Configuration and Management of Networks

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Service Provider Networks

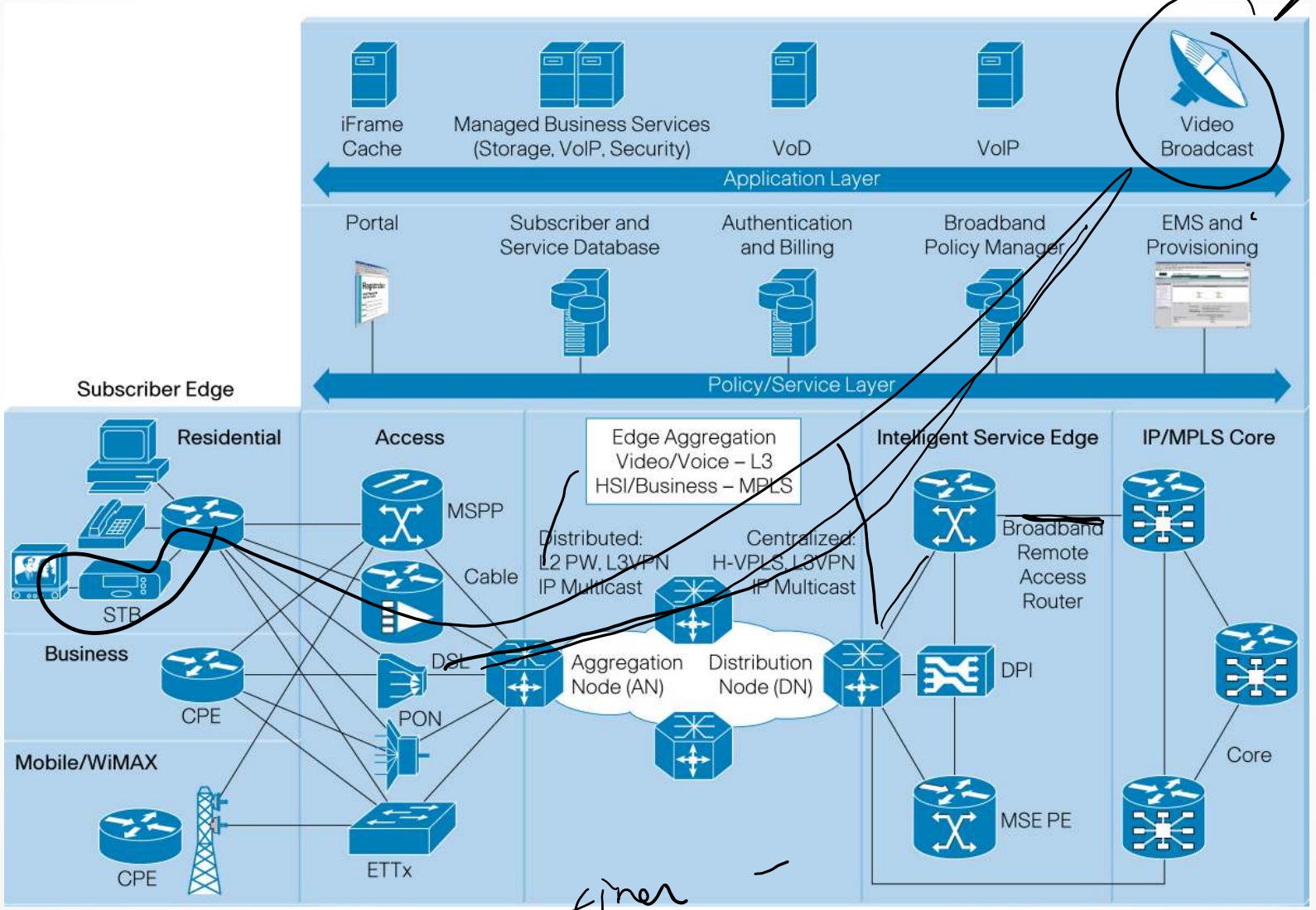
Carrier grade networks that carry customer's traffic:

- Triple play residential customers
  - Voice
  - High Speed Internet
  - Broadcast TV and Video on Demand

- Mobile Backhaul
  - Interconnection of the RAN (Radio Access Network)

- Enterprise Services
  - Enterprise inter-branch WAN connections
  - Data center networks (Cloud) interconnection

Service Provider Networks



Service Provider Networks

- **Access**: Provides access to residential and business customers over DSL, fiber, cable, or wireless.
- **Carrier Ethernet aggregation**: Aggregates the access networks across a Carrier Ethernet network and provides interconnectivity to the IP/MPLS edge and IP/MPLS core.
- **Intelligent service edge**: Interfaces services with the IP/MPLS core; this is the provider edge for both residential and business subscriber services.
- **IP/MPLS core**: Provides scalable IP/MPLS routing in the core network.
- **Policy/service layer**: Provides broadband policy management to control service delivery – a key component of the Service Exchange Framework.

Service Provider Networks

- **Carrier Ethernet Aggregation -** Multiple Layer 2/Layer 3 technologies for Ethernet transport.

  - Layer 3 routing with PIM-SSM over MPLS FRR
  - Layer 3 MPLS VPN and multicast VPN (RFC 2547bis)
  - H-VPLS
  - EoMPLS (Pseudowires)

  MPLS based

  - IEEE 802.1q (VLANS), 802.1ad(QinQ), 802.1ah (PBB)

  MEF based

Applications have different requirements that can not be addressed by a single, universal approach to network design

Service Provider Networks

Carrier Ethernet Networks - Metro Ethernet Forum (MEF) based

Ethernet Service Definition according to the Metro Ethernet Forum:

- User-to-Network Interface (UNI) – Point of demarcation to the customer.
- Ethernet Virtual Connection (EVC) – Association of two or more UNIs

Two main service types :

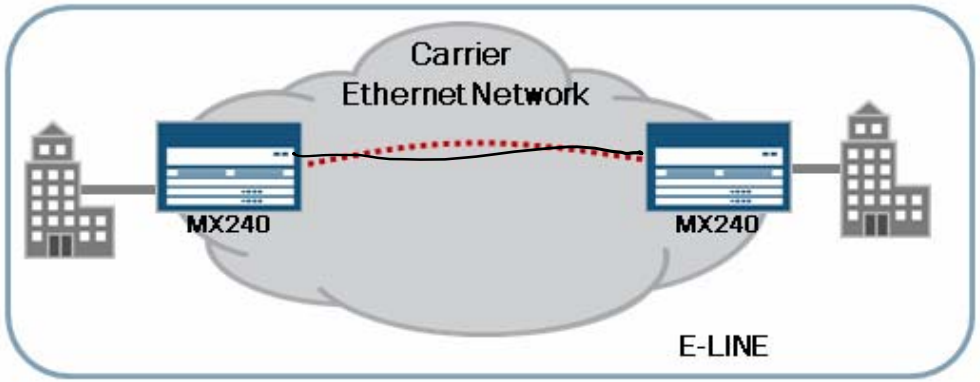
- Ethernet Line Service (ELS)—This is basically a point-to-point (P2P) Ethernet service.
- Ethernet LAN Service (E-LAN)—This is a multipoint-to-multipoint (MP2MP) Ethernet.

Service Provider Networks – Ethernet Challenges

- Scalability:
  - Millions of customer end stations
    - The service provider environment learns a large number of MAC addresses
  - Redundant connections between the service provider and the customers for resiliency
    - Spanning tree protocols simply cannot scale
- SLAs:
  - Native Ethernet frames do not provide quality of service
    - Best effort had been generally accepted in LAN network
- OAM:
  - Fault management and performance monitoring
  - Monitoring and troubleshooting Ethernet access links
  - Circuit protection

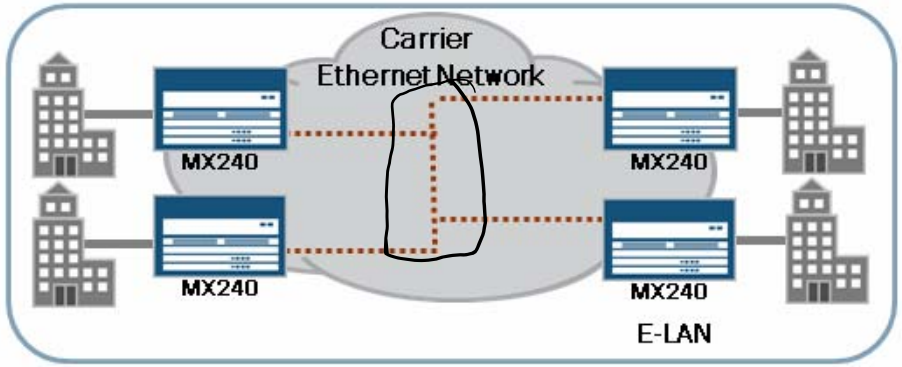
Service Provider Networks

- E-Line service EVCs
  - Two types:
    - Ethernet Private Line (port-based)
    - Virtual Private Line (VLAN-based)
  - Allow for communication between only two UNIs



Service Provider Networks

- E-LAN service EVCs
  - Two types:
    - Ethernet Private LAN (port-based)
    - Virtual Private LAN (VLAN-based)
  - Allows for communication between two or more UNIs
    - Ingress broadcast or multicast frames at one UNI are forwarded to all other UNIs



Service Provider Networks – Carrier Ethernet

- IEEE 802.1Q VLANs allow the customer's local bridged networks to scale:
  - VLAN tags allow for up 4094 separate broadcast domains
- Service provider scaling issues (for Ethernet virtual connections):
  - Service provider network needs to be aware of customer's bridging (spanning tree) and VLAN administration
  - Problem of overlapping VLAN IDs between service provider customers
  - Service provider bridges learn and store customer MAC addresses

