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Partie 1AS: Temporisation et synchronisation pour les applications sensibles au temps des réseaux locaux pontés

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Abstract: Protocols, procedures, and managed objects for the transport of timing over local area networks are defined in this standard. It includes the transport of synchronized time, the selection of the timing source (i.e., best master), and the indication of the occurrence and magnitude of timing impairments (i.e., phase and frequency discontinuities).

Keywords: best master, frequency offset, Grandmaster Clock, Grandmaster PTP Instance, PTP End Instance, PTP Relay Instance, IEEE 802.1AS™, phase offset, synchronization, syntonization, time-aware system

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This introduction is not part of IEEE Std 802.1AS-2020, IEEE Standard for Local and Metropolitan Area Networks—Timing and Synchronization for Time-Sensitive Applications.

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IEEE Standard for
Local and Metropolitan Area Networks—

Timing and Synchronization for Time-Sensitive Applications

1. Overview

1.1 Scope

This standard specifies protocols, procedures, and managed objects used to ensure that the synchronization requirements are met for time-sensitive applications, such as audio, video, and time-sensitive control, across networks, for example, IEEE 802 and similar media. This includes the maintenance of synchronized time during normal operation and following addition, removal, or failure of network components and network reconfiguration. It specifies the use of IEEE 1588™ specifications where applicable in the context of IEEE Std 802.1Q™-2018.[1] Synchronization to an externally provided timing signal [e.g., a recognized timing standard such as Coordinated Universal Time (UTC) or International Atomic Time (TAI)] is not part of this standard but is not precluded.

1.2 Purpose

This standard enables systems to meet the respective jitter, wander, and time-synchronization requirements for time-sensitive applications, including those that involve multiple streams delivered to multiple end stations. To facilitate the widespread use of packet networks for these applications, synchronization information is one of the components needed at each network element where time-sensitive application data are mapped or demapped or a time-sensitive function is performed. This standard leverages the work of the IEEE 1588 Working Group by developing the additional specifications needed to address these requirements.

[1] Information on references can be found in Clause 2.

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2. Normative references

The following referenced documents are indispensable for the application of this standard (i.e., they must be understood and used; therefore, each referenced document is cited in text, and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 754™-2008, IEEE Standard for Floating-Point Arithmetic.[2, 3]

IEEE Std 802®-2014, IEEE Standard for Local and Metropolitan Area Networks—Overview and Architecture.

IEEE Std 802c™-2017, IEEE Standard for Local and Metropolitan Area Networks—Overview and Architecture—Amendment 2: Local Medium Access Control (MAC) Address Usage.

IEEE Std 802.1AC™-2016, IEEE Standard for Local and metropolitan area networks—Media Access Control (MAC) Service Definition.

IEEE Std 802.1AX™-2014, IEEE Standard for Local and metropolitan area networks—Link Aggregation.

IEEE Std 802.1Q™-2018, IEEE Standard for Local and Metropolitan Area Networks—Bridges and Bridged Networks.

IEEE Std 802.3™-2018, IEEE Standard for Ethernet.

IEEE Std 802.11™-2016, IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.

IEEE Std 1588™-2019, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems.

IERS Bulletin C (see https://www.iers.org/IERS/EN/Publications/Bulletins/bulletins.html).

IETF RFC 2863 (June 2000), The Interfaces Group MIB, K. McCloghrie and F. Kastenholz.[4]

IETF RFC 3410 (Dec. 2002), Introduction and Applicability Statements for Internet Standard Management Framework, J. Case, R. Mundy, D. Partain, and B. Stewart.

IETF RFC 3418 (Dec. 2002), Management Information Base (MIB) for the Simple Network Management Protocol (SNMP), R. Presuhn, ed.

ISO 80000-3:2006, Quantities and units — Part 3: Space and time.[5]

[2] IEEE publications are available from The Institute of Electrical and Electronics Engineers (https://standards.ieee.org).

[3] The IEEE standards or products referenced in this clause are trademarks owned by The Institute of Electrical and Electronics Engineers, Incorporated.

[4] IETF Requests for Comments (RFCs) are available from the Internet Engineering Task Force (https://www.rfc-editor.org).

[5] ISO publications are available from the International Organization for Standardization (https://www.iso.org) and the American National Standards Institute (https://www.ansi.org).

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ITU-T Recommendation G.984.3, Amendment 2, Gigabit-capable Passive Optical Networks (G-PON): Transmission convergence layer specification—Time-of-day distribution and maintenance updates and clarifications.[6]

ITU-T Recommendation G.9960, Unified high-speed wire-line based home networking transceivers—System architecture and physical layer specification [with ITU-T G.9961, commonly referred to as "G.hn"].

ITU-T Recommendation G.9961, Data link layer (DLL) for unified high-speed wire-line based home networking transceivers [with ITU-T G.9960, commonly referred to as "G.hn"].

MoCA® MAC/PHY Specification v2.0, MoCA-M/P-SPEC-V2.0-20100507, Multimedia over Coax Alliance (MoCA).[7]

[6] ITU-T publications are available from the International Telecommunications Union (https://www.itu.int).

[7] MoCA specifications are available from the Multimedia over Coax Alliance (http://www.mocalliance.org/specs).

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3. Definitions

For the purposes of this standard, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[8]

3.1 accuracy: The mean of the time or frequency error between the clock under test and a reference clock over an ensemble of measurements (see IEEE Std 1588-2019).

3.2 Bridge: Either a MAC Bridge or a VLAN-aware Bridge, as specified in Clause 5 of IEEE Std 802.1Q-2018.

3.3 clock: A physical device that is capable of providing a measurement of the passage of time since a defined epoch.

3.4 device: An entity implementing some functionality, e.g., a clock, a time-aware system, a port.

3.5 direct communication: A communication of IEEE 802.1AS information between two PTP Instances with no intervening PTP Instance.

3.6 end station: A device attached to a local area network (LAN) or metropolitan area network (MAN) that acts as a source of, and/or destination for, traffic carried on the LAN or MAN.

3.7 event message: A message that is timestamped on egress from a PTP Instance and ingress to a PTP Instance.

NOTE—See 8.4.3.[9]

3.8 fractional frequency offset: The fractional offset, y, between a measured clock and a reference clock as defined by the following:

$$y = \frac{f_m - f_r}{f_r}$$

where f_m is the frequency of the measured clock and f_r is the frequency of the reference clock. The measurement units of f_m and f_r are the same.

3.9 frequency offset: The offset between a measured frequency and a reference frequency as defined by $f_m - f_r$, where f_m is the frequency of the measured clock and f_r is the frequency of the reference clock. The measurement units of f_m and f_r are the same.

3.10 general message: A message that is not timestamped.

3.11 gPTP communication path: A segment of a generalized precision time protocol (gPTP) domain that enables direct communication between two PTP Instances.

NOTE—See 8.1.

3.12 grandmaster-capable PTP Instance: A PTP Instance that is capable of being a Grandmaster PTP Instance.

[8] *IEEE Standards Dictionary Online* is available at https://dictionary.ieee.org/.

[9] Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement the standard.

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3.13 Grandmaster Clock: In the context of a single PTP domain, the synchronized time of a PTP Instance that is the source of time to which all other PTP Instances in the domain are synchronized.

3.14 Grandmaster PTP Instance: A PTP Instance containing the Grandmaster Clock.

3.15 local area network (LAN): A network of devices, whether indoors or outdoors, covering a limited geographic area, e.g., a building or campus.

3.16 local clock: A free-running clock, embedded in a respective entity (e.g., PTP Instance, CSN node), that provides a common time to that entity relative to an arbitrary epoch.

3.17 message timestamp point: A point within an event message serving as a reference point for when a timestamp is taken.

3.18 message type: The message type of a message is the name of the respective message, e.g., Sync, Announce, Timing Measurement Frame.

3.19 precision: A measure of the deviation from the mean of the time or frequency error between the clock under test and a reference clock (see IEEE Std 1588-2019).

3.20 primary reference: A source of time and/or frequency that is traceable to international standards. *See also:* **traceability.**

3.21 PTP End Instance: A PTP Instance that has exactly one PTP Port.

3.22 PTP Instance: An instance of the IEEE 802.1AS protocol, operating in a single time-aware system within exactly one domain. A PTP Instance implements the portions of IEEE Std 802.1AS indicated as applicable to either a PTP Relay Instance or a PTP End Instance.

NOTE—As used in IEEE Std 802.1AS, the term *PTP Instance* refers to an IEEE 1588 PTP Instance that conforms to the requirements of IEEE Std 802.1AS.

3.23 PTP Link: Within a domain, a network segment between two PTP Ports using the peer-to-peer delay mechanism of IEEE Std 802.1AS. The peer-to-peer delay mechanism is designed to measure the propagation time over such a link.

NOTE—A PTP Link between PTP Ports of PTP Instances is also a gPTP Communication Path (see 3.11).

3.24 PTP Relay Instance: A PTP Instance that is capable of communicating synchronized time received on one PTP Port to other PTP Ports, using the IEEE 802.1AS protocol.

NOTE—A PTP Relay Instance could, for example, be contained in a bridge, a router, or a multi-port end station.

3.25 recognized timing standard: A recognized standard time source that is a source external to IEEE 1588 precision time protocol (PTP) and provides time that is traceable to the international standards laboratories maintaining clocks that form the basis for the International Atomic Time (TAI) and Coordinated Universal Time (UTC) timescales. Examples of these sources are National Institute of Standards and Technology (NIST) timeservers and global navigation satellite systems (GNSSs).

3.26 reference plane: The boundary between a PTP Port of a PTP Instance and the network physical medium. Timestamp events occur as frames cross this interface.

3.27 residence time: The duration of the time interval between the receipt of a time-synchronization event message by a PTP Instance and the sending of the next subsequent time-synchronization event message on another PTP Port of that PTP Instance. Residence time can be different for different PTP Ports. The term *residence time* applies only to the case where syncLocked is TRUE.

