The Study on the Vehicle-to-Vehicle Communication model in the Vehicle-Communication-Based Train Control System (VBTC)

Ying Lin, PhD, Beijing Hollysys Co., Ltd.
Yuemiao Wang, PhD, Beijing Hollysys Co., Ltd.
Xiaoliang Wang, MSc, Beijing Hollysys Co., Ltd.
Chunming He, PhD, Beijing Hollysys Co., Ltd.

SUMMARY

Vehicle-Communication-Based Train Control System (VBTC) is one of the next generation train control systems based on the vehicle-to-vehicle communication. Unlike the traditional centralized train control systems which are based on the bidirectional communications between the on-board controller and wayside controller, the VBTC system is a decentralized train control system where train operation is self-disciplined by the on-board controllers. Based on the operation plan scheduled by the ATS, the on-board controller of a VBTC system obtains and calculates essential information, such as the train moving direction, speed and position data, and movement authority (MA), protecting the safety movements of the train. Limited by the communication capacity of the radio communication system, communication with all the other on-board controllers in the network at the same time is unachievable. Therefore, we propose a Vehicle-to-Vehicle Communication model which divides all the trains into Direct Relation Trains (DRT), Indirect Relation Trains (IRT) and None Relation Trains (NRT), according to their relative positions on the network. Each train on the network can distinguish its DRTs, IRTs, and NRTs by the proposed model so that it can communicate directly with its DRTs, communicate with its IRTs via its DRTs, and not communicate with its NRTs. As a result, a train can at least acquire information of two trains in one direction on the network without overloading the radio communication system. The vehicle-to-vehicle communication model is verified on our engineering prototype of a VBTC system. The verification results indicate that the model can resolve the challenges of the vehicle-to-vehicle communication in the VBTC system, supporting the development of the VBTC system theoretically and practically.

1 INTRODUCTION

Railway Control Systems are the vital systems to ensure the operation safety and efficiency of railway systems. The railway control system which is largely applied into the metro railway is mainly the Communication-Based Train Control (CBTC) system, which has achieved high safety and reliability. However, more and more disadvantages are merging during the CBTC system application. Firstly, there are too many wayside equipment in a CBTC system, which leads to too many interfaces between different equipment and too much data interaction between these equipment. Secondly, the CBTC system architecture is relatively complex because its control logic is realized by bidirectional communication between the on-board and wayside subsystems. Lastly, the CBTC system adopts centralized control concept so that its maintenance can be costly and its flexibility can be limited. Therefore, the Vehicle-to-Vehicle Communication-Based Train Control system is proposed to address these challenges. Different from CBTC systems, the VBTC system is a system of which control logic is mainly realized by Vehicle-On-Board Controller (VOBC). The Automatic Train Supervision (ATS) system in VBTC system manages the operation plans for the trains on the network and the Objective Controller Server (OCS) is designed to execute the control command sent from the VOBC and the ATS, reporting the wayside equipment state to the VOBC and ATS[1][2][3][4].

The Vehicle-to-Vehicle Communication model is one of the key technologies in VBTC systems. Limited by the capacity of the communication network, it is unachievable for one VOBC to connect with all of the other VOBCs in the whole network. Therefore, we propose a Vehicle-to-Vehicle Communication model which divides all the trains into Direct Relation Trains (DRTs), Indirect Relation Trains (IRTs) and None Relation Trains (NRTs), according to their relative positions on the network. Based on the divisions, one VOBC only need to communicate with its DRTs so that the communication load can be minimized.

2 THE STRUCTURE OF VBTC SYSTEM

The VBTC system consists of the ATS subsystem, the VOBC subsystem, the OCS subsystem, the DCS subsystem (Digital Communication System), Balise and Signals, which is typically depicted below:

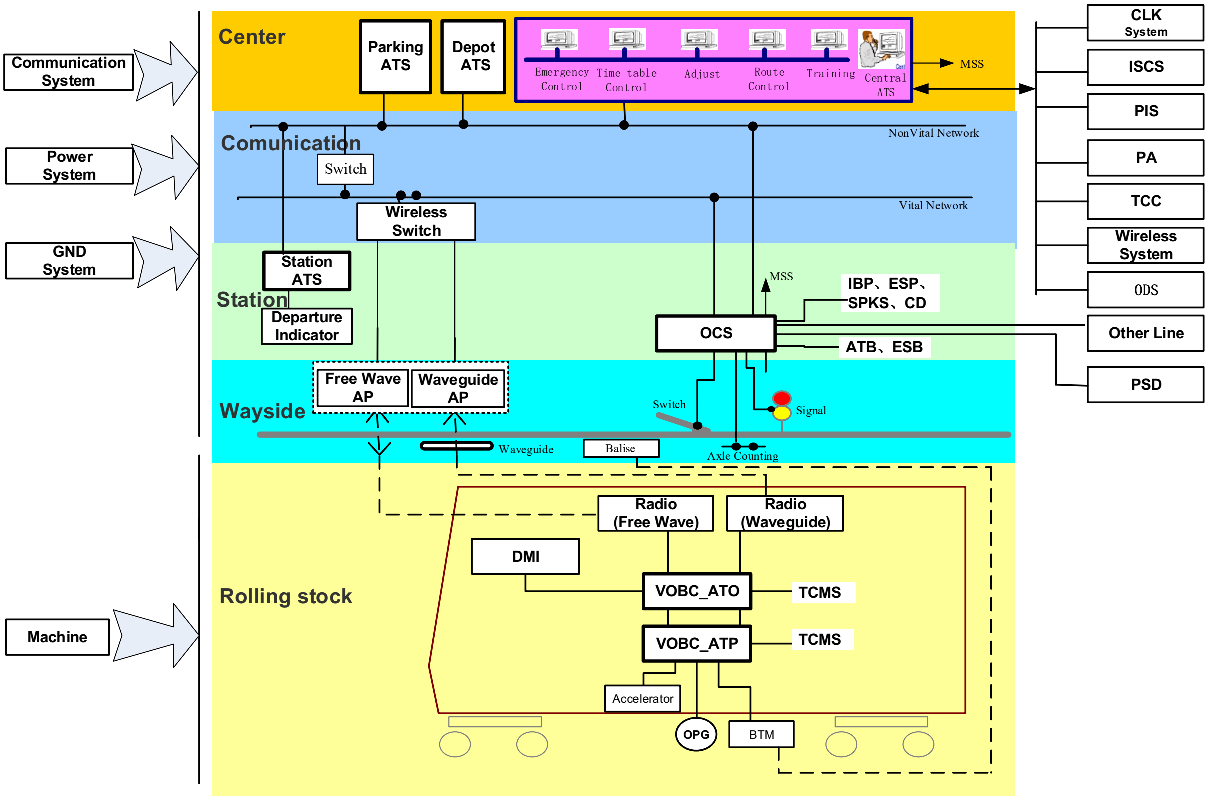

Figure 1: The Structure of VBTC System

- ATS subsystem

As the command and manage centre of metro operation, ATS draws up operation plans for the VBTC system and supervise the execution progress of the plans. The main functions of ATS are planning, supervising and rescheduling. Some other auxiliary functions may be involved such as data analysis, vehicle maintenance in depot, and so on.

- VOBC subsystem

VOBC is the kernel subsystem of the VBTC system. Based on the VOBC in traditional CBTC system, the VOBC in VBTC realize some new functions, which includes the management of the vehicle-to-vehicle communication, automatic route management, movement authority (MA) calculation, switch control. Based on the added functions, the Automatic Train Protection (ATP) and the Automatic Train Operation (ATO) can be achieved in VBTC systems.

- OCS subsystem

The OCS subsystem is a command execution unit which executes the command sent from the VOBC, such as the switch control commands and the PSD (Platform Safety Door) control command. According to the operation scenarios of traditional CBTC system, the OCS shall collect the conditions of the ESB (Emergency Stop Button), ATB (Automatic Turnback Button) on the platform and PSD, reporting the collected data to VOBC periodically. As a result, the functions such as emergency braking, automatic reversing, and linkage actions between the train doors and PSD can be realized.

➢ Axle Counting

On IL level (Inter-Locking level), the OCS which is upgrade from Computer Inter-Locking (CI) is used to for track occupation detection.

