A Study on the Integrated Wireless Network for Railway

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Abstract: This research aims to conduct a study on the feasibility of LTE communication method for development of the dedicated integrated railway wireless network, which has carried out an empirical analysis by establishing the dedicated integrated railway wireless network in approximately 12km section between Illo station and Daebul station at Honam line. Korean wireless communication methods for railway safety are different depending on each line, which makes it difficult for railway workers to cooperate with and causes various problems. There is the ever-present risk of accidents due to call disconnection between wireless communication systems, frequency interference from commercial network, and crosstalk. This study has verified the feasibility of 4th generation communication system, LTE over the dedicated integrated railway wireless network as a solution for the above mentioned problems. The result shows it exceeded existing performance standards of Europe GSM-R in every test item despite the location constraint of train track on base station establishment.

Key-Words: GSM-R, LTE-R, Train Control System, Railway Wireless Network

1 Introduction

Current Korean wireless communication methods for railway are different at each line, which leads to inefficient operation. According to the time of their establishment, wireless communication and wireless train control adopt the methods of Very High Frequency(VHF), Trunked Radio System(TRS)-Tetra, TRS-Astro, and WiFi. Since communication terminals are different depending on each method, cooperation between control agent, train driver and maintenance worker is difficult at a line point where different methods overlap. Consequently, various problems arise and there is the risk of railway operating interruption and accident occurrence due to disconnection and communication interruption between different railway radio systems, and frequency interference and cross talk between commercial network and existing railway radio system in case of unlicensed band of ISM 2.4GHzWiFi uses. For this reason, studies on establishment of the integrated wireless network for national railway for the benefit of securing safety of future railway and improving traffic efficiency are being emphasized greatly. According to such demand, this study has commenced in April 2012, and the development and test for the integrated wireless network is currently being conducted at Honamline(Daebul–Illo) from April 2013.

From the international view, UIC(International Union of railway) has announced an outlook for the future of European integrated wireless network for railway, GSM-R(Global System for Mobile communication-Railway) with the theme of “next generation wireless communication standard for railway” on 4th of October, 2012, at Paris World Conference where railway communication experts of each country were invited. It presented market demand in accordance with changes of railway communication technology in European countries, wireless communication technology for railway, and trends of wireless communication for railway. In particular, it made mention of management and problem of GSM-R currently in operation, and crisis of GSM-R arising from increase of new services such as video surveillance, real-time train performance monitoring, etc.[1] The integrated wireless network for railway is the system under which the development and application is possible for an innovative system combining stability of information communication by wireless and safety of control of moving train.[2] Some countries put train control system with the safe and simple structure by wireless to practical use, applying information communication technology to railway system and dividing roles of ground and on-board control devices. The typical example is ERTMS/ETCS in Europe, which currently control main line and high-speed railways using GSM-
Rdeveloped by allocating part of GSM band exclusively for railway. This paper describes the wireless network and system development of ground and on-board services for Long Term Evolution-Railway (LTE-R) established in the section (Illo-Daebul) of Honam line as well as the test methods and results for comparison with a total of 6 items for quality of service standards of GSM-R. It intends to demonstrate the feasibility of LTE services exclusively for railway through 6 tests.

2. Development of ground system of Korean dedicated integrated wireless network for railway (LTE-R)

2.1 Overview of ground-based system of integrated wireless network for railway

This research has established LTE-R network comprised of 2 DU (Digital Unit) and 9 RRH (Remote Radio Head) in the section of Honam line (Illo-Daebul, about 12km) since April of 2012. It adopts 10MHz frequency width (5Mhz*2) of 2.6GHz Frequency Division Duplex (FDD) which is test frequency and will change it into secured frequency exclusively for railway in the future. LTE-R test network has been developed, largely divided into ground-based wireless network and train-borne wireless devices. Test for ground wireless network is divided into EPC, LSM-C, eNB, LSM-R, and HSS according to component equipment as illustrated in Fig. 1.