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NOTE 1—See 10.2.5.15 for the definition of the variable syncLocked.

NOTE 2—If a PTP Port of a PTP Instance sends a time-synchronization event message without having received a time-synchronization event message, e.g., if syncLocked is FALSE or if sync receipt timeout occurs (see 10.7.3.1), the duration of the interval between the most recently received time-synchronization event message and the sent time-synchronization event message is mathematically equivalent to residence time; however, this interval is not normally called a *residence time*.

3.28 stability (of a clock or clock signal): A measure of the variations over time of the frequency error (of the clock or clock signal). The frequency error typically varies with time due to aging and various environmental effects, e.g., temperature.

3.29 synchronized time: The time of an event relative to the Grandmaster Clock.

NOTE—If there is a change in the Grandmaster PTP Instance or its time base, the *synchronized time* can experience a phase and/or frequency step.

3.30 synchronized clocks: Absent relativistic effects, two clocks are synchronized to a specified uncertainty if they have the same epoch and their measurements of the time of a single event at an arbitrary time differ by no more than that uncertainty.

NOTE—See 8.2.2.

3.31 syntonized clocks: Absent relativistic effects, two clocks are syntonized to a specified uncertainty if the duration of a second is the same on both, which means the time as measured by each advances at the same rate within the specified uncertainty. The two clocks might or might not share the same epoch.

3.32 time-aware system: A device that contains one or more PTP Instances and/or PTP services (e.g., Common Mean Link Delay Service).

NOTE 1—See 11.2.17 for a description of the Common Mean Link Delay Service.

NOTE 2—A time-aware system can contain more than one PTP Instance in the same domain and/or different domains.

3.33 timestamp measurement plane: The plane at which timestamps are captured. If the timestamp measurement plane is different from the reference plane, the timestamp is corrected for ingressLatency and/or egressLatency. *See:* **reference plane**.

NOTE—For timestamping on egress and ingress, see 8.4.3.

3.34 traceability: See 3.1.81 in IEEE Std 1588-2019.

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4. Acronyms and abbreviations

Ack	acknowledgment
ADEV	Allan deviation
ARB	arbitrary
BC	Boundary Clock
BMC	best master clock
BMCA	best master clock algorithm
CID	Company identification (allocated by the IEEE)
CMLDS	Common Mean Link Delay Service
CSN	coordinated shared network
CTC	channel time clock
EPON	IEEE 802.3™ Ethernet Passive Optical Network, as specified in IEEE Std 802.3-2018
FTM	Fine Timing Measurement
G.hn	ITU-T G.9960 and ITU-T G.9961
GM	Grandmaster
GMT	Greenwich mean time
GNSS	global navigation satellite system
GPS	global positioning (satellite) system
gPTP	generalized precision time protocol (IEEE Std 802.1AS)
IERS	International Earth Rotation and Reference Systems Service
IP	Internet Protocol
ISS	Internal Sublayer Service
LAN	local area network
LCI	location configuration information
LLC	logical link control
MAC	media access control
MACsec	media access control security

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MIB	Management Information Base
MLME	IEEE 802.11™ MAC layer management entity
MPCP	IEEE 802.3 multipoint control protocol
MPCPDU	IEEE 802.3 MPCP data unit
MD	media-dependent
NMS	Network Management System
NTP	network time protocol[10]
OLT	IEEE 802.3 optical line terminal
ONU	IEEE 802.3 optical network unit
OSSP	organization-specific slow protocol
OUI	Organizationally Unique Identifier
P2P	peer-to-peer
PICS	Protocol Implementation Conformance Statement
POSIX®	portable operating system interface (see ISO/IEC 9945:2003 [B17][11])
PTP	IEEE 1588 precision time protocol
PTPDEV	PTP deviation
RTT	round-trip time
SI	international system of units
SMI	Structure of Management Information
SMIv2	Structure of Management Information version 2
SNMP	Simple Network Management Protocol
STA	station
TAI	International Atomic Time
TC	Transparent Clock
TDEV	time deviation

[10] Information available at https://www.ietf.org/rfc/rfc1305.txt.
[11] The numbers in brackets correspond to the numbers in the bibliography in Annex G.

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TDM	time division multiplexing
TDMA	time division multiple access
TLV	type, length, value
TM	Timing Measurement
UCT	unconditional transfer
UTC	Coordinated Universal Time
VLAN	virtual local area network
WLAN	wireless local area network

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5. Conformance

This clause specifies the mandatory and optional capabilities provided by conformant implementations of this standard.

5.1 Requirements terminology

For consistency with existing IEEE and IEEE 802.1 standards, requirements placed upon conformant implementations of this standard are expressed using the following terminology:

a) ***shall*** is used for mandatory requirements.
b) ***may*** is used to describe implementation or administrative choices ("may" means "is permitted to," and hence, "may" and "may not" mean precisely the same thing).
c) ***should*** is used for recommended choices (the behaviors described by "should" and "should not" are both permissible but not equally desirable choices).

The Protocol Implementation Conformance Statement (PICS) proforma (see Annex A) reflects the occurrences of the words shall, may, and should within the standard. The words shall, may, and should, as used in Annex A itself, reflect the use of the PICs and not conformance to the standard.

The standard avoids needless repetition and apparent duplication of its formal requirements by using ***is***, ***is not***, ***are***, and ***are not*** for definitions and the logical consequences of conformant behavior. Behavior that is permitted but is neither always required nor directly controlled by an implementer or administrator, or whose conformance requirement is detailed elsewhere, is described by ***can***. Behavior that never occurs in a conformant implementation or system of conformant implementations is described by ***cannot***. The word ***allow*** is used as a replacement for the phrase "support the ability for," and the word ***capability*** means "can be configured to."

5.2 Protocol Implementation Conformance Statement (PICS)

The supplier of an implementation that is claimed to conform to this standard shall complete a copy of the PICS proforma provided in Annex A and shall provide the information necessary to identify both the supplier and the implementation.

5.3 Time-aware system requirements

An implementation of a time-aware system shall support at least one IEEE 1588 precision time protocol (PTP) Instance.

5.4 PTP Instance requirements and options

5.4.1 Summary of requirements

An implementation of a PTP Instance shall:

a) Implement the generalized precision time protocol (gPTP) requirements specified in Clause 8.
b) Support the requirements for time-synchronization state machines (10.1.2, 10.2.1, 10.2.2, 10.2.3, 10.2.4, 10.2.5, and 10.2.6).
c) Support at least one PTP Port.
d) On each supported PTP Port, implement the PortSyncSyncReceive state machine (10.2.8).

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e) Implement the ClockSlaveSync state machine (10.2.13).
f) Support the following best master clock algorithm (BMCA) requirements:
   1) Implement the BMCA (10.3.2, 10.3.3, 10.3.4, 10.3.5, 10.3.6, 10.3.8, and 10.3.10).
   2) For domain 0, implement specifications for externalPortConfigurationEnabled value of FALSE (10.3.1).
   3) Implement the PortAnnounceReceive state machine (10.3.11).
   4) Implement the PortAnnounceInformation state machine (10.3.12).
   5) Implement the PortStateSelection state machine (10.3.13).
   6) Have the BMCA as the default mode of operation, with externalPortConfiguration FALSE, on domain 0.
   7) Implement at least one of the possibilities for externalPortConfigurationEnabled (i.e., FALSE, meaning the BMCA is used, and TRUE, meaning external port configuration is used) on domains other than domain 0.
g) Implement the SiteSyncSync state machine (10.2.7).
h) Implement the state machines related to signaling gPTP capability (10.4).
i) For receipt of all messages and for transmission of all messages except Announce (see 10.6.3) and Signaling (see 10.6.4), support the message requirements as specified in 10.5, 10.6, and 10.7.
j) Support the performance requirements in B.1 and B.2.4.

5.4.2 PTP Instance options

An implementation of a PTP Instance should:

a) Support the performance requirements in B.2.2 and B.2.3.

An implementation of a PTP Instance may:

b) Support the following media-independent master capability on at least one PTP Port:
   1) Implement the PortSyncSyncSend state machine (10.2.12).
   2) Implement the PortAnnounceTransmit state machine (10.3.16).
   3) Implement the AnnounceIntervalSetting state machine (10.3.17).
   4) For transmit of the Announce message, support the message requirements as specified in 10.5, 10.6, and 10.7.
c) Support the following for Grandmaster PTP Instance capability:
   1) Support the media-independent master capability specified in item b) of 5.4.2.
   2) Support the requirements for a grandmaster-capable PTP Instance (10.1.3).
   3) Implement the ClockMasterSyncSend state machine (10.2.9).
   4) Implement the ClockMasterSyncOffset state machine (10.2.10).
   5) Implement the ClockMasterReceive state machine (10.2.11).
d) Support more than one PTP Port as a PTP Relay Instance (5.4.3).
e) Support transmit of the Signaling message according to the message requirements as specified in 10.5 and 10.6.
f) Support more than one PTP Instance; such support allows for more than one domain (7.2.3).

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g) Support the following external port configuration capability on at least one port:
   1) Implement specifications for externalPortConfigurationEnabled value of true (10.3.1).
   2) Implement the PortAnnounceInformationExt state machine (10.3.14).
   3) Implement the PortStateSettingExt state machine (10.3.15).
h) Implement the SyncIntervalSetting state machine (10.3.18).
i) Implement one or more of the application interfaces specified in Clause 9; A PTP Instance that claims to support application interfaces shall state which application interfaces are supported.
j) Support timing and synchronization management as specified in Clause 14.
k) Support the use of a remote management protocol. A PTP Instance that claims to support remote management shall:
   1) State which remote management protocol standard(s) or specification(s) are supported (see A.19).
   2) State which standard(s) or specification(s) for managed object definitions and encodings are supported for use by the remote management protocol (see A.19).
   3) If the Simple Network Management Protocol (SNMP) is supported as a remote management protocol, support the managed object definitions specified as Structure of Management Information version 2 (SMIv2) Management Information Base (MIB) modules in Clause 15.
l) Implement both BMCA and external port configuration on domains other than domain 0; if both possibilities are implemented on domains other than domain 0, the default value of externalPortConfigurationEnabled shall be FALSE.

