

## 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

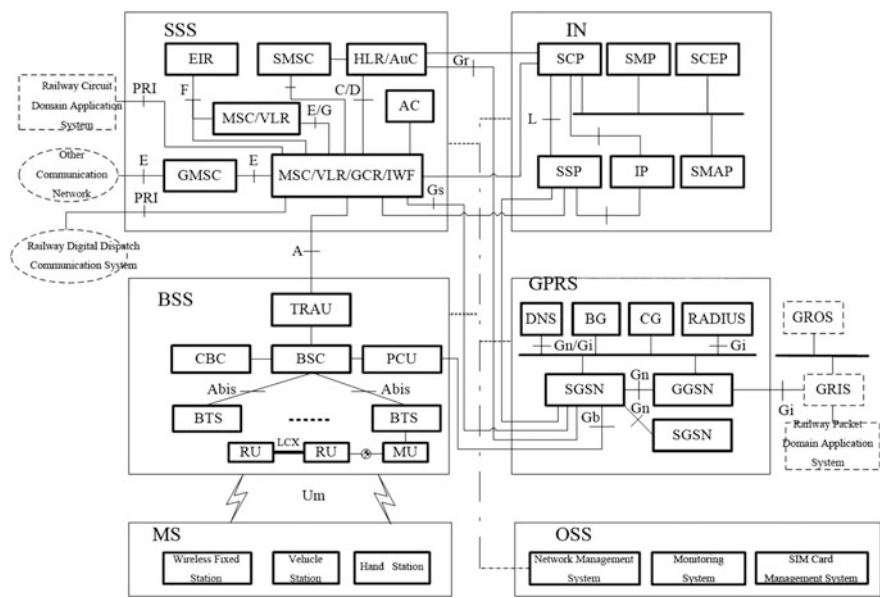


Fig. 2.1 GSM-R system structure

- 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 in 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.

d. Intelligent Peripheral (IP)

Under the control of SCP, IP offers a variety of specialized resources according to the corresponding service logical program. And these resources contain the receiver of DTMF, signal generator, record notice, etc.

e. Service Management Point (SMP)

SMP can deploy and offer GSM-R intelligent network services. It has the management of the SCP service logic. Besides, the addition, deletion, and modification of the user service data are included. It can also manage and modify some related information of SSP.

f. Service Management Access Point (SMAP)

SMAP has the function of service-managed access, and it can access to SMP for service manager. Besides, the SMAP can modify, add, and delete users' data and service performance by SMP.

g. Service Context Entering Point (SCEP).

SCEP is used for developing and producing GSM network intelligent service first, after that, it tests and verifies these services. Third, service logic, management logic, and service data, which are verified and are of intelligent service, should be input into SMP.

## ***2.1.4 General Packet Radio Service (GPRS) Subsystem***

GPRS subsystem is responsible for providing packet-based traffic service for wireless users. It includes core layer and wireless access layer.

The core layer consists of several functional entities, such as SGSN、GGSN、DNS、RADIUS, etc.

The wireless access layer consists of PCU, base station, and terminal.

GPRS wireless access layer network should make full use of the equipment resources of GSM-R system, to protect investment; and it shares frequency resources of GSM-R system. Also, it uses the base station of GSM-R system to achieve wireless coverage, rather than increasing the GPRS system base station.

a. Service GPRS Support Node (SGSN)

SGSN is the GPRS support node of MS service, and it can achieve mobility management and route searching.

b. Gateway GPRS Support Node (GGSN)

GGSN is the gateway between GPRS network and extra data network. It achieves router selection, transformation into extra network protocol.

c. Domain Name Server (DNS)

DNS is responsible for providing the domain name resolution functions for GPRS network internal SGSN, GGSN, and other network nodes.

d. RADIUS Service (RADIUS)

RADIUS is responsible for the storage of user identity information, and completes the user's identification and authentication.

e. Packet Control Unit (PCU)

PCU is charge of the data packet, wireless channel management, error detection, and automatic retransmission.

f. Border Gateway (BG)

BG is used for interconnecting with different GPRS networks. It has basic security function; besides, it can add some related functions according to roaming protocol of different networks.

g. Charge Gateway (CG)

CG can collect the ticket record of every GPRS support node, and also, it can store, back up, and merge the ticket, and then, transfers these ticket records to charge center.

h. GPRS Network Interface Equipment

GPRS home server (GROS) is responsible for the implementation of GPRS GSM-R terminal (GPRS terminal for short) to check the current IP GRIS/M-GRIS address.

GPRS interface server (GRIS) is responsible for the implementation of data forwarding, protocol conversion between GPRS terminal, and railway application system.

### ***2.1.5 Base Station Subsystem***

Through wireless interface, the BSS directly connects with the mobile station, which is responsible for the wireless signal receiving and transmitting and radio resource management. Besides, it connects with the MSC, to realize the communication between mobile users or mobile users along with fixed network, and to transmit system signal and user information.

BSS consists of the following part:the base station controller (BSC), the transcoder/rate adaptor unit (TRAU), the cell broadcast center (CBC), the base transceive station (BTS), the weak field devices, and other functional entities.

a. Base Station Controller (BSC)

BSC is the control part of BSS, which is responsible for the management of all kinds of interfaces, the management of the radio resources and wireless parameters, the signal processing of the call establishment, and the channel assignment in the cell.

b. Transcoder/Rate Adaptor Unit (TRAU)

TRAU is responsible for providing voice coding and rate adaptation functions between BSC and MSC, and it converts the 16kbit/s voice or data into 64kbit/s data.

c. Cell Broadcast Center (CBC)

CBC is responsible for managing the cell broadcasting message service.

d. Base Transceiver Station (BTS)

BTS is the wireless receiving/transmitting device, which is controlled by the BSC and served for some cell, to complete the transformation between BSC and wireless channel. Also, it can realize the wireless transmission along with the related control functions between BSC and MS by the air interface. BTS has the rate matching, channel coding/decoding, modulation/demodulation, and other air interface physical layer functions.

e. Relay Transmission Equipment

Relay transmission device is used for the wireless coverage of GSM-R weak electric field area, including repeater station, trunk amplifier, leaky coaxial cable, antenna, and so on.

### ***2.1.6 Operation and Support Subsystem (OSS)***

OSS includes network equipment maintenance management system (“network management system” for short) and user management system.

a. Network Management System

It provides the interface of the system devices for the operator, and collects and monitors the operation information and status of the whole network. Besides, it can produce system operation report according to the requirement of the operators, to provide the basis for network planning and adjustment. The basis contains operation and maintenance center (OMC) and network management center (NMC), and so on.

According to the subject, the system can be divided into the exchange, grouping, intelligent network, wireless (including the base station and the weak field equipment), and other network management system.

b. Monitoring System

- Interface monitoring system, including different interfaces: the Abis, A, PRI, Gb, Gn, and Gi, along with C, D, E, G, L, and No.7 signaling monitoring interface subsystem, comprehensive analysis, gateway, and network subsystems. It consists of collecting equipment, data processing equipment, a comprehensive analysis of the server, and the client; the main functions include acquisition, storage signaling and user data; parsing the raw signal and service data; real-time monitoring and display, information query, reporting capabilities and comprehensive analysis; and so on.
- Other monitoring system can monitor the leaky cable, antenna, and tower, including on-site monitoring equipment and monitoring center equipment.

c. SIM Card Management System

It is responsible for managing the related data of the network user, offering many operating functions shown as follows: opening account, deleting account,

and changing the authority of user service, to support the usual operation of service.

SIM card management system includes an application server, database server, data storage device, SIM card management terminal, SIM card maintenance terminal, gateway interface, SIM card-making terminal, SIM card reader, and so on.

### **2.1.7 Terminal**

The terminal is a device which is used for direct operation and use of the GSM-R system, and is used for accessing the GSM-R network device, including a mobile station and a wireless fixed station.

#### **a. Mobile Station**

Mobile station includes (locomotive, automobile) car station, hand station, train control data transmission equipment, train rail information transmission device, disaster prevention detection information transmission, and vehicle safety detection information transmission terminal.

The terminal consists of mobile device and SIM card.

#### **b. Wireless Fixed Station**

Wireless fixed station is the wireless terminal for nonmobile state, and it has the same service function with mobile station.

