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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

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ISO/IEC/IEEE 8802-1Q was prepared by the LAN/MAN of the IEEE Computer Society (as IEEE Std 802.1Q-2018) 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 second edition cancels and replaces the first edition (ISO/IEC/IEEE 8802-1Q:2016), which has been technically revised. It also incorporates the Amendments ISO/IEC/IEEE 8802-1Q:2016/Amd.1:2017, ISO/IEC/IEEE 8802-1Q:2016/Amd.2:2018, ISO/IEC/IEEE 8802-1Q:2016/Amd.3:2017, ISO/IEC/IEEE 8802-1Q:2016/Amd.4:2017, ISO/IEC/IEEE 8802-1Q:2016/Amd.5:2017, ISO/IEC/IEEE 8802-1Q:2016/Amd.6:2019, ISO/IEC/IEEE 8802-1Q:2016/Amd.7:2019 and the Corrigendum ISO/IEC/IEEE 8802-1Q:2016/Cor.1:2017.

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IEEE Std 802.1Q™-2018
(Revision of
IEEE Std 802.1Q-2014)

IEEE Standard for
Local and Metropolitan Area Networks—

Bridges and Bridged Networks

Sponsor

**LAN/MAN Standards Committee
of the
IEEE Computer Society**

Approved 7 May 2018

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, Rapid Spanning Tree Protocol, RSTP, PBN, Provider Bridged Network, Shortest Path Bridging Protocol, SPB Protocol, Time-Sensitive Networking, TSN, Virtual Bridged Network, virtual LAN, VLAN Bridge

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Introduction

This introduction is not part of IEEE Std 802.1Q-2018, IEEE Standard for Local and metropolitan area networks—Bridges and Bridged Networks.

IEEE Std 802.1Q-2018 incorporates 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
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

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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 [B17].[1]

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
> USA

Grateful acknowledgment

The working group would like to acknowledge and thank Diane Lacey for her invaluable work on the final publication of this standard.

[1] Numbers in brackets correspond to the numbers in the bibliography in Annex U.

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IEEE Standard for
Local and metropolitan area networks—

Bridges and Bridged Networks

1. Overview

IEEE 802® Local Area Networks (LANs, 3.108)[2] of all types can be connected together with Media Access Control (MAC) Bridges (3.149) or Virtual Local Area Network (VLAN) Bridges (3.291), collectively known as Bridges (3.23). 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.

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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) Management Information Based (MIB) modules for the management of VLAN Bridge capabilities including spanning tree protocols and Provider Bridges.
k) Defines the operation of the Multiple Spanning Tree Algorithm and Protocol (MSTP).
l) 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.
m) 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

n) 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.
o) 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.
p) Specifies the functionality of a generic VLAN Bridge component within a system and the specific requirements of derived C-VLAN and S-VLAN components.
q) 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).
r) 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.
s) Specifies the incorporation of flow metering, transmission queue management, and transmission selection algorithms within the forwarding process of a Bridge.

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t) 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.
u) 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.
v) 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.
w) 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.
x) Describes the functions to be performed within the PBN in order to support and maintain the connectivity provided to customer service instances.
y) Establishes the requirements for Bridge Management in the PBN, identifying the managed objects and defining the management operations.
z) 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

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

ac) 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.
ad) Supports discard of frames with unknown destination addresses for B-VIDs under provisioned control.
ae) Supports the operation of Continuity Check, Loopback, and Linktrace protocols on provisioned traffic engineered paths.

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

ai) MRP and the operation of MRP entities.[3]
aj) The generic frame formats used in MRP exchanges.
ak) The MMRP application of MRP, and the frame formats that it uses.
al) 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

am) 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.
an) 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.
ao) 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.
ap) 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 containing I-TAGs on particular Backbone VLANs (B-VLANs) potentially coexisting with PBN traffic carried as frames without I-TAGs on other B-VLANs.
aq) 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.
ar) Describes the use of redundant Bridges and access LANs to protect backbone service access against failure of any of those systems or components.

[3] MRP replaces the Generic Attribute Registration Protocol (GARP), defined in IEEE Std 802.1D™-2004 [B17], 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.

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as) 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.
at) 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.
au) 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

av) 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.
aw) 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

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

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.[4]

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

[4] Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

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ba) 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

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

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

bf) 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

bg) 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

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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

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

bk) Specifies the calculation of symmetric sets of SPTs, each rooted at a Bridge within an SPT Region comprising Bridges operating compatible protocols and configurations.
bl) 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.
bm) 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.
bn) 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.
bo) Specifies a protocol that automatically assigns SPVIDs for each VLAN supported by SPBV.
bp) 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.
bq) 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.
br) Describes the addressing of ISIS-SPB entities and specifies the group MAC addresses they use.
bs) Specifies the use of loop prevention (for SPBV and for multicast frames for SPBM) and loop mitigation (for unicast frames for SPBM).
bt) 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.

This standard specifies protocols, procedures, and managed objects that

bu) 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).
bv) Provide for discovery, configuration, and operation of reflective relay (8.6.1) for a Bridge Port.
bw) Provide for discovery of, and coordinated configuration of, edge relays (ERs) and other devices that utilize the reflective relay service.

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bx) Provide for dynamic profile-driven port configuration.
by) 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.
bz) 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

ca) Describes the use of explicit trees, e.g., to improve resiliency and decrease the probability of congestion.
cb) 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.
cc) Supports management selection of explicit trees for support of any given VLAN within an SPT Region.
cd) 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.
ce) Specifies the use of ISIS-PCR for recording bandwidth assignments.
cf) Specifies redundancy for ISIS-SPB and ISIS-PCR.

This standard also

cg) 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.
ch) Defines enhancements for scheduled traffic to allow transmissions scheduled relative to a known timescale.
ci) Defines frame preemption to interrupt transmission of preemptible frames by express frames.

This standard specifies protocols, procedures, and managed objects that

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

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2. Normative references

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

ANSI X3.159, American National Standards for Information Systems—Programming Language—C.[5]

IEEE Std 802®, IEEE Standard for Local and metropolitan area networks: Overview and Architecture.[6,7]

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 Standards for Local and metropolitan area networks—Port Based Network Access Control.

IEEE Std 802.3™, IEEE Standard for Ethernet.

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

IEEE Std 802.11™, 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.[8]

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[5] ANSI publications are available from the American National Standards Institute (https://www.ansi.org/).
[6] IEEE publications are available from The Institute of Electrical and Electronics Engineers (https://standards.ieee.org/).
[7] The IEEE standards or products referred to in this clause are trademarks of The Institute of Electrical and Electronics Engineers, Inc.
[8] IETF documents (i.e., RFCs) are available from the Internet Engineering Task Force (https://tools.ietf.org/html/).

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

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

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

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

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

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

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ISO/IEC 8802-11, 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.

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[9] ISO and ISO/IEC documents are available from the International Organization for Standardization (https://www.iso.org/). ISO/IEC publications are also available in the United States from Global Engineering Documents (https://global.ihs.com/). Electronic copies are available in the United States from the American National Standards Institute (https://www.ansi.org/)
[10] ITU-T publications are available from the International Telecommunications Union (https://www.itu.int/).

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[11] MEF technical specifications are available from the MEF Forum (https://www.mef.net/).

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