Standards of Future Railway Wireless Communication in Korea

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Abstract: Railway wireless communication has become an indispensable part to provide the reliability and safety of the railway operation as well as the improved railway services. In addition, advanced mobile communication technologies have triggered new railway customer services. Thanks to many benefits of the 4th-generation mobile communication technology, long-term evolution (LTE), this technology is one of promising candidates for the future railway mobile telecommunication. In this paper, we present and discuss the requirements for the future railway mobile telecommunication. The LTE technology is evaluated according to these requirements. We also introduce the current state of standardization for the future railway mobile telecommunication and its implementation plan.

Key-Words: LTE-R, Railway communication, Railway signalling, GSM-R

1 Introduction

Recently, railway wireless communication together with the train control has been crucial for the reliability and safety of the railway operation. Accordingly, there have been many researches on the next-generation wireless communication system for railway instead of Global System for Mobile - Railway (GSM-R). In particular, these research works are actively carried out in Europe that has built advanced railway infrastructure [1].

The next-generation railway communication system should support the high availability of the network, the reliability of the fast mobility for high-speed trains, and the stability of train operation. In addition, this system is required to efficiently transmit a large amount of data to provide various railway services. Furthermore, it should be interoperable with different railway signalling and communication equipment.

The most important issue in the next-generation railway wireless communication system is to secure a dedicated frequency. Although Europe already secured the dedicated frequency for GSM-R, they are pursuing to have additional frequencies for the next-generation integrated wireless network for railway. The railway operators in Japan and the United States have also been trying to obtain the dedicated frequency for railway over the past decade. In Korea, we have prepared a basic plan to establish the integrated wireless network dedicated to railway since 2012 and performed the preliminary feasibility study and international standardization activities. Furthermore, we have proposed a project to prove the frequency bandwidth used for railway only in 2012 and various activities to secure the dedicated frequency for railway have been done [1-2].

2 Requirement of Railway Wireless Communication

The integrated wireless network for railway has its own requirements for Mission Critical operations such as accident prevention of trains, immediate reaction to emergency and on-time operation. This section is organized as follows. The section 2.1 describes general requirements of the wireless communication system for the next-generation railway wireless network and in section 2.2, the functional requirements (which should fulfill additionally for safe train operation) of the wireless communication system are discussed.

2.1 General requirements

The next-generation integrated wireless network for railway should achieve not only safe operation of trains but also advanced railway services provided in the future. Therefore, it should meet the general communication requirements as follows [3-4].

(1) *High-speed movement*: In general, the maximum speed of the high-speed train is 300 km/h or more. In addition, stable wireless connection should be guaranteed at the moving speed of 500 km/h or more in the future. Particularly, when considering the direct communication between oncoming trains

(i.e. direct-mode operation), train mobility of 1000 km/h or more should be taken into account.

(2) *Broadband wireless transmission technology*: The future railway communication will include the video transmission function (for real-time monitoring of passenger and/or car states in case of unmanned operation) as well as various railway customer services. As a result, the broadband wireless transmission technology that can transfer a large amount of data in real time is essential.

(3) *Low latency*: In European Train Control System (ETCS) Level 2, the maximum latency of end-to-end communication for train control is specified as 500 msec. Shorter communication delay time is required if we consider the increasing speed of trains in the future. In addition, the voice call setup and connection should be quickly performed less than one second for an emergency event.

(4) *Network reliability and availability*: The integrated wireless network for railway should provide the network reliability and availability where the network reliability refers to the stable transmission of data information for the safety of railway operation; and the network availability stands for continuous use in spite of various situations of failure.

(5) *Quality of Service (QoS)*: The up-to-date wireless networks support various QoS depending on different types of traffic and services. In particular, the train control signal which can directly affect the safe operation of trains is mixed with general information signals in the integrated wireless network for railway. Therefore, for more efficient and safe management of resources in a wireless network, the exquisite QoS control is required in the next-generation integrated wireless network for railway.

(6) *Independent frequency and network*: For the high reliability, availability, and safety of the network, it is necessary to independently configure both wired and wireless networks by separating from common commercial networks. This standalone configuration enables to protect the safety of train operation from the commercial network failure or external attack and provide the network operation and maintenance with high stability.

(7) *Open standard*: If the next-generation railway wireless network based on open standards of wireless communication technologies is constructed, the existing system and/or equipment that have been already verified in other industries can be directly used and as a result, the high stability is expected. In addition, it leads to the reduction of the network construction cost thanks to mass production. Furthermore, due to the long life cycle of the technology, these technologies can be used to construct and maintenance the network for a long period. Moreover, it enables to interoperate with the existing railway network and/or other communication networks.