5.4.3 PTP Relay Instance requirements

An implementation of a PTP Relay Instance shall:

a) Support more than one PTP Port.
b) Support the PTP Instance requirements specified in 5.4.
c) Support the media-independent master capability specified in item b) of 5.4.2.

5.5 MAC-specific timing and synchronization methods for full-duplex IEEE 802.3 links

An implementation of a time-aware system with IEEE 802.3 media access control (MAC) services to physical ports shall:

a) Support full-duplex operation, as specified in 4.2 and Annex 4A of IEEE Std 802.3-2018.
b) Support the requirements as specified in Clause 11.
c) Implement the SyncIntervalSetting state machine (10.3.18).

An implementation of a PTP Instance with IEEE 802.3 MAC services to physical ports may:

d) Support asymmetry measurement mode as specified in 10.3.12, 10.3.13, 10.3.16, 11.2.14, 11.2.15, 11.2.19, and 14.8.45.
e) Support one-step capability on receive as specified in 11.2.14.
f) Support one-step capability on transmit as specified in 11.2.15.
g) Support the OneStepTxOperSetting state machine specified in 11.2.16.
h) Support propagation delay averaging, as specified in 11.2.19.3.4.

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5.6 MAC-specific timing and synchronization methods for IEEE Std 802.11-2016

An implementation of a time-aware system with IEEE 802.11 MAC services to physical ports shall:

a) Support the requirements as specified in Clause 12.
b) Support at least one of
    1) the media-dependent master state machines (12.5.1), or
    2) the media-dependent slave state machine (12.5.2).

An implementation of a PTP End Instance with IEEE 802.11 MAC services to physical ports shall:

c) Support at least one of TIMINGMSMT as specified in IEEE Std 802.11-2016 or FINETIMINGMSMT as specified in IEEE Std 802.11-2016.

An implementation of a PTP Relay Instance with IEEE 802.11 MAC services to physical ports shall:

d) Support the requirements of TIMINGMSMT as specified in IEEE Std 802.11-2016.

An implementation of a PTP Relay Instance with IEEE 802.11 MAC services to physical ports should:

e) Support FINETIMINGMSMT as specified in IEEE Std 802.11-2016.

NOTE—In order to maintain backward compatibility with existing TM-based PTP End Instances that support only Timing Measurement (TM), the PTP Relay Instance is required to support TM. PTP End Instances are allowed to support TM or Fine Timing Measurement (FTM), or both to permit PTP End Instances compliant with this standard to implement only the FTM standard, which requires a PTP Relay Instance that supports FTM.

5.7 MAC-specific timing and synchronization methods for IEEE 802.3 EPON

An implementation of a time-aware system with IEEE 802.3 Ethernet Passive Optical Network (EPON) MAC services to physical ports shall:

a) Support the requirements as specified in IEEE Std 802.3-2018 for multipoint MAC Control (64.2 and 64.3) and multipoint physical coding sublayer (PCS) and physical medium attachment (PMA) extensions (Clause 65).
b) Support the requirements as specified in Clause 13.

5.8 MAC-specific timing and synchronization methods for coordinated shared network (CSN)

An implementation of a time-aware system with CSN MAC services to physical ports shall:

a) Support the requirements as specified in Clause 16.
b) Support at least one MoCA port (16.6.2) or ITU-T G.hn port (16.6.3).

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6. Conventions

6.1 General

This clause defines various conventions and notation used in the standard, i.e., naming conventions, service specification method and notation, and data type definitions.

6.2 Service specification method and notation

The method and notation for specifying service interfaces is described in Clause 7 of IEEE Std 802.1AC-2016.

6.3 Lexical form syntax

A lexical form refers to the following:

— A name
— A data type

The conventions illustrated in the following list regarding lexical forms are used in this standard:

a) Type names: e.g., ClockQuality (no word separation, initial letter of each word capitalized).
b) Enumeration members and global constants: e.g., ATOMIC_CLOCK (word separation underscored, all letters capitalized).
c) Fields within PTP messages, instances of structures, and variables: e.g., secondsField, clockQuality, clockIdentity (two-word field names at a minimum, no word separation, initial word not capitalized, initial letter capitalization on subsequent words).
d) Members of a structure: e.g., clockQuality.clockClass (no word separation, structure name followed by a period followed by the member name).
e) Data set names: e.g., defaultDS, parentDS, portDS, currentDS, timePropertiesDS (no word separation, initial word not capitalized, initial letter capitalization on subsequent words, end marked by the letters DS).
f) Data set members: e.g., defaultDS.clockQuality.clockClass (data set name followed by a period followed by a member name followed by a period followed by a member name).
g) PTP message names: e.g., Sync, Pdelay_Req (word separation underscored, initial letter of each word capitalized).

When a lexical form appears in text, as opposed to in a type, or a format definition, the form is to be interpreted as singular, plural, or possessive as appropriate to the context of the text.

6.4 Data types and on-the-wire formats

6.4.1 General

The data types specified for the various variables and message fields define logical properties that are necessary for correct operation of the protocol or interpretation of IEEE 1588 precision time protocol (PTP) or IEEE 802.11 message content.

NOTE—Implementations are free to use any internal representation of data types if the internal representation does not change the semantics of any quantity visible via communications using the IEEE 802.1AS protocol or in the specified operations of the protocol.

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6.4.2 Primitive data types specifications

All non-primitive data types are derived from the primitive types in Table 6-1. Signed integers are represented in twos complement form.

Table 6-1—Primitive data types

Data type	Definition
Boolean	TRUE or FALSE
EnumerationN	N-bit enumerated value
UIntegerN	N-bit unsigned integer
IntegerN	N-bit signed integer
Nibble	4-bit field not interpreted as a number
Octet	8-bit field not interpreted as a number
OctetN	N-octet field not interpreted as a number, with N > 1
Float64 (see NOTE)	IEEE 754™ binary64 (64-bit double-precision floating-point format)
NOTE—The Float64 data type was called Double in the 2011 edition of this standard. The semantics of the data type has not changed.	

6.4.3 Derived data type specifications

6.4.3.1 ScaledNs

The ScaledNs type represents signed values of time and time interval in units of 2^{-16} ns.

typedef Integer96 ScaledNs;

For example: –2.5 ns is expressed as:

0xFFFF FFFF FFFF FFFD 8000

Positive or negative values of time or time interval outside the maximum range of this data type are encoded as the largest positive or negative value of the data type, respectively.

6.4.3.2 UScaledNs

The UScaledNs type represents unsigned values of time and time interval in units of 2^{-16} ns.

typedef UInteger96 UScaledNs;

For example: 2.5 ns is expressed as:

0x0000 0000 0000 0002 8000

Values of time or time interval greater than the maximum value of this data type are encoded as the largest positive value of the data type.

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6.4.3.3 TimeInterval

The TimeInterval type represents time intervals, in units of 2^{-16} ns.

typedef Integer64 TimeInterval;

For example: 2.5 ns is expressed as:

0x0000 0000 0002 8000

Positive or negative time intervals outside the maximum range of this data type are encoded as the largest positive and negative values of the data type, respectively.

6.4.3.4 Timestamp

The Timestamp type represents a positive time with respect to the epoch.

```
struct Timestamp
{
        UInteger48 seconds;
        UInteger32 nanoseconds;
};
```

The seconds member is the integer portion of the timestamp in units of seconds.

The nanoseconds member is the fractional portion of the timestamp in units of nanoseconds.

The nanoseconds member is always less than 10^9.

For example:

+2.000000001 seconds is represented by seconds = 0x0000 0000 0002 and nanoseconds= 0x0000 0001

6.4.3.5 ExtendedTimestamp

The ExtendedTimestamp type represents a positive time with respect to the epoch.

```
struct ExtendedTimestamp
{
        UInteger48 seconds;
        UInteger48 fractionalNanoseconds;
};
```

The seconds member is the integer portion of the timestamp in units of seconds.

The fractionalNanoseconds member is the fractional portion of the timestamp in units of 2^{-16} ns.

The fractionalNanoseconds member is always less than $(2^{16})(10^9)$.

For example:

+2.000000001 seconds is represented by seconds = 0x0000 0000 0002 and fractionalNanoseconds = 0x0000 0001 0000

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6.4.3.6 ClockIdentity

The ClockIdentity type identifies a PTP Instance.

typedef Octet8 ClockIdentity;

6.4.3.7 PortIdentity

The PortIdentity type identifies a port of a PTP Instance.

```
struct PortIdentity
{
        ClockIdentity clockIdentity;
        UInteger16 portNumber;
};
```

6.4.3.8 ClockQuality

The ClockQuality represents the quality of a clock.

```
struct ClockQuality
{
        UInteger8 clockClass;
        Enumeration8 clockAccuracy;
        UInteger16 offsetScaledLogVariance;
};
```

6.4.4 Protocol data unit (PDU) formats

6.4.4.1 General

The data types defined in 6.4.2 and 6.4.3 shall be mapped onto the wire according to the mapping rules for the respective medium, e.g., IEEE Std 802.3-2018 and IEEE Std 802.11-2016, and the terms of 6.4.4.

IEEE 802.1AS PDUs consist of the messages defined or referenced in Clause 10, Clause 11, Clause 12, and Clause 13, based on the data types defined in 6.4.2 and 6.4.3. The internal ordering of the fields of the IEEE 802.1AS PDUs is specified in 6.4.4.3 to 6.4.4.5.

