LET’S
BUILD
TOMORROW
TODAY

Deploying MPLS-based Layer 2 Virtual Private Networks

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BRKMPL-2101

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Agenda

- Motivation and Overview
- Ethernet Point-to-Point L2VPNs
- Ethernet Multipoint L2VPNs
  - VPLS
  - EVPN and PBB-EVPN
- Advanced Topics
  - Resiliency Solutions
  - Load-Balancing
- Deployment Use Cases
- Summary

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L2VPN Motivation and Overview

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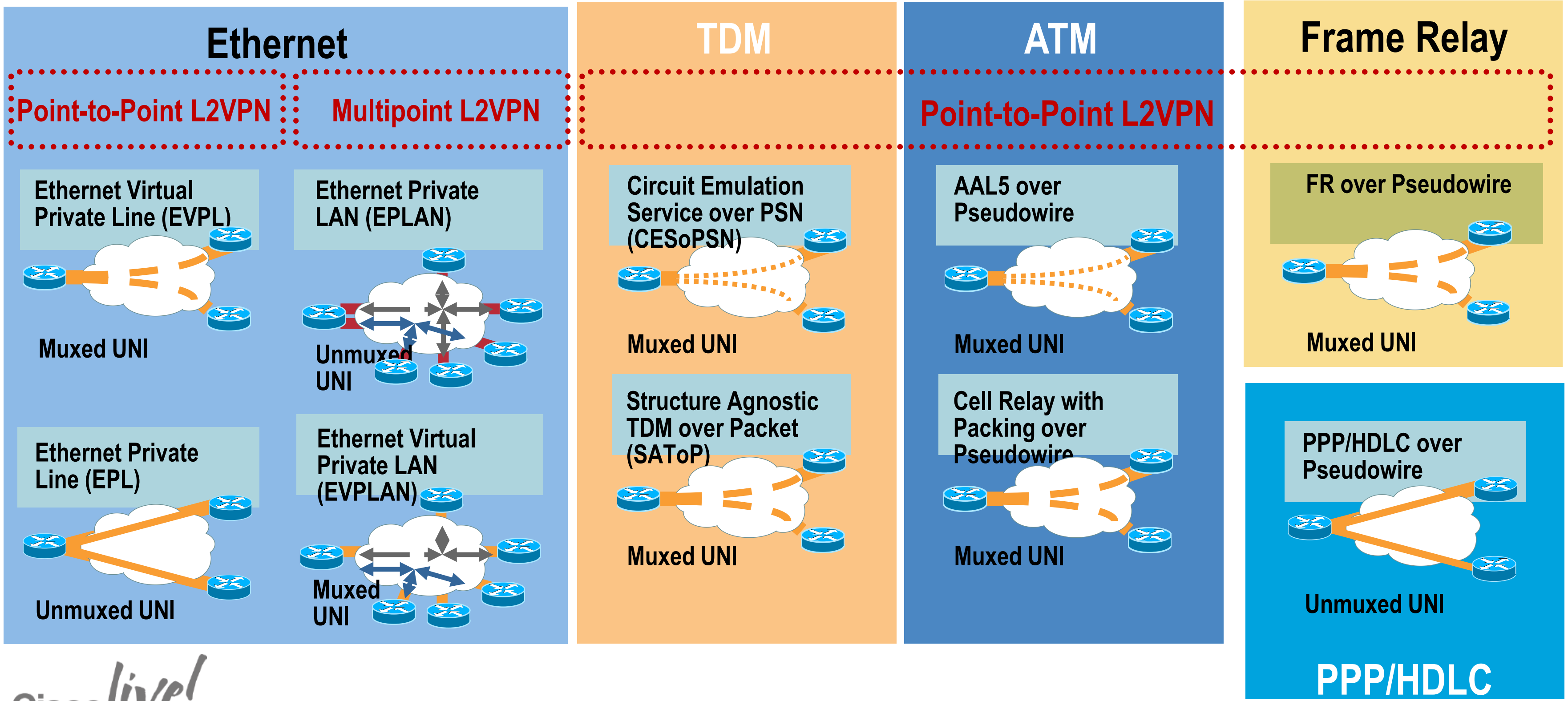
What is a Layer 2 VPN?

L2VPN Transport Services



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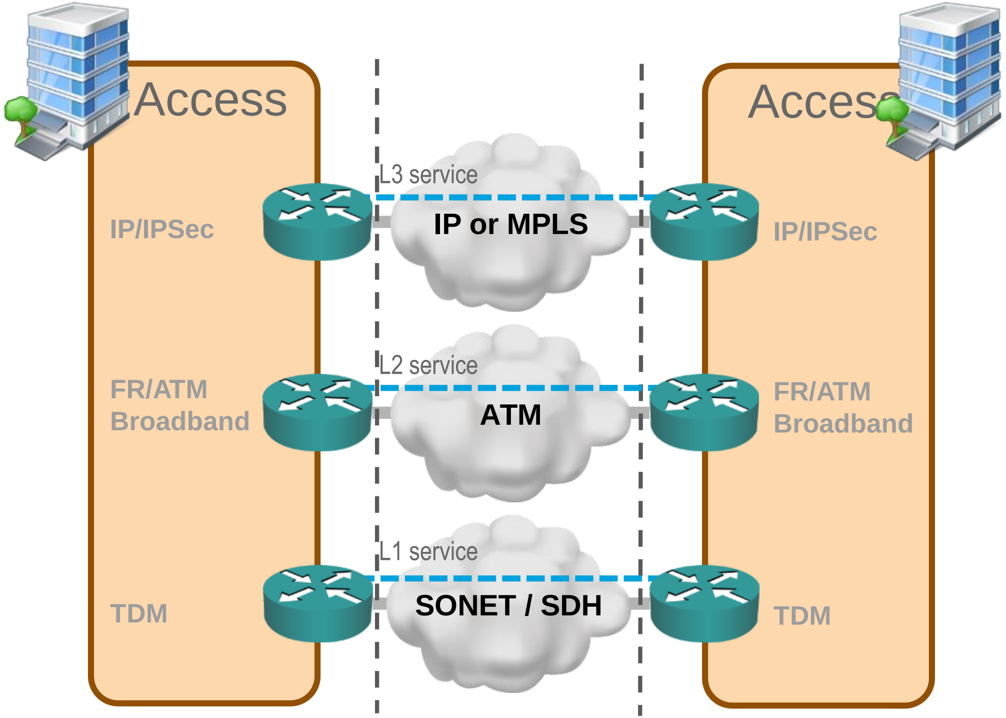
Motivation for L2VPNs

Old and New Drivers

- Network Consolidation (circa 2000)
  - Multiple access services (FR, ATM, TDM) required multiple core technologies
- Enterprise Ethernet WAN Connectivity Services (circa 2005+)
  - Ethernet well understood by Enterprise / SPs
  - CAPEX (lower cost per bit) / Growth (100GE)
  - Layer 2 VPN replacement to ATM/Frame Relay
  - Internet / Layer 3 VPN access (CE to PE)
- Data Center Interconnection (DCI)
- Mobile Backhaul Evolution
  - TDM /PDH to Dual/Hybrid to All-packet (IP/Ethernet)
  - Single (voice + data) IP/Ethernet mobile backhaul universally accepted solution



Typical Service Provider (circa 2000)

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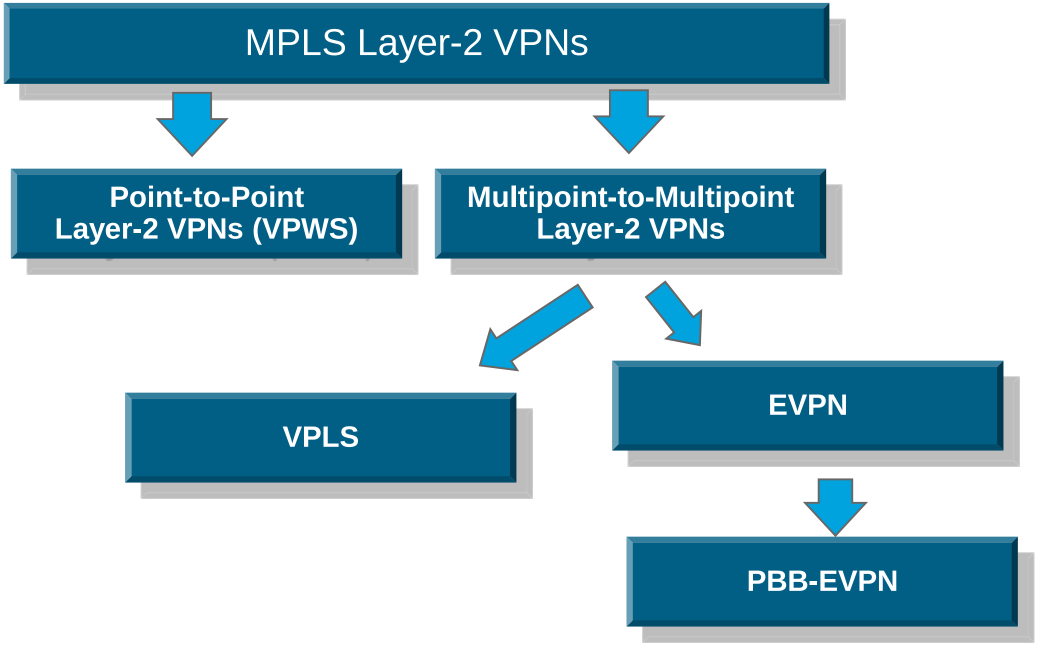
MPLS Layer-2 Virtual Private Networks

Technology Options

- VPWS services
  - Point-to-point
  - Referred to as Pseudowires (PWs)
- VPLS services
  - Multipoint
- EVPN
  - Multipoint with BGP-based MAC learning
- PBB-EVPN
  - Combines scale tools from PBB (aka MAC-in-MAC) with BGP-based MAC learning from EVPN



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Ethernet Point-to-Point L2VPNs

Virtual Private Wire Service (VPWS)

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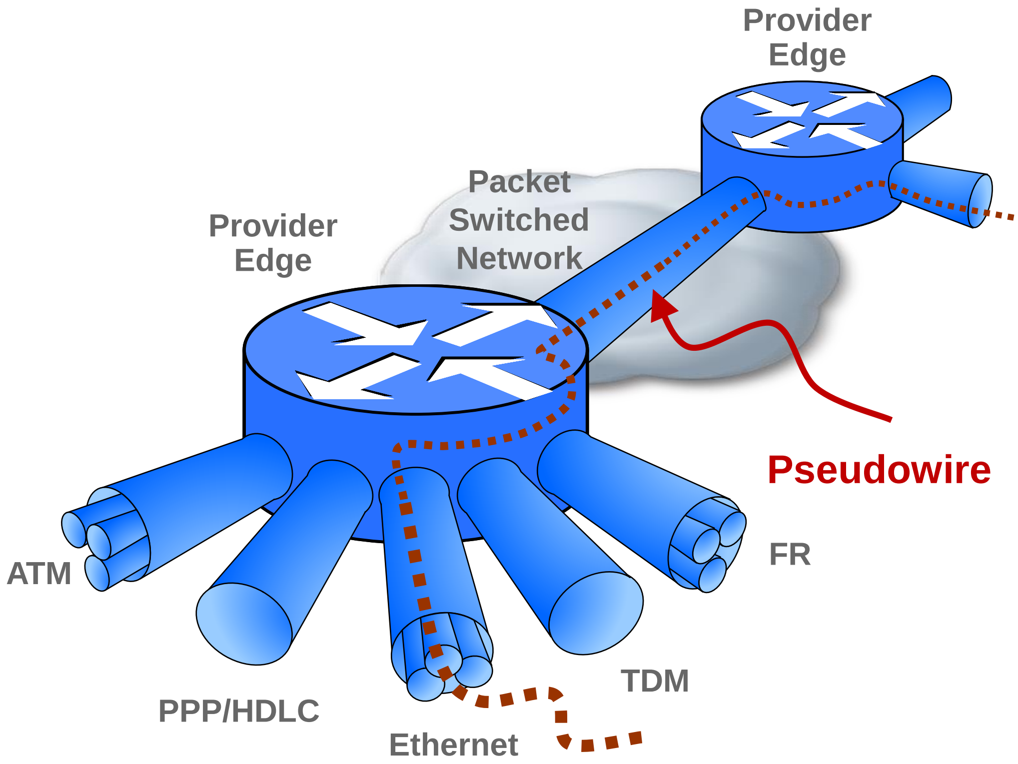
Layer 2 VPN Enabler

The Pseudowire

- L2VPNs are built with Pseudowire (PW) technology
- PWs provide a common intermediate format to transport multiple types of network services over a Packet Switched Network (PSN)
- PW technology provides Like-to-Like transport and also Interworking (IW)



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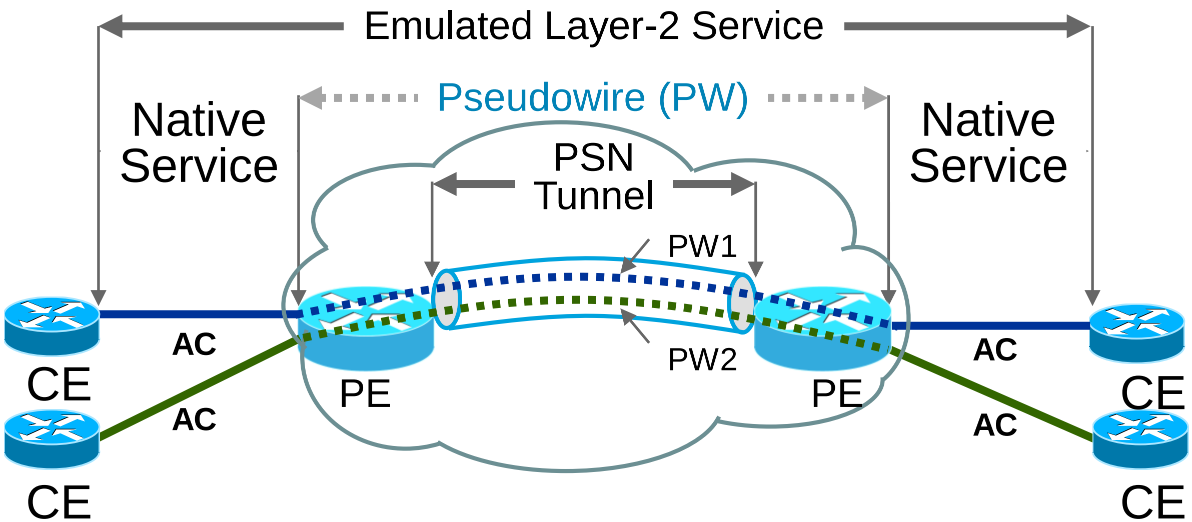
Pseudowire Reference Model

- Any Transport Over MPLS (AToM) is Cisco's implementation of VPWS for IP/MPLS networks
- An Attachment Circuit (AC) is the physical or virtual circuit attaching a CE to a PE
- Customer Edge (CE) equipment perceives a PW as an unshared link or circuit



Ref: RFC 3985 Pseudo Wire Emulation Edge-to-Edge (PWE3) Architecture, March 2005

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Layer 2 Transport over MPLS

Control Connection

Tunnelling Component

Demultiplexing Component

Layer 2 Encapsulation

- Targeted LDP session / BGP session / Static
  - Used for VC-label negotiation, withdrawal, error notification

The “emulated circuit” has three (3) layers of encapsulation

- Tunnel header (Tunnel Label)
  - To get PDU from ingress to egress PE
  - MPLS LSP derived through static configuration (MPLS-TP) or dynamic (LDP or RSVP-TE)
- Demultiplexer field (VC Label)
  - To identify individual circuits within a tunnel
  - Could be an MPLS label, L2TPv3 header, GRE key, etc.
- Emulated VC encapsulation (Control Word)
  - Information on enclosed Layer 2 PDU
  - Implemented as a 32-bit control word

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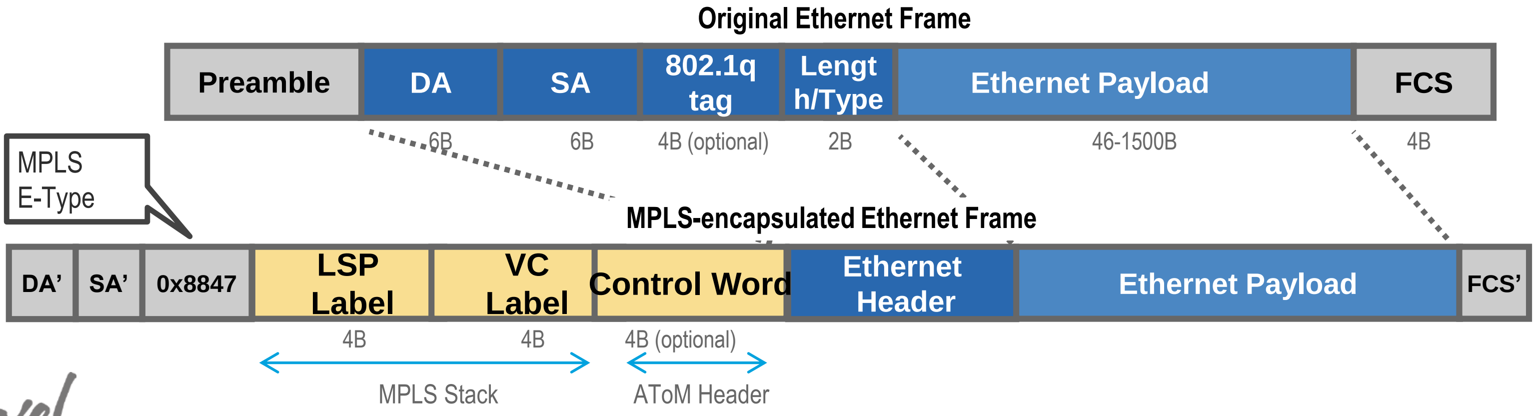
How Are Ethernet Frames Transported?

- Ethernet frames transported without Preamble, Start Frame Delimiter (SFD) and FCS
- Two (2) modes of operation supported:
  - Ethernet VLAN mode (VC type 0x0004) – created for VLAN over MPLS application
  - Ethernet Port / Raw mode (VC type 0x0005) – created for Ethernet port tunneling application



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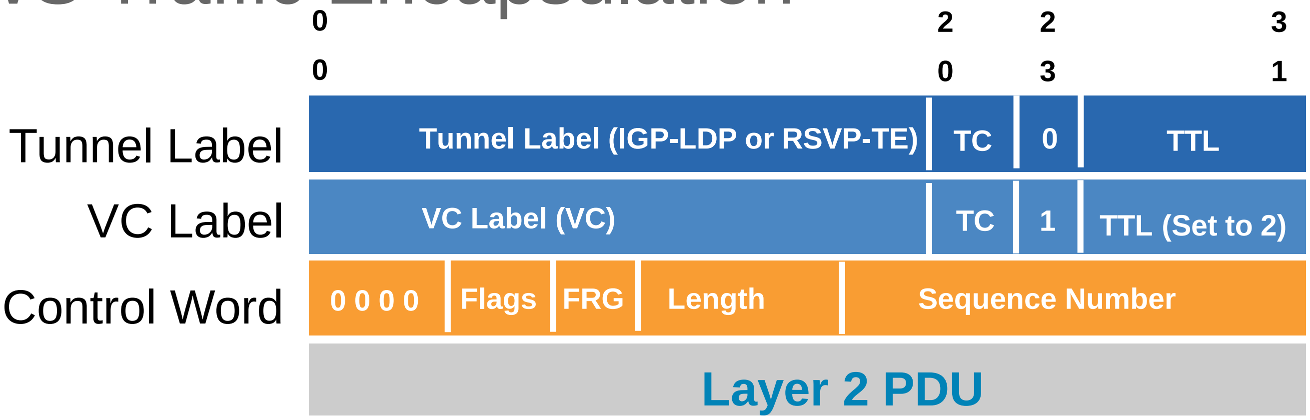
VPWS Traffic Encapsulation



- Three-level encapsulation
- Packets switched between PEs using Tunnel label
- VC label identifies PW
- VC label signaled between PEs
- Optional Control Word (CW) carries Layer 2 control bits and enables sequencing

Control Word	
Encap.	Required
ATM N:1 Cell Relay	No
ATM AAL5	Yes
Ethernet	No
Frame Relay	Yes
HDLC	No
PPP	No
SAToP	Yes
CESoPSN	Yes

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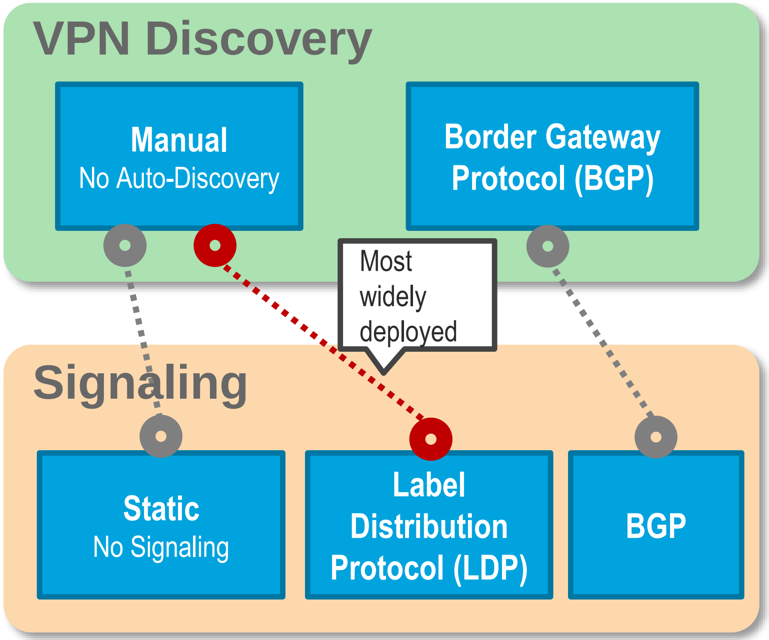
VPWS

Discovery and Signaling Alternatives

- VPWS Signaling
  - LDP-based (RFC 4447)
  - BGP-based (RFC 6624)
- VPWS with LDP-signaling and No auto-discovery
  - Most widely deployed solution
- Auto-discovery for point-to-point services not as relevant as for multipoint



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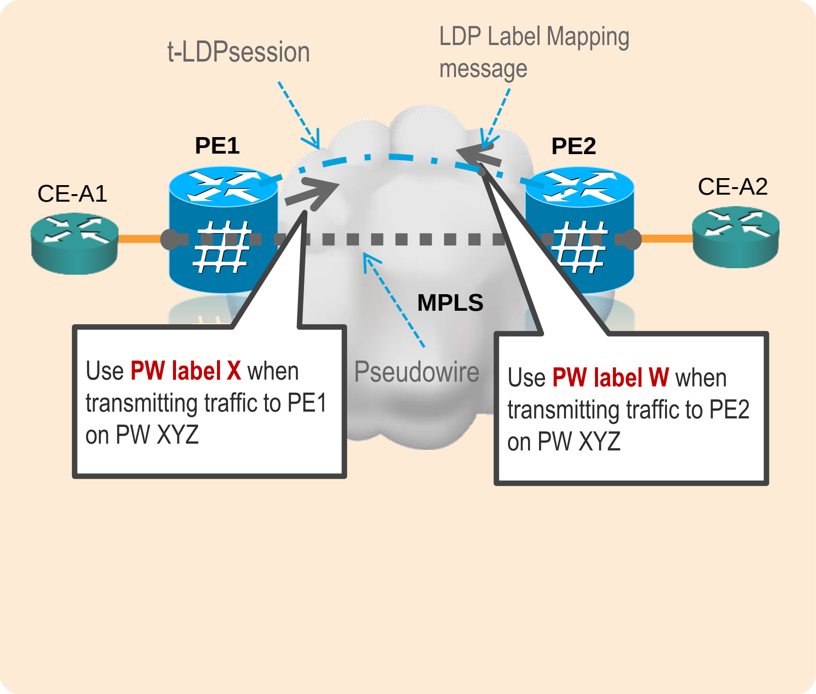
LDP Signaling

Overview

- RFC 4447 defines use of LDP protocol for setting up and maintaining pseudowires
  - Targeted LDP (t-LDP) session between PE routers
- PW label bindings exchanged using LDP Label Mapping messages
- Two Forward Equivalency Classes (FEC) element types defined
  - LDP PWid FEC Element (FEC 128) - Used in manual provisioning scenarios
  - LDP Generalized PWid FEC Element (FEC 129) – Used in auto-discovery scenarios



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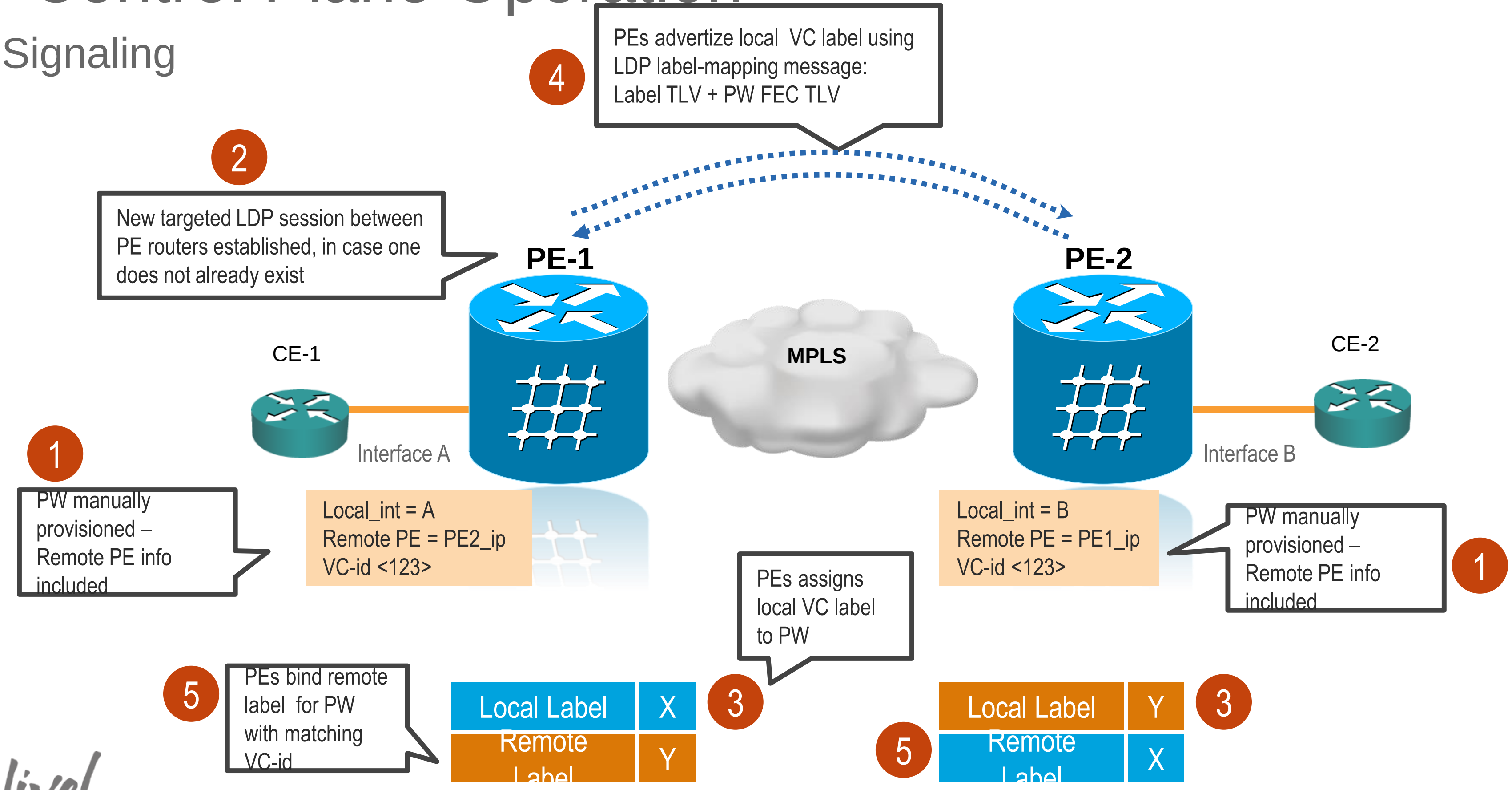
PW Control Plane Operation

LDP Signaling



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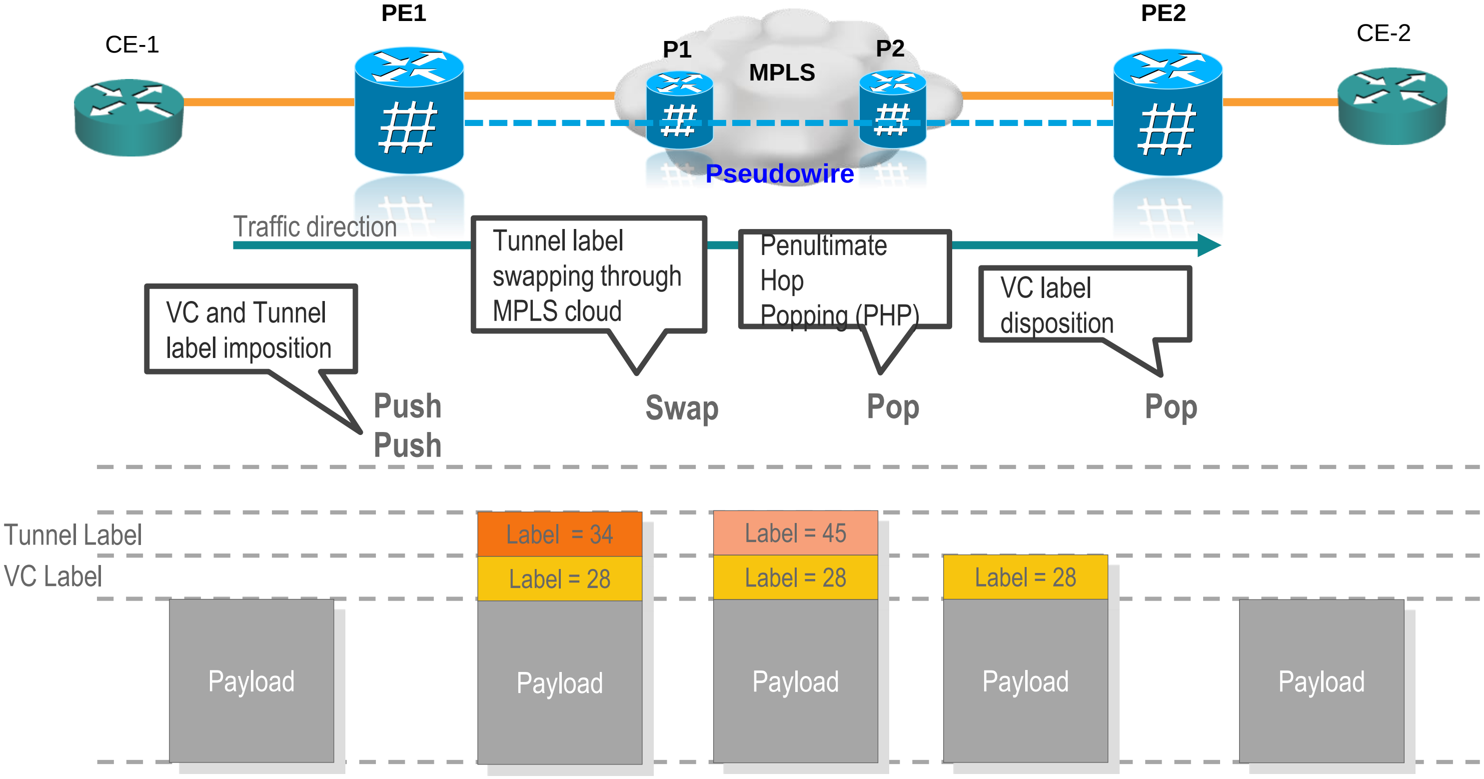
VPWS Forwarding Plane Processing



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Ethernet Multipoint L2VPNs

Virtual Private LAN Service (VPLS)

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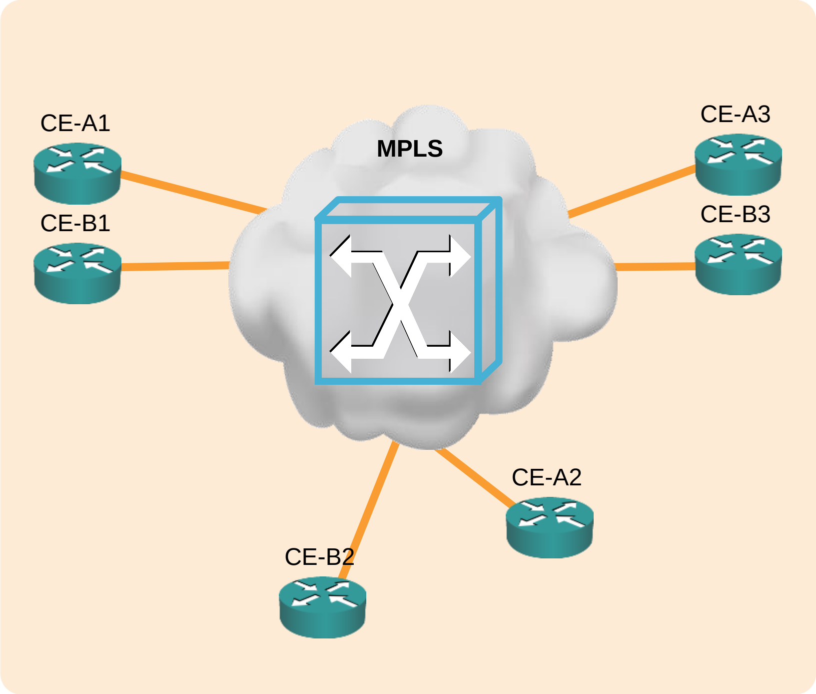
Virtual Private LAN Service

Overview

- Defines Architecture to provide Ethernet Multipoint connectivity sites, as if they were connected using a LAN
- VPLS operation emulates an IEEE Ethernet switch
- Two (2) signaling methods
  - RFC 4762 (LDP-Based VPLS)
  - RFC 4761 (BGP-Based VPLS)



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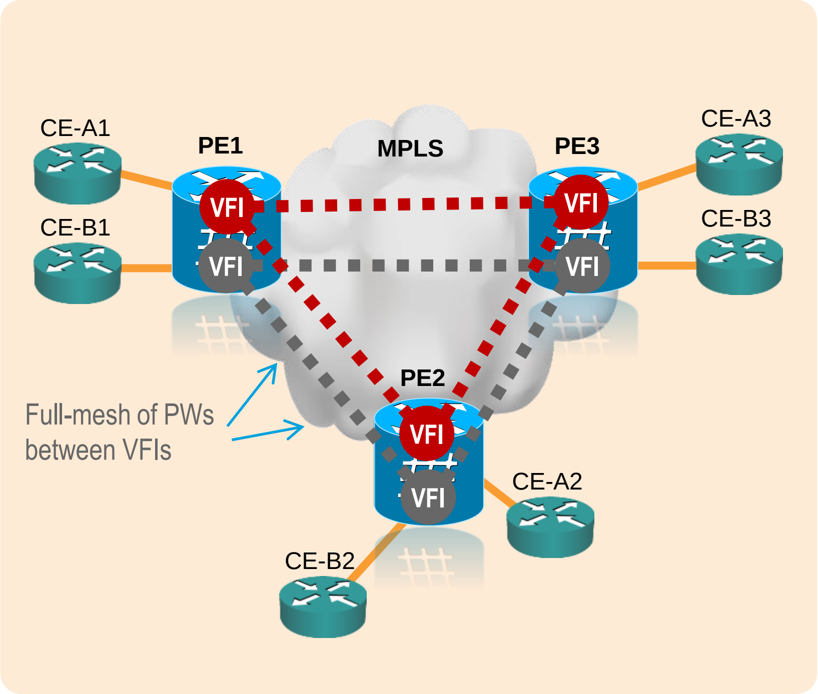
Virtual Private LAN Service

Reference Model

- VFI (Virtual Forwarding Instance)
  - Also called VSI (Virtual Switching Instance)
  - Emulates L2 broadcast domain among ACs and VCs
  - Unique per service. Multiple VFIs can exist same PE
- AC (Attachment Circuit)
  - Connect to CE device, it could be Ethernet physical or logical port
  - One or multiple ACs can belong to same VFI
- VC (Virtual Circuit)
  - EoMPLS data encapsulation, tunnel label used to reach remote PE, VC label used to identify VFI
  - One or multiple VCs can belong to same VFI
  - PEs must have a full-mesh of PWs in the VPLS core



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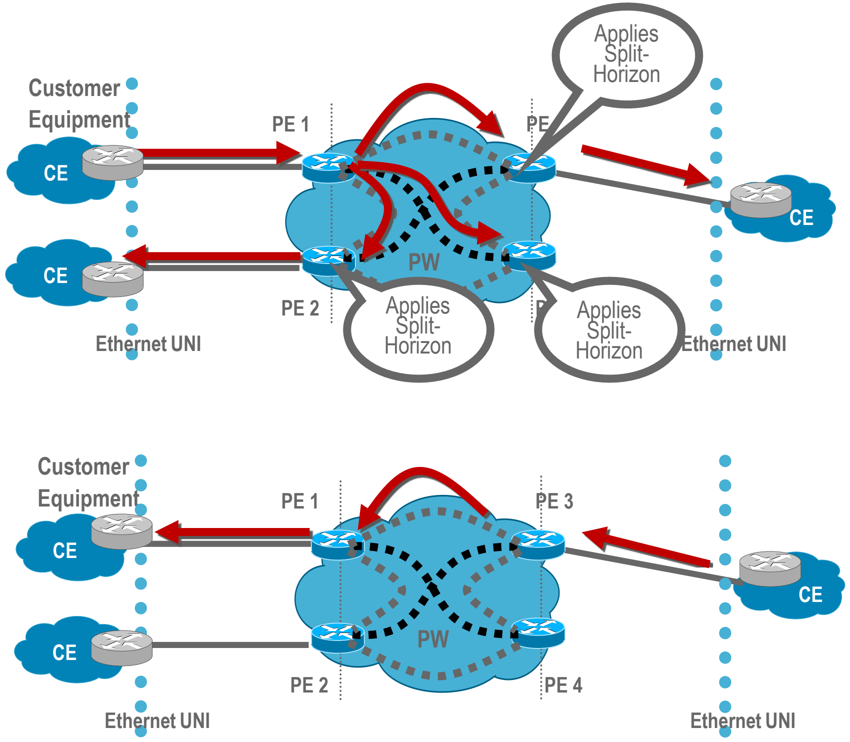
Virtual Private LAN Service

Operation

- Flooding / Forwarding
  - Forwarding based on destination MAC addresses
  - Flooding (Broadcast, Multicast, Unknown Unicast)
- Split-Horizon and Full-Mesh of PWs for loop-avoidance in core
  - SP does not run STP in the core
- MAC Learning/Aging/Withdrawal
  - Dynamic learning based on Source MAC and VLAN
  - Refresh aging timers with incoming packet
  - MAC withdrawal upon topology changes



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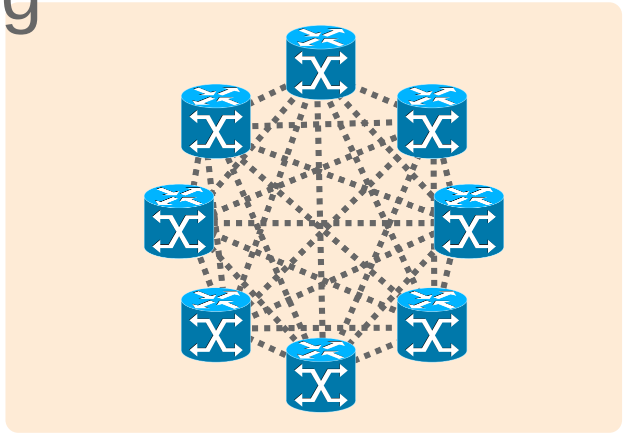
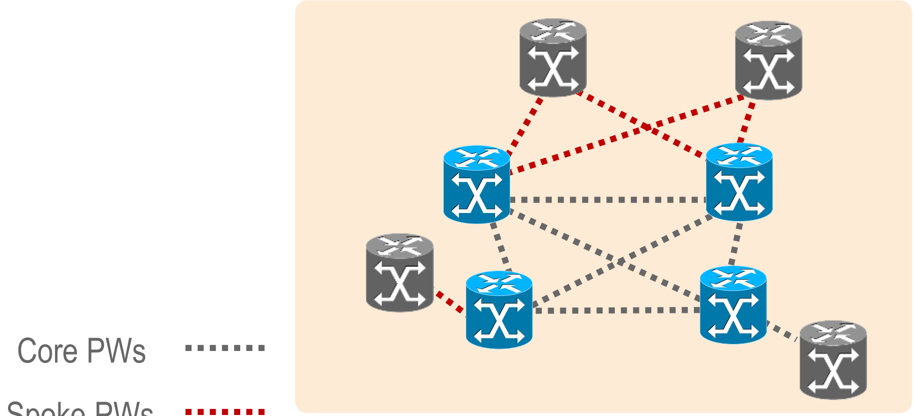
Why H-VPLS? Improved Scaling

- Flat VPLS
  - Potential signaling overhead
  - Packet replication at the edge
  - Full PW mesh end-to-end
- Hierarchical-VPLS
  - Minimizes signaling overhead
  - Packet replication at the core only
  - Full PW mesh in the core





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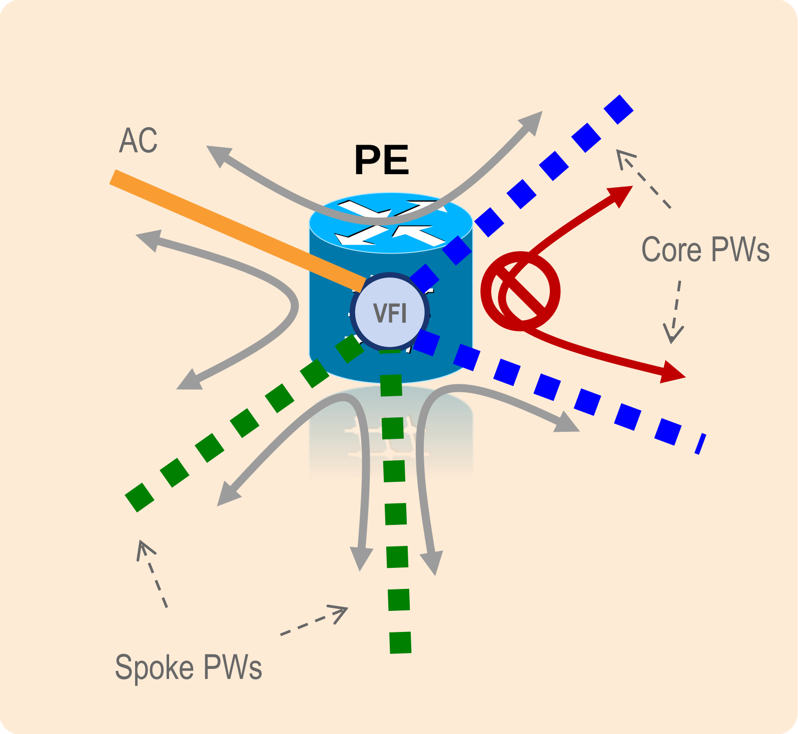
VPLS Operation

Loop Prevention

- Core PW – Split Horizon ON
- Spoke PW – Split Horizon OFF (default)
- Split-Horizon Rules
  - Forwarding between Spoke PWs
  - Forwarding between Spoke and Core PWs
  - Forwarding between ACs and Core / Spoke PWs
  - Forwarding between ACs
  - Blocking between Core PWs



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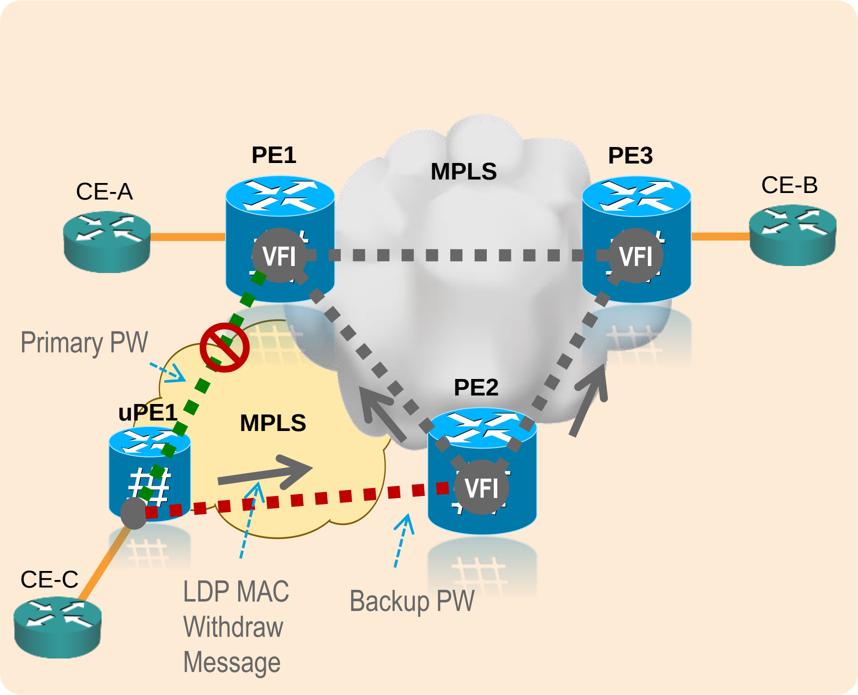
VPLS Operation

MAC Address Withdrawal

- Remove (flush) dynamic MAC addresses upon Topology Changes
  - Faster convergence – avoids blackholing
  - Uses LDP Address Withdraw Message (RFC 4762)
- H-VPLS dual-home example
  - U-PE detects failure of Primary PW
  - U-PE activates Backup PW
  - U-PE sends LDP MAC address withdrawal request to new N-PE
  - N-PE forwards the message to all PWs in the VPLS core and flush its MAC address table



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Ethernet Multipoint L2VPNs

VPLS Signaling and Auto-Discovery

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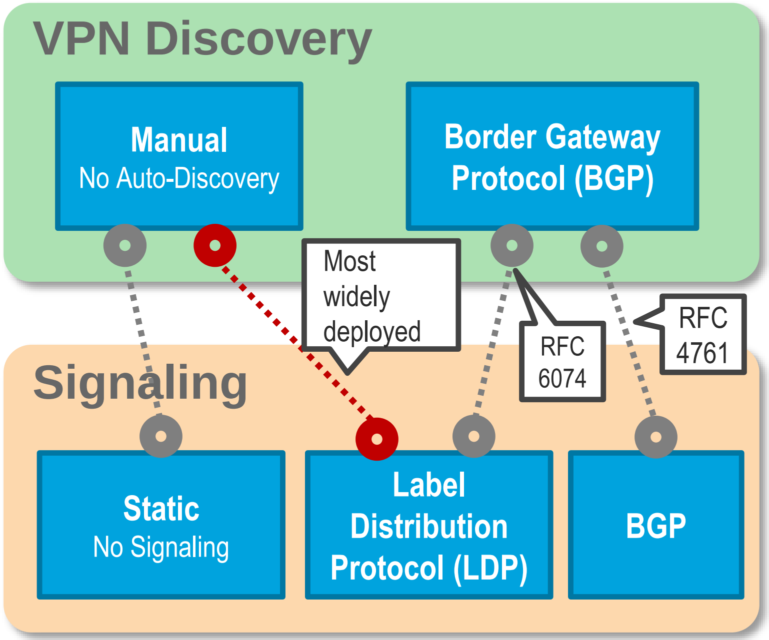
VPLS

Discovery and Signaling Alternatives

- VPLS Signaling
  - LDP-based (RFC 4762)
  - BGP-based (RFC 4761)
- VPLS with LDP-signaling and No auto-discovery
  - Most widely deployed solution
  - Operational complexity for larger deployments
- BGP-based Auto-Discovery (BGP-AD) (RFC 6074)
  - Enables discovery of PE devices in a VPLS instance



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Ethernet Multipoint L2VPNs

VPLS with LDP Signaling and BGP-based AutoDiscovery (BGP-AD)

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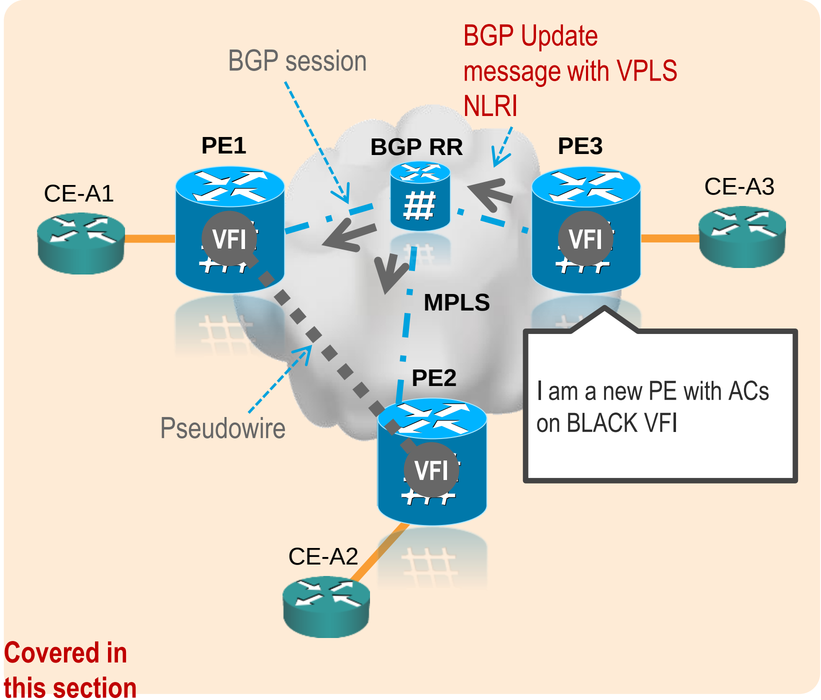
BGP Auto-Discovery (BGP-AD)

- Eliminates need to manually provision VPLS neighbors
- Automatically detects when new PEs are added / removed from the VPLS domain
- Uses BGP Update messages to advertize PE/VFI mapping (VPLS NLRI)
- Typically used in conjunction with BGP Route Reflectors to minimize iBGP full-mesh peering requirements
- Two (2) RFCs define use of BGP for VPLS AD[1]
  - RFC 6074 – when LDP used for PW signaling
  - RFC 4761 – when BGP used for PW signaling



Covered in this section

(1) VPLS BGP NLRIs from RFC 6074 and 4761 are different in format and thus not compatible, even though they share same AFI / SAFI values

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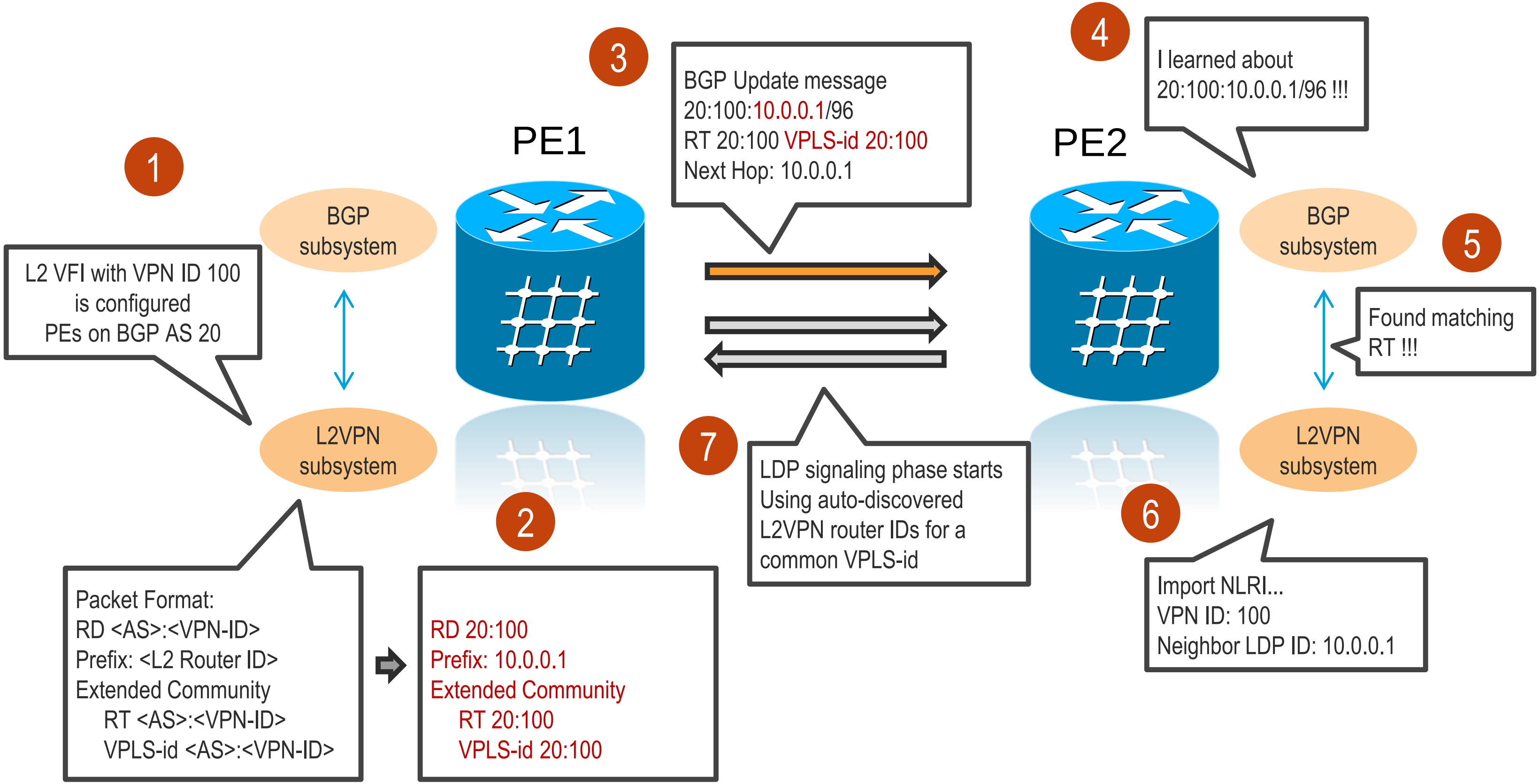
BGP Auto-Discovery in Action



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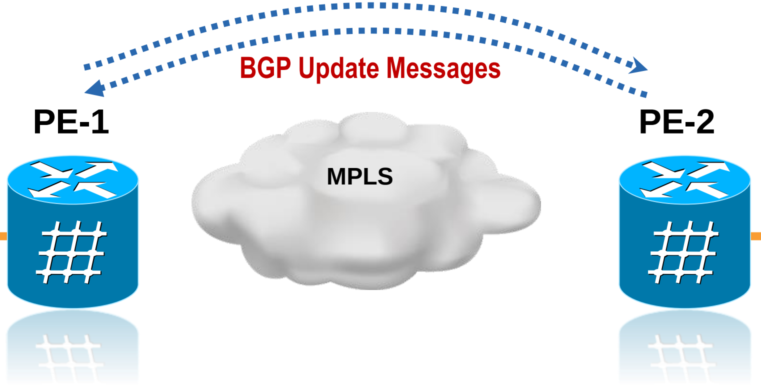
What is Discovered? NLRI + Extended Communities

BGP ASN = 100
BGP Rtr ID = 1.1.1.10
BGP neighbor = 2.2.2.20

L2VPN Rtr ID = 10.10.10.10
VPN ID = 111
RT = auto (100:111)
RD = auto (100:111)
VPLS-ID = auto (100:111)



BGP ASN = 100
BGP Rtr ID = 2.2.2.20
BGP neighbor = 1.1.1.10

L2VPN Rtr ID = 20.20.20.20
VPN ID = 111
RT = auto (100:111)
RD = auto (100:111)
VPLS-ID = auto (100:111)

	PE-1	PE-2
	Source Address = 1.1.1.10	**Source Address = 2.2.2.20**
	Destination Address = 2.2.2.20	**Destination Address = 1.1.1.10**
NLRI	**Length = 14**	**Length = 14**
NLRI	**Route Distinguisher = 100:111**	**Route Distinguisher = 100:111**
NLRI	**L2VPN Router ID = 10.10.10.10**	**L2VPN Router ID = 20.20.20.20**
Extended Communities	**VPLS-ID = 100:111**	**VPLS-ID = 100:111**
Extended Communities	**Route Target = 100:111**	**Route Target = 100:111**

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What is Signaled?

BGP ASN = 100
BGP Rtr ID = 1.1.1.10
BGP neighbor = 2.2.2.20

L2VPN Rtr ID = 10.10.10.10
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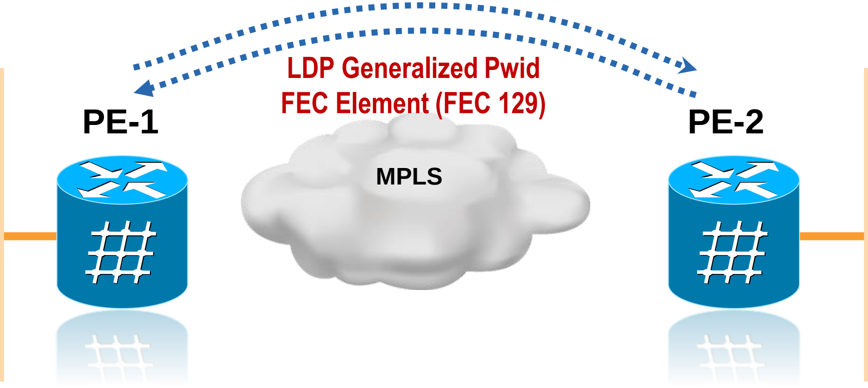

BGP ASN = 100
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L2VPN Rtr ID = 20.20.20.20
VPN ID = 111
RT = auto (100:111)
RD = auto (100:111)
VPLS-ID = auto (100:111)

FEC 129

PE-1	PE-2
AGI = VPLS-ID = 100:111	**AGI = VPLS-ID = 100:111**
SAII = Local L2VPN ID = 10.10.10.10	**SAII = Local L2VPN ID = 20.20.20.20**
TAII = Remote L2VPN ID = 20.20.20.20	**TAII = Remote L2VPN ID = 10.10.10.10**

Local and Remote (discovered) L2VPN router ID and VPLS-ID used for PW signaling

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Ethernet Multipoint L2VPNs

VPLS with BGP-based Signaling and AutoDiscovery

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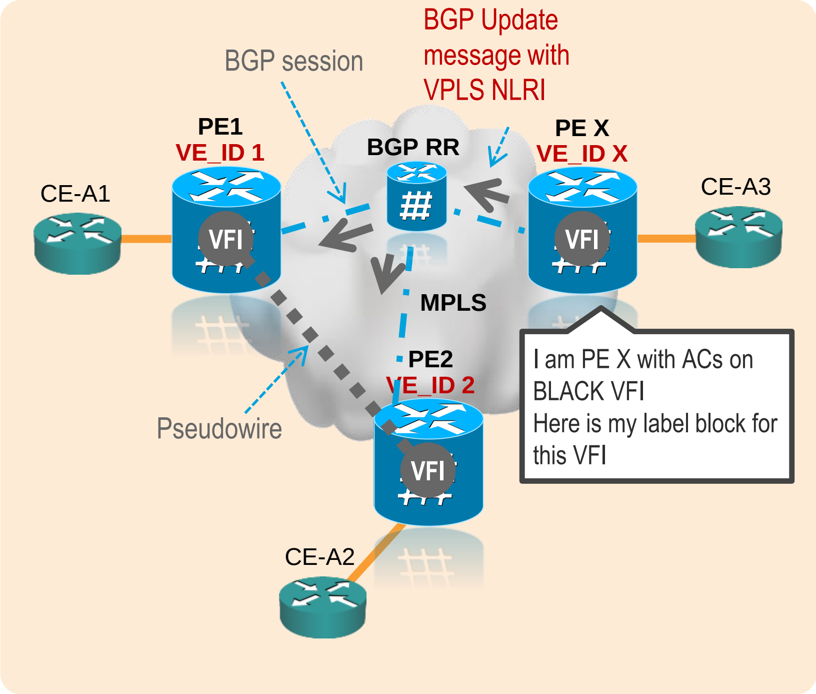
BGP Signaling and Auto-Discovery

Overview

- RFC 4761[1] defines use of BGP for VPLS PE Auto-Discovery and Signaling
- All PEs within a given VPLS are assigned a unique VPLS Edge device ID (VE ID)
- A PE X wishing to send a VPLS update sends the same label block information to all other PEs using BGP VPLS NLRI
- Each receiving PE infers the label intended for PE X by adding its (unique) VE ID to the label base
  - Each receiving PE gets a unique label for PE X for that VPLS



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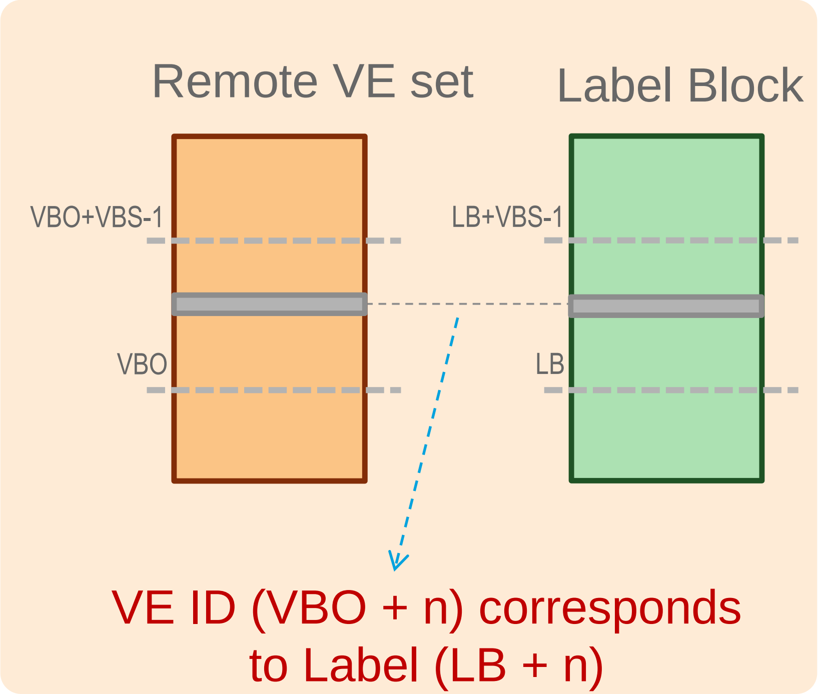
BGP Signaling and Auto-Discovery

Label Blocks

- RFC 4761 is primarily based on the concept of Label Blocks
  - Contiguous set of local labels
  - Label Block boundary advertised using BGP VPLS NLRI
- Label Base (LB) – start of label block
- VE Block Size (VBS) – size of label block
- VE Block Offset (VBO) – start of remote VE set



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Topic covered in detail in **BRKMPL-2333**

Ethernet Multipoint L2VPNs

Ethernet VPN Family Overview

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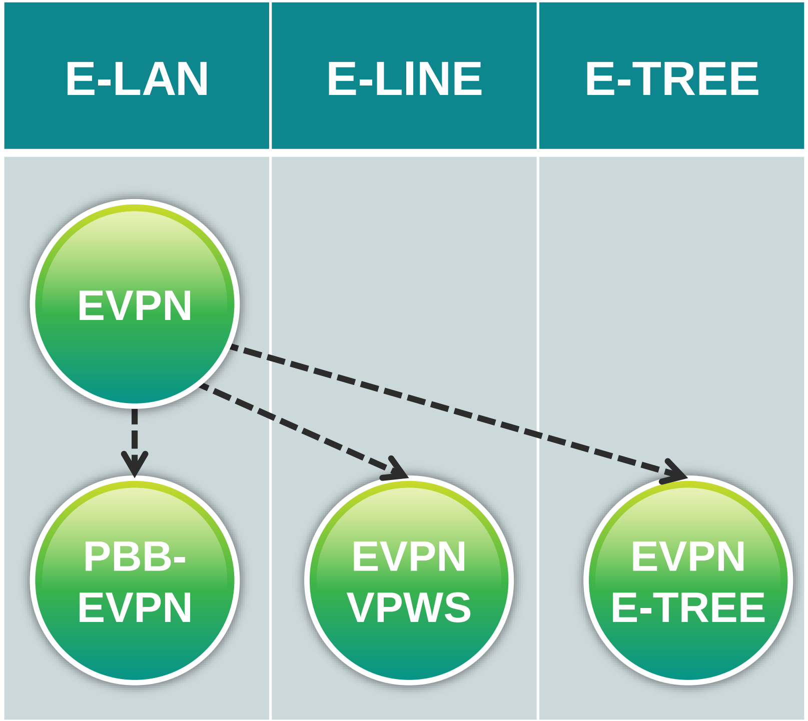
What is xEVPN?

- xEVPN family introduces next generation solutions for Ethernet services
  - BGP control-plane for Ethernet Segment and MAC distribution and learning over MPLS core
  - Same principles and operational experience of IP VPNs
- No use of Pseudowires
  - Uses MP2P tunnels for unicast
  - Multi-destination frame delivery via ingress replication (via MP2P tunnels) or LSM
- Multi-vendor solutions under IETF standardization



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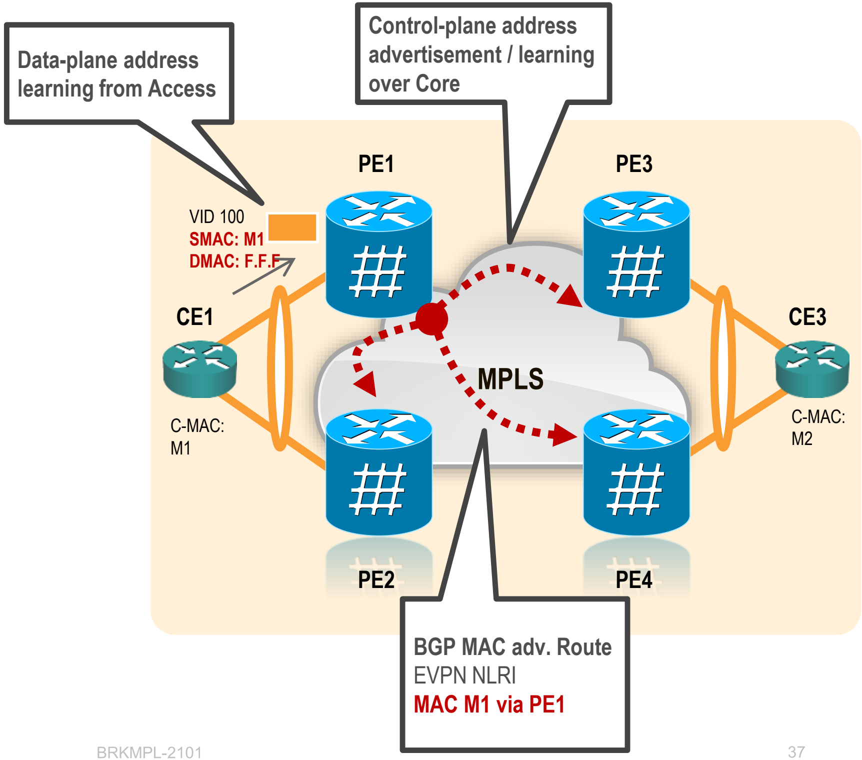
Ethernet VPN

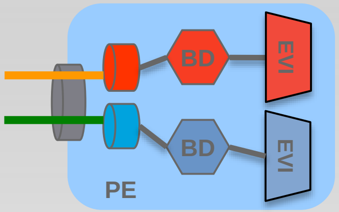
Highlights

- Next generation solution for Ethernet multipoint (E-LAN) services
- PEs run Multi-Protocol BGP to advertise & learn Customer MAC addresses (C-MACs) over Core
  - Same operational principles of L3VPN
- Learning on PE Access Circuits via data-plane transparent learning
- No pseudowire full-mesh required
  - Unicast: use MP2P tunnels
  - Multicast: use ingress replication over MP2P tunnels or use LSM
- Under standardization at IETF – draft-ietf-l2vpn-evpn



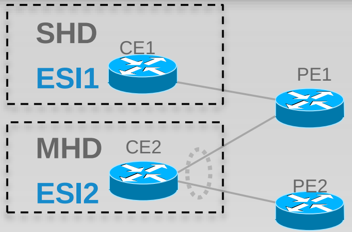
Concepts

EVPN Instance (EVI)



- EVI identifies a VPN in the network
- Encompass one or more bridge-domains, depending on service interface type
  - Port-based
  - VLAN-based (shown above)
  - VLAN-bundling
  - VLAN aware bundling (NEW)

Ethernet Segment



- Represents a 'site' connected to one or more PEs
- Uniquely identified by a 10-byte global Ethernet Segment Identifier (ESI)
- Could be a single device or an entire network
  - Single-Homed Device (SHD)
  - Multi-Homed Device (MHD)
  - Single-Homed Network (SHN)
  - Multi-Homed Network (MHN)

BGP Routes

Route Types
[1] Ethernet Auto-Discovery (AD) Route
[2] MAC Advertisement Route
[3] Inclusive Multicast Route
[4] Ethernet Segment Route

- EVPN and PBB-EVPN define a single new BGP NLRI used to carry all EVPN routes
- NLRI has a new SAFI (70)
- Routes serve control plane purposes, including:
  - MAC address reachability
  - MAC mass withdrawal
  - Split-Horizon label adv.
  - Aliasing
  - Multicast endpoint discovery
  - Redundancy group discovery
  - Designated forwarder election

BGP Route Attributes

Extended Communities
ESI MPLS Label
ES-Import
MAC Mobility
Default Gateway

- New BGP extended communities defined
- Expand information carried in BGP routes, including:
  - MAC address moves
  - C-MAC flush notification
  - Redundancy mode
  - MAC / IP bindings of a GW
  - Split-horizon label encoding

Used by PBB-EVPN

Topic covered in detail in **BRKMPL-2333**

Ethernet Multipoint L2VPNs

Provider Backbone Bridging (PBB) Ethernet VPN (PBB-EVPN)

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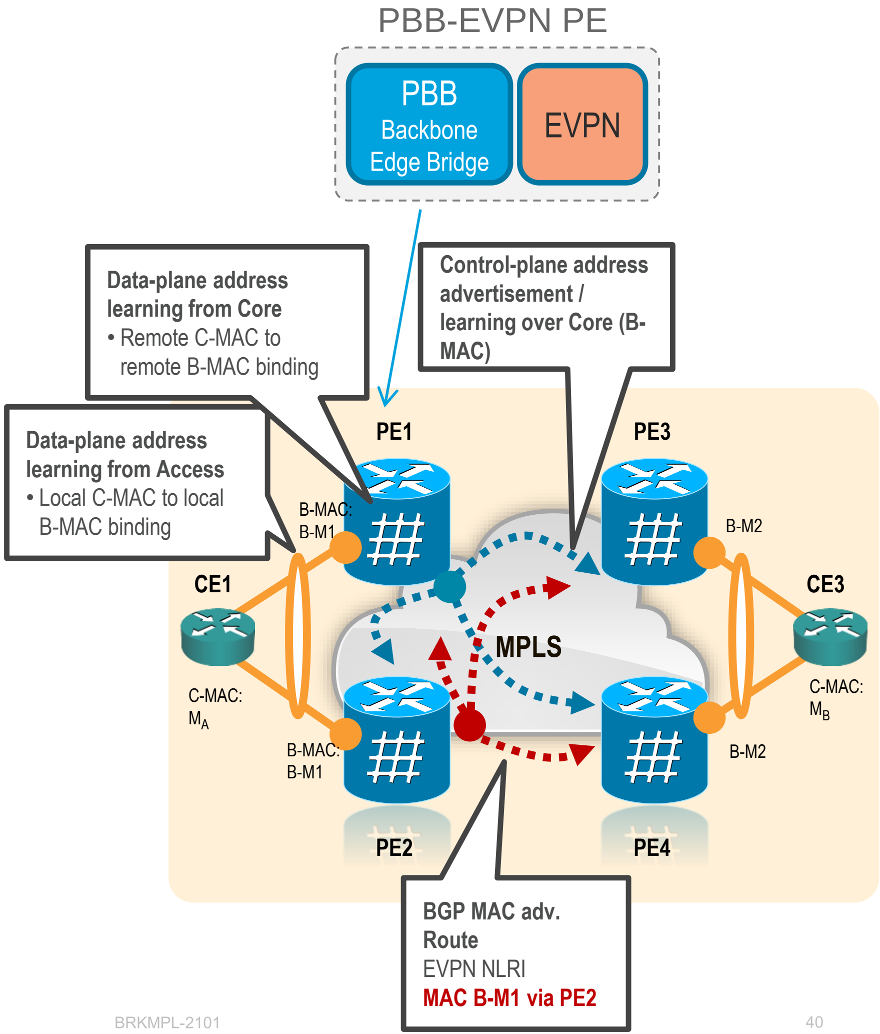
PBB Ethernet VPN

Highlights

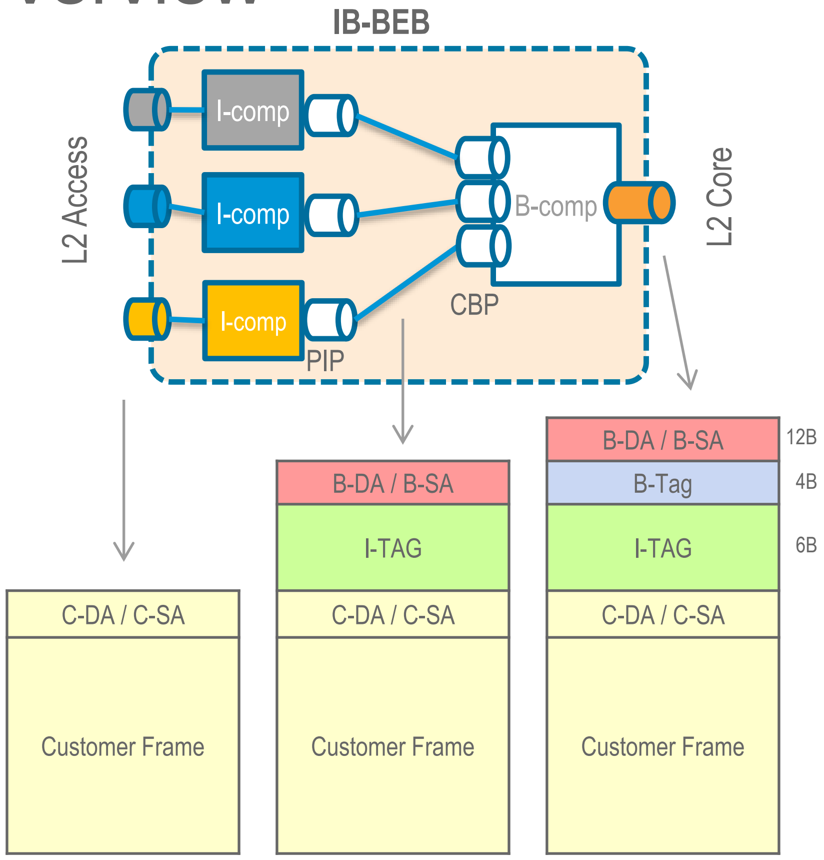
- Next generation solution for Ethernet multipoint (E-LAN) services by combining Provider Backbone Bridging (PBB - IEEE 802.1ah) and Ethernet VPN
- Data-plane learning of local C-MACs and remote C-MAC to B-MAC binding
- PEs run Multi-Protocol BGP to advertise local Backbone MAC addresses (B-MACs) & learn remote B-MACs
  - Takes advantage of PBB encapsulation to simplify BGP control plane operation – faster convergence
  - Lowers BGP resource usage (CPU, memory) on deployed infrastructure (PEs and RRs)
- Under standardization at IETF – WG draft: draft-ietf-l2vpn-pbb-evpn



Provider Backbone Bridging Overview

- PBB (IEEE 802.1ah-2008) defines an architecture that includes
  - 2^{24} service instances (I-SID) per B-VLAN
  - MAC-in-MAC
- I-Component
  - Learns & forwards using C-MACs
  - Maintains a mapping table of C-MACs to B-MACs
  - Performs PBB encap/decap on PIP
- B-Component
  - Learns & forwards using B-MACs
  - Push / pop B-VLAN on CBP

IB-BEB = I-/B-comp Backbone Edge Bridge
I-SID = Backbone Service Instance Identifier
PIP = Provider Instance Port
CBP = Customer Backbone Port



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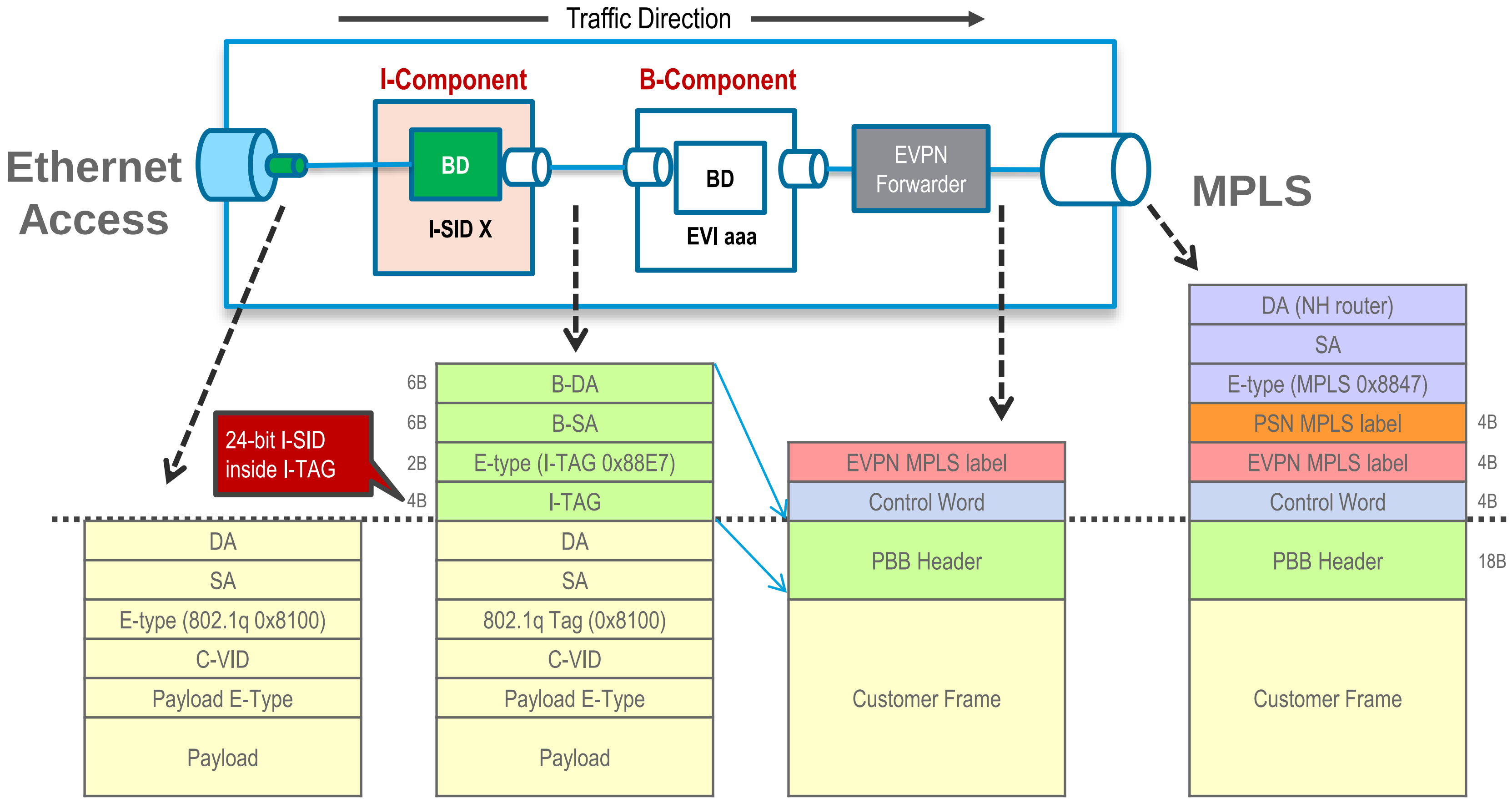
PBB-EVPN Encapsulation



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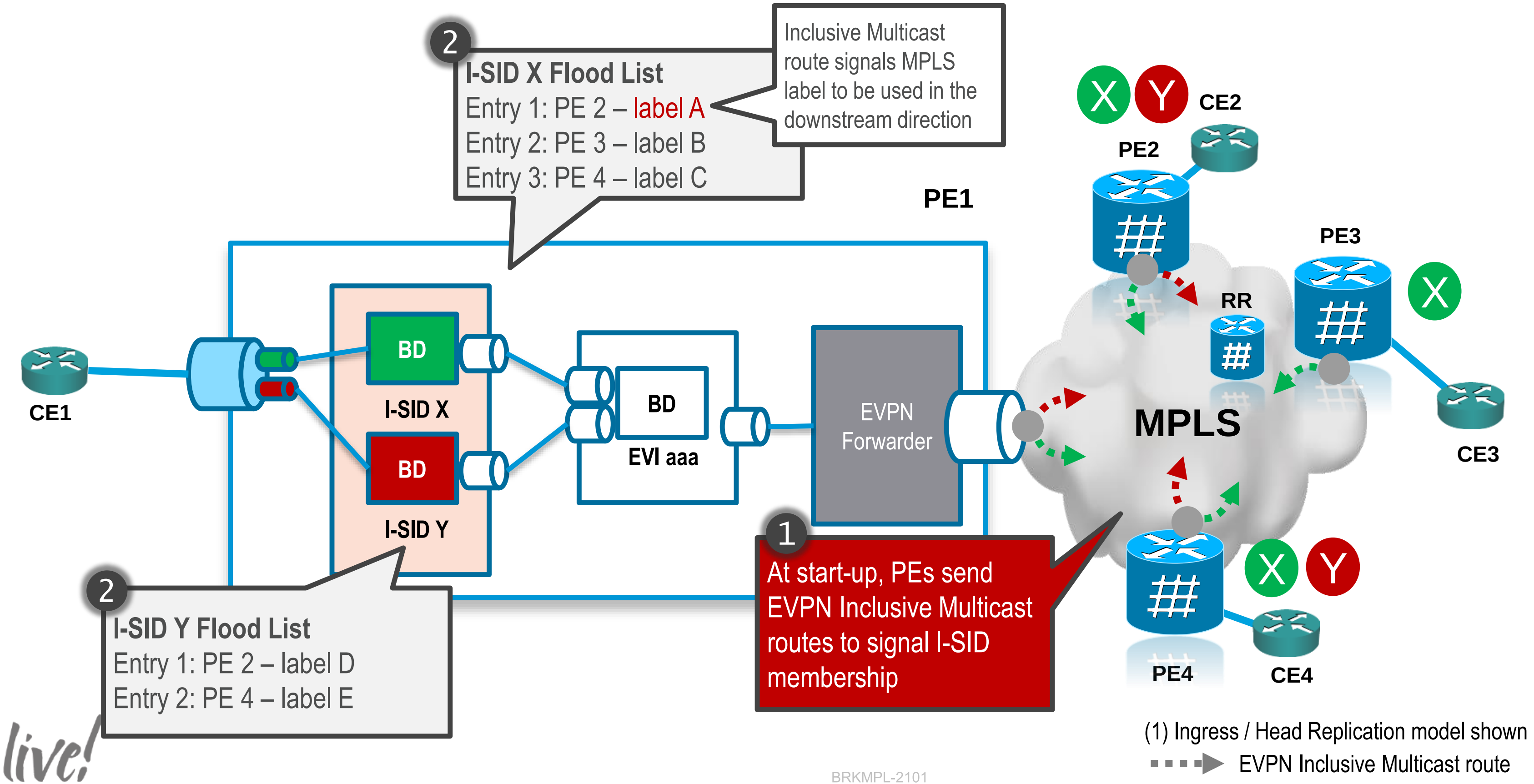
PBB-EVPN Operation

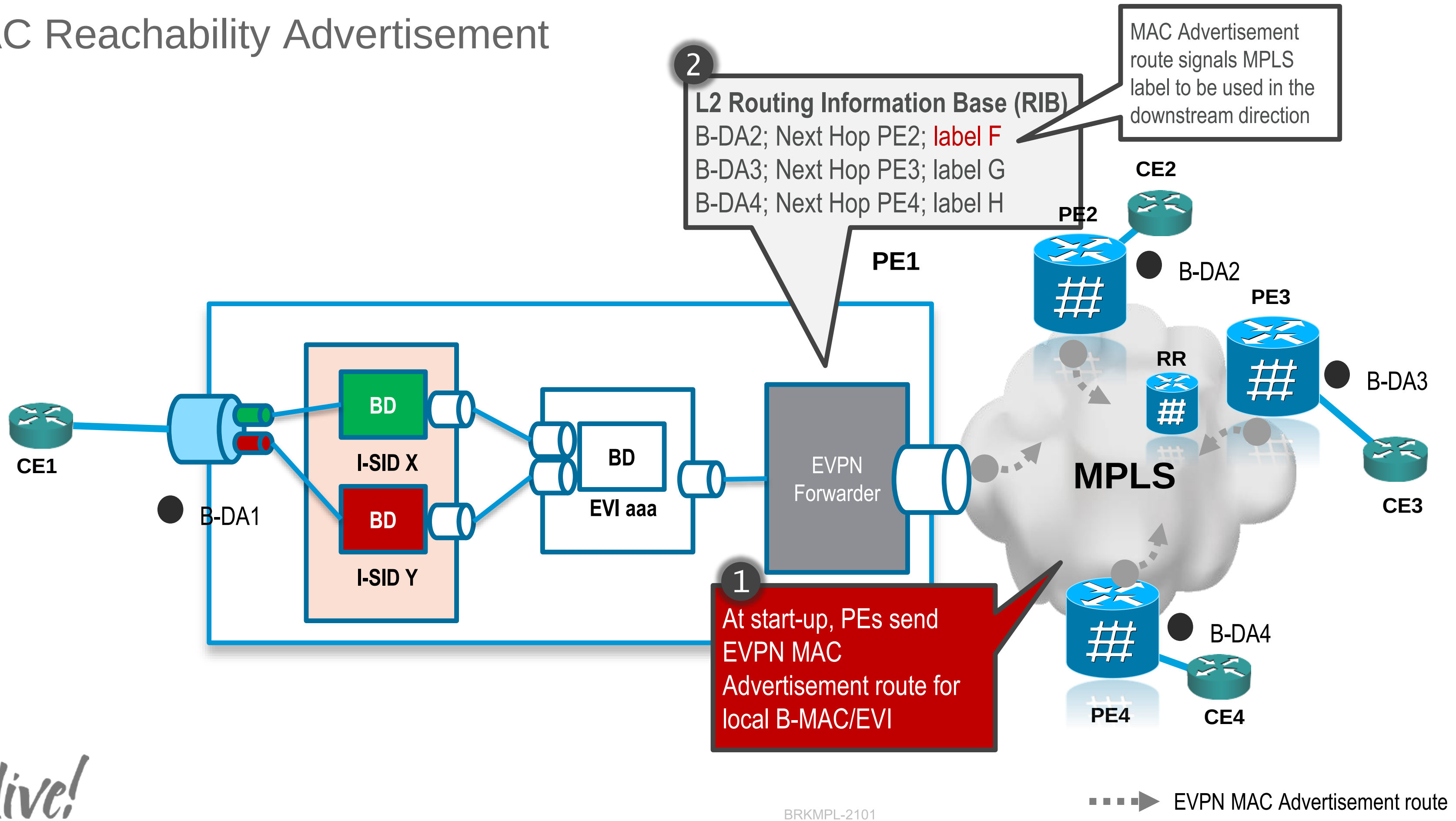
Multicast Tunnel ID / Endpoint Discovery[1]



(1) Ingress / Head Replication model shown

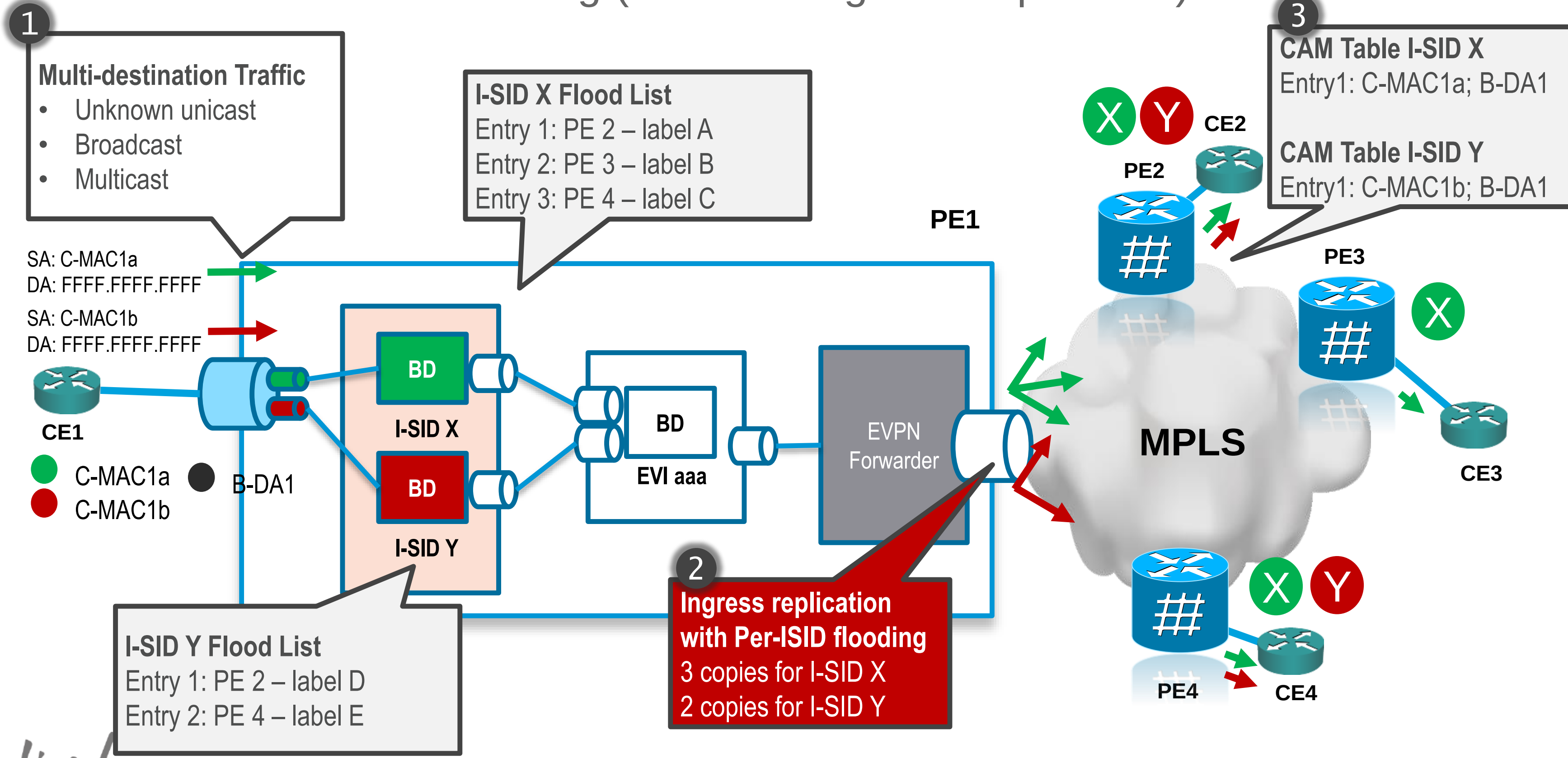
PBB-EVPN Operation

B-MAC Reachability Advertisement



PBB-EVPN Operation

Multi-Destination Traffic Forwarding (Per-ISID Ingress Replication)



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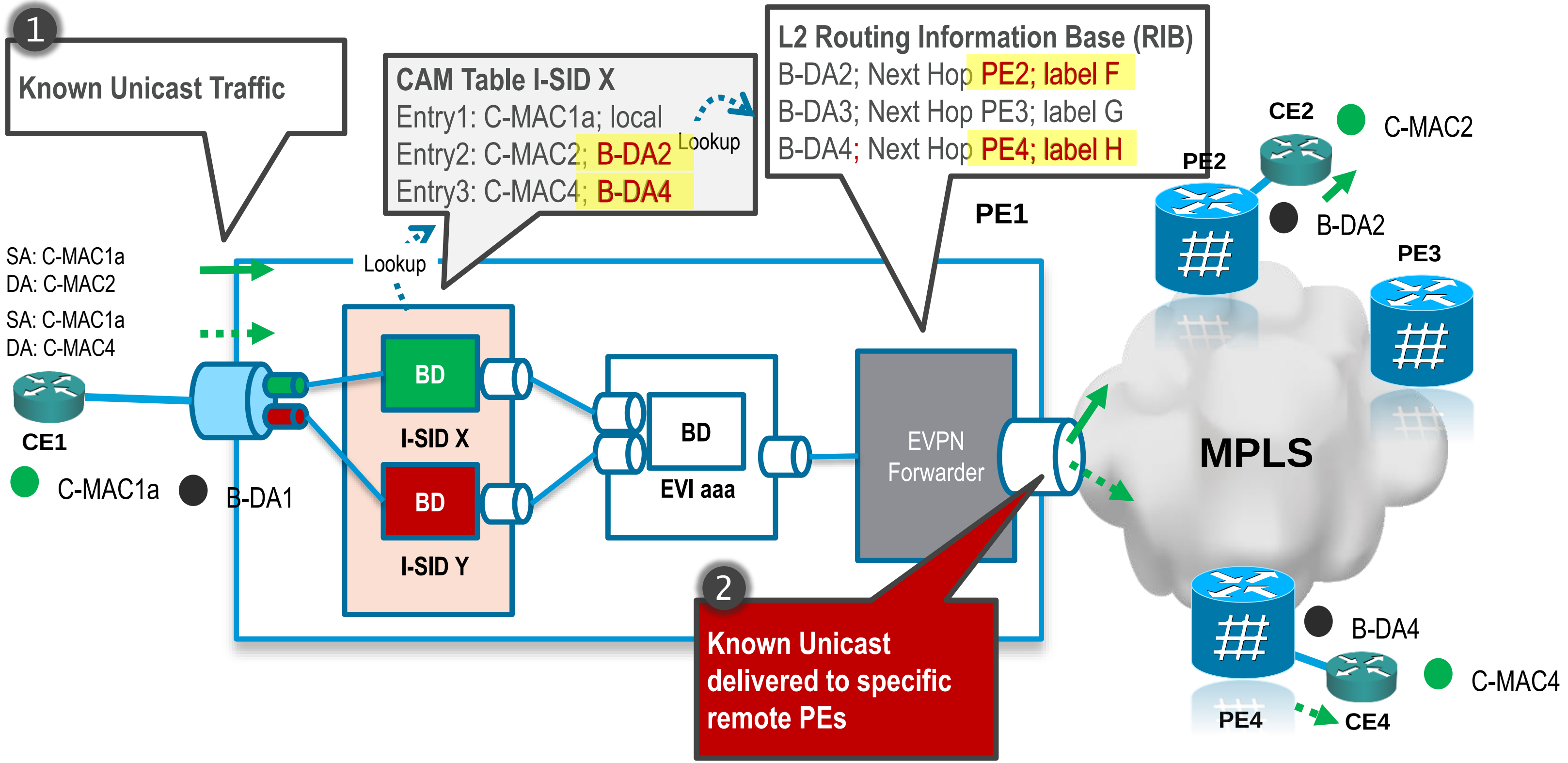
PBB-EVPN Operation

Known Unicast Traffic Forwarding



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Introducing PBB-EVPN in Cisco ASR 9000

- Introducing the next-generation of L2VPNs – Provider Backbone Bridging Ethernet VPN (PBB-EVPN)
- Support across Cisco ASR 9000 series router family
  - From ASR9001-S to ASR9922
- Support starting with Cisco IOS-XR release 4.3.2[1] (FCS 09/2013)
- Enhanced Ethernet Line Cards (Typhoon) required as Ingress and Egress linecards

(1) PBB-EVPN support started in IOS-XR 4.3.2 and 5.1.1 releases

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Advanced Topics Resiliency

Two-Way Pseudowire Redundancy and mLACP

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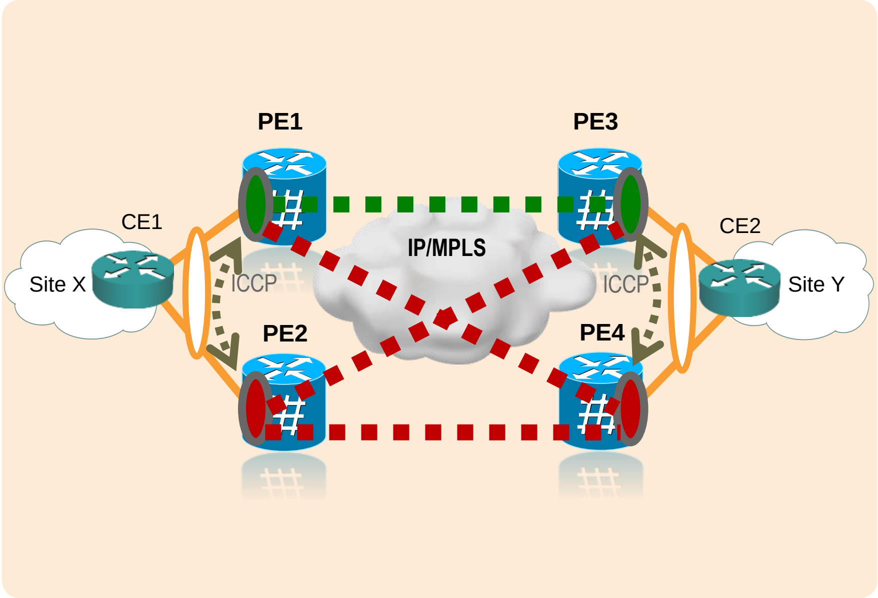
Two-Way Pseudowire Redundancy

Overview

- Allows dual-homing of two local PEs to two remote PEs
- Four (4) pseudowires: 1 primary & 3 backup provide redundancy for dual-homed devices
- Two-Way PW redundancy coupled with Multi-Chassis LAG (MC-LAG) solution on the access side
  - LACP state used to determine PW AC state
  - InterChassis Communication Protcol (ICCP) used to synchronize LACP states



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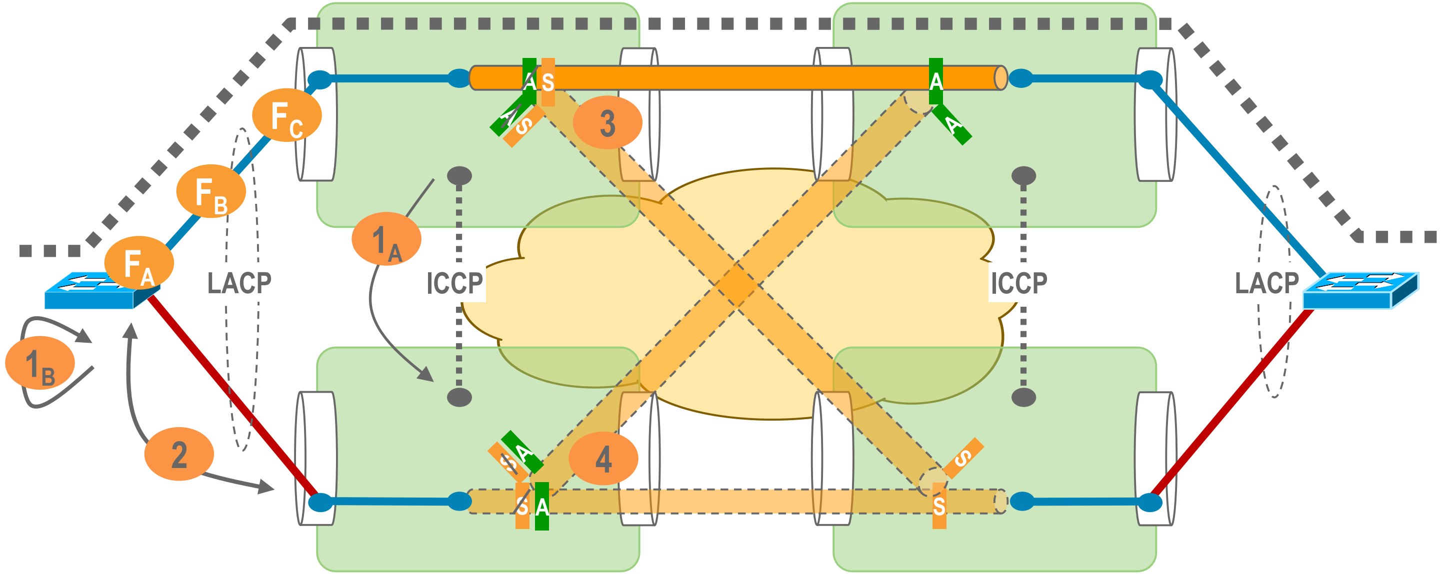
E-LINE Availability Model

Active / Backup Access Node Redundancy (mLACP)

VPWS

- Port / Link Failures



Events	
I	Initial state
F_{A-C}	Port / Link Failures
1_A	Active PoA detects failure and signals failover over ICCP
1_B	Failover triggered on DHD
2	Standby link brought up per LACP proc.
3	Active PoA advertises “Standby” state on its PWs
4	Standby PoA advertises “Active” state on its PWs

Forwarding EoMPLS PW

Non-Forwarding EoMPLS PW

- For VPWS Coupled Mode, attachment circuit (AC) state (Active/Standby) drives PW state advertised to remote peers

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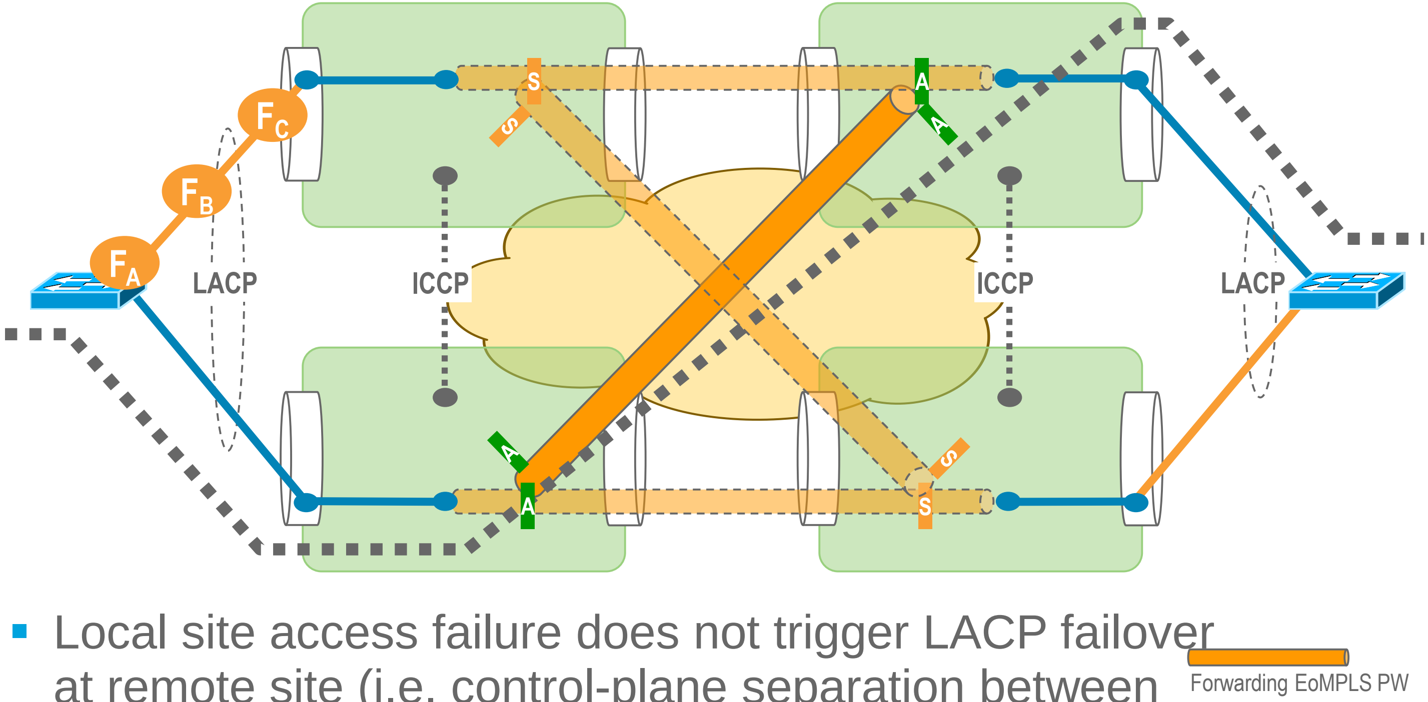
E-LINE Availability Model

Active / Backup Access Node Redundancy (mLACP)

- Port / Link Failures (cont.)

VPWS



Events	
I	Initial state
F_{A-C}	Port / Link Failures
1_A	Active PoA detects failure and signals failover over ICCP
1_B	Failover triggered on DHD
2	Standby link brought up per LACP proc.
3	Active PoA advertises "Standby" state on its PWs
4	Standby PoA advertises "Active" state on its PWs
E	End State

- Local site access failure does not trigger LACP failover at remote site (i.e. control-plane separation between sites)

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Advanced Topics Resiliency

ITU-T G.8032 Access Redundancy

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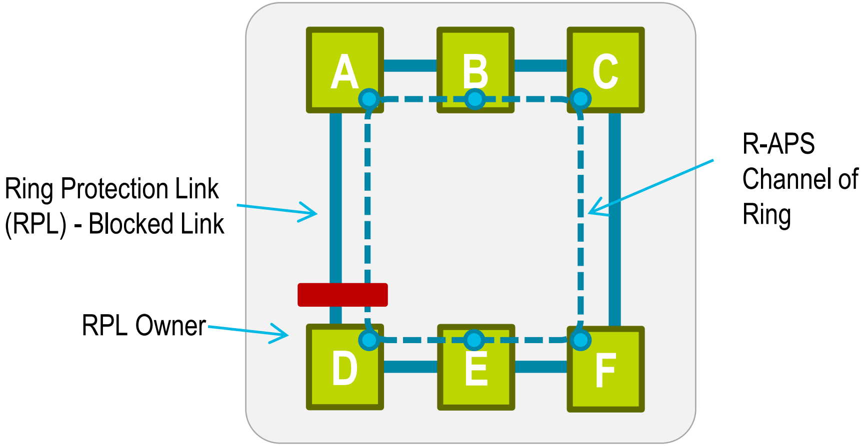
ITU-T G.8032 Overview

- Standards-based protection switching for Ethernet ring topologies
  - Defined by ITU-T Study Group 15 [G.8032/Y.1344] (v1 – 06/08; v2 – 03/10)
- Ring traffic forwarding based on Ethernet bridging rules – Layer 2 Rings
- Loop avoidance by blocking of designated ring link under normal conditions
- Uses a dedicated Control Channel (VLAN) carrying control messages - Ring APS
- Leverages Ethernet CFM / ITU-T Y.1731 for Fault Detection (CCM)
- Single Ring or Multi-Ring network topologies
- Supports MAC flushing, load-balancing, revertive / non-revertive switching and administrative switching commands



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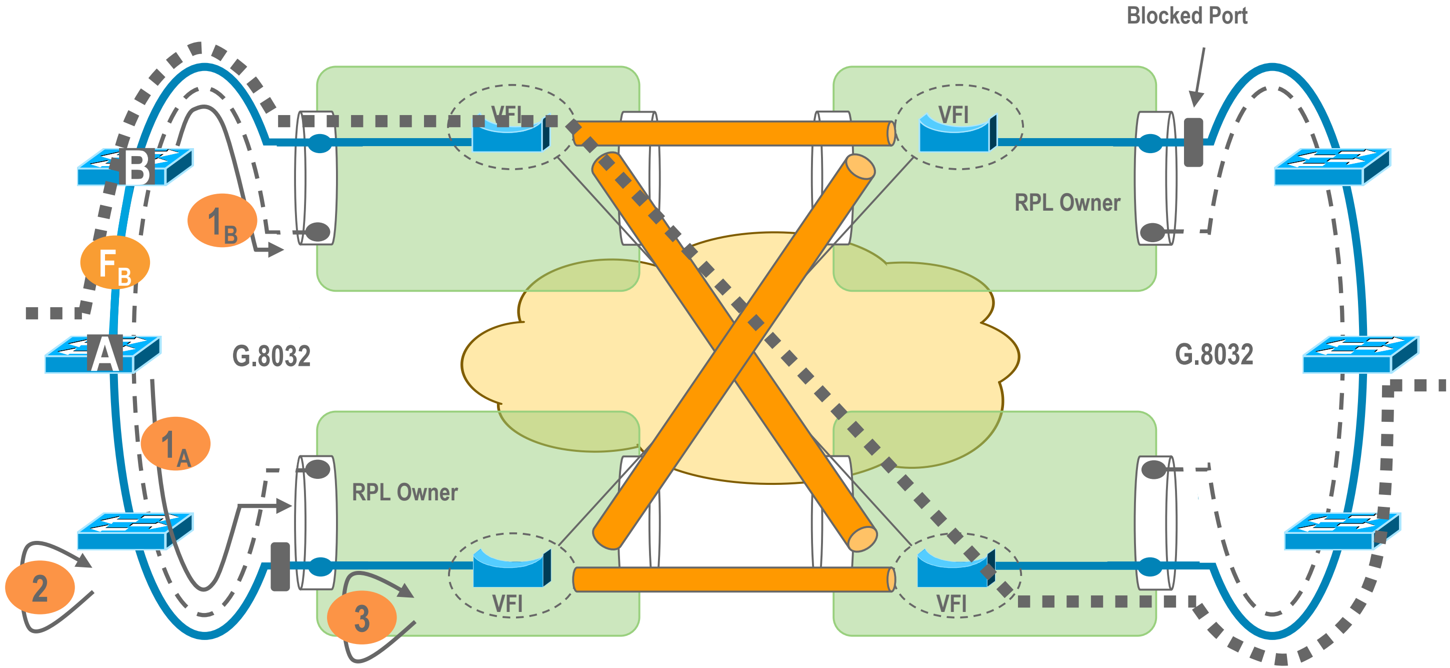
E-LINE Availability Model

Ring Access Node Redundancy (G.8032)

VPLS

- G.8032 Ring Span Failure



Events	
I	Initial state
F_B	Ring Span failure
$1_{A\text{-}B}$	Access switches “A” and “B”detect link failure. Send R-APS Signal Fail (SF) on the ring
2	Access nodes in the ring flush MAC tables and propagate R-APS SF
3	RPL owner AGG node receives R-APS and unblocks RPL owner port

- G.8032 Open Ring without R-APS Virtual Channel, terminating on Aggregation Nodes
- VLAN load balancing using two ERP instances with RPL Owners on Aggregation Nodes.

Forwarding EoMPLS PW
Non-Forwarding EoMPLS PW
R-APS Channel vlan

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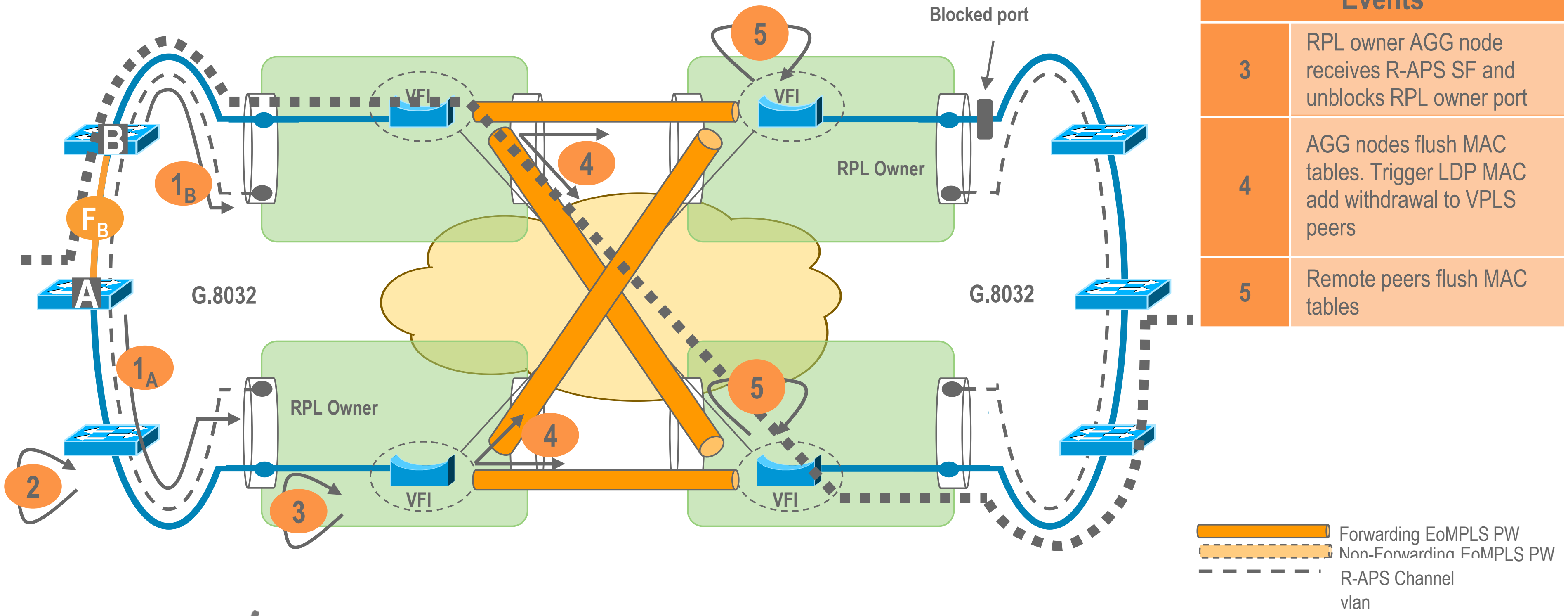
E-LINE Availability Model
Ring Access Node Redundancy (G.8032)

VPLS

- G.8032 Ring Span Failure (cont.)



Events	
3	RPL owner AGG node receives R-APS SF and unblocks RPL owner port
4	AGG nodes flush MAC tables. Trigger LDP MAC add withdrawal to VPLS peers
5	Remote peers flush MAC tables

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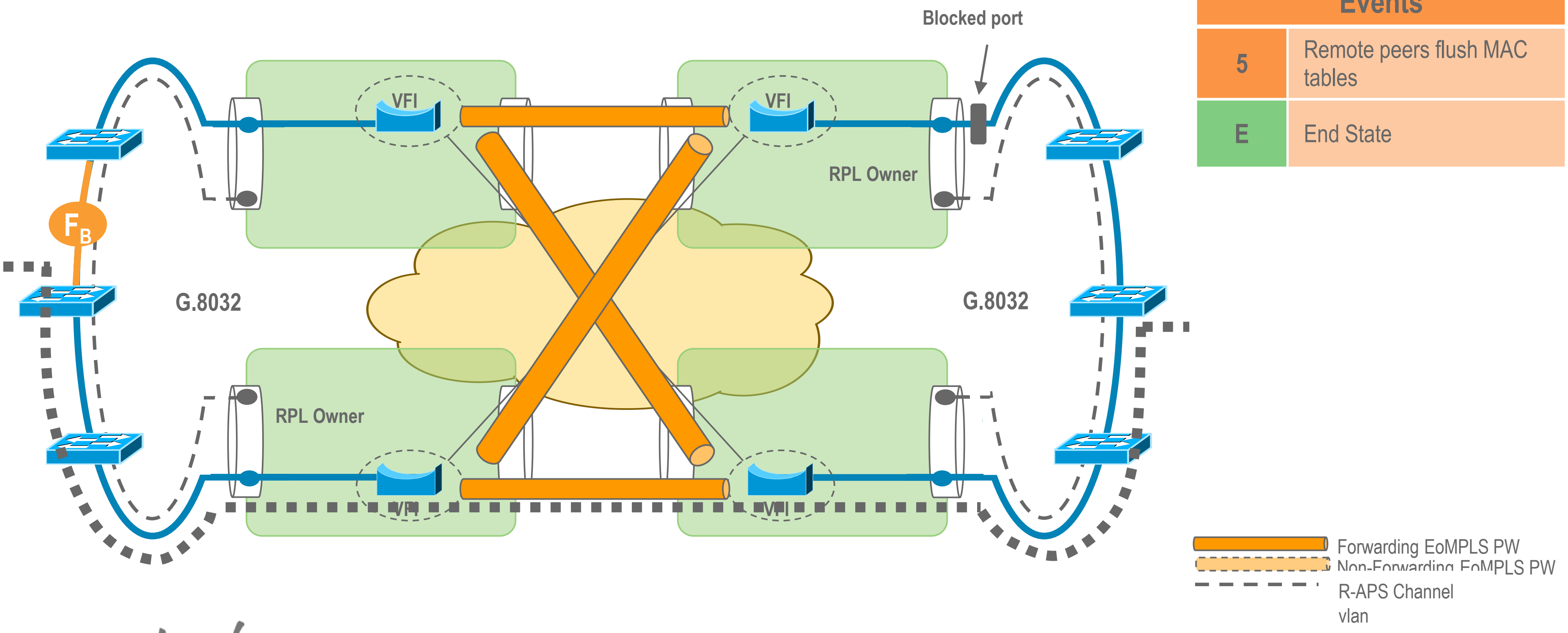
E-LINE Availability Model

Ring Access Node Redundancy (G.8032)

VPLS

- G.8032 Ring Span Failure (cont.)



Events	
5	Remote peers flush MAC tables
E	End State

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Advanced Topics
L2VPN Load Balancing

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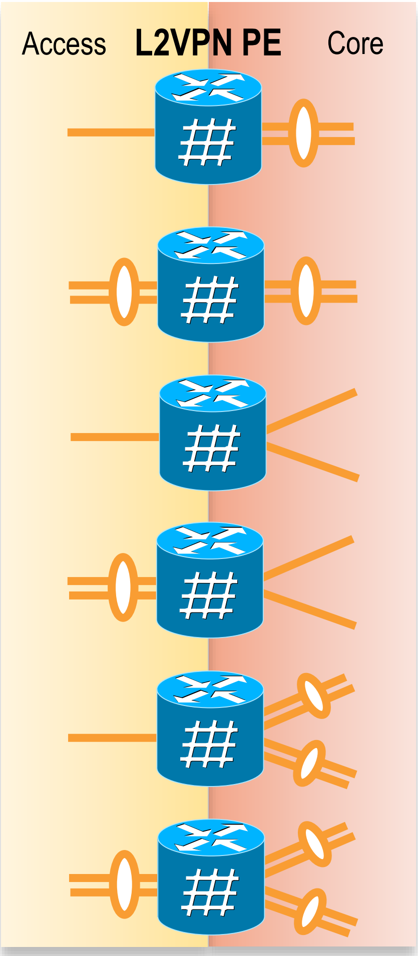
Load-balancing Questions

- How do we make LERs distribute flows within the same PW across ECMPs?
- How do we make LERs distribute flows within the same PW across members of core-facing bundle interface?
- How do we make LSRs distribute flows within the same PW across ECMPs?
- How do we make LSRs distribute flows within the same PW across members of core-facing bundle interface?



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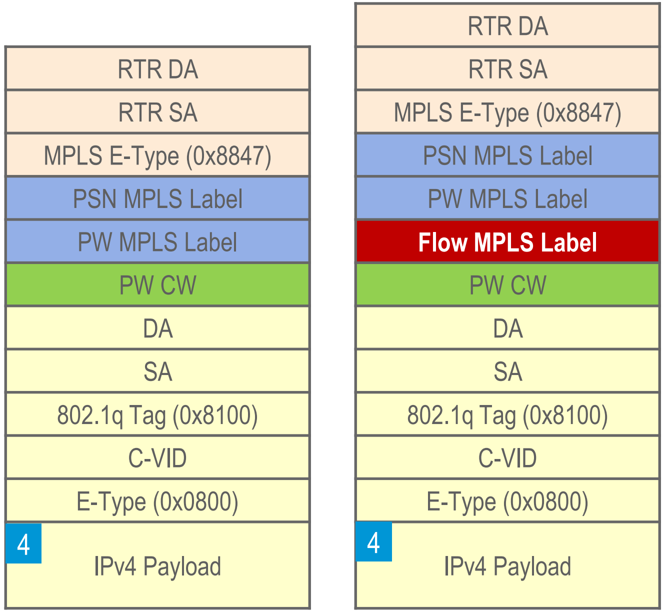
Flow Aware Transport PWs (RFC6391)

- Problem: How can LSRs load-balance traffic from flows in a PW across core ECMPs and Bundle interfaces?
- LSRs load-balance traffic based on IP header information (IP payloads) or based on bottom of stack MPLS label (Non-IP payloads)
  - PW traffic handled as Non-IP payload
- RFC6391 defines a mechanism that introduces a Flow label that allows P routers to distribute flows within a PW
  - PEs push / pop Flow label
  - P routers not involve in any signaling / handling / manipulation of Flow label



EoMPLS frame without Flow Label

EoMPLS frame with Flow Label

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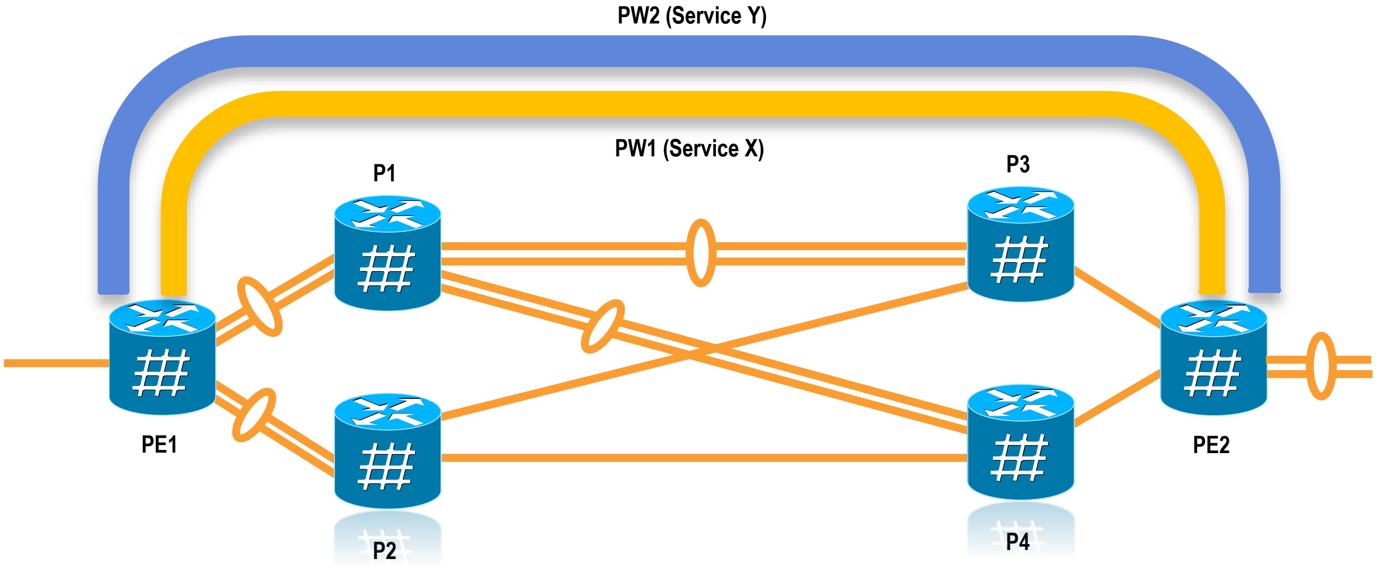
L2VPN Load-balancing (E2E Scenario) (1/2)



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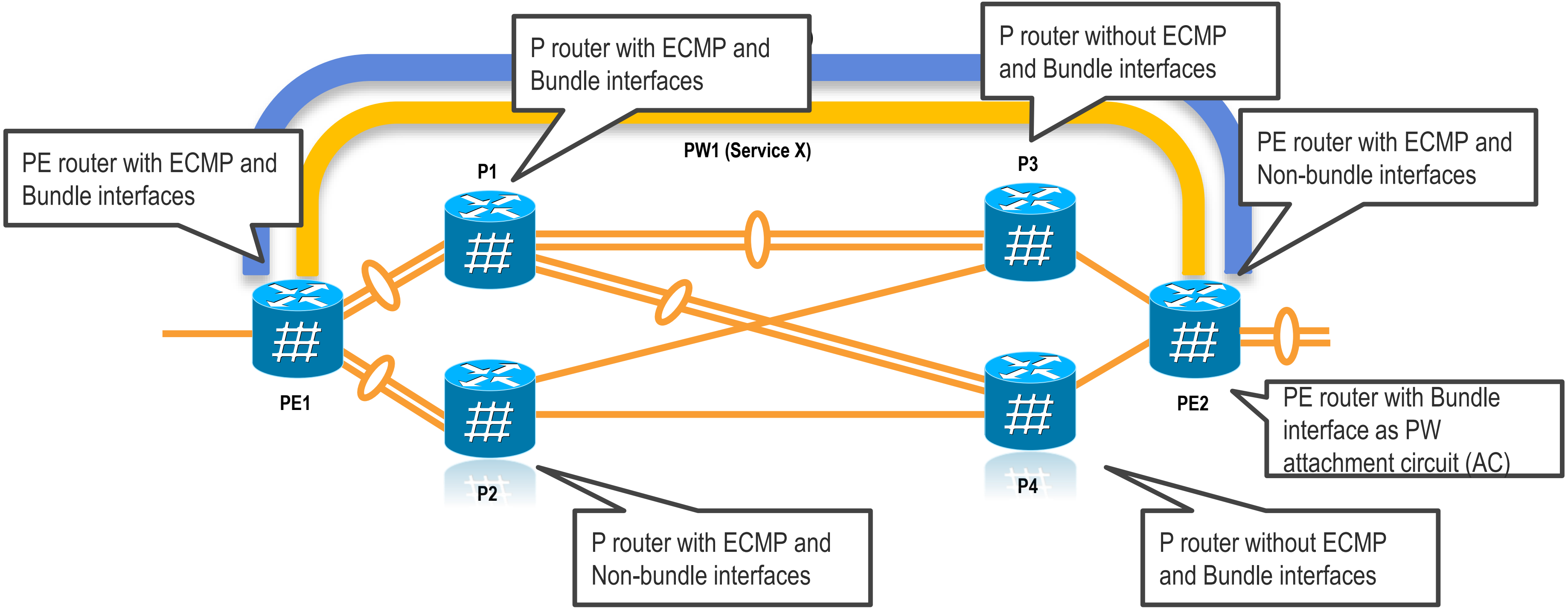
L2VPN Load-balancing (E2E Scenario) (2/2)



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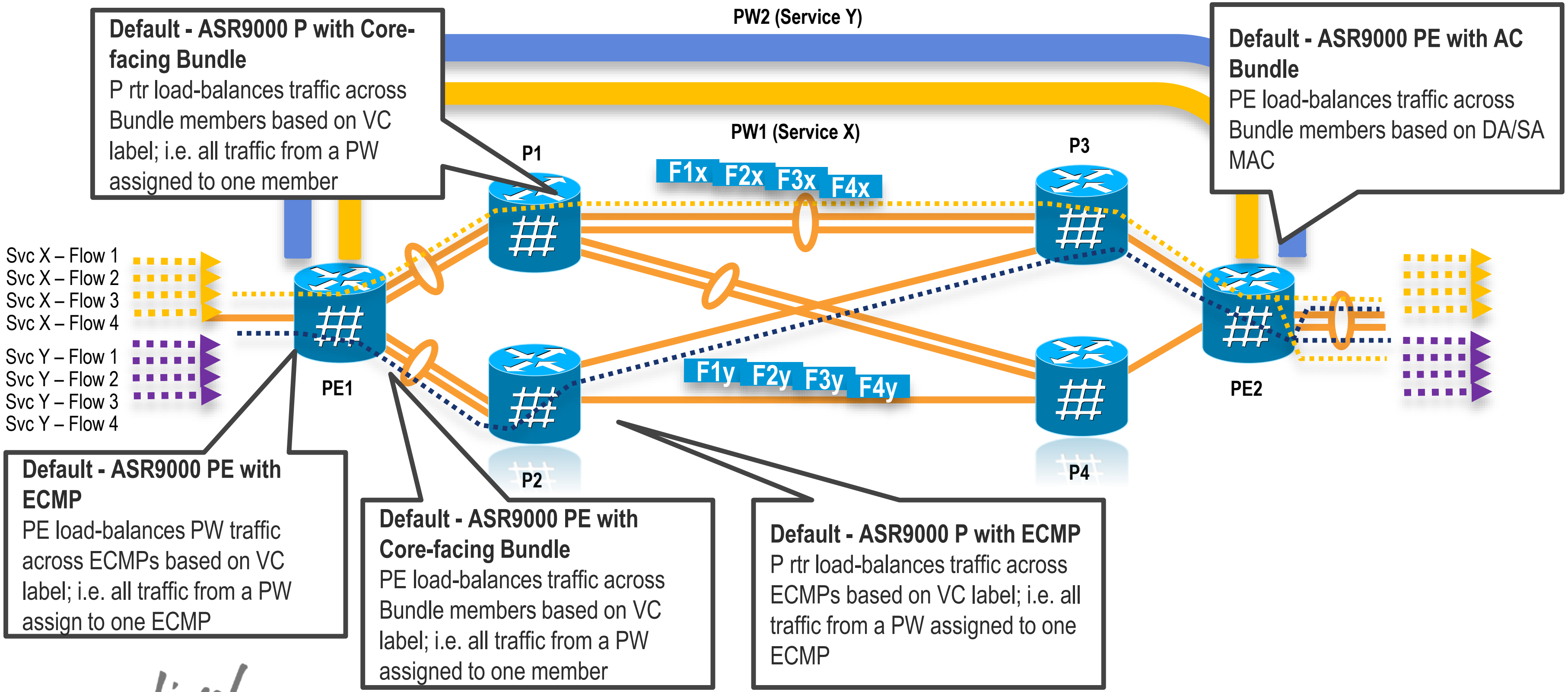
L2VPN Load-balancing (Per-VC LB)



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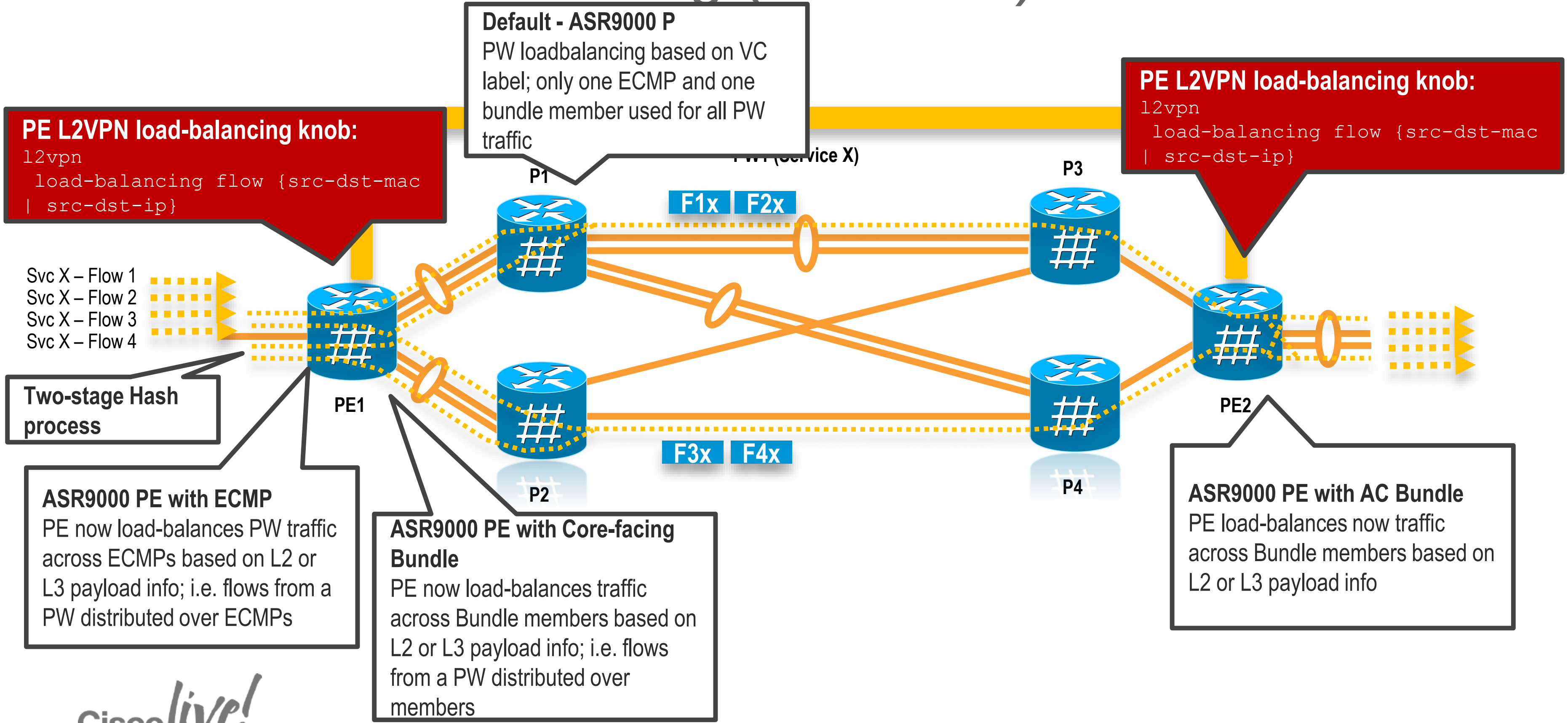
L2VPN Load-balancing (L2/L3 LB)



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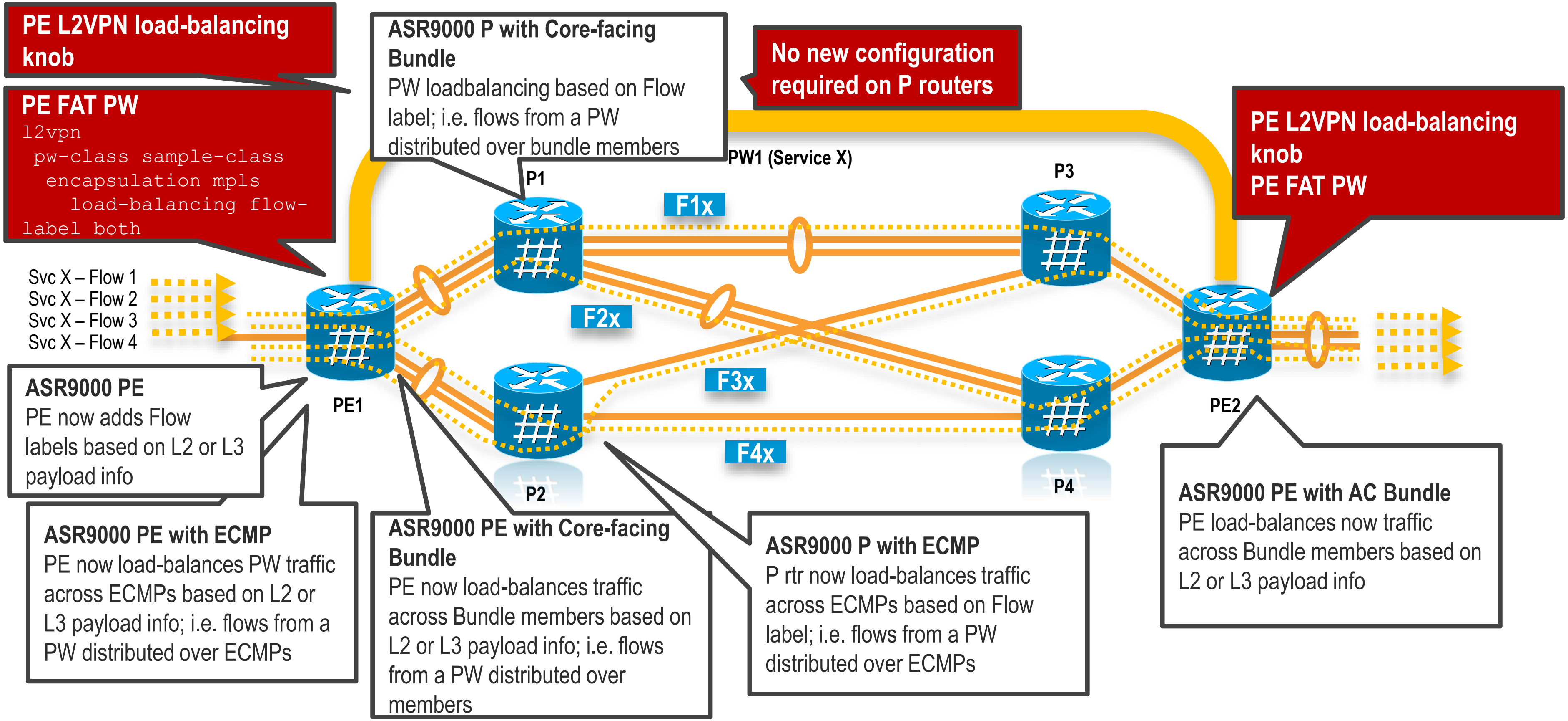
L2VPN Load-balancing (L2/L3 LB + FAT)



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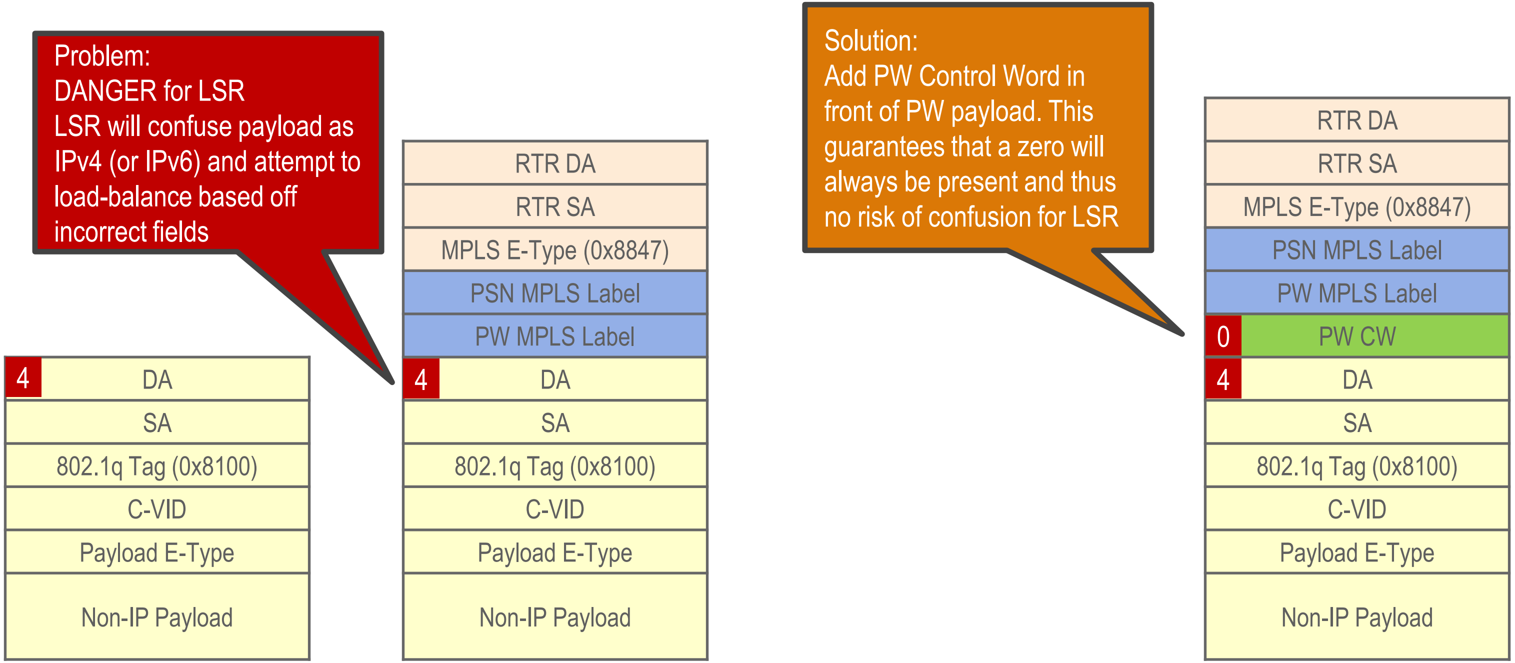
Significance of PW Control-Word



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Deployment Use Cases

Data Center Interconnect – VPLS on Nexus 7000

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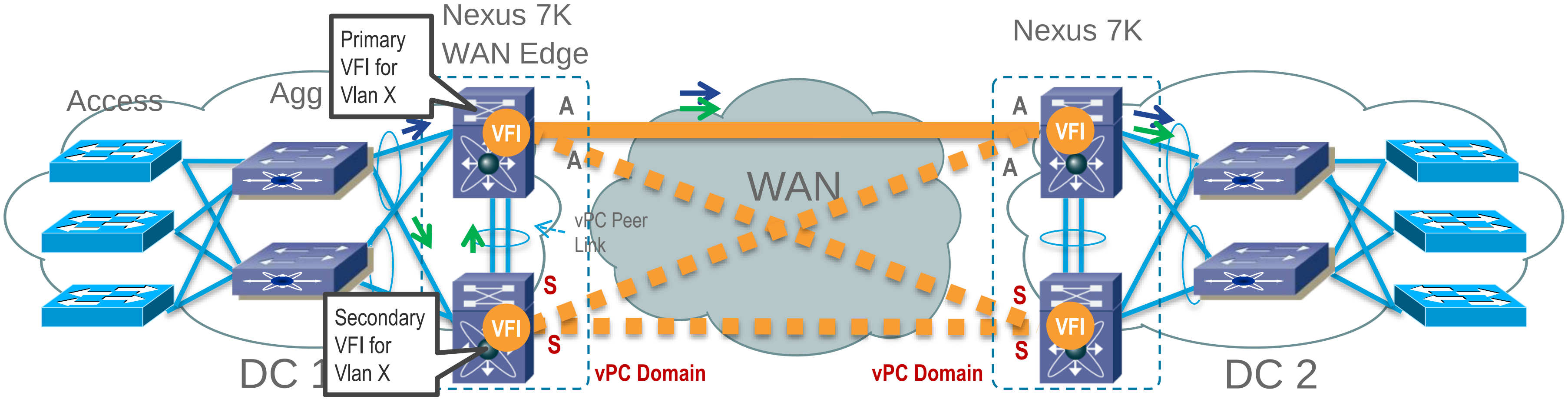
Data Center Interconnect with VPLS

Nexus 7000



- Nexus 7000 as DC WAN Edge provides VPLS Multi-Homing with Virtual Port Channel (vPC)
- User configuration sets VFI as primary / secondary on vPC members
  - vPC members can alternate in Active / Standby responsibilities for different VLANs
- PW status signaled as Active / Standby on primary / secondary VFIs respectively
  - Single PW activated to forward traffic between pair of data center sites
  - vPC Peer Link used to forward traffic to / from vPC member with VFI in primary designation

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Data Center Interconnect with VPLS

Sample Configuration – Nexus 7000

PE 1

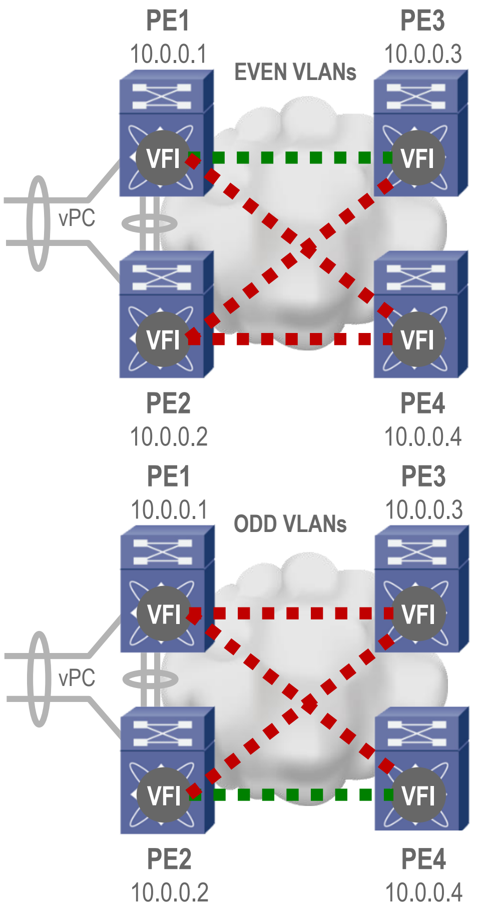
- Primary VFI owner for EVEN vlans
- Secondary owner for ODD vlans

```
vlan 80-81
!
vlan configuration 80
 member vfi vpls-80
!
vlan configuration 81
 member vfi vpls-81
!
l2vpn vfi context vpls-80
  vpn id 80
  redundancy primary
  member 10.0.0.3 encapsulation mpls
  member 10.0.0.4 encapsulation mpls
!
l2vpn vfi context vpls-81
  vpn id 81
  redundancy secondary
  member 10.0.0.3 encapsulation mpls
  member 10.0.0.4 encapsulation mpls
!
interface port-channel50
 switchport mode trunk
 switchport trunk allowed vlan 80,81
```

PE 2

- Primary VFI owner for ODD vlans
- Secondary owner for EVEN vlans

```
vlan 80-81
!
vlan configuration 80
 member vfi vpls-80
!
vlan configuration 81
 member vfi vpls-81
!
l2vpn vfi context vpls-80
  vpn id 80
  redundancy secondary
  member 10.0.0.3 encapsulation mpls
  member 10.0.0.4 encapsulation mpls
!
l2vpn vfi context vpls-81
  vpn id 81
  redundancy primary
  member 10.0.0.3 encapsulation mpls
  member 10.0.0.4 encapsulation mpls
!
interface port-channel50
 switchport mode trunk
 switchport trunk allowed vlan 80,81
```



Note: Virtual Port Channel (vPC) configuration not shown

Deployment Use Cases

E-LAN with per-flow load-balancing – ASR 9000 (PBB-EVPN)

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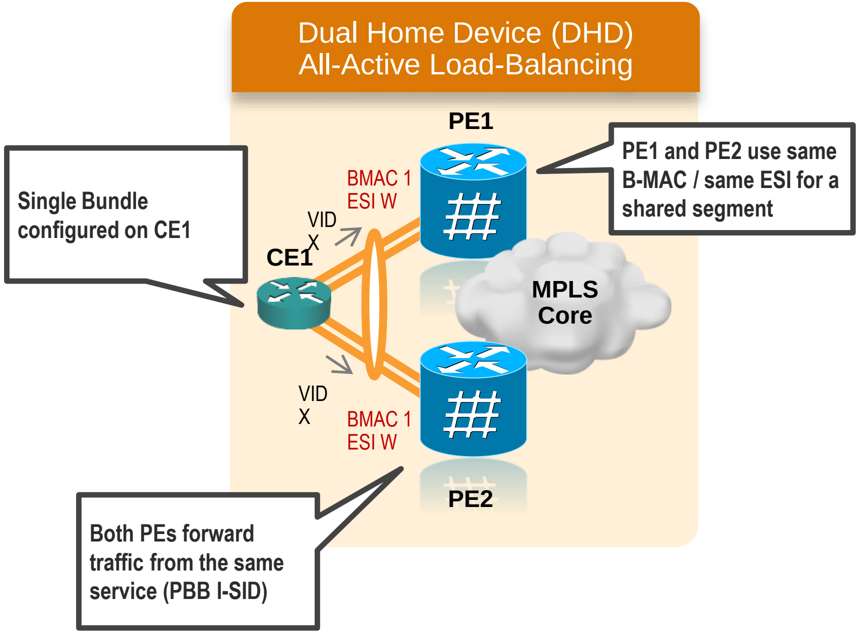
PBB-EVPN

Multi-Homing Scenarios – All-Active Load-Balancing

- Dual Home Device / Multi Home Device[1] scenarios and All-Active LB
  - A.k.a. Active / Active per-flow (AApF) LB
  - Both PEs forward traffic associated with a given PBB I-SID
- PEs attached to Ethernet Segment using bundle interfaces
  - Single bundle (manual or LACP) configured on CE
- PEs on same segment must share the same source B-MAC and ESI
  - ESI and B-MAC auto-sensed from CE LACP information
- DF election (manual or automatic)



(1) Standard does not limit solution to only dual homing

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PBB-EVPN Dual Home Device (DHD)

MINIMAL Configuration

All-Active (per-FLOW) Load-Balancing

```
PE1
redundancy iccp group 66
   mlacp node 1
   mlacp system priority 1
   mlacp system mac 0111.0222.0111
   mode singleton
   backbone interface GigabitEthernet 0/0/0/1

interface Bundle-Ether25
 mlacp iccp-group 66

interface Bundle-Ether25.1 l2transport
 encapsulation dot1q 777

l2vpn
 bridge group gr1
  bridge-domain bd1
   interface Bundle-Ether25.1
   pbb edge i-sid 256 core-bridge core_bd1

 bridge group gr2
  bridge-domain core_bd1
   pbb core
    evpn evi 1000

router bgp 64
 bgp router-id 1.100.100.100
 address-family l2vpn evpn
 neighbor 2.100.100.100
  remote-as 64
  address-family l2vpn evpn
```

Auto-sensed B-MAC SA
Auto-sensed ESI
Auto RD for Segment Route
Auto RT for EVI
Auto RD for EVI
A/A Per-flow LB (default)
Auto DF / service carving

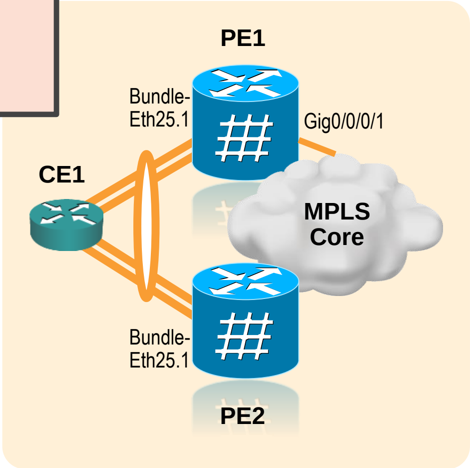
PE2 should use same RG #
PE2 should use different mlacp node id
PE2 should use same mlacp system mac and system priority

ICCP in singleton mode (i.e.No peer neighbor configuration)

PBB I-component and B-component configuration. ISIDs must match on both PEs
No need to define B-VLAN

Mandatory EVI ID configuration

BGP configuration with new EVPN AF



Note: MPLS / LDP configuration required on core-facing interfaces (not shown)

Summary

- MPLS is a mature technology with widespread L2VPN deployments by Service Providers and Enterprises around the globe
    - Ethernet-based WAN services and Data Center Interconnect are key applications driving deployments of L2VPN today
- L2VPNs can be deployed addressing key requirements including: Resiliency, Auto-Discovery, Load-Balancing and OAM
- EVPN / PBB-EVPN are next-generation L2VPN solutions based on BGP control-plane for MAC distribution/learning over the core

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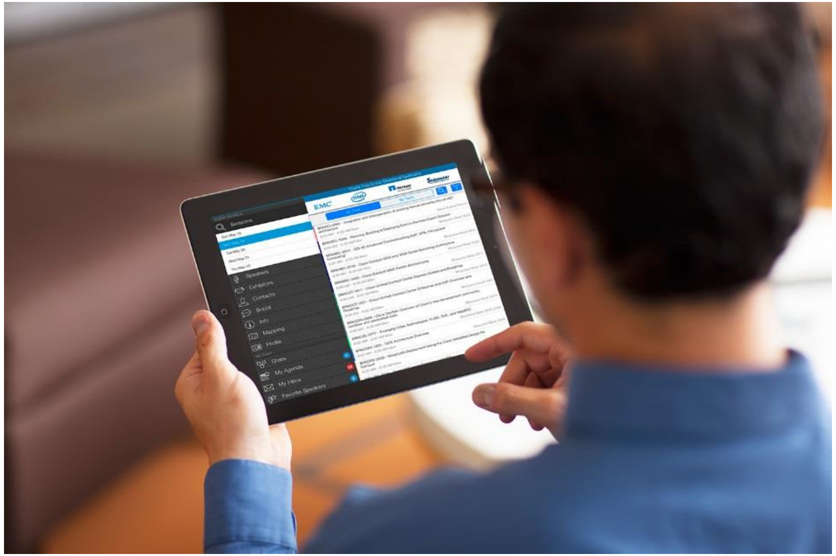

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Thank you

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TOMORROW starts here.

Backup Slides

Ethernet Point-to-Point L2VPNs

Virtual Private Wire Service (VPWS)

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VPWS (EoMPLS) LDP Signaling

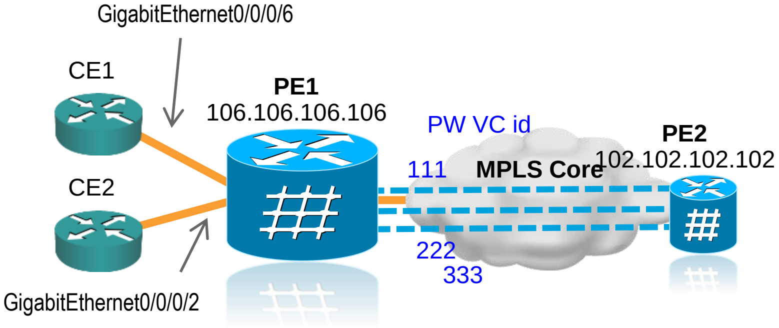
Cisco IOS XR

```
hostname PE1
!
interface Loopback0
 ipv4 address 106.106.106.106 255.255.255.255
```

```
l2vpn
 xconnect group Cisco-Live
  p2p xc-sample-1
   interface GigabitEthernet0/0/0/2.100
   neighbor 102.102.102.102 pw-id 111

  p2p xc-sample-2
   interface GigabitEthernet0/0/0/2.200
   neighbor 102.102.102.102 pw-id 222

  p2p xc-sample-3
   interface GigabitEthernet0/0/0/6
   neighbor 102.102.102.102 pw-id 333
```



Single-tagged VLAN traffic to PW

```
interface GigabitEthernet0/0/0/2.100 l2transport
 encapsulation dot1q 100
 rewrite ingress tag pop 1 symmetric
```

Single-tagged range VLAN traffic to PW

OR

Entire port traffic to PW

```
interface GigabitEthernet0/0/0/2.200 l2transport
 encapsulation dot1q 999-1010
 rewrite ingress tag push dot1q 888 symmetric
```

```
interface GigabitEthernet0/0/0/6
 l2transport
```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VPWS (EoMPLS) LDP Signaling

Cisco IOS (VLAN-based services)

```
hostname PE1
!
interface Loopback0
 ip address 106.106.106.106 255.255.255.255
```

```
interface GigabitEthernet2/4.300
 encapsulation dot1q 300
 xconnect 102.102.102.102 111 encapsulation mpls
```

Sub-interface based xconnect

OR

```
interface GigabitEthernet2/4
 service instance 10 ethernet
  encapsulation dot1q 300
  rewrite ingress tag pop 1 symmetric
  xconnect 102.102.102.102 111 encapsulation
mpls
```

Service-Instance (EFP) based xconnect

OR

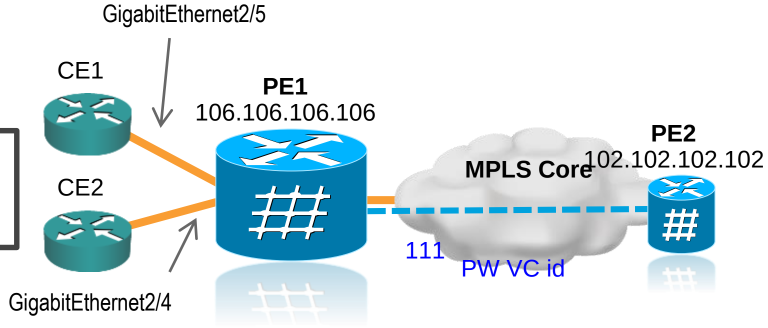
```
interface Vlan 300
 xconnect 102.102.102.102 111 encapsulation mpls
!
interface GigabitEthernet2/4
 switchport mode trunk
 switchport trunk allowed vlan 300
```

Interface VLAN (SVI) based xconnect + Switchport trunk / access

OR

```
interface Vlan 300
 xconnect 102.102.102.102 111 encapsulation mpls
!
interface GigabitEthernet2/4
 service instance 10 ethernet
  encapsulation dot1q 300
  rewrite ingress tag pop 1 symmetric
  bridge-domain 300
```

Interface VLAN (SVI) based xconnect + Service instance BD



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VPWS (EoMPLS) LDP Signaling

Cisco IOS (Port-based services)

```
hostname PE1
!
interface Loopback0
 ip address 106.106.106.106 255.255.255.255
```

```
interface GigabitEthernet2/5
 xconnect 102.102.102.102 222 encapsulation mpls
```

Main interface based xconnect

OR

```
interface GigabitEthernet2/5
 service instance 1 ethernet
  encapsulation default
  xconnect 102.102.102.102 111 encapsulation mpls
```

Service-Instance (EFP) based xconnect (encap default)

OR

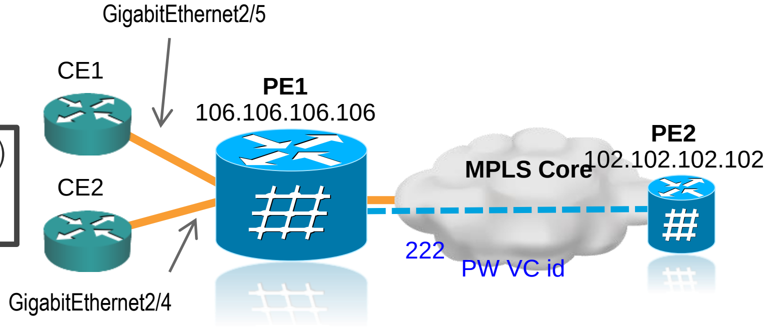
```
interface Vlan 300
 xconnect 102.102.102.102 111 encapsulation mpls
!
interface GigabitEthernet2/5
 switchport mode dot1q-tunnel
 switchport access vlan 300
```

Interface VLAN (SVI) based xconnect + Switchport dot1q-tunnel

OR

```
interface Vlan 300
 xconnect 102.102.102.102 111 encapsulation mpls
!
interface GigabitEthernet2/5
 service instance 1 ethernet
  encapsulation default
  bridge-domain 300
```

Interface VLAN (SVI) based xconnect + Service instance BD



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VPWS (EoMPLS) LDP Signaling

Cisco IOS / NX-OS (NEW Service-based CLI)

```
hostname PE1
!
interface Loopback0
 ip address 106.106.106.106 255.255.255.255
```

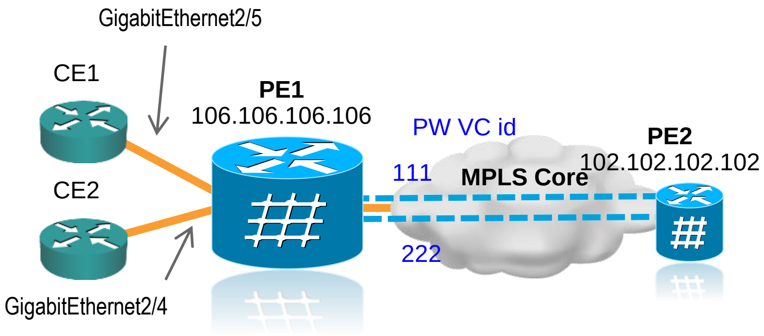
```
l2vpn xconnect context sample-xconnect
 member Pseudowire1 102.102.102.102 111 encap mpls
 member GigabitEthernet2/4 service instance 333
!
interface GigabitEthernet2/4
 service instance 333 ethernet
  encapsulation dot1q 300
  rewrite ingress tag pop 1 symmetric
```

```
bridge-domain 300
 member Pseudowire2 192.0.0.5 222 encap mpls
 member GigabitEthernet2/4 service instance 333
!
interface GigabitEthernet2/4
 service instance 333 ethernet
  encapsulation dot1q 300
  rewrite ingress tag pop 1 symmetric
```

OR

For NX-OS

```
vlan 400
vlan configuration 400
 member Pseudowire2 102.102.102.102 222 encapsulation mpls
!
interface GigabitEthernet2/5
 switchport mode trunk
 switchport trunk allowed vlan 400
```



NEW
PWs modeled as virtual interfaces. PW and EFPs now members of BD/Xconn context

NEW
Service-based CLI Xconn context / Bridge-Domain or VLAN configurations

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Backup Slides

Ethernet Multi-Point L2VPNs

VPLS with LDP Signaling

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VPLS LDP Signaling / Manual provisioning

Cisco IOS

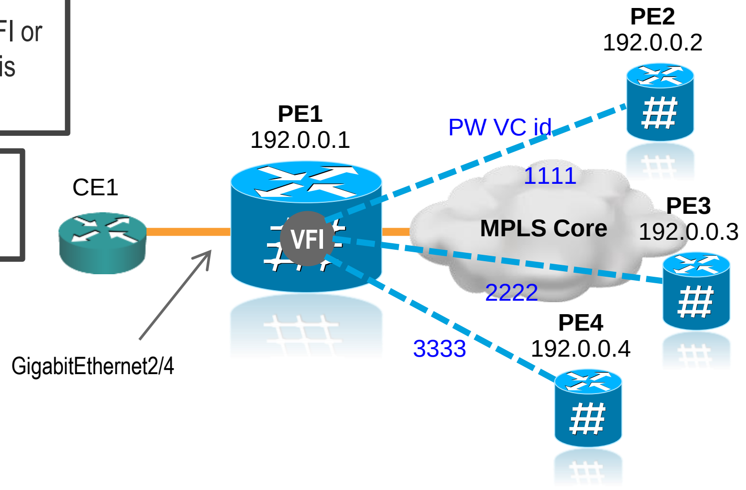
```
hostname PE1
!
interface Loopback0
 ip address 192.0.0.1 255.255.255.255
!
l2 vfi sample-vfi manual
 vpn id 300
 neighbor 192.0.0.2 encapsulation mpls
 neighbor 192.0.0.3 2222 encapsulation mpls
 neighbor 192.0.0.4 3333 encapsulation mpls
!
interface Vlan300
 xconnect vfi sample-vfi
```

VPN ID defined per VFI or on a per-neighbor basis

Core PWs Full-mesh

VFI associated to VLAN interface (SVI) via xconnect cmd

Bridge-Domain or VLAN/switchport configurations




```
interface GigabitEthernet2/4
 service instance 333 ethernet
  encapsulation dot1q 333
  rewrite ingress tag pop 1 symmetric
  bridge-domain 300
```

OR

```
interface GigabitEthernet2/4
 switchport mode trunk
 switchport trunk allowed vlan 300
```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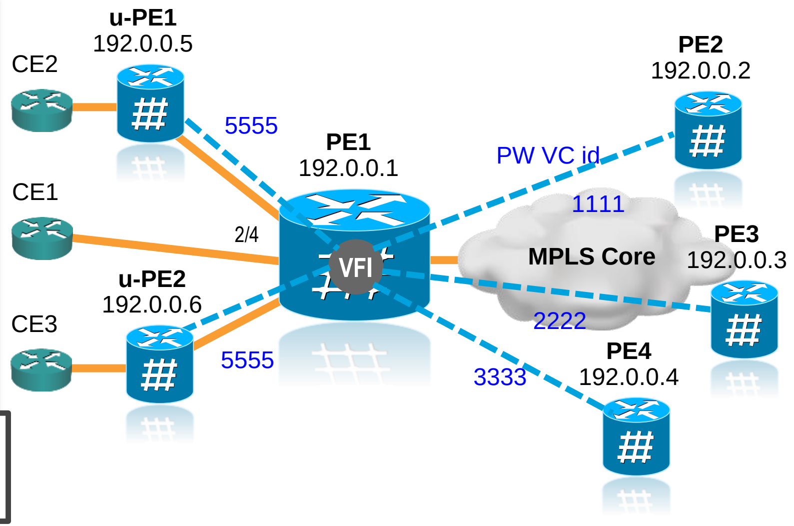
H-VPLS LDP Signaling / Manual provisioning

Cisco IOS

```
hostname PE1
!
interface Loopback0
 ip address 192.0.0.1 255.255.255.255
!
l2 vfi sample-vfi manual
 vpn id 300
 neighbor 192.0.0.2 encapsulation mpls
 neighbor 192.0.0.3 2222 encapsulation mpls
 neighbor 192.0.0.4 3333 encapsulation mpls
 neighbor 192.0.0.5 5555 encapsulation mpls no-split-horizon
 neighbor 192.0.0.6 5555 encapsulation mpls no-split-horizon
!
interface Vlan300
 xconnect vfi sample-vfi
```

Spoke PWs

Bridge-Domain or VLAN/switchport configurations




```
interface GigabitEthernet2/4
 service instance 333 ethernet
  encapsulation dot1q 333
  rewrite ingress tag pop 1 symmetric
  bridge-domain 300
```

OR

```
interface GigabitEthernet2/4
 switchport mode trunk
 switchport trunk allowed vlan 300
```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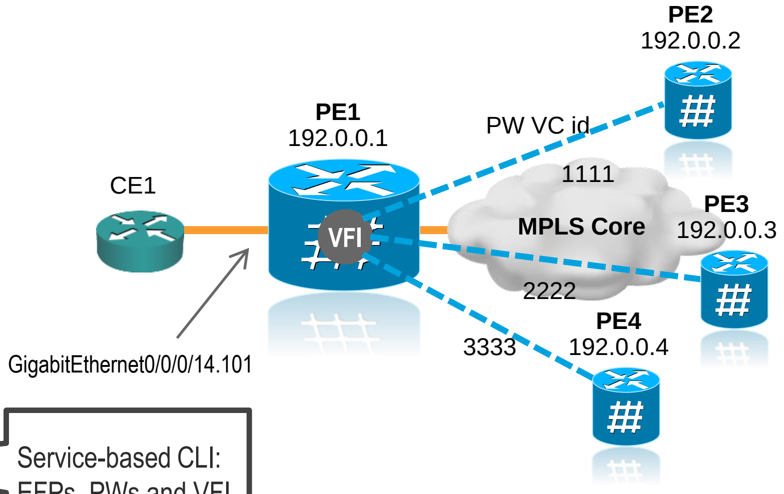
VPLS LDP Signaling / Manual provisioning

Cisco IOS XR

```
hostname PE1
!
interface Loopback0
 ipv4 address 192.0.0.1 255.255.255.255
!
interface GigabitEthernet0/0/0/14.101 l2transport
 encapsulation dot1q 101
 rewrite ingress tag pop 1 symmetric
```

```
l2vpn
 bridge group Cisco-Live
  bridge-domain bd101
   interface GigabitEthernet0/0/0/14.101
   vfi vfi101
    vpn-id 1111
    neighbor 192.0.0.2 pw-id 1111
    neighbor 192.0.0.3 pw-id 2222
    neighbor 192.0.0.4 pw-id 3333
```



Service-based CLI: EFPs, PWs and VFI as members of Bridge Domain

VPN ID defined per VFI or on a per-neighbor basis

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H-VPLS LDP Signaling / Manual provisioning

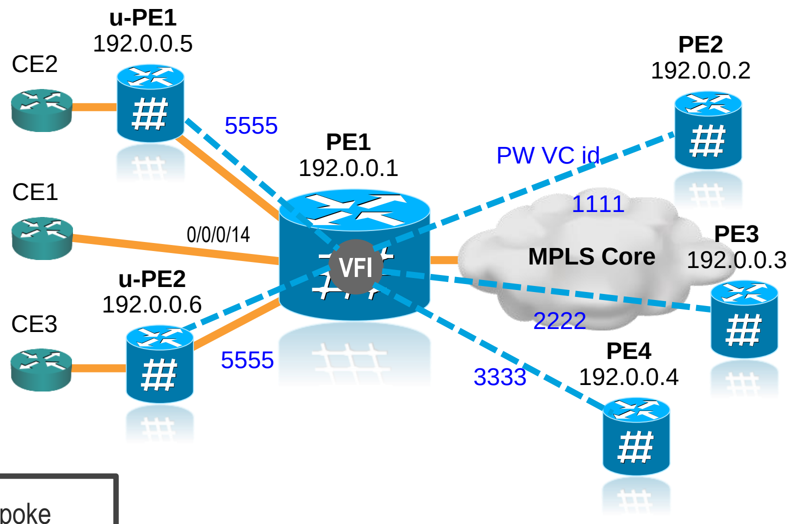
Cisco IOS XR

```
hostname PE1
!
interface Loopback0
 ipv4 address 192.0.0.1 255.255.255.255
!
interface GigabitEthernet0/0/0/14.101 l2transport
 encapsulation dot1q 101
 rewrite ingress tag pop 1 symmetric
```

```
l2vpn
 bridge group Cisco-Live
  bridge-domain bd101
   interface GigabitEthernet0/0/0/14.101
   neighbor 192.0.0.5 pw-id 5555
   neighbor 192.0.0.6 pw-id 5555
   !
   vfi vfi101
    vpn-id 1111
    neighbor 192.0.0.2 pw-id 1111
    neighbor 192.0.0.3 pw-id 2222
    neighbor 192.0.0.4 pw-id 3333
```

Spoke PWs

Core PWs Full-mesh



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VPLS LDP Signaling / Manual provisioning

Cisco IOS / NX-OS (NEW Service-based CLI)

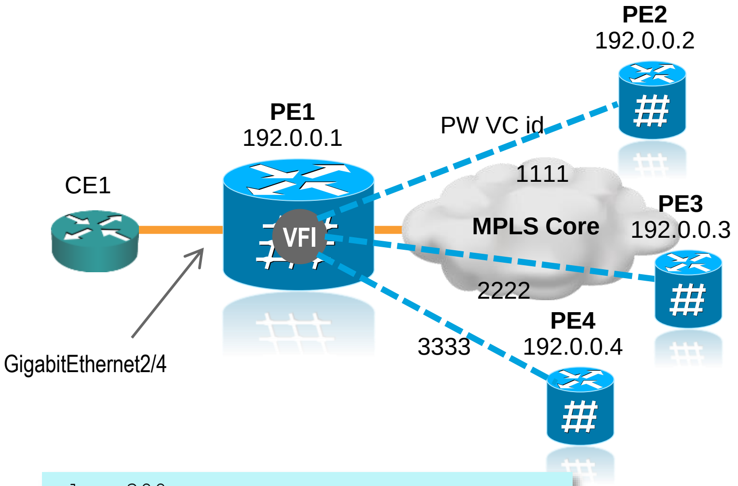
```
hostname PE1
!
interface Loopback0
 ip address 192.0.0.1 255.255.255.255

l2vpn vfi context sample-vfi
 vpn id 1111
 member Pseudowire1 192.0.0.2 encapsulation mpls
 member Pseudowire2 192.0.0.3 2222 encapsulation mpls
 member Pseudowire3 192.0.0.4 3333 encapsulation mpls
!
```

Core PWs Full-mesh

NEW
PWs modeled as virtual interfaces. VFI and EFPs now members of BD

NEW
Service-based CLI Bridge-Domain or VLAN/switchport configurations




```
bridge-domain 300
 member vfi sample-vfi
 member GigabitEthernet2/4 service instance 333
!
interface GigabitEthernet2/4
 service instance 333 ethernet
  encapsulation dot1q 300
  rewrite ingress tag pop 1 symmetric
```

OR

For NX-OS

```
vlan 300
vlan configuration 300
 member vfi sample-vfi
!
interface GigabitEthernet2/4
 switchport mode trunk
 switchport trunk allowed vlan 300
```

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H-VPLS LDP Signaling / Manual provisioning

Cisco IOS (NEW Service-based CLI)

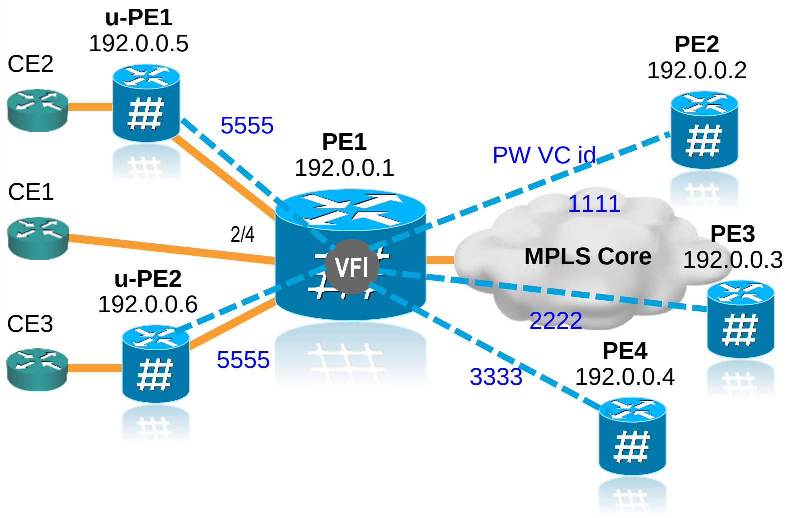
```
hostname PE1
!
interface Loopback0
 ip address 192.0.0.1 255.255.255.255
!
l2vpn vfi context sample-vfi
 vpn id 1111
 member Pseudowire1 192.0.0.2 encapsulation mpls
 member Pseudowire2 192.0.0.3 2222 encapsulation mpls
 member Pseudowire3 192.0.0.4 3333 encapsulation mpls
!
```

NEW
PWs modeled as virtual interfaces. VFI, spoke PW, EFPsmembers of BD

NEW
Service-based CLI Bridge-Domain configurations

```
bridge-domain 300
 member vfi sample-vfi
 member Pseudowire4 192.0.0.5 5555 encapsulation mpls
 member Pseudowire5 192.0.0.6 5555 encapsulation mpls
 member GigabitEthernet2/4 service instance 333
!
interface GigabitEthernet2/4
 service instance 333 ethernet
  encapsulation dot1q 300
  rewrite ingress tag pop 1 symmetric
```

Spoke PWs



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Backup Slides

Ethernet Multi-Point L2VPNs

VPLS with LDP Signaling and BGP-based AutoDiscovery (BGP-AD)

Cisco live!

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VPLS LDP Signaling and BGP-AD

Cisco IOS

BGP Auto-Discovery attributes
VPLS VFI attributes
Signaling attributes

```
hostname PE1
!
interface Loopback0
 ip address 102.102.102.102 255.255.255.255
!
router bgp 100
 bgp router-id 102.102.102.102
 neighbor 104.104.104.104 remote-as 100
 neighbor 104.104.104.104 update-source Loopback0
 !
 address-family l2vpn vpls
  neighbor 104.104.104.104 activate
  neighbor 104.104.104.104 send-community extended
 exit-address-family
```

BGP L2VPN AF

```
l2 vfi sample-vfi autodiscovery
 vpn id 300
 vpls-id 100:300
!
interface Vlan300
 xconnect vfi sample-vfi
```

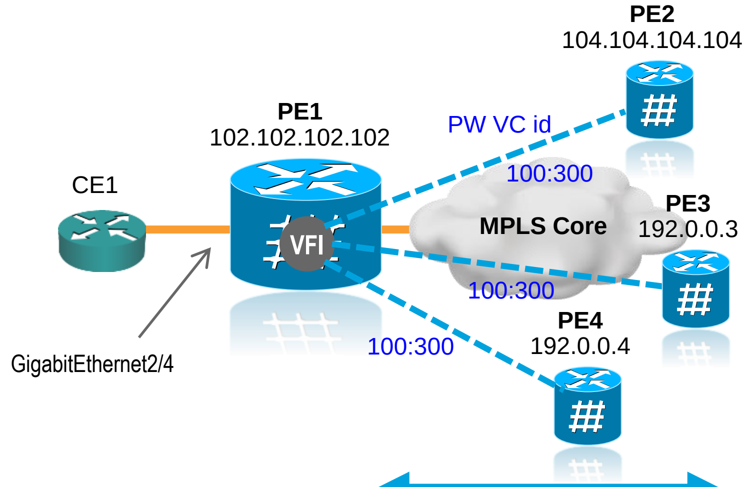
Bridge Domain-based Configuration

OR

VLAN/switchport-based Configuration

```
interface GigabitEthernet2/4
 service instance 333 ethernet
  encapsulation dot1q 333
  rewrite ingress tag pop 1 symmetric
  bridge-domain 300
```

```
interface GigabitEthernet2/4
 switchport mode trunk
 switchport trunk allowed vlan 300
```



BGP AS 100
BGP Auto-Discovery

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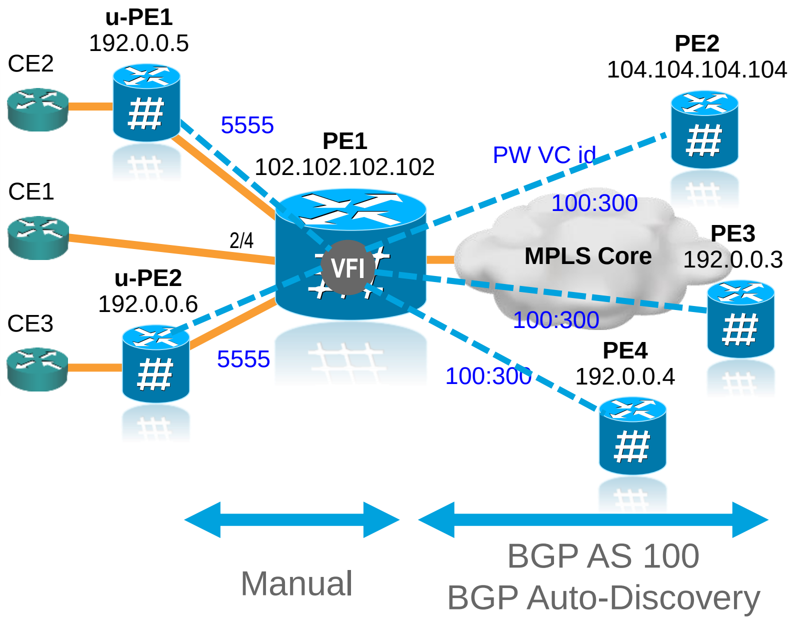
H-VPLS LDP Signaling and BGP-AD / Manual provisioning

Cisco IOS

```
hostname PE1
!
interface Loopback0
 ip address 102.102.102.102 255.255.255.255
!
l2 vfi sample-vfi autodiscovery
 vpn id 300
 vpls-id 100:300
 neighbor 192.0.0.5 5555 encapsulation mpls no-split-horizon
 neighbor 192.0.0.6 5555 encapsulation mpls no-split-horizon
```

Manually provisioned Spoke PWs



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VPLS LDP Signaling and BGP-AD

Cisco IOS XR

BGP Auto-Discovery attributes
VPLS VFI attributes
Signaling attributes

```
hostname PE1
!
interface Loopback0
 ipv4 address 106.106.106.106 255.255.255.255
!
interface GigabitEthernet0/0/0/2.101 l2transport
 encapsulation dot1q 101
 rewrite ingress tag pop 1 symmetric
```

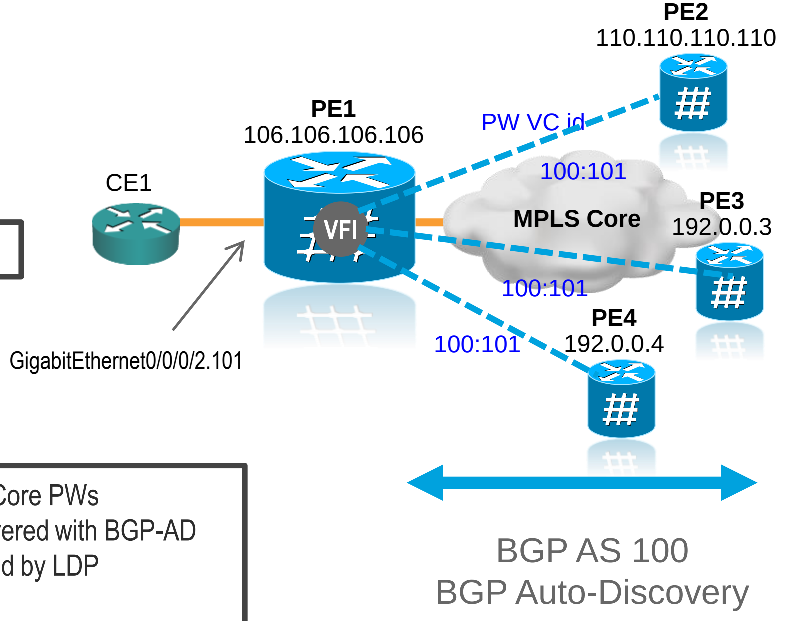
```
router bgp 100
 bgp router-id 106.106.106.106
 address-family l2vpn vpls-vpws
 neighbor 110.110.110.110
  remote-as 100
  update-source Loopback0
  address-family l2vpn vpls-vpws
```

BGP L2VPN AF

```
l2vpn
 bridge group Cisco-Live
  bridge-domain bd101
   interface GigabitEthernet0/0/0/2.101
   vfi vfi101
    vpn-id 11101
    autodiscovery bgp
     rd auto
     route-target 100:101
     signaling-protocol ldp
      vpls-id 100:101
```

Full-mesh Core PWs auto-discovered with BGP-AD and signaled by LDP

PW ID = VPLS-id (100:101)



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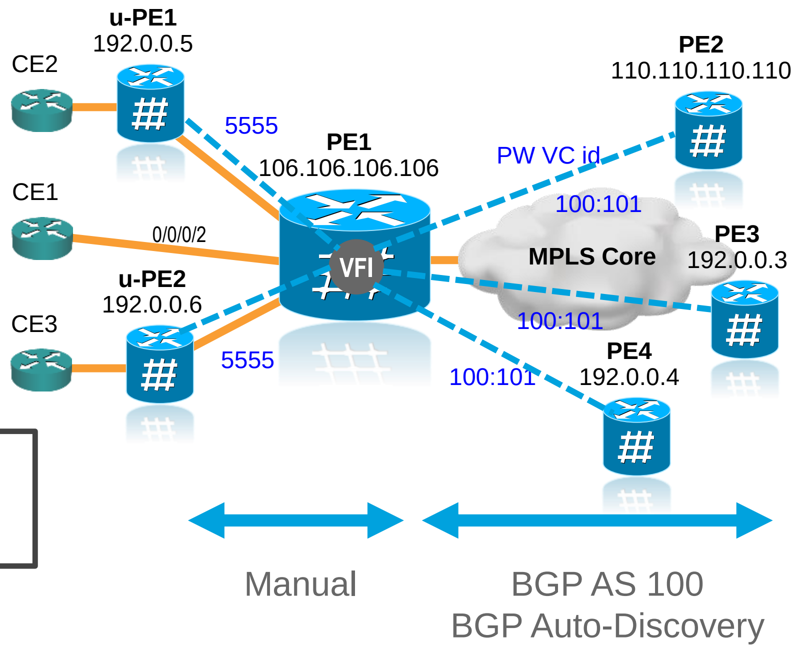
H-VPLS LDP Signaling and BGP-AD / Manual provisioning

Cisco IOS XR

```
hostname PE1
!
l2vpn
 bridge group Cisco-Live
  bridge-domain bd101
   interface GigabitEthernet0/0/0/2.101
   !
   neighbor 192.0.0.5 pw-id 5555
   !
   neighbor 192.0.0.6 pw-id 5555
   !
   vfi vfi101
    vpn-id 11101
    autodiscovery bgp
     rd auto
     route-target 100:101
     signaling-protocol ldp
      vpls-id 100:101
```

Manually provisioned Spoke PWs



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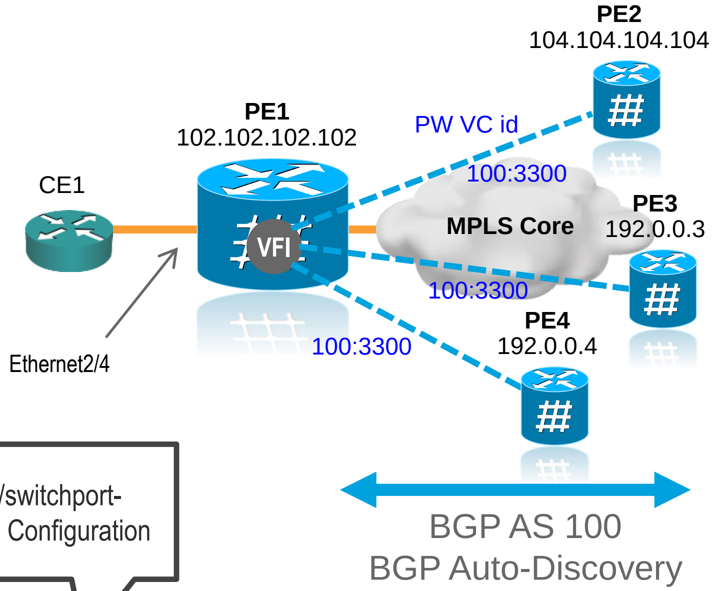
VPLS LDP Signaling and BGP-AD

Cisco NX-OS

```
hostname PE1
!
interface Loopback0
 ip address 102.102.102.102 255.255.255.255
```

```
l2vpn vfi context sample-vfi
  vpn id 3300
  autodiscovery bgp signaling ldp
   vpls-id 100:3300
!
router bgp 100
  neighbor 104.104.104.104 remote-as 100
    update-source loopback 0
    address-family l2vpn vpls
      send-community extended
```



Bridge Domain-based Configuration **OR** VLAN/switchport-based Configuration

```
system bridge-domain 300
!
bridge-domain 300
 member vfi sample-vfi
 member Ethernet2/4 service instance 333
!
interface Ethernet2/4
 service instance 333 ethernet
  encapsulation dot1q 300
```

```
vlan 300
vlan configuration 300
 member vfi sample-vfi
!
interface Ethernet2/4
 switchport
 switchport mode trunk
 switchport trunk allowed vlan 300
```

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VPLS LDP Signaling and BGP-AD

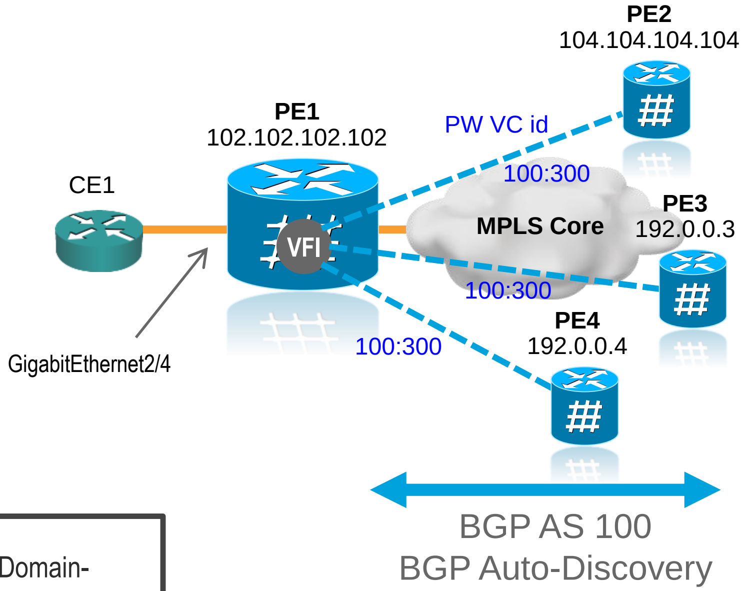
Cisco IOS (NEW Service-based CLI)


```
hostname PE1
!
interface Loopback0
 ip address 102.102.102.102 255.255.255.255
!
router bgp 100
 bgp router-id 102.102.102.102
 neighbor 104.104.104.104 remote-as 100
 neighbor 104.104.104.104 update-source Loopback0
 !
 address-family l2vpn vpls
  neighbor 104.104.104.104 activate
  neighbor 104.104.104.104 send-community extended
 exit-address-family
```

```
l2vpn vfi context sample-vfi
  vpn id 300
  autodiscovery bgp signaling ldp
   vpls-id 100:300
!
bridge-domain 300
 member vfi sample-vfi
 member GigabitEthernet2/4 service instance 333
```

Bridge Domain-based Configuration

```
interface GigabitEthernet2/4
 service instance 333 ethernet
  encapsulation dot1q 333
  rewrite ingress tag pop 1 symmetric
```



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H-VPLS LDP Signaling and BGP-AD / Manual provisioning

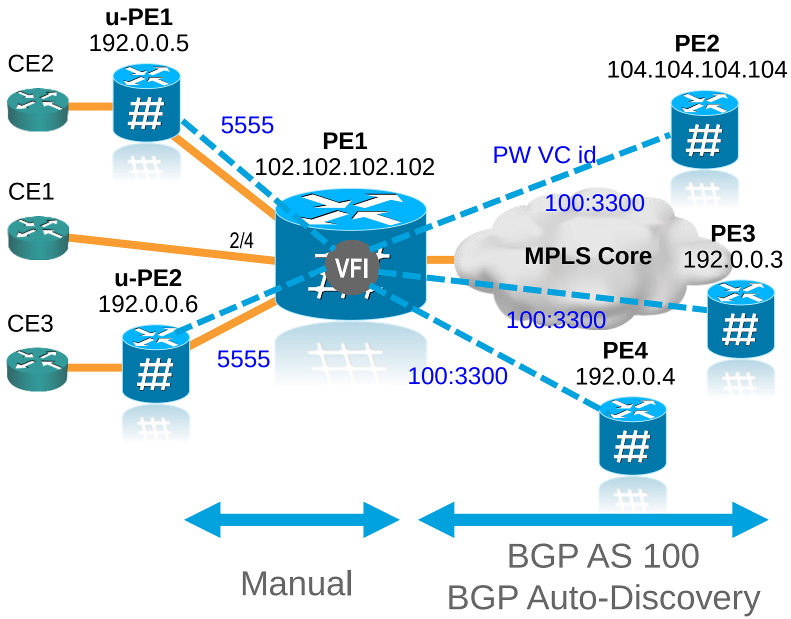
Cisco IOS (NEW Service-based CLI)

```
hostname PE1
!
l2vpn vfi context sample-vfi
  vpn id 3300
  autodiscovery bgp signaling ldp
   vpls-id 100:3300
```

```
bridge-domain 300
 member vfi sample-vfi
 member Pseudowire4 192.0.0.5 5555 encapsulation mpls
 member Pseudowire5 192.0.0.6 5555 encapsulation mpls
 member GigabitEthernet2/4 service instance 333
```

Bridge Domain-based Configuration

Manually provisioned Spoke PWs



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Backup Slides

Ethernet Multi-Point L2VPNs

VPLS with BGP-based Signaling and AutoDiscovery

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VPLS BGP Signaling and BGP-AD

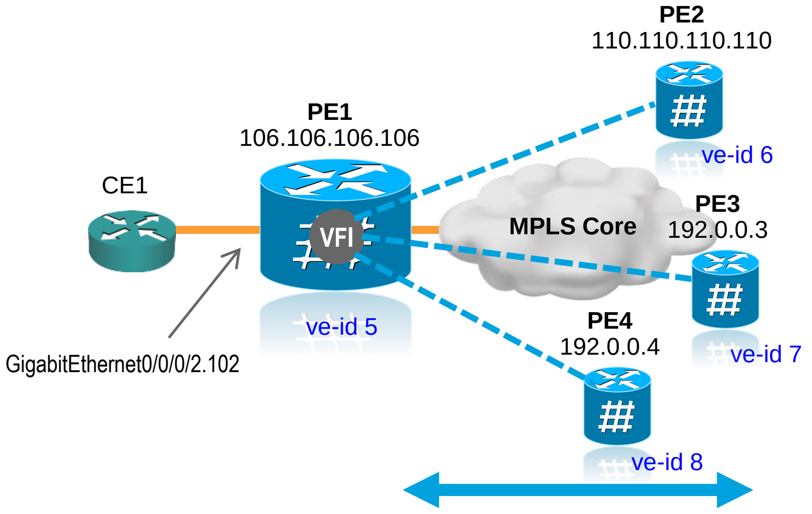
Cisco IOS XR

BGP Auto-Discovery attributes
VPLS VFI attributes
Signaling attributes

```
hostname PE1
!
interface Loopback0
 ipv4 address 106.106.106.106 255.255.255.255
!
router bgp 100
 bgp router-id 106.106.106.106
 address-family l2vpn vpls-vpws
 neighbor 110.110.110.110
  remote-as 100
  update-source Loopback0
  address-family l2vpn vpls-vpws
```

```
l2vpn
 bridge group Cisco-Live
  bridge-domain bd102
   interface GigabitEthernet0/0/0/2.102
   vfi vfi102
    vpn-id 11102
    autodiscovery bgp
     rd auto
     route-target 100:102
     signaling-protocol bgp
      ve-id 5
```

VE-id must be unique in a VPLS instance



BGP AS 100
BGP Signaling and Auto-Discovery

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VPLS BGP Signaling and BGP-AD

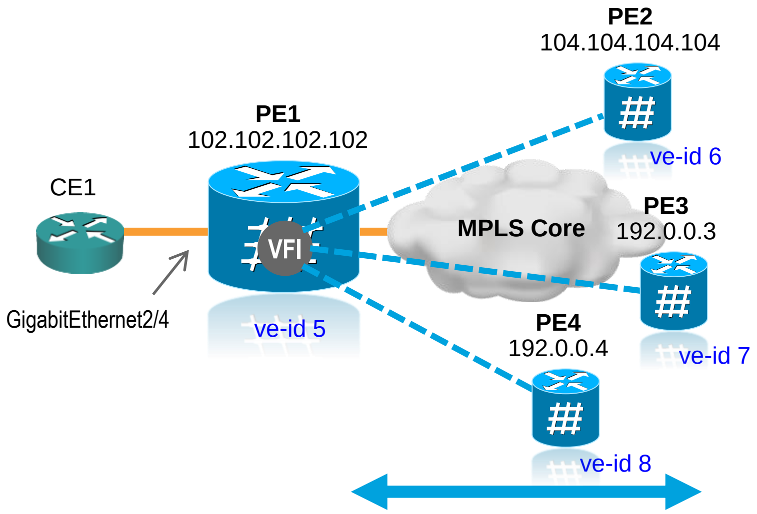
Cisco IOS (NEW Service-based CLI)

```
hostname PE1
!
interface Loopback0
 ip address 102.102.102.102 255.255.255.255
!
router bgp 100
 bgp router-id 102.102.102.102
 neighbor 104.104.104.104 remote-as 100
 neighbor 104.104.104.104 update-source Loopback0
 !
 address-family l2vpn vpls
  neighbor 104.104.104.104 activate
  neighbor 104.104.104.104 send-community extended
  neighbor 104.104.104.104 suppress-signaling-protocol ldp
 exit-address-family
```

```
l2vpn vfi context sample-vfi
  vpn id 3300
  autodiscovery bgp signaling bgp
    ve id 5
    ve range 10
```



```
bridge-domain 300
 member vfi sample-vfi
 member GigabitEthernet2/4 service instance 333
!
interface GigabitEthernet2/4
 service instance 333 ethernet
  encapsulation dot1q 300
  rewrite ingress tag pop 1 symmetric
```

BGP AS 100
BGP Signaling and Auto-Discovery

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VPLS BGP Signaling and BGP-AD

Cisco NX-OS

```
hostname PE1
!
interface Loopback0
 ip address 106.106.106.106 255.255.255.255
!
router bgp 100
  neighbor 110.110.110.110 remote-as 100
    update-source Loopback 0
    address-family l2vpn vpls
      suppress-signaling-protocol ldp
      send-community extended
```

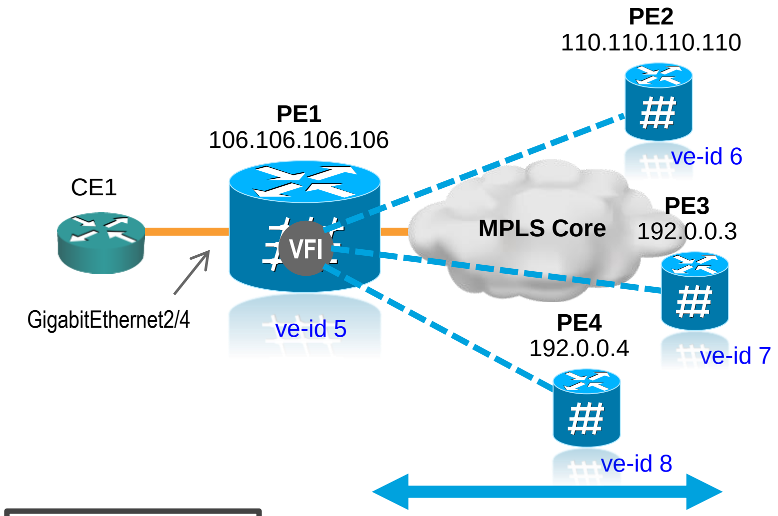
VE-id must be unique in a VPLS instance

```
l2vpn vfi context sample-vfi
  vpn id 3300
  autodiscovery bgp signaling bgp
    ve id 5
    ve range 10
```

Bridge Domain-based Configuration **OR** VLAN/switchport-based Configuration

```
system bridge-domain 300
!
bridge-domain 300
 member vfi sample-vfi
 member Ethernet2/4 service instance 333
!
interface Ethernet2/4
 service instance 333 ethernet
  encapsulation dot1q 300
```

```
vlan 300
vlan configuration 300
 member vfi sample-vfi
!
interface Ethernet2/4
 switchport
 switchport mode trunk
 switchport trunk allowed vlan 300
```



BGP AS 100
BGP Signaling and Auto-Discovery

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PBB-EVPN IOS-XR Implementation Configuration and Examples

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PBB-EVPN Single Home Device (SHD)

MINIMAL Configuration

Chassis B-MAC SA
Null ESI
Auto RD for Segment Route
Auto RT for EVI
Auto RD for EVI

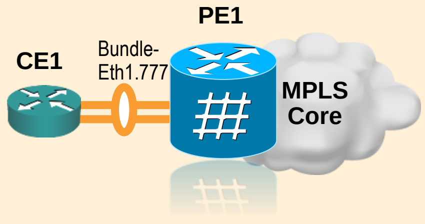
```
PE1

interface Bundle-Ether1.777 l2transport
  encapsulation dot1q 777

l2vpn
 bridge group gr1
  bridge-domain bd1
   interface Bundle-Ether1.777
   pbb edge i-sid 256 core-bridge core_bd1

 bridge group gr2
  bridge-domain core_bd1
   pbb core
    evpn evi 1000

router bgp 64
 bgp router-id 1.100.100.100
 address-family l2vpn evpn
 !
 neighbor 2.100.100.100
  remote-as 64
  update-source Loopback0
  address-family l2vpn evpn
```

PBB I-component
Includes I-SID assignment

PBB B-component
No need to define B-VLAN

Mandatory - Globally unique identifier for all PEs in a given EVI

BGP configuration with new EVPN AF



Note: MPLS / LDP configuration required on core-facing interfaces (not shown)

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PBB-EVPN Single Home Device (SHD) with PW access

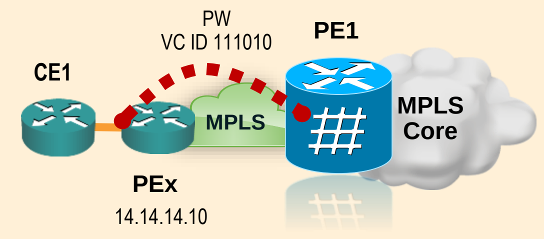
```
PE1

l2vpn
 bridge group gr1
  bridge-domain bd1
   neighbor 14.14.14.10 pw-id 111010
   !
   pbb edge i-sid 256 core-bridge core_bd1

 bridge group gr2
  bridge-domain core_bd1
   pbb core
    evpn evi 1000

router bgp 64
 bgp router-id 1.100.100.100
 address-family l2vpn evpn
 !
 neighbor 2.100.100.100
  remote-as 64
  update-source Loopback0
  address-family l2vpn evpn
```

PBB I-component includes:
- Access PW
- I-SID assignment

PBB B-component
No need to define B-VLAN

Mandatory - Globally unique identifier for all PEs in a given EVI

BGP configuration with new EVPN AF



Note: MPLS / LDP configuration required on core-facing interfaces (not shown)

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PBB-EVPN Dual Home Device (DHD)

MINIMAL Configuration

All-Active (per-FLOW) Load-Balancing

```
PE1
redundancy iccp group 66
   mlacp node 1
   mlacp system priority 1
   mlacp system mac 0111.0222.0111
   mode singleton
   backbone interface GigabitEthernet 0/0/0/1
interface Bundle-Ether25
 mlacp iccp-group 66

interface Bundle-Ether25.1 l2transport
 encapsulation dot1q 777
l2vpn
 bridge group gr1
  bridge-domain bd1
   interface Bundle-Ether25.1
   pbb edge i-sid 256 core-bridge core_bd1
 bridge group gr2
  bridge-domain core_bd1
   pbb core
    evpn evi 1000
router bgp 64
 bgp router-id 1.100.100.100
 address-family l2vpn evpn
 neighbor 2.100.100.100
  remote-as 64
  address-family l2vpn evpn
```

Auto-sensed B-MAC SA
Auto-sensed ESI
Auto RD for Segment Route
Auto RT for EVI
Auto RD for EVI
A/A Per-flow LB (default)
Auto DF / service carving

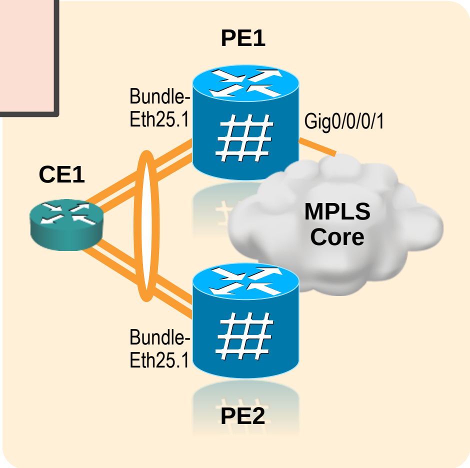
PE2 should use same RG #
PE2 should use different mlacp node id
PE2 should use same mlacp system mac and system priority

ICCP in singleton mode (i.e.No peer neighbor configuration)

PBB I-component and B-component configuration. ISIDs must match on both PEs
No need to define B-VLAN

Mandatory EVI ID configuration

BGP configuration with new EVPN AF



Note: MPLS / LDP configuration required on core-facing interfaces (not shown)

PBB-EVPN Dual Home Device (DHD)

MINIMAL Configuration

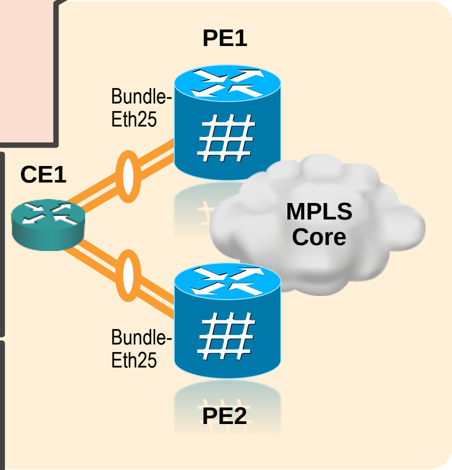
Single-Active (per-Service) Load-Balancing and Dynamic Service Carving

```
PE1

interface Bundle-Ether25.1 l2transport
 encapsulation dot1q 777

evpn
 interface Bundle-Ether25
  ethernet-segment
   identifier system-priority 1 system-id 0300.0b25.00ce
   load-balancing-mode per-service
l2vpn
 bridge group gr1
  bridge-domain bd1
   interface Bundle-Ether25.1
   pbb edge i-sid 256 core-bridge core_bd1

 bridge group gr2
  bridge-domain core_bd1
   pbb core
    evpn evi 1000

router bgp 64
 bgp router-id 1.100.100.100
 address-family l2vpn evpn
```

Chassis B-MAC SA (def.)
Manual ESI
Auto RD for Segment Route
Auto RT for EVI
Auto RD for EVI
A/A Per-Service LB
Auto Service Carving (def.)

A/A per-service (per-ISID) load balancing with dynamic Service Carving
ESI must match on both PEs

PBB I-component and B-component configuration.
ISIDs must match on both PEs
No need to define B-VLAN
Mandatory EVI ID configuration



Note: MPLS / LDP configuration
acing interfaces (not
gleton) config (not

Data-Plane considerations for Ethernet transport

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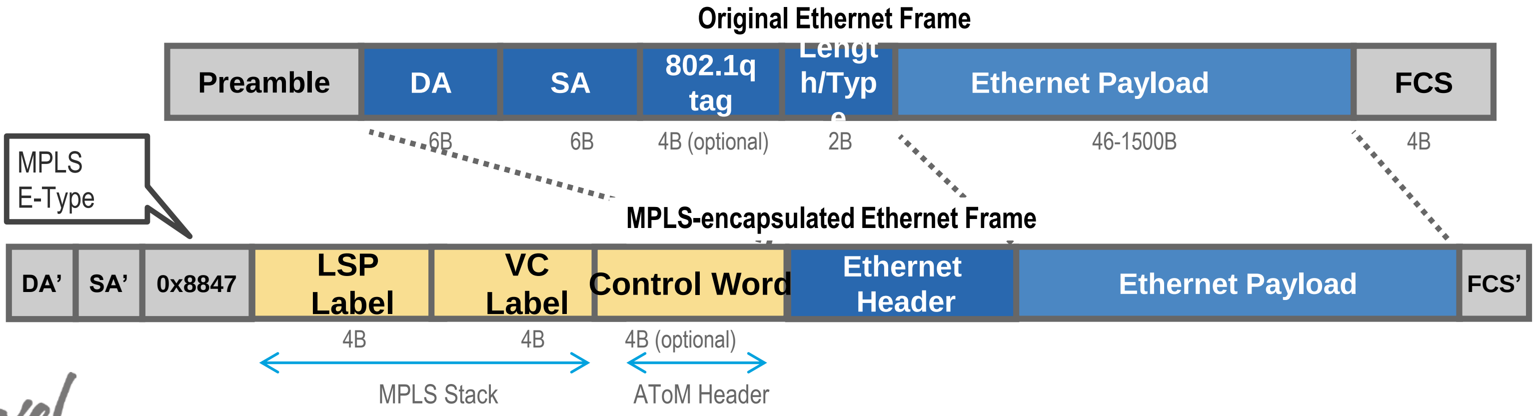
How Are Ethernet Frames Transported?

- Ethernet frames transported without Preamble, Start Frame Delimiter (SFD) and FCS
- Two (2) modes of operation supported:
  - Ethernet VLAN mode (VC type 0x0004) – created for VLAN over MPLS application
  - Ethernet Port / Raw mode (VC type 0x0005) – created for Ethernet port tunneling application



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Ethernet PW VC Type

- VC type used must match on PEs
- Cisco IOS devices by default will generally attempt to bring up an Ethernet PW using VC type 5
  - If rejected by remote PE, then VC type 4 will be used – VC Type auto-sensing
- Alternatively, Cisco IOS and IOS-XR devices can be explicitly configured to use either VC type 4 or 5

IOS

```
7604-2#show running-config
pseudowire-class test-pw-class-VC4
 encapsulation mpls
 interworking vlan
!
pseudowire-class test-pw-class-VC5
 encapsulation mpls
 interworking ethernet
```

IOS-XR

```
RP/0/RSP0/CPU0:ASR9000-2#show running-config l2vpn
l2vpn
 pw-class test-pw-class-VC4
  encapsulation mpls
   transport-mode vlan

 pw-class test-pw-class-VC4-passthrough
  encapsulation mpls
   transport-mode vlan passthrough

 pw-class test-pw-class-VC5
  encapsulation mpls
   transport-mode ethernet
```


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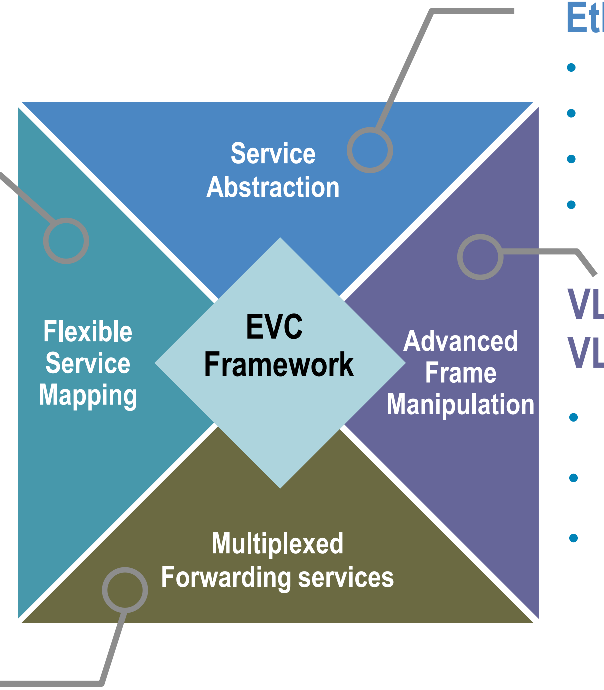
Introducing Cisco EVC Framework

Functional Highlights

Flexible service delimiters

- Single-tagged, Double-tagged
- VLAN Lists, VLAN Ranges
- Header fields (COS, Ethertype)

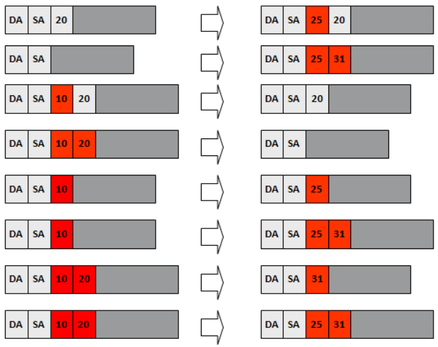


Ethernet Service Layer

- Ethernet Flow Point (EFP)
- Ethernet Virtual Circuit (EVC)
- Bridge Domain (BD)
- Local VLAN significance

VLAN Header operations - VLAN Rewrites

- POP
- PUSH
- SWAP



ANY service – ANY port

- Layer 2 Point-to-Point
- Layer 2 Multipoint
- Layer 3

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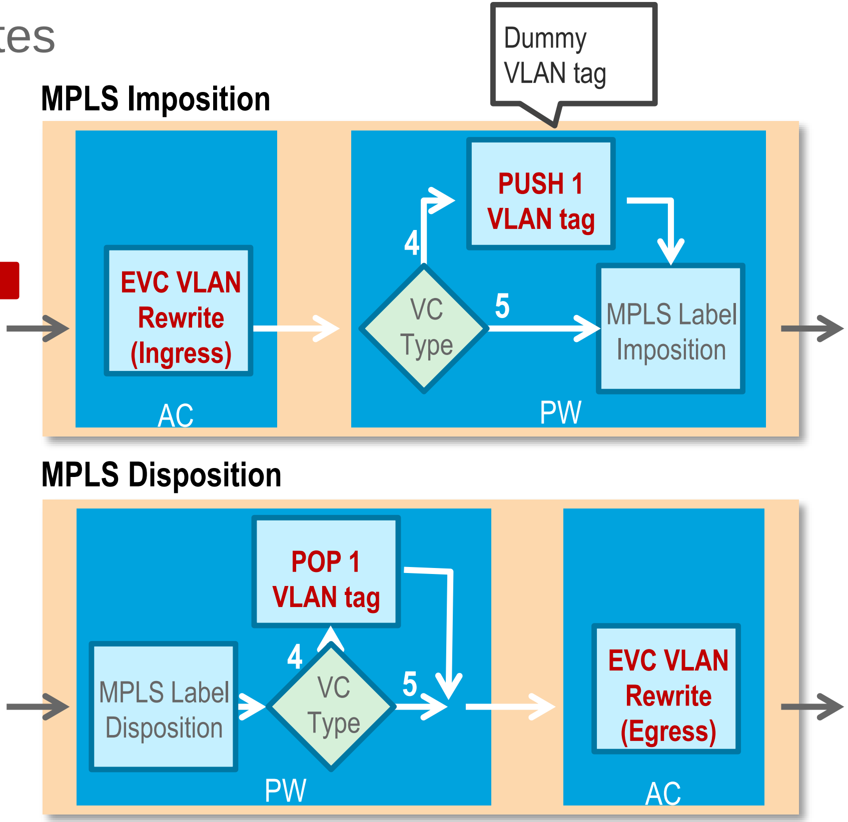
Encapsulation Adjustment Considerations

EoMPLS PW VC Type and EVC VLAN Rewrites

- VLAN tags can be added, removed or translated prior to VC label imposition or after disposition
  - Any VLAN tag(s), if retained, will appear as payload to the VC
- VC label imposition and service delimiting tag are independent from EVC VLAN tag operations
  - Dummy VLAN tag – RFC 4448 (sec 4.4.1)
- VC service-delimiting VLAN-ID is removed before passing packet to Attachment Circuit processing



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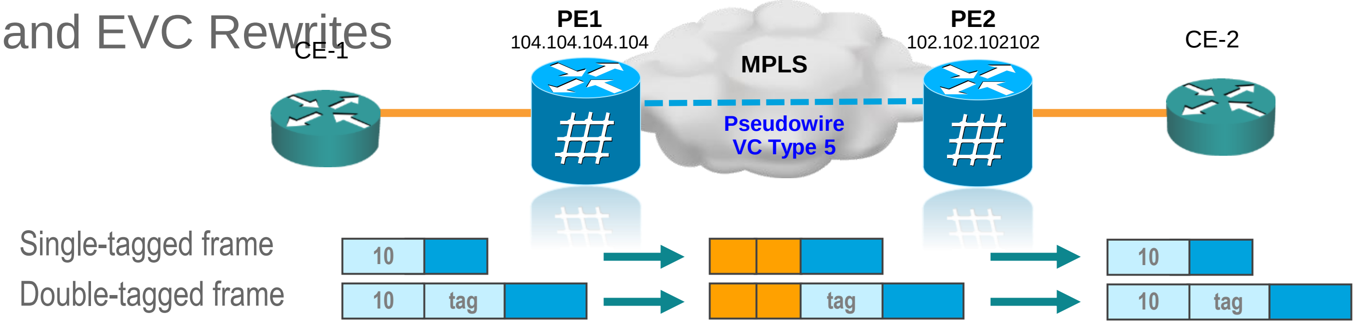
Encapsulation Adjustment Considerations

VC 5 and EVC Rewrites



IOS-XR

- POP VLAN 10
- No Push of Dummy tag (VC 5)

```
l2vpn
 pw-class class-VC5
  encapsulation mpls
   transport-mode ethernet

 xconnect group Cisco-Live
  p2p xc-sample-1
   interface GigabitEthernet0/0/0/2.100
   neighbor 102.102.102.102 pw-id 111
    pw-class class-VC5
```

```
interface GigabitEthernet0/0/0/2.100 l2transport
 encapsulation dot1q 10
 rewrite ingress tag pop 1 symmetric
```

- No service-delimiting vlan expected (VC 5)
- PUSH VLAN 10

IOS

```
pseudowire-class class-VC5
 encapsulation mpls
 interworking ethernet
```

```
interface GigabitEthernet2/2
 service instance 3 ethernet
 encapsulation dot1q 10
 rewrite ingress tag pop 1 symmetric
 xconnect 104.104.104.104 111 encap mpls pw-class class-VC5
```

MPLS label

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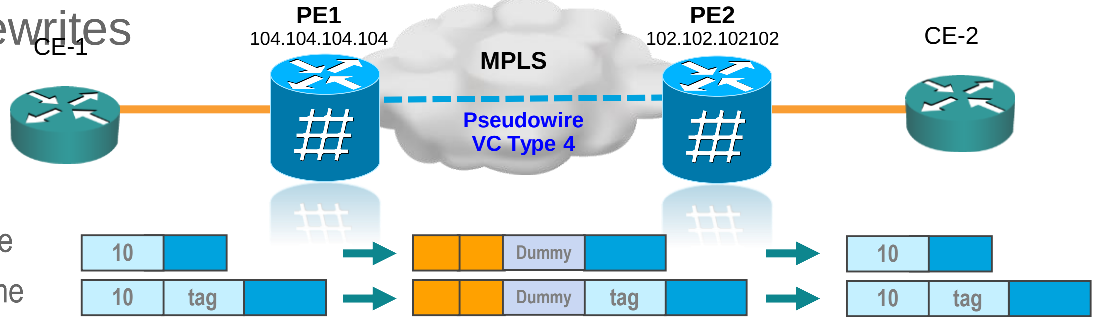
Encapsulation Adjustment Considerations

VC 4 and EVC Rewrites



Single-tagged frame

Double-tagged frame

- POP VLAN 10
- Push Dummy tag (VC 4)

- POP service-delimiting vlan (VC 4)
- PUSH VLAN 10

IOS-XR

```
l2vpn
 pw-class class-VC4
  encapsulation mpls
   transport-mode vlan

 xconnect group Cisco-Live
  p2p xc-sample-1
   interface GigabitEthernet0/0/0/2.100
   neighbor 102.102.102.102 pw-id 111
    pw-class class-VC4
```

```
interface GigabitEthernet0/0/0/2.100 l2transport
 encapsulation dot1q 10
 rewrite ingress tag pop 1 symmetric
```

IOS

```
pseudowire-class class-VC4
 encapsulation mpls
 interworking vlan
```

```
interface GigabitEthernet2/2
 service instance 3 ethernet
 encapsulation dot1q 10
 rewrite ingress tag pop 1 symmetric
 xconnect 104.104.104.104 111 encap mpls pw-class class-VC4
```

MPLS label

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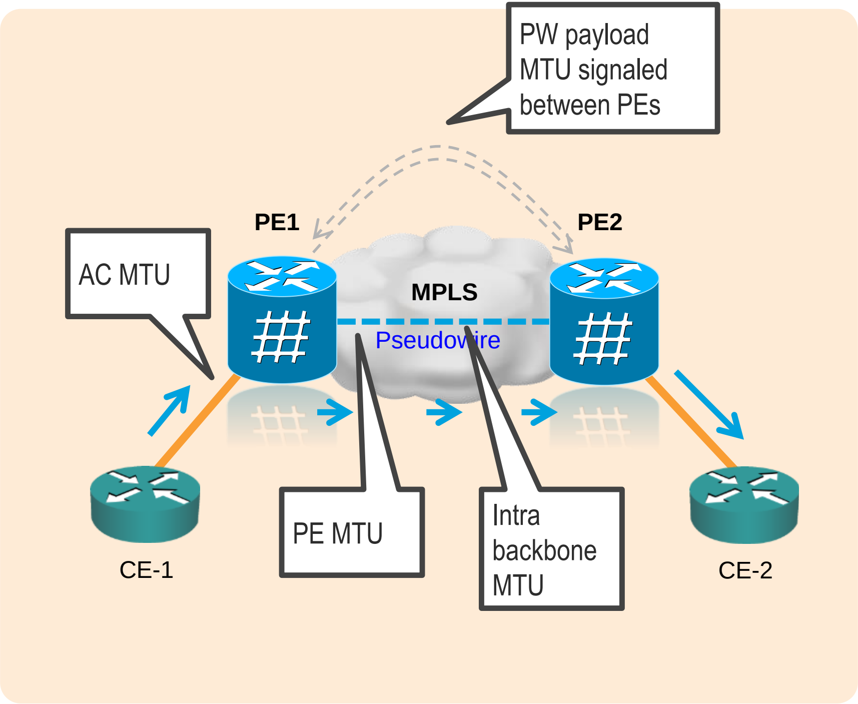
MTU Considerations

- No payload fragmentation supported
- Incoming PDU dropped if MTU exceeds AC MTU
- PEs exchange PW payload MTU as part of PW signaling procedures
    - Both ends must agree to use same value for PW to come UP
    - PW MTU derived from AC MTU
- No mechanism to check Backbone MTU
    - MTU in the backbone must be large enough to carry PW payload and MPLS stack



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Ethernet MTU Considerations

Cisco IOS

- Interface MTU configured as largest ethernet payload size
  - 1500B default
  - Sub-interfaces / Service Instances (EFPs) MTU always inherited from main interface
- PW MTU used during PW signaling
  - By default, inherited from attachment circuit MTU
  - Submode configuration CLI allows MTU values to be set per subinterface/EFP in xconnect configuration mode (only for signaling purposes)
  - No MTU adjustments made for EFP rewrite (POP/PUSH) operations

```
interface GigabitEthernet0/0/4
 description Main interface
 mtu 1600
```

```
ASR1004-1#show int gigabitEthernet 0/0/4.1000 | include MTU
  MTU 1600 bytes, BW 100000 Kbit/sec, DLY 100 usec,
```

Sub-interface MTU inherited from Main interface

```
interface GigabitEthernet0/0/4.1000
 encapsulation dot1Q 1000
 xconnect 106.106.106.106 111 encapsulation mpls
  mtu 1500
```

PW MTU used during signaling can be overwritten

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Ethernet MTU Considerations

Cisco IOS XR

- Interface / sub-interface MTU configured as largest frame size – FCS (4B)
  - 1514B default for main interfaces
  - 1518B default for single-tagged subinterfaces
  - 1522B default for double-tagged subinterfaces
- PW MTU used during PW signaling
  - AC MTU – 14B + Rewrite offset
  - E.g. POP 1 (- 4B), PUSH 1 (+ 4B)

```
interface GigabitEthernet0/0/0/2
 description Main interface
 mtu 9000
```

```
interface GigabitEthernet0/0/0/2.100 l2transport
 encapsulation dot1q 100
 rewrite ingress tag pop 1 symmetric
 mtu 1518
```

By default, sub-interface MTU inherited from Main interface

Sub-interface MTU can be overwritten to match remote AC

```
RP/0/RSP0/CPU0:PE1#show l2vpn xconnect neighbor 102.102.102.102 pw-id 11
Group Cisco-Live, XC xc-sample-1, state is down; Interworking none
  AC: GigabitEthernet0/0/0/2.100, state is up
    Type VLAN; Num Ranges: 1
    VLAN ranges: [100, 100]
    MTU 1500; XC ID 0x840014; interworking none
    Statistics:
(snip)
```

XC MTU = 1518 – 14 – 4
= 1500B

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Advanced Topics

Multi-Segment Pseudowire

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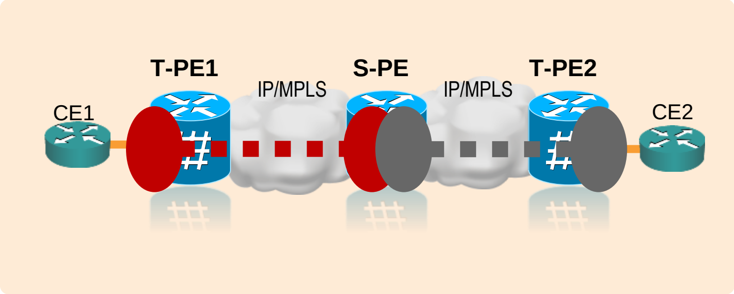
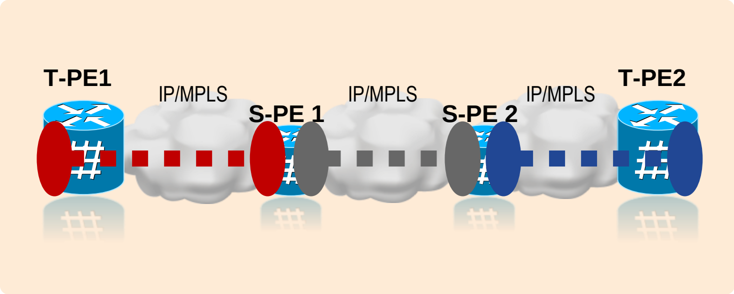
Multi-Segment Pseudowire

Overview

- Separate IGP processes (or areas) for separate MPLS Access networks
- T-PE – Terminating Provider Edge
  - Customer facing PE, hosting the first or last segment of a MS-PW
- S-PE – Switching Provider Edge
  - Switches control / data planes of preceding and succeeding segments
  - Control Word, sequencing, or original packet header not examined
  - VC labels swapped
  - VC Type, MTU should match end-to-end
  - One or more S-PEs can be used depending on number of segments
- MS-PW uses same signaling procedures and TLVs described in RFC 4447





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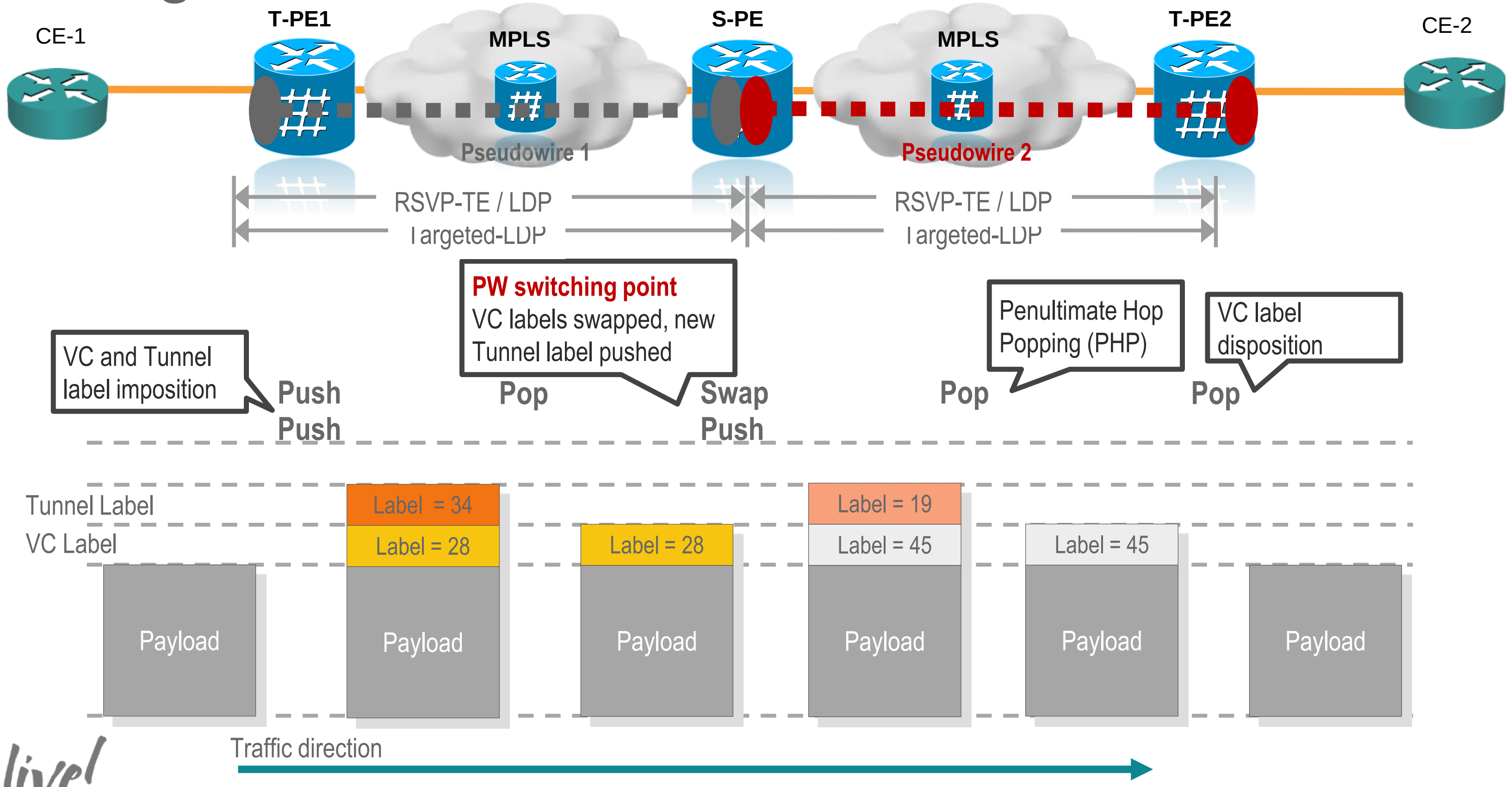
Multi-Segment Pseudowires



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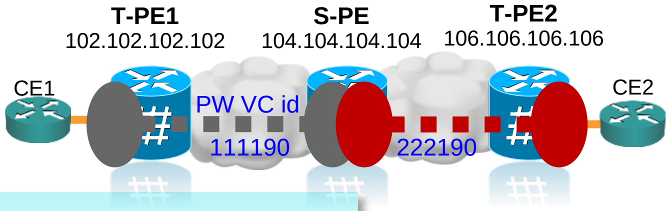
Configuring MS-PWs

Cisco IOS

```
hostname S-PE
interface Loopback0
 ip address 104.104.104.104 255.255.255.255
```

```
l2 vfi sample-ms-pw-1 point-to-point
 neighbor 106.106.106.106 222190 encapsulation mpls
 neighbor 102.102.102.102 111190 encapsulation mpls
```

MS-PW




```
7604-3#show xconnect peer 102.102.102.102 vcid 111190
Legend:    XC ST=Xconnect State  S1=Segment1 State  S2=Segment2 State
  UP=Up       DN=Down            AD=Admin Down      IA=Inactive
  SB=Standby  HS=Hot Standby     RV=Recovering      NH=No Hardware

XC ST  Segment 1                         S1 Segment 2                         S2
------+---------------------------------+--+---------------------------------+--
UP     mpls 106.106.106.106:222190       UP mpls 102.102.102.102:111190       UP
```

```
7604-3#show xconnect peer 102.102.102.102 vcid 111190 detail
Legend:    XC ST=Xconnect State  S1=Segment1 State  S2=Segment2 State
  UP=Up       DN=Down            AD=Admin Down      IA=Inactive
  SB=Standby  HS=Hot Standby     RV=Recovering      NH=No Hardware

XC ST  Segment 1                         S1 Segment 2                         S2
------+---------------------------------+--+---------------------------------+--
UP     mpls 106.106.106.106:222190       UP mpls 102.102.102.102:111190       UP
          Local  VC label 65536               Local  VC label 65549
          Remote VC label 16029               Remote VC label 47
          pw-class:                           pw-class:
```

S-PE labels for each PW segment

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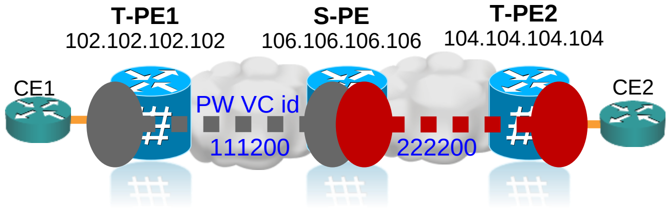
Configuring MS-PWs

Cisco IOS XR

```
hostname S-PE
interface Loopback0
 ipv4 address 106.106.106.106 255.255.255.255
```

```
l2vpn
 xconnect group Cisco-Live
  p2p xc-sample-8
   neighbor 102.102.102.102 pw-id 111200
   !
   neighbor 104.104.104.104 pw-id 222200
```

MS-PW




```
RP/0/RSP0/CPU0:ASR9000-2#show l2vpn xconnect group Cisco-Live xc-name xc-sample-8
Legend: ST = State, UP = Up, DN = Down, AD = Admin Down, UR = Unresolved,
        SB = Standby, SR = Standby Ready, (PP) = Partially Programmed

XConnect                    Segment 1                       Segment 2
Group      Name       ST    Description            ST       Description            ST
------------------------    ------------------------------  ------------------------------
Cisco-Live xc-sample-8
                      UP    102.102.102.102 111200 UP       104.104.104.104 222200 UP
----------------------------------------------------------------------------------------
```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Advanced Topics

L2VPN Inter – Autonomous Systems (I-AS)

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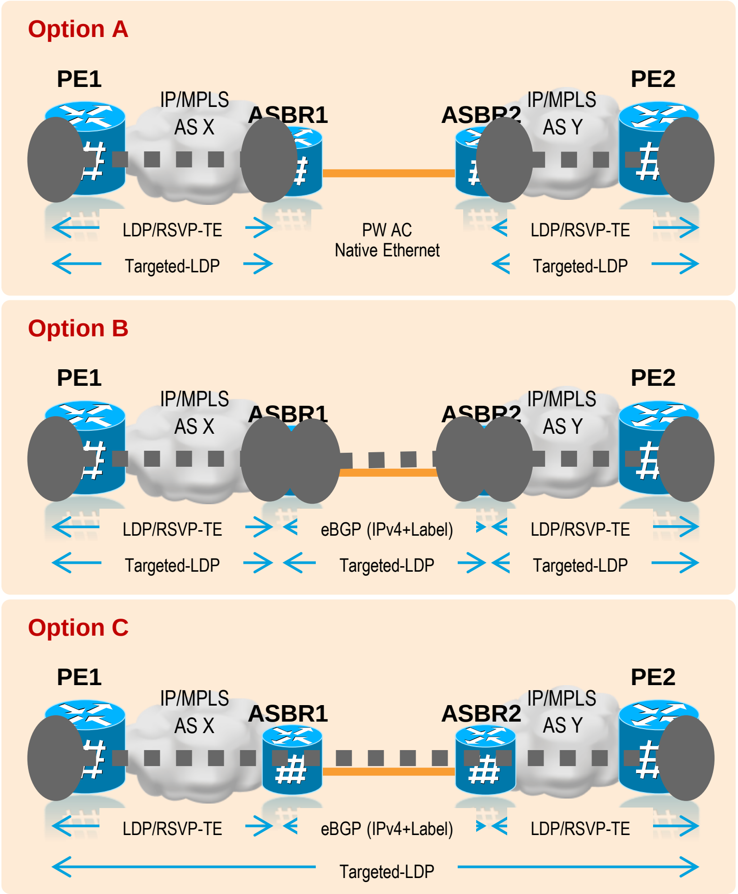
L2VPN Inter-AS

- Three (3) deployment models
- Option A
  - No reachability information shared between AS
- Option B
  - Minimal reachability information shared between AS
  - ASBR configured as S-PEs (multi-segment PWs)
  - eBGP (IPv4 prefix + label) used to build PSN tunnel between AS
- Option C
  - Significant reachability information shared between AS
  - Single-segment PW signaled across AS boundary



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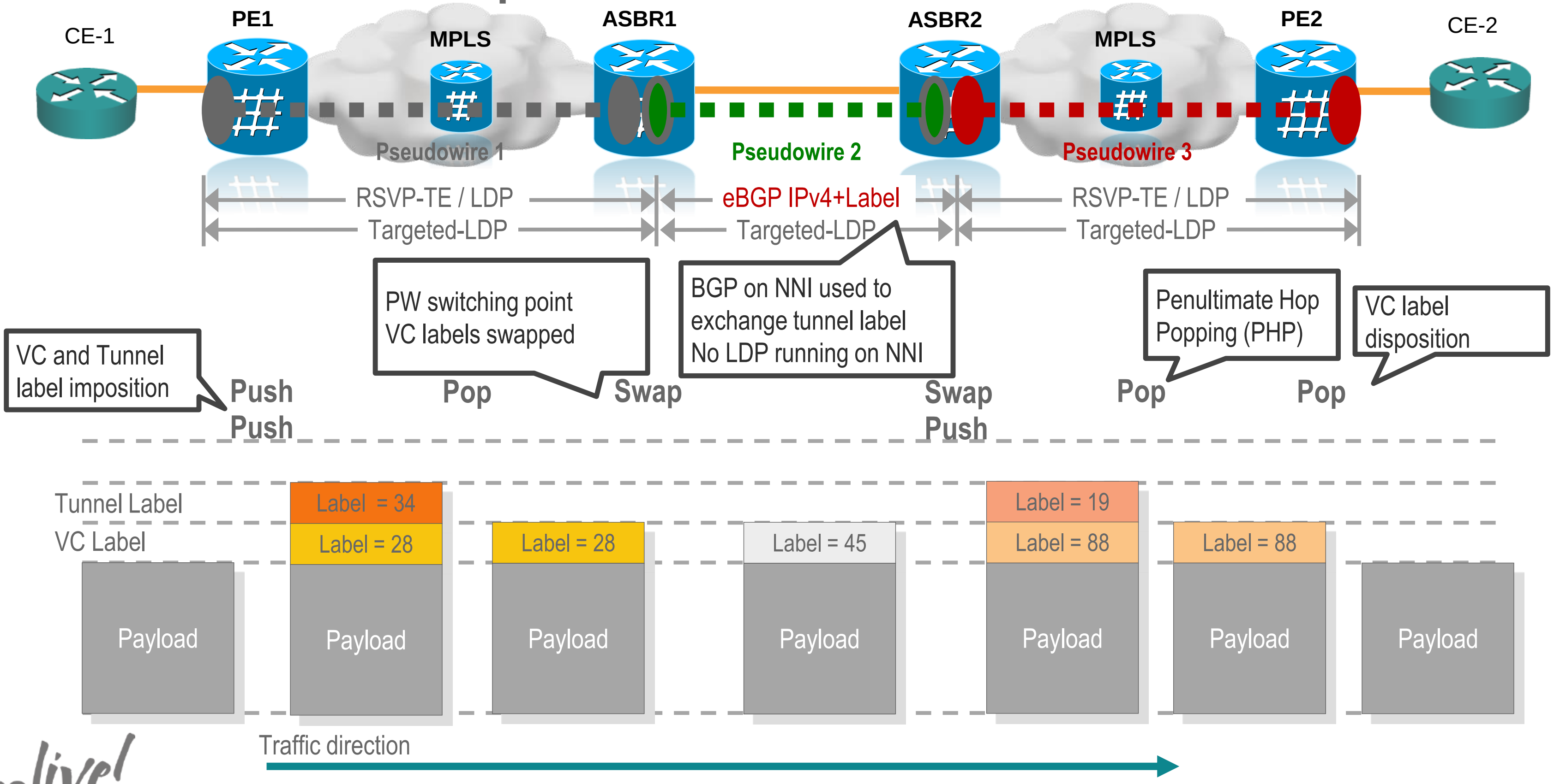
L2VPN Inter-AS Option B



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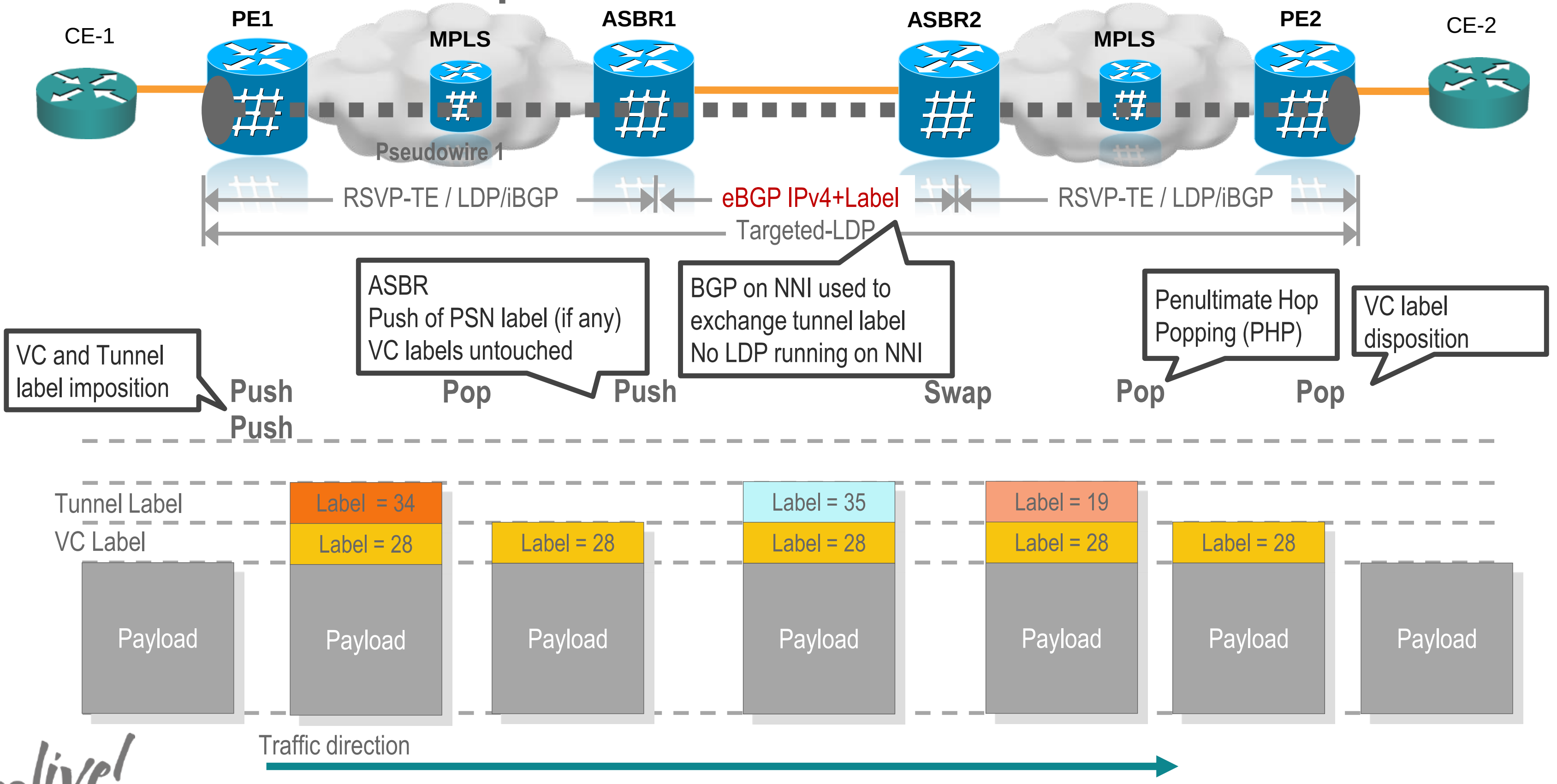
L2VPN Inter-AS Option C



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Advanced Topics Resiliency

Pseudowire Redundancy

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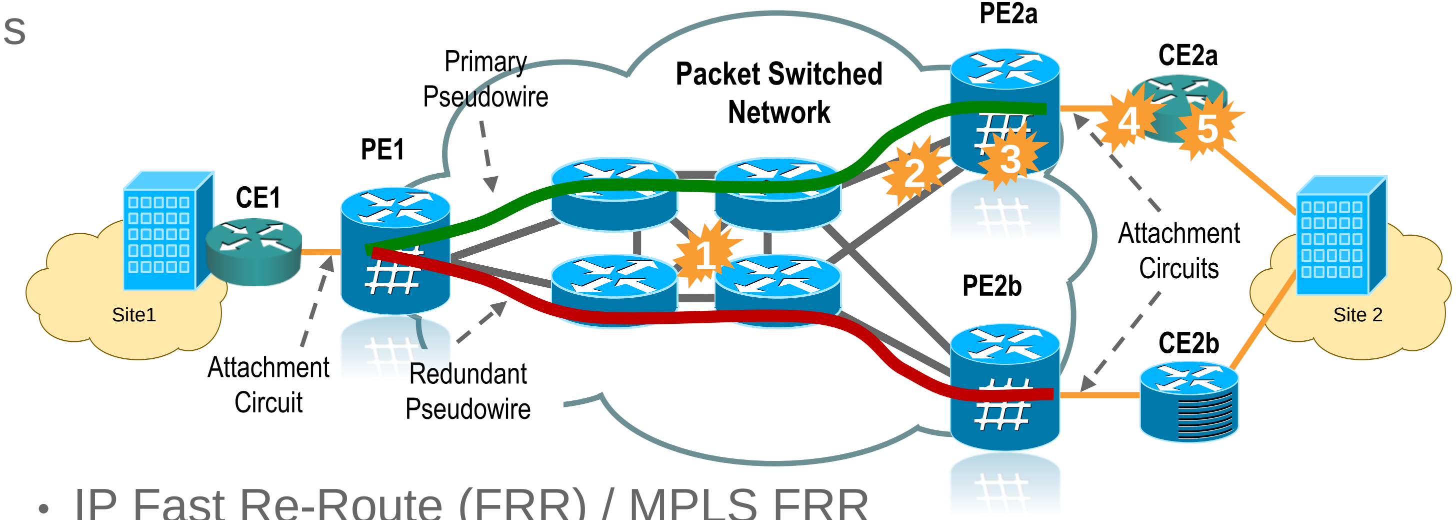
High Availability in L2VPN Networks

Solutions



- IP Fast Re-Route (FRR) / MPLS FRR
  - 1 PSN core failure
- Pseudowire Redundancy:
  - 2 PSN end-to-end routing failure – Redundant PEs
  - 3 PE failure – Redundant PEs
  - 4 Attachment circuit failure – AC Diversity
  - 5 CE failure – Redundant CEs

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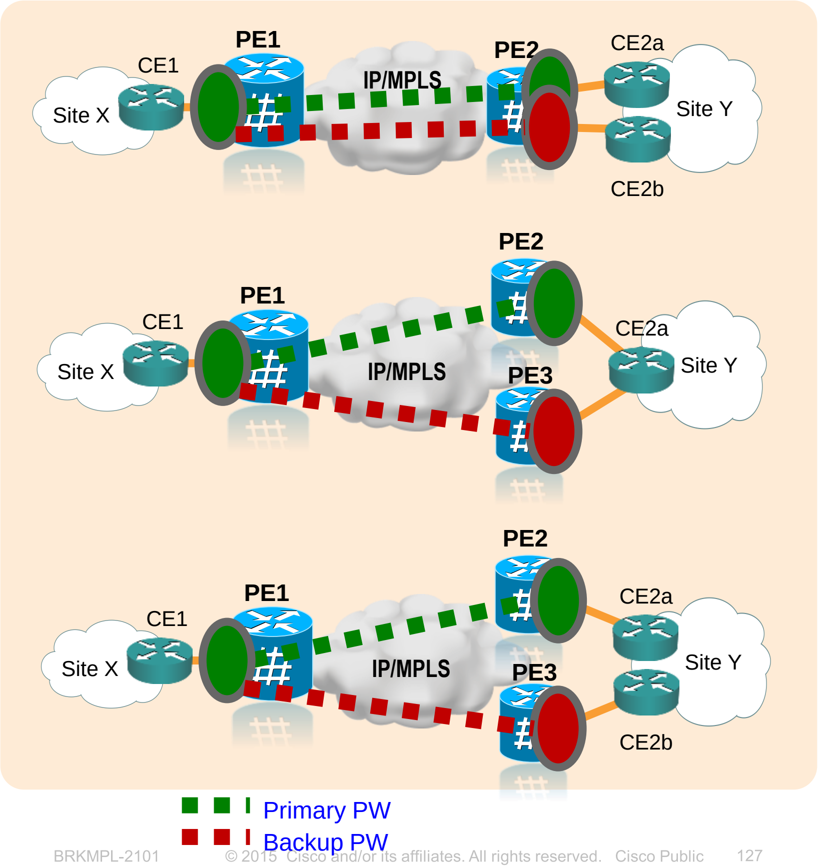
One-Way Pseudowire Redundancy

Overview

- Allows dual-homing of one local PE to one or two remote PEs
- Two pseudowires - primary & backup provide redundancy for a single AC
- Faults on the primary PW cause failover to backup PW
- Multiple backup PWs (different priorities) can be defined
- Alternate LSPs (TE Tunnels) can be used for additional redundancy



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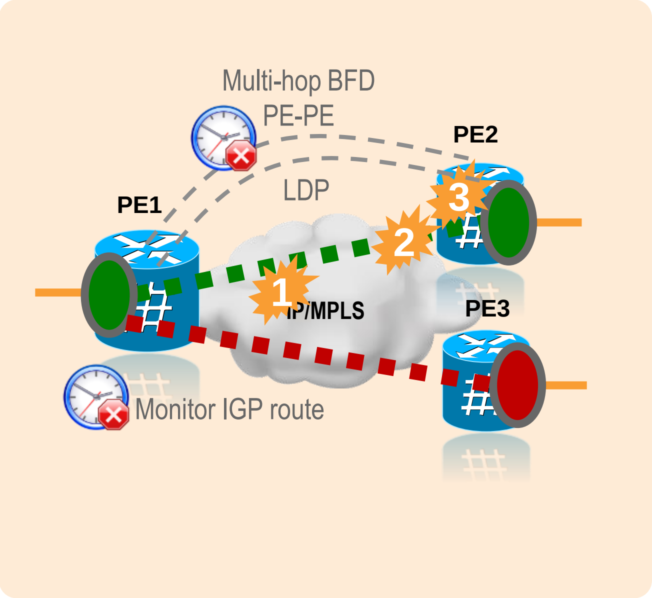
One-Way Pseudowire Redundancy

Failure Protection Points

- Failure 1 - Core failures handled by IGP re-routing / IP/MPLS FRR do not trigger pseudowire switchover
- Failure 2 - Loss of route to remote PE as notified by IGP (PE isolation)
- Failure 3 - Loss of Remote PE
- How to detect PE failures?
  - LDP Fast Failure Detection (FFD) (a.k.a. Route-Watch)
    - Monitors IGP route availability for LDP peer (2-3 sec or sub-sec with Fast IGP)
  - LDP session timeout (default = 3 x 30 sec)
  - BFD timeout (multi-hop PE-to-PE BFD session) (a.k.a. “xconnect client” IOS feature)



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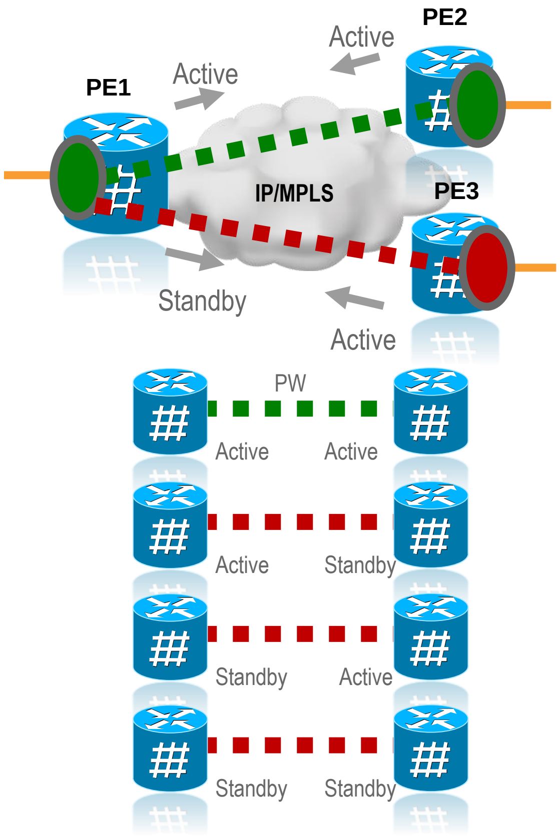
Pseudowire Redundancy

Preferential Forwarding Status Bit

- Extensions to PW status codes (RFC 6870)
- Allows PEs to signal local forwarding status of the PW (Active or Standby)
- A PW is selected for forwarding when declared as Active by both PEs
- Minimize service downtime during PW failover
  - Backup PWs always signaled before failures and held in Standby mode
- Allows VCCV capability over a backup PW
  - OAM over backup PWs
  - SP monitors backup PWs prior to its usage



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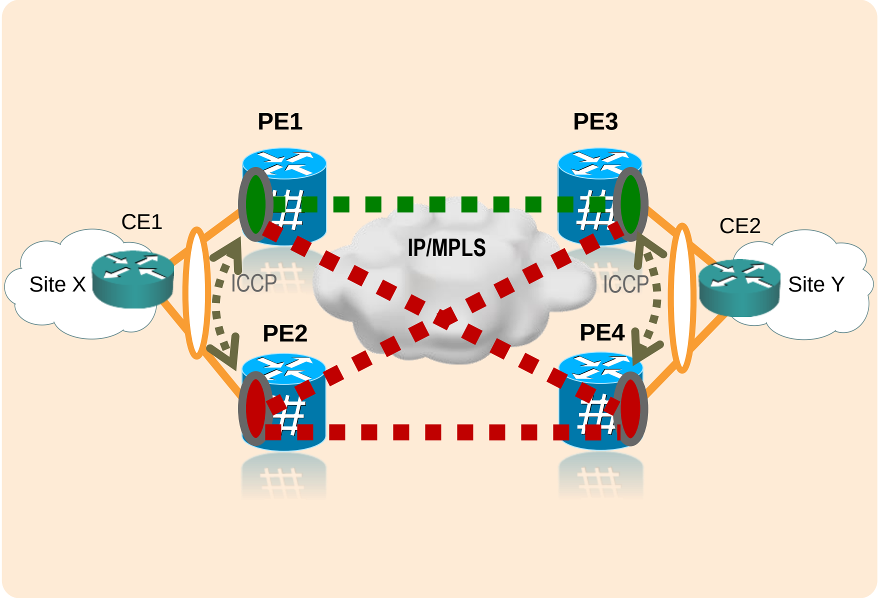
Two-Way Pseudowire Redundancy

Overview

- Allows dual-homing of two local PEs to two remote PEs
- Four (4) pseudowires: 1 primary & 3 backup provide redundancy for dual-homed devices
- Two-Way PW redundancy coupled with Multi-Chassis LAG (MC-LAG) solution on the access side
  - LACP state used to determine PW AC state
  - InterChassis Communication Protcol (ICCP) used to synchronize LACP states



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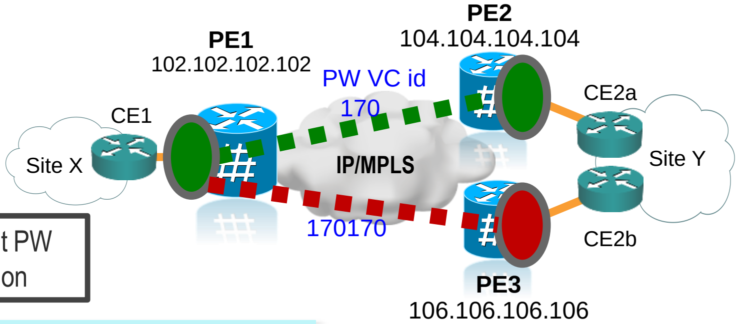
Configuring Pseudowire Redundancy

Cisco IOS

```
hostname PE1
interface Loopback0
 ip address 102.102.102.102 255.255.255.255
```

```
interface GigabitEthernet2/4
 service instance 170 ethernet
  encapsulation dot1q 170
  rewrite ingress tag pop 1 symmetric
  xconnect 104.104.104.104 170 encapsulation mpls
   backup peer 106.106.106.106 170170
   mtu 1500
```

Redundant PW configuration




```
7604-2#show xconnect peer 104.104.104.104 vcid 170
Legend:    XC ST=Xconnect State  S1=Segment1 State  S2=Segment2 State
  UP=Up       DN=Down            AD=Admin Down      IA=Inactive
  SB=Standby  HS=Hot Standby     RV=Recovering      NH=No Hardware

XC ST  Segment 1                         S1 Segment 2                         S2
------+---------------------------------+--+--------------------------------+--
UP pri ac   Gi2/4:170(Eth VLAN)          UP mpls 104.104.104.104:170          UP
```

Primary PW in UP state

```
7604-2#show xconnect peer 106.106.106.106 vcid 170170
Legend:    XC ST=Xconnect State  S1=Segment1 State  S2=Segment2 State
  UP=Up       DN=Down            AD=Admin Down      IA=Inactive
  SB=Standby  HS=Hot Standby     RV=Recovering      NH=No Hardware

XC ST  Segment 1                         S1 Segment 2                         S2
------+---------------------------------+--+--------------------------------+--
IA sec ac   Gi2/4:170(Eth VLAN)          UP mpls 106.106.106.106:170170       SB
```

Redundant PW in Standby state

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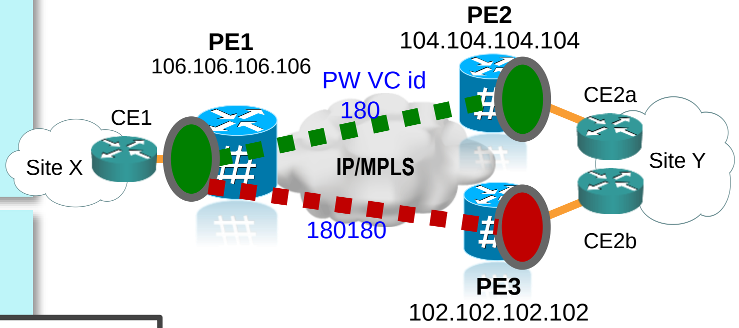
Configuring Pseudowire Redundancy

Cisco IOS XR

```
hostname PE1
interface Loopback0
 ipv4 address 106.106.106.106 255.255.255.255
!
interface GigabitEthernet0/0/0/2.180 l2transport
 encapsulation dot1q 180
 rewrite ingress tag pop 1 symmetric
```




```
l2vpn
 xconnect group Cisco-Live
  p2p xc-sample-6
   interface GigabitEthernet0/0/0/2.180
   neighbor 104.104.104.104 pw-id 180
    pw-class sample-CW-ON
    backup neighbor 102.102.102.102 pw-id 180180
     pw-class sample-CW-ON
```

Redundant PW configuration

```
RP/0/RSP0/CPU0:ASR9000-2#show l2vpn xconnect group Cisco-Live xc xc-sample-6
Sun Apr 15 20:18:50.180 UTC
Legend: ST = State, UP = Up, DN = Down, AD = Admin Down, UR = Unresolved,
        SB = Standby, SR = Standby Ready, (PP) = Partially Programmed

XConnect                   Segment 1                     Segment 2
Group       Name       ST   Description            ST    Description            ST
------------------------   ----------------------------  -----------------------------
Cisco-Live xc-sample-6
                       UP   Gi0/0/0/2.180          UP    104.104.104.104 180    UP
                                                         Backup
                                                         102.102.102.102 180180 SB
----------------------------------------------------------------------------------------
```

Primary PW in UP state
Redundant PW in Standby state

Deployment Use Cases

Data Center Interconnect – ASR 9000

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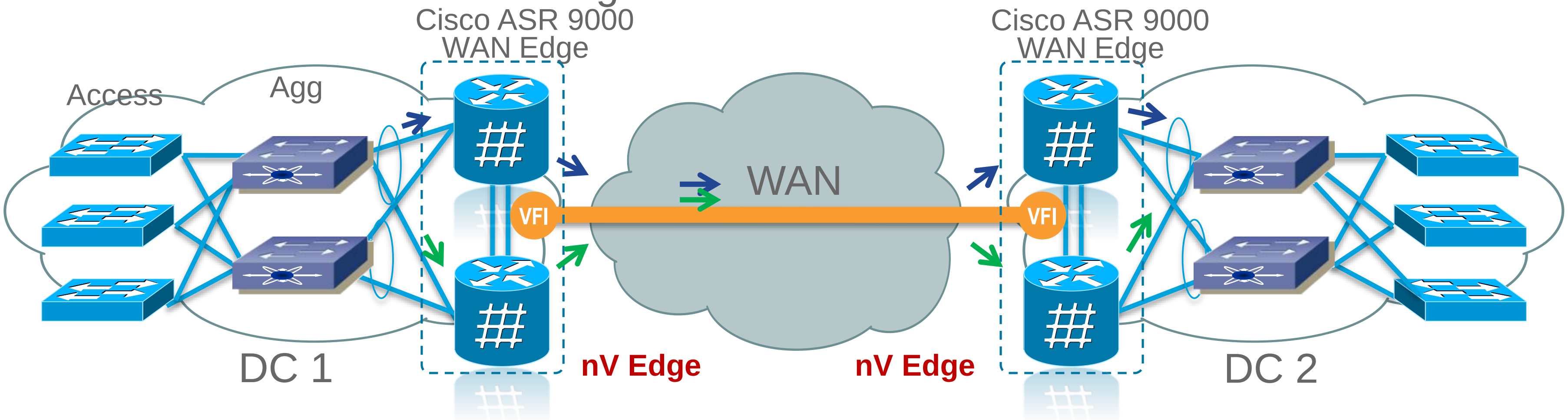
Data Center Interconnect with VPLS

ASR 9000 Use Case 1 – nV Edge

ASR9000 sessions:
BRKARC-2003
BRKSPG-2904



- ASR 9000 as DC WAN Edge provides VPLS with Network Virtualization (nV) for DCI applications
- nV and VPLS provides:
  - Single-Chassis (Virtual) Redundancy solution – Network Virtualization Cluster
  - Access Multi-Homing solution with Multichassis EtherChannel
  - Single control and management plane, distributed data plane – single VFI / single PW between DC pairs
  - Flow-based load balancing over Pseudowire using Flow Aware Transport (FAT) PW
  - Scalability (MAC address table, number of VFIs / PWs)

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Data Center Interconnect with VPLS

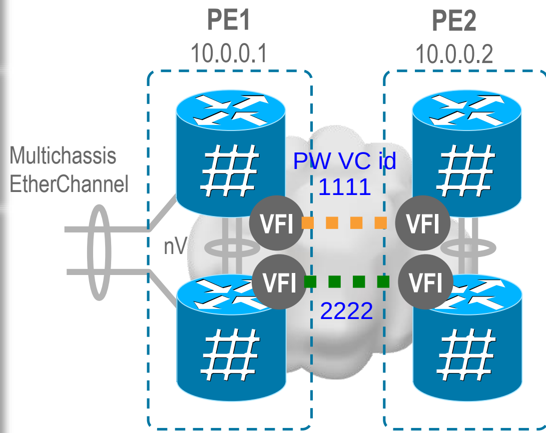
ASR 9000 Use Case 1 – nV Edge Sample Configuration

PE 1

```
hostname PE1
!
interface Loopback0
 ipv4 address 10.0.0.1 255.255.255.255

interface bundle-ethernet1.1 l2transport
 encapsulation dot1q 80
interface bundle-ethernet1.2 l2transport
 encapsulation dot1q 81

l2vpn
 pw-class sample-flow-lb
  encapsulation mpls
   load-balancing
    load-balancing flow-label
!
 bridge group DCI
  bridge-domain bd-80
   interface bundle-ethernet1.1
   vfi vfi1111
    neighbor 10.0.0.2 pw-id 1111
     pw-class sample-flow-lb
!
  bridge-domain bd-81
   interface bundle-ethernet1.2
   vfi vfi2222
    neighbor 10.0.0.2 pw-id 2222
     pw-class sample-flow-lb
```

PE 2

```
hostname PE2
!
interface Loopback0
 ipv4 address 10.0.0.2 255.255.255.255

interface bundle-ethernet1.1 l2transport
 encapsulation dot1q 80
interface bundle-ethernet1.2 l2transport
 encapsulation dot1q 81

l2vpn
 pw-class sample-flow-lb
  encapsulation mpls
   load-balancing
    load-balancing flow-label
!
 bridge group DCI
  bridge-domain bd-80
   interface bundle-ethernet1.1
   vfi vfi1111
    neighbor 10.0.0.1 pw-id 1111
     pw-class sample-flow-lb
!
  bridge-domain bd-81
   interface bundle-ethernet1.2
   vfi vfi2222
    neighbor 10.0.0.1 pw-id 2222
     pw-class sample-flow-lb
```

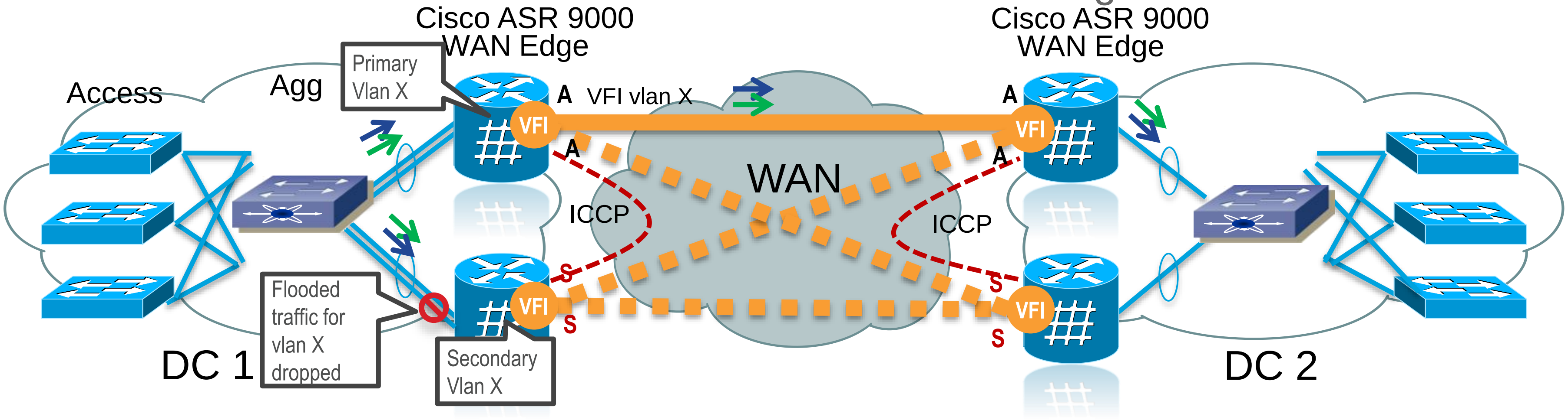


Single PW per VFI/ Vlan

Note: nV cluster configuration not shown
Etherchannel configuration imcomplete

Data Center Interconnect with VPLS

ASR 9000 Use Case 2 – ICCP-based Service Multi-Homing



- ASR 9000 as DC WAN Edge device provides VPLS with service multi-homing for DCI applications
- Service Multi-homing and VPLS provides:
  - Geo-Redundant dual-home DCI layer solution
  - Active / Active per VLAN load balancing
  - Distributed Control / Management / Data Plane
  - Forwarding state coordination via Inter-Chassis Communication Protocol (ICCP)

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Deployment Use Cases

Data Center Interconnect – Catalyst 6500

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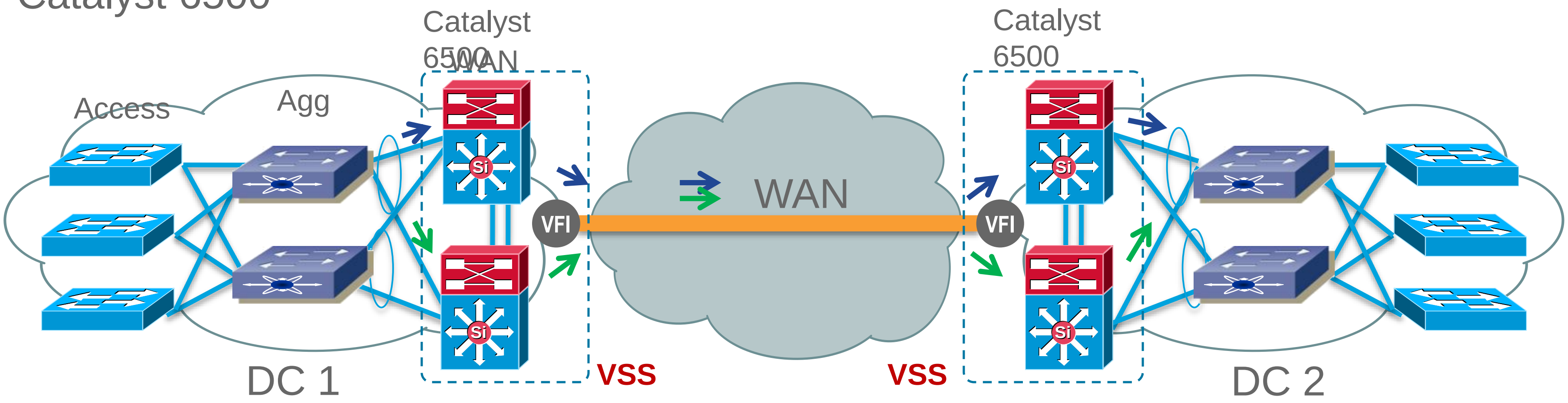
Data Center Interconnect with VPLS

Catalyst 6500



- DC WAN Edge device (Catalyst 6500) implements VPLS with Advanced –VPLS (A-VPLS) for DCI applications
- A-VPLS provides:
  - Single-Chassis (Virtual) Redundancy solution – Virtual Switching System (VSS)
  - Multichassis EtherChannel (MEC)
  - Flow-based load balancing over WAN using Flow Aware Transport (FAT) PW
  - Simplified configuration

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Data Center Interconnect with VPLS

Sample Configuration – Catalyst 6500

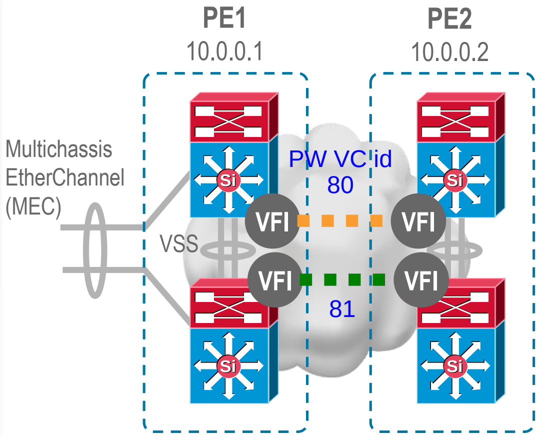
Virtual Ethernet interface modeled as Switchport trunk towards VFIs

PE 1

```
hostname PE1
!
interface Loopback0
 ip address 10.0.0.1 255.255.255.25
!
pseudowire-class sample-class
 encapsulation mpls
 load-balance flow
 flow-label enable

interface virtual-ethernet 1
 transport vpls mesh
  neighbor 10.0.0.2 pw-class sample-class
 switchport
 switchport mode trunk

interface port-channel50
 switchport
 switchport mode trunk
 switchport trunk allowed vlan 80,81
```

PE 2

```
hostname PE2
!
interface Loopback0
 ip address 10.0.0.2 255.255.255.255
!
pseudowire-class sample-class
 encapsulation mpls
 load-balance flow
 flow-label enable

interface virtual-ethernet 1
 transport vpls mesh
  neighbor 10.0.0.1 pw-class sample-class
 switchport
 switchport mode trunk

interface port-channel50
 switchport
 switchport mode trunk
 switchport trunk allowed vlan 80,81
```



Single PW per Vlan per VSS pair

Note: Complete Virtual Switching System (VSS) / Multichassis EtherChannel (MEC) configuration not shown

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TOMORROW starts here.