IEEE STANDARDS ASSOCIATION

IEEE Standard for
Local and metropolitan area networks—

Time-Sensitive Networking for Fronthaul

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 802.1CM™-2018

IEEE Std 802.1CM™-2018

IEEE Standard for
Local and metropolitan area networks—

Time-Sensitive Networking for Fronthaul

Sponsor

LAN/MAN Standards Committee
of the
IEEE Computer Society

Approved 7 May 2018

IEEE-SA Standards Board

Abstract: This standard defines profiles that select features, options, configurations, defaults, protocols, and procedures of bridges, stations, and LANs that are necessary to build networks that are capable of transporting fronthaul streams, which are time sensitive.

Keywords: bridged network, fronthaul, IEEE 802®, IEEE 802.1™, IEEE 802.1CM™, synchronization, time-sensitive networking, TSN, Virtual Local Area Network, VLAN, VLAN Bridge

---

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Print: ISBN 978-1-5044-4909-0 STD23131
PDF: ISBN 978-1-5044-4910-6 STDPD23131

Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page, appear in all standards and may be found under the heading "Important Notices and Disclaimers Concerning IEEE Standards Documents." They can also be obtained on request from IEEE or viewed at http://standards.ieee.org/IPR/disclaimers.html.

Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents

IEEE Standards documents (standards, recommended practices, and guides), both full-use and trial-use, are developed within IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association ("IEEE-SA") Standards Board. IEEE ("the Institute") develops its standards through a consensus development process, approved by the American National Standards Institute ("ANSI"), which brings together volunteers representing varied viewpoints and interests to achieve the final product. IEEE Standards are documents developed through scientific, academic, and industry-based technical working groups. Volunteers in IEEE working groups are not necessarily members of the Institute and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE Standards do not guarantee or ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. Implementers and users of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, and interference protection practices and all applicable laws and regulations.

IEEE does not warrant or represent the accuracy or content of the material contained in its standards, and expressly disclaims all warranties (express, implied and statutory) not included in this or any other document relating to the standard, including, but not limited to, the warranties of: merchantability; fitness for a particular purpose; non-infringement; and quality, accuracy, effectiveness, currency, or completeness of material. In addition, IEEE disclaims any and all conditions relating to: results; and workmanlike effort. IEEE standards documents are supplied "AS IS" and "WITH ALL FAULTS."

Use of an IEEE standard is wholly voluntary. The existence of an IEEE standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document, should rely upon his or her own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

Translations

The IEEE consensus development process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English version published by IEEE should be considered the approved IEEE standard.

Official statements

A statement, written or oral, that is not processed in accordance with the IEEE-SA Standards Board Operations Manual shall not be considered or inferred to be the official position of IEEE or any of its committees and shall not be considered to be, or be relied upon as, a formal position of IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position of IEEE.

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE. However, IEEE does not provide consulting information or advice pertaining to IEEE Standards documents. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to comments or questions except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in revisions to an IEEE standard is welcome to join the relevant IEEE working group.

Comments on standards should be submitted to the following address:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
Piscataway, NJ 08854 USA

Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not imply compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under U.S. and international copyright laws. They are made available by IEEE and are adopted for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making these documents available for use and adoption by public authorities and private users, IEEE does not waive any rights in copyright to the documents.

Photocopies

Subject to payment of the appropriate fee, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Updating of IEEE Standards documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. A current IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect.

Every IEEE standard is subjected to review at least every ten years. When a document is more than ten years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit the IEEE-SA Website at http://ieeexplore.ieee.org/ or contact IEEE at the address listed previously. For more information about the IEEE SA or IEEE's standards development process, visit the IEEE-SA Website at http://standards.ieee.org.

Errata

Errata, if any, for all IEEE standards can be accessed on the IEEE-SA Website at the following URL: http://standards.ieee.org/findstds/errata/index.html. Users are encouraged to check this URL for errata periodically.

Patents

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE-SA Website at http://standards.ieee.org/about/sasb/patcom/patents.html. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

Participants

At the time of approval of this standard, the IEEE 802.1 Working Group had the following membership:

Glenn Parsons, *Chair*
John Messenger, *Vice Chair*
János Farkas, *Chair, Time-Sensitive Networking Task Group*, *Editor*

Ralf Assmann
Shenghua Bao
Gordon Bechtel
Jens Bierschenk
Steinar Bjørnstad
Christian Boiger
Paul Bottorff
Radhakrishna Canchi
David Chen
Feng Chen
Weiying Cheng
Paul Congdon
Rodney Cummings
Hesham ElBakoury
Norman Finn
Mickaël Fontaine
Geoffrey Garner
Eric W. Gray
Craig Gunther
Marina Gutiérrez
Stephen Haddock
Mark Hantel
Marc Holness
Lokesh Kabra
Michael Karl
Stephan Kehrer
Hajime Koto
Yizhou Li
Christophe Mangin
Scott Mansfield
James McIntosh
Robert Moskowitz
Tero Mustala
Tomoki Ohsawa
Donald R. Pannell
Walter Pienciak
Michael Potts
Wei Qiu
Karen Randall
Maximilian Riegel
Jessy V. Rouyer
Soheil Samii
Atsushi Sato
Frank Schewe
Michael Seaman
Johannes Specht
Patricia Thaler
Paul Unbehagen
Hao Wang
Tongtong Wang
Xinyuan Wang
Karl Weber
Brian Weis
Jordon Woods
Takahiro Yamaura
Xiang Yu
Nader Zein

The following members of the individual balloting committee voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

Thomas Alexander
Butch Anton
Stefan Aust
Gordon Bechtel
Harry Bims
Steinar Bjørnstad
Christian Boiger
Demetrio Bucaneg, Jr.
William Byrd
Juan Carreon
Keith Chow
Todor Cooklev
Rodney Cummings
Lars Ellegaard
Marc Emmelmann
Yonggang Fang
János Farkas
Norman Finn
Avraham Freedman
Matthias Fritsche
Yukihiro Fujimoto
Devon Gayle
Eric W. Gray
Randall Groves
Stephen Haddock
Marco Hernandez
Werner Hoelzl
Noriyuki Ikeuchi
Atsushi Ito
Raj Jain
SangKwon Jeong
Piotr Karocki
Stuart Kerry
Yongbum Kim
Mark Laubach
Han Hyub Lee
Hyeong Ho Lee
John Lemon
Michael Lynch
Elvis Maculuba
Richard Maiden
Roger Marks
John Messenger
Michael Montemurro
Nick S. A. Nikjoo
Satoshi Obara
Robert O'Hara
Glenn Parsons
Bansi Patel
Clinton Powell
Alon Regev
Maximilian Riegel
Robert Robinson
Jessy V. Rouyer
Peter Saunderson
Michael Seaman
Thomas Starai
Walter Struppler
Bo Sun
Richard Tse
Mark-Rene Uchida
Dmitri Varsanofiev
Kari Vierimaa
George Vlantis
Khurram Waheed
Lisa Ward
Hung-Yu Wei
Andreas Wolf
Oren Yuen
Nader Zein
Zhen Zhou

When the IEEE-SA Standards Board approved this standard on 7 May 2018, it had the following membership:

Introduction

This introduction is not part of IEEE Std 802.1CM-2018, IEEE Standard for Local and metropolitan area networks—Time-Sensitive Networking for Fronthaul.

This standard defines profiles that select features, options, configurations, defaults, protocols and procedures of bridges, stations, and LANs that are necessary to build networks that are capable of transporting fronthaul streams, which are time-sensitive.

Contents

IEEE Standard for
Local and metropolitan area networks—

Time-Sensitive Networking for Fronthaul

1. Overview

1.1 Scope

This standard defines profiles that select features, options, configurations, defaults, protocols and procedures of bridges, stations, and LANs that are necessary to build networks that are capable of transporting fronthaul streams, which are time-sensitive.

NOTE—Stream and flow are used as synonyms in this document.[1]

1.2 Purpose

The purpose of this standard is to specify defaults and profiles that enable the transport of time-sensitive fronthaul streams in Ethernet bridged networks.

1.3 Introduction

Fronthaul provides connectivity between functional blocks of a cellular base station (BS). The fronthaul flows between these functional blocks have stringent quality of service requirements. The successful support of fronthaul flows in a bridged network requires the selection of specific features and options that are specified in a number of different standards, some developed by IEEE Project 802®, and others (in particular, those that relate to functionality in OSI layer 3 and above; ISO/IEC 7498:1994 [B11]) developed by other standards organizations.[2]

This standard selects features and options that support OSI layers 1 and 2 in bridges and end stations from the following specifications:

— Virtual Local Area Network (VLAN) Bridge specification in IEEE Std 802.1Q™.[3]
— MAC service specifications in IEEE Std 802.1AC™.

[1]Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.
[2]The numbers in brackets correspond to those of the bibliography in Annex C
[3]Information on references can be found in Clause 2.

— MAC/PHY technology specifications in IEEE Std 802.3™.
— Interspersing express traffic specification in IEEE Std 802.3br™.
— Frame preemption specification in IEEE Std 802.1Q.
— Time synchronization and Precision Time Protocol (PTP) specifications in IEEE Std 1588™.
— Telecom profile specification in ITU-T G.8275.1, which is based on IEEE Std 1588.
— Synchronous Ethernet specification in ITU-T G.8261, G.8262, and G.8264.

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

a) Describes fronthaul requirements (Clause 6), specifying two classes of requirements (6.2, 6.3) that depend on the BS functional decomposition, and specifying synchronization requirements (6.4) that apply to both classes.
b) Describes how the operation of bridges and bridged networks affects the quality of service provided by the fronthaul bridged network (Clause 7), providing details to assist in the calculation of latency (7.1, 7.2, 7.3), the selection of network synchronization methods (7.4), and the potential impact of the use of flow control (7.5) and Energy Efficient Ethernet (EEE, 7.6).
c) Specifies two bridge profiles (Clause 8) that support the construction of bridged networks meeting fronthaul requirements. Profile A (8.1) is applicable to bridges that do not support frame preemption (7.3), while Profile B (8.2) involves frame preemption to accommodate larger non-fronthaul flows and frame sizes while preserving fronthaul traffic guarantees.
d) Discusses the applicability (Clause 9) of the synchronization methods described in 7.4 to the time synchronization categories defined in 6.4.1.
e) Defines fronthaul profile conformance requirements (Clause 5) for bridges meeting either Profile A or Profile B requirements, for end stations and for synchronization.
f) Provides a Profile Conformance Statement (PCS, Annex A) to support clear detailed statements of equipment conformance to fronthaul profile requirements.

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 the 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.

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

IEEE Std 802.1AC™, IEEE Standard for Local and Metropolitan Area Networks—Media Access Control (MAC) Service Definition.

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

IEEE Std 802.3™, IEEE Standard for Ethernet.

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

IEEE Std 1588™, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems.

ITU-T G.8261, Timing and synchronization aspects in packet networks.[6]

ITU-T G.8262, Timing characteristics of a synchronous Ethernet equipment slave clock.

ITU-T G.8264, Distribution of timing information through packet networks.

ITU-T G.8271.1, Network limits for time synchronization in packet networks.

ITU-T G.8272, Timing characteristics of primary reference time clocks.

ITU-T G.8272.1, Timing characteristics of enhanced primary reference time clocks.

ITU-T G.8273.2, Timing characteristics of telecom boundary clocks and telecom time slave clocks.

ITU-T G.8273.3, Timing characteristics of telecom transparent clocks.

ITU-T G.8275.1, Precision time protocol telecom profile for phase/time synchronization with full timing support from the network.

MEF 10.3, Ethernet Services Attributes Phase 3.[7]

---

[4]IEEE publications are available from The Institute of Electrical and Electronics Engineers (http://standards.ieee.org/).
[5]The IEEE standards or products referred to in this clause are trademarks of The Institute of Electrical and Electronics Engineers, Inc.
[6]ITU-T publications are available from the International Telecommunications Union (http://www.itu.int/).
[7]MEF technical specifications are available from the MEF Forum (https://www.mef.net/).

3. Definitions

For the purposes of this document, the following terms and definitions apply. *The IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[8]

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

— bridge
— end station
— Ethernet
— forwarding
— frame
— Local Area Network (LAN)

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

— bridged network
— latency
— port
— priority-tagged frame
— traffic class
— untagged frame
— Virtual Local Area Network (VLAN)
— VLAN Bridge
— VLAN-tagged frame

The following terms are specific to this standard:

Category: An identifier of time synchronization requirements.[9]

NOTE—See 6.4.1.

Class: A collective term for fronthaul interfaces that applies a particular functional decomposition of a cellular base station and a particular treatment of fronthaul information flows.

NOTE—See 6.2 and 6.3.

fronthaul: The connectivity between the functional blocks (e.g., baseband processing and radio frequency blocks) of a cellular base station.

periodic: Repeating continuously, with a constant time (the period) between each occurrence.

Synchronous Ethernet: A method to distribute frequency synchronization over the Ethernet physical layer according to IEEE Std 802.3 and ITU-T Recommendations G.8261, G.8262, G.8264.[10]

time window: A time interval (among back-to-back time intervals of the same duration), within which packets of a specified flow can be sent.

---

[8]IEEE Standards Dictionary Online is available at: http://dictionary.ieee.org.

[9]The Categories used in this standard are defined by the Requirements for the eCPRI Transport Network [B6].

[10]Synchronous Ethernet has been defined to be fully conformant to IEEE Std 802.3, as documented in the relevant ITU-T Recommendations G.8261, G.8262, G.8264.

4. Acronyms and abbreviations

3GPP	3rd Generation Partnership Project
BC	boundary clock
BS	base station
C&M	Control and Management
CBR	Constant Bit Rate
CPRI	Common Public Radio Interface
CRC	Cyclic Redundancy Check
cTE	constant Time Error
C-VLAN	Customer VLAN
dTE	dynamic Time Error
eRE	eCPRI Radio Equipment[11]
eREC	eCPRI Radio Equipment Control
EEE	Energy Efficient Ethernet
EISS	Enhanced Internal Sublayer Service
ESMC	Ethernet Synchronization Messaging Channel
E-UTRA	Evolved Universal Terrestrial Radio Access
FID	Filtering Identifier
FLR	Frame Loss Ratio
GM	Grandmaster
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HPF	High Priority Fronthaul
IET	Interspersing Express Traffic
IPG	Inter Packet Gap
IQ	In-phase and Quadrature modulation
ISS	Internal Sublayer Service
LAN	Local Area Network
LPF	Low Priority Fronthaul
LPI	Low Power Idle
MAC	Medium Access Control

[11] eCPRI is a not an acronym; eCPRI is specified by the eCPRI Interface Specification [B5].

max|TE|	maximum absolute Time Error
max|TE|$_{relative}$	maximum absolute relative Time Error
MPF	Medium Priority Fronthaul
OFDM	Orthogonal Frequency Division Multiplexing
PCS	Profile Conformance Statement
PDU	Protocol Data Unit
PHY	physical layer
PICS	Protocol Implementation Conformance Statement
PRTC	Primary Reference Time Clock
PTP	Precision Time Protocol
PVID	Port VID
RE	Radio Equipment
REC	Radio Equipment Control
RSTP	Rapid Spanning Tree Protocol
SC	Slave Clock
SFD	Start Frame Delimiter
SyncE	Synchronous Ethernet
TAI	Temps Atomique International—International Atomic Time
T-BC	Telecom Boundary Clock
TC	transparent clock
TE	Time Error
TDM	Time Division Multiplexing
T-GM	Telecom Grandmaster
TSN	Time-Sensitive Networking
T-TC	Telecom Transparent Clock
T-TSC	Telecom Time Slave Clock
UE	User Equipment
UNI	User Network Interface
VID	VLAN Identifier
VLAN	Virtual LAN

5. Conformance

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

5.1 Requirements terminology

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

a) ***Shall*** is used for mandatory requirements;

b) ***May*** is used to describe implementation or administrative choices ("may" means "is permitted to," and hence, "may" and "may not" mean precisely the same thing);

c) ***Should*** is used for recommended choices (the behaviors described by "should" and "should not" are both permissible but not equally desirable choices).

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

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

5.2 Profile Conformance Statement (PCS)

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

5.3 Bridge requirements

This subclause defines the conformance requirements for bridge implementations claiming conformance to this standard. Each bridge implementation supports one or more profiles defined in this standard. Each profile includes the common bridge requirements (5.3.1). A bridge implementation that conforms to the provisions of this standard shall support Profile A requirements (5.3.2).

