IEC/IEEE 60802 Profile Contribution

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Abstract

This document includes a contribution to the IEC/IEEE 60802 joint project for specifying the TSN Profile for Industrial Automation (TSN-IA). The contribution is intended to assist the specification process on IEC/IEEE 60802.

The contribution is based on:

[1] “Industrial Use Cases”, IEC/IEEE JWG Contributor group:
http://www.ieee802.org/1/files/public/docs2018/60802-industrial-use-cases-0618-v07.pdf

[2] “Requirements IEC/IEEE 60802”, IEC/IEEE JWG:
http://www.ieee802.org/1/files/public/docs2018/60802-industrial-requirements-0918-v06.pdf

Log

V0.1	2018-09-03	Initial version
V0.2	2018-09-20	with Oslo interim comments

All the essential information that TC/SC officers, WG and MT convenors, Project Team leaders and experts will need to understand their roles and responsibilities in the standards development process along with supporting material are given here: http://www.iec.ch/standardsdev/resources/?ref=menu

ISO/IEC Directives Part 2 and the document template are publicly available in the IEC web sites:
http://www.iec.ch/members_experts/refdocs/iec/isoiecdir2%7Bed8.0.RLV%7Den.pdf
http://www.iec.ch/standardsdev/resources/draftingpublications/writing_formatting/IEC_template/

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Time-sensitive networking profile for industrial automation

1 Scope

This International Standard IEC/IEEE 60802 defines time-sensitive networking profiles for industrial automation. The profiles select features, options, configurations, defaults, protocols and procedures of bridges, end stations, and LANs to build industrial automation networks.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEEE P802.1AS-Rev/D7.0, August 2, 2018 – *IEEE Draft standard for Local and metropolitan area networks – Timing and Synchronization for Time-Sensitive Applications*

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

IEEE 802.1AE™-2006, *IEEE Standard for Local and metropolitan area networks – Media Access Control (MAC) Security*

IEEE 802.1AEbn™–2011, *IEEE Standard for Local and metropolitan area networks – Media Access Control (MAC) Security Amendment 1: Galois Counter Mode—Advanced Encryption Standard—256 (GCM-AES-256) Cipher Suite*

IEEE 802.1AEbw™–2013, *IEEE Standard for Local and metropolitan area networks* – Media Access Control (MAC) Security Amendment 2: Extended Packet Numbering

IEEE P802.1AEcg/D1.5, October 25, 2016[1], *IEEE Draft Standard for Local and metropolitan area networks—Media Access Control (MAC) Security Amendment 3: Ethernet Data Encryption devices*

IEEE 802.1AR™-2009, *IEEE Standard for Local and metropolitan area networks – Secure Device Identity*

IEEE 802.1Q™-2014, *IEEE Standard for Local and metropolitan area networks – Media Access Control (MAC) Bridges and Virtual Bridged Local Area Networks,* available at <http://www.IEEEorg>

IEEE P802.1Qcc/ D1.1, September 1, 2016, *IEEE Standard for Local and Metropolitan Area Networks—Bridges and Bridged Networks Amendment: Stream Reservation Protocol (SRP) Enhancements and Performance Improvements*

IEEE 802.1Qch™-2017, *IEEE Standard for Local and Metropolitan Area Networks—Bridges and Bridged Networks—Amendment: Cyclic Queuing and Forwarding*

IEEE 802.1Qci™-2017, *IEEE Standard for Local and Metropolitan Area Networks—Bridges and Bridged Networks—Amendment: Per Stream Filtering and Policing*

IEEE 802.1CB™-2017, *IEEE Standard for Local and metropolitan area networks—Frame Replication and Elimination for Reliability*

IEEE P802.1CS/ D0.0, *IEEE Standard for Local and metropolitan area networks—LRP (Registration)*

IEEE P802.1Qcj/D0.1 March 7, 2016, *IEEE Standard for Local and Metropolitan Area Networks— Bridges and Bridged Networks—Automatic Attachment to Provider Backbone Bridging (PBB) services*

IEEE P802.1Qcp/ D0.7 December 12, 2016, *IEEE Standard for Local and Metropolitan Area Networks—Bridges and Bridged Networks—Amendment: YANG Data Model*

IEEE P 802.1Qcr/D0.2, October 20, 2017, *IEEE Standard for Local and Metropolitan Area Networks—Bridges and Bridged Networks—Amendment: Asynchronous Traffic Shaping*

IEEE 802.1X-2010, *IEEE Standard for Local and Metropolitan Area Networks—Port-based Network Access Control,* available at <http://www.IEEEorg>

IEEE 802.3-2015, *IEEE Standard for Ethernet,* available at <http://www.IEEEorg>

IEEE 802.3bp™-2016, *IEEE Standard for Ethernet - Amendment 4: Physical Layer Specifications and Management Parameters for 1 Gb/s Operation over a Single Twisted-Pair Copper Cable*

IEEE 802.3br™-2016, *IEEE Standard for Ethernet - Amendment 5: Specification and Management Parameters for Interspersing Express Traffic*

IEEE 802.3bu™-2016, *IEEE Standard for Ethernet – Amendment #: Physical Layer and Management Parameters for Power over Data Lines (PoDL) of Single Balanced Twisted-Pair Ethernet*

IEEE P802.3bv™/D3.3, 12th December 2016, *IEEE Standard for Ethernet – Amendment 9: Physical Layer Specifications and Management Parameters for 1000 Mb/s Operation Over Plastic Optical Fiber*

IEEE P802.3cg, IEEE Standard for Ethernet – Amendment: Physical Layer Specifications and Management Parameters for 10 Mb/s Operation over Single Balanced Twisted-pair Cabling and Associated Power Delivery

3 Terms, definitions, symbols, conventions and abbreviated terms

For the purposes of this document, the terms and definitions given in IEC 61784-2, IEEE 802, IEEE 802.3, IEEE 802.1Q and IEEE 802.1AS and the following apply.

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

3.1 TSN-IA defined Terms

…

3.2 List of terms and definitions given in IEC 61784-2, IEEE 802, IEEE 802.3, IEEE 802.1Q and IEEE 802.1AS

For ease of understanding the most important terms used within this profile document are listed but not repeated.

Table 1 – List of terms

Term	Source

3.3 Abbreviated terms and acronyms

IA industrial automation

PCS Profile Conformance Statement

3.4 Conventions

3.4.1 Conventions for (sub)clause selections of referenced documents

(Sub)clause selections of referenced documents are done in tables, as shown in Table 2 and Table 3. The selected base specifications are indicated just before the selection table(s) or in the table title. Selections are done at the highest (sub)clause level possible to define the profile selection unambiguously.

Table 2 – Layout of profile (sub)clause selection tables

Clause	Header	Presence	Constraints

Table 3 – Contents of (sub)clause selection tables

Column	Text	Meaning
Clause	<#> Next clauses Next Annexes	(Sub)clause number of the base specifications any following clauses up to the last clause of the base specification any following annexes up to the last annex of the base specification
Header	<text>	(Sub)clause title of the base specifications
Presence	NO	This (sub)clause is not included in the profile
	YES	This (sub)clause is fully (100 %) included in the profile in this case no further detail is given
	—	Presence is defined in the following (sub)clauses
	Partial	Parts of this (sub)clause are included in the profile
	Optional	This (sub)clause may be additionally included in the profile
Constraints	See <#>	Constraints/remarks are defined in the given (sub)clause, table or figure of this profile document
	—	No constraints other than given in the reference document (sub)clause, or not applicable
	<text>	The text defines the constraint directly; for longer text table footnotes or table notes may be used

If sequences of (sub)clauses match or do not match the profile, then the numbers are concatenated.

