

**IEEE Standard for
Local and metropolitan area networks—**

**Timing and Synchronization for
Time-Sensitive Applications in
Bridged Local Area Networks**

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 802.1AS™-2011

30 March 2011

IEEE Standard for
Local and metropolitan area networks—
Timing and Synchronization for
Time-Sensitive Applications in
Bridged Local Area Networks

Sponsor
LAN/MAN Standards Committee
of the
IEEE Computer Society

Approved 10 February 2011
IEEE SA-Standards Board

Abstract: This standard defines a protocol and procedures for the transport of timing over bridged and virtual bridged local area networks. 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, IEEE 802.1AS, phase offset, synchronization, syntonization, time-aware system

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2011 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 30 March 2011. Printed in the United States of America.

IEEE and 802 are registered trademarks in the U.S. Patent & Trademark Office, owned by the Institute of Electrical and Electronics Engineers, Incorporated.

POSIX is a trademark of the Institute of Electrical and Electronics Engineers, Incorporated.

MoCA is a registered trademark of the Multimedia over Coax Alliance.

PDF: ISBN 978-0-7381-6536-3 STD97070
Print: ISBN 978-0-7381-6537-0 STDPD97070

IEEE prohibits discrimination, harassment and bullying. For more information, visit <http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html>. No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. The IEEE develops its standards through a consensus development process, approved by the American National Standards Institute, which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and serve without compensation. While the IEEE administers the process and establishes rules to promote fairness in the consensus development process, the IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

Use of an IEEE Standard is wholly voluntary. The IEEE disclaims liability for any personal injury, property or other damage, of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance upon this, or any other IEEE Standard document.

The IEEE does not warrant or represent the accuracy or content of the material contained herein, and expressly disclaims any express or implied warranty, including any implied warranty of merchantability or fitness for a specific purpose, or that the use of the material contained herein is free from patent infringement. IEEE Standards documents are supplied "AS IS."

The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation, or every ten years for stabilization. When a document is more than five years old and has not been reaffirmed, or more than ten years old and has not been stabilized, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

In publishing and making this document available, the IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity. Nor is the IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing this, and any other IEEE Standards document, should rely upon his or her independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration. A statement, written or oral, that is not processed in accordance with the IEEE-SA Standards Board Operations Manual shall not be considered the official position of IEEE or any of its committees and shall not be considered to be, nor be relied upon as, a formal interpretation of the IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position, explanation, or interpretation of the IEEE.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Recommendations to change the status of a stabilized standard should include a rationale as to why a revision or withdrawal is required. Comments and recommendations on standards, and requests for interpretations should be addressed to:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
Piscataway, NJ 08854
USA

Authorization to photocopy portions of any individual standard for internal or personal use is granted by The Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Introduction

This introduction is not part of IEEE Std 802.1AS-2011, IEEE Standard for Local and metropolitan area networks—Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks.

This standard specifies the protocol and procedures used to ensure that the synchronization requirements are met for time-sensitive applications, such as audio and video, across bridged and virtual bridged local area networks consisting of LAN media where the transmission delays are fixed and symmetrical; for example, IEEE 802.3TM full-duplex links. 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 1588TM specifications where applicable in the context of IEEE Std 802.1DTM-2004 and IEEE Std 802.1QTM-2005.^a Synchronization to an externally provided timing signal (e.g., a recognized timing standard such as UTC or TAI) is not part of this standard but is not precluded.

This is the first edition of IEEE Std 802.1AS.

This standard contains state-of-the-art material. The area covered by this standard is undergoing evolution. Revisions are anticipated within the next few years to clarify existing material, to correct possible errors, and to incorporate new related material. Information on the current state of this and other IEEE 802[®] standards may be obtained from:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
Piscataway, NJ 08854
USA

Notice to users

Laws and regulations

Users of these documents should consult all applicable laws and regulations. Compliance with the provisions of this standard does not imply compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Copyrights

This document is copyrighted by the IEEE. It is made available for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making this document available for use and adoption by public authorities and private users, the IEEE does not waive any rights in copyright to this document.

^aInformation on references can be found in Clause 2.

Updating of IEEE documents

Users of IEEE standards should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect. In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit the IEEE Standards Association website at <http://ieeexplore.ieee.org/xpl/standards.jsp>, or contact the IEEE at the address listed previously.

For more information about the IEEE Standards Association or the IEEE standards development process, visit the IEEE-SA website at <http://standards.ieee.org>.

Errata

Errata, if any, for this and all other standards can be accessed at the following URL: <http://standards.ieee.org/reading/ieee/updates/errata/index.html>. Users are encouraged to check this URL for errata periodically.

Interpretations

Current interpretations can be accessed at the following URL: <http://standards.ieee.org/reading/ieee/interp/index.html>.

Patents

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. A patent holder or patent applicant has filed a statement of assurance that it will grant licenses under these rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses. Other Essential Patent Claims may exist for which a statement of assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

Participants

At the time this standard was submitted to the IEEE-SA Standards Board for approval, the IEEE 802.1 Working Group had the following membership:

Tony Jeffree, *IEEE 802.1 Working Group Chair*

Paul Congdon, *IEEE 802.1 Vice Chair*

Michael Johas Teener, *Audio-Video Bridging Task Group Chair*

Geoffrey Garner, *Editor*

IEEE 802.1AS Clause Editors

Christopher Hall, *Clause 5, Annex A*

Kevin B. Stanton, *Clause 5, Clause 12, Annex A*

Michael Johas Teener, *Clause 7*

Yongbum Kim, *Clause 15*

Yuanqiu Luo, **Frank Effenberger**, *Clause 13*

Philippe Klein, *Annex F*

Zehavit Alon

Ting Ao

Wanqun Bao

Paul Bottorff

Rudolf Brandner

Craig Carlson

Diego Crupnicoff

Claudio Desanti

Zheming Ding

Donald Eastlake, 3rd

Janos Farkas

Donald Fedyk

Norman Finn

Ilango Ganga

Anoop Ghanwani

Eric Gray

Craig Gunther

Stephen Haddock

Daya Kamath

Hal Keen

Michael Krause

Vinod Kumar

Lin Li

Ben Mack-Crane

Menu Menuchehry

John Messenger

John Morris

Eric Multanen

David Olsen

Donald Pannell

Glenn Parsons

Joseph Pelissier

Karen Randall

Derek Rohde

Dan Romascanu

Jessy Rouyer

Panagiotis Saltsidis

Michael Seaman

Rakesh Sharma

Takeshi Shimizu

Nurit Sprecher

Robert Sultan

Patricia Thaler

Chien-Hsien Wu

The following members of the individual balloting committee voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

Thomas Alexander
Butch Anton
Danilo Antonelli
Galina Antonova
Lee Armstrong
Hugh Barrass
William Byrd
Juan Carreon
Keith Chow
Charles Cook
Wael Diab
Russell Dietz
Thomas Dineen
Frank Effenberger
C. Fitzgerald
Prince Francis
Yukihiro Fujimoto
Geoffrey Garner
Devon Gayle
Mariana Goldhamer
Sergiu Goma
David Goodall
Randall Groves
Craig Gunther
C. Guy
Joseph Gwinn
Stephen Haddock
Marek Hajduczenia
Christopher Hall
Karl Heubaum
David Hunter
C. Huntley

Akio Iso
Atsushi Ito
Raj Jain
Tony Jeffree
Girault Jones
Shinkyō Kaku
Piotr Karocki
Stuart J. Kerry
Max Kicherer
Yongbum Kim
Gerald L. Kolbe
Seiji Kozaki
Bruce Kraemer
Paul Lambert
Jeremy Landt
Li Li
Greg Luri
Eric Lynskey
Elvis Maculuba
Arthur Marris
Peter Martini
Jeffery Masters
Jonathon Mclendon
Gary Michel
Jose Morales
Bruce Muschlitz
Michael S. Newman
Nick S. A. Nikjoo
Paul Nikolich
Satoshi Obara
David Olsen

Stephen Palm
Glenn Parsons
Subburajan
Ponnuswamy
Maximilian Riegel
Robert Robinson
Jessy Rouyer
Randall Safier
John Santhoff
Peter Saunderson
Bartien Sayogo
Shusaku Shimada
Gil Shultz
Matthew Squire
Manikantan Srinivasan
Kevin B. Stanton
Thomas Starai
Walter Struppler
Joseph Tardo
William Taylor
Michael Johas Teener
Patricia Thaler
David Thompson
Geoffrey Thompson
Solomon Trainin
Mark-Rene Uchida
Dmitri Varsanofiev
Prabodh Varshney
Ludwig Winkel
Kunpeng Wu
Oren Yuen
Zhen Zhou

When the IEEE-SA Standards Board approved this standard on 10 February 2011, it had the following membership:

Robert M. Grow, *Chair*
Richard H. Hulett, *Vice Chair*
Steve M. Mills, *Past Chair*
Judith Gorman, *Secretary*

Karen Bartleson
Victor Berman
Ted Burse
Clint Chaplin
Andy Drozd
Alexander Gelman
Jim Hughes

Young Kyun Kim
Joseph L. Koepfinger*
John Kulick
David J. Law
Hung Ling
Oleg Logvinov
Ted Olsen

Ronald C. Petersen
Thomas Prevost
Jon Walter Rosdahl
Sam Sciacca
Mike Seavey
Curtis Siller
Don Wright

*Member Emeritus

Also included are the following nonvoting IEEE-SA Standards Board liaisons:

Satish K. Aggarwal, *NRC Representative*
Richard DeBlasio, *DOE Representative*
Michael Janezic, *NIST Representative*

Lisa Perry
IEEE Standards Program Manager; Document Development

Kathryn Bennett
IEEE Standards Program Manager; Technical Program Development

Contents

1.	Overview.....	1
1.1	Scope.....	1
1.2	Purpose.....	2
2.	Normative references.....	3
3.	Definitions	5
4.	Acronyms and abbreviations	9
5.	Conformance.....	11
5.1	Requirements terminology.....	11
5.2	Protocol Implementation Conformance Statement (PICS).....	11
5.3	Time-aware Bridge and end station requirements	11
5.4	MAC-specific timing and synchronization methods for IEEE 802.3 full-duplex links	12
5.5	MAC-specific timing and synchronization methods for IEEE Std 802.11-2007	12
5.6	MAC-specific timing and synchronization methods for IEEE 802.3 EPON	12
5.7	MAC-specific timing and synchronization methods for coordinated shared network (CSN)...	13
6.	Conventions	15
6.1	General.....	15
6.2	Service specification method and notation	15
6.3	Data types and on-the-wire formats.....	15
7.	Time synchronization model for a bridged local area network	19
7.1	General.....	19
7.2	Architecture of a time-aware bridged local area network.....	19
7.3	Time synchronization	21
7.4	Time-aware system architecture	24
7.5	Differences between gPTP and PTP	25
8.	IEEE 802.1AS concepts and terminology	27
8.1	gPTP domain.....	27
8.2	Timescale	27
8.3	Communication path asymmetry	28
8.4	Messages.....	29
8.5	Ports	30
8.6	Time-aware system characterization	32
9.	Application interfaces	37
9.1	Overview of the interfaces	37
9.2	ClockSourceTime interface	38
9.3	ClockTargetEventCapture interface	38
9.4	ClockTargetTriggerGenerate interface	39
9.5	ClockTargetClockGenerator interface	40
9.6	ClockTargetPhaseDiscontinuity interface	41

10.	Media-independent layer specification	43
10.1	Overview	43
10.2	Time-synchronization state machines	44
10.3	Best master clock selection and announce interval setting state machines	67
10.4	Message attributes	85
10.5	Message formats	87
10.6	Protocol timing characterization	95
11.	Media-dependent layer specification for full-duplex, point-to-point links	99
11.1	Overview	99
11.2	State machines for MD entity specific to full-duplex, point-to-point links	105
11.3	Message attributes	122
11.4	Message formats	124
11.5	Protocol timing characterization	131
12.	Media-dependent layer specification for IEEE 802.11 links	133
12.1	Overview	133
12.2	Messages	135
12.3	Determination of asCapable	135
12.4	State machines	136
12.5	Format of VendorSpecific information element	143
12.6	Synchronization message interval	144
13.	Media-dependent layer specification for interface to IEEE 802.3 Ethernet passive optical network link	145
13.1	Overview	145
13.2	Message attributes	149
13.3	Message format	149
13.4	Determination of asCapable	151
13.5	Layering for IEEE 802.3 EPON links	151
13.6	Service interface definitions	152
13.7	MD entity global variables	154
13.8	State machines	154
13.9	Message transmission intervals	158
14.	Timing and synchronization management	159
14.1	General	159
14.2	Default Parameter Data Set	159
14.3	Current Parameter Data Set	161
14.4	Parent Parameter Data Set	164
14.5	Time Properties Parameter Data Set	165
14.6	Port Parameter Data Set	166
14.7	Port Parameter Statistics	170
14.8	Acceptable Master Table Parameter Data Set	173
15.	Managed object definitions	175
15.1	Internet Standard Management Framework	175
15.2	Structure of the MIB	175
15.3	Security considerations	175
15.4	Textual conventions defined in this MIB	179
15.5	IEEE 802.1AS MIB module	179

Annex A (normative) Protocol Implementation Conformance Statement (PICS) proforma	231
A.1 Introduction.....	231
A.2 Abbreviations and special symbols.....	231
A.3 Instructions for completing the PICS proforma.....	232
A.4 PICS proforma for IEEE Std 802.1AS-2011	233
A.5 Major capabilities	235
A.6 Media access control methods	236
A.7 Minimal time-aware system.....	236
A.8 Signalling.....	237
A.9 Best master clock	238
A.10 Grandmaster-capable system	239
A.11 Media-independent master	240
A.12 Media-dependent, full-duplex, point-to-point link.....	241
A.13 Media-dependent IEEE 802.11 link	243
A.14 Media-dependent IEEE 802.3 EPON link	243
A.15 Media-dependent CSN link.....	244
A.16 Media-dependent MoCA link	244
A.17 Media-dependent ITU-T G.hn link	244
 Annex B (normative) Performance requirements	245
B.1 LocalClock requirements	245
B.2 Time-aware system requirements	249
B.3 End-to-end time-synchronization performance	250
B.4 End-to-end jitter and wander performance	250
 Annex C (informative) Time-scales and epochs.....	253
C.1 Overview	253
C.2 TAI and UTC	253
C.3 NTP and GPS	254
C.4 Time-scale conversions.....	255
C.5 Time zones and GMT	256
 Annex D (normative) State diagram notation	257
 Annex E (normative) Media-dependent layer specification for CSN Network.....	259
E.1 Overview	259
E.2 Coordinated Shared Network characteristics	259
E.3 Layering for CSN links.....	260
E.4 Path delay measurement over a CSN backbone	262
E.5 Synchronization messages	265
E.6 Specific CSN requirements.....	268
E.7 Grandmaster capability	269
E.8 CSN clock and node requirements.....	269
 Annex F (informative) PTP profile included in this standard	271
F.1 Identification.....	271
F.2 PTP attribute values	271
F.3 PTP options.....	271
F.4 LocalClock and time-aware system performance requirements	272
 Annex G (informative) Bibliography	273



List of figures

Figure 7-1—Time-aware network example.....	20
Figure 7-2—Time-aware network of Figure 7-1 after an access network link failure	21
Figure 7-3— Example delay measurement	22
Figure 7-4—Time-aware system model	24
Figure 8-1—Propagation asymmetry.....	28
Figure 8-2—Definition of message timestamp point, reference plane, timestamp measurement plane, and latency constants	30
Figure 9-1—Application interfaces	37
Figure 10-1—Model for media-independent layer of time-aware system.....	44
Figure 10-2—Time-synchronization state machines—overview and interrelationships.....	46
Figure 10-3—SiteSyncSync state machine.....	56
Figure 10-4—PortSyncSyncReceive state machine	58
Figure 10-5—ClockMasterSyncSend state machine	60
Figure 10-6—ClockMasterSyncOffset state machine	61
Figure 10-7—ClockMasterSyncReceive state machine	63
Figure 10-8—PortSyncSyncSend state machine	65
Figure 10-9—ClockSlaveSync state machine	67
Figure 10-10—Example master/slave hierarchy of time-aware systems	69
Figure 10-11—Best master clock selection state machines—overview and interrelationships	74
Figure 10-12—PortAnnounceReceive state machine.....	79
Figure 10-13—PortAnnounceInformation state machine.....	80
Figure 10-14—PortRoleSelection state machine.....	83
Figure 10-15—PortAnnounceTransmit state machine	84
Figure 10-16—AnnounceIntervalSetting state machine.....	85
Figure 11-1—Propagation delay measurement using peer delay mechanism	100
Figure 11-2—Transport of time-synchronization information	102
Figure 11-3—Model for time-aware system with full-duplex, point-to-point links.....	105
Figure 11-4—Detail of MD entity time-synchronization state machines for full-duplex, point-to-point links	106
Figure 11-5—Peer delay mechanism state machines—overview and interrelationships.....	106
Figure 11-6—MDSyncReceiveSM state machine.....	111
Figure 11-7—MDSyncSendSM state machine.....	114
Figure 11-8—MDPdelayReq state machine	118
Figure 11-9—MDPdelayResp state machine	120
Figure 11-10—LinkDelaySyncIntervalSetting state machine	121
Figure 12-1—Timing measurement procedure for IEEE 802.11 links	134
Figure 12-2—Media-dependent and lower entities in stations with IEEE 802.11 links	135
Figure 12-3—Master state machine.....	137
Figure 12-4—Slave state machine	141
Figure 12-5—Format of VendorSpecific information element when Type = 0.....	143
Figure 13-1—IEEE 802.3 EPON time-synchronization interfaces.....	148
Figure 13-2—IEEE 802.3 EPON interface model.....	152
Figure 13-3—State machine for IEEE 802.3 EPON requester.....	156
Figure 13-4—State machine for IEEE 802.3 EPON responder.....	157
Figure B.1—Wander generation (TDEV) requirement for LocalClock entity.....	247
Figure B.2—ADEV limit corresponding to wander generation requirement of Figure B.1	248
Figure B.3—PTPDEV limit corresponding to wander generation requirement of Figure B.1	249
Figure B.4—MTIE masks met for maximum endpoint filter bandwidths of Table B.4	251
Figure E.1—Example of CSN backbone in an AVB LAN	260
Figure E.2—Media-dependent and lower entities in CSN nodes	261
Figure E.3—Path types over CSN as IEEE 802.1AS backbone.....	262