6.4.4.2 Numbering of bits within an octet

Bits are numbered with the most significant bit being 7 and the least significant bit being 0.

NOTE—The numbering and ordering of bits within an octet of a PDU, described here, is independent of and unrelated to the order of transmission of the bits on the underlying physical layer.

6.4.4.3 Primitive data types

Numeric primitive data types defined in 6.4.2 shall be formatted with the most significant octet nearest to the beginning of the PDU followed in order by octets of decreasing significance.

The Boolean data type TRUE shall be formatted as a single bit equal to 1 and FALSE as a single bit equal to 0.

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Enumerations of whatever length shall be formatted as though the assigned values are unsigned integers of the same length, e.g., Enumeration16 shall be formatted as though the value had type UInteger16.

6.4.4.4 Arrays of primitive types

All arrays shall be formatted with the member having the lowest numerical index nearest to the beginning of the PDU followed by successively higher numbered members, without any padding. In octet arrays, the octet with the lowest numerical index is termed the most significant octet.

When a field containing more than one octet is used to represent a numeric value, the most significant octet shall be nearest to the beginning of the PDU, followed by successively less significant octets.

When a single octet contains multiple fields of primitive data types, the bit positions within the octet of each of the primitive types as defined in the message field specification shall be preserved. For example, the first field of the header of PTP messages is a single octet composed of two fields, one of type Nibble bit 4 through bit 7, and one of type Enumeration4 bit 0 through bit 3 (see 11.4.2 and 10.6.2).

6.4.4.5 Derived data types

Derived data types defined as structs shall be formatted with the first member of the struct nearest to the beginning of the PDU followed by each succeeding member, without any padding. Each member shall be formatted according to its data type.

Derived data types defined as typedefs shall be formatted according to its referenced data type.

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7. Time-synchronization model for a packet network

7.1 General

This clause provides a model for understanding the operation of the generalized precision time protocol (gPTP), which specifies the operation of time-aware systems on a packet network. Although this standard is based on the precision time protocol (PTP) described in IEEE Std 1588-2019 (and, indeed, is a proper profile of IEEE Std 1588-2019 in particular configurations), there are differences, which are summarized in 7.5.

Although this standard has been written as a stand-alone document, it is useful to understand the IEEE 1588 architecture as described in Clause 6 of IEEE Std 1588-2019.

7.2 Architecture of a time-aware network

7.2.1 General

A time-aware network consists of a number of interconnected time-aware systems that support the gPTP defined within this standard. These time-aware systems can be any networking device, including, for example, bridges, routers, and end stations. A set of time-aware systems that are interconnected by gPTP-capable network elements is called a *gPTP network.* Each instance of gPTP that the time-aware systems support is in one *gPTP domain*, and the instances of gPTP are said to be part of that gPTP domain. A time-aware system can support, and therefore be part of, more than one gPTP domain. The entity of a single time-aware system that executes gPTP in one gPTP domain is called a *PTP Instance*. A time-aware system can contain multiple PTP Instances, which are each associated with a different gPTP domain. There are two types of PTP Instances:

a) PTP End Instance, which, if not a Grandmaster PTP Instance, is a recipient of time information, and
b) PTP Relay Instance, which, if not a Grandmaster PTP Instance, receives time information from the Grandmaster PTP Instance (perhaps indirectly through other PTP Relay Instances), applies corrections to compensate for delays in the local area network (LAN) and the PTP Relay Instance itself, and retransmits the corrected information.

This standard defines mechanisms for delay measurements using standard-based procedures for the following:

c) IEEE 802.3 Ethernet using full-duplex point-to-point links (11)
d) IEEE 802.3 EPON links (Clause 13)
e) IEEE 802.11 wireless (Clause 12)
f) Generic coordinated shared networks (CSNs, e.g., MoCA and G.hn) (Clause 16)

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7.2.2 Time-aware network consisting of a single gPTP domain

Figure 7-1 illustrates an example time-aware network consisting of a single gPTP domain, using all the above network technologies [i.e., item c) through item f) of 7.2.1], where end stations on several local networks are connected to a Grandmaster PTP Instance on a backbone network via an EPON access network.

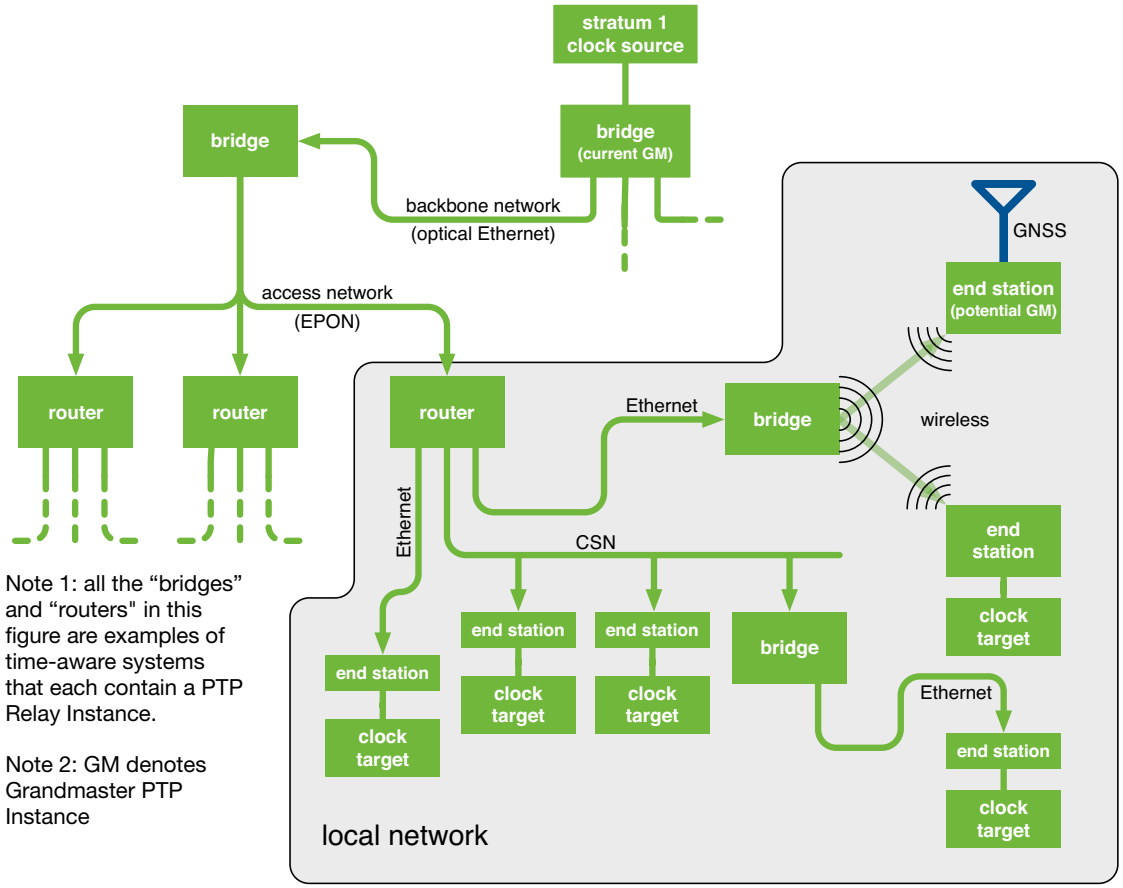

Figure 7-1—Time-aware network example

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Any PTP Instance with clock sourcing capabilities can be a potential Grandmaster PTP Instance, and a selection method (the *best master clock algorithm*, or BMCA) ensures that all of the PTP Instances in a gPTP domain use the same Grandmaster PTP Instance.[12] The BMCA is largely identical to that used in IEEE Std 1588-2019, but somewhat simplified. In Figure 7-1 the BMCA process has resulted in the Grandmaster PTP Instance being on the network backbone. If, however, the access network fails, the systems on a local network automatically switch over to one of the potential Grandmaster PTP Instances on the local network that is as least as "good" as any other. For example, in Figure 7-2, the access network link has failed, and a potential Grandmaster PTP Instance that has a GNSS reference source has become the active Grandmaster PTP Instance. As a result, now two gPTP domains exist where there used to be one. Finally, note that when a time-aware system supports more than one domain, one of the domains supported must be domain 0 for backward compatibility with the 2011 edition of this standard, though domain 0 is not necessarily active in a time-aware system.

