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Ethernet-Tree (E-Tree) Support in Virtual Private LAN Service (VPLS)

Abstract

This document specifies a generic Virtual Private LAN Service (VPLS) solution, which uses VLANs to indicate root or leaf traffic to support Ethernet-Tree (E-Tree) services. A VPLS Provider Edge (PE) model is illustrated as an example for the solution. In the solution, E-Tree VPLS PEs are interconnected by Pseudowires (PWs), which carry the VLAN indicating the E-Tree attribute. The MAC address-based Ethernet forwarding engine and the PW work in the same way as specified in RFC 4762 and RFC 4448, respectively. A signaling mechanism is described to support E-Tree capability and VLAN mapping negotiation.

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1. Introduction

The Ethernet-Tree (E-Tree) service is defined in the Metro Ethernet Forum (MEF) Technical Specification MEF 6.2 [MEF6.2] as a Rooted-Multipoint Ethernet Virtual Connection (EVC) service. An MEF 6.2 E-Tree solution must meet the following design requirements: the Ethernet frames from a root may be received by any other root or leaf, and the frames from a leaf may be received by any root, but must not be received by a leaf. Further, an E-Tree service may include multiple roots and multiple leaves. Although Virtual Private Multicast Service (VPMS) [VPMS] and Point-to-Multipoint (P2MP) multicast are somewhat simplified versions of this service, in fact, they are both multicast services and are different from an E-Tree service that may include both unicast and multicast traffic.

[RFC7152] gives the requirements for providing E-Tree solutions in the VPLS and the need to filter leaf-to-leaf traffic. [RFC7387] further describes a Multiprotocol Label Switching (MPLS) framework for providing E-Tree. Though there were proposals for using the Pseudowire (PW) control word or PWs to indicate the root/leaf attribute of an E-Tree frame, both methods are limited in that they are only applicable to "VPLS only" networks.

A VPLS PE usually consists of a bridge module itself (see [RFC4664] and [RFC6246]); and moreover, E-Tree services may cross both Ethernet and VPLS domains. Therefore, it is necessary to develop an E-Tree solution both for "VPLS only" scenarios and for interworking between Ethernet and VPLS.

IEEE 802.1 has incorporated the generic E-Tree solution into 802.1Q [IEEE-802.1Q-2014], which is an improvement on the traditional asymmetric VLAN mechanism. In the asymmetric VLAN mechanism as described in Section B.1.3 of IEEE 802.1Q [IEEE-802.1Q-2003], a VLAN ID is used to indicate the traffic from a server, and multiple VLAN IDs are used to indicate the traffic from the clients (one VLAN ID per client). In the new IEEE 802.1Q solution, only two VLANs are used to indicate root/leaf attributes of a frame: one VLAN ID is used to indicate the frames originated from the roots and another VLAN ID is used to indicate the frames originated from the leaves. At a leaf port, the bridge can then filter out all the frames from other leaf ports based on the VLAN ID. It is better to reuse the same mechanism in VPLS than to develop a new mechanism. A new mechanism would introduce more complexity to interwork with the new IEEE 802.1Q solution.

This document specifies how the Ethernet VLAN solution can be used to support generic E-Tree services in VPLS. The solution specified here is fully compatible with the IEEE bridge architecture and with IETF

Pseudowire Emulation Edge-to-Edge (PWE3) technology, thus it will not change the FIB (such as installing E-Tree attributes in the FIB) or need any specially tailored implementation. Furthermore, VPLS scalability and simplicity are also maintained. With this mechanism, it is also convenient to deploy a converged E-Tree service across both Ethernet and MPLS networks.

A typical VPLS PE model is introduced as an example; the model is then extended in which a Tree VSI is connected to a VLAN bridge with a dual-VLAN interface.

This document then discusses the PW encapsulation and PW processing such as VLAN mapping options for transporting E-Tree services in VPLS.

Finally, this document describes the signaling extensions and processing procedures for E-Tree support in VPLS.

2. Conventions Used in This Document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

3. Terminology

AC: Attachment Circuit

B-VLAN: Backbone VLAN

C-VLAN: Customer VLAN

E-Tree: Ethernet Tree, a Rooted-Multipoint EVC service as defined in [MEF6.2]

EVC: Ethernet Virtual Connection, as defined in [MEF4]

FIB: Forwarding Information Base, also known as "forwarding table"

I-SID: Backbone Service Instance Identifier, as defined in IEEE 802.1ah [IEEE-802.1Q-2014]

Leaf AC: An AC attached with a leaf

Leaf VLAN: A VLAN Identifier (ID) used to indicate all the frames that are originated at a leaf AC. It may be a C-VLAN, an S-VLAN, or a B-VLAN

OAM: Operations, Administration, and Maintenance

PBB: Provider Backbone Bridge

PE: Provider Edge

PW: Pseudowire

Root AC: An AC attached with a root

Root VLAN: A VLAN ID used to indicate all the frames that are originated at a root AC. It may be a C-VLAN, an S-VLAN, or a B-VLAN

S-VLAN: Service VLAN

T-VSI: Tree VSI, a VSI with E-Tree support

VLAN: Virtual Local Area Network

VPLS: Virtual Private LAN Service

VSI: Virtual Switching Instance as defined in [RFC4664], also known as "VPLS Forwarder" in [RFC7041]

4. PE Model with E-Tree Support

The problem scenario of E-Tree as shown in Figure 1 of [RFC7152] is a simplification of the L2VPN architecture. Several common VPLS PE architectures are discussed in more detail in [RFC4664] and [RFC6246].

Below, an E-Tree solution in VPLS is demonstrated with the help of a typical VPLS PE model. Its use in other PE models is discussed in Appendix A.

4.1. Existing PE Models

According to [RFC4664], there are at least three models possible for a VPLS PE, including:

- o A single bridge module, a single VSI;
- o A single bridge module, multiple VSIs;
- o Multiple bridge modules, each attaches to a VSI.

