Performance of Profinet RT over TSN

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Abstract. Profinet IO does use VLAN tags with priority 6. Time Sensitive Networks (TSN) with Time-Aware Scheduling (TAS) are permitting to define timeslots for different priorities. The transmission delay of Profinet IO frames over a simple TSN-TAS link is measured for different load conditions and evaluated.

Keywords: Time Sensitive Networks (TSN), Time-Aware scheduling (TAS), Profinet, Real Time Ethernet

1. Introduction

Time Sensitive Networks (TSN) [1] [2] define a set of distinctive features which can be used, to get a better performance of Ethernet based networks in term of real-time for different applications. One field of applications are automation networks, where the transmission delay of messages and the jitter[1] are some examples of possible performance parameters. The transmission delay can be influenced by other traffic to be handled on the same network infrastructure.

Special automation network protocols like Profinet IO [3] have adopted measures to reduce the transmission delay and its jitter. In Profinet RT this is done by using inside the Ethernet frame a Virtual LAN (VLAN) tag. The VLAN tag inserts a priority field and a VLAN-ID number into the frame. Priority 0 is the lowest and priority 7 is the highest priority. Frames with the highest priority are transmitted first over one port. Profinet RT frames are required to use VLAN-Priority 6, and therefore are processed before most of other Ethernet frame, which should result in a lower delay and less jitter (compare [4] page 96).

One of the TSN features is Time-Aware Scheduling (TAS) [5]. Every switch port - a bridge port in the terminology of standards - runs a synchronized, repeating schedule that turns on and off each of the 8 queues with up to nanosecond precision. These 8 queues are assigned to the 8 different VLAN priorities. A timeslot is assigned and reserved for every specific VLAN priority.

The questions raised and to be studied in this paper are:

- Is it possible to use Profinet RT over TSN-TAS with the existing products in the market?
- What is the gain for the transmission delay time by using Profinet RT over TSN-TAS?
- What happens with the transmission delay time in heavy network load conditions?

2. Experimental Setup

A commercial Profinet IO-Controller is connected to an IO-Device. With the configuration tool of the controller the IO-Device is assigned to the IO-Controller and a cyclic data exchange of output data from the Controller to the Device and input data from the Device to the Controller is defined. The update time of the cyclic data exchange is set to 250µs. Every 250µs the Controller will send the output data to the Device. The assigned number of data does fit into a minimal frame with a duration of 6,7 µs if transmitted with 100 Mbit/s.

As an Ethernet network two TSN enabled switches are used, which are connected to each other over a 1 Gbit/s connection as outlined in Figure 1. The connections to the Controller and the Device are 100Mbit/s fullduplex.

[1] Jitter is the variation in time length of the transmission delay time or the cycle time

For the measurement the netANALYZER [6] device equipped with two Taps are inserted. The Taps are looped into the connection to the Controller and to the Device as shown in Figure 1. The netANALYZER timestamps the Ethernet frames with a time resolution of 1 ns (measurement accuracy of 5 ns) and reports the delay times between the two Taps in a table file. The graphics are generated out of these tables with Matlab.

