Internet Draft Document
L2VPN Working Group

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draft-ietf-l2vpn-vpls-ldp-06.txt
Expires: August 2005

Feb 2005

Virtual Private LAN Services over MPLS

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Abstract

This document describes a virtual private LAN service (VPLS) solution using pseudo-wires, a service previously implemented over other tunneling technologies and known as Transparent LAN Services (TLS). A VPLS creates an emulated LAN segment for a given set of users. It delivers a layer 2 broadcast domain that is fully capable of learning and forwarding on Ethernet MAC addresses that is closed to a given set of users. Multiple VPLS services can be supported from a single PE node.

This document describes the control plane functions of signaling demultiplexor labels, extending [PWE3-CTRL]. It is agnostic to discovery protocols. The data plane functions of forwarding are also

described, focusing, in particular, on the learning of MAC addresses. The encapsulation of VPLS packets is described by [PWE3-ETHERNET].

Conventions

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 RFC 2119

Placement of this Memo in Sub-IP Area

RELATED DOCUMENTS

www.ietf.org/internet-drafts/draft-ietf-l2vpn-requirements-01.txt
www.ietf.org/internet-drafts/draft-ietf-l2vpn-l2-framework-03.txt
www.ietf.org/internet-drafts/draft-ietf-pwe3-ethernet-encap-02.txt
www.ietf.org/internet-drafts/draft-ietf-pwe3-control-protocol-01.txt

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1. Introduction

Ethernet has become the predominant technology for Local Area Networks (LANs) connectivity and is gaining acceptance as an access technology, specifically in Metropolitan and Wide Area Networks (MAN and WAN respectively). The primary motivation behind Virtual Private LAN Services (VPLS) is to provide connectivity between geographically dispersed customer sites across MAN/WAN network(s), as if they were connected using a LAN. The intended application for the end-user can be divided into the following two categories:

- Connectivity between customer routers: LAN routing application
- Connectivity between customer Ethernet switches: LAN switching application

Broadcast and multicast services are available over traditional LANs. Sites that belong to the same broadcast domain and that are connected via an MPLS network expect broadcast, multicast and unicast traffic to be forwarded to the proper location(s). This requires MAC address learning/aging on a per LSP basis, packet replication across LSPs for multicast/broadcast traffic and for flooding of unknown unicast destination traffic.

[PWE3-ETHERNET] defines how to carry L2 PDUs over point-to-point MPLS LSPs, called Pseudo-Wires (PW). Such PWs can be carried over MPLS or GRE tunnels. This document describes extensions to [PWE3-CTRL] for transporting Ethernet/802.3 and VLAN [802.1Q] traffic across multiple sites that belong to the same L2 broadcast domain or VPLS. Note that the same model can be applied to other 802.1 technologies. It describes a simple and scalable way to offer Virtual LAN services, including the appropriate flooding of broadcast, multicast and unknown unicast destination traffic over MPLS, without the need for address resolution servers or other external servers, as discussed in [L2VPN-REQ].

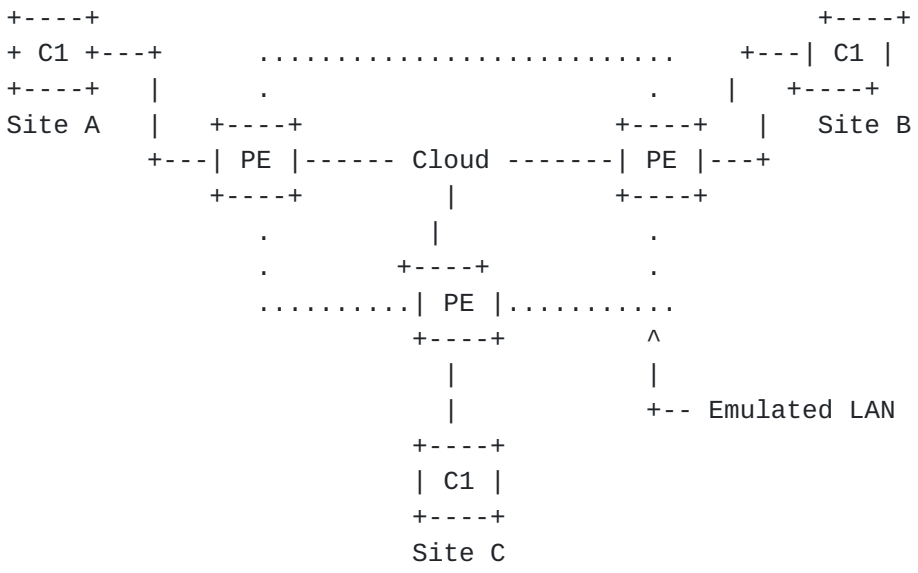
The following discussion applies to devices that are VPLS capable and have a means of tunneling labeled packets amongst each other.

While MPLS LSPs may be used to tunnel these labeled packets, other

technologies may be used as well, e.g., GRE [MPLS-GRE]. The resulting set of interconnected devices forms a private MPLS VPN.

2. Topological Model for VPLS

An interface participating in a VPLS must be able to flood, forward, and filter Ethernet frames.



The set of PE devices interconnected via PWs appears as a single emulated LAN to customer C1. Each PE device will learn remote MAC address to PW associations and will also learn directly attached MAC addresses on customer facing ports.

We note here again that while this document shows specific examples using MPLS transport tunnels, other tunnels that can be used by PWs, e.g., GRE, L2TP, IPSEC, etc., can also be used, as long as the originating PE can be identified, since this is used in the MAC learning process.

The scope of the VPLS lies within the PEs in the service provider network, highlighting the fact that apart from customer service delineation, the form of access to a customer site is not relevant to the VPLS [L2VPN-REQ].

The PE device is typically an edge router capable of running the LDP signaling protocol and/or routing protocols to set up PWs.
In addition, it is capable of setting up transport tunnels to other PEs and of delivering traffic over a PW.

2.1. Flooding and Forwarding

One of attributes of an Ethernet service is that packets to

broadcast packets and to unknown destination MAC addresses are flooded to all ports. To achieve flooding within the service provider network, all address unknown unicast, broadcast and

multicast frames are flooded over the corresponding PWs to all relevant PE nodes participating in the VPLS.

Note that multicast frames are a special case and do not necessarily have to be sent to all VPN members. For simplicity, the default approach of broadcasting multicast frames can be used. The use of IGMP snooping and PIM snooping techniques should be used to improve multicast efficiency.

To forward a frame, a PE MUST be able to associate a destination MAC address with a PW. It is unreasonable and perhaps impossible to require PEs to statically configure an association of every possible destination MAC address with a PW. Therefore, VPLS-capable PEs SHOULD have the capability to dynamically learn MAC addresses on both physical ports and virtual circuits and to forward and replicate packets across both physical ports and PWs.

2.2. Address Learning

Unlike BGP VPNs [BGP-VPN], reachability information does not need to be advertised and distributed via a control plane. Reachability is obtained by standard learning bridge functions in the data plane.

A PW consists of a pair of uni-directional VC LSPs. The state of this PW is considered operationally up when both incoming and outgoing VC LSPs are established. Similarly, it is considered operationally down when one of these two VC LSPs is torn down. When a previously unknown MAC address is learned on an inbound VC LSP, it needs to be associated with the its counterpart outbound VC LSP in that PW.

Standard learning, filtering and forwarding actions, as defined in [802.1D-ORIG], [802.1D-REV] and [802.1Q], are required when a logical link state changes.

2.3. Tunnel Topology

PE routers are assumed to have the capability to establish transport tunnels. Tunnels are set up between PEs to aggregate traffic. PWs are signaled to demultiplex the L2 encapsulated packets that traverse the tunnels.

In an Ethernet L2VPN, it becomes the responsibility of the service provider to create the loop free topology. For the sake of simplicity, we define that the topology of a VPLS is a full mesh of tunnels and PWs.

2.4. Loop free L2 VPN

For simplicity, a full mesh of PWs is established between PEs. Ethernet bridges, unlike Frame Relay or ATM where the termination

point becomes the CE node, have to examine the layer 2 fields of the packets to make a switching decision. If the frame is directed to an unknown destination, or is a broadcast or multicast frame, the frame must be flooded.

Therefore, if the topology isn't a full mesh, the PE devices may need to forward these frames to other PEs. However, this would require the use of spanning tree protocol to form a loop free topology that may have characteristics that are undesirable to the provider. The use of a full mesh and split-horizon forwarding obviates the need for a spanning tree protocol.

Each PE MUST create a rooted tree to every other PE router that serves the same VPLS. Each PE MUST support a "split-horizon" scheme in order to prevent loops, that is, a PE MUST NOT forward traffic from one PW to another in the same VPLS mesh (since each PE has direct connectivity to all other PEs in the same VPLS).

Note that customers are allowed to run STP such as when a customer has "back door" links used to provide redundancy in the case of a failure within the VPLS. In such a case, STP BPDUs are simply tunneled through the provider cloud.

3. Discovery

The capability to manually configure the addresses of the remote PEs is REQUIRED. However, the use of manual configuration is not necessary if an auto-discovery procedure is used. A number of auto-discovery procedures are compatible with this document ([RADIUS-DISC], [BGP-DISC]).

4. Control Plane

This document describes the control plane functions of Demultiplexor Exchange (signaling of VC labels). Some foundational work in the area of support for multi-homing is laid. The extensions to provide multi-homing support should work independently of the basic VPLS operation, and are not described here.

4.1. LDP Based Signaling of Demultiplexors

In order to establish a full mesh of PWs, all PEs in a VPLS must have a full mesh of LDP sessions.

Once an LDP session has been formed between two PEs, all PWs are signaled over this session.

In [PWE3-CTRL], two types of FECs are described, the FEC type 128 PWid FEC Element and the FEC type 129 Generalized PWid FEC Element.

The original FEC element used for VPLS was compatible with the PWid FEC Element. The text for signaling using PWid FEC Element has been moved to Appendix 1. What we describe below replaces that with a

more generalized L2VPN descriptor through the Generalized PWid FEC Element.

4.1.1. Using the Generalized PWid FEC Element

[PWE3-CTRL] describes a generalized FEC structure that is be used for VPLS signaling in the following manner. The following describes the assignment of the Generalized PWid FEC Element fields in the context of VPLS signaling.

Control bit (C): Depending on whether, on that particular PW, the control word is desired or not, the control bit may be specified.

PW type: The allowed PW types in this version are Ethernet and Ethernet VLAN.

VC info length: Same as in [PWE3-CTRL].

AGI, Length, Value: The unique name of this VPLS. The AGI identifies a type of name, the length denotes the length of Value, which is the name of the VPLS. We will use the term AGI interchangeably with VPLS identifier.

TAII, SAII: These are null because the mesh of PWs in a VPLS terminate on MAC learning tables, rather than on individual attachment circuits.

Interface Parameters: The relevant interface parameters are:

- MTU: the MTU of the VPLS MUST be the same across all the PWs in the mesh.

- Optional Description String: same as [PWE3-CTRL].

- Requested VLAN ID: If the PW type is Ethernet VLAN, this parameter may be used to signal the insertion of the appropriate VLAN ID.

4.1.2. Address Withdraw Message Containing MAC TLV

When MAC addresses are being removed or relearned explicitly, e.g., the primary link of a dual-homed MTU-s (Multi-Tenant Unit switch) has failed, an MAC Address Withdraw Message with the list of MAC addresses to be relearned can be sent to all other PEs over the corresponding directed LDP sessions.

The processing for MAC List TLVs received in an Address Withdraw Message is:

For each MAC address in the TLV:

- Relearn the association between the MAC address and the interface/PW over which this message is received

For a MAC Address Withdraw message with empty list:
- Remove all the MAC addresses associated with the VPLS instance (specified by the FEC TLV) except the MAC addresses learned over this link (over the PW associated with the signaling link over which the message is received)

The scope of a MAC List TLV is the VPLS specified in the FEC TLV in the MAC Address Withdraw Message. The number of MAC addresses can be deduced from the length field in the TLV.

4.2. MAC Address Withdrawal

It MAY be desirable to remove or relearn MAC addresses that have been dynamically learned for faster convergence.

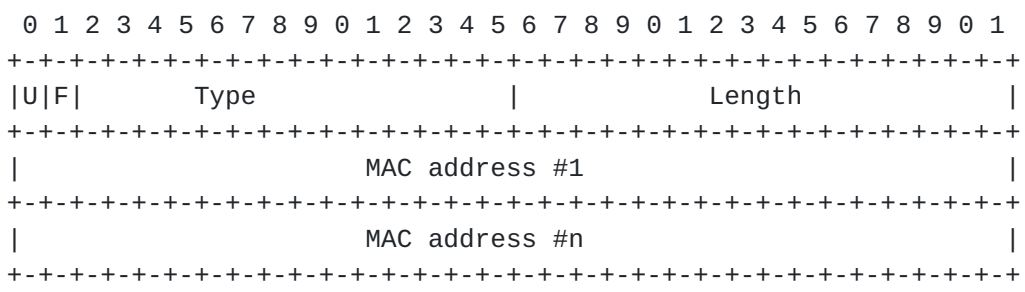
We introduce an optional MAC List TLV that is used to specify a list of MAC addresses that can be removed or relearned using the LDP Address Withdraw Message.

The Address Withdraw message with MAC TLVs MAY be supported in order to expedite removal of MAC addresses as the result of a topology change (e.g., failure of the primary link for a dual-homed MTU-s). If a notification message is sent on the backup link (blocked link), which has transitioned into an active state (e.g., similar to Topology Change Notification message of 802.1w RSTP), with a list of MAC entries to be relearned, the PE will update the MAC entries in its FIB for that VPLS instance and send the message to other PEs over the corresponding directed LDP sessions.

If the notification message contains an empty list, this tells the receiving PE to remove all the MAC addresses learned for the specified VPLS instance except the ones it learned from the sending PE (MAC address removal is required for all VPLS instances that are affected). Note that the definition of such a notification message is outside the scope of the document, unless it happens to come from an MTU connected to the PE as a spoke. In such a scenario, the message will be just an Address Withdraw message as noted above.

4.2.1. MAC List TLV

MAC addresses to be relearned can be signaled using an LDP Address Withdraw Message that contains a new TLV, the MAC List TLV. Its format is described below. The encoding of a MAC List TLV address is the 6-byte MAC address specified by IEEE 802 documents [g-ORIG] [802.1D-REV].



U bit: Unknown bit. This bit MUST be set to 1. If the MAC address format is not understood, then the TLV is not understood, and MUST be ignored.

F bit: Forward bit. This bit MUST be set to 0. Since the LDP mechanism used here is Targeted, the TLV MUST NOT be forwarded.

Type: Type field. This field MUST be set to 0x0404 (subject to IANA approval). This identifies the TLV type as MAC List TLV.

Length: Length field. This field specifies the total length of the MAC addresses in the TLV.

MAC Address: The MAC address(es) being removed.

The LDP Address Withdraw Message contains a FEC TLV (to identify the VPLS in consideration), a MAC Address TLV and optional parameters. No optional parameters have been defined for the MAC Address Withdraw signaling.

5. Data Forwarding on an Ethernet VC PW

This section describes the dataplane behavior on an Ethernet PW used in a VPLS. While the encapsulation is similar to that described in [PWE3-ETHERNET], the NSP functions of stripping the service-delimiting tag and using a "normalized" Ethernet packet are described.

5.1. VPLS Encapsulation actions

In a VPLS, a customer Ethernet packet without preamble is encapsulated with a header as defined in [PWE3-ETHERNET]. A customer Ethernet packet is defined as follows:

- If the packet, as it arrives at the PE, has an encapsulation that is used by the local PE as a service delimiter, i.e., to identify the customer and/or the particular service of that customer, then that encapsulation is stripped before the packet is sent into the VPLS. As the packet exits the VPLS, the packet may have a service-delimiting encapsulation inserted.

- If the packet, as it arrives at the PE, has an encapsulation that is not service delimiting, then it is a customer packet whose encapsulation should not be modified by the VPLS. This covers, for example, a packet that carries customer-specific VLAN-Ids that the service provider neither knows about nor wants to modify.

As an application of these rules, a customer packet may arrive at a customer-facing port with a VLAN tag that identifies the customer's VPLS instance. That tag would be stripped before it is encapsulated in the VPLS. At egress, the packet may be tagged again, if a service-delimiting tag is used, or it may be untagged if none is used.

Likewise, if a customer packet arrives at a customer-facing port over an ATM or Frame Relay VC that identifies the customer's VPLS instance, then the ATM or FR encapsulation is removed before the packet is passed into the VPLS.

Contrariwise, if a customer packet arrives at a customer-facing port with a VLAN tag that identifies a VLAN domain in the customer L2 network, then the tag is not modified or stripped, as it belongs with the rest of the customer frame.

By following the above rules, the Ethernet packet that traverses a VPLS is always a customer Ethernet packet. Note that the two actions, at ingress and egress, of dealing with service delimiters are local actions that neither PE has to signal to the other. They allow, for example, a mix-and-match of VLAN tagged and untagged services at either end, and do not carry across a VPLS a VLAN tag that has local significance only. The service delimiter may be an MPLS label also, whereby an Ethernet PW given by [PWE3-ETHERNET] can serve as the access side connection into a PE. An RFC1483 PVC encapsulation could be another service delimiter. By limiting the scope of locally significant encapsulations to the edge, hierarchical VPLS models can be developed that provide the capability to network-engineer VPLS deployments, as described below.

5.2. VPLS Learning actions

Learning is done based on the customer Ethernet packet, as defined above. The Forwarding Information Base (FIB) keeps track of the mapping of customer Ethernet packet addressing and the appropriate PW to use. We define two modes of learning: qualified and unqualified learning.

In unqualified learning, all the customer VLANs are handled by a single VPLS, which means they all share a single broadcast domain

and a single MAC address space. This means that MAC addresses need to be unique and non-overlapping among customer VLANs or else they cannot be differentiated within the VPLS instance and this can

result in loss of customer frames. An application of unqualified learning is port-based VPLS service for a given customer (e.g., customer with non-multiplexed UNI interface where all the traffic on a physical port, which may include multiple customer VLANs, is mapped to a single VPLS instance).

In qualified learning, each customer VLAN is assigned to its own VPLS instance, which means each customer VLAN has its own broadcast domain and MAC address space. Therefore, in qualified learning, MAC addresses among customer VLANs may overlap with each other, but they will be handled correctly since each customer VLAN has its own FIB, i.e., each customer VLAN has its own MAC address space. Since VPLS broadcasts multicast frames by default, qualified learning offers the advantage of limiting the broadcast scope to a given customer VLAN.

For STP to work in qualified mode, a VPLS PE must be able to forward STP BPDUs over the proper VPLS instance. In a hierarchical VPLS case (see details in Section 10), service delimiting tags (Q-in-Q or Martini) can be added by MTU-s nodes such that PEs can unambiguously identify all customer traffic, including STP/MSTP BPDUs. In a basic VPLS case, upstream switches must insert such service delimiting tags. When an access port is shared among multiple customers, a reserved VLAN per customer domain must be used to carry STP/MSTP traffic. The STP/MSTP frames are encapsulated with a unique provider tag per customer (as the regular customer traffic), and a PEs looks up the provider tag to send such frames across the proper VPLS instance.

6. Data Forwarding on an Ethernet VLAN PW

This section describes the dataplane behavior on an Ethernet VLAN PW in a VPLS. While the encapsulation is similar to that described in [PWE3-ETHERNET], the NSP functions of imposing tags, and using a "normalized" Ethernet packet are described. The learning behavior is the same as for Ethernet PWs.

6.1. VPLS Encapsulation actions

In a VPLS, a customer Ethernet packet without preamble is encapsulated with a header as defined in [PWE3-ETHERNET]. A customer Ethernet packet is defined as follows:

- If the packet, as it arrives at the PE, has an encapsulation that is part of the customer frame, and is also used by the local PE as a service delimiter, i.e., to identify the customer and/or the particular service of that customer, then that encapsulation is preserved as the packet is sent into the VPLS,

unless the Requested VLAN ID optional parameter was signaled.

In that case, the VLAN tag is overwritten before the packet is sent out on the PW.

- If the packet, as it arrives at the PE, has an encapsulation that does not have the required VLAN tag, a null tag is imposed if the Requested VLAN ID optional parameter was not signaled.

As an application of these rules, a customer packet may arrive at a customer-facing port with a VLAN tag that identifies the customer's VPLS instance and also identifies a customer VLAN. That tag would be preserved as it is encapsulated in the VPLS.

The Ethernet VLAN PW is a simple way to preserve customer 802.1p bits.

A VPLS MAY have both Ethernet and Ethernet VLAN PWs. However, if a PE is not able to support both PWs simultaneously, it can send a Label Release on the PW messages that it cannot support with a status code "Unknown FEC" as given in [RFC3036].

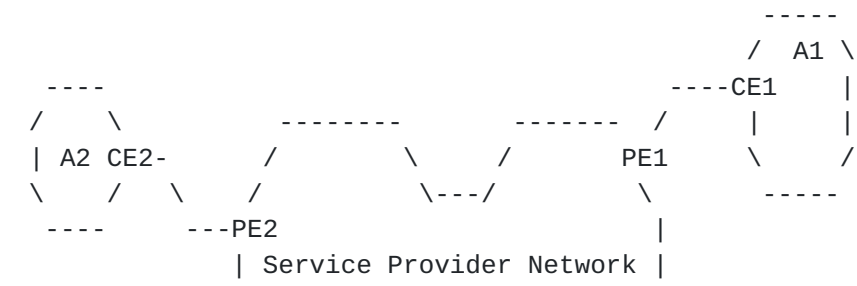
7. Operation of a VPLS

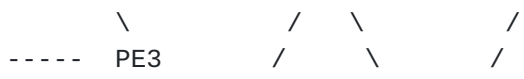
We show here an example of how a VPLS works. The following discussion uses the figure below, where a VPLS has been set up between PE1, PE2 and PE3.

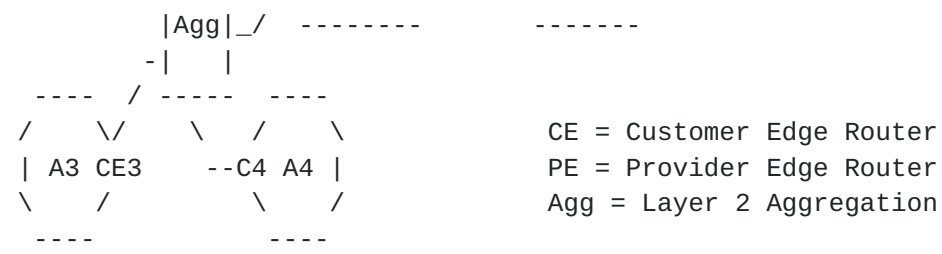
Initially, the VPLS is set up so that PE1, PE2 and PE3 have a full mesh of Ethernet PWs. The VPLS instance is assigned a unique VCID.

For the above example, say PE1 signals VC Label 102 to PE2 and 103 to PE3, and PE2 signals VC Label 201 to PE1 and 203 to PE3.

Assume a packet from A1 is bound for A2. When it leaves CE1, say it has a source MAC address of M1 and a destination MAC of M2. If PE1 does not know where M2 is, it will multicast the packet to PE2 and PE3. When PE2 receives the packet, it will have an inner label of **201. PE2 can conclude that the source MAC address M1 is behind PE1,** since it distributed the label 201 to PE1. It can therefore associate MAC address M1 with VC Label 102.




PE3



7.1. MAC Address Aging

PEs that learn remote MAC addresses need to have an aging mechanism to remove unused entries associated with a VC Label. This is important both for conservation of memory as well as for administrative purposes. For example, if a customer site A is shut down, eventually, the other PEs should unlearn A's MAC address.

As packets arrive, MAC addresses are remembered. The aging timer for MAC address M SHOULD be reset when a packet is received with source MAC address M.

8. A Hierarchical VPLS Model

The solution described above requires a full mesh of tunnel LSPs between all the PE routers that participate in the VPLS service. For each VPLS service, n*(n-1)/2 PWs must be setup between the PE routers. While this creates signaling overhead, the real detriment to large scale deployment is the packet replication requirements for each provisioned VCs on a PE router. Hierarchical connectivity, described in this document reduces signaling and replication overhead to allow large scale deployment.

In many cases, service providers place smaller edge devices in multi-tenant buildings and aggregate them into a PE device in a large Central Office (CO) facility. In some instances, standard IEEE 802.1q (Dot 1Q) tagging techniques may be used to facilitate mapping CE interfaces to PE VPLS access points.

It is often beneficial to extend the VPLS service tunneling techniques into the MTU (multi-tenant unit) domain. This can be accomplished by treating the MTU device as a PE device and provisioning PWs between it and every other edge, as an basic VPLS. An alternative is to utilize [PWE3-ETHERNET] PWs or Q-in-Q logical interfaces between the MTU and selected VPLS enabled PE routers. Q-in-Q encapsulation is another form of L2 tunneling technique, which can be used in conjunction with MPLS signaling as will be described later. The following two sections focus on this alternative approach. The VPLS core PWs (Hub) are augmented with access PWs (Spoke) to form a two-tier hierarchical VPLS (H-VPLS).

Spoke PWs may be implemented using any L2 tunneling mechanism, expanding the scope of the first tier to include non-bridging VPLS

PE routers. The non-bridging PE router would extend a Spoke PW from a Layer-2 switch that connects to it, through the service core network, to a bridging VPLS PE router supporting Hub PWs. We also describe how VPLS-challenged nodes and low-end CEs without MPLS capabilities may participate in a hierarchical VPLS.

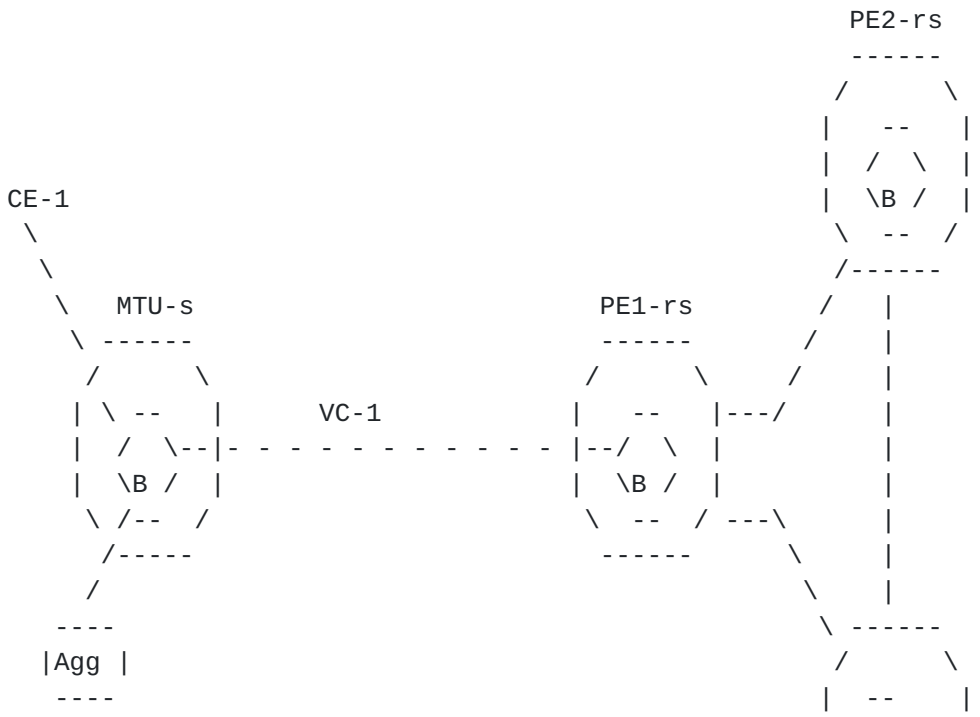
8.1. Hierarchical connectivity

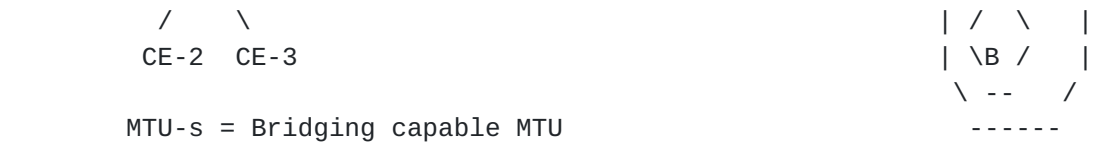
This section describes the hub and spoke connectivity model and describes the requirements of the bridging capable and non-bridging MTU devices for supporting the spoke connections.

For rest of this discussion we will refer to a bridging capable MTU device as MTU-s and a non-bridging capable PE device as PE-r. A routing and bridging capable device will be referred to as PE-rs.

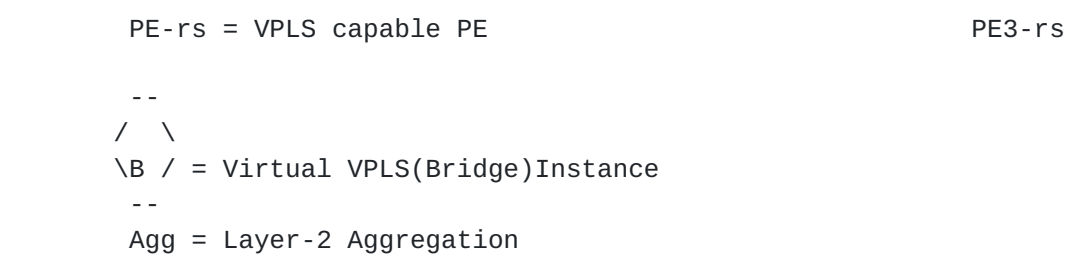
8.1.1. Spoke connectivity for bridging-capable devices

As shown in the figure below, consider the case where an MTU-s device has a single connection to the PE-rs device placed in the CO. The PE-rs devices are connected in a basic VPLS full mesh. For each VPLS service, a single spoke PW is set up between the MTU-s and the PE-rs based on [PWE3-CTRL]. Unlike traditional PWs that terminate on a physical (or a VLAN-tagged logical) port at each end, the spoke PW terminates on a virtual bridge instance on the MTU-s and the PE-rs devices.





MTU-s = Bridging capable MTU



The MTU-s device and the PE-rs device treat each spoke connection like an access port of the VPLS service. On access ports, the combination of the physical port and/or the VLAN tag is used to associate the traffic to a VPLS instance while the PW tag (e.g., VC label) is used to associate the traffic from the virtual spoke port with a VPLS instance, followed by a standard L2 lookup to identify which customer port the frame needs to be sent to.

8.1.1.1. MTU-s Operation

MTU-s device is defined as a device that supports layer-2 switching functionality and does all the normal bridging functions of learning and replication on all its ports, including the virtual spoke port. Packets to unknown destination are replicated to all ports in the service including the virtual spoke port. Once the MAC address is learned, traffic between CE1 and CE2 will be switched locally by the MTU-s device saving the link capacity of the connection to the PE-rs. Similarly traffic between CE1 or CE2 and any remote destination is switched directly on to the spoke connection and sent to the PE-rs over the point-to-point PW.

Since the MTU-s is bridging capable, only a single PW is required per VPLS instance for any number of access connections in the same VPLS service. This further reduces the signaling overhead between the MTU-s and PE-rs.

If the MTU-s is directly connected to the PE-rs, other encapsulation techniques such as Q-in-Q can be used for the spoke connection PW.

8.1.1.2. PE-rs Operation

The PE-rs device is a device that supports all the bridging functions for VPLS service and supports the routing and MPLS encapsulation, i.e. it supports all the functions described for a basic VPLS as described above.

The operation of PE-rs is independent of the type of device at the other end of the spoke PW. Thus, the spoke PW from the PE-r is treated as a virtual port and the PE-rs device will switch traffic between the spoke PW, hub PWs, and access ports once it has learned the MAC addresses.

8.1.2. Advantages of spoke connectivity

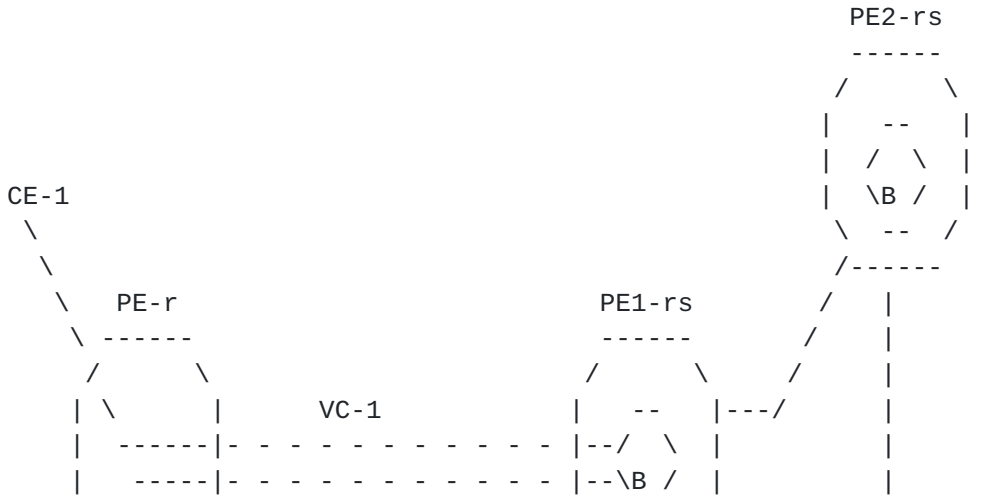
Spoke connectivity offers several scaling and operational advantages for creating large scale VPLS implementations, while retaining the ability to offer all the functionality of the VPLS service.

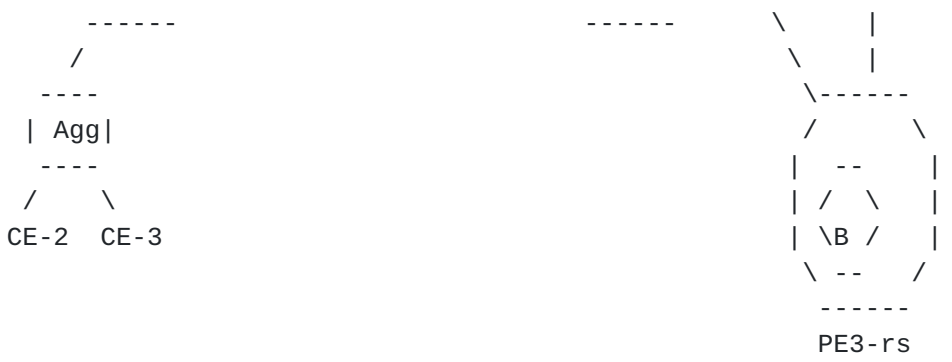
- Eliminates the need for a full mesh of tunnels and full mesh of PWs per service between all devices participating in the VPLS service.
- Minimizes signaling overhead since fewer PWs are required for the VPLS service.
- Segments VPLS nodal discovery. MTU-s needs to be aware of only the PE-rs node although it is participating in the VPLS service that spans multiple devices. On the other hand, every VPLS PE-rs must be aware of every other VPLS PE-rs device and all of it's locally connected MTU-s and PE-r.
- Addition of other sites requires configuration of the new MTU-s device but does not require any provisioning of the existing MTU-s devices on that service.
- Hierarchical connections can be used to create VPLS service that spans multiple service provider domains. This is explained in a later section.

8.1.3. Spoke connectivity for non-bridging devices

In some cases, a bridging PE-rs device may not be deployed in a CO or a multi-tenant building while a PE-r might already be deployed. If there is a need to provide VPLS service from the CO where the PE-rs device is not available, the service provider may prefer to use the PE-r device in the interim. In this section, we explain how a PE-r device that does not support any of the VPLS bridging functionality can participate in the VPLS service.

As shown in this figure, the PE-r device creates a point-to-point tunnel LSP to a PE-rs device.





Then for every access port that needs to participate in a VPLS service, the PE-r device creates a point-to-point [PWE3-ETHERNET] PW that terminates on the physical port at the PE-r and terminates on the virtual bridge instance of the VPLS service at the PE-rs.

The PE-r device is defined as a device that supports routing but does not support any bridging functions. However, it is capable of setting up [PWE3-ETHERNET] PWs between itself and the PE-rs. For every port that is supported in the VPLS service, a [PWE3-ETHERNET] PW is setup from the PE-r to the PE-rs. Once the PWs are setup, there is no learning or replication function required on part of the PE-r. All traffic received on any of the access ports is transmitted on the PW. Similarly all traffic received on a PW is transmitted to the access port where the PW terminates. Thus traffic from CE1 destined for CE2 is switched at PE-rs and not at PE-r.

Note that in the case where PE-r devices use Provider VLANs (P-VLAN) as demultiplexors instead of PWs, and PE-rs can treat them as such, PE-rs can map these "circuits" into a VPLS domain and provide bridging support between them.

This approach adds more overhead than the bridging capable (MTU-s) spoke approach since a PW is required for every access port that participates in the service versus a single PW required per service (regardless of access ports) when a MTU-s type device is used. However, this approach offers the advantage of offering a VPLS service in conjunction with a routed internet service without requiring the addition of new MTU device.

8.2. Redundant Spoke Connections

An obvious weakness of the hub and spoke approach described thus far is that the MTU device has a single connection to the PE-rs device. In case of failure of the connection or the PE-rs device, the MTU device suffers total loss of connectivity.

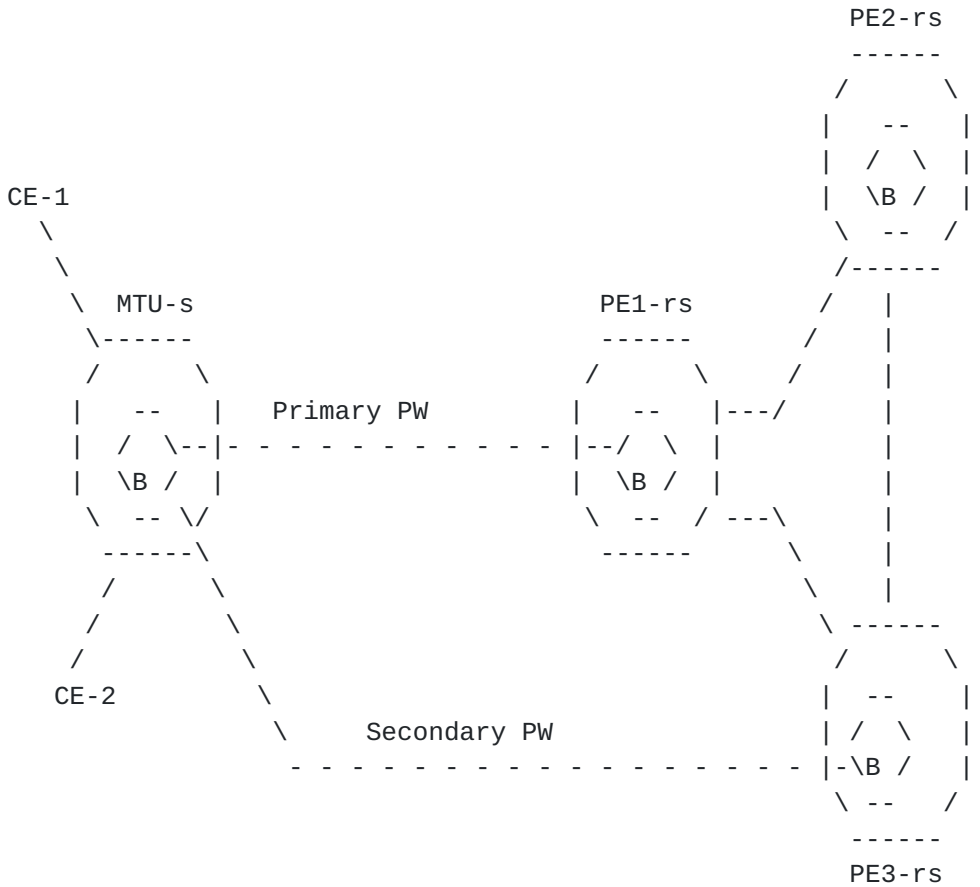
In this section we describe how the redundant connections can be

provided to avoid total loss of connectivity from the MTU device. The mechanism described is identical for both, MTU-s and PE-r type of devices

8.2.1. Dual-homed MTU device

To protect from connection failure of the PW or the failure of the PE-rs device, the MTU-s device or the PE-r is dual-homed into two PE-rs devices, as shown in figure-3. The PE-rs devices must be part of the same VPLS service instance.

An MTU-s device will setup two [PWE3-ETHERNET] PWs (one each to PE-rs1 and PE-rs2) for each VPLS instance. One of the two PWs is designated as primary and is the one that is actively used under normal conditions, while the second PW is designated as secondary and is held in a standby state. The MTU device negotiates the PW labels for both the primary and secondary PWs, but does not use the secondary PW unless the primary PW fails. Since only one link is active at a given time, a loop does not exist and hence 802.1D spanning tree is not required.



8.2.2. Failure detection and recovery

The MTU-s device controls the usage of the PWs to the PE-rs nodes.

Since LDP signaling is used to negotiate the PW labels, the hello messages used for the LDP session can be used to detect failure of the primary PW.

Upon failure of the primary PW, MTU-s device immediately switches to the secondary PW. At this point the PE3-rs device that terminates the secondary PW starts learning MAC addresses on the spoke PW. All other PE-rs nodes in the network think that CE-1 and CE-2 are behind PE1-rs and may continue to send traffic to PE1-rs until they learn that the devices are now behind PE3-rs. The relearning process can take a long time and may adversely affect the connectivity of higher level protocols from CE1 and CE2. To enable faster convergence, the PE3-rs device where the secondary PW got activated may send out a flush message (as explained in section 4.2), using the MAC TLV as defined in Section 6, to all PE-rs nodes. Upon receiving the message, PE-rs nodes flush the MAC addresses associated with that VPLS instance.

8.3. Multi-domain VPLS service

Hierarchy can also be used to create a large scale VPLS service within a single domain or a service that spans multiple domains without requiring full mesh connectivity between all VPLS capable devices. Two fully meshed VPLS networks are connected together using a single LSP tunnel between the VPLS "border" devices. A single spoke PW per VPLS service is set up to connect the two domains together.

When more than two domains need to be connected, a full mesh of inter-domain spokes is created between border PEs. Forwarding rules over this mesh are identical to the rules defined in section 5.

This creates a three-tier hierarchical model that consists of a hub-and-spoke topology between MTU-s and PE-rs devices, a full-mesh topology between PE-rs, and a full mesh of inter-domain spokes between border PE-rs devices.

This document does not specify how redundant border PEs per domain per VPLS instance can be supported.

9. Hierarchical VPLS model using Ethernet Access Network

In this section the hierarchical model is expanded to include an Ethernet access network. This model retains the hierarchical architecture discussed previously in that it leverages the full-mesh topology among PE-rs devices; however, no restriction is imposed on the topology of the Ethernet access network (e.g., the topology between MTU-s and PE-rs devices are not restricted to hub and spoke).

The motivation for an Ethernet access network is that Ethernet-based networks are currently deployed by some service providers to offer

VPLS services to their customers. Therefore, it is important to provide a mechanism that allows these networks to integrate with an IP or MPLS core to provide scalable VPLS services.

One approach of tunneling a customer's Ethernet traffic via an Ethernet access network is to add an additional VLAN tag to the customer's data (which may be either tagged or untagged). The additional tag is referred to as Provider's VLAN (P-VLAN). Inside the provider's network each P-VLAN designates a customer or more specifically a VPLS instance for that customer. Therefore, there is a one to one correspondence between a P-VLAN and a VPLS instance. In this model, the MTU-S device needs to have the capability of adding the additional P-VLAN tag for non-multiplexed customer UNI port where customer VLANs are not used as service delimiter. If customer VLANs need to be treated as service delimiter (e.g., customer UNI port is a multiplexed port), then the MTU-s needs to have the additional capability of translating a customer VLAN (C-VLAN) to a P-VLAN in order to resolve overlapping VLAN-ids used by different customers. Therefore, the MTU-s device in this model can be considered as a typical bridge with this additional UNI capability.

The PE-rs device needs to be able to perform bridging functionality over the standard Ethernet ports toward the access network as well as over the PWs toward the network core. The set of PWs that corresponds to a VPLS instance would look just like a P-VLAN to the bridge portion of the PE-rs and that is why sometimes it is referred to as Emulated VLAN. In this model the PE-rs may need to run STP protocol in addition to split-horizon. Split horizon is run over MPLS-core; whereas, STP is run over the access network to accommodate any arbitrary access topology. In this model, the PE-rs needs to map a P-VLAN to a VPLS-instance and its associated PWs and vise versa.

The details regarding bridge operation for MTU-s and PE-rs (e.g., encapsulation format for QinQ messages, customer's Ethernet control protocol handling, etc.) are outside of the scope of this document and they are covered in [802.1ad]. However, the relevant part is the interaction between the bridge module and the MPLS/IP PWs in the PE-rs device.

9.1. Scalability

Given that each P-VLAN corresponds to a VPLS instance, one may think that the total number of VPLS instances supported is limited to 4K. However, the 4K limit applies only to each Ethernet access network (Ethernet island) and not to the entire network. The SP network, in this model, consists of a core MPLS/IP network that connects many Ethernet islands. Therefore, the number of VPLS instances can scale accordingly with the number of Ethernet islands (a metro region can be represented by one or more islands). Each island may consist of many MTU-s devices, several aggregators, and one or more PE-rs

devices. The PE-rs devices enable a P-VLAN to be extended from one island to others using a set of PWs (associated with that VPLS instance) and providing a loop free mechanism across the core network through split-horizon. Since a P-VLAN serves as a service

delimiter within the provider's network, it does not get carried over the PWs and furthermore the mapping between P-VLAN and the PWs is a local matter. This means a VPLS instance can be represented by different P-VLAN in different Ethernet islands and furthermore each island can support 4K VPLS instances independent from one another.

9.2. Dual Homing and Failure Recovery

In this model, an MTU-s can be dual or triple homed to different devices (aggregators and/or PE-rs devices). The failure protection for access network nodes and links can be provided through running MSTP in each island. The MSTP of each island is independent from other islands and do not interact with each other. If an island has more than one PE-rs, then a dedicated full-mesh of PWs is used among these PE-rs devices for carrying the SP BPDU packets for that island. On a per P-VLAN basis, the MSTP will designate a single PE-rs to be used for carrying the traffic across the core. The loop-free protection through the core is performed using split-horizon and the failure protection in the core is performed through standard IP/MPLS re-routing.

10. Significant Modifications

Between rev 05 and this one, these are the changes:

- Incorporated comments from WG last call
- Fixed idnits

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12. Acknowledgments

We wish to thank Joe Regan, Kireeti Kompella, Anoop Ghanwani, Joel Halpern, Rick Wilder, Jim Guichard, Steve Phillips, Norm Finn, Matt

Squire, Muneyoshi Suzuki, Waldemar Augustyn, Eric Rosen, Yakov Rekhter, and Sasha Vainshtein for their valuable feedback.

We would also like to thank Rajiv Papneja (ISOCORE), Winston Liu (Ixia), and Charlie Hundall (Extreme) for identifying issues with the draft in the course of the interoperability tests.

13. Security Considerations

A more comprehensive description of the security issues involved in L2VPNs is covered in [VPN-SEC]. An unguarded VPLS service is vulnerable to some security issues which pose risks to the customer and provider networks. Most of the security issues can be avoided through implementation of appropriate guards. A couple of them can be prevented through existing protocols.

- Data plane aspects
    - Traffic isolation between VPLS domains is guaranteed by the use of per VPLS L2 FIB table and the use of per VPLS PWs
    - The customer traffic, which consists of Ethernet frames, is carried unchanged over VPLS. If security is required, the customer traffic SHOULD be encrypted and/or authenticated before entering the service provider network
    - Preventing broadcast storms can be achieved by using routers as CPE devices or by rate policing the amount of broadcast traffic that customers can send.
- Control plane aspects
    - LDP security (authentication) methods as described in [RFC-3036] SHOULD be applied. This would prevent unauthorized participation by a PE in a VPLS.
- Denial of service attacks
    - Some means to limit the number of MAC addresses (per site per VPLS) that a PE can learn SHOULD be implemented.

IANA Considerations

The type field in the Mac TLV is defined as 0x404 in section 4.2.1 and is subject to IANA approval.

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Release Statement

By submitting this Internet-Draft, the authors accept the provisions of Section 4 of RFC 3667.

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802.1j-1992 and 802.6k-1992. It incorporates P802.11c, P802.1p and P802.12e." ISO/IEC 15802-3: 1998.

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[802.1ad] "IEEE standard for Provider Bridges", Work in Progress, December 2002.

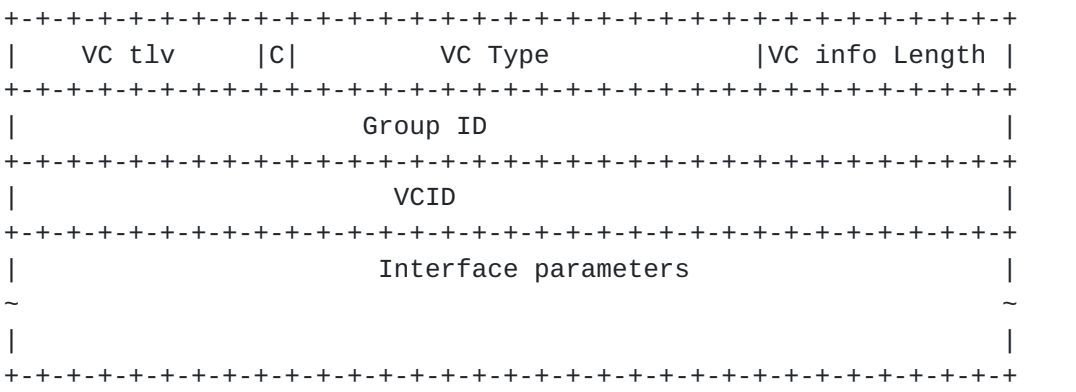
Appendix: VPLS Signaling using the PWid FEC Element

This section is being retained because live deployments use this version of the signaling for VPLS.

The VPLS signaling information is carried in a Label Mapping message sent in downstream unsolicited mode, which contains the following VC FEC TLV.

VC, C, VC Info Length, Group ID, Interface parameters are as defined in [PWE3-CTRL].

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
```



We use the Ethernet PW type to identify PWs that carry Ethernet traffic for multipoint connectivity.

In a VPLS, we use a VCID (which has been substituted with a more general identifier, to address extending the scope of a VPLS) to identify an emulated LAN segment. Note that the VCID as specified in [PWE3-CTRL] is a service identifier, identifying a service emulating a point-to-point virtual circuit. In a VPLS, the VCID is a single service identifier.

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