## **2.2 GSM-R Network Hierarchical Structure**

### **2.2.1 Mobile Switching Network**

GSM-R network structure should meet the needs of railway traffic control. In order to make the network structure simple, clear, and easy to operate, maintain and manage, the whole network is divided into mobile service sink network and mobile service local network.

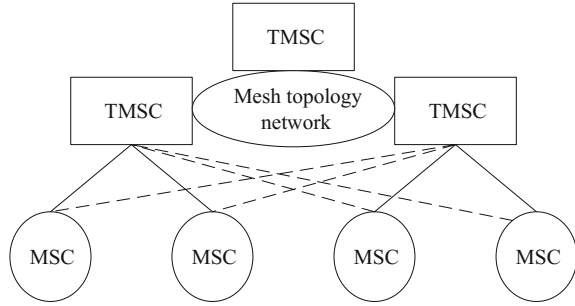
#### **a. Mobile Service Sink Network**

The mobile service sink network is composed of a tandem mobile switching center (TMSC) and a trunk line that connects with the nodes.

The railway should be divided into three areas, setting TMSC in the center of the biggest area. Each TMSC is responsible for a number of mobile switching centers (MSC). TMSC is responsible for the transfer of long-distance traffic between different MSCs in this area. It also collects the long-distance traffic of the MSC in the area to other TMSC.

The network structure among TMSCs is mesh topology.

**Fig. 2.2** The GSM-R network structure of the whole railway



#### b. Mobile Service Local Network

The whole railway establishes several mobile service local networks.

Mobile service local network contains MSC, GMSC, HLR, and other equipments. A few mobile services share a HLR local network.

In a local network, it should be set one or several MSCs, or using one MSC to cover several mobile service local networks according to the amount of services. MSC is responsible for dredging or handling the traffic between different mobile users (or between mobile users and fixed users).

MSC should be connected to the adjacent TMSCs. According to the requirement, different MSCs can be directly connected.

The GSM-R network structure is shown in Fig. 2.2.

### 2.2.2 Intelligent Network

GSM-R intelligent network, based on the ITU-T/3GPP intelligent network, uses the CAMEL3 protocol standard in order to achieve some of the railway-specific services.

GSM-R intelligent network is composed of SSP, SCP, IP (intelligent peripherals), SMP, SMAP, and SCEP, as well as the link connecting these nodes. The network structure is shown in Fig. 2.3.

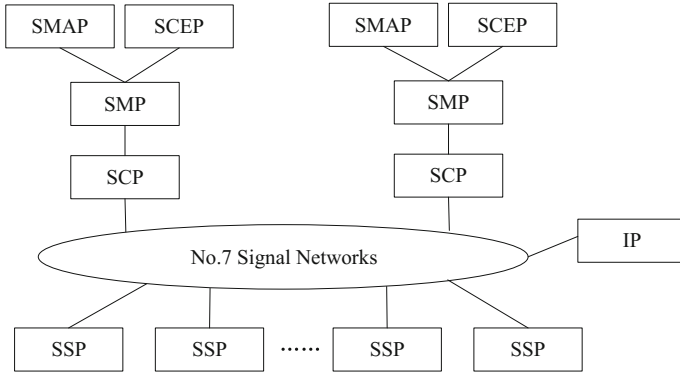
### 2.2.3 General Packet Radio Service Network

GPRS network should be divided into two levels: GPRS backbone network and GPRS local network.

#### a. GPRS backbone network

The GPRS backbone network is composed of backbone routers and data links which connect with the nodes, and it is responsible for forwarding the data





**Fig. 2.3** The GSM-R intelligent network structure

services between different local networks. GPRS backbone network should be divided into three major areas, and establish the backbone routers in the large areas. Network structure between backbone routers is mesh topology.

b. GPRS local network

- The railway sets several GPRS local networks. Local network consists of SGSN, GGSN and DNS, RADIUS server and other devices, as well as the local area network connected to these devices.
- GPRS local network should be set up by the same access and the edge router accesses to the corresponding backbone router. In order to ensure the reliability of the network, the edge router should be set up in pairs, and access to different backbone routers, respectively.
- According to the requirements, different local networks can be directly linked.

The GPRS network structure is shown in Fig. 2.4.

## 2.3 LTE-R Architecture

The Evolved Packet Core (EPC), the subsystem of core network, is composed of Mobile Management Entity (MME), Home Subscriber Server (HSS), Serving Gateway (S-GW), Packet Gateway (P-GW), Multimedia Broadcast Multicast Service Gateway (MBMS-GW), Broadcast Multicast Service Center (BM-SC), Multicell/multicast Coordination Entity (MCE), routers and other equipment. The key technology of trunking communication system was proposed in 3GPP LTE R13 according to the special demand of railway operation. In addition, the Mission-Critical Push To Talk (MCPTT) server network element was identified based on 3GPP R13 standard. The LTE-R system block diagram is shown in the figure below.

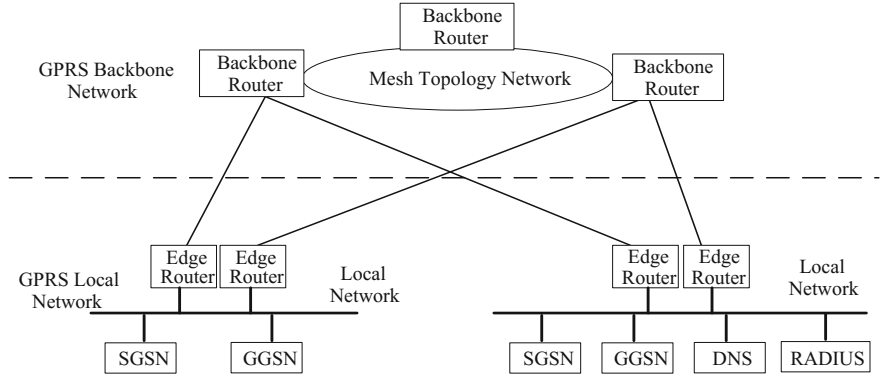


Fig. 2.4 The GSM-R network structure

**MME:** MME provides the necessary support for mobility management. Further functions include paging, security control, bearer control of core network, mobility control as idle mode UE. The MME is a key component of EPC, which is primarily responsible for control plane function related to user mobility and session management, and the main functions are as follows:

(1) Network Access Control (Fig. 2.5)

MME supports authentication and authorization for the UE. The authentication function manages whether to permit access request according to the usage of system resources. Safety management includes the following:

**Authentication:** MME realizes the mutual authentication and key agreement between network and UE through authentication function, in order to ensure the request of UE authorized in current network. Generally, the mobility management comes along with this function. International Mobile Subscriber Identification Number (IMSI), Globally Unique Temporary UE Identity (GUTI), and other identities are checked here.

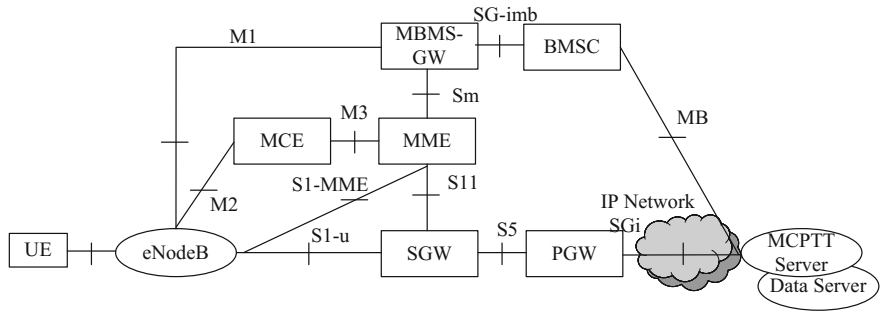


Fig. 2.5 LTE-R system block diagram

**GUTI allocation:**As a temporary user ID, GUTI protects the security of IMSI on the air interface. MME should assign the GUTI value after the first attachment to UE.

**UE identification:**User identification function is used to identify the effectivity. Equipment identification function is used to check the legality of the device.

**Send function under the security context of AS:**MME will contain AS security context in Initial Context Setup Request message for eNB. AS security context includes AS algorithm list and KSI, eNB will make choice of AS algorithm referring to the ability of the UE for realizing confidentiality and integrity protection of RRC signaling.

**Confidentiality and integrity protection of NAS signaling:**MME will add the list of NAS security algorithm, KSI and UE/MME selection security algorithm to UE NAS security mode command, and use the generated key to realize the NAS signaling confidentiality and integrity protection.

