# A New Data Link Protocol for Railway Signaling Systems

**Jong-Gyu Hwang*, Jae-Ho Lee*, Yong-Jin Park** and Gwi-Tae Park*****

**Abstract** - In accordance with the computerization of railway signaling systems, the interface link between signaling equipment has been replaced by a digital communication channel and the importance of this communication link has become increasingly significant. However, there are some problems with the present state of railway signaling. First, different communication protocol is applied to interfaces between signaling although they have the same functions. Next, the communication protocols currently used in the railway fields contain various illogical components such as structure, byte formation, error correction scheme and so on. To solve these matters, a new data link protocol for railway signaling systems is designed. In this paper, the structure of protocol and the results of performance analyses are presented. It will be expected to increase the safety, reliability and efficiency of maintenance of signaling systems by using the designed communication protocol for railway signaling in Korea.

**Keywords:** Data Link Protocol for Railway Signaling Systems, Local Data Transmission System and Electronic Interlocking System.

## 1. Introduction

In accordance with the computerization of railway signaling systems, the interface link between railway signaling equipment has been replaced by a digital communication channel and the importance of this communication link has become increasingly significant. Most railway signaling is operated under coarse environments such as terribly high and low temperatures, vibration, EMI, etc. Even under such conditions, railway signaling systems must be safely operated. Thus, a high reliability of performance for safe operation is essential for not only signaling equipment, but also for communication links between signaling.

There are several standard communication protocols for railway signaling systems in other countries. Among the national standard protocols, SAAT and BR 1631 protocol are representative ones. The SAAT protocol is a French standard protocol for railway signaling systems applied by the SNCF (French National Railway Authority) in the French railway field, and the BR 1631 protocol is UK's national protocol. The above two national standard protocols are only applied in each country [2-3]. The safety, reliability and efficiency of maintenance for signaling systems have improved by application of their standard protocols. However, their country's protocols are not considered to be international standards and therefore, the above-mentioned protocols cannot be applied to the KNR's signaling systems.

There are questionable matters on currently used communication protocol for railway signaling systems in Korea. First, the existing communication protocol for railway signaling contains varied communication procedures to be applied to interfacing between signaling, despite having identical functions, simply because they are offered from different manufacturers. This creates a number of difficulties in the maintenance of the signaling communication equipment. The other is that the existing protocol is questionable in the aspects of structure, byte formation, error correction scheme, etc. According to these matters, there have been many difficulties related to the maintenance and decrease of reliability on the communication link. So, the KNR (Korea National Railroad) has essentially required for a reliable standard protocol to be implemented. More detail concerning the troubles with conventional protocols are described in section 2.

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. In this research, we developed a simulation tool to analyze the performance of data link control protocol for railway signaling. The simulation tool is developed based

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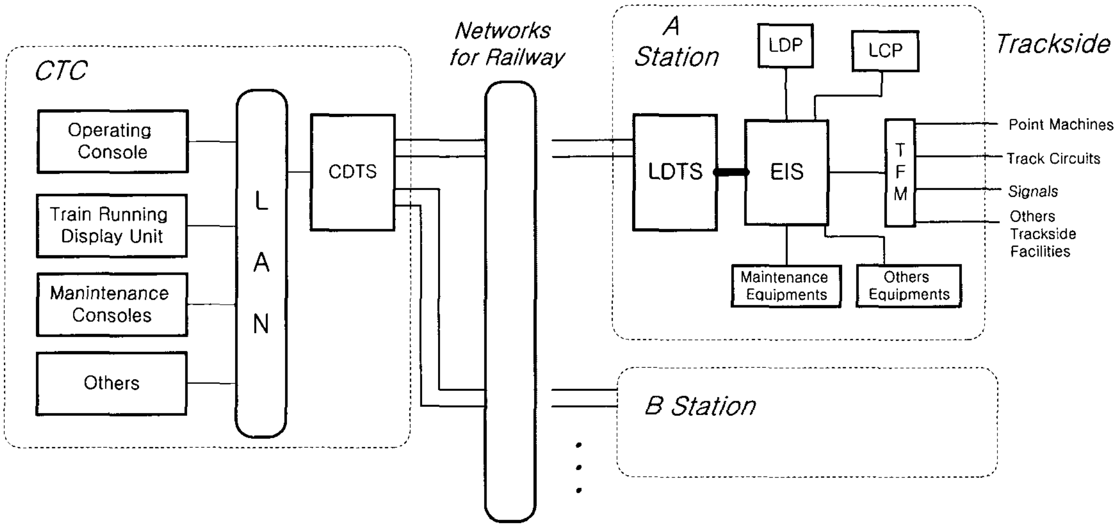



*CTC : Centralized Traffic Control*
*LDTS : Local data Transmission System*
*LCP : Local Control Panel*
*TFM : Trackside Functional Module*
*CDTS : Central Data Transmission System*
*LDP : Local Display Panel*
*EIS : Electronic Interlocking System*

**Fig. 1** Configuration of Railway Signaling Systems

on Matlab and can easily regulate various data link control conditions. The main purpose of data link control simulation is the analysis of link throughput, bit error rate, frame error rate and other metrics under variable communication link conditions such as signal type, propagation speed, physical link conditions, ARQ methods, etc. [5-8]. The performance of data link control protocol for railway signaling is to perform evaluation through developing a simulation tool, and we design the communication protocol for railway signaling based on the analysis of the simulated results.

The designed communication protocol has been adopted as a Korea Railway Standard by the KNR. The structure of the designed communication protocol for Korea railway signaling and the comparative analysis results between existing and newly designed communication for signaling equipment is presented.

## 2. Conventional Data Link Protocol for Railway Signaling

In this research we have reviewed the existing communication protocol for interfacing between signaling equipment currently used in the railway field. First of all, we survey the communication protocol between the EIS (Electronic Interlocking System) and the LDTS (Local Data Transmission System), which is representative signaling equipment of the KNR. Fig. 1 shows the configuration of railway signaling systems for the KNR. Among this configuration, the interface link between the EIS and the LDTS is only concentrated in the survey. The LDTS, which is located in the signaling equipment room, receives the commands from CTC (Centralized Traffic Control) for control of field signaling equipment such as the EIS, point machines, signals, etc., and then relays them to the EIS. Conversely, the LDTS transfers state information of the field signaling equipment from the EIS to CTC. The EIS transfers the commands from the LDTS to other field signaling equipment such as point machines, signals, etc. If this link contains any faults or errors, they may lead to a severe accident because the interface link is the essential hub-link for controlling and monitoring railway signaling, so the interface link is a significant link from the point of view of safety of the railway signaling operation. Fig. 2 shows the configuration of the LDTS and the EIS.

Several communication protocols are currently applied to the above mentioned interface link between the LDTS and the EIS. One of them, the I/O protocol, which it is broadly called, is used widely in the field. Thus, the structure and performance analysis of the I/O protocol only is presented in this paper. We found that the I/O protocol does have certain drawbacks.

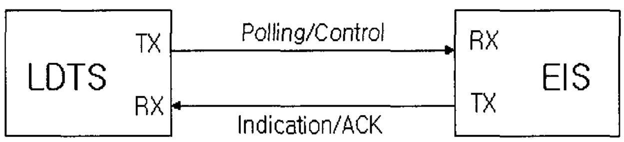



**Fig. 2** Interface Link between LDTS and EIS

| Flag | Bit 7 6 5 4 3 2 1 0 | | |
|---|---|---|---|
| 1 | Destination Type Number | | Destination ID Number |
| 0 | Source Type Number | | Source ID Number |
| 0 | Long/ Short Bit | LONG : MESSAGE TYPE, BIT 0 - 6<br>SHORT : MESSAGE TYPE, BIT 0 - 6 | |
| 0 | Long : Length of Message(including bytes 1-4)<br>Short : Termination Checksum | | |
| 0 | Long : Data Byte 1 . . . n | | |

**Fig. 3** Message Frame Format (EIS => LDTS)

First, the byte formation differs from the generic byte formation. One byte generally consists of 8 bits but one byte in the existing protocol is composed of 9 bits as shown in Fig. 3. The reason for this is that at the time it was developed, the Korean computing systems were able to support 9 bits byte formation efficiently. As revealed in Fig 2, the 9th bit of the first byte of message frame is set to '1' and the 9th bit of residual bytes of the message frame is set to '0'. The '1' set of the 9th bit indicates the start of a transmission message. It is ineffective to have a valuable field indicating message initialization. Therefore, the I/O is referred to as a 9th communication protocol throughout Korean railway fields. However, the computer life cycle is too rapid to catch the efficient but isolated computing system like 9 bits byte formation. As a result, generic 8 bits byte formation should be accepted as a standardization of protocol.

Another uncommon point in the I/O protocol is the existence of the 'Destination and Source Type/ID' field. In a point-to-point communication protocol, there is no need for these unusual fields as they do not assist with practical message transmission format. This malformation for the transmission of message frames is an inheritance that existing protocol acquired when they didn't convert to new protocol when conventional electric interlocking equipment, communicating multi-drop type to I/O board, was replaced with newer electronic equipment. That is, the LDTS still considers the EIS as relay-based electric interlocking equipment. Besides the above two matters, there are additional minor troubles in the protocol, but these two drawbacks are major points.

## 3. Performance analysis of ARQ schemes

The elementary performance criteria of the communication system are bit error rate (or bit error probability), which is the first calculation step for data link protocol simulation. Transmitted-bit error rate can be expressed as equ. (1)[4-5].

$$P_b = Q(\sqrt{E_b(1-\cos\theta)/N_0} \quad (1)$$

Where $P_b$ : transmitted-bit error probability,

$E_b$ : signal energy of a bit

$N_0$ : noise power per bandwidth,

$\theta$ : angle between two binary signal vectors

$Q$ : cumulative standardized gaussian probability density function

In eq. (1), if the two binary signal vectors are orthogonal, $\theta$ is zero and if the two binary signal vectors are antipodal (or bipolar), $\theta$ is negative, so that antipodal signals have 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 (unipolar and bipolar). With equation (1), frame error rate is obtained as equations (2) and (3).

$$P_c = (1-P_b)^n,\ P_d = 1 - P_c - P_n,$$
$$P_n = 2^{(k-n)}[1+(1-2P_b)^n - 2(1-P_b)^n] \quad (2)$$

$$P_{fe} = P_n/(1-P_d) \quad (3)$$

Where $P_c$ : no error probability,

$P_n$ : error 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

In equation (2), $P_n$ is able to model to some modified error detection code such as parity check, check sum, CRC, etc. The above-represented model is employed when using CRC code for transmitted-bit error detection. The main purpose of data link control simulation for performance analysis is to verify throughput, frame error rate or etc. under various link conditions such as signal type and signaling rate, $E_b/N_0$ , physical link conditions, error control and ARQs. Generic ARQ schemes used in data link control are Stop-and-Wait (SW) ARQ, Go-Back-N (GBN) ARQ and Selective-Reject (SR) ARQ. From several calculation steps under link conditioning parameters, link throughput values can be obtained as equation (4) in case of SW ARQ.

$$\eta_{sw-ARQ} = \frac{k}{T_D R_S} = \frac{k}{n + n'} \quad (4)$$

Where $T_D$ : transmission delay time,

$R_s$ : symbol rate

$n'$ : $T_{dca} \times R_s$

$T_{dca}$ : delay time for transmission

The above modeling of equation (4) can be obtained under the assumption of no error detection during message transmission. From this modeling we can find that the throughput, $\eta_{sw-ARQ}$, is decreased by an increase in $T_D$. If an error is detected within transmitted data at the receiver, the average number of retransmissions of identical messages is as follows:

$$N_R = (1 - P_d) + 2P_d(1 - P_d) + 3P_d^2(1 - P_d) + \ldots$$
$$= \frac{1}{1 - P_d} \quad (5)$$

From equations (4) and (5) throughput values can be obtained as illustrated in equation (6) in case of SW ARQ with the existence of transmitted-bit error.

$$\eta_{sw} = \frac{k}{(T_D N_R) R_S} = \frac{(k/n)(1 - P_r)}{n + n'} \quad (6)$$

A similar modeling procedure is able to apply to other schemes, such as GBN and SR ARQ, used in data link control. Link throughput for these two ARQ schemes is expressed as equations (7) and (8), respectively.

[Go-Back-N ARQ]

$$\eta_{GBN} = \frac{(k/n)(1 - P_d)}{1 + (n'/n)P_d} \quad (7)$$

[Selective-Reject ARQ]

$$\eta_{SR} = \frac{k}{n}(1 - P_d) \quad (8)$$

The simulation for performance analysis of data link control protocol is carried out based on the above modeling. Fig. 4 shows examples of simulated results under the following conditions: 6 bytes (message frame), 9600 bps (transmission rate), 10m (link distance), CRC 16 code (error detection code) and so on. The appropriate data link control scheme is decided through these simulations by tuning of each data link control parameter respectively in this research.

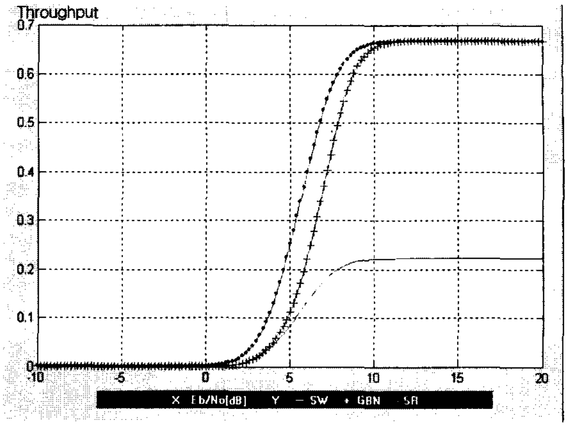



**Fig. 4** Throughput with CRC 16 error detection code

## 4. Proposed data link protocol

As mentioned above in the introduction, the present state of communication protocol for Korean railway signaling does contain certain problems. That is, there are some uncommon points in regards to protocol structure and different protocols are applied to interface links, despite identical functions. The new communication protocol of Korean 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 data link control protocol. The performance of data link control protocol for railway signaling is analyzed through this simulation tool to design new protocol and the communication protocol for railway signaling is designed from these simulated results. The designed communication protocol is adopted as a Korea Railway Standard by the KNR. In this section the designed communication protocol for railway signaling will be described concisely.

The designed protocol has an advanced structure and mechanism thereby removing drawbacks of the existing protocol. Furthermore, the protocol is able to be more accurate at communication by a combination of the 'STX' and 'ETX' fields. These added fields provide the same role as the existing 9th scheme. The 'STX' field signifies the start of the transmission frame, and the 'ETX' signifies the end of one. Also, the uncommon frame format in conventional files, 'Destination and Source Type/ID', has been removed. To improve the error detection performance during transmission of message frame, the BCC error detection code has been transferred to the CRC 16 error detection code. The application of this error detection code is expected to contribute to the decrease of frame error rate during communication. The simulated results for those will be represented in the next section. The designed transmission message format is as follows:

**Table 1** Message Format

| STX | Data Length | Sequence No. | Message Type | Data | CRC | ETX |
|---|---|---|---|---|---|---|
| 1 byte | 1 byte | 1 byte | 1 byte | N byte | 2 bytes | 1 byte |

Where

STX: start of frame,

Data Length: message length from Sequence Number to ETX (maximum 255 bytes),

Sequence Number: 0x00 ~ 0xFF, - Message Type: transmitted message types

Data: variable according to information,

CRC: CRC-16 code ( $X^{16} + X^{15} + X^{2} + 1$ )

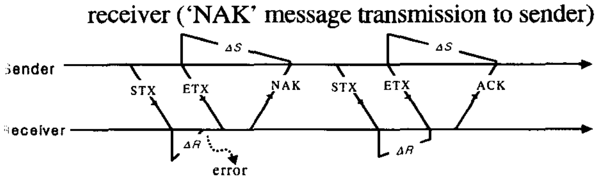
ETX: end of frame

The SW ARQ scheme is applied to error correction based on the CRC 16 error detection code, and the 'ACK/NAK' control message is used for error correction and flow control. A message must be retransmitted in case of error detection. The following is a description of the retransmission mechanism.

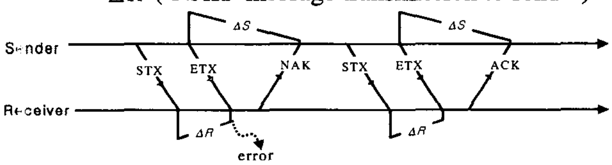
(a) If the following cases occur to the sender, the same message must be retransmitted to the receiver up to a maximum of 3 times.

