

IEEE Standard for
Local and metropolitan area networks—

Media Access Control (MAC) Bridges and Virtual Bridged Local Area Networks

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

IEEE
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Abstract: This standard specifies how the MAC Service is supported by Virtual Bridged Local Area Networks, the principles of operation of those networks, and the operation of VLAN-aware Bridges, including management, protocols, and algorithms.

Keywords: Bridged Local Area Networks, local area networks (LANs), MAC Bridges, metropolitan area networks, Multiple Spanning Tree Protocol (MSTP), Rapid Spanning Tree Protocol (RSTP), Virtual Bridged Local Area Networks (virtual LANs)

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Introduction

This introduction is not part of IEEE Std 802.1Q-2011, IEEE Standard for Local and metropolitan area networks—Media Access Control (MAC) Bridges and Virtual Bridged Local Area Networks.

The MAC Bridge standardization activities that resulted in the development of IEEE Std 802.1D™, 1993 Edition [B9],^a introduced the concept of Filtering Services in Bridged Local Area Networks, and mechanisms whereby filtering information in such LANs may be acquired and held in a Filtering Database.

IEEE Std 802.1D, 1998 Edition, a revision of IEEE Std 802.1D, 1993 Edition, extended this concept of Filtering Services to define additional capabilities aimed at

- a) The provision of expedited traffic capabilities, to support the transmission of time-critical information in a LAN environment.
- b) The use of signaled priority information as the basis for identifying expedited classes of traffic.
- c) The provision of filtering services that support the dynamic definition and establishment of Groups in a LAN environment, and the filtering of frames by Bridges such that frames addressed to a particular Group are forwarded only on those LANs that are required to reach members of that Group.
- d) The provision of a Generic Attribute Registration Protocol (GARP) that is used to support the mechanism for providing Group filtering capability and is made available for use in other attribute registration applications.

This standard, first published as IEEE Std 802.1Q-1998, makes use of the concepts and mechanisms of LAN Bridging that were introduced by IEEE Std 802.1D, and it defines additional mechanisms that allow the implementation of Virtual Bridged Local Area Networks. The following mechanisms are described:

- e) Virtual LAN Services.
- f) The operation of the Forwarding Process that is required.
- g) The structure of the Filtering Database that is required.
- h) The nature of the protocols and procedures that are required to provide Virtual LAN services, including the definition of the frame formats used to represent VLAN identification information, and the procedures used to insert and remove VLAN identifiers (VIDs) and the headers in which they are carried.
- i) The ability to support end-to-end signaling of priority information regardless of the intrinsic ability of the underlying MAC protocols to signal priority information.
- j) The management services and operations that are required to configure and administer networks.

The 2005 Revision of the standard incorporated three amendments, IEEE Std 802.1u™-2001, IEEE Std 802.1v™-2001, and IEEE Std 802.1s™-2002, into the text of IEEE Std 802.1Q-1998. These amendments describe enhancements to the standard to allow

- k) Dynamic Group and VLAN registration to be restricted, based on the contents of static filtering entries.
- l) VLAN classification according to link layer protocol type.
- m) Support for VLANs carried over multiple Spanning Tree instances.

^aNumbers in brackets correspond to the number in the bibliography in Annex M.

This revision of the standard incorporates amendments IEEE Std 802.1ad™-2005, IEEE Std 802.1ak™-2007, IEEE Std 802.1ag™-2007, IEEE Std 802.1ah™-2008, IEEE Std 802-1Q-2005/Cor-1-2008, IEEE Std 802.1ap™-2008, IEEE Std 802.1Qaw™-2009, IEEE Std 802.1Qay™-2009, IEEE Std 802.1aj™-2009, IEEE Std 802.1Qav™-2009, IEEE Std 802.1Qau™-2010, and IEEE Std 802.1Qat™-2010 into the text of IEEE Std 802.1Q-2005. These amendments describe enhancements to the standard to allow

- n) A service provider to use the architecture and protocols defined in this standard to offer the equivalent of separate LANs, Bridged Local Area Networks, or Virtual Bridged Local Area Networks to a number of customers, while requiring no cooperation between the customers, and minimal cooperation between each customer and the service provider.
- o) The distribution and registration of VLAN membership information using the Multiple VLAN Registration Protocol (MVRP), and the distribution of group membership information using the Multiple MAC Registration Protocol (MMRP), replacing the previous protocols, GVRP and GMRP.
- p) Support of Connectivity Fault Management (CFM) capabilities for detecting, isolating, and reporting connectivity faults.
- q) Interconnection of multiple Provider Bridged Networks, allowing a Provider to support up to 2^{24} service instances.
- r) Management of VLAN Bridges via SNMP MIB modules.
- s) Diagnosis of data-dependent connectivity faults.
- t) Support for traffic engineering.
- u) The use of Bridging technology as a two-port MAC relay.
- v) Support for the relay of time sensitive data streams.
- w) Support for congestion management of long-lived data flows within network domains of limited bandwidth-delay product. This is achieved by enabling bridges to signal congestion to end stations capable of transmission rate limiting to avoid frame loss.
- x) Network resources to be reserved for specific traffic streams traversing a bridged local area network.
- y) The use of IEEE 802.17™ and IEEE 802.20™ media in bridged local area networks.

