Performance Evaluation System of Communication Network for Train Control System Using Radio Communication

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This paper describes the development of a method to evaluate the performance of communication networks, in order to improve the efficiency of their design for radio-based train control systems. This method makes it possible to estimate the possible influence on operations of a new communication system, while avoiding the time and cost of conducting tests on actual lines. So the system development size and cost for not only a design stage, but also a prototype and an experiment can be reduced. In this paper, the author presents an outline of the performance evaluation system, and show examples of performance evaluation of a communication network.

Keywords: simulation, radio-based train control system, communication network, network performance

1. Introduction

Radio-based train control systems have been developed and increasingly used for railways as information and communication technology, known as ICT, progresses [1, 2]. Innovation in train control systems using ICT, aim to improve safety, flexibility of operations, and reduce maintenance costs. Train control systems transmit safety related information, such as train location and stopping positions, from track to train via radio communication. Therefore, the performance of the communication network including the radio data transmission circuit, is critical. If there is a fall in the quality of the communication network performance, such as loss of data on a radio data transmission circuit or transmission delay between track and train, it is safer to stop the train. However, it reduces the availability of the train control system. To avoid this type of situation therefore, it is necessary to improve the design of the communication network. The design process however consumes significant resources in cost and time and there on limits to what can be tested examine the performance of the network.

As such, this paper describes the development of a method to evaluate the performance of communication networks, in order to improve the efficiency of their design for radio-based train control systems. The method involves simulating the functions in a communication network taking into account radio data transmission quality along a line. This evaluation method will enable estimates to be made of the impact of any malfunction on the train control system. This paper presents an outline of the performance evaluation system, and provides an example of the performance evaluation of a communication network.

2. Developing the performance evaluation system for communication networks

2.1 Object modeling

The performance evaluation system commences with the modeling of the objects to be examine, according to the

standard configuration in JIS E 3801 [3, 4], which sets out the specifications for the radio based train control system (Japan radio train control system, hereafter referred to as “JRTC”). Annex E of JIS E 3801-2 contains some example JRTC configurations. Figure 1 shows a simple overall JRTC. Traffic on lines equipped with the JRTC is managed and monitored by the OCC (Operations Control Center). Train location data is used not only to ensure safe train operations by locking points and manage other traffic related equipment, it is also used to manage train movements and issuing authorizations for each train. Each train to be monitored and controlled is equipped with onboard devices. These are connected to data communication equipment.

JRTC works by transmitting safety related data between the track and the train via radio. Trackside devices manage information collected from trains, and calculate the location to which each train can move safely, according to the status of trackside installations, such as points and level crossings, and transmit movement authorizations and limits for each train. Each train has a fixed train protection profile, which will ensure it stops before the danger

Fig. 1 Example of JRTC configuration of

point, and prevents the train breaking speed limits. These profiles are set according to train performance, and track conditions, such as gradient and curves which in turn depend on train location. The elements outlined with a dashed line in Fig. 1 are the crucial elements for communication reliability and are the objects which have been modeled in the performance evaluation system. The evaluation method can be used for other radio based train control systems by adjusting the modeled parts.

2.2 Implementation of communication network model

2.2.1 Equipment model

A model is proposed in Figure 2 based on the JRTC configuration in Fig. 1. This model consists of two parts: the radio data transmission circuit model [5] and the communication network model for the radio based train control system.

The radio data transmission circuit model expresses functions below the second layer (data link layer) of the "Open Systems Interconnection (OSI) reference model" defined by the International Organization for Standardization (ISO). It simulates framing, error control, cryptography, modulation, diversity, radio wave propagation and radio noise environment along the railway line, and so on. And the simulation results of radio transmission quality will be handed on communication network simulation.

The communication network model expresses functions in layers above the second layer of the OSI reference model. To evaluate a JRTC communication network it is necessary to take into account not only data transmission lines but also control processing equipment (e.g. wayside equipment or onboard control equipment) which transmit control information. Thus, these pieces of equipment have been modeled as two general parts: a control processing part corresponding to the application layer, and a transmission processing part that processes data transmission.

