PTPV1 AND PTPV2 TRANSLATION IN FTI SYSTEMS

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Abstract:

A Flight Test Instrumentation (FTI) system may consist of equipment that either supports PTPv1 (IEEE 1588 Std 2002) or PTPv2 (IEEE 1588 Std 2008). The challenge in such time distributed system is the poor compatibility between the two PTP protocol versions. This paper describes how to combine the PTP versions in the same network with minimum or no manual configuration.

Keywords: Ethernet, Time Synchronisation, PTP version translation

1. INTRODUCTION

Ten years ago there were very few network based data acquisition systems. One reason for this was the fact that there was no network based time synchronization solution that provided the accuracy and precision required for data acquisition systems, particularly the accuracy needed for wideband analog measurements. The release of the IEEE 1588 Precision Time Protocol (PTP) Version 1 standard in 2002 radically changed that.

PTP was a critical turning point for the FTI community since it enabled them to adopt networked based solutions for data acquisition systems, and move away from an IRIG-B synchronized system. Initially, with an Ethernet based data acquisition systems, there was a simplified Keep It Simple and Stupid (KISS) approach in terms of the network implementation and design, and it was based on the PTP protocol version 1 (PTPv1). The key factor driving this was the perceived risk of adopting a “new” Ethernet technology. It is fair to say that now the use of Ethernet technology for on-board FTI applications has been proven as a reliable backbone infrastructure for on-board data acquisition. As a result of the widespread acceptance of Ethernet there is increasing demand to take advantage of more networking technologies, standards and protocols to support advanced operations and system-wide optimization, for example using Quality of Service, packet filtering, IGMP snooping, etc.

The PTP standard was updated in 2008 to version 2 (PTPv2). The update to the standard was driven by the industrial, utility, and telecommunications sectors where PTP is used to provide high accurate time synchronization between machines or telecom base stations. The drawback of the version update is the backward compatibility between both versions, and without a translation device, the compatibility between a V1 and V2 equipment is not possible.

The remainder of this paper is structured as follows: Section two provides an overview of the Precision Time Protocol (PTP) and the main difference between the two versions. The co-existence of these time protocols within a single system creates a challenge for the network design, particularly since PTPv2 is not backward compatible. The solution for such *hybrid* systems is described in chapter 3 and involves the use of a PTP protocol translation technique that allows both PTPv1 and PTPv2 Slave Clocks to be synchronized by the same Grand Master Clock that either runs PTPv1 or PTPv2.

2. PRECISION TIME PROTOCOL

The impact of PTP for FTI systems cannot be understated. The release of the PTPv1 standard was effectively the catalyst that facilitated the paradigm shift towards the adoption of Ethernet technologies to replace the traditional proprietary N-wire solutions. Before the development of PTP, the time synchronization accuracy of N-wire solutions was <1µsec or using standard networking protocols such as the Network Time Protocol (NTP) was <1msec, neither of which was sufficient to meet the timing requirements of the data acquisition system. By using the PTP protocol, all distributed DAUs in a networked FTI system, regardless of topology or the number of devices, can be synchronized to within 100ns.

2.1 GENERAL ABOUT PTP

PTP is a network protocol originally defined in the IEEE 1588-2002 standard that allows the distribution of precise time synchronization information across a network with a high degree of accuracy. This accuracy is achieved using hardware assistance to generate PTP packet timestamps as close to the Ethernet wire as possible. The PTP architecture comprises at least one Grand Master Clock and a distributed system of Slave Clocks in the DAUs and other sink devices. The Grand Master Clock continuously transmits synchronization messages to the Slave Clock at defined intervals. These time messages are sent to a specific multicast address.

2.2 PTP V1

In order to ensure the most precise value of the timestamp T1 embedded in the synchronization message (Sync), the Grand Master Clock sends a Follow-up message that contains the timestamp T1 after the transmission of the Sync message. The Slave Clock receives the Sync and the corresponding Follow-up message at a time T2 measured by its own clock. At this point, the Slave Clock only knows the time when the Grand Master Clock sent the Sync and Follow-up message, but it does not know the one way propagation delay for the time messages nor does it know its time offset from the Grand Master Clock. To do this, another message exchange is required to measure the delay between Slave Clock and Grand Master Clock. For this purpose, the Slave Clock sends a Delay-Request packet to the Grand Master Clock at time T3. The Grand Master Clock receives the request packet at time T4 and issues a Delay-Response message that carries the measured value T4 back to the Slave Clock. The Slave Clock now knows the times, T1, T2, T3, and T4 that enable it to calculate the delay and offset. Note that the Delay-Request-Response exchange between the Slave Clock and

Grand Master Clock occurs at pseudo-random intervals to prevent a flood of messages at the Grand Master Clock from all the DAUs in the system.

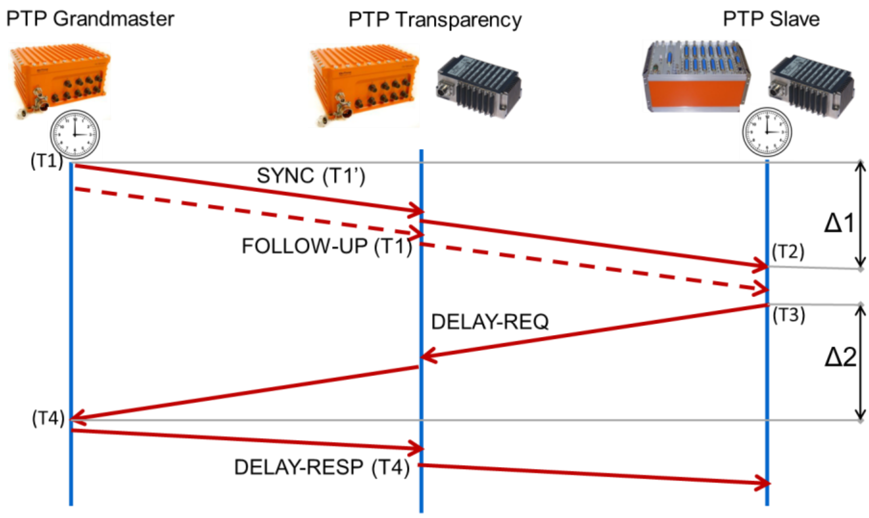

Figure 1: PTP v1 Operation

PTPv1 Algorithm
Where:
$\Delta 1 = T2 - T1$
$\Delta 2 = T4 - T3$

Propagation delay $= (\Delta 1 + \Delta 2)/2$
Offset $= (\Delta 1 - \Delta 2)/2$

For the purposes of reliability, there may be more than one Grand Master Clock in the network. In this case, the Slave Clocks use an algorithm called the Best Master Clock Algorithm (BMCA) to automatically select the best clock in the network. The BMCA enables the Slave Clock to synchronize to the best clock in the network as determined by several criteria including an administratively assigned priority or preference, the clock quality in terms of its stratum and accuracy, estimated stability, and observed variance.

A Slave Clock in the network assumes that the propagation delay to be the same for both directions between the Grand Master Clock and the Slave Clock. This is far from true in an FTI data acquisition network. Such a network is heavily asymmetric in that the DAU generate and transmit a lot of data upstream but receive very little data on the downstream. This means that the Delay-Request messages originating from the Slave Clock may experience higher Ethernet switch latency upstream than the corresponding Sync messages from the Grand Master Clock. The PTPv1 standard proposes Boundary Clock implementations in the Ethernet switches in order to solve this problem, while [4]suggests a different and much simple technique that is based on PTP transparency for PTP event packets. This PTP transparency technique has been introduced in FTI networks that are based on PTPv1, see [5] for details. Note that the PTPv1 standard does not specify PTP transparency.

Another limitation of the PTPv1 protocol for FTI systems is that the minimum interval between PTPv1 Sync messages cannot be set lower than one second.

2.2 PTPV2

PTPv2 adds several enhancements such as a formal specification for the Transparent Clock implementation in the switch, smaller Sync messages for bandwidth optimization, faster update rates, and extensibility options to allow, for example, health information about the synchronization status of the system.

