1 Title:

High accuracy extension/option/profile

2 Author:

Maciej Lipinski

3 Affiliation:

CERN – European Organization for Nuclear Research / Warsaw University of Technology

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5 Clauses of IEEE 1588-2008 (V2) proposed for revision:

- Changes required in clauses: 7.6.2.5, 14.1.1, Annex F.4 and Annex J
- Changes considered useful in clauses: 3.1, 5.3.3, 7.5.3, 9.3.1 and 9.5.10

6 Character of the proposed revision:

New feature. This revision proposes extending PTPv2 to enable a high accuracy of synchronization – the sub-nanosecond level of accuracy that is beyond what is achievable by the current implementations.

7 Reason or rational for the proposed revision

It has been shown [1][2] that PTPv2 can be implemented in such a way that a sub-nanosecond accuracy and picoseconds jitter of synchronization can be achieved over a number of boundary clocks and several kilometers of cables. Such an implementation benefits from additional mechanisms (i.e. Synchronous Ethernet [3], phase detection [5]) incorporated into PTPv2 in a way that keeps interoperability with current implementations while improving greatly the performance. The mechanisms used could be incorporated into the IEEE 1588 standard to indicate to the vendors the optional means to enhance PTP's performance and to ensure interoperability of such high-accuracy implementations. The presented solution is based on [6].

8 Proposed revision:

In this section four types of changes are proposed:

1. Section 8.1 – addition/modification of the transport annex;
2. Section 8.2 – addition of an optional "high accuracy" clause;
3. Section 8.3 – addition of the "Default High Accuracy" profile to Annex J ;
4. Section 8.4 – minor changes to the existing clauses to accommodate (1)-(3).

8.1 Syntonization capability of IEEE 802.3/Ethernet (modification of Annex F.4)

It is proposed to extend Annex F (it is also possible to add a new annex) such that the physical syntonization of clocks is foreseen (i.e. by using Synchronous Ethernet). Proposed changes to Table F.2 and the addition of a new Table F.3 are presented below.

Table 1: Table F.2 – Ethernet transportSpecific field (Changes to existing Table F.2)

Enumeration	**Value**(hex)	**Specification**
DEFAULT	0	All PTP layer 2 Ethernet transmission not covered by another enumeration value
ETHERNET_AVB	1	This value is reserved for use in connection with the standard being developed by the IEEE 802.1 AVB Task Group as P802.1AS
ETHERNET_SYNCE	2-6	Ethernet + Synchronous Ethernet, further specified in Table F.3
Reserved	6-F	Reserved for assignment in future version s of the standard

Table 2: Table F.3 - Syntonization capable Ethernet transportSpecific values (new table)

Value(hex)	**Specification**
2 or 3	Syntonization distribution topology aligned with PTP topology (i.e SyncE without using Ethernet Synchronization Messaging Channel (ESMC) [4])
4 or 5	Syntonization distribution topology independent from PTP topology (i.e. SyncE using Ethernet Synchronization Messaging Channel (ESMC) [4])
2 or 4	Recovered clock loopback disabled
3 or 5	Recovered clock loopback enabled

When recovered clock loopback is enabled, a port (acting as a slave) which recovers frequency from the incoming data stream shall, after proper phase alignment, encode such frequency into the outgoing data stream and send it back to the source (a port acting as a master).

8.2 High Accuracy (optional) clause

It is proposed to add an optional clause that could be implemented by devices for high accuracy synchronization. The actions which are defined in this clause take place while a PTP link is being established; that is in the UNCALIBRATED state of the BMC-selected slave port and in the MASTER state of the BMC-selected master port. This clause presents the following requirements to the hardware/implementation:

- It shall feature constant rx/tx latencies during operation and inform higher layers about these latencies values (e.g. measure rx/tx latencies using calibration pattern).
- It shall provide timestamps with a sufficient precision (i.e. using syntonization-capable Ethernet mapping, transportSpecific=0x3, and phase detection techniques), the fractional nanosecond part of a timestamps shall be included in the correctionField as specified in PTPv2.
- It shall be able to generate the calibration pattern on request (RD+K28.7 code group, Appendix 36A.2 of IEEE802.3).
- It shall provide an estimation of the asymmetry using parameters provided by this clause (e.g. using Link Delay Model, tx/rx latencies and relative delay coefficient as explained in [6]).

8.2.1 Definition of Data Set Fields

The implementation-specific Data Set fields are defined to store per-port clause specific data: (1) values of hardware characteristics (e.g.: rx/tx latencies); (2) configuration parameters (e.g.: whether a calibration pattern is required, calibration period/pattern); (3) current state of the High Accuracy State Machine (section 8.2.3). The (re-)initialization methods and values are defined.

8.2.2 Definition TLVs

It is proposed to define TLVs recognized by tlvType HIGH_ACCURACY_OPTION (extension to clause 14.1.1) of the format presented in Table 3. Different messages of such TLV type are recognized by messageID as defined in Table 4. These TLVs are used to exchange clause-specific data and trigger transitions in the High Accuracy State Machine (section 8.2.3). They are carried in Signaling Messages or suffixed to an Announce message (see Table 4).

