A Study on the Application of Train to Train Communication in Train Control Systems

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Abstract — With the rapid development of GPS and wireless communication, train control technology is becoming the focus of system-wide optimization and intelligent control. Active train safety protection has become an important development direction. This paper introduces the background and significance of applying the train to train communication (T2T) into train control system, and suggests a design scheme and key working procedure of the system. The two trains interval tracing scenario was chosen to model and simulate the system by colored Petri Nets. For the fail-safe requirement, the fault model was specially introduced into system modeling to verify the functional correctness of the T2T based train control system. We also analyzed the packet loss rate with different channel qualities and different information transmission intervals. Our work provides the theoretical basis and suggestions for real system applications.

Keywords- train-train communication; train control system; CPN modeling

I. INTRODUCTION

Train control technology has been used to solve the safety and automation of train operation over the past decades. However, train control system in widely used is almost based on train-ground communication, ground equipment generates movement authority for each train according to the front track condition, and sends it to onboard, the onboard equipment calculate the permission speed and prevent the train over speeding or rear-end collisions. It is formed a linear information flow of “front train”→“ground”→“behind train”. With the rapid development of GPS, sensor and wireless communication technology, train control technology in USA, Europe and Japan has been started to focus on system-wide optimization and intelligentization[1][2]. The new vehicle-vehicle communication (V2V) technology has provided the new condition for the onboard active safety protection[3], train control system based train to train (T2T) communication can break through the traditional limit that ground transmits the onboard information, improve the system safety, and optimize the system structure. Therefore, introducing T2T communication into train control system is of great significance and development prospect.

However, the study of T2T communication in train control area are still at an early schematic studies and testing system development. JR East in Japan suggested translating ground controlling into onboard active controlling based on T2T communication in the next generation train control system[4][5]. Alstom group in France developed a simplified CBTC train control system based on T2T communication which has been tested run in Lille[6][7].

This paper analyzed the characteristics of T2T communication in railway, and suggested a T2T based train control system framework and working process, described the fault-security policy when communication failure occurs. In this paper, it chose a multi-train movement scenario as an example, and a built colored Petri nets model of train to train communication train control system to simulate and analyze the communication performance and system functions. Meanwhile, this paper proposed several suggestions for the establishment of real system.

II. THE DESIGN OF A TRAIN CONTROL SYSTEM BASED ON TRAIN-TRAIN COMMUNICATION

The meaning of train control system based on T2T communication is that extending the train-ground communication to train-train communication, the trains can directly transmit data without ground equipment. The new system achieves the redistribution of functionality by transforming some ground functions into onboard, thus it can reduce the number of ground equipment and optimize the system structure. Through T2T communication, the train can directly identify the front train’s position and determine the movement authority by itself.

Because of the safety-critical and the specificity of railway operation, there are some new features of T2T applying in train control system which include some challenges as well as convenience. Specific information as follows:

- The speed of moving communication nodes is more than 80km/h, and the high speed mobile nodes has higher requirement of the channel quality.
- The train nodes move regularly, so that we can predict its movement locus easily. After all the train can only be one dimensional moving and there won’t be any crossroad.
The fixed nodes is far more than mobile nodes in T2T based train control system, thus there is no need to consider the broadcast storm problem.

With the powerful computing ability and large storage capacity, mobile nodes is easier to realize the functions such as accurate positioning.

According to the above characteristics, the structure of a T2T based train control system can be suggested shown in Figure 1. T2T based train control system includes mobile nodes (trains), database station, relay station, control center(CTC), etc. The main work of T2T network is following: realizing the information interaction between train and train, train and CTC, train and interlocking, providing safe real-time data for the generation of movement authority, assuring function correctness when train registering, initiating, cancelling, normally running, shunting, etc.

Here we choose 2 trains interval tracing scenario to illustrate the work procedure of T2T based train control system. (1) A train requests to establish a connection with the front train. First the information will choose the node that is closest to the behind train. Then the information will be transmitted through other fixed nodes according to the direction of the train moving. The mode of transmission is Multi-hop. (2) When the front train has gotten the request from the train behind, it sends agreement to the back train, the information transmitting process is the same as step 1 except the direction of information transmission is opposite. (3) After the behind train receive the agreement from the front train, it confirms the message and ask for the position of the front train. (4) The front train send its real-time position, which means entering the data transmission normally. If there is a communication failure, according to the fault - security principle, the work process is: (1) the train takes full service braking until the train stops. (2) The train gets connection with CTC after the train stops for two minutes. (3) The train turns to Onsight(OS) mode which driver is responsible for driving. (4) The train check the communication condition every moment when it runs in OS mode. The sequence diagram of T2T communication is shown in Figure 2.
III. THE MODELING OF T2T BASED TRAIN CONTROL SYSTEM

We chose the scenario 2 trains interval tracing to build the CPN model according to the above design scheme of T2T based train control system. In this scenario, the modeling of whole communicate process adopted parting-module way to do the research and the whole model could be divided into three parts: sending module modeling, codes transmitting module modeling and message receiving module modeling.

