IEEE P802.1DG™/D3.2

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

Abstract: This standard specifies profiles for bounded latency automotive in-vehicle Bridged IEEE 802.3 Ethernet networks based on IEEE 802.1 Time-Sensitive Networking (TSN) standards.
Keywords: TSN, Time-Sensitive Networking, Bridging, Bridges, Bridged Local Area Networks, IEEE 802®, IEEE 802.1Q™, IEEE 802.1DG™, local area networks (LANs), MAC Bridges, Virtual Bridged Local Area Networks (virtual LANs), Automotive In-Vehicle Ethernet Communications.

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This introduction is not part of IEEE P802.1DG™/D3.2, 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

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

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

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Local and metropolitan area networks—

Time-Sensitive Networking Profile for Automotive In-Vehicle Ethernet Communications

1. Overview

1.1 Scope

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

1.2 Purpose

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

1.3 Requirements terminology

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

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

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

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

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

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

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

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

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

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

All other clauses use the following terminology:

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

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

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

1.4 Introduction

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

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

1.5 Outline of the document structure

In Clause 5, the present standard specifies Bridge and End Station requirements as well as optional port requirements. All normative language is aggregated in Clause 5. Clauses 6. through 10. describe the TSN features in more detail and provide references to the base standards.

1.6 Reference conventions

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

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 G)
[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 G.

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.

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[802] IEEE Std 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: Extended 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

4. Abbreviations

This present standard uses the following abbreviations:

ATS	Asynchronous Traffic Shaper
BE	Best Effort
CBS	Credit Based Shaper
CQF	Cyclic Queuing and Forwarding
ECU	Electronic Control Unit
EISS	Enhanced Internal Sublayer Service
EST	Enhancements for Scheduled Traffic
FRER	Frame Replication and Elimination for Reliability
ICV	Integrity Check Value
IVN	In-Vehicle Network
IPG	InterPacket Gap
IPV	Internal Priority Value
ISS	Internal Sublayer Service
MEF	Metro Ethernet Forum
MSDU	MAC Service Data Unit
RSTP	Rapid Spanning Tree Protocol
TDMA	Time Division Multiple Access
SDU	Service Data Unit
SFD	Start of Frame Delimiter
SotA	Software over the Air update
TC	Traffic Class

5. Port Requirements

5.1 Introduction

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

5.2 Profile Conformance Statements (PCS)

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

5.3 Physical Layer requirements

A Port of a Station claiming compliance with this standard shall support an IEEE 802.3 point-to-point full-duplex ([802.3]:1.4.345) link segment ([802.3]:1.4.379).

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

5.4 Bridge requirements

5.4.1 Mandatory Bridge requirements

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

a) Process frames as specified in 6.1.
b) Support C-VLAN tags ([Q]:5.5)
c) Comply to PR-A as specified in 5.6.
d) Comply to PR-B as specified in 5.7.
e) Comply to PR-C as specified in 5.8.
f) Support the Learning Process as specified in 6.14.
g) Support Congestion Separation as specified in 7.2.
h) Support the maximum SDU size as specified in 6.17.1
i) Support the Frame Filtering ([Q]:8.6.3) as specified in 6.15
j) Support the Static IPV configuration as specified in 6.18.1
k) Have all Stream Gates ([Q]:8.6.5.4) in the OPEN state by default (6.18) unless the capability optionally provided by PR-D as specified in 5.9 is activated.

5.4.2 Bridge options

a) A Bridge claiming conformance to this present standard should support Time Synchronization as specified in 6.4.
b) A Bridge claiming conformance to this present standard may comply to PR-D as specified in 5.9 on any number of ports.

c) A Bridge claiming conformance to this present standard may comply to PR-E as specified in 5.10 on any number of ports.

d) A Bridge claiming conformance to this present standard may support Hop-by-Hop MACsec as defined in 6.5.2 on any number of ports.

e) A Bridge claiming conformance to this present standard may discard frames, as specified in 6.24.

5.5 End Station requirements

5.5.1 Mandatory End Station ingress requirements

Any End Station claiming conformance to this present standard shall:

a) Comply with PR-B as specified in 5.7.

b) Perform Destination MAC address filtering

c) Support Out-facing Ingress Stream Identification Function(s) ([CB]:9.1.1.5) as specified in 6.10.2

d) Support Ingress filtering ([Q]:8.6.2) as specified in 6.13

e) Support Stream Filter assignment ([Q]:8.6.5.3 b) as specified in 6.16

f) Process frames on ingress in the order as specified in 6.2

5.5.2 Mandatory End Station egress requirements

Any End Station claiming conformance to this present standard shall:

a) Support one or more shaping mechanisms to generate traffic conformant as input to the shapers deployed in the network.

b) Support max. SDU Size Filtering ([Q]:8.6.5.3.1) as specified in 6.17.1

c) Support Queuing frames ([Q]:8.6.6) as specified in 6.20

d) Support Transmission selection ([Q]:8.6.8) as specified in 6.21

e) Process frames on egress in the order specified in 6.3

5.5.3 End Station Options

Any End Station claiming conformance to this present standard may:

a) Support Time Synchronization as specified in 6.4.

b) Comply with PR-D as specified in 5.9.

c) Comply with PR-E as specified in 5.10.

d) Support Hop-by-Hop MACsec processing ([AE]:11.4) as specified in 6.5.2

e) Support Stream Gating on ingress ([Q]:8.6.5.4) as specified in 6.18.3

f) Support Flow metering on ingress ([Q]:8.6.5.5)

5.6 Port Requirements A (PR-A)

A port of a Station claiming conformance to PR-A shall:

a) Support the Port-based VLAN Classification ([Q]:6.9.1 f)) as specified in 6.7
b) Support the Priority Code Point Decoding ([Q]:6.9.3) as specified in 6.8
c) Support the Priority Regeneration ([Q]:6.9.4) as specified in 6.9
d) Support the Ingress Stream Identification Function(s) ([CB]:6.2) as specified in 6.10.1
e) Support the Active topology enforcement ([Q]:8.6.1) as specified in 6.12
f) Support the Ingress Filtering ([Q]:8.6.2) as specified in 6.13
g) Support Egress Filtering ([Q]:8.6.4)
h) Support Queuing Frames ([Q]:8.6.6) as specified in 6.20
i) Support Transmission Selection as specified in 6.21
j) Support the Egress VID Translation ([Q]:6.9 g)) as specified in 6.23

5.7 Port Requirements B (PR-B)

A port of a Station claiming conformance to PR-B shall:

a) Support the Acceptable Frame Types ([Q]:6.9 c)) as specified in 6.6
b) Support the Maximum SDU Size Filtering as specified in 6.17
c) Support the Flow Metering ([Q]:8.6.5.5) as specified in 6.19
d) Support the Flooding Protection as specified in 6.11

5.8 Port Requirements C (PR-C)

A port of a Station claiming conformance to PR-C shall:

a) Provide the capabilities for the strict priority algorithm ([Q]:8.6.8 b))
b) Provide the capabilities for the Credit Based Shaper ([Q]:8.6.8.2) as detailed in Clause 9.
c) Provide the capabilities for the Asynchronous Traffic Shaper ([Q]:8.6.11) as specified in Clause 8.

5.9 Port Requirements D (PR-D)

A port of a Station claiming conformance to PR-D shall:

a) Activate Time Synchronization (6.4)
b) Provide the capabilities for the Enhancements for Scheduled Traffic ([Q]:8.6.8.4) as specified in Clause 10
c) Enable the Time dependent IPV configuration as per 6.18.2.
d) Enable the Time dependent gate states as per 6.18.3.

5.10 Port Requirements E (PR-E)

A port of a Station claiming conformance to PR-E shall:

a) Support the preemptable MAC as per 6.25.1.

b) Support the express MAC as per 6.25.2.

6. IEEE 802.1 Features

6.1 Bridge Processing

a) Default Priority Assignment ([AC]:13.1)
b) Hop-by-Hop MACsec processing ([AE]:11.4)
c) Support of the EISS ([Q]:6.9)
d) Frame Type Acceptance filter ([Q]:6.9 c))
e) Out-facing Ingress Stream Identification Function(s) ([CB]:9.1.1.5)
f) Port-based VLAN Classification ([Q]:6.9 d))
g) Priority Code Point Decoding ([Q]:6.9.3)
h) Priority Regeneration ([Q]:6.9.4)
i) Active topology enforcement ([Q]:8.6.1)
j) Ingress filtering ([Q]:8.6.2)
k) Frame filtering ([Q]:8.6.3)
l) Egress filtering ([Q]:8.6.4)
m) Stream filter assignment ([Q]:8.6.5.3 b) and c))
n) Maximum SDU Size Filtering ([Q]:8.6.5.3.1)
o) Stream Gating ([Q]:8.6.5.4)
p) Flow metering ([Q]:8.6.5.5)
q) ATS Eligibility Time Assignment ([Q]:8.6.5.6)
r) In-facing Egress Stream Identification Function(s) ([CB]:9.1.1.4)
s) FRER Functionality (C.8)
t) Out-facing Egress Stream Identification Function(s) ([CB]:9.1.1.3)
u) Queuing frames ([Q]:8.6.6)
v) Queue Management (6.24)
w) Transmission selection ([Q]:8.6.8)
x) Priority Code Point Encoding ([Q]:6.9.3)
y) Egress VID translation ([Q]:6.9 g))
z) Support of the EISS ([Q]:6.9)
aa) Hop-by-Hop MACsec processing ([AE]:11.4)
ab) Support of the ISS ([Q]:6.7.1)

NOTE—Potentially not all listed feature are required, depending on the port requirements (Clause 5) applied.

6.2 End Station Receive Path Processing Order (ingress)

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

a) Hop-by-Hop MACsec processing ([AE]:11.2)
b) Frame Type Acceptance filter ([Q]:6.9 c))
c) Destination MAC address filtering as per 5.5.1 item b)
d) Ingress filtering ([Q]:8.6.2)
e) Out-facing Ingress Stream Identification Function(s) ([CB]:9.1.1.5)

f) Stream filter assignment ([Q]:8.6.5.3 b)
g) Maximum SDU Size Filtering ([Q]:8.6.5.3.1)
h) Stream Gating ([Q]:8.6.5.4)
i) Flow metering ([Q]:8.6.5.5)

NOTE—Potentially not all listed feature are required, depending on the port requirements (Clause 5) applied.

6.3 End Station Transmission Path Processing Order (egress)

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

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

NOTE—Potentially not all listed feature are required, depending on the port requirementles (Clause 5) applied.

6.4 Time Synchronization

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

a) IEEE Std 802.1AS-2020 [AS-2020]
b) IEEE Std 802.1AS-2011 [AS-2011]
c) AVnu Automotive profile [B7]
d) AUTOSAR Time Synchronization Protocol [AR897]
e) IEEE Std 1588-2019 ([B1] and its profiles: https://sagroups.ieee.org/1588/ptp-profiles/)

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

6.5 MACsec processing ([AE])

6.5.1 General MACsec considerations

The present standard does not address the details of a MACsec implementation. If an integrator chooses to implement MACsec in (parts of) the network, they at least need to consider MACsec's impact on for example Preemption (5.10), EST gate schedule (5.9), Shapers (5.8), and policing (5.7). As this list is not claiming completeness, the implementer is advised to consider further implications.

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

6.5.2 Hop-by-Hop MACsec

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

6.6 Acceptable Frame Types ([Q]:6.9 c))

The Acceptable Frame Types parameter can take the following values:

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

Frames not matching the Acceptable Frame Types parameter are discarded silently.

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

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

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

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

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

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

6.8 Priority Code Point Decoding ([Q]:6.9.3)

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

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

6.9 Priority Regeneration ([Q]:6.9.4)

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

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

6.10.1 Stream Identification Function(s) for Bridges

Only passive out-facing stream identification functions are configurable, with the Identification Mask Length as stated in 6.10.3.

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

The Stream Identification functions operate on the *M_UNITDATA.indication* parameters of the Internal Sublayer Service (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 (*n*)	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

6.10.2 Stream Identification Function(s) for End Stations

Only passive out-facing stream identification functions are configurable, with the Identification Mask Length as stated in 6.10.3.

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

6.10.3 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
- — the port information of TCP and UDP

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

NOTE 2—End-to-End MACsec is out of scope (Annex B.2), as it is not covered by [CB]. Hop-by-Hop MACsec (6.5.2) is covered earlier in the ingress processing.

6.11 Flooding protection

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

a) flooded to all ports after Egress filtering ([Q]:8.6.4) by default, or

b) discarded (a counter can be implemented), or

c) forwarded to a specific (management) Port

6.12 Active topology enforcement ([Q]:8.6.1)

If ingress filtering ([Q]:8.6.2) did not cause the received frame to be discarded, the source address and VID are submitted to the Learning Process (6.14). The Learning Process can be configured by management, under which conditions learning is enabled or disabled is not further specified here.

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

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

6.13 Ingress Filtering ([Q]:8.6.2)

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

6.14 The Learning Process ([Q]:8.7)

The Learning Process:

a) Supports shared C-VLAN learning of source MAC addresses ([Q]:Annex F).
b) Supports independent C-VLAN learning of source MAC addresses ([Q]:Annex F).
c) Can disable learning per ingress port.
d) Can disable a change of ingress port once a source MAC address has been leaned on that port (one-shot-mode).

6.15 Frame Filtering ([Q]:8.6.3)

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

a) The *destination_address* parameter ([Q]:8.6.3 a))
b) The *vlan_identifier* parameter ([Q]:8.6.3 b))
c) The Filtering Database (FDB) entries ([Q]:8.6.3 d))
d) The default Group Filtering behavior ([Q]:8.6.3 e))

6.15.1 The Filtering Database (FDB)

The Filtering Database (FDB) conforms to [Q]:8.8.

The FDB allows for at least 1024 address entries.

6.15.2 Reserved Addresses (01-80-C2-...)

The Reserved Addresses of [Q]:Table 8-1 and [Q]:Table 8-2 are supported.

NOTE—Frames addressed to Reserved Addresses can carry a C-VLAN Tag on wire and have an associated *vlan_identifier* parameter.

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

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

6.16 Stream Filter ([Q]:8.6.5.3)

A Stream Filter is identified by

a) a *stream_handle* specification ([Q]:8.6.5.3 b)) AND
b) a *priority* specification ([Q]:8.6.5.3 c)).

Frames assigned to the same Stream Filter are processed together in the same SF-Instances of Max. SDU Size Filtering (6.17.2), Stream Gating (6.18), Flow Metering (6.19), and ATS eligibility time assignment (8.2).

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

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

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

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

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

6.17 Maximum SDU Size Filtering

6.17.1 Service Data Unit (SDU) Size

The SDU size considered here is specifically the MSDU size (Figure C-1), as described in Annex C.4.

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

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

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

All stream filters will have a Max SDU Size filter configured to the max of 2000 octets (6.17.1) or a user selected value.

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

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

6.18 Stream Gates ([Q]:8.6.5.4)

6.18.1 Static IPV configuration

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

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

The allowed range for the *IPV* parameter is not specified explicitly in [Q]. In practice, stations can use a number of methods to assign a frame an *IPV*, and thus to an output queue. This standard does not restrict such behavior (see also 6.20.1).

6.18.2 Time dependent IPV configuration

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

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

6.18.3 Time dependent gate states

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

6.19 Flow Metering ([Q]:8.6.5.5)

All Stream Filters have a Flow Meter configured.

The MEF 10.3 algorithm is supported with:

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

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

Frames are either:

g) Permitted to pass (green) OR
h) Dropped (red)

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

6.20 Queuing Frames ([Q]:8.6.6)

Queuing frames is performed per egress port.

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

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

a) If stream gates ([Q]:8.6.5.4) are not supported, the frame's associated *priority* parameter is used.
b) If stream gates are supported and the *IPV* parameter assigned to the frame is *Null*, the frame's associated *priority* parameter is used.
c) If stream gates are supported and the *IPV* parameter assigned to the frame is Non-*Null*, the *IPV* parameter is used (see also 6.18.1).

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

6.20.1 Number of Traffic Class Queues

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

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

6.21 Transmission Selection

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

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

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

6.21.2 Port Transmission Selection ([Q]:8.6.8 b))

For each port, frames are selected for transmission on the basis of the TCs that the port supports (6.21.1) and the operation of the transmission selection algorithms supported by the corresponding queues on that port. For a given port and traffic class, frames are selected from the corresponding queue for transmission if and only if:

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

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

6.22 Transmission Gates ([Q]:8.6.8.4)

a) Support the Enhancements for Scheduled Traffic (EST) according to Clause 10.
b) Support of EST is not required on any egress port where ATS or CBS are activated on any TC Queue.

NOTE 1—A rational for the restriction in b) can be found in [B5] and 10.6.

6.23 Egress VID Translation ([Q]:6.9 g))

Egress VID Translation is performed per egress port.

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

6.24 Frame Discard

Discarding a Frame is an intentional action by the Management Entity.

The Bridge can discard a Frame:

c) Due to policing, if a flow metering algorithm ([Q]:8.6.5.5) determines that discard is necessary. ([Q]:6.5.2 b)7))
d) Due to policing, if a shaping algorithm ([Q]:8.6.11.3.7) determines that discard is necessary.
e) Due to policing, if the frame exceeds the queueMaxSDU ([Q]:8.6.8.4) for the TC queue. ([Q]:6.5.2 b)8))
f) Due to policing, if the max. SDU Size Filter ([Q]:8.6.5.3.1) determines that discard is necessary.
g) Due to congestion, if there is a risk of or actual exhaustion ([Q]:6.5.2 b) 2)) of internal buffer capacity.
h) Due to an unknown egress port, if the FDB ([Q]:8.8) disallows the forwarding. ([Q]:6.5.2 b) 6))
i) Due to an invalid ingress port, if one-shot-learning (6.14) is active.
j) Due to security considerations, if the device attached to the port is not authorized (IEEE Std 802.1X) for access to the network. ([Q]:6.5.2 b)5))

6.25 Preemption

6.25.1 Preemptable MAC ([Q]:6.7.1 a))

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

6.25.2 Express MAC ([Q]:6.7.1 b))

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

6.26 Egress filtering ([Q]:8.6.4)

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 present.

7. Congestion

7.1 Definitions

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

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

7.2 Congestion Separation

Congestion separation is to be performed on each Bridge locally.

a) A Bridge is configurable to segregate the Buffers for different Traffic, so Buffer overruns in one segregated block can lead to discarding of Frames within that one Traffic aggregate, but not for the other Traffic aggregates.

b) Frames are not forwarded on egress, if the bandwidth exceeds a configured maximum.

c) Frames are discarded if the bandwidth exceeds a configured maximum on ingress.

7.3 Causes for Congested Traffic

Traffic can become congested, if:

a) The Shaper (CBS, ATS, EST) on egress is configured with a too low rate or a too small burst size.

b) Excessively large lower priority Frames block the transmission.

c) A large higher Priority Burst blocks the transmission.

Therefore in order to prevent Traffic from becoming congested:

d) Bandwidth needs for all Traffic must be well known.

e) All traffic goes through a max. SDU Size Filter ([Q]:8.6.5.3.1).

f) All higher priority traffic (and therefore all traffic, except the lowest TC) goes through a Flow Meter ([Q] 8.6.5.5).

7.4 Causes for Congesting Traffic

Traffic causes congestion, if:

a) Bursts of random size occur, as no shaping is implemented.

b) A Shaper (CBS, ATS, EST) with a mis-configured rate or burst size is active.

c) The Traffic contains excessively large Frames.

Therefore in order to prevent Traffic from causing congestion:

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

8. Asynchronous Traffic Shaper (ATS)

8.1 Configuration

Every ATS Scheduler Instance is configured through:

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

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

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

8.3 Implicit policing

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

a) The MEF Committed Information Rate: MEF-CIR(ATS) = ATS-CIR
b) The MEF Committed Burst Size: MEF-CBS(ATS) = ATS-MRT * ATS-CIR
c) The MEF Excess Information Rate: MEF-EIR(ATS) = 0
d) The MEF Excess Burst Size: MEF-EBS(ATS) = 0
e) The MEF Coupling Flag: MEF-CF(ATS) = False (0)
f) The MEF Color Mode Flag: MEF-CM(ATS) = color-blind

NOTE—The *length(frame)* parameter ([Q]:8.6.11.3.11) used in the ATS ProcessFrame procedure ([Q]:8.6.11.3) includes the media-dependent overhead ([Q]:12.4.2.2), while the MEF flow meter (6.19) only has the MSDU size available for policing. Any resulting deviations are not accounted for in the current standard.

8.4 Policing Configuration

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

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

Frames in the queue of a TC configured with the ATS selection algorithm are subject to the same Lifetime limitations as all other Frames provided to this TC of this port (6.24).

8.5 Instance and TC Queue Assignment

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

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

Frames being processed by an ATS Scheduler Instance are queued into the same numerical TC on every hop as they traverse the network.

Frames that arrive on different ports are never to be processed by the same ATS Scheduler Instance.

Frames that use a different TC anywhere in the network are never processed by the same ATS Scheduler Instance.

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

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

8.6 ATS Scheduler Groups

All ATS Scheduler Instances processing Frames in a specific upstream TC arriving on one specific ingress port belong to the same ATS scheduler Group.

If one ATS Scheduler Instance within an ATS scheduler Group has a significantly higher Committed Information Rate, than a second ATS Scheduler Instance within the same ATS scheduler Group (ATS-CIR[1] >> ATS-CIR[2]), the Group Eligibility Time shared between the two ATS Scheduler Instances leads to a potentially undue delay of Frames if an ingress burst of Frames destined for the lower rate (ATS-CIR[2]=r2) ATS Scheduler Instance within the Group pushes the Eligibility Time for the higher rate ATS Scheduler Instance into the future. Worst case the Frame of the higher rate ATS Scheduler Instance might be discarded, if ATS-MRT[1] < L2/r2, where L2 is the Frame’s length.

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

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: MEF-CIR(CBS) = CBS-IS

b) The MEF Committed Burst Size: MEF-CBS(CBS) = *maxBurstSize*

c) The MEF Excess Information Rate: MEF-EIR(CBS) = 0

d) The MEF Excess Burst Size: MEF-EBS(CBS) = 0

e) The MEF Coupling Flag: MEF-CF(CBS) = False (0)

f) The MEF Color Mode Flag: MEF-CM(CBS) = color-blind

Where *maxBurstSize* = (max. SDU size + media-dependent overhead)
+ *maxInterferenceTime* * *portTransmitRate* * CBS-IS / (*portTransmitRate* - 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-1) to be included in the bandwidth. The MEF flow meter (6.19) only has the MSDU size available for policing. The resulting deviations are not accounted for in the current standard.

9.3 Configuration Rules

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

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

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

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

10. Enhancements for Scheduled Traffic ([Q]:8.6.8.4)

10.1 Introduction

The EST ([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 EST is used on a port, by default no other shapers are used on TCs whose gates open and close for that port.

If EST 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 EST 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 Time Division Multiple Access (TDMA) systems, finding the perfect schedule across applications, ECUs and relays can be an NP-hard problem [B4].

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 µs.

10.3 Phased Mode

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

10.3.1 Phased Mode Configuration

The GateControlList has at least 32 entries per port.

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

10.4 Cyclic Queuing and Forwarding (CQF)

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

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

10.5 EST Latency and Efficiency Considerations

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

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

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

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

10.6 Combining EST with other Shapers

10.6.1 General EST considerations

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

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

10.6.2 Combining CBS with EST

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

10.6.3 Combining ATS with EST

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

Annex A

PCS proforma (normative)

A.1 Introduction

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

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

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

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

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

A.2 Abbreviations and special symbols

A.2.1 Status symbols

M mandatory

O optional

O.n optional, but support of at least one of the group of options labeled by the same numeral n is required

X prohibited

pred:conditional-item symbol, including predicate identification: see A.3.4

¬ logical negation, applied to a conditional item's predicate

A.2.2 General abbreviations

N/A not applicable

PCS Profile Conformance Statement

A.3 Instructions for completing the PCS proforma

A.3.1 General structure of the PCS proforma

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

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

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

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

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

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

A.3.2 Additional information

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

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

A.3.3 Exception Information

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

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

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

A.3.4 Conditional status

A.3.4.1 Conditional items

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

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

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 status symbol, M or O.

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

A.3.4.2 Predicates

A predicate is one of the following:

a) An item-reference for an item in the PCS proforma: The value of the predicate is true if the item is marked as supported and is false otherwise;

b) A predicate-name, for a predicate defined as a Boolean expression constructed by combining item-references using the Boolean operator OR: The value of the predicate is true if one or more of the items is marked as supported;

c) The logical negation symbol “¬” prefixed to an item-reference or predicate-name: The value of the predicate is true if the value of the predicate formed by omitting the “¬” symbol is false, and vice versa.

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

A.4 Bridge PCS

NOTE—Covers section 5.4.

Table A-1—Bridge PCS

Item	Feature	Status	References	Support
PCS—1	Does the Bridge process frames as specified?	M	5.4.1:a)	Yes [ ]
C-VLAN	Does the Bridge support C-VLAN tags?	M	5.4.1:b)	Yes [ ]
B-PR-A	Does the Bridge support PR-A?	M	5.4.1:c)	Yes [ ]
B-PR-B	Does the Bridge support PR-B?	M	5.4.1:d)	Yes [ ]
B-PR-C	Does the Bridge support PR-C?	M	5.4.1:e)	Yes [ ]
PCS—2	Does the Bridge support the Learning Process?	M	5.4.1:f)	Yes [ ]
PCS—3	Does the Bridge support Congestion Separation?	M	5.4.1:g)	Yes [ ]
PCS—4	Does the Bridge support the maximum SDU Size?	M	5.4.1:h)	Yes [ ]
PCS—5	Does the Bridge support Frame Filtering?	M	5.4.1:i)	Yes [ ]
PCS—6	Does the Bridge support static IPV configuration?	M	5.4.1:j)	Yes [ ]
PCS—7	Are the Bridge's Stream Gates open by default?	M	5.4.1:k)	Yes [ ]
B-TimeSync	Does the Bridge support Time Synchronization? If Yes, provide details on the supported profile: ____	PR-D-TimeSync:M	5.4.2:a)	Yes [ ] No [ ]
B-PR-D	Does the Bridge support PR-D?	O	5.4.2:b)	Yes [ ] No [ ]
B-PR-E	Does the Bridge support PR-E?	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—8	Does the Bridge support discarding frames with exceeded lifetime?	O	5.4.2:e)	Yes [ ] No [ ]

A.5 End Station PCS

NOTE—Covers section 5.5.

Table A-2—End Station PCS

Item	Feature	Status	References	Support
E-PR-B	Does the end station support PR-B?	M	5.5.1:a)	Yes [ ]
PCS—9	Does the end station perform Destination MAC address filtering?	M	5.5.1:b)	Yes [ ]
PCS—10	Does the end station support Out-facing Ingress Stream Identification Function(s)?	M	5.5.1:c)	Yes [ ]
PCS—11	Does the end station support Ingress filtering?	M	5.5.1:d)	Yes [ ]
PCS—12	Does the end station support Stream Filter assignment?	M	5.5.1:e)	Yes [ ]
PCS—13	Does the end station process frames in the specified order upon ingress?	M	5.5.1:f)	Yes [ ]
PCS—14	Does the End Station support egress shaping mechanisms? If Yes, provide details on the supported mechanisms: ___________________________________	M	5.5.2:a)	Yes [ ]
PCS—15	Does the end station support max. SDU Size Filtering?	M	5.5.2:b)	Yes [ ]
PCS—16	Does the end station support Queuing frames?	M	5.5.2:c)	Yes [ ]
PCS—17	Does the end station support Transmission selection?	M	5.5.2:d)	Yes [ ]
PCS—18	Does the end station process frames in the specified order upon egress?	M	5.5.2:e)	Yes [ ]
E-TimeSync	Does the End Station support Time Synchronization? If Yes, provide details on the supported profile: ___________________________________	PR-D-TimeSync:M	5.5.3:a)	Yes [ ] No [ ]
E-PR-D	Does the End Station support PR-D?	O	5.5.3:b)	Yes [ ] No [ ]
E-PR-E	Does the End Station support PR-E?	O	5.5.3:c)	Yes [ ] No [ ]
PCS—19	Does the End Station support Hop-by-Hop MACsec?	O	5.5.3:d)	Yes [ ] No [ ]
PCS—20	Does the End Station support Stream Gating on ingress?	O	5.5.3:e)	Yes [ ] No [ ]
PCS—21	Does the End Station support Flow metering on ingress?	O	5.5.3:f)	Yes [ ] No [ ]

A.6 Port Requirements A (PR-A) PCS

NOTE—Covers section 5.6.

Table A-3—PR-A PCS

Item	Feature	Status	References	Support
PCS—22	Does the Station’s Port support Port-based VLAN Classification?	B-PR-A:M	5.6:a)	Yes [ ] No [ ]
PCS—23	Does the Station’s Port support Priority Code Point Decoding?	B-PR-A:M	5.6:b)	Yes [ ] No [ ]
PCS—24	Does the Station’s Port support Priority Regeneration?	B-PR-A:M	5.6:c)	Yes [ ] No [ ]
PCS—25	Does the Station’s Port support Ingress Stream Identification Function(s)?	B-PR-A:M	5.6:d)	Yes [ ] No [ ]
PCS—26	Does the Station’s Port support Active topology enforcement?	B-PR-A:M	5.6:e)	Yes [ ] No [ ]
PCS—27	Does the Station’s Port support Ingress Filtering?	B-PR-A:M	5.6:f)	Yes [ ] No [ ]
PCS—28	Does the Station’s Port support Egress Filtering	B-PR-A:M	5.6:g)	Yes [ ] No [ ]
PCS—29	Does the Station’s Port support Queuing Frames?	B-PR-A:M	5.6:h)	Yes [ ] No [ ]
PCS—30	Does the Station’s Port support Transmission Selection?	B-PR-A:M	5.6:i)	Yes [ ] No [ ]
PCS—31	Does the Station’s Port support Egress VID Translation?	B-PR-A:M	5.6:j)	Yes [ ] No [ ]

A.7 Port Requirements B (PR-B) PCS

NOTE—Covers section 5.7.

Table A-4—PR-B PCS

Item	Feature	Status	References	Support
PCS—32	Does the Station’s Port support the Acceptable Frame Types Filter?	B-PR-B:M E-PR-B:M	5.7:a)	Yes [ ] No [ ]
PCS—33	Does the Station’s Port support the Maximum SDU Size Filtering?	B-PR-B:M E-PR-B:M	5.7:b)	Yes [ ] No [ ]
PCS—34	Does the Station’s Port support Flow Metering?	B-PR-B:M E-PR-B:M	5.7:c)	Yes [ ] No [ ]
PCS—35	Does the Station’s Port support Flooding Protection?	B-PR-B:M E-PR-B:M	5.7:d)	Yes [ ] No [ ]

1 ## A.8 Port Requirements C (PR-C) PCS

2 Covers section 5.8.

Table A-5—PR-C PCS

Item	Feature	Status	References	Support
PR-C-SP	Does the Station's Port provide the capabilities for the strict priority algorythm?	B-PR-C:M	5.8:a)	Yes [ ] No [ ]
PR-C-CBS	Does the Station's Port provide the capabilities for the Credit Based Shaper?	B-PR-C:M	5.8:b)	Yes [ ] No [ ]
PR-C-ATS	Does the Station's Port provide the capabilities for the Asynchronous Traffic Shaper	B-PR-C:M	5.8:c)	Yes [ ] No [ ]

3 ## A.9 Port Requirements D (PR-D) PCS

4 NOTE—Covers section 5.9.

Table A-6—PR-D PCS

Item	Feature	Status	References	Support
PR-D-TimeSync	Does the Station's Port have Time Synchronization activated?	B-PR-D:M E-PR-D:M	5.9:a)	Yes [ ] No [ ]
PCS—36	Does the Station's Port provide the capabilities for the Enhancements for Scheduled Traffic?	B-PR-D:O E-PR-D:M	5.9:b)	Yes [ ] No [ ]
PCS—37	Does the Station's Port have the Time dependent IPV configuration enabled?	B-PR-D:O E-PR-D:M	5.9:c)	Yes [ ] No [ ]
PCS—38	Does the Station's Port have the Time dependent gate states enabled?	B-PR-D:O E-PR-D:M	5.9:d)	Yes [ ] No [ ]

5 ## A.10 Port Requirements E (PR-E) PCS

6 NOTE—Covers section 5.10.

Table A-7—PR-E PCS

Item	Feature	Status	References	Support
PR-D-pMAC	Does the System support the preemptable MAC	B-PR-E:M E-PR-E:M	5.10:a)	Yes [ ] No [ ]
PR-D-eMAC	Does the System support the express MAC	B-PR-E:M E-PR-E:M	5.10:b)	Yes [ ] No [ ]

Annex B

Intentional Limitations (informative)

B.1 Shaper Interactions

In [B5] a line of reasoning is given why combining the ATS (Clause 8) or CBS (Clause 9) mechanisms with EST (Clause 10) may lead to a more complicated configuration in certain network topologies. While [Q] allows such combinations (10.6), the present standard does not give guidance on how such configurations affect network behavior.

B.2 End-to-End MACsec

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

B.3 Preemption Interactions

While [Q] certainly allows combinations of Preemption (6.25) with for example EST (Clause 10), the present standard does not give guidance on how such configurations affect network behavior.

Annex C

Terminology (informative)

C.1 Automotive Stations (IEEE Std 802)

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

C.1.1 Automotive Bridge

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

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

C.1.2 Automotive End Station

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

C.2 Automotive Electronic Control Unit (ECU)

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

C.3 Communication Aggregates

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

C.4 Frame Content as Received

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

A Frame in the context of this present standard contains,

a) One MAC Source Address,
b) one MAC Destination Address,
c) an optional C-VLAN Tag (see below),

d) and one (last) Ethertype.

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

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

C.4.1 Packet and Frame size

The bandwidth and latency characteristics of an Ethernet network are sensitive to the packet ([802.3]:Figure 3-1) sizes that are used in the network. Specifically when analyzing the queuing delay (e.g. [Q]:Annex L.3.1.1) of a specific frame X, another frame Y of any priority could have been selected for transmission an arbitrarily small time before frame X became eligible for transmission. The actual packet length of frame Y is dependent on the exact header structure and physical layer overhead (see Figure C-1). All relevant shaping mechanisms (ATS (Clause 8), CBS (Clause 9) and EST (Clause 10)) specifications refer to lengths as including (media-dependent) overhead ([Q]:12.4.2.2). For ATS it is explicitly stated in [Q]:8.6.11.3.11. 8.6.8.4, for CBS this can best be seen in [Q]:L.2 item b), and for EST in [Q]:8.6.8.4 NOTE 1.

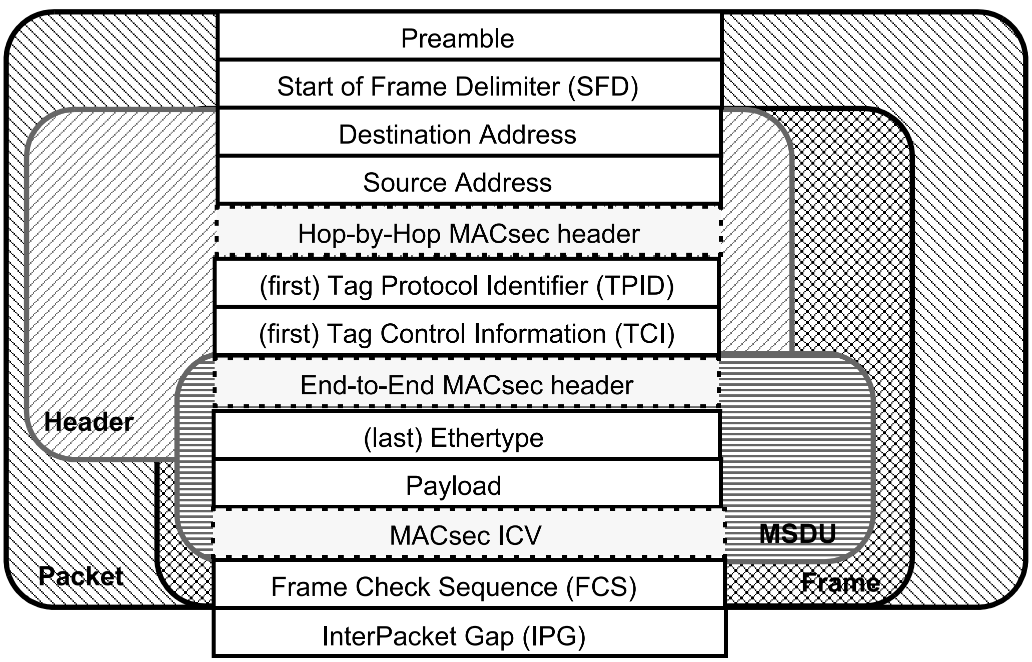

Figure C-1—Packet and Frame formats

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

As this standard considers only C-VLAN tags ([Q]:9.5 a)), an Untagged Frame in the context of this present standard carries a value other than 0x8100 in the outermost (first) Ethertype (Figure C-1), when processed in the EISS ([Q]:6.8).

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

As this standard considers only C-VLAN tags ([Q]:9.5 a)), a (VLAN) Tagged Frame ([Q]:3.267) in the context of this present standard carries a TPID of 0x8100 ([Q]:Table 9-1) in the outermost (first) Ethertype (Figure C-1) and a non-Zero VID field, when processed in the EISS ([Q]:6.8).

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

As this standard considers only C-VLAN tags ([Q]:9.5 a)), a Priority-Tagged Frame in the context of this present standard carries a TPID of 0x8100 in the outermost (first) Ethertype (Figure C-1) and a VID field of all Zero, when processed in the EISS ([Q]:6.8).

C.4.5 Hop-by-Hop MACsec

If MACsec is applied Hop-by-Hop, the SecTAG ([AE]:9.3) is placed between the Source Address and the C-TAG ([Q]:9.5 a)) of the Frame (Figure C-1), as depicted in [AE]:Figure 6-2.

C.5 Bandwidth

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

B = D/T.

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

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

B = F*L/T.

The following factors influence Frame size (L):

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

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

d) Actual data available for transmission.
e) Maximum allowed SDU size (causing segmentation or fragmentation).
f) Retransmissions of lost Frames in reliable Flows (e.g. TCP [B6]).

C.6 Network Traffic Classification

C.6.1 Automotive Network Traffic Patterns

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

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

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

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

The so called "Best Effort" (BE) Traffic in the vehicle consists of distribution of SotA data, web access by the occupants, map downloads, and similar not time triggered Frames. This is the most bursty traffic in the IVN. In contrast to an IT or home network, this traffic does however have a need to be guarded against losses (C.9). Since a high percentage of traffic in the IVN is dominated by some sort of time triggered events, the Bandwidth available for BE Traffic is not as temporarily varying as in an office or home network installation. Retransmissions due to Frame loss present an unpredictable source of bandwidth demand, which in turn increases the risk of frame loss. This kind of feedback loop is best avoided.

C.6.2 Scheduled Traffic

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

C.7 Scheduler vs. Shaper

This present standard defines the terms as follows:

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

If the Resource assigned by a Scheduler is (access to) Bandwidth, then a Scheduler will implicitly perform Traffic Shaping. E.g.: The Enhancements for Scheduled Traffic (EST of Clause 10) is based on Scheduling access to a transmission port based on a timetable.

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

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

C.8 FRER Functionality

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

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

In particular FRER Functionality entails:

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

C.9 Frame Loss

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

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

Annex D

Stream Identification (informative)

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

The out-facing ([CB]:3.) passive stream identification functions serve to assign a *stream_handle* to the Frames they match in the input/up direction to be used by the FRER functionality (Annex C.8) or the Stream Filtering (6.16). As this present standard does not make use of FRER, only the later usage is relevant. A passive in-facing ([CB]:3.) stream identification function therefore can not serve any purpose in the context of this present standard, as the assigned *stream_handle* in the input/up direction could only be used by the FRER functionality.

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

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

NOTE 1—This description ignores the potential issues with the internal LAN ([CB]:Figure 6-5) and the in-facing stream identification functions removing the stream_handle, thereby preventing the Stream Filter (6.16) to identify Frames.

Annex E

Non-real-time capable Protocols (informative)

Some protocols like TCP [B6] are intended to provide reliable data transfer, which in effect means, they need to retransmit data, in case the receiver reports it as not having arrived within a certain time-frame. These potential retransmissions makes the bandwidth demand for such TCP-flows unpredictable. An unpredictable bandwidth presents a fundamental problem for configuring any of the TSN features described in Clause 6, be it schedulers, shapers, or policers. In a scenario where frames are lost (e.g., due to congestion or due to bit errors) the retransmission may trigger a policer to drop the unexpected higher bandwidth, leading to further retransmissions, i.e., more bandwidth demand (see also C.6.1). Furthermore it becomes difficult for such flows to configure a EST cycle fulfilling the stability condition described in 10.6.1.

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

Annex F

Egress Shaping in End Stations (informative)

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

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

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

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

Annex G

Bibliography (informative)

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

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