Development of Wireless Communication System for LTE-R based Train Control

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***Abstract*— A train control system demands not only a high degree of safety operation, but also needs to guarantee quality service. In order to avoid a failure of the train control system, most components of train control devices are designed with redundancy. In this paper, we present a wireless communication system for LTE-R based train control which is based on a redundant method. This system consists of a railway LTE communication system (LTE-R) as the main device and a commercial LTE system as the standby device in a redundant manner. If the LTE-R system fails to communicate, commercial LTE will be replaced immediately. We developed the wireless communication hardware and software for the Korean Train Control System-3 (KTCS-3), the next generation Korean train control system. In order to measure the basic functionality and performance of this system, we evaluated the wireless communication system using a variety of scenarios.**

Keywords—LTE-R, Train communication, Train control, Redundancy network

I. INTRODUCTION

In order to increase the capacity of railroads and reduce the cost of operation, the train control system has evolved from a wired system to a wireless system. Recent research shows that upgrading a wired train control system to a wireless train control system can increase transportation capacity by up to 42% [1]. In 1990, the Union Internationale des Chemins de fer (UIC) launched Global System for Mobile Communications – Railway(GSM-R), the world's first wireless train control system for European railways. Communications-Based Train Control (CBTC) also introduces a WiFi radio communication based train control to the metro rail way system. Despite its many advantages, the reason for the limited use of the wireless based train control system in limited area is the enormous cost of building communications infrastructure on existing railway lines. Dedicated railway frequency allocation, which has high frequency efficiency and wide bandwidth for railway communication, is also difficult to implement wireless based train control system. The last reason for the difficulty in implementing wireless based train control is that the governments are reluctant to invest in outdated technologies such as GSM-R and WiFi for the communications infrastructure of the next generation train control system.

In 2012, Korea's Ministry of Land, Infrastructure and Transport established a basic plan for the next generation of train communication and control systems. As a result, Long Term Evolution for Railway (LTE-R) was selected as the next generation railway communication system in Korea. In 2017, the world's first LTE-R infrastructure for high-speed rail way was built on Korea Train Express (KTX) line (Manjong – Gangneung station). In the urban railway sector, LTE-R has also been implemented in Busan Subway Line 1 in 2017, Gimpo, Incheon and Seoul Subway has introduced LTE-R as its next train communication system [2]. Although LTE-R infrastructure is being installed, it is still used only for voice communications in train operations and railway maintenance. The wireless train control system was used for testing purposes only. At present, there is no commercial operation of wireless train control system in Korea. There are a number of issues that need to be addressed before a wireless train control system can be commercialized.

Since the communication device of the wireless train control system needs to be reliable and stable for the safe operation of the train, it has special requirements. In this paper, we present requirements of wireless communication system for train control. These requirements for LTE-R based train control have been defined by GSM-R and the European train control system. In order to meet these requirements, we propose the redundant network structure that can be applied to LTE-R infrastructure. This redundant network structure is carefully verified by OPNET network simulations, which are reflection of real high-speed rail operation. In addition, we present onboard and track-side communication devices for LTE-R based train control system. These devices are tested to see how they work and perform in various test scenarios.

II. REQUIREMENT OF COMMUNICATION

The communication for the wireless train control system must provide a stable and reliable communication connection during high- speed train operation. There are key requirements of communication for wireless train control that differentiate it from other wireless communications systems. Table 1. shows the requirements of communication for wireless train control which are analyzed and summarized by GSM-R and the European wireless train control system [3].

TABLE I. REQUIREMENT OF COMMUNICATION FOR WIRELESS TRAIN CONTROL

Requirements	Target values	Probability (%)
Connection establishment delay	< 8.5 sec ≦ 10 sec	95 100
Connection establishment error ratio	< 10^{-2}	-
Transfer delay	≦ 0.5 sec	99
Network registration delay	≦ 30 sec ≦ 35 sec	95 99
Received Signal Power (RSRP)	≧ - 95 dBm ≧ - 110 dBm	98
Handover success rate	> 99.5%	-
Transmission interference period	< 0.8 sec < 1 sec	95 99
Error free period	≧ 20 sec ≧ 7 sec	95 99
Connection loss rate	< 10^{-2}/h	-

Network availability	≧ 99.9984%	-

Although the LTE-R communication system meets most of the requirements listed in table 1, it is difficult to achieve the required network availability. Most wireless communication cannot meet the requirement of five-nine network availability for train control. This requirement is difficult to meet even 5G wireless communication system. To increase network availability, GSM-R introduces network redundancy approach that enables instant switching from main device to backup device in the event of a communication failure. LTE-R system can be made in redundant network in a similar way. Unlike the GSM system, the LTE system is based on Orthogonal Frequency Division Multiplexing (OFDM), which means it uses the same frequency band as neighboring base stations [4]. If the LTE-R base station overlaps with the same cell coverage, there will be severe frequency interference. That is why we are introducing commercial LTE as a backup network. Fig. 1. shows the redundant network using commercial LTE as a backup network in case of communication failure in the LTE-R network [5].

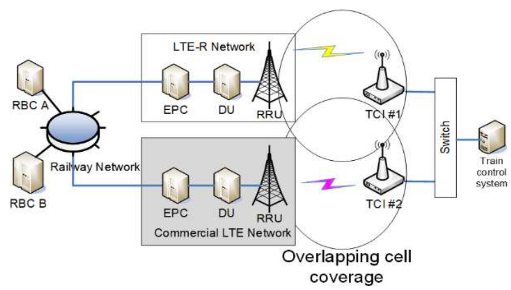

Fig. 1. Redundant network using commercial LTEand LTE-R

III. OPNET NETWORK SIMULATION

To verify the performance of the network availability proposed in Fig. 1, we simulated its performance using OPNET network simulator. OPNET is a tool for the simulation of its performance and behavior prior to the actual construction of the real communication network. The redundant network configuration of the KTX line (Manjong - Gangneung station) using LTE and LTE-R in OPNET is shown in Fig. 2.

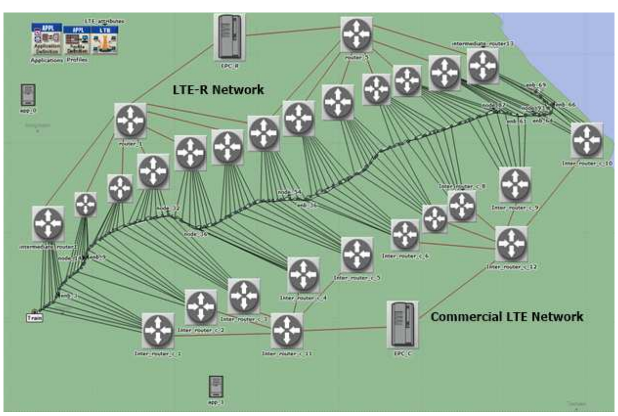

Fig. 2. OPNET simulation for redundant network

We performed a scenario where the train communicated train control signal in every 0.5 sec and the train was traveling at a speed of more than 250 km/h in the OPNET simulation. During the simulation, if LTE-R fails to transmit the train control signal due to severe interference, equipment malfunction and radio link failure, commercial LTE is immediately replaced. In order to intentionally cause a communication failure, we placed the jammers near the LTE-R base stations. Fig. 3. shows the HARQ downlink packet loss result where the jammers are operating. It can be seen that the average value and the maximum value of packet loss in communication failure of the LTE-R only model increased by more than 20 times and 24 times respectively, compared to no failure. The average and maximum packet loss in the redundant model were each reduced by 13 times compared to the LTE-R-only model [6].

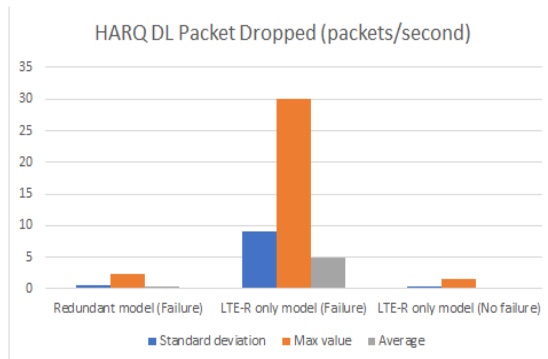

Fig. 3. Packet loss result in OPENT simulation

IV. DEVELOPMENT OF REDUNDANT NETWORK

In recent years, the Korean government has sponsored the development of the 'Korean Train Control System – 3 (KTCS-3) technology, which controls trains using a wireless communication network instead of track-side train control equipment [7]. Since train control relies entirely on wireless communication, failing to communicate will result in serious consequences for safe train operations. In this paper, we present redundant wireless communication devices using LTE-R and commercial LTE network for KTCS-3 system.

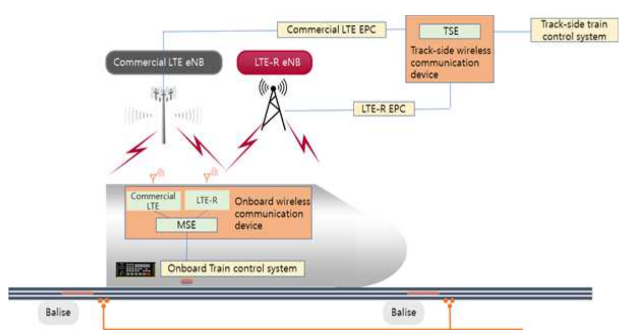

Fig. 4. Wireless communication devices for KTCS-3

When the track-side train control system sends train control message to the onboard train control system, the track-side switching equipment (TSE) in the track-side wireless communication device transmits the train control message over two routes at the same time. Each train control message in LTE-R and commercial LTE is received separately by the on-board wireless communication device. One of two transmitted train control messages is selected by the mobile switching equipment in the on-board wireless communication device. After selecting a train control message, the onboard wireless communication device sends the train control message to the onboard train control system.

(Track-side device) **(Onboard device)**

Fig. 5. Wireless communication devices for KTCS-3

In this paper, we will present the development of wireless communication devices for track-side and on-board applications for KTCS-3 system. The track-side device shown in Fig. 5. is composed of two power supply units, two data processing units, a monitor unit, and an LCD display. Two power supplies operate in active-active mode to prevent power interruption if one power supply fails. Two data processing units are used to process train control messages that are delivered in two different ways. The monitor unit and LCD display show traffic status. This includes throughput, packet loss rate, and latency of train control messages. The configuration of the on-board device shown in Fig. 5. is the same as the track-side device, except that it has an LTE modem in the data processing unit.

We tested 18 required functions of on-board and track-side wireless communication devices such as 2 path transmit and receive function, packet loss and recovery test. We manipulated the data traffic to generate some packet losses on one of the traffic paths. We observed that all traffic data was received even if one of the traffic paths had a packet loss rate of more than 10%.

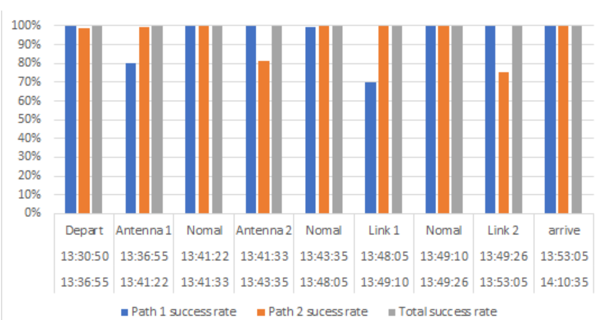

Fig. 6. Field test result of wireless communication devices for KTCS-3

The result of the wireless communication device's field test by running a KTX train from Osong to Jeong-eup station is shown in Fig. 6. Antenna 1 in Fig. 6. means that we intentionally removed one of the antennas in onboard device to cause communication failure. Similarly, Antenna 2 in Fig. 6. means that we intentionally removed the other antenna in onboard device to cause communication failure. Link 1 and Link 2 in Fig 6. means that we intentionally disconnected each ethernet cable in the track-side device, one at a time, to cause communication failure. As you can see, the data transfer rate of path 1 and path 2 would decrease. However, the total data transfer rate always remains 100%.

V. CONCLUSION

It is known to be a very challenging engineering task to implement mobile communication devices on wireless based train control system. Although the Korean railway industry has adopted LTE-R as its main communication system, it is not sufficient for train control. To increase the network availability of the LTE-R communication system for wireless train control, we introduced commercial LTE as a secondary communication system. Using the OPNET network simulator, we have verified the functionality and performance of our proposed method. We also developed wireless communication devices for KTCS-3, the next-generation train control system. 18 required functions have been carefully evaluated, and a variety of performance tests have been conducted during the real KTX train operations. As a result, we confirmed that one of the traffic path failed to communicate train control message, reserved traffic path immediately recover the traffic communication of train control.

ACKNOWLEDGMENT

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