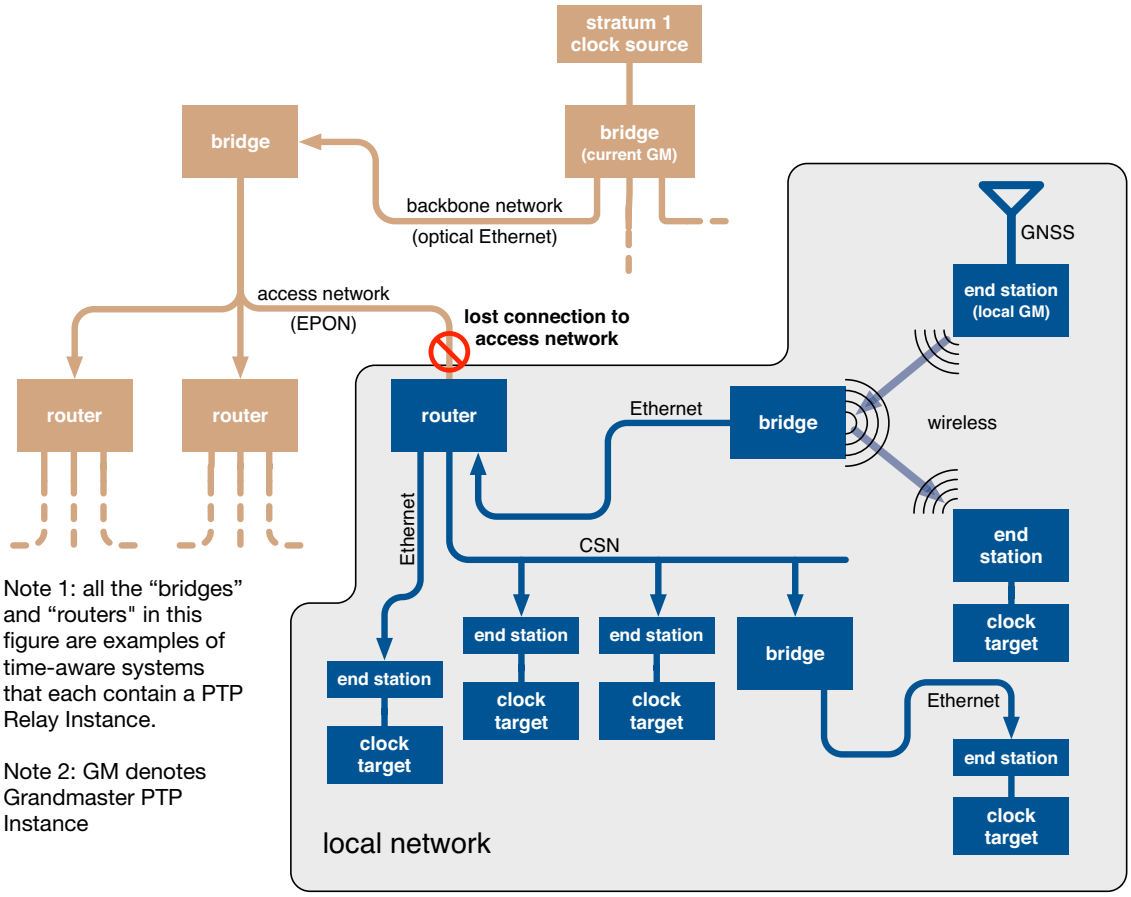

Figure 7-2—Time-aware network of Figure 7-1 after an access network link failure

[12] There are, however, short periods during network reconfiguration when more than one Grandmaster PTP Instance might be active while the BMCA process is taking place.

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7.2.3 Time-aware network consisting of multiple gPTP domains

Figure 7-3 illustrates an example time-aware network consisting of multiple gPTP domains that could be used in an industrial application. Specifically, in this example the network has two timescales/domains, where domain 0 uses the PTP timescale and domain 1 uses the arbitrary (ARB) timescale (see 8.2). Notice that not all PTP Instances in domain 1 (within the blue shorter-dashed area) have domain 0 active in this example, even though every time-aware system supports domain 0 for backward compatibility with the 2011 edition of this standard. In addition, it is required that all PTP Instances belonging to the same domain have direct connections among them in their physical topology (e.g., time cannot be transported from one PTP Instance in domain 0 to another PTP Instance in domain 0 via a time-aware system that does not have domain 0 active). In addition, the time-aware systems for which both domains are active are depicted by slanted internal hatching, representing two independent, active PTP Instances.

As in the single-domain case, any of the network technologies of 7.2.1 can be used. The Grandmaster PTP Instance of each domain is selected by the BMCA; in this case, a separate, independent instance of the BMCA is invoked in each domain.

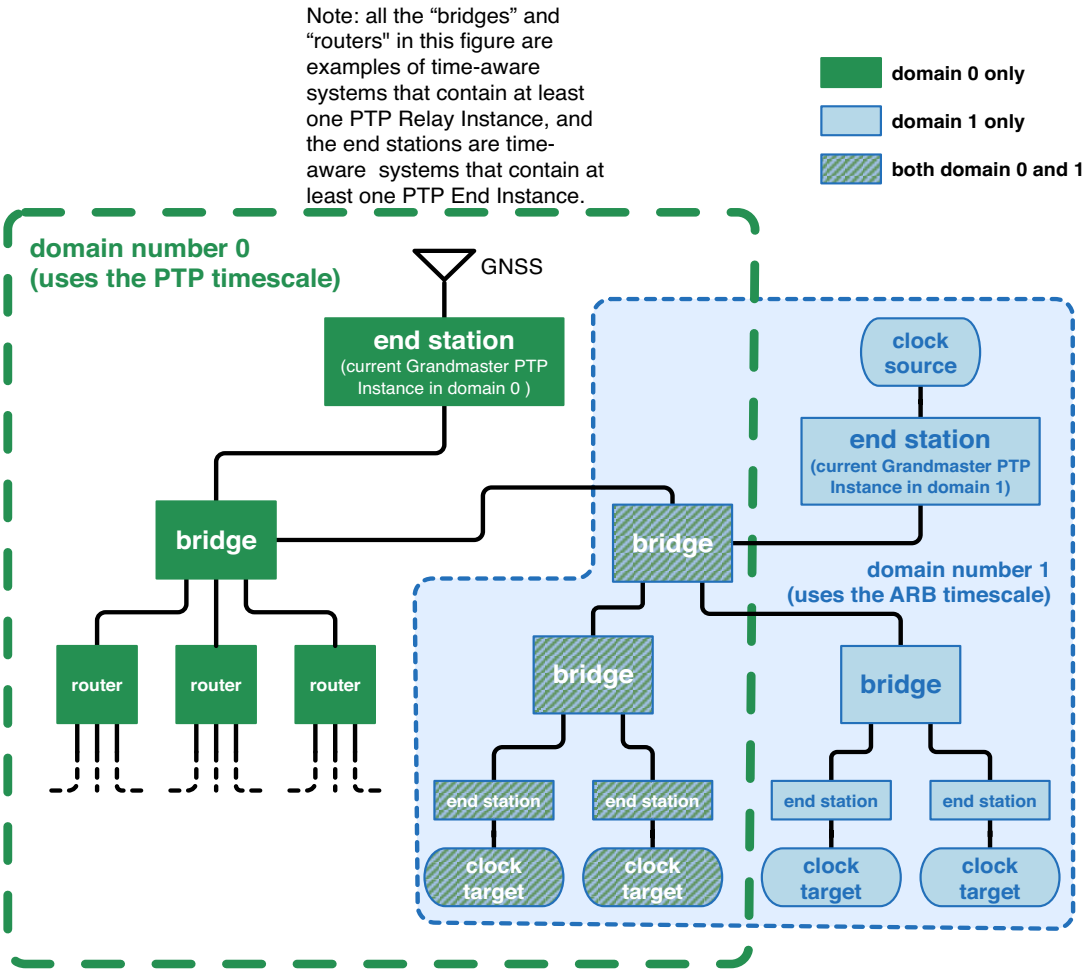

Figure 7-3—Time-aware network example for multiple gPTP domains

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7.2.4 Time-aware networks with redundant Grandmaster PTP Instances and/or redundant paths

7.2.4.1 General

Redundancy has many levels of sophistication, performance, and cost. Therefore, the appropriate level and/or amount of redundancy required in a time-aware network can be very different for each application. Nonetheless, all solutions for redundancy consist of a detection component, a correction component, and an action component. The detection component detects that something is not working correctly. The correction component determines the appropriate corrective action. The action component performs the required action(s) to fix the detected problem.

7.2.4.2 Redundancy specified in this standard (BMCA)

This standard provides a basic level of redundancy as follows:

— A detection component that triggers when the current Grandmaster PTP Instance stops working (i.e., loss of Sync messages and Announce messages for a period of time) or if the link to the Grandmaster PTP Instance goes down (i.e., immediate loss of Sync messages and Announce messages).
— A correction component that triggers the Best Master Clock Algorithm (BMCA) and the sending of Announce messages so that a new Grandmaster PTP Instance can be elected.
— An action component, where the winning Grandmaster PTP Instance starts sending Announce messages and Sync messages and all the PTP Instances listen to this new Grandmaster PTP Instance.

7.2.4.3 Redundacy not fully specified in this standard

In addition to providing the basic level of redundancy, this standard provides the ability to support more sophisticated network configurations that provide additional levels of Grandmaster PTP Instance and clock path redundancy. Figure 7-4 through Figure 7-6 are examples of such networks that provide these additional levels of redundancy as a way to deal with these failures. The information necessary to implement and configure these network configurations is contained in this standard.

In order to take advantage of these failure correction configurations, new types of fault detection are required. The category of fault detection where a Grandmaster PTP Instance completely fails and stops sending clock information is supported as mentioned above.

Other types of faults involve instability of the Grandmaster Clock, such as time glitches, excess jitter, or wander, or various other impairments that could occur in the Grandmaster Clock. Techniques for identifying these types of failures, and the appropriate correction necessary, are not specified in this standard. However, if other techniques or standards are used for detection and correction of these types of failures, this standard provides the means to recover from these errors.

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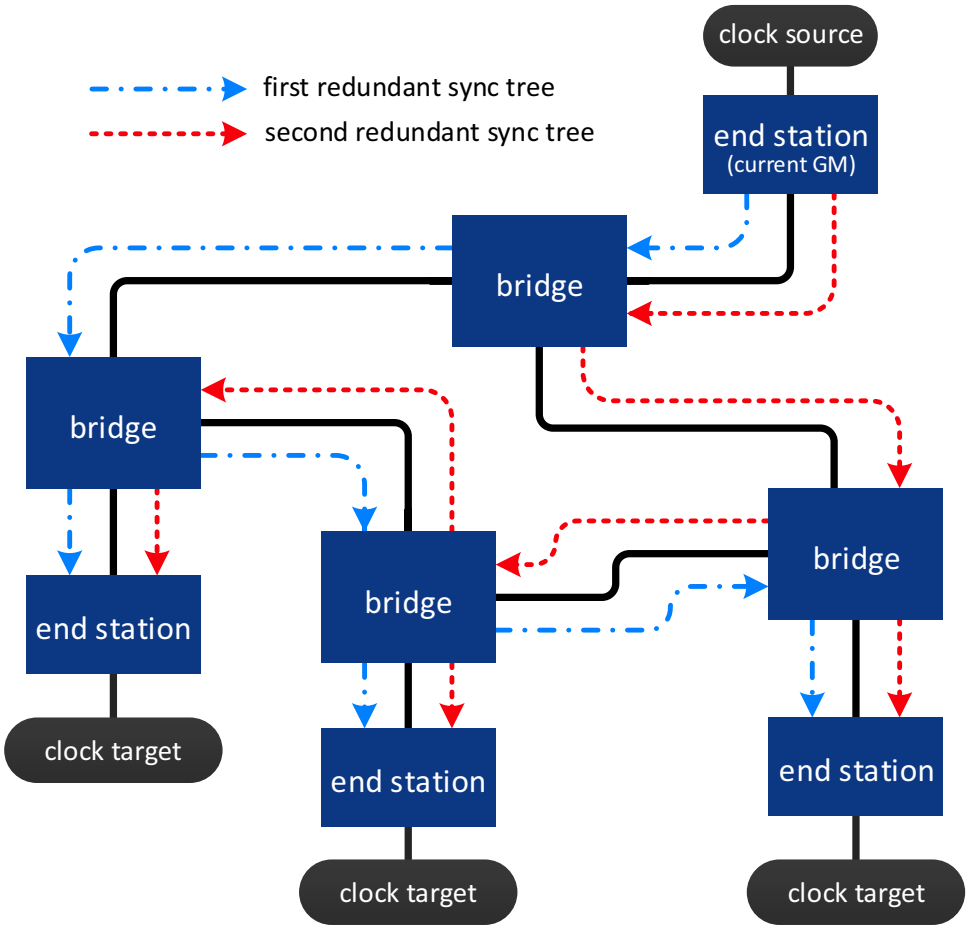
Figure 7-4 shows an example network realizing two redundant synchronization trees from a single GM, with each synchronization tree in a different gPTP domain (there are a total of two gPTP domains).



Note 1: The methods used for merging the redundant sync msgs received at each end station are not specified in this standard.
Note 2: All the “bridges” in this figure are examples of time-aware systems that contain PTP Relay Instances, and the end stations are examples of time-aware systems that contain PTP End Instances.
Note 3: GM denotes Grandmaster PTP Instance

Figure 7-4—Time-aware network example for synchronization path redundancy, with one clock source providing time to two domains

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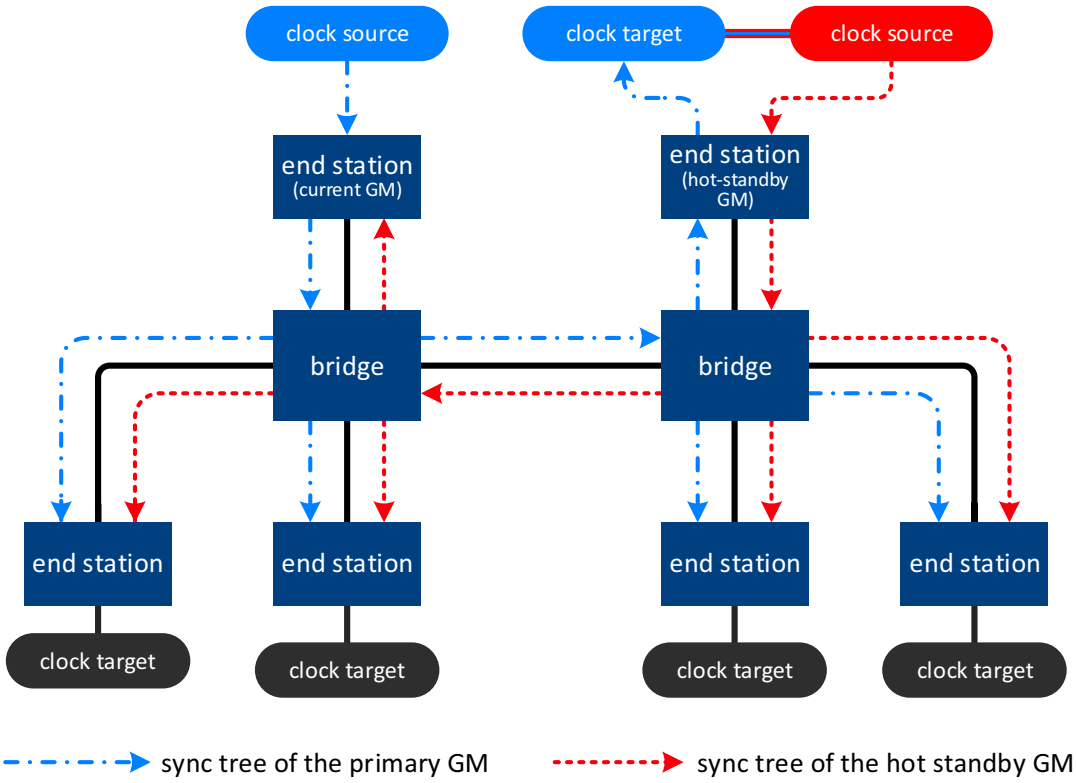
Figure 7-5 shows an example network with two redundant GMs, one as primary GM and the other as secondary GM, where each GM has one of the two redundant synchronization trees originating from it. This example supports hot-standby operating mode. In this mode, the secondary GM has to be synchronized to the primary GM, because it is part of the synchronization tree of the primary GM as shown in the figure.



Note 1: The methods used for merging the redundant sync msgs received at each end station are not specified in this standard.

Note 2: All the "bridges" in this figure are examples of time-aware systems that contain PTP Relay Instances, and the end stations are examples of time-aware systems that contain PTP End Instances.

Note 3: GM denotes Grandmaster PTP Instance

Figure 7-5—Time-aware network example for GM redundancy with one primary GM and one hot-standby GM, which are separated in two gPTP domains

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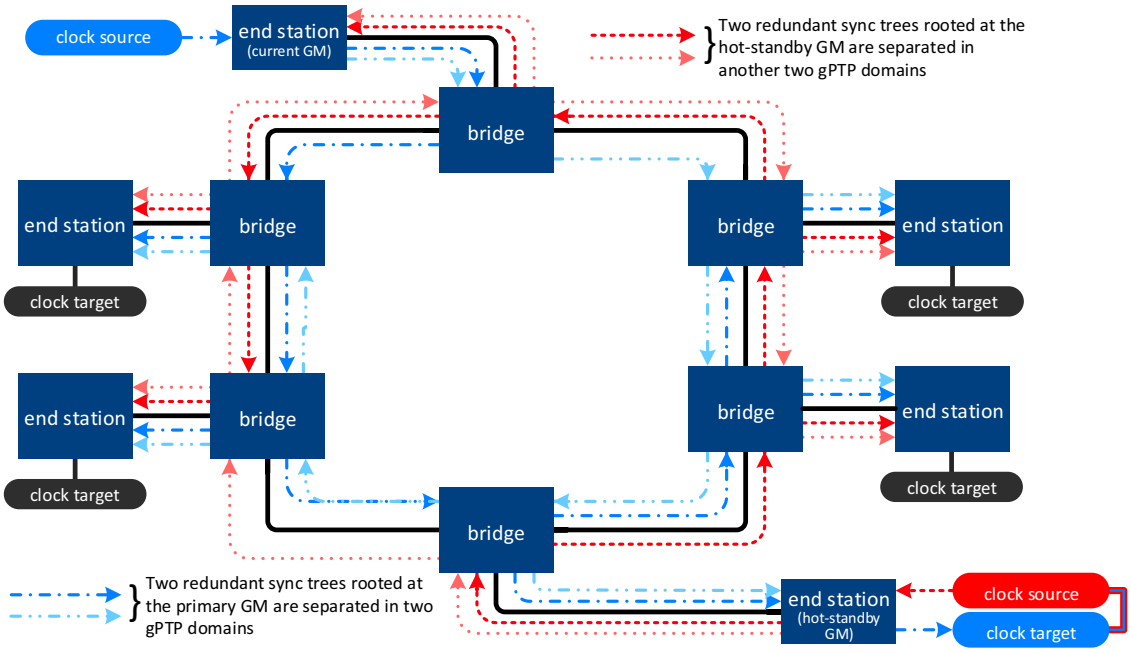
Figure 7-6 shows another example network, which involves ring topology, using the redundancy features of both Figure 7-4 and Figure 7-5.

For the techniques shown in the examples of Figure 7-4, Figure 7-5, and Figure 7-6, the detection component, correction component, and action component are not fully specified in this standard.



Note 1: The methods used for merging the redundant sync msgs received at each end station are not specified in this standard.
Note 2: All the "bridges" in this figure are examples of time-aware systems that contain PTP Relay Instances, and the end stations are examples of time-aware systems that contain PTP End Instances.
Note 3: GM denotes Grandmaster PTP Instance

Figure 7-6—Time-aware network example for GM+synchronziation path redundancy, with one primary and one hot-standby GM. Each GM establishes two sync trees, resulting in a total of four Sync trees that are separated in four gPTP domains

7.3 Time synchronization

7.3.1 General

Time synchronization in gPTP is done the same way (in the abstract) as is done in IEEE Std 1588-2019: a Grandmaster PTP Instance sends information including the current synchronized time to all directly attached PTP Instances. Each of these PTP Instances must correct the received synchronized time by adding the propagation time needed for the information to transit the gPTP communication path from the Grandmaster PTP Instance. If the PTP Instance is a PTP Relay Instance, then it must forward the corrected time information (including additional corrections for delays in the forwarding process) to all the other attached PTP Instances.

