열차제어시스템과 SCADA 장치간 네트워크 기반 데이터 전송 프로토콜의 성능분석

論 文
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Performance Analysis of Network-based Data Transmission Protocol between Railway Signaling and SCADA Systems

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Abstract - According to the computerization of railway signaling systems, the interface link between the signaling systems has been replaced by the digital communication channel. At the same time, the importance of the communication link is more pronounced than before. In this paper, new Network-based protocol between railway signaling and SCADA (Supervisory Control and Data Acquisition system) has designed and the overview of designed protocol is briefly represented. And also this paper addresses an analysis of newly designed train control systems. Fame error rates of the data transmissions are calculated and compared for the two cases that the CTC (Centralized Traffic Control)/SCADA has an extra data transmission error control (CRC16) besides the inherent error control of the Ethernet and that the CTC/SCADA has no extra data transmission error control. With simulation results it has been verified that the additional error control code contributes to lowering the frame error rate. It will be expected to increase the safety, reliability and efficiency of maintenance of the signaling systems by using the designed protocol for railway signaling system.

Key Words : Railway Signaling Systems, Centralized Traffic Control, Supervisory Control and Data Acquisition System, Network-Based Communication Protocol

1. Introduction

There are many computerized equipment in railway signaling systems such as system, EIS (Electronic Interlocking System), ATC (Automation Train Control) system, and LDTS (Local Data Transmission System) and so on. Lots of information is exchanged among the computerized railway signaling systems. For this reason, it is required the standard communication protocol with high reliability for railway signaling systems. Among them, in this research, we concentrate the interface link between CTC and SCADA system. The CTC system is located at the central control and monitoring center, and total trains are operated by this system. The SCADA system has a role for controlling and monitoring of railway centenaries system. The very important information has to be exchanged between above two systems. The importance of protocol for railway signaling systems was emphasized by increase of the information exchange among computerized signaling systems [1][2][4].

There are questionable matters on currently used communication protocol for railway signaling systems in Korea. Among them, the main matters are follows. The existing communication protocol for railway signaling contains different communication procedures to be applied to interfacing between signaling despite same functions, because they are offered from different manufacturers. And there is no interface link between two systems in several existing protocol.

According to these matters, there have been many difficulties related to the maintenance and decrease of reliability on the communication link. So, the KORAIL (Korea Railway Corporation) has essentially required a reliable standard protocol to be implemented. In order to solve these problems, a new protocol with high reliability is essentially required. For the improvement of reliability and the standardization of protocols for railway signaling systems, various signaling operation characteristics and schemes; error correction methods, flow control methods, ARQ, data link control protocol, etc., must be examined for application in railway signaling systems[3][4][5]. In this paper, fame error rates of the data transmissions are calculated and compared in case of the CTC/SCADA has an additional error control code (CRC16) besides the

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inherent error control code (CRC32) of the Ethernet frame, and in case of the protocol has no extra data transmission error control. With the results of the simulation, it has been verified that the additional error control code contributes to lowering the frame error rate.

2. Network-based Protocol between CTC and SCADA

2.1 Configuration of Interface Link

Recently according to the computerization of railway signaling systems such as CTC, EIS, and ATC and so on, the importance of protocol for railway signaling systems is emphasized by increase of information exchange among computerized signaling systems. For this reason, it is required the protocol with high reliability for railway signaling systems. Among them, in this research, we concentrate the interface link between CTC and SCADA. The CTC system is a major railway signaling system and SCADA system has a role for control and monitoring of railway centenaries system.

