Virtual Private Networks

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based on several industrial presentations

Outline

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- L3 MPLS VPN
  - Review
- L2 VPN
  - VXLAN
  - EVPN
    - BGP control plane
    - Use cases

What is a Virtual Private Network?

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- VPN is a set of sites or groups which are allowed to communicate with each other
- VPN is defined by a set of administrative policies
  - Policies established by VPN customers
  - Policies could be implemented completely by VPN service providers
- Flexible inter-site connectivity
  - Ranging from complete to partial mesh
- Sites may be either within the same or in different organizations
  - VPN can be either intranet or extranet
- Site may be in more than one VPN
  - VPNs may overlap
- Not all sites have to be connected to the same service provider
  - VPN can span multiple providers

Traditional vs L3 VPNs

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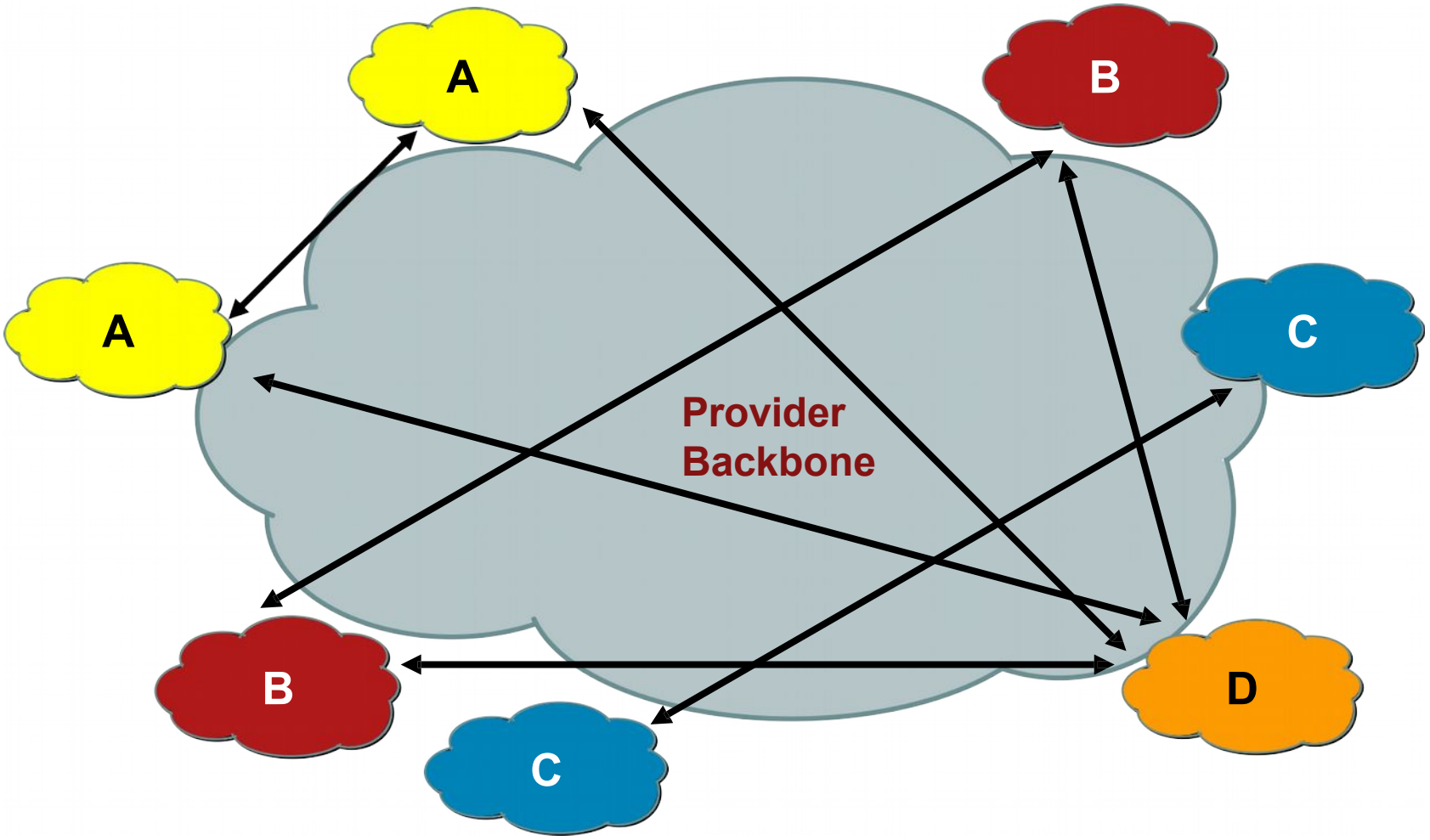
- Traditional VPNs (wo. MPLS)
  - Customer endpoints (CPE) connected via Layer 2 such as Frame Relay DLCI, ATM VC or point-to-point connection
  - Provider network is not responsible for distributing site routers as routing relationship is between the customer endpoints
    - Provider will need to manually fully mesh end points if any-to-any connectivity is required
- Layer 3 VPN
  - Customer end points peer with providers' routers at L3
  - Provider network responsible for distributing routing information to VPN sites
  - Don't have to manually fully mesh customer endpoints to support any-to-any connectivity

VPN model



Implementation

how to

checkmate VPNs in three moves:
(1) make PEs reachable each other using IP,
(2) use BGP for announcing customer prefixes, and
(3) use MPLS for tunnels inside the backbone

Implementation

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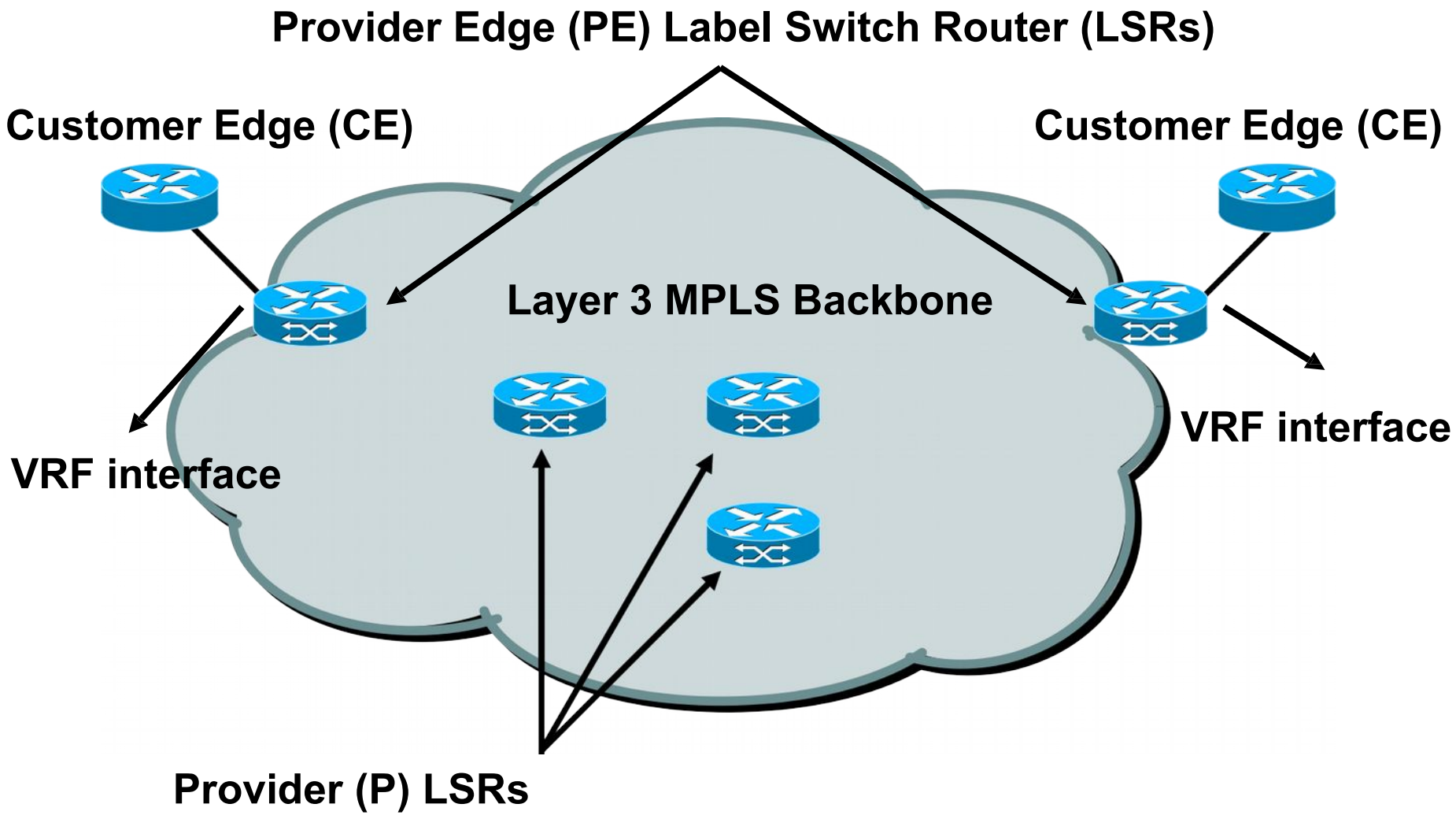
- Control Plane
  - BGP
- Data Plane
  - IP/MPLS using IGP and MPLS signaling (e.g. LDP)

MPLS VPN Architecture



MPLS VPN Building Blocks

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- MPLS framework (labels) in the core
  - IGP (any)
  - LDP or MPLS Traffic Engineering
- VRF (Virtual Routing/Forwarding) context to keep VPNs seperate
  - VRF on PE interface towards CE
  - VRF routing table

VRF knowledge only needed on edge routers

- RD attached to prefixes to make VPN prefixes unique
  - RD is 64 bits
  - RD allows for overlapping VPN prefixes
- Route targets (ext BGP community) attached to VPN prefixes to allow prefixes to be imported/exported to VPNs
- BGP in the core to advertise VPN prefix and VPN label to all Provider Edge (PE) routers

MPLS VPN Building Blocks

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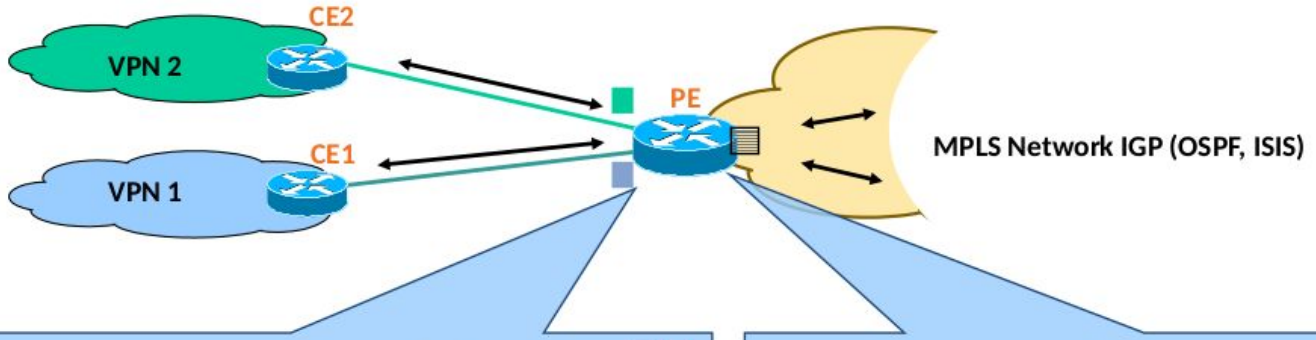
Separate Routing Tables at PE