Table 3: HIGH_ACCURACY_OPTION TLV format

Bits								Octets	TLV Offset
7	6	5	4	3	2	1	0		
tlvType								2	0
lengthField								2	2
messageID								2	10
dataField								N	12

8.2.3 High Accuracy State Machine

The High Accuracy State Machine (HASM) controls the process of establishing a high accuracy (abbreviated *HA* in the figures) link between two ports implementing high accuracy option. The HASM shall be non-preemptive with regard to the execution of the PTP State Machine. It enables syntonization over the physical layer, optional measurement of tx/rx latencies and exchange of their values across the link. The HASM shall be executed in the PTP UNCALIBRATED state on the port on which the recommended (by BMC) state is SLAVE – called Slave – and in the PTP MASTER state on the port on which the recommended state is MASTER – called Master. The HASM is depicted in Figure 1 and described in Table 5. The HASM shall be started when a port in non-Slave state is recommended (by BMC) to be Slave and appropriate conditions are fulfilled (e.g. both communicating ports implement the high accuracy option) – D_HA_SETUP_REQ transition event is triggers.

Table 4: Message ID values/types

Message Name	**MessageId value (hex)**	**Sent in message type**
SLAVE_PRESENT	0x1000	Signaling
LOCK	0x1001	Signaling
LOCKED	0x1002	Signaling
CALIBRATE	0x1003	Signaling
CALIBRATED	0x1004	Signaling
HIGH_ACCURACY_ON	0x1005	Signaling
ANN_SUFIX	0x2000	Announce

Table 5: State definitions

Port State	**Description**
IDLE	The HASM shall be in the IDLE state while establishing of High Accuracy link is not being performed.
PRESENT	Slave-only state. Upon entering this state, the Slave sends a SLAVE_PRESENT message to the Master and waits for the *LOCK* message.
M_LOCK	Master-only state. Upon entering this state, the Master sends the *LOCK* message. In this state, the Master waits for the Slave to finish successfully the frequency locking process (indicated by reception of the *LOCKED* message).
S_LOCK	Slave-only state. The Slave locks its clock signal to the frequency distributed over the physical layer by the Master.
LOCKED	Slave-only state. Upon entering this state, the Slave sends the *LOCKED* message to inform that it is syntonized, and waits for the *CALIBRATE* message.
CALIBRATION	In this state, optional calibration of the port's rx and/or tx latencies can be performed. Upon entering this state, the Port sends a *CALIBRATE* message to the other Port. In this message the characteristics of calibration pattern are sent. If calibration is not needed, the next state is entered, otherwise an indication from the hardware that the calibration has been finished successfully is awaited.
CALIBRATED	Upon entering this state the WR Port sends a CALIBRATED message with the values of its rx/tx latencies.
RESP_CALIB_REQ	The Port's action in this state depends on the content of CALIBRATION message. If required, the calibration pattern shall be enabled (sent). The pattern shall be disabled on exiting the state (after the timeout or reception of the *CALIBRATED* message).
HA_LINK_ON	Upon entering this state, the Master sends the HIGH_ACCURACY_LINK_ON message. In this state, the values of the clause-defined Data Set fields are set. The *IDLE* state is entered unconditionally. The execution of the HASM is considered to be completed successfully.

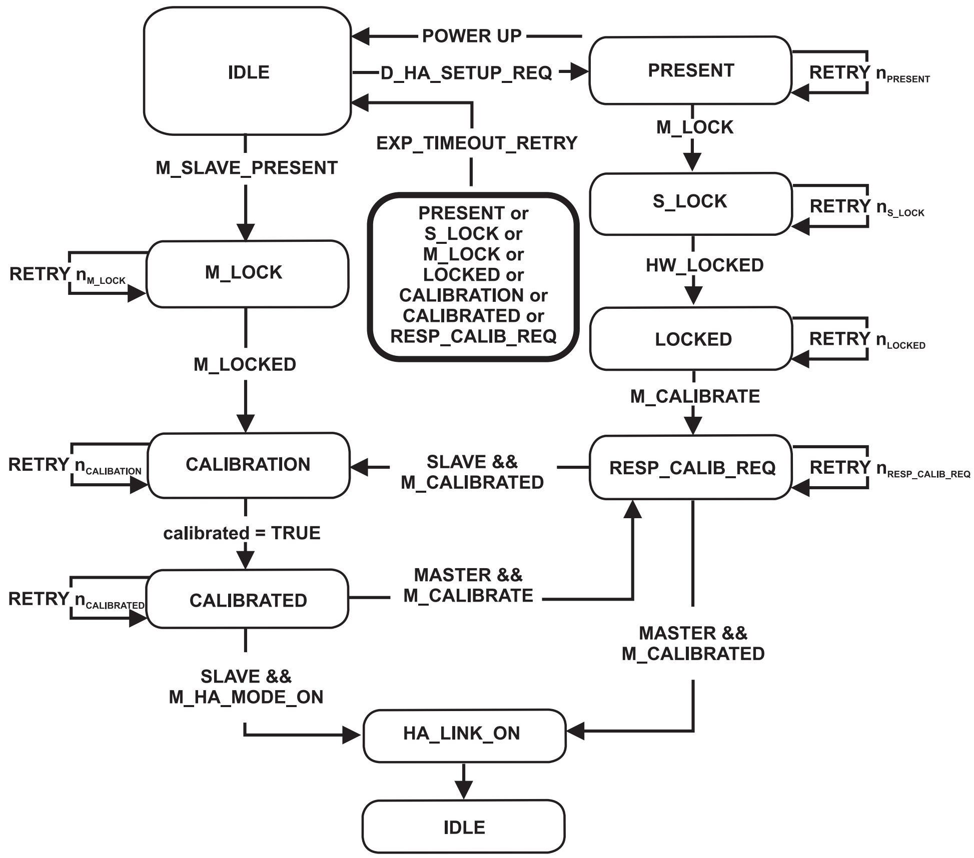

Figure 1: High Accuracy State Machine

8.2.4 Event definition

The implementation of two PTP State Machine transition events described as *implementation-specific* is defined in this clause. The **SYNCHRONIZATION_FAULT** shall occur when syntonization break is detected by hardware (e.g. link disconnected) or the high accuracy mode is exited out of another reason (e.g. management). It shall result in clearing the record of foreign masters. The **MASTER_CLOCK_SELECTED** shall occur on the successful completion of the HASM execution on the port selected by BMC as Slave and being in PTP_UNCALIBRATED state. Consequently, the PTP_SLAVE state shall be entered.

8.3 High Accuracy Default Profile (addition to Annex J)

The delay request-response mechanism shall be the only path delay measurement mechanism for this profile. It shall define default mapping using Annex F (networkProtocol=0003) with the transportSpecific flag set to 3 (i.e. SyncE without ECMS and with recovered clock loopback enabled). However, using transportSpecific flag set to 0 (DEFAULT) is allowed if the link partner is not SyncE-capable. Such a situation shall be detected and handled properly by a port implementing this profile, therefore guaranteeing backward-compatibility and interoperability. By default the "High Accuracy" option shall be active. If a link-partner uses mapping defined in Annex F with DEFAULT transport Specific field, the "High Accuracy" option shall be disabled.

8.4 Changes to clauses of PTPv2

Required changes:	
Clause 7.6.2.5:	Table 6 – add accuracies greater then 25ns
Clause 14.1.1:	Table 34 – add HIGH_ACCURACY_OPTION tlvType
Possibly helpful changes:	
Clause 3.1:	Add time definition (time = time of day and/or frequency)
Clause 5.3.3:	Add picoseconds to the Timestamp structure
Clause 7.5.3:	Add High Accuracy State Machine as an example in the NOTE
Clause 9.3.1:	Add profile-specific decision code to enable e.g. choice of secondarySlave
Clause 9.5.10:	Waive the requirement of sending Follow_Up message prior to the transmission of a subsequent Sync Message – this is to enable resending Sync Messages when detecting that Sync Message was sent on clock-adjustment and the timestamp is faulty.

9 Benefits of the proposed revision

This revision allows a high-accuracy implementation of the PTP protocol by providing to an implementer a standardized way of deriving a stable frequency from the physical medium, evaluating physical delays, using phase detection for enhancing timestamping precision and evaluating link asymmetry. Moreover, the modification proposed in section 8.1 can be useful in a currently developed (by ITU-T) PTP Telecom profile.

10 Backward compatibility to IEEE-1588:

A: Complete backward compatibility, i.e. V2 and the revised version interoperate although V2 devices do not receive benefits of revision.

References

[1] M. Lipiński, T. Włostowski, J. Serrano, P. Alvarez and P. Moreira *Performance results of the first White Rabbit installation for CNGS time transfer*. ISPCS2012 Proccedings, 2012

[2] M. Lipiński, T. Włostowski, J. Serrano, P. Alvarez *White Rabbit: a PTP Application for Robust Sub-nanosecond Synchronization*. ISPCS2011 Proccedings, 2011

[3] ITU-T G.8262/Y.1362 *Timing characteristics of a synchronous Ethernet equipment slave clock*. TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU, 07/2010.

[4] ITU-T G.8264/Y.1364 *Distribution of timing information through packet network*. TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU, 10/2008.

[5] J. Serrano, P. Alvarez, M. Cattin, E. G. Cota, J. H. Lewis, P. Moreira, T. Włostowski and others, *The White Rabbit Project*. ICALEPCS TUC004, 2009.

[6] Emilio G. Cota, Maciej Lipinski, Tomasz Wostowski, Erik van der Bij, Javier Serrano *White Rabbit Specification: Draft for Comments*. CERN, Geneva 07/2011.