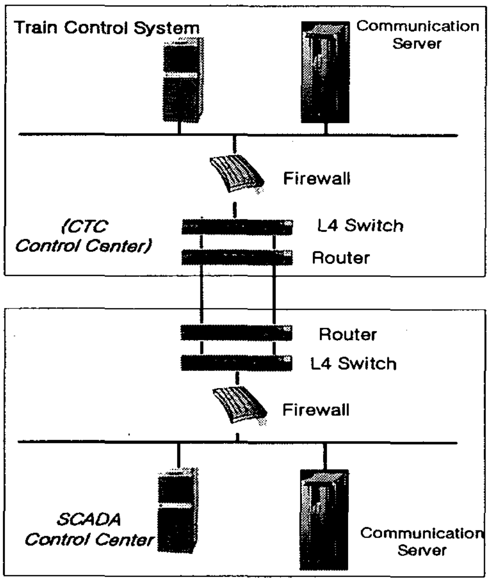

Fig. 1 Configuration of SCADA CTC link

Few years ago, there was no interface link between these two systems in Korea, so these two systems have been operated separately. However, the importance of the interface between SCADA and CTC has been continuously stressed as the upgrade of train running speed, such as Korean high-speed train (KTX), because CTC for railway signaling has been needed the catenary's information for safety operation of high-speed trains. Fig. 1 shows the configuration of interface link between these two systems by network router equipment. The SCADA systems send the state information such as powered centenaries sections or not, and reversely CTC systems sends the location information or train number of running trains to SCADA systems. Followings are summarized information for interface between these two systems.

- CTC ⇒SCADA
  - ·CTC system state information message: currently occupied section no. and trains no. of running trains
  - ·Control message : ACK/NAK
- SCADA ⇒ CTC
  - ·SCADA system state information message: centenaries section ID and state information of each section (powered section of not)
  - ·Control message: ACK/NAK

2.2 Structure of Designed Protocol

For the above-mentioned configuration of interface link between CTC and SCADA, we have designed new protocol for this interface link by the network-based structure. The designed protocol has used the well-known TCP/IP protocol for Ethernet LAN as a transport and network layer protocols. Fig. 2 shows the configuration of TCP/IP protocol-based message format on the Ethernet. So the functions for transport and network layers are not defined, but only the transmitted data field is defined to the new designed protocol. This protocol will be applied to vital railway signaling systems for safely at the phase of train control, so it is significant to reflect the function for improvement of reliability and safety at protocol design. Therefore, the 'Transmitted Data' field is very important step at TCP/IP-based protocol design for safety-critical system such as railway signaling systems.

Ethernet Header	IP header	TCP header	**Transmitted Data**	Ethernet tailor

Fig. 2 Configuration of transmitted message format

Length	Field	Remarks
1 byte	**STX**	Message Header
2 bytes	**Data Length**	Message Information
1 byte	**Sequence Number**	
1 byte	**Message Type**	
N bytes	**Data**	
2 bytes	**CRC**	

Where
- STX: start of frame
- Data Length: message length from Sequence no. to data
- CRC: CRC-16($X^{16}+X^{15}+X^{2}+1$)

