Advances in High-speed Rail Technology

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Dedicated Mobile Communications for High-speed Railway

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Review of the Development of Dedicated Mobile Communications for High-Speed Railway

1.1 Railway Development in China

In recent years, a large number of reforms and improvements in technologies have been achieved in China railway system to promote the development of transportation and communication in railways. These reforms and improvements include the heavy-loan transportation, the electrification upgrade, several-time speed up for all lines, the development of passenger railway lines, and the development of high-speed railways.

In 2010, the investment in the infrastructure construction for railways is 707.459 billion. It is a number of 107.012 billon increase over last year's figure, which equals to a 17.8% increase. At the end of 2010, there are about 91,000 km of railway in service, achieving the target of the "11th Five-Year Plan" for the railway construction. Also in 2010, there are 329 large and medium-sized projects (excluding the local railways) under construction in railway infrastructure network, and the number of newly started projects is 97.

In 2011, the investment in the infrastructure construction for railways is 460.127 billion. Some major projects, such as Beijing–Shanghai high-speed railway and Guangzhou–Shenzhen–Hong Kong express railway line, are in operation in this year. The 3348.9 km new line of track laying, 2174.3 km double-track laying, and 3430.9 km electrified railways have been completed. There are 299 large and medium-sized projects (excluding the local railways) under construction in railway infrastructure network, and the number of newly started projects is 15.

In 2012, the investment in the infrastructure construction for railways is 521.5 billion, with year-on-year growth of 13.3%. The investment is more than 20 billion in total for Shanghai railway administration, Beijing railway administration, Nanning railway administration, Guangzhou railway group corporation, Guiguang railway corporation, and Jinyulu railway corporation. From September to December, the investment in all the railways is 284.8 billion, which increases more than double compared to the same period of the previous year, and the average

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monthly investment is more than 70 billion. Totally 68 projects have been completed, including the Harbin–Dalian express railway, Beijng–Shijiazhuang–Wuhan express railway, Harbin–Hami express railway, and so on. In this year, 5389 km new line of track laying, 4792 km double-track laying, and 6073 km electrified railways have been completed, and among which the new high-speed line of track laying is 2722 km. There are 301 large and medium-sized projects (excluding the local railways) under construction in railway infrastructure network, and the number of newly started projects is 28.

In 2013, more major projects have been completed, including the Nanjing–Hangzhou high-speed railway, Hangzhou–Ningbo high-speed railway, Tianjin–Qinhuangdao high-speed railway, Xiamen–Shenzhen high-speed railway, Xi'an–Baoji high-speed railway, and so on. Forty-nine new projects are under construction, including Chongqing–Guiyang high-speed railway, Hohhot–Zhangjiakou high-speed railway, Jiujiang–Jingdezhen–Quzhou high-speed railway, and so on. The investment in all the railways is 663.8 billion, and the total length of new railways is 5586 km. As a result, a new milestone is reached in the history of the development in China railways: there are more than 100,000 km railways in service, including more than 10,000 km high-speed railways.

In 2014, the construction of railways has been accelerated. The nationwide investment in the infrastructure construction for railways is 808.8 billion, and the total length of new railways in service is 8427 km. Both numbers achieve a highest record in history. There are more than 5000 km high-speed railways in service, including a large number of major projects such as Lanzhou–Xinjiang high-speed railway, Guizhou–Guangzhou high-speed railway, Nanning–Guangzhou high-speed railway, and the Changhuai section in Shanghai–Kunming high-speed railway. Therefore, the conditions are created and the foundations are laid to achieve the target of the "12th Five-Year Plan" for the railway development. By the end of 2014, there are 112,000 km railways in service, including 16,000 km high-speed railways. In order to promote the development of high-speed railway and intercity high-speed railway, the "Design Specification Standards for High-Speed Railway" and the "Design Specification Standards for Intercity High-Speed Railway" have been officially unveiled, which can also provide technical supports to promote the "exportation" of China high-speed railway.

In 2015, the nationwide investment in railways is 823.8 billion, and the total length of new railways in service is 9531 km. There are also 61 new projects under construction.

During the "12th Five-Year Plan" period, the total investment in railways comes to 3580 billion, and the total length of new railways in service is 30500 km. By the end of 2015, there are 121,000 km railways in service, ranking second in the world. Taking up more than 60% of the high-speed railways, there are more than 19,000 km in service in China, ranking first in the world (Fig. 1.1 and Table 1.1).

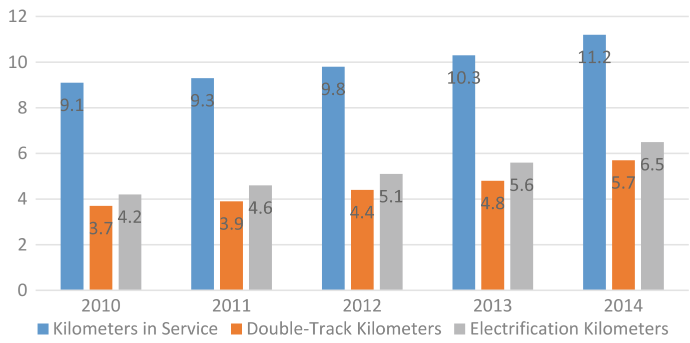

Fig. 1.1 km of railways in China (from National Railway Administration of the People's Republic of China)

Table 1.1 km of railways in China (from National Railway Administration of the People's Republic of China)

	2010	2011	2012	2013	2014
Kilometers in service	9.1	9.3	9.8	10.3	11.2
Double-Track kilometers	3.7	3.9	4.4	4.8	5.7
Electrification kilometers	4.2	4.6	5.1	5.6	6.5

1.2 High-Speed Railway Development in the World

For half a century, with the development of economy and technology in the world, high-speed railway, a major mobile equipment of railway passenger transport, got a rapid development. With Japan's Shinkansen, bullet train, France's TGV, Germany's ICE, Italy's ETR, and so on as the representative, high-speed railway gave birth to a new field of technologies with unique technique and complete system in modern industry. It also achieved remarkable achievements and gave a strong support for the development of the world economy and the progress of civilization.