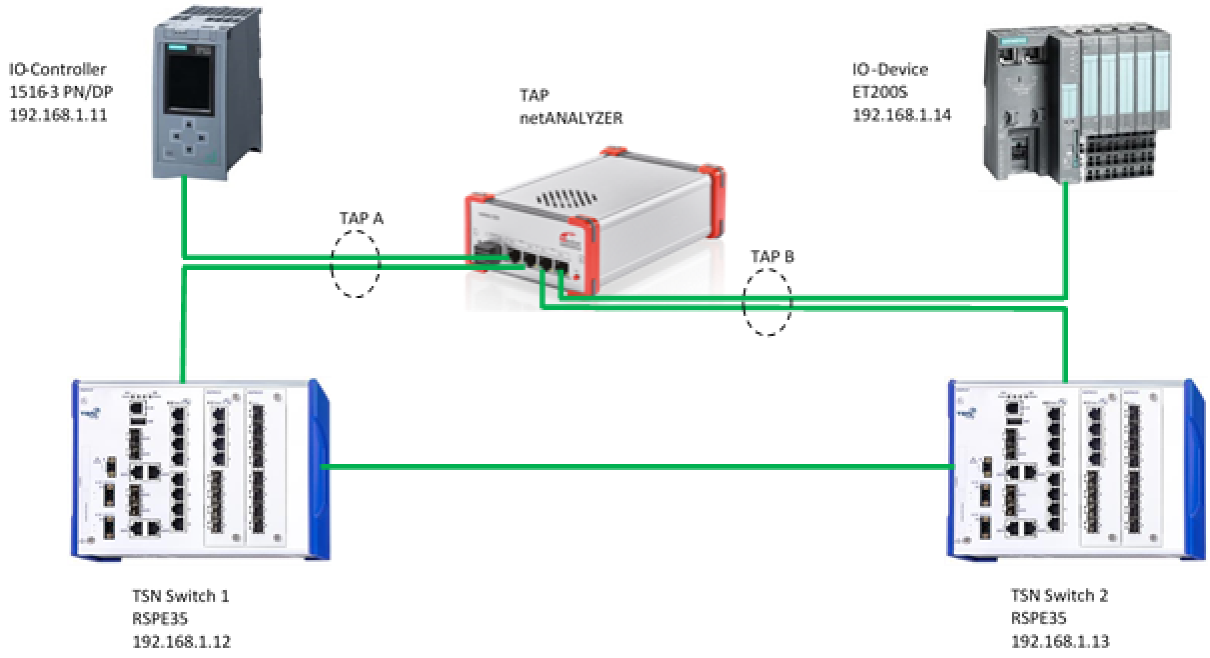

Figure 1 : Setup of the hardware for the measurements

The load is injected by a software Jperf [7] version 2.02 on a Windows 10 platform. A PC as a client sends the load on a free port to one of the switches and a second PC as a server does receive this load (PCs not shown in Figure 1). The Jperf graphical user interface uses iperf.exe network performance measurement tool. It generates as much data as possible to get the upper limit of the throughput. This is 346 Mbit/s for a 1 Gbit/s link typically.

According to IEEE 802.1Q a device does forward a frame with a VLAN tag with VLAN-ID ≥ 1. The Profinet RT devices use VLAN-ID = 0 as default value. If a switching device receives such a frame the VLAN-ID is replaced with the one assigned to the device. Profinet RT does not accept this.

If the switching devices are configured into the "VLAN-Unaware-Modus" the VLAN-ID is not interpreted and just copied. The Profinet RT frames are always interpreted as priority 6 frames, put into the corresponding transmission queue 6 and transmitted only in the reserved timeslot for this priority 6 is active. As long as there are no other frames appearing in the network with the same priority, this timeslot is reserved for the Profinet IO application only.

3. Measurements

Three different configurations are measured.

- In the first configuration the switches are operated as "normal" switches. They just use the VLAN priority to order the frames according their priority inside the transmission queue inside the switches.
- In the second configuration the switches are configured to give 900 µs out of 1 ms reserved for the VLAN priority 6 to be used by Profinet RT.
- In the third configuration the switches are using the same cycle of 250 µs like Profinet IO and only 25 µs is not reserved for Profinet RT.

All configurations are measured without any additional traffic and with the maximal load generated by the Jperf tool.

3.1 Standard Profinet RT

At the switches standard ports are used to transmit the Ethernet frames between the two switches. The cycle time of Profinet RT is defined to 250 us. Every measurement is done for two minutes, so 480’000 minimal Ethernet frames will be transmitted from the controller to the device.

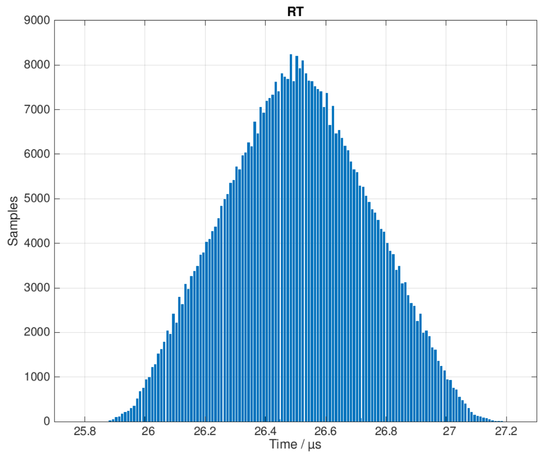

Figure 2 : Distribution of the delay time between the two taps for standard Profinet cyclic process data without any additional load on the network

The delay of the two switches for these Profinet RT minimal frames without any further configuration has a gauss-distribution in the range of 25,8 to 27,2 µs with an average delay of 26,5 µs and a standard deviation of 0,42 µs.