Fig. 1 Ground schematic of LTE-R

2.2 Functions of ground system integrated wireless network for railway

2.2.1 eNB (evolved NodeB)
eNB is the system between UE and MME/S-GW, which provides wireless communication service to on-board terminal. eNB performs functions of transmitting and receiving radio signal to and from UE, modulation and demodulation packet traffic signal, efficient use of wireless resource, packet scheduling for ensuring QoS (Quality of Service), wireless bandwidth allocation, and proceeding ARQ (Automatic Repeat Request)/HARQ (Hybrid Automatic Repeat Request). In addition, eNB controls connection to packet session and handover.

2.2.2 MME (Mobility Management Entity)
MME is the system between eNB and S-GW and performs a role of controlling Mobility for many eNB. When UE accesses an initial network, MME takes a request from eNB. MME allocates S-GW and P-GW after taking subscriber authentication and information about the subscriber. If UE is in idle mode, MME also carries out paging to UE, after taking a request from S-GW.

2.2.3 S-GW (Serving Gateway)
S-GW is the system between eNB and P-GW. S-GW matches many eNB with IP network, transfers and receives traffic between eNB and P-GW, controls QoS (DSCP marking), and deals with charging (Roaming case). S-GW provides an interface for many servers (PCRF (Policy and Charging Rules Function), DNS (Domain Name Service) server, OFCS (Offline Charging System)) within operational/service networks. In particular, its function includes changing bearer path for movement and handover between eNBs, performing as an anchor point between 3GPP access nodes in the case of LTE.

2.2.4 P-GW (PDN Gateway)
P-GW is the system between S-GW and PDN, which matches many S-GW to IP network, transmits and receives traffic between external network and UE, controls QoS (DSCP marking, rate limiting), and deals with charging. P-GW provides an interface for many servers (PCRF, AAA (Authentication, Authorization and Accounting) server, DNS (Domain Name Service) server and OFCS, OCS (Online Charging System) Roaming case). S-GW provides an interface for many servers (PCRF (Policy and Charging Rules Function), DNS (Domain Name Service) server, OFCS (Offline Charging System)) within operational/service networks. P-GW also has a function of DHCP (Dynamic Host Configuration Protocol) Client and Server, which allows it to
manage and allocate IP address and related setting information to UE. Moreover, it offers handover between Non-3GPPs, and Non-3GPP and 3GPP by providing PMIP (Proxy MIP) interworking with Non-3GPP system including CDMA2000.

### 2.2.5 EMS (Element Management System)

EMS provides an interface for system management so that operator can operate and maintain MME, S-GW, and P-GW. EMS can be classified into two: LSM-C controlling EPC core network, and LSM-R handling DU and RU below eNB.

### 3. Development of on-board system of Korean national integrated wireless network for railway (LTE-R)

On-board system can be largely classified into three; on-board terminal equipment, portable terminal, and dedicated service for railway. On-board terminal equipment in Fig. 2 is designed to transmit and receive various data including voice, video, and train operational information between on-board and ground-based installations by wireless in order to ensure safe operation of train. It consists of train radio control panel (TRCP), train LTE control system (TLCS), train interface control system (TICS), and train video control system (TVCS).

**Fig. 2 On board (Train) equipment of LTE-R**

TRCP (Train Radio Control Panel) is designed to operate on-board terminal equipment. It controls TICS (Train Interface Control System) and TVCS (Train Video Control System), and makes VoIP and PTT voice calls with TLCS (Train LTE Control System).

TLCS (Train LTE Control System) is a wireless send/receive device based on LTE. It connects LTE network and exchanges voice, video and control data with each terminal. The following Fig. 3 illustrates software structure of TLCS.

**Fig. 3 Software structure of TLCS**

TICS (Train Interface Control System) provides an interface between each units to allow control of on-board broadcasting device, LED indicator, CCTV, on train radio control panel (TRCP), and train control management system (TCMS).

