A Delay Analysis of Mass Volume Train Security Detection Network

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Abstract. Mass volume train security detection network is a reliable and real-time onboard train communication network based on the train level and vehicle level Ethernet network, which will send and transmit large capacity status and fault diagnosis data, the event log data, passenger information which are stored in different vehicles equipments for fault diagnosis and intelligent maintenance. The topology structure and onboard devices logic relation of the train security detection network is presented. Then, a delay model of different topology structure is analysed, which indicate that the onboard ring network is superior to the bus network topology. Finally, the analysis is confirmed by simulation results. The research results will improve control and network function of train.

1. Introduction

Railways are an important critical infrastructure because they transport commodities and people. For train based on electric multiple units require onboard communication network to transmit traction and braking information so as to make the motor units to go harmoniously, status of all motors and trailer cars is transmitted through the network to the central control unit in cab for condition monitoring and fault diagnosis. In practice, onboard security detection network not only can decrease length of onboard train wire, and reduce the total weight of train, also improve the system integration, reliability and maintainability. Train onboard security detection network based Ethernet is used to transmit operating controlling, condition monitoring, fault diagnosis and passenger service information. It refers to all bus technology to connect embedded subsystem to form onboard local area network so as to realize resource sharing, cooperation, distributed monitoring [1, 2].

Onboard security detection and fault diagnosis system requires that security detection network has highly real-time performance, good maintainability and expansibility, high broadband and interoperability, distributed task processing and data fusion. TCN having the low transmission rate, can not meet the requirements of mass volume data transmission and security detection system. Therefore, train security detection network which can transmit mass capacity data is becoming a developing trend. Ethernet based on IEEE Std 802.3, has been widely applied in industry field. Researchers have been able to meet real-time applications time requirements by changing packet format for real-time control messages, or by giving higher priority for these messages [3, 4, 5].

Rolling stock has rugged environment, vehicles often need to be coupled and uncoupled. Compared to conventional TCN, Ethernet devices will reduce costs and increase functionalities. The IEC/TC9 WG43 group is revising TCN standard and add Ethernet as train backbone, in order to promote Ethernet technique widely used train communication network. Regional trains in Germany and the Netherlands are currently being delivered by BOMBARDIER with an onboard Ethernet network. The Bombardier Transportation system will integrate all the intelligent devices onboard into one Ethernet network which will fully replace the TCN in two or three years. SIEMENS is studying how to use the industrial Ethernet PROFINET as the train communication network. Japan Railway union is studying based on Ethernet INTEROS train communication network. ALSTON is studying train and consist Ethernet, and cooperating with the French rail operator SNCF to test the onboard Ethernet

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performance of all TGV train [6, 7].

2. Topology and Onboard Devices Logic Relation of Train Security Detection Network

The system and devices connect with train security detection network comprise all sensors, AP (Access Point), FP (Fusion Point), ND (network noDe), CP (Central Point), DSM (Diagnostic Service Machine), and onboard wireless communication platform. The main function is as follows:

AP1 (Access Point 1) is responsible for connecting the FP and the sensors that is used to collect the data of traction, running brake system and vehicle body balance. Then, AP1 convert sensor signal to the data identified by the FP with a unified communication protocol. AP1 includes conditioning devices which realize data pre-processing and diagnosis of the above onboard intelligent sensors.

Bogie AP2 (Access Point 2) is responsible for connecting bogie sensor, axle box composite sensor and FP, and converts the sensor signal to the data identified by the FP with unified communication protocol. AP2 also includes conditioning devices likes AP1.

The FP is physically responsible for the connection to the AP and ND, and logically in charge of the local car AP's data management and vehicle network management.

The CP is onboard system gateway, which is responsible for dynamic networking, network management and maintenance, network interface configuration, flow distribution, data cache, and using TCP/IP protocol to send and receive data.

The ND is responsible for data transmission with 100Mbps broadband, and realizes the network management of train level, VLAN division, priority control, and dynamic networking.

The DSM transmits data with the CP, mobile channel control devices through the security detection network and receives data from the FP. According to the running, traction, braking, auxiliary and surveillance subsystem, the DSM is responsible for encoding and decoding data packet, controlling and storage date flow, and making safety assessment and prioritization, realizing fault diagnosis and early warning.

OMCP includes an onboard wireless communication host, real-time channel unit and static channel unit. The OMCP communicates with the CP, diagnostic service host machine through security detection network, and realize the data cache, confirm on-line and off-line large capacity transmission mechanism, data packing, control the dynamic transmission unit and static transmission unit, achieve data transmission via static and dynamic modulation.

The logic and topology relation of train security detection network is shown in Figure 1. Data from intelligent sensors will transmit controlling and diagnosis data from AP, FP, ND to train level network. The existing TCN network data will be converted by the TCN gateway, then be transmitted to train level network through the ND. The DSM and the OMCP connect the train level network directly through the ND. The CP is responsible for the management and control of train level network through the ND. The DSM sends data to ground system through the OMCP.

Train security detection network based Ethernet/IP technology, using TCP/IP protocol, divided into train level ETDN (Ethernet Train Detection Network) and vehicle level EVDN (Ethernet Vehicle Detection Network). The ETDN network throughout the train, realize the train network management, VLAN division, priority, dynamic networking, and so on. The EVDN network includes a single, two, three, four or more vehicles consisting of fixed organization, in charge of data and network management of local vehicle and group. The ETDN network is composed by zero, one, two or more the EVDN sensing network. As one fixed operation urban train, the train is simplified as one EVDN network. Train security detection network architecture is shown in Figure 1, The TS (Train Switch) mainly refers to the ND, which can realize the ETDN and the EVDN network data conversion. The VS (Vehicle Switch) includes NP and FP. The ED (End Device) comprises a variety of sensor, AP, CP, DSM and OMCP, other devices provides data source for the TS and VS.

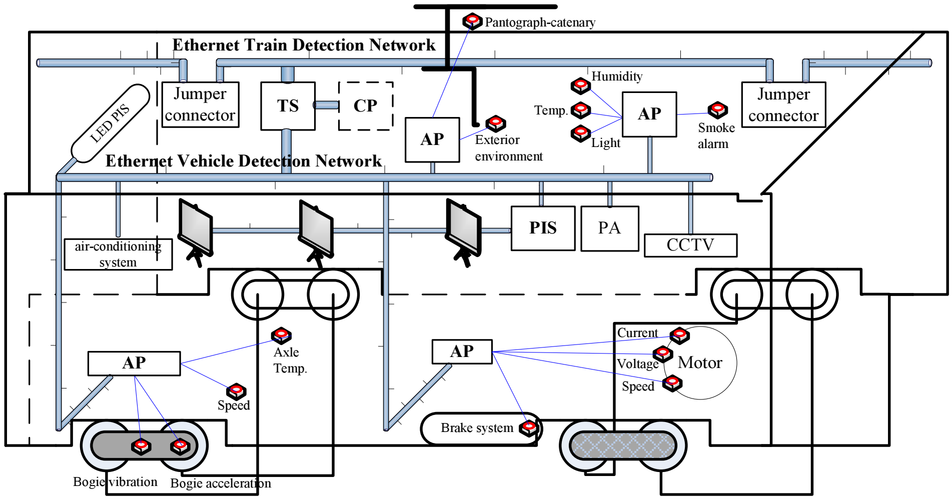

Figure 1. The train security detection network architecture.

3. Delay Analysis of Different Topology Structure

The studies have proved, as a starting point, that switched Ethernet for train communication network applications, specifically for train security detection network, is a feasible solution. The topology structure of train security detection network is shown in Figure 1, nodes which include sensors and actuators communicate with a dedicated controller with different sampling period in the security detection network. In the train network, as the restriction of network bandwidth and the uncertainty of data change, data collision and network congestion exist. Therefore, network delay appears when data changes between lots of network node. Network delay will affect overall operational security and stability of a railway operation. Packet end-to-end delays and number of lost packets are measured, guaranteeing zero packet loss and delays within the sampling period of the network nodes.

Network delay is the time from the transmitting terminal data packet goes into waiting status to received by the receiving terminal, it can be calculated as follow:

$$\tau = \tau_t + \tau_p + \tau_s + \tau_r \tag{1}$$

(1) τ_t, data sending delay, the time of transmitting terminal encapsulates sending information layer by layer into data packet and be in the queue.

(2) τ_p, transmission delay, the time of data packet transfer in the physical media, dues to the size of data packet, physical media, network bandwidth and the transmission distance.

(3) τ_s, data processing delay, switches usually use store-and-forward mode, CRC check, extract destination address, and decide output port by checking table. Thus, delay will be increased when data volume is increase.

(4) τ_r, data receiving delay, the delay after remote host receives and verifies data packet, then decodes it layer by layer and sends to application layer.

The train security detection network topology is complex and the amount of network node is large, process delays coming from some nodes in the intermediate link is a main component of network delay. Switch process delays including: exchange delay, which fixed by the function of switch and specific values can be provided by the manufacture. Frame forwarding delay, fixed by the transfer mode and frame length. Buffer delay, which will based on input flow mode, such as regular mode or not regular mode. The hop counts can be reduced when data transferred from bottom terminal equipment to server by optimizing train security detection network topology structure and nodes deployed, consequently, it can effectively avoid switch delay.