When the train get connected with the front train, the message from the front train need to be send in course. The steps are listed below. (1) The train data should be copied to the packet sending module in order to finish the synchronization of complete information. (2) This module need to confirm the sending context by checking the timestamp in real system which is replaced by variable ‘n’ in this modeling and simulation. Every circulation of sending and receiving, n will be plus one and waiting for next round. (3) The front train sends message and the train behind receives the message. (4) This module need keep record about the sending and receiving. The CPN model of this part are shown in Figure 3.

After the message is sent, the fixed nodes will receive, judge and retransmit it. The steps of this part are following: (1) The fixed node receive and decode the packet and the front train information. (2) The fixed node compares ‘n’ which is on behalf of timestamp with preset value ‘k’ in order to check whether the information is effective. (3) According to the checking results, change the value of ‘n’ and ‘k’ and send the feedback for the next round sending. (4) If the receiving message is right, the fixed code store and forward the message. The CPN model are shown in Figure 4.

After the message packet is transmitted from the fixed code, the message receiving module of the second train will receive and save the message, this process is similar with fixed codes receiving packets. The step is: (1) The second train receives and decodes the packet to get the front train information. (2) The second train compares ‘n’ which is on behalf of timestamp with preset value ‘k’ in order to check whether the information is effective. (3) According to the checking results, change the value of ‘n’ and ‘k’ and send the feedback for the next round sending. (4) Stored the information. The CPN model of this module is shown in Figure 5.

When the train data or feedback are lost, ‘n’ and ‘k’ will remain unchanged. Thus, serial numbers that the front train receives will be same as before. So, it will ask for message with the last serial number and retransmission function will be realized. We can figure out the packet loss probability by counting for the retransmission times. The CPN model of this module is shown in Figure 6.
The most basic principle of railway is fail-safe and it is necessary to consider what the trains will do when there is communication failure. There are two links between the two trains, which are “train – relay station – train” and “train – fixed codes – train”. The two links are corresponding to ‘link1’ and ‘link2’ in Fig. 10. When the train gets its speed and position, it will set up these two communication links with the train ahead. If there is one link gets connected, the flag bit is set 1 and 0 if both of links are failure. When the two links are both failure, the system must ensure fail-safe.
The way and process of ensuring fail-safe are following: (1) When the train can’t get the message from the train ahead, it will take the message that the last time received as EOA for the front train can never run back. (2) After the train stops, it will report the condition of it to CTC, such as communicate status and position. (3) CTC will send the broken-down train information to other train on this line through relay station. (4) When the train stops for 2 minutes, it can ask CTC for OS driving if the condition if satisfied. (5) When the train is running under OS, it constantly check the connection with the front train. If the communicate condition is satisfied, it changes to T2T communication and goes into FS mode driving. The fail-safe model is shown in Figure 7.

IV. SIMULATION AND ANALYSIS

We combined the modules above and built the overview model with CPN Tools 4.0 as the simulation environment. The model and simulation results are shown in Figure 8. ‘Train1’ in top left of Figure 8 means data that the front train need to send and ‘train 2’ in top right of the figure means data that the train behind receives. “code” in this figure means fixed nodes of which function is transmitting message. Because the transmitting media among nodes is optical fiber and the transmission loss is very low, so it is simplified as one node here. In this simulation, train 1 has ten messages to send and each message has one serial number. If train 2 can’t get one message, it will ask for one more time according to the number until it receive all of the ten messages. The simulation result is shown in Figure 8.

In this simulation, it can set different failures to make train2 couldn’t receive the information from train1. We could observe the system working process and behavior in different condition. The simulation results are following: (1) The flag bit is 1 if one of ‘link1’ and ‘link2’ is normal and train2 could get all messages. (2) If none of ‘link1’ and ‘link2’ is normal, train 2 couldn’t get train1 information, but it can stop on time and turn to OS when it stops two minutes later. And CTC or other trains can get train1 position, lest affect other trains’ operation.

The design suggestions of actual system: although safety processes can protect the train from crash, it will affect the operation efficiency. Therefore, we need to consider using effective retransmission algorithm to ensure the train can receive information within a certain time limit and avoid it going into the fault-processing mode.

We can also get the relation between different channel quality and delivery rate by setting the value of channel quality. Figure 9 shows the delivery rates in different conditions and the rates come from 100 times simulation each channel quality. From the results we can see the delivery rate will lift with the channel quality rise. The trends tend to be linear.

The design suggestions of actual system: It is necessary to choose optical fiber as transmission media among fixed codes for there is nearly no loss using optical fiber. But the channel quality between trains is not easy to control, therefore it reinforces that effective retransmission algorithm is needed, so that the message can be received though the loss rate is high.

V. CONCLUSIONS

With the developing of communication and control technology, the research on the application of T2T communication in train control system is the development trend to increase the train intelligent degree. This paper first analyzed the current research on T2T based train control system and the feasibility of applying it in the field of railway. Then the T2T based train control system general design scheme and main working procedure are illustrated. The scenario that trains interval tracing was chosen to build CPN model and simulate. It is verified the functional correctness and fail-safety of the T2T based train control system. Finally, in this passage the simulation of the delivery rate under different channel quality and sending interval was analyzed. Meanwhile, it provided a theoretical basis and the suggestions for the real system established.

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