Challenges of LTE High-Speed Railway Network to Coexist with LTE Public Safety Network

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***Abstract*— As the speed of train trialled by the French National Rail Corporation has reached more than 500 km/h, the secure and continuous connection to the train control system has only grown more important. In this paper, current status and progress of national disaster safety network project and LTE-based integrated wireless network for railway in Korea, firstly, and the major challenges of LTE-R network to coexist with LTE public safety network are addressed in the aspect of the air interface requirements for the essential railway services. In our view, it is the most important thing at present for designing and planning LTE railway network to eliminate – not to mitigate or reduce – the radio interference, especially from the adjacent LTE public safety network to LTE-based wireless train control because they use the same frequency band.**

***Keywords*— LTE Railway Network, LTE-R, Public Safety Network, PS-LTE**

I. Introduction

The need to upgrade the existing wired and wireless railway systems and the fundamental challenges of LTE to become next generation high-speed railway communication system have already been addressed in many notable research projects [1-2]. As the speed of train trialled by the French National Rail Corporation has reached more than 500 km/h, the secure and continuous connection to the train control system has gotten more and more important [3-7].

In South Korea the national disaster safety network project worth over 1.8 billion dollars to be built using LTE for public safety on 700 MHz frequency band has been started in 2014, the frequency band for the next-generation railway network and e-navigation network is assigned to the same 700 MHz frequency band as the public safety network. Although not only the standardization of 3GPP LTE for public safety is ongoing, but also FRMTS (Future Railway Mobile Telecommunication System) project launched in 2013 under UIC (International Union of Railway) 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 more than 350 km/h, the commercialization project of LTE-based communication and train control system for the conventional and high-speed railway has also been started in 2014.

Accordingly, in this paper current status and progress between these two LTE-based network construction projects, firstly, and the major challenges of LTE-R network to coexist with LTE public safety network are introduced in the aspect of the air interface requirements for the essential railway services.

II. Related Work

In many developed countries, GSM (Global System for Mobile communications) based railway-only wireless network (GSM-R) has been established for a broad, generic, high speed railway since the year 2000, and LTE-based network project began to be developed by 2025. The United States and Canada constructed the ATCS (Advanced Train Control System) for the city metro up to 110 km/h up by using WiFi-based driverless automatic operation technology, the CBTC (Communication Based Train Control) on the ISM (Industrial Scientific Medical) bands. Japan is using a VHF and UHF-band for the railway voice communication and plans to expand gradually in the future to use ATACS (Advanced Communication System and Train Administrations) in the band 400MHz, which includes interval control, telephone control, crossing control, and operational management functions for the high speed rail. China continuing to expand high-speed rail has developed CTCS (Chinese Train Control System) which are based on ETCS (European Train Control System as the reference model in 2002, and will build the GSM-R based train service monitoring and control system by 2015, which can support the national train of speed up to 350 km/h.

Spain signed the agreement with Huawei and Alcatel-Lucent for R&D of LTE-R in 2011, and standardizing LTE-R with integrated multimedia solutions. Alstom France announced testing LTE-based CBTC system with train control, voice communications, and broadband data communications for city rail railway with Huawei in 2014. Currently, Nokia Siemens from among GSM-R network companies has the vision of LTE-R solutions which can provide a WiFi connection to the railroad car by the mobile access router to connect GSM/GPRS, WLAN, HSDPA, and LTE backhaul network. Huawei announced that LTE solutions are being tested for trains of 430 km/h, which have the features of 20 MHz bandwidth, 2X2 MIMO technology, and data rate up to 100 Mbps. Alcatel Lucent proposes the vision of LTE wireless access network between the trains and the tracks of the station, and IP/MPLS backhaul.

III. KEY FEATURES OF LTE RAILWAY NETWORKS AND LTE PUBLIC SAFETY NETWORK

As mentioned above, CBTC and GSM-R systems are widely used worldwide. CBTC is based either on WiFi standard or on a proprietary technology with ISM bands, and GSM-R with the specified frequency bands as shown in Table 1. CBTC systems often use RF interference mitigation techniques, such as FHSS (Frequency Hopping Spread Spectrum) radio, and highly directive antenna.

TABLE 1. COMPARISON BETWEEN CBTC NETWORK AND LTE-BASED RAILWAY NETWORK

Parameter	Comparison between CBTC and GSM-R	
	CBTC network	**GSM-R network**
Frequency	ISM bands (e.g., 900 MHz, 2.4 GHz, 5.8 GHz)	400, 900, 1800 MHz
Target user	**Automatic train control**, railway personnel	
Standard	WiFi or proprietary technology	A Part of ERTMS, EIRENE
Data rate	A few tens of Mbps	< 10 kbps
Coverage	About 50 ~ 500 m	About 1 ~ 10 km
Mobility	Typically less than 120 km/h	Up to 500 km/h w/o any communication loss
Voice call services	N/A	Voice group call, voice broadcast call, railway emergency call, etc.