EXAMPLE Concatenated (sub)clauses

1 – 6	—	YES	—
7 – 11	—	NO	—

Conventions for different cases in selection tables, which apply for multiple or different device types (end-station, bridge):

1. Presence column value YES and NO Constraints given: This (sub)clause is fully (100 %) included in the profile for all device types

2. Presence column value YES and some Constraints given: the constraints can limit the applicability to a device type
3. Presence column value PARTIAL and general Constraints without device type constraints given: the constraints can limit the applicability to all device types
4. Presence column value PARTIAL and general Constraints with device type constraints given: the constraints limit the applicability to a device types
5. Presence column value NO and no Constraints given: This (sub)clause is not included in the profile for all device types
6. Subclauses, which are dedicated to a specific device type, do not need to repeat the device type applicability in the Constraints column.

Table 4 shows an example of a selection table that apply for multiple device types (end-station, bridge). The Clause numbers used in Table 4 corresponds to the list numbers above.

Table 4 – Example of a selection table that apply for multiple device types

Clause	Header	Presence	Constraints
1	Xyz	YES	–
2	Xyz	YES	Applicable to device type end-station only
3	Media Access Control (MAC) frame and packet specifications	PARTIAL	The option xyz does not apply
4	Xyz	PARTIAL	The option xyz does not apply Applicable to device type end-station only
5	Xyz	NO	-
6	End-station behavior	YES	-

3.4.2 Convention for Capitalizations

Capitalized terms are either based on the rules given in the ISO/IEC Directives Part 2 or emphasize that these terms have a specific meaning throughout this document.

The following capitalized terms are used:

– Bridge
– Ethernet
– Internet
– Universal Time
– Working Clock

Parameter names are capitalized for example

– MinimumFrameMemory
– NetworkCycleTime
– NetworkCycle
– Phase
– ReductionRatio
– Sequence.

4 Overview of TSN in Industrial Automation

4.1 Control Loop Basic Model

4.1.1 Basic Model

TBD: Add some text about: Controller, Device, integrated Bridges

Control loops are fundamental building blocks of industrial automation systems. Control loops include: process sensors, a controller function, and output signals. Control loops may require guaranteed low latency or more relaxed bounded latency network transfer quality.

To achieve the needed quality for Control loops the roundtrip delay of the exchanged data is essential.

Figure 1 shows the whole transmission path from Controller application to Device application(s) and back. The blue and red arrows show the contributions to the e2e (end-to-end) latency respectively.

Figure 1 Table 5 and show three levels of a control loop:

- Application - within End Station,
- Network Access - within End Station,
- Network / Bridges - within Bridges.

Applications may or may not be synchronized to the Network Access depending on the application requirements. Applications which are synchronized to Network Access are called “isochronous applications”. Applications which are not synchronized to Network Access are called “non-isochronous applications”.

Network Access is synchronized to a common working clock or to a local timescale[WL(TS1].

Network / Bridges may or may not be synchronized to a common working clock depending on whether the Enhancements for Scheduled Traffic (IEEE 802.1Q-2018) are applied.

Figure 1 – Principle data flow of control loop

Transfer Times contain PHY and MAC delays. Both delays are asymmetric and vendor specific. Device vendors should take into account these transfer times when their application cycle models are designed (see Figure 1).

Table 5 – Application types

<table>
<tr><th>Level</th><th colspan="2">Isochronous Application</th><th colspan="3">Non-isochronous Application</th></tr>
<tr><td>Application</td><td colspan="2">Synchronized to network access</td><td colspan="3">Synchronized to local timescale</td></tr>
<tr><td>Network access</td><td colspan="4">Synchronized to working clock,
Stream Class based scheduling, Preemption</td><td>Synchronized to local timescale,
Stream Class based scheduling, Preemption</td></tr>
<tr><td rowspan="2">Network/Bridges</td><td>Synchronized to working clock</td><td>Free running</td><td>Synchronized to working clock</td><td>Free running</td><td>Free running</td></tr>
<tr><td>Scheduled traffic + Strict Priority + Preemption</td><td>Strict Priority or other Shaper + Preemption</td><td>Scheduled traffic + Strict Priority + Preemption</td><td>Strict Priority or other Shaper + Preemption</td><td>Strict Priority or other Shaper + Preemption</td></tr>
</table>

4.1.2 Quantities

Editor Note: Proposals:

- **move this clause to normative Annex A;**
- **define the relevant normative parameters there;**
- **giving quantities is mandatory for conformance;**
- **define the required quantities for a limited set of different classes (optional);**
- **allow "wildcard" numbers for the defined parameters.**
- **Align terminology (talker/producer, network diameter)**

The following quantities shall be supported in a single TSN domain:

- Stations: >= 1024
- Network diameter: >= 64
- Streams per PLC for Controller-to-Device (C2D) communication:
  - >= 512 talker and >= 512 listener streams;
    >= 1024 talker and >= 1024 listener streams in case of seamless redundancy;
- Streams per PLC for Controller-to-Controller (C2C) communication:
  - >= 64 talker and >= 64 listener streams;
    >= 128 talker and >= 128 listener streams in case of seamless redundancy.
- Streams per Device for Device-to-Device (D2D) communication:
  - >= 2 talker and >= 2 listener streams;
    >= 4 talker and >= 4 listener streams in case of seamless redundancy.

Example calculation of data flow quantities for eight PLCs – without seamless redundancy:

- 8 x 512 x 2 = 8192 streams for C2D communication, plus
- 8 x 64 x 2 = 1024 streams for C2C communication
- (8192 + 1024) * 2000 = 18432000 Bytes data of all streams

5 Conformance

5.1 General

A claim of conformance to this document is a claim that the behavior of an implementation of a bridge or of an end station meets the mandatory requirements of this document and may support options identified in this document.

~~3.5~~5.2 Conformance test concept

This document specifies the general methodology of a conformance test for a TSN-IA device. Conformance test implementation and conformance test execution are not defined in this document. The concept of this conformance test is to verify the capabilities of the device under test (DUT) against this document. The conformance test shall assure the interoperability of devices which claim conformance with this profile.

Figure 2 gives an overview of the conformance test related to the definitions of this document.