2.2 Functional requirements

Unlike a commercial network offering ordinary voice/video calls and simple wireless data, the integrated wireless network for railway requires peculiar features to railway [5-7]. In addition, these features are directly related to not only the safety, punctuality, and efficiency of train operation but also the immediate reaction to emergency cases such as system failure, disaster, and so on. In this section, we describe the additional functions such as configuration of railway communication network, exclusive voice call function for railway, and exclusive voice call processing functions for railway.

Table 1 QoS parameters for GSM-R (ETCS)

QoS parameters	Demand value
Call setup time	≤ 10s (100%)
Connection establish failure probability	< 1% (100%)
Data transmission delay	≤ 0.5s (99%)
Error rate	< 1%/h (100%)
Duration of transmission failures	< 1s (99%)

(1) *Communication functions for train control*: When using the wireless communication to transmit data regarding the train position, train status, and moving authority between the in-service train and the control center, the high availability of wireless connection is required for the seamless transmission and reception of data. To this end, GSM-R requires the receiver sensitivity of > -90dBm at end terminals over the cell coverage of 95%. Furthermore, we summarized the minimum QoS requirements of GSM-R radio access for ETCS train control signal in Table 1. In other words, the probability of the transmission error over one train line should be less

than 1% per hour and 99% of ETCS data should have the latency of < 0.5 seconds [8].

(2) D*uplication feature of network and coverage*: Since the integrated wireless network for railway delivers the important data related to the safety of the train operation (including a train position, train operation control, and train status monitoring), wireless communication network should have much higher availability than that of common commercial network. Thus, by duplicating wired network equipment as well as wireless coverage, as shown in Fig. 1, train terminals always have the hot standby function. In other words, the end terminal can receive the data from two base stations at the same time. The network should be designed to avoid any interference with failures of a certain network/base station [9-10].

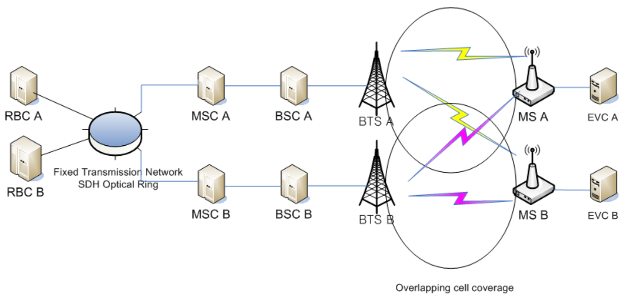

Fig. 1 Fully duplicated network with overlaid radio cell coverage for GSM-R system

(3) *Video surveillance function*: Real-time video surveillance of the passenger cabin is one of essential functions for safe train operation in the next-generation wireless network for railway. Furthermore, since the video information on the current conditions of main railway facilities such as tunnels and crossing points can be delivered to a driver in real time, a driver can operate the train more safely. However, GSM-R which is an integrated wireless network for Europe railway does not provide this monitoring function due to its low bandwidth and old-fashioned features.

(4) *Exclusive voice call function for railway*: Voice call function reflected the railway characteristics is necessary for the safe and efficient train operation. The exclusive voice call function includes the voice call between a train driver and the control center, emergency call in case of emergency, group call between users in a certain area or specific users, broadcasting for the railway workers within a certain area. In the next generation integrated wireless network for railway, digital voice over IP (VoIP) technology will be introduced. In such case, the delay time of the voice codec between both ends becomes critical to determine the service quality in voice calls. In general, the delay time of < 200 msec between two voice codecs is required to provide the adequate call quality.

(5) *Exclusive voice call processing function for railway*: If any accident and/or failure occur during train operation, a train driver and/or supervisor should be able to respond immediately to the emergency situation. Therefore, not only very short time for voice call setup but also exclusive call processing function for railway are necessary. For example, GSM-R recommend the emergency call setup time of 1 sec and the urgent group call setup time between crews of < 2 sec. Table 2 shows the requirements of call setup time defined GSM-R [7].