TVCS (Train Video Control System) stores video from CCTV installed in train in a storage device by compressing the CCTV video with H.264 codec, and transfers real-time video of the passenger car through LTE network when control center requests video transmission and emergency occurs. The following Fig. 4 illustrates hardware structure of TVCS.

**Fig. 4 Hardware structure of TVCS**

Equipment for provision of dedicated railway services (VoIP/PTT voice call, multi-party voice call, on-board CCTV monitoring, etc.) is composed of command server, video server, Call Server Manager, PTT Server, Call Server, command device, etc.

Although there is no problem in establishing both TT and Call (VoIP) Server in one physical equipment, the separate development has been conducted, considering physical capacity of sever can proceed up to 150 calls since the target was processing more than 100 calls at the same time in each server.

Command server manages status information of the terminal and system through DB by interworking with Call Server, PTT Server and Call Server.
Manager. Command device displays system state information collected in command server by means of GUI and handles management of group, fault, and control of a terminal. VoIP and PTT voice calls to each terminal are available due to setting up both microphone and speaker. Call Server has the main function of dealing with VoIP call and offers VoIP voice call by controlling sessions including initiation and end of sessions with SIP.

3.1 Voice Call(VoIP) Function

On-board system is implemented with functions of voice call, PTT(Push To Talk), and VoIP that railway currently is using, through LTE-R network installed on the ground, as presented in Fig. 6.

1) TRCP: Transferring voice and text to driver’s call control panel
2) TLCS: Sending/receiving voice and video data of TRCP terminal and TVCS by accessing LTE
3) Control Station: Voice call with the driver onboard, sending text, broadcasting, and emergency intercom call.
4) Real-time video monitoring
5) Control Server: Identification number(ID) management, call group management, other registration information management
6) Call Server: Server for 1:1 VoIP call
7) PTT Server: Server for 1:1/1:group PTT call

If the control center(Command terminal) requests 1:1 VoIP call by pressing the identification number of a driver(TRCP), Call Server receives the request and transfers it to driver(TRCP)(Flow no.1 in Fig. 5). After the bearer session has been established between the control center(command terminal) and the driver(TRCP), a check will be made to see if voice call is normal between two clients(Flow no.2 in Fig. 5). Detailed flow of iLTE-R VoIP call is as in the following Fig. 6.

3.2 Group Call(Conference call) Function

If the control center(Command terminal) requests group PTT call by pressing PTT group number in which identification numbers of drivers(TRCP) are registered (Flow no.1 in Fig. 7), PPT Server receives the request and transfers it to the drivers(TRCP).

After the bearer session has been established between the control center(command terminal) and the drivers(TRCP), a check will be made to see if voice of a client who has obtained PPT Key is normally transferred to other clients(Flow no.2 in Fig. 7).

After selections were made in order as “group”, and then “the desired group for a call”, and then “PTT button” on a command terminal, it displays real-time command information and train called by command information.

4. Test of Korean integrated wireless network for railway(LTE-R)
LTE-R test network has been developed, while being largely divided into ground-based wireless network and on-board wireless network. Test of ground-based wireless network has been processed on a total of 179 items for EPC, LSM-C, eNB, LSM-R and field test according to component equipment.

Table 1: LTE-R test items for Handover

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>X2 based Handover</td>
<td>- confirming X2 Handover is normally done (98% success rate)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Handover must be completed in 60ms without call drop.</td>
</tr>
<tr>
<td>6.2</td>
<td>S1 based Handover</td>
<td>- confirming S1 Handover is normally done.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(98% success rate)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Handover must be completed in 60ms without call drop.</td>
</tr>
</tbody>
</table>

Table 1 summarizes test items and criteria for handover of EPC equipment. The field test has been processed as a separate test item in the handover test, where the path for field test was selected, and source and target cell of eNBs in the test path was identified before two-way Intra/Inter eNB Neighbor was formed.