(1) Development and progress of the Shinkansen, bullet train in Japan
Japan is the first country in the world to open up a high-speed train. Starting in 1964, Begin with 0 series high-speed trains, after 50 years of continuous improvement, 100 series, 200 series, 300 series, 400 series, 500 series, 700 series, N700 series, and E1–E7 series Shinkansen, bullet trains have been developed successively. At the same time, 300X, WIN350, STAR21, and other high-speed test trains are also developed. By the basic characteristics of the Shinkansen, bullet train can be summarized as follows: power-distributed type electric vehicle group, aluminum alloy train body, high light-weight level, and high aerodynamic performance. Light-weight non-bolster bogie, the semi-active suspension system is adopted in the 500 series and 700 series trains.

(2) Development and progress of the TGV (AGV) series high-speed trains in French
The development of TGV series high-speed train in France began at the end of 1960s. The plan is to design the diesel multiple unit (DMUs) at first and change to the development of high-speed electric multiple unit (EMUs) in 1975. Since the first TGV high-speed train vehicle has been successfully developed, the French have developed three generations of power concentrated TGV high-speed EMU. At this stage, the French is developing a new generation of high-speed trains—AGV power-distributed high-speed EMU.
(3) Development and progress of ICE/Velaro series high-speed trains in Germany
Germany ICE/Velaro series of high-speed trains is one of the world's most successful high-speed trains. The main representative models are ICE 1–3, ICT models, and E Velaro and RUS Velaro high-speed train. Its main features are that the power is centralized in the early stage and the latter is dominated by dynamic dispersion, the aluminum alloy train body, Bolsterless bogie and magnetic rail brake and eddy current brake braking system, moderate passenger number, complete function, high technical level, reasonable overall layout of structure, high-grade built-in, and high performance to operate and maintain.
(4) Development and progress of ETR series high-speed train in Italy
Italy ETR series of high-speed trains are all tilting train except ETR 500, so it is also called the Pendolino train. ETR series of high-speed trains include the first-generation ETR 401, the second-generation ETR 450, the third generation of ETR 460, ETR 470 and ETR 480, s220, and ETR 500 (power centralized high-speed tilting EMUs), and the fourth-generation ETR 600 models. At present, the Ansaldo Breda company is developing ETR 1000 high-speed train, called the type 1000. ETR 1000 high-speed train uses 4M4T marshaling structure, traction power is 9800 kilowatts, construction speed is 360 km/h, and the number passenger is 469. At present, the train is being tested and plans to put into use in 2016.
(5) Development of other typical high-speed trains in the world
The Swedish design a power centralized tilting EMU–X2000 type high-speed train. The trains can travel in the existing line and the working principle is using active train body swinging device to make the body swing an angle, to compensate for line under ultra high to ensure comfort while train is passing through the curve section, so as to improve the curving speed. Spanish designed and manufactured the Talgo series of high-speed trains, which is the representative models of high-speed railway; the tractive power is 8000 kilowatts, construction speed is 350 km/h, and the seating capacity is 300 people. British IC series high-speed trains are mainly used on the East and West Coast main line. The representative models are IC 225 intercity trains, construction speed is 225 km/h, which is the only single-ended dynamic Changbian power centralized high-speed train in the world.

(6) Technical characteristics and development trend of high-speed trains in foreign countries
At present, the main technical characteristics of foreign high-speed trains are described as follow: higher speed, many countries have been competing to develop high-speed train with the construction speed exceeds 360 km/h. The articulated high-speed train adopts the power dispersion technology, which has the better running quality, higher light-weight level, and the better utilization rate of the vehicle interior space. The train body tilting technique is adopted to effectively improve the speed of the curve; Focus on the overall aerodynamic shape of the train design, thereby reducing the running resistance of the train; Using permanent magnet motor traction technology, which has high power density, high power conversion efficiency, overload protection ability, and so on. By the design of the energy absorbing structure, the safety performance of the train is improved.

1.2.1 High-Speed Railway Development in China

Since 1990s, China began to carry out a large number of scientific research about the design and construction of high-speed railway construction technology, high-speed trains, operation and management of the basic theory and key technology organizations. At the same time, the Qinhuangdao–Shenyang dedicated passenger line was built and realizes the six time speed up for the existing railway. At December 2002, Qinhuangdao Shenyang passenger dedicated line was completed, which is the first railway passenger dedicated line designed and constructed by China own with the target speed of 200 km/h, infrastructure reserved 250 km/h. Independently developed the “China Star” EMUs in Qin Shen passenger dedicated line created “China Railway first speed”—321.5 K km/h.

In January 2004, the government approved the “medium- and long-term railway network planning,” to determine the railway network to expand the scale, improve the structure, improve quality, expanse the transport capacity rapidly, and improve the level of equipment quickly. By 2020, the national railway operating mileage reach to 10 million km, achieve separation of passenger and freight traffic in the busy main lines railway electrification rate and the double track rate reach to 50%, the transport capacity meets the needs of national economic and social development, and the main technical equipment reach or close to the international advanced level. In November 2007, the state issued “comprehensive transportation network in the long-term development plan,” which announced that, by 2020, the total size of the railway network will reach or exceed 120 thousand kilometers, and double track rate and electrification rate reach 50 and 60%. In October 2008, the Chinese government issued “Medium and long term railway network planning (2008 adjustment),” which announced that, by 2020, the national railway operating mileage will exceed 12 million kilometers and passenger dedicated line reach more than 1.6 million kilometers, double track railway electrification rate and the rate reach 50% and 60%, respectively.

What is more, a railway network with reasonable layout, clear structure, perfect function, and smooth convergence will be built and the transport capacity will meet the needs of the national economic and social development, and the main technical equipment reach or close to the international advanced level. The focus is to project the “four vertical and four horizontal” and the intercity passenger transport system in economically developed and densely populated areas. The “four vertical” passenger dedicated line includes Beijing Shanghai passenger dedicated line, including Bengbu to Hefei, Nanjing to Hangzhou passenger line, through the Beijing Tianjin to the Yangtze River Delta and the eastern coastal economically developed areas, Beijing–Wuhan–Shenzhen–Guangzhou passenger dedicated line, connecting the northern and the Southern China area, Beijing–Shenyang–Harbin (Dalian) railway passenger dedicated line, including Jinzhou to Yingkou passenger line and Hangzhou–Ningbo–Fuzhou–Shenzhen passenger dedicated line, connecting the Yangtze River, the Pearl River Delta, and the southeast coastal areas. The “Four horizontal” passenger dedicated line includes Zhengzhou Xuzhou to Lanzhou passenger dedicated line, connecting the northwest and East China, Nanchang–Changsha–Guiyang–Kunming passenger dedicated line, connecting the southwest, central China and East China, Shijiazhuang Qingdao to Taiyuan passenger dedicated line, connecting the north and East China and Nanjing Chongqing Wuhan to Chengdu passenger dedicated line, connecting the southwest and East China. At the same time, the construction of Jiujiang–Nanchang, Liuzhou–Nanning, Mianyang–Chengdu–Leshan, Harbin–Qigihar, Harbin–Mudanjiang, Changchun–Jilin, Shenyang–Dandong, and other passenger lines are carrying on with the purpose to expand the coverage of passenger dedicated line. In the ring Bohai Sea, Yangtze River Delta, Pearl River Delta, Zhuzhou and Xiangtan, as well as the Chengdu Chongqing and the urban agglomeration in the Central Plains, Wuhan city circle, Guanzhong Urban Group, on the west side of the Straits of urban group economically developed and densely populated areas in the construction of intercity passenger transport system, covering major cities and towns in the region. According to the medium- and long-term railway network plan, through the construction of Beijing–Shenyang, Shangqiu–Hangzhou–Beijing, Nanchang–Ganzhou railway passenger dedicated line and Beijing–Shanghai, Beijing–Guangzhou, Beijing–Haerbin, coastal, Longhai, Shangha–Kunming, Shanghai–Wuhan–Chengdu as the backbone, we built the “four vertical and four horizontal” high-speed rail network, while supporting the construction Guiguang, HeFu, and other high-speed rail line extension and further form the China’s high-speed rail network with rich tentacles, high network access, and strong capacity.

On August 1, 2008, China’s first full independent intellectual property rights, the world’s first class level of high-speed railway Beijing Tianjin intercity railway traffic was put into operation.

On December 26, 2009, the longest railway built in one time and with the most complex engineering type in the world, Wuhan–Guangzhou high-speed railway, was put into operation with speed of 305 km/h.

On February 6, 2010, the world's first high-speed railway built in the wet Subsidence Loess Area, Zhengzhou–Xi'an high-speed railway connecting the central and Western of China with speed of 350 km/h, was put into use.

On June 30, 2011, the longest railway built in one time in the world, Beijing–Shanghai high-speed railway, was put into use. The length of this high-speed railway is 1318 km and connects the most two developed areas of eastern China, Beijing and Shanghai. The designed speed is 350 km/h and the initial operating speed is 300 km/h. In December 3, 2010, a new generation of "harmony" EMU CRH380AL in the Beijing–Shanghai high-speed railway from Bengbu to Zaozhuang creates a new record speed with 486.1 km/h in the test section.

On December 1, 2012, the world's first high-speed rail line in the cold region, Harbin–Dalian high-speed railway, was put into use. The length of this high-speed railway is 921 km and connects the main cities in the northeast of China. As a result, it will only cost 4 h and 40 min from Harbin to Dalian in the winter.

On December 26, 2012, the full line of Beijing–Guangzhou high-speed railway line was put into use. Beijing–Guangzhou high-speed railway passes through Beijing, Hebei, Henan, Hubei, Hunan, and Guangdong with length of 2298 km, which is the longest operating mileage of high-speed railway in the world. The designed speed is 350 km/h and the initial operating speed is 300 km/h.

By the end of 2014, Qinhuangdao–Shenyang railway, the Beijing–Tianjin intercity railway, Shijiazhuang–Taiyuan passenger dedicated line, Hangzhou–Shenzhen railway, Beijing–Guangzhou high-speed railway, Chengguan railway, Pipeng railway, Shanghai–Nanjing high-speed railway, Changjiu intercity railway, Hainan East Ring railway, Guangzhou–Zhuhai intercity lines, Changchun–Jilin intercity line, Beijing–Shanghai high-speed railway, Hefei–Bengbu high-speed railway, Shenyang–Dalian high-speed railway, Ningbo–Hnagzhou high-speed railway, the Tianjin–Qinhuangdao high-speed railway, Panying high-speed railway, Liunan dedicated passenger railway, Wuhan–Xianning intercity line and Shanghai–Hankou railway, Shanghai–Hangzhou section of Shanghai–Kunming high-speed railway, Guangzhou–Shenzhen section of Guangzhou–Shenzhen–Hong Kong Express railway, Shenyang–Harbin section of Beijing–Harbin high-speed railway, Zhengzhou–Xi'an section and Xi'an–Baoji section of Xuzhou–Lanzhou high-speed railway, HeNing section and HanYi section of NingRong high-speed railway, LiangYu section of HuRong high-speed railway, and GenWu section of NanGuang high-speed railway were all put into use.

By 2015, a number of new high-speed railways are put into operation, such as, Hefei–Fuzhou high-speed railway, Shenyang–Dandong high-speed railway, Jilin–Huichun high-speed railway, and Chengdu–Chongqing high-speed railway. The total operating mileage of China's high-speed railway comes to 1.9 million kilometers. After more than 10 years of unremitting efforts, with technical innovation, China's high-speed rail has made a series of significant breakthroughs in many technical fields, such as, high-speed trains, communication signals processing, traction power supply, operation management, security monitoring, and system integration. As a result, a high-speed railway technology system with Chinese characteristics and the overall level of technology reaching the world's advanced ranks is formed.

1.3 The Active Role of Mobile Communications for Railway

Along with the continuous development of modern railway transportation, higher and higher requirements for the wireless communication system are raised. Mobile communication system is crucial for the high-speed railway. Currently, application services such as train dispatching command, CTCS-3 level train operation control information, train dispatching order, radio train number check information, as well as dynamic monitoring information of signaling equipment are supported by the Global System of Mobile communication for Railways (GSM-R).

Due to the development of fourth-generation mobile communication technologies, high-speed railway broadband mobile communication system (LTE-R) should not be viewed merely as a GSM-R substitute, but also it can supply high-speed information transmitting channels for automatic train operation, train security video surveillance, train state monitoring and remote fault diagnostics, infrastructure wireless monitoring, emergency business disposal and passenger information service, and so on. LTE-R turns to be the information platform for the Internet of Things for railways, and also the basis of security assurance for high-speed railway operation.

(1) Dispatching Command and Safety Production

As the renewal and replacement of train dispatching radio communication system, railway mobile communication system is designed to support kinds of mobile voice communications, for instance, section business movement, emergency rescue, shunting marshaling operations, station yard wireless communication, and so forth.

Meanwhile, the requirements for mobile and fixed wireless data transmission, for example, radio train number transmission, train rear end air pressure, locomotive state information, train axle temperature detection, line bridge and tunnel monitoring, railway power supply status monitoring, crossing protection, and the like need to be addressed in LTE-R.

Safety information distribution and pre-alarm system takes mobile train as the main part, which ensures the construction wayside along rail tracks, the track maintenance, and the safety of both equipment and staffs in level crossing, train or station, thus reducing accidents.

(2) Train Operation Control Safety Protection

Railway mobile communication delivers the train-to-infrastructure security data transmission in CTCS-3 level train operation control system, providing a real-time transparent duplex transmission channel for the train control system, ensuring train secure operation at a high speed. Simultaneously, the railway mobile communication system is also capable of carrying safety data transmission of locomotive synchronization operation control, guaranteeing synchronization operation between heavy haul railway multi-locomotives, and improving operation efficiency.

(3) Railway Informatization

Passengers are viewed as the principal part of mobile information service system, which requires on-board ticketing services, mobile e-commerce and passenger mobile value-added services, and the like.

Railway network moving bodies such as locomotives, trains, and containers demand real-time dynamic tracking information transmission, to supply mobile transmission channels for real-time online information query and various management information systems. Obviously, railway informatization is an inevitable choice.

(4) Railway Mobile Internet

Railway Mobile Internet is considered as an integral part of "'the Internet plus 'railway'" strategy, whose development will contribute to accelerate the depth integration in the field of Internet and railway, to facilitate technological progress and efficiency promotion as well as organization reform of railway transportation, to promote the innovation and production on the railway sector, and to improve resource utilization efficiency and fine management level significantly.

In the complicated and rapidly changing railway environment, in order to achieve some advanced functions of large-scale high-speed railway network, such as train running status enquire, railway essential factors online level improvement, and train secure operation control, the next generation of railway mobile communication system with characteristics of large bandwidth, high real time, and high reliability comes to be an indispensable foundation.

1.4 GSM for Railway

Global System for Mobile Communications for Railway (GSM-R, GSM for Railway) is a communication system based on GSM technology, which strengthens the railway dispatching communication and is used in high-speed mobile environment. The China railway's overall goal of developing mobile communication network is to establish a comprehensive mobile communication platform for voice and data, and to build an integrated communication system with dispatching communication, train control, public mobile, and information transmission.

Railway digital mobile communication network construction is a systematic project, and closely related to railway dispatching communication, train control, and operation management. It should make full use of mobile communication technology, combine with the actual needs for railway transportation, and form a covering system-wide railway mobile communication network to provide a mobile integrated communication platform for railway transportation.