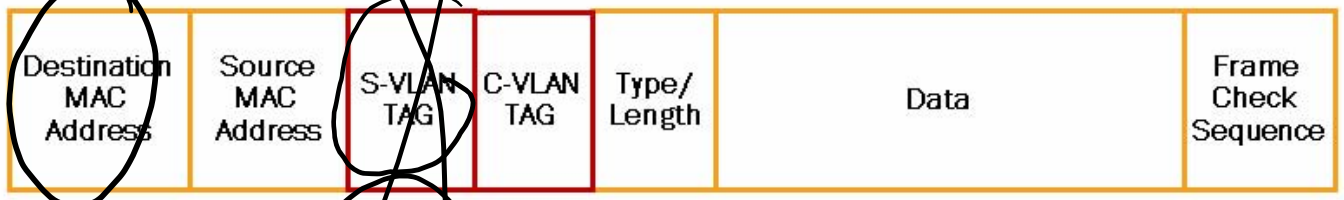
Service Provider Networks – Carrier Ethernet

- IEEE 802.1ad provides the standard for stacking VLAN tags:
  - Allows the service provider to provide LAN service through the service provider network
    - Each outer tag (S-VLAN tag) represents a customer (4094 possible)
    - Inner tag (C-VLAN tag) represents any of a customer's 4094 VLANs
    - The service provider and the customer use unique spanning-tree domains
    - Allows for VLAN translation between service provider bridged networks
- Service provider scaling issues:
  - Service provider bridges learn and store customer MAC

Service Provider Networks – Carrier Ethernet

Provider Bridging

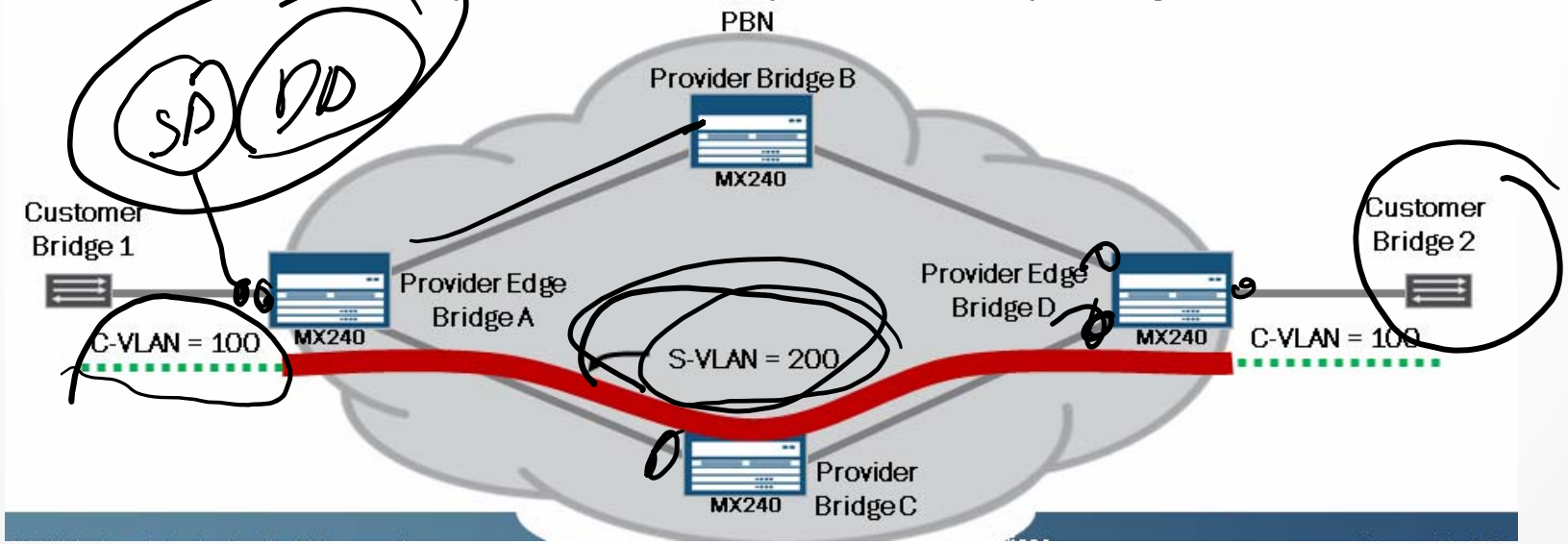
- Defined by the IEEE 802.1ad standard:
  - Allows for service providers to offer the equivalent of separate Ethernet LANs to their customers
    - Easy for the customer to understand (Ethernet)
    - Easy for the service provider to provision (1 VLAN equals 1 customer)
  - Requires the use of 2 stacked VLAN tags
    - C-VLAN—typically controlled by the customer
    - S-VLAN—controlled by the service provider



Service Provider Networks – Carrier Ethernet

Provider Bridging

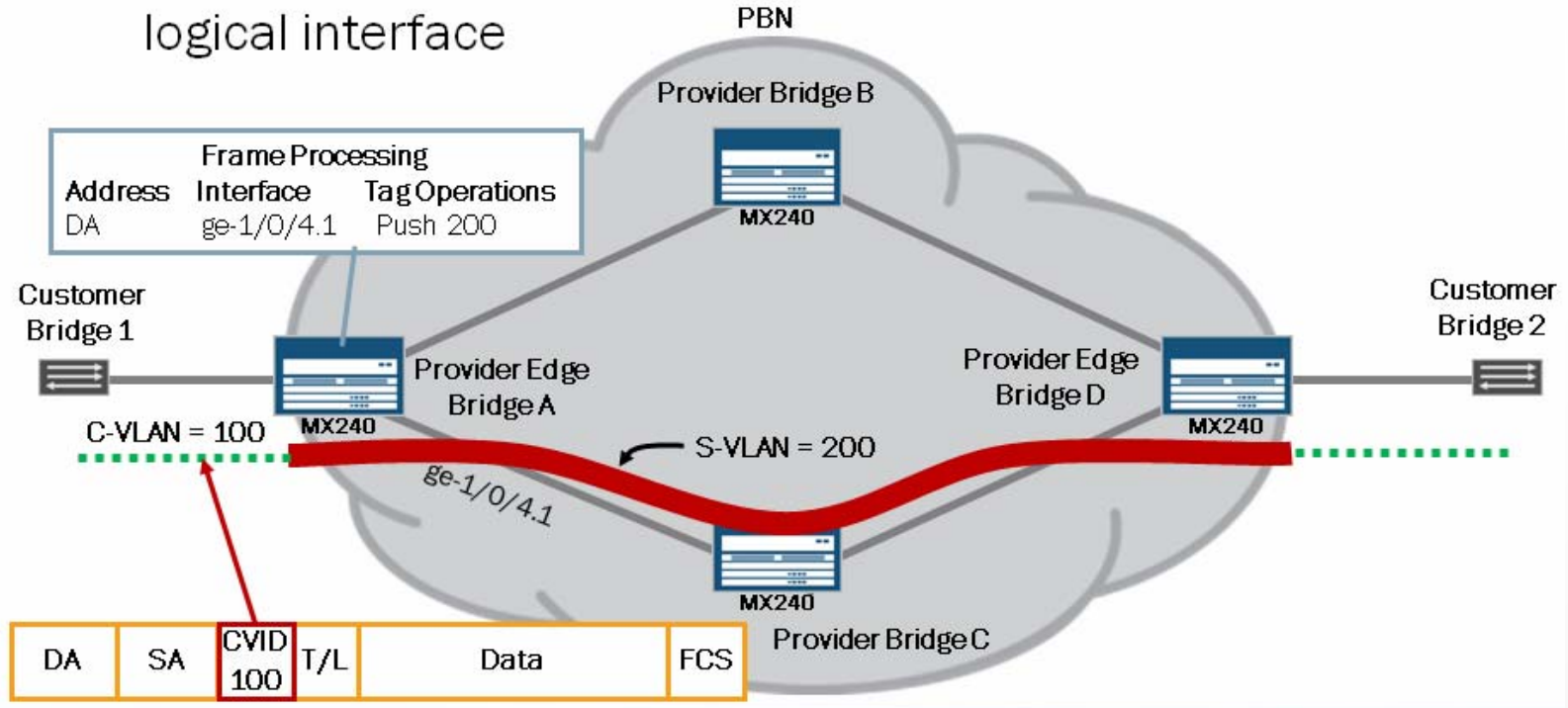
- Service provider provides an EVC to the customer:
  - Customer uses 802.1Q-tagged frames (C-VLAN 100) to connect to the remote site while the service provider network is transparent
    - S-VLAN tagging of the customer frames during transmission across the service provider network provides transparency



Service Provider Networks – Carrier Ethernet

Provider Bridging

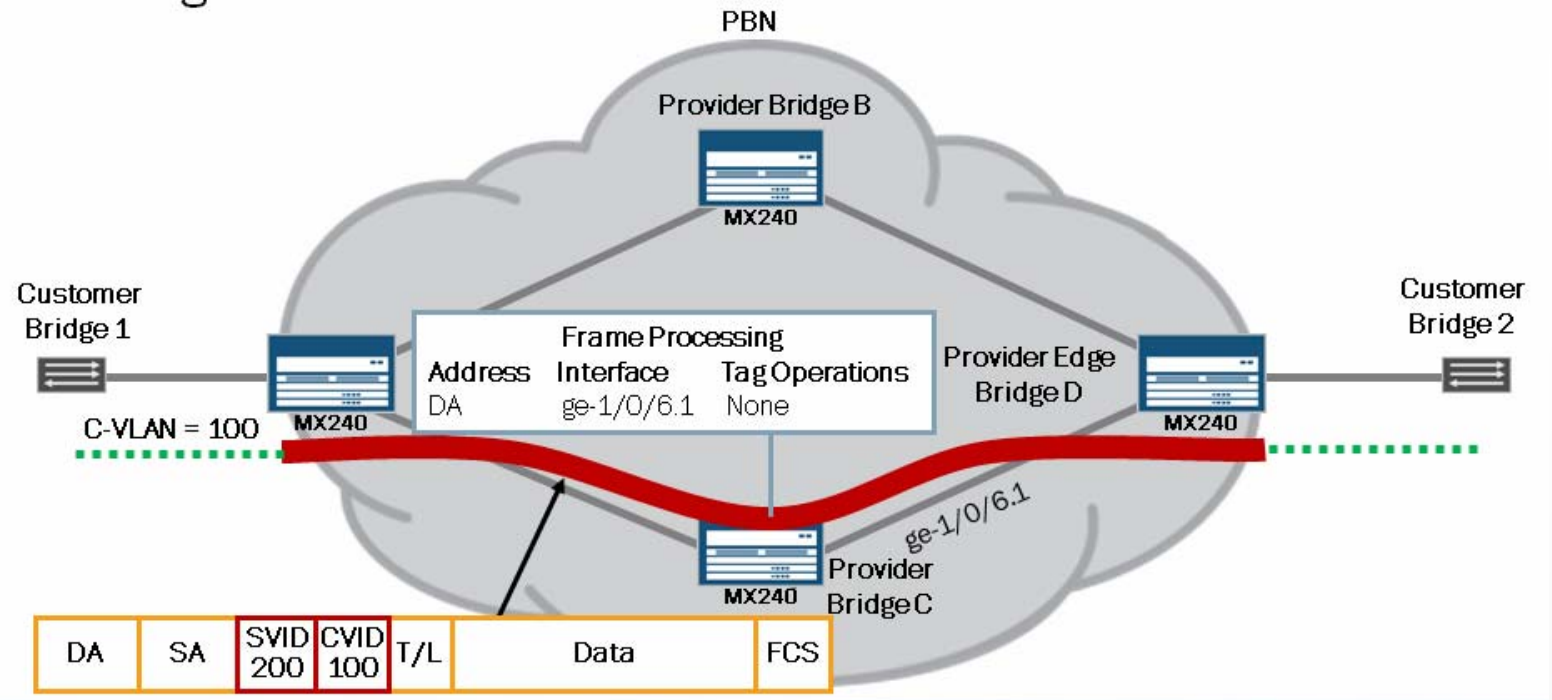
- Frames with a single C-VLAN tag with VLAN ID 100 arrive at Bridge A:
  - Bridge A performs a MAC lookup to determine the outgoing logical interface