5.3.1 Common bridge requirements

A minimum set of features specified in IEEE Std 802.1Q are required for a bridge to support this standard. That is, the bridge shall be a VLAN Bridge supporting the minimum set of features identified in this subclause. The requirements of this subclause do not imply that a VLAN Bridge implementation that conforms to the provisions of this standard has to support options specified in IEEE Std 802.1Q-2018 other than those identified in this subclause.

A bridge implementation that conforms to the provisions of this standard shall:

a) Conform to the relevant standard for the MAC technology implemented at each port in support of the MAC Internal Sublayer Service (ISS), as specified in IEEE Std 802.1AC;
b) Implement full duplex IEEE 802.3 MAC with data rate of 1 Gbps or greater on each port;
c) Support the capability of 2000 octets maximum size MAC Protocol Data Unit (PDU) on each port;
d) Support the capability to disable MAC control PAUSE if it is implemented;
e) Support the capability not to assert Low Power Idle (LPI) on each port that supports Energy Efficient Ethernet (EEE, specified in IEEE Std 802.3);
f) Meet the VLAN Bridge requirements stated in items a) through f) in 5.4 of IEEE Std 802.1Q-2018;
g) Support an active topology enforcement mechanism;
h) Meet the VLAN Bridge requirements stated in items g) and h) in 5.4 of IEEE Std 802.1Q-2018 if the supported active topology enforcement mechanism is the Rapid Spanning Tree Protocol (RSTP);
i) Meet the VLAN Bridge requirements stated in items i) through n) in 5.4 of IEEE Std 802.1Q-2018;
j) Support at least the Acceptable Frame Types parameter value of Admit All frames on each port [see item l) in 5.4 of IEEE Std 802.1Q-2018];
k) Support the use of at least one VLAN Identifier (VID);
l) Meet the VLAN Bridge requirements stated in items p) through r) in 5.4 of IEEE Std 802.1Q-2018;
m) Support the ability to allocate the Port VID (PVID) and all other VIDs to the single Filtering Identifier (FID) if only a single FID is supported [item q) in 5.4 of IEEE Std 802.1Q-2018], i.e., support shared VLAN learning (8.8.8 of IEEE Std 802.1Q-2018);
n) Support a minimum of three traffic classes (3.268 of IEEE Std 802.1Q-2018) on all ports;
o) Support the strict priority algorithm for transmission selection (8.6.8.1 of IEEE Std 802.1Q-2018) on each port for each traffic class;
p) Support flow metering (8.6.5 of IEEE Std 802.1Q-2018) with the token bucket bandwidth profile specified in MEF 10.3;
q) Support the capability to disable Priority-based flow control if it is implemented (Clause 36 of IEEE Std 802.1Q-2018).

5.3.2 Bridge requirements for Profile A

A bridge implementation for which a claim of conformance to Profile A (8.1) is made, shall support items a) through q) of the common bridge requirements (5.3.1).

5.4 Bridge options

A bridge implementation that conforms to the provisions of this standard may:

a) Support MEF 10.3 token sharing for the token bucket bandwidth profile, which is used for flow metering [item p) in 5.3.1; 8.6.5 of IEEE Std 802.1Q-2018];
b) Support Profile B (5.4.1, 8.2);
c) Support synchronization in the bridged network (5.4.2, Clause 9).[12]

5.4.1 Bridge requirements for Profile B

A bridge implementation for which a claim of conformance to Profile B (8.2) is made, shall:

[12]Support of synchronization in the bridged network is optional if methods [items c) and d) in 7.4] that put no requirements on the bridged network are available to be used to support synchronization.

a) Support items a) through q) of the common bridge requirements (5.3.1);

b) Support Frame Preemption, i.e.,

   1) Support item ad) in 5.4.1 of IEEE Std 802.1Q-2018 (see also 7.3);
   2) Support Interspersing Express Traffic (IEEE Std 802.3br, see also 7.3)[13];
   3) Support Frame Preemption and Interspersing Express Traffic on each port whose data rate is not higher than 10Gbps;
   4) Support the configuration of 64-octet fragment size for Interspersing Express Traffic at each port for which Interspersing Express Traffic is enabled.

5.4.2 Bridge requirements for synchronization

A bridge implementation for which a claim of conformance to support synchronization in the bridged network (Clause 9) is made, shall:

a) Support untagged frames on all ports;

b) Support the ITU-T G.8275.1 telecom profile (full timing support from the network) and one or more of the related clocks:

   1) Support Telecom-Boundary Clock (ITU-T G.8273.2), or
   2) Support Telecom-Transparent Clock (ITU-T G.8273.3), or
   3) Support Primary Reference Time Clock or enhanced Primary Reference Time Clock, and Grandmaster functionality (ITU-T G.8272 or ITU-T G.8272.1);

c) Support Synchronous Ethernet functions (ITU-T G.8264) including the Ethernet Synchronization Messaging Channel (ESMC), and the related clock specification, i.e., Synchronous Ethernet slave clock (ITU-T G.8262).

NOTE—Untagged frames can be used for packet timing [item a) in 7.4] and physical layer frequency synchronization [item b) in 7.4]. The untagged frame is defined by 3.281 of IEEE Std 802.1Q-2018.

5.5 End station requirements

This subclause defines the conformance requirements for end station implementations claiming conformance to this standard. An end station implementation that conforms to the provisions of this standard shall:

a) Support priority-tagged (see 3.184 of IEEE Std 802.1Q-2018) or VLAN-tagged frames on all ports;

b) Support a minimum of three traffic classes on all ports.

5.6 End station options

An end station implementation that conforms to the provisions of this standard may:

a) Support time synchronization via the bridged network (5.6.1);

b) Support Synchronous Ethernet functions (ITU-T G.8264) including the ESMC, and the related clock specification, i.e., Synchronous Ethernet slave clock (ITU-T G.8262).

[13]At the time of publication of this standard, the relevant content of IEEE Std 802.3 was separately published as IEEE Std 802.3br™-2016.

5.6.1 End station requirements for time synchronization

An end station implementation that terminates PTP[14] and for which a claim of conformance to support time synchronization via the bridged network (Clause 9) is made, shall:

a) Support untagged frames on all ports;
b) Support ITU-T G.8275.1 telecom profile (full timing support from the network) and one or more of the related clocks, i.e.,
    1) Support Telecom-Time Slave Clock or Telecom-Boundary Clock (ITU-T G.8273.2), or
    2) Support Primary Reference Time Clock functionality[15] (ITU-T G.8272 or ITU-T G.8272.1), or
    3) Support Primary Reference Time Clock (PRTC) and Telecom Grandmaster functionality (ITU-T G.8272).

[14]See Case 1 in 6.4.
[15]An end station can deliver PRTC time synchronization via 1 PPS without PTP. In this case, ITU-T G.8275.1 is not required.

6. Fronthaul

This standard is concerned with the requirements of fronthaul and meeting these requirements with a bridged network. This clause describes fronthaul requirements.

Fronthaul provides connectivity between functional blocks (e.g., baseband processing and radio frequency blocks) of a cellular base station (BS). Fronthaul has been traditionally implemented with point-to-point connections similar to those used by the Common Public Radio Interface Specification [B4]. In this standard, a bridged network provides the connectivity between the functional blocks of a BS.

Fronthaul connects the functional blocks of a cellular BS, as illustrated in Figure 6-1. In this standard, these functional blocks are referred to as Radio Equipment (RE) and Radio Equipment Control (REC) or as eCPRI[16] Radio Equipment (eRE) and eCPRI Radio Equipment Control (eREC). That is, the eRE/RE and the eREC/REC are the two basic building blocks into which a BS can be decomposed to provide flexible BS system architectures for mobile networks. The eREC/REC (containing baseband functions) is often located in a conveniently accessible site, geographically separated from the eRE/RE (containing the radio antenna) and connected via fronthaul.

Figure 6-1—BS functional blocks and fronthaul

A bridged network can provide fronthaul connectivity. Figure 6-2 shows eRE/RE and eREC/REC are end stations, each attached to an edge port of an edge bridge. In addition to point-to-point connectivity, a bridged network is capable of providing multipoint-to-multipoint and rooted-multipoint connectivity between eRE/RE and eREC/REC if needed (see 6.2.1 of IEEE Std 802.1Q-2018). A fronthaul bridged network can support other traffic as well, as long as the fronthaul requirements are met.

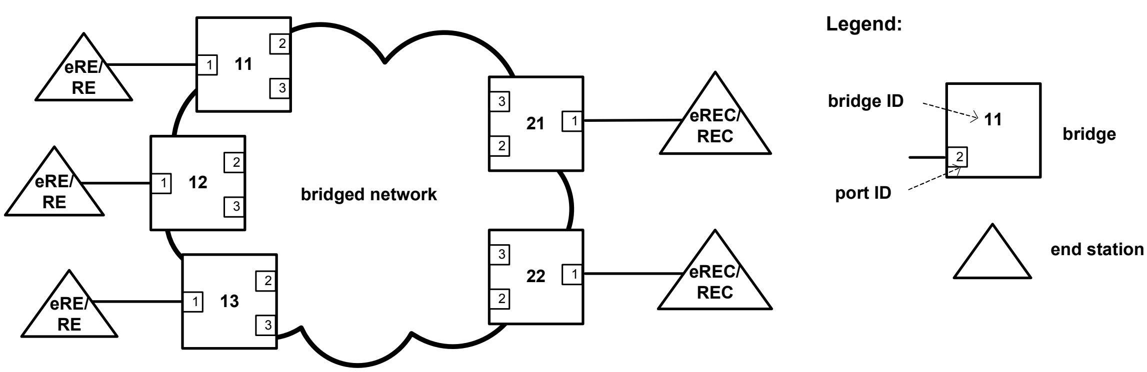

Figure 6-2—Fronthaul bridged network

NOTE—Fronthaul networks other than bridged networks are outside the scope of this standard.

[16]eCPRI is a not an acronym; eCPRI is specified by the eCPRI Interface Specification [B5].

Fronthaul network requirements depend on the air interface supported by the BS and on the BS functional decomposition. This clause:

— Provides background information on aspects of the Evolved Universal Terrestrial Radio Access (E-UTRA) (3GPP TS 36.211 [B3]) technology supported by fronthaul standards that are closely related to this standard (6.1).

— Provides background information on the Common Public Radio Interface Specification [B4] (6.2). Defines Class 1 and describes Class 1 requirements (6.2), where the BS functional decomposition is according to the Common Public Radio Interface Specification [B4].

— Provides background information on the eCPRI Interface Specification [B5] (6.3). Defines Class 2 and describes Class 2 requirements (6.3), where the BS functional decomposition is according to the eCPRI Interface Specification [B5].

— Describes time and frequency synchronization requirements (6.4) common to both Class 1 and Class 2.

Clause 8 specifies bridge profiles and fronthaul bridged network design considerations that support the Class 1 (6.2) and Class 2 (6.3) requirements. Clause 9 describes the applicability of synchronization methods (7.4) to the synchronization requirements (6.4).

6.1 Evolved Universal Terrestrial Radio Access background

The Evolved Universal Terrestrial Radio Access (E-UTRA) specifications (e.g., 3GPP TS 36.211 [B3]) define precise time intervals for data transmission. E-UTRA time intervals are defined as multiples of the basic time unit: $T_s = 1/(15000 \times 2048)$ s. E-UTRA uses Orthogonal Frequency Division Multiplexing (OFDM) where an OFDM symbol is the smallest element of an E-UTRA frame. The OFDM symbol time to carry data is $2048 \times T_s$. In addition, the full OFDM symbol time includes the time of the cyclic prefix (T_{CP}). In case of normal cyclic prefix, $T_{CP} = 160 \times T_s$ for the first symbol and $T_{CP} = 144 \times T_s$ for the following six symbols. In case of extended cyclic prefix, $T_{CP} = 512 \times T_s$ for each symbol.

The timing of packet transmission at an eRE/RE and an eREC/REC in a fronthaul interface supporting E-UTRA is related to the OFDM symbol times explained above.

NOTE—Frame refers to Ethernet frame in this document. OFDM frame refers to the OFDM frame structure (see 3GPP TS 36.211 [B3]).

6.2 Class 1 requirements

Class 1 refers to fronthaul interfaces where the functional decomposition of an E-UTRA BS (see 3GPP TS 36.104 [B1]) into RE and REC is according to Common Public Radio Interface Specification V7.0 [B4] (Table 1A),[17] and the different CPRI information flows are supported separately from each other by the fronthaul bridged network as described in 6.2.2. In the case of Class 1, RE and REC are connected by a bridged network as described in Clause 8.[18] This subclause describes Class 1 and its requirements, which are explained in 6.2.3 and 6.2.4.

[17]The Common Public Radio Interface Specification [B4] functional decomposition is called Split E in the eCPRI Interface Specification [B5].

[18]As opposed to Class 1, RE and REC are not connected by a bridged network in the Common Public Radio Interface Specification [B4].

6.2.1 CPRI background

CPRI is a digitized and serial interface that establishes a connection between REC and RE, i.e., between the blocks into which a BS is split. The REC contains the radio functions of the digital baseband domain, whereas the RE contains the analogue radio frequency functions.

REC and RE configurations are flexible, e.g., several REs can be served by one REC or one RE can be served by multiple RECs (see reference configurations in 2.3 in Common Public Radio Interface Specification V7.0 [B4]).

CPRI supports the following types of information flows (see 4.1 in Common Public Radio Interface Specification V7.0 [B4]):

a) IQ data, which is user plane information in the form of In-phase and Quadrature (IQ) modulation data,
b) Control and Management (C&M) data, which is exchanged between the control and management entities within REC and RE, and
c) Synchronization data, which is used for CPRI frame and time alignment.

These different CPRI information flow types are supported separately from each other as described in 6.2.2.

NOTE—Frame refers to Ethernet frame in this document. CPRI frame refers to the CPRI frame structure (4.2.7 in Common Public Radio Interface Specification V7.0 [B4]). CPRI frame is used only in this subclause. The CPRI frame structure is aligned with the OFDM frame structure.

6.2.2 Separation of CPRI information flows

The different CPRI information flows (6.2.1) are supported separately from each other by the fronthaul bridged network. A flow of frames supports the In-phase and Quadrature modulation (IQ) data information flow, and a separate flow of frames supports the C&M data information flow. IQ data and C&M data separation in a fronthaul bridged network is described in Clause 8.

Synchronization is always provided separately from IQ and C&M data. Subclause 7.4 describes solutions to provide synchronization for RE and REC. For instance, synchronization can be provided by the fronthaul bridged network to the mobile network via the profile for telecommunication applications (telecom profile) specified by ITU-T G.8275.1, which is based on the Precision Time Protocol (PTP) specified in IEEE Std 1588.

6.2.3 IQ data requirements

This subclause describes Class 1 IQ data information flows and their requirements. The timing of the transmission of packets carrying IQ data by an RE and an REC is related to E-UTRA OFDM (see 6.1). IQ data is exchanged between the RE and the REC regardless of whether user data is exchanged between the User Equipment (UE) and the BS. This results in periodic IQ data packet transmission. Furthermore, the same amount of IQ data is transmitted in each period of a particular IQ data flow. Therefore, an IQ data flow is a periodic Constant Bit Rate (CBR) data flow. The time interval within which one or more packets of an IQ data flow are sent is called *time window* in this document. Time windows of a given IQ data flow are back-to-back time intervals whose duration is identical. The requirements for IQ data flows are provided by the CPRI functional decomposition requirements [B7].

NOTE—Meeting the latency target (6.2.3.1) is as necessary as meeting the targeted maximum Frame Loss Ratio (FLR) (6.2.3.2) because frame(s) experiencing late delivery (characterized by the “occurrence of buffer overflow/underflow” in an end station per 6.3.2 in the eCPRI Interface Specification V1.1 [B5]) can be discarded or considered lost by the receiving end station (even if the bridged network meets the targeted maximum FLR).

6.2.3.1 Latency

The maximum end-to-end one-way latency is 100 µs for IQ data between an edge port connected to an REC and another edge port connected to an RE. This maximum end-to-end latency includes the propagation delay of the links between the bridges of the fronthaul bridged network, and internal delays in these bridges. The end-to-end one-way latency is measured from the arrival of the last bit at the ingress edge port of the bridged network to the transmission of the last bit by the egress edge port of the bridged network (see Annex L.3 of IEEE Std 802.1Q-2018).