Key features of LTE public safety network and LTE railway network are shown in Table 2.

TABLE 2. KEY FEATURES OF LTE PUBLIC SAFETY NETWORK AND LTE RAILWAY NETWORK

Parameter	Current Status and Progress	
	LTE public safety network	**LTE Railway network**
Frequency	718-728 MHz for uplink, 773-783 MHz for downlink	
Target user	Policemen, firefighters, soldiers, doctors, etc.	**Automatic train control**, railway personnel
Standard	3GPP LTE Rel.12, 13	UIC and 3GPP LTE
Data rate	25 Mbps Max. for UL, 75 Mbps Max. for DL	More than 10 Mbps
Coverage	0.55 ~ 3.3 km	About 0.2 ~ 1 km
Mobility	Less than 350 km/h	More than 350 km/h
Voice call services	GCSE, D2D ProSe, IOPS, Relay, MCPTT	Group call, broadcast call, railway emergency call, etc.

These parameters are not finalized or standardized

Basically, both LTE-based networks use the same frequency bands which are 718~728 MHz for uplink and 773~783 MHz for downlink. As it is known target users of the public safety network are policemen, firefighters, soldiers, doctors, and so on, but the LTE railway network would be provided to railway personnel and even used by the automatic train control. Because railway wireless communication together with the train control has been crucial for the reliability and safety of the railway operation, the railway operators in Europe, United States, Japan have been trying to obtain the dedicated frequency for the railway over the past decade [1]. In spite of what was expected if both networks use the same frequency band, great concerns and practical researches about air interface policies and design are urgently needed.

IV. CHALLENGES OF LTE RAILWAY NETWORK TO COEXIST WITH LTE PUBLIC SAFETY NETWORK

The previously introduced fundamental challenges of LTE-based integrated railway network toward next generation high-speed railway communication system must be addressed as follows [1-2].

- Exclusive voice service provisioning for railways.
- Handover and network performance for high-speed train.
- QoS management to support the required railway functionalities.
- Network reliability and availability.

In this paper, we focus on the challenges of the coexistence and cooperation between two LTE networks. While coexisting with LTE public safety network, for the faultless and continuous connection to train control system, the next-generation LTE-based high-speed railway network has several challenges as follows.

A. Air interface policies and design for the faultless wireless train control against the inter-LTE network interference

As previously mentioned, in our view, it is the most important thing at present for designing and planning LTE railway network to eliminate – not to mitigate or reduce – the radio interference, especially from the adjacent LTE public safety network to LTE-based wireless train control on the same frequency band. If both RU (Radio Unit) of eNodeB in the public safety network and those of the railway network are commonly connected to the same DU (Digital Unit) as in Figure 1 (a), the appropriate resource allocation method of the scheduler will be able to solve the radio interference problem as in Figure 2 (a).

Realistically, it will have higher possibility that RU of the railway network is not connected directly to DU of the public safety network as in Figure 1 (b). In this way, LTE heterogeneous network solutions via the X2 interface, such as ICIC, eICIC, FeICIC, CA-based ICIC, and CoMP-based ICIC, which mean inter-cell interference coordination, enhanced ICIC, further enhanced ICIC, carrier-aggregation based ICIC, and coordinated multi-point based ICIC respectively could be considered to mitigate the radio interference among the adjacent cells as in Figure 2 (b) [8-15].

However, these LTE heterogeneous network solutions via the X2 interface cannot eliminate the radio interferences, but just reduce the interference of the data channel and control channel from the public safety networks. Hence, to date, they are not the perfect solutions to design the faultless wireless train control networks.