The second PE model is commonly used. A typical example is further depicted in Figure 1 and Figure 2 (both figures are extracted from [RFC6246]), where an S-VLAN bridge module is connected to multiple VSIs each with a single VLAN virtual interface.

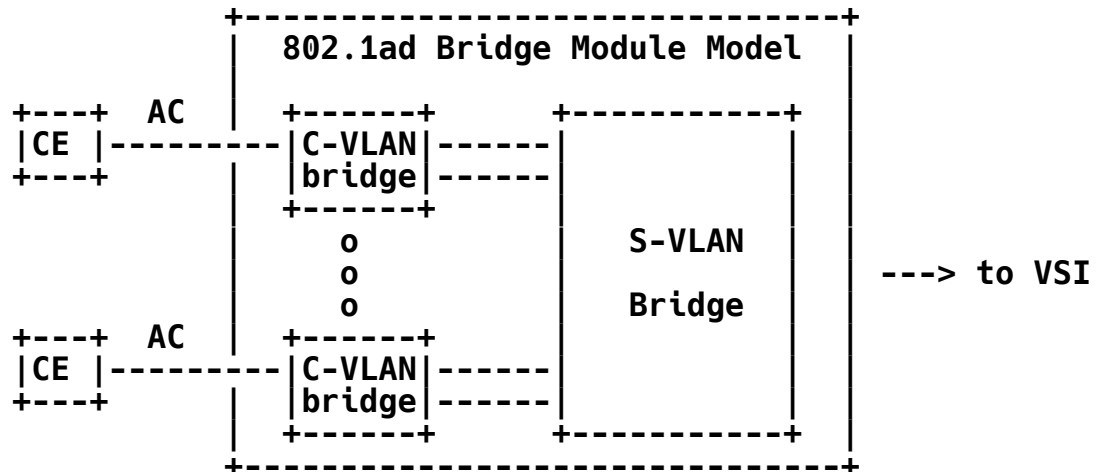


Figure 1: A Model of 802.1ad Bridge Module

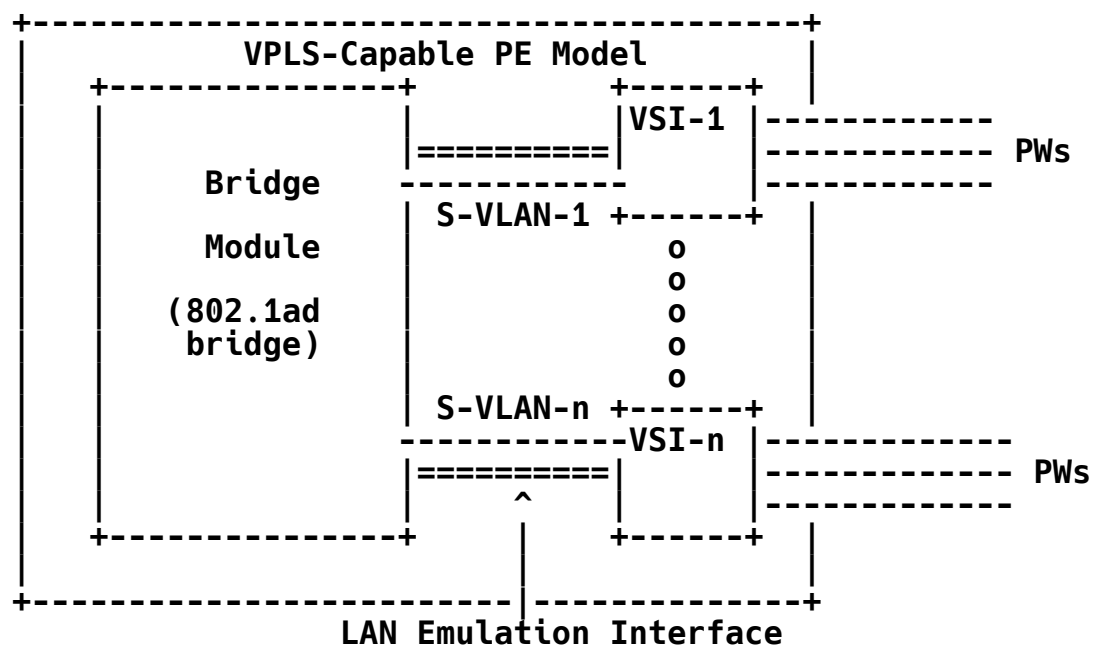


Figure 2: A VPLS-Capable PE Model

In this PE model, Ethernet frames from Customer Edges (CEs) will cross multiple stages of bridge modules (i.e., C-VLAN and S-VLAN bridge), and a VSI in a PE before being sent on the PW to a remote PE. Therefore, the association between an AC port and a PW on a VSI is difficult.

This model could be further enhanced: when Ethernet frames arrive at an ingress PE, a root VLAN or a leaf VLAN tag is added. At an egress PE, the frames with the root VLAN tag are transmitted both to the roots and the leaves, while the frames with the leaf VLAN tag are transmitted to the roots but dropped for the leaves (these VLAN tags are removed before the frames are transmitted over the ACs). It was demonstrated in [IEEE-802.1Q-2014] that the E-Tree service in Ethernet networks can be well supported with this mechanism.

Assuming this mechanism is implemented in the bridge module, it is quite straightforward to infer a VPLS PE model with two VSIs to support the E-Tree (as shown in Figure 3). But this model will require two VSIs per PE and two sets of PWs per E-Tree service, which is poorly scalable in a large MPLS/VPLS network; in addition, both of these VSIs have to share their learned MAC addresses.

