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DELAY ANALYSIS OF TRAIN ONBOARD DETECTION SENSOR NETWORK

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ABSTRACT

Recent research and development in the area of next generation train backbones have created an incentive towards the replacement of legacy interconnecting data communication architectures with newer and more innovative backbones. The onboard Ethernet technology has been applied in the train onboard detection sensor network gradually. Network delay is an important factor of detection sensor network quality. This paper analyzes the affection to the network delay of different network topology structure. In addition, the communication network model of onboard detection sensor network based on Ethernet has been constructed by the OPNET Network Modeler. According to the simulation data to analyze the network delay, link load and end-to-end throughput of bus network topology and ring network topology. This will provide technology reference for the onboard detection sensor network and train communication network topology structure optimization.

Keywords: *Detection sensor network, Delay analysis, Train Communication Network, Ethernet*

1. INTRODUCTION

With the increase of the running speed of rail transit, trains have evolved from being the first practical forms of mechanized land transport to the extremely complex and sophisticated transportation systems we currently use, which puts forward a higher requirement for the safety and reliability. Therefore, the fault diagnosis and intelligent maintenance system has become an indispensable part of modern rolling stock [1].

Traditional train onboard detection sensor network, such as LonWorks, ArcNet, CAN, Profibus, WordFIP and TCN(Train Communication Network) are based on the field bus technology, which have high performance, real-time ability and high reliability in condition monitoring, real-time control, fault diagnosis and other small data flow of information transmission. However, itcan't send large volumes data, such as advanced passenger information system. Higher transmission speed is being demanded for the train sensor network in recent years. Recent research and development in the area of next generation train backbones has created an incentive towards the replacement of legacy interconnecting data communication architectures with newer and more innovative backbones [1]. Ethernet, based on the IEEE 802.3 standard, with the advantages of large transmission capacity, low price, strong commonality, network flexible, etc., is widely used in industrial field. The IEC/TC9 is working to draft the Real-Time Ethernet (RTE) standard, to promote the application of Ethernet technology in train communication network [2]-[4]. Bombardier, an international transportation equipment manufacturer in Canada, is promoting the onboard Ethernet technology into commercial application. In 2010, they had installed onboard Ethernet equipment on regional trains of Germany and Netherlands, the hybrid train sensor network includes onboard ring Ethernet and TCN system. Bombardier wish to replace TCN network by Ethernet completely in 3 to 5 years, that is, all onboard intelligent equipment will be integrated into an Ethernet system. SIEMENS is researching on using the Industrial Ethernet PROFINET as the train sensor network. JR East has been developing a 100 Mbps Ethernet-based TCN called "INtegrated Train communication/control networks for the Evolvable Railway Operation System (INTEROS),

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has started running tests of MUE-Train with INTEROS since September of 2010. Alstom is researching train level and consists level Ethernet, and has begun the cooperation with French rail operator SNCF in testing the onboard Ethernet in all their TGV. In Dec. 2011, CSR(China Southern Railway) has used Ethernet ring network as the control and sensor network in the 500km/h test high speed train, which is based on the CRH(China Railway High-speed) 380A EMU(Electric Motor Unit) [5]-[7].

The train onboard detection sensor network based on switched Ethernet has strict requirements in network stability, safety and reliability. As used CSMA/CD in Ethernet, the real-time and certainty can't be guaranteed in information transmission, the real-time performance has been a research focus for several years. In current research, there is no further discussion on the process data delay among lots of switch in train onboard detection sensor network. The hop counts when communication data in the sensor network through switch is an important factor for network delay.

This paper is organized in the following order. Section 2 analyses the delay of different topology structure. Section 3 introduces network topology Model and the results of the simulations, to be concluded in Section 4.

2. 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 onboard detection sensor network, is a feasible solution. The topology structure of train onboard detection sensor network is shown in Figure1, sensors and actuators communicate with a dedicated controller with different sampling period in the sensor network. In the train sensor 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, such as sensors, intelligent terminals and server. Network delay will affect the system's security and stability. Packet end-to-end delays and number of lost packets is measured, guaranteeing zero packet loss and delays within the sampling period of the network nodes [8] [9].

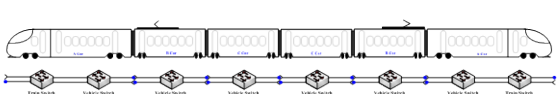

Figure1. Topology Structure Of Train Sensor Network

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 obviously increased when data volume is large.

(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.

In the train onboard detection sensor network, network topology is complex and the amount of network node is large, process delays coming from some onboard switches 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 onboard detection sensor network topology structure and nodes deployed, consequently, it can effectively avoid switch delay.

The main network topology structure is star, bus, ring and other network topology. Bus network topology is widely used in train onboard detection sensor 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.

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Assuming one train has n vehicles, each backbone switch set in the vehicle center, 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 vehicles center); terminal equipment to switch distance of one vehicle is $\frac{L}{2}$, 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 after j switch is τ_i, average network delay is τ_{ave}。

$$\tau_i = (\frac{1}{2} + k)\tau_k L + i\tau_s$$

$$\tau_{ave} = \frac{\sum_{i=1}^{n}\tau_i}{n}, i = 1,2,3,\cdots,n$$

Situation 1：Construct a bus network topology by connecting adjacent switches, and server is set in the first vehicle, as shown in Figure2.

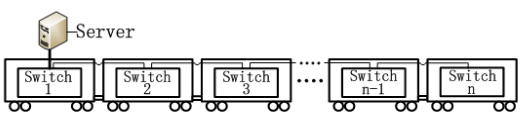

Figure2. Server Located In The Head

Delay τ_i in each vehicle can be calculated as follow:

$$\tau_i = (i - \frac{1}{2})\tau_k L + i\tau_s$$

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, , as shown in Figure3. When n is odd, $m = \frac{n+1}{2}$. When n is even, $m = \frac{n}{2}$。

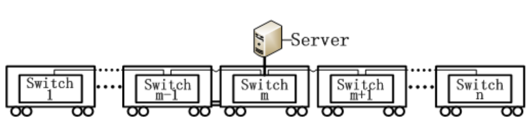

Figure3. Server Located In The Middle

Delay τ_i in each vehicle can be calculated as follow:

When $1 \le i \le m$,

$$\tau_i = (m - i + \frac{1}{2})\tau_k L + (m - i + 1)\tau_s$$

When $m \le i \le n$,

$$\tau_i = (i - m + \frac{1}{2})\tau_k L + (i - m + 1)\tau_s$$

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

When n is odd, $m = \frac{n+1}{2}$

$$\tau_{ave2} = \frac{\sum_{i=1}^{n}\tau_i}{n} = \frac{n^2 + 2n - 1}{4n}\tau_k L + \frac{n^2 + 4n - 1}{4n}\tau_s$$
$$, i = 1,2,3,\cdots,n$$

When n is even, $m = \frac{n}{2}$

$$\tau_{ave2} = \frac{\sum_{i=1}^{n}\tau_i}{n} = \frac{n+2}{4}\tau_k L + \frac{n+4}{4}\tau_s,$$
$$i = 1,2,3,\cdots,n$$

Summing up, when $n > 2$:

$$\tau_{ave1} > \tau_{ave2}$$

Conclusion 1: 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. But lots of control instructions, such as control information and condition monitoring information, are transmitted from the cab, this servers have to be set in the head. Thus, only the server of communication data which not require high real-time ability can be set in the middle of train, e.g. onboard audio and video passenger information.

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

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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), shown as Figure4.

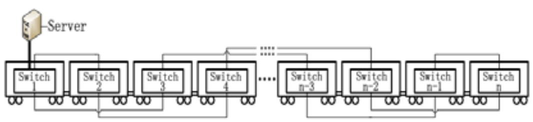

Figure4. Ring Network Topology

As shown in Figure4, all the 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 also connecting to switch 2, data in switches of even vehicle can be transferred to it directly and without going through switch 1.

Situation 3: As shown in Figure5, 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 (e.g. switch 1 and switch 3, switch 2 and switch 4) in adjacent vehicles is $2L$.

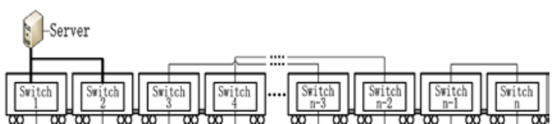

Figure5. Optimized ring network topology

Delay τ_i in each vehicle can be calculated as follow:

When i is odd,

$$\tau_i = (i-\frac{1}{2})\tau_k L + \frac{i+1}{2}\tau_s$$

When i is even,

$$\tau_i = (i-\frac{1}{2})\tau_k L + \frac{i}{2}\tau_s$$

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 $n > 1$:

$$\tau_{ave1} > \tau_{ave3}$$

Conclusion 2: 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.

3. NETWORK TOPOLOGY SIMULATION BASED ON OPNET

Under the OPNET network simulation software, we can construct an onboard Ethernet technology based rail transit sensor network model with general CRH grouping standard (4 motor cars with 4 trailers), compare the network delay, link workload and peer-to-peer throughput of bus network topology and ring network topology.

3.1 Network Topology Structure Modeling

Assume one train has 8 vehicles, 4 motor cars with 4 trailers. A switch linking with three workstations is set in a vehicle. As shown in Figure6, adjacent vehicles switches are linked up in bus network topology; and as shown in Figure7, in ring network topology, switches are linked up in interval vehicles.

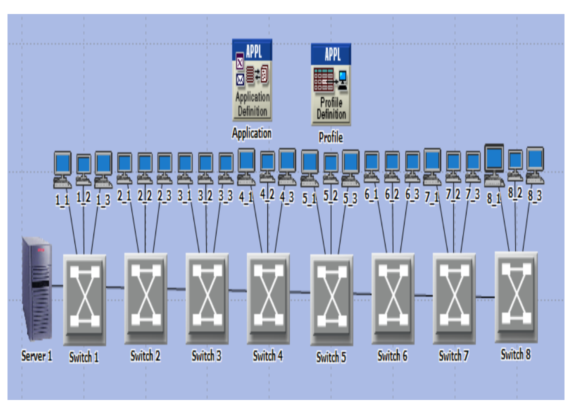

Figure6. Bus Network Topology

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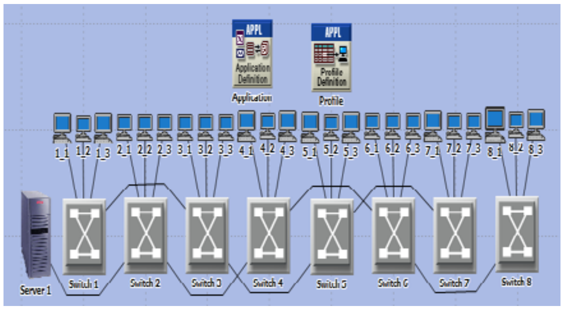

Figure7. Ring Network Topology

Set bus and ring type for the bus network topology and ring network topology, bandwidth in the two network scene both are 100Mbps. First add a transmission of Ftp application service simulating randomness information, then a transmission of Video Conferencing application service simulating vehicle monitoring information. The Ethernet delay, link workload and peer-to-peer throughput of bus network topology and ring network topology are shown in Figure8, Figure9, and Figure10.

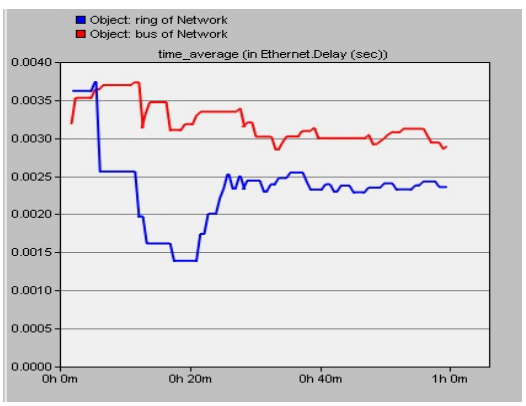

Figure8. Comparison Of Ethernet Delay

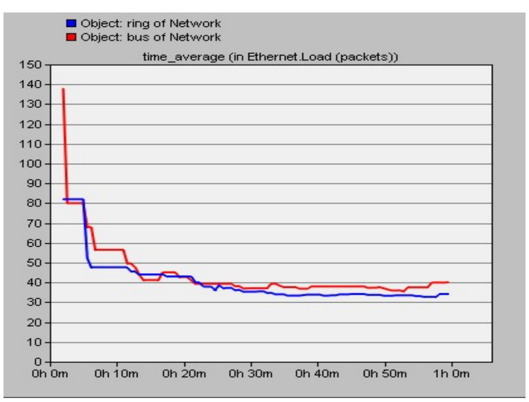

Figure9. Comparison Of Link Workload

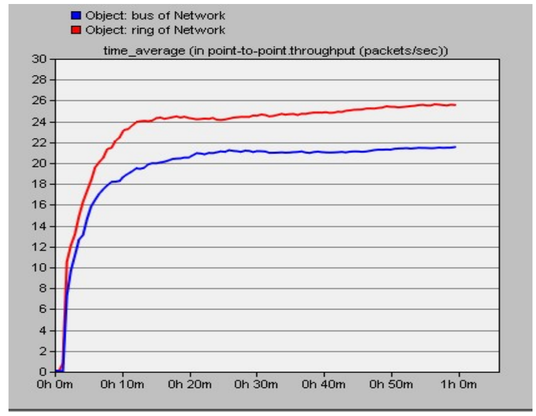

Figure10. Comparison Of End-To-End Throughput

3.2 Analysis of Simulation Result

As shown in Figure8, when the network is stable, the ring network topology delay is lower than that of bus network topology, which accordance with the requirement of delay must be lower than 25 ms in the TCN standard. From Figure9, when the network is stable after 10mins, workloads in both topologies are almost consistent, it's a bit higher in ring network topology. Obviously in Figure10, peer-to-peer throughput in ring network topology is higher than that of bus network topology. From the simulation result, ring network topology is superior to bus network topology of train sensor network.

4. CONCLUSION

More and more, the railway domain is evolving into a technically high-profile environment. In recent years, bandwidth requirements due to the installation of new embedded system on-board trains are growing rapidly. Now, the revising standard IEC 61375 is much extended. Onboard detection sensor network based on Ethernet and IP technology runs in parallel to the existing Train Communication Network or solely used for all kinds of communication in a train.

As common topology structure in traditional train communication network, bus network topology has many insufficiencies. Results obtained from the mathematical method and OPNET Network Modeler show that ring network topology is superior to bus network topology for onboard detection sensor network. The hop counts in ring network topology are reduced, there are two links chosen in each onboard switch. It will improve the train onboard detection sensor network service quality and reliability. The communication network model of onboard detection sensor network based on Ethernet will help to optimize rail transit sensor network node, reducing network delay, and

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improving network communication quality, guarantying the safety of rail transit.

In the next stage of our research, we plan to run test the communication network model of onboard detection sensor network by transmission experiments. Then, we will establish onboard radio detection sensor network using general purpose wireless communication such as 802.11 b/g/n, and analysis and verify delay of the structure so as to improve reliability.

5. ACKNOWLEDGEMENTS

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