DL FTP traffic was authorized after call connection, and then the normal operation with creation of Intra/Inter eNB Handover was checked by moving the test path. An average value was calculated after measuring delay time from RRC Connection Reconfiguration to RRC Connection Reconfiguration Complete during the handover. In the case of a test item requiring movement like the above, a real train was run in the test using communication chip mounted USB dongle terminal and on-board terminal at the same time, considering the distinct characteristics of railway. Consequently, a research on comparative testing was possible between the on-board terminal equipment which is connected to an outside antenna and has about 20dB higher signal gain and the dongle terminal in adverse condition of the shield inside of train. On-board system is implemented with functions of voice call, PTT (Push To Talk), and VoIP that communication network for railway currently is using, through LTE-R network installed on the ground, as presented in Fig. 8.

Test of on-board wireless equipment was processed as an End-to-End functional test between terminals, in other words, multiple on-board terminals and command desk terminals on the ground, not equipment functions. Table 2 presents part of test items and includes most of safety communication functions of railways operating communication systems of VHF, TRS-Tetra method, etc.

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In the case of the test item such as sending text or video, etc., although the most commonly used TRS-Tetra cannot implement such functions, wireless communication network system based on LTE-R can easily implement those on the level of the application layer on the basis of IP. It allows even an application test, even if it is at an early stage.

Table 2: LTE-R test items for on-board equipment

<table>
<thead>
<tr>
<th>Test Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conference call among drivers and controllers</td>
</tr>
<tr>
<td>VoIP emergency call with overriding driver’s calling</td>
</tr>
<tr>
<td>PTT call from controller to driver group</td>
</tr>
<tr>
<td>PTT emergency call from controller to driver</td>
</tr>
<tr>
<td>Unicasting from controller to specific driver</td>
</tr>
<tr>
<td>Transferring text message from controller to a driver</td>
</tr>
<tr>
<td>Transferring CCTV video from train to controller</td>
</tr>
</tbody>
</table>

5. Analysis of QoS results of Korean national integrated wireless network for railway (LTE-R)

Test procedures for GSM-R QoS is conducted in a total of 6 test items by focusing on mobile terminals, as shown in Table 4.[3]

There are some test items that are not necessarily any longer due to difference between LTE and...
network including Data transmission interference rate. A test item of connection establishment delay limits the elapsed time between end terminal-to-end terminal connection request and successful connection. EIRENE functional requirement specifications suggest separate test criteria regarding railway emergency calls and group calls between drivers in the same area in case of the test item.[4].

Table 3 EIRENE Function Requirements Specification

<table>
<thead>
<tr>
<th>Call type</th>
<th>GSM-R Call set-up time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railway emergency calls</td>
<td>&lt; 2s (95%)</td>
</tr>
<tr>
<td></td>
<td>&lt; 3s (99%)</td>
</tr>
<tr>
<td>Group calls between drivers in the same area</td>
<td>&lt; 5.0s (95%)</td>
</tr>
<tr>
<td></td>
<td>&lt; 7.5s (99%)</td>
</tr>
<tr>
<td>All operational mobile-to-fixed calls not covered by the above</td>
<td>&lt; 5s</td>
</tr>
<tr>
<td>All operational fixed-to-mobile calls not covered by the above</td>
<td>&lt; 7s</td>
</tr>
<tr>
<td>All operational mobile-to-mobile calls not covered by the above</td>
<td>&lt; 10s</td>
</tr>
<tr>
<td>All low priority calls</td>
<td>&lt; 10s</td>
</tr>
</tbody>
</table>

Both test of eNB call processing and test of successful call connection rate in field test include test items for GSM-R QoS. The test items show higher level of quality than GSM-R standard. Data on the test will be reflected in future LTE-R standards.

5.1 Results of connection establishment delay test

A test item of GSM-R connection establishment delay is same as a test item of ‘call connection time’ in a test of eNB call processing of LTE-R. The duration time was measured from the moment when terminal DM received the message of “RRC Connection Request” at Terminal DM to the moment terminal DM received the message of “RRC Connection Reconfiguration Complete”. The repeated measurement was conducted a total of 100 times. Average values of the result were a minimum of 0.386s, a maximum of 1.224s and an average of 0.611s, which is about 2 times better, compared with 2s of the railway emergency calls (Table 4) in the fastest test criteria of GSM-R.