Based on the fact that an Ethernet minimal frame has with 100 Mbit/s transmission speed a duration of 6,7 µs the resulting delay for two switches is rather long, longer as expected. For typical industrial switches with cut-through technology one can measure delay times down to 3,5 µs. Our interpretation is, that these switches use store-and-forward technology.

If we now load the two connected switches with the additional load from the generator and repeat the measurement.

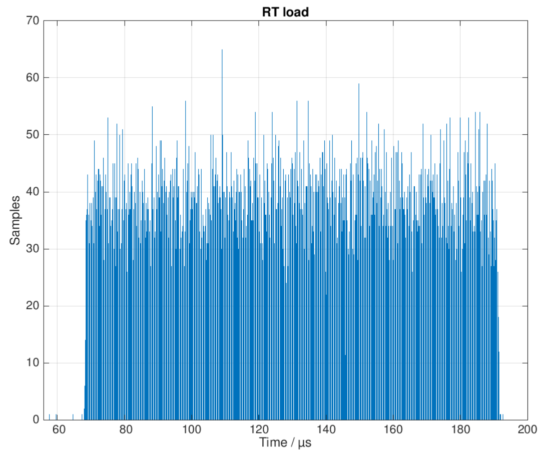

Figure 3 : Distribution of the delay time between the two taps for standard Profinet cyclic process data with additional load on the network

The distribution is now rather flat in the range of 65 to 195 µs delay time with a mean value at 129,8 µs. As a result, the increase of delay time is considerable with 40 to 160 µs. Profinet RT runs with cycle time of 250 µs, so the delay can be more than 60% of the cycle time.

3.2 Profinet RT over TSN with larger cycle time

The TSN Switches are configured with a cycle of 900 µs for priority 6 = Profinet and all other priorities only a timeslot of 100 µs. This results in a TSN cycle time of 1 ms.

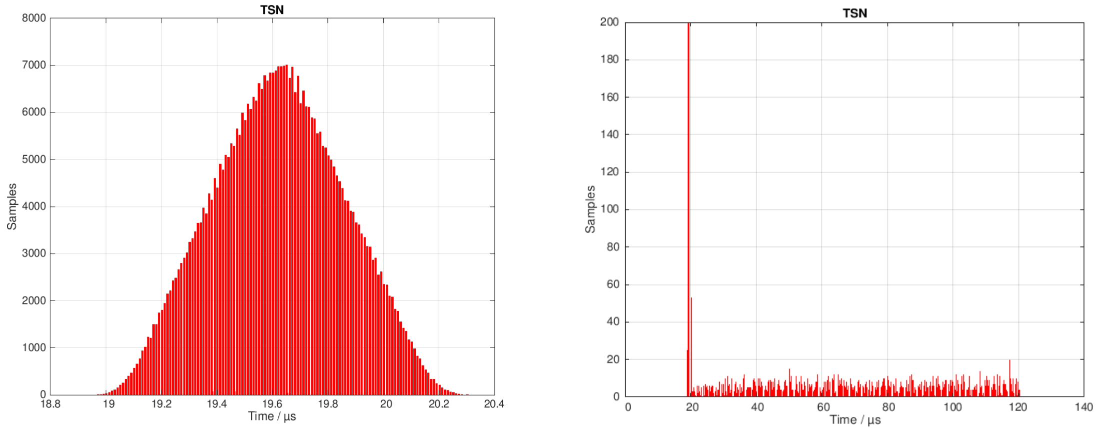

Figure 4 : Distribution of the delay time between the two taps for Profinet cyclic process data using TSN-TAS without any additional load on the network, left: general view, right: zoom to see small values

The result is a gauss-distribution in the range of 18,9 to 20,3 µs, which is rather shorter than without TSN. The average delay is with 26,5 µs rather high and the same as without TSN. If you have a closer look at the small values at right hand of Figure 4, one can see that there is an additional flat distribution added on top with an additional range of 100 µs. This is the non-synchrony of the cycle of the controller with the cycle of the switches which produces equally distributed delays in the range of the reserved period on the TSN switch for the other communication.

