CONTENTS

TITLE –

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation.

   IEEE Standards documents are developed within IEEE Societies and Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. IEEE develops its standards through a consensus development process, which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of IEEE and serve without compensation. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information contained in its standards. Use of IEEE Standards documents is wholly voluntary. IEEE documents are made available for use subject to important notices and legal disclaimers (see http://standards.IEEEorg/IPR/disclaimers.html for more information).

   IEC collaborates closely with IEEE in accordance with conditions determined by agreement between the two organizations.

2) The formal decisions of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees. The formal decisions of IEEE on technical matters, once consensus within IEEE Societies and Standards Coordinating Committees has been reached, is determined by a balanced ballot of materially interested parties who indicate interest in reviewing the proposed standard. Final approval of the IEEE standards document is given by the IEEE Standards Association (IEEE-SA) Standards Board.

3) IEC/IEEE Publications have the form of recommendations for international use and are accepted by IEC National Committees/IEEE Societies in that sense. While all reasonable efforts are made to ensure that the technical content of IEC/IEEE Publications is accurate, IEC or IEEE cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.

4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications (including IEC/IEEE Publications) transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC/IEEE Publication and the corresponding national or regional publication shall be clearly indicated in the latter.

5) IEC and IEEE do not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC and IEEE are not responsible for any services carried out by independent certification bodies.

6) All users should ensure that they have the latest edition of this publication.

7) No liability shall attach to IEC or IEEE or their directors, employees, servants or agents including individual experts and members of technical committees and IEC National Committees, or volunteers of IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board, for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC/IEEE Publication or any other IEC or IEEE Publications.

8) Attention is drawn to the normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.

9) Attention is drawn to the possibility that implementation of this IEC/IEEE Publication may require use of material 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. IEC or IEEE shall not be held responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patent 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.

International Standard IEC/IEEE 60802 has been prepared by subcommittee 65C: Industrial networks, of IEC technical committee 65: Industrial-process measurement, control and automation, in cooperation with IEEE 802.1: Higher Layer LAN Protocols Working Group of IEEE 802: LAN/MAN Standards Committee of the IEEE computer society[1], under the IEC/IEEE Dual Logo Agreement.

It is published as an IEC/IEEE dual logo standard.

The text of this standard is based on the following IEC documents:

FDIS	Report on voting
65C/XX/FDIS	65C/XX/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

International standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The IEC Technical Committee and IEEE Technical Committee have decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

The National Committees are requested to note that for this document the stability date is 2024.

THIS TEXT IS INCLUDED FOR THE INFORMATION OF THE NATIONAL COMMITTEES AND WILL BE DELETED AT THE PUBLICATION STAGE.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

1 A list of IEEE participants can be found at the following URL: (to be provided prior to publication).

INTRODUCTION

This document provides profiles for network infrastructure components (bridges) for Time Sensitive Networking (TSN) according to standards published by IEEE 802.3 and IEEE 802.1 applicable for the industrial automation domain.

NOTE There doesn't exist a standard IEEE 802.1. IEEE 802.1 is used in this document as a placeholder for the various standards of the committee IEEE 802.1. The naming conventions are described in Annex A.

These profiles meet the industrial automation market objective of converging RTE networks and office networks by defining a common, standardized network infrastructure, taking advantage of the improvements of Ethernet networks in terms of deterministic transmission bandwidth and network span.[LW1]

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[2], *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)*

———————

[2] To be published.

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

Editor Note: has to be updated before CDV stage!

…

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

Editor Note: has to be updated before CDV stage!

3.3 Abbreviated terms and acronyms

Editor Note: has to be updated before CDV stage!

IA industrial automation

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	—

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.

Editor Note: has to be updated before CDV stage!

4 Conformance tests

4.1 Concept

This document specifies the methodology of a conformance test for a TSN-IA device. 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 1 gives an overview of the conformance test related to this document.

NOTE Conformance test implementation and conformance test execution are not defined in this document.[WL(TS2]

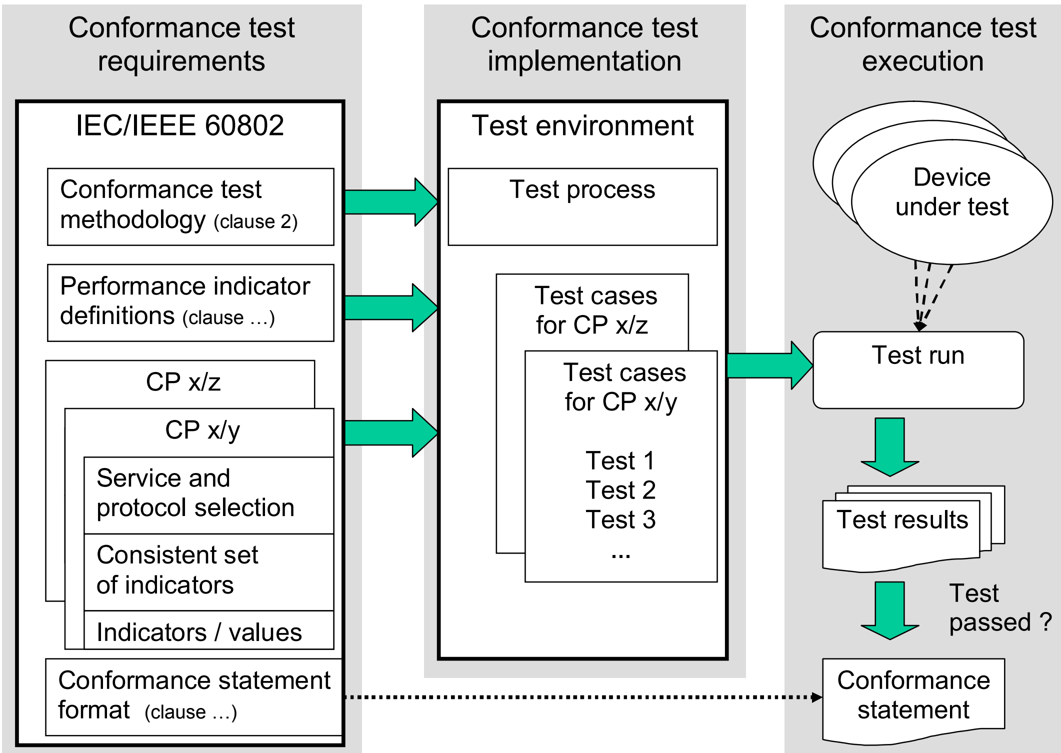

Figure 1 – Conformance test overview

4.2 Methodology

Test cases shall be developed in a way that tests are repeatable 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 CP 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.

4.3 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.

4.4 Test procedure and measuring

The test procedure shall be based on the principles of 4.3.

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.

4.5 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 4.2,
- 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.

5 TSN Profile for Industrial Automation

5.1 General

5.1.1 Structure of the profile

This document contains one TSN profile for industrial automation.

It is based on IEEE 802.1 and IEEE 802.3 applicable for the industrial automation domain. This profile 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 profile, see 5.2

   This element of the profile 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 profile, see 5.3

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

c) Clock synchronization profile, see 5.4

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

d) Management profile, see 5.5

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

e) Security profile, see 5.6

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

5.1.2 Control Loop Basic Model

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 2 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 2 and Table 4 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 shall be synchronized to a common working clock or to a local timescale[WL(TS3)].

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.

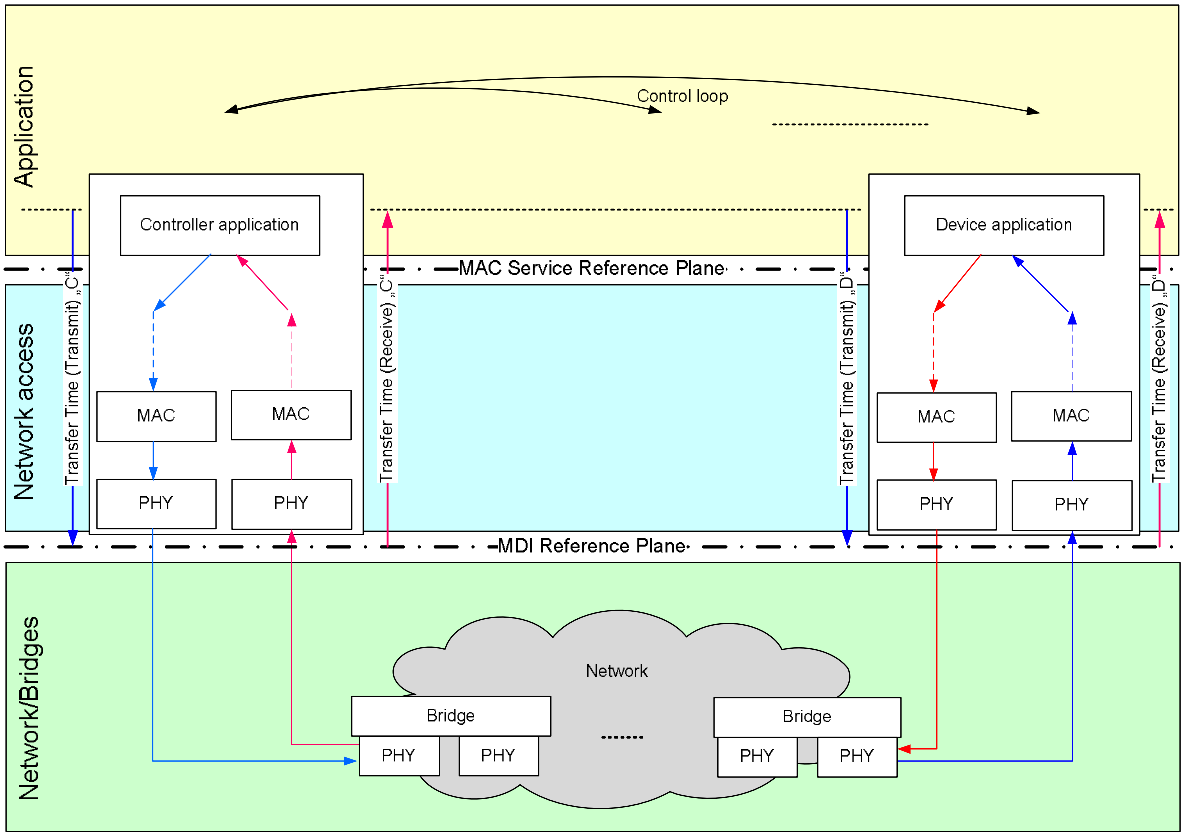

Figure 2 – Principle data flow of control loop

Transfer Times contain PHY and MAC delays. Both delays are asymmetric and vendor specific. Device vendors have to take into account these transfer times when their application cycle models are designed (see Figure 2).

Table 4 – Application types

Level	Isochronous Application		Non-isochronous Application		
Application	Synchronized to network access		Synchronized to local timescale		
Network access	Synchronized to working clock, Stream Class based scheduling, Preemption				Synchronized to local timescale, Stream Class based scheduling, Preemption
Network/Bridges	Synchronized to working clock	Free running	Synchronized to working clock	Free running	Free running
	Scheduled traffic + Strict Priority + Preemption	Strict Priority or other Shaper + Preemption	Scheduled traffic + Strict Priority + Preemption	Strict Priority or other Shaper + Preemption	Strict Priority or other Shaper + Preemption

5.1.3 Quantities

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

- Stations: >= 1024
- Network diameter: >= 64
- Maximum frame size: according to IEEE 802.3 clause 3.2.7, including envelope frames, i.e. 2000 octets
- Data flows per PLC for Controller-to-Device (C2D) communication:
  - >= 512 producer and >= 512 consumer data flows;
    >= 1024 producer and >= 1024 consumer data flows in case of seamless redundancy;
- Data flows per PLC for Controller-to-Controller (C2C) communication:
  - >= 64 producer and >= 64 consumer data flows;
    >= 128 producer and >= 128 consumer data flows in case of seamless redundancy.
- Data flows per Device for Device-to-Device (D2D) communication:
  - >= 2 producer and >= 2 consumer data flows;
    >= 4 producer and >= 4 consumer data flows in case of seamless redundancy.

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

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

5.2 IEEE 802.3 profile

5.2.1 General

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

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

   Table 5 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.

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

   Preemption is part of the interspersing express traffic option specified in IEEE 802.3br™-2016. This mechanism is part of a MAC Merge sublayer mechanism as an optional sublayer that supports interspersing express traffic with preemptable traffic by attaching an express Media Access Control (eMAC) and a preemptable Media Access Control (pMAC) to a single Physical Signaling Sublayer (PLS) service (see IEEE 802.3-2015, Clause 99).

d) Time limits for PHY delay and delay variation according to 5.2.3.

e) Time limits for MAC delay and delay variation according to 5.2.3.

f) The selected medium shall be described in the information model.

5.2.2 PHY and MAC selection

Table 5 specifies the (sub)clause selection of IEEE 802.3-2015.

Table 5 – 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 5.2.1 fulfilled.
Annex 57A - 76A	-	Partial	Applies only if 5.2.1 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 5.2.1 fulfilled.
90	Ethernet support for time synchronization protocols	YES	Relevant for IEEE 802.3br
91 - 95	-	Partial	Applies only if 5.2.1 fulfilled.
Annex 83A – 93C	-	Partial	Applies only if 5.2.1 fulfilled.

Table 6 – 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 5.2.1 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 5.2.1 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 5.2.1 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 5.2.1 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 Gbit/s; beyond optional.
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 5.2.1 fulfilled.

Amendment	Title	Presence	Constraints
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 5.2.1 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 5.2.1 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 5.2.1 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 5.2.1 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 5.2.1 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 5.2.1 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 5.2.1 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 5.2.1 fulfilled.
IEEE P802.3cg™/ Draft	IEEE Standard for Ethernet – Amendment #: 10 Mb/s Single Twisted Pair Ethernet	Partial	Applies only if 5.2.1 fulfilled.

5.2.3 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 7.
- MAC delays shall meet the upper limits of Table 8.

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

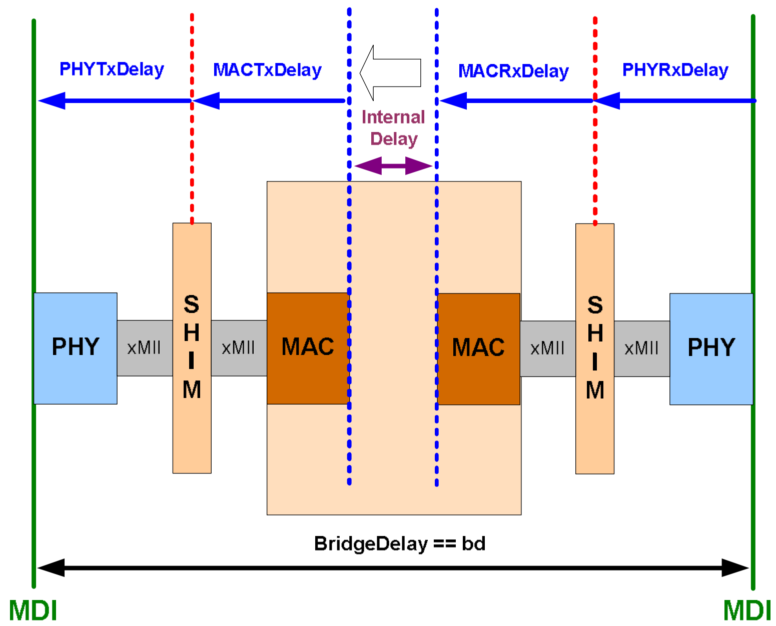

Figure 3 – Delay measurement reference points

Strict numbers such as that presented hereafter in Table 7 and Table 8 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 5.3.3.

Table 7 – Required PHY delays

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

[a] Values from 100 Mbit/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 8 – Required MAC delays

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

Link speed	Maximum RX delay	Maximum TX delay
10 Gbit/s	<< 1 µs	<< 1 µs
25 Gbit/s – 1 Tbit/s	<< 1 µs	<< 1 µs

5.3 IEEE 802.1 profile

5.3.1 General

5.3.1.1 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:

- o 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;
- o 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 5.3.3.

l) Required number of DA-MAC address entries used together with five VLANs (Default, High, High Redundant, Low and Low Redundant) according to 5.3.4.

5.3.1.2 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:

- o Network cycle,
  - < 50 % bandwidth for < 1 Gbit/s for streams;
  - < 20 % bandwidth for >= 1 Gbit/s for streams;
  - < 25 % bandwidth for non-streams;

- Reduction ratio;
- Phase;
- Sequence;
- Transmit of frames as a convoy starts at network cycle start with minimum interframe gap (IFG); 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 2, shall be <= 3 µs in addition to PHY-delay and MAC-delay;

d) Time limits for transfer time (transmit), see Figure 2, shall be <= 3 µs in addition to PHY-delay and MAC-delay;

e) Network access parameters:
- NetworkCycle according to Table 9,
- ReductionRatio according to Formula (1),
- Phase according to Formula (2),
- Sequence according to Formula (3).

Table 9 – Values of the parameter NetworkCycle

NetworkCycle [time]	10 Mbit/s [Data rate]	100 Mbit/s [Data rate]	≥ 1 Gbit/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).

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

Where

ReductionRatio	is the result of the operation
N	is actual factor for the operation

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

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

Where

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

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

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

Where

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

5.3.2 Bridge selections

5.3.2.1 Selection of IEEE 802.1Q-2018 and the related Amendments

Table 10 and Table 11 specify the bridge selections. Selections of IEEE 802.1Q™-2018 are specified in Table 10. The current amendments to IEEE 802.1Q are selected in Table 12.

Table 10 – 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 5.3.1 is fulfilled.
13 - 14		YES	Optional
15 – 16	-	NO	
17		Partial	Applies only if 5.3.1 and 5.5 is fulfilled.
18 - 23		NO	
24		Partial	Applies only if 5.3.1 is fulfilled.
25 - 33		NO	
34	Forwarding and queuing for time-sensitive streams	Partial	Applies only if 5.3.1 is fulfilled.
35		NO	
36		NO	Not coexistent with this profile.
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.
Annex C - E		NO	
Annex F - G		YES	

Clause	Header	Presence	Constraints
Annex H - Q		NO	
Annex R - S		YES	
Annex T		NO	
Annex U		YES	

Table 11 – 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 5.4.
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	NO	–
IEEE P802.1CS/ D1.5	IEEE Standard for Local and metropolitan area networks—LRP (Registration)	YES	–

Table 12 – 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 5.3.1 is fulfilled.
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	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 5.3.1 and 5.5 is fulfilled.
IEEE P 802.1Qcr/D0.0	IEEE Standard for Local and Metropolitan Area Networks—Bridges and Bridged Networks—Amendment: Asynchronous Traffic Shaping	NO	–
IEEE P 802.1Qdd/D0.0	IEEE Standard for Local and Metropolitan Area Networks—Bridges and Bridged Networks—Amendment: RAP	YES	

5.3.2.2 Other profiles

A vendor can decide to implement more than one profile per device. In this case the implemented profiles shall be coexistent. Table 13 shows other profiles.

Table 13 – 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	NO	Coexistent with this profile.
IEEE 802.1CM, 2018	IEEE Standard for Local and metropolitan area networks—Time-Sensitive Networks for Fronthaul	NO	Coexistent with this profile.

5.3.3 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 14.

Table 14 – Required Ethernet Bridge delays

Link speed	Value	Comment
10 Mbit/s	< 30 µs	Bridge delay measure from MII to MII[1)]
100 Mbit/s	< 3 µs	Bridge delay measure from MII to MII[1)]
1 Gbit/s	< 1 µs	Bridge delay measure from RGMII to RGMII[1)]
2,5 Gbit/s	< 1 µs	Bridge delay measure from XGMII to XGMII[1)]
5 Gbit/s	< 1 µs	Bridge delay measure from XGMII to XGMII[1)]
10 Gbit/s	< 1 µs	Bridge delay measure from XGMII to XGMII[1)]
25 Gbit/s – 1 Tbit/s:	< 1 µs	Bridge delay measure from XGMII to XGMII[1)]

[1)] first bit in, first bit out

5.3.4 Bridge FDB requirements

Table 15 shows the required number of supported stream FDB entries.

Table 15 may be implemented as FDB table 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 15 – 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)

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.

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

Table 16 – Expected number of non-stream FDB entries

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

The hash based FDBs shall support a neighborhood for entries according to Table 17.

Table 17 – 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.

5.3.5 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.

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

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.
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 18, Table 19, Table 20, and Table 21 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 18 – MinimumFrameMemory for 100 Mbit/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 19 – MinimumFrameMemory for 1 Gbit/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 20 – MinimumFrameMemory for 2,5 Gbit/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 21 – MinimumFrameMemory for 10 Gbit/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 Mbit/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 5.3.1.2.

5.4 Clock synchronization profile

5.4.1 General

The IEEE 802.1AS™-2019 shall apply according to Table 27.

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.

5.4.2 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.

5.4.3 Working Clock synchronization

Working Clock is used to align actions line, cell or machine wide. The assigned timescale is arbitrary. 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.

High precision working clock synchronization is a prerequisite for control loop implementations with low latency (see Figure 2).

5.4.4 General Requirements for Synchronization

Synchronization domain settings shall be according to Table 22 and Table 23.

Table 22 – Synchronization Domains

Domain	ID	Timescales	Presence	Comments
Working Clock	20	ARB	YES Mandatory	Used for network access and application synchronization. If scheduled traffic is used then also used for Bridge synchronization.
Universal Time	0	TAI	YES Mandatory	Used for Universal Time.
Redundant Working Clock	21	ARB	YES Mandatory	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.

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 23.

Table 23 – 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

The requirements concerning the overall maximum deviation to the grandmaster time in the synchronization domains in Table 24 shall be fulfilled.

Table 24 – Maximum deviation to grandmaster time requirements

Domain	Maximum deviation to grandmaster time	Comments
Working Clock	< 1 µs	Jitter less than +/- 1 µs
Universal Time	< 100 µs	Jitter less than +/- 100 µs

The maximum working clock deviation of two devices, which are synchronized to the same grandmaster, shall be < 2 µs when the working clock requirement of Table 24 is observed.

The maximum error contribution for every single network node of the domains shall be according to Table 25.

Table 25 – Maximum error contribution per network node

Error contribution	Max. error	Comments
Maximum bridge delay error	< 10 ns	Externally measured from the MDI to MDI at the local Bridge
Maximum path delay error	< 10 ns	Externally measured from the MDI to MDI at the local link

Minimal timestamp accuracy for any kind of timestamp shall be according to Table 26.

Table 26 – Timestamp accuracy

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

Table 27 specifies the clock synchronization profile. The selection of the different clock types per device shall be provided using PICS.

Table 27 – 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 5.3.1 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
7.3 – 7.5	–	YES	–
8 – 11	–	YES	–
12	Media-dependent layer specification for IEEE 802.11 links	NO	–
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	YES	–
Annex A	Protocol Implementation Conformance Statement (PICS) proforma [a)]	YES	Optional
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.

5.5 Management profile

End stations and bridges shall provide at least the required managed objects from

- IEEE 802.3
- IEEE 802.3br
- IEEE 802.1Q
- IEEE 802.1Qcc **(Editor note: if needed for delay parameters)**
- 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.

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

5.6 Security profile

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

Table 28 specifies the optional MAC-Security selection.

Table 28 – 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)

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*