International Standard

ISO/IEC/IEEE 8802-1Q

Telecommunications and exchange between information technology systems — Requirements for local and metropolitan area networks —

Part 1Q: Bridges and bridged networks

Télécommunications et échange entre systèmes informatiques — Exigences pour les réseaux locaux et métropolitains —

Partie 1Q: Ponts et réseaux pontés

Third edition
2024-08

Reference number
ISO/IEC/IEEE 8802-1Q:2024(en)

© IEEE 2022



COPYRIGHT PROTECTED DOCUMENT

© IEEE 2022
All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from IEEE at the address below.

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

Email: stds.ipr@ieee.org
Website: www.ieee.org

Published in Switzerland

Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives or www.iec.ch/members_experts/refdocs).

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. The IEEE develops its standards through a consensus development process, approved by the American National Standards Institute, which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and serve without compensation. While the IEEE administers the process and establishes rules to promote fairness in the consensus development process, the IEEE does not independently evaluate, test, or verify the accuracy of any of the information contained in its standards.

ISO and IEC draw attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO and IEC take no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO and IEC had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents and https://patents.iec.ch. ISO and IEC shall not be held responsible for identifying any or all such patent rights.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html. In the IEC, see www.iec.ch/understanding-standards.

ISO/IEC/IEEE 8802-1Q was prepared by the LAN/MAN of the IEEE Computer Society (as IEEE Std 802.1Q-2022) and drafted in accordance with its editorial rules. It was adopted, under the “fast-track procedure” defined in the Partner Standards Development Organization cooperation agreement between ISO and IEEE, by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 6, *Telecommunications and information exchange between systems*.

This third edition cancels and replaces the second edition (ISO/IEC/IEEE 8802-1Q:2020), which has been technically revised. It also incorporates the Amendments: ISO/IEC/IEEE 8802-1Q:2020/Amd 2:2021, ISO/IEC/IEEE 8802-1Q:2020/Amd 3:2021, ISO/IEC/IEEE 8802-1Q:2020/Amd 31:2021.

A list of all parts in the ISO/IEC/IEEE 8802 series can be found on the ISO and IEC websites.

© IEEE 2022 – All rights reserved

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html and www.iec.ch/national-committees.

© IEEE 2022 – All rights reserved

IEEE Std 802.1Q™-2022
(Revision of IEEE Std 802.1Q-2018)

IEEE Standard for Local and metropolitan area networks—

Bridges and Bridged Networks

LAN/MAN Standards Committee
of the
IEEE Computer Society

Approved 21 September 2022

IEEE SA Standards Board

Abstract: This standard specifies how the Media Access Control (MAC) Service is supported by Bridged Networks, the principles of operation of those networks, and the operation of MAC Bridges and VLAN Bridges, including management, protocols, and algorithms.

Keywords: Bridged Network, IEEE 802.1Q™, LAN, local area network, MAC Bridge, metropolitan area network, MSTP, Multiple Spanning Tree Protocol, PBN, Provider Bridged Network, Rapid Spanning Tree Protocol, RSTP, Shortest Path Bridging Protocol, SPB Protocol, Time-Sensitive Networking, TSN, Virtual Bridged Network, virtual LAN, VLAN Bridge

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

Copyright © 2022 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 22 December 2022. Printed in the United States of America.

IEEE and 802 are registered trademarks in the U.S. Patent & Trademark Office, owned by the Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 978-1-5044-9188-4 STD25783
Print: ISBN 978-1-5044-9189-1 STDPD25783

IEEE prohibits discrimination, harassment, and bullying.
For more information, visit http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html.
No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Copyright © 2022 IEEE. All rights reserved.

Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE Standards documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page (https://standards.ieee.org/ipr/disclaimers.html), appear in all standards and may be found under the heading “Important Notices and Disclaimers Concerning IEEE Standards Documents.”

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

IEEE Standards documents are developed within IEEE Societies and subcommittees of IEEE Standards Association (IEEE SA) Board of Governors. IEEE develops its standards through an accredited consensus development process, which brings together volunteers representing varied viewpoints and interests to achieve the final product. IEEE Standards are documents developed by volunteers with scientific, academic, and industry-based expertise in technical working groups. Volunteers are not necessarily members of IEEE or IEEE SA 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 makes no warranties or representations concerning its standards, and expressly disclaims all warranties, express or implied, concerning this standard, including but not limited to the warranties of merchantability, fitness for a particular purpose and non-infringement. In addition, IEEE does not warrant or represent that the use of the material contained in its standards is free from patent infringement. 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: THE NEED TO PROCURE 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.

Copyright © 2022 IEEE. All rights reserved.

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 is 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, nor 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 the presenter's views should be considered the personal views of that individual rather than the formal position of IEEE, IEEE SA, the Standards Committee, or the Working Group. Statements made by volunteers may not represent the formal position of their employer(s) or affiliation(s).

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE or IEEE SA. However, **IEEE does not provide interpretations, 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 subcommittees of the IEEE SA Board of Governors 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 evaluating comments or in revisions to an IEEE standard is welcome to join the relevant IEEE working group. You can indicate interest in a working group using the Interests tab in the Manage Profile & Interests area of the IEEE SA myProject system.[1] An IEEE Account is needed to access the application.

Comments on standards should be submitted using the Contact Us form.[2]

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 constitute 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.

Data privacy

Users of IEEE Standards documents should evaluate the standards for considerations of data privacy and data ownership in the context of assessing and using the standards in compliance with applicable laws and regulations.

---

[1] Available at: https://development.standards.ieee.org/myproject-web/public/view.html#landing.

[2] Available at: https://standards.ieee.org/content/ieee-standards/en/about/contact/index.html.

Copyright © 2022 IEEE. All rights reserved.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under US 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, neither IEEE nor its licensors waive any rights in copyright to the documents.

Photocopies

Subject to payment of the appropriate licensing fees, 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; https://www.copyright.com/. 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. An official 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 10 years. When a document is more than 10 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 IEEE Xplore or contact IEEE.[3] For more information about the IEEE SA or IEEE's standards development process, visit the IEEE SA Website.

Errata

Errata, if any, for all IEEE standards can be accessed on the IEEE SA Website.[4] Search for standard number and year of approval to access the web page of the published standard. Errata links are located under the Additional Resources Details section. Errata are also available in IEEE Xplore. Users are encouraged to periodically check for errata.

Patents

IEEE Standards are developed in compliance with the IEEE SA Patent Policy.[5]

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

[3] Available at: https://ieeexplore.ieee.org/browse/standards/collection/ieee.

[4] Available at: https://standards.ieee.org/standard/index.html.

[5] Available at: https://standards.ieee.org/about/sasb/patcom/materials.html.

Copyright © 2022 IEEE. All rights reserved.

filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE SA Website at https://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.

IMPORTANT NOTICE

IEEE Standards do not guarantee or ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. IEEE Standards development activities consider research and information presented to the standards development group in developing any safety recommendations. Other information about safety practices, changes in technology or technology implementation, or impact by peripheral systems also may be pertinent to safety considerations during implementation of the standard. 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.

Copyright © 2022 IEEE. All rights reserved.

Participants

At the time this standard was submitted to the IEEE-SA Standards Board for approval, the IEEE 802.1 Working Group had the following membership:

Glenn Parsons, *Chair*
Jessy V. Rouyer, *Vice Chair*
John Messenger, *Editor*
Mick Seaman, *Editor*

Astrit Ademaj
Venkat Arunarthi
Ralf Assmann
Huajie Bao
Rudy Belliardi
Christian Boiger
Paul Bottorff
Radhakrishna Canchi
Feng Chen
Abhijit Choudhury
Paul Congdon
Rodney Cummings
Josef Dorr
Hesham M. Elbakoury
Anna Engelmann
Thomas Enzinger
János Farkas
Donald W. Fedyk
Norman Finn
Geoffrey Garner
Amrit Gopal
Craig Gunther
Marina Gutierrez
Stephen Haddock
Mark Hantel
Jerome Henry
Marc Holness
Daniel Hopf
Woojung Huh
Satoko Itaya
Yoshihiro Ito
Michael Karl
Stephan Kehrer
Randy Kelsey
Marcel Kiessling
Gavin Lai
Joao Lopes
Lily Lv
Christophe Mangin
Scott Mansfield
Olaf Mater
David McCall
Larry McMillan
Hiroki Nakano
Don Pannell
Razvan Petre
Michael Potts
Dieter Proell
Karen Randall
Maximilian Riegel
Silvana Rodrigues
Atsushi Sato
Frank Schewe
Maik Seewald
Ramesh Sivakolundu
Johannes Specht
Marius Stanica
Guenter Steindl
Nemanja Stamenic
Karim Traore
Max Turner
Balazs Varga
Ganesh Venkatesan
Xinyuan Wang
Tongtong Wang
Karl Weber
Leon Wessels
Ludwig Winkel
Jordon Woods
Takahiro Yamaura
Yue Yin
Uwe Zeier
Nader Zein
William Zhao
Helge Zinner

Copyright © 2022 IEEE. All rights reserved.

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

Robert Aiello
Thomas Alexander
Harry Bims
Christian Boiger
Rich Boyer
Vern Brethour
William Byrd
Paul Cardinal
Juan Carreon
Pin Chang
Diego Chiozzi
Paul Congdon
Michael Cowan
János Farkas
Avraham Freedman
Craig Gunther
Stephen Haddock
Mark Hantel
Jerome Henry
Marco Hernandez
Werner Hoelzl
Oliver Holland
Marc Holness
Yoshihiro Ito
Raj Jain
Pranav Jha
Lokesh Kabra
Piotr Karocki
Stephan Kehrer
Randy Kelsey
Stuart Kerry
Evgeny Khorov
Yongbum Kim
Jeff Koftinoff
Gavin Lai
Hyeong Ho Lee
James Lepp
Joseph Levy
Christophe Mangin
Scott Mansfield
Roger Marks
Stephen McCann
Jonathon Mclendon
Satoshi Obara
Glenn Parsons
Arumugam Paventhan
Clinton Powell
Dieter Proell
R. K. Rannow
Alon Regev
Maximilian Riegel
Jessy V. Rouyer
Peter Saunderson
Frank Schewe
Mick Seaman
Johannes Specht
Guenter Steindl
Eugene Stoudenmire
Walter Struppler
Mitsutoshi Sugawara
Bo Sun
David Tepen
David Tremblay
Max Turner
John Vergis
Stephen Webb
Karl Weber
Scott Willy
Andreas Wolf
Dayin Xu
Yu Yuan
Oren Yuen

When the IEEE SA Standards Board approved this standard on 21 September 2022, it had the following membership:

David J. Law, *Chair*
Ted Burse, *Vice Chair*
Gary Hoffman, *Past Chair*
Konstantinos Karachalios, *Secretary*

Edward A. Addy
Ramy Ahmed Fathy
J. Travis Griffith
Guido R. Hiertz
Yousef Kimiagar
Joseph L. Koepfinger*
Thomas Koshy
John D. Kulick
Johnny Daozhuang Lin
Kevin Lu
Daleep C. Mohla
Andrew Myles
Damir Novosel
Annette D. Reilly
Robby Robson
Jon Walter Rosdahl
Mark Siira
Dorothy V. Stanley
Lei Wang
F. Keith Waters
Karl Weber
Sha Wei
Philip B. Winston
Daidi Zhong

*Member Emeritus

Copyright © 2022 IEEE. All rights reserved.

Historical participants

Since the initial publication, many IEEE standards have added functionality or provided updates to material included in this standard. The following is a historical list of participants who have dedicated their valuable time, energy, and knowledge to the creation of this material:

IEEE 802.1Q Standard	Date approved by IEEE	Officers at the time of Working Group Ballot
IEEE Std 802.1Q-1998	8 December 1998	**William P. Lidinsky**, *Chair* **Mick Seaman**, *Chair, Interworking Task Group* **Tony Jeffree**, *Coordinating Editor* **Anil Rijsinghani, Richard Hausmann, Michele Wright, Paul Langille, P. J. Singh**, *Editorial Team*
IEEE Std 802.1u-2001	17 March 2001	**Tony Jeffree**, *Chair* **Neil Jarvis**, *Vice Chair* **Mick Seaman**, *Chair, Interworking Task Group*
IEEE Std 802.1v-2001	17 March 2001	**Tony Jeffree**, *Chair* **Neil Jarvis**, *Vice Chair* **Mick Seaman**, *Chair, Interworking Task Group* **David Delany**, *Editor* **Andrew Smith**, *Editor*
IEEE Std 802.1s-2002	11 December 2002	**Tony Jeffree**, *Chair* **Neil Jarvis**, *Vice Chair* **Mick Seaman**, *Chair, Interworking Task Group* **Norman W. Finn**, *Editor*
IEEE Std 802.1ad-2005	28 March 2005	**Tony Jeffree**, *Chair* **Paul Congdon**, *Vice Chair* **Mick Seaman**, *Chair, Interworking Task Group* **Stephen R. Haddock**, *Editor*
IEEE Std 802.1Q-2005	7 December 2005	**Tony Jeffree**, *Chair and Editor* **Paul Congdon**, *Vice Chair* **Mick Seaman**, *Chair, Interworking Task Group*
IEEE Std 802.1ak-2007	22 March 2007	**Tony Jeffree**, *Chair and Editor* **Paul Congdon**, *Vice Chair* **Mick Seaman**, *Chair, Interworking Task Group*
IEEE Std 802.1ag-2007	27 September 2007	**Tony Jeffree**, *Chair* **Paul Congdon**, *Vice Chair* **Stephen R. Haddock**, *Chair, Interworking Task Group* **Norman W. Finn**, *Editor-in-Chief* **David V. Elie-Dit-Cosaque**, **Dinesh Mohan**, **Oscar Rodriguez**, **Ali Sajassi,** *Assistant Editors*

Copyright © 2022 IEEE. All rights reserved.

IEEE 802.1Q Standard	Date approved by IEEE	Officers at the time of Working Group Ballot
IEEE Std 802.1ah-2008	12 June 2008	**Tony Jeffree**, *Chair* **Paul Congdon**, *Vice Chair* **Stephen R. Haddock**, *Chair, Interworking Task Group* **Paul Bottorff, Stephen Haddock,** and **Muneyoshi Suzuki,** *Editors*
IEEE Std 802.1Q-2005/Cor-1-2008	26 September 2008	**Tony Jeffree**, *Chair and Editor* **Paul Congdon**, *Vice Chair* **Stephen R. Haddock**, *Chair, Interworking Task Group*
IEEE Std 802.1ap-2008	10 December 2008	**Tony Jeffree**, *Chair* **Paul Congdon**, *Vice Chair* **Stephen R. Haddock**, *Chair, Interworking Task Group* **Glenn Parsons**, *Editor* **David Levi,** *Assistant Editor*
IEEE Std 802.1Qaw-2009	17 June 2009	**Tony Jeffree**, *Chair* **Paul Congdon**, *Vice Chair* **Stephen R. Haddock**, *Chair, Interworking Task Group* **Linda Dunbar,** *Editor*
IEEE Std 802.1Qay-2009	17 June 2009	**Tony Jeffree**, *Chair* **Paul Congdon**, *Vice Chair* **Stephen R. Haddock**, *Chair, Interworking Task Group* **Panagiotis Saltsidis,** *Editor*
IEEE Std 802.1aj-2009	9 December 2009	**Tony Jeffree**, *Chair* **Paul Congdon**, *Vice Chair* **Stephen R. Haddock**, *Chair, Interworking Task Group* **John Messenger**, *Editor* **Brian Hassink**, *MIB Editor*
IEEE Std 802.1Qav-2009	9 November 2009	**Tony Jeffree**, *Chair and Editor* **Paul Congdon**, *Vice Chair* **Michael Johas Teener**, *Chair, Audio Video Bridging Task Group*
IEEE Std 802.1Qau-2010	25 March 2010	**Tony Jeffree**, *Chair* **Paul Congdon**, *Vice Chair* **Patricia Thaler**, *Chair, Data Center Bridging Task Group* **Norman W. Finn**, *Editor*
IEEE Std 802.1Qat-2010	30 September 2010	**Tony Jeffree**, *Chair* **Paul Congdon**, *Vice Chair* **Michael Johas Teener**, *Chair, Audio Video Bridging Task Group* **Craig Gunther**, *Editor*

Copyright © 2022 IEEE. All rights reserved.

IEEE 802.1Q Standard	Date approved by IEEE	Officers at the time of Working Group Ballot
IEEE Std 802.1Q-2011	16 May 2011	**Tony Jeffree**, *Chair and Editor* **Paul Congdon**, *Vice Chair* **Stephen Haddock**, *Chair, Interworking Task Group*
IEEE Std 802.1Qbe-2011	16 June 2011	**Tony Jeffree**, *Chair* **Paul Congdon**, *Vice Chair* **Stephen Haddock**, *Chair, Interworking Task Group* **Norman Finn**, *Editor*
IEEE Std 802.1Qbc-2011	16 June 2011	**Tony Jeffree**, *Chair* **Paul Congdon**, *Vice Chair* **Stephen Haddock**, *Chair, Interworking Task Group* **Thomas Mack-Crane**, *Editor*
IEEE Std 802.1Qbb-2011	16 June 2011	**Tony Jeffree**, *Chair* **Paul Congdon**, *Vice Chair* **Patricia Thaler**, *Chair, Data Center Bridging Task Group* **Claudio DeSanti**, *Editor*
IEEE Std 802.1Qaz-2011	16 June 2011	**Tony Jeffree**, *Chair* **Paul Congdon**, *Vice Chair* **Patricia Thaler**, *Chair, Data Center Bridging Task Group* **Craig W. Carlson**, *Editor*
IEEE Std 802.1Qbf-2011	7 December 2011	**Tony Jeffree**, *Chair* **Paul Congdon**, *Vice Chair* **Stephen Haddock**, *Chair, Interworking Task Group* **Robert Sultan**, *Editor*
IEEE Std 802.1aq-2012	29 March 2012	**Tony Jeffree**, *Chair* **Glenn Parsons**, *Vice Chair* **Stephen Haddock**, *Chair, Interworking Task Group* **Donald Fedyk**, **Mick Seaman**, *Editors*
IEEE Std 802.1Qbg-2012	14 May 2012	**Tony Jeffree**, *Chair and Editor* **Paul Congdon**, *Vice Chair* **Patricia Thaler**, *Chair, Data Center Bridging Task Group* **Paul Bottorff**, *Editor, Clauses 12 and 17*
IEEE Std 802.1Q-2011/Cor-2-2012	19 October 2012	**Tony Jeffree**, *Chair and Editor* **Glenn Parsons**, *Vice Chair and Chair, Maintenance Task Group*
IEEE Std 802.1Qbp-2014	27 March 2014	**Tony Jeffree**, *Chair* **Glenn Parsons**, *Vice Chair* **Stephen Haddock**, *Chair, Interworking Task Group* **Ben Mack-Crane**, *Editor*

Copyright © 2022 IEEE. All rights reserved.

IEEE 802.1Q Standard	Date approved by IEEE	Officers at the time of Working Group Ballot
IEEE Std 802.1D-2004	9 February 2004	**Tony Jeffree**, *Chair and Editor* **Paul Congdon**, *Vice Chair* **Mick Seaman**, *Chair, Interworking Task Group and Editor*
IEEE Std 802.1D-2004	3 November 2014	**Glenn Parsons**, *Chair* **John Messenger**, *Vice-Chair* **Tony Jeffree**, *Editor* **Stephen Haddock**, *Chair, Interworking Task Group*
IEEE Std 802.1Qcd-2015	16 February 2015	**Glenn Parsons**, *Chair* **John Messenger**, *Vice Chair* **Patricia Thaler**, *Chair, Data Center Bridging Task Group* **Eric Multanen**, *Editor*
IEEE Std 802.1Qca-2015	3 September 2015	**Glenn Parsons**, *Chair* **John Messenger**, *Vice-Chair* **János Farkas**, *Editor* **Stephen Haddock**, *Chair, Interworking Task Group*
IEEE Std 802.1Q-2014/Cor 1-2015	5 December 2015	**Glenn Parsons**, *Chair* **John Messenger**, *Vice-Chair and Chair, Maintenance Task Group* **Tony Jeffree**, *Editor*
IEEE Std 802.1Qbv-2015	5 December 2015	**Glenn Parsons**, *Chair* **John Messenger**, *Vice-Chair* **Michael Johas Teener**, *Chair, Time-Sensitive Networking Task Group* **Tony Jeffree**, *Editor*
IEEE Std 802.1Qbu-2016	30 June 2016	**Glenn Parsons**, *Chair* **John Messenger**, *Vice-Chair* **Michael Johas Teener**, *Chair, Time-Sensitive Networking Task Group* **Tony Jeffree**, *Editor*
IEEE Std 802.1Qbz-2016	30 June 2016	**Glenn Parsons**, *Chair* **John Messenger**, *Vice-Chair* **Michael Johas Teener**, *Chair, Time-Sensitive Networking Task Group* **Norm Finn**, *Editor*
IEEE Std 802.1Qci-2017	14 February 2017	**Glenn Parsons**, *Chair* **John Messenger**, *Vice-Chair* **János Farkas**, *Chair, Time-Sensitive Networking Task Group* **Tony Jeffree**, *Editor*
IEEE Std 802.1Qch-2017	15 May 2017	**Glenn Parsons**, *Chair* **John Messenger**, *Vice-Chair* **János Farkas**, *Chair, Time-Sensitive Networking Task Group* **Tony Jeffree**, *Editor*

Copyright © 2022 IEEE. All rights reserved.

IEEE 802.1Q Standard	Date approved by IEEE	Officers at the time of Working Group Ballot
IEEE Std 802.1Qcc-2018	14 June 2018	**Glenn Parsons**, *Chair* **John Messenger**, *Vice Chair* and *Acting Chair* **Jessy V. Rouyer**, *Acting Vice Chair* **János Farkas**, *Chair, Time-Sensitive Networking Task Group* **Rodney Cummings**, *Editor*
IEEE Std 802.1Qcp-2018	14 June 2018	**Glenn Parsons**, *Chair* **John Messenger**, *Vice Chair* and *Acting Chair* **Jessy V. Rouyer**, *Acting Vice Chair* **János Farkas**, *Chair, Time-Sensitive Networking Task Group* **Marc Holness**, *Editor*
IEEE Std 802.1Qcy-2019	21 March 2019	**Glenn Parsons**, *Chair* **John Messenger**, *Vice Chair* and *Acting Chair* **Jessy V. Rouyer**, *Acting Vice Chair* **János Farkas**, *Chair, Time-Sensitive Networking Task Group* **Yizhou Li**, *Editor* **Paul Bottorff**, *Editor*
IEEE Std 802.1Qcx-2020	4 June 2020	**Glenn Parsons**, *Chair* **John Messenger**, *Vice Chair* **János Farkas**, *Chair, Time-Sensitive Networking Task Group* **Marc Holness**, Editor
IEEE Std 802.1Qcr-2020	24 September 2020	**Glenn Parsons**, *Chair* **John Messenger**, *Vice Chair* **Jessy V. Rouyer**, *Secretary* **János Farkas**, *Chair, Time-Sensitive Networking Task Group* **Craig Gunther**, *Vice Chair, Time-Sensitive Networking Task Group* **Johannes Specht**, *Editor*

Copyright © 2022 IEEE. All rights reserved.

Osama Aboul-Magd
Steve Adams
Stephen Ades
Fumio Akashi
Zehavit Alon
Ken Alonge
Ann Ambler
Paul D. Amer
Yafan An
Ting Ao
Charles Arnold
Peter Ashwood-Smith
Siamack Ayandeh
Floyd Backes
Ann Ballard
Richard Bantel
John Bartlett
Sy Bederman
Alexei Beliaev
Les Bell
Amatzia Ben-Artzi
Avner Ben-Dor
Michael Berger
Caitlin Bestler
Jan Bialkowski
James S. Binder
Robert Bledsoe
Rob Boatright
Kwami Boakaye
Christian Boiger
Brad Booth
Jean-Michel Bonnamy
Mike Borza
Paul Bottorff
David Brady
Rudolf Brandner
Martin Brewer
Frank Bruns
Juan Bulnes
Bill Bunch
Jim Burns
Peter Carbone
Bob Cardinal
Craig W. Carlson
Paul Carroll
Marco Carugi
Jeffrey Catlin
Dennis Cave
Dirceu Cavendish
Alan Chambers
Steve Chan
David W. Chang
Xin Chang
Frank Chao
Ken Chapman
Alice Chen
David Chen
Feng Chen
Weiying Cheng
Rao Cherukuri
Taesik Cheung
Jade Chien
Hon Wah Chin
Chi Chong
Jin-Seek Choi
Chris Christ
Marc Cochran
Paul Congdon
Glenn Connery
Alex Conta
Jim Corrigan
Diego Crupnicoff
David Cullerot
Rodney Cummings
Uri Cummings
Ted Davies
Andy Davis
Peter Dawe
Stan Degen
Arjan de Heer
Frank Deignan
David Delaney
Prakash Desai
Claudio DeSanti
Ron Dhondy
Patrick Diamond
Aboubacar Kader Diarra
Jeffrey Dietz
Russell Dietz
Zhemin Ding
Kurt Dobbins
Eiji Doi
Barbara J. Don Carlos
Linda Dunbar
Craig Easley
Donald Eastlake, III
Peter Ecclesine
J. J. Ekstrom
Anush Elangovan
Hesham M. Elbakoury
Walter Eldon
David Elie-Dit-Cosaque
János Farkas
Donald W. Fedyk
Eldon D. Feist
Felix Feifei Feng
Norman Finn
Len Fishler
Kevin Flanagan
Yishai Fraenkel
Paul Frantz
David Frattura
Robert Frazier
Lars Henrik Frederiksen
Andre Fredette
John Fuller
Ilango Ganga
Geoffrey Garner
Anoop Ghanwani
Franz Goetz
Pat Gonia
Gerrard Goubert
Richard Graham
Mark Gravel
Michael A. Gravel
Eric W. Gray
Karanvir Grewal
John Grinham
Yingjie Gu
Craig Gunther
Mitch Gusat
Stephen Haddock
Sharam Hakimi
Mogens Hansen
Mark Hantel
Harold Harrington
John Hart
Scott Harvell
Mike Harvey
Takashi Hasegawa
Brian Hassink
Wayne Hathaway
Brian Hausauer
Richard Hausman
Hitoshi Hayakawa
Vic Hayes
Asif Hazarika
David Head
Gaby Hecht
Deepak Hegde
Ariel Hendel
Bob Herbst
John Hickey
Jeremy Hitt
David Hollender
Marc Holness
Steve Horowitz
Bob Hott
Michelle Hsiung
Charles Hudson
Jack R. Hung
Rita Hunt
David Husak
Altaf Hussain
Rahil Hussain
Thomas Hytry
Romain Insler
Ran Ish-Shalom
Jay Israel
Atsushi Iwata
Vipin K. Jain
Neil Jarvis
Tony Jeffree
Paul Hongkyu Jeong
Pankaj Jha
Markus Jochim
Michael Johas Teener
Girault Jones
Peter Jones
Shyam Kaluve
Daya Kamath
Abhay Karandikar
Allen Kasey
Prakash Kashyap
Toyayuki Kato
Manu Kaycee
Hal Keen
Srikanth Keesara
Stephan Kehrer

Copyright © 2022 IEEE. All rights reserved.