Figure E.4—Propagation delay and residence time over a CSN Backbone	262
Figure E.5—CSN node-to-node path delay measurement.....	263
Figure E.6—IEEE 802.1AS Sync Message Propagation over the CSN backbone	265

List of tables

Table 6-1—Primitive data types	15
Table 8-1—Illustration of formation of clockIdentity from EUI-48	31
Table 8-2—Default values for priority1, for the respective media	33
Table 8-3—timeSource enumeration	36
Table 10-1—Port role definitions	68
Table 10-2—Destination address for Announce and Signaling messages	86
Table 10-3—Ethertype for Announce and Signaling messages	86
Table 10-4—PTP message header	88
Table 10-5—Values for messageType field	88
Table 10-6—Values of flag bits	89
Table 10-7—Announce message fields	90
Table 10-8—Path trace TLV	91
Table 10-9—Signaling message fields	92
Table 10-10—Message interval request TLV	93
Table 10-11—Interpretation of special values of linkDelayInterval	94
Table 10-12—Interpretation of special values of timeSyncInterval	94
Table 10-14—Definitions of bits of flags field of message interval request TLV	95
Table 10-13—Interpretation of special values of announceInterval	95
Table 11-1—Destination address for Sync, Follow_Up, Pdelay_Req, Pdelay_Resp, and Pdelay_Resp_Follow_Up messages	123
Table 11-2—Ethertype for Sync, Follow_Up, Pdelay_Req, Pdelay_Resp, and Pdelay_Resp_Follow_Up messages	123
Table 11-4—Values of flag bits	125
Table 11-3—Values for messageType field	125
Table 11-6—References for sequenceId value exceptions	126
Table 11-7—Value of control field	126
Table 11-5—Value of correction field	126
Table 11-8—Sync message fields	127
Table 11-9—Follow_Up message fields	127
Table 11-10—Follow_Up information TLV	128
Table 11-11—Pdelay_Req message fields	129
Table 11-12—Pdelay_Resp message fields	130
Table 11-13—Pdelay_Resp_Follow_Up message fields	130
Table 12-1—Parameters of MLME-TIMINGMSMT.request	139
Table 12-2—Parameters of MLME-TIMINGMSMT.confirm	140
Table 12-3—Parameters of MLME-TIMINGMSMT.indication	143
Table 12-4—Values of the Type field in the VendorSpecific information element	144
Table 13-1—TIMESYNC message fields	150
Table 14-1—Default Parameter Data Set Table	162
Table 14-2—Current Parameter Data Set Table	163
Table 14-3—Parent Parameter Data Set Table	165
Table 14-4—Time Properties Parameter Data Set Table	166
Table 14-5—portRole enumeration	167
Table 14-6—Port Parameter Data Set Table	170
Table 14-7—Port Parameter Statistics Table	173
Table 14-8—Acceptable Master Table Parameter Data Set Table	174
Table 15-1—IEEE8021-AS MIB structure and object cross reference	177
Table B.1—Wander generation TDEV requirement for LocalClock entity	246
Table B.2—ADEV limit corresponding to wander generation requirement of Table B.1	247
Table B.3—PTPDEV limit corresponding to wander generation requirement of Table B.1	248

Table B.4—Maximum endpoint filter bandwidths needed to meet respective MTIE masks and peak-to-peak jitter limits.....	250
Table B.5—Breakpoints for Mask 1	251
Table B.6—Breakpoints for Mask 2	251
Table B.7—Breakpoints for Mask 3	251
Table C.1—Time-scale parameters	253
Table C.2—Time-scale conversions	255
Table D.1—State machine symbols.....	258
Table E.1—CSN TLV	267
Table E.2—Definitions and option selections per link technology	268

IEEE Standard for Local and metropolitan area networks— Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks

IMPORTANT NOTICE: This standard is not intended to ensure safety, security, health, or environmental protection. Implementers of the standard are responsible for determining appropriate safety, security, environmental, and health practices or regulatory requirements.

This IEEE document is made available for use subject to important notices and legal disclaimers. These notices and disclaimers appear in all publications containing this document and may be found under the heading “Important Notice” or “Important Notices and Disclaimers Concerning IEEE Documents.” They can also be obtained on request from IEEE or viewed at <http://standards.ieee.org/IPR/disclaimers.html>.

1. Overview

1.1 Scope

This standard specifies the protocol and procedures used to ensure that the synchronization requirements are met for time-sensitive applications, such as audio and video, across bridged and virtual bridged local area networks consisting of local area network (LAN) media where the transmission delays are fixed and symmetrical; for example, IEEE 802.3™ full-duplex links. 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 802.1D™-2004 and IEEE Std 802.1Q™-2005.¹ Synchronization to an externally provided timing signal (e.g., a recognized timing standard such as UTC or TAI) is not part of this standard but is not precluded.

1.2 Purpose

This standard enables stations attached to bridged LANs to meet the respective jitter, wander, and time synchronization requirements for time-sensitive applications. This includes applications that involve

¹Information on references can be found in Clause 2.

multiple streams delivered to multiple endpoints. To facilitate the widespread use of bridged LANs 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.

2. Normative references

The following referenced documents are indispensable for the application of this standard (i.e., they must be understood and used, so 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 P802.11v™ (D15.0, September 2010), Draft 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—Amendment 8: IEEE 802.11™ Wireless Network Management.²

IEEE Std 802.1D™-2004, IEEE Standard for Local and metropolitan area networks—Media Access Control (MAC) Bridges.^{3, 4}

IEEE Std 802.1Q™- 2005, IEEE Standard for Local and metropolitan area networks—Virtual Bridged Local Area Networks.

IEEE Std 802.1ag™-2007, IEEE Standard for Local and metropolitan area networks—Virtual Bridged Local Area Networks—Amendment 5: Connectivity Fault Management.

IEEE Std 802.3™-2008, IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area network—Specific requirements, Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications.

IEEE Std 802.3av™-2009, IEEE Standard for Information technology—Part 3: Amendment 1: Physical Layer Specifications and Management Parameters for 10 Gb/s Passive Optical Networks.

IEEE Std 802.11™-2007, 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™-2008, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems.

IETF RFC 3410 (December 2002), Introduction and Applicability Statements for Internet Standard Management Framework, Case, J., Mundy, R., Partain, D, and Stewart, B.⁵

ITU-T Recommendation G.9960 (ex. G.hn), Unified high-speed wire-line based home networking transceivers—System architecture and physical layer specification, June 2010.⁶

ITU-T Recommendation G.9961, Data link layer (DLL) for unified high-speed wire-line based home networking transceivers, June 2010.

²IEEE P802.11v/D16 (November 2010) was approved by the IEEE-SA Standards Board on 2 February 2011. It was published as IEEE Std 802.11v-2011 on 9 February 2011 and is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org>).

³IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org>).

⁴The IEEE standards or products referred to in Clause 2 are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

⁵IETF RFCs are available from the Internet Engineering Task Force Web site at <http://www.ietf.org/rfc.html>.

⁶ITU-T publications are available from the International Telecommunications Union, Place des Nations, CH-1211, Geneva 20, Switzerland/Suisse (<http://www.itu.int/>).

ITU-T Recommendation G.984.3, Amendment 2 (2009-11) Gigabit-capable Passive Optical Networks (G-PON): Transmission convergence layer specification—Time-of-day distribution and maintenance updates and clarifications, November 2009.

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

⁷MoCA specifications are available from the Multimedia over Coax Alliance at <http://www.mocalliance.org/specs>.

3. Definitions

For the purposes of this document, the following terms and definitions apply. *The IEEE Standards Dictionary: Glossary of Terms & Definitions* 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 perfect reference clock over an ensemble of measurements.