Service Provider Networks – Carrier Ethernet

Provider Bridging

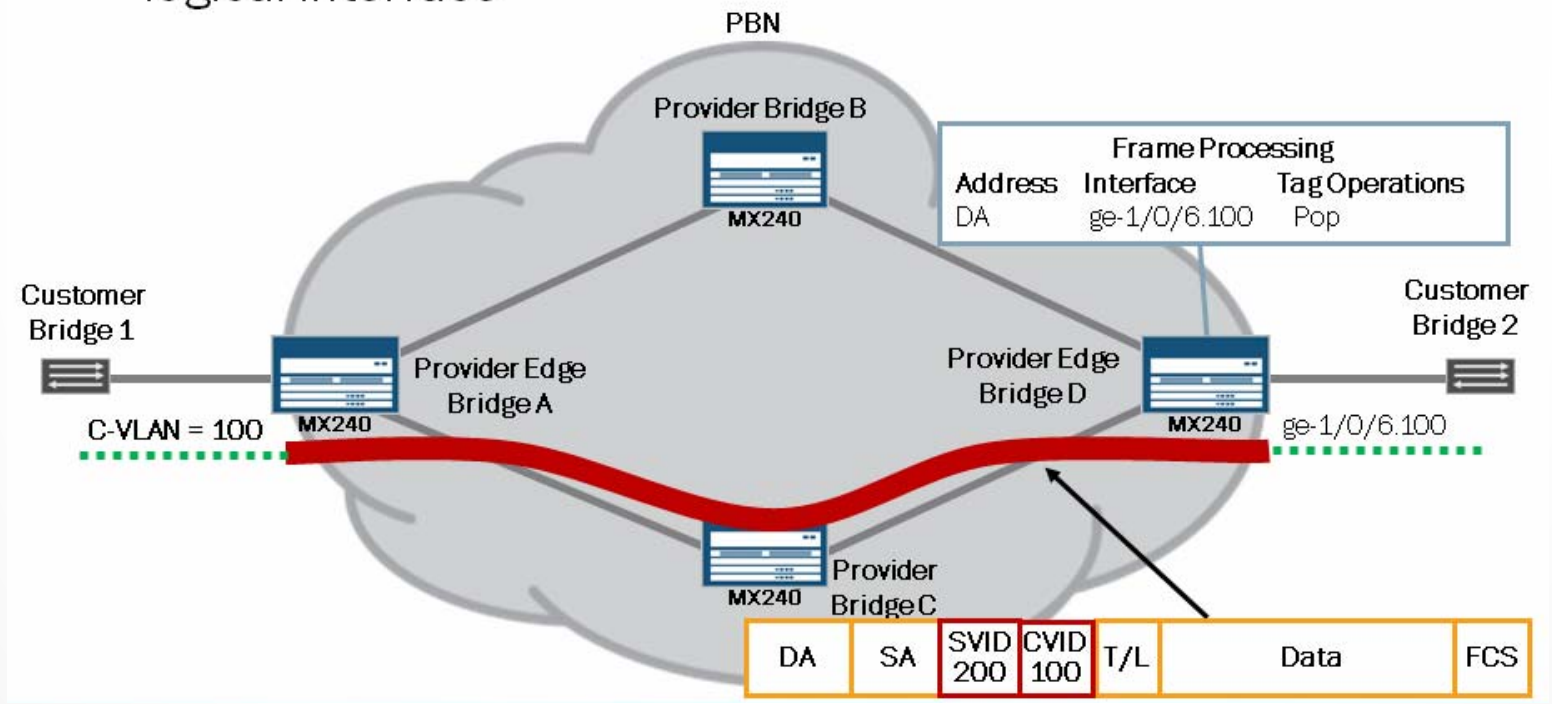
- Frames with two VLAN tags arrive at Bridge C:
  - Bridge C performs a MAC lookup to determine the outgoing logical interface



Service Provider Networks – Carrier Ethernet

Provider Bridging

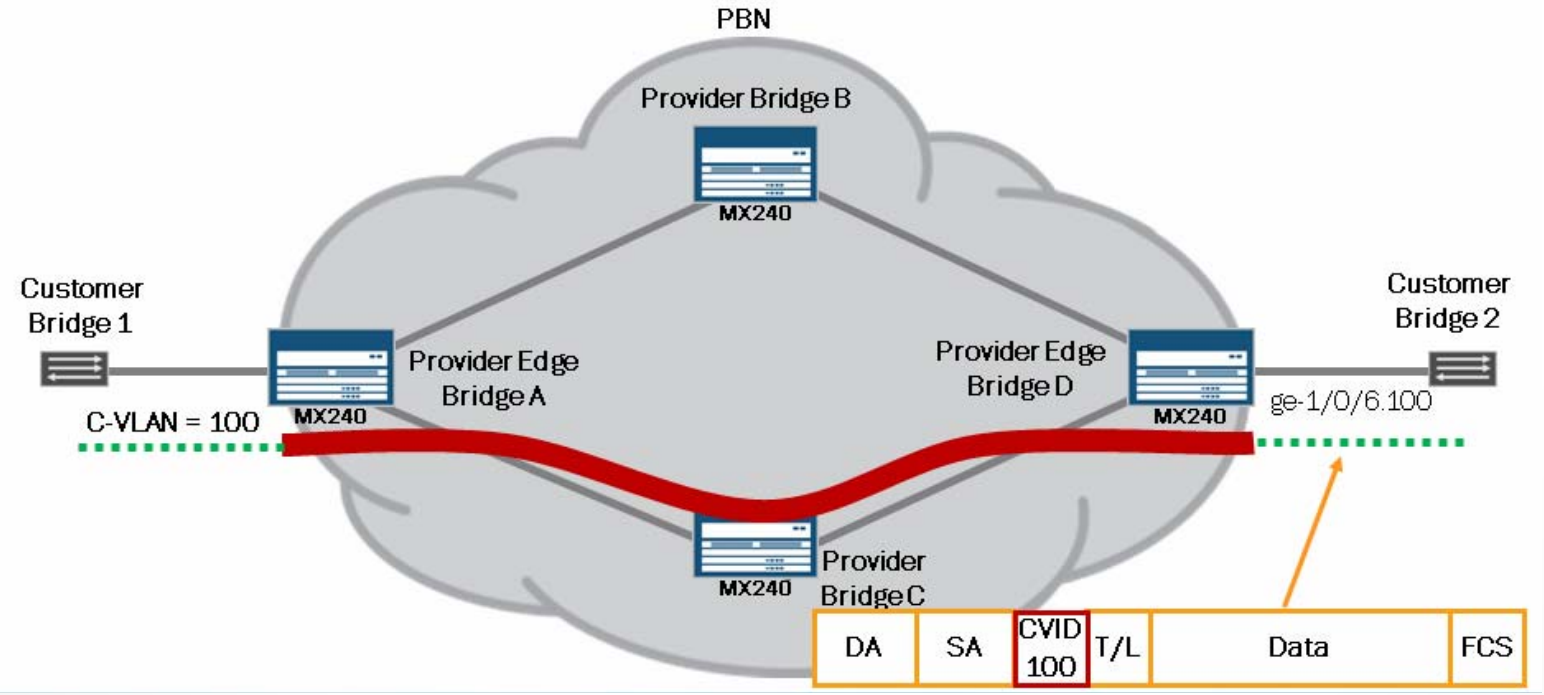
- Frames with two VLAN tags arrive at Bridge D:
  - Bridge D performs a MAC lookup to determine the outgoing logical interface



Service Provider Networks – Carrier Ethernet

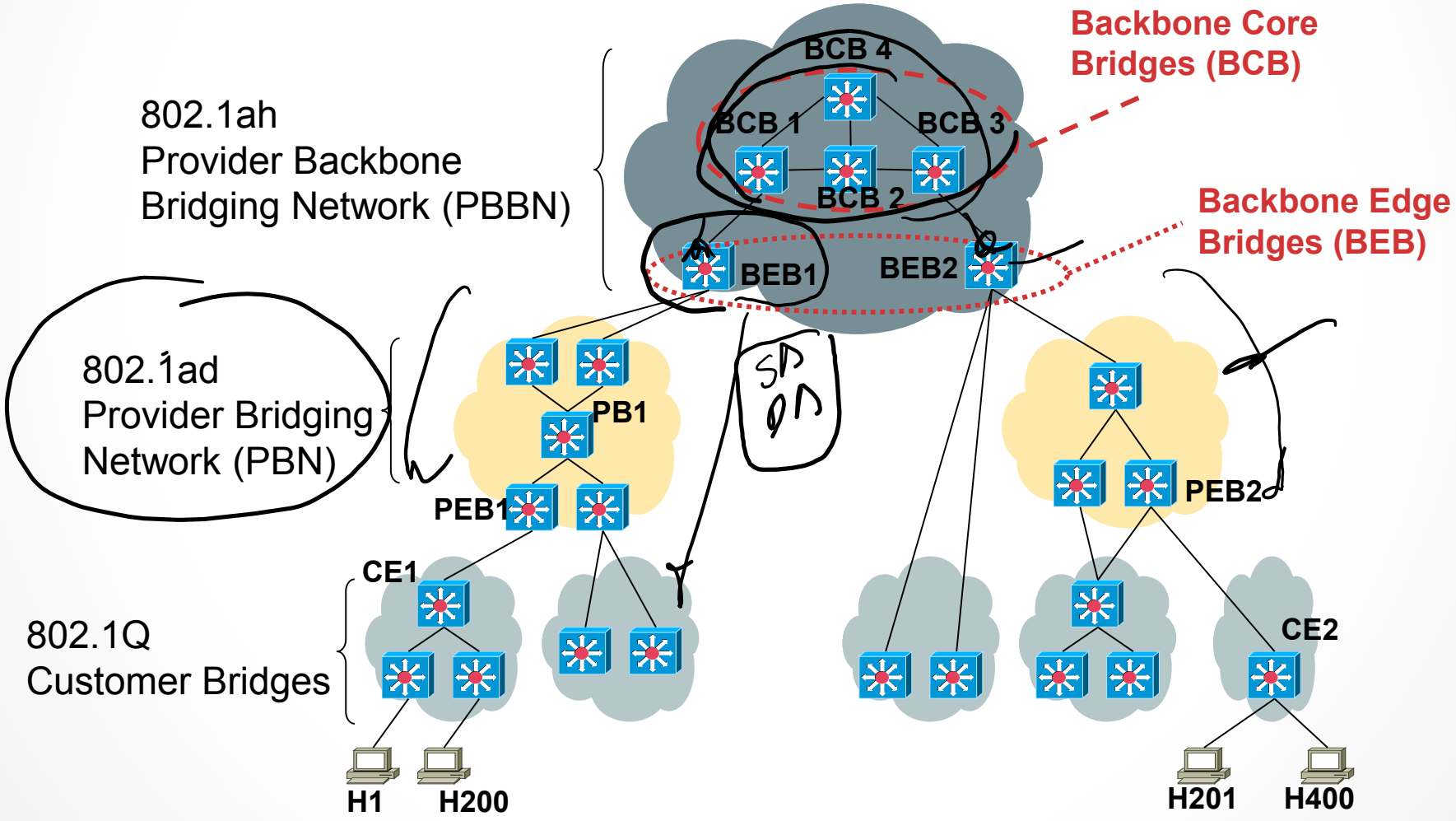
Provider Bridging

- Frames with a single VLAN tag arrive at Customer Bridge 2



Service Provider Networks – Carrier Ethernet

Provider Bridging – 802.1ah (MAC in MAC)

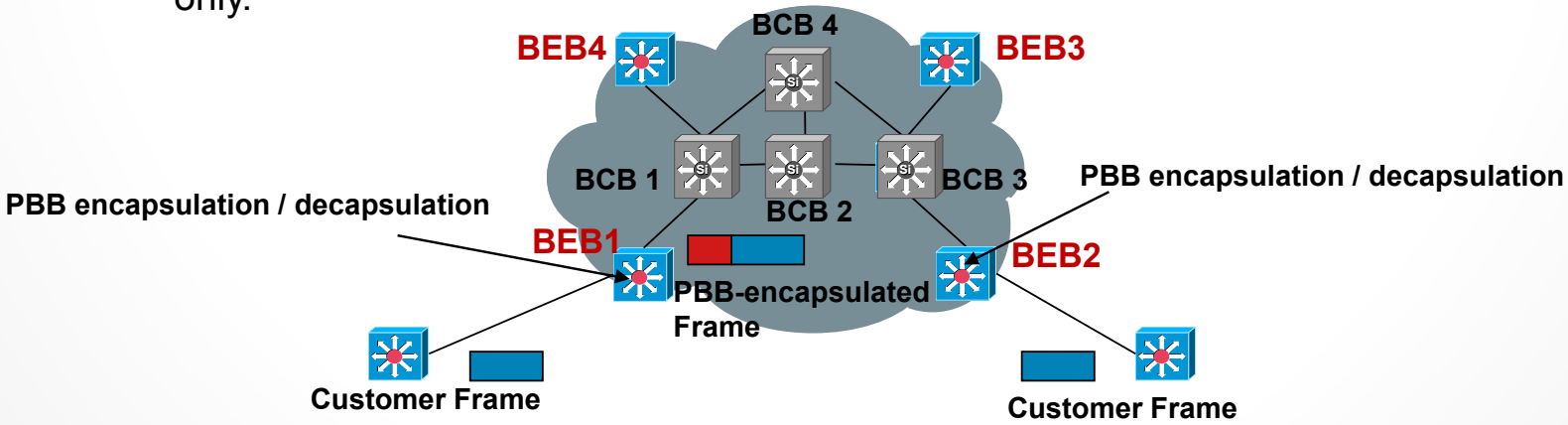


Service Provider Networks – Carrier Ethernet

Provider Bridging – 802.1ah (MAC in MAC)

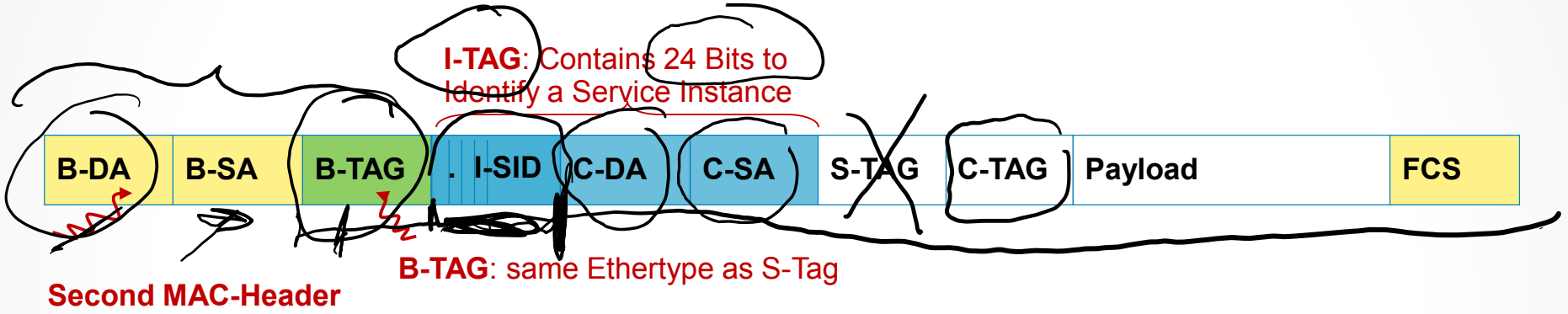
- PBB provides a ‘MAC tunneling’ scheme to transport Ethernet frames between BEBs.
- BEBs are responsible for translating frames to/from new PBB format.
- All intelligence is on BEBs. BCBs are regular 802.1ad Provider Bridges.

  Allows upgrading from 802.1ad to 802.1ah by updating the edge nodes only.



Service Provider Networks – Carrier Ethernet

Provider Bridging – 802.1ah (MAC in MAC)



- Service Instance Scalability

  New 24-bits Service Instance Identifier (I-SID) instead of 12-bits VLAN

- Domain Isolation & MAC-Address Scalability

  Encapsulate Customer MAC frames at the edge of the network into Backbone MAC frames:
  New MAC header

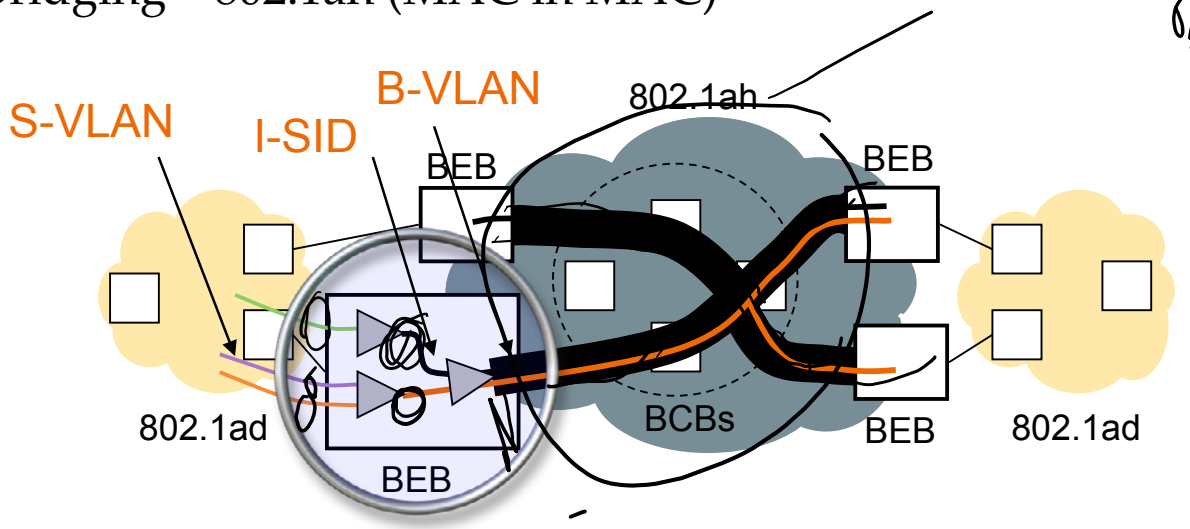
- Backwards Compatibility with IEEE 802.1ad

  Ethertype of B-VLAN is the same as 802.1ad S-VLAN (0x88a8)

  PBB leverages existing L2 control plane mechanisms

Service Provider Networks – Carrier Ethernet

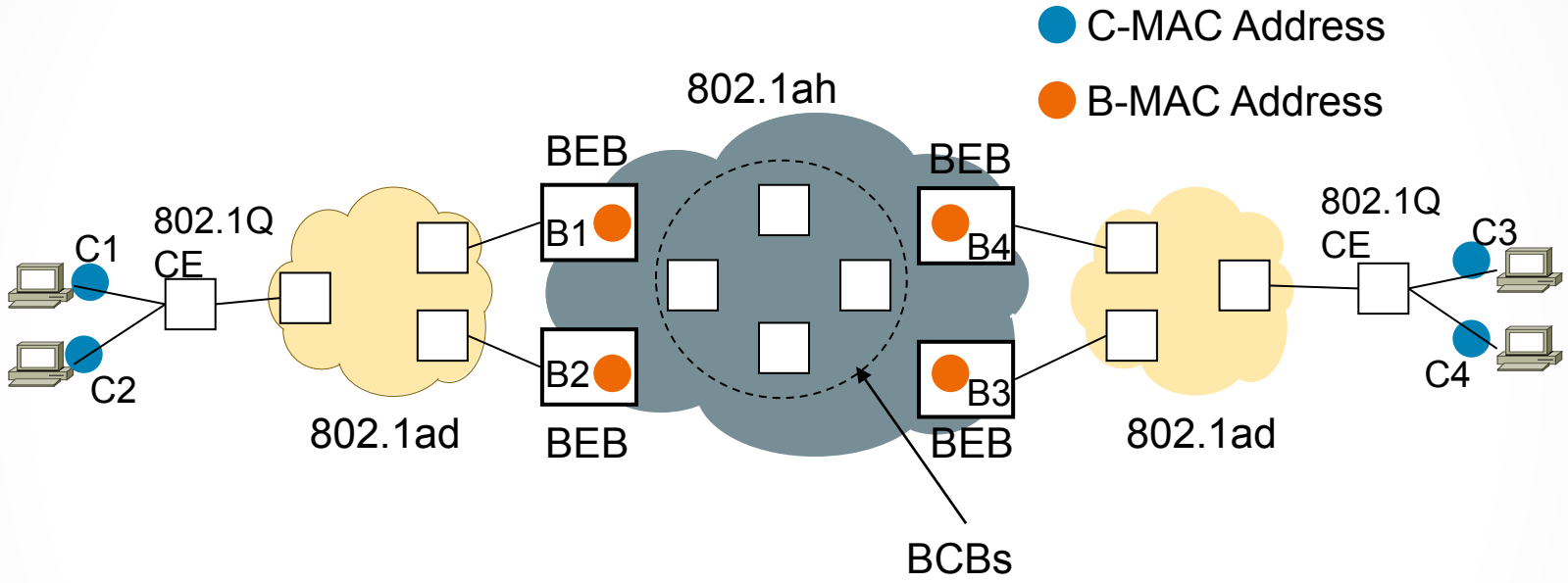
Provider Bridging – 802.1ah (MAC in MAC)



- S-VLANs from access mapped or bundled into I-SIDs on BEBs.
- I-SID provides service identification in PBB network.
  Global in scope within a single operator's network
- I-SIDs bundled into B-VLANs for transport over PBB core.
- B-VLAN defines transport topology in PBB network (e.g., a spanning-tree).

Service Provider Networks – Carrier Ethernet

Provider Bridging – 802.1ah (MAC in MAC)



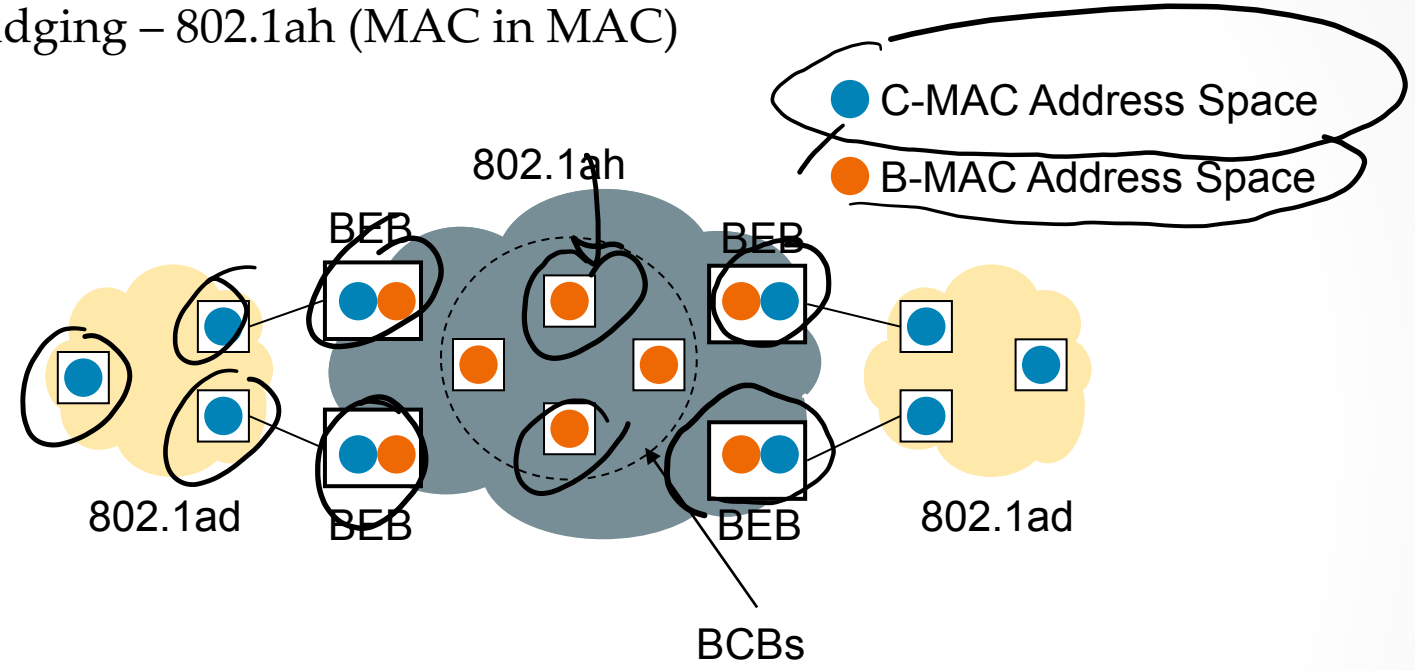
- Each BEB uniquely identified by one or more unicast B-MAC addresses.

  Additionally, a BEB may listen in to one or more B-MAC multicast group addresses

- B-MAC addresses guaranteed to be unique within a provider's network & may be administered by operator.

Service Provider Networks – Carrier Ethernet

Provider Bridging – 802.1ah (MAC in MAC)



- Backbone Edge Bridge (BEB):

  Learn and forward based on both Customer MAC (C-MAC) and Backbone MAC (B-MAC) addresses

  Build a mapping of C-MAC to B-MAC addresses

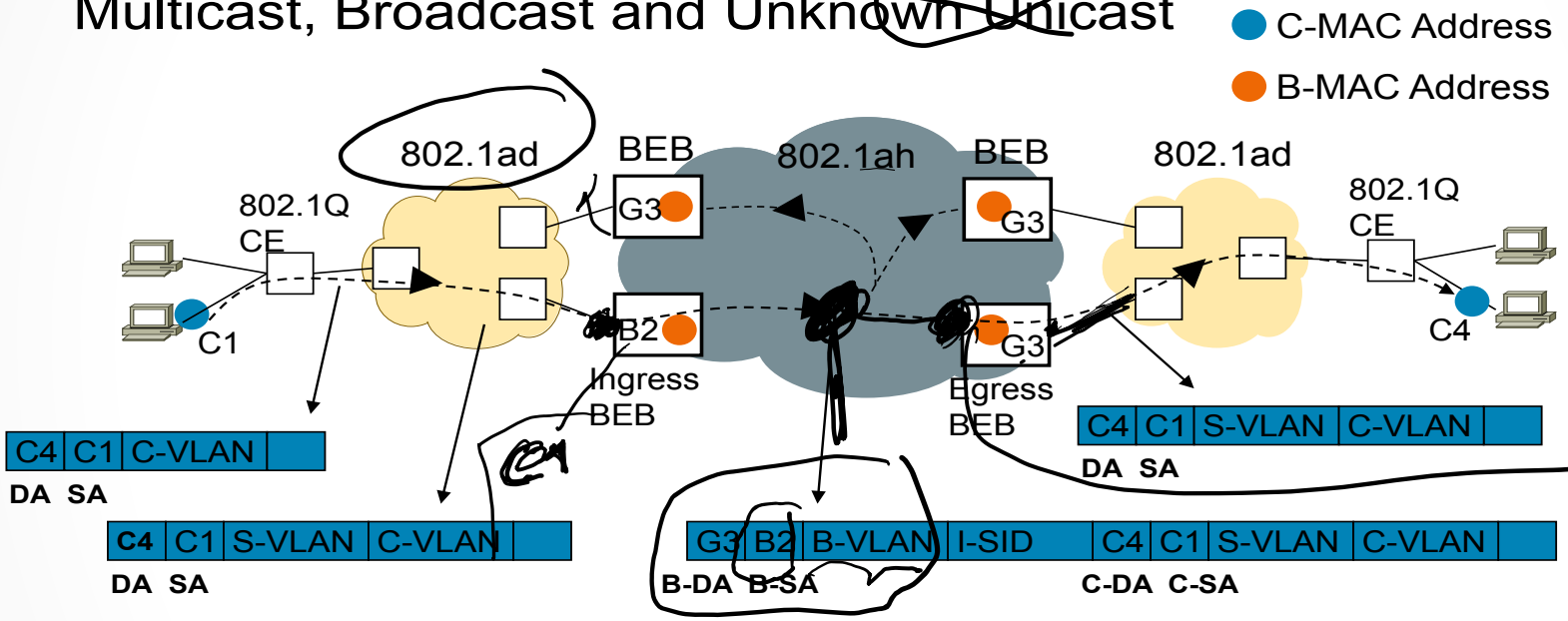
- Backbone Core Bridge (BCB):

  Learn and forward based on B-MAC addresses only

Service Provider Networks – Carrier Ethernet

Provider Bridging – 802.1ah (MAC in MAC)

