

PTP VERSION 3 IN FTI?

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Abstract:

Time synchronization based on the Precision Time Protocol (PTP) according to the IEEE 1588 standard is a core building block for state-of-the-art high-performance Flight Test Instrumentation (FTI) systems. Two versions of the IEEE 1588 standard have been launched: PTP version 1 according to IEEE 1588™ - 2002 and PTP version 2 according to IEEE 1588™ - 2008. Now a new IEEE 1588™ working group has been established with the goal to launch a new revision of the IEEE 1588™ standard; i.e. PTP version 3.

The FTI industry is using both PTP version 1 and 2. The poor backward compatibility between PTP version 2 and 1 has been a big challenge for the FTI community. Backward compatibility with older PTP versions, new functions and to what extent PTP version 3 is relevant for the FTI industry are described and discussed in this paper.

The IEEE 1588 standards define several PTP profiles for various time synchronization usages in different industries. This paper also describes how PTP is used in FTI and also proposes a PTP profile definition for FTI including special time synchronization parameters/properties taken from the iNET standardization.

Keywords: IEEE 1588, PTP version 3, PTP profile, FTI, iNET.

Introduction

The FTI industry was one of the first industries that started to use PTP. This means that there is a large install base of FTI systems that are based on PTP version 1. The poor backward compatibility between PTP version 2 according to IEEE 1588™ - 2008 and PTP version 1 according to IEEE 1588™ - 2002 represented a major challenge for the FTI community since off-the-shelf PTP version 1 and 2 clocks could not be combined in the same network. A solution to this problem was launched by OnTime Networks in 2013 by the introduction of TC/SC Ethernet switches with PTP version translation support implemented according to the principles described in [1]. These TC/SC switches made it possible to combine PTP version 1 and 2 in the same network.

What about backward compatibility for new revision of the IEEE 1588™ standard?

A PTP version 3 working group, see [2] and [3], has been established and approved by IEEE. The working group shall ensure that the resulting standard has the highest degree of

backward compatibility with previous editions of the IEEE 1588™ standard and all new features will be optional.

The scope of this working group is as follows:

- Correct known technical and editorial errors
- Better accuracy
- Definition of an SNMP MIB
- Security
- Clarify the layering, interfaces and protocol of the standard

Several IEEE 1588 PTP profiles for different industries such as profiles for telecom, power systems (C37.238), PROFINET, etc. are defined. These PTP implementations are very different and should not be combined in the same network. The de-facto PTP implementation used in FTI is to a large extent based on the default PTP profile of the IEEE 1588™ - 2002 or IEEE 1588™ - 2008 standards, but also the evolving iNET standard specifies time synchronization properties that

should be considered for such a PTP profile. This means first of all support for SNMP management of the network clocks and the possibility for generating alarms, i.e. SNMP trap, in case of synchronization loss and GMC hold-over capability in case of GPS loss.

The main PTP properties that are relevant for a FTI PTP profile for both IEEE 1588™ - 2002 or IEEE 1588™ - 2008 are as follows:

- Clock modes
- One-step vs. two step clocks
- Media
- Delay mechanism
- Transport mechanism
- Domain
- Selection of Best Master Clock
- PTP EPOCH
- Sync interval
- Delay_Req interval
- Announce interval
- PPS output
- IRIG-B 002/122
- Management
- SNMP traps
- GMC holdover
- SC accuracy
- SC time to synchronization

Abbreviations

BC	Boundary Clock
BMCA	Best Master Clock Algorithm
DST	Daylight Saving Time
E2E	End-to-End
FCS	Frame Check Sequence
FTI	Flight Test Instrumentation
GMC	Grand Master Clock
GUI	Graphical User Interface
IED	Intelligent Electronic Device
IP	Internet Protocol
IRIG	Inter-Range Instrumentation Group time codes
MAC	Medium Access Control
MC	Master Clock

OC	Ordinary Clock
P2P	Peer-two-Peer
PPM	Parts per Million
PPS	Pulse Per Second
RTOS	Real Time Operating System
SC	Slave Clock
SyncE	Synchronous Ethernet
TAI	Temps Atomique International
TC	Transparent Clock
TCP	Transmission Control Protocol
ToS	Type of Service
TZ	Time Zone
UDP	User Datagram Protocol
UTC	Coordinated Universal Time

PTP version 3

The working group formed to revise the IEEE 1588™ has established five sub-committees:

- Architecture
- High Accuracy
- Upkeep
- Management
- Security

Architecture

The charter of the Architecture sub-committee is as follows:

- “..clarify the layering, interfaces, and protocols of the standard, including the behaviour of systems that deploy different protocol options.”