Daniel Kelley
Kevin Ketchum
Keti Kilcrease
Doyeon Kim
Yongbum Kim
Alan Kirby
Kimberly Kirkpatrick
Keith Klamm
Steve Kleiman
Philippe Klein
Oliver Kleinberg
Marcel Kiessling
Yongbum Kim
Philippe Klein
Bruce Kling
Walter Knitl
Mike Ko
Raghu Kondapalli
Jouni Korhonnen
Michael Krause
Dan Krent
James Kristof
Vinod Kumar
Paul Kummer
Bruce Kwan
Paul Lachapelle
Kari Laihonen
Ashvin Lakshmikantha
Bill Lane
Paul Langille
Roger Lapuh
H. Eugene Latham
Loren Larsen
Yannick Le Goff
Marcus Leech
John Lemon
Michael Lerer
Lin Li
Bing Liao
George Lin
William P. Lidinsky
Johann Lindmeyr
Marina Lipshteyn
Gary Littleton
Robert D. Love
Yuanqui Luo
Andy Luque
Jeff Lynch
Gael Mace
Thomas Mack-Crane
Phillip Magnuson
Christophe Mangin
Mahalingam Mani
David Martin
Peter Martini
Riccardo Martinotti
Marco Mascitto
Tom McBeath
Keith McCloghrie
Bruce McClure
Tom McGowan
Alan McGuire
James McIntosh
Martin McNealis
Menucher Menuchery
Milan Merhar
Margaret A. Merrick
John Messenger
Colin Mick
Amol Mitra
Dinesh Mohan
Gabriel Montenegro
Jim Montrose
Matthew Mora
John Morris
Bob Moskowitz
Eric Multanen
Yaron Nachman
Yukihiro Nakagawa
Hiroki Nakano
Krishna Narayanaswamy
Lawrence Ng
Henry Ngai
Paul Nikolich
Kevin Nolish
Bob Noseworthy
Don O'Connor
Karen O'Donoghue
Jerry O'Keefe
Eugene O'Neil
Satoshi Obara
Hiroshi Ohta
David Olsen
Toshio Ooka
Jörg Ottensmeyer
Shlomo Ovadia
Vijoy Pandey
Don Pannell
Luc Pariseau
Glenn Parsons
Richard Patti
Ken Patton
Mark Pearson
Joseph Pelissier
Yonadav Perry
David Peterson
Roger Pfister
Thomas L. Phinney
John Pickens
Walter Pienciak
Daniel Pitt
Hayim Porat
Gideon Prat
Kirk Preiss
Ron L. G. Prince
Max Pritikin
Ray Qiu
Rene Raeber
Ananda Rajagopal
Steve Ramberg
Nigel Ramsden
Karen Randall
Shlomo Reches
Frank Reichstein
Dick Reohr
Trudy Reusser
James Richmond
Maximilian Riegel
Anil Rijsinghani
Robert Roden
Edouard Rocher
Guenter Roeck
John J. Roese
Josef Roese
Derek J. Rohde
Allyn Romanow
Dan Romascanu
Paul Rosenblum
Moran Roth
Jessy V. Rouyer
Doug Ruby
Eric Ryu
Jonathan Sadler
Ali Sajassi
Dolors Sala
Joseph Salowey
John Salter
Panagiotis Saltsidis
Sam Sambasivan
Ray Samora
Behcet Sarikaya
Alan Sarsby
Satish Sathe
John M. Sauer
Ayman Sayed
Susan Schanning
Ted Schroeder
Benjamin Schultz
Mick Seaman
Gerry Segal
Rich Seifert
Lee Sendelbach
Koichiro Seto
Daniel Sexton
Himanshu Shah
Rakesh Sharma
Ravi Shenoy
Howard Sherry
K. Karl Shimada
Fred Shu
Wu-Shi Shung
Taeshi Shimizu
Phil Simmons
Curtis Simonson
Paramjeet Singh
Rosemary V. Slager
Alexander Smith
Andrew Smith
Michel Soerensen
M. Soha
Stuart Soloway
Johannes Specht
Nurit Sprecher
Kevin B. Stanton
Larry Stefani
Wilfried Steiner
Dan Stokesberry
Sundar Subramaniam
Robert Sultan

Copyright © 2022 IEEE. All rights reserved.

Muneyoshi Suzuki
Yoshihiro Suzuki
George Swallow
Lennart Swartz
Richard Sweatt
Vahid Tabatabaee
Attila Takacs
Kenta Takumi
Francois Tallet
Robin Tasker
Angus Telfer
John Terry
Patricia A. Thaler
Jonathan Thatcher
Dave Thompson
Geoff Thompson
David Thornburg
Oliver Thorp
Michel Thorsen
Fouad Tobagi
Nathan Tobol
Jeremy Touve
Naoki Tsukutari
Fred Tuck
Chait Tumuluri
Wendell Turner
Paul Unbehagen
Dhadesugoor Vaman
Steve Van Seters
Dono van-Mierop
Peter Videcranz
John Viega
Maarten Vissers
Dennis Volpano
Manoj Wadekar
Paul Wainwright
Scott Wasson
Daniel Watts
Yuehua Wei
John Wakerly
Peter Wang
Philip Wang
Y. C. Wang
Yan Wang
Trevor Warwick
Bob Watson
Karl Weber
Yuehua Wei
Brian Weis
Alan Weissberger
Glenn Wenig
Martin White
Bert Wijnen
Deborah Wilbert
Keith Willette
Robert Williams
Val Wilson
Ludwig Winkel
Robert Winter
Michael Witkowski
Edward Wong
Jordon Woods
Michael D. Wright
Michele Wright
Chien-Hsien Wu
Min Xiao
Ken Young
Allen Yu
Wayne Zakowski
Igor Zhovnirovsky
Carolyn Zimmer
Helge Zinner
Glen Zorn
Nick Zucchero
Juan-Carlos Zuniga

Copyright © 2022 IEEE. All rights reserved.

Introduction

This introduction is not part of IEEE Std 802.1Q™-2022, IEEE Standard for Local and metropolitan area networks—Bridges and Bridged Networks.

IEEE Std 802.1Q™-2022 incorporates the text of the following amendments into IEEE Std 802.1Q™-2018.

IEEE Std 802.1Qcc™-2018	Stream Reservation Protocol (SRP) Enhancements and Performance Improvements
IEEE Std 802.1Qcp™-2018	YANG Data Model
IEEE Std 802.1Qcy™-2019	Virtual Station Interface (VSI) Discovery and Configuration Protocol (VDP) Extension to Support Network Virtualization Overlays Over Layer 3 (NVO3)
IEEE Std 802.1Qcx™-2020	YANG Data Model for Connectivity Fault Management
IEEE Std 802.1Qcr™-2020	Asynchronous Traffic Shaping

The 2018 revision of this standard incorporated the text of the following amendments into IEEE Std 802.1Q-2014.

IEEE Std 802.1Qcd™-2015	Application Virtual Local Area Network (VLAN) Type, Length, Value (TLV)
IEEE Std 802.1Qca™-2015	Path Control and Reservation
IEEE Std 802.1Q-2014 Cor 1-2015	Technical and editorial corrections
IEEE Std 802.1Qbv™-2015	Enhancements for scheduled traffic
IEEE Std 802.1Qbu™-2016	Frame preemption
IEEE Std 802.1Qbz™-2016	Enhancements to Bridging of IEEE 802.11 Media
IEEE Std 802.1Qci™-2017	Per-Stream Filtering and Policing
IEEE Std 802.1Qch™-2017	Cyclic Queuing and Forwarding

The 2014 revision of this standard incorporated the text of the following amendments into IEEE Std 802.1Q-2011.

IEEE Std 802.1Qbe™-2011	Multiple I-SID Registration Protocol
IEEE Std 802.1Qbc™-2011	Provider Bridging—Remote Customer Service Interfaces
IEEE Std 802.1Qbb™-2011	Priority-based Flow Control
IEEE Std 802.1Qaz™-2011	Enhanced Transmission Selection for Bandwidth Sharing Between Traffic Classes
IEEE Std 802.1Qbf™-2011	PBB-TE Infrastructure Segment Protection
IEEE Std 802.1Qbg™-2012	Edge Virtual Bridging
IEEE Std 802.1aq™-2012	Shortest Path Bridging
IEEE Std 802.1Q-2011/Cor 2-2012	Technical and editorial corrections
IEEE Std 802.1Qbp™-2014	Equal Cost Multiple Paths (ECMP)

The 2011 revision of this standard incorporated the text of the following amendments into IEEE Std 802.1Q-2005.

IEEE Std 802.1ad™-2005	Provider Bridges
IEEE Std 802.1ak™-2007	Multiple Registration Protocol
IEEE Std 802.1ag™-2007	Connectivity Fault Management
IEEE Std 802.1ah™-2008	Provider Backbone Bridges
IEEE Std 802-1Q-2005/Cor-1-2008	Corrections to the Multiple Registration Protocol

Copyright © 2022 IEEE. All rights reserved.

IEEE Std 802.1ap™-2008	Management Information Base (MIB) Definitions for VLAN Bridges
IEEE Std 802.1Qaw™-2009	Management of Data Driven and Data Dependent Connectivity Faults
IEEE Std 802.1Qay™-2009	Provider Backbone Bridge Traffic Engineering
IEEE Std 802.1aj™-2009	Two-Port Media Access Control (MAC) Relay
IEEE Std 802.1Qav™-2009	Forwarding and Queuing Enhancements for Time-Sensitive Streams
IEEE Std 802.1Qau™-2010	Congestion Notification
IEEE Std 802.1Qat™-2010	Stream Reservation Protocol

Clause 13 of IEEE Std 802.1Q-2011 was also revised to include an updated specification of the Rapid Spanning Tree Algorithm and Protocol (RSTP), superseding references to IEEE Std 802.1D™-2004 [B12].[6]

The 2005 revision of this standard incorporated the text of the following amendments into IEEE Std 802.1Q-1998.

IEEE Std 802.1u™-2001	Technical and Editorial Corrections
IEEE Std 802.1v™-2001	VLAN Classification by Protocol and Port
IEEE Std 802.1s™-2002	Multiple Spanning Trees

This standard was first published as IEEE Std 802.1Q-1998, making use of the concepts and mechanisms of LAN Bridging that were introduced by IEEE Std 802.1D and defining additional mechanisms to allow the implementation of Virtual Bridged Networks.

For an introduction to this standard that details each of the provisions introduced by amendments and revisions throughout its development, refer to 1.3.

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

Secretary, IEEE-SA Standards Board
445 Hoes Lane
Piscataway, NJ 08854-4141
USA

[6] The numbers in brackets correspond to those of the bibliography in Annex W.

Copyright © 2022 IEEE. All rights reserved.

Contents

1. Overview ... 74

1.1 Scope ... 74
1.2 Purpose ... 74
1.3 Introduction ... 75

2. Normative references ... 83

3. Definitions ... 87

4. Abbreviations ... 109

5. Conformance ... 115

5.1 Requirements terminology ... 115
5.2 Conformant components and equipment ... 115
5.3 Protocol Implementation Conformance Statement (PICS) ... 116
5.4 VLAN Bridge component requirements ... 116
5.4.1 VLAN Bridge component options ... 117
5.4.2 Multiple VLAN Registration Protocol (MVRP) requirements ... 123
5.4.3 VLAN Bridge requirements for congestion notification ... 123
5.4.4 Multiple Stream Registration Protocol (MSRP) requirements ... 124
5.4.5 Shortest Path Bridging (SPB) operation (optional) ... 124
5.4.6 Path Control and Reservation (PCR) (optional) ... 125
5.5 C-VLAN component conformance ... 126
5.5.1 C-VLAN component options ... 126
5.5.2 TE-MSTID (optional) ... 126
5.6 S-VLAN component conformance ... 127
5.6.1 S-VLAN component options ... 127
5.6.2 S-VLAN component requirements for Provider Backbone Bridge Traffic Engineering (PBB-TE) ... 127
5.6.3 S-VLAN component requirements for PBB-TE IPS ... 128
5.6.4 S-VLAN component requirements for ECMP with flow filtering ... 128
5.7 I-component conformance ... 128
5.7.1 I-component options ... 128
5.8 B-component conformance ... 129
5.8.1 B-component options ... 129
5.8.2 B-component requirements for PBB-TE ... 129
5.8.3 B-component requirements for PBB-TE IPS ... 130
5.8.4 B-component requirements for ECMP with flow filtering ... 130
5.9 C-VLAN Bridge conformance ... 130
5.9.1 C-VLAN Bridge options ... 130
5.10 Provider Bridge conformance ... 130
5.10.1 S-VLAN Bridge conformance ... 131
5.10.2 Provider Edge Bridge conformance ... 131
5.11 System requirements for Priority-based Flow Control (PFC) ... 131
5.12 Backbone Edge Bridge (BEB) conformance ... 131
5.12.1 BEB requirements for PBB-TE ... 132
5.13 MAC Bridge component requirements ... 132
5.13.1 MAC Bridge component options ... 132
5.14 MAC Bridge conformance ... 133
5.14.1 MAC Bridge options ... 133

Copyright © 2022 IEEE. All rights reserved.

5.15 TPMR component conformance 134
5.15.1 TPMR component options 134
5.16 TPMR conformance 134
5.16.1 TPMR options 135
5.17 T-component conformance 135
5.17.1 T-component options 135
5.18 End station requirements for MMRP, MVRP, and MSRP 135
5.18.1 MMRP requirements and options 135
5.18.2 MVRP requirements and options 136
5.18.3 MSRP requirements and options 136
5.19 VLAN-aware end station requirements for CFM 137
5.20 End station requirements—FQTSS 137
5.21 End station requirements for congestion notification 138
5.22 MAC-specific bridging methods 138
5.23 EVB Bridge requirements 139
5.24 EVB station requirements 139
5.24.1 Edge relay (ER) requirements 140
5.25 End station requirements—enhancements for scheduled traffic 141
5.26 End station requirements—enhancements for frame preemption 142
5.27 End station requirements—PSFP 142
5.28 End station requirements—Cyclic queuing and forwarding 142
5.29 TSN CNC station requirements 142
5.30 VDP-NVO3 requirements 143
5.30.1 VDP-NVO3 nNVE requirements 143
5.30.2 VDP-NVO3 tNVE requirements 143
5.31 End station requirements—ATS 143

6. Support of the MAC Service 144

6.1 Basic architectural concepts and terms 145
6.2 Provision of the MAC Service 145
6.2.1 Point-to-point, multipoint-to-multipoint, and rooted-multipoint connectivity 146
6.3 Support of the MAC Service 146
6.4 Preservation of the MAC Service 147
6.5 Quality of service (QoS) maintenance 147
6.5.1 Service availability 147
6.5.2 Frame loss 148
6.5.3 Frame misordering 148
6.5.4 Frame duplication 149
6.5.5 Transit delay 150
6.5.6 Frame lifetime 150
6.5.7 Undetected frame error rate 151
6.5.8 Maximum Service Data Unit Size 151
6.5.9 Priority 151
6.5.10 Throughput 152
6.6 Internal Sublayer Service (ISS) 153
6.7 Support of the ISS by specific MAC procedures 153
6.7.1 Support of the ISS by IEEE Std 802.3 (Ethernet) 153
6.7.2 Frame preemption 153
6.8 Enhanced Internal Sublayer Service (EISS) 154
6.8.1 Service primitives 154
6.8.2 Status parameters 155
6.8.3 Point-to-point parameters 155
6.8.4 Control primitives and parameters 155

Copyright © 2022 IEEE. All rights reserved.

6.9 Support of the EISS 156
6.9.1 Data indications 157
6.9.2 Data requests 158
6.9.3 Priority Code Point encoding 158
6.9.4 Regenerating priority 160
6.10 Support of the ISS/EISS by PIPs 161
6.10.1 Data indications 163
6.10.2 Data requests 164
6.10.3 Priority Code Point encoding 164
6.11 Support of the EISS by CBPs 165
6.11.1 Data indications 166
6.11.2 Data requests 167
6.11.3 Priority Code Point decoding 168
6.11.4 Regenerating priority 168
6.12 Protocol VLAN classification 168
6.12.1 Protocol Templates 170
6.12.2 Protocol Group Identifiers 170
6.12.3 Protocol Group Database 170
6.13 Support of the ISS for attachment to a PBN 171
6.13.1 Data requests 172
6.13.2 Data indications 172
6.14 Support of the ISS within a system 173
6.15 Support of the ISS by additional technologies 173
6.16 Filtering services in Bridged Networks 173
6.16.1 Purpose(s) of filtering service provision 174
6.16.2 Goals of filtering service provision 174
6.16.3 Users of filtering services 174
6.16.4 Basis of service 174
6.16.5 Categories of service 175
6.16.6 Service configuration 175
6.16.7 Service definition for Extended Filtering Services 175
6.17 EISS Multiplex Entity 177
6.18 Backbone Service Instance Multiplex Entity 178
6.18.1 Demultiplexing direction 179
6.18.2 Multiplexing direction 180
6.18.3 Priority Code Point encoding 180
6.18.4 Status parameters 180
6.19 TESI Multiplex Entity 181
6.20 Support of the ISS with signaled priority 182
6.20.1 Data indications 182
6.20.2 Data requests 183
6.21 Infrastructure Segment Multiplex Entity 183
6.22 PDU and protocol discrimination and media 184

7. Principles of Virtual Bridged Network operation 185

7.1 Network overview 185
7.2 Use of VLANs 186
7.3 Active topology 186
7.4 VLAN topology 187
7.5 Locating end stations 188
7.6 Ingress, forwarding, and egress rules 189

Copyright © 2022 IEEE. All rights reserved.

8. Principles of Bridge operation 190

8.1 Bridge operation 190
8.1.1 Relay 190
8.1.2 Filtering and relaying information 191
8.1.3 Duplicate frame prevention 191
8.1.4 Traffic segregation 191
8.1.5 Traffic reduction 192
8.1.6 Traffic expediting 192
8.1.7 Conversion of frame formats 192
8.2 Bridge architecture 193
8.3 Model of operation 195
8.4 Active topologies, learning, and forwarding 199
8.5 Bridge Port Transmit and Receive 200
8.5.1 Bridge Port connectivity 200
8.5.2 TPMR Port connectivity 201
8.5.3 Support of Higher Layer Entities 202
8.6 The Forwarding Process 202
8.6.1 Active topology enforcement 203
8.6.2 Ingress filtering 205
8.6.3 Frame filtering 205
8.6.4 Egress filtering 208
8.6.5 Flow classification and metering 208
8.6.6 Queuing frames 217
8.6.7 Queue management 218
8.6.8 Transmission selection 219
8.6.9 Scheduled traffic state machines 225
8.6.10 Stream gate control state machines 232
8.6.11 ATS Scheduler state machines 234
8.7 The Learning Process 238
8.7.1 Default filtering utility criteria 238
8.7.2 Enhanced filtering utility criteria 238
8.7.3 Ageing of Dynamic Filtering Entries 239
8.8 The Filtering Database (FDB) 239
8.8.1 Static Filtering Entries 242
8.8.2 Static VLAN Registration Entries 243
8.8.3 Dynamic Filtering Entries 244
8.8.4 MAC Address Registration Entries 245
8.8.5 Dynamic VLAN Registration Entries 245
8.8.6 Default Group filtering behavior 246
8.8.7 Dynamic Reservation Entries 247
8.8.8 Allocation of VIDs to FIDs 247
8.8.9 Querying the FDB 248
8.8.10 Determination of the member set for a VID 252
8.8.11 Permanent Database 252
8.8.12 Connection_Identifier 252
8.9 MST, SPB, and ESP configuration information 253
8.9.1 MST Configuration Table 254
8.9.2 MST configuration identification 254
8.9.3 FID to MSTI Allocation Table 254
8.9.4 SPT Configuration Identification 254
8.10 Spanning Tree Protocol Entity 255
8.11 MRP entities 255
8.12 Bridge Management Entity 256

Copyright © 2022 IEEE. All rights reserved.

8.13 Addressing 256
8.13.1 End stations 256
8.13.2 Bridge Ports 256
8.13.3 Use of LLC by Spanning Tree Protocol Entities 257
8.13.4 Reserved MAC addresses 257
8.13.5 Group MAC addresses for spanning tree entity 257
8.13.6 Group MAC addresses for MRP Applications 259
8.13.7 Bridge Management Entities 260
8.13.8 Unique identification of a Bridge 260
8.13.9 Points of attachment and connectivity for Higher Layer Entities 260
8.13.10 VLAN attachment and connectivity for Higher Layer Entities 264
8.13.11 CFM entities 265

9. Tagged frame format 267

9.1 Purpose of tagging 267
9.2 Representation and encoding of tag fields 267
9.3 Tag format 268
9.4 TPID formats 268
9.5 Tag Protocol identification 268
9.6 VLAN Tag Control Information (TCI) 269
9.7 Backbone Service Instance Tag Control Information (I-TAG TCI) 270

10. Multiple Registration Protocol (MRP) and Multiple MAC Registration Protocol (MMRP) 272

10.1 MRP overview 272
10.2 MRP architecture 275
10.3 MRP Attribute Propagation (MAP) 276
10.3.1 MAP Context 277
10.4 Requirements to be met by MRP 278
10.5 Requirements for interoperability between MRP Participants 278
10.6 Protocol operation 280
10.7 Protocol specification 284
10.7.1 Notational conventions and abbreviations 285
10.7.2 Registrar Administrative Controls 286
10.7.3 Applicant Administrative Controls 287
10.7.4 Protocol timers 287
10.7.5 Protocol event definitions 288
10.7.6 Protocol Action definitions 290
10.7.7 Applicant state machine 292
10.7.8 Registrar state machine 292
10.7.9 LeaveAll state machine 292
10.7.10 PeriodicTransmission state machine 295
10.7.11 Timer values 295
10.7.12 Operational reporting and statistics 296
10.7.13 Interoperability considerations 296
10.7.14 External control 297
10.8 Structure and encoding of Multiple Registration Protocol Data Units (MRPDUs) 297
10.8.1 Structure 297
10.8.2 Encoding of MRPDU parameters 299
10.8.3 Packing and parsing MRPDUs 302
10.9 Multiple MAC Registration Protocol (MMRP)—Purpose 304

Copyright © 2022 IEEE. All rights reserved.

10.10 MMRP Model of operation ... 305
10.10.1 Propagation of Group Membership information ... 306
10.10.2 Propagation of Group service requirement information ... 307
10.10.3 Source pruning ... 307
10.10.4 Use of Group service requirement registration by end stations ... 307
10.11 Default Group filtering behavior and MMRP propagation ... 307
10.12 Definition of the MMRP application ... 309
10.12.1 Definition of MRP elements ... 309
10.12.2 Provision and support of Extended Filtering Services ... 311
10.12.3 Use of “new” declaration capability ... 313
10.12.4 Attribute value support requirements ... 313
10.12.5 Registrar Administrative Controls ... 313

11. VLAN topology management ... 314

11.1 Static and dynamic VLAN configuration ... 314
11.2 Multiple VLAN Registration Protocol (MVRP) ... 315
11.2.1 MVRP overview ... 315
11.2.2 VLAN registration service definition ... 317
11.2.3 Definition of the MVRP application ... 318
11.2.4 VID translation table ... 321
11.2.5 Use of “new” declaration capability ... 321
11.2.6 New-Only Participant and Registrar Administrative Controls ... 321
11.2.7 Attribute value support requirements ... 321

12. Bridge management ... 322

12.1 Management functions ... 322
12.1.1 Configuration Management ... 322
12.1.2 Fault Management ... 323
12.1.3 Performance Management ... 323
12.1.4 Security Management ... 323
12.1.5 Accounting Management ... 323
12.2 VLAN Bridge objects ... 323
12.3 Data types ... 324
12.4 Bridge Management Entity ... 325
12.4.1 Bridge Configuration ... 325
12.4.2 Port configuration ... 328
12.5 MAC entities ... 330
12.5.1 ISS Port Number table managed object (optional) ... 330
12.6 Forwarding process ... 331
12.6.1 The Port Counters ... 331
12.6.2 Priority handling ... 332
12.6.3 Traffic Class Table ... 339
12.7 Filtering Database (FDB) ... 340
12.7.1 The Filtering Database object ... 340
12.7.2 A Static Filtering Entry object ... 341
12.7.3 A Dynamic Filtering Entry object ... 341
12.7.4 A MAC Address Registration Entry object ... 342
12.7.5 A VLAN Registration Entry object ... 342
12.7.6 Permanent Database object ... 342
12.7.7 General FDB operations ... 343
12.8 Bridge Protocol Entity ... 345
12.8.1 The Protocol Entity ... 345
12.8.2 Bridge Port ... 348

Copyright © 2022 IEEE. All rights reserved.

12.9 MRP Entities ... 352
12.9.1 The MRP Timer object ... 352
12.9.2 The MRP Attribute Type object ... 353
12.9.3 Periodic state machine objects ... 354
12.10 Bridge VLAN managed objects ... 354
12.10.1 Bridge VLAN Configuration managed object ... 355
12.10.2 VLAN Configuration managed object ... 360
12.10.3 The VID to FID allocation managed object ... 361
12.11 MMRP entities ... 363
12.11.1 MMRP Configuration managed object ... 363
12.12 MST configuration entities ... 365
12.12.1 The MSTI List ... 365
12.12.2 The FID to MSTID Allocation Table ... 366
12.12.3 The MST Configuration Table ... 367
12.13 Provider Bridge management ... 369
12.13.1 Provider Bridge Port Type managed object ... 370
12.13.2 Customer Edge Port Configuration managed object ... 371
12.13.3 Remote Customer Access managed object ... 374
12.14 CFM entities ... 376
12.14.1 Maintenance Domain list managed object ... 376
12.14.2 CFM Stack managed object ... 378
12.14.3 Default MD Level managed object ... 379
12.14.4 Configuration Error List managed object ... 380
12.14.5 Maintenance Domain managed object ... 381
12.14.6 Maintenance Association managed object ... 383
12.14.7 Maintenance association Endpoint managed object ... 386
12.15 Backbone Core Bridge (BCB) management ... 393
12.16 Backbone Edge Bridge (BEB) management ... 393
12.16.1 BEB configuration managed object ... 395
12.16.2 BEB/PB/VLAN Bridge Port configuration managed object ... 399
12.16.3 VIP configuration managed object ... 399
12.16.4 PIP configuration managed object ... 400
12.16.5 CBP Configuration managed object ... 407
12.17 DDCFM entities ... 410
12.17.1 DDCFM Stack managed object ... 410
12.17.2 Reflection Responder managed object ... 410
12.17.3 RFM Receiver managed object ... 414
12.17.4 Decapsulator Responder managed object ... 415
12.17.5 SFM Originator managed object ... 417
12.18 PBB-TE Protection Switching managed objects ... 420
12.18.1 TE protection group list managed object ... 420
12.18.2 TE protection group managed object ... 421
12.19 TPMR managed objects ... 423
12.19.1 TPMR management entity ... 424
12.19.2 MAC and PHY entities ... 426
12.19.3 Forwarding Process ... 426
12.19.4 MAC Status Propagation Entity (MSPE) ... 431
12.20 Management entities for FQTSS ... 433
12.20.1 The Bandwidth Availability Parameter Table ... 433
12.20.2 The Transmission Selection Algorithm Table ... 434
12.20.3 The Priority Regeneration Override Table ... 434
12.20.4 SR Class to Priority Mapping Table ... 434

Copyright © 2022 IEEE. All rights reserved.