3.2 Bridge: Either a MAC Bridge, as specified in Clause 5 of IEEE Std 802.1D-2004, or a VLAN-aware Bridge, as specified in Clause 5 of IEEE Std 802.1Q-2005.

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

3.4 direct communication: A communication of IEEE 802.1AS information between two time-aware systems with no intervening time-aware system.

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

NOTE—In this standard, an *end station* is sometimes referred to as a *station*.⁹

3.6 event message: A message that is timestamped on egress from a time-aware system and ingress to a time-aware system.

NOTE—See 8.4.3.

3.7 fractional frequency offset: The fractional frequency offset, y , between a measured clock and a reference clock is defined as:

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

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.

3.8 general message: A message that is not timestamped.

3.9 gPTP communication path: A segment of a generalized precision time protocol (gPTP) domain that enables direct communication between two time-aware systems.

NOTE—See 8.1.

3.10 grandmaster: The time-aware system that contains the best clock, as determined by the best master clock algorithm (BMCA), in the generalized precision time protocol (gPTP) domain.

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

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

⁸The *IEEE Standards Dictionary: Glossary of Terms & Definitions* is available at <http://shop.ieee.org/>.

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

3.13 precision: A measure of the deviation from the mean of the time or frequency error between the clock under test and a perfect reference clock.

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

3.15 recognized standard source of time: A recognized standard time source is a source external to IEEE 1588 precision time protocol (PTP) that provides time that is traceable to the international standards laboratories maintaining clocks that form the basis for the *temps atomique international* (international atomic time) (TAI) and coordinated universal time (UTC) timescales. Examples of these are National Institute of Standards and Technology (NIST) timeservers and global positioning (satellite) system (GPS).

3.16 reference plane: The boundary between a port of a time-aware system and the network physical medium. Timestamp events occur as frames cross this interface.

3.17 residence time: The duration of the time interval between the receipt of a time synchronization event message by a time-aware system, and the sending of the next subsequent time synchronization event message on another port of that time-aware system. The residence time can be different for different ports.

NOTE—If a port of a time-aware system sends a time synchronization event message without having received a time synchronization event message, i.e., if sync receipt timeout occurs (see 10.6.3.1), 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 referred to as a *residence time*.

3.18 stability: A measure of how the mean of the time or frequency error between the clock under test and a perfect reference clock varies with respect to variables such as time, temperature, etc.

3.19 synchronized time: The synchronized time of an event is the time of that event relative to the grandmaster.

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

3.20 synchronized time-aware systems: Two time-aware systems 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.

3.21 syntonized time-aware systems: Two time-aware systems are syntonized if the duration of the second is the same on both, which means the time measured by each advances at the same rate. They can but need not share the same epoch.

3.22 time-aware Bridge: A Bridge that is capable of communicating synchronized time received on one port to other ports, using the IEEE 802.1AS protocol.

3.23 time-aware end station: An end station that is capable of acting as the source of synchronized time on the network, or destination of synchronized time using the IEEE 802.1AS protocol, or both.

3.24 time-aware system: A time-aware Bridge or a time-aware end station.

3.25 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 timestamp on egress and ingress, see 8.4.3.

3.26 traceability: See IEEE Std 1588-2008, 3.1.44.

4. Acronyms and abbreviations

ACK	acknowledgement
ADEV	Allan deviation
AP	(wireless LAN) access point
AV	audio/video
AVB	audio/video bridging
AVB network	audio/video bridged network
BC	boundary clock
BMC	best master clock
BMCA	best master clock algorithm
CSN	coordinated shared network
CTC	channel time clock
EPON	IEEE 802.3 Ethernet passive optical network, as specified in IEEE Std 802.3-2008 and IEEE Std 802.3av-2009
ESS	extended service set
G.hn	ITU-T G.9960 and ITU-T G.9961
GM	grandmaster
GMT	Greenwich mean time
GPS	global positioning (satellite) system
gPTP	generalized precision time protocol
IP	Internet protocol
IS	integration service
ISO	International Organization for Standardization ¹⁰
ISS	Internal Sublayer Service
LAN	local area network
LLC	logical link control
MAC	media access control
MACsec	media access control security
MAN	metropolitan area network
MLME	IEEE 802.11 MAC layer management entity
MPCP	IEEE 802.3 multipoint control protocol
MPDPDU	IEEE 802.3 MPCP data unit
MII	media-independent interface
MD	media-dependent

¹⁰Information available at www.iso.org.

NTP	network time protocol ¹¹
OC	ordinary clock
OLT	IEEE 802.3 optical line terminal
ONU	IEEE 802.3 optical network unit
OSSP	organization-specific slow protocol
P2P	peer-to-peer
PAR	project authorization request
PICS	Protocol Implementation Conformance Statement
PLL	phased-lock loop
POSIX™	portable operating system interface (see ISO/IEC 9945:2003 [B10] ¹²)
PTP	IEEE 1588 precision time protocol
PTPDEV	PTP deviation
RTT	round-trip time
SI	international system of units
SM	state machine
TAI	temps atomique international (international atomic time)
TC	transparent clock
TDEV	time deviation
TDM	time division multiplexing
TDMA	time division multiple access
TG	task group
TS	timestamp
UCT	unconditional transfer
UTC	coordinated universal time
VLAN	virtual local area network
WG	Working Group
WLAN	wireless local area network

¹¹Information available at www.ietf.org/rfc/rfc1305.txt.

¹²The numbers in brackets correspond to those of the bibliography in Annex G.

5. Conformance

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

- a) Compose all or part of the functionality of a system;
- b) Provide, as specified by this standard, one or more instances of the MAC Service to other functional entities whose specification is outside the scope of this standard;
- c) Provide, as specified by this standard, one or more instances of the MAC Internal Sublayer Service (ISS) to other implementations or instances of the same implementation that conform to this standard.

Accordingly, and as detailed in 5.3, this clause specifies conformance requirements for common systems and for functional components within systems, possibly connected to other system components with interfaces that are not otherwise accessible.

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 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 **can not**. The word **allow** is used as a replacement for the cliché “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 Bridge and end station requirements

An implementation of timing and synchronization in Bridges shall:

- a) Conform to the requirements of IEEE Std 802.1Q-2005;
- b) Implement the generalized precision time protocol (gPTP) requirements specified in 8.2, 8.4, 8.5, and 8.6;

- c) Support the media-independent slave clock at least on one port (10.2.12), and on each supported port, implement PortSyncSyncReceive function (10.2.7.3) and ClockSlaveSync function (10.2.12.3);
- d) Support the requirements where no best master is present in the domain (10.2.12.2);
- e) Support the following best master clock algorithm (BMCA) requirements (10.3):
 - 1) Support the Time-aware system attributes and requirements (8.6.2);
 - 2) Implement the BMCA (10.3.2);
 - 3) Implement PortAnnounceReceive function (10.3.10);
 - 4) Implement PortAnnounceInformation function (10.3.11);
 - 5) Implement PortRoleSelection function (10.3.12).
- f) Implement SiteSyncSync function (10.2.6).

5.3.1 Time-aware Bridge and end station options

An implementation of Time-aware Bridge may:

- a) Support the following Grandmaster Capability (8.6.2.1 and 10.1.2):
 - 1) Implement ClockMasterSyncSend function (10.2.8);
 - 2) Implement ClockMasterSyncOffset function (10.2.9);
 - 3) Implement ClockMasterReceive function (10.2.10).
- b) Support the media-independent slave clock on more than one port (10.2.6);
- c) Support the following Media Independent Master Capability on at least one port (10.2.11):
 - 1) Implement PortSyncSyncSend function (10.2.11);
 - 2) Implement PortAnnounceTransmit function (10.3.13);
 - 3) Implement AnnounceIntervalSetting function (10.3.14);
 - 4) Conform to Announce message requirements (10.4.3);
 - 5) Support the Announce sequence number requirements (10.4.7);
 - 6) Support the Announce message PDU requirements (10.5).

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

An implementation of Time-aware Bridges with IEEE 802.3 MAC services to physical ports shall:

- a) Conform to the requirements of IEEE 802.1Q MAC-specific bridging methods;
- b) Support full-duplex operation, as specified in 11.2 and IEEE Std 802.3-2008, 4.2 and Annex 4.

5.5 MAC-specific timing and synchronization methods for IEEE Std 802.11-2007

An implementation of Time-aware Bridges with IEEE 802.11 MAC services to physical ports shall:

- a) Conform to the requirements of IEEE 802.1Q MAC-specific bridging methods;
- b) Conform to the requirements of TIMINGMSMT as specified in IEEE P802.11v (D15.0, September 2010);
- c) Support the requirements as specified in 12.2;
- d) Implement MDSync Message protocol, its message parameters and defaults (12.3).