Fig. 3 Structure of message data field

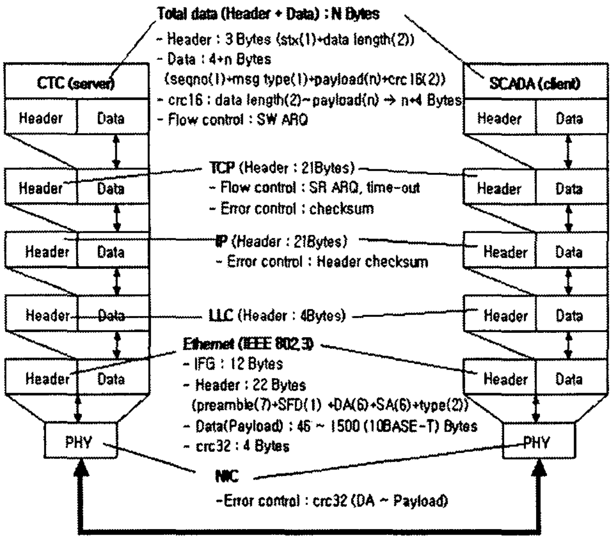

Fig. 4 Protocol Overview of data transmission between CTC and SCADA

Fig. 3 shows that the 'Transmitted Data' field of message format is consisted of two parts: message header and message information parts. In message header part, 'STX' and 'Data Length'fields are included for the function of beginning of transmitted message frame and length of information data part. And there are real transmitted fields in the message data part such as 'Sequence Number', 'Message Type', 'Data' and 'CRC'field. As you know, it is not required the 'Sequence Number', 'Message Type' and 'CRC'field in well-known data field for TCP/IP-based protocol, because similar functions for above-described several fields are already implemented in TCP and IP protocol. However those duplicated fields in the aspect of functions with some fields in TCP and IP protocol are added to improve the reliability and safety of designed protocol performance. According to those specially added fields, the designed protocol is able to apply vital control systems which require higher reliability such as railway signaling systems.

3. Performance Analysis of CTC/SCADA Protocol

As mentioned above in the introduction, the present state of communication protocol for Korean railway signaling does contain several problems. That is, there are some uncommon points in the protocol structure and different protocols are applied to interface links, despite the same functions. The new protocol of railway signaling is not expected to have these problems and it also requires the standardization of the novel designed protocol to improve operation and maintenance ability. We have deduced a performance analysis model of designed protocol. The performance of network-based protocol for interface between CTC and SCADA systems is analyzed through computer simulation. The designed communication protocol is adopted as a Korea Railway Standard by the KORAIL.

Fig. 4 shows the overview of the data transmission between CTC and SCADA systems. As this figure, there is CRC32 error detection code in the inherent Ethernet frame header. The elementary performance criterion of the communication system is the bit error rate (or bit error probability), which is the first calculation step for data link protocol simulation. The transmitted-bit error rate can be expressed as equation (1) [5][6].

$$P_b = Q(\sqrt{E_b(1-\rho)/N_0} \qquad (1)$$

Where

P_b : *transmitted-bit error probability,*

E_b : *signal energy of a bit*

N_0 : *noise power per bandwidth,*

$\rho=0$: *orthogonal signaling*

$\rho=-1$: *antipodal signaling*

Q : *cumulative standardized Gaussian probability density function*

In the above equation (1), if the two binary signal vectors are orthogonal, θ is zero and if the two binary signal vectors are antipodal, θ is negative, so that antipodal signals have the lower transmitted-bit error probability. Provided that the signal to noise ratio (E_b/N_0), P_b is calculated according to the two signal types (orthogonal and antipodal). With equation (1), frame error rate is obtained as equations (2). The derived mathematical models can be applied with inherent error detection code in Ethernet frame.

$$P_c = (1-P_b)^n, \quad P_d = 1 - P_c - P_n, \qquad (2)$$

$$P_{ud} = 2^{-kb}[1+(1-2P_b)^n - 2(1-P_b)^n]$$

$$P_{fe} = P_{ud}/(1-P_d)$$

Where

P_c : *no error probability,*

P_{ud} : *error no detection probability,*

P_d : *error detection probability by error detection code,*

P_{fe} : *frame error probability,*

n : *the number of code bit,*

k : *the number of information bit*

To improve the protocol performance to frame error rate, additional CRC16 error detection code is added in data field such as above section 2 described new standard protocol. The Following equation (3) is the frame error rate with supplemented CRC16 in data field.

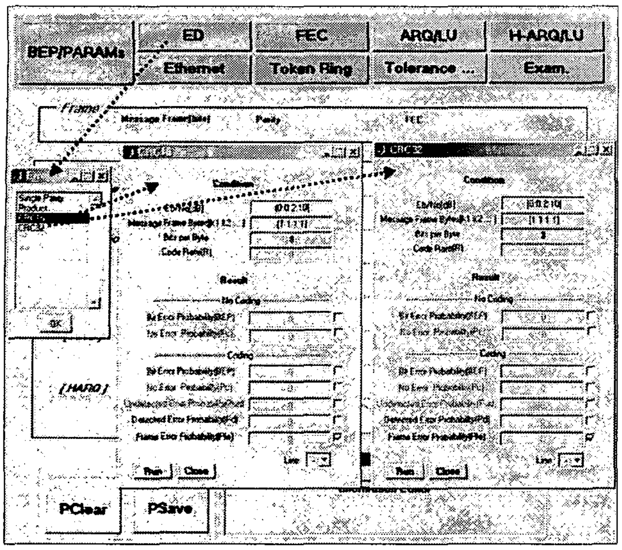

Fig. 5 Simulation program main window

$$P_{fe} = P_{fe32}\, P_{ud16}/(1 - P_{fe32}P_{a16}) \quad (3)$$

where

P_{fe32} : *frame error probability with only CRC32 code*

P_{d16} : *frame error detection probability by CRC-16 code*

P_{ud16} : *error no detection probability by CRC16 code*

The simulation for performance analysis of designed network-based protocol between CTC and SCADA is carried out on the basis of the above mathematical modeling, and the frame error probability is considered as a major performance metrics. The simulation is performed under the circumstance with/without supplemented CRC16 error detection code in data field of transmitted frame.

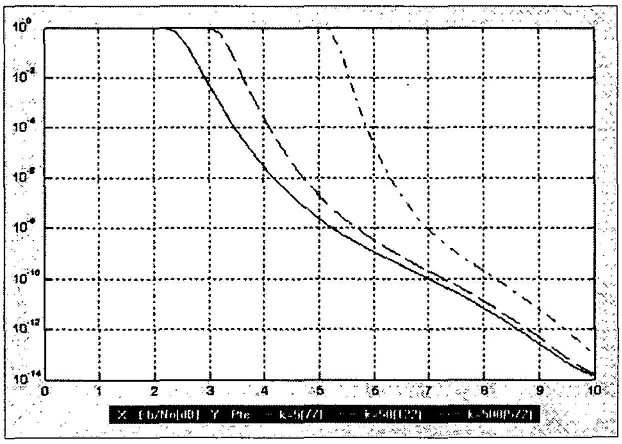

Fig. 6 Simulated results P_{fe} without additional error detection code (CRC32)

Fig.5 shows the main widow of developed simulation program, made by Matlab and Matlab GUI tool, for performance analysis of designed protocol. This developed simulation tool is consisted of BEP/PARAM part which is to calculate the bit error rate through Eb/No and to set parameters for performance simulation, ED part which is to simulate the error detection code performance, ARQ/LU part which is to calculate the throughput and transmission latency in case of each ARQ scheme, and et al.

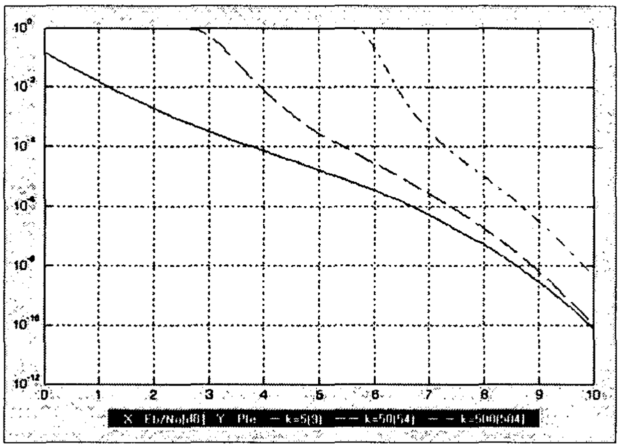

Fig. 7 Simulated results P_{fe} with additional error detection code (CRC32/CRC16)

Fig.6 indicates the frame error probability characteristics without additional error detection code (CRC32) and the result are provided for 5, 50, and 500 bytes data field length of the message frame respectively. And also, Fig. 7 indicates the frame error probability characteristics with additional error detection code (CRC32/CRC16) and the result are provided for 5, 50, and to 500 bytes data field length of the message frame respectively.

