Cisco live!

What You Make Possible
E-VPN & PBB-EVPN: the Next Generation of MPLS-based L2VPN

Samer Salam
Agenda

- Introduction
- Concepts
- BGP Routes and Attributes
- E-VPN
- PBB-EVPN
- PBB-EVPN IOS-XR Implementation
- Summary
Introduction
Overview

- PEs run Multi-Protocol BGP to advertise & learn L2 address information over Core.
- Learning on PE Access Circuits via:
  - Data-plane transparent learning, or
  - Control-plane (DHCP, ARP, IS-IS)
- No pseudowires
  - Unicast: use MP2P tunnels
  - Multicast: use ingress replication over MP2P tunnels or use LSM
Requirements for Next Generation L2VPNs

- **Multi-homing / All-active Redundancy**
  - Flow Based Load Balancing on PEs
  - Flow Based Multi-pathing in PSN
  - Geo-redundancy and Flexible Redundancy Grouping

- **Simplified Provisioning and Operation**
  - Core Auto-Discovery
  - Access Multi-homing Auto-Discovery
  - New Service Interfaces

- **Optimal Multicast with LSM**
  - P2MP Trees
  - MP2MP Trees

- **Fast Convergence**
  - Link/Port/Node Failure
  - MAC Mobility

- **Support Flexible Forwarding Policies and Topologies**

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- **Scalable for SP Virtual Private Cloud services:**
  - Support O(1Million) MAC Addresses per DC
  - Confinement of C-MAC Learning

- **Support C-MAC (VM) Mobility with MAC Summarization**

- **Seamless interworking between TRILL / 802.1Qaq / 802.1Qbp and Legacy DC**
  - Guarantee C-MAC Transparency on WAN Edge PE.

- **Fast Convergence**
  - Avoiding C-MAC address Flushing

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VPLS  
- E-VPN
Multi-Homing and Load-balancing

• All-Active Redundancy to maximize bisectional bandwidth.
• Load-balance traffic among PEs and exploit core ECMP based on flow entropy (flow can be L2/L3/L4 or combinations).
• Support geo-redundant PE nodes with optimal forwarding.
• Flexible Redundancy Grouping of PEs.
Optimal Forwarding

- Optimal forwarding for unicast and multicast.
- Shortest path – no triangular forwarding at steady-state.
- Loop-Free & Echo-Free Forwarding.
- Avoid duplicate delivery of flooded traffic.
- Multiple multicast tunneling options:
  - Ingress Replication
  - P2MP LSM tunnels
  - MP2MP
MAC Address Scalability at the PE

- Server Virtualization fueling growth in MAC Address scalability:
  - 1 VM = 1 MAC address.
  - 1 server = 10’s or 100’s of VMs
- MAC address scalability most pronounced on Data Center WAN Edge for Layer 2 extensions over WAN.
  - Example from a live network: 1M MAC addresses in a single SP data center
Seamless Interworking with TRILL, SPB & IEEE 802.1Qbp

• Support seamless inter-working of classical Ethernet & next-generation data center solutions (i.e. TRILL, IEEE 802.1Qaq or 802.1Qbp).

• Requirements:
  – Control Plane separation between DC sites
  – C-MAC address transparency on the PEs
  – Resilient DC to PE connectivity
E-VPN Instance (EVI) & Service Interfaces

- E-VPN Instance (EVI) identifies a VPN in the MPLS/IP network.
- EVI may encompass one or more bridge-domains, depending on PE’s service interface type:

  - **Port Based Service Interface**
    - All CE-VLANs

  - **VLAN Based Service Interface**
    - VLAN X
    - VLAN Y

  - **VLAN Bundling Service Interface**
    - CE-VLAN subset

  - **VLAN Aware Bundling Service Interface**
    - CE-VLAN subset

  - **New!**
Ethernet Segment

**Definition**

- Ethernet Segment is a ‘site’ connected to one or more PEs.
- Ethernet Segment could be a single **device** (i.e. CE) or an entire **network**.
  - Single-Homed Device (SHD)
  - Multi-Homed Device* (MHD) using Ethernet Multi-chassis Link Aggregation Group
  - Single-Homed Network (SHN)
  - Multi-Homed Network* (MHN)
- Uniquely identified by a 10-byte global Ethernet Segment Identifier (**ESI**).

*: Includes Dual-Homed
**Ethernet Segment**

**ESI Auto-Sensing**

**MHD with Multi-chassis LAG**
- ESI is auto-discovered via LACP.
- ESI is encoded using the CE’s LACP parameters:

<table>
<thead>
<tr>
<th>System Priority</th>
<th>System MAC Address</th>
<th>Port Key</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 bytes</td>
<td>6 bytes</td>
<td>2 bytes</td>
</tr>
</tbody>
</table>

**MHN with MST**
- ESI is auto-discovered via MST BPDU snooping.
- ESI is encoded using the IST’s root parameters:

<table>
<thead>
<tr>
<th>Bridge Priority</th>
<th>Root Bridge MAC</th>
<th>0x0000</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 bytes</td>
<td>6 bytes</td>
<td>2 bytes</td>
</tr>
</tbody>
</table>
Split Horizon

For Ethernet Segments – E-VPN

Challenge:
How to prevent flooded traffic from echoing back to a multi-homed Ethernet Segment?

- PE advertises in BGP a split-horizon label (ESI MPLS Label) associated with each multi-homed Ethernet Segment.
- Split-horizon label is only used for multi-destination frames (Unknown Unicast, Multicast & Broadcast).
- When an ingress PE floods multi-destination traffic, it encodes the Split-Horizon label identifying the source Ethernet Segment in the packet.
- Egress PEs use this label to perform selective split-horizon filtering over the attachment circuit.
Split Horizon

For Ethernet Segments – PBB-EVPN

**Challenge:**
How to prevent flooded traffic from echoing back to a multi-homed Ethernet Segment?

- PEs connected to the same MHD use the same B-MAC address for the Ethernet Segment
  - 1:1 mapping between B-MAC and ESI (for All-Active Redundancy with flow-based LB)
- Disposition PEs check the B-MAC source address for Split-Horizon filtering
  - Frame not allowed to egress on an Ethernet Segment whose B-MAC matches the B-MAC source address in the PBB header.
Split Horizon

For Core Tunnels

Challenge:
How to prevent flooded traffic from looping back over the core?

- Traffic received from an MPLS tunnel over the core is never forwarded back to the MPLS core.
- This is similar to the VPLS split-horizon filtering rule.
Designated Forwarder (DF)

DF Election

Challenge:
How to prevent duplicate copies of flooded traffic from being delivered to a multi-homed Ethernet Segment?

- PEs connected to a multi-homed Ethernet Segment discover each other via BGP.
- These PEs then elect among them a Designated Forwarder responsible for forwarding flooded multi-destination frames to the multi-homed Segment.
- DF Election granularity can be:
  - Per Ethernet Segment (Single PE is the DF)
  - Per EVI (E-VPN) or I-SID (PBB-EVPN) on Ethernet Segment (Multiple DFs for load-balancing)
Designated Forwarder (DF)

DF Filtering

MHD All-Active with Per-Flow Load Balancing

Filtering Direction: Core to Segment
Filtered Traffic: Flooded multi-destination

MHD All-Active with Per-EVI Load Balancing & MHN

Filtering Direction: • Core to Segment
• Segment to Core
Filtered Traffic: • Flooded multi-destination
• Unicast

Legend
Multi-destination Traffic
Unicast Traffic
Aliasing

E-VPN

Challenge:
How to load-balance traffic towards a multi-homed device across multiple PEs when MAC addresses are learnt by only a single PE?

- PEs advertise in BGP the ESIs of local multi-homed Ethernet Segments.
  - All-Active Redundancy Mode indicated
- When PE learns MAC address on its AC, it advertises the MAC in BGP along with the ESI of the Ethernet Segment from which the MAC was learnt.
- Remote PEs can load-balance traffic to a given MAC address across all PEs advertising the same ESI.
Aliasing

PBB-EVPN

Challenge:
How to load-balance traffic towards a multi-homed device across multiple PEs when MAC addresses are learnt by only a single PE?

- PEs connected to the same MHD use the same B-MAC address for the Ethernet Segment
  - 1:1 mapping between B-MAC and ESI (for All-Active Redundancy with flow-based LB)
- PEs advertise their B-MAC addresses independent of the C-MAC learning state.
- Remote PEs can load-balance traffic to a given C-MAC across all PEs advertising the same associated B-MAC.
Backup Path

Challenge:
How to identify PEs that have a backup path to a multi-homed Ethernet Segment?

- PEs advertise in BGP connectivity to ESIs associated with local multi-homed Ethernet Segments.
  - Active/Standby Redundancy Mode is indicated
- When PE learns a MAC address on its AC, it advertises the MAC in BGP along with the ESI of the Ethernet Segment from which the MAC was learnt.
- Remote PEs will install:
  - active path to the PE that advertised both MAC Address & ESI
  - backup path to the PE that advertised ESI only
MAC Mass-Withdraw

Challenge:
How to inform remote PEs of a failure affecting many MAC addresses quickly while the control-plane re-converges?

• PEs advertise two sets of information:
  – MAC addresses along with the ESI from the address was learnt
  – Connectivity to ESI(s)
• If a PE detects a failure impacting an Ethernet Segment, it withdraws the route for the associated ESI.
  – Remote PEs remove failed PE from the path-list for all MAC addresses associated with an ESI.
  – This effectively is a MAC ‘mass-withdraw’ function.
Challenge:
How to reduce ARP broadcasts over the MPLS/IP network, especially in large scale virtualized server deployments?

- Construct ARP caches on the E-VPN PEs and synchronize them either via BGP or data-plane snooping.
- PEs act as ARP proxies for locally attached hosts, thereby preventing repeated ARP broadcast over the MPLS/IP network.
BGP Routes and Attributes
### BGP Routes

#### Overview

- (PBB) E-VPN defines a single new BGP NLRI used to carry all E-VPN routes.
- The NLRI has a new SAFI (70).
- (PBB) E-VPN speakers must first exchange BGP capability for E-VPN AFI / SAFI per RFC4760.

<table>
<thead>
<tr>
<th>Route Type</th>
<th>Length</th>
<th>Route Type Specific</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 byte</td>
<td>1 byte</td>
<td>Variable</td>
</tr>
</tbody>
</table>

1. Ethernet Auto-Discovery (AD) Route
2. MAC Advertisement Route
3. Inclusive Multicast Route
4. Ethernet Segment Route
# BGP Routes

## Route Types and Usage

<table>
<thead>
<tr>
<th>Route</th>
<th>Usage</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethernet A-D Route</td>
<td>• MAC Mass-Withdraw</td>
<td>E-VPN only</td>
</tr>
<tr>
<td></td>
<td>• Aliasing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Advertising Split-Horizon Labels</td>
<td></td>
</tr>
<tr>
<td>MAC Advertisement Route</td>
<td>• Advertise MAC Address Reachability</td>
<td>E-VPN &amp; PBB-EVPN</td>
</tr>
<tr>
<td></td>
<td>• Advertise IP/MAC Bindings</td>
<td></td>
</tr>
<tr>
<td>Inclusive Multicast Route</td>
<td>Multicast Tunnel Endpoint Discovery</td>
<td>E-VPN &amp; PBB-EVPN</td>
</tr>
<tr>
<td>Ethernet Segment Route</td>
<td>• Redundancy Group Discovery</td>
<td>E-VPN &amp; PBB-EVPN</td>
</tr>
<tr>
<td></td>
<td>• DF Election</td>
<td></td>
</tr>
</tbody>
</table>
## BGP Routes

### Route Attributes and Usage

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Usage</th>
<th>Route Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESI MPLS Label Extended Community</td>
<td>• Encode Split-Horizon Label for Ethernet Segment.</td>
<td>Ethernet A-D Route</td>
</tr>
<tr>
<td></td>
<td>• Indicate Redundancy Mode (Active/Standby vs. All-Active)</td>
<td></td>
</tr>
<tr>
<td>ES-Import Extended Community</td>
<td>• Limit the import scope of the Ethernet Segment routes.</td>
<td>Ethernet Segment Route</td>
</tr>
<tr>
<td>MAC Mobility Extended Community</td>
<td>• E-VPN: Indicate that a MAC address has moved from one segment to another across PEs.</td>
<td>MAC Advertisement Route</td>
</tr>
<tr>
<td></td>
<td>• PBB-EVPN: Signal C-MAC address flush notification</td>
<td></td>
</tr>
<tr>
<td>Default Gateway Extended Community</td>
<td>• Indicate the MAC/IP bindings of a gateway</td>
<td>MAC Advertisement Route</td>
</tr>
</tbody>
</table>
E-VPN Startup Sequences
E-VPN Startup Sequence

**Segment Auto-Discovery**
- Ethernet Segment ID (ESI) Auto-Sensing
- Redundancy Group Membership Auto-Discovery
- Ethernet Segment Reachability Advertisement

**VPN Auto-Discovery**
- Multicast Tunnel ID / Endpoint Discovery
E-VPN Startup Sequence (cont.)

ESI Auto-Sensing

Segment Auto-Discovery

Ethernet Segment ID (ESI) Auto-Sensing

ESI (10B) can be auto-generated* from CE’s LACP information → Concatenation of CE’s LACP System Priority + System ID + Port Key

Example: 0000.0011.0022.0033.0018

CE LACP info:
- LACP System Priority (2B) e.g. 0000
- LACP System ID (MAC) (6B) e.g. 0011.0022.0033
- LACP Port Key (2B) e.g. 0018

(*) ESI can also be manually configured
E-VPN Startup Sequence (cont.)

BGP Ethernet Segment Route

Segment Auto-Discovery

Ethernet Segment ID (ESI) Auto-Sensing

Redundancy Group Membership Auto-Discovery

PE 1 Eth Segment Route
RD = RD10
ESI = ESI1
ES-Import ext. comm. (e.g. 0011.0022.0033)

MAC address portion of ESI (6B)

PE 2 Eth Segment Route
RD – RD unique per advertising PE
RD = RD20
ESI = ESI1
ES-Import ext. comm. (e.g. 0011.0022.0033)
E-VPN Startup Sequence

Designated Forwarder (DF) Election*

Segment Auto-Discovery

Ethernet Segment ID (ESI) Auto-Sensing

Redundancy Group Membership Auto-Discovery

Module Operation

<table>
<thead>
<tr>
<th>E-VPN ID (EVI)</th>
<th>EVI mod N (N = # of PEs) (e.g. EVI mod 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>101</td>
<td>1</td>
</tr>
<tr>
<td>102</td>
<td>0</td>
</tr>
<tr>
<td>103</td>
<td>1</td>
</tr>
</tbody>
</table>

Result of modulo operation is used to determine DF and BDF status

Module Operation

<table>
<thead>
<tr>
<th>PE Ordered List</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

Example: PE1 DF for EVIs 100, 102
PE1 BDF for EVIs 101, 103

Example: PE2 DF for EVIs 101, 103
PE2 BDF for EVIs 100, 102

Ordered List of discovered PEs starting from zero (lowest IP add)

Exchange of Ethernet Segment Routes

MPLS

PE1 PE2 PE3 PE4

CE1 CE3

Example: PE1 DF for EVIs 100, 102
PE1 BDF for EVIs 101, 103

(*) DF election with Service Carving shown (i.e. one DF per EVI in the segment)
E-VPN Startup Sequence (cont.)

BGP Ethernet AD Routes – Per-ESI

- **Segment Auto-Discovery**
  - Ethernet Segment ID (ESI) Auto-Sensing
  - Redundancy Group Membership Auto-Discovery
  - Ethernet Segment Reachability Advertisement

- **Per-ESI adv.**

- **Flags** – Redundancy mode - All-Active or Active-Standby
- **ESI MPLS Label** – used by local PEs for split-horizon. Downstream assigned (ingress replication) or Upstream assigned (P2MP LSP)
- **Multiple RTs** – all RTs for EVIs present in the segment

- **PE 1 Eth A-D Route (Per-ESI)**
  - RD = RD10
  - ESI = ESI1
  - ESI MPLS Label ext. comm.
    - Flag (e.g. All-Active)
    - Label (e.g. LESI11)
    - RT ext. community
      - RT-a, RT-b, RT-c, RT-d

- **RD** – RD unique per advertising PE

- **PE 2 Eth A-D Route (Per-ESI)**
  - RD = RD20
  - ESI = ESI1
  - ESI MPLS Label ext. comm.
    - Flag = All-Active
    - Label (e.g. LESI21)
    - RT ext. community
    - RT-a, RT-b, RT-c, RT-d

- **PE1**
- **PE2**
- **PE3**
- **PE4**
- **PE 1 Eth A-D Route (Per-ESI)**
  - RD = RD10
  - ESI = ESI1
  - ESI MPLS Label ext. comm.
    - Flag (e.g. All-Active)
    - Label (e.g. LESI11)
    - RT ext. community
    - RT-a, RT-b, RT-c, RT-d

- **PD – RD unique per advertising PE

- **PE 2 Eth A-D Route (Per-ESI)**
  - RD = RD20
  - ESI = ESI1
  - ESI MPLS Label ext. comm.
    - Flag = All-Active
    - Label (e.g. LESI21)
    - RT ext. community
    - RT-a, RT-b, RT-c, RT-d

- **CE1**
- **CE3**

- **MPLS**

- **Redundancy mode** – All-Active or Active-Standby
- **Multiple RTs** – all RTs for EVIs present in the segment
- **Downstream** assigned (P2MP LSP)
E-VPN Startup Sequence (cont.)

BGP Ethernet AD Routes – Per-EVI

Segment Auto-Discovery

- Ethernet Segment ID (ESI) Auto-Sensing
- Redundancy Group Membership Auto-Discovery
- Ethernet Segment Reachability Advertisement
  - Per-ESI adv.
  - Per-EVI adv.

Aliasing MPLS Label – used by remote PEs to load-balance among local PEs

RD = RD-1a
ESI = ESI1
Label (e.g. LES11)
RT ext. community
RT-a

RD – RD unique per advertising PE per EVI

PE 1 Eth A-D Route (Per-EVI)
- RD = RD-1a
- ESI = ESI1
- Label (e.g. LES11)
- RT ext. community
- RT-a

PE 2 Eth A-D Route (Per-EVI)
- RD = RD-2a
- ESI = ESI1
- Label (e.g. LES21)
- RT ext. community
- RT-a

PE3 / PE4 RIB

Path List

VPN MAC ESI
- NH
RT-a - ES1
PE1
PE2
E-VPN Startup Sequence (cont.)

BGP Inclusive Multicast Route

VPN Auto-Discovery

Multicast Tunnel ID / Endpoint Discovery

(1) Mcast MPLS label is not assigned with Inclusive Trees (P2MP LSP)

PE 1 Inclusive Multicast Route
- RD = RD-1a
- PMSI Tunnel Attribute
- Tunnel Type (e.g., Ing. Repl.)
- Label (e.g., XXXX)
- RT ext. community
- RT-a

PE 2 Inclusive Multicast Route
- RD = RD-2a
- PMSI Tunnel Attribute
- Tunnel Type (e.g., Ing. Repl.)
- Label (e.g., YYYY)
- RT ext. community
- RT-a

PE1

PMSI - P-Multicast Service Interface
BUM – Broadcast / Unknown Unicast / Multicast

CE1

MPLS

PE3

CE3

PE2

PE4

RT – RT associated with a given EVI
RD – RD unique per advertising PE per EVI
Mcast MPLS Label – used to transmit BUM traffic - downstream assigned (ing. repl.) or upstream assigned (Aggregate Inclusive P2MP LSP^)
Tunnel Type – Ingress Replication or P2MP LSP
RD = RD-1a
PMSI Tunnel Attribute
Tunnel Type (e.g., Ing. Repl.)
Label (e.g., XXXX)
RT ext. community
RT-a
E-VPN Life of a Packet
Life of a Packet

Ingress Replication – Multi-destination Traffic Forwarding

During start-up sequence, PE2 sent Per-ESI Ethernet AD route with ESI MPLS label (split-horizon) (see below)

PE 2 Eth A-D Route (Per-ESI)
RD = RD20
ESI = ESI1
ESI MPLS Label ext. comm.
Redund. Flag = All-Active
Label = L5
RT ext. community
RT-a, RT-b, RT-c, RT-d

PE 1, PE2, PE3, PE4 sent Inclusive Multicast route which include Mcast label

PE1 receives broadcast traffic from CE1. PE1 forwards it using ingress replication – 3 copies created

PSN MPLS label to reach PE3

Mcast MPLS Label assigned by PE3 for incoming BUM traffic on a given EVI

PE3 – as DF, it forwards BUM traffic towards segment

PE2 – drops BUM traffic originated on ES1

PE4 – non-DF for given EVI drops BUM traffic

PE1, PE2, PE3, PE4 sent Inclusive Multicast route which include Mcast label

During start-up sequence, PE2 sent Per-ESI Ethernet AD route with ESI MPLS label (split-horizon) (see below)

PE 2 Eth A-D Route (Per-ESI)
RD = RD20
ESI = ESI1
ESI MPLS Label ext. comm.
Redund. Flag = All-Active
Label = L5
RT ext. community
RT-a, RT-b, RT-c, RT-d

During start-up sequence, PE2 sent Per-ESI Ethernet AD route with ESI MPLS label (split-horizon) (see below)

PE 2 Eth A-D Route (Per-ESI)
RD = RD20
ESI = ESI1
ESI MPLS Label ext. comm.
Redund. Flag = All-Active
Label = L5
RT ext. community
RT-a, RT-b, RT-c, RT-d
Life of a Packet (cont.)

Unicast Traffic Forwarding

MP2P VPN Label – downstream allocated label used by other PEs to send traffic to advertised MAC

PE1 MAC Route
- RD = RD-1a
- ESI = ESI1
- MAC = M1
- Label = L1

RT ext. community

MAC advertised by route

PE1

PE3

PE2

PE4

VID 100
SMAC: M1
DMAC: F.F.F

CE1

MPLS

CE3

PE1

PE3

PE2

PE4

VID 100
SMAC: M2
DMAC: M1

MPLS

PSN MPLS label to reach PE1

MP2P VPN Label assigned by PE1 for incoming traffic for the target EVI

PE3 forwards traffic destined to M1 based on RIB information (PE1)

PE3 RIB

Path List

VPN  MAC  ESI
NH
RT-a  M1  ES1  PE1

MPLS

PE1

PE3

PE2

PE4
Life of a Packet (cont.)

Unicast Forwarding and Aliasing

MP2P VPN Label – downstream allocated label used by other PEs to send traffic to advertised MAC

During start-up sequence, PE1 sent Per-EVI Ethernet AD route

PE 2 Eth A-D Route (Per-EVI)
- RD = RD-2a
- ESI = ESI1
- Label = L1
- RT ext. community = RT-a

During start-up sequence, PE2 sent Per-EVI Ethernet AD route (see below)

PE1 MAC Route
- RD = RD-1a
- ESI = ESI1
- MAC = M1
- Label = L1

MAC advertised by route

PE1, PE3, PE4 RIB

<table>
<thead>
<tr>
<th>VPN</th>
<th>MAC</th>
<th>ESI</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PE1</td>
<td>M1</td>
<td>ESI1</td>
</tr>
<tr>
<td>PE2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Path List

- PE3, PE4 RIB
- PE3 forwards traffic on a flow (flow 1) based on RIB information (towards PE1)
- PE3 forwards traffic on a flow (flow 2) based on RIB information (towards PE2)

PSN MPLS label to reach PE1

MP2P VPN Label assigned by PE1 for incoming for target EVI

PSN MPLS label to reach PE2

Aliasing MPLS Label assigned by remote PEs to load-balance among local PEs
E-VPN Operational and Failure Scenarios
E-VPN Operational Scenarios

MAC Mobility

1. PE1 advertises MAC route for M1. Route may include MAC mobility community.

2. PE3 / PE4 install M1 route towards PE1.

3. Host M1 moves from CE1 to CE3's location.

4. After host sends traffic at new location, PE2 now adv MAC route for M1 incrementing sequence # in MAC mobility community.

5. PE1 withdraws its M1 route and installs a new one pointing to PE3.

PE1 MAC Route
- RD = RD-1a
- ESI = ESI1
- MAC = M1
- Label = L1
- MAC Mobility ext. community
  - Seq. Num = 1
- RT ext. community
  - RT-a

PE3 MAC Route
- RD = RD-3a
- ESI = ESI2
- MAC = M1
- Label = L3
- MAC Mobility ext. community
  - Seq. Num = 2

Path List
- PE1
- PE3

VPN / MAC / ESI
- PE1 / PE2 RIB
  - VPN
  - MAC
  - ESI
- RT-a M1 ES1 PE1
- RT-a M1 ES2 PE3
E-VPN Failure Scenarios / Convergence

Link / Segment Failure – Active/Active per Flow

1. PE1 detects failure of one of its attached segments
2. PE1 withdraws Per-ESI Ethernet AD route for failed segment
3. PE1 withdraws Ethernet Segment Route
4. Mass withdrawal - PE3 / PE4 remove PE1 from path list for all MAC addresses of failed segment (ES1)
5. PE2 recalculates DF/BDF. Becomes DF for all EVIs on segment
6. PE2 adv. M1 MAC route after CE traffic is hashed towards PE2
7. PE1 withdraws individual MAC advertisement routes related to failed segment
E-VPN Failure Scenarios / Convergence

PE Failure

1. PE1 experiences a node failure (e.g. power failure)

2. BGP RR / PE2 detects BGP session time-out with PE1

2. BGP RR / PE3 detects BGP session time-out with PE1

3. PE3 / PE4 invalidate routes from PE1

4. PE2 reruns DF election. Becomes DF for all EVIs on segment

5. PE2 adv. M1 MAC route after CE traffic is hashed towards PE2

6. PE3 / PE4 will forward M1 traffic towards PE2

<table>
<thead>
<tr>
<th>PE3, PE4 RIB</th>
<th>Path List</th>
</tr>
</thead>
<tbody>
<tr>
<td>VPN</td>
<td>MAC</td>
</tr>
<tr>
<td>NH</td>
<td>PE1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PE3, PE4 RIB</th>
<th>Path List</th>
</tr>
</thead>
<tbody>
<tr>
<td>VPN</td>
<td>MAC</td>
</tr>
<tr>
<td>NH</td>
<td>PE2</td>
</tr>
</tbody>
</table>
PBB-EVPN Startup Sequences
PBB-EVPN Startup Sequence

**Segment Auto-Discovery**
- ESI and B-MAC Auto-Sensing
- Redundancy Group Membership Auto-Discovery
- Backbone MAC (B-MAC) Reachability Advertisement

**VPN Auto-Discovery**
- Multicast Tunnel ID / Endpoint Discovery
**PBB-EVPN Startup Sequence (cont.)**

### ESI and B-MAC Auto-Sensing

#### Segment Auto-Discovery

ESI and B-MAC Auto-Sensing

ESI (10B) can be auto-generated* from CE's LACP information -> concatenation of CE's LACP System Priority + Sys ID + Port Key

Example: 0000.0011.0022.0033.0018

---

LACP PDU exchange

**CE LACP info:**
- LACP System ID (MAC) (6B)
  - e.g. 0011.0022.0033
- LACP System Priority (2B)
  - e.g. 0000
- LACP Port Key (2B)
  - e.g. 0018

---

Source B-MAC used at PBB-EVPN PE on a given ESI can be auto-generated* from CE's LACP information -> CE's LACP System ID MAC with U/L** (Universal / Locally Administered) bit flipped

Example: 0211.0022.0033

---

(*): ESI and B-MAC can also be manually configured

(**): U/L is second-least-significant bit of most significant byte
PBB-EVPN Startup Sequence (cont.)

BGP Ethernet Segment Route

Segment Auto-Discovery

ESI and B-MAC Auto-Sensing

Redundancy Group Membership Auto-Discovery

MAC address portion of ESI (6B)

RD – RD unique per advertising PE

PE 1 Eth Segment Route

RD = RD10
ESI = ESI1
ES-Import ext. comm.
e.g. 0011.0022.0033

PE 2 Eth Segment Route

RD = RD20
ESI = ESI1
ES-Import ext. comm.
e.g. 0011.0022.0033

PE1

PE2

PE3

PE4

CE1

CE3

MPLS
**PBB-EVPN Startup Sequence**

**Designated Forwarder (DF) Election**

### Segment Auto-Discovery

- ESI and B-MAC Auto-Sensing
- Redundancy Group Membership Auto-Discovery

### Modulo Operation

<table>
<thead>
<tr>
<th>I-SID</th>
<th>I-SID mod N (N = # of PEs)</th>
<th>PE Ordered List</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>101</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>102</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>103</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Result of modulo operation is used to determine DF and BDF status.

### PE Ordered List

<table>
<thead>
<tr>
<th>Position</th>
<th>PE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>PE1</td>
</tr>
<tr>
<td>1</td>
<td>PE2</td>
</tr>
</tbody>
</table>

Example: PE1 DF for I-SIDs 100, 102 PE1 BDF for I-SIDs 101, 103

(*) DF election with Service Carving shown (i.e. one DF per I-SID in the segment)

Exchange of Ethernet Segment Routes

DF – Designated Forwarder
BDF – Backup Designated Forwarder
I-SID – PBB 24-bit Service Instance ID

Ordered List of discovered PEs starting from zero (lowest IP add)
PBB-EVPN Startup Sequence (cont.)

BGP MAC Advertisement Route (B-MAC)

Segment Auto-Discovery

- ESI and B-MAC Auto-Sensing
- Redundancy Group Membership Auto-Discovery
- Backbone MAC (B-MAC) Reachability Advertisement

MP2P VPN Label – downstream allocated label used by other PEs to send traffic to advertised (MAC,EVI)

PE1 MAC Route
- RD = RD-1a
- ESI = MAX_ESI
- MAC = B-M1
- Label = L1

RT ext. community
- RT-a

PE2 MAC Route
- RD = RD-2a
- ESI = 1
- MAC = B-M1
- Label = L2

RT ext. community
- RT-a

PE3 / PE4 RIB
- VPN
- MAC
- ESI
- Label = L2
- RT ext. community
- RT-a

Path List
- NH
- PE1
- PE2

CE1

CE3

RD – RD unique per advertising PE per EVI

ESI – reserved ESI indicates advertised MAC is a B-MAC

B-MAC advertised by route

Label = L1

PE1

PE2

PE3

PE4

RD

ESI

MAC

VPN

Path List

MPLS

B-M1

B-M2

B-M1

B-M2

B-M1

B-M2

RD – RD unique per advertising PE per EVI

ESI – reserved ESI indicates advertised MAC is a B-MAC

B-MAC advertised by route
PBB-EVPN Startup Sequence

BGP Inclusive Multicast Route

VPN Auto-Discovery

Multicast Tunnel ID / Endpoint Discovery

(1) Mcast MPLS label is not set for Inclusive Trees (P2MP LSP)
PBB-EVPN Life of a Packet
**Life of a Packet**

**Ingress Replication – Multi-destination Traffic Forwarding**

During start-up sequence, PE1, PE2, PE3, PE4 sent Inclusive Multicast route which include Mcast label.

PE1 receives broadcast traffic from CE1, PE1 adds PBB encapsulation and forwards it using ingress replication – 3 copies created.

PSN MPLS label to assigned by PE3 for incoming BUM traffic on a given EVI.

PE3 – as DF, it forwards BUM traffic towards segment.

PE4 – non-DF for given I-SID drops BUM traffic.

Data-plane based MAC learning for C-MAC / B-MAC association.

PE2 – drops BUM traffic originated on same source B-MAC (B-M1).

Mcast MPLS Label – used to transmit BUM traffic - downstream assigned (for ingress replication).

**PE 2 Inclusive Multicast Route**
- RD = RD-2a
- PMSI Tunnel Attribute
- Tunnel Type = Ing. Repl.
- Label = L2
- RT ext. community
- RT-a

**Mcast MPLS Label**
- Used to transmit BUM traffic - downstream assigned (for ingress replication).

**PE3 MAC Table**
- I-SID xyz
- C-MAC: B-MAC
  - M1: B-M1

**PE3 MAC Table**
- I-SID xyz
- C-MAC: B-MAC
  - M1: B-M1
Life of a Packet (cont.)

Unicast Traffic Forwarding

MP2P VPN Label – downstream allocated label used by other PEs to send traffic to advertised MAC

During start-up sequence, PE1 & PE2 advertised MAC routes for B-MAC (B-M1)

<table>
<thead>
<tr>
<th>PE1 MAC Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>RD = RD-1a</td>
</tr>
<tr>
<td>ESI = 1</td>
</tr>
<tr>
<td>MAC = B-M1</td>
</tr>
<tr>
<td>Label = L1</td>
</tr>
<tr>
<td>RT ext. community</td>
</tr>
</tbody>
</table>

MAC advertised by route

PSN MPLS label to reach PE1

MP2P VPN Label assigned by PE1 for incoming traffic for the target EVI

PE3 forwards traffic destined to M1 using B-MAC B-M1 towards PE1

<table>
<thead>
<tr>
<th>PE3 RIB</th>
</tr>
</thead>
<tbody>
<tr>
<td>VPN</td>
</tr>
<tr>
<td>MAC</td>
</tr>
<tr>
<td>ESI</td>
</tr>
<tr>
<td>RT-a</td>
</tr>
<tr>
<td>B-M1</td>
</tr>
<tr>
<td>n/a</td>
</tr>
</tbody>
</table>

Path List

<table>
<thead>
<tr>
<th>NH</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE1</td>
</tr>
<tr>
<td>PE2</td>
</tr>
</tbody>
</table>

PE3 MAC Table

<table>
<thead>
<tr>
<th>I-SID xyz</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-MAC</td>
</tr>
<tr>
<td>B-MAC</td>
</tr>
</tbody>
</table>

Data-plane based MAC learning for C-MAC / B-MAC association

During start-up sequence, PE1 & PE2 advertised MAC routes for B-MAC (B-M1)
Life of a Packet (cont.)

Unicast Traffic Forwarding and Aliasing

MP2P VPN Label – downstream allocated label used by other PEs to send traffic to advertised MAC

PE1 MAC Route
- RD = RD-1a
- ESI = 1
- MAC = B-M1
- Label = L1

MAC advertised by route

During start-up sequence, PE1 & PE2 advertised MAC route for B-MAC (B-M1)

PE2 MAC Route
- RD = RD-2a
- ESI = 1
- MAC = B-M1
- Label = L2

RT ext. community
- RT-a

PE3 RIB
- VPN
- MAC
- ESI
- NH
- PE1
- C-MAC
- B-MAC
- PE2

Path List
- I-SID xyz

PE3 MAC Table
- PSN MPLS label to reach PE1
- PE3 forwards traffic on a flow (flow 1) to M1 using B-MAC B-M1 towards PE1

PSN MPLS label to reach PE2
- MP2P VPN Label assigned by PE2 for incoming traffic for target EVI

Data-plane based MAC learning for C-MAC / B-MAC association

VPN MPLS label assigned by PE1 for incoming traffic for target EVI

PE3 forwards traffic on a flow (flow 2) to M1 using B-MAC B-M1 towards PE2

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Life of a Packet (cont.)

Active / Active Load Balancing from CE

MP2P VPN Label – downstream allocated label used by other PEs to send traffic to advertised MAC

PE3 MAC Route
RD = RD-3a
ESI = 0
MAC = B-M3
Label = L3

RT ext. community
RT-a

ESI == 0 used for Single Home Device
MAC advertised by route

PE1 forwards traffic to M3 using B-MAC B-M3 towards PE3
PSN MPLS label to reach PE3
MP2P VPN Label assigned by PE3 for incoming traffic for target EVI

PE2 forwards traffic to M3 using B-MAC B-M3 towards PE3

PE1 / PE2 RIB
VPN MAC ESI
RT-a B-M3 0

Path List
NH PE3

PE1 / PE2 MAC Table
I-SID xyz
C-MAC B-MAC
M3 B-M3

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Life of a Packet (cont.)

Active / Active Per-Service Load Balancing

During startup, PE1 advertises:
- Ethernet Segment route
- MAC Route for B-MAC B-M1
PE1 elected DF for I-SID 100

PE1 MAC Route
- RD = RD-1a
- ESI = 1
- MAC = B-M1
- Label = L1
- RT ext. community
- RT-a

During startup, PE2 advertises:
- Ethernet Segment route
- MAC Route for B-MAC B-M2
PE2 elected DF for I-SID 200

PE3 / PE4 MAC Table
I-SID 100
- C-MAC: B-MAC
- M1: B-M1

PE3 / PE4 MAC Table
I-SID 200
- C-MAC: B-MAC
- M11: B-M2

MP2P VPN Label assigned by PE1 for incoming traffic for target EVI

PE3 forwards traffic to M1 using B-MAC B-M1 towards PE1

CE1 configured with two (2) separate bundles towards PEs

During startup, CE1 configured with two (2) separate bundles towards PEs

PE3 / PE4 MAC Table
I-SID 100
- C-MAC: B-MAC
- M1: B-M1

PE3 / PE4 MAC Table
I-SID 200
- C-MAC: B-MAC
- M11: B-M2

PE3 forwards traffic to M1 using B-MAC B-M1 towards PE1

CE1 configured with two (2) separate bundles towards PEs
PBB-EVPN Operational and Failure Scenarios
PBB-EVPN Operational Scenarios

MAC Mobility

1. Host M1 moves from CE1 to CE3’s location

2. Via data-plane learning, PE3 learns C-MAC M1 via B-MAC B-M1

3. PE1 learns C-MAC M1 on local port and forwards across core according to C-MAC DA to Remote B-MAC mapping

4. After host sends traffic at new location, PE3 updates C-MAC M1 location (local port.) PE3 also forwards across core according to C-MAC DA to Remote B-MAC mapping

5. Via data-plane learning, PE1 updates C-MAC M1 location (via B-MAC B-M2)

MAC Mobility event handled entirely by data-plane learning

PE1 MAC Table
I-SID xyz

<table>
<thead>
<tr>
<th>C-MAC</th>
<th>B-MAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>-</td>
</tr>
</tbody>
</table>

PE3 MAC Table
I-SID xyz

<table>
<thead>
<tr>
<th>C-MAC</th>
<th>B-MAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>B-M1</td>
</tr>
</tbody>
</table>

PE1 MAC Table
I-SID xyz

<table>
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<tr>
<th>C-MAC</th>
<th>B-MAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>B-M2</td>
</tr>
</tbody>
</table>

PE3 MAC Table
I-SID xyz

<table>
<thead>
<tr>
<th>C-MAC</th>
<th>B-MAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>-</td>
</tr>
</tbody>
</table>
PBB-EVPN Failure Scenarios / Convergence

Link / Segment Failure – Active/Active per Flow

1. PE1 detects failure of one of its attached segments

2. PE1 withdraws B-MAC advertised for failed segment (B-M1)

3. PE3 / PE4 remove PE1 from path list for B-MAC (B-M1)

4. PE2 reruns DF election. Becomes DF for all I-SIDs on segment

---

**Path List**

<table>
<thead>
<tr>
<th>PE3, PE4 RIB</th>
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</tr>
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<tbody>
<tr>
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<td>NH</td>
</tr>
<tr>
<td>MAC</td>
<td>PE1</td>
</tr>
<tr>
<td>ESI</td>
<td>PE2</td>
</tr>
</tbody>
</table>

---

**PE3, PE4 RIB**

<table>
<thead>
<tr>
<th>VPN</th>
<th>MAC</th>
<th>ESI</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT-a</td>
<td>B-M1</td>
<td>n/a</td>
</tr>
</tbody>
</table>
PBB-EVPN Failure Scenarios / Convergence

Link / Segment Failure – Active/Active per Service

1. PE1 acting as DF for a given I-SID (e.g. 100) detects failure of one of its attached segments.

2. PE1 re-adv B-MAC route for failed segment (B-M1) using MAC mobility community with incremented seq. num.

3. PE1 withdraws Ethernet Segment Route.

4. PE2 reruns DF election. Becomes DF for I-SID 100 on segment.

5. PE3 treats B-M1 route with incremented seq number as indication of a Topology Change (TC). PE3 proceeds to flush all I-SIDs in the EVI.

PE1 MAC Route
- RD = RD-1a
- ESI = 1
- MAC = B-M1
- Label = L1

MAC Mobility ext. community
- Seq. Num = 2

RT ext. community
- RT-a

PE3 treats B-M1 route with incremented seq number as indication of a Topology Change (TC). PE3 proceeds to flush all I-SIDs in the EVI.
PBB-EVPN Failure Scenarios / Convergence

PE Failure

1. PE1 experiences a node failure (e.g. power failure)

2. BGP RR / PE2 detects BGP session time-out with PE1

3. PE1 sends LACP OUT_OF_SYNC for CE1 to take port out of the bundle

4. PE2 reruns DF election. Becomes DF for all I-SIDs on segment

---

Core Isolation

1. PE1 experiences a node failure (e.g. power failure)

2. BGP RR / PE3 detects BGP session time-out with PE1

3. PE3 / PE4 invalidate routes from PE1

4. PE2 reruns DF election.

5. PE2 reruns DF election. Becomes DF for all I-SIDs on segment
PBB-EVPN IOS-XR Implementation Highlights
PBB-EVPN Model

- **Ethernet Segment Identifier**
  - ESI 1
  - ESI 2

- **BD**
  - B-MAC1
  - B-MAC2

- **EFP**
  - I-Component
  - B-Component

- **Customer Bridge Domain**
- **Core Bridge Domain**

- **E-VPN Forwarder**
PBB-EVPN

Sample Supported Access Topologies

- Null Ethernet Segment Identifier (ESI)
- Identical B-MAC on PBB-EVPN PEs (PE1 / PE2)
- Identical ESI on PBB-EVPN PEs
- Different B-MAC on PBB-EVPN PEs
- Identical ESI on PBB-EVPN PEs
- Per service (I-SID) carving (manual or automatic)
PBB-EVPN

Sample Supported Access Topologies (cont.)

- More than two (2) PEs in redundancy group
- Same as DHD Act/Act per-flow LB

- More than two (2) PEs in redundancy group
- Same as DHD Act/Act per-service LB
PBB-EVPN

Sample Supported Access Topologies (cont.)

Dual Home Network (DHN) ITU-T G.8032

- Treated as SHN by PBB-EVPN PEs (PE1 / PE2)
  - Null ESI; No DF election / No service carving
- Ring operation controlled by R-APS protocol

Dual Home Network (DHN) REP

- Treated as SHN by PBB-EVPN PEs (PE1 / PE2)
  - Null ESI; No DF election / No service carving
- Segment operation controlled by REP protocol

Dual Home Network (DHN) Active / Active Per-Service LB

- Different B-MAC on PBB-EVPN PEs (PE1 / PE2)
- Identical ESI on PBB-EVPN PEs
- Per service (I-SID) carving (manual or automatic)
PBB-EVPN IOS-XR
Implementation
Configuration and Examples
PBB-EVPN Single Home Device (SHD)

PE1

interface Bundle-Ether1.777 l2transport
  encapsulation dot1q 777

l2vpn
  bridge group gr1
  bridge-domain bd1
  interface Bundle-Ether1.777
  pbb edge i-sid 100 core-bridge-domain core_bd1

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

router bgp 64
  address-family l2vpn evpn
!
  neighbor <x.x.x.x>
  remote-as 64
  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 E-VPN AF

Note: MPLS / LDP configuration required on core-facing interfaces (not shown)
PBB-EVPN Dual Home Device (DHD)

Active / Active per-FLOW Load Balancing

**PE1**
- redundancy
- iccp
  - group 66
  - mlacp node 1
  - mlacp system mac 0aaa.0bbb.0ccc
  - mlacp system priority 1
    - mode singleton
- 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 100 core-bridge-domain core_bd1
  - bridge group gr2
    - bridge-domain core_bd1
    - pbb-core
      - evpn evi 1000
- router bgp 64
  - address-family 12vpn evpn
  - neighbor <x.x.x.x> remote-as 64
    - address-family 12vpn evpn

**PE 2 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**
**No need to define B-VLAN**

**Mandatory** EVI ID configuration

**BGP configuration with new EVPN AF**

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

**Note:** MPLS / LDP configuration required on core-facing interfaces (not shown)
PBB-EVPN Dual Home Device (DHD)

Active / Active per-Service Load Balancing and Dynamic Service Carving

PE1

interface Bundle-Ether25.1 12transport
encapsulation dot1q 777

interface Bundle-Ether25.2 12transport
encapsulation dot1q 888

12vpn
evpn

interface Bundle-Ether25

  ethernet-segment
  identifier system-priority 1 system-id 0000.0b25.00ce
  load-balancing-mode per-service

bridge group gr1
bridge-domain bd1
  interface Bundle-Ether25.1
  pbb edge i-sid 100 core-bridge-domain core_bd1

bridge-domain bd2
  interface Bundle-Ether25.2
  pbb edge i-sid 120 core-bridge-domain core_bd1

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

router bgp 64
address-family 12vpn evpn
neighbor <x.x.x.x> remote-as 64
  address-family 12vpn evpn

Default B-MAC SA
Default Service Carving
Auto RT for EVI
Auto RD for EVI
Auto RD for Segment Route

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

PBB I-components (100 and 120) 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
Highlights

• E-VPN & PBB-EVPN are next generation L2VPN Solutions that address resiliency and forwarding policy requirements.
• E-VPN & PBB-EVPN use BGP for MAC distribution/learning over the PSN.
• The following concepts were discussed:
  – Ethernet Segments
  – DF Election and Filtering
  – Split Horizon
  – Aliasing
  – Backup Path
  – MAC Mass Withdrawal
• The operation of E-VPN & PBB-EVPN was discussed.
• Overview of IOS-XR PBB-EVPN Implementation was presented.
Comparison of L2VPN Solutions

<table>
<thead>
<tr>
<th>Requirement</th>
<th>VPLS</th>
<th>E-VPN</th>
<th>PBB-EVPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-Active Redundancy with Flow Based Load-balancing</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Flow Based Multi-pathing</td>
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<td>✔</td>
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<tr>
<td>Geo-redundancy and Flexible Redundancy Grouping</td>
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<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Core Auto-Discovery</td>
<td>✔</td>
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<td>✔</td>
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<tr>
<td>Access Multi-homing Auto-Discovery</td>
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<td>✔</td>
</tr>
<tr>
<td>New Service Interfaces</td>
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<td>✔</td>
</tr>
<tr>
<td>LSM with P2MP Tree</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
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<td>LSM with MP2MP Tree</td>
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<td>✔</td>
<td>✔</td>
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<tr>
<td>Fast Convergence on Failure</td>
<td>✔</td>
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<td>✔</td>
</tr>
<tr>
<td>Fast Convergence on MAC Mobility</td>
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<td>✔ (C-MAC Transparency issue)</td>
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References

- draft-ietf-l2vpn-evpn
- draft-ietf-l2vpn-pbb-evpn
- draft-ietf-l2vpn-trill-evpn
# Acronyms—IP and MPLS

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<thead>
<tr>
<th>Acronym</th>
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<tbody>
<tr>
<td>AC</td>
<td>Attachment Circuit</td>
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<tr>
<td>AS</td>
<td>Autonomous System</td>
</tr>
<tr>
<td>BFD</td>
<td>Bidirectional Failure Detection</td>
</tr>
<tr>
<td>CoS</td>
<td>Class of Service</td>
</tr>
<tr>
<td>ECMP</td>
<td>Equal Cost Multipath</td>
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<tr>
<td>EoMPLS</td>
<td>Ethernet over MPLS</td>
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<tr>
<td>E-VPN</td>
<td>Ethernet Virtual Private Network</td>
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<tr>
<td>EVI</td>
<td>E-VPN Instance</td>
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<tr>
<td>FRR</td>
<td>Fast Re-Route</td>
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<tr>
<td>IGP</td>
<td>Interior Gateway Protocol</td>
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<tr>
<td>LDP</td>
<td>Label Distribution Protocol</td>
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<td>LER</td>
<td>Label Edge Router</td>
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<td>LFIB</td>
<td>Labeled Forwarding Information Base</td>
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<tr>
<td>LSM</td>
<td>Label Switched Multicast</td>
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<td>LSP</td>
<td>Label Switched Path</td>
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<td>Label Switching Router</td>
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<tr>
<td>MPLS</td>
<td>Multi-Protocol Label Switching</td>
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<td>NLRI</td>
<td>Network Layer Reachability Information</td>
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<td>PSN</td>
<td>Packet Switch Network</td>
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<td>QoS</td>
<td>Quality of Service</td>
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<tr>
<td>RD</td>
<td>Route Distinguisher</td>
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<td>RIB</td>
<td>Routing Information Base</td>
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<td>RR</td>
<td>Route Reflector</td>
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<td>RSVP</td>
<td>Resource Reservation Protocol</td>
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<td>RSVP-TE</td>
<td>RSVP based Traffic Engineering</td>
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<td>RT</td>
<td>Route Target</td>
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<td>Traffic Engineering</td>
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<td>tLDP</td>
<td>Targeted LDP</td>
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<td>Virtual Circuit</td>
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<td>VCID</td>
<td>VC Identifier</td>
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<td>VFI</td>
<td>Virtual Forwarding Instance</td>
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<td>VPLS</td>
<td>Virtual Private LAN Service</td>
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<tr>
<td>VPN</td>
<td>Virtual Private Network</td>
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<td>VPWS</td>
<td>Virtual Private Wire Service</td>
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<td>VRF</td>
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## Acronyms— Ethernet/Bridging

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<tr>
<td>BD</td>
<td>Bridge Domain</td>
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<td>BPDU</td>
<td>Bridge Protocol Data Unit</td>
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<tr>
<td>CE</td>
<td>Customer Equipment (Edge)</td>
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<tr>
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<td>Customer / CE VLAN</td>
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<tr>
<td>CoS</td>
<td>Class of Service</td>
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<tr>
<td>DHD</td>
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<td>LACP</td>
<td>Link Aggregation Control Protocol</td>
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<td>Local Area Network</td>
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<td>Metro Ethernet Forum</td>
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<td>MEN</td>
<td>Metro Ethernet Network</td>
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<td>MIRP</td>
<td>Multiple I-Tag Registration Protocol</td>
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<td>mLACP</td>
<td>Multi-Chassis LACP</td>
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<td>MST / MSTP</td>
<td>Multiple Instance STP</td>
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<td>MSTG-AG</td>
<td>MST Access Gateway</td>
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<td>MVRP</td>
<td>Multiple VLAN Registration Protocol</td>
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<td>PoA</td>
<td>Point of Attachment</td>
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<td>REP</td>
<td>Resilient Ethernet Protocol</td>
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<td>REP-AG</td>
<td>REP Access Gateway</td>
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<td>Spanning Tree Protocol</td>
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## Acronyms—Provider Backbone Bridging

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<td>B-Component BEB</td>
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<tr>
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<td>B-DA</td>
<td>Backbone Destination Address</td>
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<td>BEB</td>
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<td>B-MAC</td>
<td>Backbone MAC Address</td>
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<td>B-SA</td>
<td>Backbone Source Address</td>
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<td>B-Tag</td>
<td>B-VLAN Tag</td>
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<td>C-DA</td>
<td>Customer Destination Address</td>
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<td>C-VLAN / CE-VLAN</td>
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<td>DA</td>
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<td>FCS</td>
<td>Frame Check Sequence</td>
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<table>
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<td>Media Access Control</td>
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<tr>
<td>PB</td>
<td>Provider Bridge</td>
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<td>Provider Backbone Bridge / Bridging</td>
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<td>User to Network Interface</td>
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<td>VLAN</td>
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