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

An implementation of Timing-aware Bridges with IEEE 802.3 EPON MAC services to physical ports shall:

- a) Conform to the requirements of IEEE 802.1Q MAC-specific bridging methods;

- b) Support the requirements as specified in IEEE Std 802.3-2008, Multipoint MAC Control (64.2 and 64.3) and Multipoint PCS and PMA extensions (65);
- c) Implement TIMESYNC Message protocol, and its message parameters and defaults (13.3.1);
- d) Implement requester and responder functions (13.8.1 and 13.8.2).

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

An implementation of Timing-aware Bridges with CSN MAC services to physical ports shall:

- a) Conform to the requirements of IEEE 802.1Q MAC-specific bridging methods;
- b) Implement path delay calculation, as specified in E.4;
- c) Implement functionality of MDSyncSendSM and MDSyncReceiveSM state machines (E.3);
- d) Implement CSN specific Grandmaster Capability (E.6.1).

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 6.1 of IEEE Std 802.1ag-2007.

6.3 Data types and on-the-wire formats

6.3.1 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 P802.11v 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.

6.3.2 Primitive data types specifications

All non-primitive data types are derived from the primitive types in Table 6-1. Signed integers are represented in two's 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 $N > 1$
Double	Double precision (64-bit) floating-point value

6.3.3 Derived data type specifications

6.3.3.1 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 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.

6.3.3.2 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 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, respectively.

6.3.3.3 TimeInterval

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

```
struct TimeInterval
{
    Integer64 scaledNanoseconds;
};
```

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.

6.3.3.4 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

6.3.3.5 ExtendedTimestamp

The ExtendTimestamp 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 nanoseconds = 0x0000 0001 0000

6.3.3.6 ClockIdentity

The ClockIdentity type identifies a time-aware system.

```
typedef Octet8 ClockIdentity;
```

6.3.3.7 PortIdentity

The PortIdentity type identifies a port of a time-aware system.

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

6.3.3.8 ClockQuality

The ClockQuality represents the quality of a clock.

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

6.3.4 Protocol data unit (PDU) formats

6.3.4.1 General

The data types defined in 6.3.2 and 6.3.3 shall be mapped onto the wire according to the mapping rules for the respective medium, e.g., IEEE Std 802.3-2008 and IEEE Std 802.11-2007, and the terms of 6.3.4.

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 6.3.2 and 6.3.3. The internal ordering of the fields of the IEEE 802.1AS PDUs is specified in 6.3.4.3 to 6.3.4.5.

6.3.4.2 Numbering of bits within an octet

Bits are numbered with the most significant bit being 8 and the least significant bit being 1.

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.

6.3.4.3 Primitive data types

Numeric primitive data types defined in 6.3.2 shall be formatted with the most significant octet nearest 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.

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.

6.3.4.4 Arrays of primitive types

All arrays shall be formatted with the member having the lowest numerical index closest to the start 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 the start 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 bits 5–8, and one of type Enumeration4 bits 1–4, see 11.4.2 and 10.5.2.

6.3.4.5 Derived data types

Derived data types defined as structs shall be formatted with the first member of the struct closest 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.

7. Time synchronization model for a bridged local area 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 bridged packet-switched LAN. Although this standard is based on the precision time protocol (PTP) described in IEEE Std 1588-2008 (and, indeed, is a proper profile of IEEE Std 1588 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 that document.

7.2 Architecture of a time-aware bridged local area network

A time-aware bridged LAN consists of a number of time-aware systems interconnected by LANs that support the gPTP defined within this standard. A set of time-aware systems that are interconnected by gPTP-capable LANs is called a *gPTP domain*. There are two types of time-aware systems, as follows:

- a) Time-aware end station, which if not grandmaster, is a recipient of time information, and
- b) Time-aware Bridge, which if not grandmaster, receives time information from the grandmaster (perhaps indirectly through other time-aware Bridges), applies corrections to compensate for delays in the LAN and the Bridge 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 (Clause 11)
- d) IEEE 802.3 Ethernet using passive optical network (EPON) links (Clause 13)
- e) IEEE 802.11 wireless (Clause 12)
- f) Generic coordinated shared networks (CSNs, e.g., MoCA and G.hn) (Annex E)

Figure 7-1 illustrates an example time-aware network using all those network technologies, where end stations on several local networks are connected to a grandmaster on a backbone network via an EPON access network.

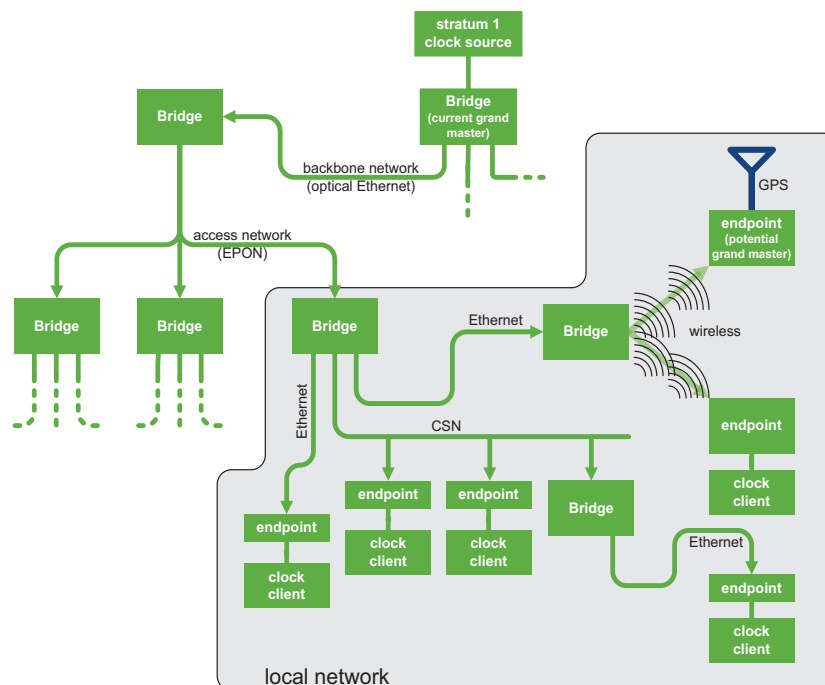


Figure 7-1—Time-aware network example

Any time-aware system with clock sourcing capabilities can be a potential grandmaster, so there is a selection method (the *best master clock algorithm*, or BMCA) that ensures that all of the time-aware systems in a gPTP domain use the same grandmaster.¹³ The BMCA is largely identical to that used in IEEE Std 1588-2008, but somewhat simplified. In Figure 7-1 the BMCA process has resulted in the grandmaster 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 grandmasters on the local network that is at least as “good” as any other. For example, in Figure 7-2, the access network link has failed, so a potential grandmaster that has a GPS reference source has become the active grandmaster, and there are now two gPTP domains where there used to be one.

¹³ There are, however, short periods during network reconfiguration when more than one grandmaster might be active while the BMCA process is taking place.

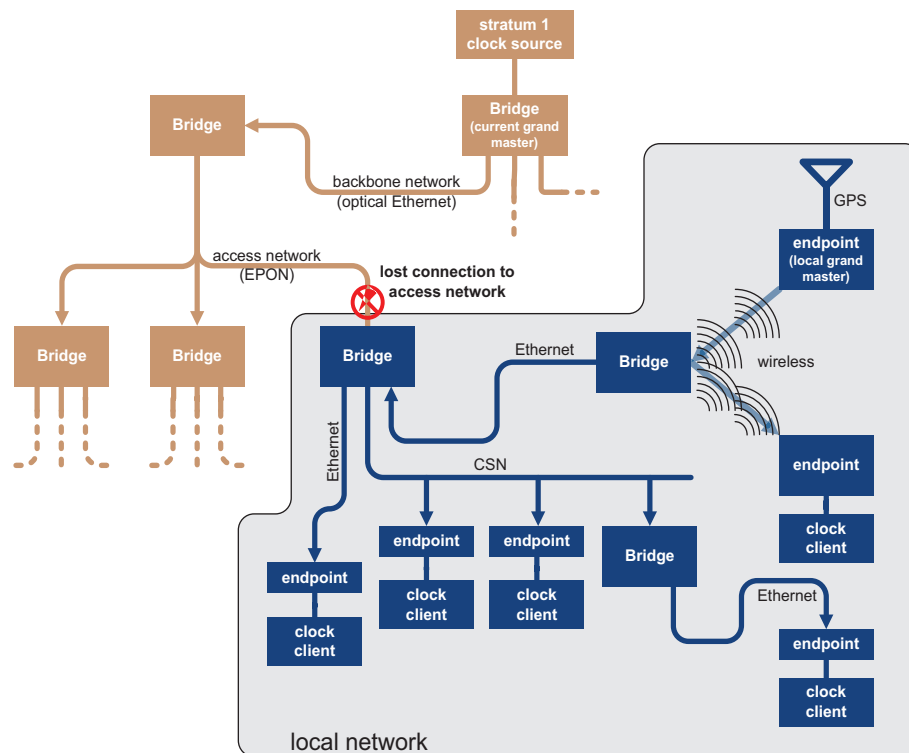


Figure 7-2—Time-aware network of Figure 7-1 after an access network link failure

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 1588-2008: a grandmaster sends information including the current synchronized time to all directly attached time-aware systems. Each of these time-aware systems must correct the received synchronized time by adding the propagation time needed for the information to transit the communication path from the grandmaster. If the time-aware system is a time-aware Bridge, then it must forward the corrected time information (including additional corrections for delays in the forwarding process) to all the other attached time-aware systems.