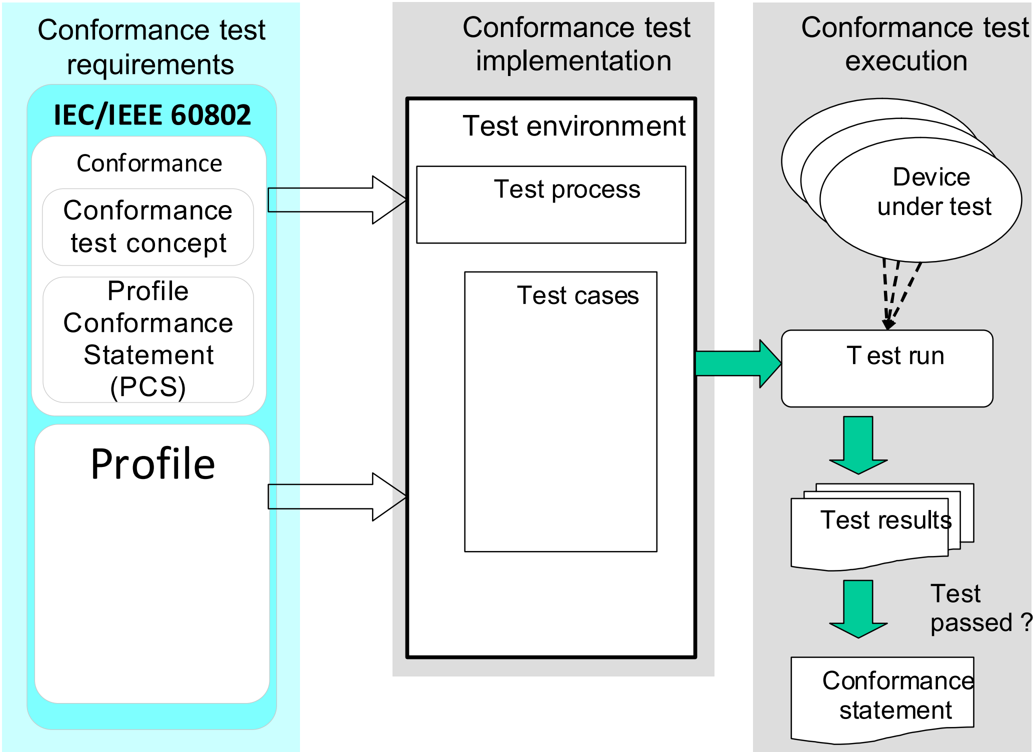

Figure 2 – Conformance test overview

5.3 Methodology

5.3.1 Terminology

Requirements placed upon conformant implementations of this document are expressed using the terminology of provisions given in ISO/IEC DIR 2: 2018, Clause 7.

NOTE The meaning of the terms shall, should and may are equivalent to the IEEE style guide as well as in IEEE 802 documents.

5.3.2 Profile Conformance Statement (PCS)

The Profile Conformance Statement (PCS) proformas (see Annex XYZ) reflect the occurrences of the words “shall,” “may,” and “should” within the document.

The supplier of an implementation that is claimed to conform to this document shall provide the information necessary to identify both the supplier and the implementation, and shall complete a copy of the PCS proforma provided in Annex XYZ, which is exempted from the copyright claim for this document.

5.3.3 Test requirements

Test cases shall be developed in a way that tests results are reproduceable and the results can be verified. Test results shall be documented and shall be used as the basis for the conformance statement.

Conformance tests of a device shall include, as appropriate, the verification of

- the availability and correctness of the specified functionality,
- network related indicator values,
- device related indicator values.

The quantities of values in this document and of the device under test shall be used.

NOTE 1 It is assumed that the quality of the test cases guarantees a high level of compatibility of a tested device. If any irregularities are reported the test cases will be adapted accordingly.

NOTE 2 A description of a conformance testing process is given in the ISO/IEC 9646 series.

~~3.6~~5.4 Test conditions and test cases

Test conditions and test cases shall be defined and documented based on a specific implementation based on this document.

For each measured value, test condition and test case documents shall be prepared and shall describe:

- test purpose;
- test setup;
- test procedure;
- criteria for compliance.

Test set-up describes the equipment set-up necessary to perform the test including measurement equipment, device under test, auxiliary equipment, interconnection diagram, and test environmental conditions.

Parts of the test environment may be emulated or simulated. The effects of the emulation or simulation shall be documented.

The test procedure describes how the test should be performed, which also includes a description of specific set of indicators required to perform this test. The criteria for compliance define test results accepted as compliance with this test.

~~3.7~~5.5 Test procedure and measuring

The test procedure shall be based on the principles of 5.4.

The sequence of measuring actions to complete a test run shall be provided.

The number of independent runs of the test shall be provided.

The method to compute the result of the test from the independent runs shall be provided if applicable.

~~3.8~~5.6 Test report

The test report shall contain sufficient information so that the test can be repeated and the results verified.

The test report shall contain at least

- the reference to the conformance test methodology according to 5.3,
- a description of the conformance test environment including network emulators, measurement equipment and the person or organization responsible for the test execution, and the date of testing,
- the device under test, its manufacturer, and hardware and software revision,
- the number and type of devices connected to the network together with the topology,
- a reference to the test case specifications,
- the measured values.

~~4~~6 TSN Profile contribution for Industrial Automation

~~4.1~~6.1 General

This profile defines a selection of features out of the standards stated in Chapter 6.

6.1.1 Structure of the profile contribution

This document contains one TSN profile contribution for industrial automation.

It is based on IEEE 802.1 and IEEE 802.3 applicable for the industrial automation domain. This profile contribution selects elements of IEEE 802.3 and IEEE 802.1 standards and defines quantities.

This document defines the following TSN-network communication elements:

a) IEEE 802.3 selection, see 6.2

This element of the profile contribution contains a selection of IEEE 802.3 related services and protocol definitions to select different PHY media and MAC speeds.

If there is more than one element specified, for example a PHY using copper and a PHY using optical fiber, then only one shall be selected for a link segment. A device can support more than one PHY. The optional add-ons like redundancy, power over Ethernet should be indicated in addition to the selection.

b) IEEE 802.1 selection, see 6.3

This element of the profile contribution contains a selection of IEEE 802.1 related services and protocols.

c) Clock synchronization selection, see 6.4

This element of the profile contribution contains a selection of Clock synchronization services and protocol definitions from IEEE 802.1AS associated to different device types.

d) IEEE 802.1AB selection, see 6.5

e) Management selection, see 6.6

This element of the profile contribution contains a selection of management system protocols and objects.

f) Security selection, see 6.7

This element of the profile contribution contains a selection of security mechanisms.

~~4.2~~6.2 IEEE 802.3 selection

~~4.2.1~~6.2.1 General

The following requirements and features according to IEEE 802.3 shall be supported:

a) Select one of the PHY speeds from 10 Mb/s to 1 Tb/s with
   - Full duplex, and
   - Synchronization according IEEE 802.1AS supported.

   Table 6 specifies the physical layer (PHY) selection and the MAC speeds within IEEE 802.3-2015. At least one PHY shall be selected out of the list of possible PHYs.

b) The maximum frame size according IEEE 802.3 chapter 3.2.7, including envelope frame, shall be supported.

TBD: check max frame size in 802.1Q

c) IEEE 802.3br™-2016 (preemption) up to 1 Gb/s; beyond optional.

NOTE May be indicated by Annex A parameter

d) Time limits for PHY delay and delay variation according to 6.2.3.

e) Time limits for MAC delay and delay variation according to 6.2.3.

f) The selected medium shall be described in the IEEE 802.3 defined managed object.

~~4.2.2~~6.2.2 PHY and MAC selection

Table 6 specifies the (sub)clause selection of IEEE 802.3-2015.