1.4.1 The Development of GSM-R

GSM-R is introduced from European railway special mobile communication system based on GSM technology, which adds the railway dispatching communication service and the high-speed railway mobility. GSM-R is an integrated economic and efficient railway wireless communication system. The development of GSM-R has experienced three stages, namely the standard formulation stage, the experimental verification stage, and the project implementation stage.

1.4.1.1 The Standard Formulation Stage

In 1992, the International Union of Railways (UIC) thought that GSM is gradually becoming the applicable standard of mobile communication, and found that the GSM technology can provide an ideal platform for new railway mobile digital communication system. Through the feasibility study, in 1993, the European railway decided to introduce the GSM technology as the foundation of the next-generation railway mobile communication system, which is GSM-R system. After that, UIC set the relevant standards and test, set up a standardized organization EIRENE, formulated a series of railway requirements specification, and designed indicators such as business functions, quality of service, and electromagnetic environment. At the same time, the continuous updating of GSM technology has laid a solid foundation for the GSM-R development.

1.4.1.2 The Experimental Verification Stage

To verify the reliability, mobility, and compatibility of GSM-R system, UIC set up another specialized organization MORANE, including railway operators, equipment manufacturers, and research institutions, which focused on the properties verification of GSM-R high-speed environment. From 1997 to 2000, the GSM-R system has been strictly tested and validated on high-speed railway in France, Italy, and Germany, respectively.

1.4.1.3 The Project Implementation Stage

Since 1999, some countries in Europe started operation test and commercial construction of GSM-R network.

Sweden is the first country to formally use the GSM-R network. In 1999, the first GSM-R network was built and put into use in Oresund Bridge from Sweden to Denmark.

From 2001 to 2004, Germany implemented the first-stage construction. From 2005 to 2007, the second stage was implemented. ETCS-2 system was tested on railway from Berlin to Leipzig. It completed debugging in 2005 and achieved commercial in 2006.

From 2002 to 2003, Italy took the test on the ETCS-2 system and the public GSM. From 2002 to 2005, the first stage was implemented.

From 2003 to 2008, France completed the basic construction.

Finland, Norway, Britain, Belgium, and Spain have successively carried out the nationwide GSM-R network construction.

1.4.2 GSM-R Key Technology and Engineering Measures

1.4.2.1 GSM-R Wireless Network

GSM-R is a mobile communication system for high-speed railway, which includes dispatching communication and train control information, and requires high quality of network service and maintenance. GSM-R wireless network optimization can draw lessons from mature GSM technology. However, GSM system is public communication services whose planning is limited in low speed and non-security. GSM-R system requires high-speed and reliable mobile communication business for railway communication.

The Main Differences Between GSM-R and GSM Wireless Networks

(1) Different frequency resources

GSM-R has only 4 MHz frequency bandwidth less than the public frequency resources, which face more limitation in the frequency planning. It should avoid the common frequency and adjacent frequency interference in the GSM-R network planning and optimization.

(2) Different covering ways

The public GSM mainly adopts planar network structure, while the GSM-R network is covered by the linear network structure.

GSM-R Wireless Network Reliability

GSM-R is related to safety and operational efficiency. Therefore, the reliability of GSM-R wireless network is higher than the public GSM network. In order to improve the reliability and maintainability of GSM-R wireless network, the corresponding measures have been taken in the railway above the speed of 300 km per h, plateau railway and heavy haul railway. The section with the speed above 300 km/h of Beijing–Shanghai high-speed railway adopt dual interleaving coverage as redundancy protection way. Qinghai–Tibet Railway and Daqin Railway employ co-site double base station.

1.4.2.2 GSM-R Core Network

GSM-R network is mainly used for special railway mobile communications business such as dispatching communication and the train control information. In the operation stage, the reliability and maintainability of GSM-R network have higher requirements than public GSM network. GSM-R core network should be provided 7×24 h of uninterrupted service, even if the planned downtime will also bring a lot of interference to the train operation and train operation organization. According to the maintenance requirements, GSM core network can interrupt service in less traffic period. In order to ensure the safe and reliable operation of the GSM-R core network, the following technical measures are usually adopted.

Equipment Protection Technology

Reliable and stable operation of the equipment is the basis of GSM-R core network business continuity. GSM-R core network devices include a circuit domain equipment (MSC, HLR, SCP, etc.) and packet domain equipment (SGSN, GGSN, etc.). It should prove functionality and performance of equipment panel, optimize implementation way, take into account the cost of project, and select the redundancy scheme (usually with 1:1, n: 1 or standby panel, etc.)

Network Protection Technology

(1) System-wide GSM-R core network public equipments in Beijing and Wuhan are host and backup for each other.

Beijing and Wuhan are respectively arranged system-wide railway GSM-R sharing equipment, such as GSM-R railway core switchboard, service control point (SCP), home location register (HLR), remote access authentication server (RADIUS), the domain name server (DNS), and GPRS home server (GROS). When the main device nodes have obstacles, standby nodes can quickly take control of all or part of the system-wide GSM-R sharing business.

(2) The railway administration has GSM-R switches. If there is breakdown, the impact will be controlled.
(3) GSM-R network employs multi-link protection. Each MSC interconnects at least with the two other MSCs. The voice relay between MSCs has at least two E1 circuits and utilizes different route transmission circuits. The packet domain also uses a reliable data link to duplex interconnect.
(4) The base station controller (BSC) arranged in the sub-line and the long line controls the influence of the BSC malfunction within coverage of the base station.
(5) GSM-R network adopts dual relay interconnection with Fixed users Access Switching (FAS).

Through the above measures, the risk of GSM-R network can be reduced. The business impact can also be controlled.