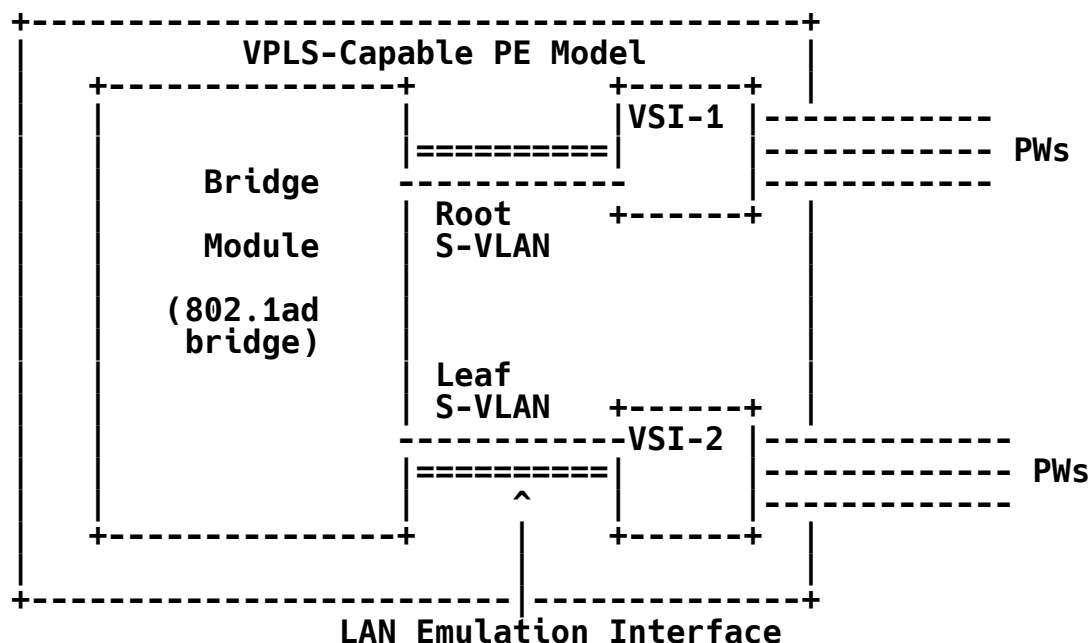


Figure 3: A VPLS PE Model for E-Tree with 2VSIs

4.2. A New PE Model with E-Tree Support

In order to support the E-Tree in a more scalable way, a new VPLS PE model with a single Tree VSI (T-VSI, a VSI with E-Tree support) is specified. As depicted in Figure 4, the bridge module is connected to the T-VSI with a dual-VLAN virtual interface, i.e., both the root VLAN and the leaf VLAN are connected to the same T-VSI, and they share the same FIB and work in shared VLAN learning. In this way, only one VPLS instance and one set of PWs is needed per E-Tree service, and the scalability of VPLS is improved.

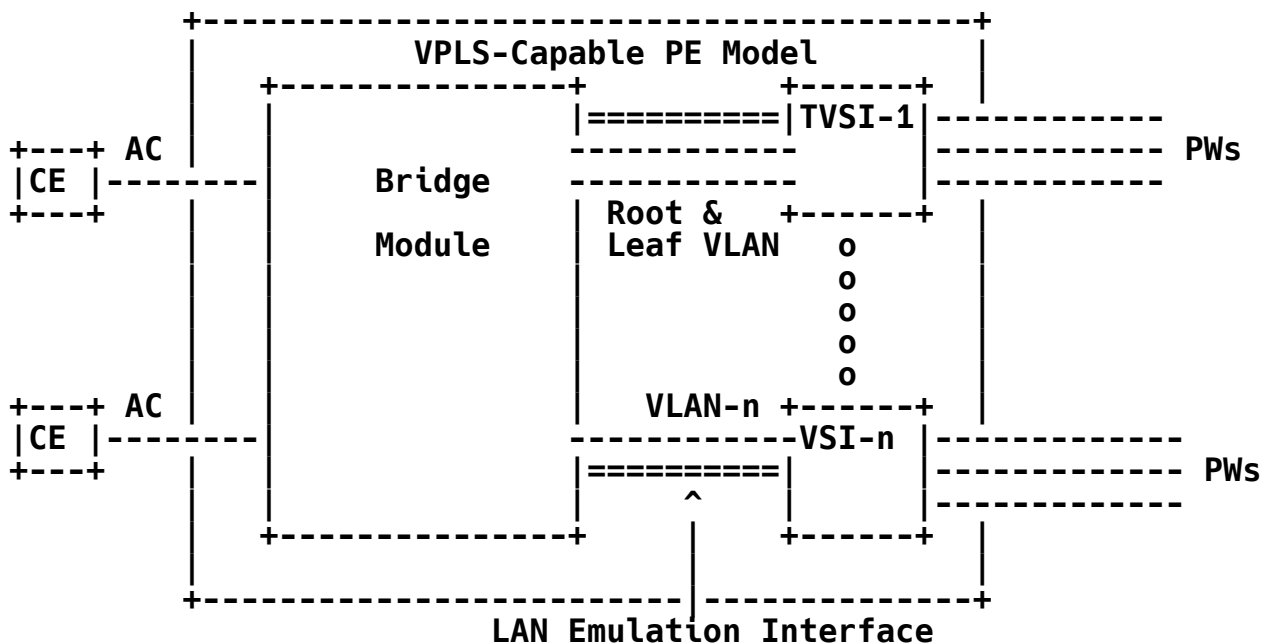


Figure 4: A VPLS PE Model for E-Tree with a Single T-VSI

For an untagged AC port (frames over this port are untagged) or a VLAN unaware port (VLAN tags in the frames are ignored), where the bridge module is a C-VLAN bridge, the Ethernet frames received from the root ACs MUST be tagged with a root C-VLAN. When the bridge module is an 802.1ad bridge [IEEE-802.1Q-2014], the Ethernet frames received from the root ACs MUST be tagged with a root S-VLAN. Note, this can be done by adding a root C-VLAN first in a C-VLAN bridge, but this is out of the scope of this document.

For a C-VLAN tagged port, the Ethernet frames received from the root ACs MUST be tagged with a root S-VLAN.

For an S-VLAN tagged port, the S-VLAN tag in the Ethernet frames received from the root ACs SHOULD be translated to the root S-VLAN in the VPLS network domain.

Alternatively, for an S-VLAN tagged port, the PBB VPLS PE model (where an IEEE 802.1ah bridge module is embedded in the PE) as described in [RFC7041] MAY be used. A root B-VLAN or a leaf B-VLAN MAY be added. The E-Tree attribute may also be indicated with two I-SID tags in the bridge module, and the frames are then encapsulated and transported transparently over a single B-VLAN. Thus, the PBB VPLS works in the same way as described in [RFC7041] and will not be discussed further in this document. When many S-VLANs are multiplexed in a single AC, PBB VPLS has the advantages of both VLAN scalability and MAC address scalability.

In a similar way, the traffic from the leaf ACs is tagged and transported on the leaf C-VLAN, S-VLAN, or B-VLAN.

In all cases, the outermost VLAN in the resulting Ethernet header is used to indicate the E-Tree attribute of an Ethernet frame; this document uses VLAN to refer to this outermost VLAN for simplicity in the latter sections.

5. PW for E-Tree Support

5.1. PW Encapsulation

To support an E-Tree service, T-VSIs in a VPLS MUST be interconnected with a bidirectional Ethernet PW. The Ethernet PW SHOULD work in the tagged mode (PW type 0x0004) as described in [RFC4448], in which case a VLAN tag MUST be carried in each frame in the PW to indicate the frame originated from either root or leaf (the VLAN tag indicating the frame originated from either root or leaf can be translated by a bridge module in the PE or added by an outside Ethernet edge device, even by a customer device). In the tagged PW mode, two service-delimiting VLANs MUST be allocated in the VPLS domain for an E-Tree. PW processing for the tagged PW will be described in Section 5.3 of this document.

A raw mode PW (PW type 0x0005 in [RFC4448]) MAY also be used to carry an E-Tree service for a PW in Compatible mode as shown in Section 5.3.2. As defined in [RFC4448], for a raw mode PW, an Ethernet frame's 802.1Q VLAN tag is not meaningful to the PEs and it passes transparently through them.

5.2. VLAN Mapping

There are two ways of manipulating VLANs for an E-Tree in VPLS:

- o Global VLAN based, that is, provisioning two global VLANs (Root VLAN and Leaf VLAN) across the VPLS network, thus no VLAN mapping is needed at all, or the VLAN mapping is done completely in the Ethernet domains.
- o Local VLAN based, that is, provisioning two local VLANs for each PE (that participates in the E-Tree) in the VPLS network independently.

The first method requires no VLAN mapping in the PW, but two unique service-delimiting VLANs must be allocated across the VPLS domain.

The second method is more scalable in the use of VLANs, but needs a VLAN mapping mechanism in the PW similar to what is already described in Section 4.3 of [RFC4448].

Global or local VLANs can be manually configured or provisioned by an Operational Support System. Alternatively, some automatic VLAN allocation algorithm may be provided in the management plane, but it is out of scope of this document.

For both methods, VLAN mapping parameters from a remote PE can be provisioned or determined by a signaling protocol as described in Section 6 when a PW is being established.

5.3. PW Processing

5.3.1. PW Processing in the VLAN Mapping Mode

In the VLAN mapping mode, two VPLS PEs with E-Tree capability are inter-connected with a PW (for example, the scenario of Figure 5 depicts the interconnection of two PEs attached with both root and leaf nodes).

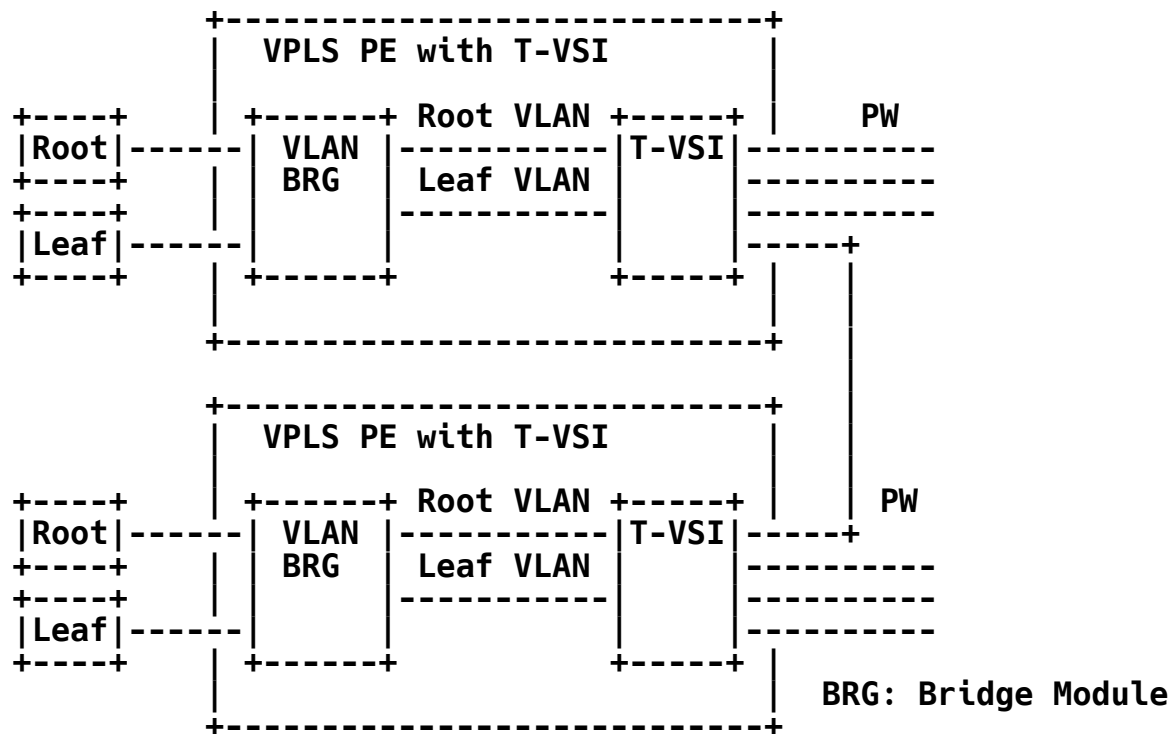


Figure 5: T-VSI Interconnected in the Normal Mode

If a PE is in the VLAN mapping mode for a PW, then in the data plane, the PE MUST map the VLAN in each frame as follows:

- o Upon transmitting frames on the PW, map from the local VLAN to the remote VLAN (i.e., the local leaf VLAN in a frame is translated to the remote leaf VLAN; the local root VLAN in a frame is translated to the remote root VLAN).
- o Upon receiving frames on the PW, map from the remote VLAN to the local VLAN, and the frames are further forwarded or dropped in the egress bridge module using the filtering mechanism as described in [IEEE-802.1Q-2014].

The signaling for VLANs used by E-Tree is specified in Section 6.

5.3.2. PW Processing in the Compatible Mode

The new VPLS PE model can work in a traditional VPLS network seamlessly in the compatibility mode. As shown in Figure 6, the VPLS PE with T-VSI can be attached with root and/or leaf nodes, while the VPLS PE with a traditional VSI can only be attached with root nodes. A raw PW SHOULD be used to connect them.

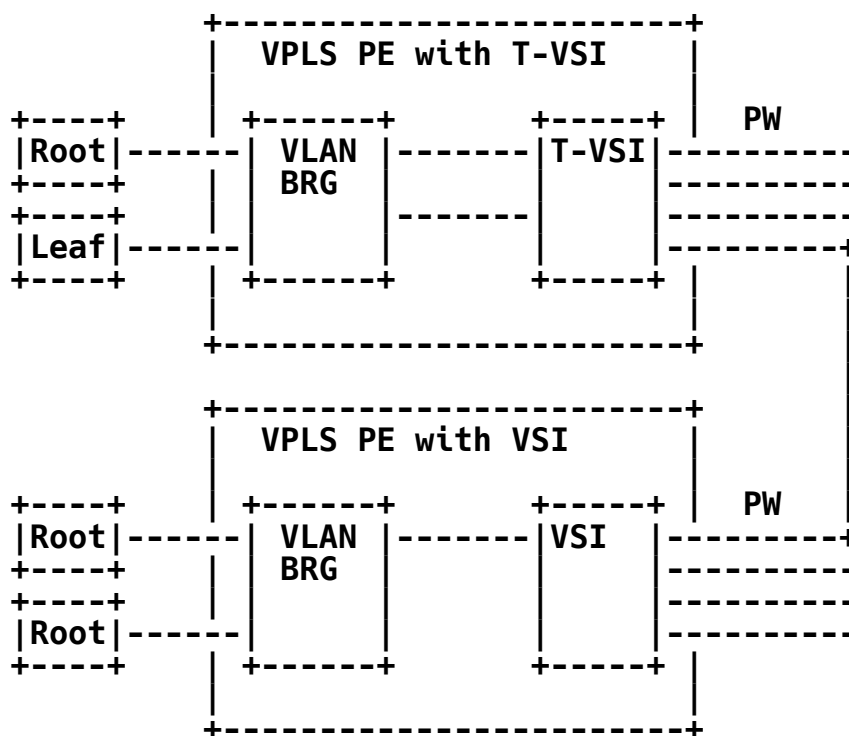


Figure 6: T-VSI Interconnected with Traditional VSI

If a PE is in the Compatible mode for a PW, then in the data plane, the PE MUST process the frame as follows:

- o Upon transmitting frames on the PW, remove the root or leaf VLAN in the frames.
- o Upon receiving frames on the PW, add a VLAN tag with a value of the local root VLAN to the frames.

5.3.3. PW Processing in the Optimized Mode

When two PEs (both with E-Tree capability) are inter-connected with a PW and one of them (e.g., PE2) is attached with only leaf nodes, as shown in the scenario of Figure 7, its peer PE (e.g., PE1) should then work in the Optimized mode for this PW. In this case, PE1 should not send the frames originated from the local leaf VLAN to PE2, i.e., these frames are dropped rather than transported over the PW. The bandwidth efficiency of the VPLS can thus be improved. The signaling for the PE attached with only leaf nodes is specified in Section 6.

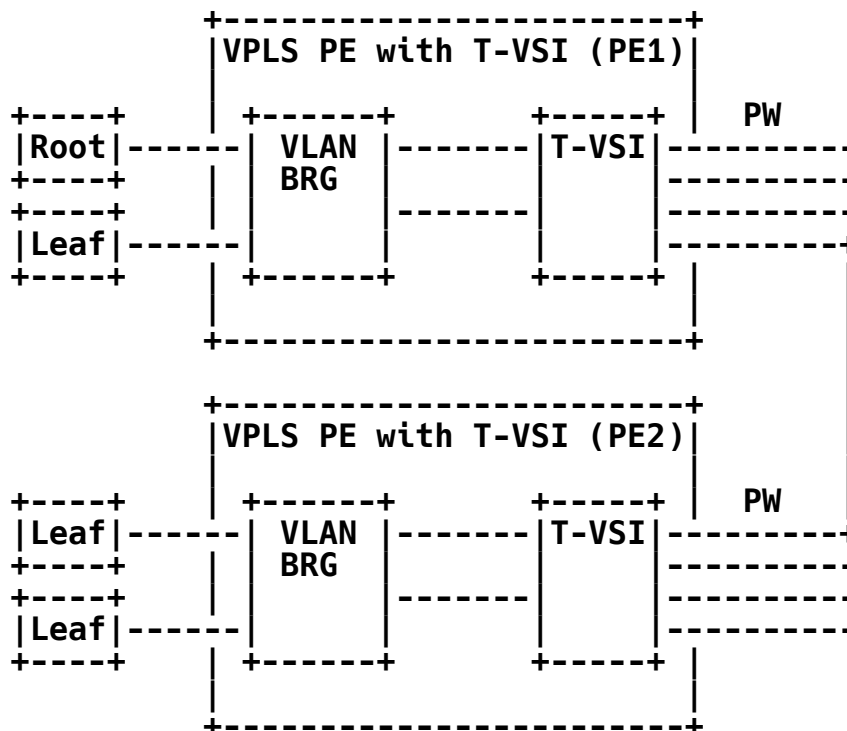


Figure 7: T-VSI Interconnected with PE Attached with Only Leaf Nodes

If a PE is in the Optimized Mode for a PW, upon transmit, the PE SHOULD drop a frame if its VLAN ID matches the local leaf VLAN ID.

6. Signaling for E-Tree Support

6.1. LDP Extensions for E-Tree Support

In addition to the signaling procedures as specified in Section 5.3.3 of [RFC4447], this document specifies a new interface parameter sub-TLV to provision an E-Tree service and negotiate the VLAN mapping function, as follows:

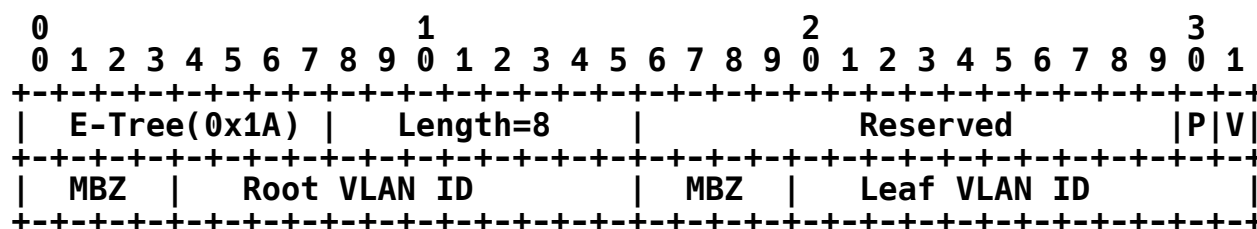


Figure 8: E-Tree Sub-TLV

Where:

- o E-Tree is the sub-TLV identifier (0x1A) as assigned by IANA.
- o Length is the length of the sub-TLV in octets.
- o Reserved, bits MUST be set to zero on transmit and be ignored on receive.
- o P is a leaf-only bit, it is set to 1 to indicate that the PE is attached with only leaf nodes, and set to 0 otherwise.
- o V is a bit indicating the sender's VLAN mapping capability. A PE capable of VLAN mapping MUST set this bit, and clear it otherwise.
- o Must Be Zero (MBZ), 4 bits MUST be set to zero on transmit and be ignored on receive.
- o Root VLAN ID is the value of the local root VLAN.
- o Leaf VLAN ID is the value of the local leaf VLAN.

When setting up a PW for the E-Tree based VPLS, two peer PEs negotiate the E-Tree support using the above E-Tree sub-TLV. Note that the PW type of 0x0004 SHOULD be used during the PW negotiation.

A PE that wishes to support an E-Tree service MUST include an E-Tree sub-TLV in its PW Label Mapping message and include its local root VLAN ID and leaf VLAN ID in the TLV. A PE that has the VLAN mapping

capability **MUST** set the V bit to 1, and a PE attached with only leaf nodes **SHOULD** set the P bit to 1.

A PE that receives a PW Label Mapping message with an E-Tree sub-TLV from its peer PE, after saving the VLAN information for the PW, **MUST** process it as follows:

- 1) For this PW, set VLAN-Mapping-Mode, Compatible-Mode, and Optimized-Mode to FALSE.
- 2) If either the root VLAN ID in the message is not equal to the local root VLAN ID, or the leaf VLAN ID in the message is not equal to the local leaf VLAN ID {

If the bit V is cleared {

If the PE is capable of VLAN mapping, it **MUST** set VLAN-Mapping-Mode to TRUE;

Else {

A Label Release message with the error code "E-Tree VLAN mapping not supported" is sent to the peer PE and exit the process;

}

}

If the bit V is set, and the PE is capable of VLAN mapping, the PE with the minimum IP address **MUST** set VLAN-Mapping-Mode to TRUE;

}

- 3) If the P bit is set

{

If the PE is a leaf-only node itself, a Label Release message with a status code "Leaf-to-Leaf PW released" is sent to the peer PE and exits the process;

Else the PE **SHOULD** set the Optimized-Mode to TRUE.

}

A PE SHOULD send a Label Mapping message with an E-Tree sub-TLV as per Section 5.3.3 of [RFC4447]. A PE MUST send a Label Mapping message with an updated E-Tree sub-TLV to all other PEs over corresponding LDP sessions when its role changes from leaf-only to not leaf-only (i.e., when a root node is added to a PE attached with only leaf nodes).

If a PE has sent a Label Mapping message with an E-Tree sub-TLV but does not receive any E-Tree sub-TLV in its peer's PW Label Mapping message, the PE SHOULD then establish a raw PW with this peer as in traditional VPLS and set Compatible-Mode to TRUE for this PW.

Data plane processing for this PW is as follows:

- o If Optimized-Mode is TRUE, then data plane processing as described in Section 5.3.3 applies.
- o If VLAN-Mapping-Mode is TRUE, then data plane processing as described in Section 5.3.1 applies.
- o If Compatible-Mode is TRUE, then data plane processing as described in Section 5.3.2 applies.
- o PW processing as described in [RFC4448] proceeds as usual for all cases.

When VPLS is set up using the Pseudowire ID (PWid) Forwarding Equivalence Class (FEC) Element (see Appendix A of [RFC4762]), its E-Tree signaling is similar to the above process. Dynamic re-configuration of E-Tree should be avoided for this case. However, when re-configuration of E-Tree is forced on a PE for some reason (e.g., a configuration error), the PE may close the LDP sessions with its peer PEs for this VPLS instance and re-install its PW labels, so that its peer PEs can send out the LDP Label Mapping messages again.

6.2. BGP Extensions for E-Tree Support

A new E-Tree extended community (0x800b) has been allocated by IANA for E-Tree signaling in BGP VPLS:

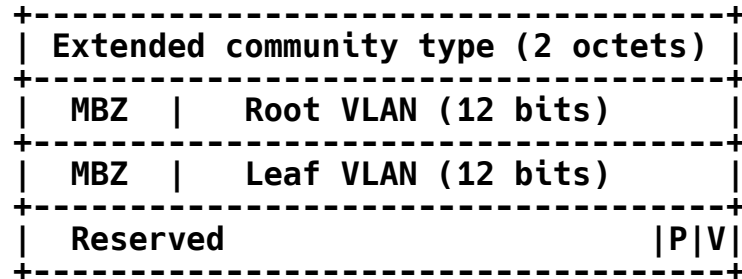


Figure 9: E-Tree Extended Community

Where:

- o Must Be Zero (MBZ), 4 bits MUST be set to zero on transmit and be ignored on receive.
- o Root VLAN ID is the value of the local root VLAN.
- o Leaf VLAN ID is the value of the local leaf VLAN.
- o Reserved, 14 bits MUST be set to zero on transmit and be ignored on receive.
- o P is a leaf-only bit, it is set to 1 to indicate that the PE is attached with only leaf nodes, and set to 0 otherwise.
- o V is a bit indicating the sender's VLAN mapping capability. A PE capable of VLAN mapping MUST set this bit, and clear it otherwise.

The PEs attached with both leaf and root nodes MUST support BGP E-Tree signaling as described in this document, and SHOULD support VLAN mapping in their data planes. The traditional PE attached with only root nodes may also participate in an E-Tree service. If some PEs don't support VLAN mapping, global VLANs as per Section 5.2 MUST be provisioned for an E-Tree service.

In BGP VPLS signaling, besides attaching a Layer2 Info Extended Community as detailed in [RFC4761], an E-Tree Extended Community MUST be further attached if a PE wishes to participate in an E-Tree service. The PE MUST include its local root VLAN ID and leaf VLAN ID

in the E-Tree Extended Community. A PE attached with only leaf nodes of an E-Tree SHOULD set the P bit in the E-Tree Extended Community to 1.

A PE that receives a BGP UPDATE message with an E-Tree Extended Community from its peer PE, after saving the VLAN information for the PW, MUST process it as follows (after processing procedures as specified in Section 3.2 of [RFC4761]):

- 1) For this PW, set VLAN-Mapping-Mode, Compatible-Mode, and Optimized-Mode to FALSE.
- 2) If either the root VLAN ID in the E-Tree Extended Community is not equal to the local root VLAN ID, or the leaf VLAN ID in the E-Tree Extended Community is not equal to the local leaf VLAN ID {

If the bit V is cleared {

If the PE is capable of VLAN mapping, it MUST set VLAN-Mapping-Mode to TRUE;

Else {

Log with a message "E-Tree VLAN mapping not supported" and exit the process;

}

}

If the bit V is set, and the PE is capable of VLAN mapping, the PE with the minimum IP address MUST set VLAN-Mapping-Mode to TRUE;

}

- 3) If the P bit is set {

If the PE is a leaf-only PE itself, forbids any traffic on the PW;

Else the PE SHOULD set the Optimized-Mode to TRUE.

}

A PE that does not recognize this attribute SHALL ignore it silently. If a PE has sent an E-Tree Extended Community but does not receive any E-Tree Extended Community from its peer, the PE SHOULD then

establish a raw PW with this peer as in traditional VPLS and set Compatible-Mode to TRUE for this PW.

The data plane in the VPLS is the same as described in Section 4.2 of [RFC4761], and data plane processing for a PW is the same as described at the end of Section 6.1 in this document.

7. OAM Considerations

The VPLS OAM requirements and framework as specified in [RFC6136] are applicable to E-Tree, as both Ethernet OAM frames and data traffic are transported over the same PW.

Ethernet OAM for E-Tree including both service OAM and segment OAM frames SHALL undergo the same VLAN mapping as the data traffic; and root VLAN SHOULD be applied to segment OAM frames so that they are not filtered.

8. Applicability

The solution specified in this document is applicable to both LDP VPLS [RFC4762] and BGP VPLS [RFC4761].

This solution is applicable to both "VPLS Only" networks and VPLS with Ethernet aggregation networks.

This solution is also applicable to PBB VPLS networks.

9. IANA Considerations

IANA allocated the following value for E-Tree in the "Pseudowire Interface Parameters Sub-TLV type Registry".

Parameter ID	Length	Description
0x1A	8	E-Tree

IANA allocated the two following new LDP status codes in the "Status Code Name Space" registry.

Range/Value	E	Description
0x20000003	1	E-Tree VLAN mapping not supported
0x20000004	0	Leaf-to-Leaf PW released

IANA allocated the following value for E-tree in the "Generic Transitive Experimental Use Extended Community Sub-Types" registry within the BGP Extended Community registry.

Type Value	Sub-Type Value	Name
=====	=====	=====
0x80	0x0b	E-Tree Info

10. Security Considerations

This solution requires implementations to prevent leaf-to-leaf communication in the data plane of VPLS when its PEs are interconnected with PWs. If all PEs enforce that, then network attacks from one leaf to another leaf are avoided, and security can be enhanced for customers with this solution. However, if a PE is compromised or inappropriately configured, a leaf node may be taken as a root node and may receive traffic from other leaf nodes inappropriately. Authenticity and integrity measures for LDP need to be considered as in RFC 5036 [RFC5036]. Security considerations as described in [RFC4448], [RFC4761], and [RFC4762] also apply.

11. References

11.1. Normative References

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Appendix A. Other PE Models for E-Tree

A.1. A PE Model with a VSI and No Bridge

If there is no bridge module in a PE, the PE may consist of Native Service Processors (NSPs) as shown in Figure 10 (adapted from Figure 5 of [RFC3985]) where any transformation operation for VLANs (e.g., VLAN insertion/removal or VLAN mapping) may be applied. Thus, a root VLAN or leaf VLAN can be added by the NSP depending on the User Network Interface (UNI) type (root/leaf) associated with the AC over which the packet arrives.

Further, when a packet with a leaf VLAN exits a forwarder and arrives at the NSP, the NSP must drop the packet if the egress AC is associated with a leaf UNI.

Tagged PW and VLAN mapping work in the same way as in the typical PE model.

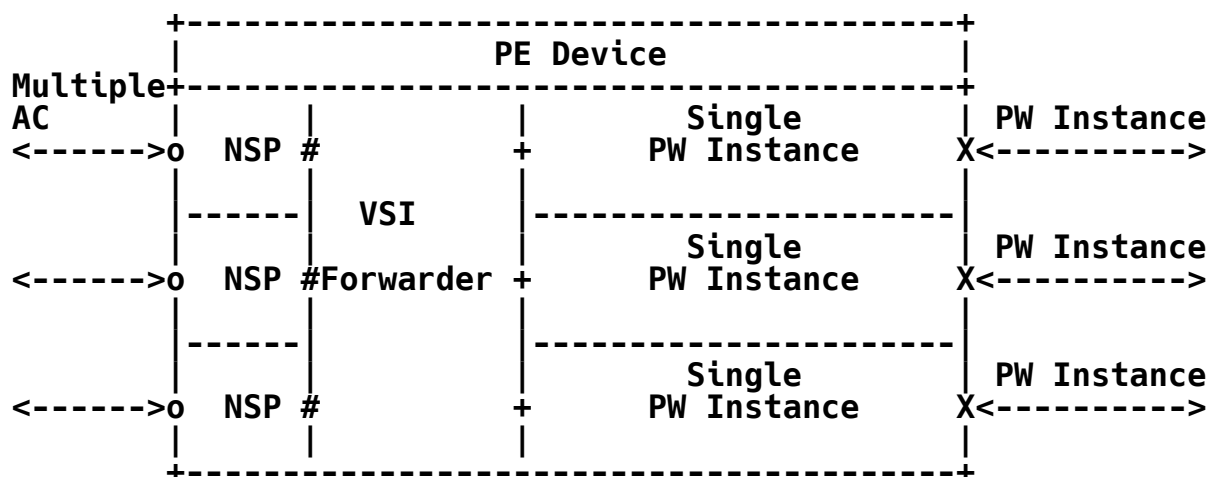


Figure 10: A PE Model with a VSI and No Bridge Module

This PE model may be used by a Multi-Tenant Unit switch (MTU-s) in a Hierarchical VPLS (H-VPLS) network or a Network-facing PE (N-PE) in an H-VPLS network with non-bridging edge devices, wherein a spoke PW can be treated as an AC in this model.

A.2. A PE Model with External E-Tree Interface

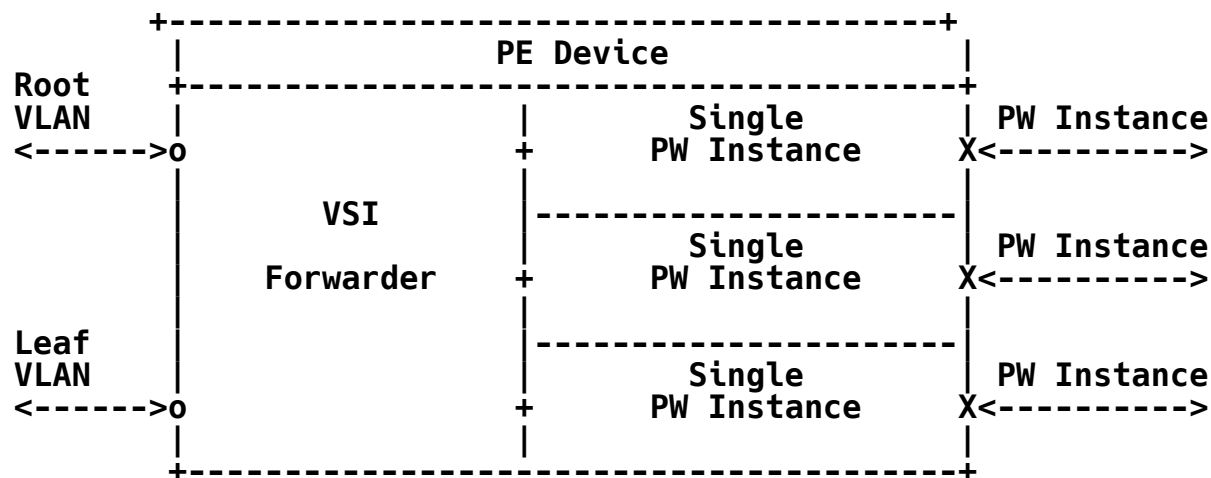


Figure 11: A PE Model with External E-Tree Interface

A more simplified PE model is depicted in A.2, where Root/Leaf VLANs are directly or indirectly connected over a single PW to the same VSI forwarder in a PE, any transformation of E-Tree VLANs, e.g., VLAN insertion/removal or VLAN mapping, can be performed by some outer equipment, and the PE may further translate these VLANs into its own local VLANs. This PE model may be used by an N-PE in an H-VPLS network with bridging-capable devices, or scenarios such as providing E-Tree Network-to-Network interfaces.

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