The ETDN topology structure is star, bus, ring and other network topology. Bus network topology is widely used in train security detection network because it has simple structure, convenient installation, and good scalability. This paper analyzes the delay of traditional bus network topology firstly. Data sending delay and data receiving delay are fixed by packet length and CPU processing performance. Thus, it will only focus on transmission delay and data processing delay.

Assuming one train has n vehicles, each TS set in the middle of vehicle, physical link length of adjacent switches is L (considering the bend in actual wiring and gap between vehicles, take this length about 1.5 times the distance of adjacent the centre vehicles); terminal equipment to switch distance of one vehicle is $L/2$, and that is kL between the switch and server, delay of each physical link length is τ_k, processing delay in each switch is τ_s, the total delays of terminal data transferred from vehicle i to server j after switch is τ_i, average network delay is τ_{ave}.

$$\tau_i = \left(\frac{1}{2} + k\right)\tau_k L + i\tau_s,\ \tau_{ave} = \frac{\sum_{i=1}^{n}\tau_i}{n}, i = 1,2,3,\cdots,n.$$

Situation 1: Construct a bus network topology by connecting adjacent switches, and server is set in the first vehicle.

Delay τ_i in each vehicle can be calculated as follow: $\tau_i = \left(i - \frac{1}{2}\right)\tau_k L + i\tau_s$

Average network delay τ_{ave1} can be calculated as follow:

$$\tau_{ave1} = \frac{\sum_{i=1}^{n}\tau_i}{n} = \frac{n}{2}\tau_k L + \frac{n+1}{2}\tau_s, i = 1,2,3,\cdots,n$$

Situation 2: Server is set in the middle of train, the first m vehicle. When n is odd, $m = (n+1)/2$. When n is even, $m = n/2$.

Delay τ_i in each vehicle can be calculated as follow:

When $1 \le i \le m$, $\tau_i = (m - i + 1/2)\tau_k L + (m - i + 1)\tau_s$.

When $m \le i \le n$, $\tau_i = (i - m + 1/2)\tau_k L + (i - m + 1)\tau_s$.

Average network delay τ_{ave2} can be calculated as follow:

When n is odd, $m = (n+1)/2$, $\tau_{ave2} = \frac{\sum_{i=1}^{n}\tau_i}{n} = \frac{n^2 + 2n - 1}{4n}\tau_k L + \frac{n^2 + 4n - 1}{4n}\tau_s,\ i = 1,2,3,\cdots,n$

When n is even, $m = n/2$, $\tau_{ave2} = \frac{\sum_{i=1}^{n}\tau_i}{n} = \frac{n+2}{4}\tau_k L + \frac{n+4}{4}\tau_s,\ i = 1,2,3,\cdots,n$.

Summing up, when $n > 2$, $\tau_{ave1} > \tau_{ave2}$.

It can effectively reduce the link transfer average distance and average hop count when server is set in the middle of train, therefore, average network delay is lower than that in the head of train.

In bus network topology, it will pass through large amount of network nodes when data transferred from the last vehicle to server. The workloads of switches near server are heavy, that will cause network congestion and delay increase frequently, and affects the service quality of communication. The whole communication network will paralyzed when one node breaks down, since they are in a same link. It is effective to replace the traditional bus network topology with ring network topology.

Connect each other switch into a loop network, i.e. connect the switches in odd vehicle, then connect the switches in even vehicle, finally connect switch 1 and switch 2, switch $n-1$ and switch n.

All data in vehicle transferred to server have to go through switch 1, and increase the workload in switch 1, thus lead to data packet congestion. If the server connects to the second switch, data in switches of even vehicle can directly transfer to server.

As connect the switches in the first and second vehicle with the server directly, then, the communication network constitutes a ring network topology. The physical link length of switches in adjacent vehicles is $2L$.

Delay τ_i in each vehicle can be calculated as follow:

When i is odd, $\tau_i = \left(i - \frac{1}{2}\right)\tau_k L + \frac{i+1}{2}\tau_s$, as i is even, $\tau_i = \left(i - \frac{1}{2}\right)\tau_k L + \frac{i}{2}\tau_s$.

Average network delay τ_{ave3} can be calculated as follow:

When n is odd, $\tau_{ave3} = \frac{\sum_{i=1}^{n}\tau_i}{n} = \frac{n}{2}\tau_k L + \frac{(n+1)^2}{4n}\tau_s,\ i = 1,2,3,\cdots,n$.

When n is even, $\tau_{ave3} = \frac{\sum_{i=1}^{n}\tau_i}{n} = \frac{n}{2}\tau_k L + \frac{(n+2)}{4}\tau_s,\ i = 1,2,3,\cdots,n$.

Summing up, when $n > 1$, $\tau_{ave1} > \tau_{ave3}$.

From the comparison of τ_{ave3} and τ_{ave1}, we can conclude that the average transfer distance in ring network topology is the same as that of bus network topology, but switch delay is only half as much. This is because there are two communication links in redundancy design of ring network topology, greatly reducing the switch hop count in data transmission, thus, network delay is decreased. Moreover, when transferring network data, every switch has two choices, once one of the links breaks down, it can choose another one.

4. The Delay Estimation under Different Tasks

This section uses the OPNET to analysis the delay estimation of data transmission based on train security detection network. There is a train level switch in each car, so the network is divided into many smaller collision domains and each collision domain achieves the isolation through the train switches. According to the before and after optimization scheme, three scenarios are set respectively, the application link bandwidth are set up to 100Mbps. The first scenario is set for bus topology, and the CP is deployed in the first carriage. The second scenario is set for bus topology, while the CP is deployed in the middle carriage of the train. The third scenario is set for onboard ring topology, and the CP is deployed in the first carriage. Each carriage has one train switch which connects with four network nodes using to simulate four devices send security, status, test and passenger service information respectively.

The network delay and link workload before and after optimization scheme are shown in Figure 2.

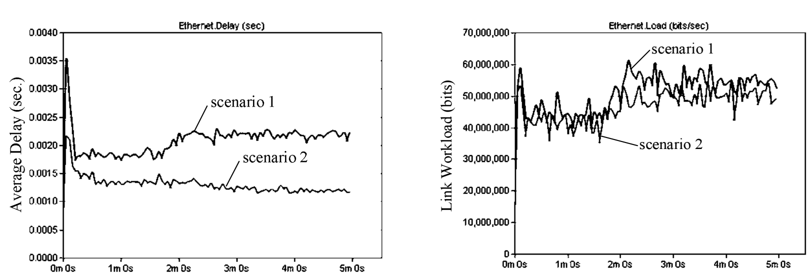

Figure 2. Delay and workload comparing based on node deployment.

The calculation and simulation results are basically identical. The left diagram of the Figure 2 is the delay comparing of the before and after optimization scheme. The network average delay before optimization scheme is about 2.2ms, while that after optimization scheme is about 1.2ms, it is basically accord with 2 times. It shows that reasonable CP node deployment can effectively reduce the train network delay. The right diagram of the Figure 2 is the workload comparing of the before and after optimization scheme. The workload is basically the same before and after optimization scheme, it shows CP node deployment has a little influence on total network traffic, and roughly in line with expectations.

The network delay and link workload of the different node topology are shown in Figure 3.

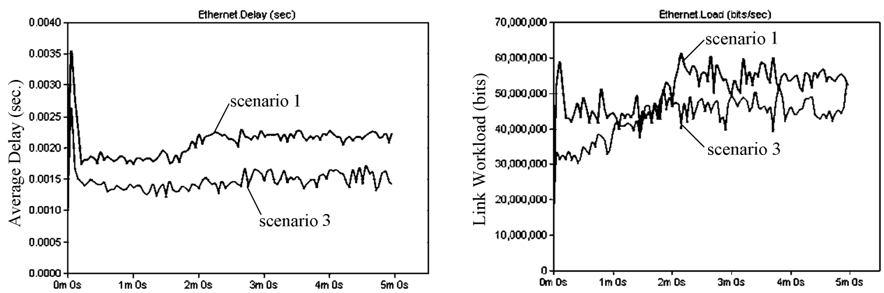

Figure 3. Delay and workload comparing based on node topology.

It can be seen from the left diagram of the Figure 3 that the network average delay of onboard bus topology after the network stability is about 2.2ms, and that of onboard ring topology is about 1.5ms. It shows the ring network topology average delay is lower than that of bus network topology, which is accordance with the requirement of delay that must be lower than 25ms in the TCN standard. The right diagram of the Figure 3 is the workload comparing of board bus and ring topology.

The CP workload of ring topology is lower than that of bus topology, which shows bus topology is more congestion than that of ring topology in the case of equal amount onboard nodes.

From the simulation, it shows that onboard ring topology has higher real-time, reliability, stability than bus topology in train security detection network.

5. Conclusions

As common topology in traditional train communication network, bus network topology has many insufficiencies. Based on mathematical method and simulation, it shows that ring network topology is superior to bus network topology for train security detection network. The hop counts in ring network topology are reduced, there are two links chosen in each train switch. The communication network model based on Ethernet will help to optimize rail transit network node, reducing network delay, and improving network communication quality, guarantying the safety of rail transit. In the next stage of our research, we intend to carry out a series of simulations to test the delay performance of security detection network by transmission experiments. Then, we will establish onboard wireless detection network using 802.11 b/g/n technology, and analysis and verify delay of the structure.

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