TSN-Insight: An Efficient Network Monitor for TSN Networks

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ABSTRACT

As Time Sensitive Network (TSN) obtains increasing attention from industry and academia, the relevant standards of TSN have been improved and the technology is evolving rapidly. However, there is a lack of efficient tools to monitor the operation of TSN. Compared with monitoring data center network and local area network, the monitoring of TSN network focus more on the time synchronization accuracy of TSN switching nodes. Therefore, we propose an effective TSN monitor—TSN-Insight. The core idea is to leverage the TSN network's high-precision time synchronization, zero packet loss and deterministic delay boundedness. We learn the structure of PTP packets for reference, and by extending the PTP packet, it can carry more information and upload it periodically to TSN-Insight for analysis and processing to monitor the TSN network's time synchronization accuracy, switch status and link status. We apply TSN-Insight to a FPGA-based TSN prototype that is developed by us independently, and the experiment results demonstrate that TSN-Insight can accurately monitor time synchronization accuracy, switch status and link status in real time.

1 INTRODUCTION

With the rapid development of industrial Internet of things (IIoT), it is of great importance to realize the deterministic forwarding of real-time information and the best-effort forwarding of non-real-time information in the industrial control network through a standardized network. In 2012, the AVB group of IEEE802.1 was formally replaced by TSN task group [1] to meet the forgoing requirements. In the era of industry 4.0, the industrial Internet has higher requirements on the autonomous control of TSN, and it needs to monitor TSN [2] to obtain a large amount of detailed network state information to support the control behavior.

In order to monitor the network status in real time, researchers obtain the fine-grained information in the network through various methods. Currently, the commonly used methods such as NetFlow [3], sFlow [4] and in-band network telemetry [5] are mainly applied to the monitoring of data center network or local area network. In NetFlow, most data domains are lost during the process of network monitoring. Only the source and destination IP addresses, protocols, types, QoS, automatic control systems and other domains are saved, while the rest of the packet information is discarded. Although NetFlow can save the first 1200 bytes of data packets, there are basically no gateways to report these data intuitively, so it is impossible to obtain enough information to describe the running status of TSN. sFlow is a pure packet sampling technique in which the length of each sampled packet is recorded, and most of the packets are discarded, leaving only the samples to be transmitted to the collector. Since this technology is sample-based, it can only be used in networks that can provide a large number of packets.

In summary, the existing work cannot satisfy the demand for TSN monitoring. The study aims to design a TSN network monitor, which can meet the monitoring requirements of real-time of TSN, network state information accuracy and time synchronization accuracy. It can display TSN's network state information in real time, and effectively analyze the monitoring data and eliminate network faults. The key idea is to design a new network monitoring mechanism for TSN, by which the synchronization node can automatically and periodically upload the extended Beacon frame to the TSN monitor for analysis and displaying the change of time synchronization accuracy.

2 DESIGN OF TSN-INSIGHT

2.1 A New Monitoring Mechanism——ePTP

The classical PTP protocol makes use of periodic data interaction between network nodes and transparent clock mechanism to achieve high precision time synchronization between network nodes. PTP message consists of PTP header and payload, which mainly contains timestamp information. Based on the design of the in-band network telemetry technology, the ePTP mechanism extends PTP packet payload and defines a new PTP packet based on the Beacon mechanism—Beacon-PTP, abbreviated as Beacon message.

Beacon message is mainly composed of two parts: the upper part of the PTP message domain and the lower part of the extension domain. To abbey PTP specification, message type field and transparent clock information are retained. The Beacon message effectively extends the reserved domain in the PTP protocol message, which enables the Beacon message to carry more data information.

The ePTP mechanism enables TSN nodes to periodically upload Beacon messages carrying TSN running status information to TSN-Insight as the source of TSN-Insight monitoring information. As shown in Figure 1, when a message is sent by a TSN node, in addition to collecting transparent clock information from the current TSN node, the configuration information of the TSN node and the link state information directly connected to the TSN node are added.

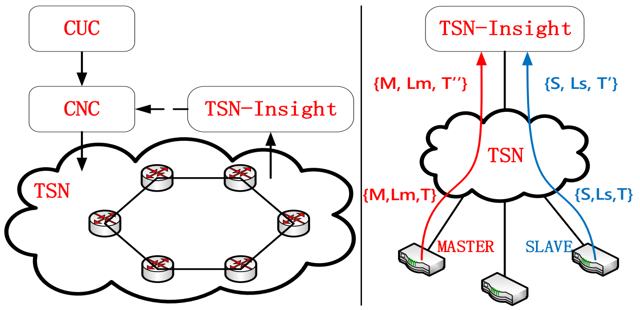

Figure 1: TSN-Insight based on ePTP Mechanism

2.2 TSN-Insight Architecture

In this part, we propose an architecture for TSN-Insight, a TSN monitor, based on the idea of in-band network telemetry, as depicted in Figure 1. The information that TSN-Insight collects from TSN can also be used by Central Network Controller (CNC).