Customer Specific Routing Table

- Routing (RIB) and forwarding table (CEF) dedicated to VPN customer
  - VPN1 routing table
  - VPN2 routing table
- Referred to as VRF table for <named VPN>

```
IOS: "show ip route vrf <name>"
IOS-XR:"sh route vrf <name> ipv4
NX-OS: "sh ip route vrf <name>"
```

Global Routing Table

- Created when IP routing is enabled on PE.
- Populated by OSPF, ISIS, etc. running inside the MPLS network

```
IOS: "show ip route"
IOS-XR:"sh route ipv4 unicast"
NX-OS: "sh ip route"
```

MPLS VPN Building Blocks

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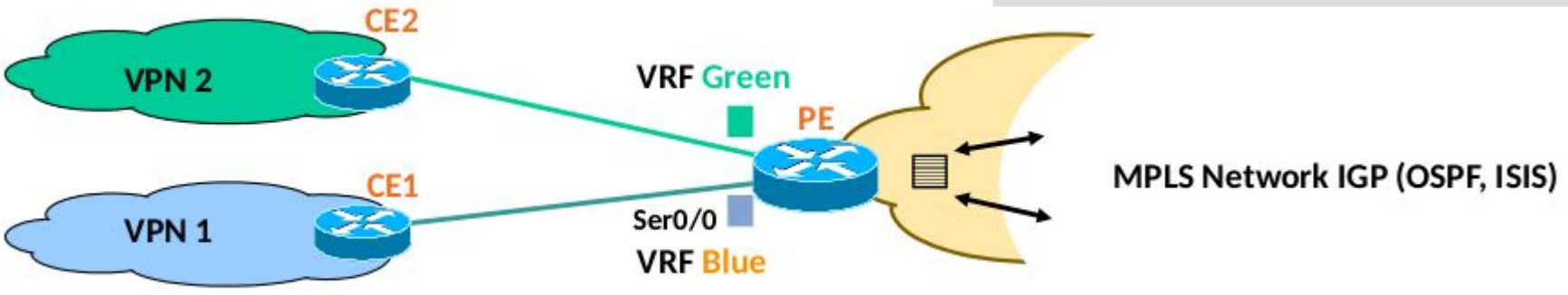
Virtual Routing and Forwarding Instance

- What's a Virtual Routing and Forwarding (VRF) ?
  - Representation of VPN customer inside the MPLS network
  - Each VPN is associated with at least one VRF
- VRF configured on each PE and associated with PE-CE interface(s)
  - Privatize an interface, i.e., coloring of the interface
  - No changes needed at CE

```
IOS_PE(conf)#ip vrf blue
IOS_PE(conf)#interface Ser0/0
IOS_PE(conf)#ip vrf forwarding blue
```



MPLS VPN Building Blocks

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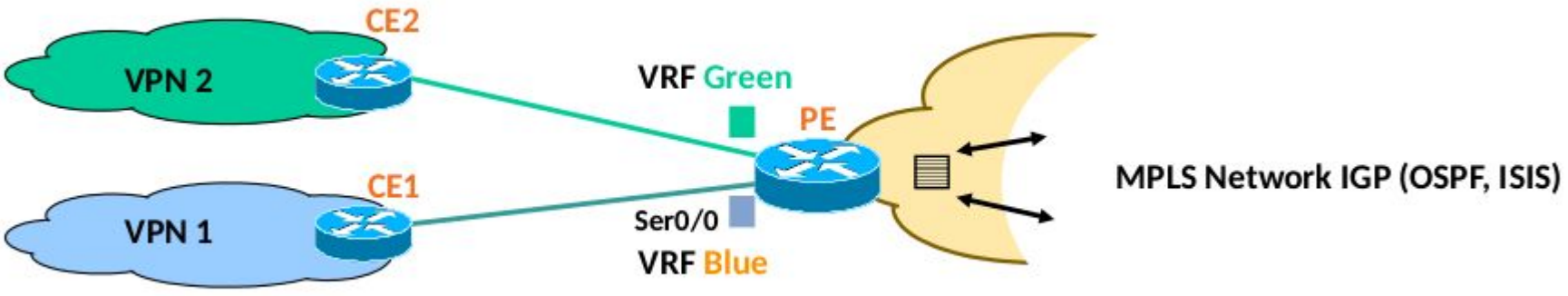
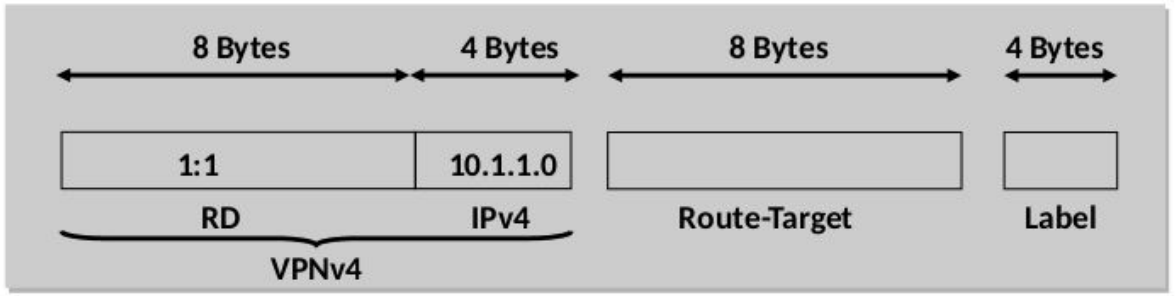
Virtual Routing and Forwarding Instance

- PE installs the internal routes (IGP) in global routing table
- PE installs the VPN customer routes in VRF routing table(s)
  - VPN routes are learned from CE routers or remote PE routers
  - VRF-aware routing protocol (static, RIP, BGP, EIGRP, OSPF) on each PE
- VPN customers can use overlapping IP addresses
  - BGP plays a key role. Let's understand few BGP specific details..



MPLS VPN Building Blocks

Control Plane = Multi-Protocol BGP (MP-BGP)

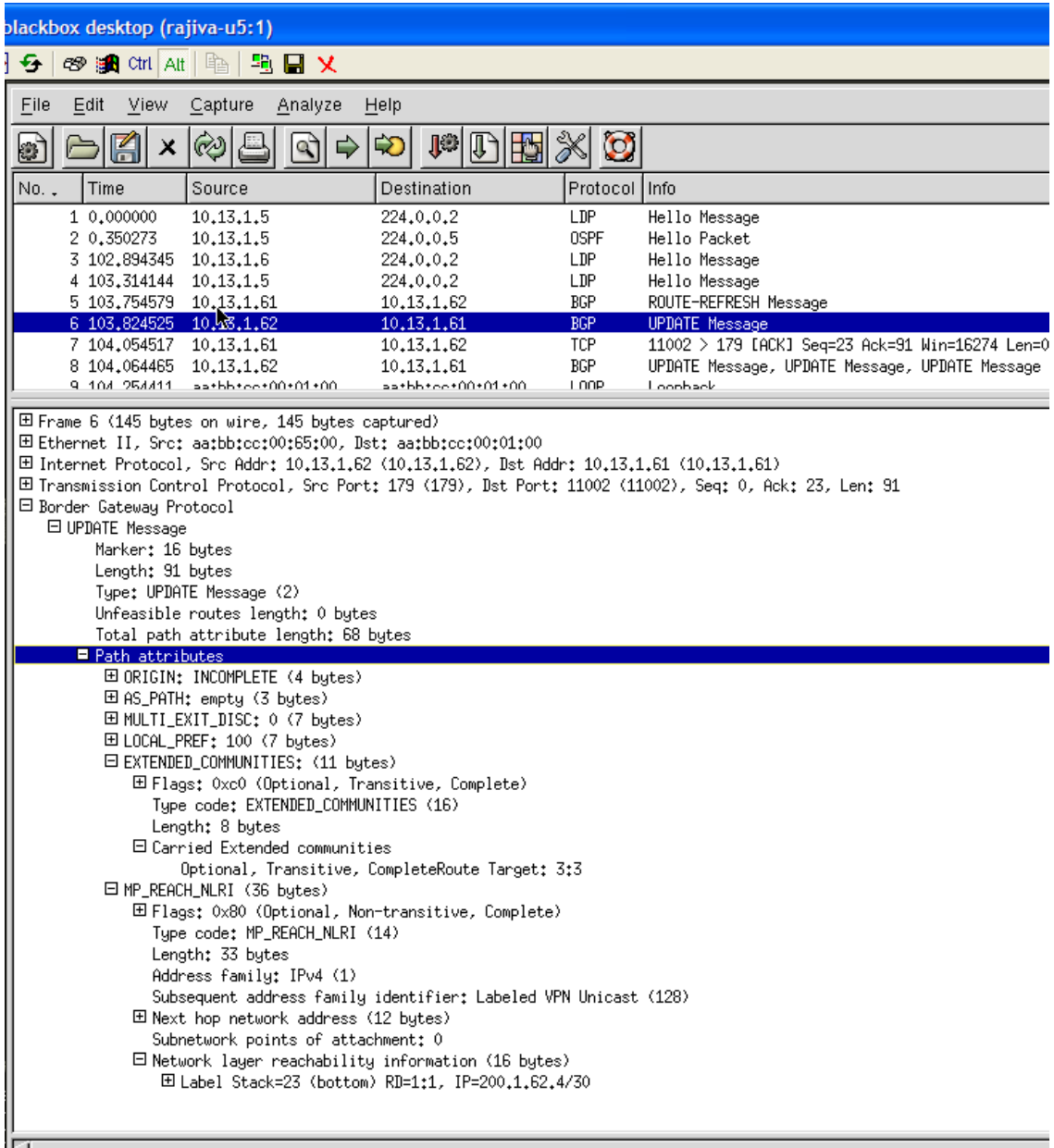


MP-BGP UPDATE Message Showing VPNv4 Address, RT, Label only

- MP-BGP Customizes the VPN Customer Routing Information as per the Locally Configured VRF Information at the PE using:
  - Route Distinguisher (RD)
  - Route Target (RT)
  - Label

MPLS VPN Control Plane

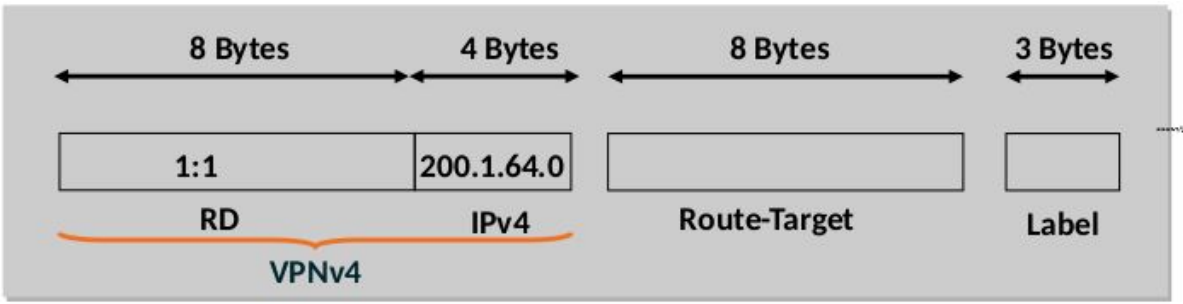
MP-BGP UPDATE Message Capture



- Visualize how the BGP UPDATE message advertising VPNv4 routes looks like.
- Notice the Path Attributes:
  - Route Target = 3:3
  - VPNv4 Prefix 1:1:200.1.62.4/30 ; Label = 23