Development of the evaluation performance system of

communication network uses OMNEST, which is an object-oriented modular discrete event network simulation framework. The programming language used is C++.

2.2.2 The control processing part

The control processing part performs JRTC specific processes, which determine the timing related to control information, transmit control information including header information such as source and destination, and receive control information before using this to process the next step. Aside from these functions, each equipment model has programmed individual characteristics. For example, the wayside equipment has functions such as managing and tracking trains, and the onboard control equipment has functions such as determining train location and braking control.

Common functions are to create control information and transmit it. These common functions output control information to other equipment models according to the timing control. The timing is set in each equipment model, along with the data size for each piece of control information. For example, by setting n bytes of data for each period t in the wayside equipment, control information with be transmitted to other connected equipment according to these parameters.

A simulation core of OMNEST manages the timing control for sending control information. It also manages the timing for arrival of control information. This is calculated on the basis of distance of equipment and data propagation. This parameter setting is done in a user friendly manner, so users can input values from the position of equipment based on mileage.

2.2.3 Transmission processing

Transmission processing handles data transmission based on the content of the control information from the control processing part and the other equipment model.

Fig. 2 Proposed communication network model

This part can combine communication protocol models from each layer along the lines of an OSI reference model, allowing some communication protocols to be changed according to the purpose required. The intra-site transmission network and the intra-site network have various possible network topologies such as star, ring, mesh, and so on. The hierarchical structure of this part provides an advantage because it is possible to replace communication protocol models to suit the network topologies.

2.2.4 Communication protocols

HDLC and TCP/IP protocol suite were used as communication protocols. HDLC is over 30 years old and it has been standardized by ISO, it has also become the prototype for various protocols. TCP / IP protocol suite on the other hand is widely used as the de facto standard and widely used in the industry. Routing protocols were also used to support multiple network topologies. Figure 3 shows the communication protocols employed for the present performance evaluation system. TCP/IP protocol suite and the routing protocols use the INET Framework, which has been published in OMNEST. These function according to specific parameters based on IEEE and RFC (Request for

Fig. 3 Communication protocols employed in the equipment model

Comments: specification issued by the organization to develop a standard technology for Internet.)

Models corresponding to physical layers incorporate the radio data transmission circuit model. The radio data transmission circuit model produces noise environment generated from train, and radio wave propagation environment in railway wayside, and outputs the bit error rate, flame loss rate and transmission delay time corresponding to the running position of the train.

2.3 Structure of the performance evaluation system

The overall structure of the performance evaluation system is shown in Fig. 4. It is operated by applying a variety of data such as definition of network configuration, simulation scenarios, configuration of the radio data transmission circuit, and train conditions. These data include various elements such as transmission speed and distance to installations, relationship between connections, radio base station location, radio system specifications, and propagation environment conditions. All this information is contained in a text file, so that the user can edit them directly.

When the user runs this system, each equipment model along with the contents of the imported file are connected, and then a network is built. And each equipment model transmits and receives control information as time progresses during the simulation. Trains are run repeatedly along the specified interval, according to two running patterns:

- Pattern A: run at the specified constant speed.
- Pattern B: stop at the specified location, and then re-accelerate.

It is possible to make multiple trains start at any specified interval. In this case, the subsequent train receives the location information obtained from the track side equipment, to which a distance margin is added to the rear end of the preceding train. A train protection braking profile is determined to ensure the safe movement of trains

Fig. 4 Overall structure of the performance evaluation system

Fig. 5 Verification result of transmission delay time

on the basis of moving blocks.

A simulation result is produced on completion of the test either when the set number of train runs has been reached, or when the specified simulation time has elapsed. The simulation result is also in text format, and can be expressed or used in a variety of ways, such as a graph or by being input into other general-purpose applications.