TSN-Insight work with ePTP mechanism. The TSN switching node will periodically upload Beacon messages to TSN-Insight, which serves as the transmission medium to transmit switch information, link information and transparent clock to TSN-Insight. As shown in Figure 1, MASTER nodes and SLAVE nodes periodically send Beacon messages to TSN-Insight. The data of Beacon message sent by the MASTER node is {M, Lm, T}. M is the state information of the MASTER node. Lm is the state information of the link directly connected to the MASTER node. T is the moment when the MASTER node sends Beacon message. The data of Beacon message sent by SLAVE node is {S, Ls, T}. S is the state information of SLAVE node, while Ls is the state information of link directly connected to SLAVE node. Because all nodes send messages to TSN-Insight at the same time (synchronized by PTP), T is also the time when SLAVE node sends Beacon message. Beacon message is transmitted through the nodes in the TSN network, and the value of transparent clock in the message will be accumulated with the value of transparent clock through the TSN switching node. When Beacon message reaches TSN-Insight through TSN network, the main data of Beacon message sent by MASTER node becomes {M, Lm, T''}, and the core data of Beacon message sent by SLAVE node becomes {S, Ls, T'}. Assuming that the clock offset between master and slave clock nodes is **offset**. The link delay from MASTER node to TSN-Insight is **M_delay**. The link delay from SLAVE node to TSN-Insight is **S_delay**. The time of Beacon message sent by MASTER node reaching TSN-Insight is **Tm**, and the time of Beacon message sent by SLAVE node reaching TSN-Insight is **Ts**, so Beacon message from MASTER clock node to TSN-Insight takes:

$$Tm = M\_delay + T'' - T \quad (1)$$

Beacon messages from SLAVE clock node to TSN-Insight takes:

$$Ts = S\_delay + T' - T \quad (2)$$

The clock deviations between MASTER and SLAVE clock nodes meet the following condition:

$$offset = Tm - Ts \quad (3)$$

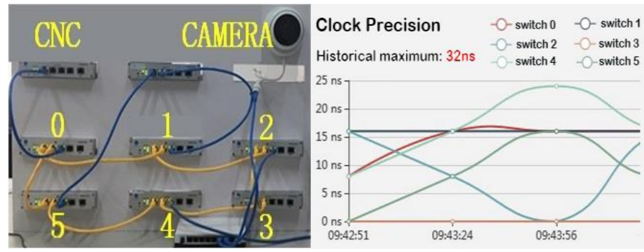

Figure 2: TSN demo & clock precision generated by TSN-Insight

By putting formula (1) and (2) into (3), the value of clock deviation offset between the MASTER and SLAVE clock nodes can be obtained as follows:

$$offset = T'' - T' + M\_delay - S\_delay \quad (4)$$

Please be noted that M_delay and S_delay are constant value that can be measured. In this way, the time precision between the SLAVE clock and the MASTER clock can be calculated. TSN-Insight use the data {M, Lm, T''} and {S, Ls, T'} to summarizes the switch information and link information to maintain a TSN global state table, including the topology information, configuration information and running state information of TSN network.

3 EVALUATION

In order to evaluate the effectiveness of TSN-Insight, we have built a circular TSN network prototype with 6 switching nodes, as shown in Figure 2. We select Node 0 externally connected to TSN-Insight, and select the clock of Node 0 as the MASTER clock of TSN network, and select Node 4 externally connected to camera to generate background data traffic, and then connect TSN-Insight with CNC. TSN-Insight runs on a virtual machine with single core CPU and 2GB RAM. The FPGA clock frequency constraint of all time synchronization nodes is 125MHz, and the synchronization period of time synchronization is 200us.

Each nodes in the TSN prototype send a Beacon packet to the TSN-Insight every one second after the synchronization. We use TSN-Insight to monitor the running state of TSN network prototype. Experimental results show that TSN-Insight can correctly visualize the topology, configuration information and operation status information of TSN network. And the synchronization time accuracy variation diagram of TSN network prototype presented by TSN-Insight is shown in Figure 2.

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