5.2 Results of Connection establishment failure probability test
A test item of GSM-R connection establishment failure probability is same as a test item of ‘successful call connection rate’ in a test of eNB call processing of LTE-R.

There was repeated process detaching after checking successful attach when LSM Client of eNB received RRC Connection Reconfiguration Complete. This test item recorded 100% since it never fails unless specific problems occur.

5.3 Results of Connection loss rate test

Test of GSM-R connection loss rate verifies whether the number of released connection is within 1% for 1 hour while call is connected. This item is related to “successful call connection rate” of “long conversation test” and field mobility test in call processing test of eNB. Long conversation test is intended to check disconnection for 24hours while a call is connected. “Successful call connection rate” item of the field mobility test is intended to record arbitrary detachment by repeating transmission of a 5MByte file to FTP after attachment. Test of successful call connection rate was performed 100 times per each terminal. The result was 1%, but the loss rate became less than 1% on the basis of an hour.

5.4 Results of Transfer delay of user data block test

GSM-R is supposed to transfer 30 Bytes of data block between end terminals. For LTE-R, 32Byte Ping of delay time was verified between on-board terminal and command server at machinery room, with “User Plane setting delay time” item in call processing test of eNB. Criteria for GSM-R is 500ms, but test results of the LTE-R test shows a wide difference with a minimum of 29ms, a maximum of 46ms, and an average of 30ms.

5.5 Results of Data transmission interference rate test

This test is based on Layer 2 High level Data Link Control (HDLC), the unique protocols stack of GSM-R network, however, it was not applied to LTE-R since HDLC has not been used after 3rd generation communication network specifications.

5.6 Results of Network registration delay test

This test is conducted along with “call connection time” test to which comparison made at connection establishment delay in the section 2.5.1.

This is designated as a separate test item for GSM-R because an initial registration takes a long time due to separate procedures, however there is no separate procedure for LTE-R. Test of “LTE-R call connection time” mentioned in the section 2.5.1, results of connect establishment delay test already includes the procedures and presents even more difference in performance compared with 30s of criteria for GSM-R.

6. Conclusion

Although new communication system usually adopts TRS-Tetra in Korea, it is planned to introduce LTE-R technology (LTE-Railway) in the long-term. Korean Railroad Research Institute (KRRI) is currently carrying out related national R&D project. LTE-R is planning to establish its own network for railway. LTE-R commercial technology development targets to support speed below 250km in 2016 and speed over 300km in 2019. All European countries require next generation integrated wireless network system and plans to develop it. European integrated wireless network is in a transition state. LTE-R and GSM-R will be operated in parallel through LTE-R development from 2015.

Steady conversion into LTE-R will be completed until 2025. [5-8]

Therefore, this study examined feasibility in order to verify whether LTE can replace GSM by fulfilling service quality standard of GSM-R, not whether LTE is superior to GSM. Connection establishment delay time presents an average of 1s which is a half of 2s for GSM-R. It will be great amount to user in real application. Data block transfer delay speed is 500ms for GSM-R, but average 30ms for LTE-R, which is as fast as a user cannot recognize. GSM-R assumes the state where various service systems are added, but LTE structure makes additional system fail to affect the test result greatly. In conclusion, LTE is feasible for the dedicated wireless communication service for railway.

Any dedicated integrated wireless network for railway has not established in Korea, but LTE-R development is processing by securing test frequency at Daebul line from this year. Integrated testing for video, voice and data is in process from April 2013. This research is for Korean LTE-R, the infrastructure technology which can be established before 5~10 years than Europe. It is necessary to
participate in the trends of technology and standardization in Europe and take the lead in international technology based on LTE-R.

References:
[4] UIC Project EIRENE FRS(Functional Requirements Specification) v7