Table 6 – PHY and MAC selection within IEEE 802.3-2015

Clause	Header	Presence	Constraints
1	Introduction	YES	Relevant for IEEE 802.3br
2	Media Access Control (MAC) service specification	YES	–
3	Media Access Control (MAC) frame and packet specifications	YES	–
4	Media Access Control	YES	–
5	Layer Management	YES	–
6	Physical Signaling (PLS) service specifications	YES	–
7	Physical Signaling (PLS) and Attachment Unit Interface (AUI) specifications	YES	–
8 - 77	Medium Attachment Unit and baseband medium specifications, type 10BASE5	Partial	Applies only if 6.2.1 fulfilled.
Annex 57A - 76A	-	Partial	Applies only if 6.2.1 fulfilled.
78	Energy-Efficient Ethernet (EEE)	NO	
79	IEEE 802.3 Organizationally Specific Link Layer Discovery Protocol (LLDP) type, length, and value (TLV) information elements	Yes	Relevant for IEEE 802.3br
80 - 89	-	Partial	Applies only if 6.2.1 fulfilled.
90	Ethernet support for time synchronization protocols	YES	Relevant for IEEE 802.3br
91 - 95	-	Partial	Applies only if 6.2.1 fulfilled.
Annex 83A – 93C	-	Partial	Applies only if 6.2.1 fulfilled.

Table 7 – CP 802PHY/2 PHY selection and the MAC speeds of Amendments

Amendment	Title	Presence	Constraints
IEEE 802.3bw™-2015	IEEE Standard for Ethernet - Amendment 1: Physical Layer Specifications and Management Parameters for 100 Mb/s Operation over a Single Balanced Twisted Pair Cable (100BASE-T1)	Partial	Applies only if 6.2.1 fulfilled.
IEEE 802.3by™-2016	IEEE Standard for Ethernet - Amendment 2: Media Access Control Parameters, Physical Layers, and Management Parameters for 25 Gb/s Operation	Partial	Applies only if 6.2.1 fulfilled.
IEEE 802.3bq™-2016	IEEE Standard for Ethernet - Amendment 3: Physical Layers and Management Parameters for 25 Gb/s and 40 Gb/s Operation, Types 25GBASE-T and 40GBASE-T	Partial	Applies only if 6.2.1 fulfilled.
IEEE 802.3bp™-2016	IEEE Standard for Ethernet - Amendment 4: Physical Layer Specifications and Management Parameters for 1 Gb/s Operation over a Single Twisted-Pair Copper Cable	Partial	Applies only if 6.2.1 fulfilled.
IEEE 802.3br™-2016	IEEE Standard for Ethernet - Amendment 5: Specification and Management Parameters for Interspersing Express Traffic	YES	Yes to all Options in 79.5 up to 1 Gb/s; beyond optional.

Amendment	Title	Presence	Constraints
IEEE 802.3bz™-2016	IEEE Standard for Ethernet - Amendment 7: Media Access Control Parameters, Physical Layers, and Management Parameters for 2.5 Gb/s and 5 Gb/s Operation, Types 2.5GBASE-T and 5GBASE-T	Partial	Applies only if 6.2.1 fulfilled.
IEEE P802.3bs™ /D2.2, 28th November 2016	IEEE Standard for Ethernet - Amendment #: Media Access Control Parameters, Physical Layers and Management Parameters for 200 Gb/s and 400 Gb/s Operation	Partial	Applies only if 6.2.1 fulfilled.
IEEE P802.3bt™/D 2.2, 28 November 2016	IEEE Standard for Ethernet - Amendment #: Physical Layer and Management Parameters for DTE Power via MDI over 4-Pair	Partial	Applies only if 6.2.1 fulfilled.
IEEE P802.3bu™/ D3.3, 11 October 2016	IEEE Standard for Ethernet – Amendment #: Physical Layer and Management Parameters for Power over Data Lines (PoDL) of Single Balanced Twisted-Pair Ethernet	Partial	Applies only if 6.2.1 fulfilled.
IEEE P802.3bv™/ D3.3, 12th December 2016	IEEE Standard for Ethernet – Amendment 9: Physical Layer Specifications and Management Parameters for 1000 Mb/s Operation Over Plastic Optical Fiber	Partial	Applies only if 6.2.1 fulfilled.
IEEE P802.3ca™/ D0.0, No Draft	IEEE Standard for Ethernet – Amendment #: Physical Layer Specifications and Management Parameters for 25 Gb/s, 50 Gb/s, and 100 Gb/s Passive Optical Networks	Partial	Applies only if 6.2.1 fulfilled.
IEEE P802.3cb-20xx™/D2.1, 15th December 2016	IEEE Standard for Ethernet – Amendment #: Physical Layer Specifications and Management Parameters for 2.5 Gb/s and 5 Gb/s Operation over Backplane	Partial	Applies only if 6.2.1 fulfilled.
IEEE P802.3cc™/ D2.0, 27th November 2016	IEEE Standard for Ethernet – Amendment #: Physical Layer and Management Parameters for Serial 25 Gb/s Ethernet Operation Over Single-Mode Fiber	Partial	Applies only if 6.2.1 fulfilled.
IEEE P802.3cd™/ D1.1, 2nd December 2016	IEEE Standard for Ethernet – Amendment #: Media Access Control Parameters for 50 Gb/s and Physical Layers and Management Parameters for 50 Gb/s, 100 Gb/s, and 200 Gb/s Operation	Partial	Applies only if 6.2.1 fulfilled.
IEEE P802.3cg™/ Draft	IEEE Standard for Ethernet – Amendment #: 10 Mb/s Single Twisted Pair Ethernet	Partial	Applies only if 6.2.1 fulfilled.

~~4.2.3~~6.2.3 PHY and MAC delay requirements

To make short control loop times feasible PHY- and MAC-delays shall meet upper limits:

- PHY delays shall meet the upper limits of Table 8.
- MAC delays shall meet the upper limits of Table 9.

Figure 3 shows the definition of PHY delay, MAC delay and Bridge delay reference points.

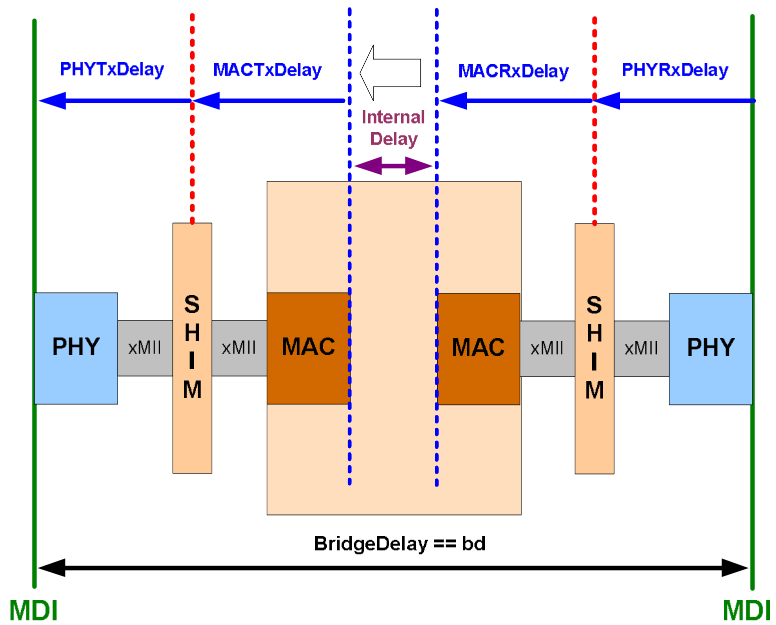

Figure 3 – Delay measurement reference points

Strict numbers such as that presented hereafter in Table 8 and Table 9 are necessary to approach the problem of short control loop times. Specifying these numbers, however, doesn't eliminate the need to publish exact values through IEEE 802.1 standardized mechanisms as applicable. Bridge delay requirements are described in 6.3.3.