Relevant topics for this sub-committee are:

State reduction

The FAULTY, PRE-MASTER and UNCALIBARTED states would become optional. This means that IEEE 802.1AS becomes a complaint profile and faster re-configuration/synchronization can be achieved.

This change is first of all an implementation requirement that will not impact the observed node's PTP protocol behaviour.

State reduction might be convenient for FTI SC if fast synchronization is required, see SC

accuracy and time to synchronization section below.

Profile isolation

Multiple PTP profiles may exist on the same network with different BMCAs. The sub-committee suggests to use a transport specific attribute in the PTP header in order to define the PTP profile that the PTP packet belongs to in order to isolate the PTP profiles available on the network.

Only one PTP profile should be used in an FTI system. This function is not considered for FTI.

Port State Configuration

Port State Configuration means that a PTP port can be BMCA capable, SC only or GMC/MC only, where manual configuration is possible.

This is not considered to be relevant for FTI. FTI should allow SC only clock modes (DAUs), while all GMC candidates should support BMCA.

PTP domains

PTP domains in IEEE 1588™ - 2002 or IEEE 1588™ - 2008 do not interact. The sub-committee suggests that domains can share the same timing data in order to offer support for multiple simultaneous GMCs and multipath PTP for time synchronization redundancy purpose.

This is not considered to be relevant for FTI. FTI should only allow one PTP domain (i.e.: 0 – default).

High Accuracy

The charter of the High Accuracy sub-committee is as follows:

- “The protocol enhances support for synchronization to better than 1 nanosecond.”

A proposal including support for SyncE for frequency synchronization at physical layer will be proposed. Frequency synchronization may be achieved through a different spanning tree than the spanning tree used for PTP. Calibration of each SC including compensation for all asymmetric components and cable delays will be part of the proposal. A “Golden Calibrator” for a given system may be required.

Data acquisition with sub-nanosecond or single digit nanoseconds accuracy in future FTI systems may be relevant. The High Accuracy section of PTP version 3 standard can then be relevant.

Upkeep

The charter of the Upkeep sub-committee is as follows:

- “Incorporate official IEEE interpretations and other known errors or needed clarification into 1588-2008 in order to provide clean version as a basis for modifications of the current P1588 working group.”
- “Once this is done serve as a “quality control” function for any modifications proposed by other committees to ensure freedom from inconsistencies and backward compatibility issues.”

This work includes clarification of the TC source address topic.

No major impact from the Upkeep section is expected for FTI.

Management

The charter of the Management sub-committee is as follows:

- “The management sub-committee will consider the management of IEEE 1588 clocks, e.g. MIB, related management protocols (SNMP and native management protocol), and OAM mechanism.”

The Management sub-committee proposal is to create a single IEEE 1588 SNMP MIB. A mechanism to allow in-service monitoring of synchronization quality will also be proposed.

An IEEE 1588 SNMP MIB as well as extended support for monitoring the synchronization quality of the PTP clocks can be convenient for FTI. IETF standardization are targeting some of the same needs, but future FTI system can benefit from this proposal from the Management sub-committee.

Security

The charter of the Security sub-committee is as follows:

- “To specify a security capability for PTP. This capability is expected to be optional.

The Security sub-committee considers technologies such as IPsec and MACsec. The requirements are based on IETF document: “draft-ietf-tictoc-security-requirements”.

FTI systems are in most cases considered as closed systems. Security related to PTP synchronization has not been an issue for FTI up to now.

PTP profile for FTI

The main PTP properties/parameters that are relevant for FTI are as follows:

Clock modes

IEEE 1588 defines the following PTP clock modes:

- Grand Master Clock (GMC)
- Ordinary Clock (OC)
- Boundary Clock (BC)
- Transparent Clock (TC)
- Slave Clock (SC) only

An OC can either act as a GMC or a SC. If the OC wins the BMCA for the network, then the clock will be the GMC for the network. If not, then the clock may be passive or run as a SC. If the OC enters SC mode then the clock will discipline its local clock based on time updates from the chosen GMC of the network, while the clock will discipline its local clock based on its local time base (e.g. GPS) if the clock enters passive mode. More than one GMC or OC in the same network means better redundancy and robustness.