12.21 Congestion Notification managed objects 435
12.21.1 CN component managed object 435
12.21.2 CN component priority managed object 435
12.21.3 CN Port priority managed object 437
12.21.4 Congestion Point managed object 438
12.21.5 Reaction Point port priority managed object 438
12.21.6 Reaction Point group managed object 439
12.22 Stream Reservation Protocol (SRP) entities 439
12.22.1 SRP Bridge Base Table 440
12.22.2 SRP Bridge Port Table 440
12.22.3 SRP Latency Parameter Table 441
12.22.4 SRP Stream Table 441
12.22.5 SRP Reservations Table 441
12.22.6 SRP Stream Preload Table 442
12.22.7 SRP Reservations Preload Table 442
12.23 Priority-based Flow Control objects 444
12.24 1:1 PBB-TE IPS managed objects 444
12.24.1 IPG list managed object 444
12.24.2 IPG managed object 446
12.25 Shortest Path Bridging managed objects 448
12.25.1 The SPB System managed object 449
12.25.2 The SPB MTID Static managed object 451
12.25.3 The SPB Topology Instance Dynamic managed object 453
12.25.4 The SPB ECT Static Entry managed object 453
12.25.5 The SPB ECT Dynamic Entry managed object 455
12.25.6 The SPB Adjacency Static Entry managed object 456
12.25.7 The SPB Adjacency Dynamic Entry managed object 457
12.25.8 The SPBM BSI Static Entry managed object 457
12.25.9 The SPB Topology Node Table managed object 459
12.25.10 The SPB Topology ECT Table managed object 460
12.25.11 The SPB Topology Edge Table managed object 460
12.25.12 The SPBM Topology Service Table managed object 461
12.25.13 The SPBV Topology Service Table managed object 462
12.25.14 The ECMP ECT Static Entry managed object 463
12.26 Edge Virtual Bridging (EVB) management 464
12.26.1 EVB system base table 467
12.26.2 SBP table entry 469
12.26.3 VSI table entry 470
12.26.4 S-channel configuration and management 471
12.26.5 ER management 473
12.27 Edge Control Protocol (ECP) management 474
12.27.1 ECP table entry 474
12.28 Path Control and Reservation (PCR) management 475
12.28.1 The PCR ECT Static Entry managed object 476
12.28.2 The PCR Topology ECT Table managed object 478
12.29 Managed objects for scheduled traffic 479
12.29.1 The Gate Parameter Table 479
12.29.2 Timing points for scheduled traffic 481
12.30 Managed objects for frame preemption 482
12.30.1 Frame Preemption Parameter table 482

Copyright © 2022 IEEE. All rights reserved.

12.31 Managed objects for per-stream classification and metering 484
12.31.1 The Stream Parameter Table 484
12.31.2 The Stream Filter Instance Table 485
12.31.3 The Stream Gate Instance Table 487
12.31.4 The Flow Meter Instance Table 490
12.31.5 The Scheduler Instance Table 490
12.31.6 The Scheduler Group Instance Table 491
12.31.7 The Scheduler Port Parameter Table 492
12.31.8 The Scheduler Timing Characteristics Table 492
12.32 Stream reservation remote management 494
12.32.1 Bridge Delay 494
12.32.2 Propagation Delay 496
12.32.3 Static Trees 496
12.32.4 MRP External Control 497

13. Spanning tree protocols 501

13.1 Protocol design requirements 502
13.2 Protocol support requirements 503
13.2.1 MSTP support requirements 503
13.2.2 SPB support requirements 503
13.3 Protocol design goals 504
13.4 RSTP overview 504
13.4.1 Computation of the active topology 505
13.4.2 Example topologies 506
13.5 MSTP overview 509
13.5.1 Example topologies 510
13.5.2 Relationship of MSTP to RSTP 513
13.5.3 Modeling an MST or SPT Region as a single Bridge 513
13.6 SPB overview 514
13.7 Compatibility and interoperability 515
13.7.1 Designated Port selection 515
13.7.2 Force Protocol Version 515
13.8 MST Configuration Identifier (MCID) 516
13.9 Spanning tree priority vectors 517
13.10 CIST Priority Vector calculations 519
13.11 MST Priority Vector calculations 521
13.12 Port Role assignments 523
13.13 Stable connectivity 524
13.14 Communicating spanning tree information 525
13.15 Changing spanning tree information 526
13.16 Changing Port States with RSTP or MSTP 527
13.16.1 Subtree connectivity and priority vectors 528
13.16.2 Root Port transition to Forwarding 528
13.16.3 Designated Port transition to Forwarding 528
13.16.4 Master Port transition to Forwarding 530
13.17 Changing Port States with SPB 532
13.17.1 Agreement Digest 534
13.18 Managing spanning tree topologies 535
13.19 Updating learned station location information 536
13.20 Managing reconfiguration 538
13.21 Partial and disputed connectivity 539
13.22 In-service upgrades 539
13.23 Fragile Bridges 541

Copyright © 2022 IEEE. All rights reserved.

13.24 Spanning tree protocol state machines 541
13.25 State machine timers 543
13.25.1 edgeDelayWhile 544
13.25.2 fdWhile 544
13.25.3 helloWhen 544
13.25.4 mdelayWhile 544
13.25.5 rbWhile 544
13.25.6 rcvdInfoWhile 544
13.25.7 rrWhile 545
13.25.8 tcDetected 545
13.25.9 tcWhile 545
13.25.10 pseudoInfoHelloWhen 545
13.26 Per Bridge variables 545
13.26.1 agreementDigest 546
13.26.2 BridgeIdentifier 546
13.26.3 BridgePriority 546
13.26.4 BridgeTimes 546
13.26.5 ForceProtocolVersion 547
13.26.6 MigrateTime 547
13.26.7 MstConfigId 547
13.26.8 AuxMstConfigId 547
13.26.9 rootPortId 547
13.26.10 rootPriority 547
13.26.11 rootTimes 547
13.26.12 TxHoldCount 547

Copyright © 2022 IEEE. All rights reserved.

13.27 Per port variables 547
13.27.1 AdminEdge 550
13.27.2 ageingTime 550
13.27.3 agree 550
13.27.4 agreed 550
13.27.5 agreedAbove 550
13.27.6 agreedDigest 550
13.27.7 agreedDigestValid 550
13.27.8 agreeDigest 550
13.27.9 agreeDigestValid 550
13.27.10 agreedMisorder 551
13.27.11 agreedN 551
13.27.12 agreedND 551
13.27.13 agreedPriority 551
13.27.14 agreedTopology 551
13.27.15 agreementOutstanding 551
13.27.16 agreeN 551
13.27.17 agreeND 551
13.27.18 AutoEdge 551
13.27.19 AutoIsolate 552
13.27.20 designatedPriority 552
13.27.21 designatedTimes 552
13.27.22 disputed 552
13.27.23 enableBPDUrx 552
13.27.24 enableBPDUtx 552
13.27.25 ExternalPortPathCost 552
13.27.26 isL2gp 552
13.27.27 isolate 553
13.27.28 fdbFlush 553
13.27.29 forward 553
13.27.30 forwarding 553
13.27.31 infoInternal 553
13.27.32 infoIs 553
13.27.33 InternalPortPathCost 553
13.27.34 learn 554
13.27.35 learning 554
13.27.36 master 554
13.27.37 mastered 554
13.27.38 mcheck 554
13.27.39 msgPriority 554
13.27.40 msgTimes 554
13.27.41 neighbourPriority 555
13.27.42 newInfo 555
13.27.43 newInfoMsti 555
13.27.44 operEdge 555
13.27.45 portEnabled 555
13.27.46 portId 555
13.27.47 portPriority 555
13.27.48 portTimes 556
13.27.49 proposed 556
13.27.50 proposing 556
13.27.51 pseudoRootId 556
13.27.52 rcvdBPDU 556
13.27.53 rcvdInfo 556

Copyright © 2022 IEEE. All rights reserved.

13.27.54 rcvdInternal 556
13.27.55 rcvdMsg 556
13.27.56 rcvdRSTP 556
13.27.57 rcvdSTP 556
13.27.58 rcvdTc 556
13.27.59 rcvdTcAck 556
13.27.60 rcvdTcn 557
13.27.61 reRoot 557
13.27.62 reselect 557
13.27.63 restrictedDomainRole 557
13.27.64 restrictedRole 557
13.27.65 restrictedTcn 557
13.27.66 role 557
13.27.67 selected 557
13.27.68 selectedRole 557
13.27.69 sendRSTP 558
13.27.70 sync 558
13.27.71 synced 558
13.27.72 tcAck 558
13.27.73 tcProp 558
13.27.74 tick 558
13.27.75 txCount 558
13.27.76 updtInfo 558
13.28 State machine conditions and parameters 558
13.28.1 allSptAgree 559
13.28.2 allSynced 559
13.28.3 allTransmitReady 559
13.28.4 BestAgreementPriority 559
13.28.5 cist 559
13.28.6 cistRootPort 559
13.28.7 cistDesignatedPort 560
13.28.8 EdgeDelay 560
13.28.9 forwardDelay 560
13.28.10 FwdDelay 560
13.28.11 HelloTime 560
13.28.12 MaxAge 560
13.28.13 msti 560
13.28.14 mstiDesignatedOrTCpropagatingRootPort 560
13.28.15 mstiMasterPort 560
13.28.16 operPointToPoint 560
13.28.17 rcvdAnyMsg 560
13.28.18 rcvdCistMsg 560
13.28.19 rcvdMstiMsg 561
13.28.20 reRooted 561
13.28.21 rstpVersion 561
13.28.22 spt 561
13.28.23 stpVersion 561
13.28.24 updtCistInfo 561
13.28.25 updtMstiInfo 561

Copyright © 2022 IEEE. All rights reserved.

13.29 State machine procedures 561
13.29.1 betterorsameInfo(newInfoIs) 562
13.29.2 clearAllRcvdMsgs() 562
13.29.3 clearReselectTree() 562
13.29.4 disableForwarding() 563
13.29.5 disableLearning() 563
13.29.6 enableForwarding() 563
13.29.7 enableLearning() 563
13.29.8 fromSameRegion() 563
13.29.9 newTcDetected() 563
13.29.10 newTcWhile() 563
13.29.11 pseudoRcvMsgs() 564
13.29.12 rcvInfo() 564
13.29.13 rcvMsgs() 565
13.29.14 rcvAgreements() 565
13.29.15 recordAgreement() 565
13.29.16 recordDispute() 566
13.29.17 recordMastered() 566
13.29.18 recordPriority() 566
13.29.19 recordProposal() 566
13.29.20 recordTimes() 566
13.29.21 setReRootTree() 567
13.29.22 setSelectedTree() 567
13.29.23 setSyncTree() 567
13.29.24 setTcFlags() 567
13.29.25 setTcPropTree() 567
13.29.26 syncMaster() 567
13.29.27 txConfig() 567
13.29.28 txRstp() 568
13.29.29 txTcn() 568
13.29.30 updtAgreement() 568
13.29.31 updtBPDUVersion() 569
13.29.32 updtDigest() 569
13.29.33 updtRcvdInfoWhile() 570
13.29.34 updtRolesTree() 571
13.29.35 uptRolesDisabledTree() 572
13.30 The Port Timers state machine 572
13.31 Port Receive state machine 573
13.32 Port Protocol Migration state machine 574
13.33 Bridge Detection state machine 574
13.34 Port Transmit state machine 575
13.35 Port Information state machine 576
13.36 Port Role Selection state machine 577
13.37 Port Role Transitions state machine 577
13.38 Port State Transition state machine 582
13.38.1 Port State transitions for the CIST and MSTIs 583
13.38.2 Port State transitions for SPTs 583
13.39 Topology Change state machine 584
13.40 Layer 2 Gateway Port Receive state machine 585

Copyright © 2022 IEEE. All rights reserved.

13.41 CEP spanning tree operation ... 585
13.41.1 PEP operPointToPointMAC and operEdge ... 585
13.41.2 updtRolesTree() ... 586
13.41.3 setReRootTree(), setSyncTree(), setTcPropTree() ... 586
13.41.4 allSynced, reRooted ... 586
13.41.5 Configuration parameters ... 586
13.42 Virtual Instance Port (VIP) spanning tree operation ... 587

14. Encoding of Bridge Protocol Data Units (BPDUs) ... 588

14.1 BPDU Structure ... 588
14.1.1 Transmission and representation of octets ... 588
14.1.2 Common BPDU fields ... 588
14.2 Encoding of parameter types ... 590
14.2.1 Encoding of Protocol Identifiers ... 590
14.2.2 Encoding of Protocol Version Identifiers ... 590
14.2.3 Encoding of BPDU types ... 590
14.2.4 Encoding of flags ... 590
14.2.5 Encoding of Bridge Identifiers ... 590
14.2.6 Encoding of External Root Path Cost and Internal Root Path Cost ... 591
14.2.7 Encoding of Port Identifiers ... 591
14.2.8 Encoding of Timer Values ... 591
14.2.9 Encoding of Port Role values ... 591
14.2.10 Encoding of Length Values ... 592
14.2.11 Encoding of Hop Counts ... 592
14.3 Transmission of BPDUs ... 592
14.4 Encoding and decoding of STP Configuration, RST, MST, and SPT BPDUs ... 592
14.4.1 MSTI Configuration Messages ... 594
14.5 Validation of received BPDUs ... 595
14.6 Validation and interoperability ... 596

15. Support of the MAC Service by PBNs ... 597

15.1 Service transparency ... 597
15.2 Customer service interfaces ... 598
15.3 Port-based service interface ... 598
15.4 C-tagged service interface ... 599
15.5 S-tagged service interface ... 600
15.6 Remote customer service interfaces (RCSIs) ... 601
15.7 Service instance segregation ... 604
15.8 Service instance selection and identification ... 604
15.9 Service priority selection ... 605
15.10 Service access protection ... 605

16. Principles of Provider Bridged Network (PBN) operation ... 606

16.1 PBN overview ... 606
16.2 Provider Bridged Network (PBN) ... 607
16.3 Service instance connectivity ... 610
16.4 Service provider learning of customer end station addresses ... 611
16.5 Detection of connectivity loops through attached networks ... 611
16.6 Network management ... 612

17. Management Information Base (MIB) ... 613

17.1 Internet Standard Management Framework ... 613

Copyright © 2022 IEEE. All rights reserved.

17.2 Structure of the MIB 613
17.2.1 Structure of the IEEE8021-TC-MIB 615
17.2.2 Structure of the IEEE8021-BRIDGE-MIB 616
17.2.3 Structure of the IEEE8021-SPANNING-TREE MIB 620
17.2.4 Structure of the IEEE8021-Q-BRIDGE-MIB 623
17.2.5 Structure of the IEEE8021-PB-MIB 628
17.2.6 Structure of the IEEE8021-MSTP-MIB 630
17.2.7 Structure of the IEEE8021-CFM-MIB 633
17.2.8 Structure of the IEEE8021-PBB-MIB 639
17.2.9 Structure of the IEEE8021-DDCFM-MIBs 642
17.2.10 Structure of the IEEE8021-PBBTE-MIB 644
17.2.11 Structure of the TPMR MIB 647
17.2.12 Structure of the IEEE8021-FQTSS-MIB 649
17.2.13 Structure of the IEEE8021-CN-MIB 650
17.2.14 Structure of the IEEE8021-SRP-MIB 652
17.2.15 Structure of the IEEE8021-MVRPX-MIB 654
17.2.16 Structure of the IEEE8021-MIRP-MIB 654
17.2.17 Structure of the IEEE8021-PFC-MIB 655
17.2.18 Structure of the IEEE8021-TEIPS-MIB 655
17.2.19 Structure of the IEEE8021-SPB-MIB 657
17.2.20 Structure of the IEEE8021-EVB-MIB 662
17.2.21 Structure of the IEEE8021-ECMP-MIB 666
17.2.22 Structure of the IEEE8021-ST-MIB 667
17.2.23 Structure of the IEEE8021-Preemption-MIB 668
17.2.24 Structure of the IEEE8021-PSFP-MIB 668
17.2.25 Structure of the IEEE8021-TSN-REMOTE-MANAGEMENT-MIB 671
17.3 MIB module relationships 673
17.3.1 Relationship of the IEEE8021-TC-MIB to other MIB modules 673
17.3.2 Relationship of the IEEE8021-BRIDGE-MIB to other MIB modules 673
17.3.3 Relationship of the IEEE8021-RSTP MIB to other MIB modules 676
17.3.4 Relationship of the IEEE8021-Q-BRIDGE-MIB to other MIB modules 676
17.3.5 Relationship of the IEEE8021-PB-BRIDGE MIB to other MIB modules 678
17.3.6 Relationship of the IEEE8021-MSTP-MIB to other MIB modules 678
17.3.7 Relationship of the IEEE8021-CFM-MIB to other MIB modules 678
17.3.8 Relationship of the IEEE8021-PBB-MIB to other MIB modules 679
17.3.9 Relationship of the IEEE8021-DDCFM to other MIB modules 680
17.3.10 Relationship of the IEEE8021-PBBTE-MIB to other MIB modules 680
17.3.11 Relationship of the IEEE8021-TPMR MIB to other MIB modules 681
17.3.12 Relationship of the IEEE8021-FQTSS-MIB to other MIB modules 681
17.3.13 Relationship of the IEEE802-CN-MIB to other MIB modules 681
17.3.14 Relationship of the IEEE8021-SRP-MIB to other MIB modules 682
17.3.15 Relationship of the IEEE8021-MVRPX-MIB to other MIB modules 682
17.3.16 Relationship of the IEEE8021-MIRP-MIB to other MIB modules 682
17.3.17 Relationship of the IEEE8021-PFC-MIB to other MIB modules 682
17.3.18 Relationship of the IEEE8021-TEIPS-MIB to other MIB modules 683
17.3.19 Relationship of the IEEE8021-SPB-MIB to other MIB modules 683
17.3.20 Relationship of the IEEE8021-EVB-MIB to other MIB modules 683
17.3.21 Relationship of the IEEE8021-ECMP-MIB to other MIB modules 683
17.3.22 Relationship of the IEEE8021-ST-MIB to other MIB modules 683
17.3.23 Relationship of the IEEE8021-Preemption-MIB to other MIB modules 684
17.3.24 Relationship of IEEE8021-PSFP-MIB to other MIB modules 684
17.3.25 Relationship of IEEE8021-TSN-REMOTE-MANAGEMENT-MIB to other MIB modules 684

Copyright © 2022 IEEE. All rights reserved.

17.4 Security considerations 684
17.4.1 Security considerations of the IEEE8021-TC-MIB 684
17.4.2 Security considerations of the IEEE8021-BRIDGE-MIB 685
17.4.3 Security considerations of the IEEE8021-SPANNING-TREE MIB 686
17.4.4 Security considerations of the IEEE8021-Q-BRIDGE-MIB 686
17.4.5 Security considerations of the IEEE8021-PB-MIB 687
17.4.6 Security considerations of the IEEE8021-MSTP-MIB 687
17.4.7 Security considerations of the IEEE8021-CFM-MIB 688
17.4.8 Security considerations of the IEEE8021-PBB-MIB 690
17.4.9 Security considerations of the IEEE8021-DDCFM-MIB 691
17.4.10 Security considerations of the IEEE8021-PBBTE-MIB 691
17.4.11 Security considerations of the IEEE8021-TPMR-MIB 692
17.4.12 Security considerations of the IEEE8021-FQTSS-MIB 692
17.4.13 Security considerations of the IEEE8021-CN-MIB 693
17.4.14 Security considerations of the IEEE8021-SRP-MIB 695
17.4.15 Security considerations of the IEEE8021-MVRPX-MIB 695
17.4.16 Security considerations of the IEEE8021-MIRP-MIB 696
17.4.17 Security considerations of the IEEE8021-PFC-MIB 696
17.4.18 Security considerations of the IEEE8021-TEIPS-MIB 696
17.4.19 Security considerations of the IEEE8021-SPB-MIB 697
17.4.20 Security considerations of the IEEE8021-EVB-MIB 697
17.4.21 Security considerations of the IEEE8021-ECMP-MIB 699
17.4.22 Security considerations of the IEEE8021-ST-MIB 699
17.4.23 Security considerations of the IEEE8021-Preemption-MIB 700
17.4.24 Security considerations of the IEEE8021-PSFP-MIB 700
17.4.25 Security considerations of the IEEE8021-TSN-REMOTE-MANAGEMENT-MIB 702
17.5 Dynamic component and Port creation 703
17.5.1 Overview of the dynamically created Bridge entities 703
17.5.2 Component creation 704
17.5.3 Port creation 705
17.6 MIB operations for service interface configuration 715
17.6.1 Provisioning PBN service interfaces 715
17.6.2 Provisioning Backbone Bridged Network service interfaces 718

Copyright © 2022 IEEE. All rights reserved.

17.7 MIB modules 724
17.7.1 Definitions for the IEEE8021-TC-MIB module 724
17.7.2 Definitions for the IEEE8021-BRIDGE-MIB module 733
17.7.3 Definitions for the IEEE8021-SPANNING-TREE-MIB module 766
17.7.4 Definitions for the IEEE8021-Q-BRIDGE-MIB module 781
17.7.5 Definitions for the IEEE8021-PB-MIB module 819
17.7.6 Definitions for the IEEE8021-MSTP-MIB module 834
17.7.7 Definitions for the CFM MIB modules 858
17.7.8 Definitions for the IEEE8021-PBB-MIB module 926
17.7.9 Definitions for the IEEE8021-DDCFM-MIB module 945
17.7.10 Definitions for the IEEE8021-PBBTE-MIB module 960
17.7.11 Definitions for the IEEE8021-TPMR-MIB module 974
17.7.12 Definitions for the IEEE8021-FQTSS-MIB module 986
17.7.13 Definitions for the IEEE8021-CN-MIB module 998
17.7.14 Definitions for the IEEE8021-SRP-MIB module 1028
17.7.15 Definitions for the IEEE8021-MVRPX-MIB module 1046
17.7.16 Definitions for the IEEE8021-MIRP-MIB module 1050
17.7.17 Definitions for the IEEE8021-PFC-MIB module 1055
17.7.18 Definitions for the IEEE8021-TEIPS-V2-MIB module 1058
17.7.19 Definitions for the IEEE8021-SPB-MIB module 1070
17.7.20 Definitions for the IEEE8021-EVB-MIB module 1106
17.7.21 Definitions for the IEEE8021-ECMP-MIB module 1130
17.7.22 Definitions for the IEEE8021-ST-MIB module 1137
17.7.23 Definitions for the IEEE8021-Preemption-MIB module 1148
17.7.24 Definitions for the IEEE8021-PSFP-MIB module 1153
17.7.25 Definitions for the IEEE8021-TSN-REMOTE-MANAGEMENT-MIB module 1173

18. Principles of Connectivity Fault Management operation 1182

18.1 Maintenance Domains and DoSAPs 1183
18.2 Service instances and MAs 1185
18.3 Maintenance Domain Levels 1186

19. CFM entity operation 1190

19.1 Maintenance Points (MPs) 1190

Copyright © 2022 IEEE. All rights reserved.

19.2 MA Endpoints (MEPs) ... 1190
19.2.1 MEP identification ... 1190
19.2.2 MEP functions ... 1192
19.2.3 MEP architecture ... 1192
19.2.4 MP Type Demultiplexer ... 1194
19.2.5 MP Multiplexer ... 1194
19.2.6 MP Level Demultiplexer ... 1194
19.2.7 MP OpCode Demultiplexer ... 1194
19.2.8 MEP Continuity Check Receiver ... 1194
19.2.9 MEP Continuity Check Initiator ... 1195
19.2.10 MP Loopback Responder ... 1195
19.2.11 MEP Loopback Initiator ... 1196
19.2.12 MEP Linktrace Initiator ... 1196
19.2.13 MEP LTI SAP ... 1196
19.2.14 MEP Linktrace SAP ... 1196
19.2.15 MEP CCM Database ... 1196
19.2.16 MEP Fault Notification Generator ... 1196
19.2.17 MEP Decapsulator Responder (DR) ... 1196
19.2.18 MEP RFM Receiver ... 1197
19.3 MIP Half Function ... 1197
19.3.1 MHF identification ... 1197
19.3.2 MHF functions ... 1197
19.3.3 MHF architecture ... 1198
19.3.4 MHF Level Demultiplexer ... 1198
19.3.5 MHF Type Demultiplexer ... 1199
19.3.6 MHF OpCode Demultiplexer ... 1199
19.3.7 MHF Multiplexer ... 1199
19.3.8 MHF Loopback Responder ... 1199
19.3.9 MHF Continuity Check Receiver ... 1199
19.3.10 MIP CCM Database ... 1199
19.3.11 MHF Linktrace SAP ... 1199
19.3.12 MHF DR ... 1199
19.3.13 MHF RFM Receiver ... 1199
19.4 MP addressing ... 1200
19.5 Linktrace Output Multiplexer (LOM) ... 1200
19.6 Linktrace Responder ... 1201

20. CFM protocols ... 1203

20.1 Continuity Check protocol ... 1204
20.1.1 MAC status reporting in the CCM ... 1206
20.1.2 Defects and Fault Alarms ... 1206
20.1.3 CCM reception ... 1206
20.2 Loopback protocol ... 1207
20.2.1 LBM transmission ... 1207
20.2.2 LBM reception and LBR transmission ... 1208
20.2.3 LBR reception ... 1209
20.3 Linktrace protocol ... 1209
20.3.1 LTM origination ... 1210
20.3.2 LTM reception, forwarding, and replying ... 1211
20.3.3 LTR reception ... 1212
20.4 CFM state machines ... 1213

Copyright © 2022 IEEE. All rights reserved.

20.5 CFM state machine timers ... 1213
20.5.1 LTFwhile ... 1213
20.5.2 CCIwhile ... 1213
20.5.3 errorCCMwhile ... 1214
20.5.4 xconCCMwhile ... 1215
20.5.5 LBIwhile ... 1215
20.5.6 FNGwhile ... 1215
20.5.7 mmCCMwhile ... 1215
20.5.8 mmLocwhile ... 1215
20.5.9 mmFNGwhile ... 1215
20.5.10 rMEPwhile ... 1215
20.6 CFM procedures ... 1215
20.6.1 CCMtime() ... 1215
20.7 Maintenance Domain variable ... 1216
20.7.1 mdLevel ... 1216
20.8 MA variables ... 1216
20.8.1 CCMinterval ... 1216
20.9 MEP variables ... 1216
20.9.1 MEPactive ... 1217
20.9.2 enableRmepDefect ... 1217
20.9.3 MAdefectIndication ... 1217
20.9.4 allRMEPsDead ... 1218
20.9.5 lowestAlarmPri ... 1218
20.9.6 presentRDI ... 1218
20.9.7 MEPprimaryVID ... 1218
20.9.8 presentTraffic ... 1218
20.9.9 presentmmLoc ... 1218
20.9.10 ISpresentTraffic ... 1218
20.9.11 ISpresentmmLoc ... 1218
20.9.12 EpMEP ... 1219
20.10 MEP Continuity Check Initiator variables ... 1219
20.10.1 CCIenabled ... 1219
20.10.2 CCIsentCCMs ... 1219
20.10.3 MACstatusChanged ... 1219
20.10.4 Npaths ... 1219
20.10.5 flowHash[ ] ... 1219
20.10.6 pathN ... 1219
20.10.7 CCMcnt ... 1220
20.11 MEP Continuity Check Initiator procedures ... 1220
20.11.1 xmitCCM() ... 1220
20.12 MEP Continuity Check Initiator state machine ... 1221
20.13 MHF Continuity Check Receiver variables ... 1221
20.13.1 MHFrecvdCCM ... 1221
20.13.2 MHFCCMPDU ... 1221
20.14 MHF Continuity Check Receiver procedures ... 1222
20.14.1 MHFprocessCCM() ... 1222
20.15 MHF Continuity Check Receiver state machine ... 1222

Copyright © 2022 IEEE. All rights reserved.

20.16 MEP Continuity Check Receiver variables 1222
20.16.1 CCMreceivedEqual 1223
20.16.2 CCMequalPDU 1223
20.16.3 CCMreceivedLow 1223
20.16.4 CCMlowPDU 1223
20.16.5 recvdMacAddress 1223
20.16.6 recvdRDI 1223
20.16.7 recvdInterval 1223
20.16.8 recvdPortState 1223
20.16.9 recvdInterfaceStatus 1223
20.16.10 recvdSenderId 1224
20.16.11 recvdFrame 1224
20.16.12 CCMsequenceErrors 1224
20.16.13 rcvdTrafficBit 1224
20.17 MEP Continuity Check Receiver procedures 1224
20.17.1 MEPprocessEqualCCM() 1224
20.17.2 MEPprocessLowCCM() 1225
20.18 MEP Continuity Check Receiver state machine 1225
20.19 Remote MEP variables 1225
20.19.1 rMEPCCMdefect 1226
20.19.2 rMEPlastRDI and rMEPlastRDI[i] 1226
20.19.3 rMEPlastPortState 1226
20.19.4 rMEPlastInterfaceStatus 1226
20.19.5 rMEPlastSenderId 1227
20.19.6 rCCMreceived 1227
20.19.7 rMEPmacAddress 1227
20.19.8 rMEPportStatusDefect 1227
20.19.9 rMEPinterfaceStatusDefect 1227
20.19.10 lastPathN 1227
20.20 Remote MEP state machine 1227
20.21 Remote MEP Error variables 1227
20.21.1 errorCCMreceived 1228
20.21.2 errorCCMlastFailure 1228
20.21.3 errorCCMdefect 1229
20.22 Remote MEP Error state machine 1229
20.23 MEP Cross Connect variables 1229
20.23.1 xconCCMreceived 1229
20.23.2 xconCCMlastFailure 1229
20.23.3 xconCCMdefect 1230
20.24 MEP Cross Connect state machine 1230
20.25 MEP Mismatch variables 1230
20.25.1 mmCCMreceived 1230
20.25.2 mmCCMdefect 1231
20.25.3 mmCCMTime 1231
20.25.4 disableLocdefect 1231
20.25.5 mmLocdefect 1231
20.26 MEP Mismatch state machines 1231
20.27 MP Loopback Responder variables 1231
20.27.1 LBMreceived 1231
20.27.2 LBMPDU 1232
20.28 MP Loopback Responder procedures 1233
20.28.1 ProcessLBM() 1233
20.28.2 xmitLBR() 1233
20.29 MP Loopback Responder state machine 1234

Copyright © 2022 IEEE. All rights reserved.

20.30 MEP Loopback Initiator variables ... 1234
20.30.1 LBMsToSend ... 1235
20.30.2 nextLBMtransID ... 1235
20.30.3 expectedLBRtransID ... 1235
20.30.4 LBIactive ... 1235
20.30.5 xmitReady ... 1235
20.30.6 LBRreceived ... 1235
20.30.7 LBRPDU ... 1235
20.31 MEP Loopback Initiator transmit procedures ... 1235
20.31.1 xmitLBM() ... 1236
20.32 MEP Loopback Initiator transmit state machine ... 1236
20.33 MEP Loopback Initiator receive procedures ... 1236
20.33.1 ProcessLBR() ... 1237
20.34 MEP Loopback Initiator receive state machine ... 1238
20.35 MEP Fault Notification Generator variables ... 1238
20.35.1 fngPriority ... 1238
20.35.2 fngDefect ... 1238
20.35.3 fngAlarmTime ... 1238
20.35.4 fngResetTime ... 1239
20.35.5 someRMEPCCMdefect ... 1239
20.35.6 someMACstatusDefect ... 1239
20.35.7 someRDIdefect ... 1239
20.35.8 highestDefectPri ... 1239
20.35.9 highestDefect ... 1239
20.36 MEP Fault Notification Generator procedures ... 1239
20.36.1 xmitFaultAlarm() ... 1240
20.37 MEP Fault Notification Generator state machine ... 1240
20.38 MEP Mismatch Fault Notification Generator variables ... 1240
20.38.1 mfngAllowed ... 1241
20.38.2 mmdefectIndication ... 1241
20.38.3 mfngAlarmTime ... 1241
20.38.4 mfngResetTime ... 1241
20.39 MEP Mismatch Fault Notification Generator procedures ... 1241
20.39.1 xmitFaultAlarm() ... 1241
20.40 MEP Mismatch Fault Notification Generator state machine ... 1241
20.41 MEP Linktrace Initiator variables ... 1241
20.41.1 nextLTMtransID ... 1242
20.41.2 ltmReplyList ... 1242
20.42 MEP Linktrace Initiator procedures ... 1244
20.42.1 xmitLTM() ... 1244
20.43 MEP Linktrace Initiator receive variables ... 1245
20.43.1 LTRreceived ... 1245
20.43.2 LTRPDU ... 1245
20.44 MEP Linktrace Initiator receive procedures ... 1245
20.44.1 ProcessLTR() ... 1246
20.45 MEP Linktrace Initiator receive state machine ... 1246
20.46 Linktrace Responder variables ... 1246
20.46.1 nPendingLTRs ... 1246
20.46.2 LTMreceived ... 1247
20.46.3 LTMPDU ... 1247

Copyright © 2022 IEEE. All rights reserved.

20.47 LTM Receiver procedures 1247
20.47.1 ProcessLTM() 1247
20.47.2 clearPendingLTRs() 1251
20.47.3 ForwardLTM() 1251
20.47.4 enqueLTR() 1252
20.48 LTM Receiver state machine 1254
20.49 LTR Transmitter procedure 1254
20.49.1 xmitOldestLTR() 1254
20.50 LTR Transmitter state machine 1254
20.51 CFM PDU validation and versioning 1254
20.51.1 Goals of CFM PDU versioning 1255
20.51.2 PDU transmission 1255
20.51.3 PDU validation 1256
20.51.4 Validation pass 1256
20.51.5 Execution pass 1257
20.51.6 Future extensions 1258
20.52 PDU identification 1258
20.53 Use of transaction IDs and sequence numbers 1258

21. Encoding of CFM PDUs 1260

21.1 Structure, representation, and encoding 1260
21.2 CFM encapsulation 1260
21.3 CFM request and indication parameters 1261
21.3.1 destination_address parameter 1261
21.3.2 source_address parameter 1261
21.4 Common CFM Header 1261
21.4.1 MD Level 1261
21.4.2 Version 1261
21.4.3 OpCode 1262
21.4.4 Flags 1262
21.4.5 First TLV Offset 1263
21.5 TLV format 1263
21.5.1 General format for CFM TLVs 1263
21.5.2 Organization-Specific TLV 1263
21.5.3 Sender ID TLV 1265
21.5.4 Port Status TLV 1266
21.5.5 Interface Status TLV 1267
21.5.6 Data TLV 1268
21.5.7 End TLV 1268
21.6 CCM format 1268
21.6.1 Flags 1269
21.6.2 First TLV Offset 1270
21.6.3 Sequence Number 1270
21.6.4 Maintenance association Endpoint Identifier 1270
21.6.5 Maintenance Association Identifier 1270
21.6.6 Defined by ITU-T G.8013/Y.1731 1273
21.6.7 Optional CCM TLVs 1273
21.7 LBM and LBR formats 1273
21.7.1 Flags 1274
21.7.2 First TLV Offset 1274
21.7.3 Loopback Transaction Identifier 1274
21.7.4 Additional LBM/LBR TLVs 1274
21.7.5 PBB-TE MIP TLV 1274

Copyright © 2022 IEEE. All rights reserved.

21.8 LTM format ... 1275
21.8.1 Flags ... 1276
21.8.2 First TLV Offset ... 1276
21.8.3 LTM Transaction Identifier ... 1276
21.8.4 LTM TTL ... 1276
21.8.5 Original MAC Address ... 1276
21.8.6 Target MAC Address ... 1276
21.8.7 Additional LTM TLVs ... 1277
21.8.8 LTM Egress Identifier TLV ... 1277
21.9 LTR format ... 1277
21.9.1 Flags ... 1277
21.9.2 First TLV Offset ... 1278
21.9.3 LTR Transaction Identifier ... 1278
21.9.4 Reply TTL ... 1278
21.9.5 Relay Action ... 1279
21.9.6 Additional LTR TLVs ... 1279
21.9.7 LTR Egress Identifier TLV ... 1279
21.9.8 Reply Ingress TLV ... 1280
21.9.9 Reply Egress TLV ... 1281

22. CFM in systems ... 1283

22.1 CFM shims in Bridges ... 1283
22.1.1 Preliminary positioning of MPs ... 1283
22.1.2 CFM and the Forwarding Process ... 1284
22.1.3 Up/Down separation of MPs ... 1286
22.1.4 Service instances over multiple Bridges ... 1288
22.1.5 Multiple VID service instances ... 1290
22.1.6 Untagged CFM PDUs ... 1290
22.1.7 MPs and non-VLAN-aware Bridges ... 1290
22.1.8 MPs and other standards ... 1291
22.1.9 CFM and IEEE 802.3 OAM ... 1293
22.2 Maintenance Entity creation ... 1293
22.2.1 Creating Maintenance Domains and MAs ... 1294
22.2.2 Creating MEPs ... 1294
22.2.3 Creating MIPs ... 1296
22.2.4 CFM configuration errors ... 1297
22.3 MPs, Ports, and MD Level assignment ... 1298
22.4 Stations and CFM ... 1298
22.5 Scalability of CFM ... 1299
22.6 CFM in Provider Bridges ... 1300
22.6.1 MPs and C-VLAN components ... 1300
22.6.2 Maintenance C-VLAN on a Port-based service interface ... 1300
22.6.3 Maintenance C-VLAN on a C-tagged service interface ... 1302
22.6.4 MPs and Port-mapping S-VLAN components ... 1302
22.7 Management Port MEPs and CFM in the enterprise environment ... 1304
22.8 Implementing CFM on Bridges that implement earlier revisions of IEEE Std 802.1Q ... 1306

23. MAC status propagation ... 1307

23.1 Model of operation ... 1309
23.1.1 MAC Status Shim (MSS) ... 1310
23.1.2 Relationship of CFM to the MSS ... 1310
23.2 MAC Status Protocol (MSP) overview ... 1310
23.3 MSP state machines ... 1315

Copyright © 2022 IEEE. All rights reserved.

23.4 State machine timers ... 1316
23.4.1 linkNotifyWhen ... 1316
23.4.2 linkNotifyWhile ... 1316
23.4.3 macNotifyWhile ... 1316
23.4.4 macRecoverWhile ... 1316
23.5 MSP performance parameters ... 1316
23.5.1 LinkNotify ... 1317
23.5.2 LinkNotifyWait ... 1317
23.5.3 LinkNotifyRetry ... 1317
23.5.4 MACNotify ... 1317
23.5.5 MACNotifyTime ... 1317
23.5.6 MACRecoverTime ... 1317
23.6 State machine variables ... 1317
23.6.1 BEGIN ... 1317
23.6.2 addConfirmed ... 1317
23.6.3 disableMAC ... 1317
23.6.4 disabledMAC ... 1317
23.6.5 disableMSS ... 1317
23.6.6 lossConfirmed ... 1317
23.6.7 macOperational ... 1318
23.6.8 mssOperational ... 1318
23.6.9 prop ... 1318
23.6.10 rxAck ... 1318
23.6.11 rxAdd ... 1318
23.6.12 rxAddConfirm ... 1318
23.6.13 rxLoss ... 1318
23.6.14 rxLossConfirm ... 1318
23.6.15 txAck ... 1318
23.6.16 txAdd ... 1318
23.6.17 txAddConfirm ... 1318
23.6.18 txLoss ... 1318
23.6.19 txLossConfirm ... 1318
23.7 State machine procedures ... 1319
23.8 Status Transition state machine (STM) ... 1319
23.9 Status Notification state machine (SNM) ... 1319
23.10 Receive Process ... 1319
23.11 Transmit Process ... 1319
23.12 Management of MSP ... 1320
23.13 MSPDU transmission, addressing, and protocol identification ... 1321
23.13.1 Destination MAC Address ... 1321
23.13.2 Source MAC Address ... 1321
23.13.3 Priority ... 1321
23.13.4 EtherType use and encoding ... 1321
23.14 Representation and encoding of octets ... 1322
23.15 MSPDU structure ... 1322
23.15.1 Protocol Version ... 1322
23.15.2 Packet Type ... 1322
23.16 Validation of received MSPDUs ... 1323
23.17 Other MSP participants ... 1323

24. Bridge performance ... 1324

24.1 Guaranteed Port Filtering Rate ... 1324
24.2 Guaranteed Bridge Relaying Rate ... 1324

Copyright © 2022 IEEE. All rights reserved.

24.3 RSTP performance requirements 1324

25. Support of the MAC Service by PBBNs 1326

25.1 Service transparency 1328
25.2 Customer service interface 1328
25.3 Port-based service interface 1329
25.4 S-tagged service interface 1330
25.5 I-tagged service interface 1332
25.6 Service instance segregation 1334
25.7 Service instance selection and identification 1334
25.8 Service priority and drop eligibility selection 1334
25.9 Service access protection 1335
25.9.1 Class II redundant LANs access protection 1337
25.9.2 Class III simple redundant LANs and nodes access protection 1337
25.10 Support of the MAC Service by a PBB-TE Region 1338
25.10.1 Provisioning TESIs 1339
25.10.2 ESP forwarding behavior 1341
25.11 Transparent service interface 1342

26. Principles of Provider Backbone Bridged Network (PBBN) operation 1344

26.1 PBBN overview 1344
26.2 PBBN example 1345
26.3 B-VLAN connectivity 1347
26.4 Backbone addressing 1347
26.4.1 Learning individual backbone addresses at a PIP 1348
26.4.2 Translating backbone destination addresses at a CBP 1349
26.4.3 Backbone addressing considerations for CFM MPs 1349
26.5 Detection of connectivity loops through attached networks 1350
26.6 Scaling of PBBs 1350
26.6.1 Hierarchal PBBNs 1350
26.6.2 Peer PBBNs 1351
26.7 Network management 1351
26.8 CFM in PBBs 1351
26.8.1 CFM over Port-based and S-tagged service interfaces 1356
26.8.2 CFM over I-tagged Service Interfaces 1357
26.8.3 CFM over hierarchal E-NNI 1357
26.8.4 CFM over peer E-NNI 1358
26.9 CFM in a PBB-TE Region 1358
26.9.1 Addressing PBB-TE MEPs 1359
26.9.2 TESI identification 1359
26.9.3 PBB-TE MEP placement in a Bridge Port 1359
26.9.4 PBB-TE MIP placement in a Bridge Port 1360
26.9.5 TESI Maintenance Domains 1360
26.9.6 PBB-TE enhancements of the CFM protocols 1360
26.9.7 Addressing Infrastructure Segment MEPs 1362
26.9.8 Infrastructure Segment identification 1363
26.9.9 Infrastructure Segment MEP placement in a Bridge Port 1363
26.9.10 Infrastructure Segment Maintenance Domains 1365
26.9.11 IPS extensions to Continuity Check operation 1365
26.10 Protection switching for point-to-point TESIs 1365
26.10.1 Introduction 1365
26.10.2 1:1 point-to-point TESI protection switching 1366
26.10.3 Protection Switching state machines 1369

Copyright © 2022 IEEE. All rights reserved.

26.11 IPS in PBB-TE Region ... 1375
26.11.1 Infrastructure Segment monitoring ... 1376
26.11.2 1:1 IPS ... 1376
26.11.3 IPS Control entity ... 1379
26.11.4 1:1 IPS state machines ... 1380
26.11.5 M:1 IPS ... 1381
26.12 Mismatch defect ... 1386
26.13 Signaling VLAN registrations among I-components ... 1387

27. Shortest Path Bridging (SPB) ... 1388

27.1 Protocol design requirements ... 1390
27.2 Protocol support ... 1391
27.3 Protocol design goals ... 1392
27.4 ISIS-SPB VLAN configuration ... 1392
27.4.1 SPT Region and ISIS-SPB adjacency determination ... 1393
27.5 ISIS-SPB information ... 1395
27.6 Calculating CIST connectivity ... 1396
27.7 Connectivity between regions in the same domain ... 1397
27.8 Calculating SPT connectivity ... 1397
27.8.1 ISIS-SPB overload ... 1398
27.9 Loop prevention ... 1398
27.10 SPVID and SPSourceID allocation ... 1398
27.11 Allocation of VIDs to FIDs ... 1400
27.12 SPBV SPVID translation ... 1401
27.13 VLAN topology management ... 1401
27.14 Individual addresses and SPBM ... 1402
27.14.1 Loop mitigation ... 1403
27.14.2 Loop prevention ... 1403
27.15 SPBM group addressing ... 1403
27.16 Backbone service instance topology management ... 1405
27.17 Equal cost shortest paths, ECTs, and load spreading ... 1406
27.18 Connectivity Fault Management for SPBM ... 1406
27.18.1 SPBM MA types ... 1406
27.18.2 SPBM MEP placement in a Bridge Port ... 1407
27.18.3 SPBM MIP placement in a Bridge Port ... 1408
27.18.4 SPBM modifications of the CFM protocols ... 1408
27.19 Using SPBV and SPBM modes ... 1409
27.19.1 Shortest Path Bridging—VID ... 1409
27.19.2 Shortest Path Bridging—MAC ... 1410
27.20 Security considerations ... 1412

28. ISIS-SPB Link State Protocol ... 1413

28.1 ISIS-SPB control plane MAC ... 1413
28.2 Formation and maintenance of ISIS-SPB adjacencies ... 1414
28.3 Loop prevention ... 1415
28.4 The Agreement Digest ... 1415
28.4.1 Agreement Digest Format Identifier ... 1415
28.4.2 Agreement Digest Format Capabilities ... 1416
28.4.3 Agreement Digest Convention Identifier ... 1416
28.4.4 Agreement Digest Convention Capabilities ... 1416
28.4.5 Agreement Digest Edge Count ... 1417
28.4.6 The Computed Topology Digest ... 1417
28.5 Symmetric shortest path tie breaking ... 1418

Copyright © 2022 IEEE. All rights reserved.

28.6 Symmetric ECT framework ... 1419
28.7 Symmetric ECT ... 1420
28.8 Symmetric ECT Algorithm details ... 1421
28.9 ECT Migration ... 1422
28.9.1 Use of a new ECT Algorithm in SPBV ... 1422
28.9.2 Use of a new ECT Algorithm in SPBM ... 1423
28.10 MAC address registration ... 1424
28.11 Circuit IDs and Port Identifiers ... 1424
28.12 ISIS-SPB TLVs ... 1424
28.12.1 MT-Capability TLV ... 1425
28.12.2 SPB MCID sub-TLV ... 1425
28.12.3 SPB Digest sub-TLV ... 1426
28.12.4 SPB Base VLAN-Identifiers sub-TLV ... 1427
28.12.5 SPB Instance sub-TLV ... 1428
28.12.6 SPB Instance Opaque ECT Algorithm sub-TLV ... 1429
28.12.7 SPB Link Metric sub-TLV ... 1431
28.12.8 SPB Adjacency Opaque ECT Algorithm sub-TLV ... 1431
28.12.9 SPBV MAC address sub-TLV ... 1432
28.12.10 SPBM Service Identifier and Unicast Address (ISID-ADDR) sub-TLV ... 1433

29. DDCFM operations and protocols ... 1436

29.1 Principles of DDCFM operation ... 1436
29.1.1 Data-driven and data-dependent faults (DDFs) ... 1436
29.1.2 Basic principle to diagnose and isolate DDFs ... 1436
29.2 DDCFM Entity operation ... 1439
29.2.1 DDCFM implementation ... 1439
29.2.2 FPT RR ... 1440
29.2.3 RR-related parameters ... 1441
29.2.4 Reflection Target and RFM Receiver ... 1442
29.2.5 RPT-related parameters ... 1442
29.2.6 Decapsulator Responder (DR) ... 1443
29.2.7 SFM Originator ... 1444
29.3 DDCFM protocols ... 1444
29.3.1 RR variables ... 1444
29.3.2 RR Filter procedures ... 1446
29.3.3 RR Encapsulation procedures ... 1447
29.3.4 RR Transmit procedure ... 1448
29.3.5 RR-related state machines ... 1449
29.3.6 RFM Receiver variables ... 1450
29.3.7 RFM Receiver procedure ... 1451
29.3.8 DR variables ... 1452
29.3.9 DR procedures ... 1452
29.3.10 Decapsulator Responder state machine ... 1454
29.4 Encoding of DDCFM PDUs ... 1454
29.4.1 RFM and SFM Header ... 1454
29.4.2 RFM format ... 1454
29.4.3 SFM format ... 1455

30. Principles of congestion notification ... 1457

30.1 Congestion notification design requirements ... 1457

Copyright © 2022 IEEE. All rights reserved.

30.2 Quantized Congestion Notification protocol (QCN) 1459
30.2.1 The CP algorithm 1460
30.2.2 Basic RP algorithm 1461
30.2.3 RP algorithm with timer 1462
30.3 Congestion Controlled Flow (CCF) 1463
30.4 Congestion Notification Priority Value (CNPV) 1464
30.5 Congestion Notification tag (CN-TAG) 1464
30.6 Congestion Notification Domain (CND) 1464
30.7 Multicast data 1465
30.8 Congestion notification and additional tags 1465

31. Congestion notification entity operation 1467

31.1 Congestion-aware Bridge Forwarding Process 1467
31.1.1 Congestion Point (CP) 1468
31.1.2 CP ingress multiplexer 1468
31.2 Congestion-aware end station functions 1468
31.2.1 Output flow segregation 1470
31.2.2 Per-CNPV station function 1470
31.2.3 Flow Select Database 1472
31.2.4 Flow multiplexer 1472
31.2.5 CNM demultiplexer 1472
31.2.6 Input flow segregation 1473
31.2.7 End station input queue 1473
31.2.8 Reception selection 1473

32. Congestion notification protocol 1474

32.1 CND operations 1474
32.1.1 CND defense 1474
32.1.2 Automatic CND recognition 1476
32.1.3 Variables controlling CND defense 1476
32.2 CN component variables 1477
32.2.1 cngMasterEnable 1478
32.2.2 cngCnmTransmitPriority 1478
32.2.3 cngDiscardedFrames 1478
32.2.4 cngErroredPortList 1478
32.3 Congestion notification per-CNPV variables 1478
32.3.1 cncpDefModeChoice 1478
32.3.2 cncpAlternatePriority 1479
32.3.3 cncpAutoAltPri 1479
32.3.4 cncpAdminDefenseMode 1479
32.3.5 cncpCreation 1479
32.3.6 cncpLldpInstanceChoice 1479
32.3.7 cncpLldpInstanceSelector 1479

Copyright © 2022 IEEE. All rights reserved.

32.4 CND defense per-Port per-CNPV variables ... 1480
32.4.1 cnpdDefModeChoice ... 1480
32.4.2 cnpdAdminDefenseMode ... 1480
32.4.3 cnpdAutoDefenseMode ... 1481
32.4.4 cnpdLldpInstanceChoice ... 1481
32.4.5 cnpdLldpInstanceSelector ... 1481
32.4.6 cnpdAlternatePriority ... 1481
32.4.7 cnpdXmitCnpvCapable ... 1481
32.4.8 cnpdXmitReady ... 1481
32.4.9 cncpDoesEdge ... 1482
32.4.10 cnpdAcceptsCnTag ... 1482
32.4.11 cnpdRcvdCnpv ... 1482
32.4.12 cnpdRcvdReady ... 1482
32.4.13 cnpdIsAdminDefMode ... 1482
32.4.14 cnpdDefenseMode ... 1482
32.5 CND defense procedures ... 1483
32.5.1 DisableCnpvRemapping() ... 1483
32.5.2 TurnOnCnDefenses() ... 1483
32.5.3 TurnOffCnDefenses() ... 1483
32.6 CND defense state machine ... 1483
32.7 Congestion notification protocol ... 1484
32.8 CP variables ... 1485
32.8.1 cpMacAddress ... 1486
32.8.2 cpId ... 1486
32.8.3 cpQSp ... 1486
32.8.4 cpQLen ... 1486
32.8.5 cpQLenOld ... 1486
32.8.6 cpW ... 1486
32.8.7 cpQOffset ... 1486
32.8.8 cpQDelta ... 1486
32.8.9 cpFb ... 1486
32.8.10 cpEnqued ... 1487
32.8.11 cpSampleBase ... 1487
32.8.12 cpDiscardedFrames ... 1487
32.8.13 cpTransmittedFrames ... 1487
32.8.14 cpTransmittedCnms ... 1487
32.8.15 cpMinHeaderOctets ... 1487
32.9 CP procedures ... 1487
32.9.1 Random ... 1487
32.9.2 NewCpSampleBase() ... 1487
32.9.3 EM_UNITDATA.request (parameters) ... 1488
32.9.4 GenerateCnmPdu() ... 1488
32.10 RP per-Port per-CNPV variables ... 1489
32.10.1 rpppMaxRps ... 1489
32.10.2 rpppCreatedRps ... 1489
32.10.3 rpppRpCentiseconds ... 1490

Copyright © 2022 IEEE. All rights reserved.

32.11 RP group variables ... 1490
32.11.1 rpgEnable ... 1490
32.11.2 rpgTimeReset ... 1490
32.11.3 rpgByteReset ... 1490
32.11.4 rpgThreshold ... 1491
32.11.5 rpgMaxRate ... 1491
32.11.6 rpgAiRate ... 1491
32.11.7 rpgHaiRate ... 1491
32.11.8 rpgGd ... 1491
32.11.9 rpgMinDecFac ... 1491
32.11.10 rpgMinRate ... 1491
32.12 RP timer ... 1491
32.12.1 RpWhile ... 1491
32.13 RP variables ... 1492
32.13.1 rpEnabled ... 1492
32.13.2 rpByteCount ... 1492
32.13.3 rpByteStage ... 1492
32.13.4 rpTimeStage ... 1492
32.13.5 rpTargetRate ... 1492
32.13.6 rpCurrentRate ... 1492
32.13.7 rpFreeze ... 1492
32.13.8 rpLimiterRate ... 1493
32.13.9 rpFb ... 1493
32.14 RP procedures ... 1493
32.14.1 ResetCnm ... 1493
32.14.2 TestRpTerminate ... 1493
32.14.3 TransmitDataFrame ... 1493
32.14.4 ReceiveCnm ... 1494
32.14.5 ProcessCnm ... 1494
32.14.6 AdjustRates ... 1494
32.15 RP rate control state machine ... 1495
32.16 Congestion notification and encapsulation interworking function ... 1497

33. Encoding of congestion notification PDUs ... 1499

33.1 Structure, representation, and encoding ... 1499
33.2 CN-TAG format ... 1499
33.2.1 Flow Identifier ... 1500
33.3 Congestion Notification Message (CNM) ... 1500
33.4 Congestion Notification Message PDU format ... 1500
33.4.1 Version ... 1500
33.4.2 ReservedV ... 1500
33.4.3 Quantized Feedback ... 1501
33.4.4 Congestion Point Identifier ... 1501
33.4.5 cnmQOffset ... 1501
33.4.6 cnmQDelta ... 1501
33.4.7 Encapsulated priority ... 1502
33.4.8 Encapsulated destination MAC address ... 1502
33.4.9 Encapsulated MSDU length ... 1502
33.4.10 Encapsulated MSDU ... 1502
33.4.11 CNM Validation ... 1502

34. Forwarding and Queuing Enhancements for time-sensitive streams (FQTSS) ... 1503

34.1 Overview ... 1503

Copyright © 2022 IEEE. All rights reserved.

34.2 Detection of SRP domains ... 1503
34.3 The bandwidth availability parameters ... 1504
34.3.1 deltaBandwidth when lockClassBandwidth is false ... 1504
34.3.2 deltaBandwidth when lockClassBandwidth is true ... 1505
34.3.3 Bandwidth availability parameter management ... 1505
34.4 Deriving actual bandwidth requirements from the size of the MSDU ... 1506
34.5 Default SR class configuration ... 1507
34.6 Transmission selection ... 1508
34.6.1 Credit-based shaper ... 1509
34.6.2 Strict priority ... 1510
34.6.3 Scheduled traffic ... 1511

35. Stream Reservation Protocol (SRP) ... 1512

35.1 Multiple Stream Registration Protocol (MSRP) ... 1513
35.1.1 MSRP and Shared Media ... 1514
35.1.2 Behavior of end stations ... 1515
35.1.3 Behavior of Bridges ... 1517
35.1.4 SRP domains and status parameters ... 1517
35.2 Definition of the MSRP application ... 1518
35.2.1 Definition of internal state variables ... 1518
35.2.2 Definition of MRP elements ... 1520
35.2.3 Provision and support of Stream registration service ... 1544
35.2.4 MSRP Attribute Propagation ... 1549
35.2.5 Operational reporting and statistics ... 1558
35.2.6 Encoding ... 1558
35.2.7 Attribute value support requirements ... 1559

36. Priority-based Flow Control (PFC) ... 1560

36.1 PFC operation ... 1560
36.1.1 Overview ... 1560
36.1.2 PFC primitives ... 1561
36.1.3 Detailed specification of PFC operation ... 1562
36.2 PFC-aware system queue functions ... 1563
36.2.1 PFC Initiator ... 1563
36.2.2 PFC Receiver ... 1563

37. Enhanced Transmission Selection (ETS) ... 1566

37.1 Overview ... 1566
37.1.1 Relationship to other transmission selection algorithms ... 1566
37.2 ETS configuration parameters ... 1566
37.3 ETS algorithm ... 1566
37.4 Legacy configuration ... 1567

38. Data Center Bridging eXchange protocol (DCBX) ... 1568

38.1 Overview ... 1568
38.2 Goals ... 1568
38.3 Types of DCBX attributes ... 1568
38.3.1 Informational attributes ... 1568
38.4 DCBX and LLDP ... 1568
38.4.1 Asymmetric attribute passing ... 1569
38.4.2 Symmetric attribute passing ... 1570

Copyright © 2022 IEEE. All rights reserved.

39. Multiple I-SID Registration Protocol (MIRP) 1572

39.1 MIRP overview 1572
39.1.1 Behavior of I-components 1574
39.1.2 Behavior of B-components 1574
39.2 Definition of the MIRP application 1574
39.2.1 Definition of MRP elements 1574
39.2.2 Alternate MIRP model for B-components 1577
39.2.3 Use of “new” declaration capability 1579
39.2.4 Attribute value support requirements 1579
39.2.5 MRP Message filtering 1579

40. Edge Virtual Bridging (EVB) 1580

40.1 EVB architecture without S-channels 1581
40.2 EVB architecture with S-channels 1582
40.3 Asymmetric EVB architecture without S-channels 1584
40.4 EVB status parameters 1586
40.4.1 EVBMode = Not supported 1586
40.4.2 EVBMode = EVB Bridge 1586
40.4.3 EVBMode = EVB station 1586
40.4.4 EVBMode = NVO3 Mode 1587
40.5 EVB Status Parameter for NVO3 Mode Support 1587
40.5.1 NVERole = nNVE 1587
40.5.2 NVERole = tNVE 1587

41. VSI Discovery and Configuration Protocol (VDP) 1588

41.1 VSI manager ID TLV definition 1588
41.1.1 TLV type 1589
41.1.2 TLV information string length 1589
41.1.3 VSI Manager ID 1589
41.2 VDP association TLV definitions 1589
41.2.1 TLV type 1590
41.2.2 TLV information string length 1590
41.2.3 Status 1590
41.2.4 VSI Type ID (VTID) 1591
41.2.5 VSI Type Version 1591
41.2.6 VSIID format 1591
41.2.7 VSIID 1592
41.2.8 Filter Info format 1592
41.2.9 Filter Info field 1593
41.2.10 VDP TLV type and status semantics 1597
41.3 Organizationally defined TLV definitions 1598
41.3.1 TLV type 1598
41.3.2 TLV information string length 1598
41.3.3 Organizationally unique identifier (OUI) or Company ID (CID) 1598
41.3.4 Organizationally defined information 1599
41.4 Validation rules for VDP TLVs 1599

Copyright © 2022 IEEE. All rights reserved.

41.5 VDP state machines ... 1599
41.5.1 State machine conventions ... 1599
41.5.2 Bridge VDP state machine ... 1600
41.5.3 Station VDP state machine ... 1601
41.5.4 VDP state machine timers ... 1602
41.5.5 VDP state machine variables and parameters ... 1602
41.5.6 Command-Response TLV field references in state machines ... 1604
41.5.7 VDP state machine procedures ... 1605

42. S-Channel Discovery and Configuration Protocol (CDCP) ... 1607

42.1 CDCP discovery and configuration ... 1607
42.2 CDCP state machine overview ... 1607
42.3 CDCP configuration state machine ... 1608
42.4 CDCP configuration variables ... 1609
42.4.1 AdminChnCap ... 1609
42.4.2 AdminRole ... 1610
42.4.3 AdminSVIDWants ... 1610
42.4.4 LastLocalSVIDPool ... 1610
42.4.5 LastRemoteSVIDList ... 1610
42.4.6 LastSVIDWants ... 1610
42.4.7 LocalSVIDPool ... 1610
42.4.8 OperChnCap ... 1610
42.4.9 OperRole ... 1610
42.4.10 OperSVIDList ... 1611
42.4.11 RemoteChnCap ... 1611
42.4.12 RemoteRole ... 1611
42.4.13 RemoteSVIDList ... 1611
42.4.14 schState ... 1611
42.5 CDCP configuration procedures ... 1611
42.5.1 SetSVIDRequest (OperRole, AdminSVIDWants, OperSVIDList) ... 1611
42.5.2 RxSVIDConfig (OperSVIDList, LastRemoteSVIDList) ... 1612
42.5.3 TxSVIDConfig (OperChnCap, RemoteChnCap, LastLocalSVIDPool, RemoteSVIDList, OperSVIDList) ... 1612

43. Edge Control Protocol (ECP) ... 1613

43.1 ECP operation ... 1613
43.2 Edge Control Sublayer Service (ECSS) ... 1614
43.3 ECP state machines ... 1614
43.3.1 State machine conventions ... 1614
43.3.2 Overview ... 1614
43.3.3 Edge Control Protocol Data Unit (ECPDU) ... 1615
43.3.4 ECP transmit state machine ... 1616
43.3.5 ECP receive state machine ... 1617
43.3.6 ECP state machine timers ... 1617
43.3.7 ECP state machine variables and parameters ... 1618
43.3.8 ECP state machine procedures ... 1619

44. Equal Cost Multiple Paths (ECMP) ... 1620

44.1 SPBM ECMP ... 1620
44.1.1 ECMP Operation ... 1620
44.1.2 ECMP ECT Algorithm ... 1621
44.1.3 Loop prevention for ECMP ... 1623

Copyright © 2022 IEEE. All rights reserved.

44.2 Support for Flow Filtering 1623
44.2.1 Flow filtering tag (F-TAG) 1624
44.2.2 F-TAG processing 1625
44.2.3 Forwarding process extension for flow filtering 1626
44.2.4 TTL Loop mitigation 1627
44.2.5 CFM for ECMP with flow filtering 1627
44.2.6 Operation with selective support for flow filtering 1629

45. Path Control and Reservation (PCR) 1630

45.1 Explicit trees 1630
45.1.1 Tree structures 1634
45.1.2 Explicit ECT Algorithms 1635
45.1.3 ISIS-PCR VLAN configuration 1637
45.1.4 Use of VIDs for strict explicit trees 1641
45.1.5 MAC addresses and ISIS-PCR 1642
45.1.6 Filtering Database entries for explicit trees 1642
45.1.7 ISIS-PCR support 1643
45.1.8 Attributes for path computation 1643
45.1.9 Topology sub-TLV 1645
45.1.10 Hop sub-TLV 1648
45.1.11 Administrative Group sub-TLV 1652
45.1.12 Bandwidth Constraint sub-TLV 1652
45.2 Reservation 1653
45.2.1 Bandwidth Assignment sub-TLV 1653
45.2.2 Timestamp sub-TLV 1654
45.2.3 Precedence ordering 1655
45.3 Redundancy 1655
45.3.1 Loop-free alternates for unicast data flows 1655
45.3.2 Static redundant trees 1656
45.3.3 Maximally Redundant Trees (MRTs) 1657
45.3.4 MRTs with centralized GADAG computation 1659

46. Time-Sensitive Networking (TSN) configuration 1664

46.1 Overview of TSN configuration 1664
46.1.1 User/Network Interface (UNI) 1664
46.1.2 Modeling of user/network configuration information 1664
46.1.3 TSN configuration models 1664
46.1.4 Stream transformation 1669
46.2 User/network configuration information 1671
46.2.1 Data types 1671
46.2.2 Protocol integration 1672
46.2.3 Talker 1673
46.2.4 Listener 1685
46.2.5 Status 1686
46.3 YANG for TSN user/network configuration 1692

47. Asynchronous Traffic Shaping (ATS) in end stations 1693

47.1 Talker transmission behavior 1693
47.1.1 ATS traffic class model in Talkers 1693
47.1.2 Simplified ProcessFrame(frame) procedure 1693
47.1.3 System clock functions and processing delays 1693
47.2 Scheduler parameter consistency 1694

Copyright © 2022 IEEE. All rights reserved.

48. YANG Data Models 1695

48.1 YANG Framework 1696
48.1.1 Interface Management (IETF RFC 8343) Model 1697
48.2 IEEE 802.1Q YANG models 1698
48.2.1 VLAN Bridge components model 1698
48.2.2 Two-Port MAC Relay (TPMR) model 1701
48.2.3 Customer VLAN Bridge model 1702
48.2.4 Provider Bridge model 1703
48.2.5 CFM Model 1706
48.2.6 Stream filters and stream gates model 1710
48.2.7 Asynchronous Traffic Shaping (ATS) model 1711
48.3 Structure of the YANG models 1712
48.3.1 VLAN Bridge components model 1713
48.3.2 Two-Port MAC Relay model 1713
48.3.3 Customer VLAN Bridge model 1713
48.3.4 Provider Bridge model 1713
48.3.5 CFM model 1714
48.3.6 Stream filters and stream gates model 1714
48.3.7 Asynchronous Traffic Shaping (ATS) model 1714
48.4 Security considerations 1716
48.4.1 Security considerations of the VLAN Bridge components model 1716
48.4.2 Security considerations of the Two-Port MAC Relay model 1717
48.4.3 Security considerations of the Customer VLAN Bridge model 1717
48.4.4 Security considerations of the Provider Bridge model 1717
48.4.5 Security considerations of the CFM model 1718
48.4.6 Security considerations of the Stream filters and stream gates model 1718
48.4.7 Security considerations of the Asynchronous Traffic Shaping model 1718
48.5 YANG schema tree definitions 1719
48.5.1 Schema for the ieee802-types YANG module 1719
48.5.2 Schema for the ieee802-dot1q-types YANG module 1719
48.5.3 Schema for the ieee802-dot1q-tsn-types YANG module 1719
48.5.4 Schema for the ieee802-dot1q-bridge YANG module 1719
48.5.5 Schema for the ieee802-dot1q-tpmr YANG module 1723
48.5.6 Schema for the ieee802-dot1q-pb YANG module 1723
48.5.7 Schema for the ieee802-dot1q-cfm-types YANG module 1723
48.5.8 Schema for the ieee802-dot1q-cfm YANG module 1724
48.5.9 Schema for the ieee802-dot1q-cfm-bridge YANG module 1726
48.5.10 Schema for the ieee802-dot1q-cfm-alarm YANG module 1727
48.5.11 Schema for the ieee802-dot1q-stream-filters-gates YANG module 1727
48.5.12 Schema for the ieee802-dot1q-ats YANG module 1728
48.6 YANG modules 1729
48.6.1 The ieee802-types YANG module 1729
48.6.2 The ieee802-dot1q-types YANG module 1734
48.6.3 The ieee802-dot1q-tsn-types YANG module 1748
48.6.4 The ieee802-dot1q-bridge YANG module 1767
48.6.5 The ieee802-dot1q-tpmr YANG module 1792
48.6.6 The ieee802-dot1q-pb YANG module 1797
48.6.7 The ieee802-dot1q-cfm-types YANG module 1800
48.6.8 The ieee802-dot1q-cfm YANG module 1811
48.6.9 The ieee802-dot1q-cfm-bridge YANG module 1830
48.6.10 The ieee802-dot1q-cfm-alarm YANG module 1838
48.6.11 The ieee802-dot1q-stream-filters-gates YANG module 1840
48.6.12 The ieee802-dot1q-ats YANG module 1846

Copyright © 2022 IEEE. All rights reserved.

Annex A (normative) PICS proforma—Bridge implementations ... 1851

A.1 Introduction ... 1851
A.2 Abbreviations and special symbols ... 1851
A.2.1 Status symbols ... 1851
A.2.2 General abbreviations ... 1851
A.3 Instructions for completing the PICS proforma ... 1852
A.3.1 General structure of the PICS proforma ... 1852
A.3.2 Additional information ... 1852
A.3.3 Exception information ... 1852
A.3.4 Conditional status ... 1853
A.4 PICS proforma for IEEE Std 802.1Q—Bridge implementations ... 1854
A.4.1 Implementation identification ... 1854
A.4.2 Protocol summary, IEEE Std 802.1Q ... 1854
A.5 Major capabilities ... 1855
A.6 Media access control methods ... 1860
A.7 Relay and filtering of frames ... 1861
A.8 Basic Filtering Services ... 1862
A.9 Addressing ... 1863
A.10 Rapid Spanning Tree Protocol (RSTP) ... 1865
A.12 Implementation parameters ... 1867
A.11 BPDU encoding ... 1867
A.13 Performance ... 1868
A.14 Bridge management ... 1869
A.15 Remote management ... 1879
A.16 Expedited traffic classes ... 1880
A.17 Extended Filtering Services ... 1880
A.18 Multiple Spanning Tree Protocol (MSTP) ... 1881
A.19 VLAN support ... 1883
A.20 Multiple MAC Registration Protocol (MMRP) ... 1886
A.21 Multiple VLAN Registration Protocol (MVRP) ... 1887
A.22 Multiple Registration Protocol (MRP) ... 1888
A.23 Connectivity Fault Management (CFM) ... 1889
A.24 Management Information Base (MIB) ... 1894
A.25 Protection Switching (PS) ... 1897
A.26 Data-driven and data-dependent connectivity fault management (DDCFM) ... 1897
A.27 Two-Port MAC Relay (TPMR) ... 1897
A.28 MAC Status Protocol (MSP) ... 1898
A.29 Forwarding and Queuing Enhancements for time-sensitive streams (FQTSS) ... 1899
A.30 Congestion notification ... 1899
A.31 Stream Reservation Protocol (SRP) ... 1900
A.32 Multiple I-SID Registration Protocol (MIRP) ... 1904
A.34 Enhanced Transmission Selection (ETS) ... 1905
A.33 Priority-based Flow Control (PFC) ... 1905
A.35 Data Center Bridging eXchange protocol (DCBX) ... 1906
A.36 Infrastructure Protection Switching (IPS) ... 1906
A.38 EVB Bridge ... 1907
A.37 Shortest Path Bridging (SPB) ... 1907
A.39 EVB station ... 1908
A.40 Edge relay (ER) ... 1909
A.42 VDP, CDCP, and ECP ... 1911
A.41 VEB and VEPA ER components ... 1911
A.43 Path Control and Reservation ... 1912
A.44 Scheduled traffic ... 1913

Copyright © 2022 IEEE. All rights reserved.

A.45 Frame preemption 1913
A.46 Per-Stream Filtering and Policing 1914
A.47 YANG 1915
A.48 Stream reservation remote management (SRRM) 1916
A.49 TSN Centralized Network Configuration (CNC) station 1917
A.50 VDP for NVO3 nNVE Devices 1918
A.51 VDP for NVO3 tNVE Devices 1919
A.52 Asynchronous Traffic Shaping 1920

Annex B (normative) PICS proforma—End station implementations 1921

B.1 Introduction 1921
B.2 Abbreviations and special symbols 1921
B.2.1 Status symbols 1921
B.2.2 General abbreviations 1921
B.3 Instructions for completing the PICS proforma 1922
B.3.1 General structure of the PICS proforma 1922
B.3.2 Additional information 1922
B.3.3 Exception information 1922
B.3.4 Conditional status 1923
B.4 PICS proforma for IEEE Std 802.1Q—End station implementations 1924
B.4.1 Implementation identification 1924
B.4.2 Protocol summary, IEEE Std 802.1Q 1924
B.5 Major capabilities 1925
B.6 Multiple MAC Registration Protocol (MMRP) 1926
B.8 Multiple Registration Protocol (MRP) 1927
B.7 Multiple VLAN Registration Protocol (MVRP) 1927
B.9 Forwarding and Queuing Enhancements for time-sensitive streams (FQTSS) 1928
B.10 Stream Reservation Protocol (SRP) 1929
B.11 Congestion notification 1932
B.13 Enhanced Transmission Selection (ETS) 1934
B.14 Data Center Bridging eXchange protocol (DCBX) 1934
B.12 Priority-based Flow Control (PFC) 1934
B.16 Frame Preemption 1935
B.17 Per-Stream Filtering and Policing 1935
B.15 Scheduled traffic 1935
B.18 Asynchronous Traffic Shaping 1936

Annex C (normative) Designated MSRP Node (DMN) Implementations 1937

C.1 DMNs on CSNs 1937
C.1.1 CSN characteristics 1937
C.1.2 DMN handling on CSN 1938
C.1.3 MSRPDU handling on a CSN 1939
C.1.4 CSN bandwidth fluctuations 1940
C.2 DMN on MoCA 1940
C.2.1 DMN Selection on MoCA Network 1940
C.2.2 MoCA network bandwidth management 1944
C.3 DMNs on IEEE 802.11 media 1945
C.3.1 MSRP handling 1946
C.3.2 BSS DMN selection 1949
C.3.3 BSS network bandwidth management 1950

Copyright © 2022 IEEE. All rights reserved.

Annex D (normative) IEEE 802.1 Organizationally Specific TLVs 1953

D.1 Requirements of the IEEE 802.1 Organizationally Specific TLV sets 1953
D.2 Organizationally Specific TLV definitions 1954
D.2.1 Port VLAN ID TLV 1954
D.2.2 Port And Protocol VLAN ID TLV 1954
D.2.3 VLAN Name TLV 1955
D.2.4 Protocol Identity TLV 1956
D.2.5 VID Usage Digest TLV 1957
D.2.6 Management VID TLV 1957
D.2.7 Congestion Notification TLV 1958
D.2.8 ETS Configuration TLV 1959
D.2.9 ETS Recommendation TLV 1961
D.2.10 Priority-based Flow Control Configuration TLV 1962
D.2.11 Application Priority TLV 1963
D.2.12 EVB TLV 1964
D.2.13 CDCP TLV 1969
D.2.14 Application VLAN TLV 1971
D.3 IEEE 802.1 Organizationally Specific TLV management 1972
D.3.1 IEEE 802.1 Organizationally Specific TLV selection management 1972
D.3.2 IEEE 802.1 managed objects—TLV variables 1973
D.4 PICS proforma for IEEE 802.1 Organizationally Specific TLV extensions 1974
D.4.1 Implementation identification 1974
D.4.2 Protocol summary, IEEE Std 802.1Q 1974
D.4.3 Major capabilities and options 1975
D.5 IEEE 802.1/LLDP extension MIB 1977
D.5.1 Internet Standard Management Framework 1977
D.5.2 Structure of the IEEE 802.1/LLDP extension MIB 1977
D.5.3 Relationship to other MIBs 1984
D.5.4 Security considerations for IEEE 802.1 LLDP extension MIB module 1985
D.5.5 IEEE 802.1 LLDP extension MIB module—version 2 1987
D.5.6 EVB extensions to the IEEE 802.1 LLDP extension MIB module 2047

Annex E (normative) Notational conventions used in state diagrams 2054

Annex F (informative) Shared and Independent VLAN Learning (SVL and IVL) 2056

F.1 Requirements for Shared and Independent Learning 2056
F.1.1 Connecting independent VLANs 2057
F.1.2 Duplicate MAC addresses 2058
F.1.3 Asymmetric VLANs and Rooted-Multipoint connectivity 2059
F.1.4 Shared learning and Shortest Path Bridging VID (SPBV) mode 2062
F.1.5 Generic constraints on SVL and IVL use 2064

Annex G (informative) MAC method-dependent aspects of VLAN support 2065

G.1 Example tagged IEEE 802.3 EtherType-encoded frame format 2065
G.2 Padding and frame size considerations 2065
G.2.1 Treatment of PAD fields in IEEE 802.3 frames 2065
G.2.2 Maximum PDU size 2066
G.2.3 Minimum PDU size 2066
G.3 Tag insertion and removal for LLC media 2067

Copyright © 2022 IEEE. All rights reserved.

G.4 IEEE 802.11 and PMPN media ... 2068
G.4.1 IEEE 802.11 Portal convergence ... 2068
G.4.2 Point-to-Multipoint Network convergence: multiple connections ... 2068
G.4.3 Point-to-Multipoint Network convergence: single connection ... 2068

Annex H (informative) Interoperability considerations ... 2069

H.1 Requirements for interoperability ... 2069
H.1.1 Static filtering requirements ... 2069
H.1.2 Configuration requirements for VLAN-tagging ... 2069
H.2 Homogeneous VLAN-aware networks ... 2070
H.2.1 Consistency of static VLAN filtering ... 2070
H.2.2 Consistent view of the “untagged VLAN(s)” on a given LAN ... 2071
H.3 Heterogeneous networks: Intermixing MAC Bridges (M) and VLAN Bridges (V) ... 2072
H.3.1 Example: Adding a VLAN Bridge to provide filtering to a MAC Bridged Network 2072
H.3.2 Example: Adding a MAC Bridge to a (previously) Homogeneous VLAN Bridged Network ... 2073
H.4 Intermixing Port-based classification and Port-and-Protocol-based classification or future enhancements in VLAN Bridges ... 2073
H.4.1 Example: Intermixing Protocol-based ingress rules ... 2074
H.4.2 Differing views of untagged traffic on a given LAN ... 2074

Annex I (informative) Priority and drop precedence ... 2075

I.1 Traffic types ... 2075
I.2 Managing latency and throughput ... 2076
I.3 Traffic type to traffic class mapping ... 2076
I.4 Traffic types and priority values ... 2078
I.5 Supporting the credit-based shaper algorithm ... 2079
I.6 Supporting drop precedence ... 2080
I.7 Priority Code Point allocation ... 2080
I.8 Interoperability ... 2081

Annex J (informative) CFM protocol design and use ... 2083

J.1 Origin of CFM ... 2083
J.2 Deployment of CFM ... 2083
J.3 MD Level allocation alternative ... 2084
J.4 Relationship of IEEE Std 802.1Q CFM to other standards ... 2084
J.5 Interpreting Linktrace results ... 2085
J.6 MP addressing: Individual and Shared MP addresses ... 2086
J.6.1 Individual MP address model ... 2087
J.6.2 Shared MP address model and the CFM Port ... 2087

Annex K (informative) TPMR use cases ... 2090

K.1 Use case 1—TPMR as User to Network Interface (UNI) demarcation device ... 2090
K.2 Use case 2—TPMRs with aggregated links ... 2091
K.3 Use case 3—Multiple TPMRs ... 2091
K.4 Special cases ... 2092

Annex L (informative) Operation of the credit-based shaper algorithm ... 2095

L.1 Overview of credit-based shaper operation ... 2095
L.2 “Class measurement intervals” in Bridges ... 2100

Copyright © 2022 IEEE. All rights reserved.

L.3 Determining worst-case latency contribution and buffering requirements 2101
L.3.1 Interference delay 2102
L.3.2 Maximum interference delay and maximum buffer requirement 2110
L.4 Operation of credit-based shaper in Coordinated Shared Network (CSN) 2111

Annex M (normative) Support for PFC in link layers without MAC Control 2112

M.1 Overview 2112
M.2 PFC PDU format 2112

Annex N (informative) Buffer requirements for PFC 2113

N.1 Overview 2113
N.2 Delay model 2113
N.3 Interface Delay 2116
N.4 Cable Delay 2116
N.5 Higher Layer Delay 2116
N.6 Computation example 2117

Annex O (informative) Preserving the integrity of FCS fields in MAC Bridges 2118

O.1 Background 2118
O.2 Basic mathematical ideas behind CRC and FCS 2119
O.3 Detection Lossless Circuit approach 2120
O.4 Algorithmic modification of an FCS 2121
O.4.1 Data changed, length unchanged 2121
O.4.2 Length changed, original data unchanged 2122
O.4.3 Preservation of detectability 2123
O.5 Conclusions 2124

Annex P (informative) Frame duplication and misordering 2125

P.1 Background 2125
P.2 Frame duplication 2125
P.3 Frame misordering 2126
P.4 Other considerations 2127

Annex Q (informative) Traffic scheduling 2128

Q.1 Motivation 2128
Q.2 Using gate operations to create protected windows 2129
Q.3 Availability of PTP 2130
Q.4 Scheduled traffic and end stations 2130
Q.5 CycleTimeExtension variables 2130

Annex R (informative) Preemption and IEEE 802.1AE MAC Security 2131

Annex S (informative) Preemption and scheduled traffic 2133

S.1 Scheduling used in isolation 2133
S.2 Preemption used in isolation 2133
S.3 Scheduling and preemption used in combination, no HOLD/RELEASE 2134
S.4 Scheduling and preemption used in combination with HOLD/RELEASE 2134
S.5 Bandwidth allocation and express traffic 2134

Copyright © 2022 IEEE. All rights reserved.

Annex T (informative) Cyclic queuing and forwarding 2136

T.1 Overview of CQF 2136
T.2 An approach to CQF implementation 2137
T.3 Use of Per-Stream Filtering and Policing for CQF 2138
T.3.1 Stream filter configuration 2138
T.3.2 Stream gate configuration 2138
T.4 Use of traffic scheduling for CQF 2139
T.5 Timing considerations 2140
T.5.1 Choice of T 2140
T.5.2 Cycle interleaving 2141
T.5.3 Cycle alignment between adjacent Ports 2143

Annex U (informative) TSN configuration examples 2144

U.1 Examples for time-aware talker 2144
U.1.1 Using enhancements for scheduled traffic 2145
U.1.2 Using strict priority 2146
U.1.3 Using per-stream scheduling 2147
U.2 Example of workflow for fully centralized models 2148

Annex V (informative) Asynchronous Traffic Shaping delay analysis framework 2152

V.1 General assumptions 2152
V.2 End-to-end delay modeling approach 2152
V.3 Buffering delays 2153
V.4 Media-dependent delays 2155
V.5 Bridge—Internal arrival time recognition delays 2155
V.6 Bridge—Internal processing delays 2155
V.7 Bridge—Internal clock offset variations 2156
V.8 Inter-device clock rate deviations 2156
V.9 Combined delay bounds 2157

Annex W (informative) Bibliography 2158

Copyright © 2022 IEEE. All rights reserved.

Figures

Figure 6-1 Internal organization of the MAC sublayer 144
Figure 6-2 Provider Instance Ports (PIPs) 162
Figure 6-3 B-Component CBP 165
Figure 6-4 Example of operation of Port-and-Protocol-based classification 168
Figure 6-5 Service access priority selection 171
Figure 6-6 Two back-to-back EISS Multiplex Entities 177
Figure 6-7 Two back-to-back Backbone Service Instance Multiplex Entities 178
Figure 6-8 Backbone Service Instance Multiplex Entities with example CFM shims 178
Figure 6-9 Two back-to-back Up and Down TESI Multiplex Entities 181
Figure 6-10 Supporting the ISS with signaled priority 182
Figure 6-11 Two back-to-back Up and Down Infrastructure Segment Multiplex Entities 183
Figure 7-1 VLAN Bridging overview 185
Figure 8-1 A Bridged Network 191
Figure 8-2 VLAN Bridge architecture 193
Figure 8-3 MAC Bridge architecture 194
Figure 8-4 Relaying MAC frames 196
Figure 8-5 Observation of network traffic 196
Figure 8-6 Operation of Spanning Tree Protocol Entity 197
Figure 8-7 Operation of MRP 197
Figure 8-8 Management Port transmission and reception 198
Figure 8-9 Infrastructure Segment MEP placement in a PNP 198
Figure 8-10 Bridge Port Transmit and Receive 201
Figure 8-11 TPMR Port Transmit and Receive 201
Figure 8-12 Forwarding process functions 203
Figure 8-13 Flow classification and metering 208
Figure 8-14 Per-stream classification for PSFP 210
Figure 8-15 Per-stream classification and metering for ATS 212
Figure 8-16 Transmission selection with gates 222
Figure 8-17 Frame timing at gate-close events 224
Figure 8-18 Scheduled traffic state machines—overview and relationships 226
Figure 8-19 Cycle Timer state machine 226
Figure 8-20 List Execute state machine 227
Figure 8-21 List Config state machine 228
Figure 8-22 Logical points of attachment of the Higher Layer and Relay Entities 261
Figure 8-23 Effect of control information on the forwarding path 261
Figure 8-24 Per-Port points of attachment 262
Figure 8-25 Single point of attachment—relay permitted 262
Figure 8-26 Single point of attachment—relay not permitted 262
Figure 8-27 Effect of Port State 263
Figure 8-28 Controlled and Uncontrolled Port connectivity 264
Figure 8-29 Ingress/egress control information in the forwarding path 264
Figure 9-1 VLAN TCI format 269
Figure 9-2 I-TAG TCI format 270
Figure 10-1 Example—Attribute value propagation from one station 273
Figure 10-2 Example—Attribute value propagation from two stations 273
Figure 10-3 Example—Registrations as pointers to the sources of declarations 274
Figure 10-4 MRP architecture 276
Figure 10-5 Format of the major components of an MRPDU 299
Figure 10-6 Operation of MMRP for a single VLAN Context 305
Figure 10-7 Example Directed Graph 306
Figure 10-8 Example of MMRP propagation in a VLAN Context 308
Figure 11-1 Operation of MVRP 316

Copyright © 2022 IEEE. All rights reserved.

Figure 12-1 Relationships among CFM managed objects 377
Figure 12-2 Relationship among BEB managed objects 394
Figure 12-3 SPB managed objects (MOs) 449
Figure 12-4 Relationships among EVB Bridge managed objects 465
Figure 12-5 Relationship among EVB station managed objects 465
Figure 12-6 Timing points for scheduled traffic 482
Figure 12-7 Timing points for PSFP 489
Figure 13-1 Diagrammatic conventions for spanning tree topologies 506
Figure 13-2 Physical topology and active topology 507
Figure 13-3 Port Roles and Port States 507
Figure 13-4 A Backup Port 508
Figure 13-5 “Ring Backbone” example 508
Figure 13-6 An MST Bridge network 510
Figure 13-7 CIST Priority Vectors, Port Roles, and MST Regions 511
Figure 13-8 MSTI Active Topology in Region 2 512
Figure 13-9 CIST and MSTI active topologies in Region 1 of the example network 525
Figure 13-10 Agreements and Proposals 529
Figure 13-11 CIST and MSTI Active Topologies in Region 2 of Figure 13-6 530
Figure 13-12 Enhanced Agreements 531
Figure 13-13 Spanning tree protocol state machines—overview and relationships 542
Figure 13-14 MSTP overview notation 543
Figure 13-15 Port Timers state machine 573
Figure 13-16 Port Receive state machine 573
Figure 13-17 Port Protocol Migration state machine 574
Figure 13-18 Bridge Detection state machine 574
Figure 13-19 Port Transmit state machine 575
Figure 13-20 Port Information state machine 576
Figure 13-21 Port Role Selection state machine 577
Figure 13-22 Disabled Port role transitions 578
Figure 13-23 Port Role Transitions state machine—MasterPort 579
Figure 13-24 Port Role Transitions state machine—RootPort 580
Figure 13-25 Port Role Transitions state machine—DesignatedPort 581
Figure 13-26 Port Role Transitions state machine—AlternatePort and BackupPort 582
Figure 13-27 Port State Transition state machine 582
Figure 13-28 Topology Change state machine 584
Figure 13-29 L2 Gateway Port Receive state machine 585
Figure 14-1 RST, MST, SPT, and STP Configuration BPDU format 589
Figure 14-2 STP TCN BPDU format 589
Figure 14-3 MSTI Configuration Message parameters and format 594
Figure 15-1 Internal organization of the MAC sublayer in a PBN 597
Figure 15-2 Port-based service interface to a PBN 598
Figure 15-3 Port-based service interface to a PBN 599
Figure 15-4 C-tagged service interface to a PBN 599
Figure 15-5 C-tagged service interface to a PBN 599
Figure 15-6 Customer Edge Ports (CEPs) 600
Figure 15-7 S-tagged service interface to a PBN 600
Figure 15-8 S-tagged interface to a PBN 601
Figure 15-9 RCSIs to a PBN 601
Figure 15-10 Remote Customer Access Ports (RCAPs) 602
Figure 15-11 C-tagged RCSI to a PBN 603
Figure 15-12 Port-based RCSI to a PBN 603
Figure 15-13 Provider Network Port (PNP) interface 604
Figure 16-1 PBN with interface examples 607
Figure 16-2 Examples of remote customer service access via a second PBN 609

Copyright © 2022 IEEE. All rights reserved.

Figure 16-3 Access service separation and “Hairpin Switching” 610
Figure 16-3 Access service separation and “Hairpin Switching” 610
Figure 17-1 C-VLAN component internal LAN managed system 675
Figure 17-2 I/B-component internal LAN managed system 680
Figure 18-1 One Maintenance Domain: operator’s view 1184
Figure 18-2 One service instance: operator’s view 1185
Figure 18-3 One service instance: customer’s view 1185
Figure 18-4 MEP and MIP Symbols 1186
Figure 18-5 MAs: one service instance in a provider network 1187
Figure 18-6 MAs: Expansion of Figure 18-5 1188
Figure 18-7 MEPs, MIPs, and MD Levels 1189
Figure 19-1 CFM Protocol shims 1190
Figure 19-2 MA Endpoint (MEP) 1193
Figure 19-3 MIP Half Function (MHF) 1198
Figure 19-4 LOM shim 1200
Figure 19-5 LOM architecture 1201
Figure 20-1 MEP state machines—overview and relationships 1214
Figure 20-2 MEP Continuity Check Initiator state machine 1221
Figure 20-3 MHF Continuity Check Receiver state machine 1222
Figure 20-4 MEP Continuity Check Receiver state machine 1226
Figure 20-5 Remote MEP state machine 1228
Figure 20-6 Remote MEP Error state machine 1229
Figure 20-7 MEP Cross Connect state machine 1230
Figure 20-8 MEP Traffic Field Mismatch state machine 1232
Figure 20-9 MEP Local Mismatch state machine 1232
Figure 20-10 MP Loopback Responder state machine 1234
Figure 20-11 MEP Loopback Initiator transmit state machine 1237
Figure 20-12 MEP Loopback Initiator receive state machine 1238
Figure 20-13 MEP Fault Notification Generator state machine 1240
Figure 20-14 MEP Mismatch Fault Notification Generator state machine 1242
Figure 20-15 MEP Linktrace Initiator receive state machine 1246
Figure 20-16 Linktrace Responder, MEPs, MHFs, and LOMs 1248
Figure 20-17 LTM Receiver state machine 1254
Figure 20-18 LTR Transmitter state machine 1255
Figure 22-1 MEPs and MIPs distinguished by VID (incomplete picture) 1284
Figure 22-2 Alternate view of Forwarding process 1285
Figure 22-3 Combining per-VLAN MPs into two shims 1286
Figure 22-4 More complete picture of MP placement in a Bridge Port 1287
Figure 22-5 Service instance spanning two Bridges protected by Up MPs 1289
Figure 22-6 Service instance spanning two Bridges protected by Down MPs 1289
Figure 22-7 MP placement in a non-VLAN-aware Bridge Port 1291
Figure 22-8 MP placement relative to other standards 1292
Figure 22-9 Creating MEPs and MIPs 1295
Figure 22-10 CFM in a Provider Edge Bridge C-tagged service interface 1301
Figure 22-11 CFM in a Provider Edge Bridge C-tagged RCSI 1303
Figure 22-12 Up MEPs in a Management Port 1304
Figure 22-13 CFM in the enterprise environment 1305
Figure 22-14 CFM on a Bridge that implements IEEE Std 802.1Q-2005 1306
Figure 23-1 TPMR connecting two Bridge Ports 1307
Figure 23-2 TPMR chain connecting Bridge Ports 1307
Figure 23-3 MSSs and the MSPE 1309
Figure 23-4 Adding connectivity 1311
Figure 23-5 Losing connectivity 1312
Figure 23-6 TPMR recovery 1313

Copyright © 2022 IEEE. All rights reserved.

Figure 23-7 Notification from one end of the link to the other ... 1314
Figure 23-8 Immediate MAC status notification at the end of a link ... 1314
Figure 23-9 MSPE state machine overview ... 1315
Figure 23-10 Status Transition state machine (STM) ... 1319
Figure 23-11 Status Notification state machine (SNM) ... 1320
Figure 23-12 MSPDU structure ... 1322
Figure 25-1 Internal organization of the MAC sublayer in a PBBN ... 1326
Figure 25-2 PBB terminology ... 1327
Figure 25-3 Customer service interface types ... 1328
Figure 25-4 Port-based service interface ... 1329
Figure 25-5 Port-based interface equipment ... 1330
Figure 25-6 Encapsulated service frames at ISS ... 1331
Figure 25-7 S-tagged service interface ... 1331
Figure 25-8 S-tagged service interface equipment ... 1332
Figure 25-9 I-tagged service interface ... 1333
Figure 25-10 I-tagged service interface equipment ... 1333
Figure 25-11 S-tagged and Port-based service interface access classifications ... 1335
Figure 25-12 I-tagged service interface access protection classifications ... 1336
Figure 25-1 Internal organization of the MAC sublayer in a PBB-TE Region ... 1339
Figure 25-14 PBB-TE Region ... 1341
Figure 25-15 Transparent service interface ... 1342
Figure 25-16 Transparent service interface equipment ... 1343
Figure 26-1 PBBN example ... 1345
Figure 26-2 CFM shim model ... 1352
Figure 26-3 CFM example applied to a Port-based and S-tagged service interface ... 1353
Figure 26-4 CFM example applied to an I-tagged Service Interface ... 1354
Figure 26-5 CFM example applied to a hierarchal E-NNI, CBP-PIP Demarc ... 1355
Figure 26-6 CFM example applied to a peer E-NNI, CBP-PIP ... 1356
Figure 26-7 Independent ESPs using the same ESP-DAs and ESP-VIDs ... 1359
Figure 26-8 PBB-TE MEP placement in a CBP ... 1360
Figure 26-9 Independent Infrastructure Segments distinguished by SMP-SA ... 1363
Figure 26-10 Infrastructure Segment MEP placement in a PNP ... 1364
Figure 26-11 Protection switching architecture ... 1365
Figure 26-12 PBB-TE point-to-point protection switching ... 1367
Figure 26-13 Mapping data traffic to the protection entity ... 1368
Figure 26-14 Relationships of the Protection switching state machines—overview ... 1369
Figure 26-15 Hold-off state machine ... 1373
Figure 26-16 Clear Manual Switch state machine ... 1373
Figure 26-17 Service Mapping state machine ... 1374
Figure 26-18 Segment terminology and properties ... 1375
Figure 26-19 Infrastructure Segment monitoring ... 1376
Figure 26-20 Working Segment and Protection Segment ... 1377
Figure 26-21 Nested IPGs ... 1378
Figure 26-22 IPS Control entity ... 1380
Figure 26-23 M:1 IPS ... 1381
Figure 26-24 M:1 IPS state machines ... 1382
Figure 26-25 M:1 Hold-off state machine ... 1385
Figure 26-26 Protection Segment Selection state machine ... 1386
Figure 27-1 Configuring VLAN support in an SPT Region (example) ... 1393
Figure 27-2 SPBM group MAC address—general format ... 1404
Figure 27-3 SPBM group MAC addresses—source rooted SPT ... 1404
Figure 27-4 SPBM group MAC addresses—shared tree ... 1405
Figure 27-5 SPBM MEP placement in a CBP ... 1407
Figure 27-6 SPBV campus network example ... 1410

Copyright © 2022 IEEE. All rights reserved.

Figure 27-7 SPT Bridge Network using SPBM example ... 1411
Figure 28-1 Agreement Digest field format ... 1416
Figure 28-2 MT-Capability TLV ... 1425
Figure 28-3 SPB MCID sub-TLV ... 1425
Figure 28-4 SPB Digest sub-TLV ... 1426
Figure 28-5 SPB Base VLAN-Identifiers sub-TLV ... 1427
Figure 28-6 SPB Instance sub-TLV ... 1428
Figure 28-7 SPB Instance Opaque ECT-ALGORITHM sub-TLV ... 1430
Figure 28-8 ECMP ECT-ALGORITHM sub-TLV ... 1430
Figure 28-9 SPB Link Metric sub-TLV ... 1431
Figure 28-10 SPB Adjacency Opaque ECT-ALGORITHM sub-TLV ... 1432
Figure 28-11 SPBV MAC Address sub-TLV ... 1432
Figure 28-12 SPBM Service Identifier and Unicast Address sub-TLV ... 1434
Figure 29-1 Forward path test (FPT) ... 1437
Figure 29-2 Return path test (RPT) ... 1438
Figure 29-3 Combination of FPT and RPT ... 1439
Figure 29-4 Detailed functions of RR ... 1440
Figure 29-5 RFM Receiver on an non-MP ... 1443
Figure 29-6 Return Path DR ... 1444
Figure 29-7 RR Filter state machine ... 1449
Figure 29-8 RR Encapsulation state machine ... 1450
Figure 29-9 RR Transmit state machine ... 1450
Figure 29-10 RFM Receiver state machine ... 1451
Figure 29-11 Decapsulator Responder state machine ... 1454
Figure 30-1 Congestion detection in QCN CP ... 1460
Figure 30-2 Sampling (reflection) probability in QCN CP as a function of |Fb| ... 1460
Figure 30-3 QCN RP operation ... 1461
Figure 30-4 Byte Counter and Timer interaction with Rate Limiter ... 1463
Figure 30-5 CP–RP peering in VLAN Bridged Network ... 1465
Figure 30-6 CP–RP peering in PBBN ... 1466
Figure 31-1 CPs and congestion-aware queues in a Bridge ... 1467
Figure 31-2 Congestion-aware queue functions in an end station ... 1469
Figure 31-3 Per-CNPV station function ... 1471
Figure 32-1 CND defense state machine ... 1484
Figure 32-2 RP rate control state machine ... 1496
Figure 32-3 CP–RP peering in any hierarchical Bridged Network ... 1497
Figure 34-1 Queuing model for a Talker station ... 1509
Figure 35-1 Operation of MSRP ... 1514
Figure 35-2 Format of the components of the reservation FirstValue fields ... 1525
Figure 35-3 Format of the components of the Domain FirstValue ... 1530
Figure 35-4 Value of StreamID TLV ... 1535
Figure 35-5 Value of StreamRank TLV ... 1535
Figure 35-6 Value of InterfaceID TLV ... 1535
Figure 35-7 Value of IEEE802-MacAddresses TLV ... 1536
Figure 35-8 Value of IEEE802-VlanTag TLV ... 1536
Figure 35-9 Value of IPv4-tuple TLV ... 1537
Figure 35-10 Value of IPv6-tuple TLV ... 1537
Figure 35-11 Value of TrafficSpecification TLV ... 1540
Figure 35-12 Value of TSpecTimeAware TLV ... 1540
Figure 35-13 Value of UserToNetworkRequirements TLV ... 1541
Figure 35-14 Value of InterfaceCapabilities TLV ... 1542
Figure 35-15 Value of StatusInfo TLV ... 1542
Figure 35-16 Value of AccumulatedLatency TLV ... 1543
Figure 35-17 Value of TimeAwareOffset TLV ... 1544

Copyright © 2022 IEEE. All rights reserved.

Figure 36-1 PFC peering ... 1560
Figure 36-2 PFC Receiver state diagram for priority n ... 1562
Figure 36-3 PFC-aware system queue functions ... 1564
Figure 36-4 PFC-aware system queue functions with Link Aggregation ... 1565
Figure 38-1 DCBX Asymmetric state machine ... 1570
Figure 38-2 Symmetric state machine ... 1571
Figure 39-1 Operation of MIRP in an I-component ... 1573
Figure 39-2 Operation of MIRP in a B-component ... 1573
Figure 39-3 Alternate model for MIRP in a B-component ... 1578
Figure 40-1 EVB architecture overview ... 1580
Figure 40-2 EVB architecture without S-channels ... 1582
Figure 40-3 EVB architecture with S-channel ... 1582
Figure 40-4 EVB components and internal LANs with S-channels ... 1583
Figure 40-5 EVB architecture without S-channels, with EVB Bridge S-VLAN component ... 1585
Figure 40-6 EVB architecture without S-channels, with EVB station S-VLAN component ... 1585
Figure 41-1 VSI manager ID TLV ... 1588
Figure 41-2 VDP association TLV ... 1589
Figure 41-3 VID Filter Info format ... 1594
Figure 41-4 MAC/VID filter format ... 1594
Figure 41-5 GroupID/VID filter format ... 1595
Figure 41-6 GroupID/MAC/VID filter format ... 1595
Figure 41-7 GroupID/VID/IPv4 filter format ... 1595
Figure 41-8 GroupID/MAC/VID/IPv4 filter format ... 1596
Figure 41-9 GroupID/VID/IPv6 filter format ... 1596
Figure 41-10 GroupID/MAC/VID/IPv6 filter format ... 1597
Figure 41-11 Organizationally defined TLV ... 1598
Figure 41-12 Bridge VDP state machine ... 1600
Figure 41-13 Station VDP state machine ... 1601
Figure 42-1 CDCP state machine—Station role ... 1608
Figure 42-2 CDCP state machine—Bridge role ... 1609
Figure 43-1 Example ECP exchange ... 1613
Figure 43-2 ECPDU structure ... 1615
Figure 43-3 ECP transmit state machine ... 1616
Figure 43-4 ECP receive state machine ... 1617
Figure 44-1 Flow Filtering TCI format ... 1624
Figure 44-2 SPBM VID MEP and ECMP path MEP placement in a CBP ... 1628
Figure 45-1 An SPT Region controlled by a single PCE ... 1631
Figure 45-2 An SPT Region controlled by multiple PCEs ... 1632
Figure 45-3 The use of the SPB Instance sub-TLV for MRT ... 1640
Figure 45-4 Shared Risk Link Group (SRLG) TLV ... 1644
Figure 45-5 Topology sub-TLV ... 1645
Figure 45-6 A strict tree and its descriptor Topology sub-TLV ... 1646
Figure 45-7 Topology sub-TLV of a loose tree ... 1647
Figure 45-8 Hop sub-TLV ... 1649
Figure 45-9 Administrative Group sub-TLV ... 1652
Figure 45-10 Bandwidth Constraint sub-TLV ... 1652
Figure 45-11 Bandwidth Assignment sub-TLV ... 1653
Figure 45-12 Timestamp sub-TLV ... 1654
Figure 45-13 A GADAG and its descriptor Topology sub-TLV ... 1660
Figure 45-14 MRT-Blue and MRT-Red for MRT Root 55 ... 1661
Figure 45-15 A GADAG for a topology with multiple blocks ... 1662
Figure 46-1 Fully distributed model ... 1665
Figure 46-2 Centralized network/distributed user model ... 1666
Figure 46-3 Fully centralized model ... 1668

Copyright © 2022 IEEE. All rights reserved.