Table 2 Call setup time for GSM-R

Item	Communication Type	Demand value
Class I	Railway emergency call	≤ 1s
Class Ia	M to M urgent group call	≤ 2s
Class II	General operation call	≤ 5s
Class III	Low priority call	≤ 10s

The function of 'Priority and Preemption' is also one of important exclusive call processing functions for railway, which forces to terminate a regular call and grants call connection authority preferentially to the call with higher precedence during train operation in emergency case. In addition, there is the unique voice call processing system used only in the railway field. The exclusive voice call processing functions in GSM-R include Functional Addressing (FA), Location Dependent Addressing (LDA), Railway Emergency Call (REC), etc. [11-12]. When supervisors or drivers call with a driver on a certain train, the FA function calls the other party with train operational number rather than calling the other party by dialing the unique number of the terminal like a common call method. LDA refers to the call processing function that allows an immediate call with one button without the need of a special dialing to a supervisor who is responsible for the area where the train locates. In case of emergency, REC is the call processing function to enable an immediate group call between a supervisor and drivers driving in the area using the

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REC button on the cab. Fig. 2 illustrates the FA, LDA, REC voice call processing functions.

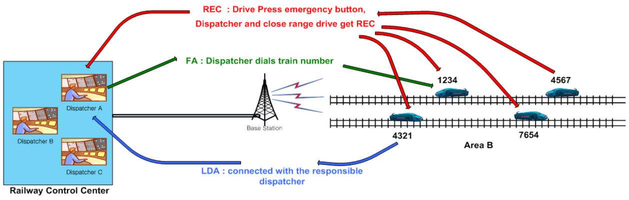

Fig. 2 Railway specific call processing features

3. Standards of Railway Wireless Communication

When the integrated wireless network for railway is deployed, one of the important parts is to ensure the interoperability of railway equipment between different manufacturers and/or different railway operators. For this purpose, it is necessary to make the standard design of the reference model specifications for the interoperability and its detailed technical information. In the case of Korea, the railway communication and signal systems have been introduced by foreign manufacturers and it results in the low compatibility with other devices depending on the characteristics by train and line. In addition, the efficiency of the operation and maintenance of the railway system is considerably poor because the communication and signal equipment has been different with each other depending on the adaptation time and the established line. In order to deal with this problem, the international standard technologies for the next generation railway communication system should be discussed. This section describes the technology and the standardization trends of the next generation railway network.

3.1 Trends in standardization of world mobile communications (3GPP)

3GPP refers to the third generation partnership project to enact the world mobile communications standard, composed of communication standards bodies including Japan, China, Europe, the United States, and South Korea. Early 3GPP business area is intended to establish the technical specifications and technical reports for third generation mobile communication systems such as Wideband Code Division Multiple Access (WCDMA). Currently, the standardization work is proceeding to create and develop the technical standards and technical report of the LTE and LTE-Advanced system, the next generation mobile communication standards. Fig. 3 shows the 3GPP standards organization.

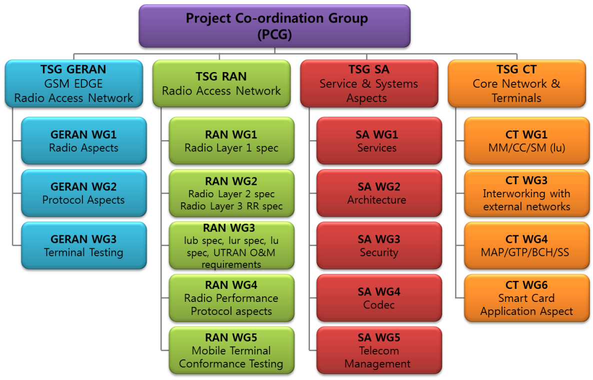

Fig. 3 3GPP Organization chart

In general, 3GPP standardization is enacted in stages. At Stage 1 (Service and System Aspects (SA) Working Group 1 (WG1)), the system requirements are defined and their validity is examined. At Stage 2 (SA WG2), the overall structure of the system is designed. Then, the detail specifications of this system are distributed to each Technical Specification Group (TSG) in accordance with its individual role and then discussed.

Recently, there have been many efforts on the research and standardization of the next generation integrated wireless network for railway based on the LTE technology in Europe. Since the public safety network has similar features to the railway network such as an exclusive communication network funded by the government, the standardization activities of the next-generation railway network cooperated with the public safety network are progressing. The next several items represent the functions related to the railway communication system in 3GPP standardizations in progress.