Table 8 – Required PHY delays

Device	RX delay [b]	TX delay [b]	Jitter
10 Mb/s	<< 1 µs	<< 1 µs	< 4 ns
100 Mb/s MII PHY	< 210 ns	< 90 ns	< 4 ns
100 Mb/s RGMII PHY	210 ns [a]	90 ns [a]	< 4 ns
1 Gb/s RGMII PHY	<< 500 ns [a]	<< 500 ns [a]	< 4 ns
2,5 Gb/s RGMII PHY	<< 500 ns [a]	<< 500 ns [a]	< 4 ns
5 Gb/s RGMII PHY	<< 500 ns [a]	<< 500 ns [a]	< 4 ns
10 Gb/s	<< 500 ns	<< 500 ns	< 4 ns
25 Gb/s to 1 Tb/s	<< 500 ns	<< 500 ns	< 4 ns

[a] Values from 100 Mb/s PHYs (or faster) are needed to allow substitution even for Gigabit or higher.
b Lower values mean more performance for control loops in conjunction with large hop counts.

Table 9 – Required MAC delays

Link speed	Maximum RX delay	Maximum TX delay
10 Mb/s	<< 1 µs	<< 1 µs
100 Mb/s	<< 1 µs	<< 1 µs
1 Gb/s	<< 1 µs	<< 1 µs
2,5 Gb/s	<< 1 µs	<< 1 µs
5 Gb/s	<< 1 µs	<< 1 µs

Link speed	Maximum RX delay	Maximum TX delay
10 Gb/s	<< 1 µs	<< 1 µs
25 Gb/s – 1 Tb/s	<< 1 µs	<< 1 µs

~~4.3~~6.3 IEEE 802.1 selection

~~4.3.1~~6.3.1 General

~~4.3.1.1~~6.3.1.1 General required Bridge features

The following requirements and features according to IEEE 802.1 shall be supported:

a) Conform to the relevant standard for the MAC technology implemented at each port in support of the MAC ISS, as specified in IEEE Std 802.1AC.

b) Support the capability of 2000 octets maximum size MAC Protocol Data Unit (PDU) on each port.

c) Support the capability to disable MAC control PAUSE if it is implemented and support the capability to disable Priority-based flow control if it is implemented.

d) Support the capability to disable support of Energy Efficient Ethernet.

e) Support the strict priority algorithm for transmission selection (8.6.8.1 in IEEE Std 802.1Q-2014) on each port for each traffic class.

f) Support a minimum of 8 Traffic Classes/Queues on every port.

g) Support flow metering according to IEEE 802.1Q, 8.6.5.

h) Support priority regeneration according to IEEE 802.1Q, 6.9.4.

i) Support of preemption according to IEEE 802.1Q-2018, 5.26, 6.7.2, 12.30, 17.2.23, 17.3.24, 17.4.24, 17.7.23, and Annex R.

j) Support of at least one of the following transmission selection options:

- Support the enhancements for scheduled traffic (as specified in IEEE 802.1Q 8.6.8.4) together with the strict priority algorithm (as specified in IEEE 802.1Q 8.6.8.1) and frame preemption (as specified in IEEE 802.1Q 6.7.1, 6.7.2, and 8.6.8);
  - synchronized to the working clock;
  - support of at least two gate control entries;
- Support of the strict priority algorithm for transmission selection (as specified in IEEE 802.1Q 8.6.8.1) and frame preemption (as specified in IEEE 802.1Q 6.7.1, 6.7.2, and 8.6.8);

k) Time limits for bridge delay and delay variation according to 6.3.3.

l) Required number of DA-MAC address entries used together with five VLANs (Default, High, High Redundant, Low and Low Redundant) according to 6.3.4.

~~4.3.1.2~~6.3.1.2 Network access

The following network access features for end stations according to IEEE 802.1 shall be supported:

a) Synchronization to working clock;

b) Stream class based scheduling with:

- Network cycle,
  - < 50 % bandwidth per link for < 1 Gb/s for streams;
  - < 20 % bandwidth per link for >= 1 Gb/s for streams;

- < 25 % bandwidth per link for non-streams;
  - Reduction ratio;
  - Phase;
  - Sequence;
  - Transmit of frames as a convoy starts at network cycle start with minimum interpacket gap (IPG); first isochronous cyclic real-time frames, second cyclic real-time frames, third non-stream frames;
  - Reception of frames before assigned network cycle based deadline;

c) Time limits for transfer time (receive), see Figure 1, shall be <= 3 µs in addition to PHY-delay and MAC-delay;

d) Time limits for transfer time (transmit), see Figure 1, shall be <= 3 µs in addition to PHY-delay and MAC-delay;

e) Network access parameters:
  - NetworkCycle according to Table 10,
  - ReductionRatio according to Formula (1),
  - Phase according to Formula (2),
  - Sequence according to Formula (3).

Table 10 – Values of the parameter NetworkCycle

NetworkCycle [time]	10 Mb/s [Data rate]	100 Mb/s [Data rate]	≥ 1 Gb/s [Data rate]
31,25 µs	n.a.	n.a.	Together with all ReductionRatios
62,5 µs	n.a.	n.a.	Together with all ReductionRatios
125 µs	n.a.	n.a.	Together with all ReductionRatios
250 µs	n.a.	Together with all ReductionRatios	Together with all ReductionRatios
500 µs	n.a.	Together with all ReductionRatios	Together with all ReductionRatios
1 ms	Together with ReductionRatio ≥ 8	Together with all ReductionRatios	Together with all ReductionRatios
2 ms	n.a.	Together with all ReductionRatios	n.a.
4 ms	n.a.	Together with all ReductionRatios	n.a.

The ReductionRatio shall be created according to Formula (1).

$$\text{ReductionRatio} = 2^{n} \mid n \in \mathbb{N}_0 \mid n \leq 10 \quad (1)$$

Where

ReductionRatio	is the result of the operation
n	is actual factor for the operation
$\mathbb{N}_0$	are the natural numbers including zero

The Phase shall be created according to Formula (2).

$$PhaseNumber = 1 \text{ to } ReductionRatio \quad (2)$$

Where

PhaseNumber	is the chosen one out the list
ReductionRatio	is the applied ReductionRatio

The Sequence shall be created according to Formula (3).

$$SequenceNumber = 1 \text{ to } MaxListLength \quad (3)$$

Where

SequenceNumber	is the chosen one out the list
MaxListLength	is the maximum possible entries per Phase

~~4.3.2~~6.3.2 Bridge selections

~~4.3.2.1~~6.3.2.1 Selection of IEEE 802.1Q-2018 and the related Amendments

TBD: Device classes: end-stations, bridges

Table 11 and Table 12 specify the bridge selections. Selections of IEEE 802.1Q™-2018 are specified in Table 11. The current amendments to IEEE 802.1Q are selected in Table 13.