NOTE 1—MEF 10.3 defines one-way frame delay from first bit to last bit (8.8.1 in MEF 10.3).

NOTE 2—No requirement on frame delay variation has been specified; see the CPRI functional decomposition requirements [B7].

6.2.3.2 Frame Loss Ratio

Frame loss can be caused by bit errors, network congestion, failures, etc. FLR is treated separately from service availability ITU-T Y.1563 [B18] because FLR is not meaningful for characterizing the quality of the service when the service is not available.

The maximum tolerable FLR between edge ports of a fronthaul bridged network for an IQ data flow is 10^{-7}.

NOTE—In this document (e.g., 6.2.3.2, 6.2.4, 6.3.2.2, and 6.3.3), the maximum FLRs are values that indicate what can be tolerated; they do not reflect actual network performance.

6.2.4 Control and Management data requirements

The requirements for C&M data are provided by the CPRI functional decomposition requirements [B7].

C&M data is not as time critical as IQ data; no specific latency requirement value is provided for C&M data in the CPRI functional decomposition requirements [B7].

The maximum tolerable FLR between edge ports of a fronthaul bridged network for a C&M data flow is 10^{-6}.

6.3 Class 2 requirements

Class 2 refers to fronthaul interfaces where the functional decomposition of an E-UTRA BS (see 3GPP TS 36.104 [B1]) into eRE and eREC is inside the radio physical layer (PHY) as specified by the eCPRI Interface Specification [B5]. eCPRI bit rates corresponding to the same end-user data rates are smaller than Common Public Radio Interface Specification [B4] bit rates due to the flexible functional decomposition provided by eCPRI. In the case of Class 2, the eCPRI protocol is used between the eRE and the eREC, and they are connected by a bridged network as described in Clause 8.

6.3.1 eCPRI background

The eCPRI functional decomposition positions the split point inside the radio physical layer (PHY) when dividing a BS into eRE and eREC. The eCPRI Interface Specification [B5] functional split is more flexible than the Common Public Radio Interface Specification [B4] functional split. The fronthaul bridged network connects the eRE and the eREC regardless of the functional decomposition selected for a specific implementation. The intra-PHY splits introduced by eCPRI are called Split $\{I_D;II_D;I_U\}$ (see 6.1.1 in the eCPRI Interface Specification V1.1 [B5]), which include multiple options.[19]

[19]Roman numerals identify split options, D/U denote downlink/uplink direction in the radio network, respectively. Uplink refers to the direction from the UE to the BS, whereas downlink is from the BS to the UE.

eCPRI distinguishes the following separate planes:

a) User Plane, which includes three types of information flows
   1) User Data, which is user information transmitted between the user equipment and the base station.
   2) Real-Time Control Data, which is time-critical control and management information directly related to the User Data.
   3) Data for other eCPRI services, e.g., User Plane support, remote reset.
b) C&M Plane, which includes control and management information exchanged between the control and management entities within the eREC and the eRE.
c) Synchronization Plane, which provides frequency and time/phase synchronization to eRECs and eREs in an eCPRI installation.

eCPRI defines a protocol for the transfer of User Plane information between eREC and eRE via a fronthaul network. eCPRI User Plane includes three service types: User Data, Real-Time Control, and other eCPRI services; they correspond to the information flows of the User Plane. eCPRI User Plane data rates are smaller than CPRI IQ data rates for the same end-user data rates due to the different functional split. User Plane data requirements are described in 6.3.2.

eCPRI C&M information is exchanged between eREC and eRE via commonly used transport protocols, e.g., the User Datagram Protocol (IETF RFC 768 [B8]), the Transmission Control Protocol (IETF RFC 793 [B9]), the Stream Control Transmission Protocol (IETF RFC 4960 [B10]), etc. That is, C&M information is not transmitted via an eCPRI-specific protocol. C&M information flows are low bit rate and not as time-critical as the majority of the User Plane data flows. Some C&M information flows are interactive traffic and used for the control of the eRE. C&M Plane data requirements are described in 6.3.3.

The eRE and eREC recover frequency and time/phase from a synchronization reference source. Synchronization information is not transmitted via an eCPRI-specific protocol. Synchronization Plane requirements are described in 6.4. Existing solutions and protocols are used to provide synchronization. Subclause 7.4 describes the possible solutions.

The different eCPRI information flows are supported separately from each other by the fronthaul bridged network and synchronization is provided by one of the solutions described in 7.4, i.e., separately from eCPRI User Data and C&M.

When used for an E-UTRA BS, eCPRI timing is related to E-UTRA OFDM frame structure and timing described in 6.1.

6.3.2 User Plane data requirements

This subclause describes Class 2 User Plane information flows and their requirements. The timing of the transmission of User Plane data by an eRE and an eREC is aligned with E-UTRA OFDM timing (see 6.1), which is periodic. That is, the time windows when one or more packets of a User Plane data flow can be sent are aligned with the OFDM timing. The traffic of a User Plane data flow carrying user data is correlated with the user data traffic of the corresponding UE (i.e., eRE and eREC exchange user data only when there is user data exchange between UE and BS). Thus, a User Plane data flow can have time windows with no packet. There is a maximum amount of data in a time window for a User Plane data flow. The requirements for User Plane data flows are described in the Requirements for the eCPRI Transport Network [B6].

6.3.2.1 Latency

The maximum end-to-end one-way latency is 100 μs for the majority of User Plane data between an edge port connected to an eREC and another edge port connected to an eRE. This User Plane data belongs to the high priority traffic class in Table 1 in the Requirements for the eCPRI Transport Network V1.1 [B6]. The maximum end-to-end latency includes the propagation delay of the links between the bridges of the fronthaul bridged network, and internal delays in these bridges. The end-to-end one-way latency is measured from the arrival of the last bit at the ingress edge port of the bridged network to the transmission of the last bit by the egress edge port of the bridged network (see Annex L.3 of IEEE Std 802.1Q-2018).

NOTE 1—MEF 10.3 defines one-way frame delay from first bit to last bit (8.8.1 in MEF 10.3).

NOTE 2—No requirement on frame delay variation has been specified; see the Requirements for the eCPRI Transport Network [B6].

The latency requirement is not that strict for User Plane (slow) data, as shown in Table 1 in the Requirements for the eCPRI Transport Network V1.1 [B6]. The maximum end-to-end one-way latency from edge port to edge port is 1 ms for User Plane (slow), which belongs to the medium priority traffic class in Table 1 in the Requirements for the eCPRI Transport Network V1.1 [B6].

6.3.2.2 Frame Loss Ratio

Frame loss can be caused by bit errors, network congestion, failures, etc. FLR is treated separately from service availability ITU-T Y.1563 [B18] because FLR is not meaningful for characterizing the quality of the service when the service is not available.

The maximum tolerable FLR between edge ports of a fronthaul bridged network for a User Plane data flow is 10^{-7}. The FLR tolerance is identical for all User Plane information flows including User Plane (slow).

6.3.3 Control and Management Plane data requirements

This subclause summarizes the requirements for Class 2 C&M Plane information flows based on the eCPRI Interface Specification [B5] and Requirements for the eCPRI Transport Network [B6].

6.3.3.1 Latency

According to the Requirements for the eCPRI Transport Network [B6], C&M information flows are not as time-critical as the User Plane data flows with 100 μs latency budget (6.3.2.1).

The maximum end-to-end one-way latency is 100 ms for the majority of C&M Plane data between an edge port connected to an eREC and another edge port connected to an eRE. This C&M Plane data belongs to the low priority traffic class in Table 1 in the Requirements for the eCPRI Transport Network V1.1 [B6].

The latency requirement is stricter for C&M Plane (fast) in Table 1 in the Requirements for the eCPRI Transport Network V1.1 [B6]. The maximum end-to-end one-way latency from edge port to edge port is 1 ms for C&M Plane (fast), i.e., the same as for User Plane (slow) (see 6.3.2.1). Therefore, similarly to User Plane (slow), C&M Plane (fast) also belongs to the medium priority traffic class in Table 1 in the Requirements for the eCPRI Transport Network V1.1 [B6].

6.3.3.2 Frame Loss Ratio

The maximum FLR that the majority of C&M Plane data flows can tolerate is 10^{-6}. This C&M Plane data belongs to the low priority traffic class in Table 1 in the Requirements for the eCPRI Transport Network V1.1 [B6].

The FLR tolerance requirement is stricter for C&M Plane (fast) data flows in Table 1 in the Requirements for the eCPRI Transport Network V1.1 [B6], where C&M Plane (fast) belongs to the medium priority traffic class. The maximum tolerable FLR between edge ports of a fronthaul bridged network for a C&M Plane (fast) data flow is 10^{-7}, which is the same as for a User Plane data flow (6.3.2.2).

6.4 Synchronization requirements

Time and frequency synchronization requirements are explained in 6.4.1 and 6.4.2, respectively. The synchronization requirements are provided by the Requirements for the eCPRI Transport Network [B6]. The synchronization requirements are applicable to both Class 1 and Class 2.

NOTE—High-frequency noise is not included in the budgeting analysis assuming it can be filtered out by the eRE/RE. As an example, ITU-T G.8271.1 assumes that noise above 0.1 Hz is filtered out by the End Application.

6.4.1 Time synchronization requirements

If the bridged network provides time synchronization, then the following timing accuracy requirements apply. Four different Categories are defined and distinguished by the Requirements for the eCPRI Transport Network [B6] with respect to time synchronization requirements; they are described in 6.4.1.1, 6.4.1.2, 6.4.1.3, and 6.4.1.4. Different timing Categories are applicable for different 3GPP features; an example is given for each Category.

Based on ITU-T G.8271.1, synchronization accuracy is specified here using maximum absolute TE (max$|TE|$) values when the requirement is expressed with respect to an internationally recognized time reference [e.g., the Temps Atomique International (TAI)] or maximum absolute relative TE (max$|TE|_{relative}$) values when the requirement is expressed between two reference points. The subclauses contained herein define the requirements at the input of the eRE/RE. Time errors (TEs) introduced by the link connected to the eRE/RE are not part of the budget for eRE/RE internal Time Error ($|TE_{eRE/RE}|$) but are included in the max$|TE|$ budget. The different TEs are illustrated in Figure 6-3.

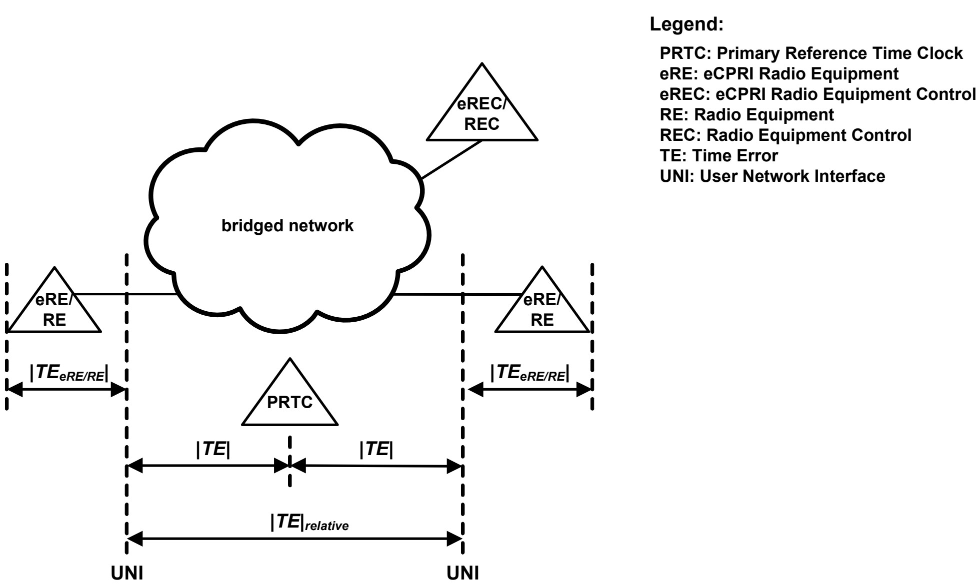

Figure 6-3—Time errors

NOTE 1—Figure 6-3 is based on Figure 7 of the eCPRI transport requirements specification (Requirements for the eCPRI Transport Network V1.1 [B6]), which uses the User Network Interface (UNI) definition of MEF 10.3.

The following interface condition cases are distinguished:

— Case 1: The Telecom Time Slave Clock (T-TSC) is integrated in eRE/RE, i.e., PTP termination is in eRE/REs. Thus, the eRE/RE has two time budgets: eRE/RE internal TE and integrated T-TSC TE. Case 1 corresponds to deployment case 1 of Figure 7-1 of ITU-T G.8271.1 (10/2017) (illustrated in Figure 6-4). Case 1 includes two sub-cases:
  1) Case 1.1: The integrated T-TSC requirements are the same as that of a standalone T-TSC Class B as specified in ITU-T G.8273.2.
  2) Case 1.2: Enhanced integrated T-TSC requirements assume a total maximum absolute TE of 15 ns.
— Case 2: The T-TSC is not integrated in eRE/REs, i.e., PTP termination is in T-TSC at the edge port, and the phase/time reference is delivered from the T-TSC to the co-located eRE/REs via a phase/time synchronization distribution interface (e.g., 1 PPS and Time of Day). Case 2 corresponds to deployment case 2 of Figure 7-1 of ITU-T G.8271.1 (10/2017) (illustrated in Figure 6-4).

According to the Requirements for the eCPRI Transport Network [B6], the budget for eRE/RE internal Time Error ($|TE_{eRE/RE}|$) depends on the Case and the Category as shown in Table 6-1.

Table 6-1—Budget for eRE/RE internal absolute Time Error

	Category A+ (6.4.1.1)	**Category A (6.4.1.2)**	**Category B (6.4.1.3)**	**Category C (6.4.1.4)**
Case 1 (1.1 & 1.2)	N/A	20 ns	20 ns	20 ns
Case 2	22.5 ns	30 ns	30 ns	30 ns

Category A+ (6.4.1.1), Category A (6.4.1.2), and Category B (6.4.1.3) requirements are expressed as relative requirements between two points at the edge of the bridged network (instead of relative to a common clock reference). Category C (6.4.1.4) requirements are expressed as an absolute requirement at the edge of the bridged network as in ITU-T G.8271.1. Category C (6.4.1.4) network limits are not derived from 3GPP requirements, but network limits specified for reference point C in 7.3 of ITU-T G.8271.1 (10/2017) are used (see reference point C in Figure 6-4). Considerations on how to measure network limits on a packet-based interface (e.g., PTP) are provided in Appendix III of ITU-T G.8271.1 (10/2017). The ITU-T has defined individual clock specifications for time distribution to address Category C (6.4.1.4) requirements. Their use for other Categories is discussed in 7.4.

NOTE 2—eRE/RE clock specification is in scope of the specifications of CPRI Cooperation; it is out of the scope of ITU-T and out of the scope of this document. The budget of the bridged network is important for this document.

NOTE 3—ITU-T recommendations under development are expected to support the requirements of Case 1.2 in Categories A and B, and Case 2 in Categories A+ and A.

FLR requirement for PTP is not specified by this standard. Requirements on PTP are described in IEEE Std 1588 and requirements for the PTP telecom profile for phase/time synchronization with full timing support from the network in ITU-T G.8275.1. These requirements do not include explicit requirements on PTP FLR; however, they provide indications on expected FLR levels that can impact PTP performance [see the requirements on message rates as specified in 6.2.8 of ITU-T G.8275.1 (06/2016)].

The requirements for the different Categories are explained in the following subclauses, they are also summarized in Table 2 in the Requirements for the eCPRI Transport Network V1.1 [B6].

6.4.1.1 Category A+

Category A+ is only applicable to Case 2. The maximum relative TE can be determined as shown by Equation (6-1):

$$\max|TE|_{relative} = 65\text{ ns} - 2 \times |TE_{eRE/RE}| = 20\text{ ns} \tag{6-1}$$

where $|TE_{eRE/RE}|$ is the budget for all respective internal eRE/RE TE.

Equation (6-1) is derived from 6.5.3.1 of 3GPP TS 36.104-2018 [B1]. The maximum Time Alignment Error is 65 ns. 20 ns budget remains for the maximum relative TE of the bridged network as $|TE_{eRE/RE}|$ is 22.5 ns (see Table 6-1).