To make this all work, there are two time intervals that must be precisely known: the forwarding delay (called the *residence time*), and the time taken for the synchronized time information to transit the gPTP communication path between two PTP Instances. The residence time measurement is local to a PTP Relay Instance and easy to compute, while the gPTP communication path delay is dependent on many things including media- dependent properties and the length of the path.

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7.3.2 Delay measurement

Each type of LAN or gPTP communication path has different methods for measuring propagation time, but they are all based on the same principle: measuring the time that a well-known part of a message is transmitted from one device and the time that the same part of the same message is received by the other device, then sending another message in the opposite direction and doing the same measurement as shown in Figure 7-7.

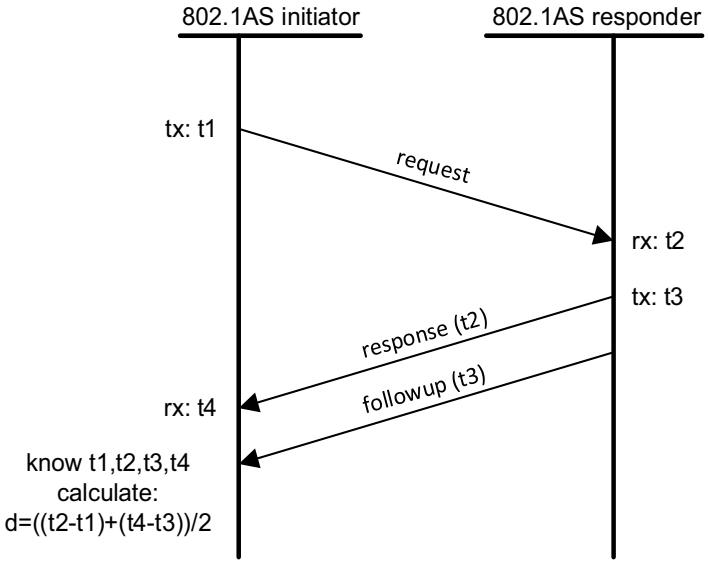

Figure 7-7—Conceptual medium delay measurement

This basic mechanism is used in the various LANs in the following ways:

a) Full-duplex Ethernet LANs use the two-step peer-to-peer (P2P) path delay algorithm as defined in IEEE Std 1588-2019, where the messages are called Pdelay_Req, Pdelay_Resp, and Pdelay_Resp_Follow_Up (see Figure 11-1).

b) IEEE 802.11 wireless LANs use the Timing Measurement (TM) procedure or the Fine Timing Measurement (FTM) procedure defined in IEEE Std 802.11-2016. The Timing measurement messages are the "Timing Measurement frame" and its corresponding "Ack" (see Figure 12-1). The Fine Timing Measurement messages are the "initial FTM request frame" and the "Fine Timing Measurement frame" and its "Ack" (see Figure 12-2).

c) EPON LANs use the discovery process, where the messages are "GATE" and "REGISTER_REQ" (see Clause 64 and Clause 77 of IEEE Std 802.3-2018).

d) CSNs either use the same mechanism as full-duplex Ethernet or use a method native to the particular CSN (similar to the way native methods are used by IEEE 802.11 networks and EPON) (see Figure 16-5).

7.3.3 Logical syntonization

The time-synchronization correction previously described is dependent on the accuracy of the delay and residence time measurements. If the clock used for this purpose is frequency locked (syntonized) to the Grandmaster Clock, then all the time interval measurements use the same time base. Since actually adjusting the frequency of an oscillator (e.g., using a phase-lock loop) is slow and prone to gain peaking effects, PTP Relay Instances can correct time interval measurements using the Grandmaster Clock frequency ratio.

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Each PTP Instance measures, at each PTP Port, the ratio of the frequency of the PTP Instance at the other end of the link attached to that PTP Port to the frequency of its own clock. The cumulative ratio of the Grandmaster Clock frequency to the local clock frequency is accumulated in a standard organizational type, length, value (TLV) attached to the Follow_Up message (or the Sync message if the optional one-step processing is enabled). The frequency ratio of the Grandmaster Clock relative to the local clock is used in computing synchronized time, and the frequency ratio of the neighbor relative to the local clock is used in correcting the propagation time measurement.

The Grandmaster Clock frequency ratio is measured by accumulating neighbor frequency ratios for two main reasons. First, if there is a network reconfiguration and a new Grandmaster PTP Instance is elected, the nearest neighbor frequency ratios do not have to be newly measured as they are constantly measured using the Pdelay messages. This results in the frequency offset relative to the new Grandmaster Clock being known when the first Follow_Up message (or first Sync message if the optional one-step processing is enabled) is received, which reduces the duration of any transient error in synchronized time during the reconfiguration. This is beneficial to many high-end audio applications. Second, there are no gain peaking effects because an error in frequency offset at one PTP Relay Instance, and resulting residence time error, does not directly affect the frequency offset at a downstream PTP Relay Instance.

7.3.4 Grandmaster PTP Instance (best master) selection and network establishment

All PTP Instances participate in best master selection so that the IEEE 802.1AS protocol can determine the synchronization spanning tree. This synchronization spanning tree can be different from the forwarding spanning tree determined by IEEE 802.1Q™ Rapid Spanning Tree Protocol (RSTP) since the spanning tree determined by RSTP can be suboptimal or even inadequate for synchronization or can be for a different topology of nodes from the synchronization spanning tree.

gPTP requires that all systems in the gPTP domain be time-aware systems, i.e., the protocol does not transfer timing over systems that are not time-aware (e.g., those that meet the requirements of IEEE Std 802.1Q-2018, but do NOT meet the requirements of the present standard). A time-aware system uses the peer-to-peer delay mechanism on each PTP Port to determine if a non-time-aware system is at the other end of the link or between itself and the Pdelay responder. If, on sending Pdelay_Req,

a) No response is received,
b) Multiple responses are received, or
c) The measured propagation delay exceeds a specified threshold, then

the protocol concludes that a non-time-aware system or end-to-end Transparent Clock (TC) (see IEEE Std 1588-2019) is present. In this case, the link attached to the PTP Port is deemed not capable of running gPTP, and the BMCA ignores it. However, the PTP Port continues to attempt the measurement of propagation delay using the peer-to-peer delay mechanism (for full-duplex IEEE 802.3 links), multipoint control protocol (MPCP) messages (for EPON), or IEEE 802.11 messages (for IEEE 802.11 links), and periodically checks whether the link is or is not capable of running the IEEE 802.1AS protocol.

7.3.5 Energy efficiency

Sending PTP messages at relatively high rates when there is otherwise little or no traffic conflicts with the goal of reducing energy consumption. This standard specifies a way to request that a neighbor PTP Port reduce the rate of sending Sync (and Follow_Up if optional one-step processing is not enabled), peer delay, and Announce messages and also to inform the neighbor not to compute neighbor rate ratio and/or propagation delay on this link. A time-aware system could do this when it enters low-power mode, but this standard does not specify the conditions under which this is done; it specifies only the actions a time-aware system takes.

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7.4 PTP Instance architecture

The model of a PTP Instance is shown in Figure 7-8.

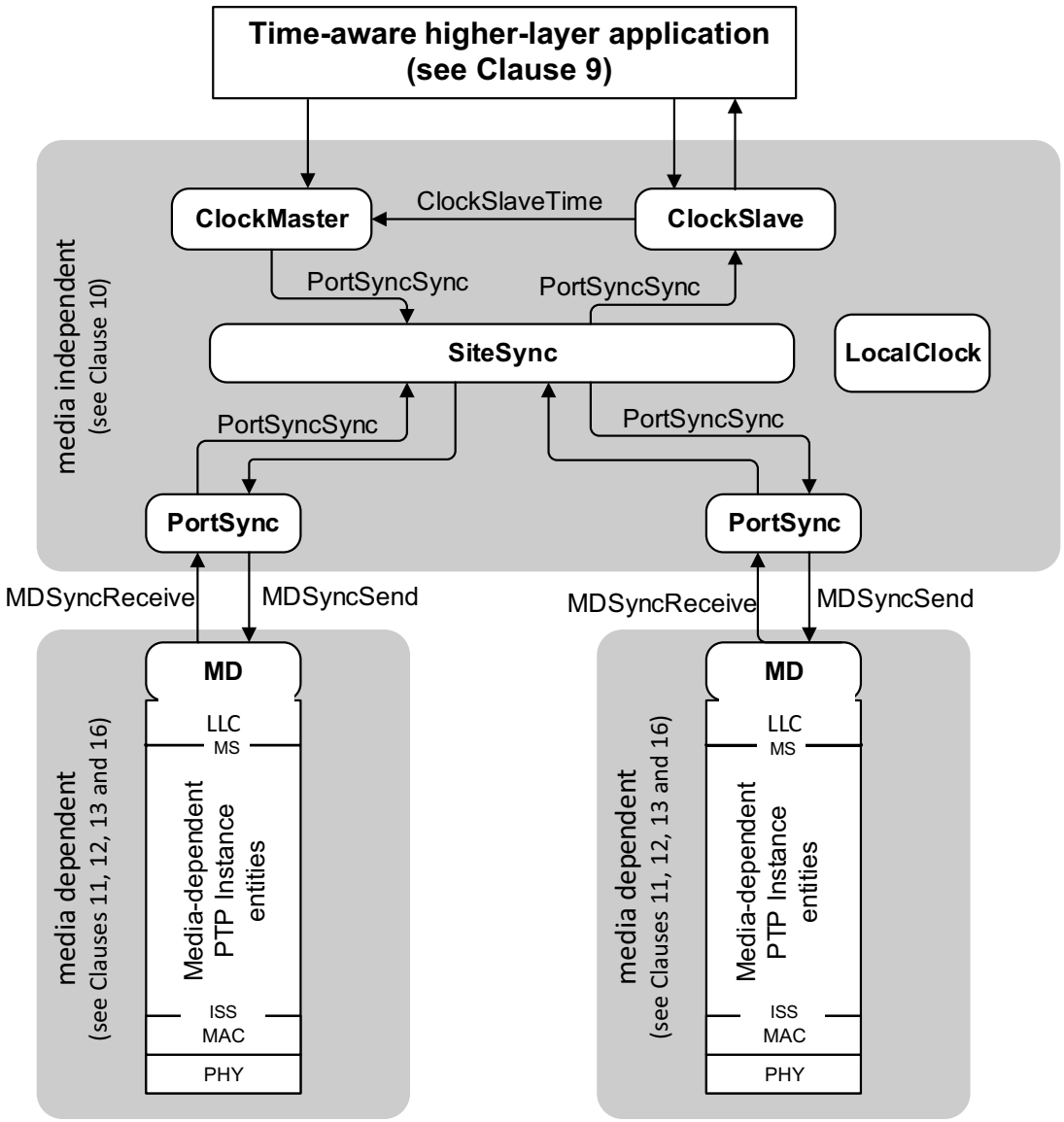

Figure 7-8—PTP Instance model

A PTP Instance consists of the following major parts:

a) If the PTP Instance includes application(s) that either use or source time information, then they interface with the gPTP information using the application interfaces specified in Clause 9.