From these two results, the designed protocol including additional CRC16 code in data field has better performance than that without additional error detection code. And also we could know from this simulation that the length of data field has been influenced in error probability. This illustrated that performance of protocol with supplemented error detection code are improved comparing with only inherent Ethernet frame error detection code.

Fig.8 shows the results of processing ratio/throughput among main installations when increasing the byte values of data, which are transferred to between SCADA/CTC, from 5 to 50, and to 500 bytes. Only those related to propagation delay are included into the factors of the delay. From the result of the Fig. 8, in the case that the result of simulation and data transmission message are 500 bytes, the processing ratio/throughput becomes nearly 0 when Eb/No is below 5 dB, while the processing ratio/throughput increases rapidly and become over 0.9 when Eb/No increasingly reaches over 6 dB.

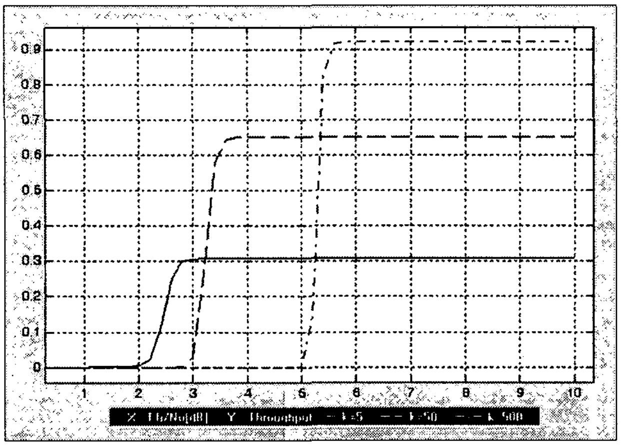

Fig. 8 Simulated throughput results with additional error detection code (CRC32/CRC16)

4. Conclusion

This paper describes the designed network-based communication protocol structure for railway signaling systems and simulated results for performance analysis of designed protocol. Existing protocols for signaling have some problems. The novel protocol is designed to solve these problems. To verify the designed protocol performances on data link control, the simulation is carried out on two protocols under the same conditions. From the performance analysis, it is verified that the new protocol achieves good performance, especially the transmitted frame error rate aspect. And also the designed protocol between railway signaling system and SCADA system is adopted as a standard protocol by KORAIL. The increase in the safety, reliability and efficiency of maintenance of railway signaling systems is expected by using the newly designed communication protocol for train control systems in Korea.

References

[1] J. G. Hwang and J. H. Lee, "Performance analysis of data link protocol for railway signaling", Proceeding of World Congress on Railway Research, Oct. 2003.

[2] J. G. Hwang and J. H. Lee, G. T. Park, and Y. J. Park, "A New Data Link Protocol for Korea Railway Signaling Systems", KIEE Int'l Trans. on EMEC, Vol.3-B, No.4, pp. 195-201, Dec. 2003

[3] S. Lin, D. J. Costello and M. J. Miller, "Automatic repeat request error control schemes", IEEE Trans. Com., Vol. 22, pp. 5-17., 1998.

[4] J. H. Lee, J. G. Hwang, and G. T. Park, "Performance Evaluation and Verification of Communication Protocol for Railway Signaling Systems", Computer Standards & Interfaces (CSI) in Elsevier, vol. 27, pp. 205-219, Feb. 2005.

[5] S. B. Wicker, "Error Control System for Digital Communication and Storage", Prentice Hall, pp. 99-128, 1995.

[6] B. Sklar, "Digital Communication Fundamentals and Applications", Prentice Hall, pp. 104-136, 2001.

[7] Bernard Sklar, "Digital Communications, 2nd ed.", Prentice Hall, 2001.

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