Configuration and Management of Networks

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Configuration and Management of Networks

Service Provider Networks

Carrier grade networks that carry customer's traffic:

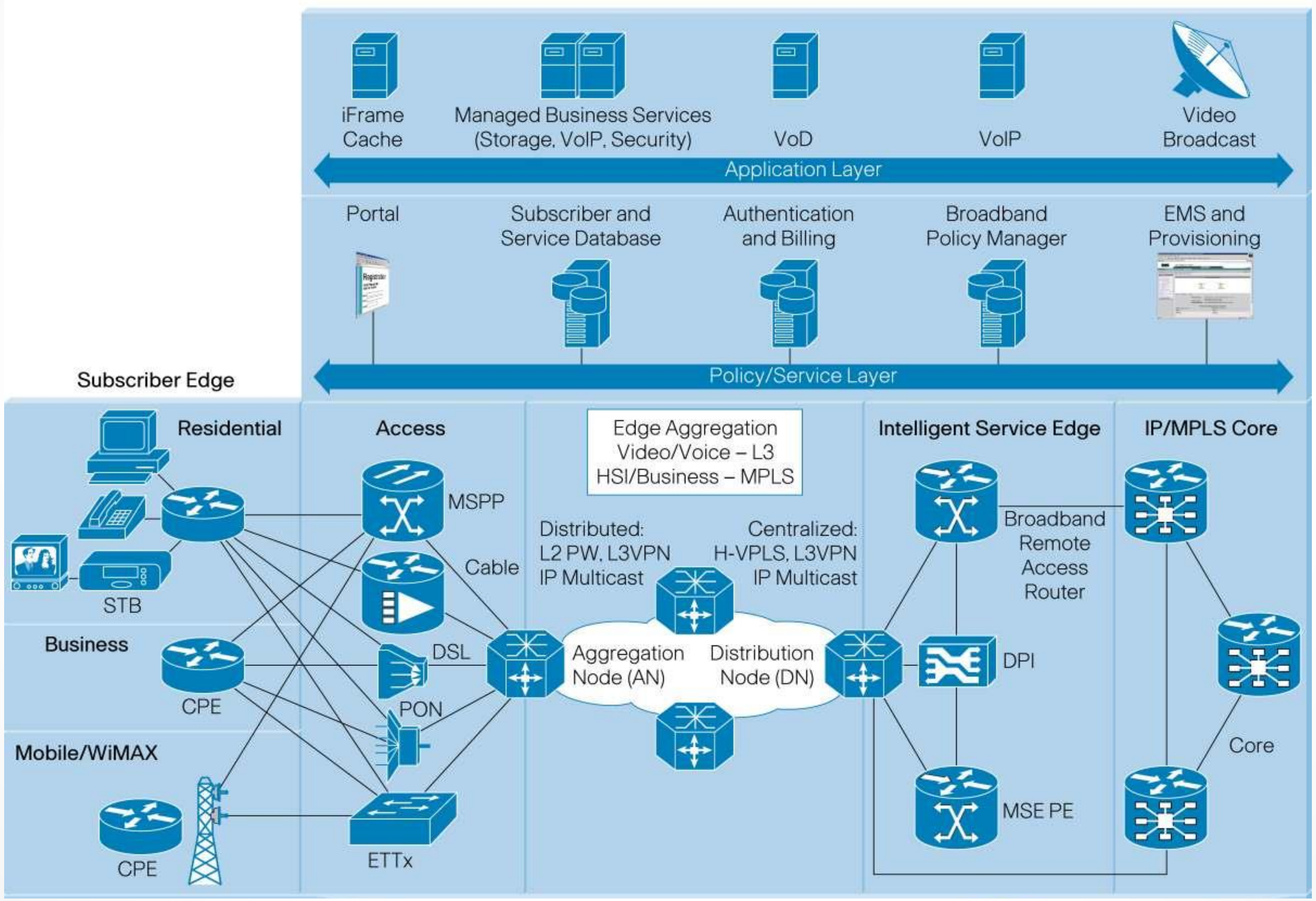
- Triple play residential customers
  - Voice
  - High Speed Internet
  - Broadcast TV and Video on Demand

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

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

Configuration and Management of Networks

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 (**Legacy**)
  - EoMPLS (Pseudowires) (**Legacy**)
  - IEEE 802.1q (VLANS), 802.1ah (PBB) (**Legacy**)
  - Layer 2 overlay technologies: EVPN-MPLS, EVPN-VXLAN

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 MEF 3.0 is the latest version

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

Main service types (**Modern Implementations favor EVPN Layer 2 overlays**):

- 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

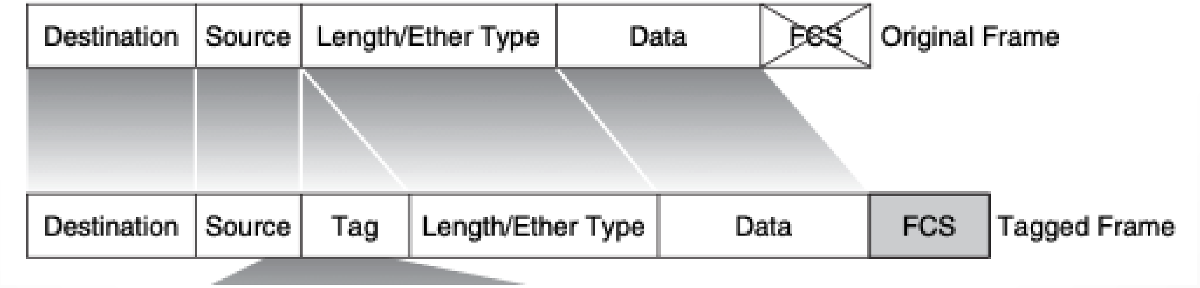
Service Provider Networks – Carrier Ethernet

Legacy Layer 2 Transport Technologies

Evolution from Simple VLANs to Provider Bridging

IEEE 802.1Q - Basic VLAN Tagging

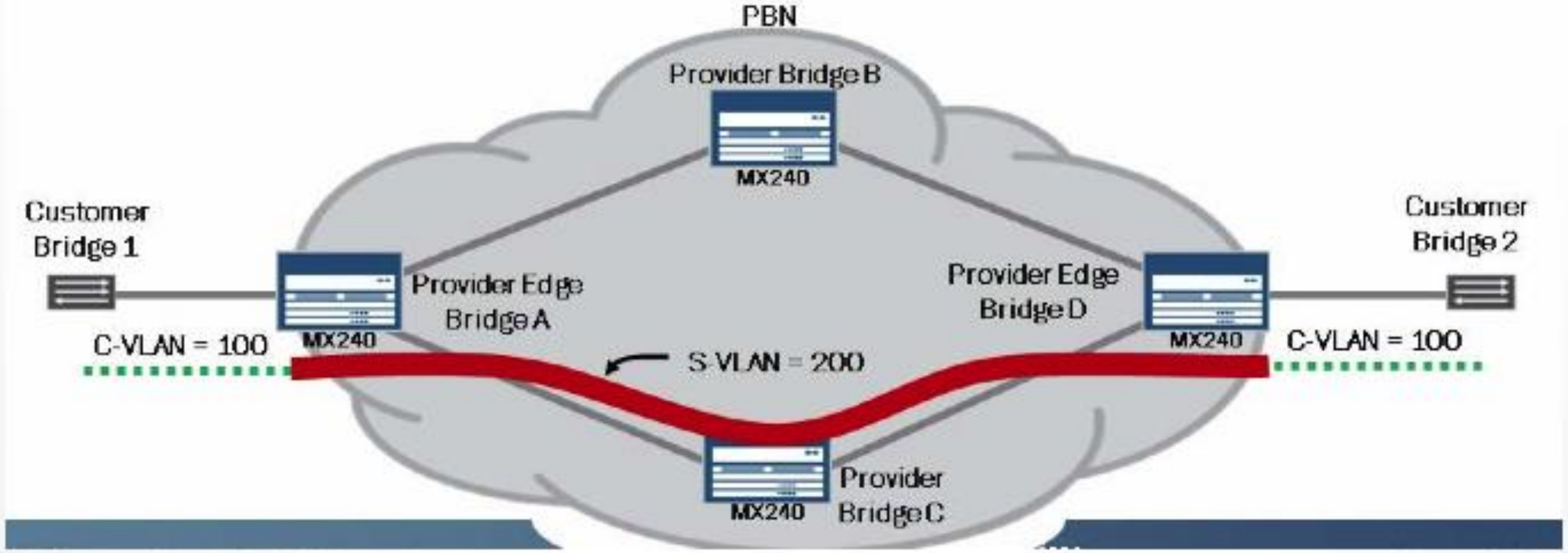
- Single 4-byte VLAN tag inserted into Ethernet frame
- 12-bit VLAN ID field → Maximum 4,096 VLANs
- Standard for enterprise LAN segmentation
- Limitation: Insufficient VLAN space for large service provider networks