Ethernet switches and routers in a network can either support BC, TC, TC/SC or GMC clock modes. BC means that one port is in SC mode and the remaining ports are in MC mode. TC clock mode means that the local switch/router clock is used for calculating the switch/router residence time for each PTP event packet forwarded through the network element. This local clock may or may not be synchronized with the GMC clock of the network. The clock drift of a SC compared to the GMC in the network is calculated and compensated is the clock is synchronized, while both the clock drift

and offset is calculated and compensated if the SC is synchronized with the GMC. A TC/SC switch contains also SC support. This means that the network element is both synchronized and synchronized with the GMC. A synchronized TC offers better accuracy compared to a TC with free running clock.

A SC only implementation means that the device only supports SC mode. This clock will discipline its local clock based on time updates from the chosen GMC of the network.

BCs are not used in today’s FTI systems. Only TC and TC/SC implementation are used. This is also valid for FTI systems based on the IEEE 1588™ - 2002 standard even though this standard does not specify TCs. The TC implementations used in FTI systems that are based on IEEE 1588™ - 2002 follows the proprietary principles presented and demonstrated by OnTime Networks at the IEEE 1588 conference in 2004, [4].

1-step vs. 2-step clock

IEEE 1588 specifies two types of clocks:

- 1-step clock
- 2-step clock

Figure 3 below shows the PTP packets used for performing time updates on a SC either based on 1-step clock or 2-step clock principles. The Sync and Delay_Req packets are PTP event packets, while the Follow_Up and Delay_Resp packets are general packets.

A one-step clock implementation is based on including the precise egress timestamp, t1, from the GMC into the Sync packet payload, while a corresponding two-step clock implementation is based on sending this timestamp in a Follow_Up packet that follows the Sync packet.

A one-step clock implementation must generate and update the Sync packet with the precise egress timestamp and perform and update the packet FCS in hardware. No Follow_up packet is required if one-step clocks are used.

Only 2-step clock implementations are used in FTI for both IEEE 1588™ - 2002 and in IEEE 1588™ - 2008.

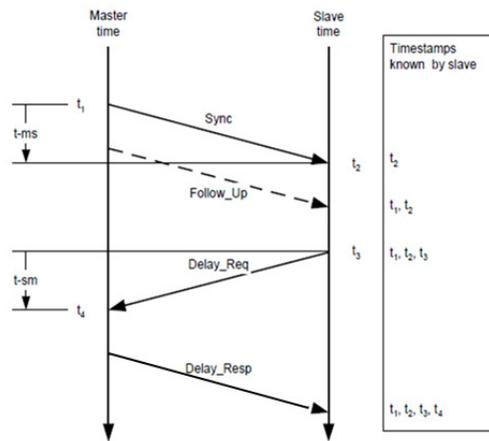


Figure 3, 1-step vs- 2-step clock

Media

IEEE 1588 can be used for several media. Wired Ethernet is by far the most used communication technology used for IEEE 1588, where both copper and fiber and any Ethernet speeds can be used. The IEEE 1588™ - 2002 or in IEEE 1588™ - 2008 standards do not specify that the duplex connectivity must be full duplex, but most PTP profiles do specify this. Note that half duplex connectivity and Ethernet PHYs/MACs supporting IEEE 1588 might not work properly.

Only full duplex connectivity is used in FTI.

Delay mechanism

The delay mechanism defined in IEEE 1588™ - 2002 is used to calculate the propagation delay between a given SC and the GMC. This principle is shown in Figure 3 above. A normal time update is based on the egress timestamp generated by the GMC when the Sync is sent from the GMC, t1, and the ingress timestamp of the same packet is generated by the SC when this packet is received on the SC, t2. The SC can also send event packets. The Delay_Req packet originates from a SC and this packet is used for the purpose of calculating the propagation delay between the GMC and the given SC. An egress timestamp is generated when this packet is sent from the SC, t3, and a corresponding ingress timestamp, t4, is generated on the GMC when the packet is received on this PTP clock.

The propagation delay is calculated based on the following formula:

$$tpd = ((t4-t1) - (t3-t2))/2$$

The above delay mechanism technique is in IEEE 1588™ - 2008 standard referred to as End-to-End (E2E).

The IEEE 1588™ - 2008 standard also introduced a new delay mechanism technique called Peer-to-Peer (P2P). P2P is based on the same principle as E2E except the propagation delay calculation performed by a PTP clock is only performed for the link partners of the PTP clock. A set of three new PTP packets are defined for P2P:

- PATH_DELAY_REQUEST
- PATH_DELAY_RESP
- PATH_DELAY_RESP_FOLLOW_UP (in case of two-step clock)

A P2P clock must update the PTP packet (Sync packets in case of one-step and Follow_Up packets in case of two-step) with the peer-delay to the PTP clock the packet is sent to. For a TC switch this means that the switch must update the PTP packet with both the switch residence time and the propagation delay of the link where the SYNC packet is received if the switch is enabled for P2P.

Only E2E is used as delay mechanism in FTI for both IEEE 1588™ - 2002 and in IEEE 1588™ - 2008.

Transport mechanism

IEEE 1588 defines several transport mechanisms for PTP. PTP can be based on unicast communication (telecom) or multicast (most other PTP profiles), PTP above layer 2 (power stations) or UDP/IP (default profile).

FTI is based on:

- PTP over UDP/IP
- Multicast with destination IP address: 224.0.1.129
- UDP destination port number 319 (event packets) and 320 (general packets)

This is valid for both IEEE 1588™ - 2002 and IEEE 1588™ - 2008.

PTP domain

IEEE 1588 defines several domains for PTP. This means that several time domains can exist in the same network. Separate MC selections will be done in a network where two or more time domains exist. Default domain is 0.

FTI only uses the default domain for both IEEE 1588™ - 2002 and in IEEE 1588™ - 2008.

Selection of Best Master Clock

The default BMCA as defined in IEEE 1588™ - 2002 or IEEE 1588™ - 2008, are used in today's FTI systems. Simpler FTI systems that are based on a single GMC without any BMCA support do also exist, but this is not recommendable since such solutions do not offer redundancy and may also represent IEEE 1588 interoperability issues when GMC and BMCA capable clocks later are installed.

PTP EPOCH

PTP is based on using TAI as its epoch. That means the number of seconds elapsed since January 1st 1970. The difference between this epoch and UTC is the accumulated number of leap seconds introduced since January 1st 1970. The current number of leap seconds is provided by the PTP GMC by the value of the currentUTCOffset parameter.

26 leap seconds have been inserted since 1970, the most recent on June 30, 2015 at 23:59:60 UTC.

The SCs in the network are responsible for converting TAI to UTC if such time representation is required and/or to compensate the time for DST or local TZ. This is valid for all for all PTP profiles.

Sync interval

The minimum interval between Sync packets was reduced in IEEE 1588™ - 2008 standard compared to IEEE 1588™ - 2002 standard. Legal range for the Sync interval is typical defined in the given PTP profile. The accuracy can be improved if the Sync interval is small, depending on the oscillator choice and the temperature variation at the SCs.

Most FTI systems are based on one (1) second Sync interval. A Sync interval range of [1, 2] seconds for IEEE 1588™ - 2002 and [0.125 .. 2] seconds for IEEE 1588™ - 2008 with one (1) second as default Sync interval for IEEE 1588™ - 2002 and 0.125ms for IEEE 1588™ - 2008 are proposed for FTI.

Delay Req interval

The minimum Delay_Req interval for IEEE 1588™ - 2002 is 60 seconds with randomization. Randomization is introduced in order to avoid that the SCs send Delay_Reqs at the same time. This interval is controlled by two parameters on the SC: PTP_DELAY_REQ_INTERVAL (30 seconds) and PTP_SYNC_INTERVAL_TIMEOUT ($2^{\wedge}(\text{Sync interval})$).

This parameter is controlled by the GMC and not each SC in the IEEE 1588™ - 2008 standard. The Delay_Req interval parameter is propagated to the SCs in the Delay_Resp packets originating from the GMC. The legal range for this parameter for IEEE 1588™ - 2008 is [Sync interval, 32 x Sync_interval] seconds with randomization.

Announce interval

The Announce packet was introduced in IEEE 1588™ - 2008 standard. Announce packets are used for BMCA. Similar parameters found in the Sync packets are used for the BMCA for IEEE 1588™ - 2002 systems. The Announce interval is typical two times the Sync interval, and this principle should also be used for FTI systems.

PPS output

The IEEE 1588 standards do not specify that a PTP clock shall have a PPS output interface, but this is highly recommended for time synchronization systems. FTI is not an exception. A PPS output is therefore proposed as a mandatory requirement for a PTP profile for FTI for both IEEE 1588™ - 2002 and IEEE 1588™ - 2008.

IRIG-B output

IRIG-B, both IRIG-B 002 (DC) and IRIG-B 122 (AM), has traditionally been used in FTI context. Compatibility between PTP and IRIG-B can be achieved if some of the PTP clocks in an FTI system can provide IRIG-B output signals. IRIG-B should be defined as a mandatory function for FTI for both IEEE 1588™ - 2002 and IEEE 1588™ - 2008 for GMC and optional for TC/SC.

Management

Chapter 15 of IEEE 1588™ - 2008 specifies IEEE 1588 management. IEEE1588 management packets are used for reading all

possible PTP parameters and also for setting all writeable PTP parameters.

The same PTP data set parameters may also be available via SNMP private MIBs.

The PTP management protocol is particular useful for verification of synchronization lock of SCs in the PTP network. The OffsetFromMaster parameter can be monitored in order to verify that a given SC is synchronized with GMC of the network and how accurate the SC is. The PTPv2Browser MS Windows tool from OnTime Networks that supports the PTP management protocol. Figure 2 shows the PTPv2Browser GUI of the OffsetFromMaster variable for two SCs in a PTP network. Monitoring the OffsetFromMaster parameter is an alternative technique to comparing PPS output signals from the GMC and SC on an oscilloscope.

The iNET standard specifies a set of time synchronization parameters available via MDL or the iNET SNMP MIB, where e.g. PTP version can be set and PTP state can be read

PTP management according IEEE 1588™ - 2008 should be defined as an optional management protocol for FTI, while management via iNET MDL and SMNP according to the iNET TmNS MIB is mandatory.

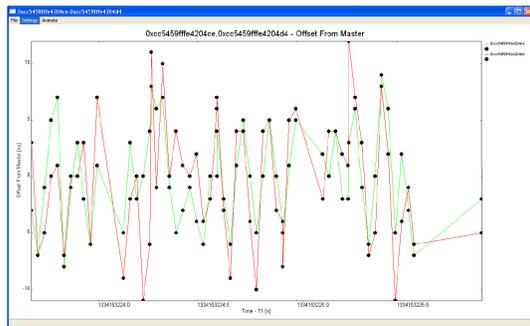


Figure 2, PTP Browser GUI, monitoring the OffsetFromMaster parameter of two SCs

SNMP traps

The iNET TmNS MIB specifies several SNMP traps that can be sent to an SNMP host station in order to immediately detect any time synchronization problems. The following traps are defined:

- timeLockLostNotificationBranch
Trap is sent from the PTP GMC if

synchronization lock from its time base is lost

- ieee1588MaxOffsetFromMasterNotificationBranch
Trap is sent from SC if the OffsetFromMaster parameter exceeds pre-defined thresholds
- ieee1588MaxJitterNotificationBranch
Trap is sent from the PTP clock if the measured jitter of the local clock exceeds pre-defined thresholds

GMC hold-over

The iNET standard specifies that an iNET GMC must offer a clock hold-over capability of minimum 0.1ppm in order to ensure that clock synchronization for the whole FTI system is kept when GPS lock is lost or when GPC lock is established after a period of no GPS lock.

0.1ppm means 100ns drift over one seconds or a maximum of 360us during one hour. This worst case drift is, however, calculated over the whole temperature range that the FTI GMC must support: i.e.: [-40 ..185]°F / [-40 ..85]°C.

Figure 3 shows that the clock drift for the CM1608F0 GMC with OCXO as oscillator from OnTime Networks after GPS lock is lost, is less than 320µs over a time period of 60 minutes when the temperature is cycled from: -40°F/-40°C to 203°F/95°C. This means clock hold-over capability better than 0.1ppm.



Figure 3, CM1608F0-AERO-GMC, clock drift

Clock drift of an oscillator when the temperature variation is less than e.g. 18°F / 10°C for a one hour period will only be a few percentage of the clock drift of the whole temperature range. That means less than 10us drift during one hour.

The GMC is supposed to stay in MASTER state when GPS lock again is found. The GMC will then start to discipline its local clock based on the new PPS input from the GPS based on its

clock servo algorithm. The SCs will correspondingly discipline their local clocks based on clock updates from the GMC that gradually will be based on GPS clock. How fast the PTP clocks are disciplined to GPS time after a GPS lock period depends on the drift amount and clock servo implementations on the GMC and SCs.

SC accuracy and time to synchronization

iNET specifies that a SC shall not drift more than 1ppm from the GMC of the network, and that time to synchronization must be less than 1 seconds for airborne systems and 3 seconds

for ground installations after the GMC becomes available.

This iNET requirement requires that the Sync interval is as small as possible. This is why the proposed Sync interval is 1s for IEEE 1588™ - 2002 and 0.125ms for IEEE 1588™ - 2008.

PTP profile for FTI

Table 1 below summarizes the proposed PTP profile for FTI:

	IEEE 1588™ - 2002 FTI PTP profile	IEEE 1588™ - 2008 FTI PTP profile
Clock modes	OC (GMC), TC(*), Slave only	OC (GMC), TC, Slave only
One-step or two step clocks	Two-step	Two-step
Media	Ethernet, full duplex according to IEEE802.3	Ethernet, full duplex according to IEEE802.3
Delay mechanism	E2E	E2E
Transport mechanism	PTP above UDP/IP, multicast with destination IP address: 224.0.1.129 and UDP destination port number 319 (event packets) and 320 (general packets)	PTP above UDP/IP, multicast with destination IP address: 224.0.1.129 and UDP destination port number 319 (event packets) and 320 (general packets)
Domain	Only default domain (0x00) is used	Only default domain (0x00) is used
Selection of Best Master Clock	Default BMCA algorithm	Default BMCA algorithm
PTP EPOCH	Time representation based in TAI, offset to UTC time (accumulated number of leap seconds) is defined in the currentUTCOffset parameter.	Time representation based in TAI, offset to UTC time (accumulated number of leap seconds) is defined in the currentUTCOffset parameter.
Sync interval	[1, 2]s, default = 1s	[0.125 .. 2]s, default = 0.125s
Delay_Req interval	60s, randomized	[Sync interval .. 32]s, default = 32s, randomized; controlled by GMC
Announce interval	NA	[1, 2, 4, 8, 16]s, default = 2s
PPS output	Mandatory	Mandatory
IRIG-B 002/122	Mandatory for GMC Optional for TC/SC	Mandatory for GMC Optional for TC/SC
Management	iNET SNMP/MDL	iNET SNMP/MDL Optional: PTP management according to IEEE 1588™ - 2008
SNMP traps	iNET MIB	iNET MIB
GMC holdover	0.1ppm, iNET requirement	0.1ppm, iNET requirement
SC accuracy	1ppm, iNET requirement	1ppm, iNET requirement
SC time to synchronization	1s/3s (airborne/ground), iNET requirement	1s/3s (airborne/ground), iNET requirement

(*) Proprietary TC implementation

Table 1

Conclusion

Backward compatibility between the new emerging PTP revision, PTP version 3, and PTP version 2 will be kept. This means that PTP version 2 and 3 can be combined in the same network. The new functions that are planned in PTP version 3 will be optional. These new functions are not expected to be crucial for the FTI industry. PTP version 2 is expected to be the preferred PTP version for FTI for the foreseeable future, but new PTP version 3 functions can be considered for FTI application with high accuracy and/or security requirements.

This paper also describes the main PTP properties/parameters that are relevant for FTI and proposes a PTP profile definition for FTI based on the PTP default profile for both IEEE 1588™ - 2002 and IEEE 1588™ - 2008 in addition to time synchronization requirements defined in the iNET standard.

Reference

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