## (2) Mobility management

Periodically update registered UE timer whose value is issued by the MME. Once the UE periodic timer is timeout, UE initiates periodic tracking area update. If the UE is not under UE E-UTRAN coverage, periodic tracking area update would perform when it gets back to the coverage area.

Attachment, detachment, tracking area list management, tracking area list update, handover, paging, and other general mobility processes.

After the MME cancels UE, the MME can notify the HSS by clearing UE message, i.e., subscription data and mobility management context of the UE.

**Service request:** UE-initiated and network-initiated service request. UE establish a security connection between the networks through service requests. Network initiates service request for the network downlink data transmit and UE signaling interaction scenarios.

**Mobility restriction:** According to area restriction information and access restriction information in user subscription, the mobility restriction is made for user.

**Multiple PDN connectivity:** MME supports multiple PDN connections for the same UE. If UE simultaneously initiated more than one PDN connection with the same APN, multiple PDN connections are to be connected to the same P-GW.

**UE reachability:** MME received the reachability request from HSS, and then stored UE reachability request. When the UE sent reachability request has been arrived, MME sends the reachability notification to HSS.

## (3) Session management

It includes EPS bearer establishment, modification, and release;The access network side bearers establish and release;As interacting with the 2G/3G network, valid mapping between EPS bearer and the PDP context is performed.

#### (4) Network element Selection

**P-GW selection:** MME provides the channel using subscription information of users for assigning a P-GW for the 3GPP PDN connection.

**S-GW selection:** MME supports network topology to select an available S-GW for the UE.

**MME selection:** In the handover progress, based on the network topology, an available MME is selected for service UE.

**HSS:** HSS is a database for storing user subscription information; key functions include storing user subscription information, user authentication, and location information.

##### (1) User data storage and management

Storing its home user data, including user information, mainly IMSI, MSISDN, and IMEI/IMEISV, purged state identification, UE-AMBR, etc.; the ODB state identification, call blocking, roaming restriction; EPS APN contract information, the QOS contract data, PDN Type, etc.; location-related information, including MME identity, P-GW address, etc.; user charging related information; authentication information, including K; as well as user authentication algorithm ID.

For the non-3GPP access network, the HSS shall be able to store non-3GPP user data, the user data at least including a user information, mainly permanent user identity NAI, APN subscription information; roaming-related information, including the 3GPP AAA identification, P-GW identification, and so on; user subscription billing parameters; authentication information, including K, as well as user authentication algorithm identification; MIP contract information.

Corresponding operation management has been implemented based on the user subscription data, including accounts, sales households; user subscription data changes, including new and existing contracting business data; batch processing user data.

##### (2) User authentication

HSS provides a set or more sets of parameters to the MME according to the MME authentication request, and supports authentication-related processing. HSS and HLR equipment shared authentication center for the HSS supporting HLR function.

##### (3) Mobility Management

Store the MME addresses for current customer services, and storing the MME network capabilities related parameters.

With the location registration notification initiated by MME, HSS completes the user location registration and updates the current service MME address.

When the following conditions occur, HSS shall initiate the request of cancellation of the original MME and carry the associated write-off type: the user first attached network; the user moves to a new MME; the network enforces to change registration status or MME address of the user; the user is deleted; and so on.

As receipt of a request sent by the MME to clear the IE, HSS should be set to give the UE “UE clear” mark.

- (4) Request notify processing from MME: According to request-specific information, HSS performs the appropriate action, such as update terminal information; set the current area to restrict access; update PDN GW address.

**S-GW** is responsible for connecting the eNBs and roam/switching between eNBs. S-GW is the gateway-oriented eNB end interface, the main functions are as follows:

- (1) Session Management

EPS session management support functions include EPS bearer establishment, modification, and release. Storage and processing is under ECM-idle and ECM-connected state for terminal EPS bearer context.

- (2) Mobility Management

S-GW helps accomplish the following mobility management program:

Based on the switch between interface X2 and S1;

Tracking area update;

The service request triggered by network side;

S1 connection release.

- (3) Routing and data forwarding

S-GW has routing function as obtained the data from one node and forwarded to the next node. After the switch between eNBs or systems, S-GW users should send “end marker” packet to the source eNB, source SGSN, or source RNC, in order to help eNB rearrangement.

- (4) QoS control

Support for the main Qos parameters bearded by EPS, including QCI, ARP, GBR, and MBR;

Support for terminals and network-initiated update bearer modification process based Qos;

Support for the bearer establishment/update access control: when resources are insufficient, the access is stetted with high ARP, and on the contrary, access is denied for low ARP;

Support for GBR and MBR bandwidth management for GBR bearer level.

Support for DSCP marking for bearer level of uplink and downlink data.

- (5) Billing

EPS supports both offline and online charging functions. S-GW and P-GW support offline charging function, S-GW with the P-GW participated complete the online charging function. After the S-GW collecting billing information, generate CDR, it goes from interface Ga to the interface CG. In CG, the bill is post-merger

processing, and then, passing through interface Bx to the billing system. It supports multiple charging modes: traffic, long, long time flow combinations, and so on.

#### (6) ISR (Optional)

Recognition: achieve appropriate treatment for EPS at ISR active and inactive state.

When active, S-GW updates only the new MME control plane address as update bearer process, as well as preserving the old SGSN information unchanged.

Under ISR activation status, S-GW changes TAU/RAU and receives MME/S4 SGSN delete session request.

P-GW: The gateway P-GW devices are responsible for connecting external packet-switched network and managing the connections between the external packets switched network and the user equipment (UE) devices. P-GW is a PDN-oriented SGi-terminated gateway which provides a stable IP access point for users as an anchor point for all the access techniques. The main functions of P-GW are shown below:

IP address assignment

For each PDN connection, UE must obtain at least one IP address (IPv4 or IPv6 prefix).

Session management

P-GW stores and processes the EPS of the terminals which are under the state of ECM idle and ECM connected to bear the context and addresses the corresponding external data network by APN. P-GW stores the mapping relationship borne by the downlink data SDF and S5/S8. For a PDN connection, P-GW supports the default bearer and the dedicated bearer.

Routing and data forwarding

P-GW has the function of utilizing GTP packet header and UDP/IP packet header to pack the PDU from the external data network, and regards corresponding address of the packet header as the identifier to utilize a point-to-point bidirectional channel to transmit the packed data to the terminal in the EPS network. For the GTP-U PDU in the external data network, P-GW removes its packed header and then forward to the external data network.

Related functions of external network access

P-GW can access the external IP network through transparent and non-transparent mode. In the non-transparent mode, P-GW should support the function of accessing RADIUS server and realizing the user identification. To guarantee the billing requirements of some data businesses, P-GW should generate the uniform RADIUS message according to the APN assignment on the P-GW side, and use the uniform RADIUS message to communicate with the external RADIUS server.

QoS control

- ① Support the main QoS parameters borne by EPS, such as QCI, ARP, GBR, MBR, and APN-AMBR;
- ② The initial bear level QoS parameters of the default bearer are assigned by the network according to the signature data (In the condition of

E-UTRAN, MME sets these initial parameters according to the signature data obtained from HSS). P-GW can change these parameters after the interaction with PCRF or based on local settings.

- ③ Support local settings PCC (strategy control and billing) rules.
- ④ Support the creation or modification of the dedicated bearer from UE and network sides, decide whether make the creation or modification or not, and assign QoS parameters for the bearer.
- ⑤ Support the realization of the bear level GBR, MBR bandwidth management function for the GBR bearer.
- ⑥ Support the APN-AMBR bandwidth management function of the uplink and downlink data streams for the non-GBR bearer.

#### DPI function

DPI can conduct the deep detection for the data message context in the application streams, and report the type and number of the data streams, cooperate with PCRF to accomplish the stream-based strategy control, and cooperate with the context billing to accomplish the stream-based billing function.

- ① Support the user-based packet filtering
- ② Support the user-level-based stream management control
- ③ Support the business-level-based stream management control

#### Billing function

Support online/offline billing and context billing functions. For offline billing system, when P-GW collects the billing information, it generates CDR to transmit to CG through Ga interface, and after the merged processing of call tickets, it transmits to the billing system through Bx interface. For online billing system, P-GW communicates with OCS through Gy reference point. CTF in P-GW generates the billing events, provides the billing information, assembles the billing information into billing events, and sends these billing events to OCF in OCS. It supports multiple billing modes: stream flow, time duration, stream flow, and time duration combinations and events.

#### PCRF selection

In the scenarios of attribution place and roaming place, it is possible to exist the condition where multiple PCRFs serve a single P-GW. P-GW conducts the selection for PCRF according to the defined process in TS 23.203, and in the meanwhile makes the PCC session in different terminals connect the correct PCRFs.

#### MBMS-GW

Gateway MBMS-GW devices are responsible for transmitting the data to eNB in the way of multicast.

#### BM-SC

BM-SC devices are responsible for the launch and authorization of the eMBMS business.

#### MCE

MCE devices are responsible for the session management and wireless assignment for the eMBMS business to accomplish the air interface dispatching.

### Core Network Architecture

Based on the business requirements, LTE core network sets the network elements such as MME, HSS, S-GW, P-GW, MBMS-GW, BM-SC, MCE, router, and the 3GPP R13-based MCPTT server.

From the technical point of view, each core network element can apply either centralized or distributed type of architecture. But from the aspect of operation and the plan of the whole network and duration, the specific establishment type of network elements should be considered various factors such as reasonability, economy, characteristic of the network element, operation management system, and maintenance management. In the meantime, in considerations of the importance of the network element and the wide range of the failure's influence, redundancy and disaster robustness should be also considered in network element setting.

The networking mode of each element is analyzed as shown in Table 2.1.

Consider the interconnection between the core networks from two different manufacturers as the example; the network architecture and the interface explanations are shown in Fig. 2.6 and Table 2.2.

Interconnection network architecture of LTE-R and dispatching communication system

For the conventional dispatching voice communication business, it is required to interconnect the LTE-R core network to the conventional FAS dispatching communication system to realize the voice communication between the train driver and the FAS terminal of the dispatcher and the station attendant.

The feasible solution is regarding the FAS system as a multiple user terminal to customize the MCPTT Server connection between the gateway and the LTE-R system. The connection applies IP interface and the protocol is suggested to use SIP. The network architecture is shown in Fig. 2.7.

For the voice business such as trunking communication, the network applies the eMBMS bearer and adds the network elements such as 3GPP R13 defined MCPTT server.

For other data businesses, the network utilizes the application system server to interconnect the SGi interface with P-GW. The network architecture is shown in Fig. 2.8.

As the direction of railway mobile communication development, LTE-R will coexist with GSM-R in a long period of time. The LTE-R system and the GSM-R system will evolve from coexistence to interconnection and eventually realize the business taking over. In the evolution from GSM-R to LTE-R, the interconnection and the transition smoothness of both the networks should be fully considered.

The detailed interconnection strategy with GSM-R is shown below: In the GSM-R network, MSC is responsible for the calling of trunking voice business and the media processing. In the LTE-R network, MCPTT server is responsible for the calling of trunking voice business and the media processing. Thus for the interconnection between the GSM-R trunking voice business and the LTE-R trunking voice business, the only requirement for voice calling realization is the interconnection between MSC and MCPTT server.



**Table 2.1** Networking mode analysis of each network element

Index	Network element name	Networking mode analysis	Networking mode	Redundancy setting
1	HSS	<p>This type of network elements is for the management and strategy control of user data, business, and dispatching. It can apply the centralized and distributed networking. Centralized networking has a better economy, and can follow the existed GSM-R network to share the developed devices and management systems. In addition, if some conditions are satisfied, such network elements as HSS can be established together with HLR in the GSM-R network in order to promote the device utilization and protect the GSM-R network investment. Therefore, based on the above analysis, centralized networking has a significant advantage</p>	<p>Centralized setting, LTE network shared devices HSS, PCRF are set over the whole railway</p>	<p>Apply the remote disaster robustness system pairwise setting whose shared devices are synchronized by dedicated data link. The transmission channel is provided by two transmission systems with different physical routings</p>
2	PCRF			
3	MME	<p>The elements in this category are routers and gateways which can be applied by centralized and distributed networking. Distributed networking is better to distribute the network traffic to each core network node to avoid the network congestion caused by the heavy traffic of one node. Therefore, distributed networking has an obvious advantage</p>	<p>Distributed networking, each network element is set on each core network node</p>	<p>Each core network node and each network element is equipped with two devices, if condition permits, those devices can be remotely set. Those two devices apply the POOL mode to achieve the load balancing</p>
4	S-GW			
5	P-GW			
6	MBMS-GW			
7	BM-SC			
8	MCE			

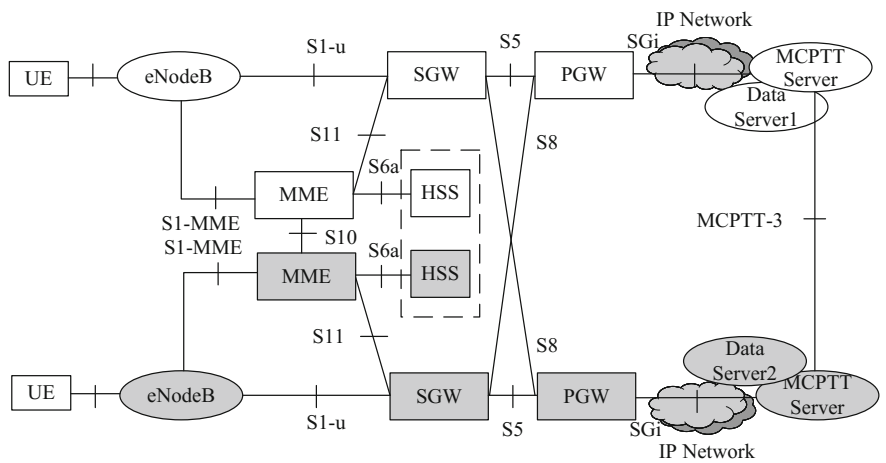


Fig. 2.6 Core network interconnection network architecture

Table 2.2 Core network interconnection interfaces

Interface	Description
S1-u	The user plane interface is between eNodeB and S-GW, which provides the user plane transmission of eNodeB and S-GW UDP/IP and GTP-U based protocol
S5	The interface which is responsible for the user plane data transmission and channel management between the Serving GW and PDN GW. It is used to process the Serving GW relocation and the PDN network required connection with the non-collocated PDN GW in order to support the UE mobility GTP-based or PMIPv6-based protocol
S1-MME	The control plane interface is between eNodeB and MME, which provides the S1-AP message transmission IP- and SCTP-based protocol
S10	The interface is between the MMEs, which is used for processing MME relocation and the transmission between MMEs
S8	The interface which is responsible for the user plane data transmission and channel management between the Serving GW and PDN GW. The difference with the interface S5 is that S5 is used for local Serving GW and local PDN GW, and S8 is used for Serving GW in the roaming place and PDN GW in the attribution place
S6a	The interface is between MME and HSS, which is used for transmission signature and data authentication
S11	The interface is between MME and Serving GW, which is mainly used for the transmission of the request message for creating, updating, and deleting the bearer
SGi	The interface is the connection interface between PDN GW and the external PDN
MCPTT-3	The interface is between MCPTTs from two different manufactures, which is proposed after R13 version

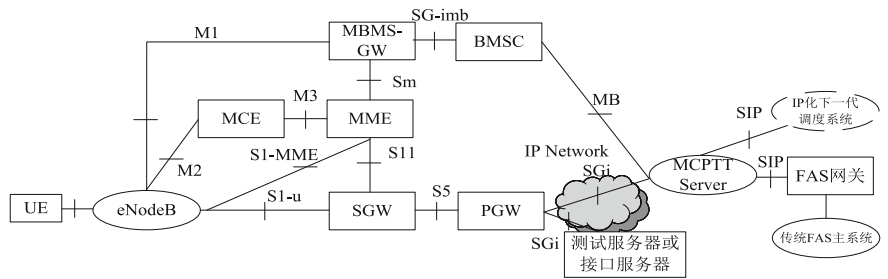


Fig. 2.7 Interconnection network architecture of LTE-R and dispatching communication system

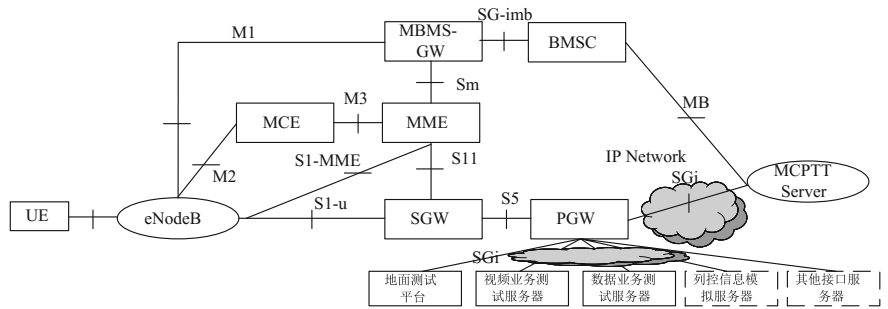


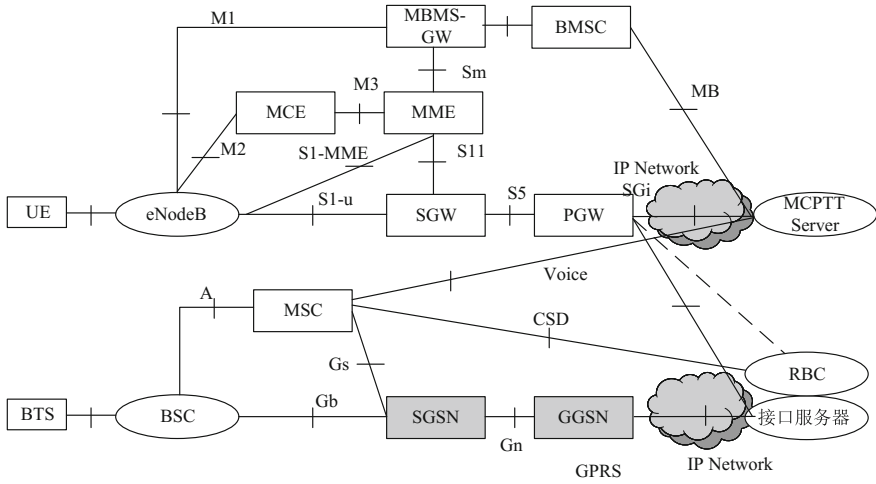
Fig. 2.8 Interconnection network architecture of LTE-R and GSM-R system

For the data business interconnection, the GSM-R has CSD and GPRS these two data communication types: CSD is from MSC to RBC through wired transmission network; and GPRS is from SGSN/GGSN to the interface server through the wired transmission network. The only requirement for realizing the grouped data interconnection with the GSM-R GPRS system is interconnecting P-GW with GGSN. The detailed interconnection network architecture is shown in Fig. 2.9.

### 2.4 Key Technologies for GSM-R

Railway has a close relationship with national economy and people's livelihood, reliability, availability, maintainability, security (RAMS) are always the key points of railway informatization construction, which are directly related to the property safety of the people. The wave propagation, wireless interference, wireless networking, encryption, and evaluation system of RAMS are the key factors which impact the transportation security and efficiency.

However, domestic research status indicates that the existing research results about the high-speed railway wave propagation channel cannot clarify the influence



**Fig. 2.9** Interconnection network architecture of LTE-R and GSM-R system

of the mobility. For the mathematical derivation of the multipath diameter distribution, although the theoretical derivation has a certain universality, different numbers of multipath propagation path environment of high-speed railway under targeted distribution modeling needs to rely on the measured data to construct a different path time-varying time-domain waveform. Using a variety of known probability distributions to fit the waveform, which is aiming to get the probability density function of the waveform, it is a good probability for the distribution of the number of multipath path constructed in accordance with the characteristics of high-speed railway in different propagation environments.

Although the current research has carried out aerial measurements and modeling studies, the antenna measurements methods of the multiple antennas, the multiple dimensions, the multiple positions in the scenes of high-speed railway and complicated situation and the antenna modeling method of angle domain, delay domain, and polarization domain are need to be studied. For deterministic modeling approach, there are some theoretical gaps in the structure composed of a complex space environment and radio wave propagation mechanism. Existing academic attempts are concentrated in the automotive field of communication; the field of rail transportation has not been touched. Therefore, it is an urgent need to make deterministic modeling methods to break the bottleneck, which is aiming to achieve modeling complex space environment and high-speed mobile broadband channel. For the half deterministic modeling approach, there is not a reliable solution to describe nonstationary characteristics of the fast time-varying channel, which is lack of the broadband channel modeling for the high-speed railway and complex space environment. Stochastic modeling is low complexity, which is essentially not be capable of characterization of nonstationary channel. Therefore, it is an urgent

need to carry out research of modeling method for the high-speed railway complex environments.

Currently, there have been many researches on the reliability and availability model of the communication system. The reliability model for GSM-R network in ETCS based on Petri nets was described [1]. A channel transmission model and the factors which may lead to the wireless connection failure were proposed. The performance analysis of GSM-R network structure in China Train Control System was investigated [2]. A distributed antenna system was proposed [3], which is aiming to adapt to the tunnel. Radio coverage with antennas requires an accurate prediction of propagation loss inside and outside the tunnel, particularly when the communication system must maintain a high quality of service along the entire track [4]. The authors presented a comprehensive analysis and modeling of shadow fading in HSR environments [5]. In [6], it is observed that the handover rate and handover initiation delay increase and decrease with the standard deviation (STD) of shadow fading, respectively.

The existing GSM-R network has some definition for the QoS metrics of dedicated services and requirements specification, but not specifically for high-speed mobile scene. Moreover, the index set is not complete. An overview of shortcoming was presented in [7]. With the increasing speed of the railway, the reliable transportation of the train control information and other railway dedicated communication traffic has a more important influence on the security of the system. Railway mobile communication system evolves to the all packet-switched network, and the service types, flow characteristics, and user behaviors for high-speed railway are different with the public network service.

To guarantee the QoS of the dedicated service and the RAMS requirements for the high-speed railway, the system needs to measure the network traffic and combine the high-speed railway service with the characteristic of user behavior to build the high-speed railway mobile communication system business model, which is aiming to accurately model the various services and restudy the quantitative relationship between the applicability of the QoS metrics for the GSM-R system and the system Markov Model state statistical properties. The system would build the performance evaluation system which is suitable for the high-speed railway mobile communication network and meet the requirements of RAMS.

The key technologies of GSM-R are based on the hot and difficult issues which GSM-R system should solve immediately. The technologies build the theoretical foundation and the technological system to achieve secure and reliable transmission of information in the high-speed railway complex environment with the system thorough research. The key technologies could better guide GSM-R system construction and development. In general, the key technologies of GSM-R could be summarized as four aspects: (1) The radio wave propagation simulation modeling theory and method for high-speed railway, (2) The interference cancelation theory for GSM-R system; (3) The key technologies of safety data transmission for high-speed railway; and (4) The performance evaluation system for GSM-R system.

- (1) The radio wave propagation simulation modeling theory and method for high-speed railway

The large-scale propagation model for high-speed railway includes the different propagation models which are suitable for different scenarios. The propagation model could optimize and modify the model according to the change of the railway surrounding environment. Moreover, the propagation model could also propose and verify the correction factor, which could build the accurate radio wave propagation model database for different high-speed railway scenarios (plains, mountains, cuttings, bridges, hills, stations, tunnels, viaducts, etc.).

The multipath fast fading distribution model mainly research the regularity of distribution for the multipath fast fading in high-speed railway and the field coverage margin due to multipath fast fading. Based on the small-scale fading and the distribution of multipath delay, the distribution of continuous burst error caused by multipath fading fast is studied in the model. Moreover, the model also studies antenna technology, channel estimation and equalization, multipath diversity, and error correction coding, which is aiming to overcome the small-scale fading impact on the security of data transmission.

Wireless coverage hole theory of high-speed railway mainly focusses on the formation mechanism about the wireless coverage hole of the high-speed railway and proposes the scientific definition, to build a model of wireless coverage hole which indicates the influence on the railway service.

On this basis, the model studies the influence of wireless coverage hole on the train control safety data transportation and analyzes on-board units of locomotive drifting in and out of wireless coverage hole, which is aiming to overcome the effects of the method of secure data transmission and eliminate wireless coverage hole technology.

- (2) The interference cancelation theory for GSM-R system

The technology mainly studies the distribution of radio interference in high-speed railway scenario, which is taking GSM-R wireless networking and frequency planning into account. Moreover, the technology also discusses the mechanism of co-channel interference and adjacent channel interference in GSM-R system according to different radio wave propagation scenarios for high-speed railway (plains, mountains, cuttings, bridges, hills, stations, tunnels, viaducts, etc.). The technology combines the environment of high-speed railway with the interference propagation path and characteristics parameters outside of the statistical data analysis system.