(1) *Group call function*: Multi-party simultaneous call is a very critical function in the railway communication network and/or mission-critical communication system such as a public safety network. In addition, this function requires very high call connection rate and very short call set-up time. 3GPP is currently discussing the standardization of the LTE-based group call (GCSE_LTE Group Communication System Enabler for LTE) fulfilled these requirements. This standard will be included in the standard 3GPP Rel-12 which will be completed by 2014.

(2) *End-to-end direct communication function*: Direct call function between terminals is one of the important mission-critical functions required in the railway network and public safety network. 3GPP has established standards of direct communication between terminals (ProSe: Proximity-based Services). However, if the wireless access standards

are revised to add the direct communication function, it may be difficult to finish the standards within a period of 3GPP Rel-12 to be completed by 2014.

(3) *Push to Talk (PTT)*: The current standard of PTT over cellular has many lacks of functions to support the mission critical operation in LTE networks. Therefore, PTT standards are planned to revise so as to allow applying to railway network or public safety network.

(4) *Mobile Relay function for High-speed Train*: 3GPP is proceeding "Mobile Relay for Train" standard research for various passenger services and smooth handover of many passengers in the train at a high speed of 300km/h. Basic research is currently in progress including case study and requirements research.

On-going standards of the group call function and the direct call function between terminals enacted by 3GPP are considered to be applicable to both railway network and public safety network in terms of the mission-critical communication. However, the railway-exclusive services (such as reliable data transmission for a train control, QoS management for various railway services, etc.) may be dealt with the International Union of Railway (UIC) own standards. Nonetheless, UIC is generally reluctant to enact its own standards only for a new railway network that extends beyond the specifications of 3GPP. This intends to avoid the precedent where railway operators were reluctant to construct a communication network due to the high CAPEX and OPEX when new railway communication standards (such as GSM-R) have been introduced.

3.2 Current status of UIC standardization

The UIC General Assembly which was held in Istanbul in 2008 announced that the advent of LTE communication system was threatening the lifecycle of GSM technology and affecting the continuous dissemination and maintenance of GSM-R equipment. As a countermeasure against these problems, the UIC (in Technical Report 2009) presented the results to examine whether LTE communication system would be applicable to the integrated railway wireless network. The main contents were that LTE technology might be relatively suitable for the future railway communication network and meet various requirements of railway, but noted that additional studies would be required only for railway communication. It should be noted that it is necessary to examine the exclusive voice call function for railway, QoS management for train control, performance of wireless communication at high-speed mobility of > 350km/h. Consequently, UIC has been promoted research on the Future Railways Telecommunication System since 2010 and published "user requirements for the future railway wireless communication system version 1.0" [13-15].

UIC has officially launched "Future Railway Mobile Telecommunication System (FRMTS)" project in 2013, which aims to develop the next-generation railway communication solutions [16]. In this project, the four subdivisions will conduct researches on requirement definition of a new wireless communication system, frequency redistribution, specifications of additional railway-exclusive features, new structure of a railway communication network, efficient conversion from GSM-R, railway signal transmission in a packet network, etc. In particular, UIC is expected to make efforts to further strengthen cooperation with the 3GPP standard body from 2013 to reflect requirements of the next-generation integrated wireless network for railway in the LTE-based communication standards. In addition, UIC has planned to strengthen cooperation with Critical Communication Broadband Group (CCBG) standard body which was formed in 2012 as well. CCBG was formed with an aim to establish the next-generation communication network standards for the private communication network with special purposes such as railway, disaster, electric power, public transportation, and military communication. The main issues of the introduction of the next-generation integrated wireless railway network based LTE present as follows.

(1) *Availability and reliability of LTE network*: Availability and reliability of the next-generation railway wireless network are very important since this network includes a train control function for the punctuality of transport and passenger safety. The network availability represents that a network should be continuously available even when various failures happen. The reliability means that the data should be transmitted safely and reliably. Bell Labs of Alcatel-Lucent has conducted analysis on the availability and reliability of the LTE network. As a result it has announced that the LTE network can ensure higher availability and reliability than GSM-R [17].

(2) *Exclusive voice call function for railway*: The current LTE standard does not support the voice call

and call processing functions such as the priority and preemption function, group call function, railway broadcast call function, and fast call set-up function. Therefore, in order to use the LTE standards in the railway network, the exclusive voice call function for railway should be supported. This function may be supported in IP Multimedia Subsystem (IMS) of the core network [17]. Consequently, it is expected that various types of voice communication services can be supported in IMS without massive changes in the core network and wireless access standard of LTE.

(3) *Wireless communication function at fast moving speed*: The LTE wireless access standard is designed to support the mobility up to 350 km/h. If the cell coverage within the minimum signal-to-noise ratio (SNR) of 20 dB is established like GSM-R standard, data loss of about 40% is occured in comparison with the stopped state when the moving speed is 350 km/h as shown in Fig. 4. The stable wireless access and performance of the wireless network should be verified for the maximum train speed of 500 km/h since KTX-HEMU with 430 km/h can be commercialized and the high-speed magnetic levitation train of > 500 km/h has the high possibility of practical application in Korea. It is necessary to verify the performance of the wireless network with respect to the carrier frequency and moving speed though the LTE technology can guarantee the wireless access at up to 500 km/h in a low frequency band [18-19].

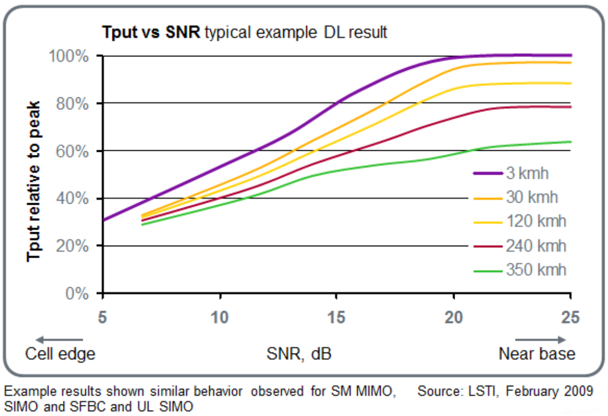

Fig. 4 LTE throughput performance versus train speed

(4) *Cell Coverage Duplication function*: The train terminals should be in automatic backup system structure (hot-standby) receiving simultaneously train control signals transmitted from two different base stations, as train control signal requires high network availability and reliability.

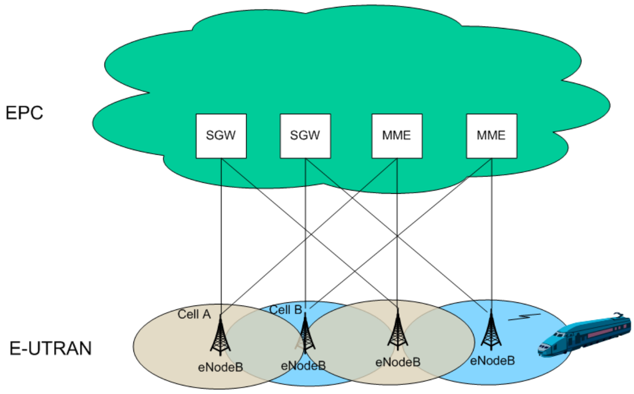

Fig. 5 Duplicated cell coverage for LTE-R

In the case of GSM-R based on Time Division Multiple Access (TDMA) technique, as performing communication in each cell by creating 4 cells by allocating 1 MHz out of entire 4 MHz frequency (frequency reuse factor = 4) and using sub-channel within the allocated 1 MHz frequency, duplicated cell coverage could be made without interference between neighboring base stations. However, in the case of LTE based on Orthogonal Frequency Division Multiple Access (OFDMA) technique, if redundant cell was made, which is needed in railway communication by using the integrated full bandwidth of the same frequency in each cell coverage, interference occurs between neighboring cells. Thus, as shown Fig. in 5, it should be duplicated with the frequency band different from the adjacent base station [20-21].

However, the purpose of duplicating cell coverage is to transmit train control signal which is critical in train operation, with reliability. Since it is very inefficient to duplicate entire frequency for transfer of train control signal with relatively small data in terms of utilizing frequency, the research on this should be conducted. Recently, studies to reduce the sub-carrier frequency interference of the adjacent base stations have been actively carried out for LTE communication. Possibilities are opening up for duplication of one frequency on the basis of this. However, rather than the interference of the sub-carrier frequencies that are transmitted and received between the adjacent base stations from the edge of the cell, the structure of the cell coverage train nested completely interference control in frequency sufficiently through field tests and various simulations it should be examined in the study.

(5) *Function Comparison of LTE/LTE-R*: Specific LTE-R standard has not been completed to date. The standards body of the UIC is in the early standardization process such as user requirement

establishment. Therefore, specific comparison is impossible, but future LTE-R standards can be expected as in Table 3, based on technologies to date, standardization trends and analysis of past GSM-R standards.