Service Provider Networks – Carrier Ethernet

EEE 802.1ad (QinQ) - **Provider Bridging**

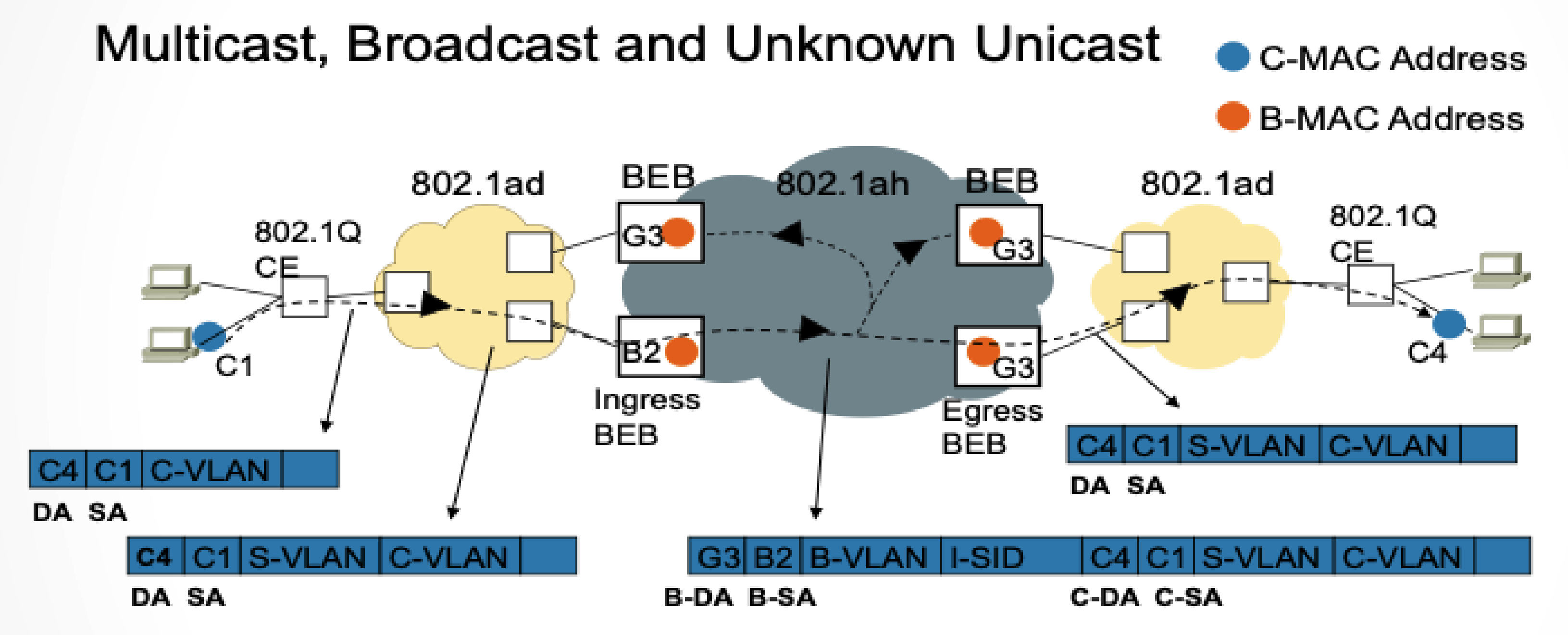
- Double VLAN tagging (VLAN stacking): C-Tag (Customer) + S-Tag (Service Provider)
- Expands VLAN space to 4,096 × 4,096 = 16.7 million combinations
- Service providers encapsulate customer VLANs within provider VLANs
- Use case: Multiple customer sites tunneled through SP backbone network
- Limitations: Customer MAC addresses still visible in SP core; limited separation of customer/provider domains



Service Provider Networks – Carrier Ethernet

EEE 802.1ah (PBB) – **Provider Backbone Bridges**

- MAC-in-MAC encapsulation - complete customer/provider domain separation
- Backbone MAC addresses (B-MAC) used for SP core switching
- 24-bit I-SID (Service Instance Identifier) for service identification
- Customer MAC (C-MAC) addresses completely hidden from backbone
- Limitations: Limitations: Complex architecture; still relies on data plane learning and flooding



Service Provider Networks – Carrier Ethernet

⚠ Challenges with All Legacy L2 Technologies:

- Data plane MAC learning → Flooding of unknown unicast, broadcast, and multicast (BUM) traffic
- Spanning Tree dependencies → Blocked links, slow convergence
- Limited scalability in large metro/aggregation networks

💡 **Modern Evolution:**

EVPN provides a unified control plane using MP-BGP for MAC learning, eliminating flooding, enabling active-active multihoming, and supporting multiple service types through a single protocol.

Service Provider Networks

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

MPLS main VPN technologies:

- Layer 3 VPNs
- Legacy Layer 2 VPNs
  - VPLS
  - Point-to-point PSW (pseudowires)
- Modern EVPN services