➢ Signal

On IL level, the signal is used to present the route information for the driver so that the driver can correctly drive the train according to the signal display.

3 VEHICLE-TO-VEHICLE COMMUNICATION MODEL

3.1 Definition: VOBC Connection Region

In the Vehicle-to-Vehicle Communication Model, all the tracks in the network are formalized as a non-direction graph, where only the connection relations between the tracks, switches and signals are remained and the information associated with directions is all omitted. Take one VOBC as the central point, three regions can be divided on the non-direction graph, including the Direct Relation Region, Indirect Relation Region and Non-direct Relation Region, which is presented below:

(1) Direct Relation Region

The train in Direct Relation Region is the Direct Relation Train, the central VOBC should establish communication connection with all the DRTs.

(2) Indirect Relation Region

The DRTs of the DRTs of the central VOBC is the Indirect Relation Train (IRT). The central VOBC does not communicate with the IRTs directly but collects IRTs' data from its DRTs. The region where IRTs belong to is defined as Indirect Relation Region.

(3) None Relation Region

The region that does not belong to Direct Relation Region or Indirect Relation Region is defined as None Relation Region. The trains in the None Relation Region is called None Relation Trains (NRTs).

To be noticed, the DRT, IRT and NRT are all trains in communication. Trains of which communication is failed are defined as None Communication Train (NCT).