Figure 5 shows transmission delay time distribution for a network built for a JR-TC test line and the same network which was used in the simulation. Correlation of the blue line of the actual measurement value and the red line of the simulation result is 0.97, confirming that the simulation result accurately reproduces the behavior of the actual network.

3. Performance evaluation of a communication network

3.1 Items to be evaluated

Items to be evaluated to measure the performance of a communication network, include bandwidth utilization and throughput, that is, data transfer amount per unit of time. The performance evaluation system, in addition to outputting these items, also outputs items that can confirm the operating status of JR-TC visually. This is effective for understanding and resolving problems of the radio based train control system, such as the evaluation of transmission delay and stability, described in the next section.

3.2 Evaluation of stability

As mentioned in section 1, communication network performance has a direct impact on the effectiveness of the JR-TC. A loss of control information or increased transmission delay are detected by onboard control equipment as a transmission anomaly, which will bring the train to an emergency stop. Even though the problem does not jeopardize safety it disrupts operational stability.

Figure 6 depicts such a situation and also shows the probability of occurrence of each event on a color scale for train location. Green indicates that there is nothing, while the red implies high probability. The top of the lines indicate the probability of wayside equipment being detected

Fig. 6 Example of evaluation result of stability

as a “communication disconnection” which will stop the train. The bottom line represents onboard equipment. The second line is the probability that an error occurs along the transmission path to the radio base station from the onboard radio station. The third line indicates the path to the onboard radio station from the radio base station. “Communication disconnection” occurs when control information is lost several times in succession. In this example, although there is a loss of control information by radio transmission along a section approximately 500 to 1200 m, it does not lead to a “communication disconnection,” and therefore JR-TC operates stably. Based on these results, radio specifications and the network configuration can be determined.

3.3 Evaluation of transmission delay

Due to processing time and transmission timing of control information in each piece of equipment, it takes a certain amount of time for the control information to be transmitted to the destination equipment. An increase transmission delay affects the train control system performance resulting loss of accuracy regarding train position.

Figure 7 is a communication network configured to check transmission delay with two simple networks between the wayside equipment and the radio base station. When the user runs a simulation, two trains move from left to right in Fig. 7, at specified intervals. The onboard radio station sends and receives control information from the radio base station, and switches the connection at the switching point, from the radio base station A to the radio base station B. Control information that the preceding train has sent is reflected as a stop limit position for the subsequent train through the wayside equipment. The graph showing time delay for the stop limit of the subsequent train to be acknowledged, is shown in Figure 8. This simulation was conducted under the following conditions:

[Constant conditions]

- Maximum train speed of 90 km/h, and acceleration and deceleration of 2.4 km/h/s.
- Communication network used Ethernet and TCP/IP protocol suite, and transmission speed of 10 Mbps.
- Switching hub and router were assumed to be the ideal device with no processing delay.
- Distance between routers in the intra-site transmission

Fig. 7 Structure of network for evaluation of transmission delay

network was 3 km, representing the theoretical distance of about two stations, and distance between pieces of equipment in the intra-site network was 100 m, which is max length for a LAN cable of 10 Base-T.

- Transmission cycle of the wayside equipment was 500 ms.
- The radio system was specially selected for use with JR-TC, and transmission speed was 9600 bps.
- Radio access control method was TDMA, a multiplexing method that divides network connections into time slices, called time slots, where each device on the TDMA network connection gets one or more time slots during which it can transmit or receive data. Each time slot was 62.5 ms. Time slot allocation was determined randomly.
- Assumption that data length of control information could fit into one time slot (approximately 75 bytes.)
- Assumption that there was no loss of information, and that all devices were operating normally.

[Variable conditions]

- Radio transmission cycle varied every 250 ms from 500 ms to 3 s. (In other words, the time slot was increased by four.)

Figure 8 shows that when the radio transmission cycle

Fig. 8 Transmission delay obtained the subsequent train

Fig. 9 Minimum headway with radio transmission delay

was long, transmission tended to increase. That is, as transmission delay increased, the subsequent train would see the preceding train as closer than its actual position. This affects headway. Figure 9 shows minimum headway at every radio transmission cycle. This was calculated using the same simulation conditions, adding a train station in the Fig.7 configuration, with a 30 second stop at the station. As a result of the increasing radio transmission cycle, the transmission delay increased, and the minimum headway got longer.

4. Response to international standards

4.1 IEC 62280

IEC 62280 [6] is an international standard that defines the basic requirements of the transmission relating to safety for railway signalling systems. The first edition was published in 2002 in two parts. It was revised and the two parts merged in February, 2014. Transmission systems which were classified into two categories, either “open” or

“closed” , are now re-classified into three categories, with no major changes to the technical content. It is introduced in detail in references 7 for an overview of this standard.

This standard requires appropriate back up measures to be in place, to counter any failure in the transmission system. The basic requirements and steps and the concept of measures are shown. Its purpose is to support the development specifications and the implementation of a transmission system with the performance required for transmission of information relating to the safety. In this performance evaluation system, it is implemented to be able to comply with the requirements and measures shown in this standard. Concretely speaking, this can evaluate the effectiveness of functions such as sequence number and timeout, in targeting six threats (repetition, deletion, insertion, resequence, corruption, delay, masquerade, except masquerade,) out of seven threats listed in IEEE 62280.

4.2 Evaluation index and method

Evaluation indices are shown in Table 1 reflecting the six possible errors.

Evaluation of the sequence in which control information is received, checks if control information transmitted between ground and onboard is exchanged in the correct order. Identification number (ID) and sequence numbers are added to control information. Receiving devices check the authenticity of arriving control information by checking the ID. Sequence numbers increase when each equipment transmits control information. Receiving devices monitor the order of sequence. The wayside equipment and the onboard control equipment record the sequence as control information is received, comparing each new number with the last, and keeping track of the order in which control information is received. This evaluation corresponds to the three possible errors: repetition, insertion, and resequence.

Evaluation of the disposal rate of control information of the second item is intended to see whether control information transmitted between the ground and the onboard is exchanged laconically. Each equipment records the amount of control information to be sent and received, and deduces whether control information is discarded in the equipment or on the transmission path. This part of the evaluation covers the possible errors of deletion and corruption of data.

Evaluation of the system response performance of the third item is intended to see that how much delay is occurred by transmitting control information between the ground and the onboard. The equipment records the simulation time difference between when the equipment transmits control information and when control information is

received. Additionally, a processing time of the equipment is considered. This performance evaluation system measures and records the turnaround time (the time starting with the wayside equipment, proceeding through the onboard control equipment, and finishing with the wayside equipment.) This results is graphed a histogram so that the system response performance is evaluated. This part of the evaluation corresponds to the possible errors due to delay.

5. Conclusion

This paper outlines the proposed communication network performance evaluation system and provides an illustrative example of how it can be applied. The evaluation system outputs metrics indicating the performance of the communication network, and is able to check the operating conditions of the JRTC by evaluating stability and transmission delay. The compatibility of this method with the relevant international standard is also described.

This method makes it possible to estimate the possible influence on operations of a new communication system, while avoiding the time and cost of conducting tests on actual lines. This approach not only reduces the cost of designing a new network, but also allows experiments to be conducted on prototype solutions before introducing them into service. In future, this evaluation system will be improved, new functions will be added and it will be possible to combine this simulation method with other tools to simulate railway traffic control and passenger behavior. And this evaluation system will develop the system that is able to evaluate performance of communication network from a view of the effect of the train operation.

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Table 1 Example of evaluation items and corresponding possible errors

Item	Method	Corresponding error
1 Checking sequence of arrival of control information	Recording numbers supposed to appear in sequence	repetition, insertion, resequence
2 Disposal rate of control information	Recording the number of transmissions	deletion, corruption
3 System response performance	Recording transmission time	delay

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