Category A+ requirement is relevant, e.g., for Multiple-Input and Multiple-Output or transmit diversity radio access technologies (used between two cooperating eRE/REs).

6.4.1.2 Category A

Category A is applicable to Case 1.2 and Case 2. The maximum relative TE can be determined as shown by Equation (6-2) and Equation (6-3) for the applicable cases:

$$\textbf{Case 1.2:}\ \max|TE|_{relative} = 130\text{ ns} - 2 \times |TE_{eRE/RE}| - 2 \times |TE_{T\text{-}TSC}| = 60\text{ ns} \tag{6-2}$$

$$\textbf{Case 2:}\ \max|TE|_{relative} = 130\text{ ns} - 2 \times |TE_{eRE/RE}| = 70\text{ ns} \tag{6-3}$$

where

$|TE_{eRE/RE}|$ is the budget for all respective internal eRE/RE TE
$|TE_{T\text{-}TSC}|$ is the budget for T-TSC TE

Equation (6-2) and Equation (6-3) are derived from 6.5.3.1 of 3GPP TS 36.104-2018 [B1]. The maximum Time Alignment Error is 130 ns. In Case 1.2, 60 ns budget remains for the maximum relative TE of the bridged network as $|TE_{eRE/RE}|$ is 20 ns (see Table 6-1) and $|TE_{T\text{-}TSC}|$ is 15 *ns* (see the Requirements for the eCPRI Transport Network [B6]). In Case 2, 70 ns budget remains for the maximum relative TE of the bridged network as $|TE_{eRE/RE}|$ is 30 ns (see Table 6-1).

Category A requirements are relevant, e.g., for intra-band contiguous carrier aggregation radio access technology (used between two cooperating eRE/REs).

6.4.1.3 Category B

Category B is applicable to Case 1.1, Case 1.2, and Case 2. The maximum relative TE can be determined as shown by Equation (6-4), Equation (6-5), and Equation (6-6) for the different cases:

$$\textbf{Case 1.1:}\ \max|TE|_{relative} = 260\text{ ns} - 2 \times |TE_{eRE/RE}| - 2 \times |TE_{T\text{-}TSC}| = 100\text{ ns} \tag{6-4}$$

$$\textbf{Case 1.2:}\ \max|TE|_{relative} = 260\text{ ns} - 2 \times |TE_{eRE/RE}| - 2 \times |TE_{T\text{-}TSC}| = 190\text{ ns} \tag{6-5}$$

$$\textbf{Case 2:}\ \max|TE|_{relative} = 260\text{ ns} - 2 \times |TE_{eRE/RE}| = 200\text{ ns} \tag{6-6}$$

where

$|TE_{eRE/RE}|$ is the budget for all respective internal eRE/RE TE
$|TE_{T\text{-}TSC}|$ is a budget for T-TSC TE

Equation (6-4), Equation (6-5), and Equation (6-6) are derived from 6.5.3.1 of 3GPP TS 36.104 [B1]. The maximum Time Alignment Error is 260 ns. In Case 1.1, 100 ns budget remains for the maximum relative TE of the bridged network as $|TE_{eRE/RE}|$ is 20 ns (see Table 6-1) and $|TE_{T\text{-}TSC}|$ is 60 ns ($|TE_{T\text{-}TSC}| = |cTE_{T\text{-}TSC}| + |dTE_{T\text{-}TSC}|$ = 20 ns + 40 ns = 60 ns according to ITU-T G.8273.2 Class B Telecom Time Slave Clock, where *cTE* is constant TE and *dTE* is dynamic TE). In Case 1.2, 190 ns budget remains for the maximum relative TE of the bridged network as $|TE_{eRE/RE}|$ is 20 ns (see Table 6-1) and $|TE_{T\text{-}TSC}|$ is 15 ns (see Requirements for the eCPRI Transport Network [B6]). In Case 2, 200 ns budget remains for the maximum relative TE of the bridged network as $|TE_{eRE/RE}|$ is 30 ns (see Table 6-1).

Category B requirements are relevant, e.g., for intra-band non-contiguous and inter-band carrier aggregation radio access technologies (used between two cooperating eRE/REs).

6.4.1.4 Category C

Category C is applicable to Case 1.1, Case 1.2, and Case 2. The maximum absolute TE at the edge of the bridged network is derived from 3GPP TS 36.133 [B2] as shown by Equation (6-7) for all cases:

$$\max|TE| = 1.1\ \mu\text{s}. \tag{6-7}$$

Figure 6-4 shows the application of ITU-T G.8271.1 deployment cases within the scope of this standard. Better-performing primary reference clocks allow a larger budget for the bridged network, e.g., enhanced PRTC in a central location as specified by ITU-T G.8272.1.

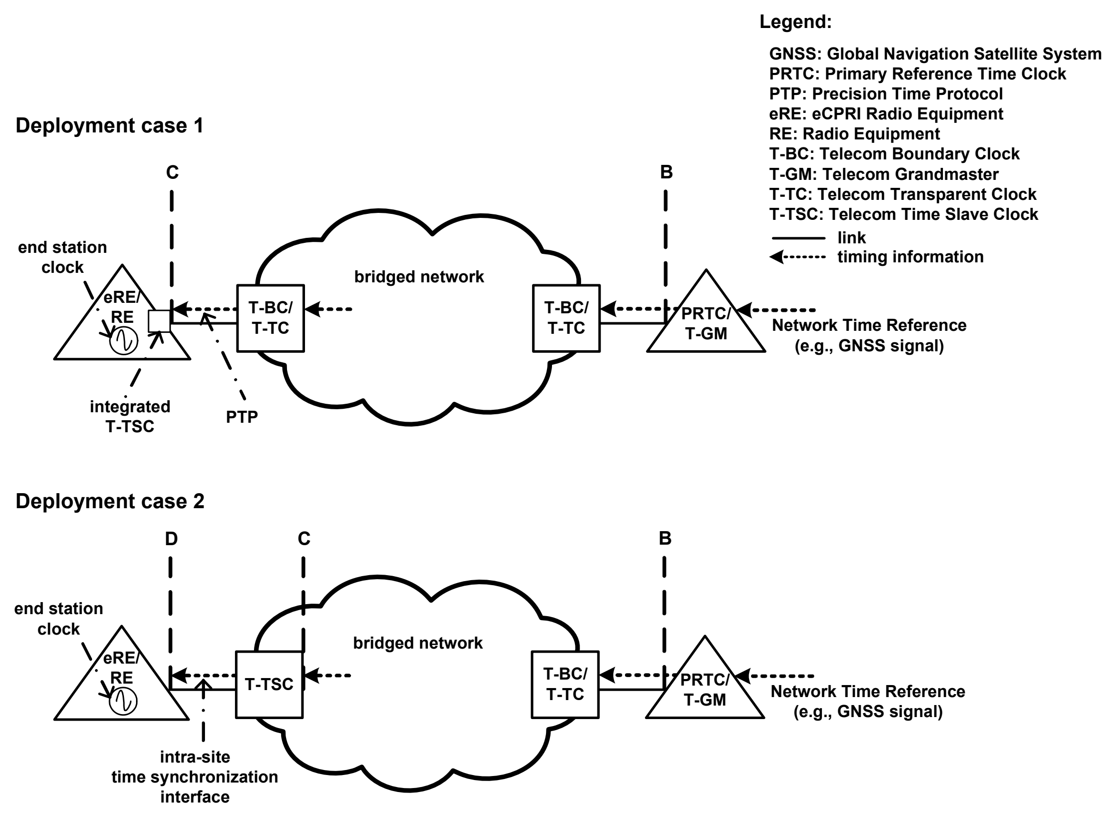

Figure 6-4—ITU-T G.8271.1 deployment cases in the scope of this standard

NOTE—Reference point A of Figure 7-1 in ITU-T G.8271.1 (10/2017) is not shown in Figure 6-4 because it is internal to the PRTC/T-GM.

Category C requirements are relevant, e.g., for E-UTRA time division duplex radio access technology.

6.4.2 Frequency synchronization requirements

The frequency synchronization requirements are based on 3GPP TS 36.104 [B1]. As applied to the bridged network, they are related to the need for the eRE/RE to recover a timing signal that meets the applicable synchronization requirements on the radio interface. In particular, ±50 ppb is required on the radio air interface (3GPP TS 36.104 [B1]) at the output of the eRE/RE. In worst case, the network should deliver at least ±16 ppb (on the long term) at the input of the eRE/RE.[20]

When frequency synchronization is recovered via Synchronous Ethernet (ITU-T G.8262), the applicable requirements at the input of the eRE/RE are defined by the Synchronous Ethernet network limits in 9.2.1 of ITU-T G.8261.

When frequency synchronization is recovered directly by the PTP signal, the requirements at the input of the eRE/RE are specified by the performance requirements of the applicable PTP profile, where reference point C in Figure 6-4 is at the input to the eRE/RE. Figure 6-4 shows the application of ITU-T G.8271.1 deployment cases that are in the scope of this standard.

NOTE—ITU-T G.8271.1 G.8273.2, G.8273.3, and G.8275.1 specify the time synchronization requirements and do not explicitly present any frequency accuracy synchronization requirement. However, a timing signal that is able to transfer accurate time synchronization implicitly also carries frequency synchronization. PTP can carry time and frequency at the same time; e.g., when ±1 µs is met in phase, ±16 ppb is also met on the long term in frequency. For instance, if the interface is able to keep ±1 µs for indefinite time, then ±16 ppb could be recovered when the input is averaged over periods longer than 1000/16 s. ±16 ppb is the network limit assumed by ITU-T G.8261.1 [B13] for mobile applications; therefore, a network that is able to meet ±16 ppb is suitable. The current versions of ITU-T G.8271.1, G.8273.2, G8273.3, and G.8275.1 assume a combination of Synchronous Ethernet and PTP.

[20]Long-term period depends on the time constant of the Phase Locked Loop.

7. Bridge and synchronization functions

This clause lists bridge and synchronization functions that are important to the operation of a fronthaul bridged network. This clause also summarizes the network characteristics that these functions support.

7.1 Latency components

Each hop of a fronthaul bridged network contributes to the end-to-end latency of a fronthaul information flow, e.g., IQ data information flow. The worst-case latency has to be taken into account when designing and configuring a fronthaul bridged network.

As discussed in Annex L.3 of IEEE Std 802.1Q-2018, the worst-case latency for a single hop from bridge to bridge, measured from the arrival of the last bit at port *n* of bridge A to the arrival of the last bit at port *m* of bridge B, can be broken out into the following components:

a) Input queuing delay. There are no input queues in the IEEE 802.1 architecture, but if present, they have to be taken into account, i.e., the worst-case input queuing delay is a component.
b) Interference delay [see following items f) and g)].
c) Frame transmission delay. The time taken to transmit one maximum size frame at the transmission rate of the port.
d) LAN propagation delay ($t_{Propagation}$). A variable delay that depends on the length of the LAN connection to the next bridge. The propagation delay of a point-to-point link corresponds to the length of the link.
e) Store-and-forward delay (t_{SF}). This includes all other elements of the forwarding delay that are a consequence of the internal processing of the bridge, including the time to select the input for transmission to the egress port, assuming that the input queue under consideration and output queues are empty. (See L.3 of IEEE Std 802.1Q-2018 for further details.)

The interference delay for frame X of a fronthaul flow can be broken out into the following components:

f) Queuing delay ($t_{Queuing}$): The delay caused by the frame that was selected for transmission an arbitrarily small time before frame X became eligible for transmission selection, plus the delay caused by queued-up frames from all flows with higher priority than the traffic class of frame X.
g) Self-queuing delay ($t_{SelfQueuing}$): The delay caused by other frames in the same traffic class as frame X. The part of the self-queuing delay caused by frames that arrive at more or less the same time from different input ports is referred to as fan-in delay; however, it is simpler to handle fan-in delay as part of the self-queuing delay. Annex B provides examples for self-queuing delay.

7.2 Bridge delay calculation

This subclause describes how to calculate the worst-case bridge delay for periodic CBR data flows of the highest priority traffic class, which is associated exclusively to the given CBR data flows, e.g., IQ data (6.2.3). Such data flows are referred to as *gold flows* in this subclause.

Equation (7-1) shows how the worst-case latency of a bridge ($t_{MaxBridge}$) can be calculated for gold flows:

$$t_{MaxBridge} = t_{SF} + t_{SelfQueuing} + t_{Queuing} + t_{MaxGoldFrameSize + Pre + SFD + IPG} \tag{7-1}$$

where

t_{SF} is the store-and-forward delay (item e) in 7.1) of the bridge
$t_{SelfQueuing}$ is the self-queuing delay (item g) in 7.1)

$t_{Queuing}$ is the queuing delay (item f) in 7.1)

$t_{MaxGoldFrameSize+Pre+SFD+IPG}$ is the transmission time for a maximum size frame (MaxGoldFrameSize) of a gold flow with Preamble (Pre), Start Frame Delimiter (SFD), and the following Inter Packet Gap (IPG)

The self-queuing delay and the queuing delay are determined by Equation (7-2) and Equation (7-3), respectively.

The worst-case self-queuing delay of egress port p for the gold flows received at ingress port j can be calculated as shown by Equation (7-2):

$$t^{j,p}_{SelfQueuing} = t_{MaxGoldFrameSize+Pre+SFD+IPG} \times \sum_{\substack{i=1 \\ i \neq j}}^{N_p} \sum_{k=1}^{F_{i,p}} G^{i,p}_k \tag{7-2}$$

where

N_p is the number of ingress ports that can receive interfering frames of gold flows transmitted by port p

$F_{i,p}$ is the number of gold flows supported between ingress port i and egress port p

$G^{i,p}_k$ is the maximum number of frames of gold flow k between ingress port i and egress port p that can be grouped together in a single time window before they are received by the ingress edge port of the bridged network

Frames received at a given ingress port do not cause self-queuing delay for other frames received at the given ingress port as long as the nominal data rate of an egress port aggregating gold flows is greater than or equal to:

a) the bandwidth required by the received data traffic of gold flows destined to the aggregating egress port, and
b) the nominal data rate of the ingress port whose traffic is aggregated.

That is, N_p–1 ingress ports have to be taken into account for the number of gold flows interfering with the gold flows of ingress port j with respect to egress port p. The total number of the aggregated gold flows supported by different ingress ports (other than the reception port of the observed flow) determine the worst-case self-queuing delay for a frame of an observed flow. That is, the sum of $F_{i,p}$ flows for N_p–1 ports gives the worst-case number of flows that can cause self-queuing delay. The data of a single time window of gold flow k is carried by G_k number of Ethernet frames, where G_k is often 1. The worst-case self-queuing delay can be then calculated taking into account the transmission time ($t_{MaxGoldFrameSize+Pre+SFD+IPG}$) of a maximum size frame of a gold flow (MaxGoldFrameSize) including the Preamble (Pre), Start Frame Delimiter (SFD), and the following Inter Packet Gap (IPG). Gold flows have self-queuing delay only due to other gold flows if there are only gold flows in the respective traffic class. The self-queuing delay is discussed further via examples in B.1.

The worst-case queuing delay ($t_{Queuing}$) for gold flows is the transmission time ($t_{MaxLoFrameSize+Pre+SFD+IPG}$) of a maximum size lower priority frame (MaxLoFrameSize) with its Preamble (Pre), Start Frame Delimiter (SFD), and the following Inter Packet Gap (IPG) as shown by Equation (7-3):

$$t_{Queuing} = t_{MaxLoFrameSize+Pre+SFD+IPG} \tag{7-3}$$

There is no queuing delay due to higher priority traffic if gold flows have the highest priority.

NOTE—If a network operator gives other traffic, e.g., network maintenance, the same or higher priority than gold flows, then the given traffic contributes to the worst-case self-queuing or queuing delay, which has to be taken into account.

7.3 Frame preemption

Frame preemption is the suspension of the transmission of a preemptable frame to allow one or more express frames to be transmitted before the transmission of the preemptable frame is resumed. IEEE Std 802.3br specifies the MAC Merge sublayer, which supports interspersing express traffic with preemptable traffic.[21] The MAC Merge sublayer supports two ways to hold the transmission of preemptable traffic in the presence of express traffic (until subsequent release): the MAC Merge sublayer can preempt (interrupt) preemptable traffic being currently transmitted, and the MAC Merge sublayer can prevent starting the transmission of preemptable traffic (see 99.1 of IEEE Std 802.3br-2016). The IEEE 802.1Q bridge forwarding process optionally supports frame preemption. The benefits provided by frame preemption decrease as the data rate of a bridge port increases.