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 communication path between two time-aware systems. The residence time measurement is local to a Bridge and easy to compute, while the communication path delay is dependent on many things including media-dependent properties and the length of the path.

7.3.2 Delay measurement

Each type of LAN or communication path has different methods for measuring propagation time, but they are all based on the same principal: 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 7-3.

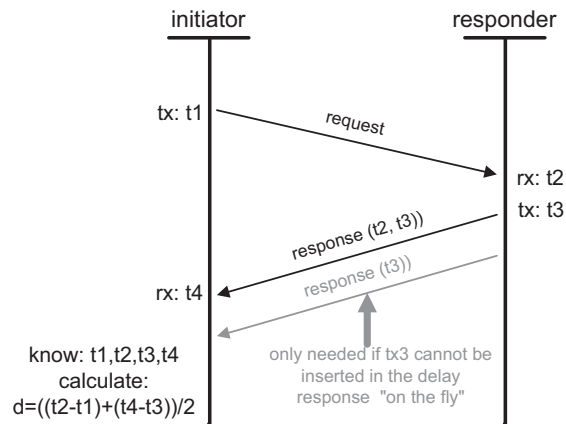


Figure 7-3— Example delay measurement

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 1588-2008, where the messages are called Pdelay_Req, Pdelay_Resp, and Pdelay_Resp_Follow_Up.
- a) IEEE 802.11 wireless LANs use the Timing measurement procedure defined in IEEE P802.11v (D15.0, September 2010), where the messages are the “timing measurement action frame” and its corresponding “ACK.”
- a) EPON LANs use the discovery process, where the messages are “GATE” and “REGISTER_REQ.”
- a) 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 and EPON).

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, then all the time interval measurements use the same time base. Since actually adjusting the frequency of an oscillator (e.g., using a PLL) is slow and prone to gain peaking effects, time-aware Bridges can correct time interval measurements using the grandmaster frequency ratio.

Each time-aware system measures, at each port, the ratio of the frequency of the time-aware system at the other end of the link attached to that port to the frequency of its own clock. The cumulative ratio of the grandmaster frequency to the local clock frequency is accumulated in a standard organizational type, length, value (TLV) attached to the Follow_Up message. The frequency ratio of the grandmaster 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 frequency ratio is measured by accumulating neighbor frequency ratios for two main reasons. First, if there is a network reconfiguration and a new grandmaster 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 being known when the first Follow_Up message is received, which reduces the duration of any transient 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 node, and resulting residence time error, does not directly affect the frequency offset at a downstream node.

7.3.4 Grandmaster (best master) selection and network establishment

All time-aware systems participate in best master selection so that the IEEE 802.1AS protocol can determine the synchronization spanning tree. This synchronization spanning tree may be different from the forwarding spanning tree determined by IEEE 802.1D and IEEE 802.1Q Rapid Spanning Tree Protocol (RSTP) since the spanning tree determined by RSTP can be suboptimal, or even inadequate for synchronization.

gPTP requires that all Bridges and end-stations in the gPTP domain be time-aware-systems, i.e., the protocol does not transfer timing over “ordinary Bridges” (those that meet the requirements of IEEE Std 802.1D-2004 or IEEE Std 802.1Q-2005, but do NOT meet the requirements of this standard). A time-aware system uses the peer delay mechanism on each port to determine if an “ordinary Bridge” is at the other end of the link or in 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 an “ordinary Bridge” or end-to-end TC (see IEEE Std 1588-2008) is present. In this case, the link attached to the port is deemed not capable of running gPTP, and BMCA ignores it. However, the port continues to attempt the measurement of propagation delay using the peer delay mechanism (for full-duplex IEEE 802.3 links), MPCP messages (for EPON), or IEEE P802.11v messages (for IEEE 802.11 links), and periodically checks whether the link is or is not capable of running IEEE 802.1AS.

7.3.5 Energy efficiency

Sending PTP messages at relatively high rates when there is otherwise little or no traffic is counter to the goal of reducing energy consumption. This standard specifies a way to request that a neighbor port reduce the rate of sending Sync (and Follow_Up), 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.

7.4 Time-aware system architecture

The model of a time-aware system is shown in Figure 7-4.

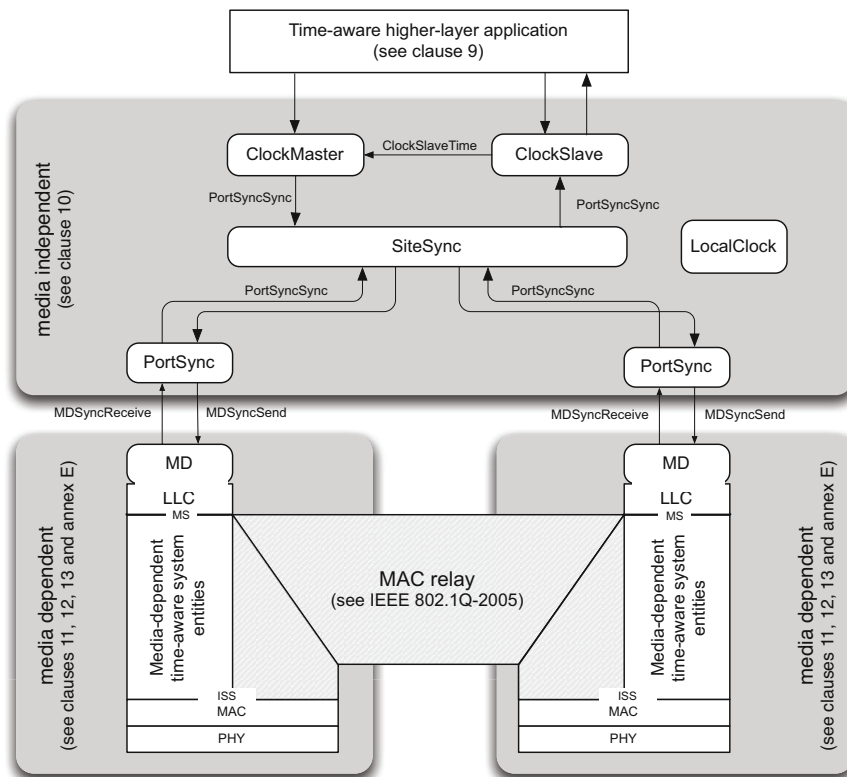


Figure 7-4—Time-aware system model

A time-aware system consists of the following major parts:

- If the time-aware system 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.
- 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 entity, while the computation of port-specific delays needed for time synchronization correction is done by the PortSync entities.
- 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.

In the case of full-duplex Ethernet ports, IEEE 1588 Sync and Follow_Up messages are used, with an additional TLV in the Follow_up used for communication of rate ratio and information on phase and frequency change when there is a change in grandmaster. The path delay is measured using the two-step IEEE 1588 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” [as defined in IEEE P802.11v (D15.0, September 2010)], which also sends everything that would be included in the Follow_up message for full-duplex Ethernet. The 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 Ethernet full-duplex, as is defined in Annex E.

7.5 Differences between gPTP and PTP

- a) gPTP assumes all communication between time-aware systems is done only using IEEE 802 MAC PDUs and addressing, while IEEE 1588 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. The information exchanged between time-aware systems has been generalized to support different packet formats and management schemes appropriate to the particular networking technology. IEEE 1588, on the other hand, is fully specified only for IP version 4, IP version 6, Ethernet LANs, and several industrial automation control protocols.
- c) In gPTP there are only two types of time-aware systems: end stations and Bridges, while IEEE 1588 has ordinary clocks, boundary clocks, end-to-end transparent clocks, and P2P transparent clocks. A time-aware end station corresponds to an IEEE 1588 ordinary clock, and a time-aware Bridge is a type of IEEE 1588 boundary clock where its operation is very tightly defined, so much so that a time-aware Bridge 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. A time-aware system measures link delay and residence time, and communicates these in a correction field.
- d) Time-aware systems only communicate gPTP information directly with other time-aware systems. That is, a gPTP domain consists ONLY of time-aware systems. Non-time-aware Bridges cannot be used to relay gPTP information. In IEEE 1588 it is possible to use non-IEEE-1588-aware Bridges 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 Ethernet full-duplex links, gPTP requires the use of the peer delay mechanism, while IEEE 1588 also allows the use of end-to-end delay measurement.
- f) For Ethernet full-duplex links, gPTP requires the use of two-step processing (use of Follow_Up and Pdelay_Resp_Follow_Up messages to communicate timestamps), while IEEE 1588 allows one-step processing (embedding timestamps in messages “on the fly” as they are being transmitted).
- g) In steady state, there is only a single active grandmaster in a time-aware network. That is, there is only a single gPTP domain, whereas IEEE 1588 allows multiple overlapping timing domains.
- h) All time-aware systems in a gPTP domain are logically syntonized, meaning that 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 1588 is optional, and the method used is not as direct and takes longer to converge.
- i) The BMCA used in gPTP is the same as that used in IEEE 1588 with the following exceptions: (1) Announce messages received on a slave port that were not sent by the receiving time-aware system are used immediately, i.e., there is no foreign-master qualification, (2) a port that the BMCA determines should be a master port enters the master state immediately, i.e., there is no pre-master state, (3) the uncalibrated state is not needed and, therefore, not used, and (4) all time-aware systems are required to participate in best master selection (even if it is not grandmaster capable).
- j) Finally, this standard includes formal interface definitions for the time-aware applications. (See Clause 9.) IEEE Std 1588-2008 does not define how an application provides or obtains time information.

8. IEEE 802.1AS concepts and terminology

8.1 gPTP domain

A gPTP domain, hereafter referred to as simply a *domain*, consists of one or more time-aware systems 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.

The domain number of a gPTP domain shall be 0.

NOTE—In steady state, all time-aware systems in a gPTP domain are traceable to a single grandmaster.

8.2 Timescale

8.2.1 Introduction

The timescale for a gPTP domain, referred to as the *PTP timescale*, is established by the grandmaster. The IEEE 802.1AS timescale is continuous and can be traceable to TAI. The value of the second is the international second, SI, within the accuracy supported by the gPTP domain. The epoch is the PTP epoch (see 8.2.2).

8.2.2 Epoch

The epoch is the origin of the timescale of a gPTP domain.

The PTP epoch is 1 January 1970 00:00:00 TAI, which is 31 December 1969 23:59:51.999918 UTC.

NOTE—The PTP epoch is set such that a direct application of the POSIX algorithm to a PTP time-scale timestamp yields the ISO 8601:2004 [B8] printed representation of TAI.

See Annex C for information on converting between common timescales.

8.2.3 UTC Offset

It is possible to calculate UTC time using the `currentUtcOffset` field value of the time properties data set, if the time source is traceable to TAI and the `currentUtcOffset` field is valid. The value of `currentUtcOffset` shall be: $\text{currentUtcOffset} = \text{TAI} - \text{UTC}$, where TAI is the TAI time and UTC is the UTC time.

NOTE—As of 0 hours 1 January 2009 UTC, UTC was behind TAI by 34 s, i.e., $\text{TAI} - \text{UTC} = +34$ s. At that moment the IEEE 802.1AS defined value of `currentUtcOffset` became +34 s (see *Service de la Rotation Terrestre* [B17] and U.S. Naval Observatory [B19]).

It is possible to calculate local time from the time provided by a gPTP domain using the `currentUtcOffset` field value of the time properties data set and knowledge of the local time zone and whether and when daylight savings time is observed.

8.2.4 Measurement of time within a gPTP domain

Time in a gPTP domain shall be measured as elapsed time since the PTP epoch.

8.3 Communication path asymmetry

This standard requires the measurement of the mean propagation time (also referred to as the *mean propagation delay*) between the two endpoint time-aware systems of a link. The measurement is performed by one of the time-aware systems, the initiator time-aware system, sending a message to the other time-aware system, the responder time-aware system. The responder then sends a message back to the initiator at a later time. The departure of the message sent by the initiator time-aware system is timestamped, and the timestamp value is retained by that system. The arrival of this message at the responder time-aware system is timestamped; the timestamp value is conveyed to the initiator time-aware system in a subsequent message. The departure of the response message sent by the responder time-aware system (in response to the message it receives from the initiator time-aware system) is timestamped, and the timestamp value is conveyed to the initiator time-aware system in a subsequent message. The arrival of this response message at the initiator time-aware system is timestamped, and the timestamp value is retained by that system. The mean propagation time is computed by the initiator time-aware system after receiving the response message, from the four timestamp values it has at this point.

Typically, the propagation time is not exactly the same in both directions, and the degree to which it differs in the two directions is characterized by the delay asymmetry. The relation between the individual propagation times in the two directions, the mean propagation time, and the delay asymmetry is as follows. Let t_{ir} be the propagation time from the initiator to the responder, t_{ri} be the propagation time from the responder to the initiator, meanPathDelay be the mean propagation time, and delayAsymmetry be the delay asymmetry. The propagation times in the two directions are illustrated in Figure 8-1.

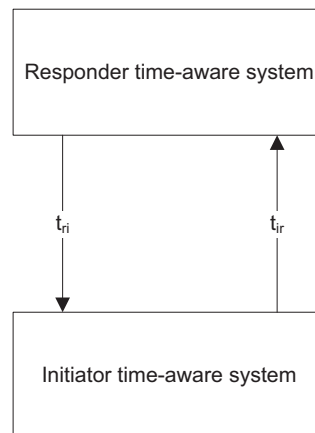


Figure 8-1—Propagation asymmetry

The meanPathDelay is the mean value of t_{ir} and t_{ri} , i.e., $\text{meanPathDelay} = (t_{ir} + t_{ri})/2$. The delayAsymmetry is defined as

$t_{ir} = \text{meanPathDelay} - \text{delayAsymmetry}$, and

$t_{ri} = \text{meanPathDelay} + \text{delayAsymmetry}$.

In other words, delayAsymmetry is defined to be positive when the responder to initiator propagation time is longer than the initiator to responder propagation time.

This standard does not explicitly require the measurement of delayAsymmetry ; however, if delayAsymmetry is modeled, it shall be modeled as specified in this clause.

NOTE—A time-aware system can change the value of delayAsymmetry during operation using methods not specified in this standard.

8.4 Messages

8.4.1 General

All communications occur via PTP messages and/or media-specific messages.

8.4.2 Message attributes

8.4.2.1 General

All messages used in this standard have the following attributes:

- a) Message class
- b) Message type

The message class attribute is defined in this clause. The message type attribute is defined in 3.12. Some messages have additional attributes; these are defined in the subclauses where the respective messages are defined.

8.4.2.2 Message class

There are two message classes, the event message class and the general message class. Event messages are timestamped on egress from a time-aware system and ingress to a time-aware system. General messages are not timestamped. Every message is either an event message or a general message.

8.4.3 Generation of event message timestamps

All event messages are timestamped on egress and ingress. The timestamp shall be the time, relative to the LocalClock entity (see 10.1) at which the message timestamp point passes the reference plane marking the boundary between the time-aware system and the network media.

The definition of the timestamp measurement plane (see 3.22), along with the corrections defined as follows, allows transmission delays to be measured in such a way (at such a low layer) that they appear fixed and symmetrical to gPTP even though the MAC client might otherwise observe substantial asymmetry and transmission variation. For example, the timestamp measurement plane is located below any retransmission and queuing performed by the MAC.

NOTE 1—If an implementation generates event message timestamps using a point other than the message timestamp point, then the generated timestamps should be appropriately corrected by the time interval (fixed or otherwise) between the actual time of detection and the time the message timestamp point passed the reference plane. Failure to make these corrections results in a time offset between time-aware systems.

NOTE 2—In general, the timestamps may be generated at a timestamp measurement plane that is removed from the reference plane. Furthermore, the timestamp measurement plane, and therefore the time offset of this plane from the reference plane, is likely to be different for inbound and outbound event messages. To meet the requirement of this clause, the generated timestamps should be corrected for these offsets. Figure 8-2 illustrates these offsets. Based on this model the appropriate corrections are as follows:

$$\langle \text{egressTimestamp} \rangle = \langle \text{egressMeasuredTimestamp} \rangle + \text{egressLatency}$$

$$\langle \text{ingressTimestamp} \rangle = \langle \text{ingressMeasuredTimestamp} \rangle - \text{ingressLatency}$$

where the timestamps relative to the reference plane, $\langle \text{egressTimestamp} \rangle$ and $\langle \text{ingressTimestamp} \rangle$, are computed from the timestamps relative to the timestamp measurement plane, $\langle \text{egressMeasuredTimestamp} \rangle$ and $\langle \text{ingressMeasuredTimestamp} \rangle$, respectively, using their respective latencies, egressLatency and ingressLatency . Failure to make these corrections results in a time offset between the slave and master clocks.

