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A Framework for E-Tree Service over MPLS Network
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Status of this Memo

Abstract

This document proposes a solution framework for supporting Metro Ethernet Forum (MEF) Ethernet Tree (E-Tree) services over a Multiprotocol Label Switching (MPLS) network. The objective is to provide a simple and effective approach to emulate E-Tree services in addition to Ethernet LAN (E-LAN) services on an existing MPLS network.

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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].

1. Introduction

1.1. Objective and Scope

This document proposes a solution framework for supporting Metro Ethernet Forum (MEF) Ethernet Tree (E-Tree) services over a MPLS network. The objective is to provide a simple and effective approach to emulate E-Tree services in addition to Ethernet LAN (E-LAN) services on an existing MPLS network.

This solution framework makes use of existing IETF specified mechanisms unless there are technical reasons why the existing mechanisms are insufficient or unnecessary.

This document does not intend to provide a full specification of the solution, but rather to identify the functional components of the overall solution, and for each component, whether it is REQUIRED or OPTIONAL, whether existing mechanism is sufficient, or whether relevant mechanism is already under development.

In this document, "current standard" refers to [RFC4385], [RFC4447], [RFC4448], [RFC4761] and [RFC4762].

1.2. Traditional Ethernet Network

In this document, traditional Ethernet network refers to the Ethernet bridge/switch network, not the Ethernet repeater/hub network.

Data frame is Ethernet frame.

Data forwarding is MAC-based forwarding, which includes MAC address learning and aging.

It is important to note that in traditional Ethernet network unicast unknown, multicast and broadcast frames are forwarded in exactly the same way to every port except the ingress port.

An Ethernet host receiving a frame checks the destination address in the frame to decide whether it is the intended destination.

1.3. MEF Multipoint Ethernet Services

MEF defines two multipoint Ethernet Service types:
- E-LAN (Ethernet LAN), multipoint-to-multipoint service
- E-Tree (Ethernet Tree), rooted-multipoint service

According to MEF's technical specification, a generic E-LAN/E-Tree service is always bidirectional in the sense that ingress frames can originate at any endpoint in the service. However, some application

scenarios of E-Tree may have unidirectional traffic only. Section 3 will discuss about different use cases.

For full specification, please refer to MEF's "Ethernet Services Definitions - Phase 2" [MEF6.1] and "Ethernet Services Attributes Phase 2" [MEF10.2].

1.3.1. Similarity between E-LAN and E-Tree

Data frame is Ethernet frame.

Data forwarding can be MAC-based forwarding or something else, to be specified by service provider in the particular service definition.

Extract from [MEF6.1] Table 7 and Table 9:

EVC Service Attribute	E-LAN/E-Tree Service Type Requirement
Unicast Service Frame Delivery	Deliver Unconditionally or Deliver Conditionally. If Delivered Conditionally, MUST specify the delivery criteria.
Multicast Service Frame Delivery	Deliver Unconditionally or Deliver Conditionally. If Delivered Conditionally, MUST specify the delivery criteria.
Broadcast Service Frame Delivery	Deliver Unconditionally or Deliver Conditionally. If Delivered Conditionally, MUST specify the delivery criteria.

It is important to note that it is not a must for a MEF multipoint Ethernet service (E-LAN or E-Tree) to use MAC-based forwarding. This document presents a solution framework for MAC-based forwarding E-Tree in section 5, and also discusses non-MAC-based forwarding E-Tree in section 6.

1.3.2. Difference between E-LAN and E-Tree

Within the context of a multipoint Ethernet service, each endpoint is designated as either a Root or a Leaf. A Root can communicate with all other endpoints in the same multipoint Ethernet service, however a Leaf can only communicate with Roots but not Leafs.

The only difference between E-LAN and E-Tree is:

- E-LAN has Root endpoints only, which implies there is no communication restriction between endpoints
- E-Tree has both Root and Leaf endpoints, which implies there is a need to enforce communication restriction between Leaf endpoints

Extract from [MEF10.2] Section 6.3:

The UNI Type MUST have the value either "Root" or "Leaf." If the type of EVC is Point-to-Point or Multipoint-to-Multipoint, then the UNI Type MUST equal "Root."

Extract from [MEF10.2] Section 6.1.2.2:
An ingress Service Frame mapped to the EVC at a Leaf UNI MUST NOT result in an egress Service Frame at another Leaf UNI but MAY result in an egress Service Frame at some or all of the Root UNIs.

It is important to note that one E-Tree service may have single or multiple Root UNIs.

Extract from [MEF6.1] Section 6.3:
In its simplest form, an E-Tree Service type can provide a single Root for multiple Leaf UNIs. Each Leaf UNI can exchange data with only the Root UNI. ... In more sophisticated forms, an E-Tree Service type may support two or more Root UNIs. In this scenario, each Leaf UNI can exchange data only with the Root UNIs. As well, the Roots can communicate with each other. In such a service, redundant access to the Root can also be provided, effectively allowing for enhanced service reliability and flexibility.

1.4. IETF Multipoint L2VPN Services

1.4.1. Virtual Private LAN Service (VPLS)

VPLS is a L2VPN service that provides multipoint-to-multipoint connectivity for Ethernet across an IP or MPLS-enabled IP Packet Switched Network. VPLS emulates the Ethernet VLAN functionality of traditional Ethernet network.

VPLS is a current IETF standard, please refer to [RFC4761] [RFC4762].

Data frame is Ethernet frame.

Data forwarding is MAC-based forwarding, which includes MAC address learning and aging.

It is important to note that the current standard VPLS treats Ethernet multicast frame in exactly the same way as Ethernet broadcast frame and does not restrict transmission of Ethernet multicast frame to a smaller set of receivers. An Ethernet host receiving a frame checks the destination address in the frame to determine whether it is the intended destination.

VPLS can be used to emulate E-LAN service over MPLS network provided that the E-LAN service uses MAC-based forwarding as service frame delivery attribute. Considerable number of service providers have adopted this approach to provide E-LAN services to customers.

1.4.2. Virtual Private Multicast Service (VPMS)

VPMS is a L2VPN service that provides point-to-multipoint

connectivity across a variety of link layers, including Frame Relay, ATM, Ethernet, PPP, etc., across an IP or MPLS-enabled IP Packet Switched Network.

In the Ethernet use case, VPMS provides single coverage of receiver membership, i.e. there is no distinct differentiation for multiple multicast groups. Destination address in Ethernet frame is not used in data forwarding.

VPMS MUST support unidirectional point-to-multipoint traffic from a sender to multiple receivers and MAY support reverse traffic in a point-to-point manner.

VPMS is currently under development. Please refer to [Draft VPMS Frmwk].

1.5. Terminology

E-Tree

An Ethernet VPN in which each Root AC can communicate with every other AC, whereas Leaf ACs can only communicate with Root ACs. Each AC on an E-Tree construct is designated as either a Root AC or a Leaf AC. There can be multiple Root ACs and Leaf ACs per E-Tree construct.

Root AC

An ingress frame at a Root AC can be delivered to one or more of any of the other ACs in the E-Tree. Please note that this AC is bidirectional.

Leaf AC

Ingress frame at a Leaf AC can only be delivered to one or more Root ACs in the E-Tree. Ingress frame at a Leaf AC MUST NOT be delivered to any Leaf ACs in the E-Tree. Please note that this AC is bidirectional.

2. Reference Model

Figure 1 below describes a generic reference model where PE1, PE2 and PE3 need to establish an E-Tree construct between different Ethernet endpoints. Each PE has 2 Root ACs and 2 Leaf ACs connected to a VSI. These VSIs are then linked together via Ethernet PWs.

In most use cases, an E-Tree construct has only a few Root ACs but many Leaf ACs. There may be only Root ACs or only Leaf ACs on a PE.

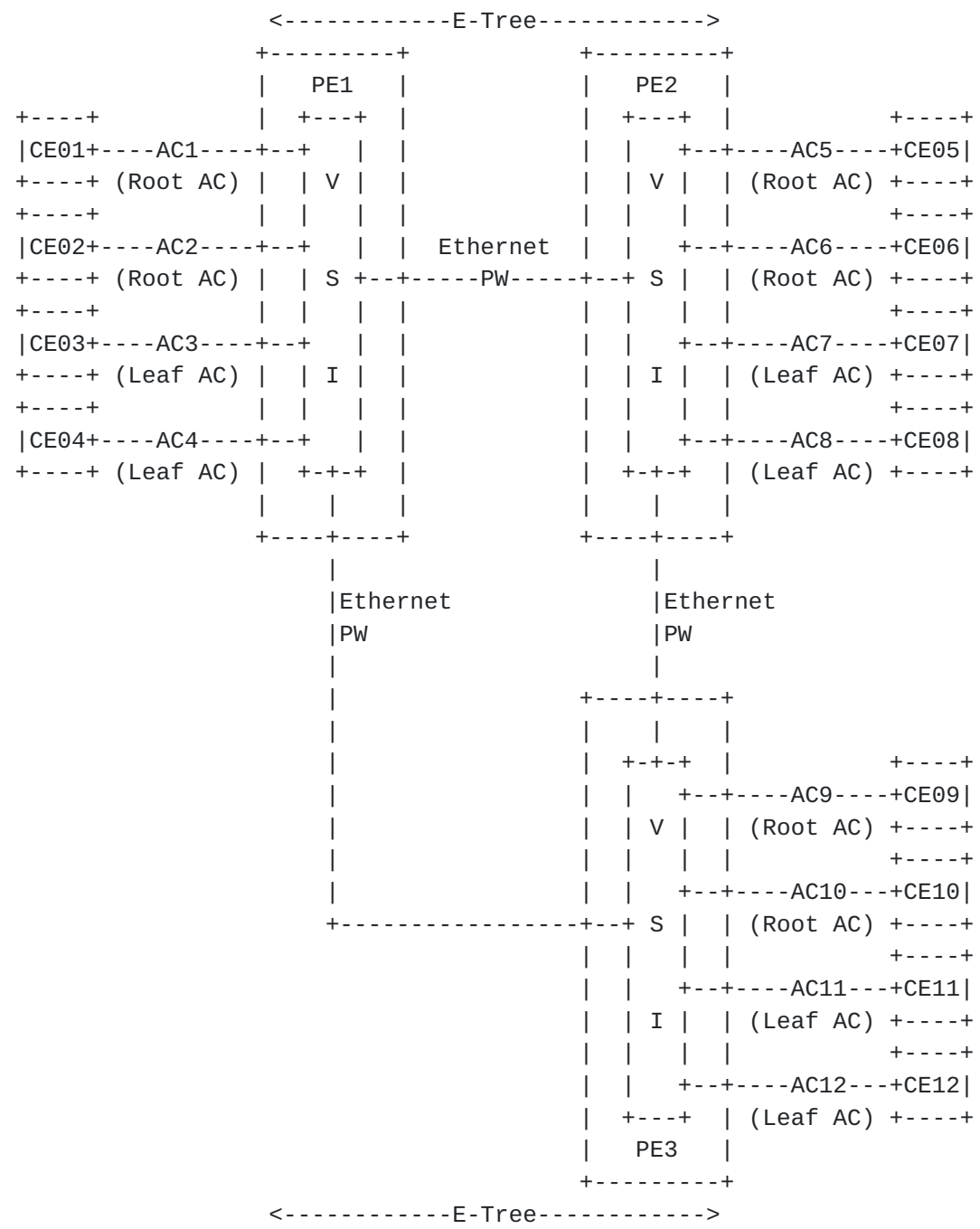

Figure 1: E-Tree Reference Model

With an E-Tree construct:
- A Root AC can receive from and transmit to any other ACs.
- A Leaf AC can receive from and transmit to any Root ACs.
- A Leaf AC cannot receive from and transmit to any other Leaf ACs.

This applies to all traffic, including Unicast Known, Unicast Unknown, Broadcast and Multicast.

When an Ethernet Frame is received on PE1 via AC1, the frame can be transmitted to any other local ACs on PE1 and via Ethernet PWs to any remote ACs on PE2 and PE3.

However when an Ethernet frame is received on PE1 via AC3, the frame can be transmitted to any other local Root ACs on PE1 and via Ethernet PWs to any remote Root ACs on PE2 and PE3, but the frame cannot be transmitted to any local Leaf ACs on PE1 nor any remote Leaf ACs on PE2 and PE3.

3. Use Cases

Table 1 below presents some major use cases.

	Use Case	Root	Leaf
1	Hub & Spoke VPN	Hub Site	Spoke Site
2	Wholesale Access	Customer's Interconnect	Customer's Subscriber
3	Mobile Backhaul	RAN NC	RAN BS
4	IEEE 1588 PTPv2 Clock Synchronisation	PTP Server	PTP Client
5	Internet Access Reference: [TR-101]	BNG Router	Subscriber
6	Broadcast Video (unidirectional only)	Video Source	Subscriber
7	Broadcast/Multicast Video plus Control Channel	Video Source	Subscriber
8	Device Management	Management System	Managed Device

Table 1: E-Tree Use cases

Common to all use cases, direct Layer 2 Leaf-to-Leaf communication is not required. For Mobile backhaul, this may not be valid for LTE X2 interfaces in the future.

If direct Layer 2 Leaf-to-Leaf communication is not allowed due to security concern, then E-Tree should be used to prohibit communication between Leaf endpoints, otherwise E-LAN is also a feasible option.

Also common to the use cases mentioned above, there may be single or

multiple Root endpoints in one E-Tree service. The need for multiple Root endpoints is usually driven by redundancy requirement. Whether a particular E-Tree service needs to support single or multiple Root endpoints depends on the target application.

A generic E-Tree service supports all the following traffic flows:
- Ethernet Unicast from Root to Leaf
- Ethernet Unicast from Leaf to Root
- Ethernet Unicast from Root to Root
- Ethernet Broadcast/Multicast from Root to Roots & Leafs
- Ethernet Broadcast/Multicast from Leaf to Roots

A particular E-Tree service may need to support all the above or only a subset depending on the target application.

Among the use cases mentioned above, broadcast video draws most attention. Actually, broadcast video is a representing example for content delivery in general, such as news feed, financial data feed, etc.

4. Challenges

4.1. Generic E-Tree Service Definition

This section highlights why the current standard VPLS is insufficient for emulating E-Tree service over MPLS network.

4.1.1. Mandatory Leaf-to-Leaf Communication Restriction

Current standard VPLS treats all ACs equal (i.e. not classified into Root or Leaf) and provides any-to-any connectivity among all ACs. The current standard VPLS does not include any mechanism of communication restriction between specific ACs, therefore is insufficient for emulating generic E-Tree service over MPLS network.

A problem occurs when there are two or more PEs with both Root AC and Leaf AC.

Let's look at the scenario illustrated in Figure 2 below. VPLS is used to emulate an E-Tree service over a MPLS network.

Note: Figure 2 is a hypothetical case solely for explaining the problem, and not meant to represent a typical E-Tree service.

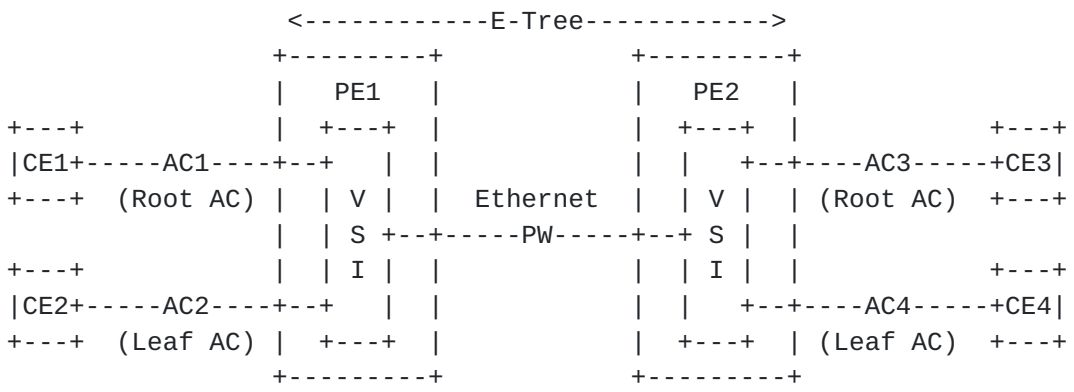

Figure 2: Problem Scenario for Leaf-to-Leaf Communication Restriction

When PE2 receives a frame from PE1 via the Ethernet PW,
- PE2 does not know which AC on PE1 is the ingress AC
- PE2 does not know whether the ingress AC is a Leaf AC or not
- PE2 does not have sufficient information to enforce the Leaf-to-Leaf communication restriction

Examples:
- CE2 sends a Broadcast/Multicast frame to PE1 via AC2
- CE2 sends a Unicast frame to PE1 via AC2, destination address in Ethernet header equal to CE4's MAC address

In order to fulfil the generic E-Tree service definition, extension to the current VPLS standard will be required. Extension to related PWE3 standard may also be required, depending on solution approach. Such extensions should have minimal impact on the emulated E-LAN services already in operation.

There are some possible ways to get around this problem that do not require extension to the current VPLS standard but they all come with significant design complexity or deployment constraints. Appendix A highlights the major ones and the related concerns.

4.2. Use Case Desirable Requirements

There are quite a variety of use cases for E-Tree. For some use cases, the generic MEF E-Tree service definition is good enough. For some other use cases, there are desirable requirements beyond that.

The challenges discussed in this section are not related to the generic MEF E-Tree service definition but the desirable requirements of specific use cases. They may be critical to the success in some E-Tree services while totally irrelevant in some others.

4.2.1. Ethernet Broadcast/Multicast Optimisation

According to MAC-based forwarding, an Ethernet broadcast/multicast/ unicast unknown frame is forwarded to all ACs other than the ingress AC, which implies point-to-multipoint traffic from the ingress PE to all other PEs in the VPLS instance.

The current standard VPLS uses only point-to-point PW between PEs. When the Ethernet destination address is broadcast, multicast or unicast unknown, the ingress PE replicates the frame on every PW towards remote PE belonging to the same VPLS instance. Depending on the mapping between the logical topology of the E-Tree service and the physical topology of the network, multiple PWs may transverse same physical link, result in multiple copies of the same payload Ethernet frame on the physical link. Such approach is inefficient in terms of bandwidth usage.

For some use cases, for example broadcast/multicast video, due to nature of the application, there is significant volume of point-to-multipoint traffic. Bandwidth optimisation for such traffic within the network becomes a concern from the service provider perspective.

[RFC5501] provides an in-depth discussion on broadcast/multicast related requirements for VPLS, see issue B (Replication of PWs on shared physical path) in section 3.2.

4.2.2. IP Multicast Optimisation

The current standard VPLS is a L2VPN service agnostic to customer's Layer 3 traffic, hence does not maintain any information about IP multicast group membership. Although a Layer 3 IP multicast packet is encapsulated in a Layer 2 Ethernet multicast frame, the current standard VPLS treats Ethernet multicast frame in exactly the same way as Ethernet broadcast frame. Therefore, such payload IP multicast packet will be forwarded to every other AC of the same VPLS instance.

A payload IP multicast packet will be forwarded to all ACs, including those with no member of the specific IP multicast group attached. Unnecessary traffic consumes bandwidth on access link and may become a concern from the customer perspective. In some cases, it may also be a security concern as the multicast frame may be forwarded to an endpoint other than the intended destinations.

A payload IP multicast packet will be forwarded to a remote PE with no member of the specific IP multicast group attached. Unnecessary traffic consumes bandwidth in the network and may become a concern from the service provider perspective.

For some use cases, for example multicast video, due to nature of the application, there is significant volume of IP multicast traffic and different IP multicast groups are required in one E-Tree service. The above may become a real concern from both the customer and service provider perspectives.

[RFC5501] provides an in-depth discussion on broadcast/multicast related requirements for VPLS, see both issue A (Replication to non-member site) and issue B (Replication of PWs on shared physical path) in section 3.2.

4.2.3. MAC-based Forwarding Unnecessary

For some use cases, for example broadcast video, due to nature of the application, there is only broadcast unidirectional traffic from Root to all other endpoints. It is unnecessary to use destination address for data forwarding. Deliver unconditionally for ingress frame at Root endpoint may be a simpler approach than MAC-based forwarding.

4.2.4. MAC-based Forwarding Security Concern

MAC-based forwarding will make an unicast frame from a Root destined for a specific Leaf being forwarded to other endpoints in addition to the intended destination when the frame is classified as unicast unknown, may be due to MAC address aged out or MAC address table overflow.

MAC address spoofing may cause an unicast frame from a Root destined for a specific Leaf being forwarded to an endpoint different from the intended destination.

If such unicast frame carries sensitive information strictly for the intended destination only, then the MAC-based forwarding may cause a security concern from the customer perspective.

For some use cases where mutually un-trusted subscribers are connected to leaf endpoints in the same E-Tree service, such as Internet access and wholesale access, this is a valid concern.

There are some possible mitigations:

- For every Leaf endpoint of the particular E-Tree service, deploy a service provider controlled router between the Leaf endpoint and the customer network
- Customer to deploy encryption for sensitive information, for example IPsec, SSL, SSH, HTTPS

Whether the MAC-based forwarding really becomes a security concern depends on the particular application and the deployment scenario. This is unlikely to be a critical concern in most cases.

5. A Solution Framework for MAC-based Forwarding E-Tree

As mentioned in section 1.3.1. E-Tree can use MAC-based forwarding or something else for data forwarding. This section presents a solution framework for MAC-based forwarding E-Tree. Section 6 will discuss other variants.

This is a VPLS-based solution. Functional components of the solution are identified and discussed in the subsections.

5.1. MAC-based Forwarding Any-to-Any Ethernet VPN

This is a REQUIRED component.

This component is the current standard VPLS and PWE3 as specified in [RFC4385] [RFC4447] [RFC4448] [RFC4761] [RFC4762], which provides any-to-any connectivity among all ACs in one VPLS instance.

This is the base component. All other REQUIRED/OPTIONAL components are to be added on top of this component.

5.2. Leaf-to-Leaf Communication Restriction

This is in response to the challenge in section 4.1.1. Mandatory Leaf-to-Leaf Communication Restriction.

This is a REQUIRED component.

This component is a minimal extension to the current VPLS and PWE3 standards, with the objective to provide a simple and effective way to support generic E-Tree services in addition to E-LAN services using VPLS on a MPLS network.

[Draft VPLS ETree Req] is a work in progress requirement draft.

Different solutions have been proposed:
- Control Word L-bit solution, [Draft CW L-bit] [Draft VPLS ETree]
- Dual VLAN solution, [Draft VPLS PE ETree]
- Two PW solution, [Draft VPLS ETree 2PW]
- Two VE ID solution [Draft VPLS ETree 2VEID]

5.3. Optional Enhancement - Point-to-Multipoint PW

This is in response to the challenge in section 4.2.1. Ethernet Broadcast/Multicast Optimisation.

This is an OPTIONAL component, applicable only when there is significant volume of Ethernet broadcast/multicast traffic.

Point-to-Multipoint pseudowire (P2MP PW) is a PW attached to a source used to distribute Layer 1 or Layer 2 format traffic to a set of receivers. P2MP PW is unidirectional but optionally bidirectional.

By using P2MP PW, the ingress PE is not responsible for replicating the payload frame on each P2P PW towards egress PE, instead the network elements along the physical path participate in replication. The replication is done by the underlying point-to-multipoint label switched path (P2MP LSP).

Extension to current VPLS standard will be required to specify how P2MP PW and P2P PW should be used and how MAC learning works on P2MP PW. Please refer to [Draft LDP-VPLS Bcast].

P2MP PW is currently under development. Please refer to [Draft P2MP PW Req] [Draft P2MP PW Sig].

It is important to note that this component will align with the recommendation in [RFC4665],
"With the exception of IPLS, an L2VPN service SHOULD be agnostic to customer's Layer 3 traffic (e.g., IP, IPX, Appletalk) encapsulated

within Layer 2 frames."

5.4. Optional Enhancement - IP Multicast in VPLS

This is in response to the challenge in section 4.2.2. IP Multicast Optimisation.

This is an OPTIONAL component, applicable only when there is significant volume of IP multicast traffic and different IP multicast groups are required in one E-Tree service.

Multicast in VPLS is currently under development, with the objective to provide efficient ways to support IP multicast services over VPLS. It covers IP multicast group membership control and also bandwidth optimisation. Please refer to [Draft Mcast VPLS].

It is important to note that this component will make use of Layer 3 IP multicast information in payload frames to improve transport efficiency, hence will not align with the recommendation in [RFC4665] that an L2VPN service SHOULD be agnostic to customer's Layer 3 traffic.

6. Non-MAC-based Forwarding E-Tree

This section presents some variants of E-Tree services which do not use MAC-based forwarding as the service frame delivery attribute.

6.1. Single Root, Broadcast Only - VPMS

This is in response to the challenge in section 4.2.3. MAC-based Forwarding Unnecessary.

VPMS provides single coverage of receiver membership. Destination address in Ethernet frame is not used in data forwarding.

For E-Tree service of single Root and only unidirectional broadcast traffic from the Root, for example certain broadcast video or similar content delivery applications, VPMS will be a much more simple and effective solution than VPLS.

VPMS is currently under development. Please refer to [Draft VPMS Frmwk].

6.2. Multiple Roots, Broadcast and Unicast

This is in response to the challenge in section 4.2.4. MAC-based Forwarding Security Concern.

This will be added in later version of this document.

7. Security Considerations

This will be added in later version of this document.

8. IANA Considerations

This will be added in later version of this document.

9. Acknowledgements

This will be added in later version of this document.

10. References

10.1. Normative References

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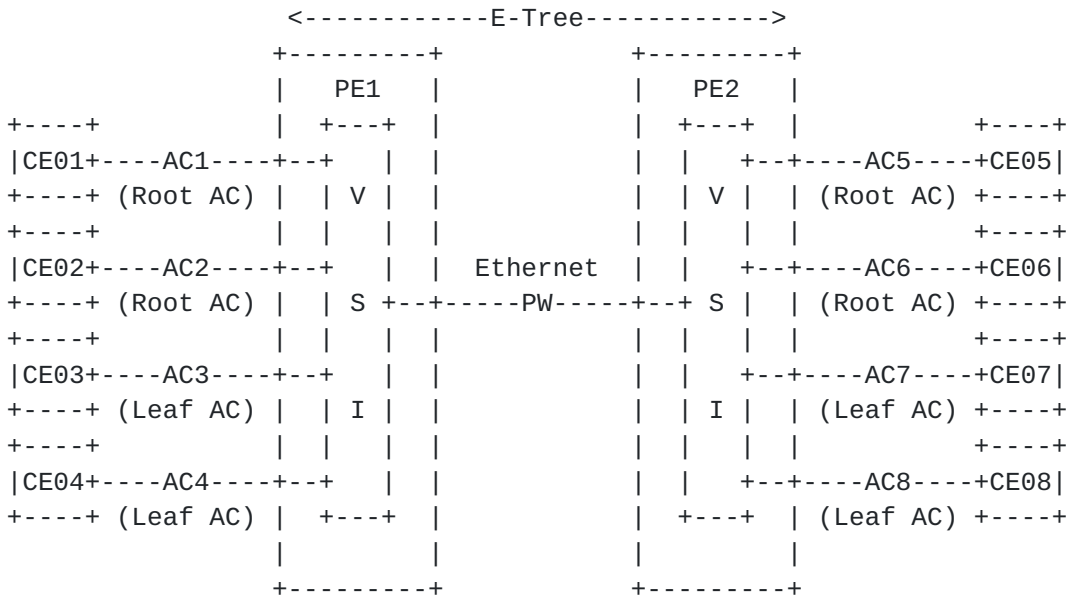
Appendix A. Some Possible Ways for Leaf-to-Leaf Communication Restriction

This appendix briefly describes the following approaches:

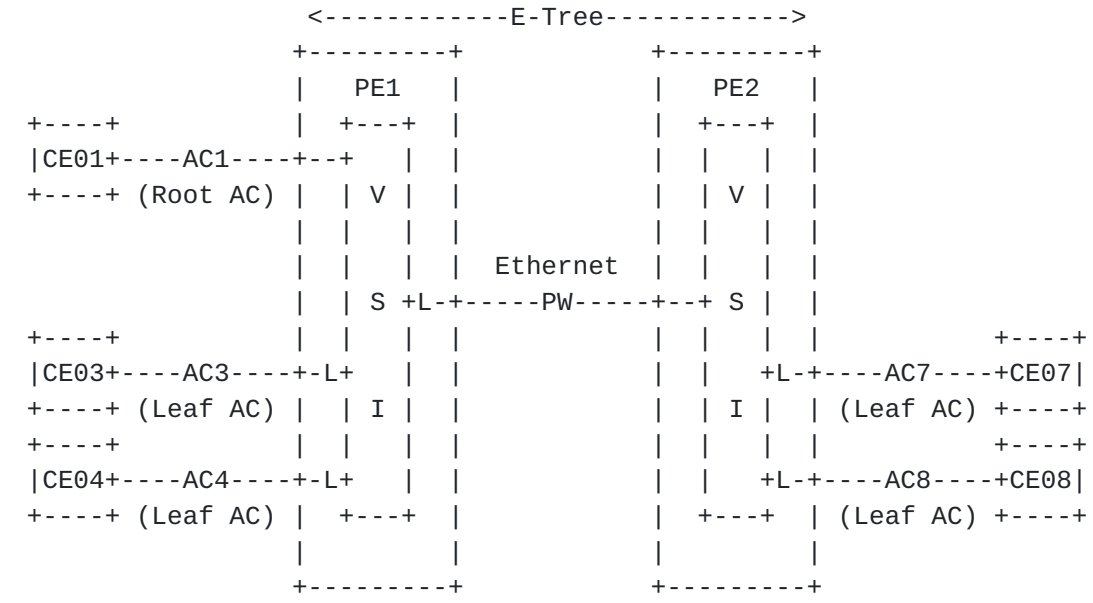
- Single Root Only (A.1)
- Only one PE has Roots (A.2)
- Only one PE with both Root & Leaf
  - Backhaul Root (A.3)
  - Backhaul Leaf (A.4)
  - H-VPLS Root (A.5)
  - H-VPLS Leaf (A.6)
- Separate PEs for Root and Leaf (A.7)
- Separate VSI for Root and Leaf
  - Internal Connection (A.8)
  - External Connection (A.9)
- Separate PWs for "From Root" traffic and "From Leaf" traffic (A.10)
- "From Root" or "From Leaf" derived from source MAC address (A.11)
- Static MAC address configuration for Root AC (A.12)

Reference Model for Leaf-to-Leaf Communication Restriction



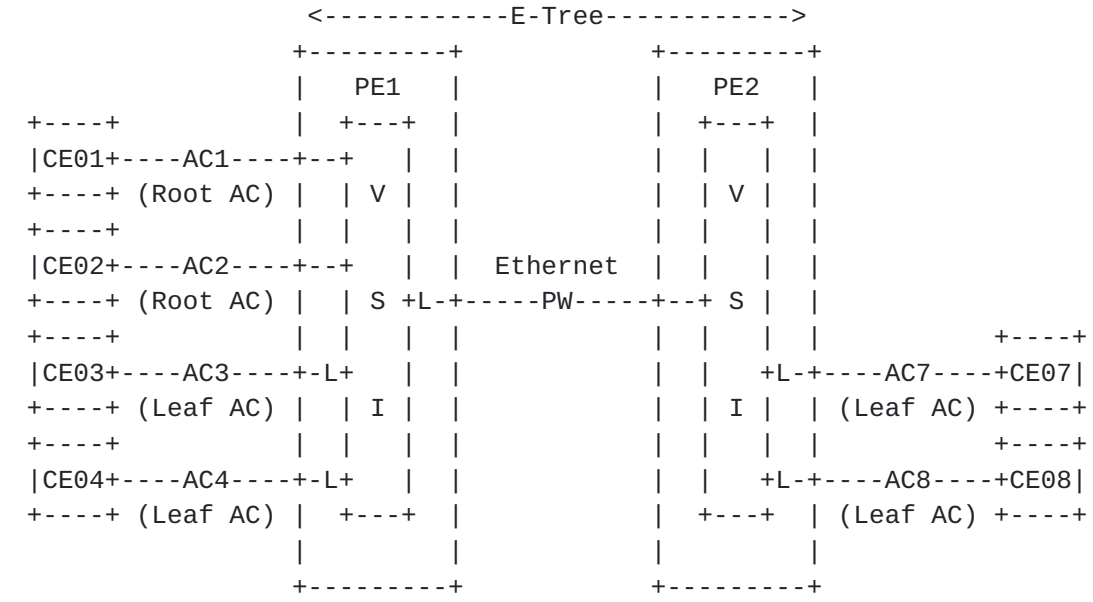
For the diagrams in this appendix, "L" indicates the particular AC or PW belonging to the PE local split horizon group specifically for Leaf-to-Leaf Communication Restriction. No communication is allowed between any two members of a split horizon group.

A.1. Single Root Only



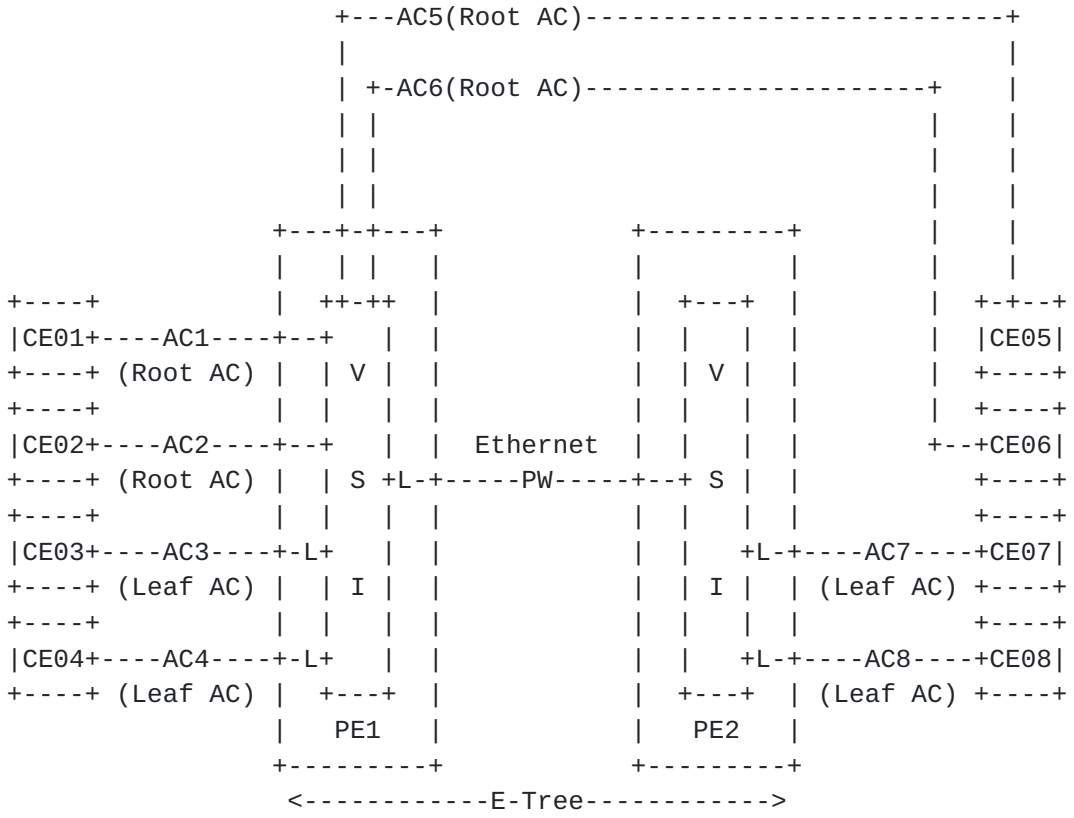
Concerns:
- Not fulfil multi-Root requirement of generic MEF E-Tree service definition

A.2. Only one PE has Roots



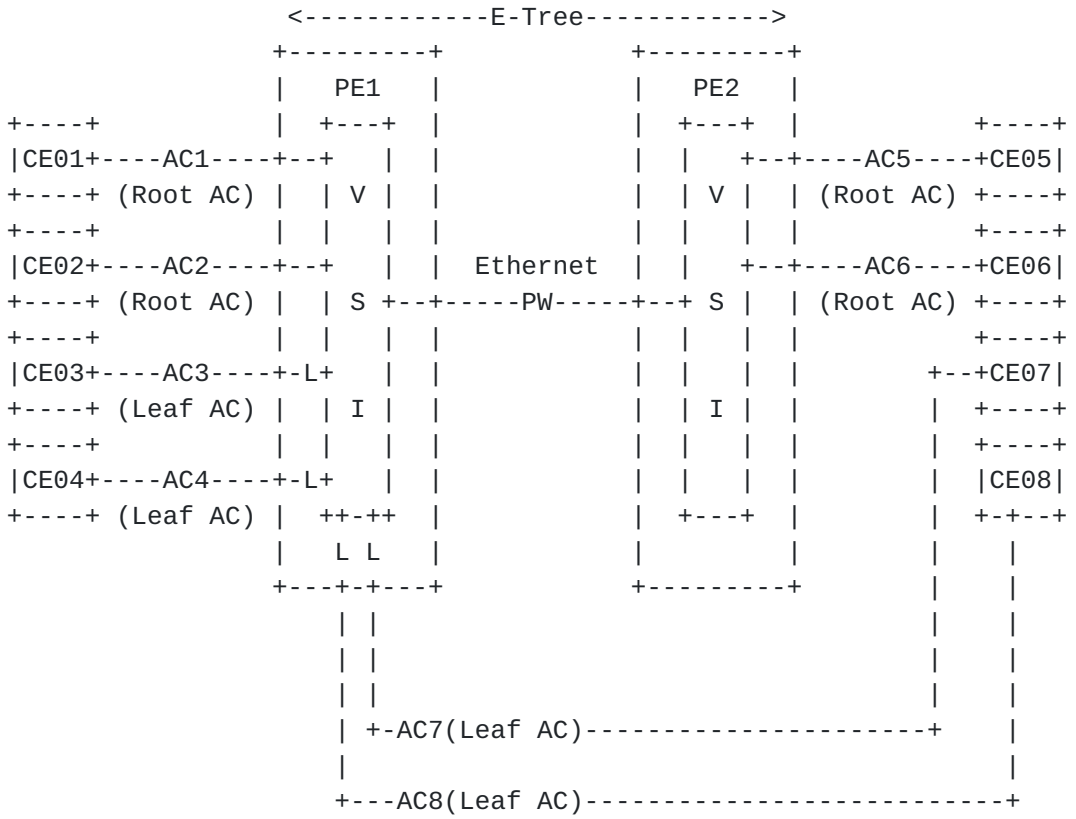
Concerns:
- Deployment constraint

A.3. Only one PE with both Root & Leaf - Backhaul Root



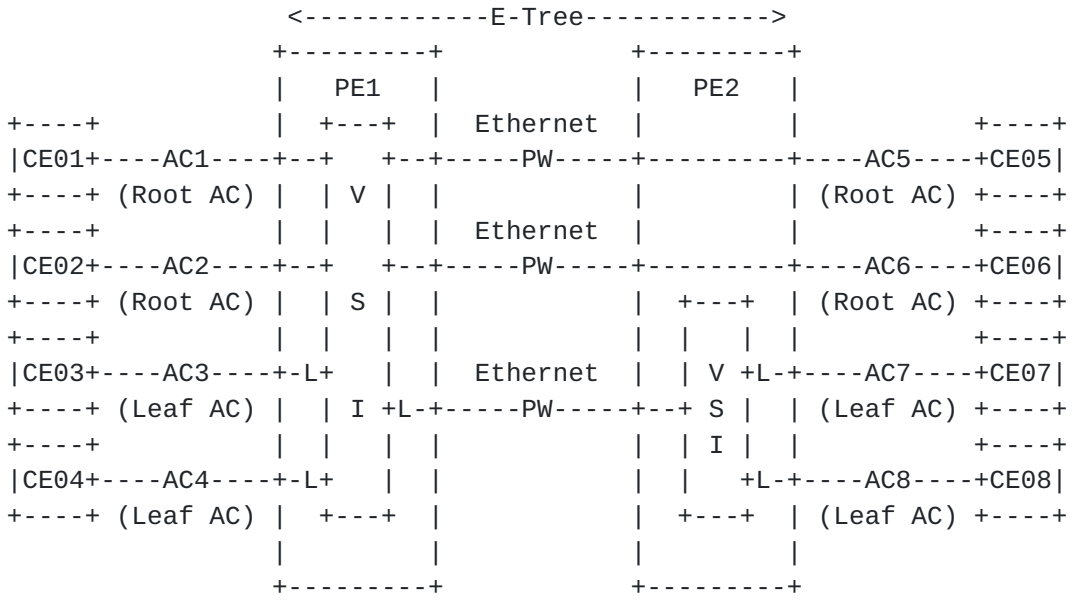
Concerns:
- Deployment constraint
- Long fibre path

A.4. Only one PE with both Root & Leaf - Backhaul Leaf



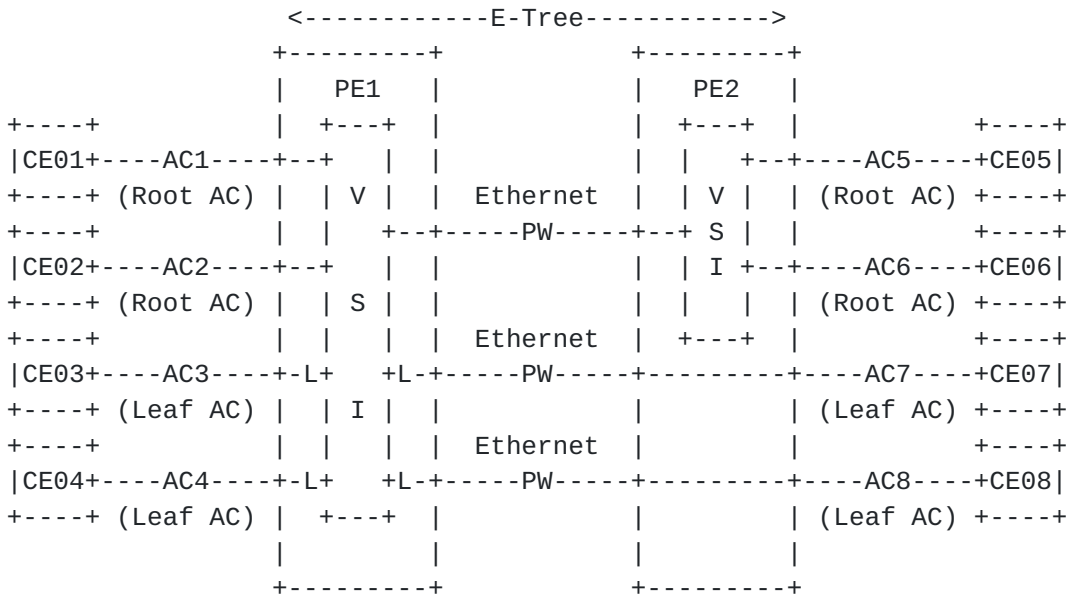
Concerns:
- Deployment constraint
- Long fibre path

A.5. Only one PE with both Root & Leaf - H-VPLS Root



Concerns:
- Design complexity
- More PW
- Hair pinning (e.g. CE05 to CE06/07/08) impact bandwidth and delay

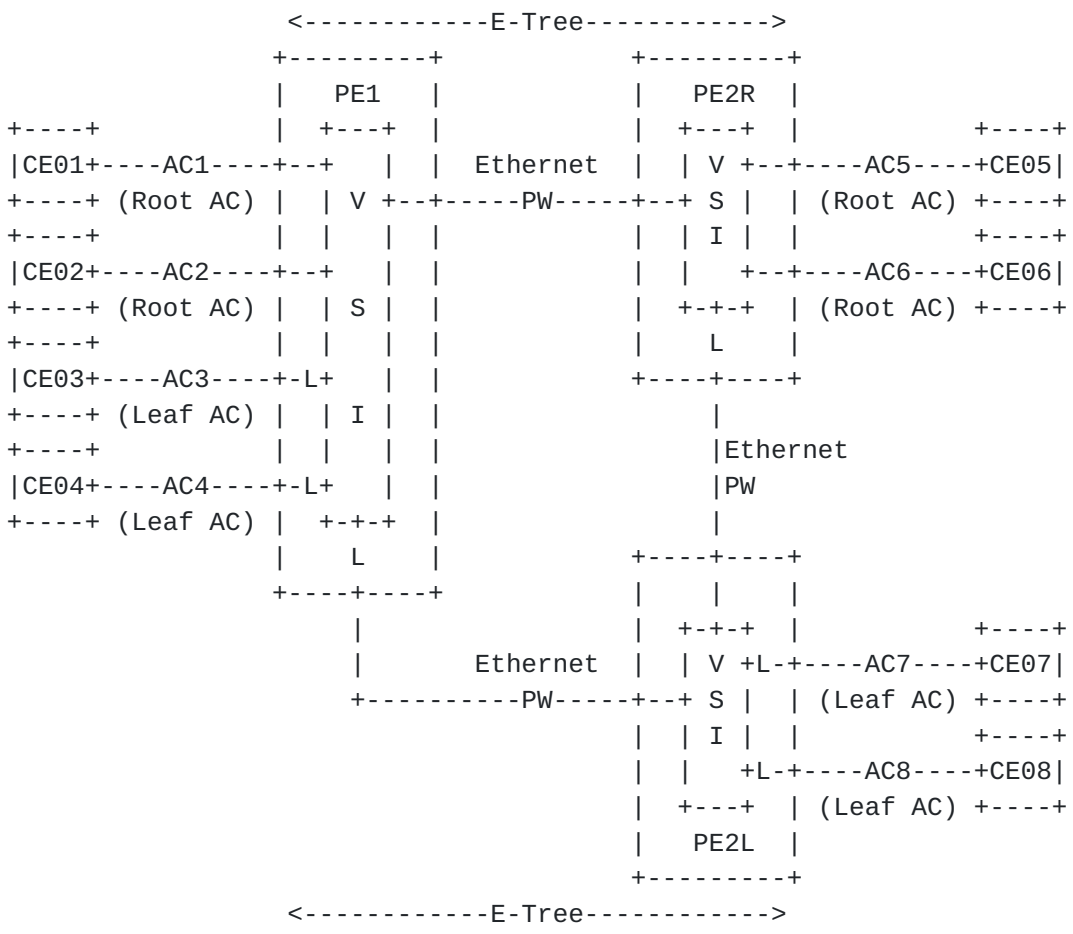
A.6. Only one PE with both Root & Leaf - H-VPLS Leaf



Concerns:
- Design complexity

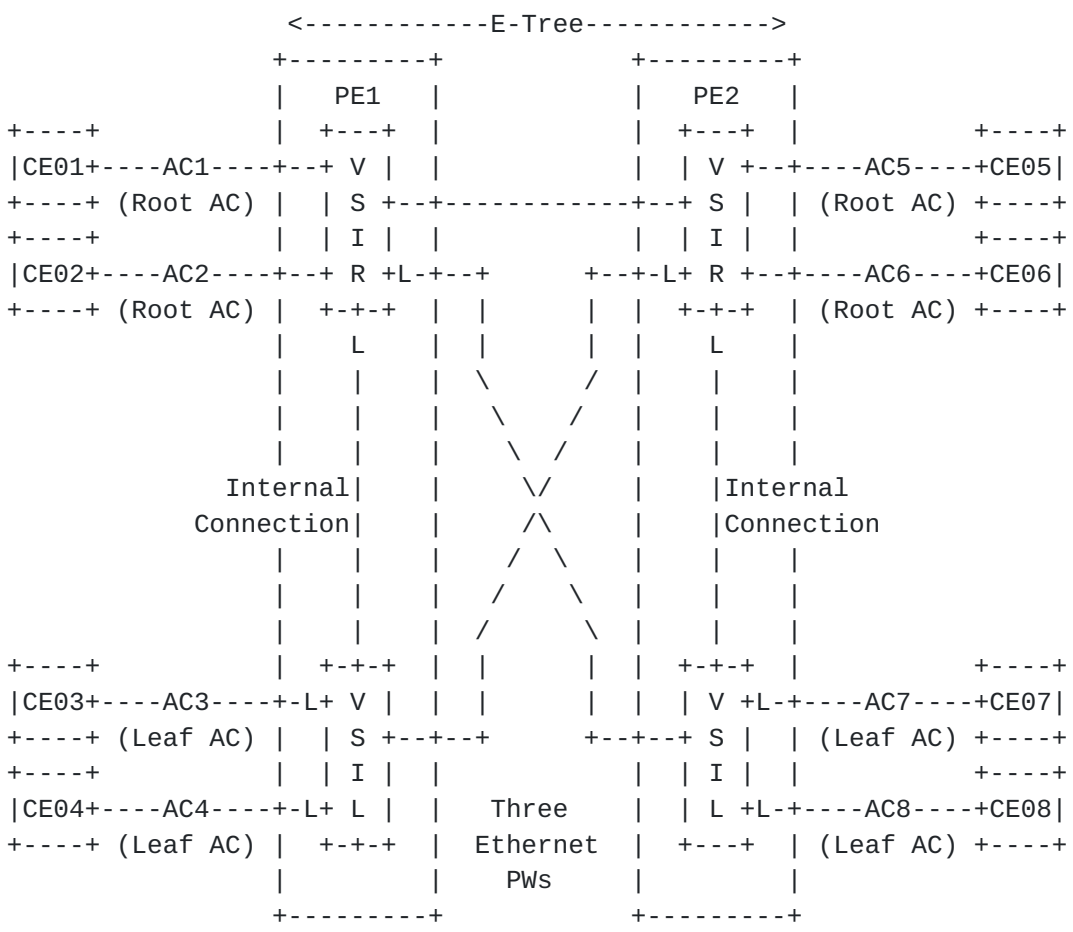
- More PW
- Hair pinning (e.g. CE08 to CE05/06) impact bandwidth and delay

A.7. Separate PEs for Root and Leaf
(PE2 split to PE2R & PE2L)



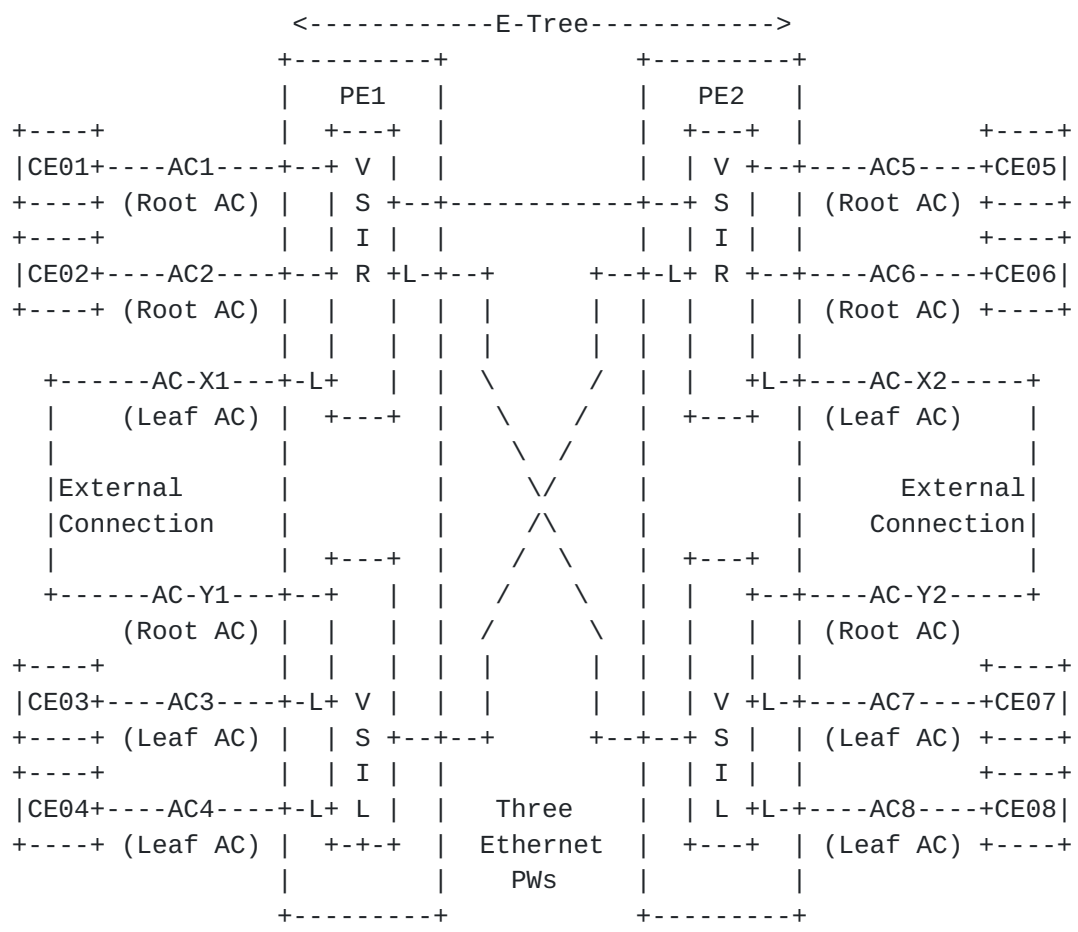
Concerns:
- Require two PEs in one POP
- More PW

A.8. Separate VSI for Root and Leaf - Internal Connection
(VSI on PE split to VSIR & VSIL)



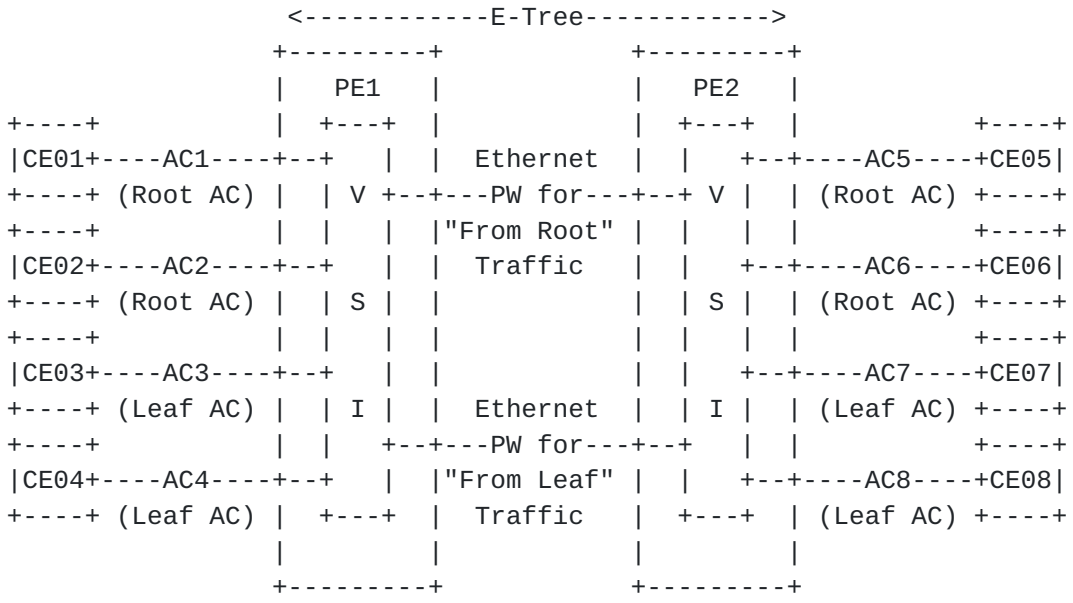
Concerns:
- Design complexity
- More VSI
- More PW
- Some vendor implementation may require additional hardware module to support internal connection between two VSIs
- Some vendor implementation may have bandwidth limitation on internal connection between two VSIs
- Some vendor implementation of service-aware management system may assume only one VSI per VPLS on one PE

A.9. Separate VSI for Root and Leaf - External Connection
(VSI on PE split to VSIR & VSIL)



Concerns:
- Design complexity
- More VSI
- More PW
- More AC (for external connection between two VSIs)
- Require additional two high speed physical ports on PE to support such external connections
- Some vendor implementation of service-aware management system may assume only one VSI per VPLS on one PE

A.10. Separate PWs for "From Root" traffic and "From Leaf" traffic



Concerns:

- More PW
- Most, if not all, vendor implementation support only one PW between two VSIs on different PEs
- Most, if not all, vendor implementation of service-aware management system assume only one PW between two VSIs on different PEs
- Asymmetric path for bidirectional traffic between Root and Leaf on different PEs (e.g. CE01-->CE07 use the "From Root" PW, CE07-->CE01 use the "From Leaf" PW)
- Require extension to current standard VPLS
  - support two PWs between two VSIs on different PEs (both active but no loop)
  - share MAC learning between the "From Root" PW and "From Leaf" PW (bidirectional traffic may be on asymmetric path)
  - in addition to standard MAC-based forwarding, select which PW to use based on whether ingress AC is Root or Leaf
  - filter Leaf-to-Leaf traffic (split horizon group at PW/AC level is not good enough because of asymmetric path)

A.11. "From Root" or "From Leaf" derived from source MAC address

Based on the current standard VPLS, a PE has no information about ACs on another PE.

This approach will need additional information exchange between ingress PE and egress PE, via OSS or peer to peer.

Concerns:
- Require system development or additional signaling between PEs
- Not an ideal solution from security perspective because of the dynamic nature of MAC address to AC mapping

A.12. Static MAC address configuration for Root AC

This approach requires additional configuration on PEs
- Disable MAC address learning for Root ACs
- Static configuration of MAC addresses per Root AC
- Add filtering for each Root AC
  - Drop ingress frame if source MAC address not equal to any of the static MAC addresses configured for the particular Root AC
- Add filtering for each Leaf AC
  - Drop ingress frame if source MAC address equal to any of the static MAC addresses configured for any Root ACs of the VPLS instance
  - Drop egress frame if source MAC address not equal to any of the static MAC addresses configured for any Root ACs of the VPLS instance

Concerns:
- No MAC address learning capability for Root ACs
- Need resources for maintaining the static MAC address configuration per Root AC

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