Figure 46-4 Example of Stream transformation in Talker end station ... 1669
Figure 46-5 Example of IEEE 802.1CB functions in Talker end station ... 1670
Figure 46-6 Example of IEEE 802.1CB functions in Listener end station ... 1670
Figure 48-1 General YANG hierarchy ... 1696
Figure 48-2 YANG root hierarchy with IEEE 802.1Q YANG modules ... 1696
Figure 48-3 Interface YANG model ... 1697
Figure 48-4 VLAN Bridge components model (MAC Relay Entities) ... 1699
Figure 48-5 Bridge Port model ... 1700
Figure 48-6 TPMR model (MAC Relay Entity) ... 1701
Figure 48-7 TPMR port model ... 1702
Figure 48-8 Provider Bridge model ... 1703
Figure 48-9 Provider Edge Bridge C-VLAN Interface model ... 1704
Figure 48-10 Provider Edge Bridge S-VLAN interface model ... 1705
Figure 48-11 Bridge to CFM YANG model ... 1707
Figure 48-12 CFM CFM MEP model relationships model relationships ... 1708
Figure 48-13 CFM MEP model ... 1709
Figure 48-14 CFM operations structure ... 1709
Figure 48-15 Stream filters and stream gates model MEP model ... 1710
Figure 48-16 Asynchronous Traffic Shaping model ... 1711
Figure C-1 CSN backbone ... 1937
Figure C-2 Bridge's CSN model for bandwidth reservation ... 1938
Figure C-3 Talker MSRPDU flow ... 1939
Figure C-4 Listener MSRPDU flow ... 1939
Figure C-5 IEEE DMN Device Attribute IE ... 1941
Figure C-6 DMN Confirmation Transaction ... 1943
Figure C-7 Bandwidth reservation—bridge model for IEEE 802.11 BSS (STA downstream Port) ... 1945
Figure C-8 Bandwidth reservation—bridge model for IEEE 802.11 BSS (STA upstream Port) ... 1946
Figure C-9 Bandwidth reservation—bridge model for IEEE 802.11 BSS (direct link setup) ... 1946
Figure C-10 MSRP/IEEE 802.11 query flows ... 1947
Figure C-11 MSRP/802.11 Talker STA to Listener STA reservation flows ... 1947
Figure C-12 MSRP/802.11 "Bridged" Listener to Talker STA reservation flows ... 1948
Figure C-13 MSRP/802.11 Listener STA to "Bridged" Talker reservation flows ... 1948
Figure D-1 Port VLAN ID TLV format ... 1954
Figure D-2 Port And Protocol VLAN ID TLV format ... 1954
Figure D-3 VLAN Name TLV format ... 1955
Figure D-4 Protocol Identity TLV format ... 1956
Figure D-5 VID Usage Digest TLV format ... 1957
Figure D-6 Management VID TLV format ... 1957
Figure D-7 Congestion Notification TLV format ... 1958
Figure D-8 ETS Configuration TLV format ... 1959
Figure D-9 ETS Recommendation TLV format ... 1961
Figure D-10 Priority-based Flow Control Configuration TLV format ... 1962
Figure D-11 Application Priority TLV format ... 1963
Figure D-12 EVB TLV format ... 1965
Figure D-13 CDCP TLV structure ... 1969
Figure D-14 Application VLAN TLV format ... 1971
Figure F-1 Connecting independent VLANs—1 ... 2057
Figure F-2 Connecting independent VLANs—2 ... 2058
Figure F-3 Duplicate MAC addresses ... 2058
Figure F-4 Asymmetric VID use: "multi-netted server" ... 2059
Figure F-5 Asymmetric VLAN use: "Rooted-Multipoint" ... 2061

Copyright © 2022 IEEE. All rights reserved.

Figure F-6 Rooted-Multipoint with tagged interfaces 2062
Figure F-7 SPBV VLAN Shared Learning and VID Translation 2063
Figure G-1 Example of IEEE 802.3 MAC frame format 2065
Figure G-2 Methods for Bridge access to IEEE 802.11 and PMPN media: example 2068
Figure H-1 Static filtering inconsistency 2071
Figure H-2 Interoperability with MAC Bridges: example 1 2072
Figure H-3 Interoperability with MAC Bridges: example 2 2073
Figure H-4 Interoperability between Port-based and Port-and-Protocol-based classification 2074
Figure J-1 Up MPs in a CFM Port 2088
Figure K-1 TPMR as UNI demarcation device 2090
Figure K-2 TPMRs with aggregated links 2091
Figure K-3 Multiple TPMRs 2091
Figure K-4 Recovery at the end of a chain 2092
Figure K-5 Near simultaneous recoveries 2093
Figure K-6 Near simultaneous failure and recovery 2093
Figure K-7 Loss with quick recovery 2094
Figure L-1 Credit-based shaper operation—no conflicting traffic 2097
Figure L-2 Credit-based shaper operation–conflicting traffic 2098
Figure L-3 Credit-based shaper operation—burst traffic 2099
Figure L-4 Interference and latency 2103
Figure L-5 Burst behavior and credit 2103
Figure L-6 Fan-in scenario 2107
Figure L-7 Permanent delay scenario 2108
Figure L-8 Building up buffer occupancy—1 2109
Figure L-9 Building up buffer occupancy—2 2109
Figure L-10 Building up buffer occupancy—3 2109
Figure L-11 Building up buffer occupancy—4 2110
Figure M-1 PFC PDU format 2112
Figure N-1 PFC delays 2113
Figure N-2 Delay model 2114
Figure N-3 Worst-case delay 2115
Figure O-1 Converting a CRC to an FCS 2120
Figure O-2 Detection Lossless Circuit 2120
Figure O-3 Field change adjustment 2122
Figure O-4 Field insertion adjustment 2123
Figure P-1 Frame duplication scenario 2126
Figure P-2 Frame misordering scenario 2127
Figure Q-1 Establishing a guard band 2129
Figure Q-2 Using gate operations 2130
Figure T-1 Example Stream Filter and Stream Gate configuration for CQF 2139
Figure T-2 Traffic scheduling example for CQF 2140
Figure T-3 Example Stream Filter and Stream Gate configuration with two values of T 2141
Figure T-4 Traffic scheduling example with two values of T 2141
Figure T-5 Interleaving example—factor of 2 2142
Figure U-1 Example of enhancements for scheduled traffic 2146
Figure V-1 Path of frames along a single hop with index k with two Bridges 2153

Copyright © 2022 IEEE. All rights reserved.

Tables

Table 6-1 Bridge transit delay 151
Table 6-2 Priority Code Point encoding 159
Table 6-3 Priority Code Point decoding 159
Table 6-4 Priority regeneration 160
Table 6-5 Default SRP domain boundary port priority regeneration override values 161
Table 6-6 Service Access Priority 172
Table 6-7 Encapsulated Addresses EtherType 179
Table 8-1 C-VLAN and MAC Bridge component Reserved addresses 206
Table 8-2 S-VLAN component Reserved addresses 207
Table 8-3 TPMR component Reserved addresses 207
Table 8-4 Stream gate control operations 214
Table 8-5 Recommended priority to traffic class mappings 217
Table 8-6 Transmission selection algorithm identifiers 220
Table 8-7 Gate operations 223
Table 8-8 Scheduled Traffic and Stream Gate procedures/variables 232
Table 8-9 Ageing time parameter value 239
Table 8-10 Combining Static and Dynamic Filtering Entries for an individual MAC address 249
Table 8-11 Combining Static Filtering Entry and MAC Address Registration Entry for "All Group Addresses" and "All Unregistered Group Addresses" 250
Table 8-12 Forwarding or Filtering for specific group MAC addresses 250
Table 8-13 Forwarding or Filtering with Dynamic Reservation Entries 251
Table 8-14 Determination of whether a Port is in a VID's member set 252
Table 8-15 Standard LLC address assignment 257
Table 8-17 ISIS-SPB Recommended Address Usage 259
Table 8-16 ISIS-SPB reserved addresses 259
Table 8-18 CCM group destination MAC addresses 266
Table 8-19 LTM group destination MAC addresses 266
Table 9-2 Reserved VID values 269
Table 9-1 IEEE 802.1Q™ EtherType allocations 269
Table 9-3 Reserved I-SID values 271
Table 10-1 MRP application addresses 279
Table 10-2 MRP EtherType values 279
Table 10-3 Applicant state table 293
Table 10-4 Registrar state table 294
Table 10-5 LeaveAll state table 294
Table 10-6 PeriodicTransmission state table 295
Table 10-7 MRP timer parameter default values 295
Table 12-1 Component table entry managed object 327
Table 12-2 Port table entry 329
Table 12-3 ISS Port Number table entry 330
Table 12-4 Bandwidth Availability Parameter Table row elements 433
Table 12-5 Transmission Selection Algorithm Table row elements 434
Table 12-6 Priority Regeneration Override Table row elements 434
Table 12-7 SR Class to Priority Mapping Table row elements 435
Table 12-9 CN component priority managed object row elements 436
Table 12-8 CN component managed object row elements 436
Table 12-10 CN Port priority managed object row elements 437
Table 12-11 Congestion Point managed object row elements 438
Table 12-13 Reaction Point group managed object row elements 439
Table 12-12 Reaction Point port priority managed object row elements 439
Table 12-14 SRP Bridge Base Table row elements 440
Table 12-15 SRP Bridge Port Table row elements 440

Copyright © 2022 IEEE. All rights reserved.

Table 12-16 SRP Latency Parameter Table row elements ... 441
Table 12-17 SRP Stream Table row elements ... 441
Table 12-19 SRP Stream Preload Table row elements ... 442
Table 12-18 SRP Reservations Table row elements ... 442
Table 12-20 SRP Reservations Preload Table row elements ... 443
Table 12-21 Priority-based Flow Control objects ... 444
Table 12-22 EVB system base table ... 468
Table 12-24 SBP table entry ... 469
Table 12-23 EVB system parameter defaults ... 469
Table 12-25 VSI table entry ... 470
Table 12-27 UAP table entry parameters ... 471
Table 12-26 VSI MAC/VLAN table entry ... 471
Table 12-28 UAP table entry ... 472
Table 12-29 S-channel interface table entry ... 473
Table 12-31 ECP table entry ... 474
Table 12-30 URP table entry ... 474
Table 12-32 The Gate Parameter Table ... 479
Table 12-33 Frame Preemption Parameter table ... 482
Table 12-34 The Stream Parameter Table ... 484
Table 12-35 Stream Filter Instance Table ... 486
Table 12-36 The Stream Gate Instance Table ... 487
Table 12-37 The Flow Meter Instance Table ... 490
Table 12-39 The Scheduler Group Instance Table ... 491
Table 12-38 The Scheduler Instance Table ... 491
Table 12-40 The Scheduler Port Parameter Table ... 492
Table 12-41 The Timing Characteristics Table ... 493
Table 12-38 Bridge Delay attributes ... 494
Table 12-39 Propagation Delay attributes ... 496
Table 12-40 Static Trees attributes ... 496
Table 12-41 MRP External Control attributes ... 498
Table 13-1 Configuration Digest Signature Key ... 516
Table 13-2 Sample Configuration Digest Signature Keys ... 517
Table 13-3 Bridge and Port Priority values ... 535
Table 13-4 Port Path Cost values ... 536
Table 13-5 Timer and related parameter values ... 544
Table 17-1 IEEE 802.1Q MIB modules ... 614
Table 17-2 IEEE8021-TC-MIB structure ... 615
Table 17-3 IEEE8021-BRIDGE-MIB structure ... 616
Table 17-4 IEEE 802.1D objects not in the IEEE8021-BRIDGE-MIB ... 620
Table 17-5 IEEE8021-SPANNING-TREE MIB structure ... 621
Table 17-6 Clause 12 objects not in the IEEE8021-SPANNING-TREE MIB ... 622
Table 17-7 IEEE8021-Q-BRIDGE MIB structure ... 623
Table 17-8 Clause 12 management not in IEEE8021-Q-BRIDGE-MIB ... 628
Table 17-9 IEEE8021-PB-MIB structure ... 628
Table 17-10 IEEE8021-MSTP-MIB structure ... 630
Table 17-11 IEEE8021-CFM-MIB structure ... 633
Table 17-12 IEEE8021-CFM-V2-MIB structure ... 637
Table 17-13 IEEE8021-PBB-MIB structure ... 639
Table 17-14 IEEE8021-DDCFM-MIB structure ... 642
Table 17-15 IEEE8021-PBBTE-MIB structure ... 644
Table 17-16 Example of ieee8021PbbTeTeSiEspTable ... 646
Table 17-17 IEEE8021-TPMR-MIB structure ... 647
Table 17-18 IEEE8021-FQTSS-MIB structure ... 649
Table 17-19 IEEE8021-CN-MIB structure ... 650

Copyright © 2022 IEEE. All rights reserved.

Table 17-20 IEEE8021-SRP-MIB structure 652
Table 17-21 IEEE8021-MVRPX-MIB structure 654
Table 17-22 IEEE8021-MIRP-MIB structure 654
Table 17-23 PFC-MIB structure 655
Table 17-24 IEEE8021-TEIPS MIB structure 655
Table 17-25 IEEE8021-SPB-MIB structure 657
Table 17-26 IEEE8021-EVB-MIB structure 662
Table 17-27 IEEE8021-ECMP-MIB structure 666
Table 17-28 IEEE8021-ST-MIB structure 667
Table 17-29 IEEE8021-Preemption-MIB structure 668
Table 17-30 IEEE8021-PSFP-MIB structure 668
Table 17-31 IEEE8021-TSN-REMOTE-MANAGEMENT-MIB structure 671
Table 17-31 PBB-TE required MIB compliances 681
Table 17-32 Sensitive managed objects: tables and notifications 689
Table 17-33 Sensitive managed objects: variables in dot1agCfmMdTable 690
Table 17-34 Sensitive managed objects (of DDCFM): tables and notifications 691
Table 17-35 Sensitive managed objects (of DDCFM) for read 691
Table 17-36 Sensitive managed objects (of EVB): tables and notifications 698
Table 17-37 Sensitive managed objects (of EVB) for read 699
Table 17-38 Provider Bridge service interface parameters 715
Table 17-39 PBB service interface parameters 719
Table 19-1 Actions taken by MP OpCode Demultiplexers 1195
Table 19-2 SAP use for LTMs and LTRs 1202
Table 20-1 Fault Alarm defects and priorities 1207
Table 20-2 Deriving enableRmepDefect and Port Status TLV in a Bridge 1217
Table 21-1 CFM PDU Encapsulation EtherType 1260
Table 21-3 OpCode Field range assignments 1262
Table 21-2 Common CFM Header format 1262
Table 21-4 TLV format 1263
Table 21-5 Type Field values 1264
Table 21-6 Organization-Specific TLV format 1264
Table 21-7 Sender ID TLV format 1265
Table 21-8 Port Status TLV format 1266
Table 21-10 Interface Status TLV format 1267
Table 21-11 Interface Status TLV values 1267
Table 21-9 Port Status TLV values 1267
Table 21-12 Data TLV format 1268
Table 21-13 End TLV format 1268
Table 21-14 CCM format 1269
Table 21-15 CCM Interval field encoding 1270
Table 21-16 CCM Maintenance Association Identifier field format: Maintenance Domain present 1271
Table 21-17 CCM Maintenance Association Identifier field format: Maintenance Domain not present 1271
Table 21-19 Short MA Name Format 1272
Table 21-18 Maintenance Domain Name Format 1272
Table 21-20 LBM and LBR formats 1273
Table 21-21 PBB-TE MIP TLV format 1274
Table 21-22 LTM format 1275
Table 21-23 LTM Flags field 1276
Table 21-24 LTM Egress Identifier TLV format 1277
Table 21-25 LTR format 1278
Table 21-26 LTR Flags field 1278
Table 21-27 Relay Action field values 1279

Copyright © 2022 IEEE. All rights reserved.

Table 21-28 LTR Egress Identifier TLV format ... 1279
Table 21-29 Reply Ingress TLV format ... 1280
Table 21-30 Ingress Action field values ... 1281
Table 21-31 Reply Egress TLV format ... 1282
Table 21-32 Egress Action field values ... 1282
Table 22-1 MEP creation ... 1295
Table 22-2 MIP creation ... 1296
Table 22-3 Bandwidth required for CCMs for 1 MA ... 1299
Table 22-4 Bandwidth required for CCMs for 1000 MAs ... 1300
Table 23-1 Time sequence diagram symbols ... 1311
Table 23-2 MSP performance parameters ... 1316
Table 23-3 MSP EtherType assignment ... 1321
Table 23-4 MSP Packet Types ... 1322
Table 24-1 Transmission and reception delays ... 1325
Table 26-1 Backbone Service Instance Group address OUI ... 1348
Table 26-2 Protection Requests Hierarchy ... 1370
Table 27-1 Allocation of VIDs to FIDs and FIDs to MSTIDs in an SPT Region (example) ... 1393
Table 28-1 Bridge Priority Masking ... 1421
Table 29-1 RFM format ... 1455
Table 29-2 SFM format ... 1456
Table 32-1 LLDP instance selection managed object overrides ... 1477
Table 32-2 CND defense mode selection managed object overrides ... 1477
Table 32-3 Determining cnpdIsAdminDefMode and cnpdDefenseMode ... 1483
Table 32-4 Correspondence of QCN and CCF message fields ... 1485
Table 32-5 NewCpSampleBase() return value as a function of cpFb ... 1488
Table 33-2 CNM Encapsulation ... 1500
Table 33-1 CN-TAG Encapsulation ... 1500
Table 33-3 Congestion Notification Message PDU ... 1501
Table 34-1 Default priority to traffic class mappings for SR classes A and B ... 1507
Table 34-2 Default priority to traffic class mappings for SR class B only ... 1508
Table 35-1 AttributeType Values ... 1522
Table 35-2 AttributeLength Values ... 1522
Table 35-3 FourPackedEvent Values ... 1523
Table 35-4 MSRP FirstValue NumberOfValues example ... 1524
Table 35-5 TSpec components examples ... 1527
Table 35-6 SR class ID ... 1530
Table 35-7 TLV types ... 1533
Table 35-8 Summary of Talker primitives ... 1546
Table 35-9 Summary of Listener primitives ... 1546
Table 35-10 Talker attribute propagation per port ... 1550
Table 35-11 Translation of Talker attributes ... 1551
Table 35-12 Incoming Listener attribute propagation per port ... 1554
Table 35-15 Listener Declaration Type Summation ... 1555
Table 35-13 Updating Dynamic Reservation Entries ... 1555
Table 35-14 Updating operIdleSlope(N) ... 1555
Table 35-16 Translation of Listener attributes ... 1556
Table 41-1 VDP TLV types ... 1589
Table 41-2 Flag values in VDP requests ... 1590
Table 41-3 Error types in VDP responses ... 1591
Table 41-4 Flag values in VDP responses ... 1591
Table 41-6 Filter Info format values ... 1592
Table 41-5 VSIID format values ... 1592
Table 43-1 ECP subtypes ... 1615
Table 44-1 ECMP ECT-ALGORITHM values ... 1623

Copyright © 2022 IEEE. All rights reserved.

Table 44-2 F-TAG EtherType ... 1624
Table 45-1 ECT-ALGORITHM values for explicit trees ... 1635
Table 45-2 Bridge Priority Masking for the LT and LTS ECT Algorithms ... 1636
Table 45-3 Hop sub-TLV flags ... 1650
Table 46-1 StreamID elements ... 1674
Table 46-2 StreamRank elements ... 1674
Table 46-3 InterfaceID elements ... 1675
Table 46-4 IEEE802-MacAddresses elements ... 1677
Table 46-5 IEEE802-VlanTag elements ... 1677
Table 46-6 IPv4-tuple elements ... 1678
Table 46-7 IPv6-tuple elements ... 1679
Table 46-8 TrafficSpecification elements ... 1680
Table 46-9 TSpecTimeAware elements ... 1680
Table 46-10 UserToNetworkRequirements elements ... 1682
Table 46-11 InterfaceCapabilities elements ... 1684
Table 46-12 StatusInfo elements ... 1687
Table 46-13 TalkerStatus enumeration ... 1687
Table 46-14 ListenerStatus enumeration ... 1688
Table 46-15 TSN Failure Codes ... 1689
Table 46-16 AccumulatedLatency elements ... 1690
Table 48-1 Summary of the YANG modules ... 1712
Table 48-2 VLAN Bridge component model YANG modules ... 1713
Table 48-3 Two-Port MAC Relay (TPMR) model YANG modules ... 1713
Table 48-4 Customer VLAN Bridge model YANG modules ... 1713
Table 48-6 CFM model YANG modules ... 1714
Table 48-7 Stream filters and stream gates model YANG modules ... 1714
Table 48-5 Provider Bridge model YANG modules ... 1714
Table 48-8 ATS model YANG modules ... 1715
Table C-1 SRP to MoCA PQoS Transaction mapping ... 1944
Table C-2 SRP TSpec to MoCA TSPEC mapping ... 1944
Table C-3 SRP StreamID to MoCA PQoS Flow transaction mapping ... 1945
Table C-4 SRP to MLME QoS Services mapping ... 1950
Table C-5 EDCA-AC for AV Streams ... 1951
Table C-6 HCCA for AV Streams ... 1952
Table D-1 IEEE 802.1 Organizationally Specific TLVs ... 1953
Table D-2 Port and protocol capability/status ... 1955
Table D-3 Priority assignment table ... 1959
Table D-4 Traffic class bandwidth assignment table ... 1960
Table D-5 TSA Assignment Table ... 1960
Table D-6 PFC Enable bit vector ... 1963
Table D-7 Application Priority Table Entry format ... 1964
Table D-8 Sel field values ... 1964
Table D-9 RRSAT flag values and meanings ... 1967
Table D-10 EVB Mode values ... 1968
Table D-11 NVE Role values ... 1969
Table D-12 Application VLAN Table Entry format ... 1971
Table D-13 Sel field values ... 1972
Table D-14 IEEE 802.1 extension MIB object group conformance requirements ... 1977
Table D-15 IEEE 802.1/LLDP extension MIB object cross reference ... 1978
Table E-1 State machine symbols ... 2055
Table I-1 Traffic type to traffic class mapping ... 2077
Table I-2 Traffic type acronyms ... 2078
Table I-3 Defining traffic types ... 2078
Table I-4 Defining traffic types—Credit-based shaper support of SR class B only ... 2079

Copyright © 2022 IEEE. All rights reserved.

Table I-5 Defining traffic types—Credit-based shaper support of SR classes A and B 2080
Table I-6 Priority Code Point encoding..... 2082
Table I-7 Priority Code Point decoding..... 2082
Table J-1 Provider MD Level allocation 2084
Table J-2 IEEE / ITU-T terminology differences..... 2084
Table N-1 IEEE 802.3 Interface Delays 2116

Copyright © 2022 IEEE. All rights reserved.

IEEE Standard for
Local and metropolitan area networks—

Bridges and Bridged Networks

1. Overview

IEEE 802® Local Area Networks (LANs, 3.110)[7] of all types can be connected together with Media Access Control (MAC) Bridges (3.150) or Virtual Local Area Network (VLAN) Bridges (3.296), collectively known as Bridges (3.24). This standard defines the operation of Bridges and Bridged Networks. VLANs facilitate the administration of logical groups of stations. Stations in the same VLAN communicate as if they were on the same LAN, while traffic between VLANs is restricted. Management of VLAN Bridges and stations allows stations to be added to, removed from, or moved between VLANs.

This standard further extends the specification of VLAN Bridges to enable a service provider organization to use a common infrastructure of Bridges and LANs to offer the equivalent of separate LANs, Bridged, or Virtual Bridged Networks to independent customer organizations.

This standard specifies protocols and protocol entities within the architecture of Bridges that provide capabilities for detecting, verifying, and isolating connectivity failures in Bridged Networks. These capabilities can be used in networks operated by multiple independent organizations, each with restricted management access to each other's equipment.

1.1 Scope

This standard specifies Bridges that interconnect individual LANs, each supporting the IEEE 802 MAC Service using a different or identical media access control method, to provide Bridged Networks and VLANs.

1.2 Purpose

Bridges, as specified by this standard, allow the compatible interconnection of information technology equipment attached to separate individual LANs.

[7] IEEE and IEEE 802 are registered trademarks in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

Copyright © 2022 IEEE. All rights reserved.

1.3 Introduction

For the purpose of compatible interconnection of information technology equipment using the IEEE 802 MAC Service supported by interconnected IEEE 802 standard LANs using different or identical media access control methods, this standard specifies the operation of MAC Bridges and VLAN Bridges. To this end, it:

a) Positions the support of VLANs within an architectural description of the MAC Sublayer.
b) Defines the principles of operation of the MAC Bridge and VLAN Bridge in terms of the support and preservation of the MAC Service, and the maintenance of quality of service (QoS).
c) Specifies an Enhanced Internal Sublayer Service (EISS) provided to the Media Access-Independent functions that provide frame relay in a VLAN Bridge.
d) Establishes the principles and a model of Virtual Bridged Network operation.
e) Identifies the functions to be performed by Bridges, and provides an architectural model of the operation of a Bridge in terms of processes and entities that provide those functions.
f) Specifies a frame format that allows a VLAN Identifier (VID) and priority information to be carried by VLAN-tagged user data frames.
g) Specifies the rules that govern the addition or removal of VLAN tags to and from user data frames.
h) Establishes the requirements for automatic configuration of VLAN topology.
i) Establishes the requirements for VLAN Bridge Management in a Virtual Bridged Network, identifying managed objects and defining management operations.
j) Defines SMIv2 (IETF STD 58)[8] Management Information Based (MIB) modules for the management of VLAN Bridge capabilities including spanning tree protocols and Provider Bridges.
k) Define YANG configuration and operational state models (Clause 48) in support of Two-Port MAC Relays, Customer VLAN Bridges, and Provider Bridges, including Connectivity Fault Management (CFM) for those Bridges.
l) Defines the operation of the Multiple Spanning Tree Algorithm and Protocol (MSTP).
m) Describes the protocols and procedures necessary to support interoperation between Multiple Spanning Tree (MST) and Single Spanning Tree (SST) Bridges in the same Virtual Bridged Networks.
n) Specifies the requirements to be satisfied by equipment claiming conformance to this standard.

To enable a service provider to use a Virtual Bridged Network to provide separate instances of the IEEE 802 MAC Service, MAC Internal Sublayer Service (ISS), and EISS to multiple independent customers, in a manner that does not require cooperation among the customers and that requires a minimum of cooperation between the customers and the provider of the MAC Service, this standard further specifies the operation of Provider Bridges. To this end, it:

o) Differentiates Customer VLANs (C-VLANs) that are under the administrative control of a single customer of a service provider, from the Service VLANs (S-VLANs) that are used by a service provider to support different customers.
p) Specifies VLAN tag formats for both C-VLANs and S-VLANs, allowing each to be distinguished and separately applied and administered by customers and by a service provider.
q) Specifies the functionality of a generic VLAN Bridge component within a system and the specific requirements of derived C-VLAN and S-VLAN components.
r) Specifies a C-VLAN Bridge as comprising a single C-VLAN component, and a Provider Bridge as encompassing Bridges that comprise a single S-VLAN component and no C-VLAN components (S-VLAN Bridge) or a single S-VLAN component and one or more C-VLAN components (Provider Edge Bridge).

[8] Information on references can be found in Clause 2.

Copyright © 2022 IEEE. All rights reserved.

s) Specifies parameters and mappings that allow the EISS to support traffic classes that comprise distinct aggregate flows supporting different QoS characteristics and provide independent guarantees to different customers, through support of priority and drop precedence marking.

t) Specifies the incorporation of flow metering, transmission queue management, and transmission selection algorithms within the forwarding process of a Bridge.

u) Positions the support of S-VLANs within the architectural description of the MAC Sublayer and specifies their relationship to media access method-dependent functions and to the media-independent functions used by customers to administer their networks, including the support of C-VLANs.

v) Allocates the reserved multicast addresses to media access method-dependent, provider network, and customer network functions, specifying the filtering to be applied in each type of VLAN Bridge component.

w) Defines the principles of network operation in terms of the support and preservation of the MAC Service, and the maintenance of QoS for each service instance, including the segregation of data belonging to different organizations.

x) Specifies customer interfaces to a Provider Bridged Network (PBN) in terms of the operation and configuration of the VLAN Bridge components of Provider Bridges, including interfaces that:
   1) Provide access to a single service instance through a Bridge Port.
   2) Allow a customer to select among and identify service instances by Customer VLAN Identifier (C-VID).
   3) Allow a customer to select among and identify service instances by Service VLAN Identifier (S-VID).
   4) Support customer signaling of priority information on a frame by frame basis.
   5) Multiplex service instances over LANs that provide access to a provider network.
   6) Support fault tolerance through redundant provision of access LANs and equipment.

y) Describes the functions to be performed within the PBN in order to support and maintain the connectivity provided to customer service instances.

z) Establishes the requirements for Bridge Management in the PBN, identifying the managed objects and defining the management operations.

aa) Specifies performance requirements, and recommends default values and applicable ranges for the operational parameters of a Provider Bridge.

This standard specifies protocols, procedures, and managed objects to support Connectivity Fault Management (CFM). These allow discovery and verification of the path, through Bridges and LANs, taken for frames addressed to and from specified network users, and support detection and isolation of a connectivity fault to a specific Bridge or LAN. To this end, it:

ab) Defines Maintenance Domains, Maintenance Associations (MAs), their constituent Maintenance Points (MPs), and the managed objects required to create and administer them.

ac) Describes the protocols and procedures used by MPs to detect and diagnose connectivity faults within a Maintenance Domain.

This standard specifies protocols, procedures, and managed objects to allow support of provisioning systems that explicitly select traffic engineered paths within Provider Backbone Bridged Networks (PBBNs) by allowing a network operator to disable unknown destination address forwarding, source address learning and spanning tree protocols for administratively selected VIDs, while allowing other network control protocols to dynamically determine active topologies for other services. These interoperable capabilities are supported by management of individual Bridges by Simple Network Management Protocol (SNMP) using an SMIv2 MIB, by extensions to the other control protocols specified in this standard, by the use of CFM with the addresses and VIDs that specify traffic engineered connections, and by 1:1 path protection switching capable of load sharing. To this end, it:

Copyright © 2022 IEEE. All rights reserved.

ad) Enables construction of active topologies by an external agent that is responsible for setting up Ethernet Switched Paths (ESPs) by splitting the B-VID space between distributed spanning tree protocols and provisioned control.

ae) Supports discard of frames with unknown destination addresses for B-VIDs under provisioned control.

af) Supports the operation of Continuity Check, Loopback, and Linktrace protocols on provisioned traffic engineered paths.

ag) Supports 1:1 protection switching capable of load sharing for Traffic Engineering service instances (TESIs).

ah) Supports protection of a group of TESIs that traverses a sequence of LANs and intervening Bridges using a method that does not require the modification of data or control frames.

ai) Provides required extension to SNMP management by SMIv2 MIB modules.

This standard does not specify operation of ESPs through multiple Provider Backbone Bridge Traffic Engineering (PBB-TE) Regions. All the Backbone Edge Bridges (BEBs) specified for use in a PBB-TE Region are combined I type and B type Backbone Edge Bridges (IB-BEBs).

This standard specifies protocols, procedures, and managed objects to support the Multiple Registration Protocol (MRP). MRP allows participants in an MRP Application to register attributes with other participants in a Bridged Network. Four applications are defined—one to register VIDs [Multiple VLAN Registration Protocol (MVRP)], one to register MAC addresses [Multiple MAC Registration Protocol (MMRP)], one to register Streams and configure associated network resources [Multiple Stream Registration Protocol (MSRP)], and one that provides the ability to flush learned MAC Address Entries held in the Filtering Database (FDB) of an I-component on a per-I-SID basis [Multiple I-SID Registration Protocol (MIRP)]. MVRP will furthermore provide for the rapid healing of network failures without interrupting services to unaffected VLANs. To this end, it specifies the following:

aj) MRP and the operation of MRP entities.[9]

ak) The generic frame formats used in MRP exchanges.

al) The MMRP application of MRP, and the frame formats that it uses.

am) The MVRP application of MRP, and the frame formats that it uses.

To allow scaling of Provider Networks to at least 2^{24} S-VLANs, this standard further specifies the operation of Provider Backbone Bridges (PBBs) by means of an architecture and Bridge protocols compatible and interoperable with PBN protocols and equipment, allowing interconnection of multiple PBNs. To this end, it:

an) Introduces BEBs that, by exchanging backbone frames that encapsulate the addresses, VLAN tags, and data of customer frames, support the virtual, media-independent equivalent of a number of independent instances of the service provided by media-dependent frame transmission procedures.

ao) Extends the parameters of the ISS and EISS to include a connection identifier, capable of referencing the backbone addresses and other parameters, used to convey customer frames from one BEB to all, or one of, the other BEBs supporting a particular backbone service instance.

ap) Specifies the format of the Backbone Service Instance tag (I-TAG) that encapsulates the customer addresses, and introduces a Backbone Service Instance Identifier (I-SID) that allows each BEB to support a number of backbone service instances and permits the unambiguous identification of up to 2^{24} backbone service instances within a single PBBN.

aq) Provides a model of BEB operation in terms of VLAN Bridge components that allows the use of Provider Bridges as Backbone Core Bridges (BCBs), with PBBN traffic carried as frames

[9] MRP replaces the Generic Attribute Registration Protocol (GARP), defined in IEEE Std 802.1D™-2004 [B12], that was used to support GVRP and GMRP in earlier revisions of IEEE Std 802.1Q. Similarly, GVRP and GMRP are replaced by MVRP and MMRP, respectively.

Copyright © 2022 IEEE. All rights reserved.

containing I-TAGs on particular Backbone VLANs (B-VLANs) potentially coexisting with PBN traffic carried as frames without I-TAGs on other B-VLANs.

ar) Specifies the interfaces that a PBBN can provide to transport service frames. These comprise a Port-based service interface that assigns all received untagged and priority-tagged frames to a single S-VLAN transported over a single backbone service instance, an S-tagged service interface capable of mapping individual S-VLANs to different backbone service instances, and an I-tagged service interface capable of mapping frames from one set of backbone service instances to another.

as) Describes the use of redundant Bridges and access LANs to protect backbone service access against failure of any of those systems or components.

at) Specifies the management of BEBs in terms of the model of operation [item ap) above], making use of defined management objects for the individual VLAN Bridge components, and adding managed objects to facilitate service creation.

au) Describes the use of CFM to detect and isolate faults in the connectivity provided to individual S-VLANs across the PBBN, in the connectivity provided to the group of S-VLANs supported by a single backbone service instance (identified by an I-SID), and in the connectivity provided to individual B-VLANs within the backbone itself.

av) Specifies extensions to MSTP to allow network administrators to protect against loops through peered PBBNs without requiring coupling of spanning trees that operate independently for each PBBN.

This standard specifies CFM protocols, procedures, and managed objects that provide confirmation of successful transmission of frames conveying specified data. This capability supports diagnosis of faults sensitive to, or caused by, particular data patterns, and their isolation to part of the transmission path. Connectivity verification can be carried out from any single point with bridged connectivity to MPs on the path, can isolate failures to communicate in a specific direction, and can be carried out while service is being provided to other users of the data path. To this end, it:

aw) Defines the extensions to CFM capabilities defined by Clause 18 through Clause 22 to facilitate diagnosis and isolation of faults sensitive to, or caused by, particular data patterns in frames transmitted by a service user.

ax) Describes the protocols and procedures for data-driven and data-dependent connectivity fault management (DDCFM).

This standard specifies the function of a Two-Port MAC Relay (TPMR), along with protocols and procedures that support its operation. A TPMR is a type of Bridge that has only two externally accessible Bridge Ports, and supports a subset of the functionality of a MAC Bridge. A TPMR is transparent to all frame-based media-independent protocols, except those explicitly addressed to it and those that are destined for reserved MAC addresses that the relay function of the TPMR is defined not to forward. It is remotely manageable through at least one of its external MACs, and signals a failure of either MAC's LAN through the other MAC. A TPMR should only be attached to point-to-point LANs. The conformance requirements for a TPMR are stated in 5.13 and 5.15.

This standard allows Bridges to provide performance guarantees for time-sensitive (i.e., bounded latency and latency variation) loss-sensitive real-time audio/video (AV) data stream transmission (AV traffic). It specifies priority regeneration and controlled bandwidth queue draining algorithms. VLAN tag encoded priority values are allocated, in aggregate, to segregate frames among queues that support AV traffic and queues that support non-AV traffic, allowing simultaneous support of both AV traffic and other bridged traffic over and between wired and wireless Local Area Networks (LANs). To this end, it:

ay) Defines status parameters that allow the boundaries of a Stream Reservation Protocol (SRP—see Clause 35) domain (35.1.4) to be identified and maintained.

az) Specifies how the priority information in frames received at SRP domain boundary ports is regenerated.

Copyright © 2022 IEEE. All rights reserved.

NOTE 1—The priorities in frames transmitted from outside an SRP domain to a Bridge inside an SRP domain are remapped in order to ensure that traffic that is not associated with a reservation does not disrupt traffic that is associated with a reservation. Hence, traffic entering an SRP domain that uses Priority Code Point values associated with reserved traffic classes will be remapped to Priority Code Point values that are not associated with reserved traffic classes.[10]

ba) Specifies how priority information is used to determine the traffic classes to be used for time-sensitive streams.

bb) Defines a credit-based shaper algorithm to shape traffic in accordance with stream reservations.

NOTE 2—The credit-based shaper algorithm operates on the outbound queues; the mechanisms specified for the support of time-sensitive AV traffic do not involve any form of ingress metering or policing.

This standard specifies protocols, procedures, and managed objects to support congestion notification. These allow a Virtual Bridged Network or a portion thereof, with a limited bandwidth-delay product, to transfer long-lived data flows with a significantly reduced chance of frame loss compared to a network without congestion notification. To this end, it:

bc) Defines a means for VLAN Bridges that support congestion notification to form Congestion Managed Domains within a Virtual Bridged Network.

bd) Defines a means for detecting congested queues in end stations and VLAN Bridges, for signaling such congestion to the end stations sourcing the frames causing the congestion, and for those end stations to control the rate of transmission of those frames.

To enable the end-to-end management of resource reservation for QoS guaranteed streams, this standard further specifies protocols, procedures, and managed objects, usable by existing higher layer mechanisms, that allow network resources to be reserved for specific traffic streams traversing a Bridged Network. To this end, it:

be) Specifies the use of Dynamic Reservation Entries (8.8.7) in the FDB to control the forwarding of frames associated with a particular Stream.

bf) Specifies a Stream Reservation Protocol (SRP). SRP facilitates the registration, deregistration, and maintenance of stream reservation information in relevant Bridges to establish end-to-end stream paths.

This standard specifies protocols, procedures, and managed objects to support topology change signaling to alter the binding (held in an I-Component) of Customer addresses to backbone addresses on a per-I-SID basis. This is accomplished by extending the use of MRP. To this end, it specifies the MIRP application of MRP and the frame formats that it uses.

NOTE 3—MIRP can only trigger the flushing of learned MAC address information; it does not propagate the registration of I-SIDs. The name Multiple I-SID Registration Protocol is chosen because MIRP is a Multiple Registration Protocol (MRP) application and can be extended to perform I-SID registrations.

This standard allows an S-tagged service interface connecting two independently administered PBNs to be used to handle traffic (identified by a single S-VID) for a given customer attached to one PBN as if the customer were directly attached to the other PBN using a Port-based or C-tagged service interface. To this end, it:

bg) Specifies the use of a Port-mapping S-VLAN component to associate selected S-VIDs registered on an external port with distinct internal ports, each of which supports a separate service interface.

This standard specifies protocols, procedures, and managed objects to support Priority-based Flow Control (PFC). These allow a Virtual Bridged Network, or a portion thereof, to enable flow control per traffic class on IEEE 802 point-to-point full-duplex links. To this end, it:

[10] Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

Copyright © 2022 IEEE. All rights reserved.

bh) Defines a means for a system to inhibit transmission of data frames on certain priorities from the remote system on the link.

This standard specifies protocols, procedures, and managed objects for enhancement of transmission selection to support allocation of bandwidth among traffic classes. When the offered load in a traffic class does not use its allocated bandwidth, Enhanced Transmission Selection (ETS) will allow other traffic classes to use the available bandwidth. Bandwidth is used by traffic classes subject to ETS when there are no frames to be transmitted for traffic classes subject to strict priority or credit-based shaper algorithms. It defines the Data Center Bridging eXchange protocol (DCBX), which controls the application of ETS and PFC.

This standard specifies Shortest Path Bridging (SPB) of unicast and multicast frames, specifying protocols to calculate multiple active topologies that can share learned station information, and support of a VLAN by multiple, per-topology, Shortest Path VLAN Identifiers (SPVIDs). To this end, it:

bi) Describes the use of shortest paths to increase throughput and minimize transit delay, while introducing a negligible rate of frame misordering.

bj) Requires that active topologies calculated by spanning tree protocols and Shortest Path Tree (SPT) protocols be stable, predictable, and reproducible to maintain the characteristics of the MAC Service provided.

bk) Requires, except in the case of SPB using Equal Cost Multiple Paths (ECMP), active topologies that are reverse path congruent and unicast-multicast congruent to permit learning of station location from the source addresses of all frames and simplify the detection and management of faults.

NOTE 4—ECMP operation does not provide (nor does this standard attempt to define for ECMP VLANs) reverse path congruence and unicast-multicast congruence as these concepts cease to have utility in an ECMP context.

bl) Specifies the calculation of symmetric sets of SPTs, each rooted at a Bridge within an SPT Region comprising Bridges operating compatible protocols and configurations.

bm) Specifies the use of Bridge Protocol Data Units (BPDUs) to identify and bound SPT Regions and to ensure loop-free interoperability with regions using the Rapid Spanning Tree Algorithm and Protocol (RSTP) and MSTP.

bn) Specifies both Shortest Path Bridging VID (SPBV) and Shortest Path Bridging MAC (SPBM) modes:
  1) for SPBV, identifying each SPT by SPVID and locating end stations by source MAC address learning.
  2) for SPBM, identifying each SPT by VID and source MAC address and distributing end station location information explicitly.

bo) Supports management selection of the Common Spanning Tree (CST), a Multiple Spanning Tree Instance (MSTI), or SPB for support of any given VLAN within an SPT Region.

bp) Specifies a protocol that automatically assigns SPVIDs for each VLAN supported by SPBV.

bq) Supports load sharing by Equal Cost Trees (ECTs) through the calculation of multiple SPT Sets, with each shortest path VLAN being assigned to one SPT Set.

br) Specifies Intermediate System to Intermediate System Protocol for Shortest Path Bridging (ISIS-SPB): the use of and extensions to the Intermediate System to Intermediate System (IS-IS) Protocol to calculate SPTs for both SPBV and SPBM.

bs) Describes the addressing of ISIS-SPB entities and specifies the group MAC addresses they use.

bt) Specifies the use of loop prevention (for SPBV and for multicast frames for SPBM) and loop mitigation (for unicast frames for SPBM).

bu) Specifies an Agreement Protocol that prevents loops, specifying the necessary state information and computation as part of ISIS-SPB and communicating agreement information for the CIST and (as a compact Digest) for SPTs in each BPDU.

Copyright © 2022 IEEE. All rights reserved.

This standard specifies protocols, procedures, and managed objects that:

bv) Provide for the discovery, configuration, and control of a pair of direct-attached Port-mapping S-VLAN components to extend the operation of a Customer Bridge to remote ports and enable coexistence of multiple services on station-resident ports (e.g., embedded bridging).

bw) Provide for discovery, configuration, and operation of reflective relay (8.6.1) for a Bridge Port.

bx) Provide for discovery of, and coordinated configuration of, edge relays (ERs) and other devices that utilize the reflective relay service.

by) Provide for dynamic profile-driven port configuration.

bz) Specifies load spreading by distributing unicast traffic over the set of available equal cost paths and assigning multicast traffic flows to a variety of trees.

ca) Specifies a flow filtering tag (F-TAG) containing a flow hash used in unicast ECMP traffic distribution and a TTL (time-to-live) field used to mitigate the effects of traffic loops resulting from transient conditions or control software errors or faults.

This standard also specifies further protocol extensions, procedures, and managed objects to IS-IS for providing capabilities beyond Shortest Path Bridging (SPB) for Bridged Networks. These extensions involve explicit path control, bandwidth reservation, and redundancy (protection, restoration) for data flows. Thus, this standard specifies bridging on explicit paths for unicast and multicast frames, specifying protocols to determine multiple active topologies. To this end, it:

cb) Describes the use of explicit trees, e.g., to improve resiliency and decrease the probability of congestion.

cc) Requires that active topologies calculated by one or multiple entities external to the routing protocol are such that the characteristics of the MAC Service are provided.

cd) Supports management selection of explicit trees for support of any given VLAN within an SPT Region.

ce) Specifies Intermediate System to Intermediate System Path Control and Reservation (ISIS-PCR): the use of and extensions to the Intermediate System to Intermediate System (IS-IS) protocol to establish explicit trees.

cf) Specifies the use of ISIS-PCR for recording bandwidth assignments.

cg) Specifies redundancy for ISIS-SPB and ISIS-PCR.

This standard also:

ch) Provides for the use of IEEE 802.11™ media as links internal to, as well as links providing access to, a Bridged Network or Virtual Bridged Network.

ci) Defines enhancements for scheduled traffic to allow transmissions scheduled relative to a known timescale.

cj) Defines frame preemption to interrupt transmission of preemptable frames by express frames.

This standard specifies protocols, procedures, and managed objects that:

ck) Allow for the filtering and policing of individual traffic streams.

cl) Allow for Asynchronous Traffic Shaping (ATS) over full-duplex links with constant bit data rates.

This standard specifies enhancements to protocols, procedures, and managed objects for the configuration of network resources for time-sensitive (i.e., bounded latency) applications. The enhancements address Time-Sensitive Networking (TSN) application requirements beyond audio/video (AV) traffic. To this end, it:

cl) Specifies a software interface between the user (i.e., time-sensitive application) and network components, such that the user provides Stream requirements (e.g., for bounded latency), and the network configures resources from Talker to Listeners to meet those requirements. This user/network interface (UNI) is specified as an information model that can be applied to any protocol.

Copyright © 2022 IEEE. All rights reserved.

cm) Specifies three models for the UNI: fully distributed, centralized network/distributed user, and fully centralized.

cn) Specifies enhancements to the Stream Reservation Protocol (SRP), using a new application version, MSRPv1. MSRPv1 integrates the UNI TLVs for the benefits of enhanced configuration. For compatibility, MSRPv1 translates to the previous version (MSRPv0).

co) Specifies enhancements to the managed objects for forwarding and queuing enhancements for time-sensitive streams (FQTSS).

cp) Specifies enhancements to the managed objects for SRP.

cq) Specifies managed objects for configuration of Bridges by a Centralized Network Configuration (CNC) component.

This standard specifies protocols, procedures, and managed objects that:

cr) Provide for Network Virtualization Overlays over Layer 3 (NVO3)-related port configuration.

Copyright © 2022 IEEE. All rights reserved.

2. Normative references

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

ANSI X3.159, American National Standards for Information Systems—Programming Language—C.[11]

IEEE Std 802®, IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture.[12, 13]

IEEE Std 802d™-2017, IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture—Amendment 1: Allocation of Uniform Resource Name (URN) Values in IEEE 802® Standards.

IEEE Std 802.1AB™, IEEE Standard for Local and metropolitan area networks—Station and Media Access Control Connectivity Discovery.

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

IEEE Std 802.1AE™, IEEE Standard for Local and metropolitan area networks—Media Access Control (MAC) Security.

IEEE Std 802.1AS™, IEEE Standard for Local and metropolitan area networks—Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks.

IEEE Std 802.1AX™, IEEE Standard for Local and metropolitan area networks—Link Aggregation.

IEEE Std 802.1BR™, IEEE Standard for Local and metropolitan area networks—Virtual Bridged Local Area Networks—Bridge Port Extension.

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

IEEE Std 802.1X™, IEEE Standard for Local and Metropolitan Area Networks—Port-Based Network Access Control.

IEEE Std 802.3™, IEEE Standard for Ethernet.

IEEE Std 802.11™, Standard for Information Technology—Telecommunications and Information Exchange between Systems—Local and Metropolitan Area Networks—Specific Requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.

IEEE Std 802.20™, IEEE Standard for Local and metropolitan area networks—Part 20: Air Interface for Mobile Broadband Wireless Access Systems Supporting Vehicular Mobility—Physical and Media Access Control Layer Specification.

IETF RFC 1035 (STD 13), Domain Names—Implementation and Specification, November 1987.[14]

[11] ANSI publications are available from the IHS Standards Store (https://global.ihs.com/).
[12] The IEEE standards or products referred to in Clause 2 are trademarks owned by The Institute of Electrical and Electronics Engineers, Incorporated.
[13] IEEE publications are available from The Institute of Electrical and Electronics Engineers (https://standards.ieee.org/).
[14] IETF RFCs are available from the Internet Engineering Task Force (https://www.ietf.org/).

Copyright © 2022 IEEE. All rights reserved.

IETF RFC 1042, A Standard for the Transmission of IP Datagrams over IEEE 802 Networks, February 1988.

IETF RFC 1390 (STD 36), Transmission of IP and ARP over FDDI Networks, January 1993.

IETF RFC 2104, HMAC: Keyed-Hashing for Message Authentication, February 1997.

IETF RFC 2119 (BCP 14), Key words for use in RFCs to Indicate Requirement Levels, March 1997.

IETF RFC 2205, Resource ReSerVation Protocol (RSVP)—Version 1 Functional Specification, September 1997.

IETF RFC 2271, An Architecture for Describing SNMP Management Frameworks, January 1998.

IETF RFC 2474, Definition of the Differentiated Services Field (DS Field) in the IPv4 and IPv6 Headers, December 1998.

IETF RFC 2578 (STD 58), Structure of Management Information Version 2 (SMIv2), April 1999.

IETF RFC 2579 (STD 58), Textual Conventions for SMIv2, April 1999.

IETF RFC 2580 (STD 58), Conformance Statements for SMIv2, April 1999.

IETF RFC 2685, Virtual Private Networks Identifier, September 1999.

IETF RFC 2737, Entity MIB (Version 2), December 1999.

IETF RFC 2750, RSVP Extensions for Policy Control, January 2001.

IETF RFC 2863, The Interfaces Group MIB, June 2000.

IETF RFC 3046, DHCP Relay Agent Information Option, January 2000.

IETF RFC 3410, Introduction and Applicability Statements for Internet Standard Management Framework, December 2002.

IETF RFC 3411, An Architecture for Describing Simple Network Management Protocol (SNMP) Management Frameworks, December 2002.

IETF RFC 3413 (STD 62), Simple Network Management Protocol (SNMP) Applications, December 2002.

IETF RFC 3414 (STD 62), User-based Security Model (USM) for version 3 of the Simple Network Management Protocol (SNMPv3), December 2002.

IETF RFC 3415 (STD 62), View-based Access Control Model (VACM) for the Simple Network Management Protocol (SNMP), December 2002.

IETF RFC 3417 (STD 62), Transport Mappings for the Simple Network Management Protocol (SNMP), December 2002.

IETF RFC 3418 (STD 62), Management Information Base (MIB) for the Simple Network Management Protocol (SNMP), December 2002.

IETF RFC 3419, Textual Conventions for Transport Addresses, December 2002.

Copyright © 2022 IEEE. All rights reserved.

IETF RFC 4122, A Universally Unique IDentifier (UUID) URN Namespace, July 2005.

IETF RFC 4188, Definitions of Managed Objects for Bridges, September 2005.

IETF RFC 4291, IP Version 6 Addressing Architecture, February 2006.

IETF RFC 4318, Definitions of Managed Objects for Bridges with Rapid Spanning Tree Protocol, December 2005.

IETF RFC 4363, Definitions of Managed Objects for Bridges with Traffic Classes, Multicast Filtering, and Virtual LAN Extensions, January 2006.

IETF RFC 4789, Simple Network Management Protocol (SNMP) over IEEE 802 Networks, November 2006.

IETF RFC 5120, M-ISIS: Multi Topology (MT) Routing in Intermediate System to Intermediate Systems (IS-ISs), February 2008.

IETF RFC 5303, Three-Way Handshake for IS-IS Point-to-Point Adjacencies, October 2008.

IETF RFC 5305, IS-IS Extensions for Traffic Engineering, October 2008.

IETF RFC 5307, IS-IS Extensions in Support of Generalized Multi-Protocol Label Switching (GMPLS), October 2008.

IETF RFC 6165, Extensions to IS-IS for Layer-2 Systems, April 2011.

IETF RFC 7365, Framework for Data Center (DC) Network Virtualization, October 2014.

IETF RFC 7810, IS-IS Traffic Engineering (TE) Metric Extensions, May 2016.

IETF RFC 7811, An Algorithm for Computing IP/LDP Fast Reroute Using Maximally Redundant Trees (MRT-FRR) , June 2016.

IETF RFC 7950, The YANG 1.1 Data Modeling Language, August 2016.

IETF RFC 8343, A YANG Data Model for Interface Management, March 2018.

IETF RFC 8394, Split Network Virtualization Edge (Split-NVE) Control-Plane Requirements, May 2018.

ISO/IEC 7498-1, Information technology—Open Systems Interconnection—Basic Reference Model: The Basic Model.[15]

ISO/IEC 8802-2, Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 2: Logical link control.

ISO/IEC 8802-11, Telecommunications and information exchange between systems—Specific requirements for local and metropolitan area networks—Part 11: Wireless LAN medium access control (MAC) and physical layer (PHY) specifications.

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

Copyright © 2022 IEEE. All rights reserved.

ISO/IEC TR 9577:1999, Information technology—Protocol identification in the network layer.

ISO/IEC 10589:2002, Information technology—Telecommunications and information exchange between systems—Intermediate System to Intermediate System intra-domain routeing information exchange protocol for use in conjunction with the protocol for providing the connectionless-mode network service (ISO 8473).

ISO/IEC TR 11802-5:1997, Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Technical reports and guidelines—Part 5: Media Access Control (MAC) Bridging of Ethernet V2.0 in Local Area Networks.

ITU-T Recommendation X.690 (2002), Information technology—ASN.1 encoding rules: Specification of Basic Encoding Rules (BER), Canonical Encoding Rules (CER) and Distinguished Encoding Rules (DER).[16]

ITU-T Recommendation G.8013/Y.1731, Operation, administration and maintenance (OAM) functions and mechanisms for Ethernet-based networks.

MEF Technical Specification 10.3 (MEF 10.3), Ethernet Services Attributes Phase 3, October 2013.[17]

[16] ITU-T publications are available from the International Telecommunications Union (https://www.itu.int/).
[17] MEF publications are available from the MEF Forum (https://www.mef.net/).

Copyright © 2022 IEEE. All rights reserved.