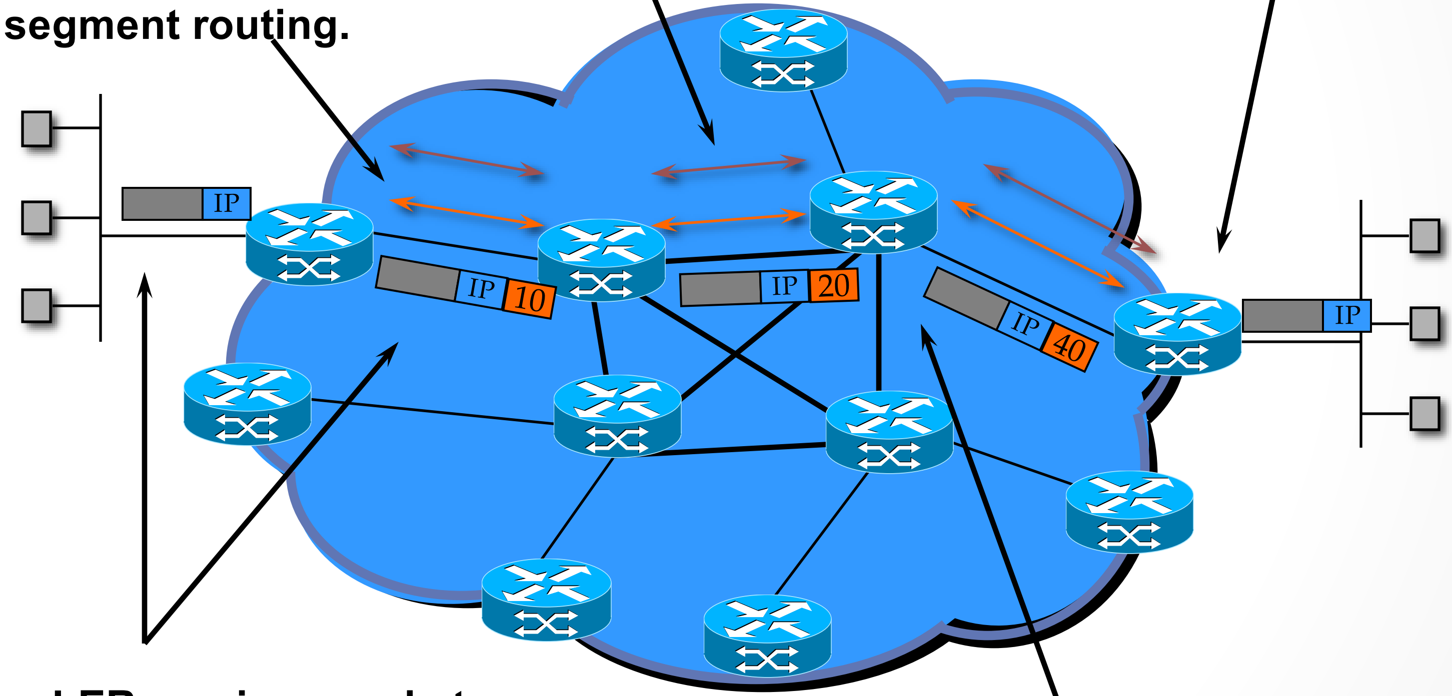
MPLS - Basic Idea

- 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)
    - Modern approaches use segment routing with labled (SIDs) learned via IGPs.

1a. Routing protocols (e.g. OSPF, IS-IS) exchange reachability to destination networks.
Or SID and SID /destination mapping in segment routing.

1b. Label Distribution Protocol (LDP) establishes label mappings to destination network
This step is not needed with segment routing.

4. LER at egress removes label and delivers packet



2. Ingress LER receives packet and "labels" packets

3. LSR forwards packets using label swapping

Service Provider Networks – Segment Routing – Simplifying MPLS

Definition: Source-based routing where the ingress router specifies the path as an ordered list of segments (instructions) implemented as MPLS labels

- Key concept: Eliminates need for LDP and RSVP-TE - **IGP (IS-IS/OSPF) distributes all necessary information**
- Encoding: SR-MPLS uses MPLS labels; each segment has a Segment ID (SID)

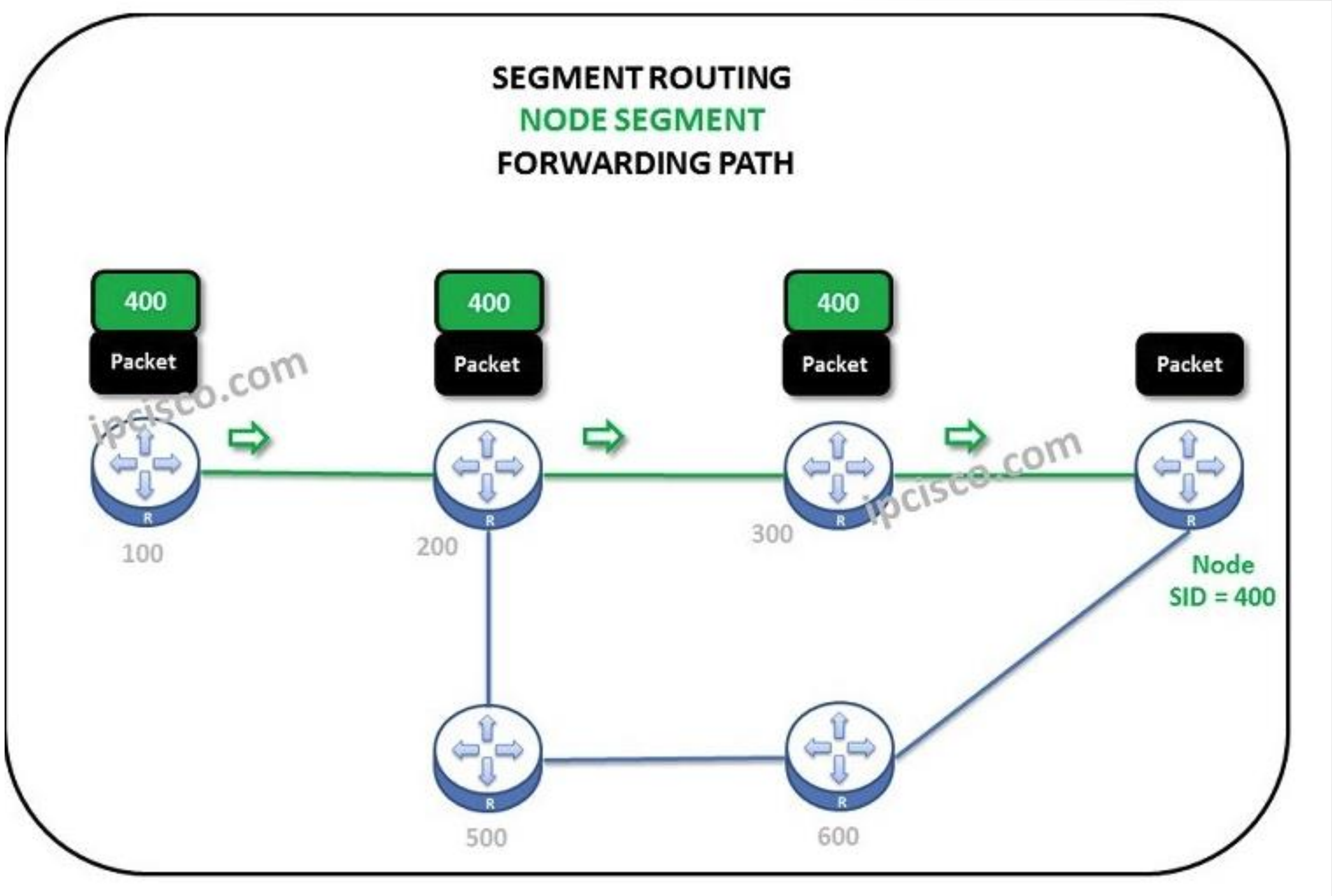
Benefits:

- Simplified control plane: No separate LDP or RSVP-TE protocols needed
- Traffic engineering without tunnels: Path encoded in label stack at ingress
- Fast reroute: TI-LFA (Topology Independent Loop-Free Alternate) for sub-50ms convergence
- Scalability: No per-flow/per-tunnel state in core routers
- SDN-ready: Centralized controller can compute and push SR paths

Service Provider Networks – Segment Routing – Simplifying MPLS

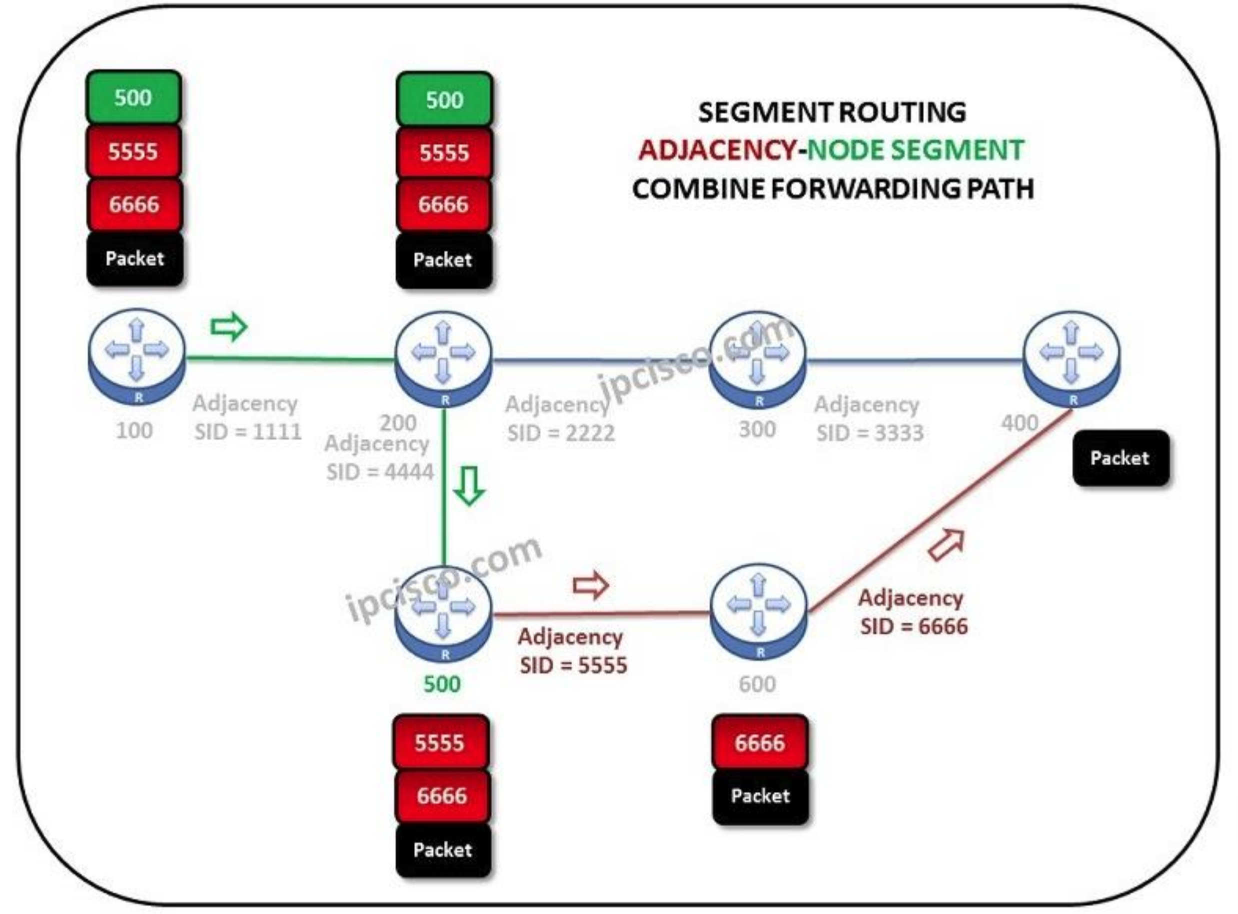
- All routers advertise the mapping between IP prefixes and SIDs.
- The ingress router looks up the SIDs corresponding to the intended destination.
- The router pushes the chosen SID stack. Can be the shortest path as per IS-IS or OSPF or Explicit Path (policy/SDN TE).

Shortest-Path uses node SID only



Service Provider Networks – Segment Routing – Simplifying MPLS

Explicit Path (policy/SDN TE) can use node SID and segment SID or just Segment SID



MPLS - Advantages

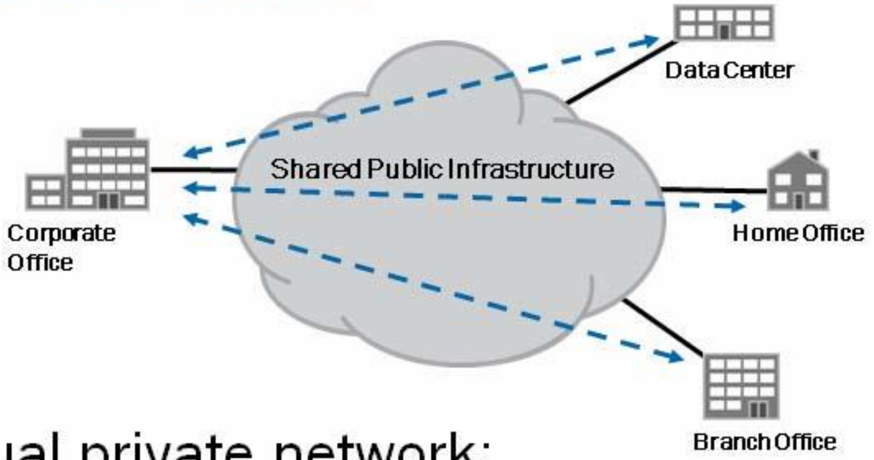
- Scalability of network layer routing. Using labels as a means to aggregate forwarding information.

- 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.

"MPLS provides the transport foundation for both traditional VPNs and modern EVPN services"

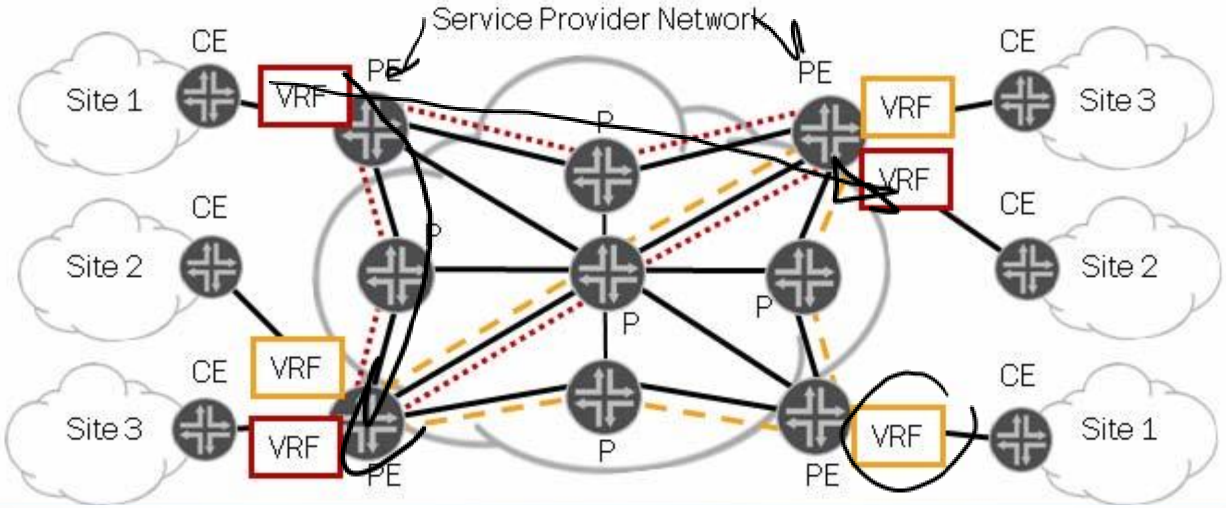
Service Provider Networks



- 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 – 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

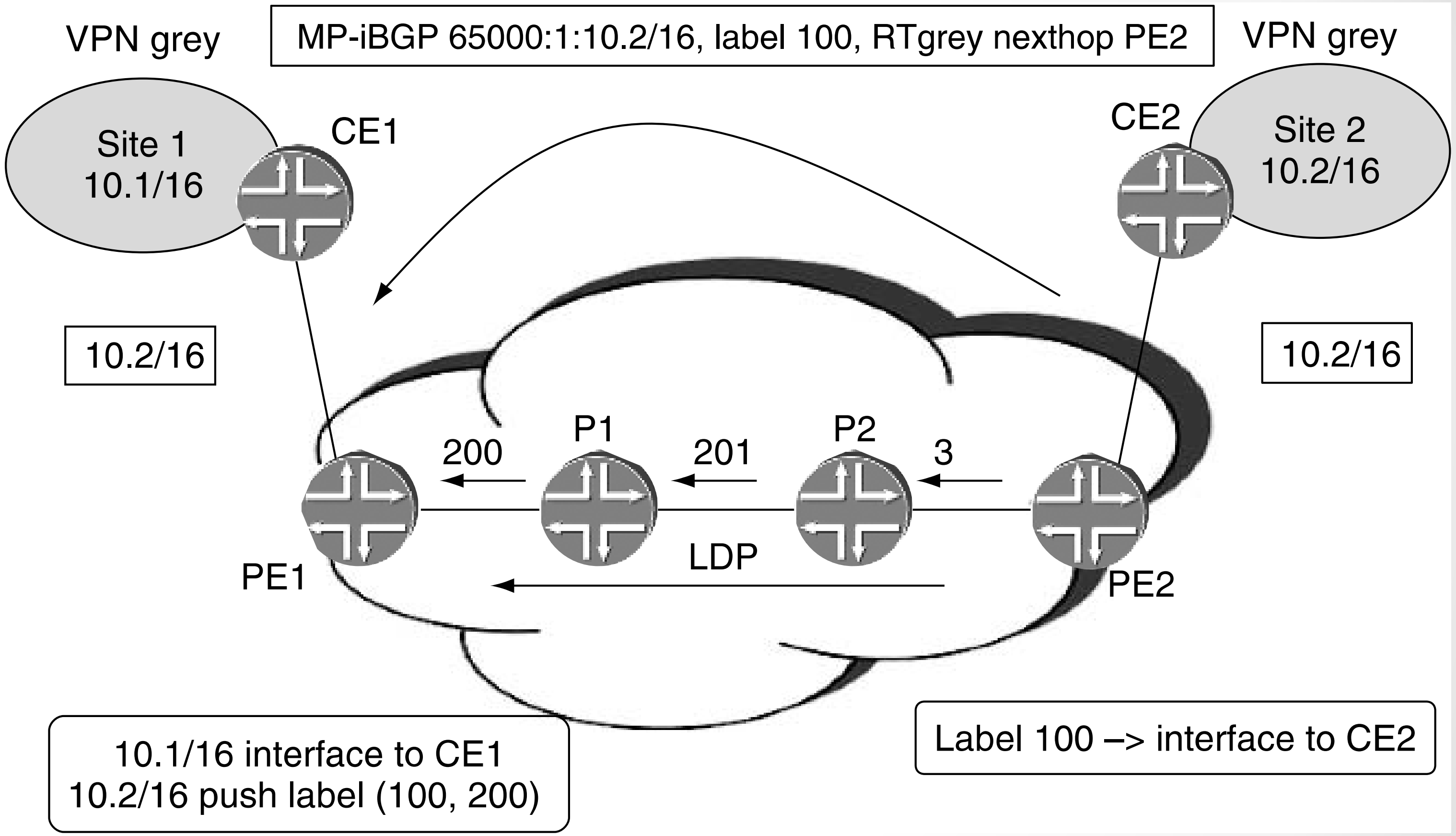


Service Provider Networks – Layer 3 VPNs

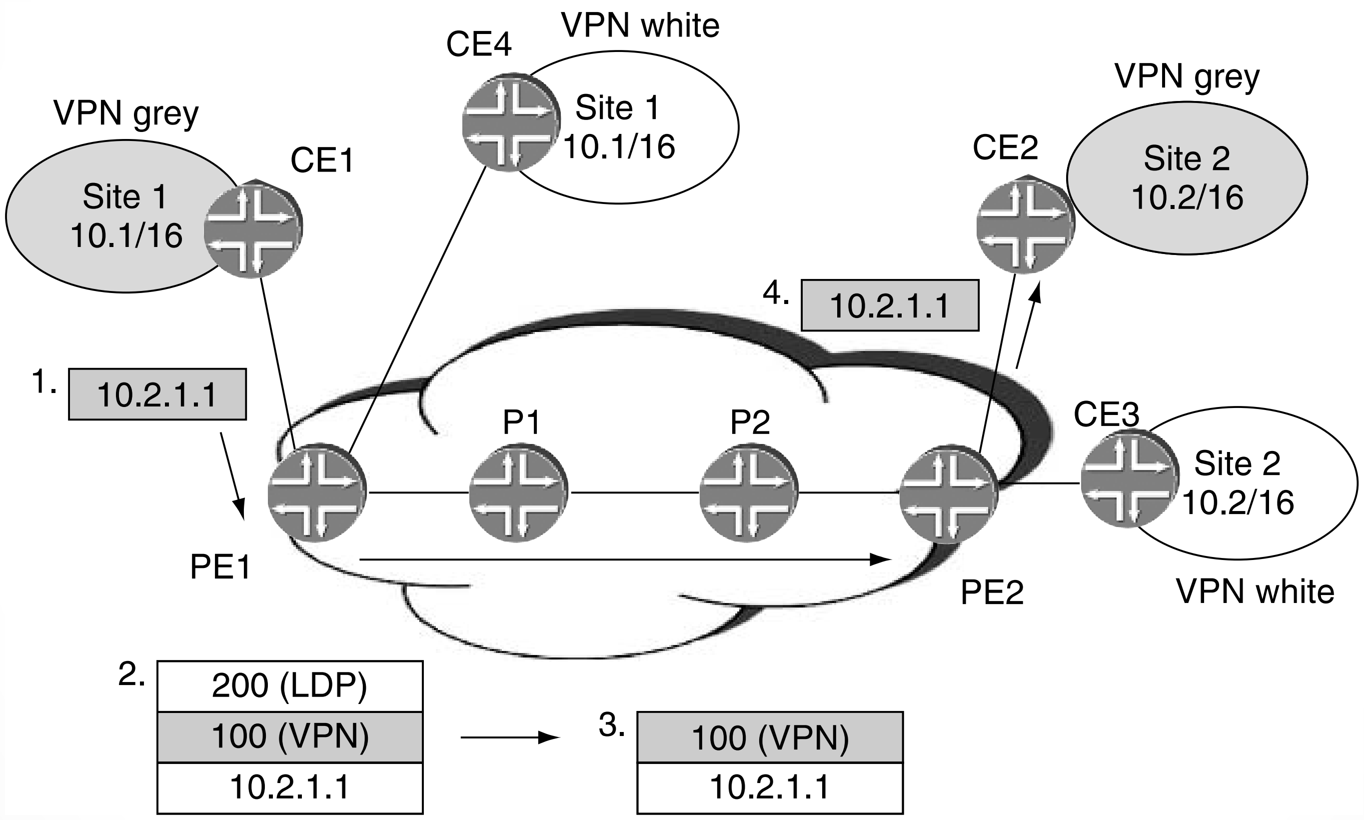
Segment Routing used to set up PE-to-PE LSPs (or legacy LDP or RSVP)

MP-BGP is used to distribute information about the VPN

- Routing and reachability for the VPN
- Labels for customers sites (tunneled in PE-PE LSP or using Segment routing)



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 – EVPN Overview

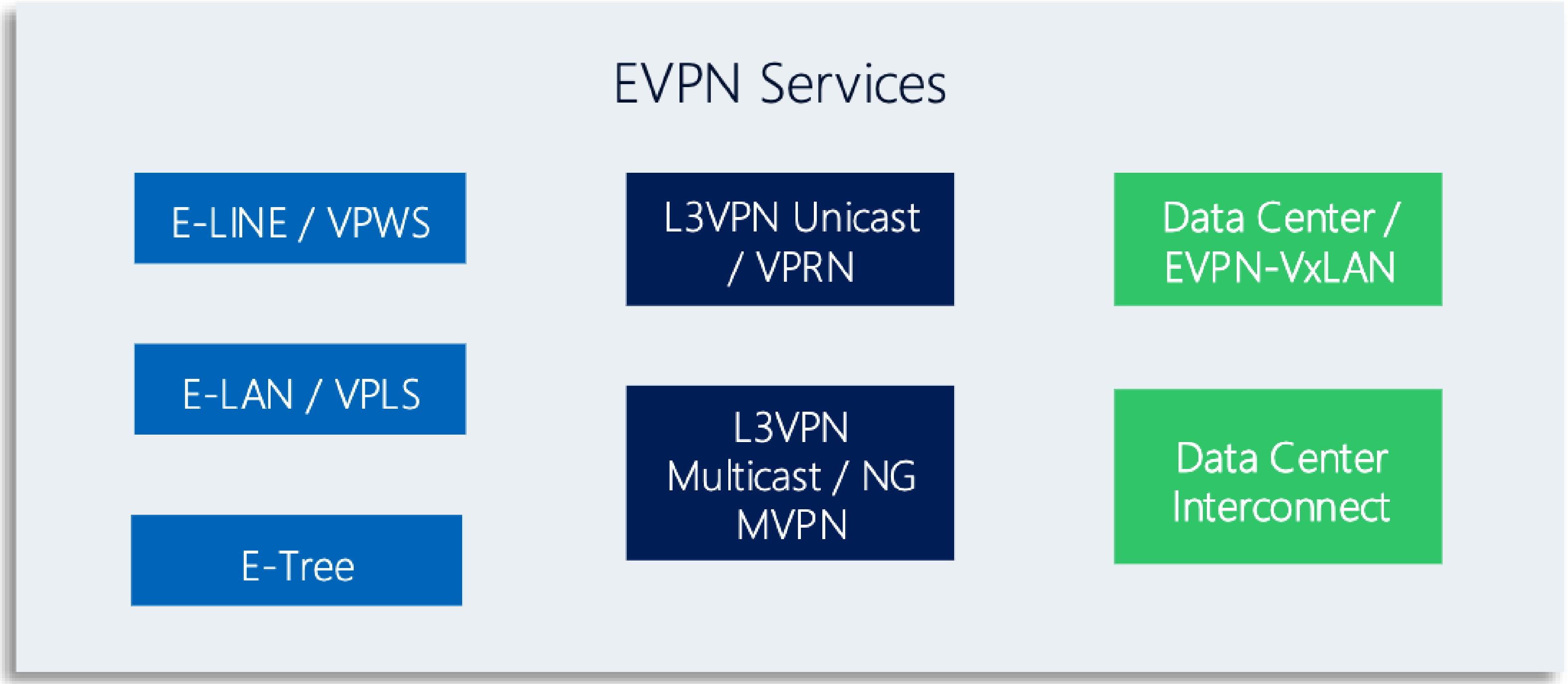
Definition: EVPN (RFC 7432) is a unified control plane for Layer 2 and Layer 3 VPN services using MP-BGP that can carry different EVPN route types.

Key innovation: Control plane MAC learning via BGP instead of data plane flooding for L2VPNs and an unified Control plane that can also do L3VPNs

Advantages:

- Reduced flooding: MAC/IP addresses learned via BGP; ARP suppression capability.
- Fast convergence: Mass withdrawal of MAC addresses on failure.
- Integrated services: Single protocol for E-LINE, E-LAN and L3VPN.
- No spanning tree: Loop prevention through BGP use.

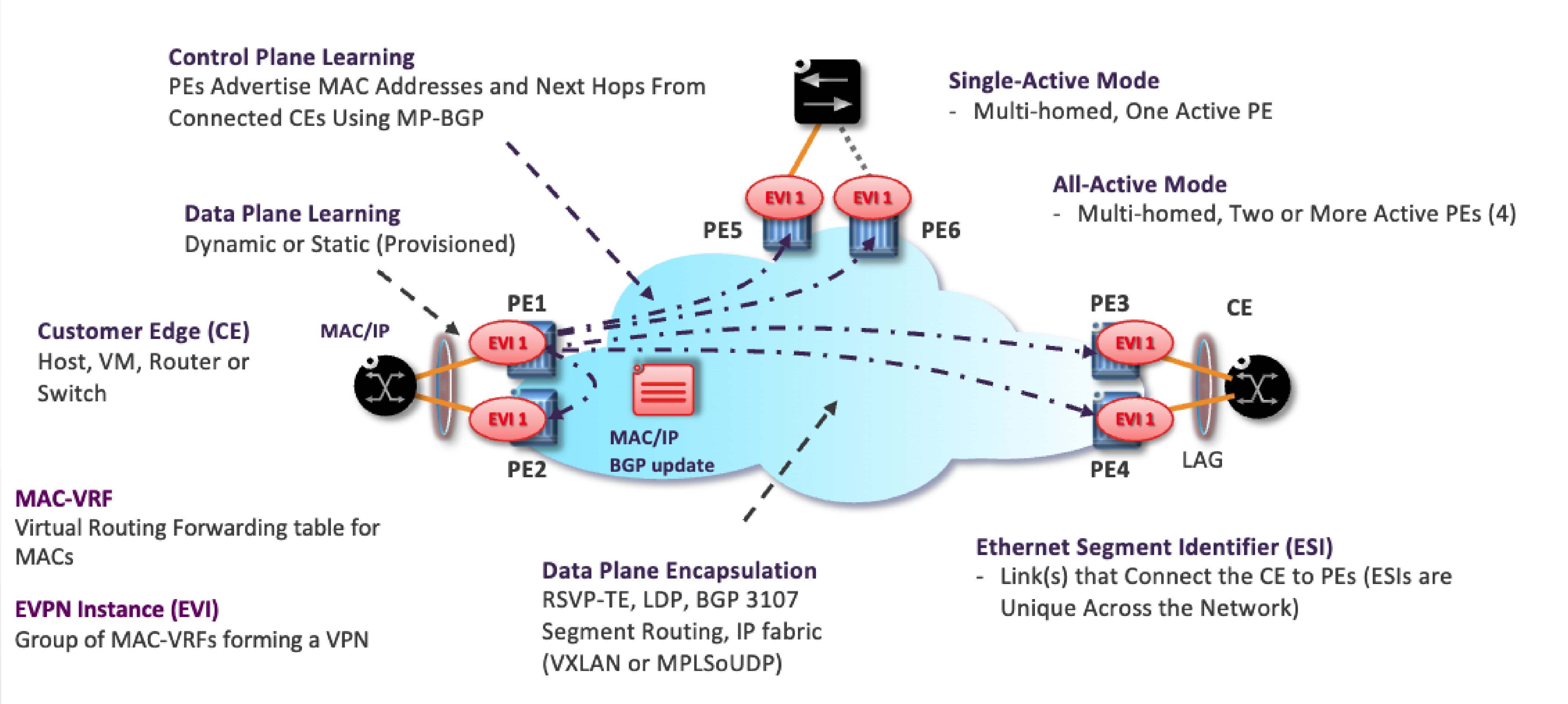
Service Provider Networks – EVPN Overview



Configuration and Management of Networks

Service Provider Networks – EVPN MPLS Architecture

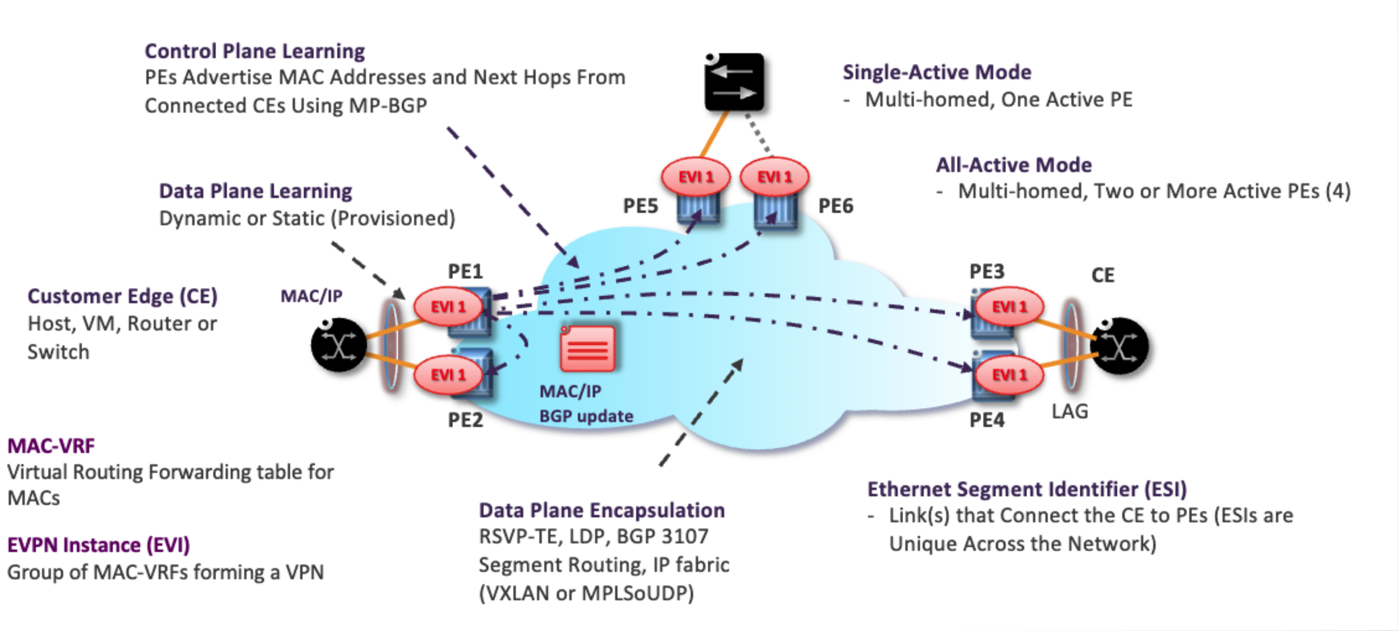
Key components:
PE routers; MP-BGP EVPN address family; MPLS LSP transport, Ethernet Segment Identifier (ESI) for multihoming.



Service Provider Networks – EVPN MPLS Architecture

PE Routers (Provider Edge) discover customer MAC addresses and advertise them via MP-BGP

MP-BGP: Multiprotocol BGP using EVPN Address Family (AFI 25, SAFI 70)
Enables PEs to exchange MAC/IP information instead of traditional IP routes

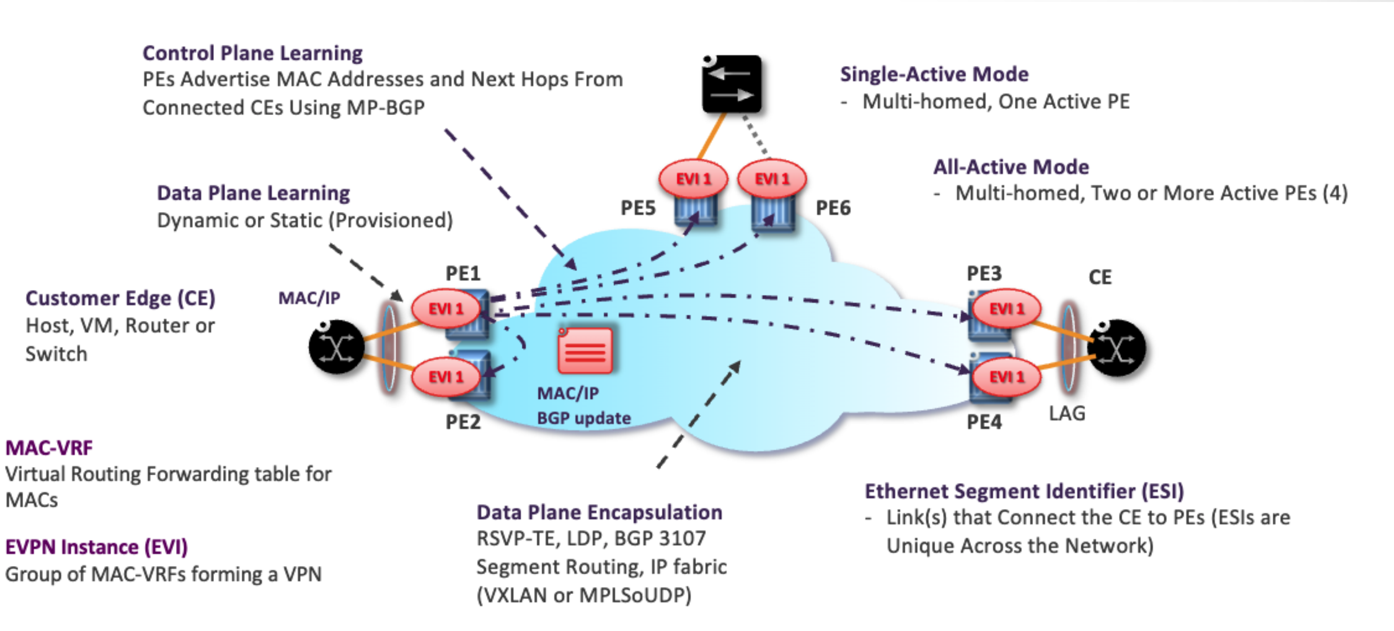


MPLS LSP Transport:
Underlying MPLS tunnels provide the IP/MPLS backbone for transporting customer traffic between Pes
Can be created by: RSVP-TE, LDP or Segment Routing

Ethernet Segment Identifier (ESI) for Multihoming
ESI: A unique 10-byte identifier assigned to each link/set of links connecting CE to PEs

Service Provider Networks – EVPN MPLS Architecture

1. PE1 connects to CE
2. CE has MAC/IP information (hosts, VMs, other devices)
3. PE1 learns these MACs/IPs (from data plane or provisioning)
4. PE1 advertises via BGP UPDATE:
   - Sends MP-BGP EVPN routes (Type 2: MAC/IP Advertisement)
   - Includes the MAC address, IP address, and next-hop (PE1's loopback)
5. PE2, PE3, PE4,PE5 and PE6 receive these BGP updates
6. Remote PEs install the MAC/IP information in their MAC-VRF



Configuration and Management of Networks

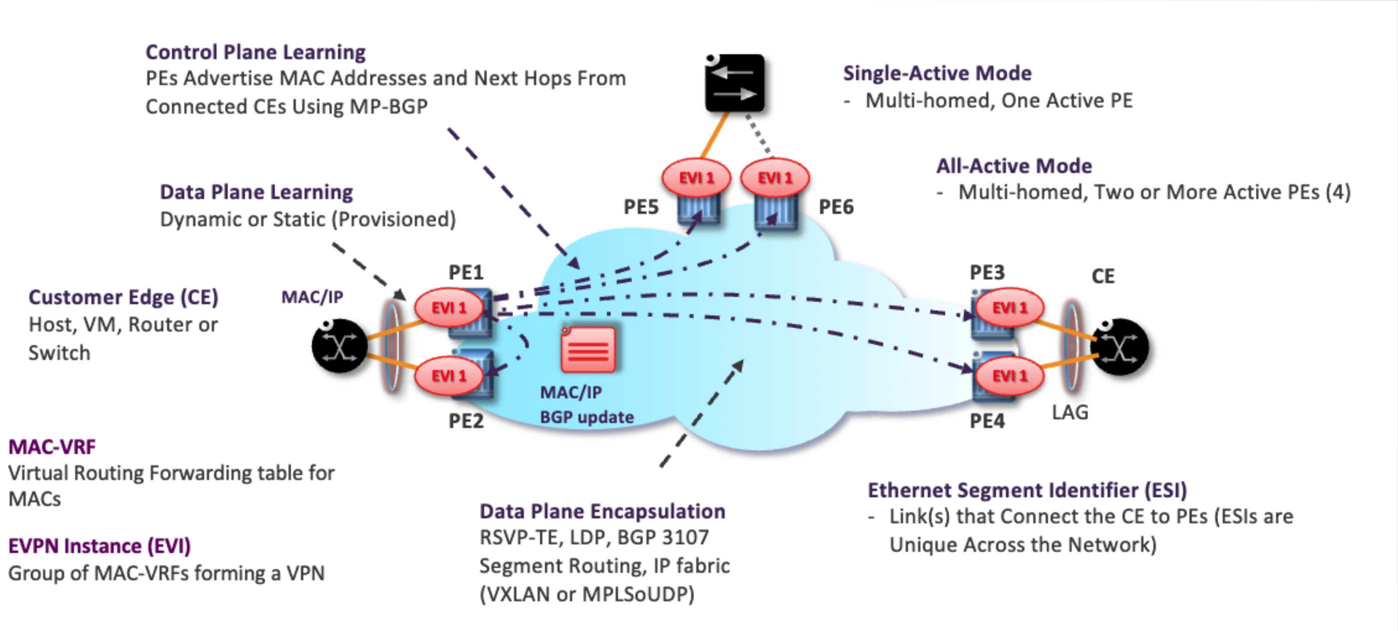
Service Provider Networks – EVPN MPLS Architecture

Dynamic (Data Plane Learning):

- CE sends unknown unicast frame to PE1
- PE1 learns the source MAC from the incoming frame
- PE1 then advertises it to other PEs via MP-BGP
- Advantage: Automatic discovery of active MACs
- Disadvantage: Depends on traffic

Static/Provisioned:

- Administrator manually provisions MAC addresses in the PE
- Or learned from provisioning system/orchestrator
- Advantage: Predictable, useful for services with known endpoints
- Disadvantage: Requires manual configuration



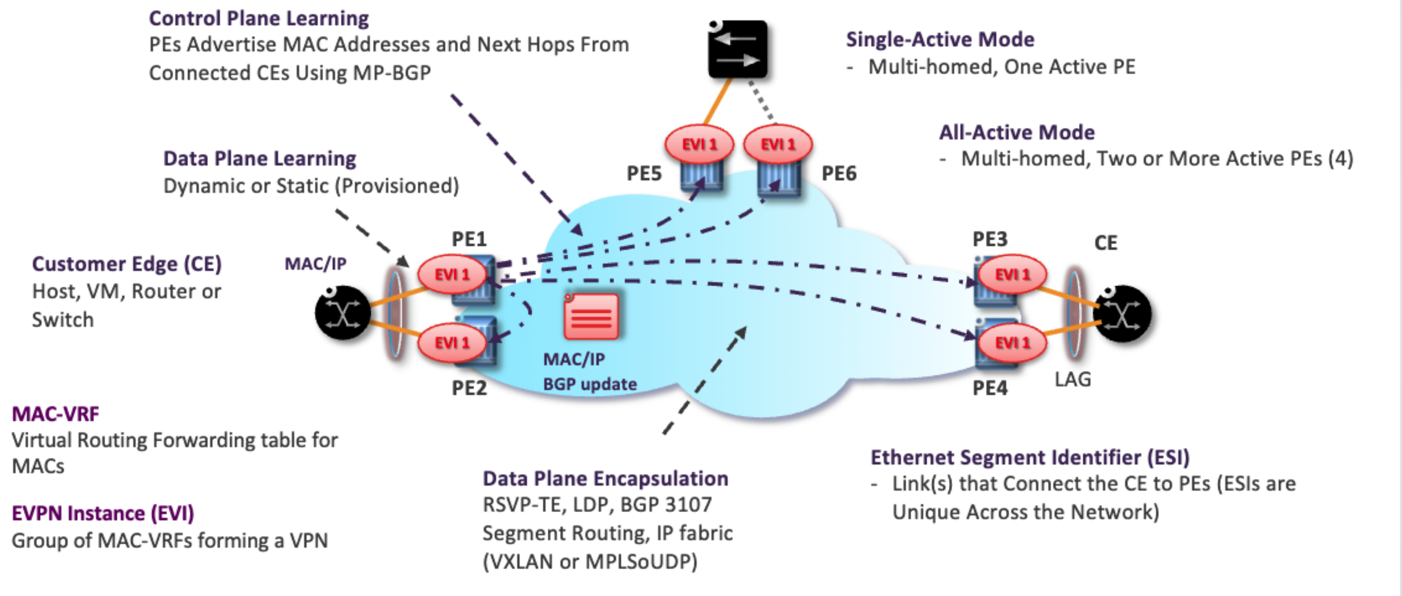
Service Provider Networks – EVPN MPLS Architecture

MAC-VRF (Data Plane Learning):

- Purpose: Forwarding table that maps MAC addresses to outgoing interfaces/MPLS tunnels
- When PE2 receives MAC/IP from PE1 via BGP:
  - PE2 installs entry: MAC=aa:aa:aa:aa:aa:aa → Next-hop=PE1
  - When frame arrives destined to aa:aa:aa:aa:aa:aa, PE2 knows to tunnel to PE1

EVPN Instance (EVI)

- L2VPN service (equivalent to VLAN in traditional networks)
- All MAC-VRFs for that customer/service



Service Provider Networks – Future Directions

Past challenges: Multiple overlay protocols (VPLS, pseudowires, PBB), complex provisioning, high OPEX

Modern Solutions:
- EVPN provides unified architecture for L2/L3 services, reducing complexity
- Segment Routing simplifies transport and traffic engineering

Current trends:
- Automation and orchestration (covered next class) streamline operations.
- Migration to EVPN in metro/aggregation networks
- EVPN-VXLAN dominance in data centers
- SRv6 (Segment Routing v6) emergence for IPv6-native networks
- 5G transport with network slicing based in SDN and Network Virtualization.