MPLS VPN Control Plane

Route-Distinguisher (rd)



- VPN customer IPv4 prefix is converted into a VPNv4 prefix by appending the RD (1:1, say) to the IPv4 address (200.1.64.0, say) => 1:1:200.1.64.0
  - Makes the customer's IPv4 address unique inside the SP MPLS network.
- Route Distinguisher (rd) is configured in the VRF at PE
  - RD is not a BGP attribute, just a field.

```
IOS_PE#
!
ip vrf
green
 rd 1:1
!
```

MPLS VPN Control Plane

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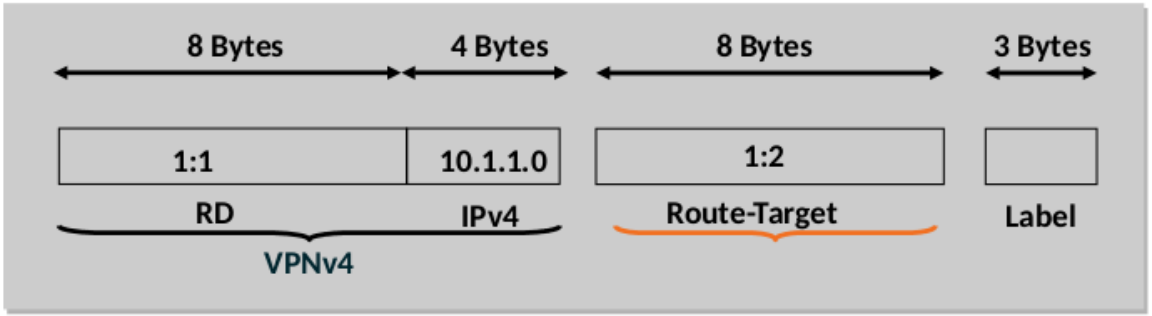
Route-Target (rt)

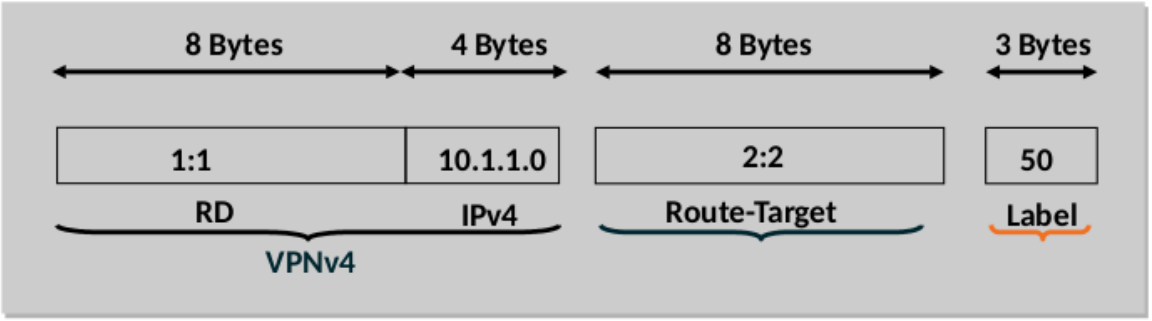


- Route-target (rt) identifies which VRF(s) keep which VPN prefixes
  - rt is an 8-byte extended community attribute.
- Each VRF is configured with a set of route-targets at PE
  - Export and Import route-targets must be the same for any-to-any IP/VPN
- Export route-target values are attached to VPN routes in PE->PE MP-iBGP advertisements

```
IOS_PE#
!
ip vrf green
 route-target import 3:3
 route-target export 3:3
 route-target export 10:3
!
```

MPLS VPN Control Plane

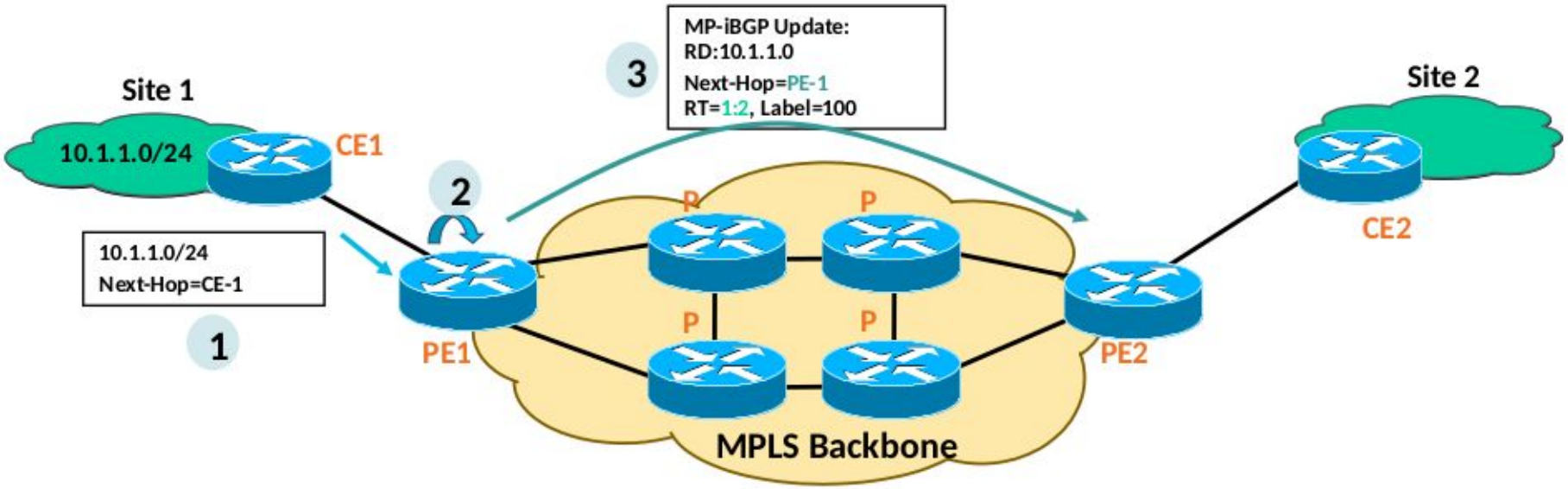
Label



- PE assigns a label for the VPNv4 prefix;
  - Next-hop-self towards MP-iBGP neighbors by default i.e. PE sets the NEXT-HOP attribute to its own address (loopback)
  - Label is not an attribute.
- PE addresses used as BGP next-hop must be uniquely known in IGP
  - Do not summarize the PE loopback addresses in the core

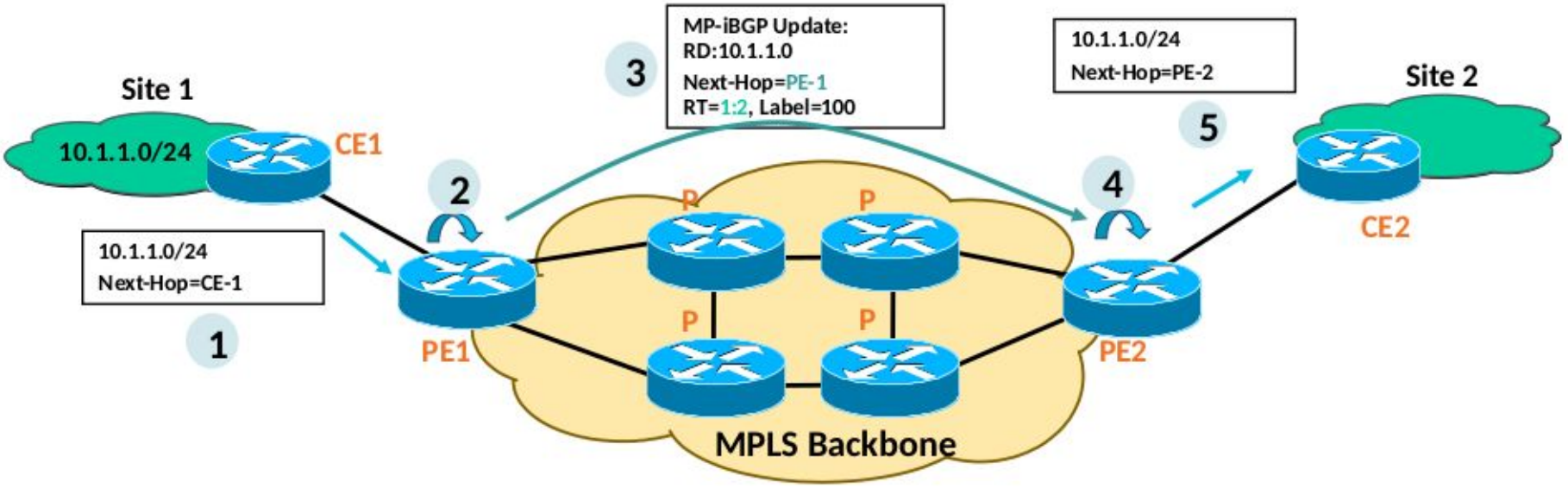
```
IOS_PE#
!
ip vrf green
 route-target import 3:3
 route-target export 3:3
 route-target export 10:3
!
```

MPLS VPN Control Plane



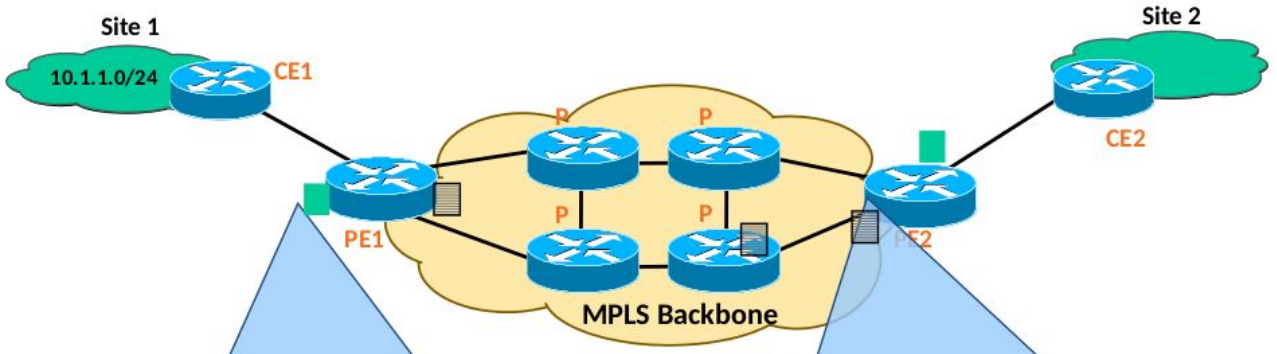
- PE1 receives an IPv4 update (eBGP/OSPF/ISIS/RIP/EIGRP)
- PE1 translates it into VPNv4 address and constructs the MP-iBGP UPDATE message
  - Associates the RT values (export RT =1:2, say) per VRF configuration
  - Rewrites next-hop attribute to itself
  - Assigns a label (100, say); Installs it in the MPLS forwarding table.
- PE1 sends MP-iBGP update to other PE routers

