Evaluation of Communication Channel for Train Safety Monitoring System

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***Abstract*—In this paper, we will introduce the necessity of real-time safety monitoring system for high-speed railway vehicle and propose a new type of safety monitoring system using a low-power wireless connection. To verify the proposed safety monitoring system is feasible, we measure the packet error rate on the moving train and show the analyzed results.**

***Keywords*—wireless, channel, sensor, railway, safety**

I. INTRODUCTION

In railway vehicles such as high-speed trains or freight trains, safety monitoring is very important to prevent passengers and freight from an accident like a derailment. And the demand of safety monitoring is being increased. Various related studies are conducted [1, 2, 3].

Safety monitoring system usually consists of safety monitoring service module and sensor module. Safety monitoring service module analyzes the key parameters which sensor module collects and make a decision on the safety status of moving a train. Sensor module acquires key parameter values such as the temperature of wheel and bearing or the vibration acceleration of wheel axles. Those values are directly related to the safety of the railway vehicles by using a physical sensor.

In this paper, we will divide the methods of safety monitoring system into real-time measurement and non-real-time measurement according to the collection interval of key parameters. In the case of real-time measurement, to exactly detect the abnormal state of a train, a large amount of sensor data is needed. In the case of vibration acceleration data, the sampling interval can be reached up to 4-5KHz. Monitoring service module and sensor module are typically connected by wire for stable and broadband data communication. And safety monitoring system is installed on the vehicle. In the case of a freight train, the power line does not reach to the underbody of the vehicle. So applying safety monitoring system to freight train is difficult. And the coverage of safety monitoring system might be very limited. Uneasiness of installation and power supply to the underbody of vehicles are the main disadvantages of real-time measurement method. Monitoring system using HBD is the representative way of non-real-time measurement. It is installed on the railroad, not on the train. So, the key parameters are measured only when train passes HBD [4, 5]. It is provided with tens of kilometers interval along the railroad. In Korea, It is installed in every 40-kilometer interval. HBD is not appropriate to the real-time detection of the safety state of a train.

We propose a new safety monitoring system using low-power wireless communication for ease installation and maintenance as well as real-time monitoring. In this type of system [6], wired connection between monitoring service module and sensor module is replaced by a wireless connection. And if energy harvest module is used as the power source of a sensor module, safety monitoring system is used for a freight train. A large amount of vibration is generated during the moving of train. Harvest module uses vibration to generate power for communication module. We think the wireless communication module based on energy harvest will be a good solution for real-time safety monitoring system for various railway vehicles.

In wireless safety monitoring system, The quality of communication channel between outside and inside of train is very important, because sensor data acquired from outside sensor module should be delivered to inside safety monitoring service module without a loss while keeping a certain transmission rate. In this paper, we primarily focus on the quality of wireless channel and communication module.

In section 2, we look at the detailed configuration of safety monitoring system for railway vehicle using wireless communication. In section 3, we will show and explain the result of packet loss rate which measured on a moving train. Finally, in section4, we make the conclusion of our study.

II. THE ARCHITECTURE OF SAFETY MONITORING SYSTEM

In this section, we will explain the detailed safety monitoring system. Figure 1 shows the configuration overview of safety monitoring system. SN and PC represent the sensor node module and pan-coordinator module respectively. In our study, we installed PC at passenger room.

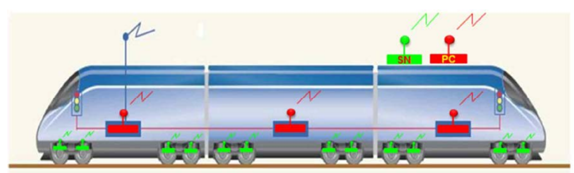


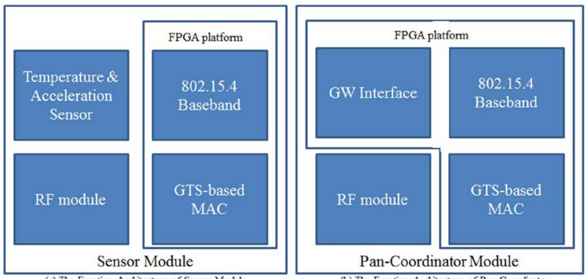
Figure 1. The Architecture of Sensing Network for Safety Monitoring

SN is attached to each wheel axles outside the vehicle. And it acquires the temperature of a wheel and the vibration acceleration of wheel axle. And the acquired sensor data is delivered to PC module. Collection interval of sensor data is dependent on the requirements of a monitoring system and the communication specification. In the case of a real-time monitoring system, temperature and vibration acceleration data are required to be sampled in thousands of cycles in a second.

PC module receives and aggregates the sensor data sent from more than one sensor modules. And the gathered sensor data is sent to gateways module. PC module may not be necessary for wireline safety monitoring system. We will explain the primary functions of SN and PC module in below.

A. IEEE802.15.4-based Sensor Modules

Figure 2 (a) shows the function architecture of sensor communication module and pan-coordinator module.



(a) The Function Architecture of Sensor Module (b) The Function Architecture of Pan-Coordinator

Figure 2. The Function Architecture of Sensor Module

The functions of sensor module consist of IEEE802.15.4 based MAC, baseband, RF and sensor. MAC and baseband are implemented by using FPGA. FPGA device is the product of Microsemi′s IGLOO [7]. It provides the ARM M1 processor core. RF module is also implemented using the commercial device of Microsystem′s LMS6002Dr [8].

The IEEE 802.15.4 technology is the specification for low-power wireless communications [9]. This is the reason that we adopted this specification for our safety monitoring system. The original IEEE 802.15.4 based MAC protocol is based on CSMA-CA. In our study, MAC is newly developed. We call it GTS (Guaranteed Time Slot)-based MAC. It assigns a wireless resource to sensor module in symbol or slot unit. More precisely, it decides the start and finish time of data transmission. Besides, it controls the operation of baseband and RF function. Baseband function is also based on the specification of IEEE 802.15.4. Its transmitter uses OQPSK (Offset QPSK) modulation scheme, and its receiver uses non-coherent type DPSK (Differential Phase Shift Keying) demodulation scheme to simplify the receiver′s architecture. Sensor module consists of physical sensors, ADC (Analog to Digital Converter) and SPI (Serial to Parallel Interface) function. Physical sensor acquires temperature and vibration acceleration value as key parameters.

B. IEEE802.15.4-based Pan-Coordinator Module

Above figure 2 (b) shows the function architecture of pan-coordinator communication module PC module includes 4 main functions that are MAC, baseband, RF and interface to a gateway. The two functions of MAC and baseband are same as the ones of SN module. They are compatible with IEEE 802.15.4 specifications. Except for gateway interface function and RF function, MAC and baseband are implemented in the IGLOO FPGA device.

As mentioned earlier, PC module′s MAC function assigns wireless channel which is for the transmission of sensor data. In our study, we assume that a plurality of sensor modules access to one PC module. In the case of CSMA-CA, as the number of sensor modules are increased. Communication throughput is severely worse due to the transmission collision among the sensor modules. Once sensor data is lost during transmission, it is difficult to recover it. So we need to lessen the data loss due to the resource contention or transmission collision among SN modules. This is why we use GTS-based MAC. And gateway interface is SPI function. It provides the wireline connection between PC module and gateway module. We will not handle the gateway module in this paper.

III. The Results of Packet Reception Rate

In this section, we will introduce the test configuration for measuring PER (Packet Error Rate) in a moving train and show the measured PER. And finally, we will give a brief analysis about the PER.

A. Test Configuration for Measuring Packet Error Rate

Below figures show SN module and PC module which is installed in HEMU train. In test configuration, we use 1 SN module and 1 PC module.

(a) Sensor module on wheel axle (b) Pan-coordinator module (c) PER monitoring display

Figure 3. The Communication Modules installed in Railway Vehicle

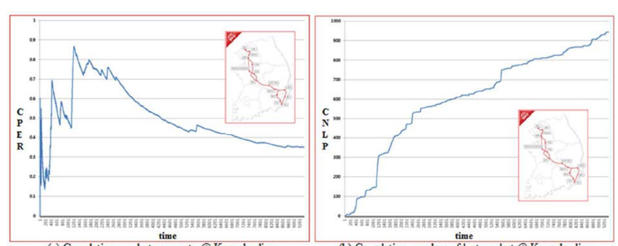
In figure 4, (a) is a picture about SN module which is installed on the wheel axle. Picture (b) shows the PC module which is laid on right next to the window of passenger room.

In our previous research [10], when HEMU train is stopped, the communication channel which satisfies the PER of less than 1 % is between wheel axle near outside passenger door and window which is the closest to the wheel axle. And the transmit power was 6dBm in that study.

We measured PER in two high-speed train lines. One is Gyeongbu-line between Gwangmyeong and Busan. The other is Honam-line between Iksan and Gwangju. PC module sends beacon packet in every 30.72 millisecond. And it calculates the PER in every one second by comparing transmitted packet counter with the received packet counter from SN module. SN module sends a reply packet to PC module whenever it receives beacon packet which contains an identifier to represent SN module itself. The beacon packet′s size is 16 bytes. The reply packet is 20 bytes long.

B. Results of Measured Packet Error Rate

Figure 4 shows PER measured in Gyeongbu–line dedicated for a high-speed train. The highest travel speed of HEMU is about 300 Km/h during test.

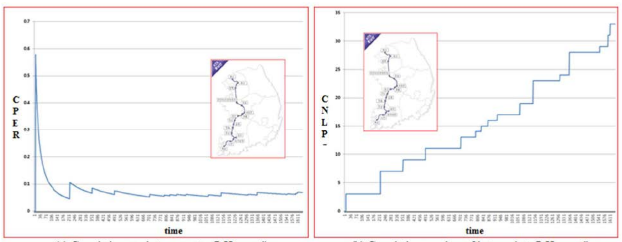


(a) Cumulative packet error rate @ Kyungbu-line (b) Cumulative number of lost packet @ Kyungbu-line

Figure 4. Measured Packet Error Rate in Gyeongbu-line

In figure 4 (a), X-axis represents elapsed time. And y-axis represents packet error rate measured in one-second interval. PER is calculated by the cumulative packet counters. In Gyeongbu-line, the maximum PER was about 0.87%. And average PER was about 0.5%. This value is almost same as the PER measured in the train being stopped. Figure 4 (b) shows the number of lost packet counters in a cumulative way. In this figure, we found an interval in which packets are lost in burst. We will examine one of burst intervals, its duration is 111 seconds, 158 packets were lost during that interval. The burst time is about 1.1% of the total time of PER measurement. But the number of lost packet is about 16.7 % of the total number of lost packet during all test time.

Figure 5 shows PER measured in Honam–line. The highest travel speed of HEMU is about 330 Km/h during the test.

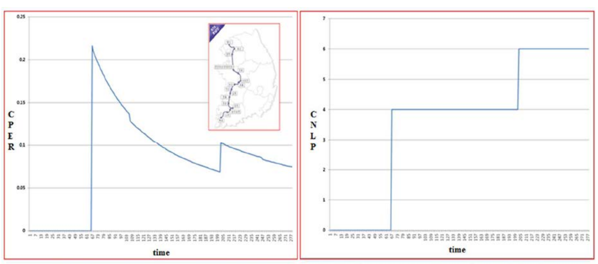


(a) Cumulative packet error rate @ Honam-line (b) Cumulative number of lost packet @ Honam-line

Figure 5. Measured Packet Error Rate in Honam-line

In Honam-line, the maximum PER was about 0.6%. And average PER was less than 0.1%. We can't find burst packet loss interval. We found that the maximum PER and average PER of Honam-line is lower than the PER of Gyeongbu-line.

Figure 6 is PER graph measured at the travel speed of 330km/h.



(a) Cumulative packet error rate @ 320-330Km/h (b) Cumulative number of lost packet @ 320-330Km/h

Figure 6. Measured Packet Error Rate in Honam-line@320-330Km/h

In Honam-line, the travel speed of 330Km/h had maintained for 5 minutes. This time is about 17 % of the total measurement time. During the high-speed section of 320-330km/h, the number of loss packet is 33. And this is about 18% of the total number of lost packet. The distribution of packet loss in high-speed section is almost same as the other section.

Throughout the BER measurement, we found that there exist communication channel which is sufficiently reliable to use for safety monitoring system using wireless technology.

IV. Conclusion

In this paper, we introduce the needs of safety monitoring system for high-speed or freight train and a new type safety monitoring system using a wireless connection. And we stressed that the stability of wireless link is the most important point in safety monitoring system.

To verify link stability, we install sensor module and pan-coordinator module in railway vehicle and measure the packet error rate and analyzes the measured PER data.

We performed the cumulative PER measurement in Gyeongbu-line and Honam-line. Throughout PER measurement, we could find an appropriate wireless channel for safety monitoring system in both Gyeongbu-line and Honam-line. In the stable channel, PER was below 1 % even while the train is moving. We also found that PER is rarely affected by the type of train line or the travel speed of a train. But we saw a burst error in a short interval in Gyeongbu-line.

Considering the result of our field test, we think that the wireless communication technology can be a good solution to the safety monitoring system of a railway vehicle.

Acknowledgment

This work was partly supported by the ICT convergence program of MSIP/ISTK [B551179-12-06-00]

References

[1] SeogJung Choi, Yong-Han Kim, Lee Tae Sub, "Case Study on the incident caused by axle bearing of the railway vehicle" in Spring Conference of KSR(Korean Society for Railway), Oct. 2014, pp.1035–1040.

[2] S. Bellaj, A.Pouzet, C.mellet, R.Vionnet, D.Chavance, "Vibroacoustic Measurement for Bearing Fault Detection on High Speed Trains," in WCRR(World Congress Railway Research), May 2011, pp. 2–7.

[3] Bu-byoung Kang, Jung-Gon Kim, Chan-Mook Jung, Seok-Jin Kwon, "Thermal image analysis method for the detection of abnormal heat under the railway vehicle," in Fall Conference of KSR, Nov. 2013.

[4] Jin-Ho Shin, et al, "A Study on the RAM prediction for HBD", in KSR2014, Oct. 2014 , pp.328-332

[5] Jae-Woo Lim, et al, "Study on Optical System of 4 Pixel Infrared Dector for detecting heat of Axle", in KSR2013, May, 2013, pp864-868.

[6] Jae-Hoon Kim, Jae-Youn Lee, "A Feasibility Study on the Energy Harvesting Technology for Real Time Monitoring System of Intelligent Railroad Vehicles,", Journal of Mechanical Science and Technology, Vol. 35, No. 9, 2011, pp. 955-960.

[7] Retrieved from "http://www.microsemi.com/products/fpga-soc/fpga/igloo-e"

[8] Lime Microsystems, "LMS6002Dr2-DataSheet-1.2r0," Dec. 2012.

[9] "IEEE Standard for Local and Metropolitan Area Network, Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)," Sept. 2011.

[10] Daegeun Park, Wangrok Oh, "Packet error rate measurement using IEEE 802.15.4-based modem on the Korea high-speed train", ICTC2015, Oct. 2015, pp.780-782.