Frame preemption takes some time; the express frame cannot be transmitted immediately. If frame preemption is possible, then the express frame can be transmitted only after the transmission of the current fragment of the preemptable frame including the Cyclic Redundancy Check (CRC) of the frame and the Inter Packet Gap (IPG). Preemption occurs only if at least 60 octets of the preemptable frame have been transmitted and at least 64 octets (including the frame CRC) remain to be transmitted. The earliest starting position of preemption is controlled by the addFragSize variable, which is a 2-bit integer value indicating, in units of 64 octets, the minimum number of octets over 64 octets required in non-final fragments by the receiver (see 99.4.4 and 79.3.7 of IEEE Std 802.3br-2016). Preemption happens within $(1240 + 512 \times \text{addFragSize})$ bit times. That is, the worst case is 1240 bit times when addFragSize = 0, which is used for the worst-case calculations in this document.

If PTP messages are carried by express frames or by frames that are smaller than 124 octets, then they are not preempted.

7.4 Network synchronization

The following list provides a high-level classification of methods that can be considered in distributing time and frequency synchronization to the eRE/REs in order to meet the synchronization requirements described in 6.4:

a) *Packet Timing* [e.g., Precision Time Protocol (PTP)]. The performance of packet timing depends on the deployment approach applied; therefore, four main deployment approaches are considered here:
   1) *Point-to-point synchronization distribution from a remote common master* (no packet switching in between). In this approach, a two-way protocol is used for time alignment. The eRE/REs that need to be time or phase aligned do not have to be co-located. Due to the distance to the remote master, the performance of the packet timing strongly depends on the characteristics of the link, e.g., asymmetry in optical transmission due to use of different wavelengths.
   2) *Co-located common master at the eRE/RE*. In this approach, the eRE/REs are co-located and the common master is co-located with the eRE/REs (whereas, the eRE/REs do not need to be co-located and the common master is remote in approach 1.) The common master can have access to a remote Primary Reference Time Clock (PRTC), in which case the common master is a PRTC traceable master, but this is not always necessary. In terms of performance of approach 2) compared with approach 1), there are significantly less concerns related to the link connecting the master. An example of approach 2) is shown in Figure 7-1, where the co-located common master is implemented in Node *n*.

[21] At the time of publication of this standard, the relevant content of IEEE Std 802.3 was separately published as IEEE Std 802.3br-2016.

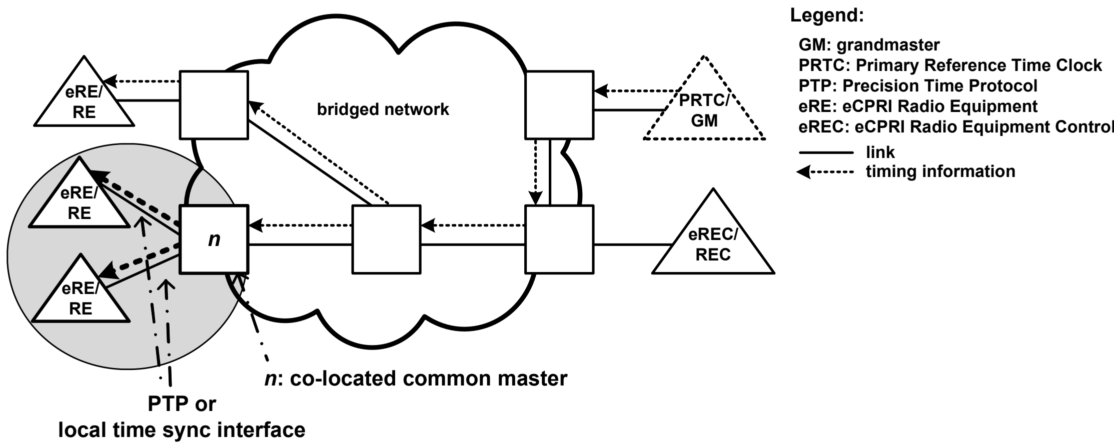

Figure 7-1—Packet timing—Co-located common master at the eRE/RE [(a)(2)]

3) *Timing distribution to a cluster of eRE/REs from the nearest common master / boundary clock*. An example is shown in Figure 7-2, where the nearest common master / boundary clock is implemented in Node *n*, which is the starting point from where the relative phase deviation can be calculated. This allows for a relatively short synchronization chain, with target performance in terms of maximum absolute TE, relative to Node *n*, depending on the length of the chain and the characteristics of the PTP clocks. As an example, 100 ns can be met in a short chain (e.g., two hops) with properly performing clocks (e.g., Class B of ITU-T G.8273.2).

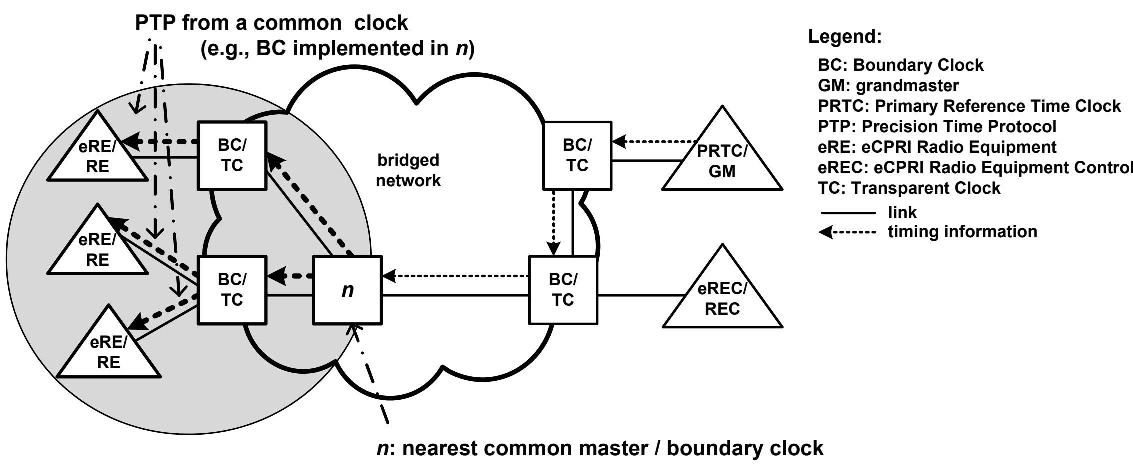

Figure 7-2—Timing distribution to a cluster of eRE/REs from the nearest common clock

NOTE 1—The figures in this document are only illustrative, i.e., the figures do not provide deployment guidance. For instance, different number of hops appear in different figures, which illustrate different cases; however, the figures do not provide guidance on the number of hops. The requirements described in Clause 6 have to be met, the number of hops depends on deployment cases, solution choices etc.

4) *General deployment* as described by an appropriate PTP profile, e.g., as described by the time synchronization architecture as per ITU-T G.8275 [B16], the telecom profile as per ITU-T G.8275.1 with network characteristics as per ITU-T G.8271.1 and clocks as per ITU-T G.8273.2 [Telecom-Boundary Clock (T-BC)] and ITU-T G.8273.3 [Telecom-Transparent Clock (T-TC)]; see example in Figure 7-3. In this case, the target performance in terms of maximum absolute TE relative to an internationally recognized time reference (e.g., TAI) is 1.1 μs at the input of the end station in order to meet 1.5 μs at the output of the end station (including some budget for synchronization network rearrangements).

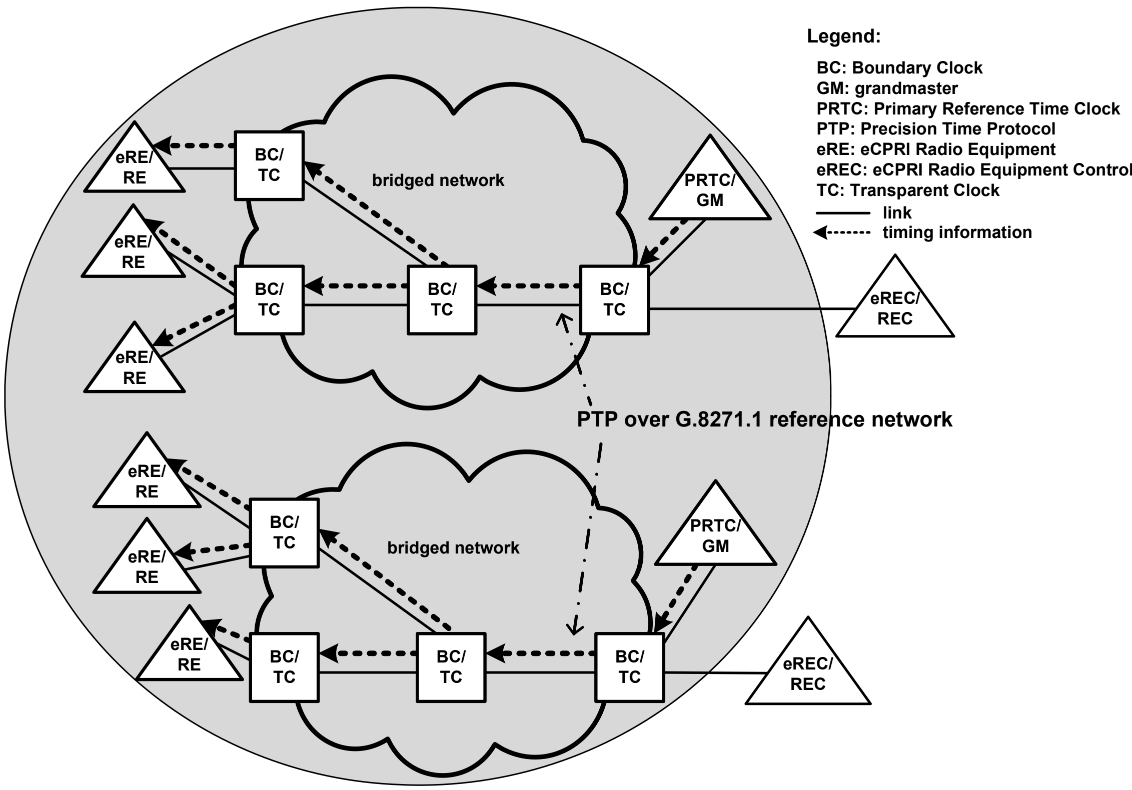

Figure 7-3—Packet timing—General deployment [(a)(4)]

NOTE 2—The transport of timing across the bridged network could be allowed by means of a partial timing support profile as specified by ITU-T G.8275.2 [B17], however, the performance that can be guaranteed over a partial timing support network (see ITU-T G.8271.2 [B15]) is generally not suitable to meet the fronthaul synchronization requirements.

b) *Physical layer frequency synchronization* (e.g., SyncE). This is specified by ITU-T (G.8261, G.8262, G.8264) as a way to deliver frequency synchronization over the physical layer. Synchronous Ethernet support of PTP operations is assumed in ITU-T G.8275.1 based networks (and ITU-T G.8273.2 clocks); an end station can use it for the purpose of frequency synchronization and/or to support PTP operations.

NOTE 3—Even if SyncE is used in a bridged network, the eRE/RE can recover both time synchronization and frequency synchronization from PTP (ITU-T G.8275.1). That is, it is optional for the eRE/RE whether or not to use SyncE even if it is used in the bridged network.

c) Global Navigation Satellite System (GNSS) at the eRE/REs. Examples of satellite systems are: Global Positioning System (GPS), Global Navigation Satellite System (GLONASS), BeiDou Navigation Satellite System (BDS), and Galileo. The expected accuracy in typical installations is of the order of 100 ns. As a reference, ITU-T G.8272 (PRTC specification) specifies 100 ns and ITU-T G.8272.1 specifies 30 ns for enhanced PRTC in a central location.

NOTE 4—100 ns GNSS accuracy assumes normal GNSS operations. However, there can be time intervals when the GNSS signal is lost, e.g., due to jamming, which can lead to worse accuracy. Suitable holdover or redundancy can be used to overcome this issue if specific performance objectives must be met during these time intervals too.

d) *Others* (e.g., Radio Base Synchronization methods with target accuracy in the µs range).

The applicability of these methods to the time synchronization Categories of 6.4 is described in Clause 9.

7.4.1 Network ownership impacts on synchronization

Different deployment scenarios can be defined in terms of network ownership and related synchronization master location when the bridged network offers support for synchronization for the mobile network, e.g., as described in MEF 22.3 [B19].

The following cases are distinguished here:

a) Same operator for the mobile and the bridged networks (Figure 7-4)
b) Different operators for the mobile and bridged networks (Figure 7-5)

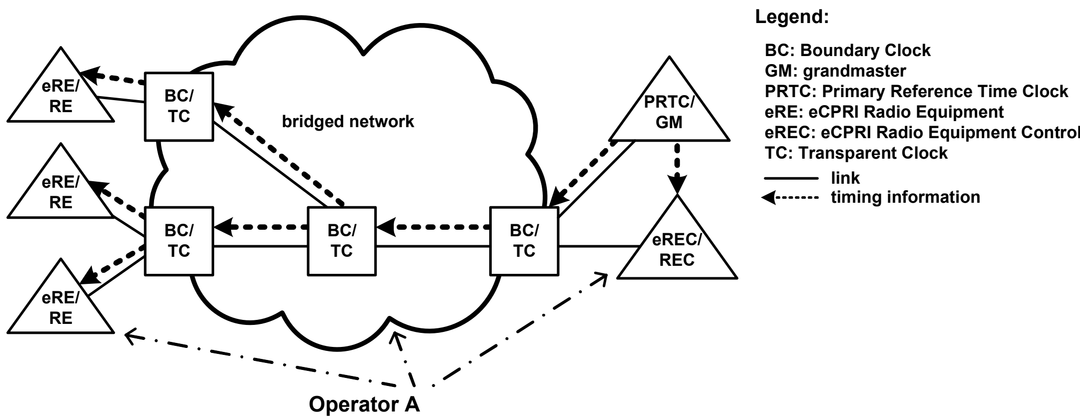

Figure 7-4—Same network operator for the mobile and bridged network

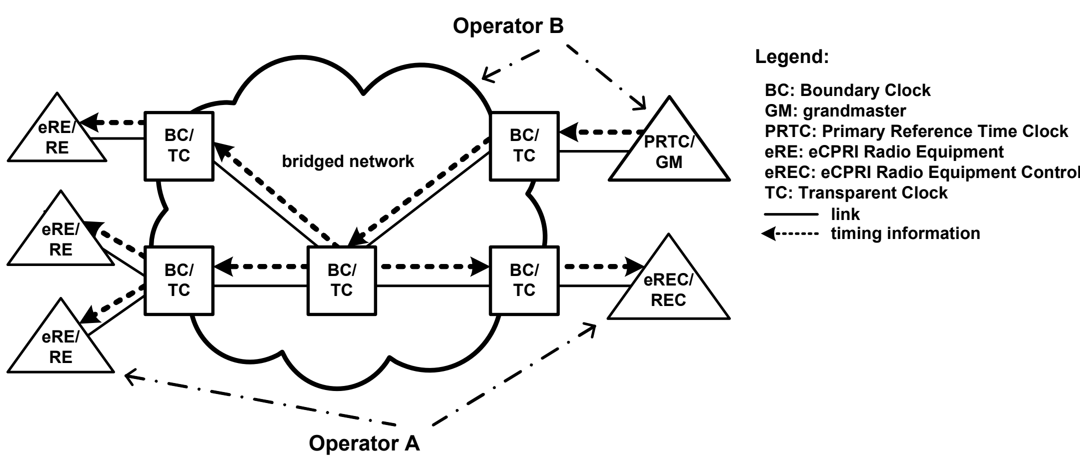

Figure 7-5—Different bridged network and mobile network operators

NOTE 1—If the bridged network and mobile network operators are different, then multiple mobile networks can use the same bridged network.

The performance of the time synchronization carried over a PTP network depends on the length of the synchronization chain (i.e., number of PTP clocks) and the highest level of performance assumes full timing support [IEEE 1588 boundary clock (BC) or transparent clock (TC) support in every node].