As part of this revision of the standard, Clause 13 was extensively revised in order to integrate the description of the Rapid Spanning Tree Protocol (RSTP) into the text of the standard rather than including it by reference to IEEE Std 802.1D.

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

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Historical participants

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IEEE 802.1Q Standard	Date approved by IEEE	Officers at the time of Working Group Letter Ballot
IEEE Std 802.1Q-1998	8 December 1998	William P. Lidinsky , <i>Chair</i> Mick Seaman , <i>Chair, Interworking Task Group</i> Tony Jeffree , <i>Coordinating Editor</i> Anil Rijasinghani, Richard Hausmann, Michele Wright, Paul Langille, P. J. Singh , <i>Editorial Team</i>
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IEEE Std 802.1Q-2005	7 December 2005	Tony Jeffree , <i>Chair and Editor</i> Paul Congdon , <i>Vice Chair</i> Mick Seaman , <i>Chair, Interworking Task Group</i>
IEEE Std 802.1ak-2007	22 March 2007	Tony Jeffree , <i>Chair and Editor</i> Paul Congdon , <i>Vice Chair</i> Mick Seaman , <i>Chair, Interworking Task Group</i>

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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
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IEEE Standard for Local and metropolitan area networks—

Media Access Control (MAC) Bridges and Virtual Bridged Local Area Networks

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1. Overview

IEEE 802® Local Area Networks (LANs)¹ of all types can be connected together with Media Access Control (MAC) Bridges, as specified in IEEE Std 802.1D™.^{2,3} This standard defines the operation of Bridges that permit the definition, operation, and administration of Virtual LANs (VLANs) within Virtual Bridged Local Area Networks.

This standard further extends the specification of VLAN-aware MAC 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 Local Area Networks to independent customer organizations.

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

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²Information on references can be found in Clause 2.

³Throughout this standard, references to IEEE Std 802.1D, without qualification as to the date of publication, refer to the most recent revision or edition of the standard that is identified in the references section (Clause 2). In those cases where the reference is intended to be to an earlier published version of the standard, the reference is qualified by the publication date of that revision or edition.

The data-driven and data-dependent connectivity fault management capabilities include tools to facilitate diagnosis and isolation of faults sensitive to, or caused by, particular data patterns in transmitted frames.

This standard specifies protocols, procedures, and managed objects that support congestion management of long-lived data flows within network domains with a bandwidth-delay product on the order of 5 Mbits or less. Such flows are typically encountered in data centers, backplane fabrics, computing clusters, and storage networks. This is achieved by enabling bridges to signal congestion to end stations capable of transmission rate limiting to avoid frame loss. This mechanism enables support for higher layer protocols that are highly loss or latency sensitive. VLAN tag encoded priority values are allocated to segregate frames subject to congestion control, allowing simultaneous support of both congestion controlled and other higher layer protocols. This standard does not specify communication or reception of congestion notification information to or from end stations outside the congestion controlled domain or encapsulation of frames from those end stations across the domain.

This standard 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 local area network. It characterizes resource requirements of traffic streams to a level sufficient for bridges to determine the required resources and provides a mechanism for dynamic maintenance of those resources.

1.1 Scope

This standard specifies Media Access Control (MAC) Bridges that interconnect individual Local Area Networks (LANs), each supporting the IEEE 802 MAC service using a different or identical media access control method, to provide Bridged Local Area Networks and Virtual LANs (VLANs).

1.2 Purpose

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

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 that support Virtual LANs (VLANs). 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 VLAN-aware Bridge in terms of the support and preservation of the MAC Service, and the maintenance of Quality of Service;
- c) Specifies an Enhanced Internal Sublayer Service provided to the Media Access Independent functions that provide frame relay in a VLAN-aware Bridge;
- d) Establishes the principles and a model of Virtual Bridged Local Area Network operation;
- e) Identifies the functions to be performed by VLAN-aware 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) Specifies the rules that govern the ability to carry user data in either Canonical format or Noncanonical format in VLAN-tagged frames;

NOTE 1—The meanings of the terms *Canonical format* and *Noncanonical format* are discussed in IEEE Std 802.⁴

- i) Establishes the requirements for automatic configuration of VLAN topology;
- j) Establishes the requirements for VLAN-aware Bridge Management in a Virtual Bridged Local Area Network, identifying managed objects and defining management operations;
- k) Defines SMIPv2 (IETF STD 58) MIB modules for the management of VLAN-aware Bridge capabilities including Spanning Tree Protocols and Provider 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 MST and SST Bridges in the same Virtual Bridged Local Area 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 Local Area Network to provide separate instances of the IEEE 802® MAC Service, MAC Internal, and Enhanced Internal Sublayer Services 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-aware bridge component within a system and the specific requirements of derived C-VLAN and S-VLAN components.
- r) Specifies a 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).
- s) Specifies parameters and mappings that allow the Enhanced Internal Sublayer Service 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-aware bridge component.
- w) Defines the principles of network operation in terms of the support and preservation of the MAC Service, and the maintenance of Quality of Service for each service instance, including the segregation of data belonging to different organizations.
- x) Specifies customer interfaces to a Provider Bridged Network in terms of the operation and configuration of the VLAN-aware 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 amongst and identify service instances by Customer VLAN Identifier (C-VID)
 - 3) Allow a customer to select amongst and identify service instances by Service VLAN Identifier (S-VID)
 - 4) Support customer signaling of priority information on a frame by frame basis

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

- 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 Provider Bridged Network in order to support and maintain the connectivity provided to customer service instances.
- z) Establishes the requirements for Bridge Management in the Provider Bridged Network, 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. 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, their constituent Maintenance Points, and the managed objects required to create and administer them;
- ac) Describes the protocols and procedures used by Maintenance Points 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 by allowing a network operator to disable unknown destination address forwarding, source address learning and spanning tree protocols for administratively selected VLANs, 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 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 VLANs that specify traffic engineered connections, and by 1:1 path protection switching capable of load sharing. To this end, it:

- ad) Enables construction of active topologies by an external agent that is responsible for setting up Ethernet Switched Paths (ESPs) by splitting the B-VLAN space between distributed spanning tree protocols and provisioned control.
- ae) Supports discard of frames with unknown destination addresses for B-VLANs 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 Engineered service instances.
- ah) Provides required extension to SNMP management by SMIv2 MIB modules.

This standard does not specify operation of Ethernet Switched Paths (ESPs) through multiple Provider Backbone Bridge Traffic Engineered (PBB-TE) Regions. All the Backbone Edge Bridges specified for use in a PBB-TE Region are IB-BEBs.

In addition, 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 Local Area Network. Two applications are defined—one to register VLANs [Multiple VLAN Registration Protocol (MVRP)] and one to register MAC addresses [Multiple MAC Registration Protocol (MMRP)]. 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.⁵
- aj) The generic frame formats used in MRP exchanges.

⁵MRP replaces the Generic Attribute Registration Protocol (GARP), defined in IEEE Std 802.1D, 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.

- ak) The Multiple MAC Registration Protocol (MMRP) application of MRP, and the frame formats that it uses.
- al) The Multiple VLAN Registration Protocol (MVRP) application of MRP, and the frame formats that it uses.

To allow scaling of Provider Networks to at least 2^{24} Service Virtual LANs, this standard further specifies the operation of Provider Backbone Bridges (PBBs) by means of an architecture and bridge protocols compatible and interoperable with Provider Bridged Network protocols and equipment, allowing interconnection of multiple Provider Bridged Networks. To this end, it

- am) Introduces Backbone Edge Bridges 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 Internal Sublayer Service (ISS) and Enhanced Internal Sublayer Service (EISS) to include a connection identifier, capable of referencing the backbone addresses and other parameters, used to convey customer frames from one Backbone Edge Bridge (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 Provider Backbone Bridged Network (PBBN).
- ap) Provides a model of Backbone Edge Bridge operation in terms of VLAN-aware bridge components that allows the use of Provider Bridges as Backbone Core Bridges, 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 Backbone VLANs.
- aq) Specifies the interfaces that a Provider Backbone Bridged Network 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.
- as) Specifies the management of Backbone Edge Bridges in terms of the model of operation [item ap) above], making use of defined management objects for the individual VLAN-aware bridge components, and adding managed objects to facilitate service creation.
- at) Describes the use of connectivity fault management (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 the Multiple Spanning Tree Protocol (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 connectivity fault management 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 maintenance points 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 connectivity fault management 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).

Additionally, 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 5.14.

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 (6.6.4) to be identified and maintained
- ay) Specifies how the priority information in frames received at SRP domain boundary ports is regenerated

NOTE 2—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.

- az) Specifies how priority information is used to determine the traffic classes to be used for time-sensitive streams
- ba) Defines a credit-based shaper algorithm to shape traffic in accordance with stream reservations

NOTE 3—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 Local Area 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-aware Bridges that support congestion notification to form Congestion Managed Domains within a Virtual Bridged LAN.
- bc) Defines a means for detecting congested queues in end stations and VLAN-aware 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 local area network. To this end it: