

1 This document is an individual contribution to the Time-Sensitive Networking Task
2 Group of the IEEE 802.1 working group, by Tongtong Wang and Norman Finn, and is
3 intended to further the progress of project P802.1DF. It is not an official draft of the
4 Task or Working Group.

1 **P802.1DF™/Dfw2**
2 **Draft Standard for Time-Sensitive**
3 **Networking Profile for Service Provider**
4 **Networks**

5
6 **Abstract:** This standard defines profiles that select features, options, configurations, defaults,
7 protocols, and procedures of bridges and end-stations defined in IEEE Std 802.1Q and IEEE Std
8 802.1CB that are necessary to provide Time-Sensitive Networking (TSN) quality of service features
9 for non-fronthaul shared service provider networks. The standard also provides use cases, and
10 informative guidance for network operators on how to configure their networks for those use cases.

11
12 **Keywords:** IEEE 802.1Q, Time-Sensitive Networking, service provider, profile, network calculus,
13 network slicing, hard partitioning.
14

1 Editors' forward

2 <<Notes>>

3 <<Throughout this document, all notes such as this one, presented between angle braces, are temporary
4 notes inserted by the Editors for a variety of purposes; these notes and the Editors' Foreword will all be
5 removed prior to publication and are not part of the normative text.>>

6 <<Comments and participation in 802.1 standards development

7 Comments on this draft are encouraged. **PLEASE NOTE: All issues related to IEEE standards presentation
8 style, formatting, spelling, etc. are routinely handled between the 802.1 Editor and the IEEE Staff Editors
9 prior to publication, after balloting and the process of achieving agreement on the technical content of
10 the standard is complete.** Readers are urged to devote their valuable time and energy only to comments
11 that materially affect either the technical content of the document or the clarity of that technical content.
12 Comments should not simply state what is wrong, but also what might be done to fix the problem.

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

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

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

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

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

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32 **PLEASE NOTE: Comments whose distribution is restricted in any way cannot be considered, and may not
33 be acknowledged. >>**

34 <<The draft text and accompanying information

35 This document currently comprises:

36 — A title page for the proposed standard including an Abstract and Keywords. This title page will be
37 retained following working group approval of this draft, i.e. prior to sponsor ballot.

1 — The editors' forewords, including this text. These include an unofficial and informal appraisal of history
2 and status, introductory notes to each draft that summarize the progress and focus of each successive
3 draft, and requests for comments and contributions on major issues.

4 — IEEE boilerplate text.

5 — A record of participants (not included in early drafts but added prior to publication).

6 — The introduction to this standard.

7 — The proposed standard proper.

8 — An Annex Z comprising the editors' discussion of issues. This annex will be deleted from the document
9 prior to sponsor ballot.

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

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

20 >>

21 << **Introductory notes to P802.1DF Draft NWF0**

22 Draft NWF0 was prepared by Tongtong Wang and Norman Finn to further the progress of P802.1DF.
23 Everything in this draft can be considered a contribution to the Time-Sensitive Networking Task Group by
24 the authors; nothing has been approved by the Task Group or Working Group.

25 >>

26 << **Project Authorization Request, Scope, Purpose, and Five Criteria**

27 A PAR (Project Authorization Request) for P802.1DF was approved by the IEEE Standards Association on
28 February 8, 2019. The following information is taken from the 802.1DF PAR and Criteria for Standards
29 Development.

30 **Scope of Proposed Project:**

31 This standard defines profiles of IEEE Std 802.1Q and IEEE Std 802.1CB that provide Time-Sensitive
32 Networking (TSN) quality of service features for non-fronthaul shared service provider networks. The
33 standard also provides use cases, and informative guidance for network operators on how to configure their
34 networks for those use cases.

35 **Purpose of Proposed Project:**

1 Service provider networks often support multiple users and applications, and can benefit from TSN Quality
2 of Service (QoS) bridging features defined in IEEE Std 802.1Q. This standard provides guidance for
3 configuration of QoS features to provide dependable bandwidth and bounded latency.

4 **Need for the Proposed Project:**

5 Next generation transport networks that have more stringent QoS requirements would benefit from TSN
6 QoS features. For example, next generation mobile networks will have an order of magnitude more cells
7 than present networks, making it essential for multiple carriers (applications/users) to share network
8 resources of a physical infrastructure. The fronthaul use cases are already addressed by IEEE Std 802.1CM.
9 QoS partitioning among applications or customers will enable high-value services that have stringent
10 bandwidth and latency requirements to efficiently share the network with best effort services.

11 **1. IEEE 802 criteria for standards development (CSD)**

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

15 **1.1 Project process requirements**

16 **1.1.1 Managed objects**

17 **Describe the plan for developing a definition of managed objects. The plan shall specify one of the**
18 **following:**

- 19 a) **The definitions will be part of this project.**
- 20 b) **The definitions will be part of a different project and provide the plan for that project or**
21 **anticipated future project.**
- 22 c) **The definitions will not be developed and explain why such definitions are not needed.**

23 Item c) The definitions of managed objects will not be developed because the proposed standard
24 will specify only profiles that use managed objects already defined in other IEEE 802 standards.

25 **1.1.2 Coexistence**

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

- 28 a) **Will the WG create a CA document as part of the WG balloting process as described in Clause**
29 **13? (yes/no)**
- 30 b) **If not, explain why the CA document is not applicable.**

31 Item b). A CA document is not applicable because this is not a wireless project

32 **1.2 5C requirements**

33 **1.2.1 Broad market potential**

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

3 a) **Broad sets of applicability.**

4 b) **Multiple vendors and numerous users.**

5 The market for next generation service provider networks, e.g. mobile networks, will be very large.
6 IEEE 802.1Q can provide bounded latency and zero congestion loss Quality of Service features. This
7 makes it likely that IEEE 802 technologies can gain a significant share of the next generation service
8 provider market.

9 b) A number of vendors and operators have expressed their support for a non-fronthaul service
10 provider network profile of IEEE 802.1 Time-Sensitive Networking.

11 **1.2.2 Compatibility**

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

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

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

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

18 b) Not applicable.

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

22 **1.2.3 Distinct Identity**

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

26 The proposed standard will address service provider networks other than fronthaul networks,
27 which are already addressed by IEEE Std 802.1CM. There are no other 802 standards or approved
28 projects that specify time-sensitive networking for non-fronthaul service provider networks.

29 **1.2.4 Technical Feasibility**

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

33 a) **Demonstrated system feasibility.**

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

1

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

4 b) The proposed standard will specify profiles for the use of other IEEE 802 standards for which
5 the technology has been proven.

6 **1.2.5 Economic Feasibility**

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

11 a) **Balanced costs (infrastructure versus attached stations).**

12 b) **Known cost factors.**

13 c) **Consideration of installation costs.**

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

15 e) **Other areas, as appropriate.**

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

18 b) The cost factors are known for the IEEE 802 standards that this specification references.

19 c) There are no incremental installation costs relative to the IEEE 802 standards that this
20 specification references.

21 d) There are no incremental operational costs relative to the existing costs associated with the
22 IEEE 802 standards that this specification references

23 e) No other areas have been identified.

24 >>

1 << IEEE boilerplate from the Word template goes here. Disclaimers, laws,
2 copyrights, lists of participants, Introduction, etc. >>

1 **Contents**

2 <After draft body is complete, select this text and click Insert Special->Add (Table of) Contents>

3

1 Draft Standard for Time-Sensitive 2 Networking Profile for Service Provider 3 Networks

4 1. Overview

5 1.1 Scope

6 This standard defines profiles that select features, options, configurations, defaults, protocols, and procedures
7 of bridges and end-stations defined in IEEE Std 802.1Q and IEEE Std 802.1CB that are necessary to provide
8 Time-Sensitive Networking (TSN) quality of service features for non-fronthaul shared service provider
9 networks. The standard also provides use cases, and informative guidance for network operators on how to
10 configure their networks for those use cases.

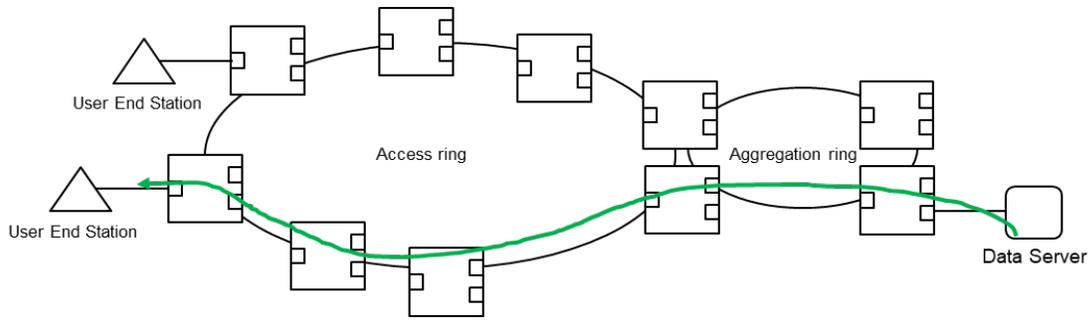
11 1.2 Purpose

12 This standard provides guidance for equipment vendors, designers, and operators of service provider
13 networks that are shared by multiple users and applications, and that need the TSN Quality of Service (QoS)
14 features offered by IEEE Std 802.1Q bridges. These networks have links with a very large bandwidth-delay
15 product. The TSN features include dependable bandwidth and bounded latency.

16 1.3 Introduction

17 Service provider networks, also called carrier networks, provide connectivity between access node and
18 content sources (usually in data centers) for multiple users and applications. While 5G new technologies
19 come into market, URLLC (Ultra Reliable Low Latency Communication) applications (e.g. vertical
20 applications / utility networks) bring on strict latency requirements over carrier networks.

21 As shown in Figure 1, a typical service provider topology is like layered ring networks with sufficient
22 redundant connections for better reliability and load balance. Usually user end stations are connected on the
23 access ring network and multiple access rings could be linked to one aggregation ring that has larger
24 bandwidth links. Backbone connections to the aggregation ring are not shown. A backbone layer is also
25 possible in service provider networks, to further aggregate traffics and communicate with other service
26 providers. Nevertheless, topology in Figure 1 is an example to show typical connections, not the constraints
27 on all scenarios. A service provider network is in one control domain in this project.



1

2

Figure 1 Example topology of service provider networks

3

4 To specify and explain the selection of features and options, this document:

5

a) Describes latency requirements for latency sensitive applications in service provider networks.

6

b) Describes how the operation of bridges and bridged networks affects the quality of service provided by the carrier bridged network (Clause x), provides details in the calculation of latency. (Clause ...), and the potential impact of the use of flow control;

7

c) Specifies multiple profiles () that support the construction of bridged networks meeting latency requirements and jitter requirements.

8

9

d) Defines service provider network profile conformance requirements () for bridges meeting either profile x requirements, for end stations and for synchronization.

10

11

e) Provides a Profile Conformance Statement (PCS, Annex A) to support clear detailed statements of equipment conformance to Service provider network profile requirements.

12

13

f) Provide basic knowledge on Network Calculus to assist network latency evaluation.

14

15

1 **2. Normative references**

2 The following referenced documents are indispensable for the application of this document (i.e., they must
3 be understood and used, so each referenced document is cited in text and its relationship to this document is
4 explained). For dated references, only the edition cited applies. For undated references, the latest edition of
5 the referenced document (including any amendments or corrigenda) applies.

6 IEEE Std 802, IEEE Standard for Local and Metropolitan Area Networks—Overview and Architecture.4, 5

7 IEEE Std 802.1Q, IEEE Standard for Local and Metropolitan Area Networks—Bridges and Bridged
8 Networks.

9 IEEE Std 802.1CB, IEEE Standard for Local and Metropolitan Area Networks—Frame Replication and
10 Elimination for Reliability

11 IEEE Std 802.1DC, IEEE Standard for Local and Metropolitan Area Networks—Quality of Service Provision
12 by Network Systems

13 IEEE Std 802.3, IEEE Standard for Ethernet.

14 IEEE Std 802.3br, IEEE Standard for Ethernet—Amendment 5: Specification and Management Parameters
15 for Interspersing Express Traffic.

16 IETF RFC xx05, (draft-ietf-detnet-ip-over-tsn) DetNet Data Plane: IP over IEEE 802.1 Time Sensitive
17 Networking (TSN).

18 IETF RFC xx07, (draft-ietf-detnet-mpls-over-tsn) DetNet Data Plane: MPLS over IEEE 802.1 Time
19 Sensitive Networking (TSN).

20 IETF RFC xx09, (draft-ietf-detnet-tsn-vpn-over-mpls) DetNet Data Plane: IEEE 802.1 Time Sensitive
21 Networking over MPLS.

1 **3. Definitions**

2 For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary*
3 *Online* should be consulted for terms not defined in this clause.¹

4 This standard makes use of the following terms defined in IEEE Std 802:

- 5 — bridge
- 6 — end station
- 7 — Ethernet
- 8 — forwarding
- 9 — frame
- 10 — Local Area Network (LAN)

11
12 This standard makes use of the following terms defined in IEEE Std 802.1Q:

- 13 — bridged network
- 14 — latency
- 15 — port
- 16 — priority-tagged frame
- 17 — traffic class
- 18 — untagged frame
- 19 — Virtual Local Area Network (VLAN)
- 20 — VLAN Bridge
- 21 — VLAN-tagged frame

22
23 The following terms are specific to this standard:

24

¹*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

1 **4. Abbreviations**

2 ATS – Asynchronous Traffic Shaping

3 CBS – Credit Based Shaper

4 DetNet – IETF Deterministic Networking

5 GBR – Guarantee Bit Rate

6 IETF – Internet Engineering Task Force

7 MPLS – Multi-Protocol Label Switching

8 QoS – Quality of Service

9 RFC – Request for Comments

10 TAS – Time Aware Shaper

1 5. Conformance

2 A claim of conformance to this standard is a claim that the behavior of an implementation of a bridge (5.3,
3 5.4) or of an end station (5.5, 5.6) meets the mandatory requirements of this standard and may support options
4 identified in this standard.

5 << Editor's note: This profile will distinguish between an end station, on the one hand, and a router, label
6 switch, or other network device defined by IETF, on the other, in order to link our standard to the relevant
7 RFCs from the IETF DetNet Working Group. It is possible that this will result in a third requirement clause.
8 >>

9 5.1 Requirements terminology

10 For consistency with existing IEEE and IEEE 802.1 standards, requirements placed upon conformant
11 implementations of this standard are expressed using the following terminology:

- 12 g) *Shall* is used for mandatory requirements;
- 13 h) *May* is used to describe implementation or administrative choices (“may” means “is permitted to,”
14 and hence, “may” and “may not” mean precisely the same thing);
- 15 i) *Should* is used for recommended choices (the behaviors described by “should” and “should not” are
16 both permissible but not equally desirable choices).

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

19 The standard avoids needless repetition and apparent duplication of its formal requirements by using *is*, *is*
20 *not*, *are*, and *are not* for definitions and the logical consequences of conformant behavior. Behavior that is
21 permitted but is neither always required nor directly controlled by an implementer or administrator, or whose
22 conformance requirement is detailed elsewhere, is described by *can*. Behavior that never occurs in a
23 conformant implementation or system of conformant implementations is described by *cannot*. The word
24 *allow* is used as a replacement for the phrase “Support the ability for,” and the word *capability* means “can
25 be configured to.”

26 5.2 Profile Conformance Statement (PCS)

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

- 1 **5.3 Bridge requirements**
- 2 **5.4 Bridge options**
- 3 **5.5 End station requirements**
- 4 **5.6 End station options**

6. Service provider networks

<< Editor's Note: This clause is a suggestion based on the presentation Suggestions for Service Provider Networks. <http://www.ieee802.org/1/files/public/docs2019/df-wangtt-SP-prof-outline-0519.pdf>

This clause will list a few representative use cases for service provider networks, and classify them from requirement perspective,

1. Bounded latency
2. Bounded jitter
 - a. Isolation
 - b. Slicing
3. Reliability

>>

Possible emerging applications on 5G carrier networks are discussed in 3GPP TS 23.501 [B1], and summarized into three types of services shown in Table 1. Bandwidth sensitive services have strict requirement on average bandwidth and loose constraints on latency, while connection services just require message delivery from time to time. A new type of service is the delay critical service, that is the subject of this standard.

Service Catalog	Examples	Packet delay budget	Packet loss rate	Default Max Data Burst
Bandwidth Sensitive Services (GBR)	Conservational Voice	100ms	10^{-2}	N/A
	Conversational Video (live streaming)	150ms	10^{-3}	N/A
	Real Time Gaming	50ms	10^{-3}	N/A
Connection Services (Non-GBR)	Buffered Streaming Video	300ms	10^{-6}	N/A
Latency Sensitive Services (Delay Critical)	Intelligent Transport Systems	30ms	10^{-5}	1354 bytes
	Smart Grid Tele-protection	5ms	10^{-5}	255 bytes

Table 1 Typical services in 5G carrier networks

6.1 Causes of packet loss

The most common causes of packet loss can be classified, for our purposes, as:

- a) Congestion: lack of buffer space for a particular frame in some network node.
- b) Equipment failure: The loss of a wire or a node in the network causes some number of packets to be lost until either the failure can be corrected, or following packets can be re-routed.
- c) Interference: Electromagnetic events can cause some number of packets to be lost, or received with checksum errors that cause them to be discarded.
- d) Random: Random thermal or quantum mechanical events in physical interfaces or buffer memory can cause the loss of a packet, typically due to a checksum error.

6.2 Causes of excessive latency

1 The most common causes of delivery latency in excess of requirements can be classified, for our purposes,
2 as:

- 3 a) Physical causes: When the path of the Stream through the network involves too many hops and/or
4 traverse links that are too long, or have a low transmission rate, delivery latency over service provider
5 networks may not be able to guarantee. This part of latency is usually stable once the routes and
6 bandwidth along the path are determined.
- 7
8 b) Interference causes: Multiple time-critical Streams in SP networks may interfere each other, while
9 micro burst happens from time to time. This part of latency is time-varying even on same data path
10 while TSN techniques are most useful to deal with it. Section 6.5 will elaborate on each TSN
11 technique.

13 **6.3 Bandwidth sensitive services**

14 Bandwidth sensitive services such as conversational voice usually have relaxed delay requirements over a
15 carrier network. Currently, all such packets traverse IP DiffServ networks (Differentiated Services, [B7],
16 [B8], [B9]) using QoS methods like strict priority, weighted round robin, etc. Since carrier networks usually
17 have large bandwidth and are utilized in as balanced a manner as possible, traffic congestion rarely happens
18 to high priority data streams. Bandwidth sensitive applications get satisfactory performance as long as
19 adequate throughput and buffering capabilities are reserved and provided in time.

20
21 <<Editor Note: Consider to provide guideline on bandwidth analysis over carrier networks,
22 considering delay guaranteed bandwidth, rather than average bandwidth>>

23 **6.4 Latency sensitive services**

24 Latency sensitive services put more stringent requirements on end-to-end latency over a carrier network; any
25 packet arriving later than a certain deadline (the tolerable deadline) is regarded as a failure of packet delivery.
26 An example of the latency sensitive service is the smart grid tele-protection application, which requires 5 ms
27 end-to-end latency over carrier networks with 99.999% reliability [B1].

28 It is important to note the difference between minimum average latency and an assurance of a finite worst-
29 case latency. In general, the best possible average latency is obtained using simple, strict priority-based
30 forwarding. The average latency for packets of a highest-priority Stream can be very near the minimum
31 latency. However, the worst-case latency for any given packet is generally many times larger than that
32 minimum. Packets delivered late are equivalent to packets lost. The techniques called out in the present
33 standard (see 6.5) are concerned with providing a finite worst-case latency. When this can be achieved, zero
34 congestion loss is a pleasant byproduct.

35 Two main requirements in latency sensitive services are bounded latency and/or bounded jitter.
36 Most of URLLC applications requires upper bound, e.g. smart grid tele-protection, while a small
37 number of use cases require bounded jitter.
38 Different requirement leads to different TSN solutions, see more analysis in section 6.5.

39
40 <<Editor's Note: Consider to provide detailed latency evaluation method and compare multiple TSN
41 techniques in section.6.5>>
42

1 6.5 Providing the services

2 There are five basic data plane techniques for providing the services described in Clause 6:

- 3 a) **FRER:** Frame Replication and Elimination for Reliability.
- 4 b) **CBS:** Credit-based shaper, defined as Enhancements for Time-Sensitive Streams in 8.6.8.2 of IEEE
5 Std 802.1Q-2018.
- 6 c) **ATS:** Per-Stream flow policing, using IEEE Std 802.1Qcr Asynchronous Traffic Shaping (ATS)
7 and/or IETF IntServ ([B2], [B3], [B4], [B5], [B6]).
- 8 d) **Scheduled Traffic:** Timed transmission windows, using 8.6.8.4 in IEEE Std 802.1Q-2018.
- 9 e) **CQF:** Time-synchronized flow windows, using Annex T in IEEE Std 802.1Q-2018 Cyclic Queuing
10 and Forwarding.
- 11 f) **Preemption:** Frame preemption, using 6.7.2 in IEEE Std 802.1Q-2018 and clause 99 in IEEE Std
12 802.3-2018.

13 There are other potential data plane techniques that are **not** addressed by the present standard:

- 14 g) **Cut-through forwarding:** The transmission of a frame is initiated before the last bit of the frame has
15 been received and the checksum examined for errors. This document assumes store-and-forward
16 operation.
- 17 h) **Overprovisioning/prioritization:** One builds a network that has significantly more physical link
18 bandwidth that is required by the critical data, with network nodes that have a large amount of buffer
19 space. Critical data is given the highest priority in the network, perhaps even higher than network
20 control protocol traffic (e.g. network topology control). This works, but only when the critical traffic
21 is a very small proportion of the total.
- 22 i) **Dedicate devices or resources:** A network is constructed for the exclusive use of one or a small
23 number of critical applications, and this network is physically isolated from other networks.
- 24 j) **Congestion detection:** This technique typically causes a flow that is experiencing congestion to slow
25 down. This is not applicable for the present standard, because the applications of interest, here,
26 typically cannot slow down the real-time physical world to accommodate the network's current load.
- 27 k) **Congestion avoidance:** Routes flows over less-congested network paths. This can work at the time
28 a flow is established, but afterwards, its efficacy declines.

29 6.5.1 Frame Replication and Elimination for Reliability

30 Frame Replication and Elimination for Reliability (FRER) is described in IEEE Std 802.1CB. See clause 7
31 in IEEE Std 802.1CB-2017 for an overview of the technique. The packet replication and packet elimination
32 techniques described in 3.2.2.2 in IETF RFC 8655 [B13] are a generalization of IEEE Std 802.1CB FRER.

33 FRER is aimed at packet loss due to equipment failure (point b) in 6.1) or interference (point c) in 6.1).²
34 Packets in a stream are sequence numbered, then replicated, and flow along two (or more) paths to a point
35 nearer the destination. At that point, the paths are combined into a single Stream, again. There, packet
36 sequence numbers are compared continuously, and the duplicates eliminated. For FRER to be useful, the cost
37 of losing packets while the network recovers from a failure must be greater than the cost of doubling the
38 bandwidth used by the critical, replicated, Streams.

39 6.5.2 Credit-Based Shaper

40 The use of CBS does not provide 100% assurance against frame loss due to congestion. CBS throttles the
41 transmission of a class of Streams (up to 7 classes per port) to the sum of the bandwidth of those Streams, at

² In rare environments, where congestion loss is eliminated (by other methods), and equipment failure and interference are very rare, FRER can improve packet loss due to random events (point d) in 6.1).

1 every hop along the path through the network. This throttling can prevent momentary bursts of critical data,
2 caused by recent interference upstream, from combining to overflow the buffer capacity of a downstream
3 node, and thus cause congestion loss (point a) in 6.1).

4 CBS algorithm works on each forwarding node can not eliminate congestion loss nor provide end to end
5 latency bound. However, it can provide bounded latency with properly computed parameters setup and
6 admission control.

7 $Delay_a = L_0/C + L_a/idleslope_a;$

8 $Delay_b = (L_0 + L_a)/C + (L_0 * Idleslope_a / (C - Idleslope_a));$

9 L_a, L_0 are maximum packet length for SR Class A and best effort class defined in FQTSS specification.
10 Also according to FQTSS specification, there is no constrained delay traffic considered.

11
12 IEEE Std 802.1Q provides for eight traffic classes. Assuming that a given network port has more than that
13 number of Streams passing through a port, then it is highly likely that any given class supports more than one
14 Stream. Interference between Streams sharing a traffic class can, in some cases, cause congestion loss. CBS
15 has been found, in practice, to provide better packet loss characteristics than other common methods, e.g.
16 Weighted Fair Queuing, but latency calculations become very difficult as the number of shared traffic classes
17 indrese. It is, however, relatively cheap to implement, because it has one shaper per traffic class, instead of
18 one per Stream.

19

20

21 **6.5.3 Asynchronous Traffic Shaping**

22 Asynchronous Traffic Shaping (ATS) is described in clause 8.6.11 of IEEE Std 802.1Qcr-2020³. With ATS,
23 each Stream gets its own state machine for regulating the flow of that Stream through the network node.
24 When ATS is implemented, an off-line network management system can compute the worst-case latency for
25 any packet belonging to a Stream, and can compute the amount of per-Stream and/or per-class buffering
26 needed at every hop along the path in order to assure that packet loss due to congestion (point a) in 6.1) is
27 mathematically impossible.

28 **6.5.4 Scheduled Traffic**

29 Etc. More difficult to configure. Also solves the congestion problem.

30 **6.6 Cyclic Queuing and Forwarding**

31 Requires time synchronization. Limited flexibility. But, zero per-hop state. Solves congestion/worst-case
32 latency problem.

³ IEEE Std 802.1Qcr will be incorporated into the next edition of IEEE Std 802.1Q following the 2019 edition of that standard.

1 **6.7 Preemption**

2 Non-critical traffic and perhaps, all traffic but the most critical traffic, can be preemptable. This lessens the
3 impact of the critical traffic on the best-effort traffic. Unless there is only one critical Stream, it offers no
4 improvement to the guaranteed worst-cast latency critical traffic; the packets cannot all preempt each other.
5 Frame preemption has more significant effect on low bandwidth port, e.g. less than 10G port, saves ~1us on
6 10GE when a preemptable 1500B packet in transmission.

1 **7. Profiles**

2 **7.1 Introduction**

3 << Editor's Note: Suggested profiles would include:

4 a)

5 >>

6 **7.2 Base Profile**

7 << Editor's Note: with existing TSN techniques, considering CBS, ATS, TAS, Paternoster, Strict
8 Priority etc. >>

9

1 8. Interface with DetNet

2 8.1 Introduction

3 The Deterministic Networking Working Group (DetNet, <https://datatracker.ietf.org/wg/detnet/documents/>)
4 of the Internet Engineering Task Force (IETF) has worked closely with the IEEE 802.1 Time-Sensitive
5 Networking Task Group, by means of common participation by individuals, to generate documents that
6 provide very similar services, for IETF routers and label switches, that TSN provides for bridged LANs.
7 Participants have endeavored to make the TSN and DetNet documents consistent and compatible. To date,
8 DetNet has published a number of RFCs. The one most relevant to the present IEEE standard include:

- 9 a) RFC 8557, Deterministic Networking Problem Statement;
- 10 a) RFC 8578, Deterministic Networking Use Cases;
- 11 b) RFC 8655, Deterministic Networking Architecture;
- 12 c) RFC xx01, (draft-ietf-detnet-data-plane-framework) DetNet Data Plane Framework;
- 13 d) RFC xx02, (draft-ietf-detnet-flow-information-model) DetNet Flow Information Model;
- 14 e) RFC xx03, (draft-ietf-detnet-ip) DetNet Data Plane: IP;
- 15 f) RFC xx04, (draft-ietf-detnet-ip-over-mpls) DetNet Data Plane: IP over MPLS;
- 16 g) RFC xx05, (draft-ietf-detnet-ip-over-tsn) DetNet Data Plane: IP over IEEE 802.1 Time Sensitive
17 Networking (TSN);
- 18 h) RFC xx06, (draft-ietf-detnet-mpls) DetNet Data Plane: MPLS;
- 19 i) RFC xx07, (draft-ietf-detnet-mpls-over-tsn) DetNet Data Plane: MPLS over IEEE 802.1 Time
20 Sensitive Networking (TSN);
- 21 j) RFC xx08, (draft-ietf-detnet-mpls-over-udp-ip) DetNet Data Plane: MPLS over UDP/IP;
- 22 k) RFC xx09, (draft-ietf-detnet-tsn-vpn-over-mpls) DetNet Data Plane: IEEE 802.1 Time Sensitive
23 Networking over MPLS;
- 24 l) RFC xx10, (draft-ietf-detnet-yang) Deterministic Networking (DetNet) Configuration YANG
25 Model;

26 << Editor's note: We expect the referenced IETF drafts, above, to achieve RFC status by the time
27 the present draft standard is published. We expect only RFCs to be referenced in the published
28 IEEE standard. >>

29
30 Section 10 of RFC 8578, use cases, gives the particular example of applying DetNet to provide network
31 slicing capability for a 5G bearer network. (See RFC 8578 for the definitions of these terms.)

32 <<Editor's note: original ideas in this section is to consider how Layer 2 reservation protocol interwork with
33 Layer 3 reservation protocols. Probably will delete if it is not clear to users >>

34 8.2 Data plane

35 If a network compliant to the present standard is intended to transport DetNet traffic, or if traffic in a
36 compliant network is to be transported over an IP or MPLS network, then it shall conform to the relevant
37 IETF standards, including RFC xx05, RFC xx07, and/or RFC xx09.

38 8.3 Control plane

39 << Editor's note: At this writing, the IETF DetNet Working Group has not made sufficient progress
40 on the control plane (e.g. resource reservation and fixed path establishment) for the present draft
41 to make normative references. In the opinion of the author, the issue is more narrowing down

1 choices than designing new protocols. It is possible that there is a need to augment some IETF
2 protocol(s) to support the Paternoster algorithm, but that algorithm has not been standardized in
3 either IEEE or IETF, yet. There is also the possibility of implementing RAP in a router or label switch.
4 This has not been sufficiently explored to determine whether it is a viable idea or not. As a
5 consequence, this section will likely point the reader to the DetNet Working Group for further
6 information. >>

- 1 **Annex A**
- 2 (informative)
- 3 **PCS Proforma—TSN for Service Provider Networks Profiles**
- 4 .

1 **Annex B**

2 (informative)

3 **A concept for network calculus**

4 << Editor's Note: Basis of Network Calculus will be introduced briefly. Also considering re-visit
5 latency evaluation for existing TSN techniques, like CBS, TAS, etc. Probably leads to maintenance
6 for 802.1Q-2018 with update on latency analysis >>

7 **Latency analysis based on Network Calculus (Informative)**

8 << Editor's Note: This clause may set an example on how to use profiles defined in this standard
9 to setup a network to satisfy a certain use cases, such as smart grid or Cloud VR applications. >>

10 << Editor's Note: briefly introduce Network Calculus methodology with examples. Illustrate how to
11 use Network calculus to analyze delay on single node and cascaded networks.>>

12
13 Network calculus theory emerged during 1990s as a latency evaluation theory for quality of service analysis
14 of packet switching networks, it is originally focus on performance analysis for IntServ model over IP
15 network. Data arrivals at a networked system are modelled by upper envelope functions. Minimum service
16 guarantees that are provided by systems, such as a router, a scheduler, or a link, are characterized by service
17 curves. Based on these concepts, network calculus offers convolution forms that enable worst case
18 performance bounds evaluation including backlog and delay. Any number of bridged system in series can be
19 transformed into a single equivalent system by convolution operation and obtain end-to-end performance.

20 **A.1 Arrival curves**

21 Flows can be described by arrival functions $F(t)$ that are given as the cumulated number of bits seen in an
22 interval $[0,t]$. Arrival curves are defined to give an upper bound on the arrival functions, where

$$23 \quad \alpha(t_2-t_1) = F(t_2) - F(t_1);$$

24 Token bucket based arrival curve is usually featured like in equation, $\alpha(t) = b + rt$, where b is burst size, r
25 is data rate;

26 << Editor's Note: diagram of token bucket arrival curves will be helpful in this section. >>

27 **A.2 Service curves**

28 The service offered by the scheduler on an output port can be characterized by a minimum service curve,
29 denoted by $\beta(t)$. A common service curve is described as rate-latency equation that includes a rate R and a
30 wait time T , $\beta(t) = \max(0, R*(t-T))$.

31 Service curves for legacy Qos methods such as Priority Queuing (PQ), Generalized Processor Sharing (GPS)
32 and Weighted Fair Queuing (WFQ) are studied and proposed in multiple academia papers[C1]; TSN
33 schedulers service curves are also under discussion and proposed in [C2][C3][C4]; In addition, aggregated
34 scheduling networks resources shall be provisioned on an aggregate basis.

35 A.3 Upper bound of queueing delay

- 1 Queuing delay bound can be easily computed by comparing arrival curve and service curve in a queuing
- 2 system, as the following equation shows,
- 3 Delay bound = $T + b/R$; where T and R are service curve parameters, and b is from arrival curve.
- 4 Detailed queuing delay for specific schedulers are provided in Section 6.5.
- 5 << Editor's Note: Consider a separate section to talk about aggregating mode. >>

1 **Annex C**

2 (informative)

3 **Network slicing**

4 << Editor's Note: Network slicing is essentially related to latency/jitter/reliability performance, TSN
5 techniques provide different features and help implement network slicing over service provider
6 networks. >>
7

1 **Annex D**

2 (informative)

3 **Bibliography**

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

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8 [B2] IETF RFC 1633, “Integrated Services in the Internet Architecture: an Overview”.

9 [B3] IETF RFC 2211, “Specification of the Controlled-Load Network Element Service”.

10 [B4] IETF RFC 2212, “Specification of Guaranteed Quality of Service”.

11 [B5] IETF RFC 2215, “General Characterization Parameters for Integrated Service Network Elements”.

12 [B6] IETF RFC 2205, “Resource ReSerVation Protocol (RSVP) ”.

13 [B7] IETF RFC 2474, Nichols, K., Blake, S., Baker, F., and D. Black, “Definition of the Differentiated
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16 [B8] IETF RFC 2475, Black, D., Wang, Z., Carlson, M., Weiss, W., Davies, E., and Blake, S., “An
17 Architecture for Differentiated Services”, RFC2475, DOI 10.17487/RFC2475, December 1998, <[https://rfc-
18 editor.org/rfc/rfc2475.txt](https://rfc-editor.org/rfc/rfc2475.txt)>.

19 [B9] IETF RFC 4594, “Configuration Guidelines for DiffServ Service Classes”.

20 [B10] IETF RFC 8100, “Diffserv-Interconnection Classes and Practice”.

21 [B11] IETF RFC 8578, “Deterministic Networking Use Cases”.

22 [B12] IETF RFC 8557, “Deterministic Networking Problem Statement”.

23 [B13] IETF RFC 8655, “Deterministic Networking Architecture”.

24 [B14] IETF RFC xx01, (draft-ietf-detnet-data-plane-framework) “DetNet Data Plane Framework”.

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28 [B18] IETF RFC xx06, (draft-ietf-detnet-mpls) “DetNet Data Plane: MPLS”.

29 [B19] IETF RFC xx08, (draft-ietf-detnet-mpls-over-udp-ip) “DetNet Data Plane: MPLS over UDP/IP”.

30 [B20] IETF RFC xx10, (draft-ietf-detnet-yang) “Deterministic Networking (DetNet) Configuration YANG
31 Model”.

32 << Editor’s note: We expect the referenced IETF drafts, above, to achieve RFC status by the time
33 the present draft standard is published. We expect only RFCs to be referenced in the published
34 IEEE standard. >>

1 **Reference**

2 [C1] "Network calculus: a theory of deterministic queuing systems for the internet", 2001,
3 <<https://arxiv.org/abs/1804.10608/>>.
4 [C2] "Improved Credit Bounds for the Credit-Based Shaper in Time-Sensitive Networking", 2019, E
5 Mohammadpour, et al.
6 [C3] "communication networking, An analytical approach", 2004, Anurag Kumar et al.
7 [C4] "Timing Analysis of AVB Traffic in TSN Networks Using Network Calculus", 2018 Luxi Zhao et al

8
9 **(informative)**

10

11 **Issues**

12

13