There are different considerations from a network synchronization perspective depending on the specific use cases.

In case a) (same network operator for the mobile and bridged network), full control over network topology is possible. The PRTC and/or PTP grandmaster could be for instance co-located with the eREC/REC. In this case, it is also possible to fully control the location in the synchronization chain of the nearest common clock, which can be relevant for the above described synchronization method [(a)(3)] (sub-bullet 3 under item a).

In case b) (different bridged network and mobile network operators), it is generally not possible to carry transparently an accurate time synchronization reference and Synchronous Ethernet (i.e., if the timing master is owned by the mobile network operator, and the reference timing signals are carried over the bridged network). In fact, in the case of time synchronization, PTP boundary clocks operate in a single PTP domain. The use of transparent clocks allows carrying time synchronization across the bridged network. Some aspects need to be carefully considered in this case due to the interaction between different network operators. For instance, this set-up implies a service level agreement between the two network operators in order to guarantee that the performance objectives are met when carrying PTP over the bridged network. Synchronous Ethernet cannot be carried transparently over a bridged network because the bridged network uses its own network clock or might not have a network clock (the Synchronous Ethernet layer is traceable to a single clock).

NOTE 2—The transport of timing across the bridged network in a transparent manner (i.e., without requiring PTP processing in the bridged network) could be allowed by means of a partial timing support profile as specified by ITU-T G.8275.2 [B17]; however, the performance that can be guaranteed over a partial timing support network (see ITU-T G.8271.2 [B15]) is generally not suitable to meet the fronthaul synchronization requirements.

In case b), the synchronization service could be provided by the bridged network (see MEF 22.3 [B19]). The timing reference signal (time and frequency synchronization) can be offered by the bridged network operator by means of proper agreement with a mobile network operator (synchronization offered as a service). In this case, the synchronization approach in (a)(3) (distributing synchronization to a cluster of eRE/REs from the nearest common master / boundary clock) is not necessarily applicable because the mobile network operator (Operator A) has in general no visibility of the topology of the bridged network (of Operator B).

7.5 Flow control

The operation of flow control protocols, for example MAC control PAUSE (IEEE Std 802.3), or Priority-based flow control (IEEE Std 802.1Q) operating on the priorities that are used to support fronthaul traffic, can invalidate latency guarantees for fronthaul traffic. Therefore, a bridge of a fronthaul bridged network shall be configurable to disable MAC control PAUSE. MAC control PAUSE is disabled on any ports that support fronthaul traffic. A bridge of a fronthaul bridged network shall be configurable to disable Priority-based flow control. Priority-based flow control is disabled for the priorities associated with fronthaul traffic on any ports that support fronthaul traffic.

Given the bridge architectural model for points of attachment for higher layer entities, as illustrated in Figure 8-19 of IEEE Std 802.1Q-2018, no higher layer entities within a bridge are subject to these restrictions on the use of flow control protocols. However, where the implementation makes use of the same MAC interface to support relayed frames and also higher layer protocol operation, and where the implementation supports other MAC control protocols that are not subject to relay by the bridge, all transmitted frames that are not relayed by the bridge are subject to the same transmission selection algorithms as relayed frames, in order to ensure that latency is not adversely affected.

7.6 Energy Efficient Ethernet

Energy Efficient Ethernet (EEE, specified in IEEE Std 802.3) specifies a Low Power Idle (LPI) mode of operation for Ethernet LANs that allows the LAN to transition to a low power state when there is no activity.

Control of the LPI state is performed by the LPI client, which determines, on the transmission side, when LPI is asserted and when it is de-asserted. When LPI is de-asserted, there is a delay (wake time) before the link is ready to operate; the longer the wake time, the longer the additional latency due to the operation of EEE. Therefore, in a fronthaul bridged network, bridges do not assert LPI on a port that supports EEE and fronthaul traffic.

8. Fronthaul profiles

The objective of the profiles specified in this standard is to allow the construction of bridged networks that meet the fronthaul requirements described in Clause 6. Two profiles are specified to meet Class 1 (6.2) and Class 2 requirements (6.3). The following subclauses describe how Profile A (8.1) and Profile B (8.2) ensure meeting the different Class 1 and Class 2 targets. Profile B extends Profile A with frame preemption to remove restrictions on the frame size of non-fronthaul flows, thus to accommodate larger non-fronthaul flows while preserving fronthaul traffic guarantees. Throughout this clause, the need to configure conformant bridges to meet fronthaul requirements is highlighted using the term “is configured” or “are configured.” Meeting the synchronization targets is addressed by Clause 9, which applies for both Profile A and Profile B.

Profile A (8.1) and Profile B (8.2) are applicable to both Class 1 (6.2) and Class 2 (6.3) because the two Classes have similar requirements. Three types of fronthaul flows can be distinguished based on their requirements. Based on Table 1 in the Requirements for the eCPRI Transport Network V1.1 [B6], this document refers to the three types of fronthaul flows and corresponding fronthaul traffic classes as follows:

a) High Priority Fronthaul (HPF) data, which includes Class 1 IQ data (6.2.3) and Class 2 User Plane data (6.3.2) with 100 µs maximum end-to-end one-way latency;
b) Medium Priority Fronthaul (MPF) data, which has 1 ms maximum end-to-end one-way latency, thus includes Class 2 User Plane (slow) data and Class 2 C&M Plane (fast) data (see Table 1 in the Requirements for the eCPRI Transport Network V1.1 [B6], and 6.3.2.1 and 6.3.3, respectively);
c) Low Priority Fronthaul (LPF) data, which has 100 ms maximum end-to-end one-way latency, thus includes Class 1 C&M Plane data (6.2.4) and Class 2 C&M Plane data (6.3.3).

As Class 1 IQ data [item a) in 6.2.1] and Class 2 User Plane data [item a) in 6.3.1] belong to HPF [preceding item a)], they are treated the same way in Profile A (8.1) and Profile B (8.2). Thus, Class 2 User Plane data flows are considered as they were CBR data flows, i.e., a User Plane data flow had the same amount of data in each time window (6.3.2). There are Class 2 User Plane data flows that do not use all the bandwidth allocated in the bridged network due to the time windows with no packet (6.3.1). This unused bandwidth can be used by any other traffic, whether fronthaul or not.

NOTE—Bandwidth considerations include that eCPRI User Data rates corresponding to the same end-user data rates are smaller than CPRI IQ data rates.

Class 2 User Plane (slow) data and Class 2 C&M Plane (fast) data belong to MPF [preceding item b)] because they have similar requirements (see Table 1 in the Requirements for the eCPRI Transport Network V1.1 [B6]).

Class 1 C&M data (6.2.4) and Class 2 C&M Plane data (6.3.3) belong to LPF [preceding item c)] because they have similar requirements.

Class 1 has only two types of fronthaul flows, therefore, HPF and LPF are enough to support Class 1, MPF is not used.

eRE, RE, eREC, and REC shall meet the end station requirements (5.5). The eRE/RE and eREC/REC transmit and receive priority-tagged (see 3.184 of IEEE Std 802.1Q-2018) or VLAN-tagged frames in order to distinguish the flows with different requirements. Thus, flows with different requirements can be supported by the same VLAN or by different VLANs. The choice of VLAN does not affect the latency of a frame; flows with different ingress priority are configured to be assigned with different traffic classes in the bridged network as described in 8.1.2.

The bridges of a fronthaul bridged network shall meet the bridge requirements (5.3) and each link of a fronthaul bridged network is a full duplex point-to-point link. Furthermore, the fronthaul bridged network is designed, configured, and operated such that it addresses the criteria specified for the profile supported (8.1, 8.2) and the synchronization targets (Clause 9) if it provides synchronization.

A fronthaul bridged network is designed, configured, and operated such that fronthaul data traffic does not overload the network during normal operation; furthermore, the data rate of each link of the fronthaul bridged network is big enough to carry the desired fronthaul data traffic including HPF, MPF, and LPF, i.e., none of the links is a bottleneck. For instance, if a bridge port aggregates fronthaul data information flows, its transmission rate is both greater than the bandwidth required by the received HPF data traffic, and not smaller than the transmission rate of any port whose fronthaul data traffic is aggregated.

8.1 Profile A

Profile A is based on bridging with strict priority queuing. Profile A does not use any advanced Ethernet or bridging function, e.g., frame preemption. Profile A shall be supported by the bridges of a fronthaul bridged network.

8.1.1 Frame size

The size of the Ethernet frames transported by a fronthaul bridged network can influence whether or not the fronthaul requirements are met.

In the case of Profile A, the maximum frame size is configured at each port of the fronthaul bridged network according to the maximum frame size rules that apply to IEEE 802.3 frames. That is, the maximum possible frame size from the destination MAC address through the end of the CRC is 2000 octets. This applies to all kinds of fronthaul data and non-fronthaul data as well. For example, if nothing but the basic IEEE 802.3 headers are being used with an IEEE 802.1Q C-VLAN tag, then the maximum frame size is 1522 octets. The maximum frame size applied in a network can be smaller than the maximum frame size allowed by IEEE Std 802.3. Furthermore, the maximum frame size applied for different traffic classes can be different. The maximum frame size actually applied for the different traffic classes is used in worst-case latency calculations.

8.1.2 Configuration of traffic classes

In the case of Profile A, traffic classes are configured throughout the entire fronthaul bridged network as follows.

The highest possible priority is configured for HPF data traffic in order to decrease the effects of other traffic. Applying the highest possible priority exclusively to the traffic class of HPF data is important to meet HPF data requirements (6.2.3, 6.3.2), which is assumed in 8.1.3 and 8.1.4.

NOTE—A network operator can decide to give other traffic, e.g., network maintenance, higher priority or as high a priority as HPF data. For instance, the highest priority traffic class can be preserved for network management, in order to handle critical network issues. Such traffic is not present during regular network operations.

The traffic class of HPF data is configured to use the strict priority algorithm (*transmission selection algorithm* of zero), which is configured in the Transmission Selection Algorithm Table (see 12.20.2 of IEEE Std 802.1Q-2018) of each bridge port supporting HPF data information flows throughout the bridged network.

MPF data is configured to a lower priority than HPF data, preferably to the priority immediately below the priority of HPF data.

LPF data is configured to a lower priority than MPF data, preferably to the priority immediately below the priority of MPF data.

8.1.3 Meeting latency targets

Traffic classes are configured as described in 8.1.2 in order to meet the latency targets when Profile A is applied.

The topology of the fronthaul bridged network is designed and forwarding paths of fronthaul data flows are configured such that the worst-case end-to-end latency is within the latency budget for a given HPF data traffic pattern. This puts a limit on the number of hops and on the total length of the links end-to-end.

The propagation delay [$t_{Propagation}$, item d) in 7.1] can be a significant part of the end-to-end latency. For instance, if the distance between eRE/RE and eREC/REC is 10 km, then the propagation delay is roughly 50 µs, which is half of the end-to-end one-way latency budget of HPF data (6.2.3.1, 6.3.2.1).

The remaining delay components depend on the number of hops in the fronthaul bridged network, the traffic pattern, the bridge characteristics, etc., i.e., on the actual deployment. Therefore, a profile cannot specify the details related to the corresponding components. Thus, a guideline is given here for worst-case delay calculations for HPF.

The worst-case delay of a bridge (7.2) can be calculated for HPF data flows as shown by Equation (7-1), which includes self-queuing delay ($t_{SelfQueuing}$) calculated according to Equation (7-2) and queuing delay ($t_{Queuing}$) calculated according to Equation (7-3). HPF data flows are gold flows (7.2), hence MaxGoldFrameSize is the maximum frame size of HPF data. MaxLoFrameSize is the maximum of the frame size of all other flows that have lower priority than HPF data.

There is no queuing delay due to higher priority traffic if HPF data has the highest priority (8.1.2).

There is no queuing delay for HPF data due to bandwidth limitation as the data rate of each link of the fronthaul bridged network is large enough to carry the HPF data traffic considered during network design (see 7.2 and the introductory text of Clause 8).

The total worst-case end-to-end latency (t_e) for an HPF data information flow is the total propagation delay end-to-end plus the sum of the worst-case bridge delays along the path of the HPF data information flow as shown by Equation (8-1):

$$t_e = \sum t_{MaxBridge} + \sum t_{Propagation} \tag{8-1}$$

where

$t_{MaxBridge}$ is the worst-case latency of a bridge calculated according to Equation (7-1)
$t_{Propagation}$ is the propagation delay of a link [item d) in 7.1]

The buffer size of the traffic class of HPF data is configured at each egress bridge port according to the HPF data transmitted via the given port in one time window as per network and traffic design. Thus, there is enough buffer space to store interfering HPF data frames of a time window, but overflow of HPF data frames to the next time window is avoided in order to meet the latency requirements.

In order to avoid ingress traffic exceeding the amount considered during network design, flow metering (8.6.5 of IEEE Std 802.1Q-2018) with the MEF 10.3 bandwidth profile per traffic class is used at the ingress of the bridged network. Therefore, edge bridges of a fronthaul bridged network shall implement the MEF 10.3 token bucket bandwidth profile, which is configured such that excess HPF traffic is discarded in order to meet the HPF requirements. That is, the ingress HPF traffic is limited to the amount that is considered during network design, e.g., for worst-case delay calculations.

The network is configured to avoid starvation of MPF and LPF traffic taking into account their bandwidth requirements.[22] Furthermore, the bandwidth design is enforced with MEF 10.3 bandwidth profile per traffic class at the ingress of the bridged network. That is, bandwidth profile is configured to limit ingress HPF, MPF, and LPF traffic to the amount that is considered during network design. Excess HPF and MPF traffic is configured to be discarded in order to avoid starvation of LPF. Excess LPF traffic can be allowed. The bandwidth profile can be configured such that unused bandwidth assigned to HPF and MPF is available to lower priority traffic classes. That is, token sharing may be enabled from HPF and MPF to lower priority traffic classes (see Annex C in MEF 10.3). For instance, non-fronthaul traffic can use the bandwidth not used by fronthaul traffic.

NOTE—There are multiple orders of magnitude differences among the latency requirements of the different fronthaul traffic types, i.e., HPF, MPF, and LPF; see 6.3.2 and 6.3.3.

8.1.4 Meeting FLR targets

The fronthaul bridged network is configured and operated such that frame loss for fronthaul traffic does not occur due to congestion. Furthermore, the fronthaul bridged network is configured and operated such that the latency targets are met as described in 8.1.3.

The probability of frame loss due to bit errors during transmission on an Ethernet link is very small compared to the FLR tolerance requirements in 6.2.3.2 and 6.2.4.

8.2 Profile B

Profile B extends Profile A (8.1) with frame preemption (see 7.3) in order to decrease the effects of non-fronthaul traffic on fronthaul traffic, hence, it provides more flexibility with respect to non-fronthaul traffic that can be transported by the bridged network. Frame preemption can be useful to avoid restrictions on the maximum frame size of non-fronthaul flows (8.2.1). The benefits provided by frame preemption decrease as the data rate of a bridge port increases.

Profile B may be supported by the bridges of a fronthaul bridged network.

As Profile B is an extension of Profile A, 8.1 considerations also apply to Profile B with the extensions described in this subclause. Frame size considerations described in 8.1.1 are applied with the extensions described in 8.2.1. Traffic classes are configured as explained in 8.1.2. Frame preemption is configured as explained in 8.2.2. The latency considerations described in 8.1.3 are applicable to Profile B with the extensions described in 8.2.3. FLR considerations are applicable to Profile B as described in 8.1.4.

8.2.1 Frame size

The size of the Ethernet frames carrying fronthaul data can influence whether or not the fronthaul data requirements are met.

In the case of Profile B, the maximum frame size rules that apply to IEEE 802.3 frames are configured for fronthaul data, i.e., for HPF, MPF, and LPF as described in 8.1.1.

Frame preemption (7.3) is applied in Profile B for non-fronthaul traffic; therefore, the frame size of non-fronthaul traffic does not influence the latency of fronthaul traffic (see 8.2.3). Thus, no maximum frame size is specified for non-fronthaul data in Profile B.

[22] Low priority traffic classes can be starved of bandwidth in a strict priority system if there is no appropriate limit on the bandwidth that high priority traffic classes can get.

8.2.2 Configuration of frame preemption

In the case of Profile B, frame preemption (7.3) is configured to be enabled throughout the entire fronthaul bridged network for each port that supports both fronthaul and non-fronthaul data information flows. Furthermore, the smallest possible fragment size, i.e., 64 octets, is configured for frame preemption at each port supporting fronthaul data information flows. This decreases the effects of non-fronthaul traffic on fronthaul data traffic.

Fronthaul data traffic is configured as express traffic in order to decrease the effects of non-fronthaul traffic. That is, the *frame preemption status* is configured *express* for the priorities assigned to fronthaul data traffic, i.e., to HPF, MPF, and LPF at each bridge port that supports fronthaul data information flows. The *frame preemption status* can be configured via the *frame preemption status table* (see 12.30.1.1 of IEEE Std 802.1Q-2018). The default *frame preemption status* value is *express*.

8.2.3 Meeting latency targets

In order to meet the latency targets, traffic classes and frame preemption are configured as described in 8.1.2 and 8.2.2. The considerations explained in 8.1.3 apply to Profile B as well with the following extensions.

A benefit of frame preemption is that the queuing delay caused by non-fronthaul traffic to fronthaul traffic is reduced to 1240 bit times, i.e., 155 octet times due to the characteristics of frame preemption (7.3).

The worst-case queuing delay for HPF is as explained in 8.1.3 because MPF and LPF are not preemptable. That is, the total worst-case end-to-end latency for an HPF data information flow can be calculated according to Equation (8-1) as explained in 8.1.3. MEF 10.3 bandwidth profile per traffic class is used at the ingress of the bridged network in order to meet the latency targets of fronthaul traffic. Bandwidth profiles are configured as described in 8.1.3.

9. Synchronization solutions

This clause discusses how the time synchronization requirements (Category A+, A, B, and C) defined in 6.4.1 can be met using the methods described in 7.4.

A fronthaul bridged network used for time synchronization needs to provide adequate timing accuracy. Methods 7.4(a) and 7.4(b) use packet timing as specified by the ITU-T G.8275.1 telecom profile and Synchronous Ethernet as specified by ITU-T G.8261, G.8262, and G.8264. GNSS [7.4(c)], and other methods [7.4(d)] do not put any requirement on the fronthaul bridged network.

NOTE—Conformance requirements for bridge and end station support of synchronization are specified in Clause 5.

9.1 Solution for Category A+

The Category A+ requirement (6.4.1.1) can be met using packet timing with co-located common master at the eRE/REs [7.4(a)(2)], which implies that the eRE/REs are co-located.

NOTE—When distributing a synchronization reference from a local common synchronization master, it is important that the Time Error (TE) between different ports of the master is limited when the end stations are connected to different ports of the master. In particular, in the case of ITU-T G.8273.2 clocks, potential constant TE is possible up to the limit specified for the ITU-T G.8273.2 clock types (e.g., ±20 ns for a Class B clock) when different physical interfaces are used. That is, an ITU-T G.8273.2 clock could be used for this application only if this source of error (caused by the difference of TE by different ports of the master) is controlled or if the same interface can be used to connect multiple end nodes (e.g., by splitting the 1 PPS output signal). The dynamic generation can be in general higher than 10 ns (e.g., 70 ns high-frequency noise) according to ITU-T G.8273.2. However, any expected high-frequency noise can be filtered by the end stations so it should not matter. Low-frequency noise is expected to be almost the same on all interfaces, therefore, it does not contribute to the relative TE.

9.2 Solutions for Category A

Category A requirements (6.4.1.2) can be met using the packet timing method with point-to-point synchronization distribution [7.4(a)(1)]. Accurate control of the link propagation delay asymmetries in the nanoseconds range is required (e.g., resulting from the use of different wavelengths in optical transmission). Category A requirements can also be met using the packet timing method with a common master co-located with the eRE/REs [7.4(a)(2)], which implies that the eRE/REs are co-located.

9.3 Solutions for Category B

Category B requirements (6.4.1.3) can be met using the packet timing method with point-to-point synchronization distribution [7.4(a)(1)], with a common master co-located with the eRE/REs [7.4(a)(2)] (where the eRE/REs are co-located), and with timing distribution to a cluster of eRE/REs from the nearest common master / boundary clock [7.4(a)(3)].

Category B requirements can also be met when the eRE/REs implement GNSS as per ITU-T G.8272 [7.4(c)]. Appropriate antenna installation and cabling are important in order to meet the time synchronization requirements; see ITU-T G.8272 for further information on factors influencing the performance of a GNSS-based PRTC.

9.4 Solutions for Category C

Category C requirements (6.4.1.4) can be met by all methods described in 7.4 assuming that the timing reference is traceable to an internationally recognized master, e.g., GNSS.

Annex A

(normative)

PCS proforma—Time-sensitive networking for Fronthaul Profiles[23]

A.1 Introduction

The supplier of an implementation that is claimed to conform to a particular profile defined in this standard shall complete the corresponding Profile Conformance Statement (PCS) proforma, which is presented in a tabular format based on the format used for Protocol Implementation Conformance Statement (PICS) proformas.

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 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 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

[23] *Copyright release for PCS proformas:* Users of this standard may freely reproduce the PCS proforma in this annex so that it can be used for its intended purpose and may further publish the completed PCS.

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	Protocol 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 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—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 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 standard.

NOTE—A possible reason for the situation described previously is that a defect in this 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.3.4.3 References to other standards

The following shorthand notation is used in the References columns of the profile tables:

<standard abbreviation>:<clause-number>

where standard abbreviation is one of the following:

Q	IEEE Std 802.1Q
Dot3	IEEE Std 802.3

Hence, a reference to “5.4.1 of IEEE Std 802.1Q” would be abbreviated to “Q:5.4.1”.

A.4 Implementation identification

Supplier	
Contact point for queries about the PCS	
Implementation Name(s) and Version(s)	
Other information necessary for full identification, e.g., name(s) and version(s) of machines and/or operating system names	

Only the first three items are required for all implementations; other information may be completed as appropriate in meeting the requirement for full identification.

NOTE—The terms “Name” and “Version” should be interpreted appropriately to correspond with a supplier’s terminology (e.g., Type, Series, Model).

A.5 Profile summary, IEEE Std 802.1CM

Identification of profile specification	IEEE Std 802.1CM-2018, IEEE Standard for Local and metropolitan area networks—Time-Sensitive Networking for Fronthaul	
Identification of amendments and corrigenda to the PCS proforma that have been completed as part of the PCS	Amd.: Amd.:	Corr.: Corr.:
Have any Exception items been required? (See A.3.3: the answer "Yes" means that the implementation does not conform to IEEE Std 802.1CM)	No [ ]	Yes [ ]

Date of statement

A.6 Implementation type

This table is used to indicate the type of implementation that the PCS describes.

Item	Feature	Status	References	Support
BGE	Is the implementation a bridge?	O.1	A.7	Yes [ ] No [ ]
EST	Is the implementation an end station?	O.1	A.8	Yes [ ] No [ ]

A.7 Bridge requirements

A.7.1 MACs

Item	Feature	Status	References	Support
MAC	Do the implementations of MAC technologies and support of the MAC Internal Sublayer Service (ISS) conform to MAC standards as specified in IEEE Std 802.1AC?	M	IEEE Std 802.1AC, Q:5.4: a), 5.3.1: a)	Yes [ ]
Dot3	Do one or more ports of the bridge support an IEEE 802.3 MAC?	M	Dot3, 5.3.1: b)	Yes [ ]
Dot3-1	Do all the IEEE 802.3 ports support full duplex operation?	Dot3:M	Dot3, 5.3.1: b)	Yes [ ]
Dot3-2	Do all the IEEE 802.3 ports support a data rate of 1 Gbps or more?	Dot3:M	Dot3, 5.3.1: b)	Yes [ ]
Dot3-3	State the number of IEEE 802.3 ports that support a data rate of 1 Gbps	Dot3:O.2	Dot3, 5.3.1: b)	Number ____[a]
Dot3-4	State the number of IEEE 802.3 ports that support a data rate of 10 Gbps	Dot3:O.2	Dot3, 5.3.1: b)	Number ____
Dot3-5	State the number of IEEE 802.3 ports that support a data rate higher than 10 Gbps	Dot3:O.2	Dot3, 5.3.1: b)	Number ____
Dot3-6	Is the configuration of the maximum size MAC PDUs to 2000 octets supported on each port?	Dot3:M	Dot3, 5.3.1: c), 8.1.1, 8.2.1	Yes [ ]
Dot3-7	Is MAC control PAUSE operation configurable to be disabled on each IEEE 802.3 port that implements it?	Dot3:M	Dot3, 5.3.1: d), 7.5	Yes [ ] N/A [ ]
Dot3-8	Is the port configurable not to assert LPI if the port supports EEE?	Dot3:M	Dot3, 5.3.1: e), 7.6	Yes [ ] N/A [ ]
Dot3-9	Do all the 1 Gbps IEEE 802.3 ports support Interspersing Express Traffic?	Dot3:O	Dot3, 5.4.1: b), 7.3, 8.2	Yes [ ] No [ ] N/A [ ]
Dot3-10	Do all the 10 Gbps IEEE 802.3 ports support Interspersing Express Traffic?	Dot3:O	Dot3, 5.4.1: b), 7.3, 8.2	Yes [ ] No [ ] N/A [ ]

[a]Where an IEEE 802.3 MAC can support multiple data rates, the number of ports is reported against the highest data rate supported.

A.7.2 IEEE Std 802.1Q requirements—bridges

Item	Feature	Status	References	Support
B-Q-1	Does the bridge support VLAN Bridge component requirements a) through f)?	M	Q:5.4, 5.3.1: f)	Yes [ ]
B-Q-2	Does the bridge support an active topology enforcement mechanism?	M	Q:5.4, 5.3.1: g)	Yes [ ]
B-Q-3	Does the bridge support RSTP?	O	Q:5.4, 5.3.1: h)	Yes [ ] No [ ]
B-Q-4	Does the bridge support VLAN Bridge component requirements g) and h) if RSTP is supported?	B-Q-3:M	Q:5.4, 5.3.1: h)	Yes [ ] N/A [ ]
B-Q-5	Does the bridge support VLAN Bridge component requirements i) through n)?	M	Q:5.4, 5.3.1: i)	Yes [ ]
B-Q-6	Does the bridge support the Acceptable Frame Types parameter value of *Admit All frames* on each port?	M	Q:5.4, 5.3.1: j)	Yes [ ]
B-Q-7	Does the bridge support the use of at least one VID?	M	Q:5.4, 5.3.1: k)	Yes [ ]
B-Q-8	Does the bridge support VLAN Bridge component requirements p) through r)?	M	Q:5.4, 5.3.1: l)	Yes [ ]
B-Q-9	If only a single FID is supported, does the bridge support the ability to allocate the PVID and all other VIDs to that single FID?	M	Q:5.4, 5.3.1: m)	Yes [ ] N/A [ ]
B-Q-10	Does the bridge support at least three traffic classes on all ports?	M	Q:8.6.6, 5.3.1: n), 8.1.2	Yes [ ]
B-Q-11	Does the bridge support the strict priority algorithm for transmission selection on each port?	M	Q:8.6.8.1, 5.3.1: o), 8.1.2	Yes [ ]
B-Q-12	Does the bridge support flow metering with the token bucket bandwidth profile specified in MEF 10.3?	M	Q:8.6.5, MEF 10.3 5.3.1: p), 8.1.3	Yes [ ]
B-Q-13	Does the bridge support token sharing with the bandwidth profile specified in MEF 10.3?	O	Q:8.6.5, MEF 10.3 5.4: a), 8.1.3	Yes [ ] No [ ]
B-Q-14	Is Priority-based flow control operation configurable to be disabled if it is implemented?	M	Q:36 5.3.1: q), 7.5	Yes [ ] N/A [ ]

A.7.2 IEEE Std 802.1Q requirements—bridges *(continued)*

Item	Feature	Status	References	Support
B-Q-15	Do all the 1 Gbps IEEE 802.3 ports support frame preemption?	O	Q:5.4.1, 5.4.1: b), 8.2.2	Yes [ ] No [ ] N/A [ ]
B-Q-16	Do all the 10 Gbps IEEE 802.3 ports support frame preemption?	O	Q:5.4.1, 5.4.1: b), 8.2.2	Yes [ ] No [ ] N/A [ ]
B-Q-17	Does the bridge support untagged frames on all ports?	B-S-1:M	5.4.2: a)	Yes [ ] N/A [ ]

A.7.3 Profile A requirements

Item	Feature	Status	References	Support
PA	Does the bridge support Profile A?	M	5.3.2, 8.1	Yes [ ]

A.7.4 Profile B requirements

Item	Feature	Status	References	Support
PB	Does the bridge support Profile B?	O	5.4: b), 8.2	Yes [ ] No [ ]
PB-1	Do the bridge ports whose data rate is not higher than 10 Gbps support Interspersing Express Traffic and Frame Preemption?	PB:M	Dot3, 5.4.1: b), 8.2.2	Yes [ ] N/A [ ]
PB-2	Is the configuration of 64-octet fragment size supported for Interspersing Express Traffic at each port for which Interspersing Express Traffic is enabled?	PB:M	Dot3, 5.4.1: b), 8.2.2	Yes [ ] N/A [ ]

A.7.5 Synchronization requirements—bridges

Item	Feature	Status	References	Support
B-S-1	Does the bridge support synchronization?	O	5.4: c)	Yes [ ] No [ ]
B-S-2	Does the bridge support the ITU-T G.8275.1 telecom profile (full timing support from the network)?	B-S-1:M	5.4.2: b), 7.4, 9	Yes [ ] N/A [ ]
B-S-3	Does the bridge support Telecom-Boundary Clock (ITU-T G.8273.2)?	B-S-2:O.3	5.4.2: b)1), 7.4, 9	Yes [ ] No [ ] N/A [ ]
B-S-4	Does the bridge support Telecom-Transparent Clock (ITU-T G.8273.3)?	B-S-2:O.3	5.4.2: b)2), 7.4, 9	Yes [ ] No [ ] N/A [ ]
B-S-5	Does the bridge support Primary Reference Time Clock and Grandmaster functionality (ITU-T G.8272 or ITU-T G.8272.1)?	B-S-2:O.3	5.4.2: b)3), 7.4, 9	Yes [ ] No [ ] N/A [ ]
B-S-6	Does the bridge support Synchronous Ethernet functions (ITU-T G.8264) including the ESMC?	B-S-1:M	5.4: c), 5.4.2: c), 7.4, 9	Yes [ ] N/A [ ]
B-S-7	Does the bridge support Synchronous Ethernet slave clock (ITU-T G.8262)?	B-S-6:M	5.4.2: c)c), 7.4, 9	Yes [ ] N/A [ ]

A.8 End station requirements

A.8.1 IEEE Std 802.1Q requirements—end stations

Item	Feature	Status	References	Support
E-Q-1	Does the end station support untagged frames on all ports?	E-S-1:M	Q:3.249, 5.6, 5.6.1: a), Clause 8	Yes [ ] No [ ]
E-Q-2	Does the end station support priority-tagged frames on all ports?	O.5	Q:3.158, 5.5: a), Clause 8	Yes [ ] No [ ]
E-Q-3	Does the end station support VLAN-tagged frames on all ports?	O:5	Q:9, 5.5: a), Clause 8	Yes [ ] No [ ]
E-Q-4	Does the end station support at least three traffic classes on all ports?	M	Q:3.239, 5.5: b), Clause 8	Yes [ ]

A.8.2 Synchronization requirements—end stations

Item	Feature	Status	References	Support
E-S-1	Does the end station support time synchronization	O	5.6: a), 7.4, 9	Yes [ ] No [ ]
E-S-2	Does the end station support the ITU-T G.8275.1 telecom profile (full timing support from the network)?	E-S-1:M	5.6, 5.6.1: b), 7.4, 9	Yes [ ] No [ ]
E-S-3	Does the end station support Telecom-Time Slave Clock (ITU-T G.8273.2)?	E-S-2:O.6	5.6.1: b)1), 7.4, 9	Yes [ ] No [ ] N/A [ ]
E-S-4	Does the end station support Primary Reference Time Clock functionality (ITU-T G.8272 or ITU-T G.8272.1)[a]?	E-S-2:O.6	5.6.1: b)2), 7.4, 9	Yes [ ] No [ ] N/A [ ]
E-S-5	Does the end station support PRTC and Telecom Grandmaster functionality (ITU-T G.8272)?	E-S-2:O.6	5.6.1: b)3), 7.4, 9	Yes [ ] No [ ] N/A [ ]
E-S-6	Does the end station support Synchronous Ethernet functions (ITU-T G.8264) including the ESMC?	O	5.6: b), 7.4, 9	Yes [ ] No [ ]
E-S-7	Does the end station support Synchronous Ethernet slave clock (ITU-T G.8262)?	E-S-6:M	5.6: b), 7.4, 9	Yes [ ] No [ ] N/A [ ]

[a]An end station can support PRTC without ITU-T G.8275.1.

Annex B

(informative)

Delay calculation examples

B.1 Self-queuing delay

The delay of a frame due to other frames belonging to the same traffic class is referred to as self-queuing delay ($t_{SelfQueuing}$) in this document [see also item g) in 7.1]. The self-queuing delay is discussed in this subclause via a generic example, which is also illustrated in the figures. Frames b, e, and h are received at port 1, frames c and f are received at port 2, and frames a, d, g, and i are received at port 3 of bridges 282 and 373. All frames are transmitted by port 4. Each flow is a periodic Constant Bit Rate (CBR) flow with the same time window, which is 1 s. All the arriving frames shown in each figure are in the same time window. The payload of each frame of each flow is 1500 octets. Frames i and g belong to the same flow, i.e., the given flow includes two frames in a time window. All the rest of the flows include a single frame in one time window. The data rate of each port is the same, i.e., 10 Gbps. The frames arrive in a burst at each ingress port and the bursts arrive at more or less the same time. Bridges 282 and 373 receive the frames in alphabetical order. The transmission order depends on bridge implementation and how race conditions are resolved among frames, as discussed in the following. We observe frame h.

If there were no frames arriving either at port 2 or at port 3, then frame h would be transmitted with no self-queuing delay, i.e., frames b and e do not cause self-queuing delay for frame h because frames b and e are transmitted before frame h is received.

A bridge implementation is likely to aim for fairness within a traffic class, e.g., a bridge implementation can assure that the frames destined to the same egress port are transmitted in the reception order. Bridge 282 provides that assurance, therefore, the example frames are transmitted in alphabetical order as illustrated in Figure B-1. Five frames can then cause self-queuing delay for frame h in the worst case. Both frames that are received at port 2, i.e., frames c and f can be transmitted before frame h. Furthermore, all frames received at port 3 before frame h, i.e., frames a, d, and g, can be also transmitted before frame h.

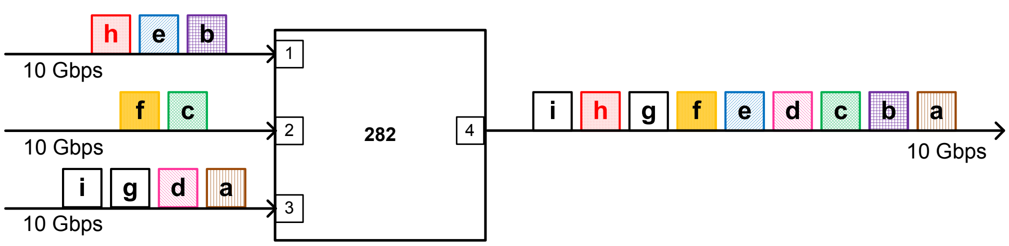

Figure B-1—Self-queuing in case of assured time order among ports

The order of transmission for frames received at the same port is specified by IEEE Std 802.1Q (see 8.6.6 of IEEE Std 802.1Q-2018). However, IEEE Std 802.1Q does not specify the order of transmission for frames received at different ports; it is implementation specific. Without such guarantee, it can happen that even frame i is transmitted before frame h as shown in Figure B-2, i.e., six frames can cause self-queuing delay. That is, each frame of bursts received at more or less the same time at different ingress ports than the observed frame and destined to the same egress port can cause self-queuing delay for the observed frame in the absolute worst case, which is taken into account in Equation (7-2).

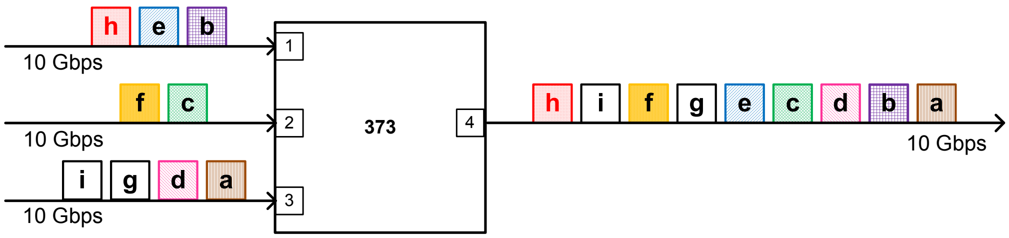

Figure B-2—Self-queuing in case of non-guaranteed order among ports

Fan-in refers to the situation when frames belonging to the same traffic class and destined to the same egress port arrive at different ingress ports more or less the same time, see also Annex L.3 of IEEE Std 802.1Q-2018. Figure B-3 illustrates fan-in situations, e.g., among frames, b, c, and a. In Figure B-3, frame c gets queued and transmitted first, then frame b; frame a is transmitted last out of these three frames. Frames e, f, and d are also in a fan-in situation, as are frames h and g. Figure B-3 illustrates an example when bridge 282 guarantees that a given frame is transmitted earlier than a frame received later than the given frame; whereas, Figure B-4 illustrates and example where bridge 373 does not provide such guarantee.

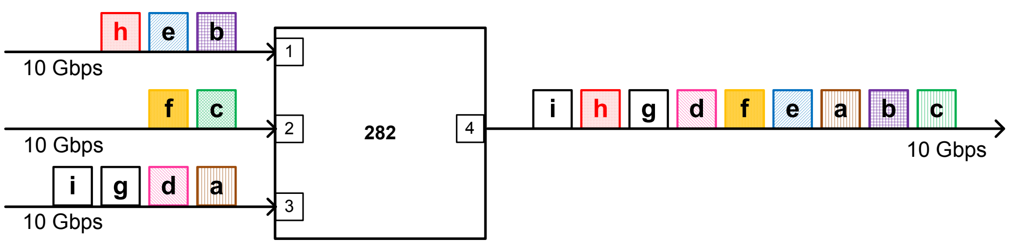

Figure B-3—Fan-in

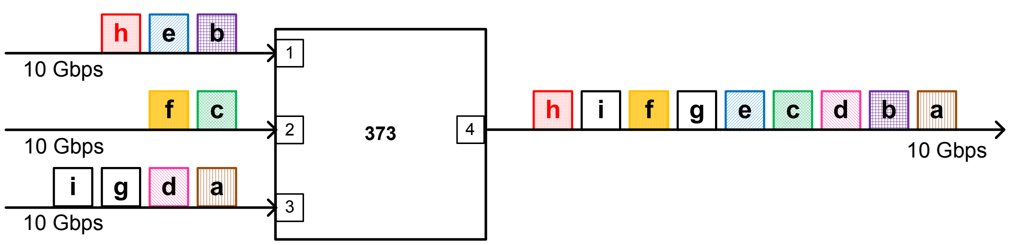

Figure B-4—Fan-in with non-guaranteed order among ports

As the figures illustrate, it is simpler to take fan-in situations into account as part of self-queuing than handling them separately when calculating the worst-case delay, see. e.g., Figure B-4 versus Figure B-2.

B.2 Example network with data flows

A generic example network and generic data flow examples are shown in Figure B-5. Each talker (T) sends data to its corresponding listener (L). T_1 has only one high priority data flow to L_1(illustrated by the solid red line), whereas all other talkers have two high priority data flows, which are illustrated by dashed and dotted lines. Each talker also has a low priority data flow to its listener.

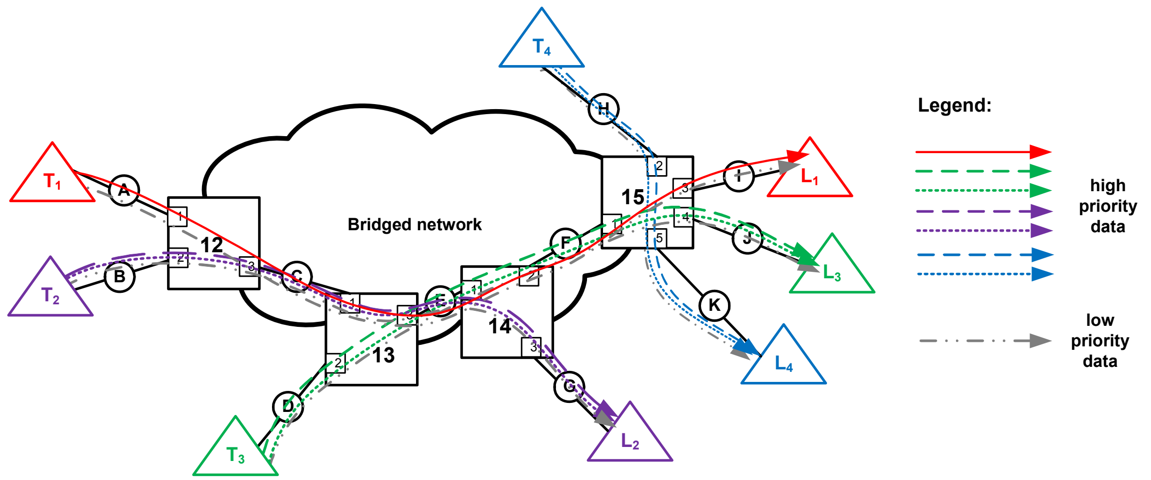

Figure B-5—Data flow example

The distance between T_1 and L_1 is the largest in terms of the number of hops, hence, this path has the worst-case latency. Therefore, the delay sensitive data flow from T_1 to L_1 is discussed in the following.

For the following analysis, the maximum data payload, i.e., 1500 octets, is chosen for each data frame, which is tagged with IEEE 802.1Q C-VLAN tag. Therefore, the frame size is 1522 octets (8.1.1) for both high and low priority data flows.

Each link is point-to-point with 10 Gbps data rate.

The worst-case store-and-forward delay (t_{SF}) is assumed to be 5 µs for each bridge in this example.

The data rate is 1.5 Gbps for each data flow in the example discussed here.

Analysis of this example is found in B.2.1.

B.2.1 Application of Profile A

Strict priority is used in Profile A (8.1). The worst-case bridge delay ($t_{MaxBridge}$) for the high priority data can be determined according to Equation (7-1) as described in 7.2.

Equation (7-1) and Equation (7-2) use $t_{MaxGoldFrameSize+Pre+SFD+IPG}$ (7.2), which is the same for each bridge in the example. It is the transmission time of 1542 octets (t_{1542}), which is 1.2336 µs for a 10 Gbps link.

The self-queuing delay ($t_{SelfQueuing}$) varies bridge by bridge as explained in the following.

Based on Equation (7-2), $t^{12}_{SelfQueuing} = 2 \times t_{1542} = 2.4672$ µs for bridge 12, because high priority data destined to port 3 arrive at two ports, ports 1 and 2, and both frames received at port 2 can delay the frame received at port 1 as illustrated in Figure B-6. (See the explanation of Figure B-2 for another example illustrating the effect.)

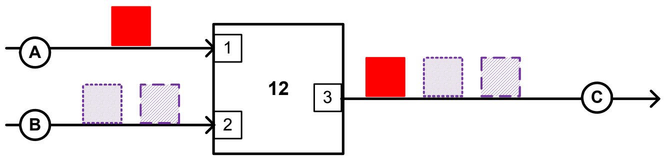

Figure B-6—Self-queuing in bridge 12

The self-queuing delay of bridge 13 is $t^{13}_{SelfQueuing} = 2 \times t_{1542} = 2.4672$ µs because both green frames received at port 2 can be transmitted by port 3 before the red frame received at port 1, as illustrated in Figure B-7.

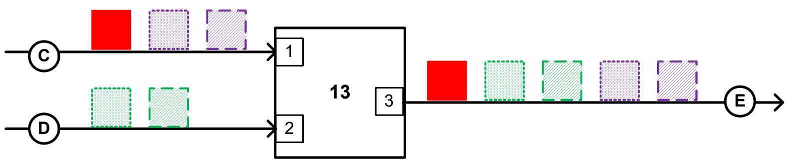

Figure B-7—Self-queuing in bridge 13

There is no self-queuing in bridge 14 because it has only one ingress port, i.e., $t^{14}_{SelfQueuing} = 0$.

Only one high priority data flow is destined to each egress port in bridge 15; therefore, there is no self-queuing, i.e., $t^{15}_{SelfQeueing} = 0$.

The queuing delay corresponds to the maximum frame size of low priority traffic (MaxLoFrameSize in 7.2), which is 1522 octets, thus $t_{Queuing} = t_{1522+Pre+SFD+IPG} = 1.2336$ µs.

The worst-case bridge delays ($t_{MaxBridge}$) are summarized in Table B-1.

Table B-1—Bridge delays for Profile A

	Bridge 12	Bridge 13	Bridge 14	Bridge 15	Total
$t_{MaxBridge}$	9.9344 µs	9.9344 µs	7.4672 µs	7.4672 µs	34.8032 µs

If the end-to-end latency budget is 100 µs for the high priority data (e.g., 6.2.3), then the total propagation delay, of links C, E, and F, can be 65.1968 µs, i.e., the distance between port 1 of bridge 12 connected to T_1 and port 3 of bridge 15 connected to L_1 can be approximately 13 km.

Annex C

(informative)

Bibliography

[B1] 3GPP Technical Specification (TS) 36.104, Evolved Universal Terrestrial Radio Access (E-UTRA); Base station (BS) radio transmission and reception.[24]

[B2] 3GPP Technical Specification (TS) 36.133, Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements for support of radio resource management.

[B3] 3GPP Technical Specification (TS) 36.211, Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation.

[B4] Common Public Radio Interface Specification, Version 7.0 (Interface Specification).[25]

[B5] Common Public Radio Interface: eCPRI Interface Specification, Version 1.1 (Interface Specification).

[B6] Common Public Radio Interface: Requirements for the eCPRI Transport Network, Version 1.1 (Requirements Specification).

[B7] CPRI functional decomposition requirements (CPRI Technical Working Group contribution).[26]

[B8] IETF RFC 768, User Datagram Protocol, August 1980; https://tools.ietf.org/html/rfc768.

[B9] IETF RFC 793, Transmission Control Protocol, September 1981; https://tools.ietf.org/html/rfc793.

[B10] IETF RFC 4960, Stream Control Transmission Protocol, September 2007; https://tools.ietf.org/html/rfc4960.

[B11] ISO/IEC 7498:1994, Information technology—Open Systems Interconnection—Basic Reference Model: The basic model.[27]

[B12] ITU-T G.8260, Definitions and terminology for synchronization in packet networks.[28]

[B13] ITU-T G.8261.1, Packet delay variation network limits applicable to packet-based methods (Frequency synchronization).

[B14] ITU-T G.827, Availability performance parameters and objectives for end-to-end international constant bit-rate digital paths.

[B15] ITU-T G.8271.2, Network limits for time synchronization in packet networks with partial timing support from the network.

[24]3GPP specifications are available at http://www.3gpp.org/.

[25]Common Public Radio Interface specifications are available at http://www.cpri.info/spec.html.

[26]Available at http://www.ieee802.org/1/files/public/docs2016/cm-CPRI-functional-decomposition-requirements-0516-v01.pdf.

[27]ISO publications are available from the International Organization for Standardization (https://www.iso.org/). IEC publications are available from the International Electrotechnical Commission (http://www.iec.ch). ISO/IEC publications are available from the American National Standards Institute (https://www.ansi.org/).

[28]ITU-T publications are available from the International Telecommunications Union (https://www.itu.int/).

[B16] ITU-T G.8275, Architecture and requirements for packet-based time and phase distribution.

[B17] ITU-T G.8275.2, Precision time protocol telecom profile for time/phase synchronization with partial timing support from the network.

[B18] ITU-T Y.1563, Ethernet frame transfer and availability performance.

[B19] MEF 22.3, Implementation Agreement—Transport Services for Mobile Networks.[29]

[29]MEF documents available at https://www.mef.net/.

Consensus

WE BUILD IT.

IEEE
standards.ieee.org
Phone: +1 732 981 0060 Fax: +1 732 562 1571