Table 11 – Selection of IEEE 802.1Q-2018

Clause	Header	Presence	Constraints
1 – 9	–	YES	–
10	Multiple Registration Protocol (MRP) and Multiple MAC Registration Protocol (MMRP)	NO	–
11- 12	-	Partial	Applies only if 6.3.1 is fulfilled.
13 - 14		YES	Optional
15 – 16	-	NO	
17		Partial	Applies only if 6.3.1 and 6.5 is fulfilled.
18 - 23		NO	
24		Partial	Applies only if 6.3.1 is fulfilled.
25 - 33		NO	
34	Forwarding and queuing for time-sensitive streams	Partial	Applies only if 6.3.1 is fulfilled.
35		NO	
36		NO	Not coexistent with this profile contribution.
37 - 42		NO	
43		YES	If IEEE 802.1CS is applied.
44 - 45		NO	
Annex A -	PICS proforma—Bridge implementations	YES	See add-on in Annex A of this document.
Annex B	PICS proforma—Bridge implementations	YES	See add-on in Annex A of this document.

Clause	Header	Presence	Constraints
Annex C - E		NO	
Annex F - G		YES	
Annex H - Q		NO	
Annex R - S		YES	
Annex T		NO	
Annex U		YES	

Table 12 – Bridge selections

Amendment	Title	Presence	Constraints
IEEE 802.1AB™-2016	IEEE Standard for Local and metropolitan area networks—Station and Media Access Control Connectivity Discovery	YES	–
IEEE 802.1AC™-2016	IEEE Standard for Local and metropolitan area networks— Media Access Control (MAC) Service Definition	YES	–
IEEE 802.1AS-2019	IEEE Standard for Local and metropolitan area networks—Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks	YES	See 6.4.
IEEE 802.1AX™-2008	IEEE Standard for Local and metropolitan area networks—Link Aggregation	NO	–
IEEE 802.1BR™-2012	IEEE Standard for Local and metropolitan area networks—Virtual Bridged Local Area Networks—Bridge Port Extension	NO	–
IEEE P802.1CB™/ D2.6, August 2016	IEEE Standard for Local and metropolitan area networks—Frame Replication and Elimination for Reliability	YES	Optional
IEEE P802.1CS/ D1.5	IEEE Standard for Local and metropolitan area networks—LRP (Registration)	YES	–

Table 13 – Bridge selections of current amendments to IEEE 802.1Q™-2018

Amendment	Title	Presence	Constraints
IEEE P802.1Qcc/ D1.1, September 1, 2016	IEEE Standard for Local and Metropolitan Area Networks—Bridges and Bridged Networks Amendment: Stream Reservation Protocol (SRP) Enhancements and Performance Improvements	Partial	Applies only if 6.3.1 is fulfilled.
IEEE P802.1Qcj/D 0.1 March 7, 2016	IEEE Standard for Local and Metropolitan Area Networks— Bridges and Bridged Networks— Automatic Attachment to Provider Backbone Bridging (PBB) services	NO	–
IEEE P802.1Qcp/ D0.7 December 12, 2016	IEEE Standard for Local and Metropolitan Area Networks—Bridges and Bridged Networks— Amendment: YANG Data Model	Partial	Applies only if 6.3.1 and 6.5 is fulfilled.
IEEE P 802.1Qcr/D0.0	IEEE Standard for Local and Metropolitan Area Networks—Bridges and Bridged Networks— Amendment: Asynchronous Traffic Shaping	YES	Optional
IEEE P 802.1Qdd/D0.0	IEEE Standard for Local and Metropolitan Area Networks—Bridges and Bridged Networks— Amendment: RAP	YES	

~~4.3.2.2~~6.3.2.2 Other profiles

A vendor can decide to implement more than one profile per device. In this case the implemented profiles shall be coexistent. Table 14 shows other profiles.

Table 14 – Other IEEE 802.1 TSN profiles

Amendment	Title	Presence	Constraints
IEEE 802.1BA™-2011	IEEE Standard for Local and metropolitan area networks—Audio Video Bridging (AVB) Systems	YES	Optional; Coexistent with this profile contribution.
IEEE 802.1CM, 2018	IEEE Standard for Local and metropolitan area networks—Time-Sensitive Networks for Fronthaul	YES	Optional; Coexistent with this profile contribution.

~~4.3.3~~6.3.3 Bridge delay requirements

Figure 3 shows the definition the Bridge delay reference points. To make short control loop times feasible Bridge-delays shall be independent from the frame size and meet the upper limits of Table 15.

Table 15 – Required Ethernet Bridge delays

Data rate	Value	Comment
10 Mb/s	< 30 µs	Bridge delay measure from MII to MII[1)]
100 Mb/s	< 3 µs	Bridge delay measure from MII to MII[1)]
1 Gb/s	< 1 µs	Bridge delay measure from RGMII to RGMII[1)]
2,5 Gb/s	< 1 µs	Bridge delay measure from XGMII to XGMII[1)]
5 Gb/s	< 1 µs	Bridge delay measure from XGMII to XGMII[1)]
10 Gb/s	< 1 µs	Bridge delay measure from XGMII to XGMII[1)]
25 Gb/s – 1 Tb/s:	< 1 µs	Bridge delay measure from XGMII to XGMII[1)]

[1)] first bit in, first bit out

~~4.3.4~~6.3.4 Bridge FDB requirements

Table 16 shows the required number of supported stream FDB entries.

Table 16 may be implemented as FDB table, using IVL mode, with a portion of DA-MAC addresses (e.g. 12 bits of Identifier and TSN-IA profile OUI) as row and the VLANs as column to ensure availability of a dedicated entry.

Table 16 – Expected number of stream FDB entries

# of VLANs	# of DA-MACs	Usage
4	4 096	Numbers of DA-MAC address entries used together with four VLANs (High, High Red, Low and Low Red)

Table 17 shows the required number of supported non-stream FDB entries.

Table 17 – Expected number of non-stream FDB entries

# of VLANs	# of entries	Usage
1	2 048	Learned and static entries for both, Unicast and Multicast

NOTE The number of entries is given by the maximum device count of 1 024 together with the 50% saturation due to hash usage rule.

The hash based non-stream FDBs shall support a neighborhood for entries according to Table 18.

Table 18 – Neighborhood for hashed entries

Neighborhood	Usage
8	Default A neighborhood of eight entries is used to store a learned entry if the hashed entry is already used. A neighborhood of eight entries for the hashed index is check to find or update an already learned forwarding rule.

~~4.3.5~~6.3.5 Bridge resource requirements

The bridges shall provide and organize their resources in a way to ensure robustness for the traffic defined in this document as shown in Formula (4).

The queuing of frames needs resources to store them at the destination port. These resources may be organized either bridge globally, port globally or queue locally. The chosen resource organization model influences the needed amount of frame resources.

For bridge memory calculation Formula (4) applies.

$$MinimumFrameMemory = (NumberOfPorts - 1) \times MaxPortBlockingTime \times Linkspeed \qquad (4)$$

Where

MinimumFrameMemory	The minimum amount of frame buffer needed to avoid frame loss from non-stream traffic due to streams blocking egress ports.
NumberOfPorts	The number of ports of the bridge without the management port.
MaxPortBlockingTime	The intended maximum blocking time of ports due to streams per millisecond, e.g. 20%(>= 1Gb/s) or 50% (<1Gb/s)
Linkspeed	The intended link speed of the ports.

Formula (4) assumes that all ports use the same link speed and a bridge global frame resource management. Table 19, Table 20, Table 21, and Table 22 show as an example the resulting values for different link speeds and fully utilized links.

The traffic from the management port to the network needs a fair share of the bridge resources to ensure the required injection performance into the network. This memory (use for the real-time frames) is not covered by this calculation.

Table 19 – MinimumFrameMemory for 100 Mb/s (50% @ 1 ms)

# of ports	MinimumFrameMemory [KiBs]	Comment
1	0	The memory at the management port is not covered by Formula (4)
2	6,25	All frames received during the 50% @ 1 ms := 500 µs at one port needed to be forwarded to the other port are stored during the allocation of this port due to stream transmission.
3	12,5	All frames received during the 50% @ 1 ms := 500 µs at two ports needed to be forwarded to the other port are stored during the allocation of this port due to stream transmission.
4	18,75	All frames received during the 50% @ 1 ms := 500 µs at three ports needed to be forwarded to the other port are stored during the allocation of this port due to stream transmission.

Table 20 – MinimumFrameMemory for 1 Gb/s (20% @ 1 ms)

# of ports	MinimumFrameMemory [KiBs]	Comment
1	0	The memory at the management port is not covered by Formula (4)
2	25	All frames received during the 20% @ 1 ms := 200 µs at one port needed to be forwarded to the other port are stored during the allocation of this port due to stream transmission.
3	50	All frames received during the 20% @ 1 ms := 200 µs at two ports needed to be forwarded to the other port are stored during the allocation of this port due to stream transmission.
4	75	All frames received during the 20% @ 1 ms := 200 µs at three ports needed to be forwarded to the other port are stored during the allocation of this port due to stream transmission.

Table 21 – MinimumFrameMemory for 2,5 Gb/s (10% @ 1 ms)

# of ports	MinimumFrameMemory [KiBs]	Comment
1	0	The memory at the management port is not covered by Formula (4)
2	31,25	All frames received during the 10% @ 1 ms := 100 µs at one port needed to be forwarded to the other port are stored during the allocation of this port due to stream transmission.
3	62,5	All frames received during the 10% @ 1 ms := 100 µs at two ports needed to be forwarded to the other port are stored during the allocation of this port due to stream transmission.
4	93,75	All frames received during the 10% @ 1 ms := 100 µs at three ports needed to be forwarded to the other port are stored during the allocation of this port due to stream transmission.

Table 22 – MinimumFrameMemory for 10 Gb/s (5% @ 1 ms)

# of ports	MinimumFrameMemory [KiBs]	Comment
1	0	The memory at the management port is not covered by Formula (4)
2	62,5	All frames received during the 5% @ 1 ms := 50 µs at one port needed to be forwarded to the other port are stored during the allocation of this port due to stream transmission.
3	125	All frames received during the 5% @ 1 ms := 50 µs at two ports needed to be forwarded to the other port are stored during the allocation of this port due to stream transmission.
4	187,5	All frames received during the 5% @ 1 ms := 50 µs at three ports needed to be forwarded to the other port are stored during the allocation of this port due to stream transmission.

A per port frame resource management leads to the same values but reduces the flexibility to use free frame resources for other ports.

A per queue per port frame resource management would increase (multiplied by the number of to be covered queues) the needed amount of frame resources dramatically almost without any benefit.

Example “per port frame resource management”:

100 Mb/s, 2 Ports, and 6 queues

Needed memory := 6,25 KOctets * 6 := 37,5 KOctets.

It is impossible to predict which queue is needed during the “stream port blocking” period.

Local network access shall conform to the defined model in this document with management defined limits and network cycle times according to 6.3.1.2.

~~4.4~~6.4 Clock synchronization selection

~~4.4.1~~6.4.1 General

The IEEE 802.1AS™-2019 shall apply according to Table 29.

Synchronization covering both universal time and working clock timescales is needed for industrial automation systems.

Redundancy for synchronization of universal time may be solved with “cold standby”. Support of "Hot standby" for universal time synchronization is not current practice - but is an option in this document and can be used depending on the application requirements.

Redundancy for Working Clock synchronization can be solved with “cold standby” or “hot standby” depending on the application requirements. Support of "hot standby" for working clock synchronization is required.

NOTE Global Time is often used as synonym term for “Universal Time”. Wall Clock is based on Universal Time and considers time zones, daylight saving time and leap seconds.

~~4.4.2~~6.4.2 Universal Time synchronization

Universal time is used to plant wide align events and actions (e.g. for “sequence of events”). The assigned timescale is TAI, which can be converted into local date and time if necessary. The goal of Universal Time synchronization is to establish a worldwide aligned timescale for time. Thus, often satellites are used as source of the time.

~~4.4.3~~6.4.3 Working Clock synchronization

Working Clock is used to align actions line, cell or machine wide. The assigned timescale is ARB. Robots, motion control, numeric control and any kind of clocked / isochronous application rely on this timescale to ensure that actions are precisely interwoven as needed. Often PLCs, Motion Controller or Numeric Controller are used as Working Clock source.

Working Clock domains may be doubled to support zero failover time for synchronization by aligning the both timescales at the Grandmaster.

TBD: two WC domains – needs more definitions – hot standby/cold standby need definitions

High precision Working Clock synchronization is a prerequisite for control loop implementations.

~~4.4.4~~6.4.4 General Requirements for Synchronization

Synchronization domain settings shall be according to Table 23 and Table 24.

Table 23 – Synchronization Domains

Domain	ID	Timescales	Presence	Constraints
Working Clock	20	ARB	YES	Used for network access and application synchronization. If scheduled traffic is used then also used for Bridge synchronization.
Universal Time	0	TAI	YES	Used for Universal Time.
Redundant Working Clock	21	ARB	YES	Used for hot standby of Working Clock. Timescale shall be identical to Working Clock.
Redundant Universal Time	1	TAI	YES	Optional. Used for hot standby of Universal Time. Timescale shall be identical to Universal Time.

TBD: ID is Domainnumber – all Timescales coded as PTP

In the working clock domain bridges shall take the roles of time aware relay and time aware endpoint, because they shall be in sync for scheduled traffic transmission.

In the Universal Time domain the role of a time aware relay is mandatory and the role of a time aware endpoint is optional for Bridges.

At least one grandmaster shall be present in every synchronization domain.

All members of a synchronization domain may take at least one of the roles specified in Table 24.

Table 24 – Synchronization Roles

Role	Working Clock		Universal Time	
	Bridge or Router	End Station	Bridge or Router	End Station
Time aware relay	mandatory	–	mandatory	–
Time aware endpoint	mandatory	mandatory	optional	mandatory
Grandmaster capable	Optional	optional	optional	optional

Editor Note: Tbd: is support of UniversalTime/Time aware endpoint mandatory or optional for end stations? Contributions are welcome.

The requirements concerning the overall maximum deviation to the grandmaster time in the synchronization domains in Table 25 shall be fulfilled.