① Reception of 'NAK' message to sender

Case I: Error detection in transmission frame by error detection code, fault of sequence number at receiver ('NAK' message transmission to sender)




Case II: No reception of 'ETX' message to receiver in spite of expiration of receiver timer setting time $\Delta R$ ('NAK' message transmission to sender)




② If sender could not receive any response message from communication receiver such as 'ACK' or NAK, even though sender timer was expired, then previous message retransmits to destination.

(b) Even though the identical message was sent 3 times, the sender could not receive any response from the destination, which the sender regards as a communication link error. Therefore, sender discards the transmission message and the link error process is executed. Then the sender periodically transmits the polling message with a 0x00 sequence number to receiver for identification of link restoration.

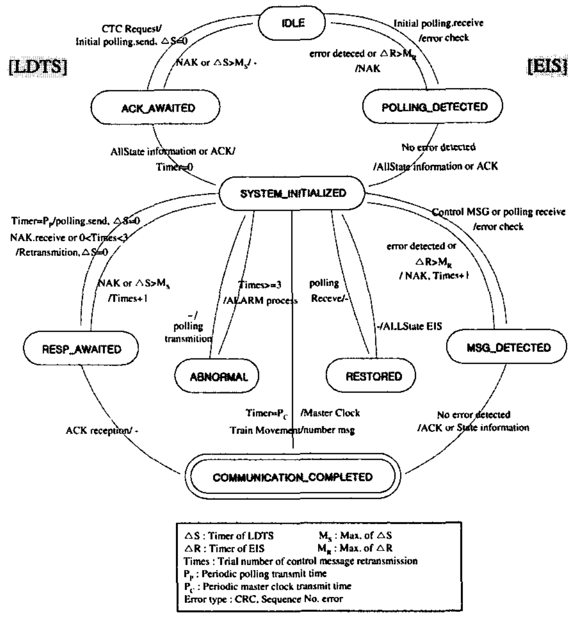



**Fig. 5** The I/O FSM modeling of designed protocol

Fig. 5 shows the I/O FSM (Finite State Machine) modeling of the designed protocol. As shown in the FSM modeling, the designed protocol is a concise mechanism with 9 communication states but the requirement for railway signaling interface is completely fulfilled.

## 4. Performance analysis of data link protocol

To verify the designed protocol performance on data link control, the simulation is performed on two protocols for railway signaling interfacing as described in sections 2 and 4 respectively under the same conditions.

The performance of data link control is simulated based on the performance analysis model presented in section 3, and frame error probability and link throughput are considered as performance metrics. These two metrics are very useful for data link control protocol. Table 2 depicts the simulation conditions for this comparative performance analysis.

**Table 2** Simulation Conditions

| | |
|---|---|
| $E_b / N_0$ | -10 ~ 20 [dB] |
| Signal type | Bipolar |
| Data field | 100 [Byte] |
| Physical link distance | 100 [m] |
| Effective noise temperature | 27[°C] |
| Media propagation speed (copper) | 2×10$^8$ [m/s] |
| ARQ scheme | SW ARQ |

With parameters shown, Table 2 simulation has been demonstrating performance characteristics of the designed protocol. Fig. 6 shows the frame error probability characteristics of the designed communication protocol and the existing one. Comparison of these results indicates that the frame error performance of the designed protocol is superior to the conventional one. Fig. 7 shows the link throughput characteristics of the two protocols, and the link throughput is greatly improved in the case of the designed protocol. These two figures demonstrate that the designed protocol has good performance by comparison to the conventional protocol.

Figs 8 and 9 show the performance characteristics of the designed protocol. Fig. 8 indicates the frame error probability characteristics and the result is provided for different values of data field length of the message frame. It is generally expected that an error probability of transmitted data be influenced on several factors such as message frame length, error control scheme, flow control scheme, etc. However, the results of Fig. 8 illustrate that the frame error probability is dependent upon transmitted message frame length but the effects for the designed protocol is low. Fig. 9 shows the results of link throughput when data field length is 7, 50 and 100 bytes.