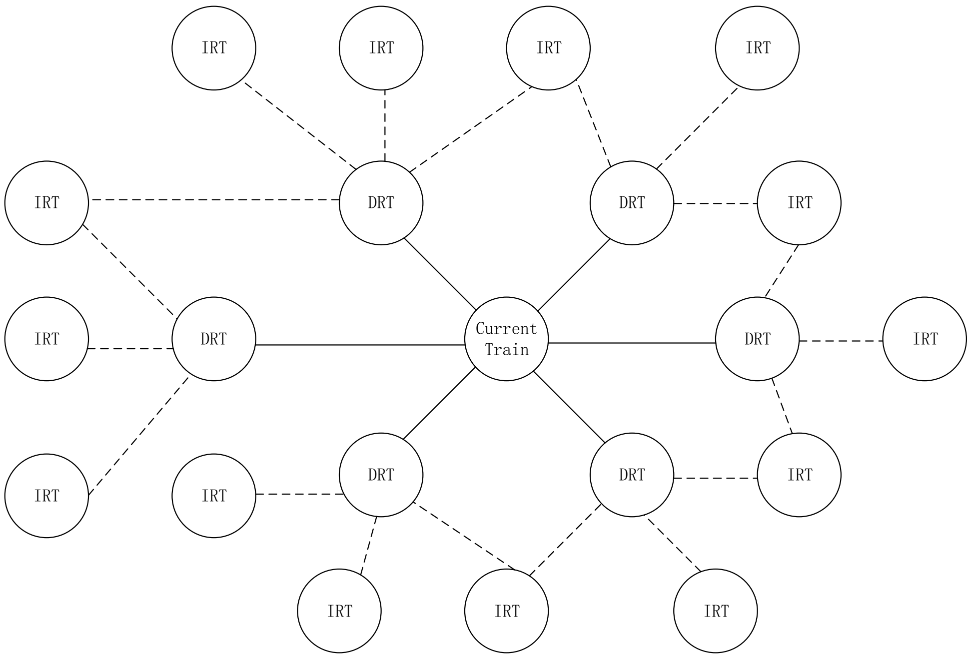

Figure 2: The Schematic of The Division Method of The DRT, IRT and NRT

The principle of dividing the DRT, IRT, and NRT is explained below,

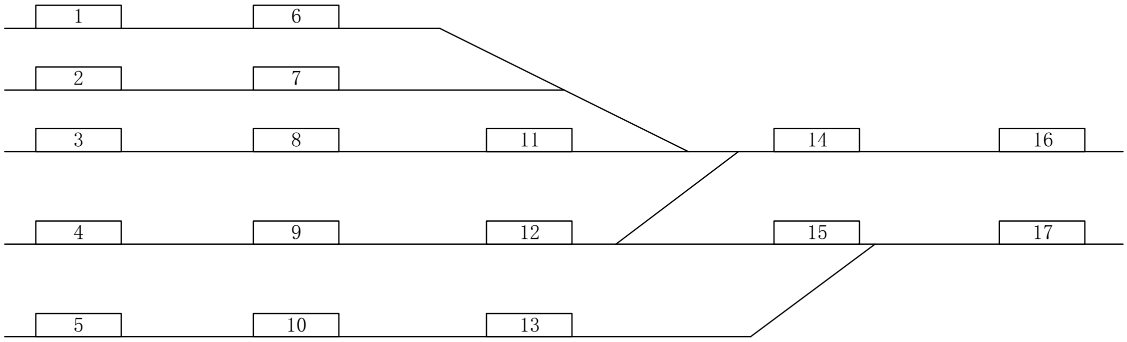

Figure 3: The Network Diagram of Railway

The non-direct diagram generated from the network diagram of railway is shown below:

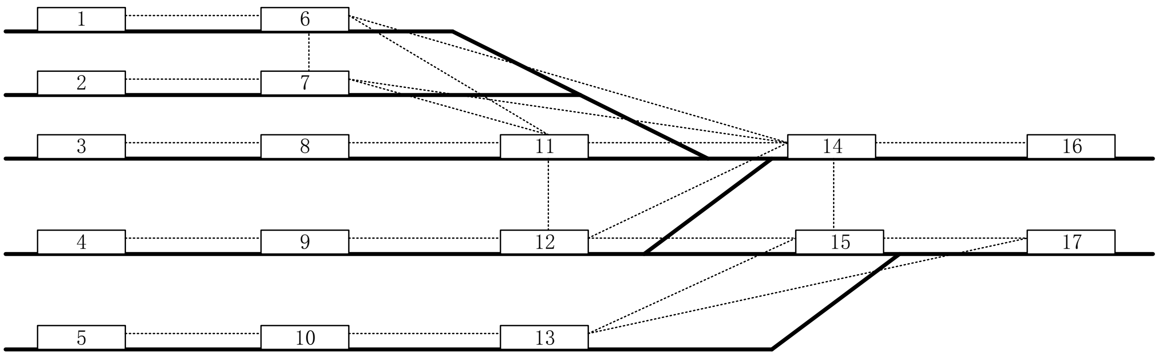

Figure 4: The Undirected Graph Based on Network Diagram of Railway of Figure 3

Choose the Train 14 as the central VOBC:

The DRTs of the Train 14 include: Train6, Train 7, Train 11, Train 12, and Train 16.

The IRTs of the Train 14 include: Train 1, Train 2, Train 8, Train 9, Train 18, and Train 19.

Choose the Train 11 as the central VOBC:

The DRTs of Train 11 include: Train6, Train7, Train 8, Train 12, and Train 14.

The IRTs of Train 11 include: Train 1, Train 2, Train 3, Train 9, Train 15, and Train 16.

Through the two cases presented above, the principle of distinguishing DRT, IRT and NRT can be summarized:

DRT is the trains on the first layer of the non-direct diagram. The first layer means: all the adjacent nodes of the VOBC. The adjacent nodes can be obtained by breadth-first searching.

IRT is the trains on the second layer of the non-direct diagram. The second layer means adjacent nodes of the nodes on the first layer, which can be obtained by breadth-first searching.

Note: if the train is DRT and IRT of another train, the train should be set as DRT.

3.2 DRT Searching Algorithm

The DRT Searching Algorithm consists of initialization module, local search module, normal search module, switch search module, cycle search module and the main function.

- Initialization module

The functions realized by the initialization module includes: loading on-board digital map, initializing the local train's position, and updating other trains' position

- Local search module

The functions realized by the local search module includes: searching whether there is DRT on the same track as the central VOBC on, initializing the search direction based on the search result.

- Normal search module

Starting from a chosen track, normal search module searches the following tracks with the determined search direction, to see whether there is DRT. If a DRT is found, the search on the certain direction is interrupted. If no DRT is found until the end of the network is achieved by the search, the search is end with no DRT found. The normal search outputs all the track ID, switch ID which have been searched, and the DRT ID which has been found by the normal search.

- Switch Search Module

Based on the searched track ID, switch ID provided by the normal search module, the switch search module calculates the list of available starting tracks, which is the input of normal search module in the next period of search.