Table 3 Function and Performance Comparison for LTE/LTE-R

Function/Performance	LTE	LTE-R	Note
Speed	350 km/h	500 km/h	
Railway voice service	Not available	Group call, Broadcast call, Railway Emergency call	IMS based
Railway call process	Not available	FA, LDA, Fast call setup	IMS based
Network	Public network	Dedicated network	IP based
Duplicate cell coverage	Not available	LTE based duplicated cell coverage scheme	
QoS for mission critical application	Not available	QoS control for railway application	

Schedule of LTE standardization and European establishment of LTE-R is as in Fig. 6. UIC will further strengthen the cooperation with 3GPP from 2013 and plans to actively participate in the establishment of the LTE Rel-12 standard which will be completed by 2014. LTE Rel-12 will include communication standards of LTE-based group and direct communication standards applicable in the railway communication. In the future, 3GPP LTE Rel.12 standards to be finished in 2014 and UIC plans to complete structure determination of the next generation railway network, the next generation railway communication standard completion, and selection of global European railway frequency in 2015 based on the research of ongoing future railway wireless communication system. In addition, UIC is expected to complete transition to and construction of IP-based railway communication infrastructure from TDM(time division multiplexing)-based railway communication infrastructure in Europe by 2017. UIC plans to reflect the various functions of CCBG's ongoing standardization of private network for special purpose to the next generation railway communication standard with reference to them by cooperating with CCBG standards bodies. The UIC will finally complete feasibility test for LTE-R, interoperability test between systems and equipment of existing and next generation railway communication, migration of future railway communication system from GSM-R to LTE-R by 2020.

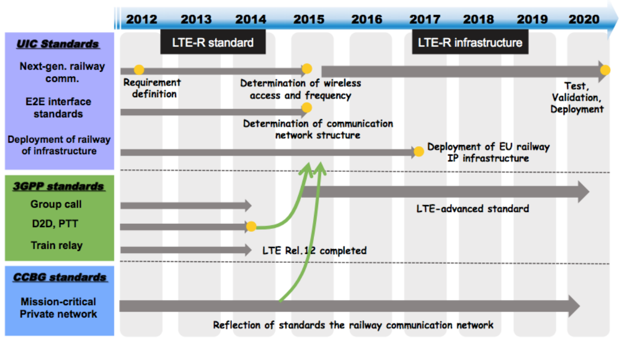

Fig. 6 LTE-R project plan

4 Discussion and Conclusion

Currently, Korean railway communication system is built on a wired network in most case and time limit of specific devices is reached, when it should be changed to the new system. Even in case of the wireless communication system, its stability and operational efficiency is greatly reduced by using a mix of various wireless communication systems. In Europe, from the viewpoint to suit the special environment of railway that require high stability and reliability of LTE communication system, optimization work is already ongoing. In terms of development of the global market and leading the railway technology, many railway communication equipment manufacturers make effort to expand the next generation integrated wireless network for railways to the international standard. In addition to voice and video, the requirements and the validity of the current dedicated frequency the railway integrated wireless network for transferring various data and train control have been examined, and the following conclusion was derived.

First, LTE wireless communication system has proposed as the wireless communication method for integrated wireless network for the railway. The LTE system is compatible with the railway environment and its future global railway standardization is expected.

Second, the frequency bandwidth for building railway integrated wireless network was considered a bandwidth of 5MHz each upward • downward.

Third, for the candidate frequency band, it is determined 700MHz, 1.8GHz, 2.5/2.6GHz band is appropriate based on the frequency currently occupancy in Korea.

Considering environment of train moving at a high speed, low-frequency band as low as possible in which the influence of Doppler frequency change is small has recommended. On the basis of these suggestions, the tests of various functions of the LTE-based railway integrated wireless network are being carried out in a 11km section of Illo~Daebul with temporarily assigned frequency 10MHz bandwidth of 2.6GHz band from the second half of 2012. Establishment of the national integrated wireless network for railway is a shortcut that can maximize the railway transport capacity in the country, strengthen the stability, advances domestic railway signal communication technology falling behind. In addition, it is required to take lead in international technology of the next generation railway communication in order to check foreign communication, and the rapid diffusion market forces and high market power of railway equipment manufacturers. Considering domestic and overseas environment, development and establishment of new national integrated wireless network for rail can be a national issue that should be promoted quickly. In order to smoothly perform the national issues, frequency distribution of domestic integrated wireless network for railway configured quickly and it is necessary to complete the successful construction of the railway integrated wireless network in Korea.

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