Application of Cooperative Communications with Dual-Stations in Wireless Mobile Environments

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Abstract. Wireless networks have been widely used in various industries, e.g., the subway communication system. However, there are many technical problems that are still unsolved. One of the most important issues about the problem is the reliability of "train-to-earth" communication. Therefore, to enhance the stability and reliability of the subway wireless communication system, we dispose the dual gateways and stations, and propose a dual-stations collaborative communication scheme. Implementation between dual gateways and dual stations are required to design a state testing scheme. Therefore, the system reliability is improved as it can detect the system malfunctions. There are three kinds of work modes where each mode has been designed to solve the stated problems previously. The experiment results show that the proposed scheme can reach the expected requirements, thus achieving the reliable and secure "train-to-earth" communication.

Keywords: Dual-stations · State testing scheme · Reliability
Communication scheme

1 Introduction

As far as we know, the subway plays an important role of urban transport as a rail transmit system. At the same time, wireless networks with the superior flexibility and convenience get more and more mature in the network applications. Moreover, wireless networks have played an increasingly important role and penetrated into all aspects of human life. Subway communication system is one of the important application [1].

However, although wireless networks are widely used in many industries, there are still many technical problems to be solved for the reliability of the requirements in the subway communication system. This is mainly determined by the particularity of the subway train-to-earth wireless communication environment. The main features are as follows: *(1) Environmental complexity.* Subway communication environment is quite complex, coupled with climate, temperature and other conditions, so the subway wireless communication mechanism in the design and use of the process must be taken into account the signal coverage

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model and the anti-jamming capability. *(2) Reliability.* The data in the subway environment is divided into two kinds, i.e., one is the control command data of the subway, and the other is the subway user access service data. For control commands, it is necessary to achieve high reliability and real-time performance in relation to the safe travel of the train. For users' service data, such as voice over internet protocol, high reliability must be also achieved. However, because of the variety of environmental interferences and noises in the process of the wireless signal transmission, its channel bit error rate is relatively high. Therefore, it is important to achieve the reliability and real-time vehicle communication in the subway communication system. *(3) Security.* Due to the particularity of the data transmission in the subway communication system, it is necessary to ensure that the network has sufficient security, otherwise it will be terrible if the criminals get the data [2–4].

Then, the above characteristics can be combined into the usability, that is, a kind of ability to complete the specified function of a product in a specified period of time, under the specified conditions and at a certain time [5,6]. The key issue that needs to be solved in the current metro traffic is to provide a wireless communication mechanism with strong fault handling capability to achieve high availability [7].

In general, based on the existing wireless networks researches and communication protocols, this paper presents an improved and feasible method which is called dual-stations cooperative communication mechanism to achieve the expected reliability standards for the subway train-to-earth wireless communication environment. The rest of this paper is structured as follows. In Sect. 2, we introduce the design of the dual-Stations communication mechanism. In Sect. 3, we apply our framework to an experiment to show that this scheme can reach the expected requirements. At last, we conclude the paper in Sect. 4.

2 Design of Communication Mechanism with Dual-Stations

In the subway communication system, because of the need to send the train control information, the system requires a high standard of reliability. Therefore, the system has designed a variety of redundant settings [7]. It can achieve high reliability and high availability through the provision of redundant communication gateway, redundant core switches, redundant station, and redundant wireless signal coverage [8].

The dual-stations cooperative communication mechanism runs between dual communication gateways and dual stations. The program is started with the device. It automatically detects the heartbeat information at regular intervals and discovers the system faults in order to improve the reliability of the system. On the basis of the state detection program, this mechanism sets three working modes for the system: hot standby mode (HSM), load balancing mode (LBM) and hot standby redundancy mode (HSRM). Each communication gateway and stations must be set to one of the hot standby mode, the load balancing mode and the hot standby redundancy mode at the same time. The operating mode can be set manually by the manual application according to the actual application requirements [9–11]. Next, we will discuss three modes in detail.

2.1 Hot Standby Mode

Figure 1 shows the hot standby mode. Under normal circumstances, the main communication gateway and the main station (STA) are in the action state. The slave communication gateway and the slave station (STA) are in the standby state and do not provide services. The uplink data is transmitted by the main station and the main communication gateway to the vehicle personal computer, and the downlink data is transmitted through the main communication gateway and the main station too. The main communication gateway and the communication gateway detect each other's working state through the state detection program. When one of the devices detects failure of the other operation of the equipment, it will transfer the main communication gateway's work by the predesigned strategy so that the system can continue to provide services. Therefore, the user does not feel any problems. The main station and the slave station keep working through the same way.

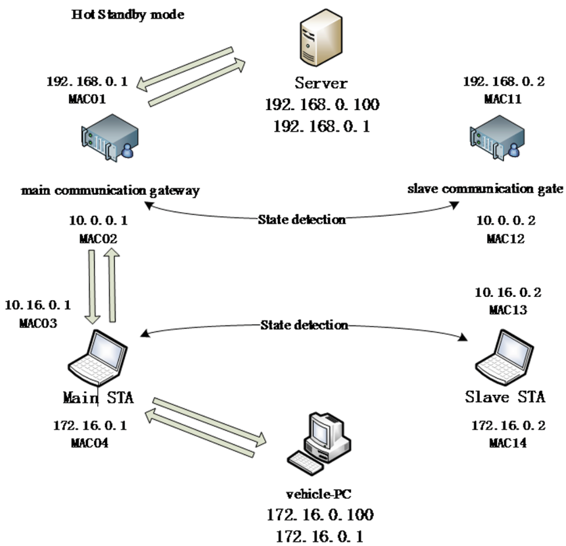

Fig. 1. Hot standby mode.

When the system fails in the hot standby mode, the processing flow of the stations is as follows (the processing flow of the communication gateway can be analogous to the station):

(1) Main stations troubleshooting process: If the interface of application port or communication port fails, we can exchange the IP address and MAC address of the main station (STA) application and the communication port with them of the slave station (STA) application port. Then the next hop routing information of the slave station to application server will be changed to the main communication gateway communication port's address. After the fault processing is completed, the uplink data is transmitted from the slave station and the main communication gateway, and the downlink data is also transmitted through the main communication gateway and the slave station.
(2) Slave stations troubleshooting process: Report the information about failures to the application server, and do not need to deal with anything.

2.2 Load Balancing Mode

Figure 2 shows the function diagram of the load balancing mode. Normally, the main communication gateway, the slave communication gateway and the main or slave stations are all in working condition. In order to achieve the load balancing of the wireless link, the system will divide the network traffic of the main station (STA) and the slave station (STA) into two parts. So the data transmission and reception of the personal computer will be completed through two wireless links to break through the limited bottleneck of the wireless link bandwidth. For the vehicle personal computer, the uplink data is transmitted through the main station and communication gateway, and the downlink data is transmitted

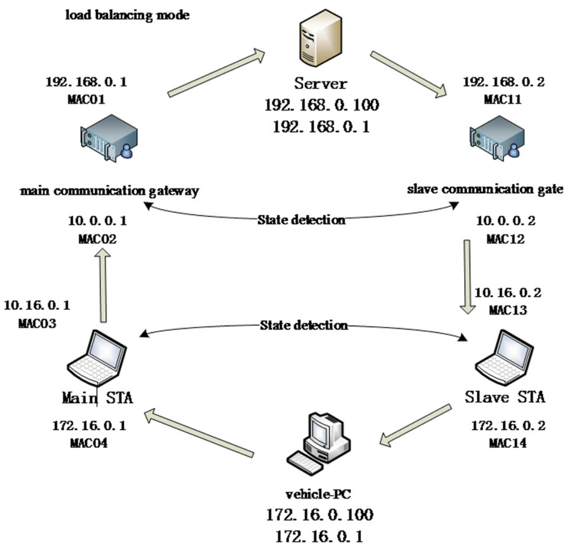

Fig. 2. Load balancing mode.

through the slave station and communication, thereby improving the overall throughput of the system and reducing the possibility of network congestion. The main communication gateway and the communication gateway detect each other's working state through the state detection program. When one of the devices detects failure of the other operation of the equipments, it will transfer the main communication gateway's work by the pre-designed strategy so that the system can continue to provide service. Meanwhile, the user does not feel any problems. Note that the main station and the slave station also through the same way to work.

When the system fails in load balancing mode, the processing flow is as follows (the processing flow of the gateway can be analogous to the station):

(1) Main stations troubleshooting process: If the interface of application port or communication port fails, we exchange the IP address and MAC address of the main station (STA) application and the communication port with them of the slave station (STA) application port. Then the next hop routing information of the slave station to the application server will be changed to the main communication gateway communication port's address. After the fault processing is completed, the uplink data is transmitted from the slave station and the main communication gateway to the vehicle personal computer, and the downlink data is transmitted through the slave communication gateway and the slave station.
(2) Slave stations troubleshooting process: It can be analogous to main stations. If the interface fails, we can exchange the IP address and MAC address. Then the next hop routing information of the slave station to the application server will be changed to the main communication gateway communication port's address. After that, the uplink data is transmitted from the main station and the main communication gateway to the vehicle personal computer. On the other hand, the downlink data is transmitted through the slave communication gateway and the main station.

2.3 Hot Standby Redundancy Mode

Figure 3 shows the hot standby redundancy mode. Under normal circumstances, both the main communication gateway and the slave communication gateway are in the action state. With regard to the vehicle personal computer, the uplink data is transmitted through the main station (STA). When the data arrive at the main station (STA), the main station copies the data to the slave station, and then the data are sent to the application server through both the main and the slave communication gateways respectively. The upper layer of the application server will deal with the repetitive packets. The downlink data will be sent to the main communication gateway through the application server. The main communication gateway will copy the data to the slave communication gateway, and then both the main and the slave communication gateway will send the data to the vehicle personal computer through the main station and the slave station

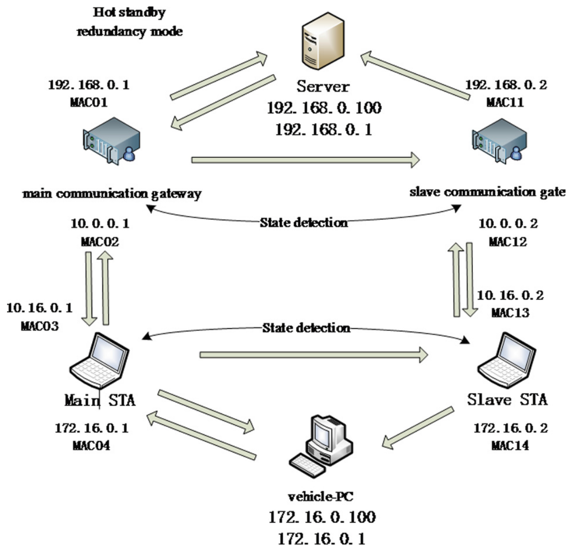

Fig. 3. Hot standby redundancy mode.

respectively. Of course, it will deal with the repetitive packets too. Moreover, the state detection mechanism is analogous to the mode before.

When the system fails in hot standby redundancy mode, the processing flow is as follows (the processing flow of the gateway can be analogous to the station):

(1) Main stations troubleshooting process:
   a. The interface of application port fails. We can exchange the IP address in the same way before. After that, the uplink data is transmitted from the slave station and the communication gateway, and the downlink data is transmitted through the main communication gateway, the slave communication gateway and the slave station.
   b. The interface of communication port fails. Do not need to deal with anymore. The uplink data is transmitted from the slave communication gateway, the slave station, and the main station. The downlink data is transmitted through the main communication gateway, the slave communication gateway and the slave station.
   c. The interface of application port and communication port all fail. The method is same as method in the fails about the interface of application port.
(2) Slave stations troubleshooting process: Report the information about failures, and do not need to deal with anything.

3 Experiments

The network topology shown in Fig. 4 is used to simulate the dual-stations cooperative communication in wireless mobile environment of the subway. Set up dual communication gateways and dual stations, which is distinguished with main and slave, in order to achieve three kinds of related work modes. The two access points' working channel are set as two channels, equipped with two wireless cards. And they are both in the station (STA) mode, using directional antennas, pointing to the vehicle in the two directions, respectively, in the 3-channel and 7-channel.

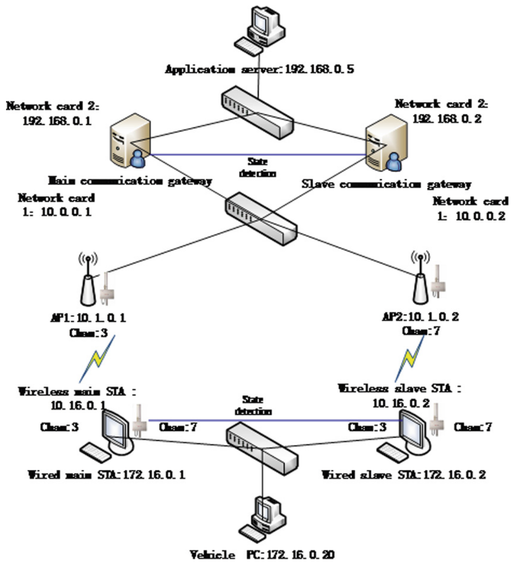

Fig. 4. The experiment network topology.

There are some criteria about the three kinds of working modes proposed in this paper, such as the networks delay, throughput and fault response time. In order to test these criteria, this paper designed four sets of test experiments: throughput comparison experiment of three kinds of work mode under normal or faulty circumstances; response time comparison experiment of three kinds of work mode under normal or faulty circumstances;

By the test conditions, the failure rate of the three working modes is determined by the continuous operation of the system for 12 h. No fault has occurred for each working mode after ten consecutive days of testing. Therefore, the fault rate of the system can be considered as 0 in this case.

Tables 1 and 2 show the throughput and the average response time experiment results (unit: Mbps) under normal circumstances. In each mode, TCP and UDP are tested with 1 KBytes, 10 KBytes and 100 KBytes packets for 30 min.

Figures 5 and 6 show the comparison of the data in Tables 1 and 2. It can be seen from the figures that the mode with the maximum throughput and minimum average response time is the load balancing mode in the use of TCP protocol. Next is the hot standby mode, and hot standby redundancy mode is

Table 1. Comparison of throughput under normal conditions (unit: Mbps)

Packet	HSM-TCP	HSM-UDP	LBM-TCP	LBM-UDP	HSRM-TCP	HSRM-UDP
1K	7.979	6.376	8.275	6.882	7.542	5.833
10K	16.404	11.863	18.524	14.579	15.404	10.863
100K	17.949	16.155	24.949	19.155	15.949	13.155

Table 2. Comparison of average response time under normal conditions (unit: s)

Packet	HSM-TCP	HSM-UDP	LBM-TCP	LBM-UDP	HSRM-TCP	HSRM-UDP
1K	0.001	0.001	0.001	0.001	0.001	0.001
10K	0.003	0.004	0.003	0.005	0.004	0.005
100K	0.031	0.040	0.021	0.038	0.035	0.048

the last. Meanwhile, the UDP protocol also have the same rule. Thus, the load balancing mode uses two links to send and receive data at the same time to achieve a balanced load of the link to improve the system throughput. But the hot standby redundancy mode send same packet twice so that the burden of system increases and the network throughput decreases.

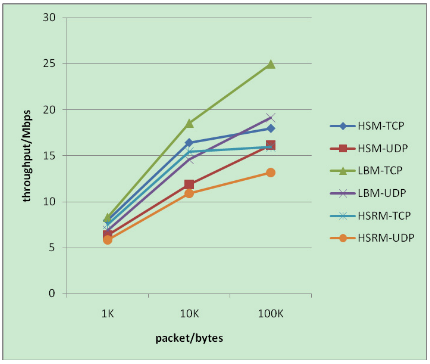

Fig. 5. Throughput comparison under normal condition.

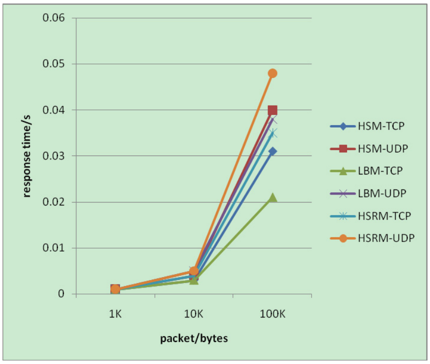

Fig. 6. Response time comparison under normal conditions.

Tables 3 and 4 show the results under faulty circumstances. There is a total of 16 types of faults include the fault of either the communication interface or the application interface in either the communication gateway or the station and the heartbeat overtime fault. The interface failure is manually by closing the corresponding network card, and the heartbeat overtime fault is manually by the machine closed. Each type is completed within one minute.

Figures 7 and 8 show the comparison of the data in table before. It can be seen from the figures that the mode with the maximum throughput and

Table 3. Comparison of throughput under faulty conditions (unit: Mbps)

Packet	HSM-TCP	HSM-UDP	LBM-TCP	LBM-UDP	HSRM-TCP	HSRM-UDP
1K	5.528	5.197	5.890	5.497	5.955	5.429
10K	13.433	8.836	14.021	9.528	14.481	10.563
100K	13.988	10.545	15.236	12.102	15.583	12.799

Table 4. Comparison of average response time under faulty conditions (unit: s)

Packet	HSM-TCP	HSM-UDP	LBM-TCP	LBM-UDP	HSRM-TCP	HSRM-UDP
1K	6.240	6.850	6.331	6.533	4.211	4.311
10K	6.402	6.833	6.890	6.998	4.221	4.821
100K	7.158	8.034	8.513	9.211	5.332	5.522

minimum average response time is the hot standby redundancy mode. Thus, the hot standby redundancy mode can keep at least one package be successfully reached in the event of most of the failure so as to achieve a higher throughput. Load balancing mode and hot standby mode only can continue delivery package when the fault has been completed.

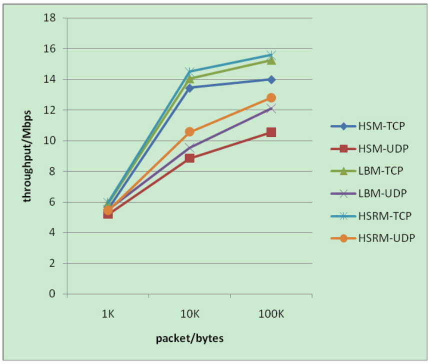

Fig. 7. Throughput comparison under normal condition.

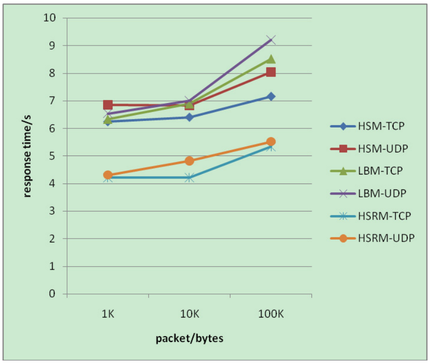

Fig. 8. Response time comparison under normal conditions.

The above experiment results show that the dual communication gateways and dual-stations can be used for cooperative communication.

In the normal case, the load balancing mode can achieve the highest throughput and the lowest average response time. Obviously, it has the best performance, the hot standby mode is the second, and the hot standby redundancy mode is the worst. Transmission delay are controlled within 500 ms, and the uplink and downlink bandwidth are maintained more than 400 Kbps. In the faulty case, the hot standby redundancy mode can achieve the highest throughput and the lowest average response time. Meanwhile, the hot standby mode is the second, and the load balancing mode is the worst. The fault response time is controlled within 10 s and the uplink and downlink bandwidth are maintained more than 400 Kbps. Therefore, the three modes can meet the expected requirements of the subway wireless communication system, and each has its advantages and disadvantages. It can be chosen according to the current system to achieve the performance criteria.

4 Conclusion

This paper makes an in-depth study on the reliable wireless communication mechanism in the subway environment. In order to ensure the stability and reliability of the wireless transmission of the subway control signal, a dual-stations cooperative communication mechanism is proposed. Moreover, by running the state detection program between the dual communication gateways and dual stations, the system reliability is improved. Based on this, the communication gateway and station will be set up in three working modes, i.e., the hot standby mode, the load balancing mode and the hot standby redundancy mode. In the event of system failure, the corresponding methods to solve the problem are provided for the three modes of operation to achieve the dual-stations cooperative communication, which can guarantee the reliability of the wireless communication networks.

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