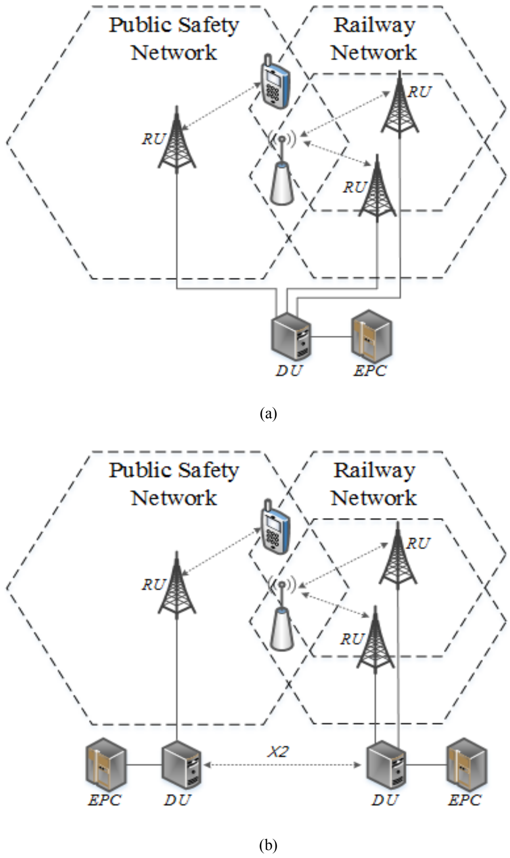

Figure 1. (a) Conceptual diagram of the air interface with common DU between LTE public safety network and LTE railway network. (b) Conceptual diagram of the air interface with different DU but have X2 interfaces mutually.

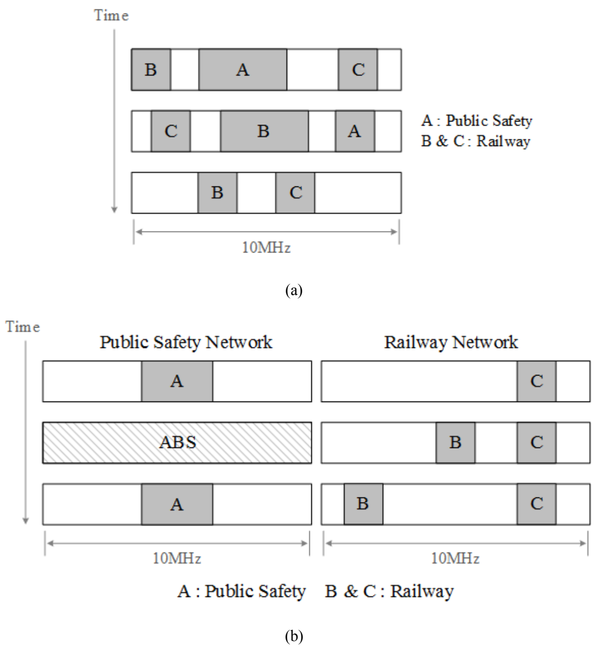

Figure 2. (a) Example of the appropriate resource allocation among the adjacent cells consist of LTE public safety and railway network. (b) Example of eICIC application to mitigate the radio interference via X2 interface in this scenario.

TABLE 3. COMPARISON OF LTE HETNET SOLUTIONS IN TERMS OF MITIGATION OF INTERFERENCE OF LTE RAILWAY NETWORK

Item	Comparison of ICIC techniques	
	Advantages	**Drawbacks**
ABS based eICIC	Elimination of PDSCH interference	Huge spectrum loss, Interference from CRS
RP-ABS based eICIC	Higher spectral efficiency than ABS	PDSCH interference
TX-based FeICIC	Handling of CRS interference	PDCCH interference, 3GPP Release 11
RX-based FeICIC	Elimination of dominant CRS interference	Additional complexity, 3GPP Release 11
CA-based ICIC	Most promising,	CA based on 2 X 5 MHz of both networks, Cross-carrier scheduling
CoMP-based ICIC	Little spectrum loss and interference in downlink	MIMO of both networks, Low latency X2 interfaces, Strict synchronization

Comparison of LTE HetNet solutions previously addressed are shown in Table 3. ABS/RP-ABS based eICIC uses the almost blank subframes (ABS) in the time domain. ABS based eICIC can eliminate the interference of the data channel (PDSCH) via an X2 interface in case of Figure 1 (b), but still cause the interferences from the common reference signals (CRS), and have the huge spectrum loss. RP-ABS could increase the spectral efficiency compared to the ABS, but cannot be used in this case, because of the remained PDSCH interference. Transmitter/receiver based FeICIC can handle CRS interference of the neighboring public safety networks, as addressed in [13]. Nevertheless, transmitter-based FeICIC still have the problem that PDCCH could not be muted, and receiver-based FeICIC could cause the complexity of the receiver, because of the iterative subtraction for the interfered signals. Realistically, nobody claims this additional complexity of the public safety networks in Korea.