1.4.2.3 GSM-R Matching Equipment Technology

The GSM-R business is implemented by network and terminal matching equipment. The GSM-R system is introduced from European standard. Due to the different dispatching communication and related equipment standard configuration, the terminal supporting technical scheme becomes the main problem after the introduction of network equipment. At present, China's railway is mainly equipped with locomotive integrated wireless communication equipment (CIR), GSM-R handheld terminal, etc. CTCS-3 class train control equipment, DMS (train control equipment dynamic monitoring system) of signal specialty, is equipped with GSM-R SIM card. The terminal used by passenger transport train conductor is also equipped with a GSM-R SIM card. With the development of the business, the terminal will also be diversified and embedded.

1.4.2.4 GSM-R Project Implementation

GSM-R project implementation includes networking scheme, numbering plan, network parameter settings, joint debugging, project acceptance, etc. Clear and detailed design of the project various stages is the basis for the project smooth implementation. GSM-R system numbering scheme is derived from the European standard. The actual project numbering scheme is directly related to operation management and GSM-R business, which is the key to the GSM-R project implementation.

1.4.2.5 GSM-R Business and Implementation

GSM-R system is a railway mobile communication network, which is a platform of railway mobile communication service. The typical services are as follows:

(1) voice business: point-to-point voice call, voice group call, voice broadcast, multiparty communication, etc.

(2) data services: circuit and data service, packet domain data service.

railway-specific business: functional addressing, location-dependent addressing, railway emergency call, etc.

1.5 Next-Generation Mobile Communication System for Railway

Mobile communication system is one of the key infrastructures of high-speed railway carrying various services such as the railway dispatching command, trains run control, fault warning and danger notices, emergency rescue, etc. In order to further guarantee the safety and high efficiency of high-speed rail network as well as achieve convenient, comfortable and green transportation, new railway mobile communication services are constantly emerging, such as railway multimedia scheduling command communication, remote video monitoring, railway infrastructure monitoring, railway Internet of Things (LoT), station-yard wireless communication, mobile ticketing, tourist information services, etc. However, the service-carrying capacity of current railway mobile communication (GSM-R) is limited and cannot satisfy the demand of the new high-speed railway mobile communication services. At the same time, along with the rapid development of mobile communication technology and industry, the size of the GSM market shrinks, which forms a strong impact on the GSM-R industrial chain. Therefore, development of the next-generation mobile communication system for railway, realization of railway mobile communication system upgrading, and meeting the needs of new services development have become an irresistible trend.

Chinese railway mobile communication system has experienced from the first-generation simulation wireless railway dispatching system to the second-generation digital mobile communication system for railway (GSM-R) development. The GSM-R system is constructed in Qinghai–Tibet railway, heavy haul railway, high-speed railway, and passenger dedicated line. The railway communication equipment running status shows that simulation wireless railway dispatching system of 70,000 km common railway needs to be upgraded. According to the railway communications industry forecasts, GSM-R system life cycle will end up around 2020. Railway mobile communication system is faced with urgent industrial upgrading; moreover, evolution from narrowband to broadband has become the trend of the times. China Railway Corporation has made decisions of developing the third generation of broadband mobile communication systems (LTE-R), made the technology roadmap, and proposed the upgrade the transition scheme.

With continuous development of railway application, the railway application system gives more requirements of the next-generation communication system needs which are quite different from those in GSM-R network times, in terms of carrying service type and bandwidth requirements.

International Union of Railways (UIC) divides railway demands into two major categories of operating communication and support communication. According to the present status and development plan for Chinese railways, combined with the divided standards of UIC, we classify the next-generation mobile communication services of Chinese railway from multiple dimensions:

(1) Considering railway maintenance management system and the current professional business requirements in our country, based on UIC division of railway demands, it can be divided into driving-related service and passenger information service in accordance with the service attribute.
(2) According to the service types, it can be divided into voice service, data service, image service, and video service (Table 1.2).

Table 1.2 Next-generation mobile communication for railway service classification according to service attribute

Number	Service attribute	Service name
1	Driving-related service	Train control information
2		Locomotive synchronization control
3		Controllable train tail information
4		Dispatching command
5		Train wireless train number check
6		Train tail information
7		Dispatching communication
8		Operation and maintenance communication
9		Train safety warning
10		Train control equipment dynamic monitoring
11		Railway freight information system(transportation, equipment management)
12		Railway freight information system(railway freight car status information)
13		Chinese locomotive remote Monitoring and Diagnosis system(CMB)
14		Train coach running diagnosis system (TCDS)
15		Train working condition monitoring
16		High-speed railway power supply safety monitoring system (6c)
17		Maintenance and repair work card control system
18		Maintenance video monitoring system
19		Communications equipment monitoring system
20		Train security video monitoring
21		Infrastructure health management system
22		Disaster monitoring system
23		Rail gap video monitor system
24		Marshaling station wireless communication

(continued)

Table 1.2 (continued)

Number	Service attribute	Service name
1	Passenger information service	Passenger transportation management information system (voice, data, image, video)
2		Public security communication
3		Mobile ticketing
4		Passenger information system (PIS)

Next-generation mobile communication system LTE-R should have the following features: (1) support the mobility of up to 500 km/h, ensure reliable switching and service quality; (2) carry safety-related services such as train control and dispatching command, require network redundancy backup and overlapping field strength coverage; (3) limited frequency resource, need to use low-frequency carrier frequency aggregation; (4) due to carrying variety of services such as load remote video monitoring, railway infrastructure monitoring, uplink volume is greater than the downlink volume; (5) fast, reliable, traceability, and multi-priority voice group call, voice broadcast and emergency calls; (6) based on position addressing and functional addressing, call limitation based on the location, access matrix based on function, and other special services; (7) differentiated quality of service (QoS) requirements; (8) special networking methods: adopt the chain network along the railway, regional coverage, adopt a combination of chain and face shape in station-yard area; and (9) strict safety management system: LTE-R system should support the ease of use and traceability required by railway operation management system and safety responsibility cognizance.

