PTP PROFILE FOR FTI

Øyvind Holmeide, **OnTime Networks AS, Oslo, Norway**
oeyvind@ontimenet.com
Markus Schmitz, **OnTime Networks LLC, Texas, USA**
markus@ontimenet.com

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: version 1 according to IEEE 1588™ - 2002 and version 2 according to IEEE 1588™ - 2008. The FTI industry/community is using both versions of the standard and the IEEE 1588 standards defines several PTP profiles for various time synchronization usages in different industries.

This paper describes how the PTP standard is being used in FTI applications, looks at the unique industry requirements and also proposes a PTP profile definition for FTI applications, including special time synchronization parameters/properties taken from the iNET standardization.

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

Introduction

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
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 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 Slave Clock 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 synthonized 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 synthonized, 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 synthonized and synchronized with the GMC. A synthonized TC offers better accuracy compared to a TC with free running clock.

A SC only implementation means that the device only supports Slave Clock 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, [1].

1-step vs. 2-step clock

IEEE 1588 specifies two types of clocks:

- 1-step clock
- 2-step clock

Figure 1 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.

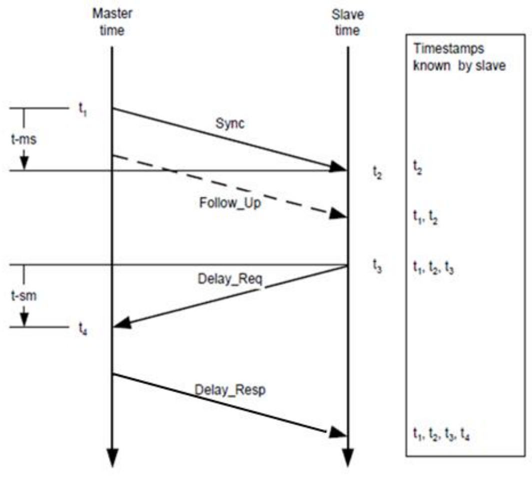

Figure 1, 1-step vs- 2-step clock

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 slave clock and the GMC. This principle is shown in Figure 1 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 slave clock when this packet is received on the slave clock, t2. The slave clock 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 exits, 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^(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.

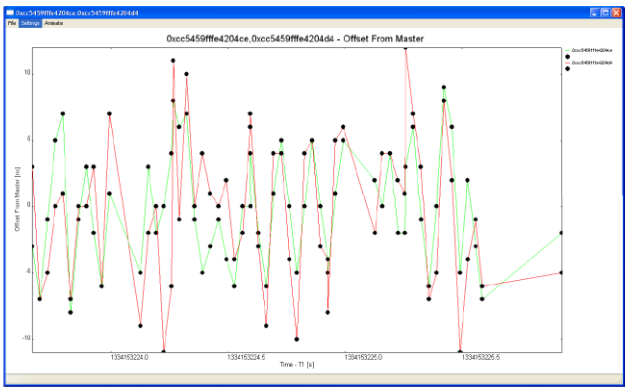

Figure 2, PTP Browser GUI, monitoring the OffsetFromMaster parameter of two SCs

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.

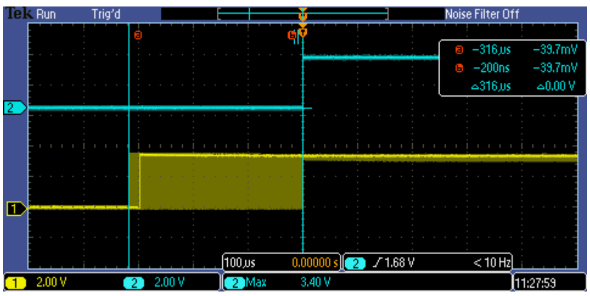

Figure 3, CM1608F0-AERO-GMC, clock drift

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.

Conclusion

This paper 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.

References

[1] S. Nylund and Ø. Holmeide, "IEEE1588 Ethernet switch transparency – No need for Boundary Clocks!", IEEE1588 conference, 2004.

	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