Experimental research on TSN network performance test based on real-time edge computing platform

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ABSTRACT

This paper proposes a time-sensitive network performance test program based on a real-time edge computing platform. It uses a real-time data engine with a time-series database as the core to realize the collection and status monitoring of the real-time communication flow of the time-sensitive network. The clock synchronization is carried out by building a specific test experimental platform and end-to-end latency performance testing, and the results show that TSN network can ensure the delay of the time sensitive flow in the transmission process and the real-time arrival of the message in the complex network environment.

Keywords: Time-sensitive network, edge computing, performance test

1. INTRODUCTION

Traditional Ethernet uses carrier sense multiple access CSMA/CD technology with collision detection to determine the communication mechanism between Ethernet nodes. Any device in the network can send data at any time, but the data transmission time is uncertain and inaccurate. Time Sensitive Networking (TSN) is a network protocol standard formulated by the IEEE working group. Its purpose is to establish a general time-sensitive mechanism for specific application requirements on the basis of compatibility with existing Ethernet to ensure network data transmission time. certainty and reliability. The application field of TSN has gradually expanded from the field of audio and video data to automobiles, and further extended to the industrial field[1-2]. TSN is located in the second layer of the data link layer of the OSI seven-layer model. Its core technologies include network bandwidth reservation, precise clock synchronization and traffic shaping, which can meet the needs of low latency and high reliability of the network. At present, TSN testing methods mostly continue the traditional Ethernet testing scheme. As TSN plays a more critical role in the IT/OT integration process, TSN performance testing needs to be closely integrated with specific application scenarios. This paper proposes a real-time edge computing platform based on Time-sensitive network performance test program, and build a specific test experimental platform, by configuring time-sensitive network communication equipment, using a real-time data engine with a time-series database as the core, to achieve TSN network clock synchronization and end-to-end delay performance test.

2. RELATED WORK

In terms of TSN testing, Chongqing University of Posts and Telecommunications proposed a time-sensitive network testing system design scheme[3]. The test system consists of five parts: Talker, Listener, TSN adapter, TSN domain and TSN test instrument, and the function of each part is designed in detail according to the test requirements. Li Shiqiang of Industrial Internet Innovation Center (Shanghai) Co., Ltd.[4] built a TSN test bed to realize the interconnection between TSN network and mainstream industrial Ethernet PROFINET and Ethernet/IP. The American Industrial Internet Consortium (IIC) has built a time-sensitive network test bed[5], which mainly studies IT/OT integration and various traffic QoS tests for manufacturing automation. Domestic edge computing industry alliances are committed to developing test bed construction schemes for OPC UA over TSN applied to different scenarios[6-8], and carry out research on the integration of edge computing, OPC UA and TSN.

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3. REAL-TIME EDGE COMPUTING PLATFORM ARCHITECTURE

3.1 Architecture overall design

The real-time edge computing platform includes a data collection abstraction layer, a data aggregation analysis component, and a data analysis edge APP. Its architecture is shown in Figure 1.

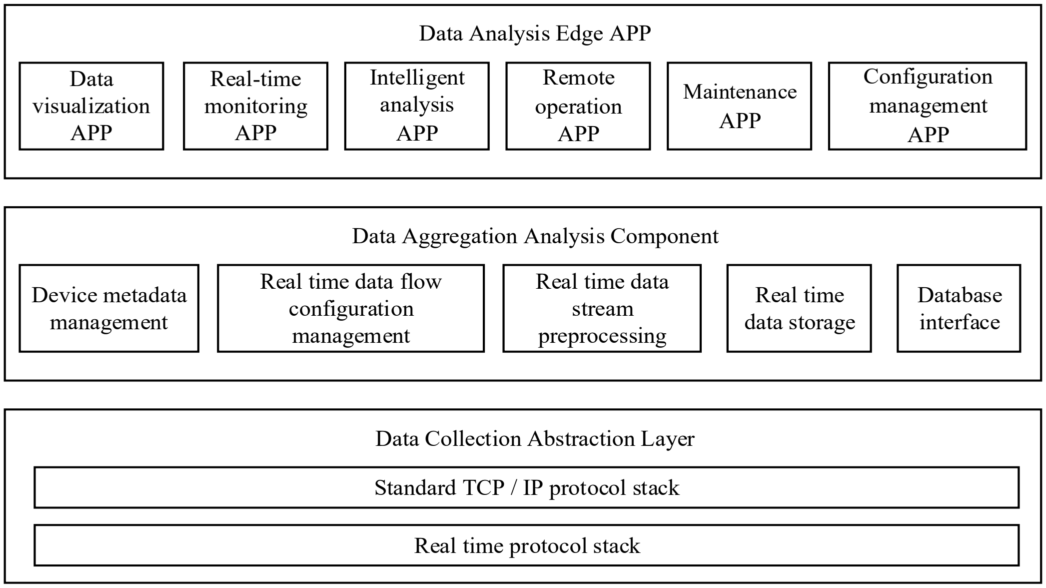

Figure 1. Real-time edge computing platform architecture.

The data collection abstraction layer includes the real-time protocol stack and standard TCP/IP protocol stack device driver microservices. The real-time Ethernet protocol stack is used to access field industrial bus devices. The standard TCP/IP protocol stack is mainly responsible for the realization of the OPC UA server, MQTT Equipment, etc. to communicate. The data aggregation analysis component provides equipment services and data services, and manages, stores, and analyses the equipment scanned by the data collection abstraction layer and the collected data. It mainly includes components such as equipment metadata management, real-time data stream configuration management, real-time data stream pre-processing, real-time data storage, and database interface. The equipment metadata management component is responsible for the automatic configuration of equipment and the establishment of an OPC UA semantic information model for the data provided by the equipment; the real-time data stream configuration management component is responsible for collecting on-site real-time data; the real-time data stream pre-processing component is storing the data stream in the database and Before submitting to the upper edge APP, pre-processing is performed, such as filtering by taking the maximum value, minimum value or average value, calculating standard deviation, and frequency domain analysis; real-time data storage components and database interface components mainly provide TDengine real-time database, MySQL and Redis Wait for the database interface to store real-time data streams. The data analysis edge APP is responsible for in-depth analysis of data in combination with specific application scenarios, and provides APP services, such as data visualization, real-time monitoring, intelligent analysis, remote operation and maintenance, and configuration management.

The real-time edge computing platform is based on a real-time operating system, supports time-sensitive network protocol stacks, and can implement a fault-tolerant safety network based on media redundancy, including:

(1) Based on IEEE802.1Qbv and 802.1Qcc, it realizes low-latency communication and software-defined network scheduling and configuration of a large-scale distributed real-time system.

(2) The frame replication and elimination mechanism based on IEEE802.1CB realizes a highly reliable network, ensuring that reliable communication can be enforced regardless of link failures, cable breaks, or other errors, and supports flexible network topologies.

(3) Adopting a TSN-based distributed high-reliability clock synchronization mechanism to support sub-microsecond clock synchronization of network nodes. The master clock selection algorithm and clock synchronization algorithm have strong robustness and are compatible with high-reliability network requirements seamless integration with Beidou clock synchronization system.

3.2 Semantic real-time data processing based on OPC UA Pub/Sub

OPC UA solves problems such as semantic interoperability, information model, information transmission based on C/S or Pub/Sub structure, and information security. TSN is responsible for providing real-time and unified underlying network support. The real-time edge computing platform combines OPC UA and TSN is combined to realize semantic-level real-time communication. First, the real-time communication requirements of OPC UA are mapped to the TSN stream configuration through the transmission mechanism. At the same time, the corresponding terminal nodes and network switching equipment are modelled based on the OPC UA meta-model, so that the terminal equipment, between the terminal equipment and the network switching equipment Semantic-level communication can be carried out between.

4. TSN TEST EXPERIMENTAL PLATFORM BASED ON REAL-TIME EDGE COMPUTING PLATFORM

This paper proposes a TSN network performance test experiment based on the above-mentioned real-time edge computing platform. The hardware architecture of the specific test experiment platform is shown in Figure 2.

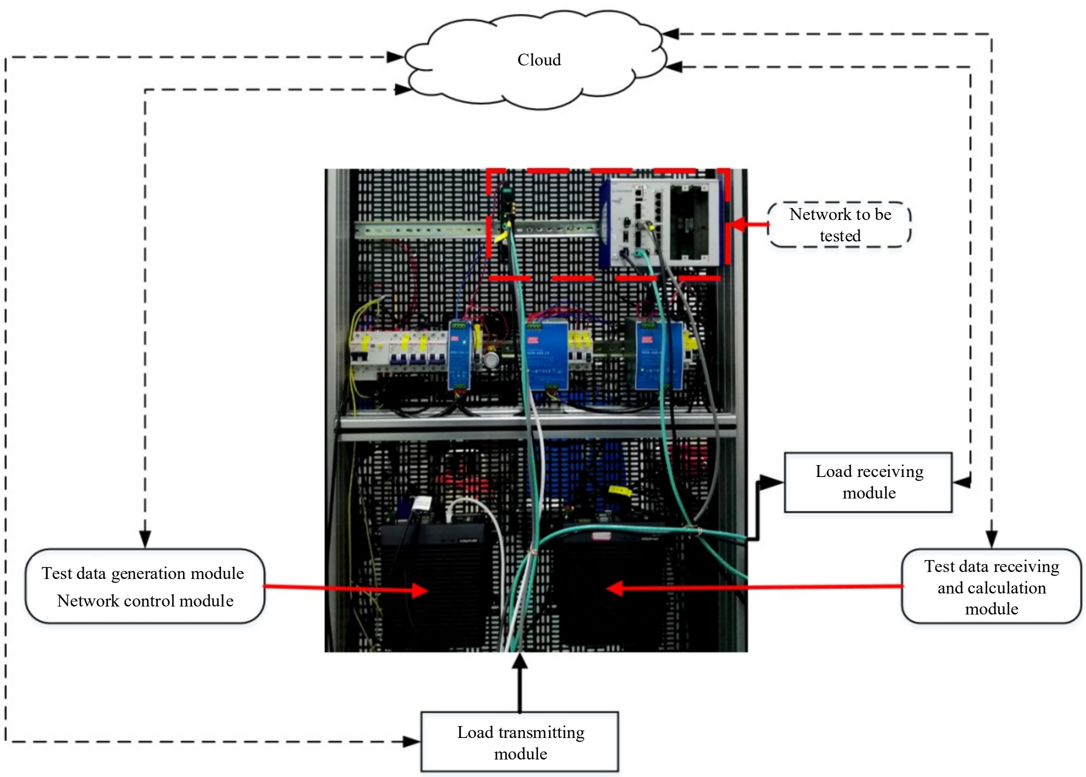

Figure 2. Hardware architecture diagram of TSN network test experimental platform.

Since continuous network performance testing requires a large amount of time series data, this article compares the performance of two open-source time series databases TDengine and Influxdb through comparative experiments. Use Go language to write and read data from TDengine and Influxdb. In the experiment, there are two variables: the number of database clients and the number of operating data for each client. The experimental results are shown in Figure 3.

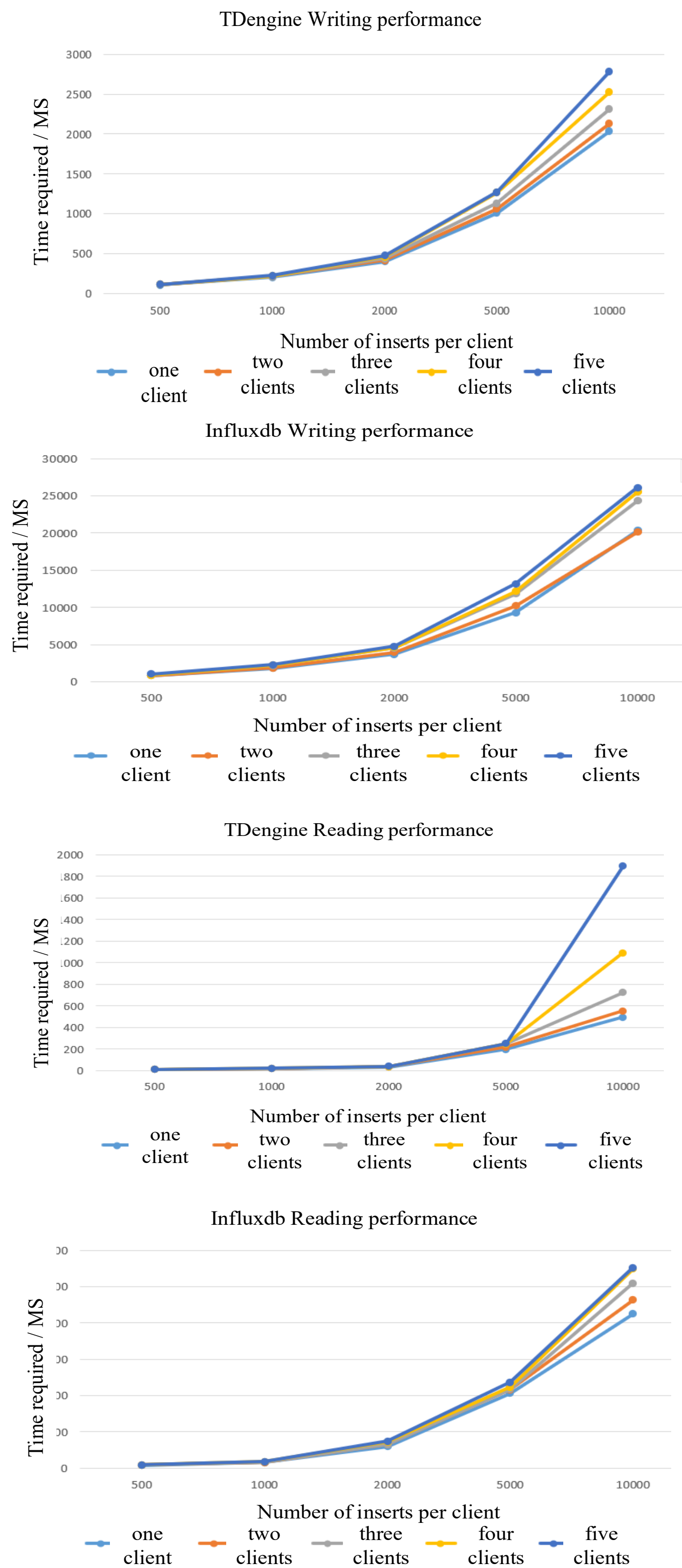

Figure 3. Performance test of time series database.

According to the above results, under the same test conditions, the write performance of TDengine is about 10 times stronger than Influxdb, but the read performance is slightly worse than Influxdb. Since time-sensitive network performance testing mainly involves high-frequency writing of multiple real-time data streams, and offline analysis can be used for reading and analysis, Influxdb has certain advantages in large-scale cluster applications, combined with the real-time edge computing platform and testing in this article Scenario, TDengine is more efficient, so this article chooses TDengine as the real-time data engine. During the experiment test, the TDengine time series database was connected with the TSN real-time data stream, and based on the OPC UA information model, the tags of the time series data were quickly created to realize data collection and subsequent data analysis.

5. CLOCK SYNCHRONIZATION AND END-TO-END DELAY PERFORMANCE TEST

5.1 Clock synchronization test

In the clock synchronization test, the best master clock algorithm (Best Master Clock Algorithm, BMCA) determines the best master clock in the network system, and sets the test data receiving calculation module as the slave clock to receive the synchronization messages sent by the best master clock, and calculate the deviation of the local clock from the best master clock. In this test, the Hessman switch is selected as the best master clock through the BMCA algorithm, and the test data receiving calculation module continues the clock synchronization test for 11.5 hours. The histogram distribution of the test results is shown in Figure 4.