b) A single media-independent part that consists of ClockMaster, ClockSlave, and SiteSync logical entities, one or more PortSync entities, and a LocalClock entity. The BMCA and forwarding of time information between logical ports and the ClockSlave and ClockMaster is done by the SiteSync

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entity, while the computation of PTP Port-specific delays needed for time-synchronization correction is done by the PortSync entities.

c) Media-dependent ports, which translate the abstract "MDSyncSend" and "MDSyncReceive" structures received from or sent to the media-independent layer and corresponding methods used for the particular LAN attached to the port.

For full-duplex Ethernet ports, IEEE 1588 Sync and Follow_Up (or just Sync if the optional one-step processing is enabled) messages are used, with an additional TLV in the Follow_Up (or the Sync if the optional one-step processing is enabled) used for communication of rate ratio and information on phase and frequency change when there is a change in Grandmaster PTP Instance. The path delay is measured using the two-step IEEE 1588 peer-to-peer delay mechanism. This is defined in Clause 11.

For IEEE 802.11 ports, timing information is communicated using the MAC Layer Management Entity to request a "Timing Measurement" or "Fine Timing Measurement" (as defined in IEEE Std 802.11-2016), which also sends everything that would be included in the Follow_up message for full-duplex Ethernet. The Timing Measurement or Fine Timing Measurement result includes all the information to determine the path delay. This is defined in Clause 12.

For EPON, timing information is communicated using a "slow protocol" as defined in Clause 13. CSNs use the same communication system used by full-duplex Ethernet, as defined in Clause 16.

7.5 Differences between gPTP (IEEE Std 802.1AS) and PTP (IEEE Std 1588-2019)

a) gPTP assumes all communication between PTP Instances is done only using IEEE 802 MAC PDUs and addressing, while IEEE Std 1588-2019 supports various layer 2 and layer 3-4 communication methods.

b) gPTP specifies a media-independent sublayer that simplifies the integration within a single timing domain of multiple different networking technologies with radically different media access protocols. gPTP specifies a media-dependent sublayer for each medium. The information exchanged between PTP Instances has been generalized to support different packet formats and management schemes appropriate to the particular networking technology. IEEE Std 1588-2019, on the other hand, has introduced a new architecture based on media-independent and media-dependent sublayers (see 6.5.2, Figure 5, and Figure 6 of IEEE Std 1588-2019); however, this architecture is optional. The architecture of IEEE Std 1588-2008 [B10], which is not based on media-independent and media-dependent layers, has been retained for Internet Protocol (IP) version 4, IP version 6, Ethernet LANs, and several industrial automation control protocols. The intent in IEEE Std 1588-2019 is that the new architecture, based on media-independent and media-dependent layers, will be used for IEEE 802.11 networks, IEEE 802.3 EPON, and CSN using the specifications of gPTP, and that the architecture must be used for transports that define native timing mechanisms if those native timing mechanisms are used.

c) In gPTP there are only two types of PTP Instances: PTP End Instances and PTP Relay Instances, while IEEE Std 1588-2019 has Ordinary Clocks, Boundary Clocks, end-to-end Transparent Clocks, and P2P Transparent Clocks. A PTP End Instance corresponds to an IEEE 1588 Ordinary Clock, and a PTP Relay Instance is a type of IEEE 1588 Boundary Clock where its operation is very tightly defined, so much so that a PTP Relay Instance with Ethernet ports can be shown to be mathematically equivalent to a P2P Transparent Clock in terms of how synchronization is performed, as shown in 11.1.3. In addition, a PTP Relay Instance can operate in a mode (i.e., the mode where the variable syncLocked is TRUE; see 10.2.5.15) where the PTP Relay Instance is equivalent to a P2P Transparent Clock in terms of when time-synchronization messages are sent. A time-aware system measures link delay and residence time and communicates these in a correction field. In summary, a PTP Relay Instance conforms to the specifications for a Boundary Clock in

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IEEE Std 1588-2019, but a PTP Relay Instance does not conform to the complete specifications for a P2P Transparent Clock in IEEE Std 1588-2019 because:

1) When syncLocked is FALSE, the PTP Relay Instance sends Sync according to the specifications for a Boundary Clock, and
2) The PTP Relay Instance invokes the BMCA and has PTP Port states.

d) PTP Instances communicate gPTP information only directly with other PTP Instances. That is, a gPTP domain consists ONLY of PTP Instances. Non-PTP Relay Instances cannot be used to relay gPTP information. In IEEE Std 1588-2019, it is possible to use non-IEEE-1588-aware relays in an IEEE 1588 domain, although this slows timing convergence and introduce extra jitter and wander that must be filtered by any IEEE 1588 clock.

e) For full-duplex Ethernet links, gPTP requires the use of the peer-to-peer delay mechanism, while IEEE Std 1588-2019 also allows the use of end-to-end delay measurement.

f) For full-duplex Ethernet links, gPTP requires the use of two-step processing (use of Follow_Up and Pdelay_Resp_Follow_Up messages to communicate timestamps), with an optional one-step processing mode that embeds timestamps in the Sync “on the fly” as they are being transmitted (gPTP does not specify one-step processing for peer delay messages). IEEE Std 1588-2019 allows either two-step or one-step processing to be required (for both Sync and peer delay messages) depending on a specific profile.

g) All PTP Instances in a gPTP domain are logically syntonized; in other words, they all measure time intervals using the same frequency. This is done by the process described in 7.3.3 and is mandatory. Syntonization in IEEE Std 1588-2019 is optional. The syntonization method used by gPTP is supported as an option in IEEE Std 1588-2019, but uses a TLV standardized as part of IEEE Std 1588-2019 (this feature is new for IEEE Std 1588-2019), while gPTP uses the ORGANIZATION_EXTENSION TLV specified in 11.4.4.3.

h) Finally, this standard includes formal interface definitions, including primitives, for the time-aware applications (see Clause 9). IEEE Std 1588-2019 describes external interfaces without describing specific interface primitives.

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8. IEEE 802.1AS concepts and terminology

8.1 gPTP domain

A gPTP domain, hereafter called simply a *domain,* consists of one or more PTP Instances and links that meet the requirements of this standard and communicate with each other as defined by the IEEE 802.1AS protocol. A gPTP domain defines the scope of gPTP message communication, state, operations, data sets, and timescale.

A domain is identified by two attributes: domain number and sdoId. The sdoId of a domain is a 12-bit unsigned integer. The sdoId is structured as a two-part attribute as follows:

— The most significant 4 bits are named the majorSdoId, and
— The least significant 8 bits are named the minorSdoId.

A time-aware system shall support one or more domains, each with a distinct domain number in the range 0 through 127. A time-aware system shall support the domain whose domain number is 0, and that domain number shall not be changed to a nonzero value. Unless otherwise specified in this standard, the operation of gPTP and the timescale in any given domain is independent of operation in any other domain.

The value of majorSdoId for a gPTP domain shall be 0x1. The value of minorSdoId for a gPTP domain shall be 0x00.

NOTE 1—The above requirements for majorSdoId and minorSdoId are for gPTP domains. The requirements for the Common Mean Link Delay Service (CMLDS) are given in 11.2.17.

Both the domainNumber and the sdoId are carried in the common header of all PTP messages (see 10.6.2.2).

NOTE 2—In the 2011 edition of this standard, the attribute majorSdoId was named transportSpecific, and its value was specified as 0x1 in 10.5.2.2.1 of Corrigendum 1. The attribute minorSdoId did not exist in the 2011 edition, but its location in the common header was a reserved field, which was specified to be transmitted as 0 and ignored on receipt.

Unless otherwise stated, information in the remainder of this document is per domain.

NOTE 3—In steady state, all PTP Instances in a gPTP domain are traceable to a single Grandmaster PTP Instance.

8.2 Timescale

8.2.1 Introduction

The timescale for a gPTP domain is established by the Grandmaster Clock. There are two types of timescales supported by gPTP:

— The timescale PTP: The epoch is the PTP epoch (see 8.2.2), and the timescale is continuous. The unit of measure of time is the second defined by International Atomic Time (TAI) (for the definition of TAI, see Service de la Rotation Terrestre [B28], with further amplification in IAU [B27]; and for more information on TAI, see Jekeli [B22], international system of units (SI) brochure [B14], and Petit and Luzum [B26]). The timescale of domain 0 shall be PTP. See IEEE Std 1588-2019 for more details.
— The timescale ARB (arbitrary): The epoch is the domain startup time and can be set by an administrative procedure. Between invocations of the administrative procedure, the timescale is continuous. Additional invocations of the administrative procedure can introduce discontinuities in

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