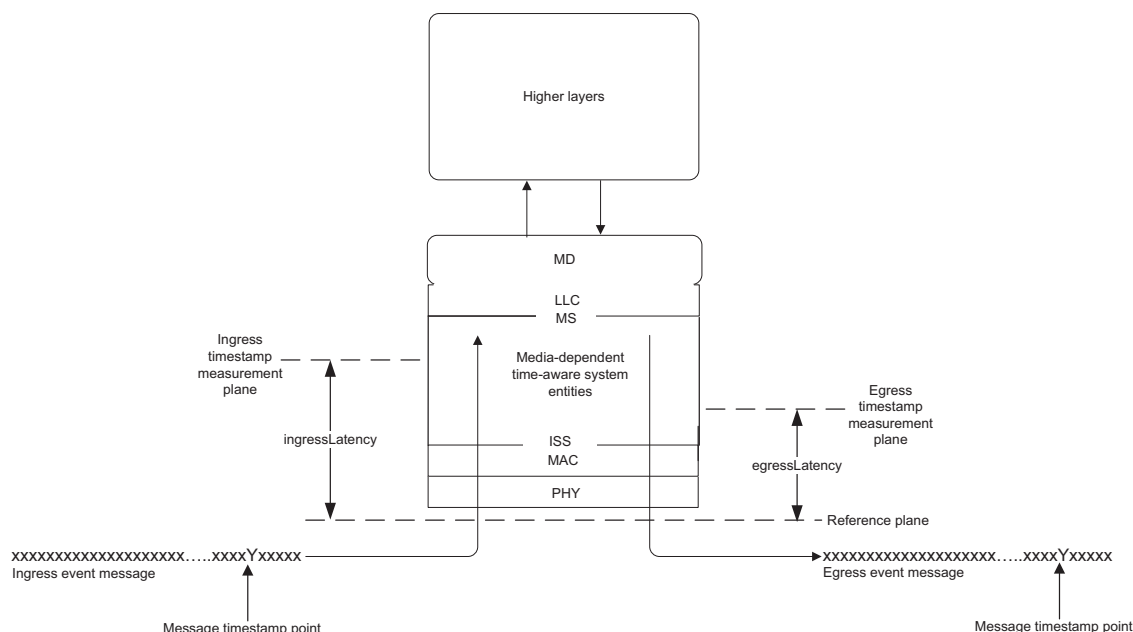


Figure 8-2—Definition of message timestamp point, reference plane, timestamp measurement plane, and latency constants

8.4.4 Priorities

The ISS priority for frames carrying IEEE 802.1AS messages shall be 6.

NOTE—Frames carrying IEEE 802.1AS messages are neither VLAN-tagged nor priority-tagged, i.e., they are untagged, see 11.3.3.

8.5 Ports

8.5.1 General

The time-aware systems in a gPTP domain interface with the network media via physical ports. gPTP defines a logical port in such a way that communication between time-aware systems is point-to-point even over physical ports that are attached to shared media. One logical port, consisting of one PortSync entity and one MD entity, is instantiated for each time-aware system with which the time-aware system communicates. In the case of shared media, multiple logical ports can be associated with a single physical port.

Unless otherwise qualified, each instance of the term *port* refers to a *logical port*.

8.5.2 Port identity

8.5.2.1 General

A port is identified by a port identity of type PortIdentity, see 6.3.3.7. The value is maintained in the portIdentity member of the port parameter data set, see 14.6.2. A port identity consists of the following two attributes:

- a) portIdentity.clockIdentity
- b) portIdentity.portNumber

8.5.2.2 clockIdentity

8.5.2.2.1 General

The clockIdentity is an 8-octet array formed by mapping an IEEE EUI-48 assigned to the time-aware system to IEEE EUI-64 format (i.e., to an array of 8 octets). The EUI-48 shall be an Ethernet MAC address owned by the organization creating the instance of a clockIdentity under the terms of this subclause. The organization owning the MAC address shall ensure that the MAC address is used in generating only a single instance of a clockIdentity, for example by requiring that the MAC address be a MAC address embedded in the device identified by the clockIdentity. The mapping rules for constructing the EUI-64 from the EUI-48 shall be those specified by the IEEE (see [B2]). The 8 octets of the created IEEE EUI-64 shall be assigned in order to the 8-octet array clockIdentity with most significant octet of the IEEE EUI-64 assigned to the clockIdentity octet array member with index 0.

NOTE 1—When using an EUI-48, the first 3 octets, i.e., the OUI portion, of the IEEE EUI-48 are assigned in order to the first 3 octets of the clockIdentity with most significant octet of the IEEE EUI-64, i.e., the most significant octet of the OUI portion, assigned to the clockIdentity octet array member with index 0. Octets with index 3 and 4 have hex values 0xFF and 0xFE respectively. The remaining 3 octets of the IEEE EUI-48 are assigned in order to the last 3 octets of the clockIdentity (see [B2]).

NOTE 2—The least and next to least significant bits of the most significant octet of the OUI indicate respectively: whether the address is an individual or group address, and whether the address is administered universally by the IEEE or locally.

NOTE 3—The clockIdentity is used by this standard as a unique identifier and not as a network address.

NOTE 4—Informative example (see [B2]): The OUI for Company X is 0xACDE48. If Company X wished to use an EUI-48 assigned number of 0xACDE48234567 as part of the clockIdentity, the resulting clockIdentity would be: 0xACDE48FFFE234567, where the 3 octet array 0x234567 would be ensured by Company X to be unique among all Company X assigned EUI-48 numbers. The byte and bit representations are illustrated in Table 8-1, see [B2].

Table 8-1—Illustration of formation of clockIdentity from EUI-48

OUI			EUI-48 assigned values		extension identifier		
octet[0] (most sig- nificant) octet[1]		octet[2]	octet[3]	octet[4]	octet[5]	octet[6]	octet[7] (least sig- nificant)
0xAC	0xDE	0x48	0xFF	0xFE	0x23	0x45	0x67
10101100 (leftmost 1 is most sig- nificant)	11011110b	01001000b	11111111b	11111110b	00100011b	01000101b	01100111b (rightmost 1 is least significant)

8.5.2.2.2 Reserved clockIdentity value

The clockIdentity value consisting of all ones shall be reserved for designating all clocks in the gPTP domain.

8.5.2.3 Port number

The portNumber value for a port on a time-aware end station (i.e., a time-aware system supporting a single port) shall be 1. The portNumber values for the ports on a time-aware Bridge supporting N ports shall be 1, 2, ..., N , respectively.

8.5.2.4 Ordering of clockIdentity and portIdentity values

Two clockIdentity values X and Y are compared as follows. Let x be the unsigned integer formed by concatenating octets 0 through 7 of X such that octet $j+1$ follows octet j (i.e., is less significant than octet j) in x ($j = 0, 1, \dots, 7$). Let y be the unsigned integer formed by concatenating octets 0 through 7 of Y such that octet $j+1$ follows octet j (i.e., is less significant than octet j) in y ($j = 0, 1, \dots, 7$). Then

- a) $X = Y$ if and only if $x = y$,
- b) $X > Y$ if and only if $x > y$, and
- c) $X < Y$ if and only if $x < y$.

Two portIdentity values A and B with members clockIdentity and portNumber are compared as follows. Let a be the unsigned integer formed by concatenating octets 0 through 7 of A .clockIdentity, such that octet $j+1$ follows octet j (i.e., is less significant than octet j) in a ($j = 0, 1, \dots, 7$), followed by octet 0 of A .portNumber, followed by octet 1 of A .portNumber. Let b be the unsigned integer formed by concatenating octets 0 through 7 of B .clockIdentity, such that octet $j+1$ follows octet j (i.e., is less significant than octet j) in b ($j = 0, 1, \dots, 7$), followed by octet 0 of B .portNumber, followed by octet 1 of B .portNumber. Then

- d) $A = B$ if and only if $a = b$,
- e) $A > B$ if and only if $a > b$, and
- f) $A < B$ if and only if $a < b$.

A portIdentity A with members clockIdentity and portNumber and a clockIdentity B are compared as follows. The unsigned integer a is formed from portIdentity A as described above. The unsigned integer b is formed by first forming a portIdentity B' whose clockIdentity is B and portNumber is 0. b is then formed from B' as described above. A and B are then compared as described in items d) through f) above.

8.6 Time-aware system characterization

8.6.1 Time-aware system type

There are two types of time-aware systems used in a gPTP domain, as follows:

- a) time-aware end station
- b) time-aware Bridge

All time-aware systems are identified by clockIdentity.

In addition, time-aware systems are characterized by the following attributes:

- c) priority1
- d) clockClass