MPLS VPN Control Plane



- PE2 receives and checks whether the RT=1:2 is locally configured as ‘import RT’ within any VRF, if yes, then
  - PE2 translates VPNv4 prefix back to IPv4 prefix
  - Updates the VRF CEF Table for 10.1.1.0/24 with label=100
- PE2 advertises this IPv4 prefix to CE2 (using whatever routing protocol)

MPLS VPN Forwarding Plane



Customer Specific Forwarding Table

- Stores VPN routes with associated labels
- VPN routes learned via BGP
- Labels learned via BGP

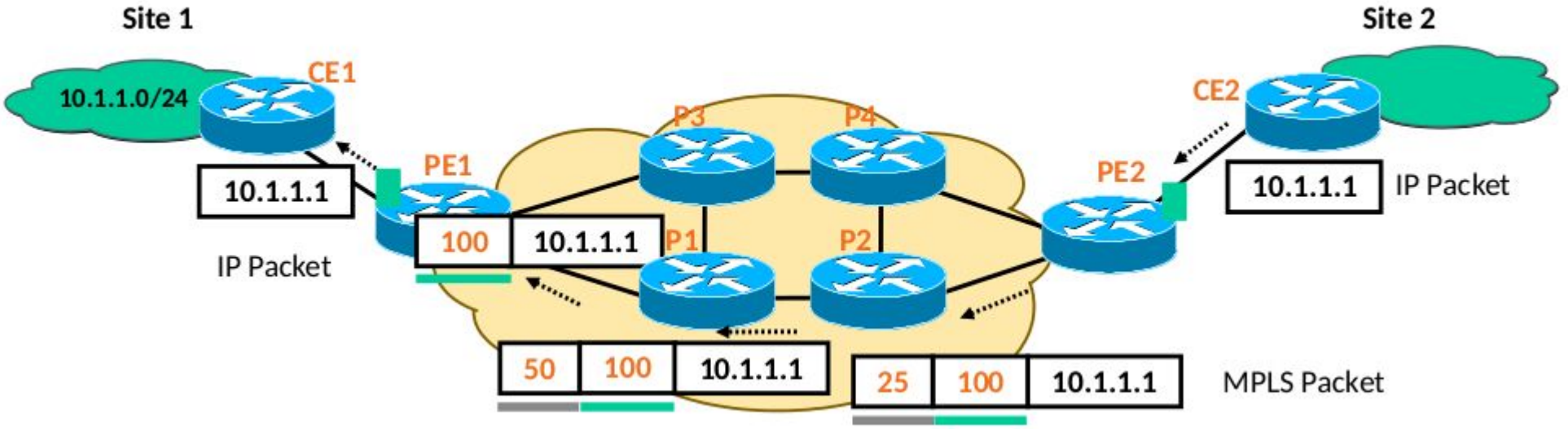
```
IOS:show ip cef vrf <name>
NX-OS: show forwarding vrf <name>
IOS-XR: show cef vrf <name> ipv4
```

Global Forwarding Table

- Stores next-hop i.e. PE routes with associated labels
- Next-hop i.e. PE routes learned through IGP
- Label learned through LDP or RSVP

```
IOS:show ip cef
NX-OS: show forwarding ipv4
IOS-XR: show cef ipv4
```

MPLS VPN Forwarding Plane



- PE2 imposes two labels (MPLS headers) for each IP packet going to site2
  - Outer label is learned via LDP; Corresponds to PE1 address (e.g. IGP route)
  - Inner label is learned via BGP; corresponds to the VPN address (BGP route)
- P1 does the Penultimate Hop Popping (PHP)
- PE1 retrieves IP packet (from received MPLS packet) and forwards it to CE1.

MPLS VPNs

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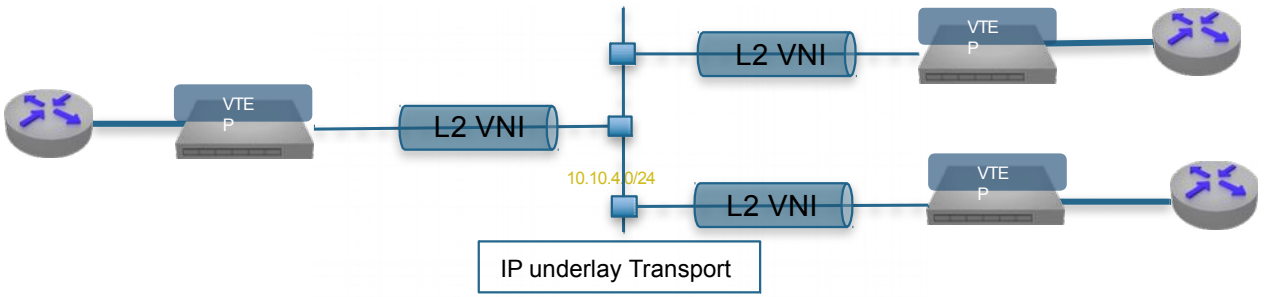
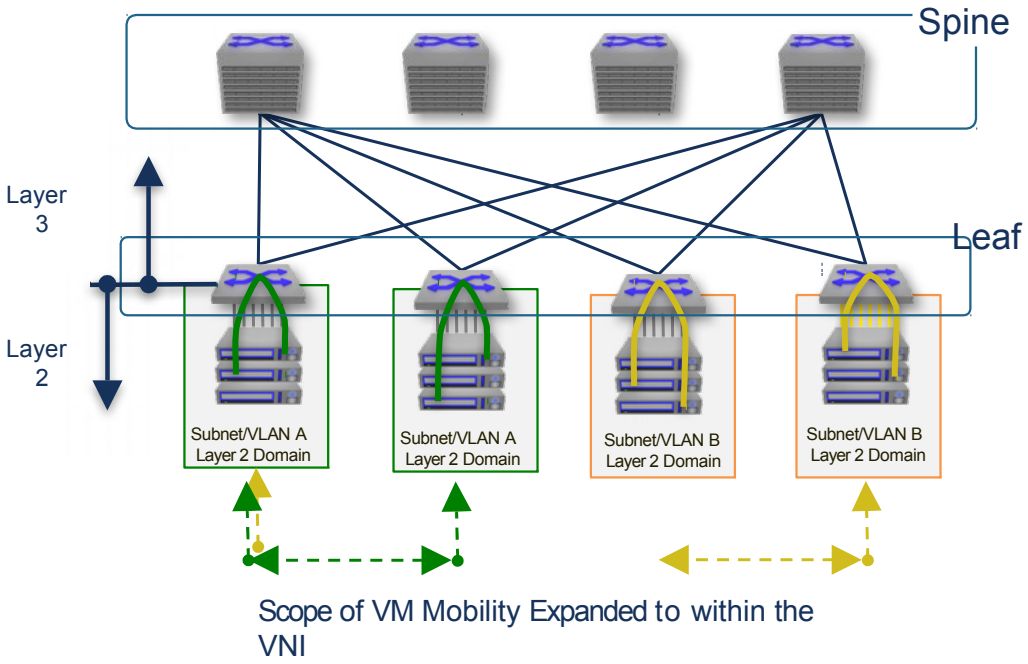
- Succesful model, has been widely implemented
- Layer 2 BGP/MPLS VPNs:
  - Psewdowires
  - VPLS
- Datacenter world: VXLAN
  - MAC in IP encapsulation
  - Scaling problems → BGP to the rescue (?)

Introducing VXLAN

- Layer 2 “Overlay Networks” on top of a Layer 3 network
  - “MAC in IP” Encapsulation
  - Layer 2 multi-point tunneling over IP UDP
  - Transparent to the physical IP underlay network
  - Provides Layer 2 scale across the Layer 3 IP fabric



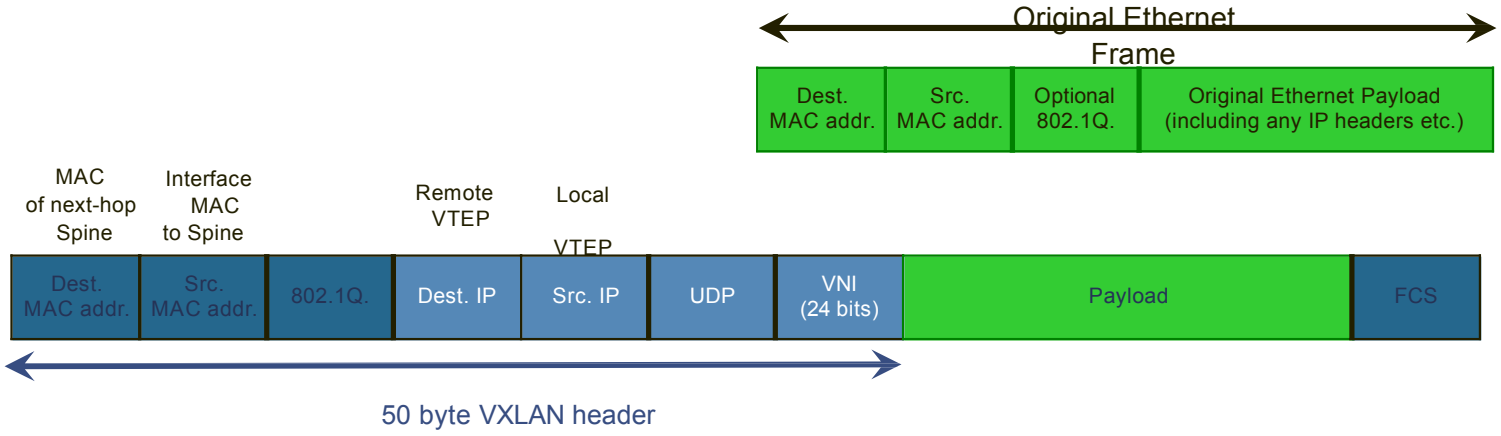
Data Center – Layer 3 Overlay Architectures



- Virtual eXtensible LAN (VXLAN)
  - IETF framework proposal, co-authored by:
    - Arista
    - VMware
    - Cisco
    - Citrix
    - Red Hat
    - Broadcom
- Enables Layer 2 interconnection across Layer 3 boundaries
  - Transparent to the physical IP network
  - Provides Layer 2 scale across the Layer 3 IP fabric
  - Abstracts the Virtual connectivity from the physical IP infrastructure
  - Enables Vmotion, etc. across IP fabrics

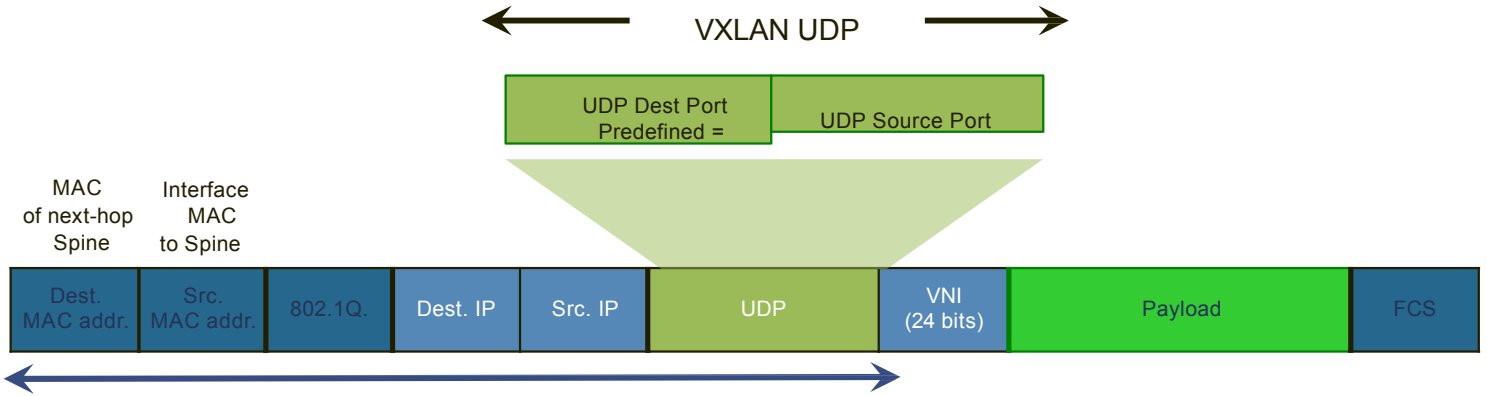
VXLAN Encapsulated Frame Format

- Ethernet header uses local VTEP MAC and default router MAC (14 bytes plus 4 optional 802.1Q header)
- The VXLAN encapsulation source/destination IP addresses are those of local/remote VTI (20 bytes)
- UDP header, with SRC port hash of the inner Ethernets header, destination port IANA defined (8 bytes)
  - Allows for ECMP load-balancing across the network core which is VXLAN unaware.
- 24-bit VNI to scale up to 16 million for the Layer 2 domain/ vWires (8 bytes)



VXLAN Encapsulated Frame Format

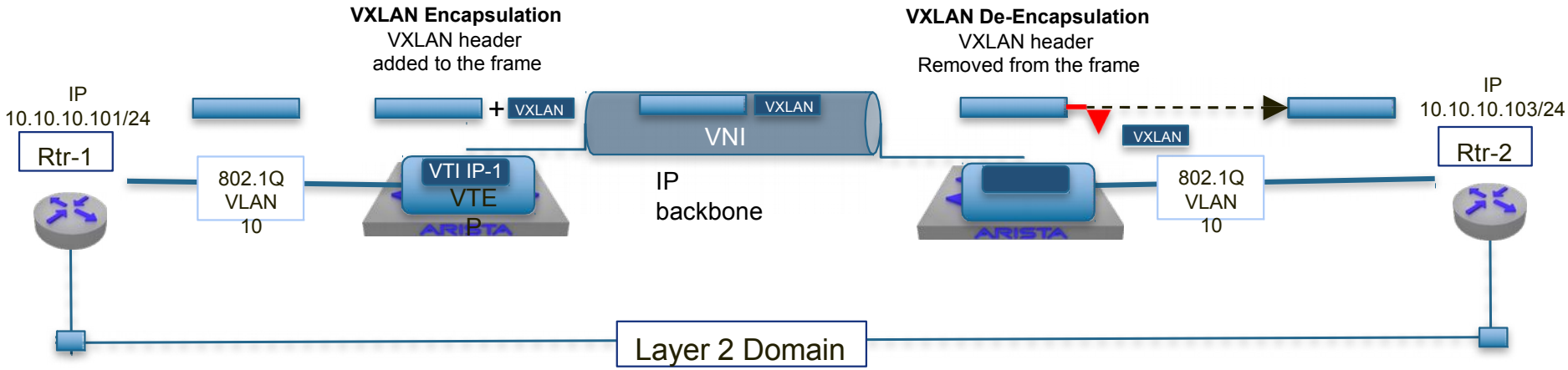
- To provide Entropy across a multi-path ECMP underlay network
  - UDP source port created from a Hash of the inner frame
  - What fields are hashed from the inner is not defined in the standard
  - Silicon vendor, will define the level of Entropy that can be achieved
  - UDP destination port, predefined in the standard as 4789



Source Port: It is recommended that the UDP source port number be calculated using a hash of fields from the inner packet - one example being a hash of the inner Ethernet frame's headers. When calculating the UDP source port number in this manner, it is RECOMMEND that the value be in the dynamic/private port range 49152-65535 [RFC6335].

VXLAN Terminology

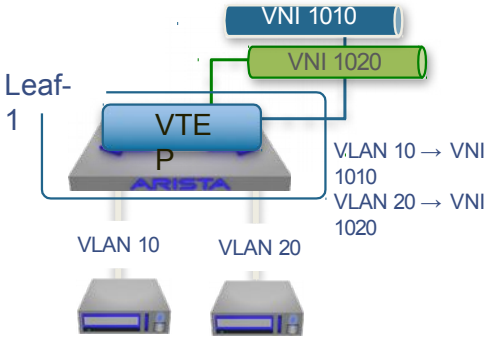
- **Virtual Tunnel End-point (VTEP).**
  - Entry point for connecting nodes into the VXLAN overlay network.
  - Responsible for the encap/decap with the appropriate VXLAN header.
- **Virtual Tunnel Identifier (VTI)**
  - An IP interface used as the Source IP address for the encapsulated VXLAN traffic
  - IP address residing in the underlay network
- **Virtual Network Identifier (VNI)**
  - A 24-bit field added within the VXLAN header.
  - Identifies the Layer 2 segment of the encapsulated Ethernet frame



VXLAN Terminology - VLAN service interfaces

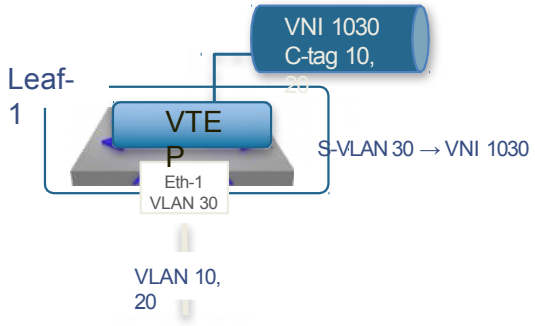
VLAN to VNI mapping

- One to One mapping between VLAN ID and the VNI
- Mapping is only locally significant,
- VLAN ID not carried on VXLAN encap frame
- Allows VLAN translation between remote VTEPs



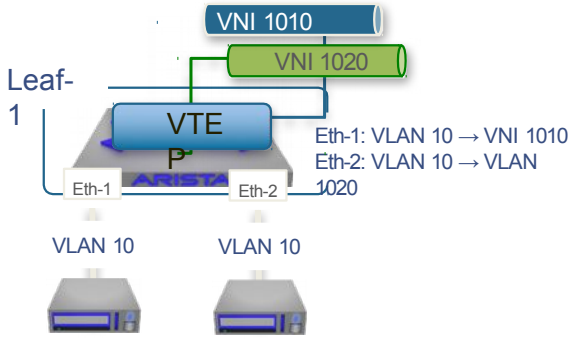
S-LAN to VNI mapping

- Mapping of the outer S-Tag to a single VNI
- Inner C-Tags are transported within a single VNI
- The inner VLAN ID are carried on VXLAN encap frame
- Ability to transport all customer VLANs across a single VXLAN point to point link



Port + VLAN to VNI mapping

- Mapping traffic to a VNI based on a combination of the ingress port and it VLAN- ID
- The VLAN ID is not carried on VXLAN encap frame
- Provides support for overlapping VLANs within a single VTEP to be mapped to different VNIs



VXLAN Control Plane Options

- **The VXLAN control plane is used for MAC learning and packet flooding**
  - Learning what remote VTEP a host resides behind
  - Allowing the mapping of remote MACs to their associated remote VTEP
  - Mechanism for forwarding of the Broadcast and multicast traffic within the Layer 2 segment (VNI)

Controller Model

- State learning driven by third-party controller
- OVSDB or OpenStack ML2 plugin for orchestration
- Data Center virtualization and Orchestration focus

IP Multicast Control Plane

- VTEP join an associated IP multicast group(s) for the VNI(s)
- Unknown unicasts forwarded to VTEPs in the VNIs via IP multicast
- Flood and learn and requires IP multicast support in the underlay
- Limited deployments

Head-End Replication (HER)

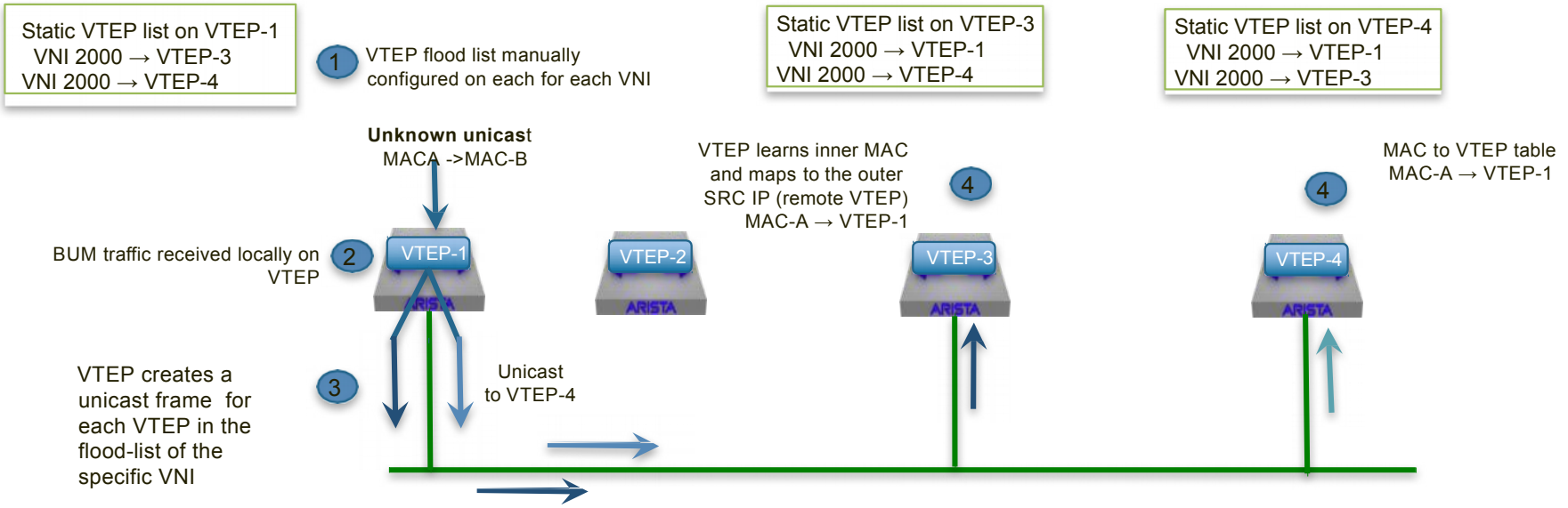
- BUM traffic replicated to each remote VTEPs in the VNIs
- Unicast Replication carried out on the ingress VTEP
- MAC learning still via flood and learn, but no requirement for IP multicast

EVPN Model

- BGP used to distribute local MAC to IP bindings between VTEPs
- Broadcast traffic handled via IP multicast or HER models
- Dynamic MAC distribution and VNI learning, configuration can be BGP intensive

VXLAN Control plane – HER

- Head-end Replication operation
  - Each VTEP is configured with an IP address “flood list” of the remote VTEPs within the VNI
  - Any Broadcast/Multicast or Unknown traffic is then replicated to the configured VTEPs in the list
  - Remote VTEPs receiving the flooded traffic learn inner source MAC from the received frame
  - VTEP’s creating a remote MAC to outer SRC IP (VTEP) mapping for the entry



VXLAN Control Plane - HER

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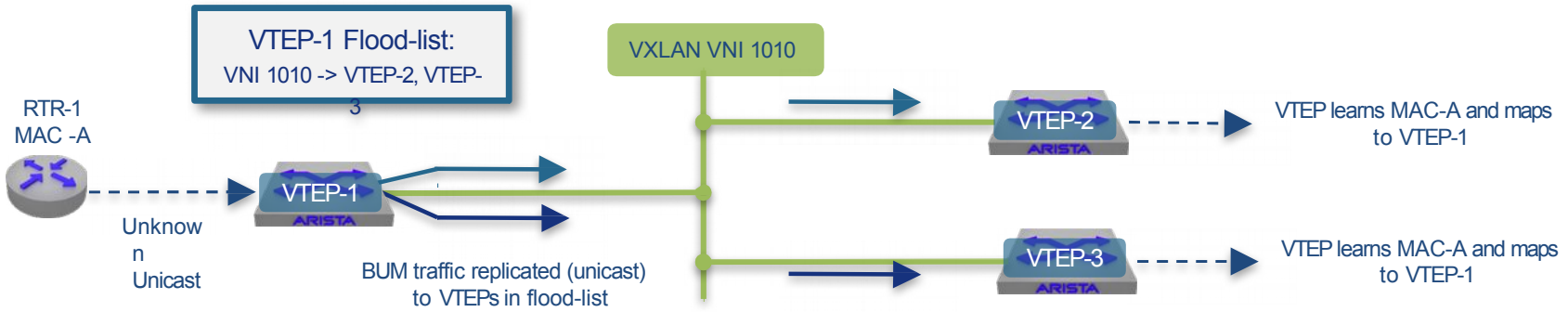


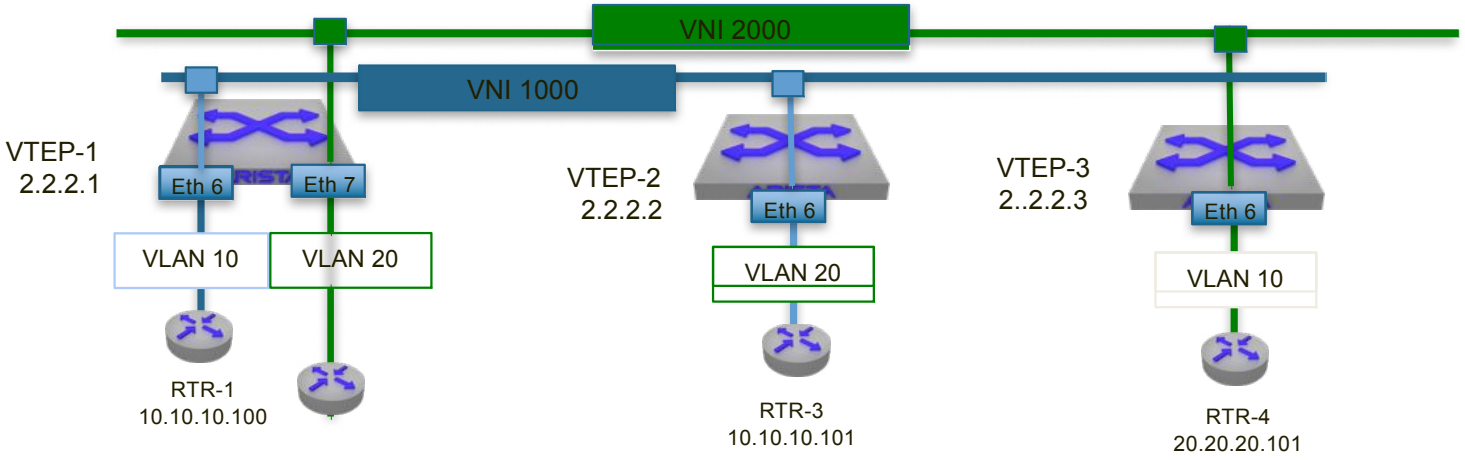
Flood list requires provisioning, MAC learning via flood and learn

VXLAN Control Plane – HER, simple config

```
!
interface Loopback2
   ip address 2.2.2.1/32
!
Interface ethernet 6
   switchport mode access
   switchport access vlan 10
!
Interface ethernet 7
   switchport mode access
  switchport access vlan 10
!
interface Vxlan1
  vxlan source-interface Loopback2
     vxlan udp-port 4789
  vxlan vlan 10 vni 1000
  vxlan vlan 20 vni 2000
  vxlan vlan 10 flood vtep 2.2.2.3
  vxlan vlan 20 flood vtep 2.2.2.2
!
```

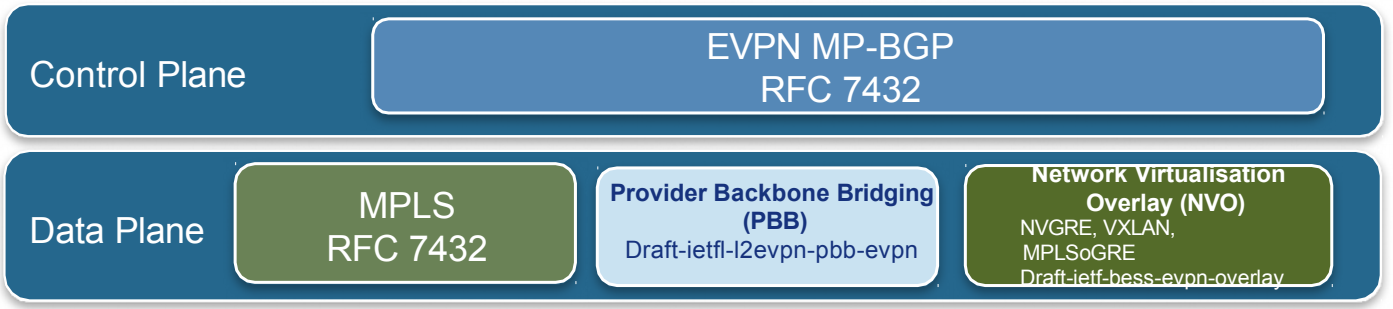
```
!
interface Loopback2
   ip address 2.2.2.2/32
!
Interface ethernet 6
   switchport mode access
   switchport access vlan 10
!
interface Vxlan1
   vxlan source-interface Loopback2
     vxlan udp-port 4789
   vxlan vlan 20 vni 2000
   vxlan vlan 20 flood vtep 2.2.2.1
!
```

```
!
interface Loopback2
   ip address 2.2.2.3/32
!
Interface ethernet 6
   switchport mode access
   switchport access vlan 20
!
interface Vxlan1
   vxlan source-interface Loopback2
     vxlan udp-port 4789
   vxlan vlan 10 vni 2000
   vxlan vlan 10 flood vtep 2.2.2.1
!
```



What is Ethernet VPN (EVPN) - Standard body for EVPN

- EVPN Standard RFC 7432
  - Specifics an BGP EVPN control plane with a MPLS data plane
  - BGP control plane, new address family to advertise MAC/IP and IP prefixes.
  - Previously known as draft-ietf-l2vpn-evpn
  - Multi-vendor authors involving vendors and operators : ALU, Cisco, Juniper, AT&T, Bloomberg and Verizon
- Proposal for EVPN with Network Virtualisation Overlay (NVO)
  - Same EVPN control plane with a VXLAN Data plane (NGRE, MPLSoGRE)
  - Draft-ietf-bess-evpn-overlay



For the EVPN Data Plane, currently 1 standard (MPLS) and 2 proposals (NVO and PBB)

RFC 8365: A Network Virtualization Overlay Solution Using Ethernet VPN (EVPN)

Ethernet VPN

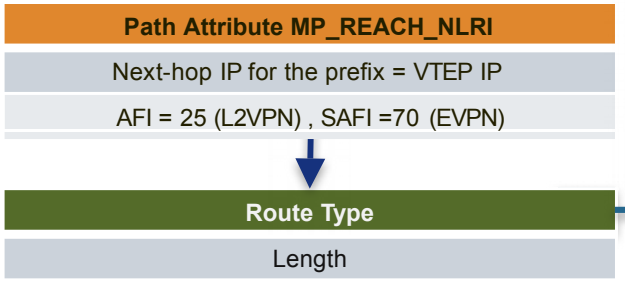
- EVPN, MP-BGP control-plane for delivering L2 and L3 VPN services with VXLAN
  - Evolution from the flood-learn mechanism of traditional L2 VPN (VPLS) service
  - Abstracts the (MP-BGP) control-plane from the (VXLAN/MPLS/PBB) forwarding plane
  - MP-BGP control plane to advertise host MAC and IP addresses and IP prefixes
  - Allows within a single MP-BGP control, L2 VPNs (hosts addresses) and L3 VPNs (IP prefixes).
- Potential use cases
  - Network virtualization (overlay) services for stretching Layer 2 connectivity
  - Integration of Layer 2 and Layer 3 VPN services in the overlay
  - Data Center Interconnect (DCI)
  - Internet Exchange Points (IXPs)

EVPN Operation

- EVPN is built on Multi Protocol BGP
  - Introduction of a new EVPN address family
    - ≫ Address Family Identifier 25 (Layer 2 VPN) subsequent AFI 70 (EVPN)
    - ≫ Advertisement of host MAC/IP binding and IP prefixes
    - ≫ Distribution of Layer 2/3 information allows support for integrated bridging and routing in VXLAN overlay networks.
  - Utilises Layer 3 VPN concepts of Route-distinguishers and Route Targets
    - ≫ Providing support for multi-tenant VXLAN overlays
    - ≫ Support for over-lapping IP address spaces between tenants
  - Multiple tenant's NLRI information carried within a single shared BGP session,
    - ≫ NOT BGP session per tenant

EVPN Operation – Route Types

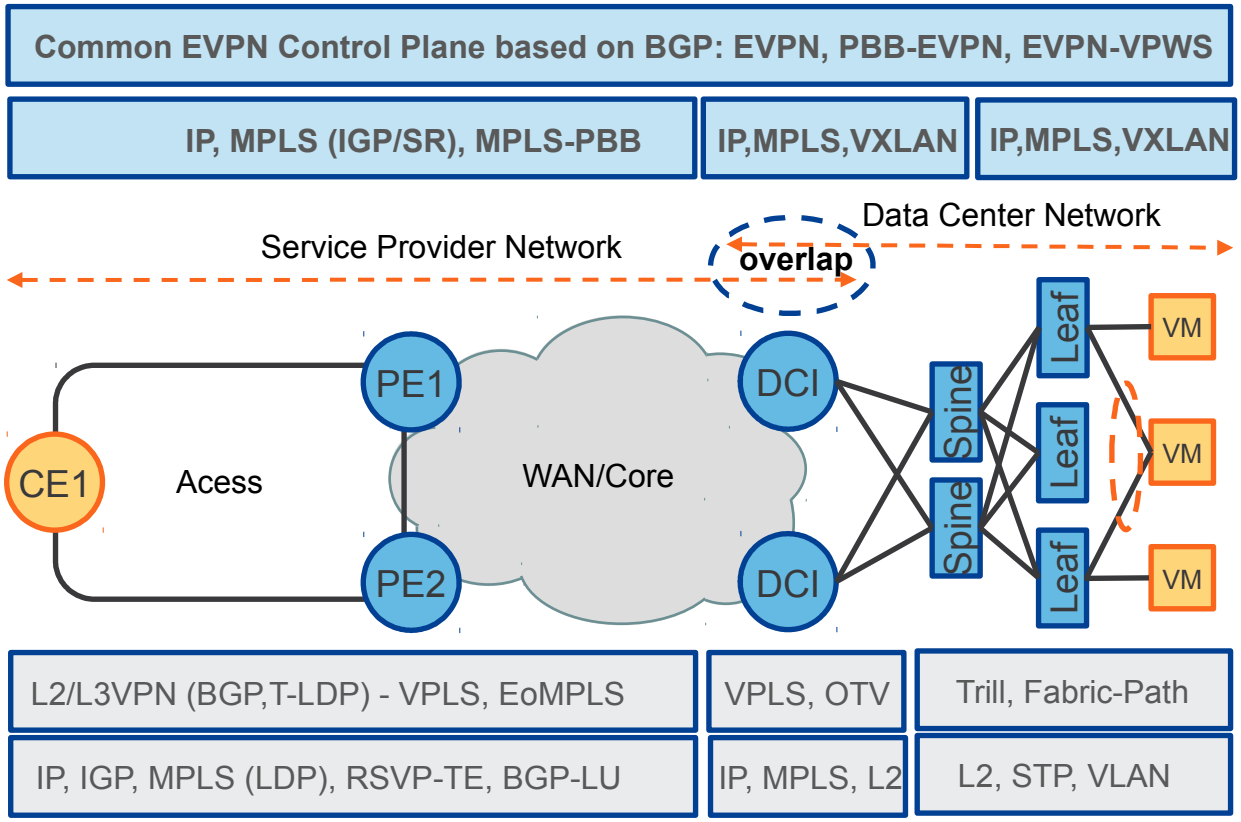
- The new EVPN NLRI defines five route types
  - Not all route type are mandatory, specific support will be based on the vendors implementation
  - Next hop (VTEP IP address) for the route is contained in the MP_REACH_NLRI path attribute



	Description
1	**Auto-Discover Segment route** – Used to support EVPNs multi-homing deployment models
2	**MAC address Route** - Advertisement of locally learnt/provisioned MAC address and optionally IP addresses.
3	**Inclusive Multicast Ethernet Route** - used to advertise VTEPs VNI membership for the creation of ingress replication lists
4	**Ethernet Segment Route** – used in multi-homing deployments to allow the dynamic discovery of shared Ethernet segments
5	**IP prefix Route,** advertisement of a IP prefix and next-hop, no MAC address for the route is advertised.

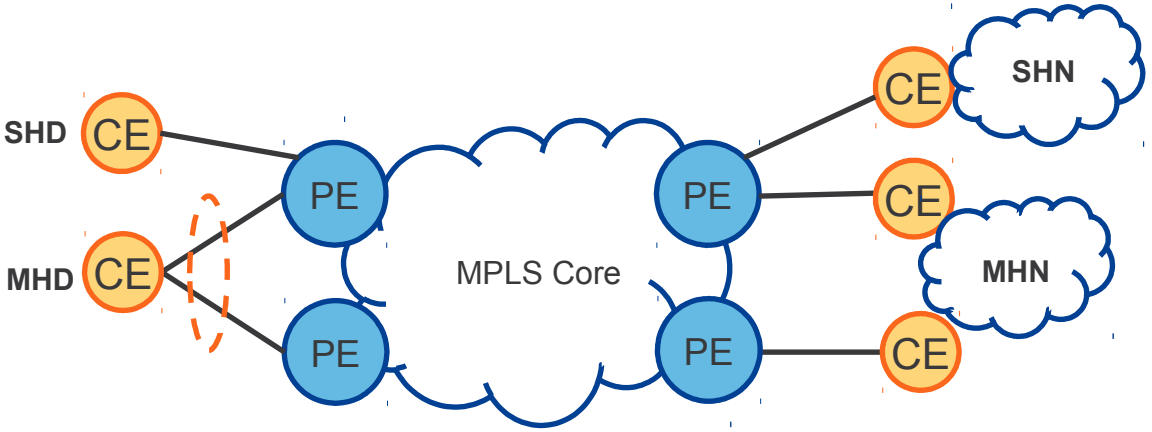
Summary:
EVPN - End-to-End Control-Plane

Evolution:



Existing Solution:

Ethernet Segment



- 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)
  - Single-Homed Network (SHN)
  - Multi-Homed Network (MHN)
- Uniquely identified by global Ethernet Segment Identifier (ESI).

Use cases

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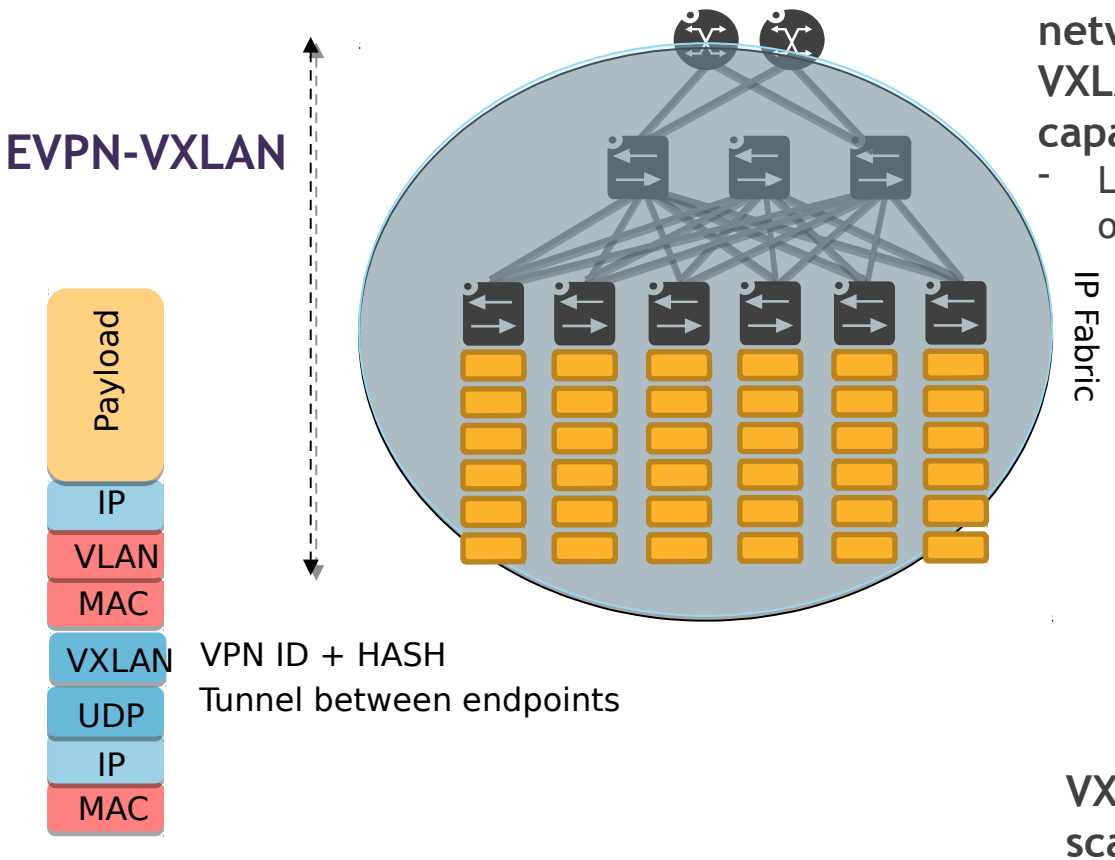
Data Center



Cloud computing and NFV are shifting DC networks to SDN-based DCs where only VXLAN and EVPN provide the required capabilities

- Legacy DC networks can't cope with 10,000s of dynamic hosts/VMs

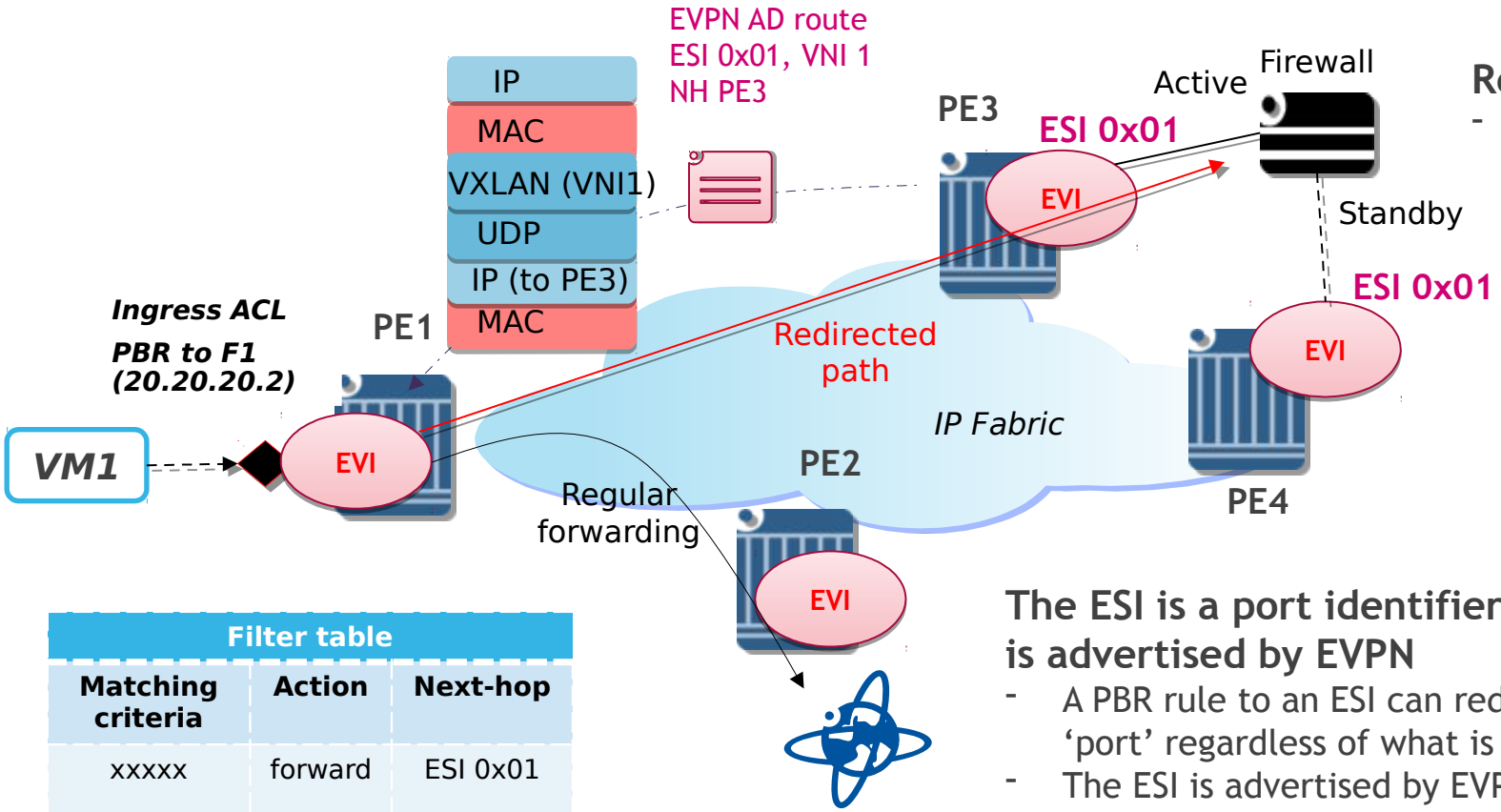
Required EVPN features

- EVPN provides L2/L3 connectivity for 1,000s of tenants in the DC
- The IP fabric can also be extended to the WAN for DC interconnect
- MAC mobility, proxy-ARP/ND, MAC protection, unknown flooding suppression, inter-subnet forwarding

VXLAN data plane provides the required scalability, performance and simplicity

- De-facto standard with assisted hardware in servers
- ECMP and fast resiliency
- Loop-free forwarding for L2
- Shortest path between any 2 endpoints

Policy Based Routing / service chaining (NFV)



Filter table		
Matching criteria	**Action**	**Next-hop**
xxxxx	forward	ESI 0x01

Required EVPN features

- EVPN AD routes per ESI

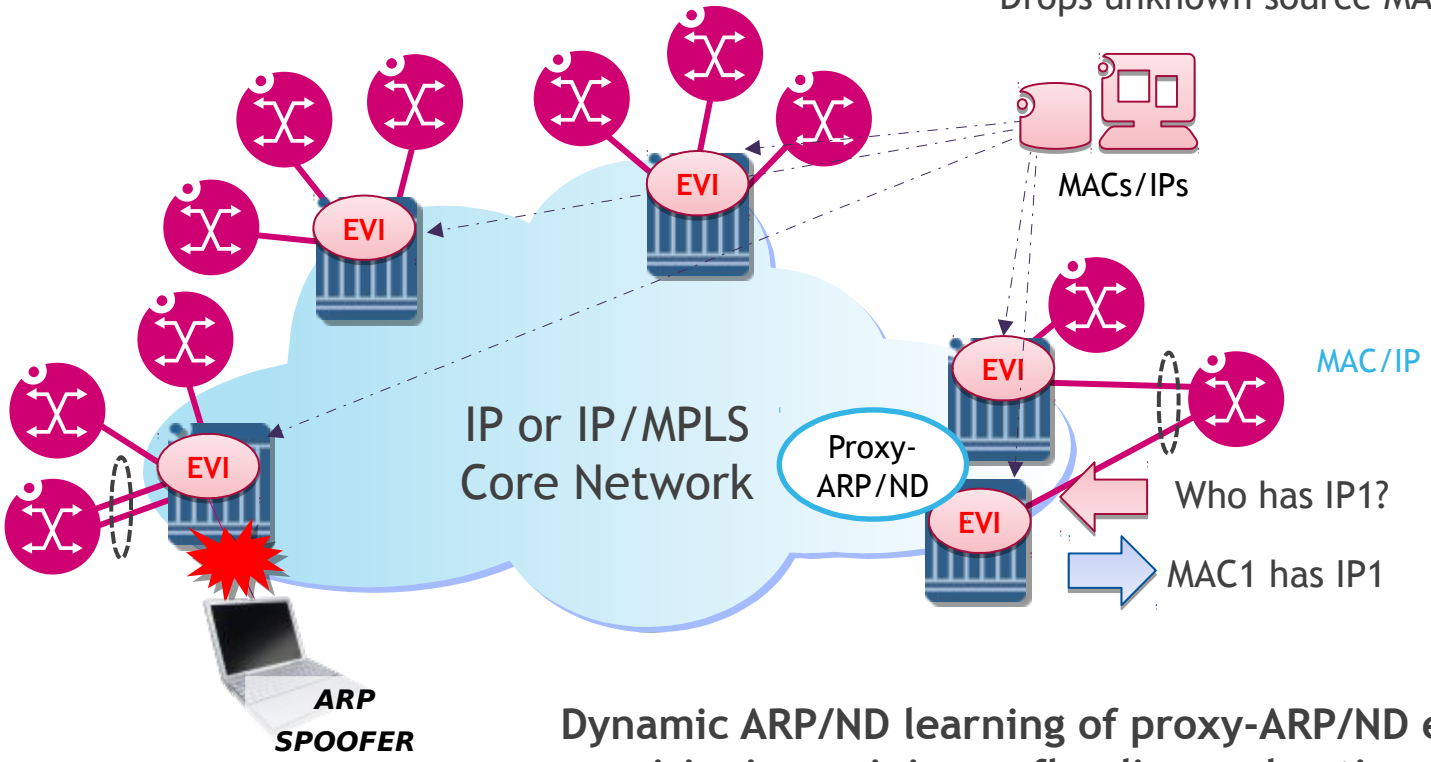
The ESI is a port identifier whose active presence is advertised by EVPN

- A PBR rule to an ESI can redirect traffic to a remote 'port' regardless of what is connected behind
- The ESI is advertised by EVPN when the FW port is active and withdrawn when the port goes inactive
- Active-active redirect is also possible (re-using the aliasing concept)

IXPs Peering fabrics

Static MAC/IP provisioning of the router interfaces for maximum security

- Suppresses unknown and ARP/ND flooding
- Drops unknown source MACs



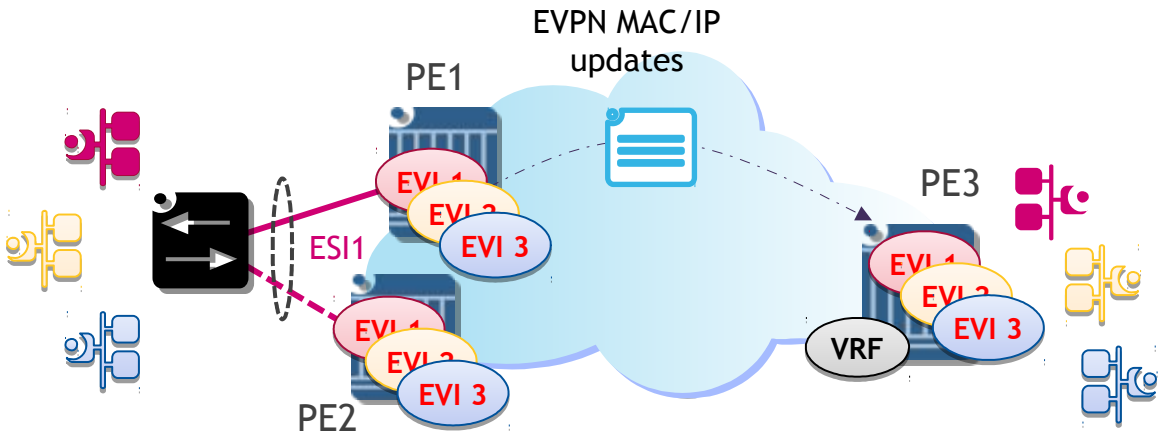
EVPN required features

- L2 interconnection over a VXLAN or MPLS peering fabric
- Proxy-ARP/ND and unknown/ARP/ND suppression
- MAC duplication, MAC protection
- Anti-spoofing operation

Dynamic ARP/ND learning of proxy-ARP/ND entries for easy provisioning, minimum flooding and anti-spoofing monitoring

- Dynamic learning of ARP/ND entries is possible
- Anti-spoofing monitors hosts claiming the same IP
  - If a duplicate is detected, an alarm is triggered and MAC/IPs put in hold-down mode
  - An option to inject an anti-spoof mac is possible too

Provider-provisioned VPNs Layer-2 and Layer-3 services



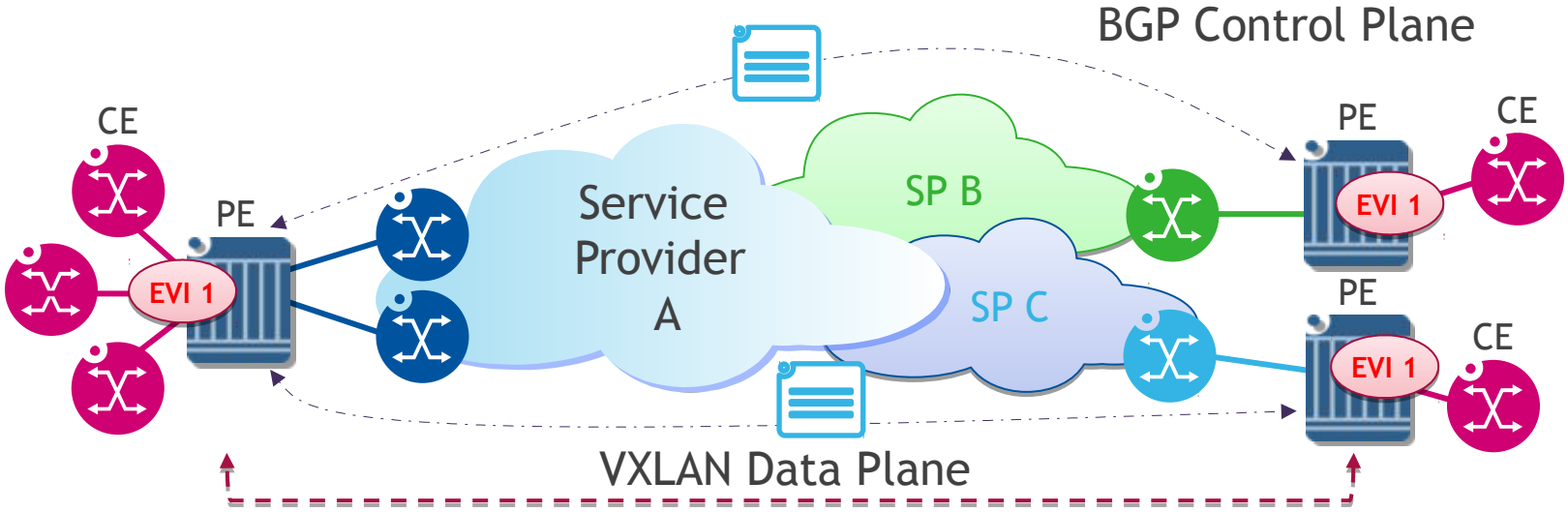
Required EVPN features

- IP-prefix advertisement and inter-subnet forwarding
- All-active multihoming for link utilization
- Single-active multihoming for better determinism
- PBB-EVPN for large layer-2 VPNs

EVPN provides layer-2 and layer-3 services

- Both services are provided through the same logical AC to the customer
- One VPN technology for both services, no need for multiple protocols
- VXLAN or MPLS data planes are possible

Enterprise-provisioned overlay VPNs



EVPN-VXLAN works over any IP service to provide a flexible Layer-2 and Layer-3 VPN

- Just requires IP connectivity between the sites, no need to run any MPLS or special configuration by the IP service provider
- Service Provider is transparent to EVPN
- EVPN overlay is transparent to service providers

VPN routing between endpoints can be controlled with BGP (ipv4) and routing policies to service providers

Routing and MAC/IP advertisements within EVPN controlled via iBGP (evpn) between PEs

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