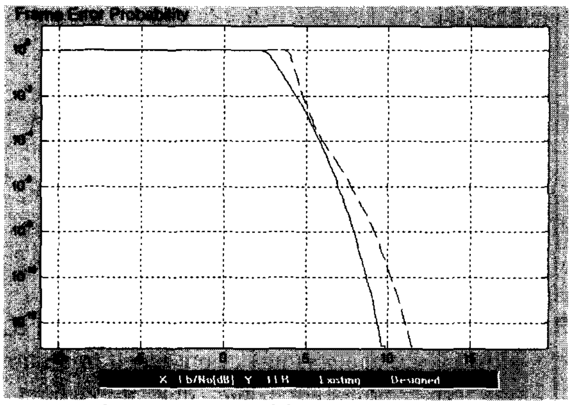



**Fig. 6** Comparison of frame error probability

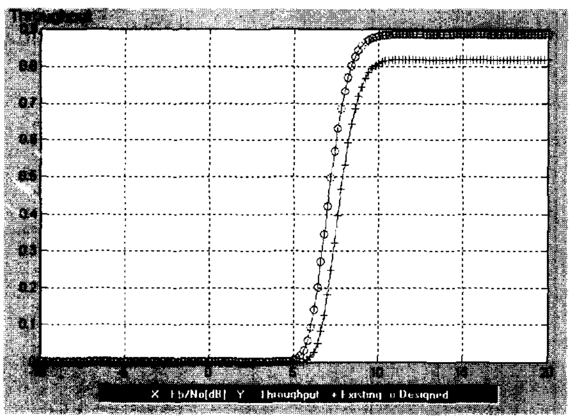


**Fig. 7** Comparison of throughput

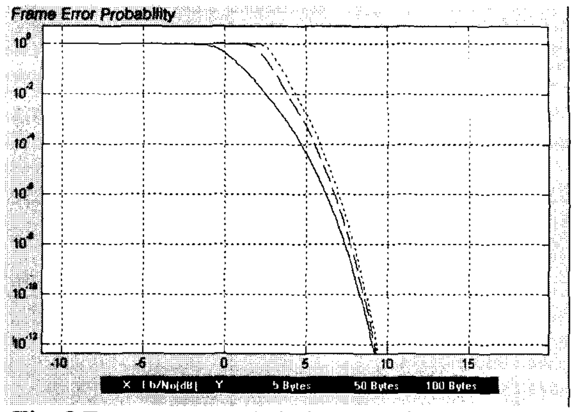



**Fig. 8** Frame error probability of designed protocol

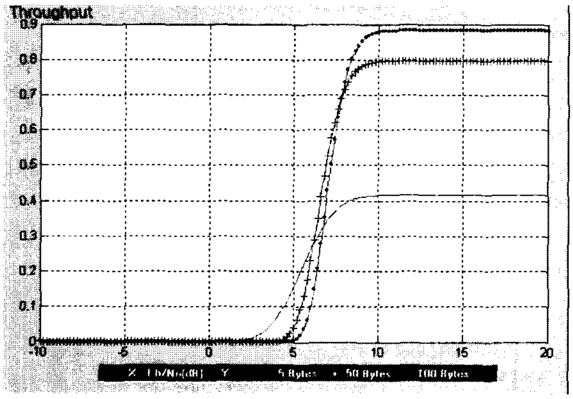



**Fig. 9** Throughput of designed protocol

This illustrated that the link throughput is dominantly dependent on transmitted frame length. An error probability of transmitted message is more essential metric than link throughput because of the requirement of high reliability for railway signaling. Therefore, variation scheme of data field length for novel protocol is well fitted to protocol scheme of railway signaling.

## 5. Conclusion

This paper describes the designed communication protocol structure for Korea railway signaling and its performance analysis results. Existing protocols for signaling do have some problems. The novel protocol for signaling is designed to solve these problems. To verify the designed protocol performance on data link control, the simulation is carried out on two protocols under identical conditions. From the performance analysis, it is verified that the innovative protocol has good performance and also that unquestionable matters surrounding protocol formation and mechanism are eliminated. An increase in the safety, reliability and efficiency of maintenance of signaling systems is expected by using the newly designed communication protocol for railway signaling in Korea.

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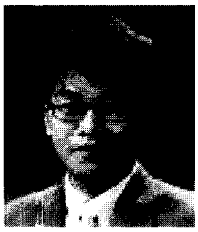

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