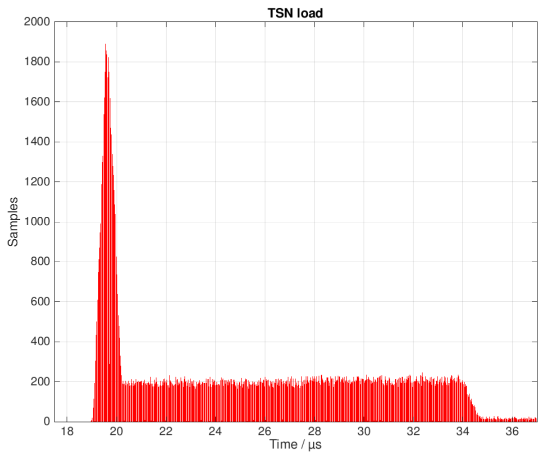

Figure 5 : Distribution of the delay time between the two taps for Profinet cyclic process data using TSN-TAS with additional load on the network

Under load conditions we see another flat distribution similar as without the TSN functionality, but rather reduced only up to 35 µs. In the next graphics are the two measurements with and without TSN compared with the same load constraints. The TSN solution gives a shorter delay, mean delay is only 34 µs, but still some prolonged delays due to the lengthy period for other communication of 100 µs. But even the maximal delays are much shorter than without TSN.

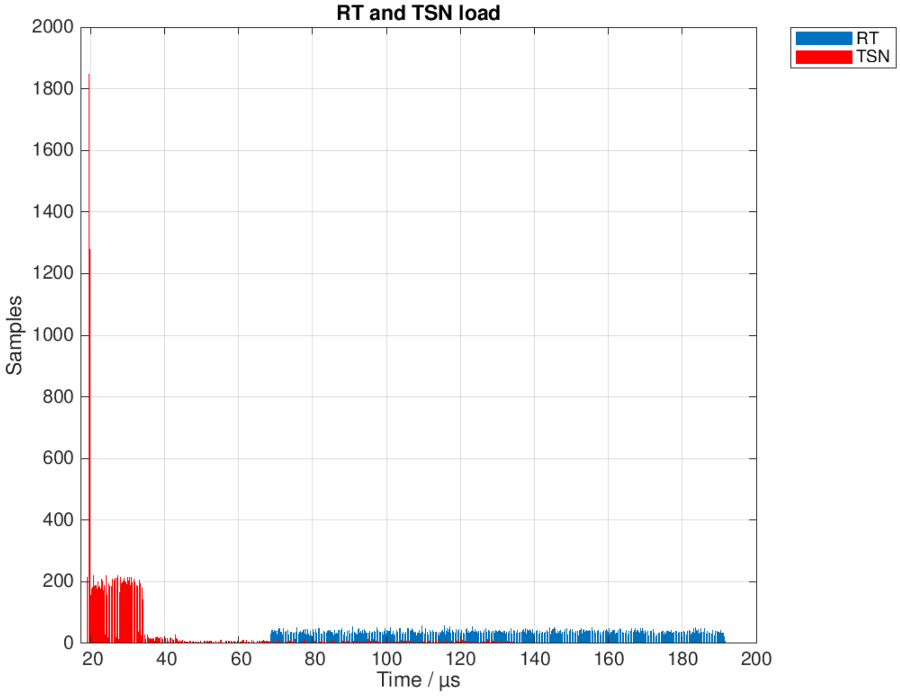

Figure 6 : Distribution of the delay time between the two taps for Profinet cyclic process data for standard RT compared to using TSN-TAS with additional load on the network

3.3 Measurement of optimized TSN

Now the cycle time of the TSN Switch is the same 250 µs as the Profinet IO cycle. In fact, the two cycles are not synchronized and may have a slightly different cycle length depending their local clock. This may even vary with the temperature of the time giving quartzes. We keep 225 µs reserved for Profinet and only 25 µs for other traffic. As the connection between the switches runs with 1 Gbit/s, the remaining capacity for other traffic is still 100Mbit/s.