An example of carrier aggregation based ICIC is shown in Figure 3. It could be a most promising solution of these interference problems, if all of transmitters and receivers for the two LTE networks have the feature of carrier aggregation whose each carrier has the individual 5 MHz bandwidth, as shown in Figure 3. And CA-based ICIC needs the cross-carrier scheduling as well as signaling and measurement overhead. CoMP-based ICIC uses MIMO antennas and beamforming techniques, thus, some particular types of antennas are required. Moreover, it needs low latency of X2 interfaces and strict synchronization between two difference DUs [13-14].

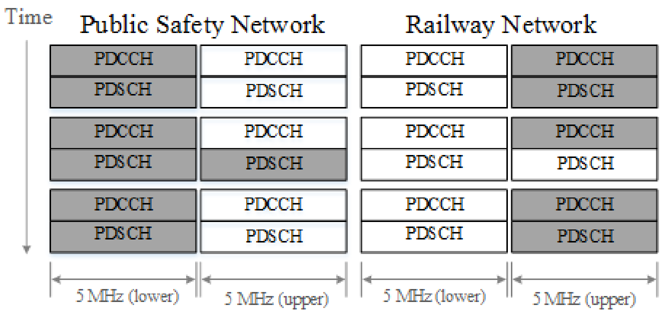

Figure 3. Example of carrier aggregatioin based ICIC technique to mitigate the radio interferences between two LTE networks

B. Duplication of network elements and coverage for the continuous connection in high-speed train

The overall network reliability can be provided by the duplication of network elements and cell coverage. Redundancy for each network element of the core network to RU and DU system should be considered to avoid any single point of failure and ensure high reliability and survivability.

C. QoS management for train control, voice services, and multimedia services against the frequent handover

The QoS requirements for the high-speed train can be much higher than the existing commercial mobile communication network such as LTE or LTE-A and even the LTE public safety network, and should be satisfied with reliability, availability, safety, and security. No matter what X2 based handover or S1 based handover, its latency should not obstruct the continuous connection to train control system and the emergency call processing [16-19].

D. Fast call setup for the railway emergency call and group call in PTT

The Latency requirements for the railway emergency call and even group call need the fast synchronization on air interface and fast call setup in PTT (Push-To-Talk). In case of emergency during railway operation, the emergency call can be the last clear chance to avoid the accident, which is one of the functional requirements as shown in Table 3 [17-18]. As it is known the most critical requirement LTE for public safety is represented by the group call set-up time that must be lower than 300 ms.

TABLE 4. FUNCTIONAL REQUIREMENTS OF TTA STANDARD FOR LTE-R

Item	Functional requirements
Voice Call Service	Individual voice call, public emergency call, broadcasting emergency call, group call, multilateral voice call
Data Service	Multimedia message service, general data service, train control service
Video Call Service	Individual video call, group video call, video image transmission
Call Function	CID filtering, call priority, exclusive user group
Railway Service	Function addressing, position-based addressing, railway emergence call, shunting mode, direct communication

E. Backward compatibility among the existing VHF and TRS network

VHF, TRS-TETRA, and TRS-ASTRO network in Korea should be substituted entirely by LTE railway network in the near future, but the adoption of a new standard or safety related devices for railway operation still need the exhaustive feasibility studies and practical tests of the new system to become the railway mobile communication system.

V. CONCLUSION

In this paper, current status and progress of national disaster safety network project and LTE-based integrated wireless network of railway in Korea, firstly, and the major challenges of the LTE railway network to coexist with LTE public safety network are introduced in the aspect of the air interface requirements for the essential railway services. Two LTE-based networks use the same frequency bands and LTE railway network would be provided to railway personnel and even used by the automatic train control.

In spite of what was expected if both networks use the same frequency band, great concerns and practical researches about air interface policies and design are urgently needed. Additionally, key challenges of the LTE railway network to coexist with LTE public safety network are as follows.

- Air interface policies and design for the faultless wireless train control against the inter-LTE network interference.
- Duplication of network elements and coverage for the continuous connection in high-speed train.
- QoS management for train control, voice services, and multimedia services against the frequent handover.
- Fast call setup for the railway emergency call and group call in PTT.
- Backward compatibility among the existing VHF and TRS network.

In our view, it is the most important thing at present for designing and planning LTE railway network to eliminate the radio interference from the adjacent LTE public safety network to LTE-based wireless train control. And eventually the reliable and continuous train control technologies using the LTE communication network at high-speed train speeds of 350 km/h can be deemed to be the core technology of international railway business.

ACKNOWLEDGMENT

This research was supported by a grant (14RTRP-B088444-01) from the Railway Technology Research Project funded by the Ministry of Land, Infrastructure and Transport (MOLIT) of the Korean government and by the Korea Agency for Infrastructure Technology Advancement (KAIA).

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