The interference propagation path characteristic parameters, which is aiming to study the relationship between carrier to interference ratio and bit error rate (BER) and block error rate (BLER) and establish moderate computational complexity for train control system C/I analysis model.

The corresponding interference cancelation technologies and protective measures study interference cancelation methods which is based on reasonable engineering design and wireless network optimization. The technologies also take security data transmission needs of high-speed railway operation control system into consideration. The technologies also propose the interference

protective measures which is according to interference detection technology of Um, A and Abis interface monitoring, comprehensive monitoring system, and early warning technology of end-to-end security data transmission quality supervision

- (3) The key technologies of safety data transmission for high-speed railway  
Nonlinear distortion handle technology of high-speed railway radio channel mainly studies the radio channel nonlinear distortion mechanism under high-speed (250 km/h ~ 500 km/h), complex terrain, and varying environmental characteristics. On this basis, the technology studies the influence of nonlinear distortion on train control system security data transmission according to the sparsity of train control data, which is aiming to research the feasibility of the general packet radio service for train control data transportation. To reduce system latency, further research would study the fast synchronization of high-speed railway wireless receiver, channel estimation and equalization, and anti-Doppler frequency shift technology.

The redundancy technology in GSM-R system studies mechanism of redundancy technology, which is aiming to establish a variety of redundancy theoretical analysis model. The technology also researches the influence of different redundancy methods (interleaving sites coverage and two base station coverages with same site) on the network performance and service. In order to analyze the feasibility of mesh network in high-speed railway applications and establish a new train control security network model, the technology studies the application of mobile switching pool in high-speed railway.

According to the openness characteristic of wireless communication systems and the demand of high-speed railway train control security data transmission, safety protocol stack and information safety system mainly study transmission mechanism of security data in openness transmission system and establish dedicated railway safety data transmission protocol stack. The system proposes the new end-to-end information security system to remedy the existing security vulnerabilities of GSM-R system which is including end-to-end mutual authentication protocol, end-to-end encryption protocols, and processes. The system also investigates the integrity protection method of train control data and online key management method for train control system.

- (4) The performance evaluation system for GSM-R system  
The system mainly studies theoretical analysis model of the RAMS for GSM-R system, and deeply analyze the relationship between RAMS and network quality of service. According to the relationship between network quality of service and field coverage, radio interference, engineering design parameters (such as base station spacing, cell coverage radius, the overlapping area size, etc.), network operation, and maintenance, the system establishes the index evaluation system for GSM-R system.

The evaluation methods of GSM-R system indicators include establishment of the index ratings and tolerance for network quality of service, field strength coverage, network operation, and maintenance. The wireless communication

system RAMS indicators methods should meet the needs of reliable transmission for train control security data. Moreover, the methods also investigate the network quality service indicator of high-speed railway control data, wireless coverage level measurement, statistical analysis and measurement technology, and comprehensive evaluation method of network operation and maintenance.

## 2.5 Key Technologies for LTE-R

The mobile communication system is an important part and the nerve center of the ground infrastructure for high-speed railway, which is aiming to provide accurate and timely information for train dispatching, train control, automatic train operation, train security video surveillance, train status monitoring, remote fault diagnosis, wireless monitoring for the infrastructures, emergency job processing, information dissemination and advertising, passenger information, and entertainment services. The system is the foundation and prerequisite to establish the operation safety and security system of high-speed railway. Currently, China's high-speed railway mobile communication systems are based on mature second generation and 2.5 generation narrowband mobile communication technology. However, the existing communication system is becoming the element limiting the number of running trains in areas with high train concentration, such as major train stations [8].

The main problems of sustainable development and the practical application are revealed in the following:

- (1) The insufficient capacity and the difficulty networking limit the development of the applications. Due to the constraints of frequency resources, wireless networking is very difficult, and the co-channel interference and adjacent channel interference are serious in the major stations and hubs regions of high-speed railway. To ensure reliable transmission of train control (CTCS3) security data, the technology must use channel guarantee technology to improve the success rate of handover and many applications (e.g., wind warning, train status monitoring, real-time information transfer) are lack of development.
- (2) The technology does not provide the real-time service to transmit security monitoring broadband data. The highest circuit domain data transmission rate is only 9.6kbps and the actual maximum packet domain data transmission rate is lower than 50kbps, limiting the development of the internet of things in railway. The technology also results in that the ground early warning monitoring data cannot upload to the train and the on-board monitoring data cannot transfer to the ground. The trains cannot communicate with each other directly, which would delay or hinder the timely failure processing.



The research about influence of high-speed mobile on handover and the corresponding measures are gradually increasing when the LTE system is applied to the railway environment. However, due to special requirements of the railway dedicated mobile communication on content, capacity, and quality, the research highly simplifies the radio wave propagation environment, wireless network of the train, and the communication requirements of passengers on the high-speed railway. Taking into account the communication requirements aggregation and group movement of the vast passengers, the performance indicators and implementations of the functions, such as handover control, should have some difference with each other. There is not particularly distinction among the currently LTE handover technology. Program selection, parameter optimization, resource allocation, automotive systems architecture, and other details of the design are closely related to the size and distribution of traffic.

Currently, some research focuses on Long-Term Evolution for Railway (LTE-R). A detailed evaluation of the BER and PSD for LTE-R suitably dimensioned for the high-speed railway channel was presented in [9]. In [10], the impact of mutual coupling on LTE-R MIMO capacity for antenna array configurations in high-speed railway scenario is investigated. The authors undertake stochastic delay analysis of train control services over a high-speed railway fading channel using stochastic network calculus [11].

Broadband mobile communication technology is an inevitable trend and selection of high-speed railway and urban rail transport development. The 7th world congress on high-speed rail was held in Beijing in 2010. The Chinese Ministry of Railways and the International Union of Railways (UIC) clearly indicate that the evolution path of railway mobile communication system will be spanning third-generation (3G) mobile communication technology, and the GSM-R technology will directly develop to next-generation broadband mobile communication technology (LTE-R). However, there are some uncertainties when the existing research of the broadband mobile communication is directly applied to high-speed railway. The following three scientific questions need to address:

**Scientific Question 1: The radio wave propagation mechanism of high-speed mobile and limited space environment.** Due to the diverse surroundings of high-speed railway, complex electromagnetic environment, several limited spaces, and strong electrical interference, the wireless channel of high-speed mobile (more than 200 km/h) shows the fast time-varying characteristics of nonstationary. World wireless communications standards organization, including the Cooperation in the field of Scientific and Technical Research (COST) and business alliance partners (WINNER, Wireless World Initiative New Radio), are lack of the research about the combination of high-speed mobile, railway special application scenario, the radio wave propagation characteristics of broadband, and wireless channel model.

**Scientific Question 2: The broadband, efficient and reliable data transmission mechanism under high-speed mobile.** The fast time-varying channel, nonstationary characteristics, severe Doppler effect, frequent handover, and fast changing of application scenarios are caused by high-speed mobile. It is difficult to track the fast varying channel by the sparse pilot pattern design and channel

estimation technology, which leads to the performance degradation of transmission rate, transmission efficiency, error rate, transceiver synchronization, channel estimation, demodulation, decoding, and other signal detection. The standards of LTE and LTE-A mainly focus on the guarantee of quality of service and data transmission rate for low-speed mobile scenarios. In the case of high-speed scenario (350 km/h), the corresponding indicators are almost blank, only maintaining basic communication. Therefore, it is an urgent need to study the key transportation technologies of high-data transmission rate to respond to the bad radio channel environment and maintain a high spectral efficiency in high-speed mobile scenario.

**Scientific Question 3: The performance evaluation and optimization of the wireless resource management mechanism for high-speed railway.** The high-speed railway should finish the performance evaluation and design requirements before the officially operation. Due to the complex radio wave propagation mechanisms and poor channel conditions, the specificity of high-speed railway is determined by the railway dedicated traffic, quality of service, and the severely limited spectrum. In order to establish the stochastic model of wireless resource management mechanism, the technology should take advantage of the stable railway speed, certain path, and predictive position and combine characteristics of wireless channel with physical properties to deeply describe the system features. Moreover, the technology proposes the analysis method to performance evaluation of wireless resource management mechanism and the optimization design, which takes queuing theory and stochastic network calculation into account.