A Sync rate of e.g. 8 Sync messages per second can significantly improve the time synchronization accuracy on the Slave Clock, particular in an environment with fast temperature changes. How much the accuracy can be improved on a Slave Clock depends on the oscillator choice and clock servo implementation.

PTPv2 path delay measurements can be performed in two different ways: With the End-to-End (E2E) or the Peer-to-Peer (P2P) mechanism. Essentially PTPv2 E2E uses the same Delay Request-Response mechanism as defined in PTPv1 as illustrated by Figure 2. PTPv2 P2P adds a peer delay mechanism which measures the peer-to-peer link delay using an additional message exchange comprising: Peer Delay Request (Pdelay_Req), Peer Delay Response (Pdelay_Resp), Peer Delay Response Follow-up (Pdelay_Resp_Follow_Up) messages. The peer delay mechanism is limited to point to-point links between peer devices e.g. DAU and the peer switch, switch and peer Grand Master Clock. These peer messages are completely confined between the peer devices and not forwarded any further unlike the “Delay request-response” messages

PTPv2 also defines Signaling, and Announce messages. In PTPv2 the mechanism for synchronization is separated from the mechanism to determine the “Grand Master Clock-Slave Clock hierarchy”. The Best Master Clock Algorithm has been improved in PTPv2. In PTPv1 the Best Master Clock Algorithm (BMCA) information is in the Sync message, and can only accept the information “Grand Master is preferred”. In PTPv2 the BMCA selection information is carried in an Announce message, and has a value from 0 to 255, with 128 the default. Both Sync and Announce messages are sent periodically by the Grand Master Clock but Sync messages are normally sent with a higher frequency. Management and signaling messages are used to query and update the PTP data sets maintained by clocks. These messages are used to transport a sequence of one or more Type Length Value (TLV) entities. In particular for FTI systems, these messages can be used to customize a PTP system, to generate certain events and for initialization and fault management to manage/monitor the health of the system synchronization status.

Where PTPv1 did not formally define the transparency implementation, in PTPv2 there are two types of Transparency Clocks (TC) defined, an End-to-End (E2E) TC and a Peer-to-Peer (P2P) TC. An E2E TC measures the time (queuing and switching delays) taken for a PTP packet to transit the switch and provides this information to clocks receiving this PTP message, but it does not provide corrections for the propagation delay of the link connected to the port receiving the PTP message. Instead it relies solely on the use of the delay request-response mechanism to make corrections for propagation delays. On the other hand, a P2P TC is a Transparent Clock that, in addition to providing Ethernet switch delay information, also provides peer-to-peer cable propagation delay information in the PTPv2 packets.

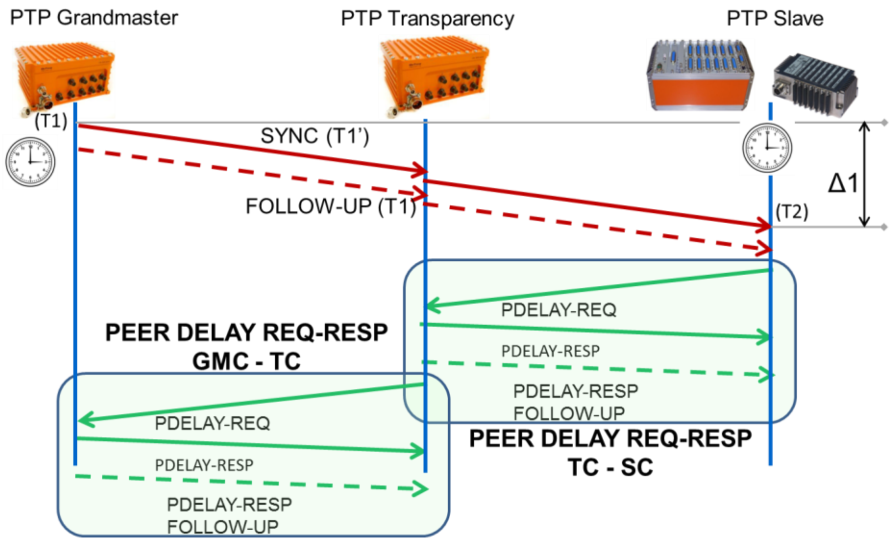

Figure 2: PTP v2 Operation

3. PTPV1 AND PTPV2 TRANSLATION

As a consequence of the adoption of PTPv2 as the de-facto time synchronization standard, new equipment is being released with PTPv2 support. Replacing old equipment with PTPv1 support has a serious cost impact. It is desirable to reuse PTPv1 compatible equipment as well as introducing new equipment supporting PTPv2. Thus a PTP version translation mechanism is needed in order to combine PTPv1 and PTPv2 nodes in the same FTI network.

Figure 3 shows an FTI system consisting of both PTPv1 and PTPv2 end nodes.

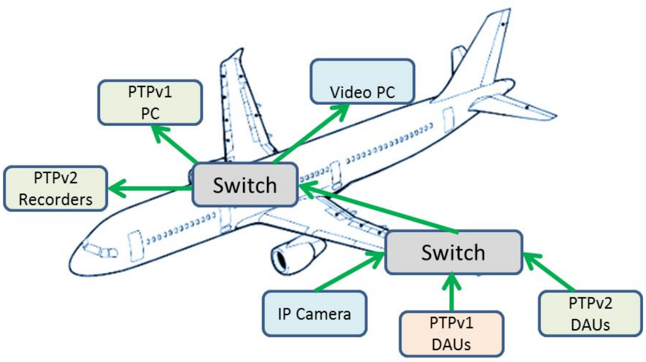

Figure 3: FTI system with PTPv1 and PTPv2 end nodes

To complicate matters even further as PTPv2 is not backward compatible with PTPv1. This means, for example, that PTPv2 Grand Master Clocks cannot synchronize PTPv1 DAUs or vice versa. But more seriously, PTPv1 TC switches cannot handle PTPv2 packets and this effectively renders the PTPv1 TC switch to become a non-PTP switch for a PTPv2 system. A single non-PTP switch in the system can degrade the synchronicity of the entire FTI network because:

- A PTPv2 switch will not be able to determine the path latency between itself and the non-PTP switch.

- The non-PTP switches will not update any of the PTPv2 switches on the switch latency they are adding to the system.

The solution to the PTP version interoperability issue is, nevertheless, the Ethernet switch. FTI Ethernet switches with Transparent Clock (TC) support according to both PTPv1 and PTPv2 protocol stack can be used in order to combine PTPv1 and PTPv2 DAUs in the same network.

Figure 4 shows an example of a network that contains equipment that either support PTPv1 or PTPv2.

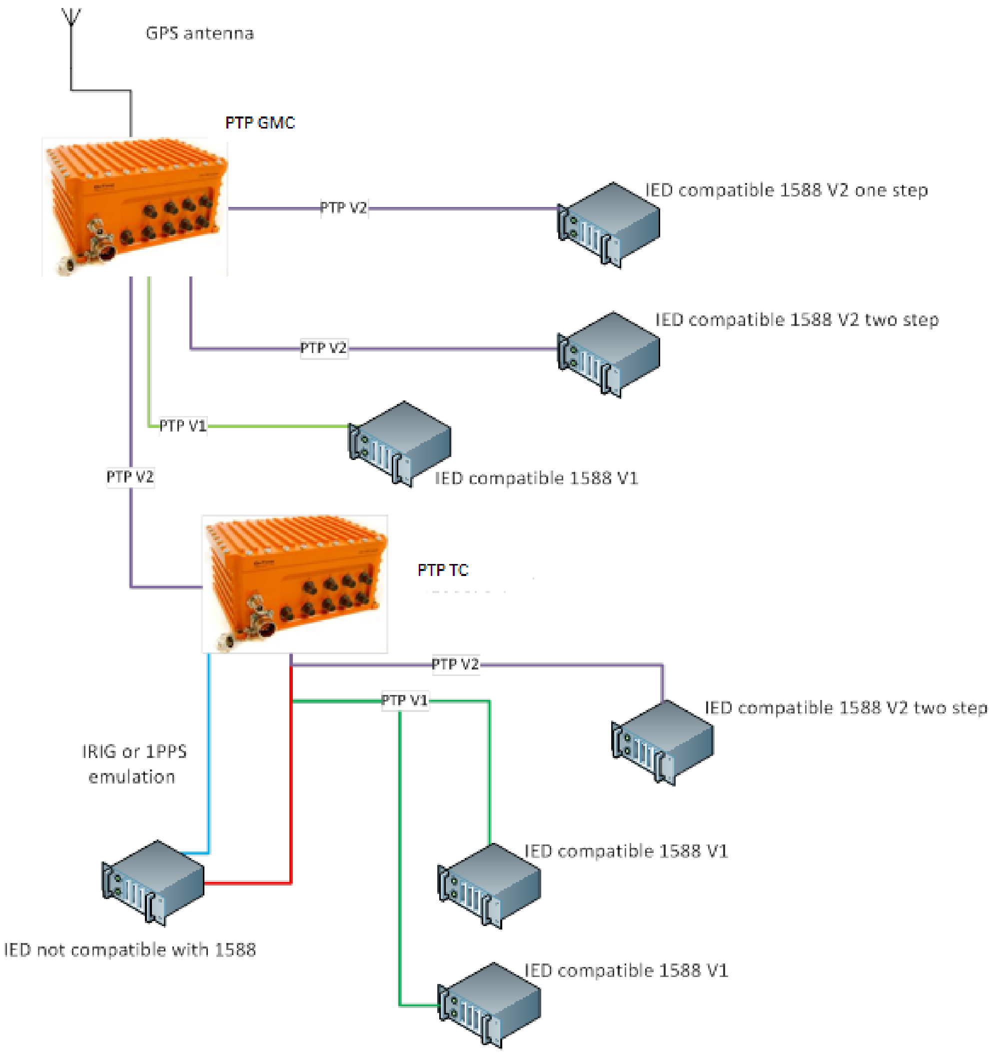

Figure 4: mixed network

An Ethernet switch port is either identified as a PTPv1 or PTPv2 capable port. The switch must run the PTPv1 TC protocol on a PTPv1 capable port and vice versa on a PTPv2 capable port.

3.1 VERSION DETECTION

Whether a port is PTPv1 or PTPv2 capable can either be static configured or automatically detected on run-time. The automatic detection of the PTP version can be achieved based on the following rule set:

- The switch port shall be default be configured as a PTPv1 capable port
- The switch port will only change to PTPv2 if a PTPv2 P2P message is received on the port.

The reason for this principle is driven from the fact that a PTPv1 clock configured as a: "Slave Clock only", never will send any PTP packets before the clock has received a valid PTPv1 Sync message. The same applies to a PTPv2 only Clock that is configured for E2E as the delay mechanism, while a PTP Slave only Clock configured for P2P will on its own initiate a P2P message immediately after the link is established.

This approach requires that manual PTP version configuration is used on the switch for clocks configured for PTPv2 and E2E as the delay mechanism. For this reason we suggest that P2P is used for future mixed system that needs automatic detection of PTP version.

5. CONCLUSIONS

Time synchronization is an important property of a data acquisition system. Time synchronization is critical in order to ensure synchronous sampling of channels, accurate time stamping, and coherency in a distributed data acquisition system. Although PTPv1 may provide what a system require, PTPv2 is now the de-facto standard for time synchronization in a LAN. Combining PTPv1 and PTPv2 equipment in the same data acquisition systems is not easy due to the fact that PTPv2 is not backward compatible with PTPv1. Several data acquisition devices support firmware upgrades which somewhat eases this upgrade procedure. But it is not always possible to do a PTP firmware upgrade on equipment, the device may need to be physically replaced which could be problematic especially if it has already been installed in the aircraft. In order to get around this problem, FTI Ethernet switches with support for both PTPv1 and PTPv2 can be used to perform PTP protocol translation from PTPv2-to-PTPv1 and vice versa.

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