Table 25 – Maximum deviation to grandmaster time requirements

Domain	Maximum absolute value of deviation from grandmaster time	Comments
Working Clock	< 1 µs	maximum deviation +/- 1 µs
Universal Time	< 100 µs	maximum deviation +/- 100 µs

Editor Note: Tbd: reference number of hops (100) – "grandmaster time" must be defined – from TAI in case of universal time

Table 26 shows the number of hops which shall be supported.

Table 26 – Maximum number of hops between grandmaster and time aware end-point

Domain	Number of hops	Comments
Working Clock	100	Grandmaster to time aware end-point. May be 200 between two time aware end-points.
Universal Time	100	From Grandmaster connected to the satellite receiver to each time aware endpoint

The maximum working clock deviation between two devices, which are synchronized to the same grandmaster, shall be < 2 µs when the working clock requirement of Table 25 is observed.

The maximum error contribution of every single network node of the domains shall be according to Table 27.

Table 27 – Maximum error contribution per network node

Error contribution	Max. error	Comments
Maximum residence time error	< 10 ns	Externally measured from the MDI to MDI at the local Bridge
Maximum link delay error	< 10 ns	Externally measured from the MDI to MDI at the local link – including the asymmetry error contribution

Minimal timestamp accuracy for any kind of timestamp shall be according to Table 28.

Table 28 – Timestamp accuracy

Timestamp	Accuracy	Comments
Working Clock	≤ 8 ns	—
Universal time	≤ 8 ns	—

Table 29 specifies the clock synchronization profile contribution. The selection of the different clock types per device shall be provided using PICS.

Editor Note: Tbd: add requirement about asymmetry compensation

Table 29 – Selection of IEEE 802.1AS-2019

Clause	Header	Presence	Constraints
1 – 6	–	YES	–
7	Time-synchronization model for a network	–	–
7.1	General	YES	–
7.2	Architecture of a time-aware network	–	–
7.2.1	General	Partial	Applies only if 6.3.1 is fulfilled.
7.2.2	Time-aware network consisting of a single gPTP domain	NO	–
7.2.3	Time-aware network consisting of multiple gPTP domains	YES	–
7.2.4	Time-aware networks with redundant grandmasters and/or redundant paths	YES	Optional-tbd
7.3 – 7.5	–	YES	–
8 – 11	–	YES	–
12	Media-dependent layer specification for IEEE 802.11 links	YES	OPTIONAL
13	Media-dependent layer specification for interface to IEEE 802.3 Ethernet passive optical network link	NO	–
14	Timing and synchronization management	YES	–
15	Managed object definitions	YES	–
16	Media-dependent layer specification for CSN Network	NO	–
Annex A	Protocol Implementation Conformance Statement (PICS) proforma [a)]	YES	Optional. tbd
Annexes B – G	–	YES	–

[a)] Copyright release for PICS proformas: Users of IEEE 802.1AS may freely reproduce the PICS proforma in this IEEE 802.1AS-2011, Annex A so that it can be used for its intended purpose and may further publish the completed PICS.

Editor NOTE: A contribution is welcome.

6.5 IEEE 802.1AB selection

The IEEE 802.1AB shall apply according to Table 30.

LLDP is used to discover the topology or to check it.

Table 30 – Selection of IEEE 802.1AB

Clause	Header	Presence	Constraints
1 – N	–	YES	–
–	–	–	–
–	–	–	–

~~4.5~~6.6 Management selection

6.6.1 General

End stations and bridges shall provide at least the managed objects, which are required by this profile contribution, from

- IEEE 802.3
- IEEE 802.3br
- IEEE 802.1Q
- IEEE 802.1Qca
- IEEE 802.1Qcc
- IEEE 802.1CBcv
- IEEE 802.1AS
- IEEE 802.1AB
- IETF RFC 1213
- …

These managed objects shall be represented preferred in the YANG format; if the YANG (RFC 6020) format is not available then MIB format (RFC 2358) shall be provided.

6.6.2 Protocols

Required access protocols are SNMP (RFC 4789) for a MIB representation and Netconf (RFC 4741) for YANG representation of the device local data base.

~~4.6~~6.7 Security selection

Media Access Control (MAC) Security according to IEEE 802.1AE can be used as an option.

Table 31 specifies the optional MAC-Security selection.

Table 31 – MAC-Security selection

Amendment	Title	Presence	Constraints
IEEE 802.1AE™-2006	IEEE Standard for Local and metropolitan area networks – Media Access Control (MAC) Security	YES	Optional
IEEE 802.1AEbn™–2011	IEEE Standard for Local and metropolitan area networks – Media Access Control (MAC) Security Amendment 1: Galois Counter Mode—Advanced Encryption Standard—256 (GCM-AES-256) Cipher Suite	YES	If IEEE 802.1AE™-2006 is used then this is mandatory.
IEEE 802.1AEbwTM–2013	IEEE Standard for Local and metropolitan area networks – Media Access Control (MAC) Security Amendment 2: Extended Packet Numbering	YES	If IEEE 802.1AE™-2006 is used then this is mandatory.
IEEE P802.1AEcg/ D1.5, October 25, 2016	IEEE Draft Standard for Local and metropolitan area networks—Media Access Control (MAC) Security Amendment 3: Ethernet Data Encryption devices	YES	If IEEE 802.1AE™-2006 is used then this is mandatory.
IEEE 802.1AR™-2009	IEEE Standard for Local and metropolitan area networks – Secure Device Identity	YES	If IEEE 802.1AE™-2006 is used then this is mandatory.
IEEE 802.1X™-2010	IEEE Standard for Local and metropolitan area networks – Port Based Network Access Control	YES	Optional
IEEE 802.1Xbx-2014	IEEE Standard for Local and metropolitan area networks – Port Based Network Access Control Amendment 1: MAC Security Key Agreement Protocol (MKA) Extensions	YES	Optional

The IEEE P802.1AEcg enables multiple, per traffic class, transmit secure channels for MAC and thus will also meet strict ordering requirements (within traffic class, with express or preemptible transmission being selected for all the priorities allocated to a traffic class) for preemption.

Secure Device Identifiers (DevIDs) are designed to be used as interoperable secure device authentication credentials with Extensible Authentication Protocol (EAP) and other industry standard authentication and provisioning protocols.

Annex A
(informative)

PCS

The following PCS apply:

TBD

~~Annex A~~Annex B
(informative)

IEEE 802.1 principles

The standards created by the IEEE 802.1 committee are organized in the following way:

- The ones with capital letters, e.g. IEEE 802.1Q or IEEE 802.1AX are independent standards.
- Amendments to these standards are identified by lower case letters; for example IEEE 802.1ah, IEEE 802.1Qbg or IEEE 802.1AEbn.
- Periodically the amendments get merged into a revision of the main standard, for example IEEE 802.1ah and IEEE 802.1Qay are part of IEEE 802.1Q-2014.
- IEEE 802.1Q can be considered as many individual standards integrated into a single document:
  - IEEE 802.1Q, Clause Y through Clause 9 give a general overview of the IEEE 802.1Q bridge architecture.
  - To get oriented on an additional area, it's best to read the Clause titled the "Principles of <area>".
  - Once oriented, references in the (sub)clause of IEEE 802.1Q, Clause X Conformance for the relevant device can be helpful.

Bibliography

IEEE 1588™-2008, *IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems*