

IEEE P802.1DG™/D3.0

Draft Standard for Local and metropolitan area networks — Time-Sensitive Networking Profile for Automotive In-Vehicle Ethernet Communications

Prepared by the Time-Sensitive Networking Task Group of IEEE 802.1 of the
LAN MAN Standards Committee
of the
IEEE Computer Society

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18 **Abstract:** This standard specifies profiles for bounded latency automotive in-vehicle Bridged IEEE
19 802.3 Ethernet networks based on IEEE 802.1 Time-Sensitive Networking (TSN) standards.

20 **Keywords:** TSN, Time-Sensitive Networking, Bridging, Bridges, Bridged Local Area Networks,
21 IEEE 802®, IEEE 802.1Q™, IEEE 802.1DG™, local area networks (LANs), MAC Bridges, Virtual
22 Bridged Local Area Networks (virtual LANs), Automotive In-Vehicle Ethernet Communications.

1 Editor's Foreword

<< Editor's note: This whole section 0. is considered an Editor's Note and will be deleted before publication! >>

0.1 Editor's Notes

<< Editor's note: Throughout this document, all notes presented in italics, between angle braces, and with a gray background, are temporary notes inserted by the Editor for a variety of purposes; these notes and the Editor's Foreword will all be removed prior to publication and are not part of the published document. >>

<< Editor's note: All Editor's Notes after section 0. have been deleted before Working Group Ballot. >>

0.2 Comments and participation in 802.1 standards development

Comments on this draft are encouraged!

PLEASE NOTE: All issues related to IEEE standards presentation style, formatting, spelling, etc. are routinely handled between the 802.1 Editor and the IEEE Staff Editors prior to publication, after balloting and the process of achieving agreement on the technical content of the standard is complete.

Readers are urged to devote their valuable time and energy only to comments that materially affect either the technical content of the document or the clarity of that technical content. Comments should not simply state what is wrong, but also what might be done to fix the problem.

Full participation in the development of this draft requires individual attendance at IEEE 802 meetings. Information on 802.1 activities, working papers, and email distribution lists etc. can be found on the 802.1 website:

<http://ieee802.org/1/>

Use of the email distribution list is not presently restricted to 802.1 members, and the working group has had a policy of considering ballot comments from all who are interested and willing to contribute to the development of the draft. Individuals not attending meetings have helped to identify sources of misunderstanding and ambiguity in past projects. Non-members are advised that the email lists exist primarily to allow the members of the working group to develop standards, and are not a general forum.

All participants in IEEE standards development have responsibilities under the IEEE patent policy and should familiarize themselves with that policy. See <http://standards.ieee.org/about/sasb/patcom/materials.html>.

Comments on this document may be sent to the 802.1 email exploder, to the editors, or to the Chairs of the 802.1 Working Group and Time-Sensitive Networking Task Group.

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2 be acknowledged.*

3 **0.3 Introductory notes to P802.1DG Draft 3.0**

4 Draft 3.0 was prepared by Max Turner based on the few comments received during TG ballot of Draft 2.4
5 and is the first draft to go to WG ballot. Annex Z has been removed, since there were no further comments
6 on the topics mentioned there. All Editor's Notes except for the Foreword in clause 0. have been removed,
7 except for one concerning References Conventions in section 1.6. In the Requirements Terminology section
8 1.3 unused terminology has been removed. All change bars have been removed, as the full document is open
9 for commenting. An Outline was added in section 1.5. Editorial cleanup (typos, page breaks, ...) has been
10 performed throughout the document since the previous draft.

11 **0.4 Introductory notes to P802.1DG Draft 2.4**

12 Draft 2.4 was prepared by Max Turner based on the comments received during TG ballot of Draft 2.3. The
13 PCS have now been fully populated. This is intended to be the last TG ballot draft.

14 **0.5 Introductory notes to P802.1DG Draft 2.3**

15 Draft 2.3 was prepared by Max Turner based on the comments received during TG ballot of Draft 2.2.

16 **0.6 Introductory notes to P802.1DG Draft 2.2**

17 Draft 2.2 was prepared by Max Turner based on the comments received during TG ballot of Draft 2.1. The
18 Time Synchronization Conformance Module was removed, as were some more specialized Bridge features.
19 The later have been moved to Annex for future reference. A very rudimentary draft version of some PCS
20 was included in Annex A. The document structure was straightened out, in that only Clause 5 contains
21 normative language. A longer section on normative and informative language was added, it's usefulness
22 must still proof itself based on further comments.

23 **0.7 Introductory notes to P802.1DG Draft 2.1**

24 Draft 2.1 was prepared by Max Turner based on the comments received during TG ballot of Draft 2.0. A
25 contribution on Talker requirements ([https://www.ieee802.org/1/files/public/docs2023/dg-hoffleit-
26 EndstationProfile-0723-v01.pdf](https://www.ieee802.org/1/files/public/docs2023/dg-hoffleit-EndstationProfile-0723-v01.pdf)) was also considered with editorial liberty.

27 **0.8 Introductory notes to P802.1DG Draft 2.0**

28 << Editor's note: Drafts before 2.0 used [http://www.ieee802.org/1/files/public/docs2019/dg-finn-auto-prof-
29 outline-0119-v02.pdf](http://www.ieee802.org/1/files/public/docs2019/dg-finn-auto-prof-outline-0119-v02.pdf), presented 15 Jan 2019 at the IEEE 802.1interim in Hiroshima, Japan as the basis for
30 their outline. >>

31 Draft 2.0 was prepared by Max Turner based on the structure of IEEE P802.1DC, and the functionality
32 described in the AUTOSAR Ethernet specifications, as well as the OPEN Alliance TC11 work.

33 The document structure of previous drafts, which was originally suggested by [http://www.ieee802.org/1/
34 files/public/docs2019/dg-finn-auto-prof-outline-0119-v02.pdf](http://www.ieee802.org/1/files/public/docs2019/dg-finn-auto-prof-outline-0119-v02.pdf) (presented on Jan. 15th 2019 during the IEEE
35 802.1 interim meeting in Hiroshima, Japan) was abandoned. The previous Annex Z was deleted. The

1 Bibliography, the Abbreviations, and the Definitions will be repopulated once new text has reached
2 consensus.

3 The Draft creates a completely new modular profile structure. As there were no contributions on the
4 excluded topics from Draft 1.4, these will remain excluded.

5 Further topics have been excluded:

- 6 — Life Cycle
- 7 — Security
- 8 — Safety
- 9 — Topology
- 10 — Redundancy
- 11 — Protocols

12 As indicated in [https://www.ieee802.org/1/files/public/docs2023/dg-turner-finn-profile-commented-0223-](https://www.ieee802.org/1/files/public/docs2023/dg-turner-finn-profile-commented-0223-v01.pdf)
13 [v01.pdf](https://www.ieee802.org/1/files/public/docs2023/dg-turner-finn-profile-commented-0223-v01.pdf) (presented in the call on Feb. 21st 23)

14 In order to avoid duplication, the time synchronization section has been removed and replaced by a
15 reference to the AUTOSAR Time Synchronization specifications.

16 Draft 2.0 will go through Task Group ballot and further development of the document will be based on
17 comment resolution as well as further discussions in AUTOSAR and Open Alliance.

18 **0.9 Introductory notes to P802.1DG Draft 1.4**

19 Draft 1.4 was prepared by Max Turner based on Draft 1.3, contributions during the Task Group meetings as
20 well as input collected by the editor personally outside Task Group meetings. The draft focuses on
21 informative text in order to align the group on some basic concepts before normative language is added. The
22 structure of the document was revised to a large degree since Draft 1.3, so the reader is advised to read the
23 whole document and not try to focus just on changes, which may not all be obvious.

24 Draft 1.4 will go through Task Group ballot and further development of the document will be based on
25 comment resolution as well as further contributions during Task Group meetings.

26 What Draft 1.4 specifically does not cover:

- 27 — Wireless links of any sort (cellular, wifi, ...)
- 28 — Ethernet encapsulation (USB, APIX, ...)
- 29 — Environmental Specifications (AEC Q100, temp., EMC, EMI, ...)
- 30 — Layer 1 details, except for a note in Section on Latency
- 31 — Link Aggregation
- 32 — TPMR specifics
- 33 — Smart Charge Communication
- 34 — OBD to Tester (ISO 13400) details
- 35 — Robo-Taxi specific requirements, except notes in Annex K
- 36 — Profile definitions or requirements

37 All of the above are open to be included in future documents, given enough input on comments and
38 contributions.

1 As this Draft 1.4 is very much a request for input, the editor is looking for comments with proposed
2 resolution! Approve votes without comments are not considered helpful at the current stage of work, neither
3 are comments without any remedy or input.

4 **0.10 Introductory notes to P802.1DG Draft 1.3**

5 Draft 1.3 was prepared by Craig Gunther as a result of comment resolution on Draft 1.2. The purpose of
6 Draft 1.3 is to establish a baseline for further development, via contributions by Task Group members, of the
7 profile conformance requirements and any additional tutorial information. Draft 1.3 is not intended to go to
8 Task Group ballot. It is expected that the Task Group participants will submit text for inclusion in the
9 creation of D1.4 which will then be submitted for the next Task Group ballot.

10 This draft also addresses the concept of packet bursts related to 802.1CB missing packet recovery. It now
11 correctly states that bursts might or might not be present depending on egress shaping, whereas in previous
12 drafts they erroneously stated that bursts were always expected.

13 This document currently comprises:

- 14 — A title page for the proposed standard including an Abstract and Keywords. This title page will be
15 retained following working group approval of this draft, i.e. prior to Standards Association (a.k.a.
16 Sponsor) ballot.
- 17 — The editors' forewords, including this text. These include an unofficial and informal appraisal of
18 history and status, introductory notes to each draft that summarize the progress and focus of each
19 successive draft, and requests for comments and contributions on major issues.
- 20 — IEEE boilerplate text.
- 21 — A record of participants (not included in early drafts but added prior to publication).
- 22 — The introduction to this standard.
- 23 — The proposed standard proper.
- 24 — An Annex Z comprising the editors' discussion of issues. This annex will be deleted from the
25 document prior to sponsor ballot.

26 During the early stages of draft development, 802.1 editors have a responsibility to attempt to craft
27 technically coherent drafts from the resolutions of ballot comments and the other discussions that take place
28 in the working group meetings. Preparation of drafts often exposes inconsistencies in editors instructions or
29 exposes the need to make choices between approaches that were not fully apparent in the meeting. Choices
30 and requests by the editors' for contributions on specific issues will be found in the editors' introductory
31 notes to the current draft, at appropriate points in the draft, and in Annex Z. Significant discussion of more
32 difficult topics will be found in the last of these.

33 The ballot comments received on each draft, and the editors' proposed and final disposition of comments,
34 are part of the audit trail of the development of the standard and are available, along with all the revisions of
35 the draft on the 802.1 web site (for address see above).

36 **0.11 Introductory notes to P802.1DG Draft 1.2**

37 Draft 1.2 was prepared for the second Task Group ballot by Craig Gunther, as a result of comment resolution
38 on Draft 1.1. Revision bars in Draft 1.2 are relative to Draft 1.1. The major focus of Draft 1.2 is to introduce
39 profile(s) and move the tutorial content from clause 6 to Annex E. Regarding the profile(s), there are lots of
40 questions in the Editor's note in clause 14 and items in Annex Z that the TG is going to have to address to
41 complete the profile(s).

1 Text from Draft 1.1 was changed as per ballot comments, but not all the requests for new figures or text have
2 been completed in Draft 1.2; however, corresponding Editor's notes or Annex Z entries were added so as to
3 not lose track of the resolution of those comments. Significant changes from Draft 1.1 include:

- 4 a) Clause 14 introduces the Base and Extended profiles including tables specifying which TSN
5 features will be included in each profile and how they are configured.
- 6 b) Clause 6.2 through the end of clause 6 has been moved to the new Informative Annex E. No change
7 bars or addition/deletion markings were included with this move. Any changes made after the text
8 was moved to Annex E are highlighted appropriately.
- 9 c) Introduced the concept of Trusted and Untrusted networks and devices.
- 10 d) Removed all examples from Annex A (PCS). These PCS entries will be added as the profile(s) are
11 developed.
- 12 e) Unresolved comments from Draft 1.1 have been recorded in Annex Z if the specific solution is not
13 yet known. If a solution is understood but not yet implemented, or a more appropriate location than
14 Annex Z is determined, an Editor's note has been put in those specific locations.

15 **0.12 Introductory notes to P802.1DG Draft 1.1**

16 Draft 1.1 was prepared by Craig Gunther for the initial Task Group ballot. Draft 1.0 was reviewed at the
17 September 2019 interim in Edinburgh, the September 23 one-day interim in Detroit, and on the P802.1DG
18 bi-weekly call on October 1. Based on comments received during those presentations, and especially from
19 comments provided by the Editors of IEEE P802.1AS-Rev and IEEE Std 802.1CB-2017, updates to D1.0
20 have been included in the creation of this draft D1.1.

21 **0.13 Introductory notes to P802.1DG Draft 1.0**

22 Draft 1.0 was prepared by Craig Gunther for review before the initial Task Group ballot. Clause 6 now
23 includes an introduction to in-vehicle networks and how TSN could influence those designs. New
24 educational/tutorial information for 802.1CB Frame Replication and Elimination for Reliability (FRER) and
25 802.1AS Timing and Synchronization for Time-Sensitive Applications. The intent of these sections is to
26 help those familiar with the concepts, but not the details of those TSN standards. This is not meant as a recap
27 of the TSN standards, but a summarization of important details and discussion of subtle points that are often
28 overlooked or forgotten. It is the Editor's intent that additional TSN standards will be added to this clause as
29 those standards are identified for IVN use. It is the Editor's opinion that many who will use this standard are
30 not involved with 802.1 in general and TSN in particular. As such, the Editor feels this approach will be
31 extremely beneficial to that audience. Opinions in favor or against this approach are solicited. There is a
32 substantial amount of work in this approach and if readers of this standard do not perceive a benefit then it
33 would be best to spend that time on other areas of this standard.

34 Clause 14 is a placeholder to gather opinions on how we should determine what constitutes a profile. The
35 Editor would like to get some direction so the next draft can fully address a simple profile, if possible, and
36 update Clause 6 and other clauses as needed.

37 Clause 3 (definitions) and Annex D (bibliography) have also been updated.

38 **0.14 Introductory notes to P802.1DG Draft 0.1**

39 Draft 0.1 was prepared by Craig Gunther as a vehicle to continue to gather all the boiler plate text and
40 generate a starting point for future drafts. Clause A boiler plate text was completed. A new clause B was
41 introduced to hold extended definition of terms, beyond that specified in clause 3. This draft is not intended

1 for Task Group ballot. Everything in this draft can be considered a contribution to the Time-Sensitive
2 Networking Task Group by the editor; nothing has been approved by the Task Group or Working Group.

3 **0.15 Introductory notes to P802.1DG Draft 0.0**

4 Draft 0.0 was prepared by Craig Gunther as a vehicle to gather all the boiler plate text and generate a starting
5 point for future drafts. This draft is not intended for Task Group ballot. Everything in this draft can be
6 considered a contribution to the Time-Sensitive Networking Task Group by the editor; nothing has been
7 approved by the Task Group or Working Group.

8 **0.16 Project Authorization Request, Scope, Purpose, and Five Criteria**

9 A PAR (Project Authorization Request) for P802.1DG was approved by the IEEE Standards Association on
10 February 8, 2019. The following information is taken from the 802.1DG PAR.

11 **0.16.1 Scope of Proposed Project:**

12 This standard specifies profiles for secure, highly reliable, deterministic latency, automotive in-
13 vehicle Bridged IEEE 802.3 Ethernet networks based on IEEE 802.1 Time-Sensitive Networking
14 (TSN) standards and IEEE 802.1 Security standards.

15 **0.16.2 Purpose of Proposed Project:**

16 This standard provides profiles for designers and implementers of deterministic IEEE 802.3
17 Ethernet networks that support the entire range of in-vehicle applications including those requiring
18 security, high availability and reliability, maintainability, and bounded latency.

19 **0.16.3 Need for the Proposed Project:**

20 The automotive segment does not have a standards-based profile for IEEE 802.1 Time-Sensitive
21 Networking (TSN) standards as usage can vary widely based on the networking scenarios. The lack
22 of a profile makes the definition of the automotive manufacturer's requirements and the
23 implementation of those requirements by suppliers more difficult and costly. Thus there is a need for
24 standardization of the selection and use of IEEE 802 standards and features in order to be able to
25 deploy secure highly reliable converged networks.

26 **0.16.4 IEEE 802 criteria for standards development (CSD)**

27 The CSD documents an agreement between the WG and the Sponsor that provides a description of
28 the project and the Sponsor's requirements more detailed than required in the PAR. The CSD
29 consists of the project process requirements, 1.1, and the 5C requirements, 1.2.

30 **1.1 Project process requirements**

31 **1.1.1 Managed objects**

32 Describe the plan for developing a definition of managed objects. The plan shall specify
33 one of the following:

- 34 a) The definitions will be part of this project.
- 35 b) The definitions will be part of a different project and provide the plan for that project or
36 anticipated future project.
- 37 c) The definitions will not be developed and explain why such definitions are not needed.

38 Item c) is applicable to this project because this project will specify profiles that define the
39 use and configuration of functions specified in other IEEE 802 standards, thus relying on

the managed objects specified by the referred standards.

1.1.2 Coexistence

A WG proposing a wireless project shall demonstrate coexistence through the preparation of a Coexistence Assurance (CA) document unless it is not applicable.

a) Will the WG create a CA document as part of the WG balloting process as described in Clause 13? (yes/no)

b) If not, explain why the CA document is not applicable.

b) This project is not a wireless project; therefore, the CA document is not applicable.

1.2 5C requirements

1.2.1 Broad market potential

Each proposed IEEE 802 LMSC standard shall have broad market potential. At a minimum, address the following areas:

a) Broad sets of applicability.

b) Multiple vendors and numerous users.

a) IEEE 802.1 Time-Sensitive Networking (TSN) gives an opportunity to unify networking for automotive in-vehicle deterministic Ethernet networks. TSN is the foundation to provide interoperability and connectivity for automotive applications on converged networks to simultaneously support operational traffic that has pre-determined latency requirements. However, the breadth of choices in the use of the TSN features inhibits the interoperability of products designed for a particular market. By narrowing the focus, this profile expands the market for Bridges, End Stations, network interface cards, and integrated circuits. The specification and use of TSN features in these scenarios via TSN profiles is beneficial for suppliers offering and/or developing TSN products, e.g., in order to ease interoperability and deployment.

b) Many automotive manufacturers and suppliers consider TSN as the next generation Ethernet networking technology enabler to meet the deterministic latency, security and high reliability requirements for networking within the vehicle. The TSN profiles for automotive are essential for them.

1.2.2 Compatibility

Each proposed IEEE 802 LMSC standard should be in conformance with IEEE Std 802, IEEE 802.1AC, and IEEE 802.1Q. If any variances in conformance emerge, they shall be thoroughly disclosed and reviewed with IEEE 802.1 WG prior to submitting a PAR to the Sponsor.

a) Will the proposed standard comply with IEEE Std 802, IEEE Std 802.1AC and IEEE Std 802.1Q?

b) If the answer to a) is no, supply the response from the IEEE 802.1 WG.

a) Yes, this standard will comply with IEEE Std 802, IEEE Std 802.1AC and IEEE Std 802.1Q.

The review and response is not required if the proposed standard is an amendment or revision to an existing standard for which it has been previously determined that compliance with the above IEEE 802 standards is not possible. In this case, the CSD statement shall state that this is the case.

1.2.3 Distinct Identity

Each proposed IEEE 802 LMSC standard shall provide evidence of a distinct identity. Identify standards and standards projects with similar scopes and for each one describe why the proposed project is substantially different.

No other IEEE 802 standard or project defines Time-Sensitive Networking profiles for automotive in-vehicle Ethernet communications.

1.2.4 Technical Feasibility

Each proposed IEEE 802 LMSC standard shall provide evidence that the project is technically feasible within the time frame of the project. At a minimum, address the following items to demonstrate technical feasibility:

a) Demonstrated system feasibility.

b) Proven similar technology via testing, modeling, simulation, etc.

a) The proposed standard will specify profiles for the use of IEEE 802 standards, for which system feasibility has been demonstrated.

b) The proposed standard will use IEEE 802 standards for which the technology has been proven.

1.2.5 Economic Feasibility

Each proposed IEEE 802 LMSC standard shall provide evidence of economic feasibility. Demonstrate, as far as can reasonably be estimated, the economic feasibility of the proposed project for its intended applications. Among the areas that may be addressed in the cost for performance analysis are the following:

a) Balanced costs (infrastructure versus attached stations).

b) Known cost factors.

c) Consideration of installation costs.

d) Consideration of operational costs (e.g., energy consumption).

e) Other areas, as appropriate.

a) The well-established cost balance between infrastructure and attached stations will not be changed by the proposed standard.

b) The cost factors are known for the IEEE 802 standards that will be used by the proposed standard.

c) There are no incremental installation costs relative to the IEEE 802 standards that will be used by the proposed standard.

d) There are no incremental operational costs relative to the existing costs associated with the IEEE 802 standards that will be used by the proposed standard.

e) No other areas have been identified.

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4 **Introduction to IEEE P802.1DG™/D3.0IEEE P802.1DG™/D3.0**

This introduction is not part of IEEE P802.1DG™/D3.0, IEEE Standards for Local and Metropolitan Area Networks—Draft Standard for Local and metropolitan area networks —Time-Sensitive Networking Profile for Automotive In-Vehicle Ethernet Communications

5 This Standard defines the Time-Sensitive Networking Profile for Automotive In-Vehicle Ethernet
6 Communications.

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

11 Secretary, IEEE-SA Standards Board
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13 P.O. Box 1331
14 Piscataway, NJ 08855-1331
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1 IEEE P802.1DG™/D3.0

2 Draft Standard for 3 Local and metropolitan area 4 networks—

5 6 Time-Sensitive Networking Profile for 7 Automotive In-Vehicle Ethernet 8 Communications

9 1. Overview

10 1.1 Scope

11 This standard specifies profiles for bounded latency automotive in-vehicle Bridged IEEE 802.3 Ethernet
12 networks based on IEEE 802.1 Time-Sensitive Networking (TSN) standards.

13 1.2 Purpose

14 This standard provides profiles for designers and implementers of automotive IEEE 802.3 Ethernet
15 networks that support the entire range of in-vehicle applications.

16 1.3 Requirements terminology

17 “Supported” - The capability is present, but might not execute in a certain situation or configuration.

18 “Activated” - The capability is present (i.e., it is supported), and will execute in this situation or
19 configuration.

20 If a functionality is described to be in a certain state “by default”, this means that other conformance
21 modules might still require a different setting, but if no further conformance clauses apply, this is the desired
22 setting.

23 The following terminology is used in Clause 5 and Annex A:

24 The word “shall” is used for mandatory requirements strictly to be followed in order to conform to the
25 standard and from which no deviation is permitted (“shall” equals “is required to”).

26 The word “should” indicates that among several possibilities one is recommended as particularly suitable,
27 without mentioning or excluding others; or that a certain course of action is preferred but not necessarily
28 required (“should” equals “is recommended that”, but not required).

1 The word “may” is used to describe implementation or administrative choices (“may” means “is permitted
2 to” but not required to, and hence, “may” and “may not” mean precisely the same thing). This technically
3 applies to literally anything that is not in the other categories above.

4 The term “shall be supported” means implementation is mandatory, but activation is optional.

5 The term “shall be activated” means implementation is mandatory and activation is mandatory.

6 The term “shall not be activated” means activation is prohibited (the phrase “shall not be supported” is
7 deemed useless, as it is not testable).

8 All other clauses use the following terminology:

9 The words “might” or “can” are used for statements of possibility (“might”/“can” mean “there is a
10 possibility that”).

11 The neutral words “is” or “does” are used to describe a capability, procedure, or behavior; independent of it
12 being required, prohibited, recommended, discouraged, or permitted.

13 “Not activated” - The function may still execute but perform a neutral operation (e.g., map all input onto
14 themselves at the output instead of modifying them)

15 **1.4 Introduction**

16 This Time-Sensitive Networking Profile for Automotive In-Vehicle Ethernet Communications standard
17 addresses the use of Time-Sensitive Networking (TSN) techniques to meet the bandwidth, latency, and
18 synchronization needs for communications within automotive vehicles. The profile introduces the subtleties
19 of the operation of the TSN standards and the side-effects of the choices made when configuring various
20 TSN functionalities.

21 The goal of this standard is to provide information to OEMs, Tier 1 and Tier 2 that will help them with the
22 design of vehicular systems enabling bounded latency in automotive in-vehicle networks. As the TSN suite
23 of standards are broad and intended for use in a variety of environments, this standard narrows the focus
24 from the broad set of available TSN features to those that are applicable to in-vehicle networks (IVN). This
25 standard determines the TSN features that are directly applicable to IVNs and explains how the associated
26 TSN standards are used, including recommendations about how to configure optional parameters.

27 **1.5 Outline of the document structure**

28 The present standard in Clause 5 specifies Bridge and End Station requirements as well as optional
29 conformance modules. All normative language is aggregated in Clause 5. Clauses 6. through 10. describe
30 the TSN features in more detail and provide references to the base standards.

31 **1.6 Reference conventions**

32 The present standard makes frequent references to specific sections in several other standards and
33 amendments. To make these references less cumbersome the present standard uses the notation described in
34 Table 1-1.

35 << Editor’s note: The editor found the IEEE-SA convention for cross-document cross-references, “x.y in IEEE
36 Std 802.1Q-2018” to be unwieldy because of the large number of references to the above documents,
37 sometimes three or four in one sentence; hence, the alternative presented above. >>

Table 1-1—Conventions for references

Reference shorthand notation	Complete reference
[AC]:x.y	section x.y in IEEE std 802.1AC-2016
[CB]:x.y	section x.y in IEEE Std 802.1CB-2017
[CBdb]:x.y	section x.y in IEEE Std 802.1CBdb-2021
[Q]:x.y	section x.y in IEEE Std 802.1Q-2022
[B##]:x.y	section x.y in any document from the Bibliography (Annex H)
[AR###]:x.y	section x.y in AUTOSAR document ID ### of R23-11
[AE]:x.y	section x.y in IEEE Std 802.1AE-2018
[802.3]:x.y	section x.y in IEEE Std 802.3-2022
x.y	section x.y in the present standard

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies. Non-normative references (i.e., that provide additional information not required for the application of this document) are given in Annex H.

NOTE 1—The inclusion of a document in this list of normative references indicates that information in that document is necessary to implement the present standard. It does not imply that any other part of that referenced document is required to be implemented by a system conformant to the present standard.

NOTE 2—Active projects for the IEEE 802.1 Working Group can be found on the homepage: <https://1.ieee802.org>.

NOTE 3—IEEE 802.1 standards can be downloaded from through the IEEE GET Program: <https://standards.ieee.org/products-programs/ieee-get-program/>.

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[802] 802®-2014 IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture

[CB] IEEE Std 802.1CB™, IEEE Standard for Local and metropolitan area networks—Frame Replication and Elimination for Reliability.

[CBdb] IEEE Std 802.1CBdb™, IEEE Standard for Local and metropolitan area networks—Frame Replication and Elimination for Reliability. Amendment 2: Extend Stream Identification Functions.

[Q] IEEE Std 802.1Q™, IEEE Standard for Local and metropolitan area networks—Bridges and Bridged Networks.

[802.3] IEEE Std 802.3-2022, IEEE Standard for Ethernet.

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

3. Definitions

The present standard uses terminology that is more consistent with automotive uses, without contradicting the established IEEE 802 terminology.

This standard makes use of the following terms defined in IEEE Std 802 ([802]):

— Bridge

— End Station

— Station

This standard makes use of the following terms defined in IEEE Std 802.3 ([802.3]):

— Frame

— Packet

11

4. Abbreviations

This present standard uses the following abbreviations:

3	ATS	Asynchronous Traffic Shaper
5	BE	Best Effort
7	CBS	Credit Based Shaper
9	CQF	Cyclic Queuing and Forwarding
11	ECU	Electronic Control Unit
13	EISS	Enhanced Internal Sublayer Service
15	FRER	Frame Replication and Elimination for Reliability
17	ICV	Integrity Check Value
19	IVN	In Vehicle Network
21	IPG	InterPacket Gap
23	IPV	Internal Priority Value
25	MEF	Metro Ethernet Forum
27	MSDU	MAC Service Data Unit
29	TAS	Time Aware Shaper
31	TC	Traffic Class
33	SDU	Service Data Unit
35	SFD	Start of Frame Delimiter
37	SotA	Software over the Air update

39

1 5. Conformance Modules

2 5.1 Introduction

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

5 5.2 Profile Conformance Statements (PCS)

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

9 5.3 Physical Layer requirements

10 A Port of a Station claiming compliance with this standard shall support an IEEE 802.3 point-to-point full-
11 duplex ([802.3]:1.4.276) link segment ([802.3]:1.4.309).

12 NOTE—This is consistent with the overlapping limitations imposed in [Q], [BA], and [AS-2020].

13 5.4 Bridge requirements

14 5.4.1 Mandatory Bridge requirements

15 Any Bridge claiming conformance to this present standard shall on all of its ports:

- 16 a) Process ingress frames in the order as specified in 6.1.
- 17 b) Process egress frames in the order as specified in 6.2.
- 18 c) Support C-VLAN tags ([Q]:5.5)
- 19 d) Comply to CM-IS as specified in 5.6.
- 20 e) Comply to CM-Pol as specified in 5.7.
- 21 f) Comply to CM-BS as specified in 5.8.
- 22 g) Support the Learning Process as specified in 6.15.
- 23 h) Support Congestion Separation as specified in 7.2.
- 24 i) Support the maximum SDU size as specified in 6.18.1
- 25 j) Support the Frame Filtering ([Q]:8.6.3) as specified in 6.16
- 26 k) Support the Static IPV configuration as specified in 6.19.1
- 27 l) By default, all Stream Gates ([Q]:8.6.5.4) shall always be in the state OPEN state (6.19).

28 NOTE—Item l) is changed to a non-default state, when option CM-TAS (Item b) of 5.4.2) is activated.

29 5.4.2 Bridge options

- 30 a) A Bridge claiming conformance to this present standard should support Time Synchronization as
31 specified in 6.5.
- 32 b) A Bridge claiming conformance to this present standard may comply to CM-TAS as specified in
33 5.10 on any number of ports.

- 1 c) A Bridge claiming conformance to this present standard may comply to CM-Pre as specified in 5.11
- 2 on any number of ports.
- 3 d) A Bridge claiming conformance to this present standard may support Hop-by-Hop MACsec as
- 4 defined in 6.6.2 on any number of ports.
- 5 e) A Bridge claiming conformance to this present standard may discard frames after the frame's
- 6 lifetime is reached, as specified in 6.25.

7 5.5 End Station requirements

8 5.5.1 Mandatory End Station ingress path requirements

9 Any End Station claiming conformance to this present standard shall:

- 10 a) Comply with CM-Pol as specified in 5.7.
- 11 b) Perform Destination MAC address filtering
- 12 c) Support Out-facing Ingress Stream Identification Function(s) ([CB]:9.1.1.5) as specified in 6.11.2
- 13 d) Support Ingress filtering ([Q]:8.6.2) as specified in 6.14
- 14 e) Support Stream Filter assignment ([Q]:8.6.5.3 b) as specified in 6.17
- 15 f) Process frames on ingress in the order as specified in 6.3

16 5.5.2 Mandatory End Station egress path requirements

17 Any End Station claiming conformance to this present standard shall:

- 18 a) Support one or more shaping mechanisms to generate traffic conformant as input to the shapers
- 19 deployed in the network.
- 20 b) Support max. SDU Size Filtering ([Q]:8.6.5.3.1) as specified in 6.18.1
- 21 c) Support Queuing frames ([Q]:8.6.6) as specified in 6.21
- 22 d) Support Transmission selection ([Q]:8.6.8) as specified in 6.22
- 23 e) Process frames on egress in the order specified in 6.4

24 5.5.3 End Station Options

25 Any End Station claiming conformance to this present standard may:

- 26 a) Support Time Synchronization as specified in 6.5.
- 27 b) Comply with CM-TAS as specified in 5.10.
- 28 c) Comply with CM-Pre as specified in 5.11.
- 29 d) Support Hop-by-Hop MACsec processing ([AE]:11.4) as specified in 6.6.2
- 30 e) Support Stream Gating on ingress ([Q]:8.6.5.4) as specified in 6.19.3
- 31 f) Support Flow metering on ingress ([Q]:8.6.5.5)

1 5.6 Conformance Module Ingress Selection (CM-IS)

2 A port of a Station claiming conformance to CM-IS shall:

- 3 a) Support the Port-based VLAN Classification ([Q]:6.9.1 f)) as specified in 6.8
- 4 b) Support the Priority Code Point Decoding ([Q]:6.9.3) as specified in 6.9
- 5 c) Support the Priority Regeneration ([Q]:6.9.4) as specified in 6.10
- 6 d) Support the Ingress Stream Identification Function(s) ([CB]:6.2) as specified in 6.11.1
- 7 e) Support the Active topology enforcement ([Q]:8.6.1) as specified in 6.13
- 8 f) Support the Ingress Filtering ([Q]:8.6.2) as specified in 6.14
- 9 g) Support Egress Filtering ([Q]:8.6.4)
- 10 h) Support Queuing Frames ([Q]:8.6.6) as specified in 6.21
- 11 i) Support Transmission Selection as specified in 6.22
- 12 j) Support the Egress VID Translation ([Q]:6.9 g)) as specified in 6.24

13 5.7 Conformance Module Basic Policing (CM-Pol)

14 A port of a Station claiming conformance to CM-Pol shall:

- 15 a) Support the Acceptable Frame Types Filter ([Q]:6.9 c)) as specified in 6.7
- 16 b) Support the Maximum SDU Size Filtering as specified in 6.18
- 17 c) Support the Flow Metering ([Q]:8.6.5.5) as specified in 6.20
- 18 d) Support the Flooding Protection as specified in 6.12

19 5.8 Conformance Module Basic Shap

20 5.9 ers (CM-BS)

21 A port of a Station claiming conformance to CM-BS shall:

- 22 a) Provide the capabilities for the Credit Based Shaper ([Q]:8.6.8.2) as detailed in Clause 9.
- 23 b) Provide the capabilities for the Asynchronous Traffic Shaper ([Q]:8.6.11) as specified in Clause 8.

24 5.10 Conformance Module Time Aware Shaper (CM-TAS)

25 A port of a Station claiming conformance to CM-TAS shall:

- 26 a) Activate Time Synchronization (6.5)
- 27 b) Provide the capabilities for the Time Aware Shaper ([Q]:8.6.8.4) as specified in Clause 10
- 28 c) Enable the Time dependent IPV configuration as per 6.19.2.
- 29 d) Enable the Time dependent gate states as per 6.19.3.

5.11 Conformance Module Preemption (CM-Pre)

A port of a Station claiming conformance to CM-Pre shall:

- a) Support the preemptable MAC as per 6.26.1.
- b) Support the express MAC as per 6.26.2.

1 6. IEEE 802.1 Features

2 6.1 Bridge Receive Path Processing Order (ingress)

3 On the receive path (ingress), the IEEE 802.1 Features are executed in the following order, if they are
4 activated:

- 5 a) Default Priority Assignment ([AC]:13.1)
- 6 b) Hop-by-Hop MACsec processing ([AE]:11.4)
- 7 c) Support of the EISS ([Q]:6.9)
- 8 d) Frame Type Acceptance filter ([Q]:6.9 c))
- 9 e) Out-facing Ingress Stream Identification Function(s) ([CB]:9.1.1.5)
- 10 f) Port-based VLAN Classification ([Q]:6.9 d))
- 11 g) Priority Code Point Decoding ([Q]:6.9.3)
- 12 h) Priority Regeneration ([Q]:6.9.4)
- 13 i) Active topology enforcement ([Q]:8.6.1)
- 14 j) Ingress filtering ([Q]:8.6.2)
- 15 k) Frame filtering ([Q]:8.6.3)
- 16 l) Egress filtering ([Q]:8.6.4)
- 17 m) Stream filter assignment ([Q]:8.6.5.3 b) and c))
- 18 n) Maximum SDU Size Filtering ([Q]:8.6.5.3.1)
- 19 o) Stream Gating ([Q]:8.6.5.4)
- 20 p) Flow metering ([Q]:8.6.5.5)
- 21 q) ATS Eligibility Time Assignment ([Q]:8.6.5.6)

22 NOTE 1—Potentially not all listed feature are required, depending on the conformance modules (Clause 5) applied.

23 6.2 Bridge Transmit Path Processing Order (egress)

24 On the transmit path (egress), the IEEE 802.1 Features are executed in the following order, if they are
25 activated:

- 26 a) In-facing Egress Stream Identification Function(s) ([CB]:9.1.1.4)
- 27 b) FRER Functionality (C.8)
- 28 c) Out-facing Egress Stream Identification Function(s) ([CB]:9.1.1.3)
- 29 d) Queuing frames ([Q]:8.6.6)
- 30 e) Queue Management (6.25)
- 31 f) Transmission selection ([Q]:8.6.8)
- 32 g) Priority Code Point Encoding ([Q]:6.9.3)
- 33 h) Egress VID translation ([Q]:6.9 g))
- 34 i) Support of the EISS ([Q]:6.9)
- 35 j) Hop-by-Hop MACsec processing ([AE]:11.4)
- 36 k) Support of the ISS ([Q]:6.7.1)

37 NOTE—Potentially not all listed feature are required, depending on the conformance modules (Clause 5) applied.

1 6.3 End Station Receive Path Processing Order (ingress)

2 Frames are processed in the following order by the listed features, if they are activated.

- 3 a) Hop-by-Hop MACsec processing ([AE]:11.2)
- 4 b) Frame Type Acceptance filter ([Q]:6.9 c))
- 5 c) Destination MAC address filtering as per 5.5.1 item b)
- 6 d) Ingress filtering ([Q]:8.6.2)
- 7 e) Out-facing Ingress Stream Identification Function(s) ([CB]:9.1.1.5)
- 8 f) Stream filter assignment ([Q]:8.6.5.3 b)
- 9 g) Maximum SDU Size Filtering ([Q]:8.6.5.3.1)
- 10 h) Stream Gating ([Q]:8.6.5.4)
- 11 i) Flow metering ([Q]:8.6.5.5)

12 NOTE—Potentially not all listed feature are required, depending on the conformance modules (Clause 5) applied.

13 6.4 End Station Transmission Path Processing Order (egress)

14 Frames are processed in the following order by the listed features, if they are activated.

- 15 a) Maximum SDU Size Filtering ([Q]:8.6.5.3.1)
- 16 b) Shaping as per 5.5.2 item a)
- 17 c) Queuing frames ([Q]:8.6.6)
- 18 d) Transmission selection ([Q]:8.6.8)
- 19 e) MACsec processing ([AE]:11.4)

20 NOTE—Potentially not all listed feature are required, depending on the conformance modules (Clause 5) applied.

21 6.5 Time Synchronization

22 Time synchronization is an essential component of in-vehicle applications using this standard; however, this
23 standard does not specify a particular solution for time synchronization as different solutions have already
24 been deployed in the field. Some examples of time synchronization specifications that can be used in
25 applications requiring time synchronization are as follows:

- 26 a) IEEE Std 802.1AS-2020 [AS-2020]
- 27 b) IEEE Std 802.1AS-2011 [AS-2011]
- 28 c) AVnu Automotive profile [B8]
- 29 d) AUTOSAR Time Synchronization Protocol [AR897]
- 30 e) IEEE Std 1588-2019 ([B1] and its profiles: <https://sagroups.ieee.org/1588/ptp-profiles/>)

31 NOTE—It is up to the system integrator to select time synchronization solutions that meet their application's
32 requirements.

1 6.6 MACsec processing ([AE])

2 6.6.1 General MACsec considerations

3 The present standard does not address the details of a MACsec implementation. If an integrator chooses to
4 implement MACsec in (parts of) the network, they at least need to consider MACsec's impact on for
5 example Preemption (5.11), TAS gate schedule (5.10), Shapers (5.8), and policing (5.7). As this list is not
6 claiming completeness, the implementer is advised to consider further implications.

7 Annex C.4.5 describes the placement of the SecTAG in the Frame's header.

8 6.6.2 Hop-by-Hop MACsec

9 On a VLAN aware Port, on ingress the SecTAG is processed before the VLAN Tag, if MACsec is applied
10 Hop-by-Hop.

11 6.7 Acceptable Frame Types Filter ([Q]:6.9 c))

12 The Acceptable Frame Types Filter supports the following filter rules:

- 13 a) Admit Only VLAN-tagged frames (C.4.3)
- 14 b) Admit Only Untagged (C.4.2) and Priority-tagged frames (C.4.4)
- 15 c) Admit All frames

16 Frames not matching the activated Filter rule, are discarded silently. Counters can be present to keep track of
17 the number of frames dropped or passed.

18 6.8 Port-based VLAN Classification ([Q]:6.9.1 f))

19 If Port-based VLAN classification is activated, and Port-and-Protocol-based VLAN classification is not
20 activated, and:

- 21 a) the Frame is Untagged (C.4.2), or
- 22 b) Priority-tagged (C.4.4), or
- 23 c) the VID translation table is activated and the translation already set the *vlan_identifier* parameter to
24 Zero,

25 the *vlan_identifier* parameter is set/changed to the Port-VID (PVID) value for the port.

26 NOTE 1—Port-and-Protocol-based VLAN classification is not required by the present standard, but could still be active
27 in the device.

28 NOTE 2—The VID translation table is not required by the present standard, but could still be active in the device.

29 6.9 Priority Code Point Decoding ([Q]:6.9.3)

30 The *drop_eligible* parameter is set to the received DEI Field's value (1 bit).

31 The *priority* parameter is set to the received PCP Field's value (3 bit).

6.10 Priority Regeneration ([Q]:6.9.4)

If the Priority Regeneration is activated, the *priority* is set/changed according to the Priority Regeneration configuration.

6.11 Ingress Stream Identification Function(s) ([CB]:6.2)

6.11.1 Stream Identification Function(s) for Bridges

Only passive out-facing stream identification functions are configurable, with the Identification Mask Length as stated in 6.11.3.

NOTE 1—Please refer to the informative Annex D on Stream Identification for a rationale why only out-facing ingress stream identification functions are supported.

The Stream Identification functions operate on the *M_UNITDATA.indication* parameters of the ISS ([AC]:12.2).

All frames passing through the stream identification functions in the UP direction are assigned a *stream_handle*. A *stream_handle* of value *Null* (a negative denotes the *Null* value) indicates no matching stream identification function was found.

Bridges with the number of ports as given in Table 6-1 support the listed number of identification functions.

Table 6-1—Identification profile for Bridges

Number of ports (<i>n</i>)	Minimum number of Identification functions
less than 5 ($2 < n < 5$)	128
more than 4, but less than 10 ($4 < n < 10$)	192
more than 9 ($n > 9$)	256

6.11.2 Stream Identification Function(s) for End Stations

Only passive out-facing stream identification functions are configurable, with the Identification Mask Length as stated in 6.11.3.

A minimum number of 64 Identification functions is supported on an ingress Port.

6.11.3 Identification Mask Length ([CBdb])

All filter masks are long enough to cover:

- MAC addressing
- one VLAN tag
- the addresses, DSCP, and next header field of an IPv6 and protocol field of an IPv4 header

1 — the port information of TCP and UDP

2 NOTE 1—IPv6 extension headers and IPv4 options are out of scope, as they are not covered by [CB].

3 NOTE 2—End-to-End MACsec is out of scope (Annex B.1.2), as it is not covered by [CB]. Hop-by-Hop MACsec

4 (6.6.2) is covered earlier in the ingress processing.

5 6.12 Flooding protection

6 If a query to the FDB ([Q]:8.8) using the Destination MAC address and VID of a received frame does not
7 return at least one potential transmission Port, the management entity can configure for the frame to be:

- 8 a) flooded to all ports after Egress filtering ([Q]:8.6.4) by default, or
- 9 b) discarded (a counter can be implemented), or
- 10 c) forwarded to a specific (management) Port

11 6.13 Active topology enforcement ([Q]:8.6.1)

12 If ingress filtering ([Q]:8.6.2) did not cause the received frame to be discarded, the source address and VID
13 are submitted to the Learning Process (6.15). The Learning Process can be configured by management,
14 under which conditions learning is enabled or disabled is not further specified here.

15 A loop-free network topology is ensured through configuration, the Rapid Spanning Tree Algorithm and
16 Protocol (RSTP) are not required.

17 The forwarding of any frames to a port can be disabled by management. The conditions under which
18 management allows or disables the forwarding are not further specified here.

19 6.14 Ingress Filtering ([Q]:8.6.2)

20 Frames received on a port that is not in the member set ([Q]:8.8.10) associated with the Frame's associated
21 *vlan_identifier* parameter are discarded.

22 6.15 The Learning Process ([Q]:8.7)

23 The Learning Process:

- 24 a) Supports shared VLAN learning of source MAC addresses ([Q]:Annex F).
- 25 b) Supports independent VLAN learning of source MAC addresses ([Q]:Annex F).
- 26 c) Can disable learning per ingress port.
- 27 d) Can disable a change of the source port, once a source MAC address has been learned (one-shot-
28 mode)

29 6.16 Frame Filtering ([Q]:8.6.3)

30 The set of potential transmission ports ([Q]:8.6.1) for each received Frame is reduced on the basis of:

- 31 a) The *destination_address* parameter ([Q]:8.6.3 a))
- 32 b) The *vlan_identifier* parameter ([Q]:8.6.3 b))

- 1 c) The Filtering Database (FDB) entries ([Q]:8.6.3 d))
- 2 d) The default Group Filtering behavior ([Q]:8.6.3 e))

3 6.16.1 The Filtering Database (FDB)

- 4 The Filtering Database (FDB) conforms to [Q]:8.8.
- 5 The FDB allows for at least 1024 address entries.
- 6 The ageing ([Q]:8.7.3) of learned entries can be disabled.

7 6.16.2 Reserved Addresses (01-80-C2-...)

- 8 The Reserved Addresses of [Q]:Table 8-1 and [Q]:Table 8-2 are supported.
- 9 Frames addressed to Reserved Addresses can carry a VLAN Tag on wire and have an associated
- 10 *vlan_identifier* parameter. The exact forwarding behavior of VLAN tagged Frames to Reserved Addresses is
- 11 implementation specific.

12 6.16.3 Bridge Protocol Data Units (BPDUs) ([Q]:14)

- 13 BPDUs are forwarded to a defined management port. The further handling of BPDUs is currently not
- 14 mandated by the present standard.

15 6.17 Stream Filter ([Q]:8.6.5.3)

- 16 A Stream Filter is identified by

- 17 a) an *SF-stream_handle* AND
- 18 b) an *SF-priority* value.

- 19 Either one or both can be set to a wildcard value that matches any value.

- 20 Frames assigned to the same Stream Filter are processed together in the same SF-Instances of Max. SDU
- 21 Size Filtering (6.18.2), Stream Gating (6.19), Flow Metering (6.20), and ATS eligibility time assignment
- 22 (8.2).

- 23 More than one stream filter instance can be configured to use a specific Stream Gating, Flow Metering, and
- 24 ATS eligibility time assignment instance.

- 25 A Frame with multiple egress ports passes only through a single Stream Filter.

- 26 A certain instance can be configured for one or more Stream Filters, meaning Frames with different
- 27 associated *stream_handle* parameters might be processed by the same SF-Instance.

- 28 If the Frames are intended to go through a CBS, a Stream Filter configuration is suggested in the “Credit
- 29 Based Shaper” section (Clause 9).

- 30 If the Frames are intended to go through an ATS, a Stream Filter configuration is suggested in the
- 31 “Asynchronous Traffic Shaper” section (Clause 8).

1 6.18 Maximum SDU Size Filtering

2 6.18.1 Service Data Unit (SDU) Size

3 The SDU size considered here is specifically the MSDU size (Figure C-2), as described in Annex C.4.

4 All IEEE 802.1 features support at least a maximum MSDU size of 2000 octets, to allow for envelope
5 frames ([802.3]:1.4.310).

6 NOTE 1—This is not a requirement on the actual PHY/MAC attached!

7 6.18.2 Per Stream Filter Maximum SDU Size ([Q]:8.6.5.3.1)

8 All Stream Filters have a Max. SDU Size Filter configured.

9 6.18.3 Per Traffic Class Maximum SDU Size ([Q]:8.6.8.4)

10 A per TC max. SDU size filter can be configured and activated, even if no gate schedule is configured, i.e.
11 even if all transmission gates are always open.

12 6.19 Stream Gates ([Q]:8.6.5.4)

13 6.19.1 Static IPV configuration

14 A static *IPV* assignment per Stream Gate can be configured.

15 An *IPV* value of *Null* (a negative denotes the *Null* value [Q]:17.7.24) causes the received frame's *priority*
16 parameter to be used as the *IPV*.

17 The allowed range for the *IPV* parameter is not specified explicitly in [Q]. In practice, stations can use a
18 number of methods to assign a frame an *IPV*, and thus to an output queue. This standard does not restrict
19 such behavior (see also 6.21.1).

20 6.19.2 Time dependent IPV configuration

21 A minimum of three (3) time dependent *IPV* assignment slots can be configured. These use a separate
22 schedule from the transmission gates.

23 An *IPV* value of *Null* (a negative denotes the *Null* value [Q]:17.7.24) causes the received frame's *priority*
24 parameter to be used as the *IPV*.

25 6.19.3 Time dependent gate states

26 Based on a separate schedule from the transmission gates, the Stream Gates are assuming either the *OPEN*
27 or the *CLOSED* state. If a frame arrives while it's associated stream gate is closed, it is discarded. A counter
28 for discarded and passed frames can be available.

1 6.20 Flow Metering ([Q]:8.6.5.5)

2 All Stream Filters have a Flow Meter configured.

3 The MEF 10.3 algorithm is supported with:

- 4 a) A configurable MEF Committed Information Rate: MEF-CIR > 0
- 5 b) A configurable MEF Committed Burst Size: MEF-CBS > 0
- 6 c) A MEF Excess Information Rate: MEF-EIR = 0
- 7 d) A MEF Excess Burst Size: MEF-EBS = 0
- 8 e) A MEF Coupling Flag: MEF-CF = False (0)
- 9 f) A MEF Color Mode Flag: MEF-CM = color-blind

10 Items a) through e) of the above list represent a Single Rate Two Color Meter. Item f) makes it color blind on
11 ingress, which is consistent with the egress behavior.

12 Frames are either:

- 13 g) Permitted to pass (green) OR
- 14 h) Dropped (red)

15 At this processing stage only the MSDU size (Annex C.4) is known, i.e. neither the media-dependent
16 overhead ([Q]:12.4.2.2) at ingress nor at egress are known. It is therefore not possible to easily deduce the
17 actual bandwidth used by the Packet on wire.

18 6.21 Queuing Frames ([Q]:8.6.6)

19 Queuing frames is performed per egress port.

20 The default priority to traffic class (TC) mapping is performed according to [Q]:Table 34-1.

21 Each frame is mapped to a traffic class using the Traffic Class Table for the respective egress port. The
22 parameters used for this mapping are determined as follows:

- 23 a) If stream gates ([Q]:8.6.5.4) are not supported, the frame's associated *priority* parameter is used.
- 24 b) If stream gates are supported and the *IPV* parameter assigned to the frame is *Null*, the frame's
25 associated *priority* parameter is used.
- 26 c) If stream gates are supported and the *IPV* parameter assigned to the frame is Non-*Null*, the *IPV*
27 parameter is used (see also 6.19.1).

28 NOTE 1—A negative value for the *IPV* denotes the *Null* value.

29 6.21.1 Number of Traffic Class Queues

30 No less than 8 Traffic Classes (TCs) per egress port are supported.

31 NOTE—Since [Q] does not give any indication on how to handle a port with more than 8 Traffic Class Queues, it is up
32 to the implementer to follow the concepts laid out in [Q] and this present standard in principle in case more queues are
33 available.

1 6.22 Transmission Selection

2 6.22.1 Per TC-Queue Transmission Selection ([Q] 8.6.8 a))

3 The operation of the transmission selection algorithm activated for a given TC Queue determines if there is
4 a frame available for transmission or not.

- 5 a) All TC Queues on all ports support the ATS Transmission Selection algorithm of [Q]:8.6.8.5.
- 6 b) At least the two numerically highest value Traffic Class Queues (highest priority) on any port
7 support the Credit Based Shaper transmission selection of [Q]:8.6.8.2.

8 6.22.2 Port Transmission Selection ([Q]:8.6.8 b))

9 For each port, frames are selected for transmission on the basis of the TCs that the port supports (6.22.1) and
10 the operation of the transmission selection algorithms supported by the corresponding queues on that port.
11 For a given port and traffic class, frames are selected from the corresponding queue for transmission if and
12 only if:

- 13 a) The operation of the transmission selection algorithm supported by that queue determines that there
14 is a frame available for transmission; AND
- 15 b) For each queue corresponding to a numerically higher value of traffic class supported by the port,
16 the operation of the transmission selection algorithm supported by that queue determines that there
17 is no frame available for transmission.

18 The order in which frames are selected for transmission from the queue maintains the ordering requirement
19 specified in [Q]:8.6.6.

20 6.23 Transmission Gates ([Q]:8.6.8.4)

- 21 a) Support the Time Aware Shaper (TAS) according to Clause 10.
- 22 b) Support of TAS is not required on any egress port where ATS or CBS are activated on any TC
23 Queue.

24 NOTE 1—A rational for the restriction in b) can be found in [B6] and 10.6.

25 6.24 Egress VID Translation ([Q]:6.9 g))

26 Egress VID Translation is performed per egress port.

27 The egress VID Translation as specified by [Q]:6.9 g) is supported.

28 6.25 Limiting Frame lifetime ([Q]:6.5.6)

29 To prevent a buffer overrun, a Relay might discard frames.

1 6.25.1 Frame Discard

2 Discarding a Frame is an intentional action by the Management Entity. This will be based on:

- 3 a) Policing rules - limit potentially congesting traffic
- 4 b) Prevention of Buffer overrun - discard Frames from congested traffic
- 5 c) Unknown egress port
- 6 d) Security considerations

7 The Bridge can discard a Frame:

- 8 e) Due to policing, if a flow metering algorithm ([Q]:8.6.5.5) determines that discard is necessary.
9 ([Q]:6.5.2 b)7))
- 10 f) Due to policing, if a shaping algorithm ([Q]:8.6.11.3.7) determines that discard is necessary.
- 11 g) Due to policing, if the frame exceeds the queueMaxSDU ([Q]:8.6.8.4) for the TC queue. ([Q]:6.5.2
12 b)8))
- 13 h) Due to policing, if the max. SDU Size Filter ([Q]:8.6.5.3.1) determines that discard is necessary.
- 14 i) Due to congestion, if there is a risk of or actual exhaustion ([Q]:6.5.2 b) 2)) of internal buffer
15 capacity.
- 16 j) Due to an unknown egress port, if the FDB ([Q]:8.8) disallows the forwarding. ([Q]:6.5.2 b) 6))
- 17 k) Due to an invalid ingress port, if one-shot-learning (6.15) is active.
- 18 l) Due to security considerations, if the device attached to the port is not authorized (IEEE Std 802.1X)
19 for access to the network. ([Q]:6.5.2 b)5))

20 6.26 Preemption

21 6.26.1 Preemptable MAC ([Q]:6.7.1 a))

22 The TCs queuing frames to the preemptable MAC do not include the numerically highest.

23 6.26.2 Express MAC ([Q]:6.7.1 b))

- 24 a) Use a single TC for queuing frames to the express MAC.
- 25 b) Have no shapers configured for the TC queuing frames to the express MAC.
- 26 c) Configure the TC queuing frames to the express MAC as the numerically highest.

27 6.27 Egress filtering ([Q]:8.6.4)

28 Frames are not transmitted on a Port, if the member set ([Q]:8.8.10) for the frame's VID on that Port is not
29 present.

30

1 7. Congestion

2 7.1 Definitions

3 Congesting Traffic is providing excess ingress bandwidth, i.e. more Buffer is (or would be) required to store
4 Frames than was expected/configured.

5 Congested Traffic is under-served on egress, i.e. Frames accumulate in the Buffer of the Relay as they do not
6 get selected for transmission.

7 7.2 Congestion Separation

8 Congestion separation is to be performed on each Bridge locally.

- 9 a) A Bridge is configurable to segregate the Buffers for different Traffic, so Buffer overruns in one
10 segregated block can lead to discarding of Frames within that one Traffic aggregate, but not for the
11 other Traffic aggregates.
- 12 b) Frames are not forwarded on egress, if the bandwidth exceeds a configured maximum.
- 13 c) Frames are discarded if the bandwidth exceeds a configured maximum on ingress.

14 7.3 Causes for Congested Traffic

15 Traffic can become congested, if:

- 16 a) The Shaper (CBS, ATS, TAS) on egress is configured with a too low rate or a too small burst size.
- 17 b) Excessively large lower priority Frames block the transmission.
- 18 c) A large higher Priority Burst blocks the transmission.

19 Therefore in order to prevent Traffic from becoming congested:

- 20 d) Bandwidth needs for all Traffic must be well known.
- 21 e) All traffic goes through a max. SDU Size Filter ([Q]:8.6.5.3.1).
- 22 f) All higher priority traffic (and therefore all traffic, except the lowest TC) goes through a Flow Meter
23 ([Q] 8.6.5.5).

24 7.4 Causes for Congesting Traffic

25 Traffic causes congestion, if:

- 26 a) Bursts of random size occur, as no shaping is implemented.
- 27 b) A Shaper (CBS, ATS, TAS) with a mis-configured rate or burst size is active.
- 28 c) The Traffic contains excessively large Frames.

1 Therefore in order to prevent Traffic from causing congestion:

- 2 d) All Traffic is shaped on egress at every Talker.
- 3 e) Bandwidth needs for all Traffic must be well known.
- 4 f) All traffic goes through a max. SDU Size Filter ([Q]:8.6.5.3.1).

5

1 8. Asynchronous Traffic Shaper (ATS)

2 8.1 Configuration

3 Every ATS Instance is configured through:

- 4 a) Committed Information Rate (ATS-CIR)
- 5 b) Committed Burst Size (ATS-CBS)
- 6 c) Maximum Residence Time (ATS-MRT)
- 7 d) ATS Scheduler Group membership
- 8 e) Egress TC

9 8.2 ATS Eligibility Time Assignment ([Q]:8.6.5.6)

10 ATS Eligibility Time Assignment is performed according to [Q]:8.6.5.6.

11 8.3 Implicit policing

12 An ATS Instance will discard a Frame if its Length exceeds the product of Maximum Residence Time and
13 Committed Information Rate. This is independent of the Committed Burst Size (ATS-CBS) configured for
14 the ATS instance.

15 An ATS Instance will discard a Frame if during Maximum Residence Time more data arrives than the
16 product of Maximum Residence Time and Committed Information Rate.

17 The implicit ATS policing is therefore equivalent to a MEF Flow Meter with the following configuration:

- 18 a) The MEF Committed Information Rate: $\text{MEF-CIR(ATS)} = \text{ATS-CIR}$
- 19 b) The MEF Committed Burst Size: $\text{MEF-CBS(ATS)} = \text{ATS-MRT} * \text{ATS-CIR}$
- 20 c) The MEF Excess Information Rate: $\text{MEF-EIR(ATS)} = 0$
- 21 d) The MEF Excess Burst Size: $\text{MEF-EBS(ATS)} = 0$
- 22 e) The MEF Coupling Flag: $\text{MEF-CF(ATS)} = \text{False (0)}$
- 23 f) The MEF Color Mode Flag: $\text{MEF-CM(ATS)} = \text{color-blind}$

24 The *length(frame)* parameter ([Q]:8.6.11.3.11) used in the ATS algorithm ([Q]:8.6.11.3) includes the egress
25 media-dependent overhead ([Q]:12.4.2.2), while the MEF flow meter (6.20) only has the MSDU size
26 available for policing. Any resulting deviations are not accounted for in the current standard.

27 8.4 Policing Configuration

28 Any Frame to be processed by an ATS Instance is subject to a max. SDU Size Filter, where the ATS-CBS is
29 at least as large as the max. SDU Size configured in the Filter.

30 Additional Flow Meter policing is not required for Frames to be processed by an ATS Instance.

31 Frames in the egress Buffer of a TC configured with the ATS selection algorithm are subject to the same
32 Lifetime limitations as all other Frames provided to this TC of this port (6.25).

1 8.5 Instance and TC Queue Assignment

2 For Frames being processed by an ATS Instance, by default no IPV assignment is activated in the Stream
3 Gates.

4 NOTE—This is to ensure frames with an assigned eligibility time are placed into a queue where the transmission
5 selection algorithm is set to ATS.

6 The *priority* parameter associated with the ingress Frame is therefore mapped to the egress TC Queue in
7 Queuing Frames.

8 Frames being processed by an ATS Instance are queued into the same numerical TC on every hop as they
9 traverse the network ([B2]:QAR3).

10 Frames which ingress on different ports are never to be processed by the same ATS Instance ([B2]:QAR1).

11 Frames which use a different TC anywhere in the network are never processed by the same ATS Instance
12 ([B2]:QAR2).

13 In an End Station the Applications can be identified as the equivalent to the ingress ports of a Bridge. If no
14 Middleware is present and every Application generates Frames just for its own communication needs, an
15 ATS Instance per Application can ensure proper egress behavior.

16 In cases where data from different Applications with different operational cycles is aggregated into Frames
17 by a Middleware (e.g. AUTOSAR's nPDU Feature in [AR416]:7.2.2), the trigger conditions in the
18 Middleware can be configured such that proper egress behavior is ensured. Combining Middleware
19 triggering and lower layer shaping can create hard to predict egress behavior and is to be avoided.

20 8.6 ATS Scheduler Groups

21 All ATS Instances processing Frames in a specific upstream TC (according to [B2]:QAR3) arriving on one
22 specific ingress port belong to the same ATS scheduler Group.

23 If one ATS Instance within an ATS scheduler Group has a significantly higher Committed Information Rate,
24 than a second ATS Instance within the same ATS scheduler Group ($\text{ATS-CIR}[1] \gg \text{ATS-CIR}[2]$), the Group
25 Eligibility Time shared between the two ATS Instances leads to a potentially undue delay of Frames if an
26 ingress burst of Frames destined for the lower rate ($\text{ATS-CIR}[2]=r_2$) ATS Instance within the Group pushes
27 the Eligibility Time for the higher rate ATS Instance into the future. Worst case the Frame of the higher rate
28 ATS Instance might be discarded, if $\text{ATS-MRT}[1] < L_2/r_2$, where L_2 is the Frame's length.

29 If all ATS assignment rules are followed throughout the network, including the Talkers, the order of Frames
30 can not be distorted in a way to create the above problem.

31

9. Credit Based Shaper (CBS)

9.1 Credit Based Shaper configuration

Every CBS TC Queue is configured through:

- a) Idle Slope (CBS-IS)
- b) Egress TC

Additionally the following information is needed in order to configure a CBS flow:

- c) *portTransmitRate*, the line-rate of the egress Port
- d) the media-dependent overhead ([Q]:12.4.2.2) of the egress Port
- e) *maxInterferenceTime*, the equivalent in time to [Q]:L.1 d) to allow for a more generalized description

9.2 Policing Configuration

The CBS does not provide implicit Policing. Any Frame to be processed in a CBS TC Queue is subject to a max. SDU Size Filter and a Flow Meter.

Suggested Flow Meter policing for CBS Traffic:

- a) The MEF Committed Information Rate: $\text{MEF-CIR}(\text{CBS}) = \text{CBS-IS}$
- b) The MEF Committed Burst Size: $\text{MEF-CBS}(\text{CBS}) = \text{maxBurstSize}$
- c) The MEF Excess Information Rate: $\text{MEF-EIR}(\text{CBS}) = 0$
- d) The MEF Excess Burst Size: $\text{MEF-EBS}(\text{CBS}) = 0$
- e) The MEF Coupling Flag: $\text{MEF-CF}(\text{CBS}) = \text{False (0)}$
- f) The MEF Color Mode Flag: $\text{MEF-CM}(\text{CBS}) = \text{color-blind}$

Where $\text{maxBurstSize} = (\text{max. SDU size} + \text{media-dependent overhead}) + \text{maxInterferenceTime} * \text{portTransmitRate} * \text{CBS-IS} / (\text{portTransmitRate} - \text{CBS-IS})$
(derived from [Q]:(L-4))

If different streams are combined to be processed by a single CBS instance and are rate limited by a single MEF flow meter, then the MEF-CIR becomes the sum of all stream rates (CBS-IS).

If the streams go through separate MEF flow meters then each stream must be configured with its own MEF-CIR, while the CBS will use the sum of all stream rates (CBS-IS).

The latency calculations in [BA]:6.6 assume Packet size and IPG (Figure C-2) to be included in the bandwidth. The MEF flow meter (6.20) only has the MSDU size available for policing. The resulting deviations are not accounted for in the current standard.

1 9.3 Configuration Rules

2 As can be derived from Annex L of [Q], CBS can create undesired Buffer occupancy and latency in Bridges.

3 Traffic which was shaped together in one CBS instance on the previous (upstream) Bridge but uses different
4 egress ports on this bridge, is configured with the aggregated bandwidth on this port and on the further
5 downstream path in order to avoid undue shaping delays.

6 Traffic egressing a Bridge on the last link to the Listener need not be shaped using CBS.

7 NOTE—This might require more buffer in the End Station and cause delays for lower priority traffic, while shaping can
8 cause additional delays for the CBS shaped traffic [Q]:Annex L.3.1.3.

10. Time Aware Shaper

10.1 Introduction

The TAS ([Q]:8.6.8.4) can be operated in three modes:

- a) Bus mode (10.2)
- b) Phased Mode (10.3)
- c) Cyclic Queuing and Forwarding - CQF (10.4)

If TAS is used on a port, by default no other shapers are used on TCs whose gates open and close for that port.

If TAS is used for Scheduled Traffic (Annex C.6.2) only one single TC for Scheduled Traffic is open for transmission at any time. All TCs for non Scheduled Traffic are open during a common time interval in between the Scheduled Traffic TCs openings.

If TAS is used, the transmission windows are configured so the time synchronization messages can be transmitted at the desired message intervals (within allowed tolerances) in order to achieve the required time synchronization accuracy.

As with all TDMA systems, finding the perfect schedule across applications, ECUs and relays can be an NP-hard problem [B5].

10.2 Bus Mode

In order to replicate the behavior one would get from a shared medium being accessed by synchronized Stations on a shared TDMA schedule, the bus mode opens a communication path from a single talker Station to all potential listener Stations on the entire network. The gate opening on all ports is intended to be as close to the actual transmission time as possible in order to avoid a waste in bandwidth. The open time must be long enough for the data to traverse all links and Bridges and must therefore also include store and forward delays of Bridges. This typically results in a less efficient bandwidth utilization, especially when different line-rates are mixed.

The most simple Bus Mode configuration involves only two intervals. The much shorter one is intended to transmit high priority traffic from maybe just a single talker to the relevant listeners. The second longer period is considered as non gated and other traffic patterns can be employed. In terms of worst-case latency the long period is added for all of the traffic in the shorter window and the short window plus its implicit guard-band can be considered a long interfering frame for the other traffic during the longer period. As the topology (number of hops) will influence the short period it may have to be configured for a maximum value if the exact number of hops is not known.

10.2.1 Bus Mode Configuration

The GateControlList has at least 8 entries per port.

The time resolution required for bus mode depends on the line rate, but is at least 10 μ s.

1 10.3 Phased Mode

2 In order to allow data to flow from a talker to a listener on a pre-defined path at the lowest possible latency,
3 while trying to not block the communication on other paths for longer than needed, each Bridge involved
4 will be configured with a guard-band and schedule to allow an incoming frame to immediately be
5 transmitted on the destination port.

6 10.3.1 Phased Mode Configuration

7 The GateControlList has at least 32 entries per port.

8 The time resolution required for phased mode depends on the line rates in the network and is not defined by
9 this present standard.

10 10.4 Cyclic Queuing and Forwarding (CQF)

11 In contrast to the other modes, which are derived from other systems and the general TDMA operation, this
12 mode was explicitly described in [Q]:Annex T.

13 While the other modes are intended to reach a minimum latency, this approach is based on minimizing jitter
14 by maximizing the latency for each frame. The Bridges must be able to store the data which is received in
15 each interval, likely leading to rather short intervals or large buffer requirements. Upon opening the
16 transmission gate the data is burst on a strict priority basis. Technically it is possible to use shapers in order
17 to intersperse the traffic during transmission, but this will not affect the given (maximum) bounded latency.

18 10.5 TAS Latency and Efficiency Considerations

19 One can refer to the Bus Mode and the Phased Mode as minimum latency configurations, while Cyclic
20 Queuing and Forwarding (CQF) must be viewed as a bounded maximum latency configuration.

21 The latency of a frame passing through a TAS enabled Relay Port is dominated in all three cases by the time
22 the gate for its particular stream is closed ($operCycleTime - gateOpenTime$). Since the bandwidth available
23 for a stream is determined by the ratio of $operCycleTime$ over $gateOpenTime$, the latency increases in
24 principle for streams with low bandwidth requirements, assuming the link overall is not excessively over-
25 provisioned.

26 Note that frequent opening and closing of gates is costly irrespective of the mode because of the associated
27 guard-bands. Imprecise synchronization can additionally require over-provisioning of the TAS-schedule
28 ($gateOpenTime$ in *GateControlList*) and lead to less efficient utilization of the available bandwidth.

29 In a Talker an alignment latency is introduced if applications attempt to transmit data while the gate in the
30 network interface is closed for said traffic. Lowest latency can only be achieved if applications in Talkers
31 and Listeners are synchronized to the TAS-schedule of the network, i.e., supply data only at times when
32 transmission is possible and consume data immediately when it is received.

1 10.6 Combining TAS with other Shapers

2 10.6.1 General TAS considerations

3 For Bus Mode and Phased Mode it is obviously counter intuitive to apply other shaping mechanisms to
4 frames which are intended to pass through the network as quickly as possible. In order to achieve bounded
5 latency in any of the three modes, it is vital for the transmission queues for any TC to be empty when its
6 transmission gate closes. For CQF this is a fundamental design criterion ([Q]:Annex T.1). Otherwise another
7 *operCycleTime* is added to the frame's latency.

8 The present standard refers to traffic matching best with the concepts of Bus Mode and Phased Mode as
9 Scheduled Traffic (Annex C.6.2). This implicitly creates a CQF scenario for all other traffic, as it gets
10 queued up while Scheduled Traffic is transmitted and then must be transmitted entirely in the window left
11 for all the other queues. Assuming this window is sufficiently long, traffic arriving during said window will
12 also need to be transmitted before its gate closes again to prevent buffer overruns (i.e. Frame loss) and limit
13 latency. In network calculus this is referred to as a stability condition.

14 10.6.2 Combining CBS with TAS

15 According to [Q]:8.6.8.2 d) the *idleSlope* for CBS is modified, if TAS is used on the egress port. In effect no
16 credit is accumulated while the transmission gate is closed for a CBS TC, independent of frames queued.
17 This will cause a shaped transmission as soon as the gate opens, with a proportionally higher shaping rate. In
18 turn introducing additional delays, which need to be accounted for in the latency calculations. Furthermore
19 lower priority TCs open concurrently can transmit frames within the shaping gaps, which may be beneficial
20 for their latency, but cause further delays for the stream under consideration.

21 10.6.3 Combining ATS with TAS

22 The (virtual) credit of an ATS shaper instance is unaware of the transmission gate state. Assignment of
23 eligibility times continues the same way upon arrival of the frame, independent of the transmission gate
24 state. This will lead to the transmission of a burst of frames (depending on relative priority amongst those
25 TCs which are open concurrently) as soon as the transmission gate opens. While this has less impact on the
26 added latency (no further shaping delay) for the stream under consideration, it will block frames in lower
27 priority TCs from transmission, thereby increasing their latency.

28 10.6.4 Combining preemption with TAS

29 There are fundamentally two use-cases, where the combination of TAS and preemption is interesting to
30 examine further.

31 The TAS transmission selection algorithm of [Q]:8.6.8.4, checks if there is sufficient time available to
32 transmit the entirety of an eligible packet (i.e., including the media-dependent overhead), before the next
33 gate-close event. The packet is not transmitted, if this is not the case. However, a long frame in a
34 preemptable TC queue may start being transmitted and then be preempted (multiple times) by short express
35 frames, leading to the potentially significant tail end of the preemptable packet to be transmitted outside the
36 assigned *gateOpenTime* and therefore violating its bandwidth allocation, potentially causing congestion.

37

1 Annex A

2 PCS proforma

(normative)

4 A.1 Introduction

5 The supplier of an implementation that is claimed to conform to a particular profile defined in this present
6 standard shall complete the corresponding Profile Conformance Statement (PCS) proforma.

7 The tables do not contain an exhaustive list of all requirements that are stated in the referenced standards; for
8 example, if a row in a table asks whether the implementation is conformant to Standard X, and the answer
9 “Yes” is chosen, then it is assumed that it is possible, for that implementation, to fill out the PCS proforma
10 defined in Standard X to show that the implementation is conformant; however, the tables in this present
11 standard will only further refine those elements of conformance to Standard X where particular answers are
12 required for the profiles defined here.

13 The profiles are not intended to be mutually exclusive; it is possible that a given implementation can support
14 more than one of the profiles defined in this present standard. If that is the case, then either the PCS for the
15 implementation should be filled out in order to reflect the support of multiple profiles, or a separate PCS
16 should be filled out to reflect each profile supported.

17 A completed PCS proforma is the PCS for the implementation in question. The PCS is a statement of which
18 capabilities and options of the protocol have been implemented. The PCS can have a number of uses,
19 including use by the following:

- 20 a) Protocol implementer, as a checklist to reduce the risk of failure to conform to the standard through
21 oversight;
- 22 b) Supplier and acquirer—or potential acquirer—of the implementation, as a detailed indication of the
23 capabilities of the implementation, stated relative to the common basis for understanding provided
24 by the standard PCS proforma;
- 25 c) User—or potential user—of the implementation, as a basis for initially checking the possibility of
26 interworking with another implementation (note that, while interworking can never be guaranteed,
27 failure to interwork can often be predicted from incompatible PCSs);
- 28 d) Protocol tester, as the basis for selecting appropriate tests against which to assess the claim for
29 conformance of the implementation.

30 A.2 Abbreviations and special symbols

31 A.2.1 Status symbols

- 32 M mandatory
- 33 O optional
- 34 O.n optional, but support of at least one of the group of options labeled by the same numeral n
is required
- 36 X prohibited
- 37 pred:conditional-item symbol, including predicate identification: see A.3.4
- 38 \neg logical negation, applied to a conditional item’s predicate

1 A.2.2 General abbreviations

- 2 N/A not applicable
3 PCS Profile Conformance Statement

4 A.3 Instructions for completing the PCS proforma

5 A.3.1 General structure of the PCS proforma

6 The first part of the PCS proforma, implementation identification and protocol summary, is to be completed
7 as indicated with the information necessary to identify fully both the supplier and the implementation.

8 The main part of the PCS proforma is a fixed-format questionnaire, divided into several subclauses, each
9 containing a number of individual items. Answers to the questionnaire items are to be provided in the
10 rightmost column, either by simply marking an answer to indicate a restricted choice (usually Yes or No) or
11 by entering a value or a set or range of values. (Note that there are some items where two or more choices
12 from a set of possible answers can apply; all relevant choices are to be marked.)

13 Each item is identified by an item reference in the first column. The second column contains the question to
14 be answered; the third column records the status of the item—whether support is mandatory, optional, or
15 conditional; see also A.3.4. The fourth column contains the reference or references to the material that
16 specifies the item in the main body of this present standard, and the fifth column provides the space for the
17 answers.

18 A supplier may also provide (or be required to provide) further information, categorized as either Additional
19 Information or Exception Information. When present, each kind of further information is to be provided in a
20 further subclause of items labeled Ai or Xi, respectively, for cross-referencing purposes, where i is any
21 unambiguous identification for the item (e.g., simply a numeral). There are no other restrictions on its format
22 and presentation.

23 A completed PCS proforma, including any Additional Information and Exception Information, is the
24 Protocol Implementation Conformation Statement for the implementation in question.

25 NOTE—NOTE—Where an implementation is capable of being configured in more than one way, a single PCS may be
26 able to describe all such configurations. However, the supplier has the choice of providing more than one PCS, each
27 covering some subset of the implementation's configuration capabilities, in case that makes for easier and clearer
28 presentation of the information.

29 A.3.2 Additional information

30 Items of Additional Information allow a supplier to provide further information intended to assist the
31 interpretation of the PCS. It is not intended or expected that a large quantity will be supplied, and a PCS can
32 be considered complete without any such information. Examples might be an outline of the ways in which a
33 (single) implementation can be set up to operate in a variety of environments and configurations, or
34 information about aspects of the implementation that are outside the scope of this present standard but that
35 have a bearing on the answers to some items.

36 References to items of Additional Information may be entered next to any answer in the questionnaire and
37 may be included in items of Exception Information.

1 A.3.3 Exception Information

2 It may occasionally happen that a supplier will wish to answer an item with mandatory status (after any
3 conditions have been applied) in a way that conflicts with the indicated requirement. No preprinted answer
4 will be found in the Support column for this item. Instead, the supplier shall write the missing answer into
5 the Support column, together with an Xi reference to an item of Exception Information, and shall provide the
6 appropriate rationale in the Exception item itself.

7 An implementation for which an Exception item is required in this way does not conform to this present
8 standard.

9 NOTE—NOTE—A possible reason for the situation described previously is that a defect in this present standard has
10 been reported, a correction for which is expected to change the requirement not met by the implementation.

11 A.3.4 Conditional status

12 A.3.4.1 Conditional items

13 The PCS proforma contains a number of conditional items. These are items for which both the applicability
14 of the item itself, and its status if it does apply—mandatory or optional—are dependent on whether certain
15 other items are supported.

16 Where a group of items is subject to the same condition for applicability, a separate preliminary question
17 about the condition appears at the head of the group, with an instruction to skip to a later point in the
18 questionnaire if the “Not Applicable” (N/A) answer is selected. Otherwise, individual conditional items are
19 indicated by a conditional symbol in the Status column.

20 A conditional symbol is of the form “pred: S” where pred is a predicate as described in A.3.4.2, and S is a
21 status symbol, M or O.

22 If the value of the predicate is true (see A.3.4.2), the conditional item is applicable, and its status is indicated
23 by the status symbol following the predicate: The answer column is to be marked in the usual way. If the
24 value of the predicate is false, the “Not Applicable” (N/A) answer is to be marked.

25 A.3.4.2 Predicates

26 A predicate is one of the following:

- 27 a) An item-reference for an item in the PCS proforma: The value of the predicate is true if the item is
28 marked as supported and is false otherwise;
- 29 b) A predicate-name, for a predicate defined as a Boolean expression constructed by combining item-
30 references using the Boolean operator OR: The value of the predicate is true if one or more of the
31 items is marked as supported;
- 32 c) The logical negation symbol “¬” prefixed to an item-reference or predicate-name: The value of the
33 predicate is true if the value of the predicate formed by omitting the “¬” symbol is false, and vice
34 versa.

35 Each item whose reference is used in a predicate or predicate definition, or in a preliminary question for
36 grouped conditional items, is indicated by an asterisk in the Item column.

1 A.4 Bridge PCS

2 NOTE—Covers section 5.4.

Table A-1—Bridge PCS

Item	Feature	Status	References	Support
PCS—1	Does the Bridge process frames in the specified order upon ingress?	M	5.4.1:a)	Yes [] No []
PCS—2	Does the Bridge process frames in the specified order upon egress?	M	5.4.1:b)	Yes [] No []
C-VLAN	Does the Bridge support C-VLAN tags?	M	5.4.1:c)	Yes [] No []
B-CM-IS	Does the Bridge support Ingress Selection?	M	5.4.1:d)	Yes [] No []
B-CM-Pol	Does the Bridge support policing?	M	5.4.1:e)	Yes [] No []
B-CM-BS	Does the Bridge support Basic Shaping?	M	5.4.1:f)	Yes [] No []
PCS—3	Does the Bridge support the Learning Process?	M	5.4.1:g)	Yes [] No []
PCS—4	Does the Bridge support Congestion Separation?	M	5.4.1:h)	Yes [] No []
PCS—5	Does the Bridge support the maximum SDU Size?	M	5.4.1:i)	Yes [] No []
PCS—6	Does the Bridge support Frame Filtering?	M	5.4.1:j)	Yes [] No []
PCS—7	Does the Bridge support static IPV configuration?	M	5.4.1:k)	Yes [] No []
PCS—8	Are the Bridge's Stream Gates open by default?	M	5.4.1:l)	Yes [] No []
B-TimeSync	Does the Bridge support Time Synchronization? If Yes, provide details on the supported profile: <hr/>	O CM-TAS- TimeSync:M	5.4.2:a)	Yes [] No []
B-CM-TAS	Does the Bridge support the TAS?	O	5.4.2:b)	Yes [] No []
B-CM-Pre	Does the Bridge support Preemption?	O	5.4.2:c)	Yes [] No []
B-MACsec	Does the Bridge support Hop-by-Hop MACsec?	O	5.4.2:d)	Yes [] No []
PCS—9	Does the Bridge support discarding frames with exceeded lifetime?	O	5.4.2:e)	Yes [] No []

1 A.5 End Station PCS

2 NOTE—Covers section 5.5.

Table A-2—End Station PCS

Item	Feature	Status	References	Support
E-CM-Pol	Does the end station support policing?	M	5.5.1:a)	Yes [] No []
PCS—10	Does the end station perform Destination MAC address filtering?	M	5.5.1:b)	Yes [] No []
PCS—11	Does the end station support Out-facing Ingress Stream Identification Function(s)?	M	5.5.1:c)	Yes [] No []
PCS—12	Does the end station support Ingress filtering?	M	5.5.1:d)	Yes [] No []
PCS—13	Does the end station support Stream Filter assignment?	M	5.5.1:e)	Yes [] No []
PCS—14	Does the end station process frames in the specified order upon ingress?	M	5.5.1:f)	Yes [] No []
PCS—15	Does the End Station support egress shaping mechanisms? If Yes, provide details on the supported mechanisms: _____	M	5.5.2:a)	Yes [] No []
PCS—16	Does the end station support max. SDU Size Filtering?	M	5.5.2:b)	Yes [] No []
PCS—17	Does the end station support Queuing frames?	M	5.5.2:c)	Yes [] No []
PCS—18	Does the end station support Transmission selection?	M	5.5.2:d)	Yes [] No []
PCS—19	Does the end station process frames in the specified order upon egress?	M	5.5.2:e)	Yes [] No []
E-TimeSync	Does the End Station support Time Synchronization? If Yes, provide details on the supported profile: _____	O CM-TAS- TimeSync:M	5.5.3:a)	Yes [] No []
E-CM-TAS	Does the End Station support the Time Aware Shaper?	O	5.5.3:b)	Yes [] No []
E-CM-Pre	Does the End Station support Preemption?	O	5.5.3:c)	Yes [] No []

Table A-2—End Station PCS

Item	Feature	Status	References	Support
PCS—20	Does the End Station support Hop-by-Hop MAC-sec?	O	5.5.3:d)	Yes [] No []
PCS—21	Does the End Station support Stream Gating on ingress?	O	5.5.3:e)	Yes [] No []
PCS—22	Does the End Station support Flow metering on ingress?	O	5.5.3:f)	Yes [] No []

¹ A.6 Conformance Module Ingress Selection (CM-IS) PCS

² NOTE—Covers section 5.6.