- Cycle Search Module

Periodically call the normal search module and switch search module until all the achievable tracks have been covered by the search. The cycle search module outputs all the DRTs found by the multiple search.

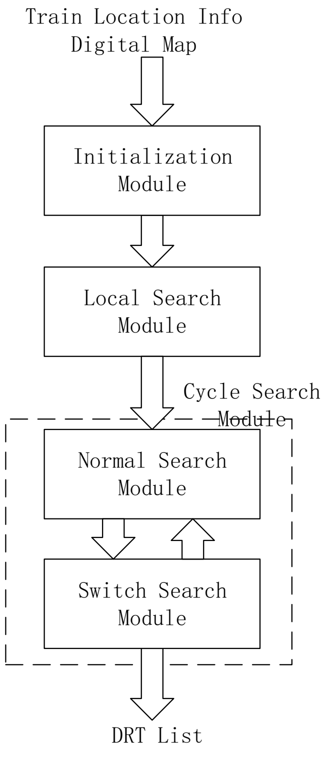

Figure 5: The flow chat of the DRT Searching Algorithm

4 SIMULATION AND VERIFICATION

To verify the correctness of the Vehicle-to-Vehicle Communication Model, we simulate the DRT Searching Algorithm to investigate whether the algorithm can correctly find all the DRTs for all the trains on the network. The case is based on the network shown in Figure 3.

Table 1: The DRT Search Result

Central Train ID	DRT ID List
1	[6]
2	[7]
3	[8]
4	[9]
5	[10]
6	[14, 7, 11, 12, 15, 1]
7	[14, 6, 11, 12, 15, 2]
8	[11, 3]
9	[12,4]
10	[5,13]
11	[8, 14, 6, 12, 7, 15]
12	[9, 15, 14, 11, 6, 7]
13	[17, 15, 10]
14	[16, 11, 6, 12, 7, 15]
15	[17, 13, 12, 14, 11, 6, 7]
16	[14]
17	[15, 13]

To verify the applicability of the Vehicle-to-Vehicle Communication Model, Chongqing Metro Line 3 is chosen as the simulation network. Hardware-In-the-Loop (HIL) testing platform is built to test the main functions of the VBTC system can be achieved based on the Vehicle-to-Vehicle Communication Model. The functions which have been test include ATS functions, OCS functions, VOBC functions, system tracking interval, and the performance of the wireless communication system.

The HIL testing platform consists of: 1 set of ATS, 1 set of OCS, 3 sets of VOBC, 1 set of DSU, 1 set of simulated wayside equipment, 3 sets of simulated VOBCs. The architecture of the HIL testing platform is illustrated below:

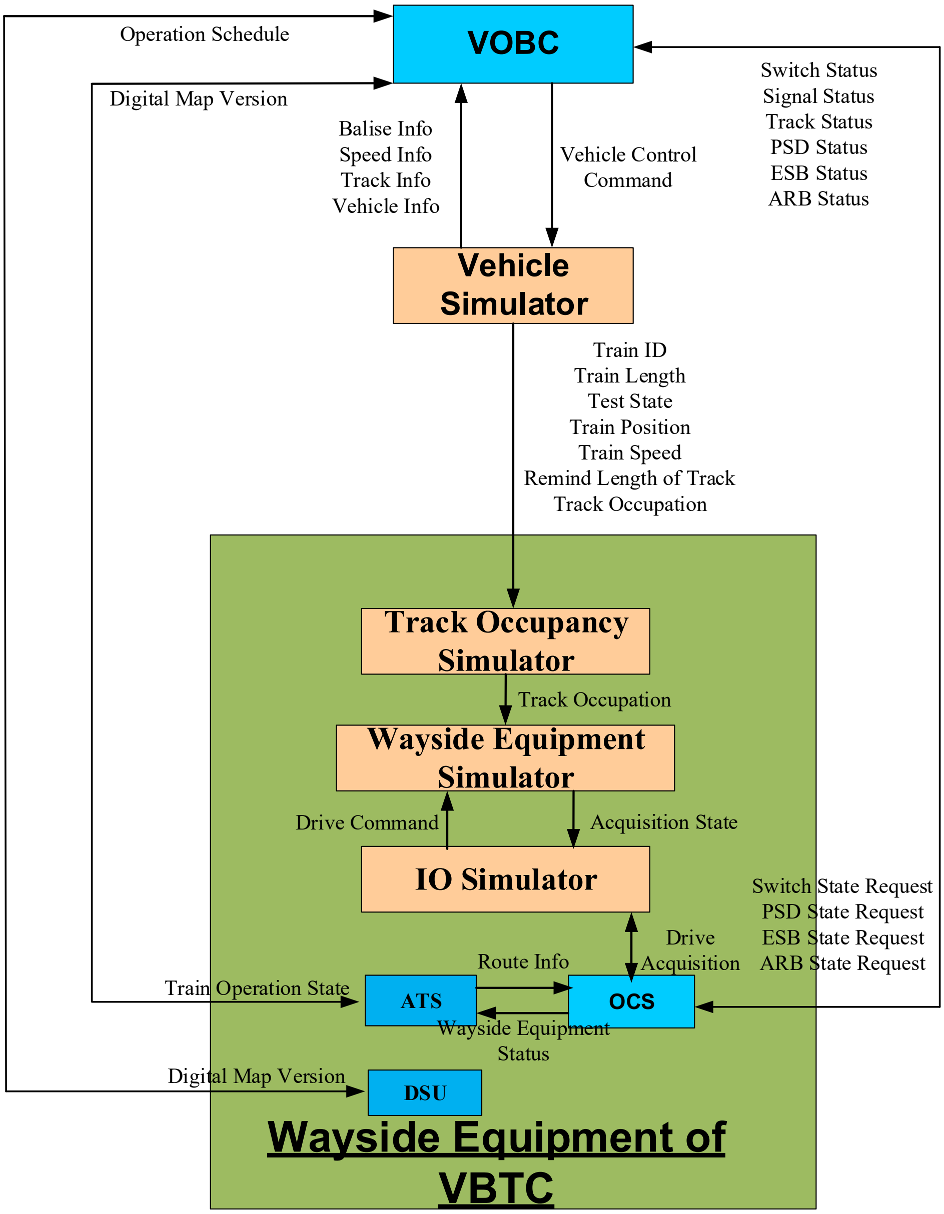

Figure 6: The HIL Testing Platform

Through the verification on the HIL testing platform, the Vehicle-to-Vehicle Communication Model can satisfy the performance requirements on a real time system and the functional requirements on a safety critical system. The period of the VOBC is less than 250 milliseconds. The tracking interval on the main line is 60 seconds and the network load is under 50% on average. All the system requirement specifications have been achieved[5].

5 CONCLUSION

The Vehicle-to-Vehicle Communication Model is one of the key technologies of the VBTC system. The VOBC Connection Region is proposed to divide the non-direct diagram of the network so that the trains on the network can be divided in the DRTs, IRTs, and NRTs. Since the central train only needs to connect with DRTs, communication load can be largely reduced by the proposed Vehicle-to-Vehicle Communication Model. The verification and testing results on the HIL testing platform indicates that the proposed model can significantly improve the system performance, satisfying all the system requirements on wireless communication. Therefore, ATP and ATO function can be fully achieved by the VBTC system.

6 REFERENCES

1. Tingkai Xia, Ke Cui. Prospect for the development of CBTC system in the next generation. Urban Mass Transit, Vol. 5: 7 - 11, 2018.

2. Ahmed Miske El Hadrami, Huiming Liu. Autonomy in railways: Autonomous train control and autonomous operation. Urban Mass Transit, Vol. 5: 37 - 39, 2018.

3. Jikang Xu. The research of a new type CBTC system based on train – train communication. Railway signaling & communication, Vol. 50, No.6: 78 – 80, 2014.

4. David Briginshaw. Alstom's simplified CBTC technology to debut in Lille. International Railway Journal, Vol. 6, 2013.

5. Rail Transit Vehicle Interface Standards Committee of the IEEE Vehicular Technology Society. IEEE 1474.1TM IEEE Standard for Communications-Based Train Control (CBTC) Performance and Functional Requirements. the United States of America: The Institute of Electrical and Electronics Engineers, Inc ,2005.