In order to carry out the research in the next-generation mobile communication system for railway, China Railway Corporation established a specialized working group. Specific organizational structure is as follows:

References

1. http://www.nra.gov.cn/fwyd/hyjc/gcjs2/952/201311/t20131126_3181.html
2. http://www.nra.gov.cn/fwyd/hyjc/gcjs2/952/201311/t20131126_3180.html
3. http://www.nra.gov.cn/fwyd/hyjc/gcjs2/952/201312/t20131214_3637.html
4. http://www.nra.gov.cn/fwyd/hyjc/gcjs2/952/201403/t20140307_5400.html
5. http://www.nra.gov.cn/fwyd/hyjc/gcjs2/952/201503/t20150306_12658.html
6. http://www.nra.gov.cn/fwyd/hyjc/gcjs2/952/201602/t20160203_20922.html
7. http://www.nra.gov.cn/fwyd/hyjc/gstl_/zggstL/201602/t20160215_21046.html
8. http://www.nra.gov.cn/fwyd/hyjc/gstl_/zggstL/gstllc/201602/t20160216_21067.html
9. Zhong Z, Li X, Jiang W (2007) Railway comprehensive digital mobile communication system. China Railway Publishing House, Aug-Sep
10. Hofestadt H (1995) GSM-R: global system for mobile radio communications for railways. In: International conference on electric railways in a United Europe. IET, 1995, pp 111–115
11. Sniady A, Soler J (2012) An overview of GSM-R technology and its shortcomings. In: 2012 12th international conference on ITS telecommunications (ITST). IEEE, 2012, pp 626–629
12. He R, Zhong Z, Ai B et al (2014) A standardized path loss model for the GSM-railway based high-speed railway communication systems. In: 2014 IEEE 79th vehicular technology conference (VTC Spring). IEEE, 2014, pp 1–5
13. Zhao L, Chen X, Ding J (2010) Interference clearance process of GSM-R network in China. In: 2010 2nd international conference on mechanical and electronics engineering (ICMEE). IEEE, 2010, pp V1-424–V1-428
14. Xun D, Xin C, Wenyi J (2010) The analysis of GSM-R redundant network and reliability models on high-speed railway. In: 2010 International conference on electronics and information engineering (ICEIE). IEEE, 2010, pp V2-154–V2-158
15. Jie S, Xiaojin Z, Tingting G (2010) Performance analysis of GSM-R network structure in China train control system. In: 2010 International conference on electronics and information engineering (ICEIE). IEEE, 2010, pp V2-214–V2-218
16. Briso C, Cortes C, Arques FJ et al (2002) Requirements of GSM technology for the control of high speed trains. In: The 13th IEEE international symposium on personal, indoor and mobile radio communications. IEEE, 2002, pp 792–793
17. Ning B, Tang T, Gao Z et al (2006) Intelligent railway systems in China. IEEE Intell Syst 21 (5):80–83
18. Matolak DW, Berbineau M, Michelson DG et al (2015) Future railway communications. IEEE Commun Mag 53(10):60–61
19. Bertout A, Bernard E (2012) Next generation of railways and metros wireless communication systems. ASPECT, Institution of Railways Signal Engineers
20. Ai B, Cheng X, Kürner T et al (2014) Challenges toward wireless communications for high-speed railway. IEEE Trans Intell Transp Syst 15(5):2143–2158
21. Ai B, Guan K, Rupp M et al (2015) Future railway services-oriented mobile communications network. IEEE Commun Mag 53(10):78–85
22. Tingting G, Bin S (2010) A high-speed railway mobile communication system based on LTE. In: 2010 International conference on electronics and information engineering (ICEIE), vol 1. IEEE, V1-414–V1-417
23. Dong H, Ning B, Cai B et al (2010) Automatic train control system development and simulation for high-speed railways. IEEE Circuits Syst Mag 10(2):6–18
24. Kim RY, Kwak JS, Hwang HC (2012) Technical challenges of railroad communications using long term evolution. In: 2012 International conference on ICT convergence (ICTC). IEEE, pp 563–564
25. Briso-Rodríguez C, Lopez CF, Fernandez JRO et al (2014) Broadband access in complex environments: LTE on railway. IEICE Trans Commun 97(8):1514–1527

Chapter 2
Key Issues for GSM-R and LTE-R

2.1 GSM-R Architecture

2.1.1 GSM-R Network Composition

GSM-R network consists of GSM-R digital mobile communication system (GSM-R system) and trunk transmission circuit.

GSM-R system contains four parts, which are network subsystem(NSS), base station subsystem(BSS), operation and support subsystem(OSS), and terminal device. Network subsystem includes mobile switching subsystem (SSS), mobile intelligent network (IN) subsystem, and general packet radio service subsystem. Fig. 2.1 shows the system structure of GSM-R and main interfaces.

2.1.2 Mobile Switching Subsystem

SSS mainly has several functions as follows: user service switching function, and user data and mobility management, and security management database functions as needed. SSS consists of a series of function entities, including MSC, HLR, and VLR. Mutual communication between the various functional entities by No.7 signaling protocol, each functional entity, is as follows:

a. Mobile Service Switching Center(MSC)
   MSC, as the core of the network, is in charge of mobility management and call control. Gateway MSC (GMSC) is a gateway office between GSM-R network and other communication networks.
b. Visitor Location Register(VLR)
   VLR, as a dynamic database, is responsible for storing the information of registered users, which have come into the control area, and to provide the necessary data call connection for mobile users. When the MS roams to a new

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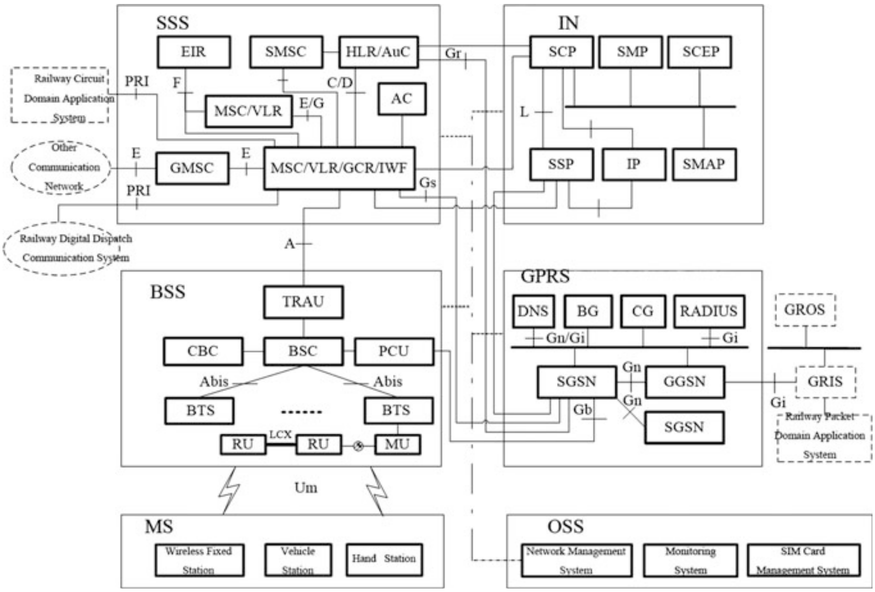

Fig. 2.1 GSM-R system structure

VLR area, the HLR initiates location registration to the VLR, and obtains the necessary user data; when the MS roams out of control, it needs to delete the user data. The VLR stores the ID list, which belongs to the user groups. When users roam, these information can be obtained by the home location register (HLR).

c. Home Location Register (HLR)
HLR is the mutual device for the CS domain and the PS domain, and it is also a database for mobile user management. HLR stores all the mobile user data in this area, such as the identification sign, the location information, the signing service, etc. When a user is roaming, HLR receives a new location information, and requires the former VLR to delete all user data. HLR provides routing information when the user is called.

d. Authentication Center (AuC)
AuC is the mutual device for the CS domain and the PS domain, which stores user authentication algorithm and encryption key entities. By HLR, AuC sends authentication and encryption data to the VLR, MSC, and SGSN, to ensure the legality and safety of communication. Each AuC and the corresponding HLR are matched, only passing the HLR and other network entities to communicate.

e. Interworking Functional Unit (IWF)
IWF is in charge of offering transformation of rates and protocols between GSM-R network and fixed-network data terminals. Its function depends on the interconnect services and the network structure.

f. Group Call Register (GCR)
GCR is used for storing the group ID of mobile users, and the mobile station makes use of voice group call service (VGCS), as well as voice broadcast service (VBS) calls the cell message. Besides, it should check whether the MSC, which starts to call, is charge of dealing with.
g. Short Message Service Center (SMSC)
SMSC is in charge of sending short message to MSC.
h. Acknowledge Center (AC)
AC is used for recording and storing relative information, which is about railway emergency call.
i. Equipment Identity Register (EIR)
EIR contains one or more databases, which can store IMEIs. These IMEIs can be classified as white list, black list, and gray list. According to the IMEI of the users, the network decides whether it will offer services for users.

2.1.3 Mobile Intelligent Network Subsystem

IN subsystem is the intelligent network functional entity, which is introduced into SSS. It separates the network switching function and the service control function, and realizes the intelligent control of the call.

GSM-R intelligent network consists of GSM service switching point (gsmSSP), GPRS service switching point (gprsSSP), intelligent peripheral (IP), service control point (SCP), service management point (SMP), service management access point (SMAP), and service context entering point (SCEP).

a. GSM Service Switching Point (gsmSSP)
As the interface between the MSc and SCP, gsmSSP has the function of service switching. gsmSSP can detect GSM-R intelligent services request, and it communicates with the SCP, requests the SCP response, also allows the service logic in the SCP affects call processing.
b. GPRS Service Switching Point (gprsSSP)
gprsSSP possesses the function of service switching. As the interface between the SGSN and SCP, it can detect GPRS intelligent service request. It communicates with the SCP, requests the SCP response, also allows the service logic in the SCP affects call processing.
c. Service Control Point (SCP)
SCP has the service control function, which contains the service logic of GSM-R intelligent network. Through the instructions issued by the SSP, it can complete the control of connecting and charging for intelligent network services, in order to achieve a certain part of the railway services. Meanwhile, it also has the function of service data, user data, and network data included, to provide the service control function in the implementation of GSM-R intelligent network service real-time extraction.