Table A-3—CM-IS PCS

Item	Feature	Status	References	Support
PCS—23	Does the Station's Port support Port-based VLAN Classification?	O B-CM-IS:M	5.6:a)	Yes [] No []
PCS—24	Does the Station's Port support Priority Code Point Decoding?	O B-CM-IS:M	5.6:b)	Yes [] No []
PCS—25	Does the Station's Port support Priority Regeneration?	O B-CM-IS:M	5.6:c)	Yes [] No []
PCS—26	Does the Station's Port support Ingress Stream Identification Function(s)?	O B-CM-IS:M	5.6:d)	Yes [] No []
PCS—27	Does the Station's Port support Active topology enforcement?	O B-CM-IS:M	5.6:e)	Yes [] No []
PCS—28	Does the Station's Port support Ingress Filtering?	O B-CM-IS:M	5.6:f)	Yes [] No []
PCS—29	Does the Station's Port support Egress Filtering	O B-CM-IS:M	5.6:g)	Yes [] No []
PCS—30	Does the Station's Port support Queuing Frames?	O B-CM-IS:M	5.6:h)	Yes [] No []
PCS—31	Does the Station's Port support Transmission Selection?	O B-CM-IS:M	5.6:i)	Yes [] No []
PCS—32	Does the Station's Port support Egress VID Translation?	O B-CM-IS:M	5.6:j)	Yes [] No []

1 A.7 Conformance Module Basic policing (CM-Pol) PCS

2 NOTE—Covers section 5.7.

Table A-4—CM-Pol PCS

Item	Feature	Status	References	Support
PCS—33	Does the Station's Port support the Acceptable Frame Types Filter?	B-CM-Pol:M E-CM-Pol:M	5.7:a)	Yes [] No []
PCS—34	Does the Station's Port support the Maximum SDU Size Filtering?	B-CM-Pol:M E-CM-Pol:M	5.7:b)	Yes [] No []
PCS—35	Does the Station's Port support Flow Metering?	B-CM-Pol:M E-CM-Pol:M	5.7:c)	Yes [] No []
PCS—36	Does the Station's Port support Flooding Protection?	B-CM-Pol:M E-CM-Pol:M	5.7:d)	Yes [] No []

3 A.8 Conformance Module Basic Shapers (CM-BS) PCS

4 Covers section 5.8.

Table A-5—CM-BS PCS

Item	Feature	Status	References	Support
CM-BS-CBS	Does the Station's Port provide the capabilities for the Credit Based Shaper?	O B-CM-BS:M	5.8:a)	Yes [] No []
CM-BS-ATS	Does the Station's Port provide the capabilities for the Asynchronous Traffic Shaper	O B-CM-BS:M	5.8:b)	Yes [] No []

5 A.9 Conformance Module Time Aware Shaper (CM-TAS) PCS

6 NOTE—Covers section 5.10.

Table A-6—CM-TAS PCS

Item	Feature	Status	References	Support
CM-TAS-TimeSync	Does the Station's Port have Time Synchronization activated?	B-CM-TAS:M E-CM-TAS:M	5.10:a)	Yes [] No []
PCS—37	Does the Station's Port provide the capabilities for the Time Aware Shaper?	B-CM-TAS:O E-CM-TAS:M	5.10:b)	Yes [] No []
PCS—38	Does the Station's Port have the Time dependent IPV configuration enabled?	B-CM-TAS:O E-CM-TAS:M	5.10:c)	Yes [] No []
PCS—39	Does the Station's Port have the Time dependent gate states enabled?	B-CM-TAS:O E-CM-TAS:M	5.10:d)	Yes [] No []

¹ **A.10 Conformance Module Preemption (CM-Pre) PCS**

² NOTE—Covers section 5.11.

Table A-7—CM-Pre PCS

Item	Feature	Status	References	Support
CM-Pre-pMAC	Does the System support the preemptable MAC	B-CM-Pre:M E-CM-Pre:M	5.11:a)	Yes [] No []
CM-Pre-eMAC	Does the System support the express MAC	B-CM-Pre:M E-CM-Pre:M	5.11:b)	Yes [] No []

³

1 Annex B

2 Limitations

(informative)

4 B.1 Intentionally not covered by this standard

5 B.1.1 Shaper Interactions

6 In [B6] a line of reasoning is given why combining the ATS (Clause 8) or CBS (Clause 9) mechanisms with
7 TAS (Clause 10) may lead to a more complicated configuration in certain constellations. While [Q] allows
8 such combinations (10.6), the present standard does not give guidance on how such configurations affect
9 network behavior.

10 B.1.2 End-to-End MACsec

11 The present standard does not give guidance on how to use End-To-End MACsec, but considers it to be just
12 another protocol to be transported across the network.

13 B.1.3 Preemption Interactions

14 While [Q] certainly allows combinations of Preemption (6.26) with for example TAS (Clause 10), the
15 present standard does not give guidance on how such configurations (10.6.4) affect network behavior.

16

1 Annex C

2 Terminology

(informative)

4 C.1 Automotive Stations (IEEE Std 802)

5 The IEEE 802.1 family of standards define features for Relays, Bridges [Q] and End Stations (IEEE Std
6 802), which are part of the profile definitions in this present standard.

7 C.1.1 Automotive VLAN Bridge

8 The combination of a Bridge Management Entity, a MAC Relay Entity and at least two Bridge ports is
9 referred to as a Bridge (IEEE Std 802.1Q).

10 The Bridge Management Entity can act as an End Station for certain protocols related to infrastructure
11 services, like e.g. time synchronization, service discovery, or diagnostics.

12 C.1.2 Automotive End Station

13 An End Station is the source or the destination of the MAC Client Data (IEEE Std 802.3) in a Frame.

14 C.2 Automotive Electronic Control Unit (ECU)

15 In this present standard an ECU is any encased electronic device inside a vehicle. It is linked to other ECUs
16 through power and communication connections.

17 C.3 Communication Aggregates

18 A Frame is defined by [802.3] as the core part of a Packet (see also C.4). Multiple Packets sharing a
19 common source and destination, but traveling along different paths in a network topology, are considered to
20 belong to Member Streams. A unidirectional Flow of Packets from one source to one or more destinations is
21 referred to as a Stream, as per IEEE Std 802.1Q. All Packets which are part of a specific functional
22 communication relation between two or more End Stations are considered to be part of one Flow. Any
23 Packet sharing a certain characteristic (ingress port, or VLAN-ID, or destination MAC address, or ...) at a

1 specific point in or along the network topology can be referred to as Traffic.

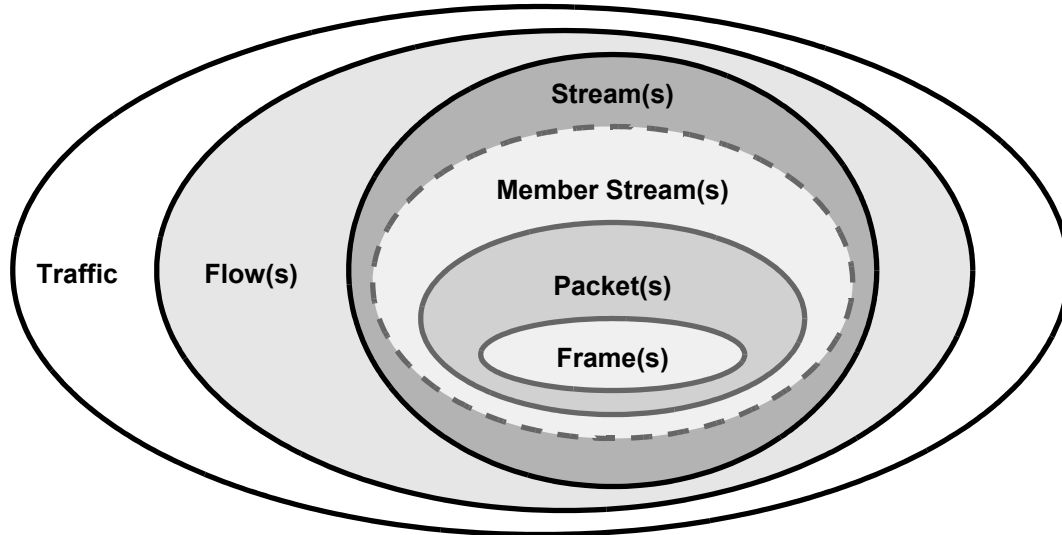


Figure C-1—Aggregate hierarchy

2 C.4 Frame Content as Received

3 This present standard uses the definitions of Packet and Frame as defined in [802.3]:Figure 3-1. The media-
 4 dependent overhead of [Q]:12.4.2.2 can be described as the Packet size plus the IPG (Figure C-2) minus the
 5 Frame size. The MSDU for this present standard (Figure C-2) is the *mac_service_data_unit* as passed from/
 6 to the EISS of [Q]:6.8.1.

7 A Frame in the context of this present standard contains,

- 8 a) One MAC Source Address,
- 9 b) one MAC Destination Address,
- 10 c) an optional C-VLAN Tag (see below),
- 11 d) and one (last) Ethertype.

12 The C-VLAN Tag ([Q]:9) is composed of:

- 13 e) A (first/outer Ethertype) Tag Protocol Identifier (TPID) of 0x8100
- 14 f) a Priority Code Point (PCP)
- 15 g) a Drop Eligible Indicator bit (DEI)
- 16 h) a VLAN Identifier (VID)

17 C.4.1 Packet and Frame size

18 The bandwidth and latency characteristics of an Ethernet network are sensitive to the packet ([802.3]:Figure
 19 3-1) sizes that are used in the network. Specifically when analyzing the queuing delay (e.g. [Q]:Annex
 20 L.3.1.1) of a specific frame X, another frame Y of any priority could have been selected for transmission an
 21 arbitrarily small time before frame X became eligible for transmission. The actual packet length of frame Y
 22 is dependent on the exact header structure and physical layer overhead (see Figure C-2). All relevant

1 shaping mechanisms (ATS (Clause 8), CBS (Clause 9) and TAS (Clause 10)) specifications refer to lengths
2 as including (media-dependent) overhead ([Q]:12.4.2.2). For ATS it is explicitly stated in [Q]:8.6.11.3.11.
3 8.6.8.4, for CBS this can best be seen in [Q]:L.2 item b), and for TAS in [Q]:8.6.8.4 NOTE 1.

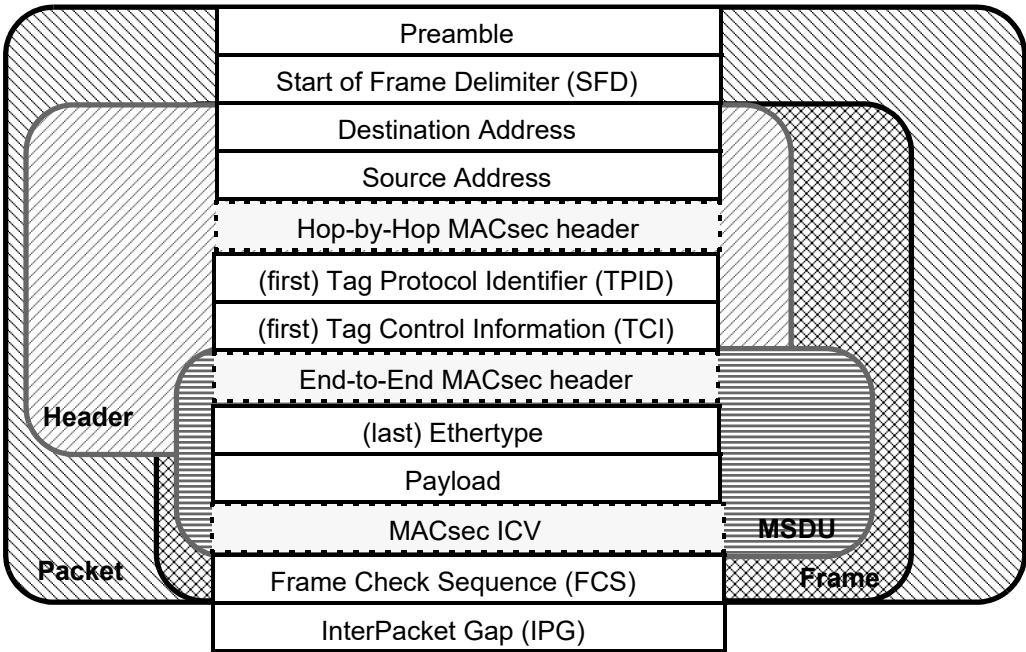


Figure C-2—Packet and Frame formats

4 **C.4.2 Untagged Frame ([Q]:3.286)**

5 An Untagged Frame in the context of this present standard carries a value other than 0x8100 in the most
6 outer (first) Ethertype (Figure C-2).

7 **C.4.3 VLAN Tagged Frame ([Q]:9.5)**

8 A (VLAN) Tagged Frame ([Q]:3.267) in the context of this present standard carries a TPID of 0x8100
9 ([Q]:Table 9-1) in the most outer (first) Ethertype (Figure C-2) and a non-Zero VID field. IEEE Std 802.1Q
10 ([Q]:9.5 a)) refers to this tag as a C-TAG.

11 **C.4.4 Priority-Tagged Frame ([Q]:6.9)**

12 A Priority-Tagged Frame in the context of this present standard carries a TPID of 0x8100 in the most outer
13 (first) Ethertype (Figure C-2) and a VID field of all Zero. IEEE Std 802.1Q ([Q]:9.5 a)) refers to this tag as a
14 C-TAG.

15 **C.4.5 Hop-by-Hop MACsec**

16 If MACsec is applied Hop-by-Hop, the SecTAG ([AE]:9.3) is placed between the Source Address and the C-
17 TAG ([Q]:9.5 a)) of the Frame (Figure C-2), as depicted in [AE]:Figure 6-2.

1 C.5 Bandwidth

2 Bandwidth (B) is in general defined as the quotient of amount of Data (D) over an interval of Time (T):

3 $B = D/T$.

4 Any Ethernet communication link operates at a certain Line Rate (R). While the link is transmitting data, the
5 instantaneous Bandwidth is always equal to the Line Rate. Only if the Time interval (T) includes a period
6 where no data is transmitted on the link, can the Bandwidth of Traffic on that link drop below the Line Rate.
7 It is therefore not advisable to give Bandwidth information without an indication of the period of Time over
8 which it is measured.

9 One can also define Bandwidth as a number of Frames (F) of equal length (L) over an interval of Time (T):

10 $B = F \cdot L / T$.

11 The following factors influence Frame size (L):

- 12 a) Header information at all ISO/OSI Layers.
- 13 b) Serialization of transported data.
- 14 c) Safety and Security overhead.

15 The following factors influence the number of Frames (F) over a period of Time (T):

- 16 d) Actual data available for transmission.
- 17 e) Maximum allowed SDU size (causing segmentation or fragmentation).
- 18 f) Retransmissions of lost Frames in reliable Flows (e.g. TCP [B7]).

19 C.6 Network Traffic Classification

20 C.6.1 Automotive Network Traffic Patterns

21 The number of frames on the IVN is dominated by cyclic messages to monitor or control (safety critical)
22 functionality. Their periodicity varies between about 1ms and 500ms, i.e. less than 1000 frames per second
23 per stream. Due to the mostly low to medium Frame size (Annex C.4), the average Bandwidth (Annex C.5)
24 demand is low, but there is a large number of such streams, which are critical to the operation of the vehicle.

25 High resolution sensors (cameras, LIDARs, RADARs) can generate (1.5k Byte) frames (Annex C.4) at a
26 rate of 10s of thousands per second. This traffic dominates the Bandwidth (Annex C.5) in the IVN.

27 Acoustic sensors for active noise cancellation can generate a small frame about every 20µs. These can be
28 considered to have the highest latency constraint within the IVN, but at very low Bandwidth.

29 FlexRay (Annex E) enables a request-response exchange (2 messages) to happen within less than 100µs, i.e.
30 within a single FlexRay cycle.

31 The so called “Best Effort” (BE) Traffic in the vehicle consists of distribution of SotA data, web access by
32 the occupants, map downloads, and similar not time triggered Frames. This is the most bursty traffic in the
33 IVN. In contrast to an IT or home network, this traffic does however have a need to be guarded against
34 losses (C.9). Since a high percentage of traffic in the IVN is dominated by some sort of time triggered
35 events, the Bandwidth available for BE Traffic is not as temporarily varying as in an office or home network

1 installation. Retransmissions due to Frame loss present an unpredictable source of bandwidth demand,
2 which in turn increases the risk of frame loss. This kind of feedback loop is best avoided.

3 **C.6.2 Scheduled Traffic**

4 The application independent term “Scheduled Traffic” is to denote streams, where transmission, reception,
5 and response are tightly coupled in the time domain. While no absolute numbers are given, the latency and
6 periodicity can be assumed to be below a few 100µs.

7 **C.7 Scheduler vs. Shaper**

8 This present standard defines the terms as follows:

- 9 a) Scheduling: Is the action of assigning Resources
- 10 b) Traffic Shaping: Is a Bandwidth management technique
- 11 c) Policing: Is the rule or bandwidth based Discarding of frames

12 If the Resource assigned by a Scheduler is (access to) Bandwidth, then a Scheduler will implicitly perform
13 Traffic Shaping. E.g.: The Time Aware Shaper (TAS of Clause 10) is based on Scheduling access to a
14 transmission port based on a timetable.

15 Strict Priority Queuing (SPQ) assigns access to a transmission port based on priority. But SPQ does not
16 manage the bandwidth, as the highest priority can get 100% access to the transmission port.

17 An ingress Rate Limiter discards frames (policies them) in case they arrive too frequently. Less bandwidth is
18 required for the left over egress traffic, but one would usually not call this shaping.

19 **C.8 FRER Functionality**

20 Frame Replication and Elimination for Reliability (FRER) as well as Stream Identification are defined in
21 IEEE Std 802.1CB ([CB]).

22 In the context of this present standard the FRER Functionality is referring to all those functions defined in
23 [CB], except the Stream Identification functions ([CB]:6).

24 In particular FRER Functionality entails:

- 25 a) Sequencing function ([CB]:7.4)
- 26 b) Individual recovery function ([CB]:7.5)
- 27 c) Sequence encode/decode function ([CB]:7.6)
- 28 d) Stream splitting function ([CB]:7.7)
- 29 e) Redundancy Tag ([CB]:7.8)
- 30 f) Sequence information ([CB]:7.9 and [CB]:7.10)

1 C.9 Frame Loss

2 A Frame can be lost if the Relay is unable to process it:

- 3 a) Due to an invalid FCS on ingress. ([Q]:6.5.2 a))
- 4 b) If the SDU size ([802.3]:3.2.7) of the frame exceeds the maximum supported SDU size of the PHY/
5 MAC on egress. ([Q]:6.5.2 b)3))
- 6 c) If the SDU size ([802.3]:3.2.7) of the frame exceeds the maximum supported SDU size of the
7 Relay's IEEE 802.1 Features on ingress.
- 8 d) If the SDU size ([802.3]:3.2.7) of the frame is below the minimum supported SDU size of the PHY/
9 MAC on ingress. ([802.3]:4.2.3.3)

10

1 Annex D

2 Stream Identification

(informative)

4 D.1 Configuring Stream Identification

5 The Stream Identification of [CB]:6. differentiates active and passive stream identification functions. All
6 stream identification functions assign a *stream_handle* to the Frame they match in the input/up ([CB]:3.)
7 direction. The Active Destination MAC and VLAN Stream Identification of [CB]:6.6 modifies a frame in
8 the input/up as well as in the output/down ([CB]:3.) direction. Passive stream identification functions have
9 no effect on frames in the output/down direction.

10 The out-facing ([CB]:3.) passive stream identification functions serve to assign a *stream_handle* to the
11 Frames they match in the input/up direction to be used by the FRER functionality (Annex C.8) or the Stream
12 Filtering (6.17). As this present standard does not make use of FRER, only the later usage is relevant. A
13 passive in-facing ([CB]:3.) stream identification function therefore can not serve any purpose in the context
14 of this present standard, as the assigned *stream_handle* in the input/up direction could only be used by the
15 FRER functionality.

16 The Active Destination MAC and VLAN Stream Identification ([CB]:6.6) is used in the FRER context of
17 [CB] to allow frame replication of IP unicast Frames in the Relay by changing the original MAC unicast
18 destination address to a groupcast address and thereby triggering egress to multiple ports. Due to its ISO/
19 OSI layer violating ([CB]:8.1 j)) nature and the ensued configuration complexity, this present standard
20 discourages the use of active stream identification.

21 In conclusion there is no need to configure an in-facing stream identification function in the context of this
22 current standard.

23 NOTE 1—This description ignores the potential issues with the internal LAN ([CB]:Figure 6-5) and the in-facing stream
24 identification functions removing the *stream_handle*, thereby preventing the Stream Filter (6.17) to identify Frames.

1 Annex E

2 FlexRay

(informative)

4 E.1 How Ethernet can be used to replace FlexRay

5 Often TAS is seen as the ideal way to replace TDMA systems like FlexRay [B3] on Bridged Ethernet
6 infrastructure. In many discussions around the topic it is unclear what the exact boundaries are in which
7 Ethernet could be used to replace FlexRay. This section is aimed at giving the reader a better understanding
8 of the quantitative numbers involved.

9 We assume a 100Mbit/s Ethernet link, keeping in mind FlexRay was 10Mbit/s. We further assume a full-
10 duplex Bridged system on Ethernet without cut-through forwarding [B4] or preemption [Q]:6.7.1.

11 As a goal we want to achieve a latency of around 100 μ s between the generation of data by one scheduled
12 application and the use of same data by another scheduled application on another ECU.

13 The applications are scheduled on each ECU per a global time-table, which uses 6.5 as its base. The exact
14 accuracy to which such a scheduling can occur is not further considered here, but does contribute to the
15 latency. Due to the inaccuracies at which an application may be scheduled and how long it will run, data on
16 one ECU is delivered from multiple scheduled applications at roughly the same time. Due to jitter the frames
17 from these applications enter an egress queue at a basically random order. For latency purposes we need to
18 concern ourselves with the very last frame to be transmitted. Assuming each frame is 100 Bytes long, this
19 means every frame introduces a latency of 8 μ s. If the 5 applications generated the data at the same time, it
20 will then take at least 40 μ s to transmit these 5 frames.

21 All applications could generate data at the same time and all ECUs therefore begin transmitting at exactly
22 the same time. Postulating a full multicast, this means any ECU needs to receive 4 times 5 frames, which
23 will take around 168 μ s, taking into account the store and forward delay of a single relay, and is therefore not
24 a viable option as it exceeds the preset time budget.

25 In a second model system we assume the ECUs are scheduled in a way, so they transmit at different time
26 slots during a well defined interval, but the 5 applications on each ECU still generate data at exactly the
27 same time. As we use full-duplex links and again use a single relay, it now takes 48 μ s for each set of 5
28 frames to reach the other 4 ECUs.

29 Assuming an additional relay just adds the store and forward delay to each frame, we could have 2 relays
30 and use 56 μ s for each set of 5 frames to reach the other 4 ECUs.

31 Obviously we have over provisioned this system, as there are now a maximum of 3 ECUs which can send
32 into one relay at the same time, so there is potential for optimization and for certain constellations 3 relays
33 may be possible.

34 If, as was assumed for Flex Ray, all the applications are actually synchronized across the ECUs, then the
35 data generation and transmission from each application happens at a defined point in time, creating a CQF
36 (10.4) like pattern in the network without having to configure gates in the relay, but still achieving the same
37 latency guarantees, assuming there is no interfering non scheduled traffic.

1 Annex F

2 Non-real-time capable Protocols (informative)

4 F.1 Configuration proposal for TCP

5 Some protocols like TCP [B7] are intended to provide reliable data transfer, which in effect means, they
6 need to retransmit data, in case the receiver reports it as not having arrived within a certain time-frame.
7 These potential retransmissions makes the bandwidth demand for such TCP-flows unpredictable. An
8 unpredictable bandwidth presents a fundamental problem for configuring any of the TSN features described
9 in Clause 6, be it schedulers, shapers, or policers. In a scenario where frames are lost (e.g., due to congestion
10 or due to bit errors) the retransmission may trigger a policer to drop the unexpected higher bandwidth,
11 leading to further retransmissions, i.e., more bandwidth demand (see also C.6.1). Furthermore it becomes
12 difficult for such flows to configure a TAS cycle fulfilling the stability condition described in 10.6.1.

13 As is discussed in 7.4 the most rigorous policing is happening in the numerically highest TCs, as they can
14 have the most deteriorating effect on congestion. It is therefore not considered advisable to place TCP-flows
15 in the numerically highest TCs.

16

1 Annex G

2 Egress Shaping in End Stations

(informative)

4 G.1 End Station Shaper Variants

5 In a Bridge the source of the egress traffic at one Port is the ingress on all other Ports. Data can arrive
6 simultaneously on any ingress Port, but needs to be transmitted in a serial fashion on the egress Port.
7 Queuing frames according to Priority into TCs and the use of Shapers allows to control the order in which
8 frames are transmitted, as well as their spacing.

9 For an End Station the ultimate source of data are the Applications. The Applications are themselves
10 scheduled by the Operating System (OS). In some environments Applications deliver data to a Middleware
11 (MW), which may have mechanisms to pack different data elements into various Frames, so one Frame does
12 not just carry the data from one Application. This obviously requires some data collection and potential
13 trigger conditions on how many of the planned Applications will need to have contributed to the payload of
14 a Frame before it is actually transmitted by the Middleware. Therefore OS and MW have the capability to
15 shape the transmitted traffic.

16 In case a Middleware is not present, some OSs like Linux offer shaping mechanisms in software (SW), like
17 the Hierarchical Token Bucket (HTB). Also CBS like mechanisms are available in SW. Since SW on a
18 Talker can have more information available for its configuration, it can be much more flexible in assigning
19 Frames to certain shaper instances.

20 The shaping mechanisms are not very different. It is mainly the granularity at which Frames can be assigned
21 to Shapers and the number of Shaper Instances available, that actually make a difference in the overall
22 egress behavior.

23

1 Annex H

2 Bibliography (informative)

4 Bibliographical references are resources that provide additional or helpful material but do not need to be
5 understood or used to implement this present standard. Reference to these resources is made for
6 informational use only.

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4