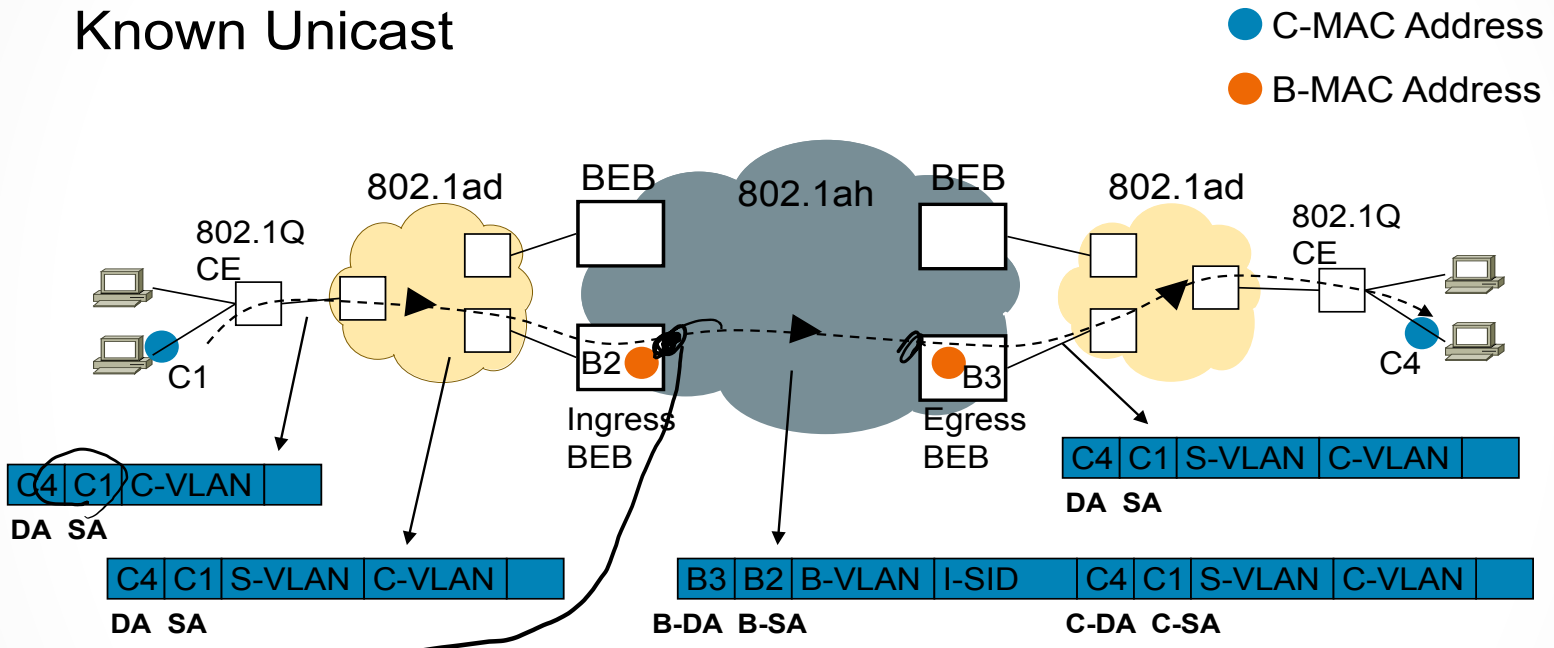
Multicast, Broadcast and Unknown Unicast



- Ingress BEB encapsulates frame with PBB header
  - B-MAC DA is set to B-MAC multicast group address
  - B-MAC SA set to ingress BEB's MAC address
  - I-SID determined based on S-VLAN & B-VLAN determined based on I-SID
- One or multiple egress BEBs listen in to the group address

Service Provider Networks – Carrier Ethernet

Provider Bridging – 802.1ah (MAC in MAC)



- Ingress BEB encapsulates frame with PBB header
  - B-MAC DA is set to egress BEB's MAC address (learnt via reverse traffic)
  - B-MAC SA set to ingress BEB's MAC address
  - I-SID determined based on S-VLAN & B-VLAN determined based on I-SID
- Egress BEB strips off PBB encapsulation

Service Provider Networks

MPLS is used in many different applications:
– Unicast IP routing
– Multicast IP routing
– MPLS TE
– QoS
– MPLS VPNs

MPLS Three main VPN technologies:
- Layer 3 VPNs
- Layer 2 VPNs
  - VPLS
  - Point-to-point PSW (pseudowires)

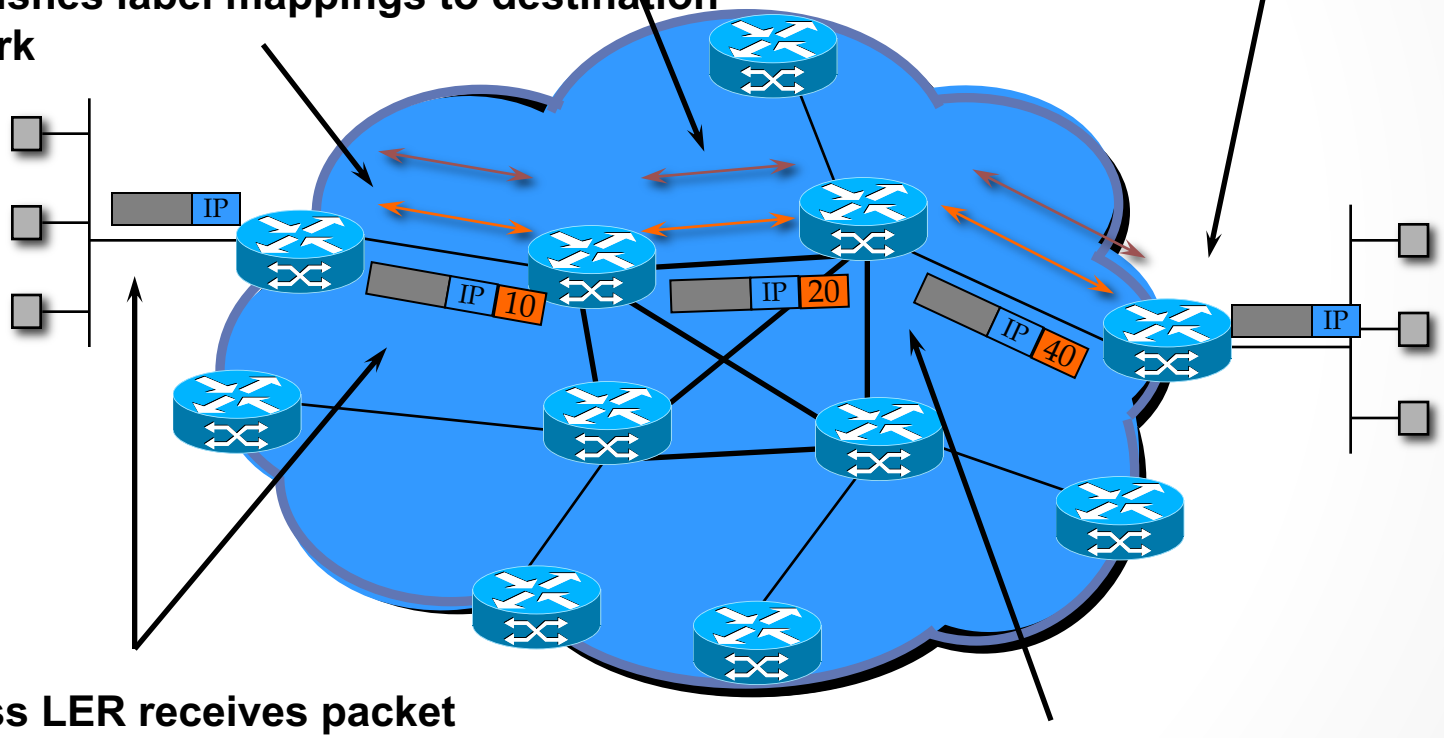
MPLS - Basic Idea

- Packets are switched, not routed, based on labels
- Labels are filled in the packet header
- Basic operation:
  - Ingress LER (Label Edge Router) pushes a label in front of the IP header
  - LSR (Label Switch Router) does label swapping
  - Egress LER removes the label
- The key : establish the forwarding table
  - Link state routing protocols
    - Exchange network topology information for path selection
    - OSPF-TE, IS-IS-TE
  - Signaling/Label distribution protocols:
    - Set up LSPs (Label Switched Path)
    - LDP, RSVP-TE, CR-LDP, BGP (can also be used)

1a. Routing protocols (e.g. OSPF-TE, IS-IS-TE) exchange reachability to destination networks

1b. Label Distribution Protocol (LDP) establishes label mappings to destination network

4. LER at egress removes label and delivers packet



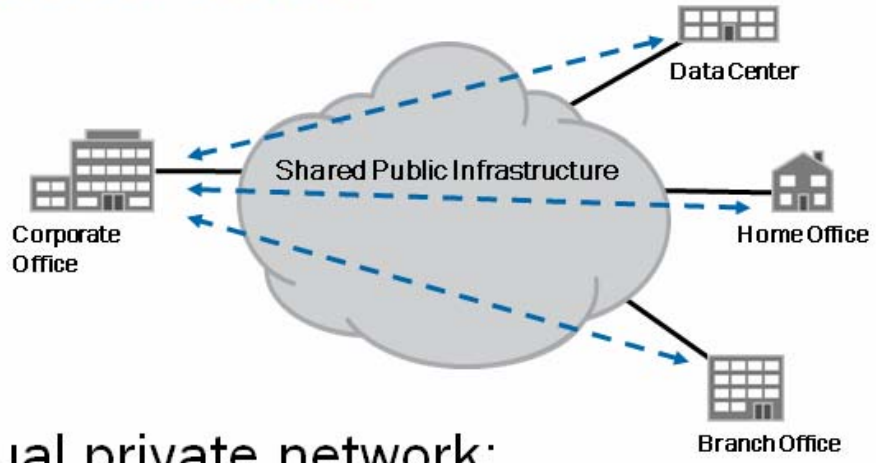
2. Ingress LER receives packet and "labels" packets

3. LSR forwards packets using label swapping

MPLS - Advantages

- Scalability of network layer routing. Using labels as a means to aggregate forwarding information.
- Labels provide forwarding along an explicit path different from the one constructed by destination-based forwarding. Better QoS and TE capabilities
- Recursion is provided for; hence tunnels can exist within tunnels. Several VPN traffic separation possibilities.

Service Provider Networks

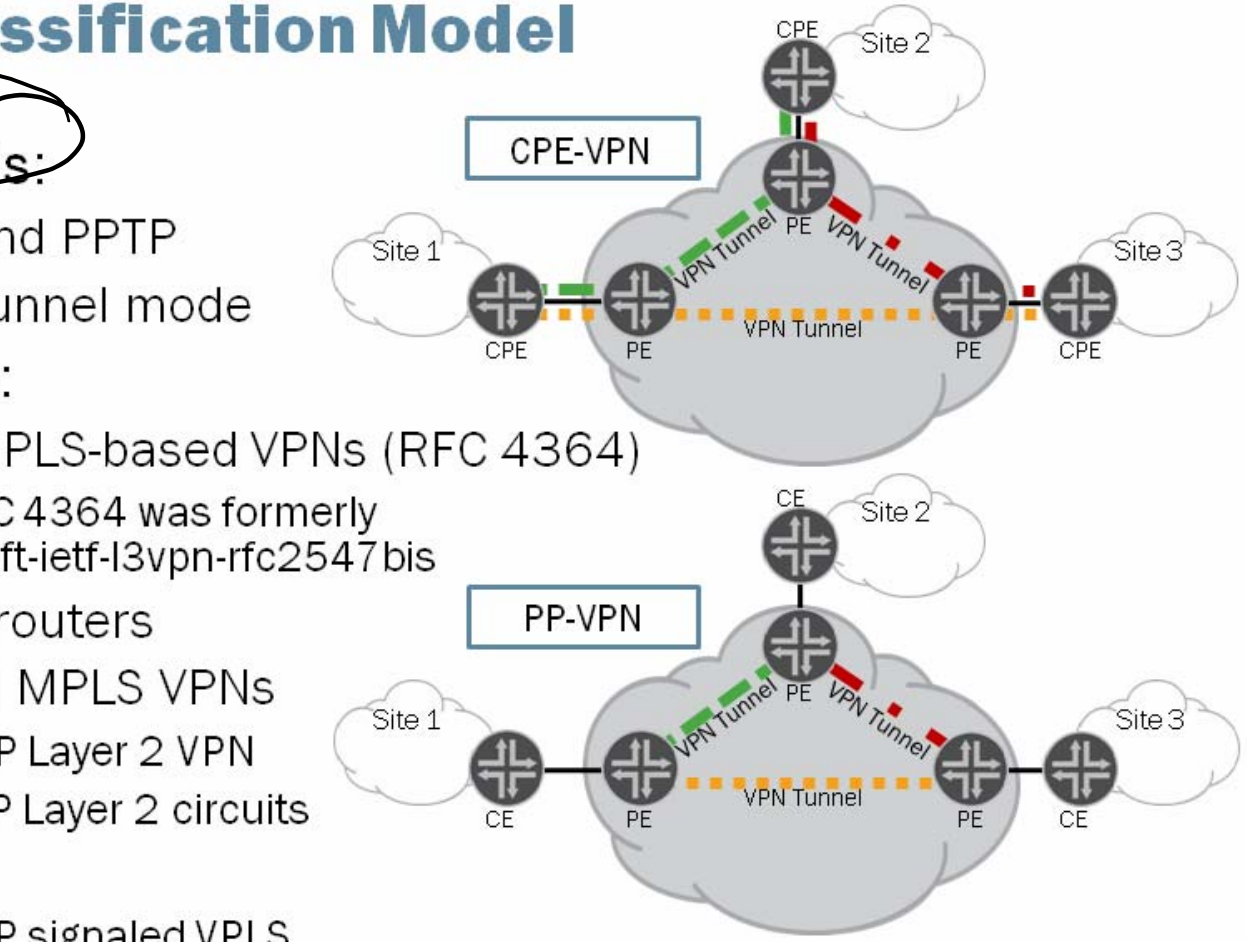


- Virtual private network:
  - A private network constructed over a shared infrastructure
  - Virtual: Not a separate physical network
  - Private: Separate addressing and routing
  - Network: A collection of devices that communicate
  - Constraints are key—restricted connectivity is the goal

Service Provider Networks

VPN Classification Model

- CPE-VPNs:
  - L2TP and PPTP
  - IPsec tunnel mode
- PP-VPNs:
  - BGP/MPLS-based VPNs (RFC 4364)
    - RFC 4364 was formerly draft-ietf-l3vpn-rfc2547bis
  - Virtual routers
  - Layer 2 MPLS VPNs
    - BGP Layer 2 VPN
    - LDP Layer 2 circuits
  - VPLS
    - BGP signaled VPLS
    - LDP signaled VPLS

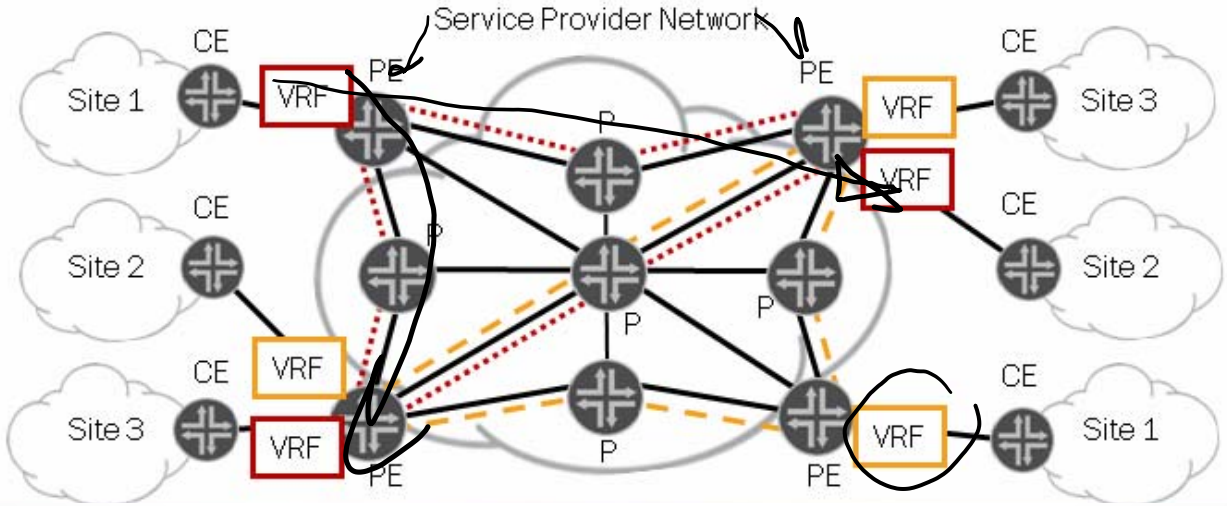


Service Provider Networks – Layer 3 Vs. Layer 2 VPNs

- Layer 3 characteristics
  - Provider's routers participate in customer's Layer 3 routing
  - Provider's routers manage VPN-specific routing tables, distributes routes to remote sites
  - CE routers advertise their routes to the provider
- Layer 2 characteristics
  - Customer maps its Layer 3 routing to the circuit mesh
  - Provider delivers Layer 2 circuits to the customer, one for each remote site
  - Customer routes are transparent to provider

Service Provider Networks – Layer 3 VPNs

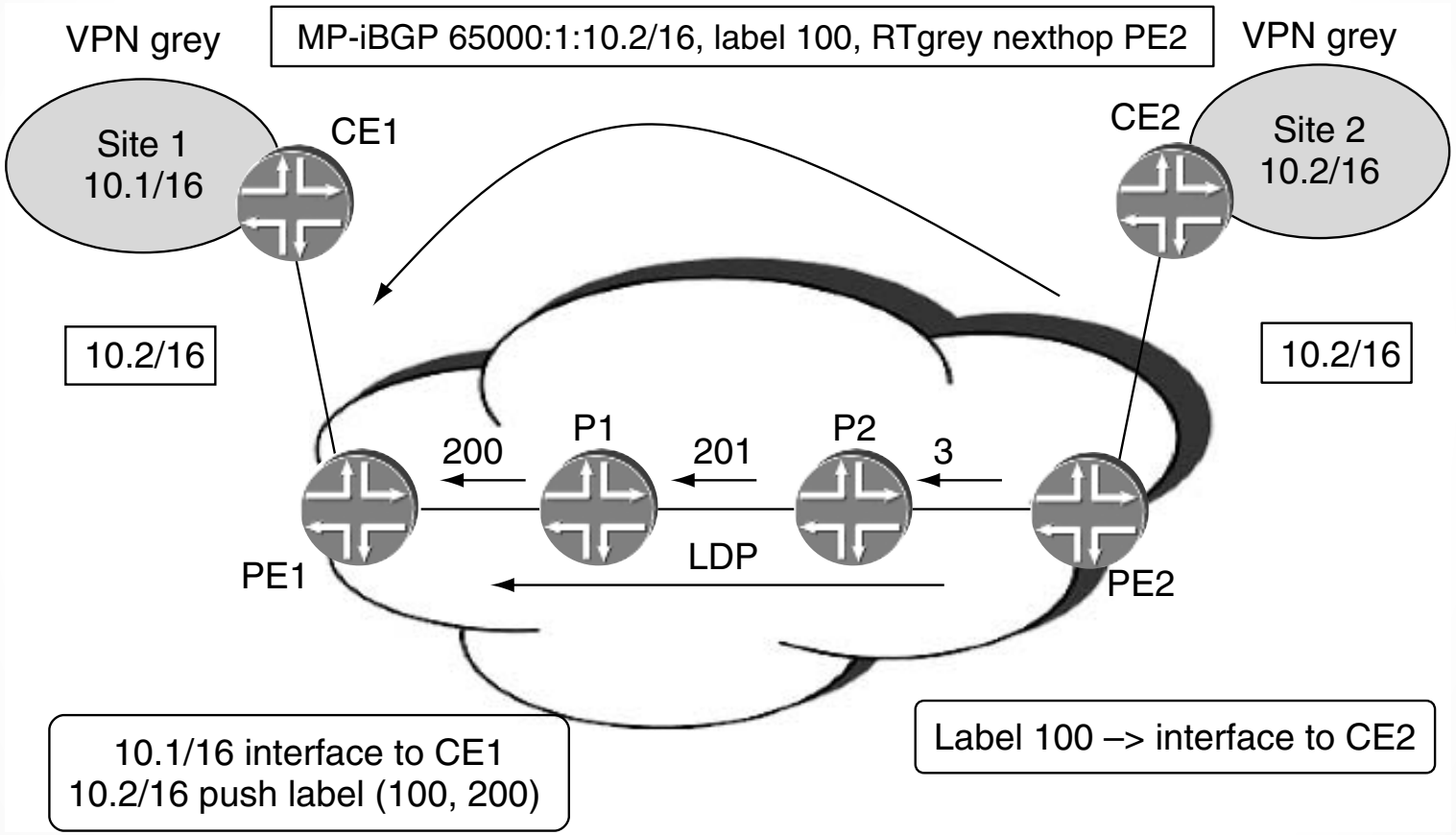
- Application: Outsource VPN
  - PE router maintains VPN-specific forwarding tables for each of its directly connected VPNs
  - Conventional IP routing between CE and PE routers
  - VPN routes distributed using MP-BGP
    - Uses extended communities
  - VPN traffic forwarded across provider backbone using MPLS



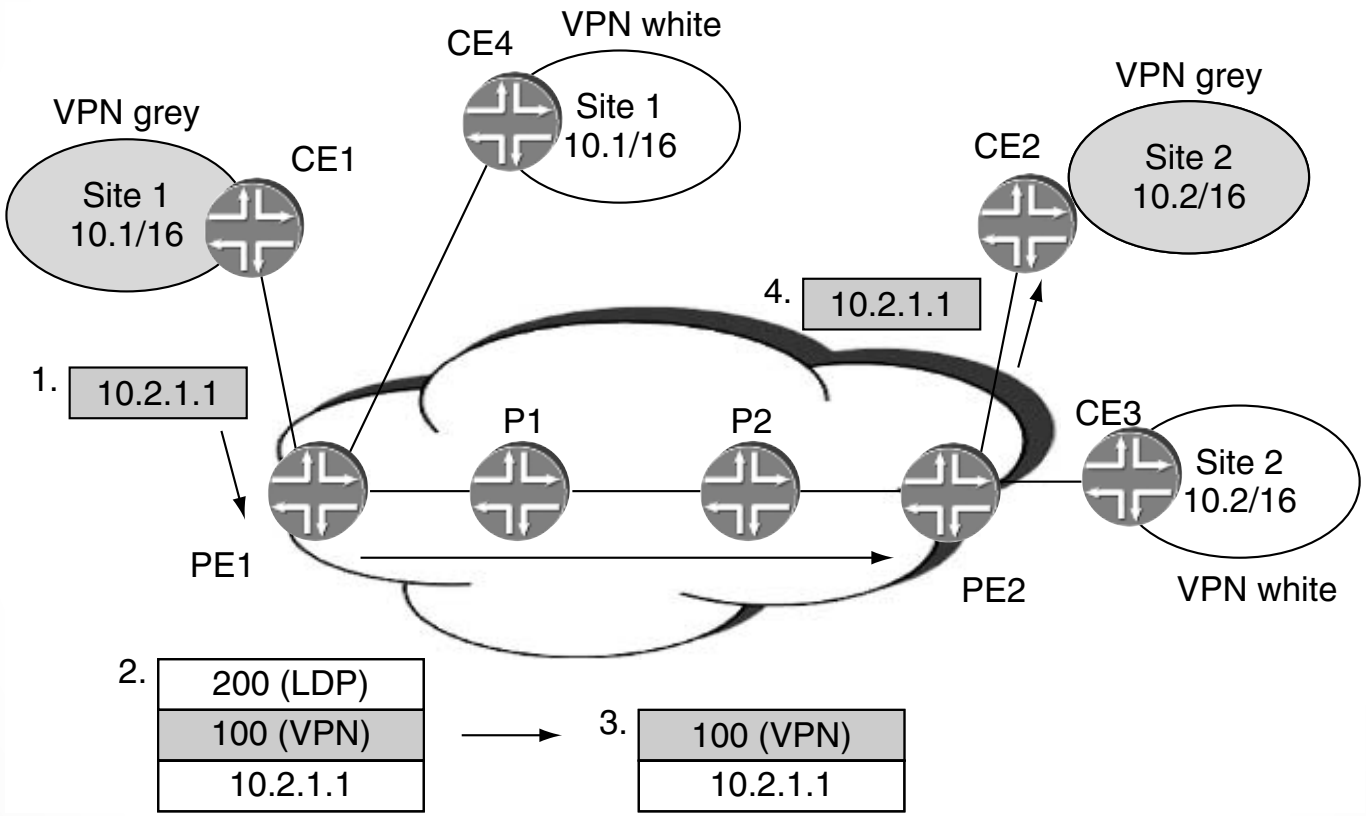
Service Provider Networks – Layer 3 VPNs

- LDP or RSVP is used to set up PE-to-PE LSPs
- MP-BGP is used to distribute information about the VPN
  - Routing and reachability for the VPN
  - Labels for customer sites (tunneled in PE-PE LSP)
- Constrain connectivity by route filtering
  - Flexible, policy-based control mechanism

Service Provider Networks – Layer 3 VPNs



Service Provider Networks – Layer 3 VPNs

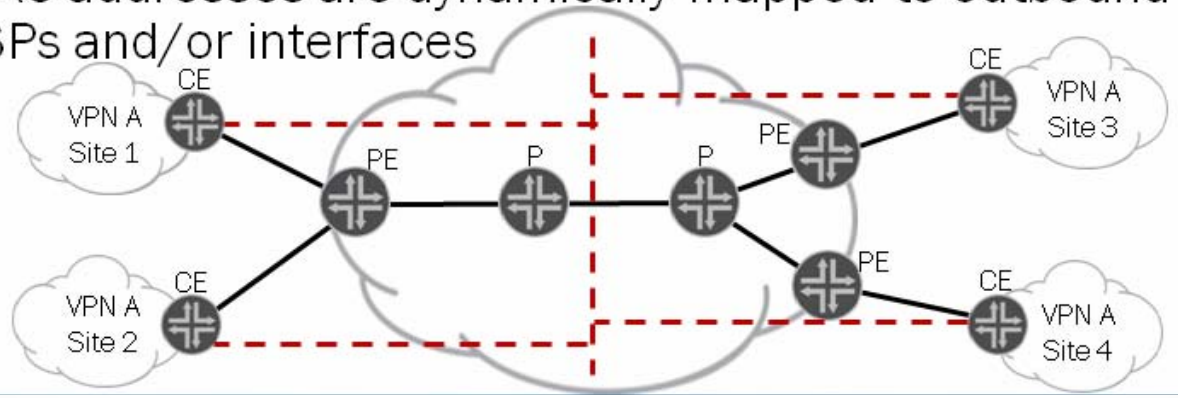


Service Provider Networks – Layer 3 VPNs Advantages:

- Subscriber:
  - Offload routing complexity to provider
  - Suits enterprises that do not want to build core routing competency into their organizations
- Provider:
  - VPN-specific routing information is not maintained on all backbone routers
  - Value-added service (revenue opportunity)

Service Provider Networks – Layer 2 VPNs: VPLS

- To the customer in a VPLS environment, the provider's network appears to function as a single LAN segment
  - Acts similarly to a learning bridge
- Administrator does not need to map local circuit IDs to remote sites
  - PE device learns MAC address from received Layer 2 frames
  - MAC addresses are dynamically mapped to outbound MPLS LSPs and/or interfaces



Service Provider Networks – Layer 2 VPNs: VPLS

- The discovery aspect. How does a PE know which other PEs have members of a particular VPLS attached?
- The signaling aspect. How is a full mesh of pseudowires set up between those PEs?

LDP based using targeted LDP sessions (manual configuration) no auto discovery of VPLS members, LDP signaling of the pseudowires

BGP based – Using BGP to announce VPLS members and pseudowires labels, then LDP or RSPV can be used for signaling the pseudowires.

Service Provider Networks – Protocols by service

Service	Recommended Transport Protocols	Transport Function
Residential High-Speed Internet	EoMPLS or IEEE 802.1ad	Backhaul Internet traffic from the access network to the Broadband Remote Access Router for AAA and service control. Provide QoS, tiered, quota-based, and usage-based Internet access.
Residential VoIP	EoMPLS *or* Layer 3 IP Routing over MPLS FRR	Connect signaling traffic to softswitch and RTP traffic to Internet or core IP network. Provide QoS.
Residential IPTV	Layer 3 PIM SSM over MPLS FRR	Broadcast TV service with massive scalability, fast recovery from failures, and excellent QoE.
Residential Video on Demand	Layer 3 IP Routing over MPLS FRR	Video-on-demand service with massive scalability, fast recovery from failures, and excellent QoE.
Business Ethernet Private Line (EPL)	EoMPLS or IEEE 802.1ad	Transport of Ethernet circuit at full data rate with no statistical multiplexing. This requires QoS.
Business Ethernet Virtual Private Line (EVPL)	EoMPLS or IEEE 802.1ad	Transport of Ethernet Virtual Connection with CIR/EIR and statistical multiplexing gain.
Business MPLS VPN	MPLS or IEEE 802.1ad	Transport of subscriber Ethernet Virtual Connection to MSE router that is the provider edge of the MPLS VPN service. CIR/EIR guarantees bandwidth.
Business E-LAN	H-VPLS *or* IEEE 802.1ad	Multipoint virtual LAN service for business customers. CIR/EIR guarantees bandwidth.
Mobile Backhaul	EoMPLS or IEEE 802.1ad	Pseudowire backhaul for 3G, WiMAX, and Wi-Fi networks.

Service Provider Networks – Challenges

Overly complicated – Service and transport mixed up.

Complicated management and high OPEX for a shrinking revenue.

Management of tunnels and provisioning of services is very static

New directions include SDN and increased Layer 2 capabilities.

New Layer 2 protocols simplify the network and might reduce the need for MPLS and complex operation

SDN provides tools for separating control and service planes from transport and virtualization of networks in the edge

New software-controlled implementations for some of the services (e.g. SD WAN)