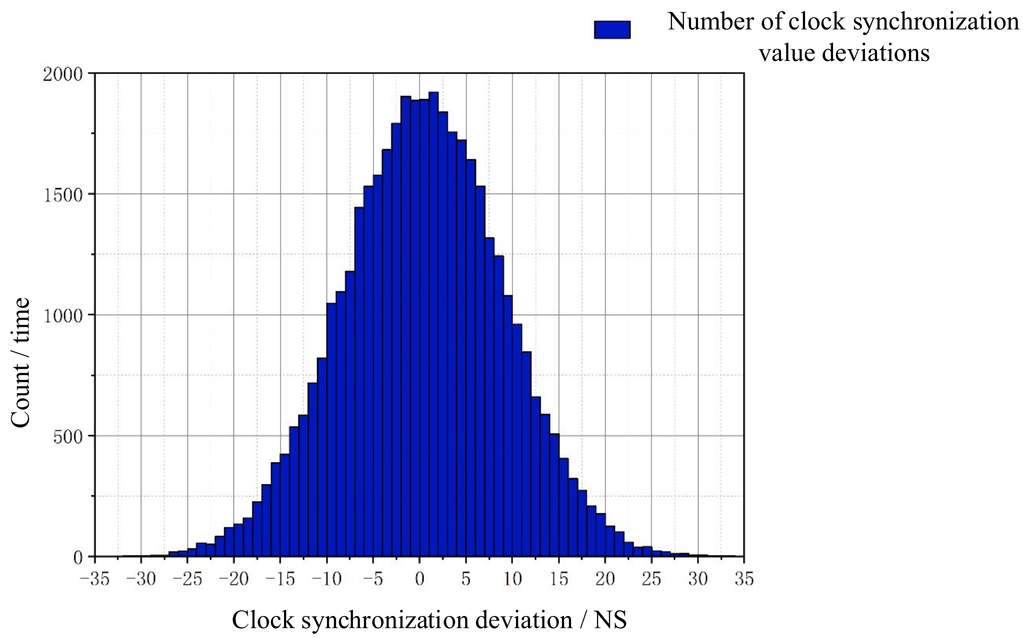

Figure 4. Clock synchronization performance test.

It can be seen from Figure 4 that the clock deviation is concentrated around 0ns, and the maximum synchronization deviation is 34ns. In the range of 11.5 hours, the average deviation of the clock is -0.133ns, and the standard deviation is 8.625 after calculation. Therefore, it can be deduced that the system under test has good clock synchronization performance and can meet the requirements of TSN standard for clock synchronization performance.

5.2 Delay and jitter performance testing

This test experiment platform is designed to test the delay and jitter of the message under different network environments, and the test results reflect the transmission performance of the network. The TSN network enables TAS traffic shaping to achieve TSN network effects, and adds surprise traffic to the network to be tested to simulate the normal load traffic transmitted by the network, and simulates different loads in the network by setting surprise streams of different sizes. In order to reflect the TSN network's guarantee of the transmission quality of time-sensitive streams, the test packet stream is set to be a time-sensitive stream and the priority of the load stream is higher than that of the time-sensitive stream to prevent the priority transmission selection algorithm from affecting the results. Figure 5 shows the delay of test packets passing through the TSN network and ordinary Ethernet under different load flow conditions. The devices in the network to be tested all support gigabit transmission rates, so the input load flow is set to 500M, 900M, 970M, 1000M, and 1100M to reflect different network environments. Since time-sensitive flows are generally periodic messages, in order to evenly test the delay and jitter within a period of time, the sending period of the time-sensitive flows is set to be $100\mu s$.

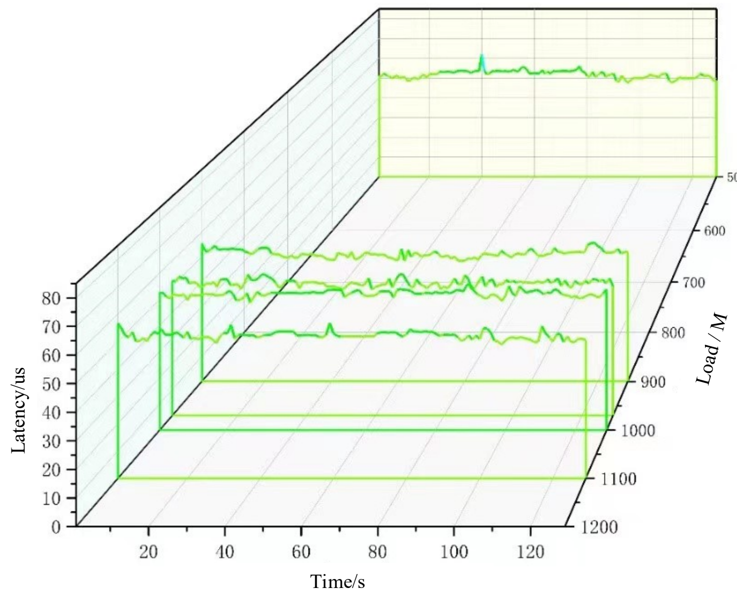

Figure 5. TSN transmission delay test.

The test results show that the TSN network can guarantee the delay of time-sensitive traffic load in the transmission process under different network load conditions and ensure the real-time transmission.

6. SUMMARY

The traditional Ethernet conformance test scheme mainly tests the single performance of network equipment. With the implementation of intelligent manufacturing, the demand for performance testing and performance evaluation of the underlying transmission network is increasing. On the basis of proposing a real-time edge computing platform architecture, this paper builds a TSN network performance testing experimental platform to conduct clock synchronization tests, delay and jitter performance test experiments. The follow-up functions of the test platform will be gradually improved, and the test results will guide the subsequent TSN network deployment and application.

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