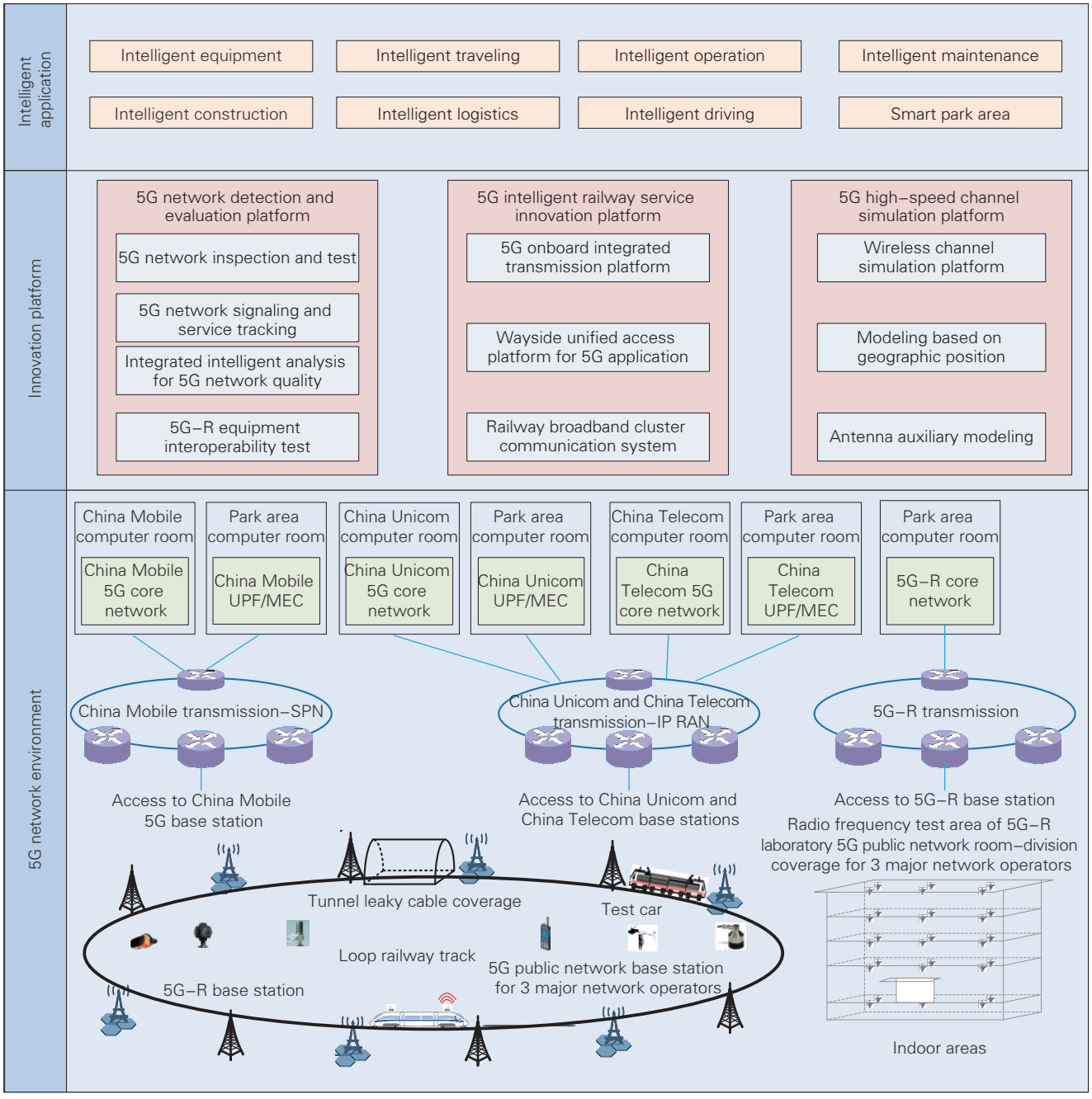



**Fig. 1** Overall scheme of railway 5G integrated innovation test platform

innovation platform, and the 5G high-speed channel simulation platform to provide services for supporting the innovation tests including the 5G network inspection and test, the 5G network signaling and service tracking, the integrated intelligent analysis for 5G network quality, the railway broadband cluster communication, and the wireless channel simulation.

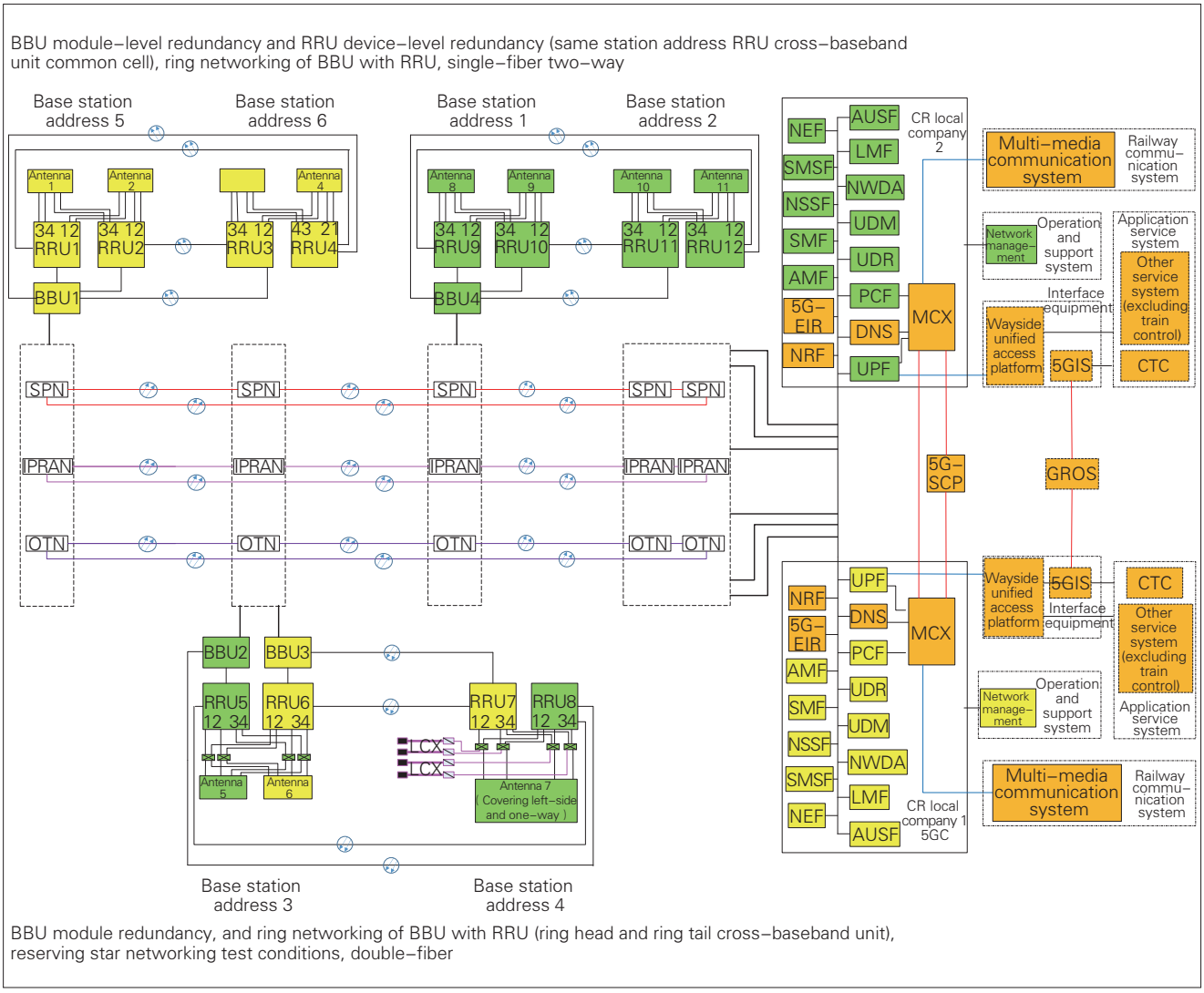
(3) Intelligent applications. They support the different railway intelligent applications including intelligent equipment, intelligent construction, intelligent traveling, intelligent logistics, intelligent operation, intelligent driving, intelligent maintenance and smart park area.

## 3 5G-R Test System Scheme

### 3.1 Network architecture

The 5G-R test system adopts the independent networking (Stand Alone, SA) mode, which includes the core network, carrier network, wireless access network, and operation and support system. The 5G-R test system network architecture is shown in Fig. 2.

The 5G-R test system network links to different wireless access network through allocating the carrier network with two sets of core networks and the three systems to form two 5G-R networks of interoperability. Among them, the two core networks imitate the core networks of different CR local companies (remote




BBU module redundancy, and ring networking of BBU with RRU (ring head and ring tail cross–baseband unit), reserving star networking test conditions, double–fiber

**Fig. 2** 5G-R test system network architecture

redundancy), the carrier networks with three systems provide the test conditions of the 5G-R for the selection of carrier network, and different base stations imitate different ways of base-station redundancy and networking. The operation and support system is composed of two-set independent network management systems to implement management and maintenance for the two 5G-R networks respectively.

## 3.2 Core network

The 5G-R core network adopts the service-based architecture which includes the network element equipment for the Access and Mobility Management Function (AMF), the Service Management Function (SMF), the Point Coordination Function (PCF), the secondary Network Storage Function (NRF), the unified data management function/authentication server function (Unified Data Management, UDM/Authentication Server Function, AUSF), the Network Slicing Selection Function (NSSF), the Short Message Service Function (SMSF), the User Plane Function (UPF), the Network Exposure Function (NEF), the secondary service control point of service communication agent (Service Control Point, SCP), the key services (Mission Critical, MC), the Domain Name System (DNS), the Remote Authentication Dial in User Service (RADIUS), and the location service.

As shown in right side of Fig. 2, the scheme of the 5G-R test system is allocated with two sets of core network to imitate two CR local companies respectively and form the remote redundancy mode with interoperability between the two core networks, which can achieve the service routing, test switching and test verification across the companies. The core network of each CR local company includes the common equipment of the core network, the equipment of the company's core network (5G Core Network, 5GC), the MC equipment of the company's core network, the wayside unified access platform of the company's core network, and the 5G-R interface server of the company's core network (5G-R Interface Server, 5GIS).

## 3.3 Carrier network

The carrier network is allocated with three kinds of systems such as

the Slicing Packet Network (SPN), the Internet protocol radio access network (Internet Protocol Radio Access Network, IP RAN), and the Optical Transport Network (OTN), which will be used for data return between the core network and the base station equipment. Different schemes are adopted by the carrier network in light of the railway's different scenarios under the systems of SPN, IP RAN, and OTN.

#### 3.3.1 Scenario 1

Two sets of packet device are allocated at the nodes of Base Band Unit (BBU). Between the two stations, the packet device uses the optical fiber and the channel local convergent layer to set up the station ring, for which the track-side volume adopts the rate of 100 Gbit/s. The packet device of the section and that of the station use the optical cable to form the sectional ring network and the track-side volume adopts the rate of 10 Gbit/s.

#### 3.3.2 Scenario 2

One set of packet device is allocated at the nodes of BBU. Between the two stations, the packet device uses the optical fiber and the channel local convergent layer to set up the station ring, for which the track-side volume adopts the rate of 50~100 Gbit/s. The packet device of the section and that of the station use the optical cable to form the sectional ring network and the track-side volume adopts the rate of 10 Gbit/s.

#### 3.3.3 Scenario 3

One set of packet device is allocated at the nodes of BBU. Between the two stations, the packet device uses the optical fiber to set up the station ring, for which the track-side volume adopts the rate of 10~100 Gbit/s.

### 3.4 Radio access network

#### 3.4.1 Outdoor areas

(1) Coverage scheme. Multiple base station addresses are allocated along the loop railway track and the schematic diagram of 5G-R track-side station address planning is referred to as in Fig. 3. The base station equipment adopts the distribution architecture, which is composed of BBU and the Radio frequency Remote Unit (RRU) and supports the frequency of 2 100 MHz. RRU links the antenna on the communication tower pole and the leaky cable in the tunnel through the feeder line to achieve the coverage of the 5G-R signal for the loop railway track. The loop line between BBU and RRU supports the star-type, chain-type and ring-type networking models, those between BBU and RRU, and among RRUs support the single/dual optical fiber connection, BBU supports no less than 3 RRU rings, each ring supports no less than 3 sets of RRU, and 6 RRU along the line can be set up as the common-cell mode according to the test needs.

The schematic diagram of 5G-R leaky cable coverage is referred to as in Fig. 4. Four pieces of 5G-R leaky cables are allocated at one side of the tunnel wall top with the leaky cable spacing of 30 cm to link the RRU device at the tunnel portal through the feeder line.

(2) Networking scheme. As shown in the left side of Fig. 2, the 5G-R wireless access network adopts the redundancy networking scheme, for which two kinds of networking modes are allocated respectively in light of the two scenarios for the railway.

**Scenario 1.** Adopting BBU module-level redundancy, RRU device-level redundancy (same station address RRU cross-baseband unit common cell), BBU and RRU ring-type networking, and 4T4R modes. Adopting 2T2R mode in case of RRU single-point failure.

**Scenario 2.** Adopting BBU de-

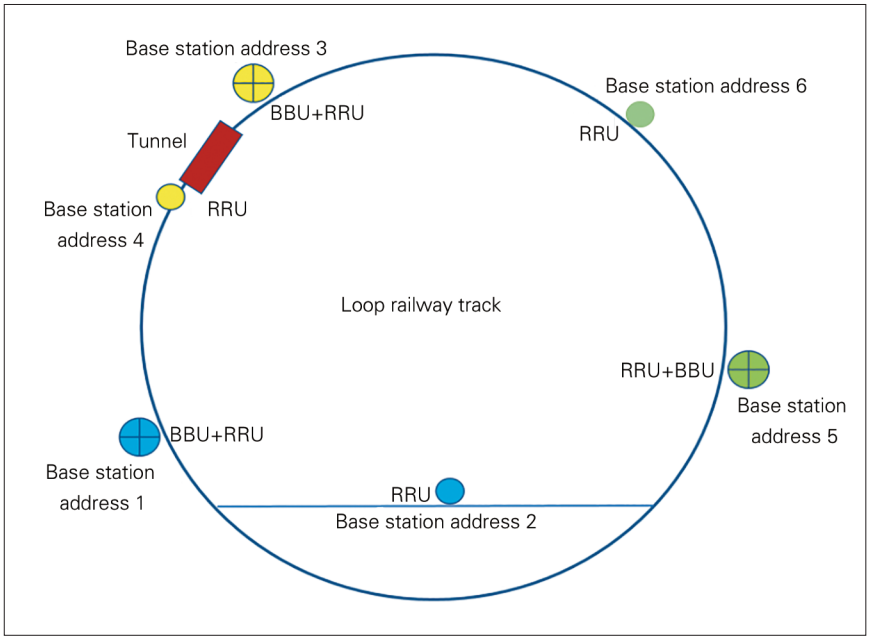



**Fig. 3** Schematic diagram of 5G-R track-side station address planning

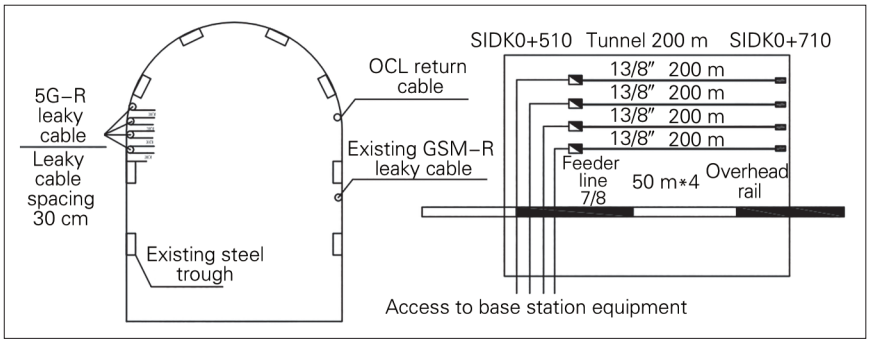



**Fig. 4** Schematic diagram of 5G-R tunnel leaky cable coverage

vice-level redundancy, RRU device-level redundancy, BBU and RRU ring-type networking, and 4T4R modes.

### 3.4.2 Laboratory areas

Dedicated radio frequency test area is allocated in the laboratory to lead in the 5G-R signal from the RRU equipment through the radio frequency cable, and coordinate with the high-speed channel simulation platform and shielding box so as to achieve the tests for terminal in the shielding environment and further realize the simulation verification for the characteristics of railway communication wireless channel in the condition of train speed at 500 km/h.

## 4 Test System Scheme of 5G Public Network

### 4.1 Network architecture

The degrees of coverage for operators' 5G public networks in different regions vary due to the widespread areas of railway coverage in China, which might exist great differences for the operators' 5G communication quality in different sections of railway during train operation and lead to the occurrence of the 5G communication transfer demands. For such situations, the loop railway track has realized the full coverage of the 5G networks for the 3 major network operators of China Mobile, China Unicom and China Telecom to meet the demands of railway based on applications and test verifications for the 5G public network. The network architecture of 5G public network is shown in Fig. 5.

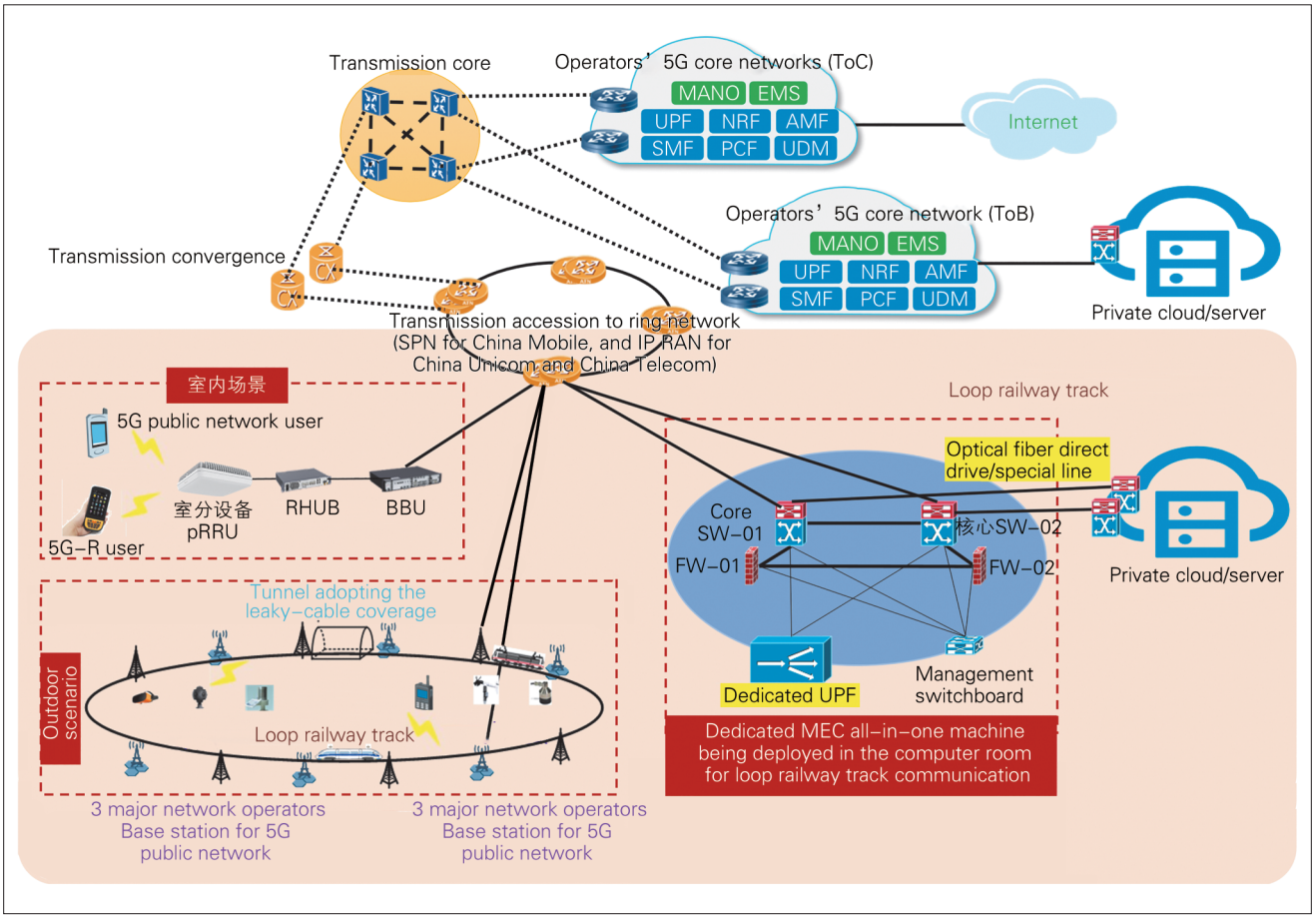



**Fig. 5** Network architecture of the 5G public network

### 4.2 Core network

The loop railway track adopts the 5G public network (with priority mode for China Mobile, 5G mixed dedicated network mode for China Unicom[4], and neighboring mode for China Telecom[5]), for which one set of UPF (including UPF + data communication equipment + firewall, etc.) is allocated respectively in the computer room of the loop railway track communication to connect respectively with the 5G base station of the loop railway track, the own application system and the operators' core networks by using the UPF equipment, thus achieving the local distribution of data for dedicated network of the loop railway track and meet the demands of local 5G communication service, and of the public 5G communication that still uses the operators' ToB and ToC for the remote communication and the outside communication.

Within the loop railway track, the users' data can be distributed to lo-

cal directly through the dedicated UPF equipment and by means of the technologies such as the 5G network slicing and Generic Routing Encapsulation (GRE) and the Layer Two Tunneling Protocol (L2TP) to meet the requirements of high security and low delay for the physical isolation and data local unloading of the users' communication.

The users of the 5G public network can also make use of the 5G slicing technology and the UPF of the operators' side or the core network, and through the technical systems such as the Internet Protocol Security Virtual Private Network (VPN), the Virtual Private Dial-up Network (VPDN), and the Access Point Name (APN) to achieve the dedicated 5G communication channel (refer to Fig. 6).

## 4.3 Carrier network

The carrier network of the 5G public network for loop railway track includes the IP RAN and SPN. Among them, China Unicom and China Telecom share the infrastructure of transmission and adopt IP RAN[6], while China Mobile adopts the SPN. The carrier networks are divided into three layers as follows:

(1) Access ring. The base-station side transmission group rings form the transmission access ring, which links the 5G base stations and the local UPF respectively and connects with the core network through the transmission of the convergent layer and the core layer;

(2) Convergent layer. It is the convergent point for multiple access rings to share the UPF and form the remote edge computation through the connection with the convergent layer;

(3) Core layer. It links with the core network to achieve connection of the base station with the core network.

## 4.4 Radio access network

### 4.4.1 Loop railway track areas

China Unicom and China Telecom adopt the shared base station infrastructure mode to achieve the simultaneous coverage of signal, which means that China Unicom builds the 5G base station infrastructure to meet simultaneously the 5G signal coverage For China Unicom and China Telecom; and China Mobile builds the 5G base station facilities on its own to cover the 5G signal independently. The schematic diagram of 5G public network coverage station addresses for loop railway track is referred to as in Fig. 7.

The 5G for all the 3 major network operators adopts the large-scale Active Antenna Unit (AAU) + BBU base station mode. Among them, China Mobile with the frequency of 2 515~2 675 MHz, China Telecom with the frequency of 3 400~3 500 MHz, and China Unicom with the frequency of 3 500~3 600 MHz[7]. China Tower builds 6 new towers along the loop railway track, sets up the 5G base stations by adopting the way of sharing from the 3 major network operators, and coordinates with the 5G base stations established by the existing tower surrounding the loop line, thus achiev-

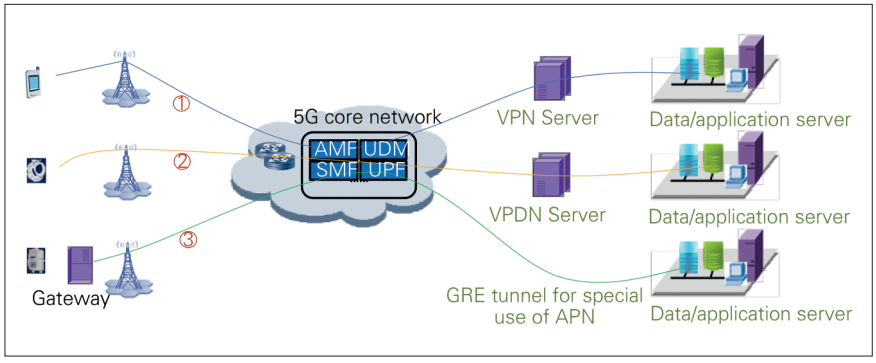



**Fig. 6** Deployment scheme for mobile 5G core network

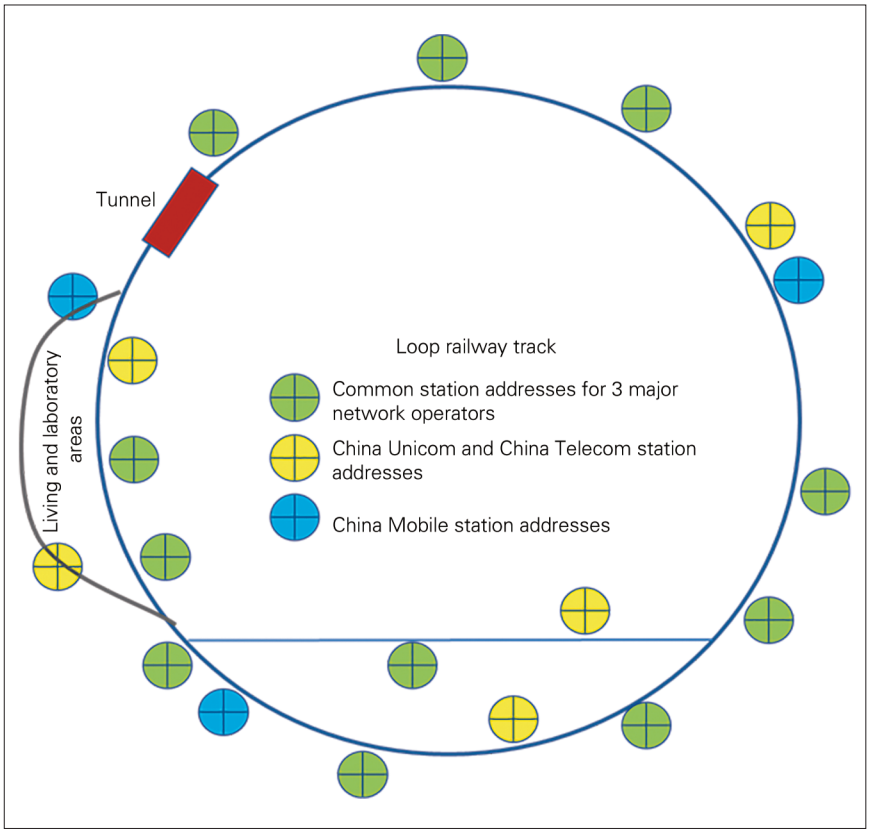



**Fig. 7** Schematic diagram of 5G public network coverage station addresses for loop railway track

ing the 5G public network coverage.

#### 4.4.2 Indoor areas

The indoor 5G coverage of the 3 major network operators adopts the room-division coverage scheme. Based on the need of coverage, one BBU links with multiple RRUs with each RRU pairing with different numbers of antenna to achieve differentiated coverage in different areas. The principles of 5G coverage for the 3 major network operators are basically the same, for which the coverage scheme of China Mobile is hereby taken as the case for introduction:

(1) The flat floor of the building is covered with omnidirectional ceiling antenna;

(2) The lecture hall, large conference room and open laboratory are covered with directional plate antenna;

(3) Other interior and corridor are covered with omnidirectional ceiling antenna;

(4) The elevator is covered with log-periodic antenna;

(5) The antenna is connected with RRU of 4G and 5G through the combiner, and RRU is connected with the core network through BBU and the wire transmission system.

## 5 Railway 5G Integrated Innovation Test Platform

### 5.1 5G network detection and evaluation platform

The 5G network detection and evaluation platform achieves the intelligent integrated analyses on the functions, performance detection as well as network operation state mainly through the four sub-systems as follows:

(1) 5G network inspections and tests. They can be used to achieve the detection of the electromagnetic environment, field-strength coverage, service quality and application functions for the 5G-R and the 5G public network, provide technical support means for the 5G network optimization and operation, and also offer the verification instruments for the tests of network performance, and the carrying capacity[8]. The system includes the 5G network detection software, 5G field-strength measurement receiver, 5G signaling acquisition module, vector signal generator, digital spectrum analyzer, network analyzer, wireless comprehensive tester, technological equipment for test, and automatic testing software.

(2) 5G network signaling and service tracking. It is used to achieve the tracking and monitoring for the 5G-R user signaling and all application service data, and the tracking and monitoring for the 5G-R public network application service data, providing technical means for monitoring the network and service quality.

(3) Integrated intelligent analysis for 5G network quality. It is used to achieve the integrated intelligent analysis of the track-measured data for the 5G-R and 5G public network, network management KPI, and the data offered from the data source for signaling tracking and services, monitor the deviation of the network state, and realize the warning in advance for the network abnormality and retrospective search for the network problem.

(4) 5G-R equipment interoperability tests. They are used to achieve the interoperability tests for the equipment such as the core network, wireless network, terminal, carrier network, etc. in the 5G-R network according to the technical requirements for the 5G-R standard by CHINA RAILWAY, and support the upgrading verification of its current network equipment for the 5G-R[9].

### 5.2 5G intelligent railway service innovation platform

The 5G intelligent railway service innovation platform offers the vehicle-wayside unified access platform for development, commissioning and test as well as the railway broadband cluster communication service for the innovation of multiple railway application services through the three subsystems as follows:

(1) 5G onboard integrated transmission platform. It is used to offer the vehicle-wayside wireless data transmission passage for different onboard access services, make unified access to the 5G onboard integrated transmission platform for all service systems when there are demands for vehicle-wayside wireless transmission, and result in the unified achievements for the vehicle-wayside wireless transmission function of the service. The 5G onboard integrated transmission platform possesses the passages for 2-way access to 5G public network and data transmission, those for 2-way access to 5G-R and data transmission, those for access to the networks such as the 5G mmWave and data transmission, and the functions for sending the information of time, latitude and longitude, speed, etc. to the onboard service system.

(2) Wayside unified access platform for 5G application. It is used to offer interfaces and achieve protocol matching for different railway application wayside equipment access to the 5G network, and result in the achievement of unified security management and access verification. The wayside unified access platform for 5G application possesses the functions for access to 5G public network and data transmission, those for access to 5G-R and data transmission, those for conducting verification for the legitimacy of the 5G network terminal equipment, and those for performing precise control over the access authority of the service systems by the 5G network users.

(3) Railway broadband cluster communication system. It is used to achieve the functions for the multimedia dispatching voice, data and video communication based on 3GPP MC standard in the condition of the 5G network. Through the high rate of the 5G network, the functions that the traffic controller can shift and watch the real-time monitoring video of the driver and the driver shift and watch the video of the railway station are achieved to offer richer information interaction and provide more complete support for the dispatching and command. The railway broadband cluster communication system is com-

posed of the multiple units including the MC public management, users' database, MCPTT voice application (Mission Critical Push To Talk, key voice service), MCVideo video application (Mission Critical Video, key video service), MCData data application (Mission Critical Data, key data service), and intelligent network application, possessing the service functions for voice individual call/group call and video individual call/group call, those for offering data and document distribution, and those for supporting the call-related services including call hold, call forwarding, and call restriction[10].

### 5.3 5G high-speed channel simulation platform

The 5G high-speed channel simulation platform can achieve the simulation verification of the wireless channel characteristics for the 5G railway communication in the condition with the train speed of 500 km/h. A simulation system of the 5G high-speed wireless network that can repeat, self-define the network topology structure and self-define the editing of the wireless channel will be established in the laboratory through the platform to imitate the precise and controllable 5G HSR network environment, thus bringing the 5G network of the complex HSR sites to the laboratory.

## 6 Conclusions

As the core technology of the new capital construction, 5G is the important support for rail transportation digitized and smart construction. Researches and applications of the 5G technology in the railway scenarios need the platform tests and inspections so as to guarantee security and actual effects. The railway 5G integrated application innovation laboratory of National Railway Track Test Center builds the networking test platform for the railway 5G-R and 5G public network convergence, foster the railway 5G communication test environment for the combination of interior and exterior fields, concurrent dynamic and static considerations and side-by-side existence of the public and private networks, and support the network detection and evaluation, and the intelligent railway service innovation tests as well as the high-speed channel simulation function so as to provide the dynamic and static test environments and technology supports for the railway 5G scientific research, standards, research and development, and tests.

(Translated by ZHENG Mingda)

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