### ***2.5.1 The Application Requirements of the Next-Generation Railway Mobile Communication System***

- (1) Demand mining, definition, and classification of the traffic  
The technology should mine the demand of each traffic department for the broadband mobile communication services and accurately classify the demand and the definition of traffic, which is aiming to predict the development trend of the railway mobile communication traffic.
- (2) Traffic modeling  
The technology need to establish the traffic model of air interface in wireless network side and core network side, which is aiming to confirm the parameters of air interface traffic model (including the RRC connection, uplink and downlink data rate, downstream traffic/upstream traffic, average connection duration, busy concentration factor, etc.) and the parameter of core network traffic model (including the number of users, uplink and downlink data traffic of network, types of traffic, tracking location area of recognizable traffic, user groups, etc.).

## (3) The QoS of the traffic

The technology should analyze the QoS of various services and confirm the traffic metrics (including peak rate, average rate, the lowest rate, the access delay, end-to-end transmission delay, handover interrupt latency). Moreover, the technology also should confirm the QoS class identification of each service (QoS Class Identifier, QCI), including the resource type, priority, packet delay budget, packet loss rate, etc.

### ***2.5.2 The Technology System and Network Architecture of the Next-Generation Railway Mobile Communication System***

## (1) The performance evaluation technology of TD-LTE and FDD-LTE in railway scenario.

In various railway typical scenarios (viaducts, cuttings, tunnels, stations, marshaling yard, etc.), the technology mainly studies the performance evaluation of TD-LTE and LTE FDD for high-speed adaptability, traffic bearing capacity, coverage capacity, interference, and analyze the mechanism of the differences between the two systems, which is aiming to propose the selection advice of the next-generation railway mobile communication system.

## (2) The fusion networking technology of TD-LTE and FDD-LTE in railway scenario.

The technology should apply vertical handover, cell reselection, and load balancing to the fusion networking of TD-LTE and FDD-LTE in railway scenario. Moreover, the technology should take full advantage of TD-LTE and FDD-LTE and realize the data transportation of high transmission rate, reliable and low latency on the basis of low complexity, construction cost, and limited frequency.

## (3) The network redundancy technology of the next-generation railway mobile communication

In order to propose the redundant network architecture, the technology makes full use of the access network of the next-generation railway mobile communication network (redundant wireless coverage, backups carrier frequency, BBU backup) and the redundancy backup technology of core network (MME/P-GW/S-GW/HSS), which could guarantee the reliability of the access network and core network.

## (4) The network architecture of the next-generation railway mobile communication

In order to confirm the function of each network element and performance indicator, the technology should confirm the network architecture of the next-generation railway mobile communication system and define the interface function of each element.

### ***2.5.3 Frequency and Bandwidth Requirements of the Next-Generation Railway Mobile Communication System***

- (1) Adaptability under different frequencies in railway scenario  
Compare and make quantitative analysis of the performances within different frequencies under the various typical scenarios in railway, such as the viaduct, cutting, tunnel, railway stations, marshaling yards, and so on. And the performances are included wireless coverage, i.e., the cellular radius, channel capacity, interference, and so on.
- (2) The spectrum requirements in the next-generation railway mobile communication system  
According to the frequency distribution and national frequency planning in our country, as well as the 3 GPP LTE frequency planning, combined with the business requirements and system research, determine the next-generation railway mobile communication system spectrum requirements [12].
- (3) The frequency planning technology in next-generation railway mobile communication system  
Analyze the distribution characteristics of intercell interference and the influence to the performance of the system under different scenarios (yard, viaduct, and lines section) in railway. Then put the frequency planning and frequency reuse scheme into use.
- (4) The analysis of the bandwidth demand in next-generation railway mobile communication system  
Analyze the system bandwidth requirements in the next-generation railway mobile communication system, based on the business requirements in the next-generation railway mobile communication system by studying the volume calculation method.

### ***2.5.4 The Key Technology in the Next-Generation Railway Mobile Communication System***

In order to ensure the reliability and security of the next-generation railway mobile communication system, the key techniques are network technology, network planning technology, interconnection technology, high-speed adaptive technology, efficient transmission, and the information security technology [13].

- (1) Network technology in the next-generation railway mobile communication system  
The network technology mainly includes network hierarchy, mobility management entity (MME), home subscriber server (HSS), a service GateWay (S-GW), PDN GateWay (P-GW), the domain name server (DNS), the 3A

server (AAA), Policy and Charging Rules Function (PCRF), IP multimedia subsystem (IMS), base station equipment (eNodeB), the setting scheme of the data bearing network, routing scheme, numbering scheme, and the addressing principle.

- (2) Network planning technology in the next-generation railway mobile communication system

Based on the cover characteristic which is linear cover in the railway scenario, analyze the relationship between the coverage level and the performances (transmission rate, system capacity, transmission reliability, and the success probability of the handover) of the system. To meet the different business QoS requirements, the cell edge coverage probability, the shadow fading margin allowance, the fast fading margin, the interference margin, and other technical indicators, we should improve the transmission reliability, the handover success probability, and system capacity [14].

- (3) Interconnection technology in the next-generation railway mobile communication system

Interconnection technology mainly includes the interconnection between the next-generation railway mobile communication system and railway system application technology, such as scheduling, train running control, synchronous control of railway locomotives, and railway fixed telephone communication network connectivity.

- (4) High-speed adaptive technology in the next-generation railway mobile communication system

Analyze the influence of wireless radio waves propagation and wireless channel caused by high-speed movement. Study the Doppler frequency shift estimation, adaptive antenna, and inter-carrier interference (ICI) cancelation technology. In order to improve the high-speed adaptability in the next-generation railway mobile communication system, and support the highest speed, mean while, guarantee the QoS requirements [15].

- (5) Efficient transmission and the information security technology

In the high-speed movement scenario, the Doppler will seriously affect the communication quality and influence the transmission of train control signals and the passengers' signals. Therefore, the high-speed movement characteristics put forward the new challenge of the physical layer transmission techniques. It is of great significance to develop the high-speed railway multi-way relay network coding and the physical layer security, cognitive radio signal perception, recognition and carrier aggregation, the pilot signal design, and channel estimation in the high-speed railway multi-relay communications. The key problem is how to reduce the influence of the channel time-varying characteristics (i.e., serious Doppler principle caused by high-speed movement). Therefore, the cognitive radio signal perception, recognition, and carrier aggregation, as well as the pilot signal design and channel estimation in the multi-way relay networks, should be mainly studied. Take advantage of the multi-relay network coding to improve the communication reliability. Design

the effective transmission scheme from the perspective of physical layer security.

a. Network coding and physical layer security in high-speed railway multi-way relay networks

At present, the study of multi-way relay communication mainly focused on the low-speed movement scenario [16]. Therefore, it remains to be further studied in the high-speed scenario, especially the transmission design combined with the network coding, the combination and the joint design of other new techniques. In the typical physical layer security transmission, most assume that the transceivers and eavesdroppers are fixed, and the perfect CSI are known at the transceivers. However, the physical layer security in the high-speed railway should consider its own dynamic characteristic and the particularity of various scenarios. Thus, a new physical layer security which is suitable for the high-speed railway should be studied. By exploring the essence features of the multi-way relay communications in the high-speed railway scenarios, design a general model of multi-way relay network coding [17]. Based on the asymmetry of the communications within the carriage and train-ground communication, develop a joint optimization scheme between relay, base station, and users in the railway, as well as efficient and safe signal transmission methods.

- The design of vehicle relay scheme against high-speed movement  
By exploring the relay algorithms combined with the physical layer network coding, develop the mechanism of joint design and optimization to against the serious Doppler principle caused by high-speed movement. Establish a general multi-way relay communication model for all kinds of communication requirements. Furthermore, design a vehicle relay scheme based on zero-forcing, minimum mean square error, user fairness, and maximum user throughput criterions.
- The physical layer security algorithm design for high-speed railway  
By analyzing the security capacity in the high-speed railway scenario, develop exact broad band physical layer security transmission schemes with limited power, spectrum, and infrastructures, and analyze the secure transmit rate of these schemes.

b. Cognitive radio perception, recognition, and carrier aggregation in high-speed railway

Cognitive radio is an important way to solve the severely restriction of railway spectrum resources [18]. However, the existing research has not been involved the spectrum perception and modulation recognition algorithms in high-speed movement scenarios. The robustness algorithms of perception recognition by using a more effective mathematical tool need to be further studied. This algorithm will guarantee the control signal without interference and improve the spectrum efficiency of public networks. In addition, the study of carrier aggregation technology with high-speed

movement still remains on introduction. It is important to further study the carrier aggregation methods suitable for high-speed railway communications.

By effectively perceive the train control signal and the passengers' spectrum, to determine the duty criterion and carrier aggregation of train control signal and vehicle user signal. By the modulation recognition technology of unknown signal to explore the illegal signal evade method within the control signal spectrum and the restrain the interference to users.

- The study of spectrum perception in high-speed movement scenario  
The spectrum perception under high-speed movement includes a wide range of spectrum perception technology, as well as fast and efficient for the time-varying channel spectrum perception technology. Network node cognitive method can effectively improve the recognition efficiency. Spectrum perception technology, as a kind of signal means of security, can avoid train control signal being attacked by malicious signal. In addition, using of spectrum perception to seek the free spectrum, so as to enhance the passenger business information transmission.
  - The study of modulation recognition in high-speed movement scenario  
Multiple signal and different modulation recognition technologies in high-speed movement scenarios are able to extract more effective signal characteristics, enhance the degree of differentiation of different signals. Effective mathematical tool can further improve the recognition performance. In view of the high-speed scenarios lead to Doppler extension, non-sensitive feature extraction frequency, it is important to design modulation recognition algorithms with low complexity, wide application range, and strong robustness.
  - The design of carrier aggregation in high-speed movement scenario  
In view of the limited special railway spectrum and the discrete spectrum distribution, study the changes of aggregation caused by the position. Analyze impact on the wireless carrier aggregation caused by the surrounding environment, the running status, and the relative motion. The dynamic carrier aggregation methods under different mobile speeds and different spatial locations.
- c. Pilot design and channel estimation in high-speed railway relay networks  
Aliasing time-varying channel estimation is an important component in wireless broadband high-speed railway relay networks, and it is also prerequisites to ensure reliable and efficient communication. There have not any effective and accurate time-varying channel estimation algorithms for high-speed railway relay networks by far. Therefore, the optimal pilot design remains to be studied.  
Explore the statistical feature of the aliasing time-varying channel in relay networks, by designing the optimal pilot pattern to realize the high precision aliasing time-varying channel estimation in relay networks.

- Optimal pilot design in relay networks  
In view of the high-speed railway wireless relay communication system, explore the aliasing time-varying channel modeling and analyze the statistical characteristics. Design effective base extension model to approximate the aliasing time-varying relay channel. In addition, explore the optimal pilot with the minimum channel error or maximum channel capacity. Study the features and methods of the parameters estimation and pilot design in relay networks time-varying channel.
  - High precision aliasing equivalent time-varying channel estimation in relay networks  
Explore aliasing equivalent time-varying channel parameters in relay system. Design high precision aliasing equivalent time-varying channel estimation algorithms and derive the estimate error and CRLB lower bound. Study the channel capacity and the lower bound with imperfect channel state information [19].
- d. The information security technology in the next-generation railway communication system  
Analyze the security threats faced by the next-generation railway mobile communication system. Study the authentication, encryption algorithm, key distribution and management in the next-generation railway mobile communication system.

### ***2.5.5 Hybrid Networking of GSM-R and the Next-Generation Mobile Communication System***

Wireless heterogeneous network can take fully reuse of the severely limited frequency resource by deploying low power stations. By different wireless accesses, this heterogeneous network can improve radio coverage, increase spectrum and energy efficiency, and enhance the fairness. But the related research about this area is still relatively weak, and some key problems are still in the blank. Therefore, we need to design the system framework based on the typical scenarios, inherent characteristics, and demands in high-speed railway. Furthermore, the effective management should be conducted by considering the features, such as linear coverage, intermittent service, and great difference between different business demands, so as to solve the limited resources, high mobility problems in next-generation high-speed railway communication systems. Then, we should design a heterogeneous mobile communication network suitable for the high-speed railway and a security system to meet the high reliable requirements.

- (1) Bearing business in hybrid network



The next-generation railway mobile communication system can carry the existing GSM-R voice business, electricity expressway. Hybrid network can realize the business bearing from both networks and optimal allocation between these two networks.

(2) The connectivity and terminal blends in hybrid network

The database sharing mechanism between these two networks and the connectivity of the equipment from GSM-R and next-generation mobile communication system.

(3) Network selection, reside, and vertical handover technology in the hybrid network

Determine the choice of the network, network resides, and vertical switch during the switching protocol process. Establish a new network selection, network resides, and switching selection strategy, develop the features of these two networks. Reduce the ping-pong effect and improve the QoS.

(4) The use of GSM-R resources in hybrid network

Take full use of the existing GSM-R equipment, such as computer room, tower, power source, power amplifier, transmission, and so on. Reduce the costs of network construction and maintenance in the hybrid network.

The research on edge coverage provides reference and basis for the network planning design. And network planning scheme will also affect the coverage radius and fading margin settings, which affects the edge coverage level. Based on the network planning schemes in next-generation railway mobile communication, study the network information safety of and the interconnection with different railway applications such as scheduling communication interface.

### ***2.5.6 The Evaluation and Optimization of High-Speed Railway Wireless Resource Management Mechanism***

Study the high-speed railway wireless business modeling and performance evaluation system, the interference management mechanism of high-speed movement heterogeneous networks, and the high mobility wireless communication management mechanism. Model the typical business and evaluation system should consider the dedicated business and special QoS requirements. Under this business model and evaluation system, the spectrum resources serious limitations, high-speed mobility, and trajectories determination will cause a lot of challenges. Then study the interference and mobility management mechanism in the heterogeneous network.

- (1) High-speed railway wireless business modeling and performance evaluation system
  - a. Business modeling in high-speed wireless network

Based on the business situation and demands of the high-speed railway mobile communication system, analyze the future business development trends and characteristics of high-speed wireless network. Further study the statistical features and user behavior characteristics of high-speed railway wireless networks. Study how to set up the business service system, flow model, and user behavior model based on the train control [20] and business requirements of high-speed railway mobile communication system.
  - b. High-speed railway wireless network performance evaluation system

Based on high-speed railway RAMS requirements, study high-speed railway wireless QoS indicators and evaluation methods. The research content includes the quantitative relationship between QoS index and the transient and steady-state solutions of the stochastic model, and how to build a high-speed railway broadband mobile communication system of performance evaluation system.
- (2) Interference management mechanism in the high-speed mobile heterogeneous wireless network
  - a. The high-speed railway heterogeneous wireless network architecture

Study the high-speed railway heterogeneous wireless network system architecture, topology, the network planning, etc. Considering the infestation deployment between railway interval, small cell deployment in hot spots, relay deployment outside the train, and distribution antennas and Wi-Fi inside the train builds a radio coverage network architecture from a wide range of hot spots inside the train to improve the network capacity and ensure the safety of redundancy backup [21].
  - b. The interference management mechanism of the high-speed railway heterogeneous wireless network

By establishing the grouping markov channel model and the corresponding signal design method and cross-layer interference management mechanism, study effects of high-speed train mobile for signal transmission and the robustness interference management mechanism of heterogeneous network under imperfect channel state information. Take use of the fixed running speed, determined routine, and predictable position to conduct the interference management based on the interference prediction information. Based on the oriented [22] business resource management, develop real-time distributed resource management mechanism.

## (3) High-speed mobile wireless mobility management mechanism

- a. Mobility management mechanism in high-speed railway LTE-R wireless communication systems

Design LTE-R system wireless networking and vehicle-mounted system architecture with handover function in high-speed railway environment. To realize the location management in high-speed railway environment, the handover management mechanisms which used to guarantee the railway communication quality include handover trigger, handover algorithm, and pilot design [23].

- b. Mobility management mechanism in high-speed railway large-capacity communication system

Build the large-capacity user mobility model in high-speed railway scenario. Study network mode, system architecture, handover management, and wireless resource management in multiple relays train-ground wireless communication network.

## 2.6 Summary

This chapter analyzes the network architecture and key technologies of GSM-R and LTE-R system. LTE-R as the next-generation communication system is the essential trend for the future HSR, and LTE-R will coexist with GSM-R in a long time. The two dedicated communication systems will be compatible, interoperability, and ultimately to achieve integration.

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