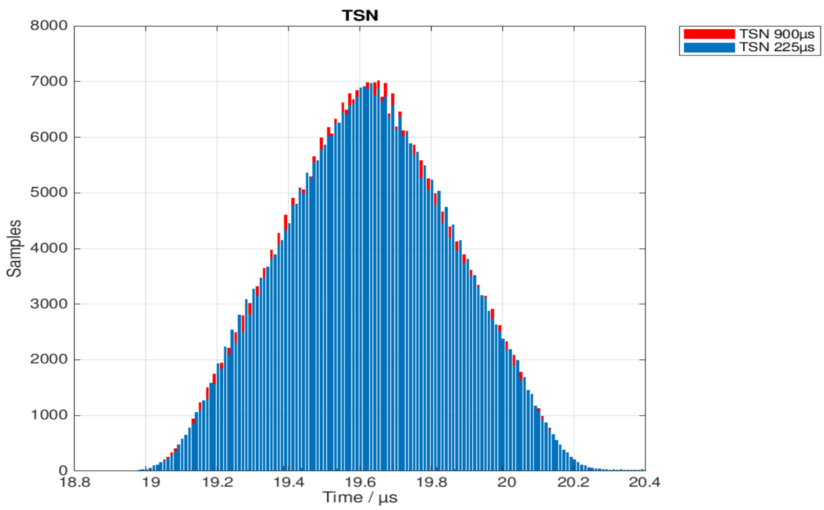

Figure 7 : Distribution of the delay time between the two taps for Profinet cyclic process data using TSN-TAS without any additional load on the network

In a first approach this does not change the distribution, but if we have a closer look to the details you see what we expected: the flat part of the delay distribution gets only an addition of 25µs.

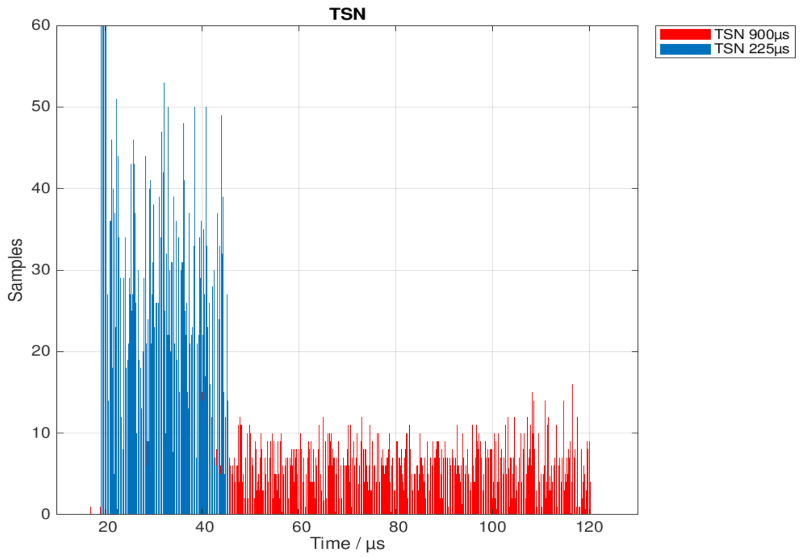

Figure 8 : Distribution of the delay time between the two taps for Profinet cyclic process data using TSN-TAS with additional load on the network, with zoom to small values

4. Conclusions

Yes, it is possible to use Profinet RT over TSN-TAS. Yes, it is also possible to see an improvement in delay time of frames using TSN instead of normal switch functionality under load conditions and even without any additional load.

But the benefit is rather small. The main problem is the lack of synchronization of the cycles of Profinet IO and the TSN cycles of the switches. The switches are synchronized to each other, but not the cycles of the Profinet controller and devices. This does automatically lead to additional delays, which are typically longer than the gain with the usage of TSN.

The only solution is to include TSN also in the Profinet controllers and devices and to synchronize the application cycle to the TSN cycle. This is exactly what the PI organization is planning to offer in the future [8].

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