L2VPN TUTORIAL

Path to Convergence

Muhammad Waris Sagheer (waris@cisco.com)

Paresh Shah (pashah@cisco.com)

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Agenda

1. Introduction to L2VPNs
2. Signaling Concepts
3. VPWS Transports
4. VPWS Service Interworking
5. Virtual Private LAN Service
6. Pseudo Wire Stitching
7. Quality of Service
8. Demonstration
9. Q&A

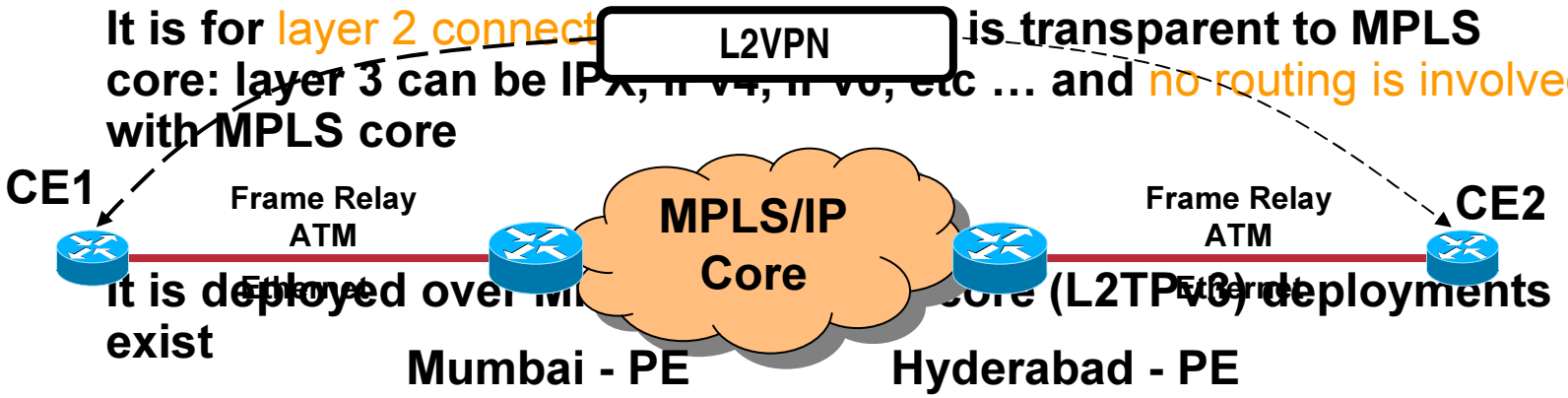
Introduction to L2VPNs

What is L2VPN?

- **L2VPN provides an end-to-end layer 2 connection to an enterprise office in Mumbai and Hyderabad over a SP's MPLS or IP core**

It can be Ethernet, Frame Relay, ATM, HDLC, PPP, etc …

It is for layer 2 connect… is transparent to MPLS core: layer 3 can be IPX, IPv4, IPv6, etc … and no routing is involved with MPLS core



It is deployed over M… core (L2TPv3) deployments exist

Why is L2VPN needed?

- **Allows SP to have a single infrastructure for both IP and legacy services**

  Migrate legacy ATM and Frame Relay services to MPLS/IP core without interruption to existing services

  Provisioning new L2VPN services is incremental (not from scratch) in existing MPLS/IP core

  Capital and Operational savings **of converged IP/MPLS network**

- **SP provides new point-2-point or point-2-multipoint services**

  Customer can have their own routing, qos policies, security mechanisms, etc …

- **Based on IETF drafts that promote open architecture and vendor interoperability**

Layer 3 and Layer 2 VPN Characteristics

LAYER 3 VPNS

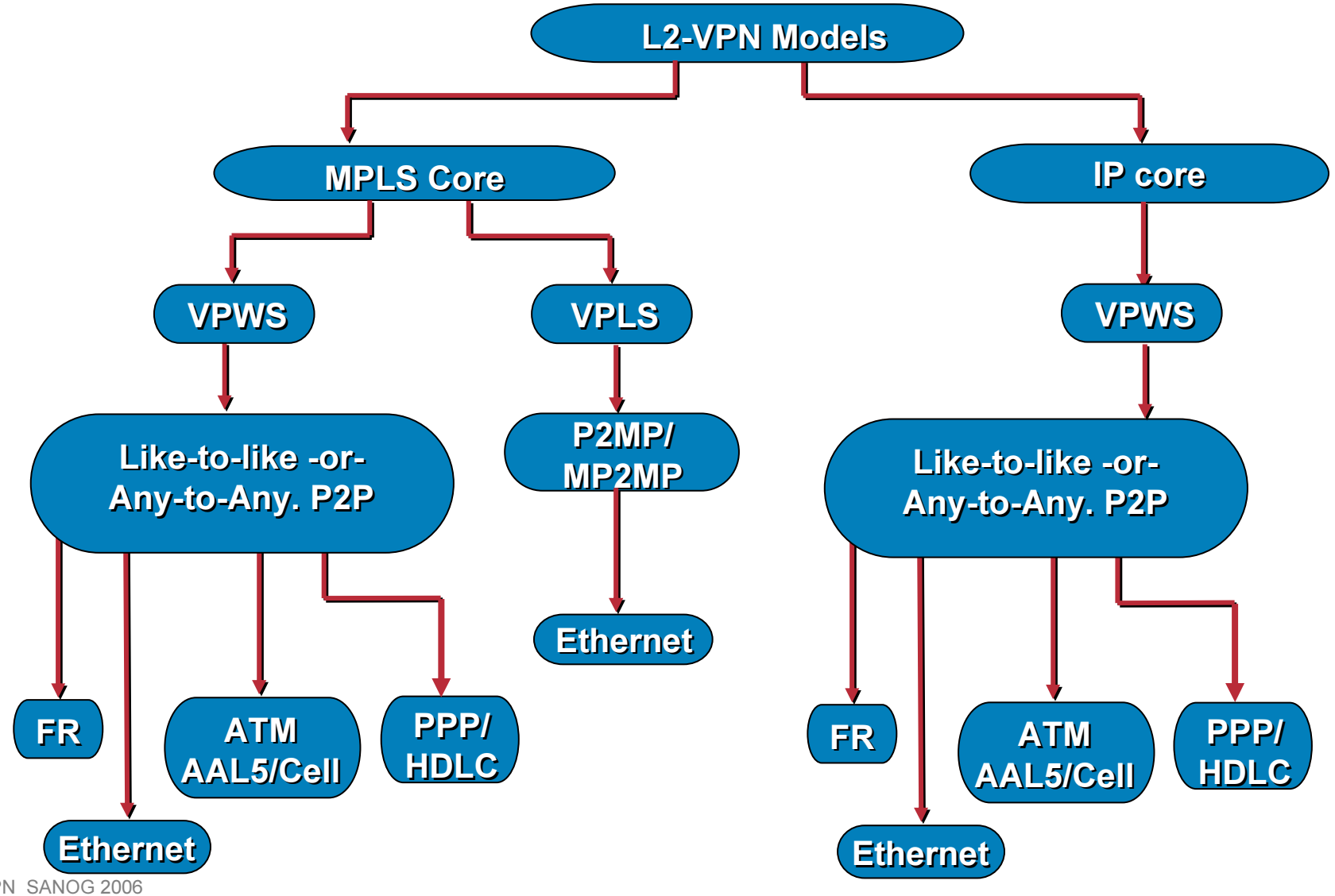
- SP devices forward customer packets based on Layer 3 information (e.g. IP addresses)
- SP is involved in customer IP routing
- Support for any access or backbone technology
- IP specific
- Foundation for L4–7 services!
- Example: RFC 2547bis VPNs (L3 MPLS-VPN)

LAYER 2 VPNS

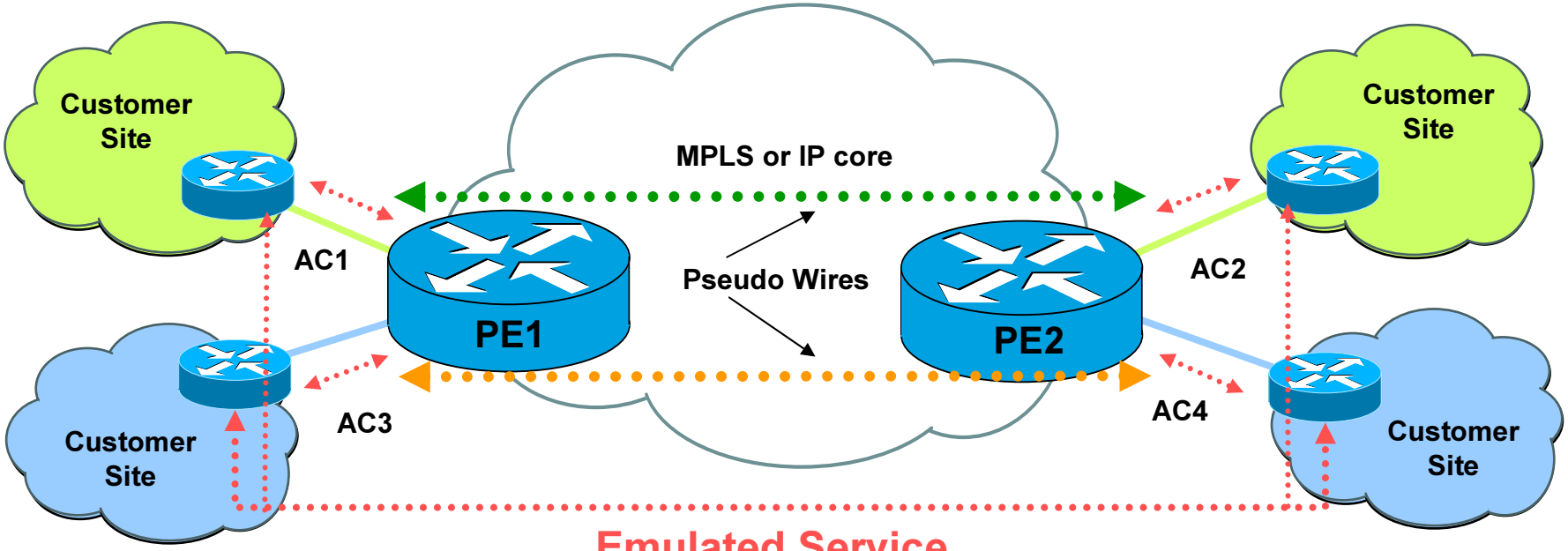
- SP devices forward customer frames based on Layer 2 information (e.g. DLCI, VPI/VCI, MAC, VLAN ID)
- No SP involvement in customer IP routing
- Enterprise stays in control of L3 policies (Routing, QoS)
- Multiprotocol support
- Example: FR—ATM—Ethernet

The Choice of L2VPN over L3VPN Will Depend on How Much Control the Enterprise Wants to Retain.
L2 VPN Services Are Complementary to L3 VPN Services

L2VPN Models



VPWS - Pseudo Wire Reference Model



A pseudo-wire (PW) is a connection between two provider edge (PE) devices which connects two attachment circuits (ACs).

Emulated Services:

- Ethernet
- 802.1Q (VLAN)
- ATM VC or VP
- HDLC
- PPP
- Frame Relay PVC

Pseudo Wire –
Basic Building Blocks

Control Connection

Adds scale thru: Session Management, Error Notification, L2 Access management interworking, etc.

Required Components

Transport Component

This is the delivery header of the encapsulated packet. This can be a Label (MPLS) or an IP Header. (Typically the IP address of the Loopback interface on Provider Edge (PE) routers.

Tunneling Component

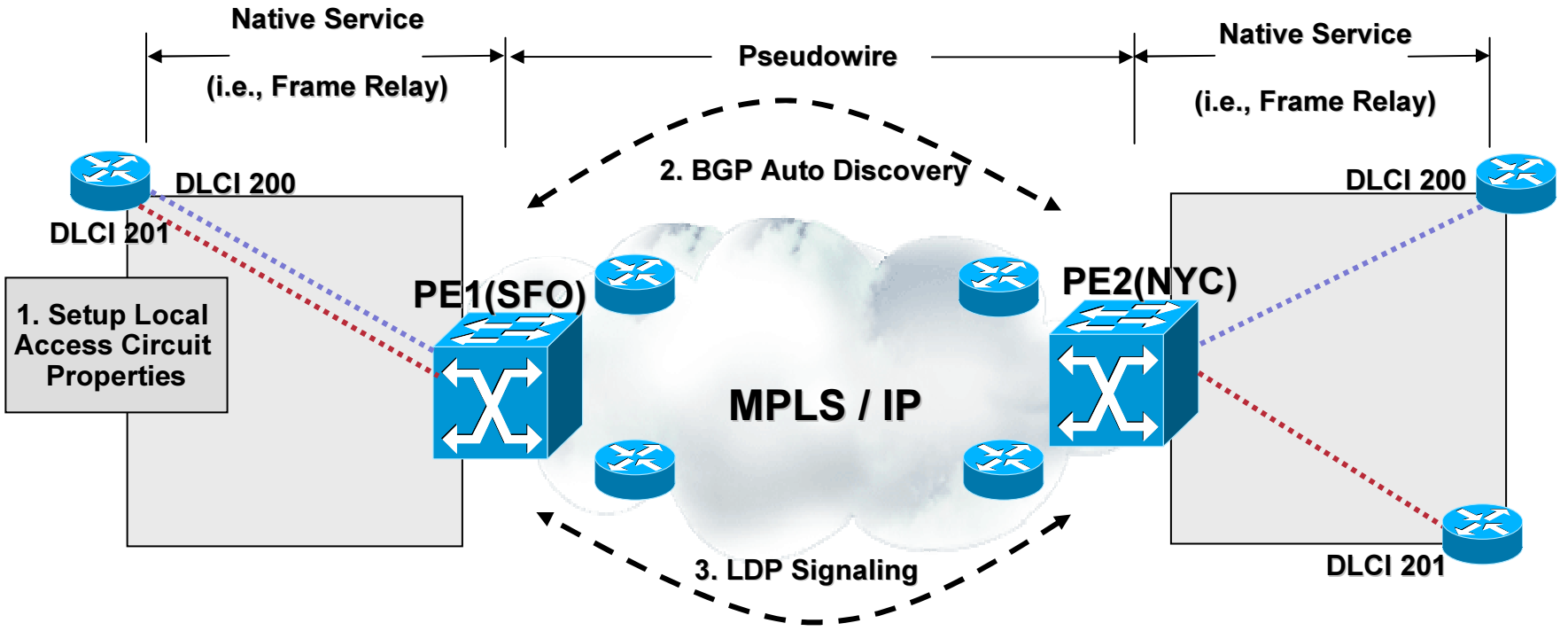
A Unique identifier used to identify a particular circuit / port on a given PE. (VC Label or VC ID)

L2 PDU

The Layer 2 PDU that is the subject of transport (I.e. traffic received from the Customer Edge router, typically Ethernet, Frame Relay, HDLC frames,..etc.)

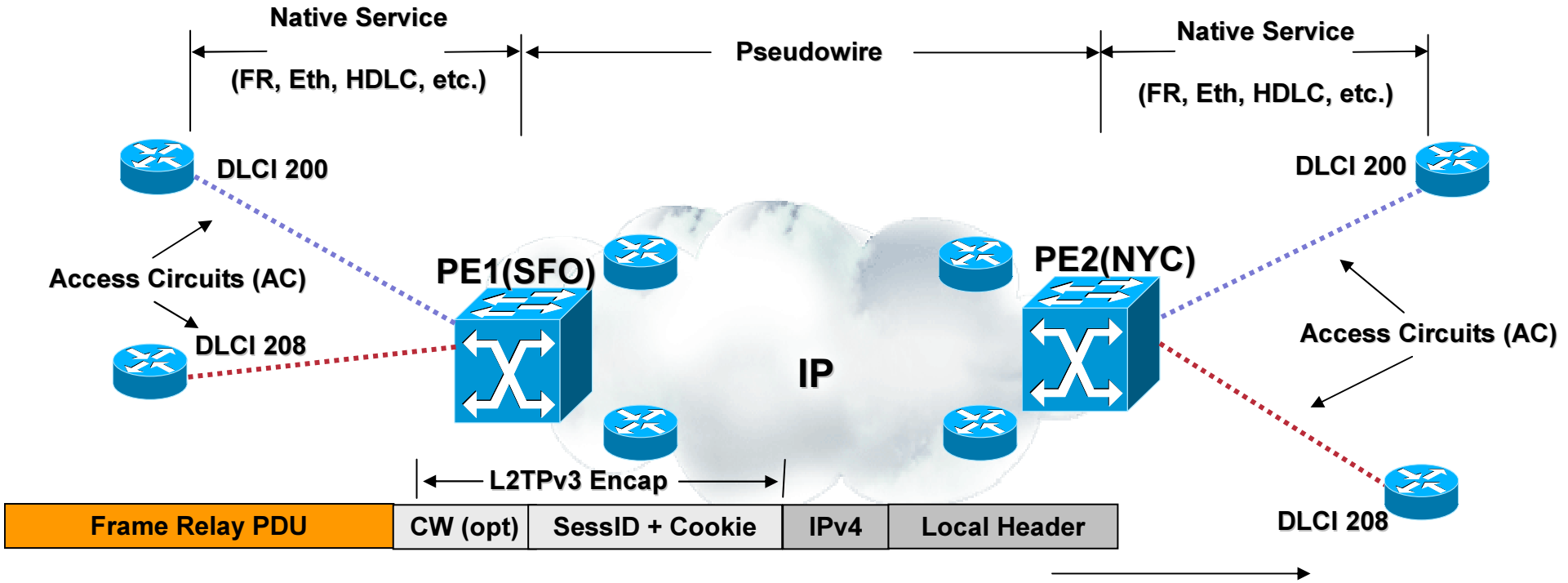
"Connectivity between PEs assumed; verified through ICMP or LSP ping."

Building Blocks for L2VPNs –
Control Plane, Generic Requirements (MPLS Example)



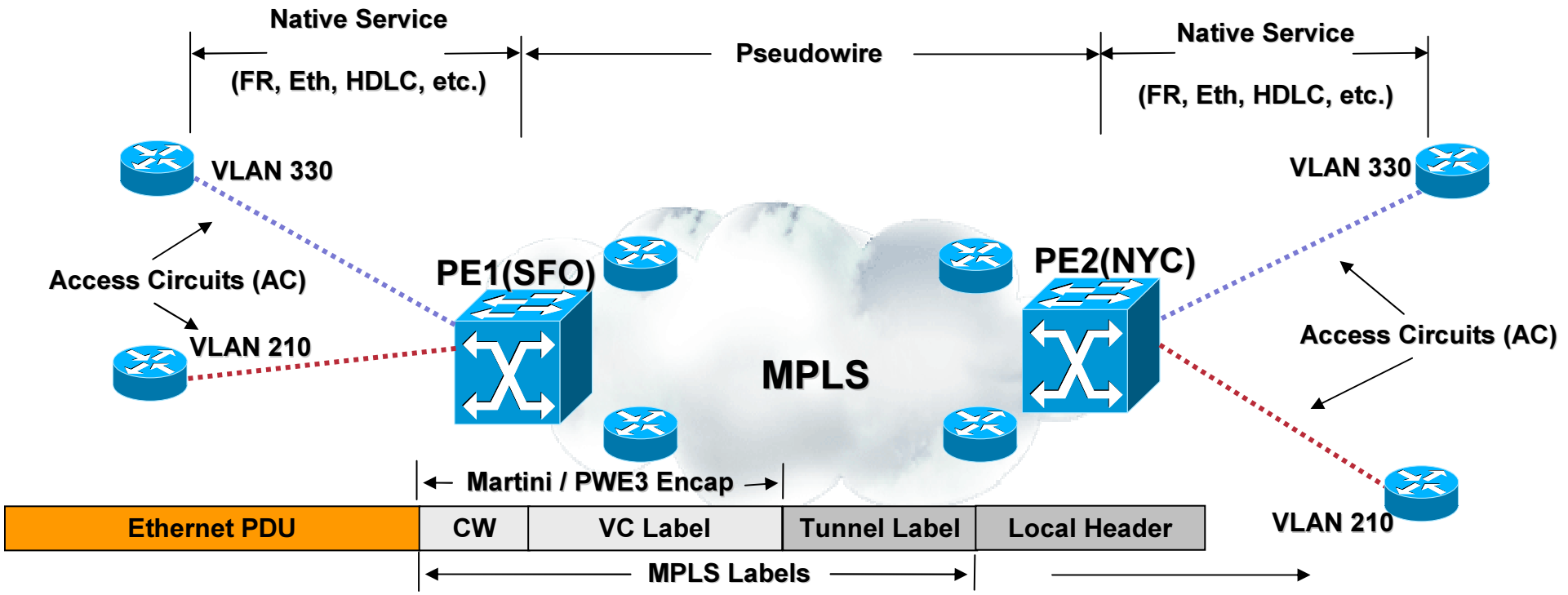
- The appearance of **Native Service** support from CE to CE (SP network is transparent)
- Ability to **Discover** other PE members for a given VPNs (i.e., BGP)
- Requires **Signaling** and **Interwork** with native services (i.e., Frame Relay LMI)
- **Packet Forwarding** – Negotiating the appropriate VC Label / Session ID

Building Blocks for L2VPNs –
Data Plan Components – IP Core (IP Example)



Transport Header	Delivery Header (IPv4 Header) = Transport an L2 PDU from ingress to egress PE; comprised of IPv4 loopback addresses (DA, SA)
Tunneling Header	4 byte Session ID + Optional 8 byte Cookie = Signalled or Statically configured
L2 PDU	L2 Specific Sublayer + Customer Payload (Layer 2 PDU)

Building Blocks for L2VPNs –
Data Plan Components – MPLS Core (Ethernet)

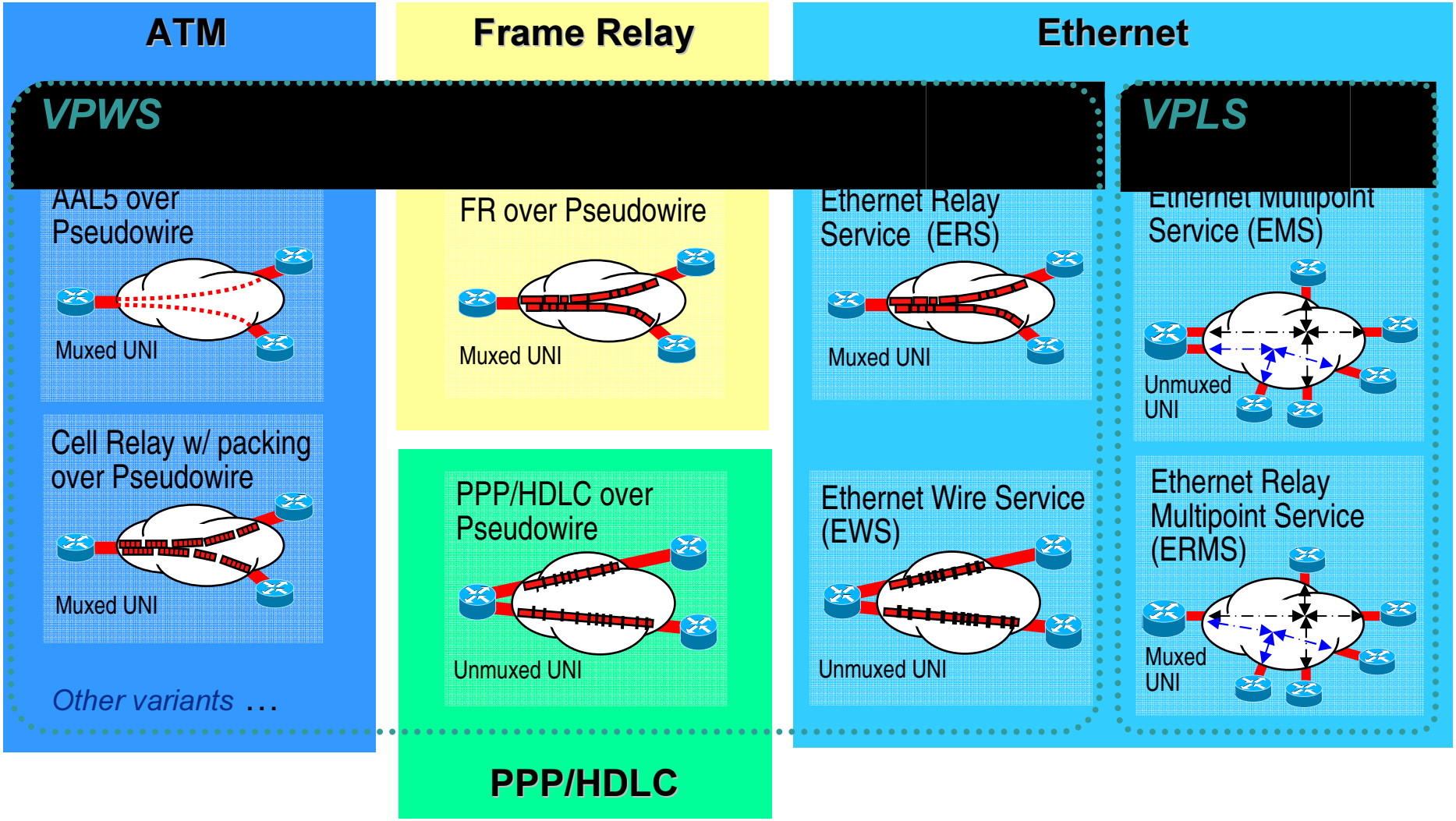


Transport Header — Tunnel Label (MPLS Label) (4 Byte) = Established thru LDP link establishment or RSPV-TE signalling. Forms a uni-directional path to the destination PE

Tunneling Header — VC Label (MPLS Label) (4 Byte) = Signalled thru Extended LDP session established between PE pairs (Martini ; PWE3 based drafts)

L2 PDU — Control Word (opt.) (4 Byte) + Customer Payload (may not transport entire L2 header)

Service Offerings –
L2VPN Transport Services



IETF Standardization Activity

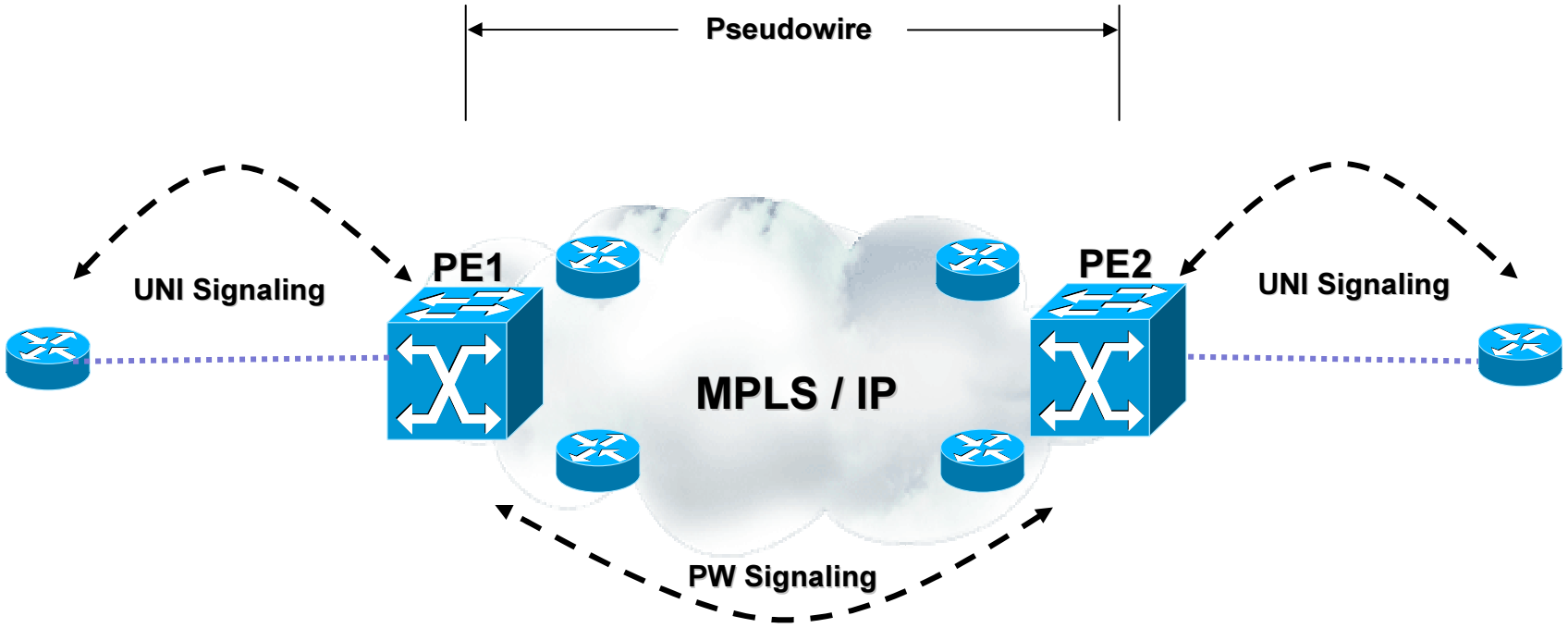
- **IETF working group PWE3**
  - ‘Pseudo Wire Emulation Edge to Edge’;
  - Requirements detailed in
    - *draft-ietf-pwe3-requirements*
    - *draft-ietf-pwe3-framework*
- **Develop standards for the encapsulation & service emulation of “pseudo wires”**
  - Across a packet switched backbone
- **Focused on Point-to-Point circuit emulation**
  - PSN tunnel -> GRE, MPLS, L2TP
  - Service -> Ethernet, ATM, PPP, FR, HDLC and so on ..

Pseudo Wire –
Cisco IETF Technology Adoption

- **Layer 2 Transport (VPWS)**
  - **L2TPv3**
    - draft-ietf-l2tpext-l2tp-base-xx
    - draft-ietf-l2tpext-l2tpmib-base-xx
  - **MPLS (P2P, formerly draft-martini)**
    - draft-ietf-pwe3-control-protocol-xx
    - draft-ietf-pwe3-[atm, frame-relay, ethernet, etc.]
- **Layer 2 VPN (VPLS)**
    - draft-ietf-l2vpn-vpls-ldp-xx (LDP Based Signalling)
- **Auto-Provisioning**
    - draft-ietf-ppvpn-bgpvpn-auto-xx (BGP auto-discovery)

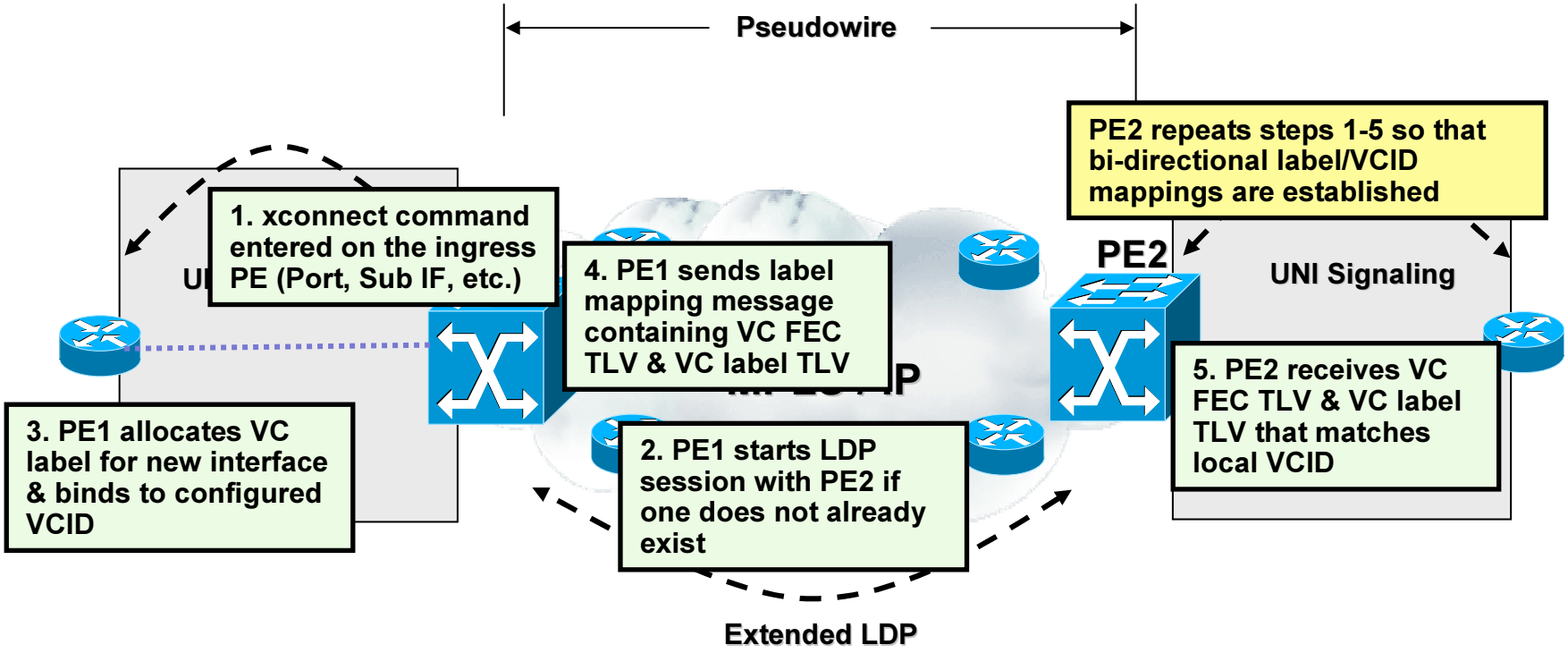
Signaling Concepts

Virtual Private Wire Service – *Provisioning – Overview*



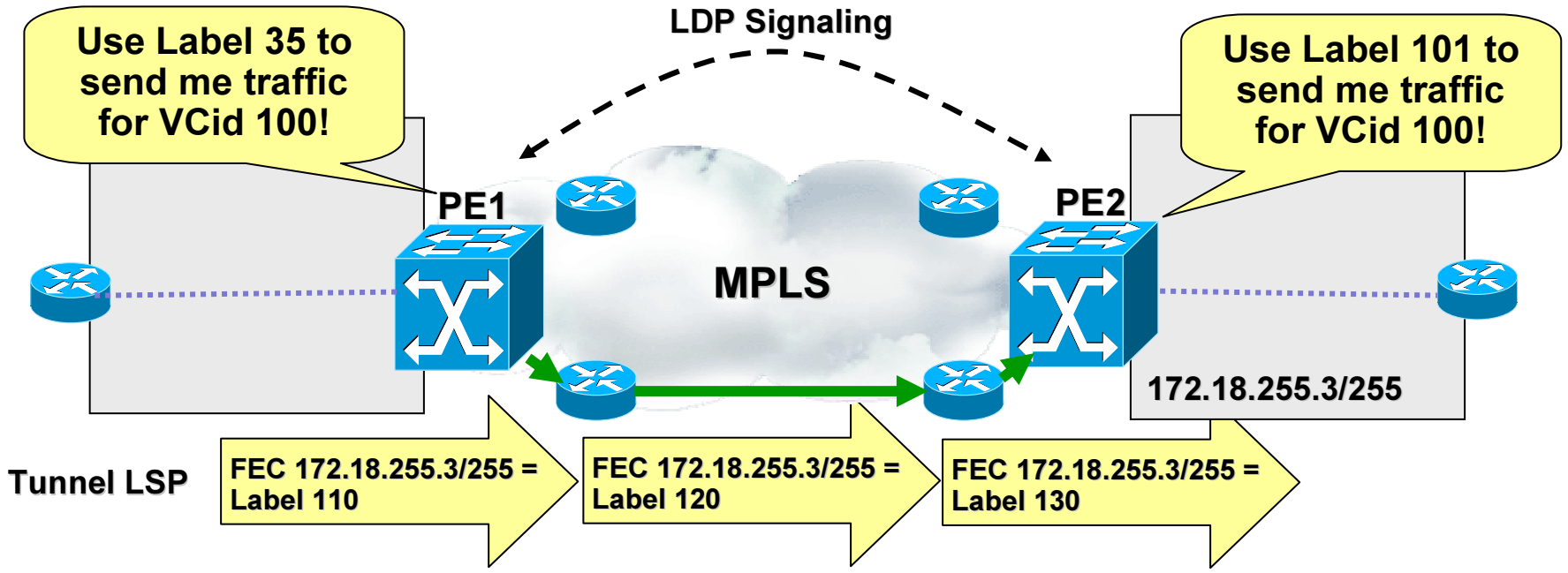
- Establishment of a control connection (LCCE Signaling or LDP)
- Provide an interface to local UNI to (activate, deactivate, delete) attachment circuits (ACs)
- Negotiate Session IDs (L2TPv3) & PW labels (LDP) between PEs.

Any Transport over MPLS – *Provisioning*



- One LDP session can signal multiple pseudowires
- Provides a dynamic mechanism to interface with UNI signaling
- Requires a common VCID to successfully bind ACs together.
- Pseudowire (VC) labels are assigned by the remote peer and don't require global uniqueness between PEs.

Virtual Private Wire Service –
LDP Signaling – Forwarding Equivalence Class



- FEC = "Forwarding Equivalence Class" : a set of packets forwarded in the same manner by an MPLS LSR
  - L2VPNs – FEC is used to bind a PW label to VC ID / Service type*
  - L3VPNs – FEC is used to bind a VPN label to set of customer prefixes
- Used to MUX customer data onto a given Tunnel
  - Similar concept to DLCI, VPI/VCI in Frame and ATM networks

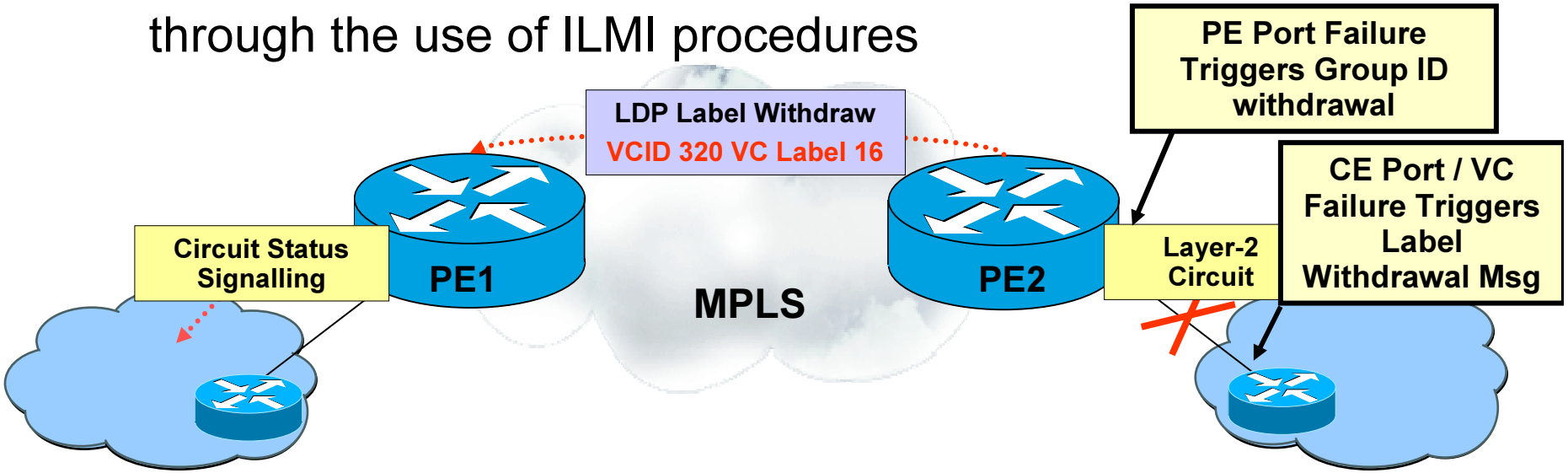
Virtual Private Wire Service–
VC Label Withdrawal Procedures - Example

- **If a PE router detects a condition that affects normal service it MUST withdraw the corresponding VC label**

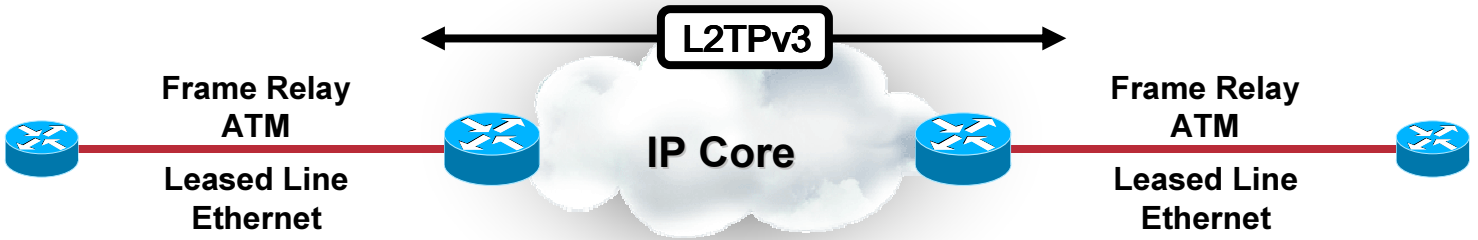
  Through the use of LDP signalling

- **A PE router may provide circuit status signalling**

  FR MUST through the use of LMI procedures; ATM SHOULD through the use of ILMI procedures

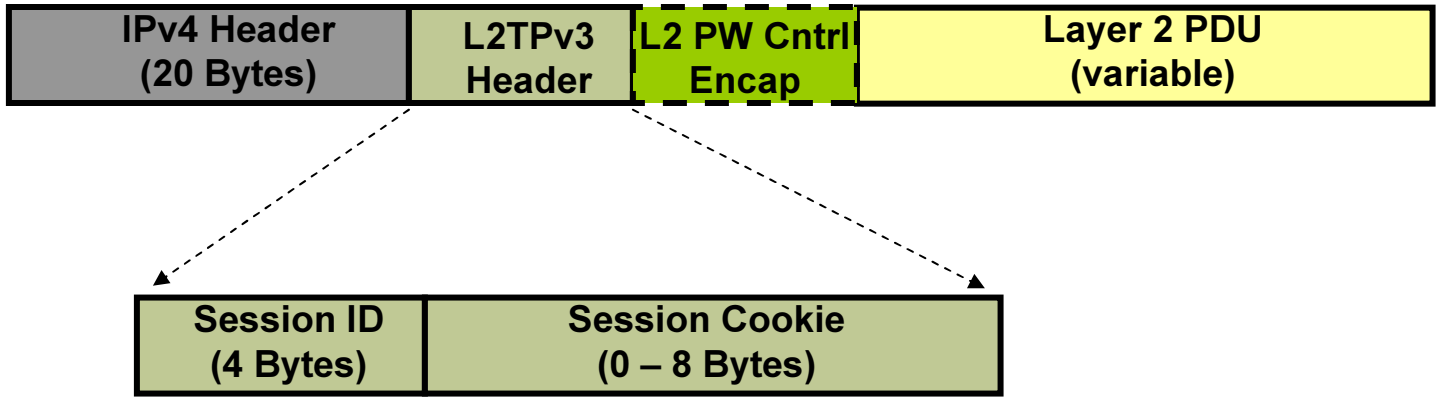


Layer 2 Tunneling Protocol version 3 –
The Native IP Service Provider's Answer to VPWS



- Designed for Service Providers with Native IP networks
- Based on L2TP (used in Remote Access) & Cisco innovation Universal Transport Interface (UTI)
- Open "standards track" architecture allows for extensibility
- Fixed header allows for high performance / HW accelerated decapsulation
- With IGP reachability, simple edge configuration is the only thing required!

Layer 2 Tunneling Protocol version 3 – *Data Messages Format*



IPv4 Header - The delivery header for the Tunnel. Always destined for an LCCE.

L2TPv3 header – Consists of two parts; (1) **Session ID** used to uniquely identify the correct Session on the Remote system, and (2) the **Cookie** used as an added measure of session integrity or validation between peers.

L2-Specific Sublayer - Sequence numbers, priority bits, and any additional flags needed to support the L2 emulation for the given PW type. There is a default defined in the L2TPv3 base specification, though this may vary among PW types if necessary.

Payload - Payload to be transported by L2TPv3. Typically the entire link-level frame.

Virtual Private Wire Service – Summary

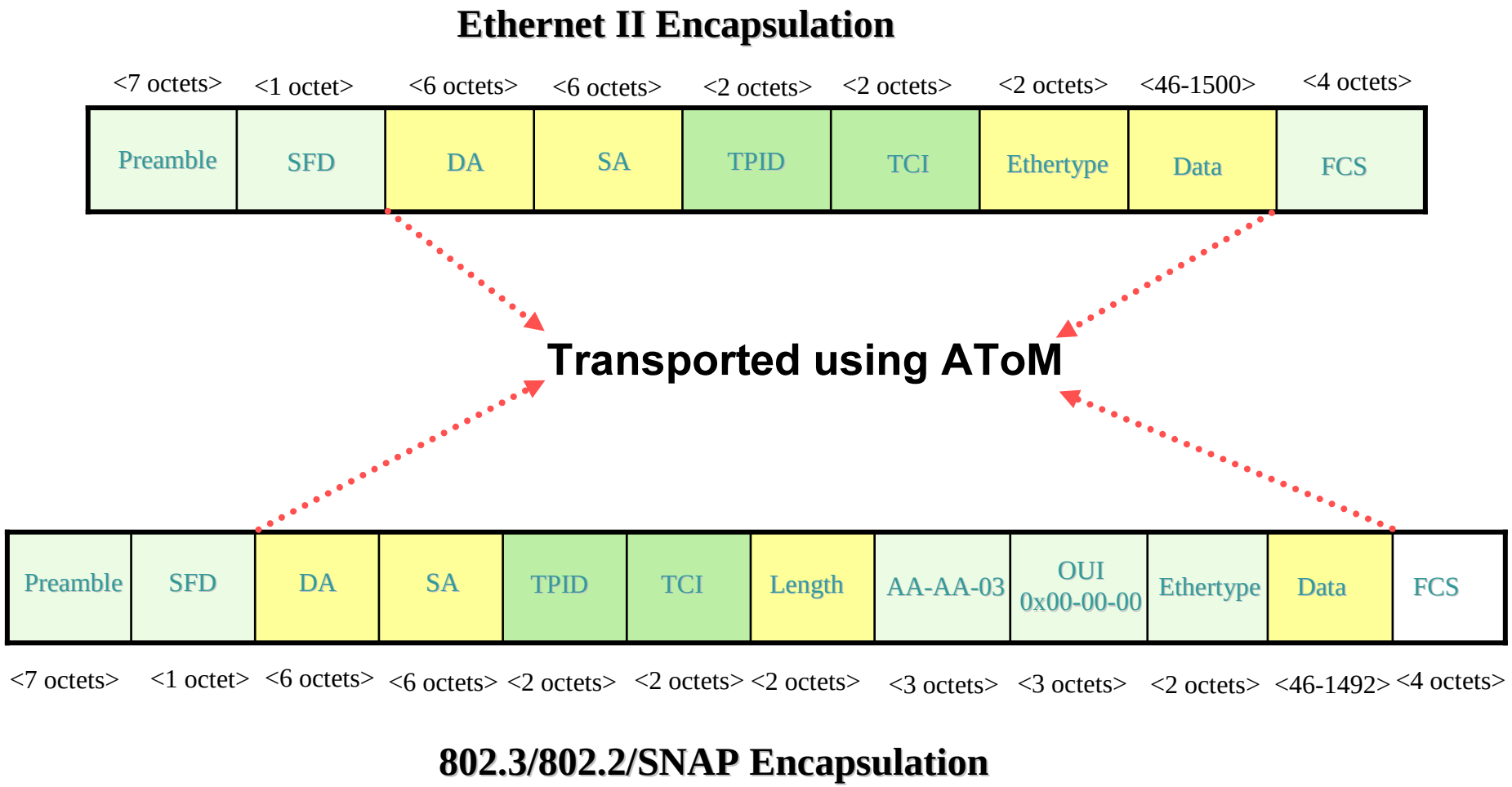
- MPLS PW & L2TPv3 are point-to point technologies for the transport of Layer 2 PDUs across and native or MPLS enabled IP cores.
- MPLS PW uses Directed LDP sessions to exchange PW Labels between participating peers while L2TPv3 uses Control messages to negotiate Session IDs
- MPLS PW & L2TPv3 can use an optional Control Word to preserve information in transported PDUs
- MPLS PW & L2TPv3 provides interworking with access circuit management protocols to maintain VC status consistency (i.e. label withdrawal or call disconnect notification in the event of edge service loss, etc.)

VPWS Transports

VPWS Transports

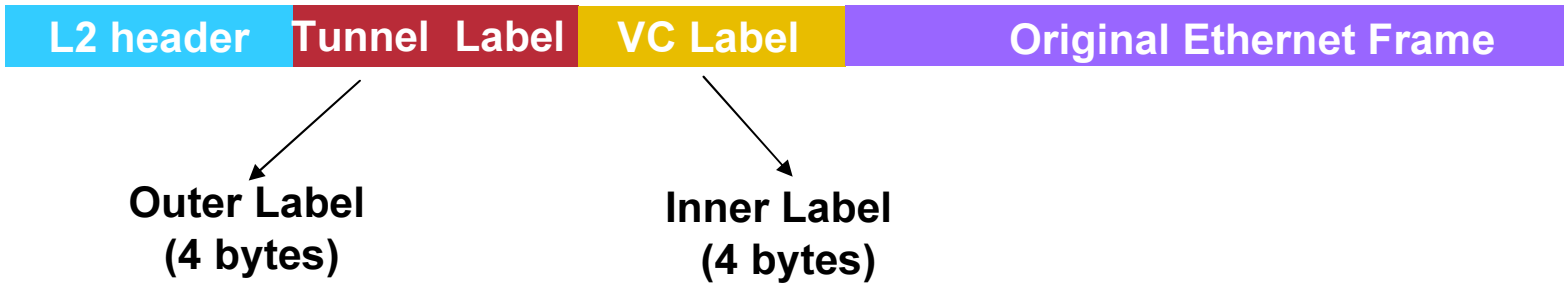
- EoMPLS
- FRoMPLS
- ATMoMPLS
- PPPoMPLS
- HDLCoMPLS

EoMPLS Transport Formats



EoMPLS Encapsulation

- PE router encapsulates VLAN packet and route it across MPLS backbone
- Two levels of labels (8 bytes)
  - Tunnel label, outer label,to forward the packet across the network
  - VC-based label, to bind L2 interface where packets must be forwarded
- VC (virtual circuit), 32 bit identifier used uniquely to identify the VC per tunnel
- VC type-0x0004 is used for VLAN over MPLS application
- VC type-0x0005 is used for Ethernet port tunneling application (port transparency)
- VC is an label switch path (LSP) tunnel



EoMPLS Encapsulation Details

- **Ethernet PDUs are transported without the preamble, SFD and FCS**

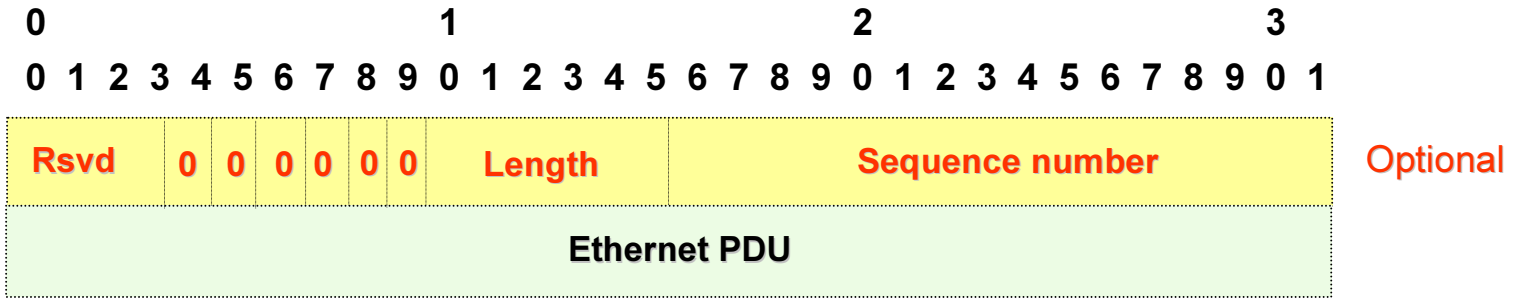
  but including all VLAN information such as VCID

- **The control word is optional**

  C bit is set by default in Cisco implementation (except 7600)

- **If the control word is used then the flags must be set to zero**

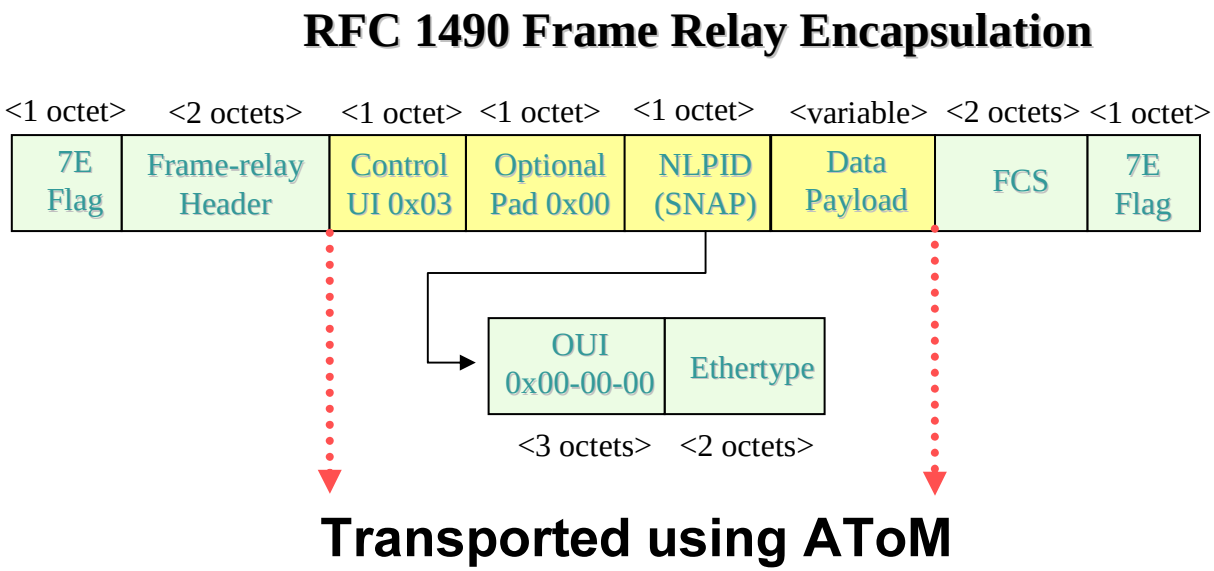
  The VLAN tag is transmitted unchanged but may be overwritten by the egress PE router

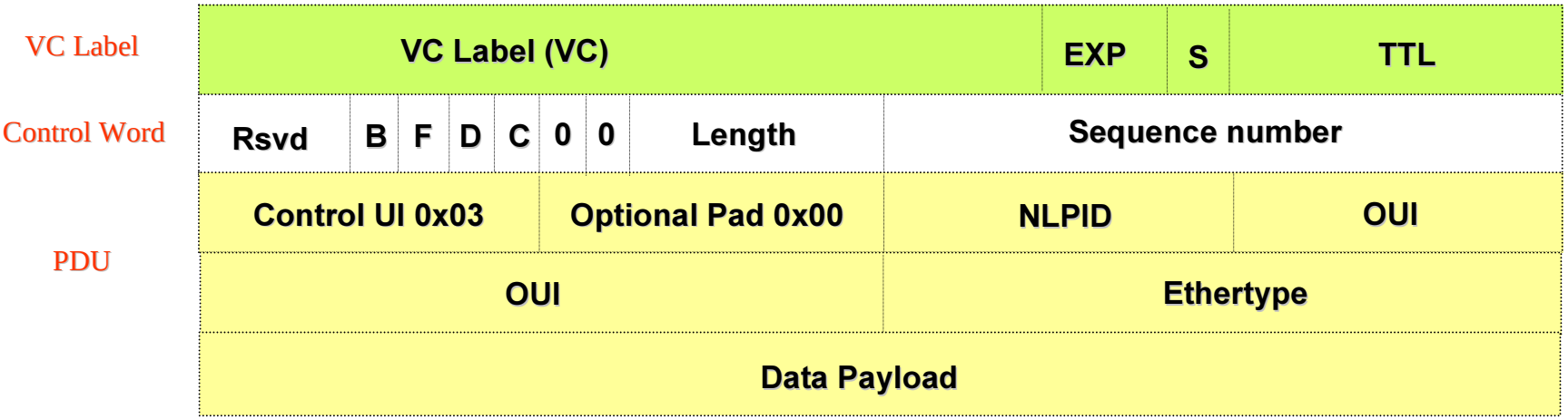


VPWS Transports

- EoMPLS
- FRoMPLS
- ATMoMPLS
- PPPoMPLS
- HDLCoMPLS

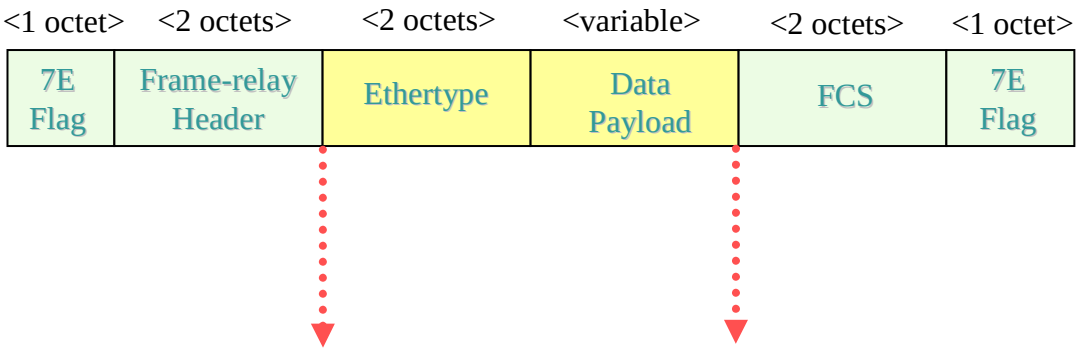
RFC 1490 Encapsulation



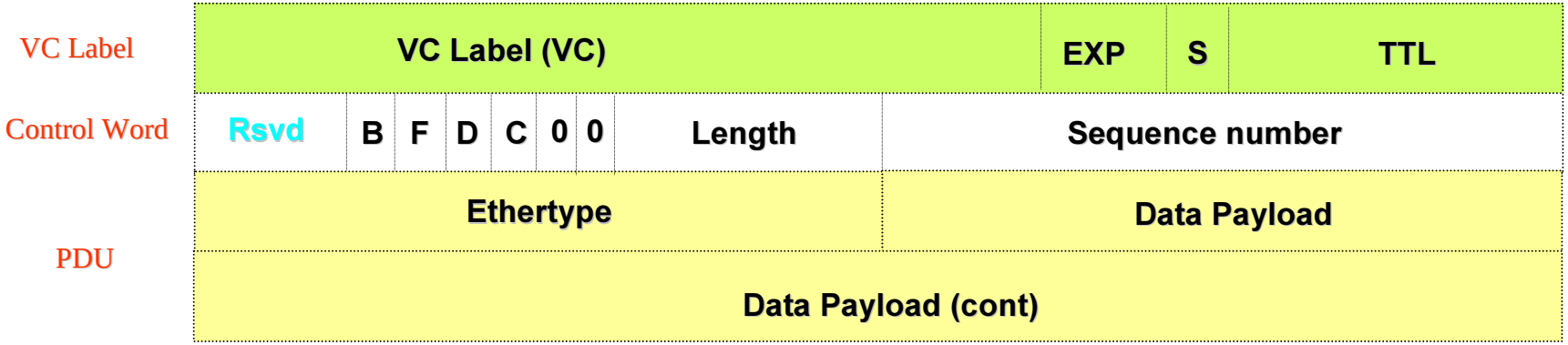


Cisco Proprietary Encapsulation

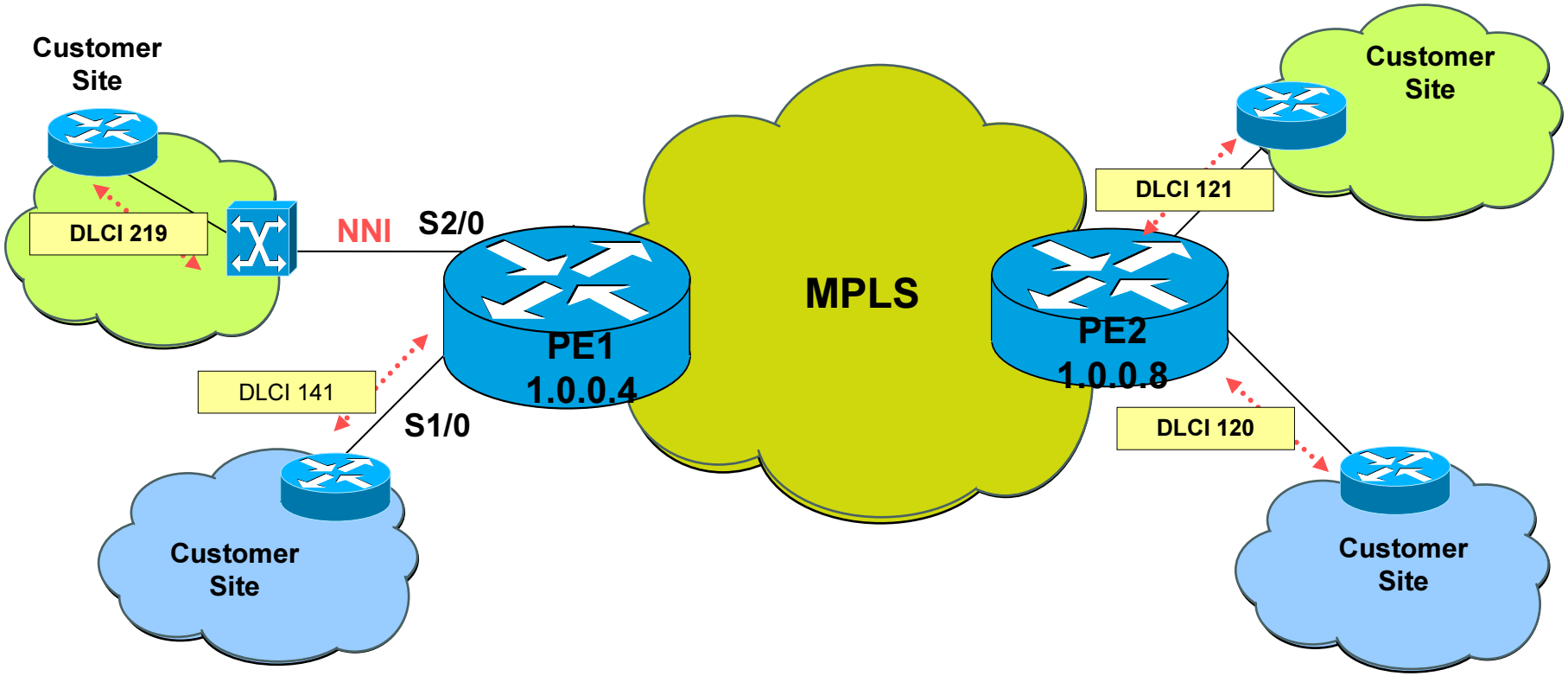
Cisco Frame Relay Encapsulation



Transported using AToM



Distributed DLCI Switching



Frame-relay DLCI to DLCI Transport

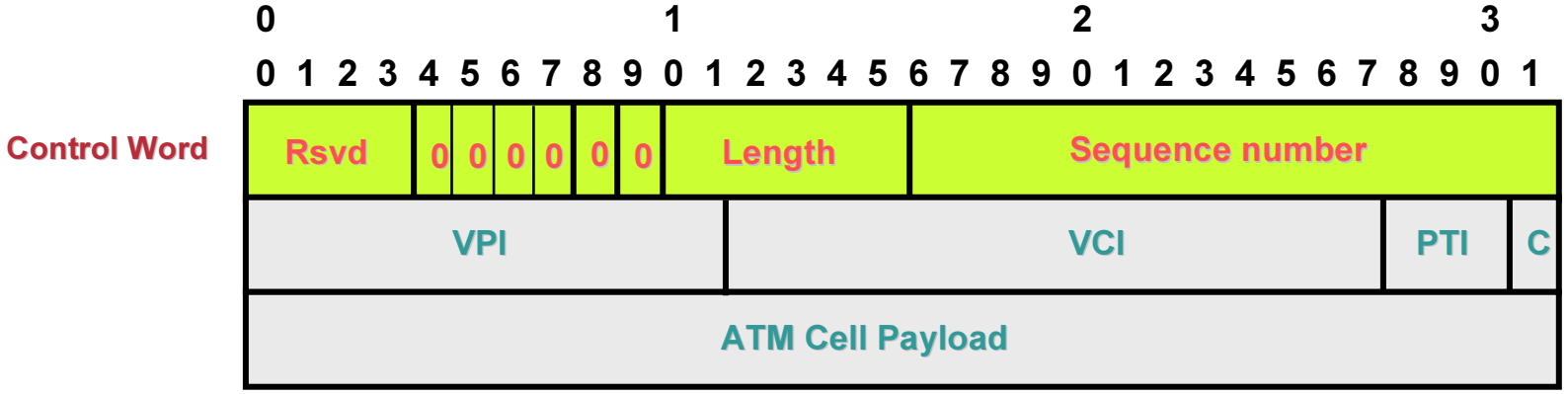
VPWS Transports

- EoMPLS
- FRoMPLS
- ATMoMPLS
- PPPoMPLS
- HDLCoMPLS

Cell Relay Over MPLS

- **Single Cell per MPLS packet**
  - **Applying labels per cell**
  - **Do not distinguish between payload cells and signaling**
  - **OAM and RM also transported**
- **Control Word is optional**
- **HEC is not carried inside MPLS network**
- **Idle cells are not carried over MPLS network**

Cell Relay Encapsulation Details



- Single cell is encapsulated
- Control word is optional
- Control word flags should be set to zero and ignored

ATM Cell Packing – Why Important?

Overview:

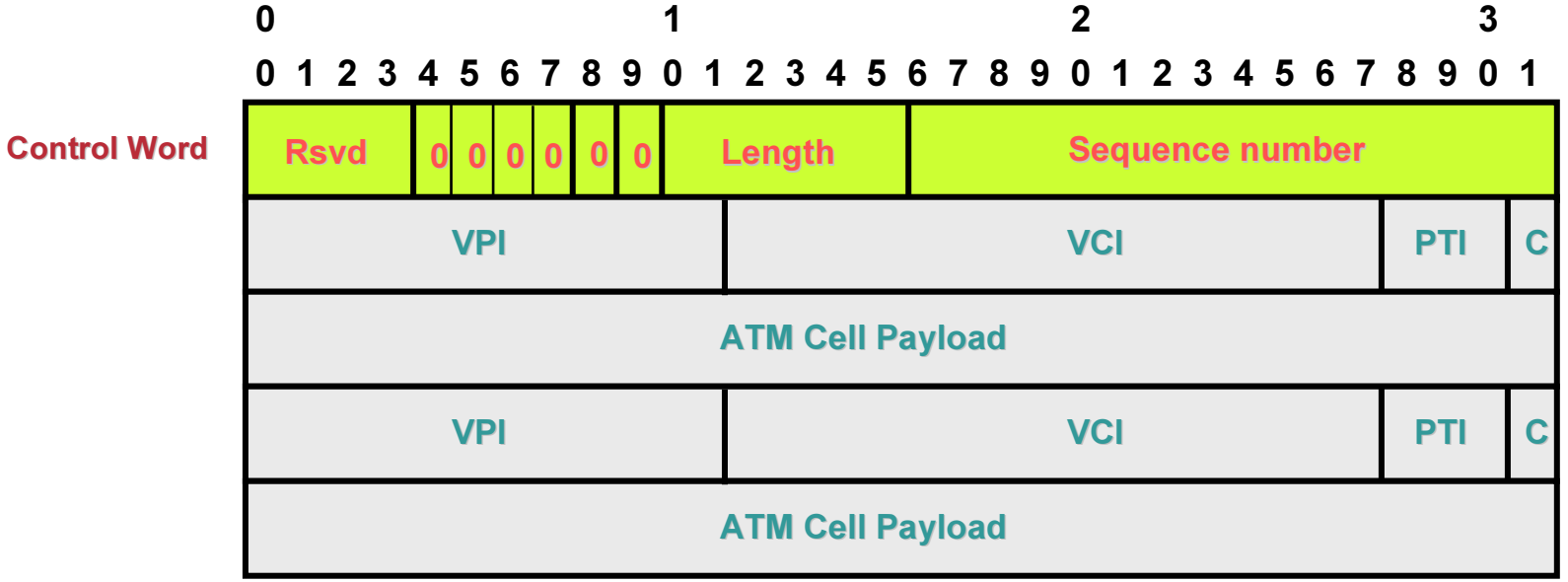
- Used to mitigate Cell to MPLS Packet MTU inefficiencies
- Concatenated ATM Cell (52 Bytes); No HEC
- Maximum 28 Cells per MPLS Frame (<1500 byte MTU)

Components:

- Maximum cells to pack
- Maximum Cell Packing Timeout (MCPT)

- PE will send packed cells based on the minimum configured packing characteristics between the two PEs. Each PE honors the MNCP configured on the other.

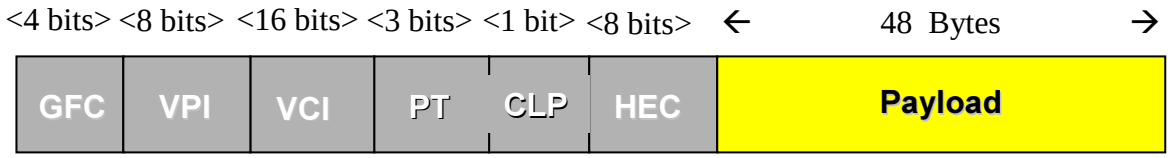
Cell Packing Encapsulation Details



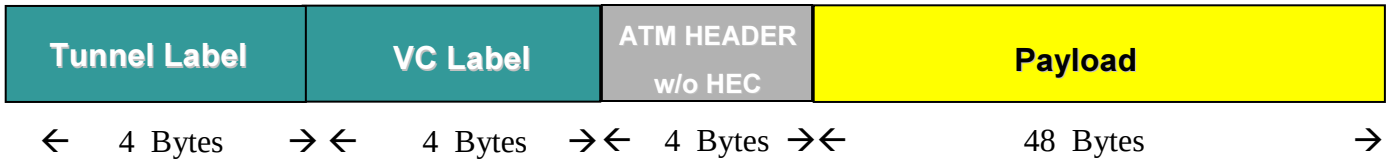
- Multiple cells are packed per MPLS packet
- All cells must belong to the same VC / VP
- Packing controlled by max number of cells and timer
- Control word is optional

Cell Packing Encapsulation

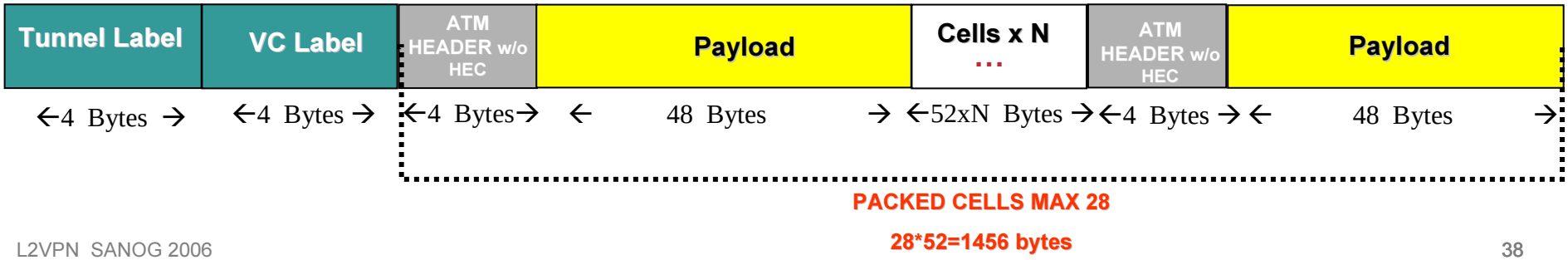
- **ATM Cell**



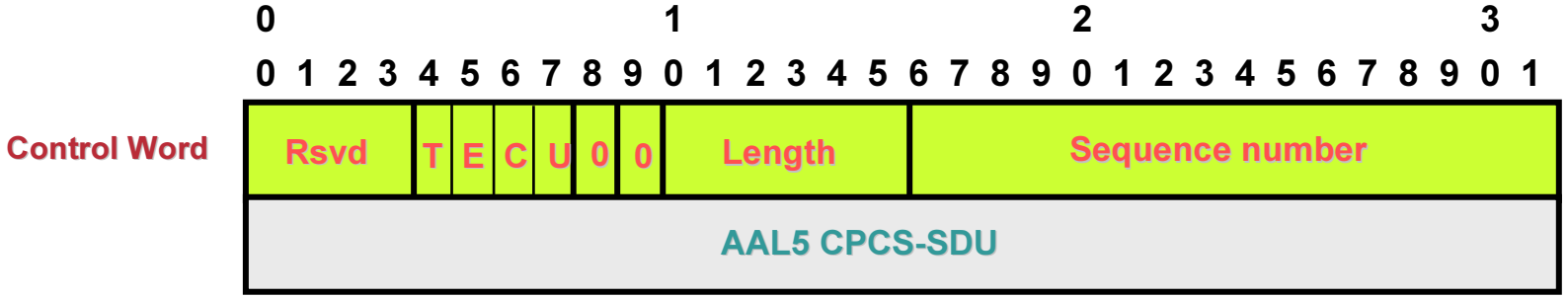
- **Single Cell Relay**



- **Packed Cell Relay**



AAL5 Encapsulation Details



- AAL5 SDUs are encapsulated
- Control word is required
- Control word flags encapsulate transport type, EFCI, CLP, C/R bit
- Service allows transport of OAM and RM cells

VPWS Transports

- EoMPLS
- FRoMPLS
- ATMoMPLS
- PPPoMPLS & HDLCoMPLS

Cisco HDLC & PPP Encapsulation Details

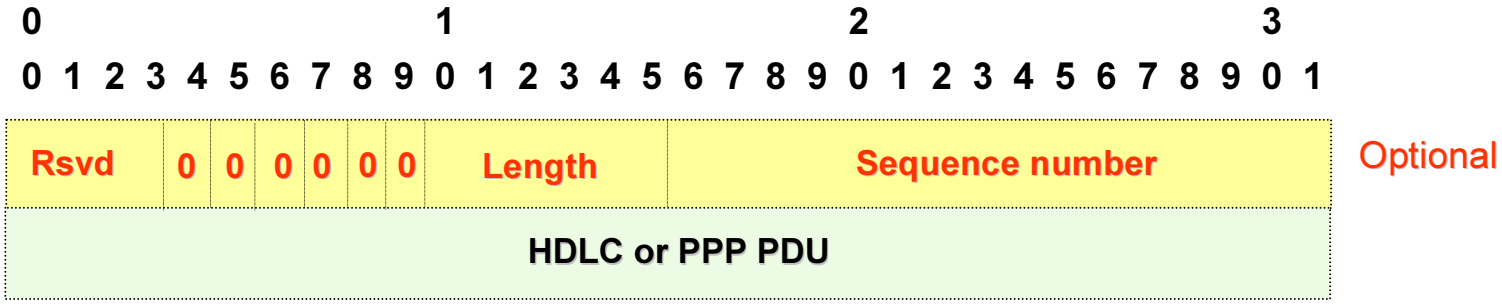
- **Cisco HDLC & PPP PDUs are transported without flags or FCS**

  PPP frames also do not carry HDLC address & control information

- **The control word is optional**

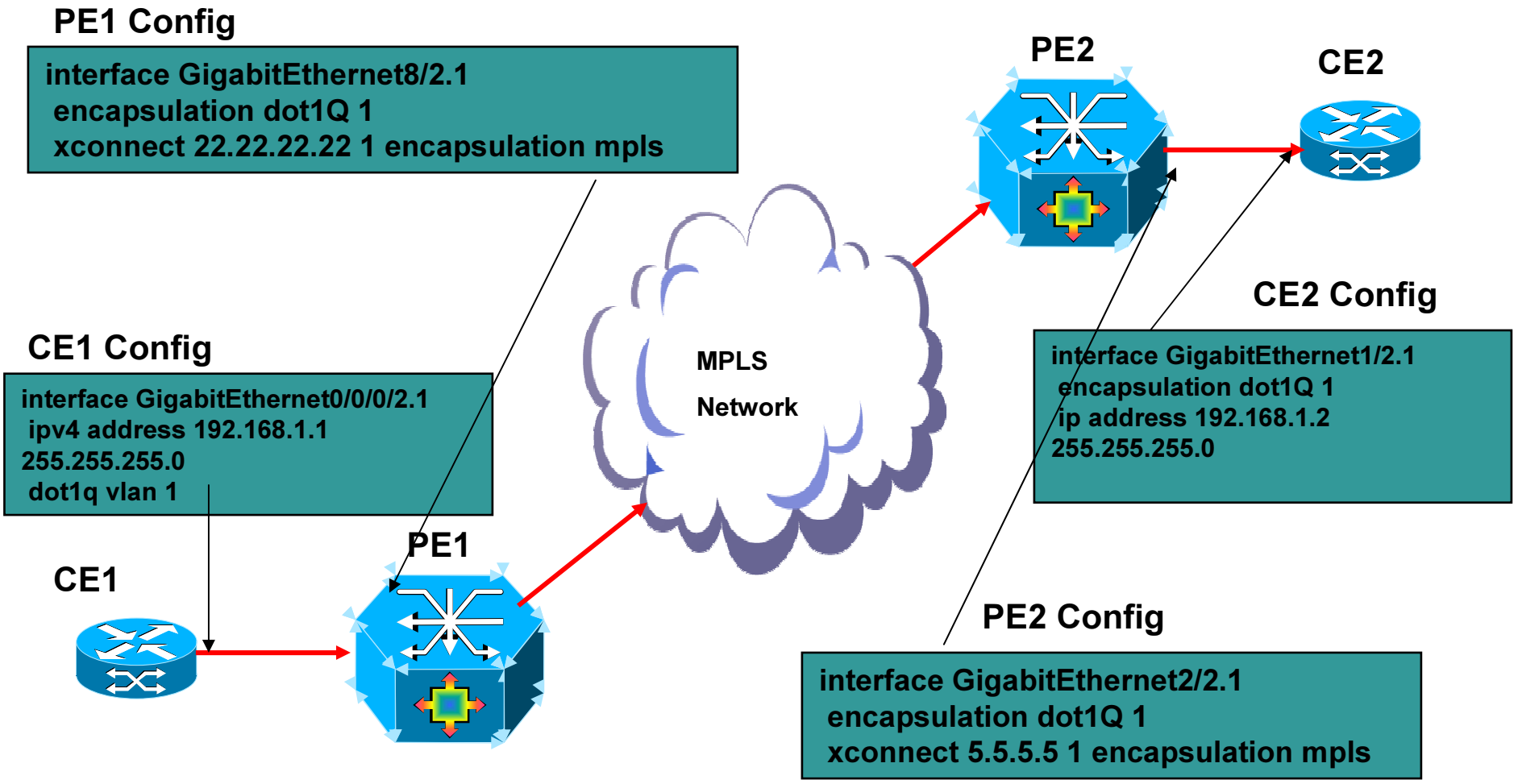
  C bit is set by default in Cisco Implementation

- **If the control word is used then the flags must be set to zero**

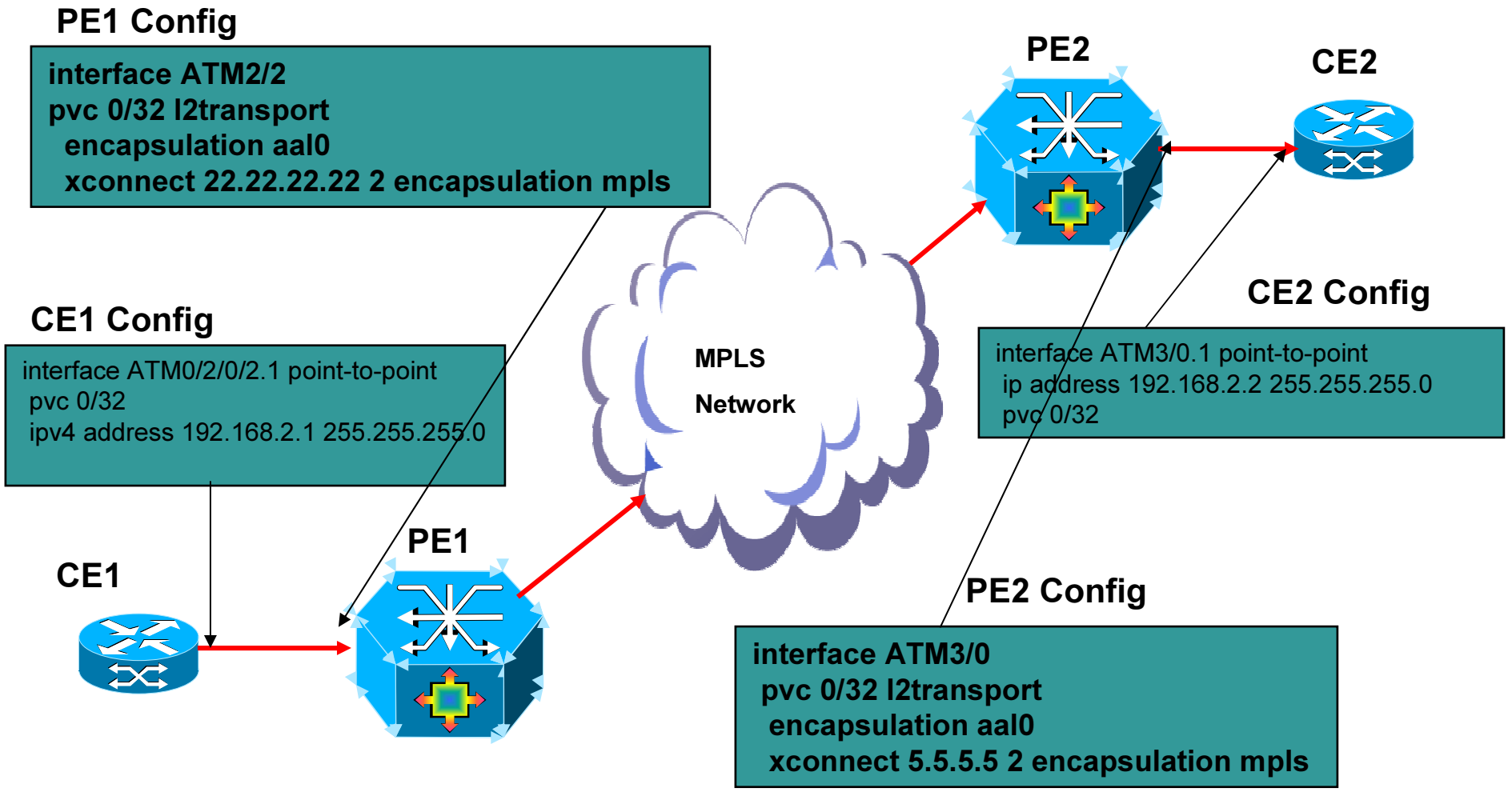


DEMO

Point to Point
VLAN over MPLS



Point to Point
Cell Relay over MPLS



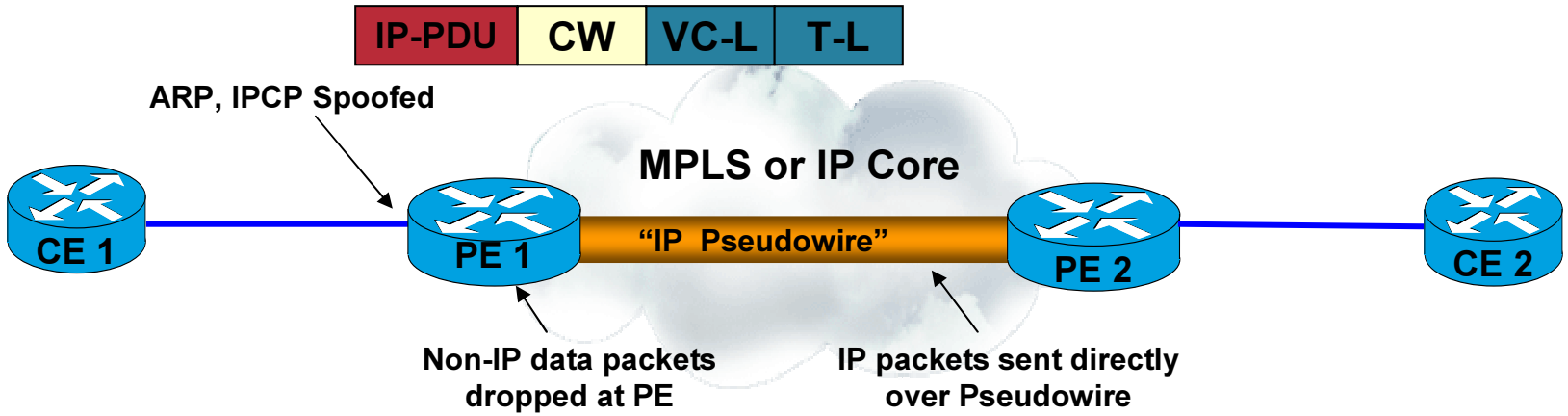
VPWS Service Interworking

L2VPN Service Interworking –
Overview – What is it's purpose?

L2VPN Service Interworking enables:

- **Flexibility for the Service Provider in offering access circuits that best meet the customer's needs (i.e. multiple services on a common port)**
- **Expanded transport options from Like-to-Like → Any-to-Any**
- **Allows different Layer 2 encapsulations to connect at opposite ends of the network. (i.e. ATM PVC → Ethernet 802.1Q VLAN)**
- **Provide circuit based services in addition to packet based services**
- **Transparent trunking of customer IGP independent of access media**

IP Interworking



Ethernet

Frame Relay

PPP/HDLC

ATM

Any -2- Any

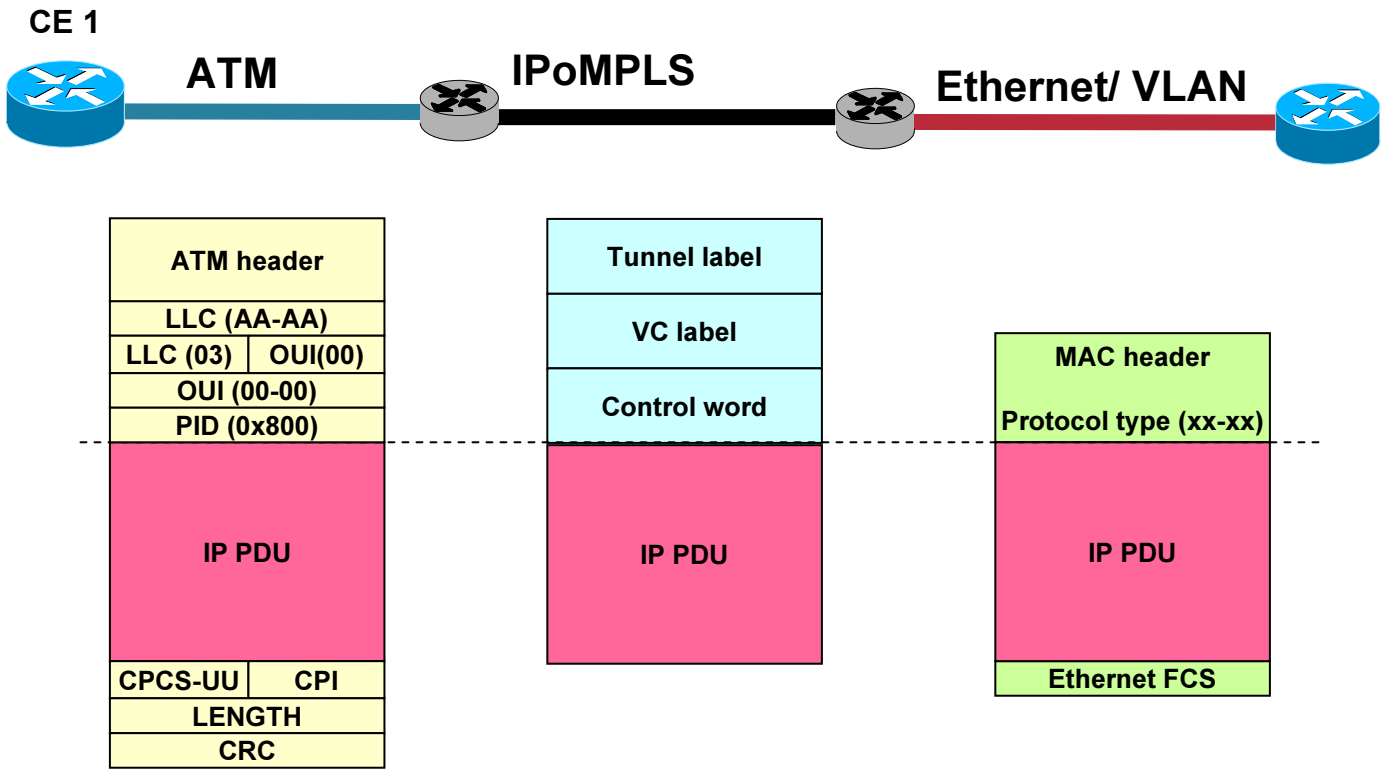
Ethernet

Frame Relay

PPP/HDLC

ATM

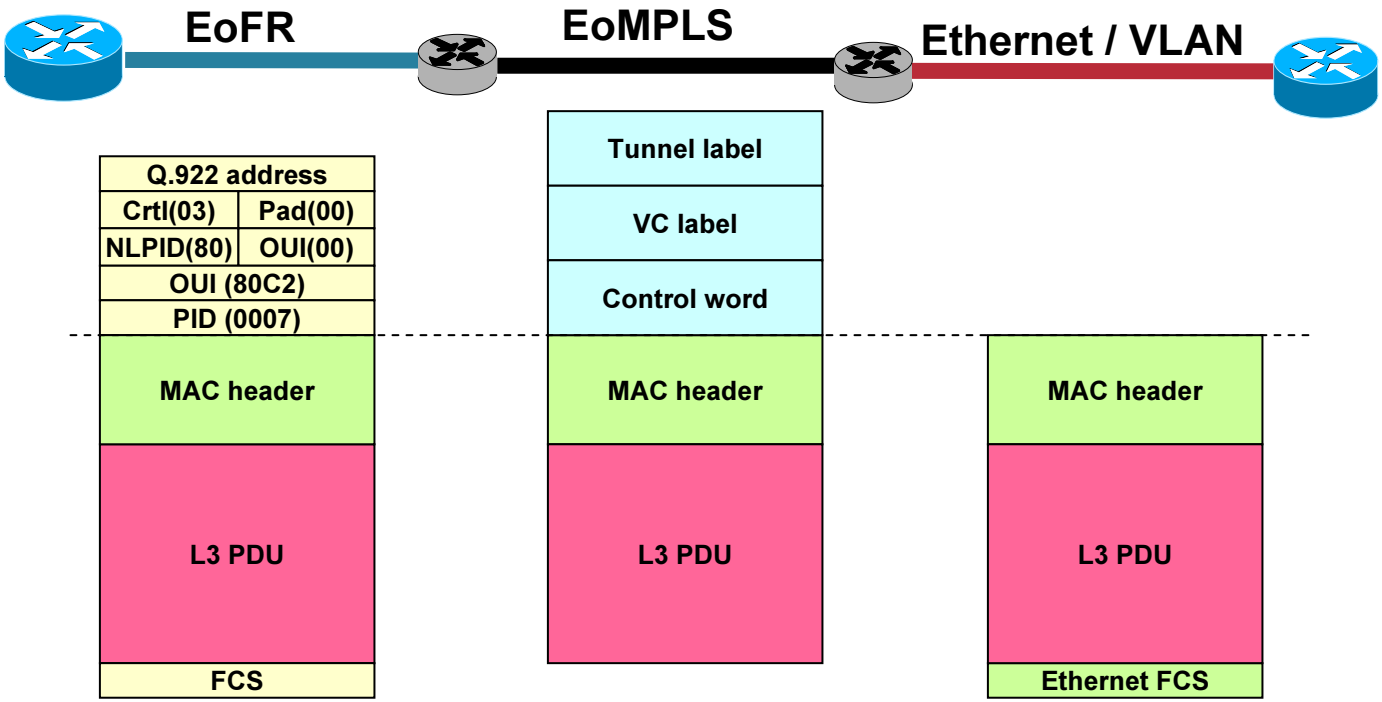
Ethernet to AAL5: IP interworking



Ethernet to FR bridged interworking

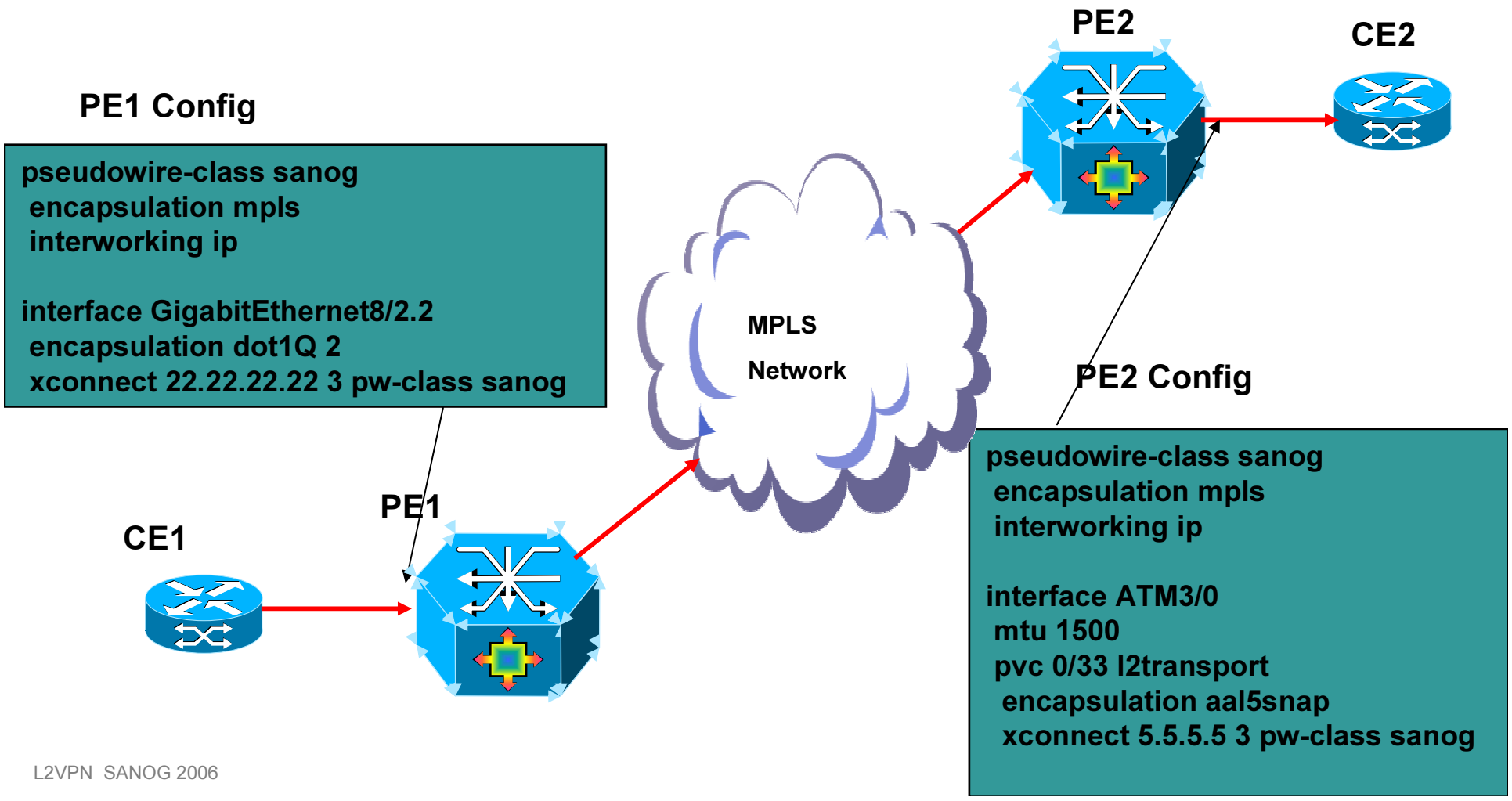
CE 1

Running RBE/IRB (RFC2427)



DEMO

Point to Point
VLAN to ATM Interworking



Virtual Private LAN Service (VPLS)

Virtual Private LAN Service

- **VPLS Overview**
- **VPLS Architectures**

VPLS – Overview

- **Architecture**

  It is an end-to-end architecture that allows IP/MPLS networks to provide Layer 2 multipoint Ethernet services while using LDP as signaling protocol

- **Bridge emulation**

  Emulates an Ethernet bridge

- **Bridge functions**

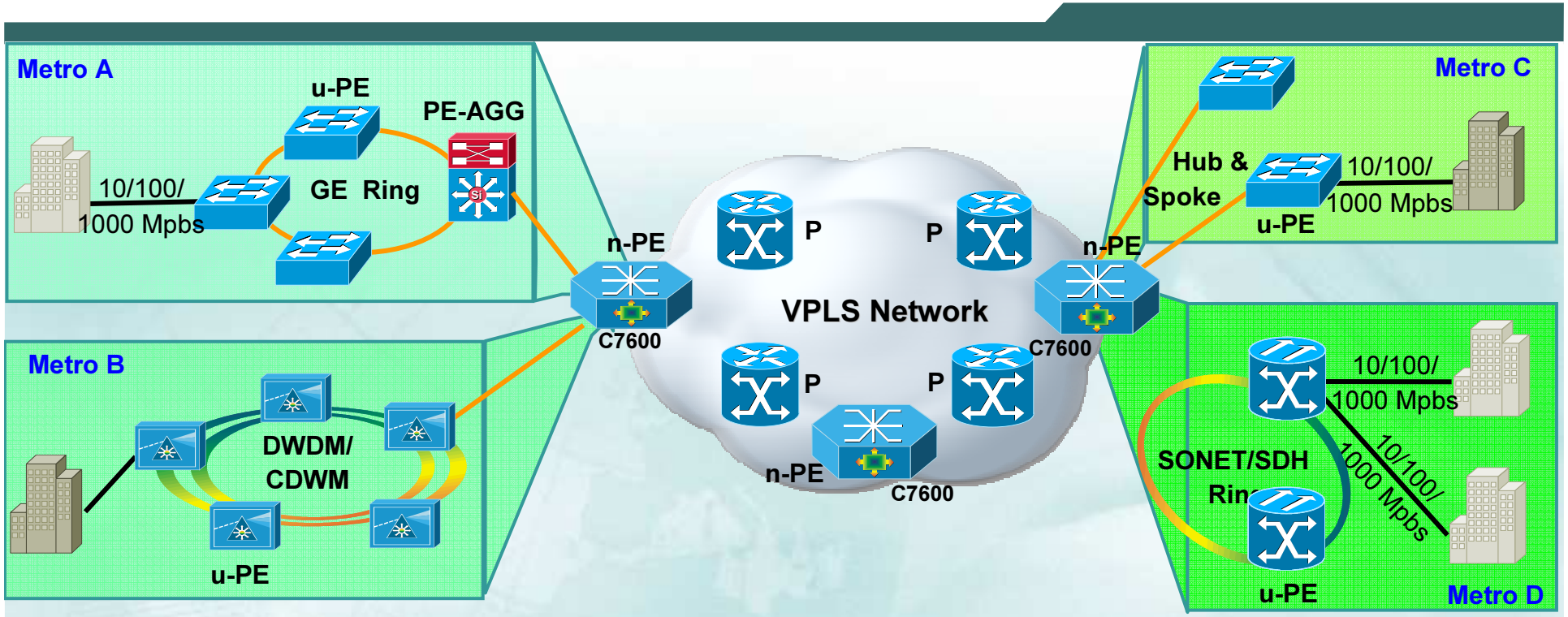
  Operation is the same as for an Ethernet bridge, ie forwards using the destination MAC address, learns source addresses and floods broad-/multicast and unknown frames

- **Several drafts in existence**

  draft-ietf-l2vpn-vpls-ldp-xx.txt

  draft-ietf-l2vpn-vpls-bgp-xx-txt

VPLS Overview for Metro Ethernet



- Delivers Ethernet-based multipoint L2 VPN service
- Enhances L2 VPN scalability (geographic sites & no. of customers)
- Leverages existing SP MPLS Core
- Supports operational speeds of GB to 10 GB
- On track for IETF standardization: Draft Lasserre-Kompella
- Uses familiar Ethernet user network interface

VPLS: Requirements

A Virtual Switch MUST operate like a conventional L2 switch!

Flooding / Forwarding:

- MAC table instances per customer and per customer VLAN (L2-VRF idea) for each PE
- VSI will participate in learning, forwarding process

Address Learning / Aging:

- Self Learn Source MAC to port associations
- Refresh MAC timers with incoming frames
- New additional MAC TLV to LDP

Loop Prevention:

- Create partial or full-mesh of EoMPLS VCs per VPLS
- Use “split horizon” concepts to prevent loops
- Announce EoMPLS VPLS VC tunnels

VPLS Characteristics

- **Auto-discovery of VPN membership**

  Reduces VPN configuration and errors associated with configuration

- **Signaling of connections between PE devices associated with a VPN**

- **Forwarding of frames**

  AToM uses Interface based forwarding

  VPLS uses IEEE 802.1q Ethernet Bridging techniques

- **Loop prevention**

  MPLS Core will use a full mesh of PWs and "split-horizon" forwarding

  H-VPLS edge domain may use IEEE 802.1s Spanning Tree, RPR, or SONET Protection

VPLS Overview: VSI Functions

- **MAC Address Management**

1. **Dynamic Learning of MAC Address on Physical Ports and VC**
2. **Aging of MAC address**
3. **Withdraw of MAC address**
4. **Flooding of Multicast, Unicast, Unknown**

- **Data Forwarding**
- **Customer STP BPDU tunneled across SP Cloud.**

VPLS Overview: VPLS Learning

- **Unqualified**
  - Single port assigned for all customer VLANs
  - Single broadcast domain for all customer VLANs
  - Single MAC address space (no overlap!)
- **Qualified**
  - Each VLAN has its own VPLS instance
  - A VLAN has its own broadcast space and MAC address space
  - Customer MAC addresses MAY overlap
  - One FIB per customer VLAN
  - Broadcast domain limited to VLAN scope

  MTM – Mac Table Management

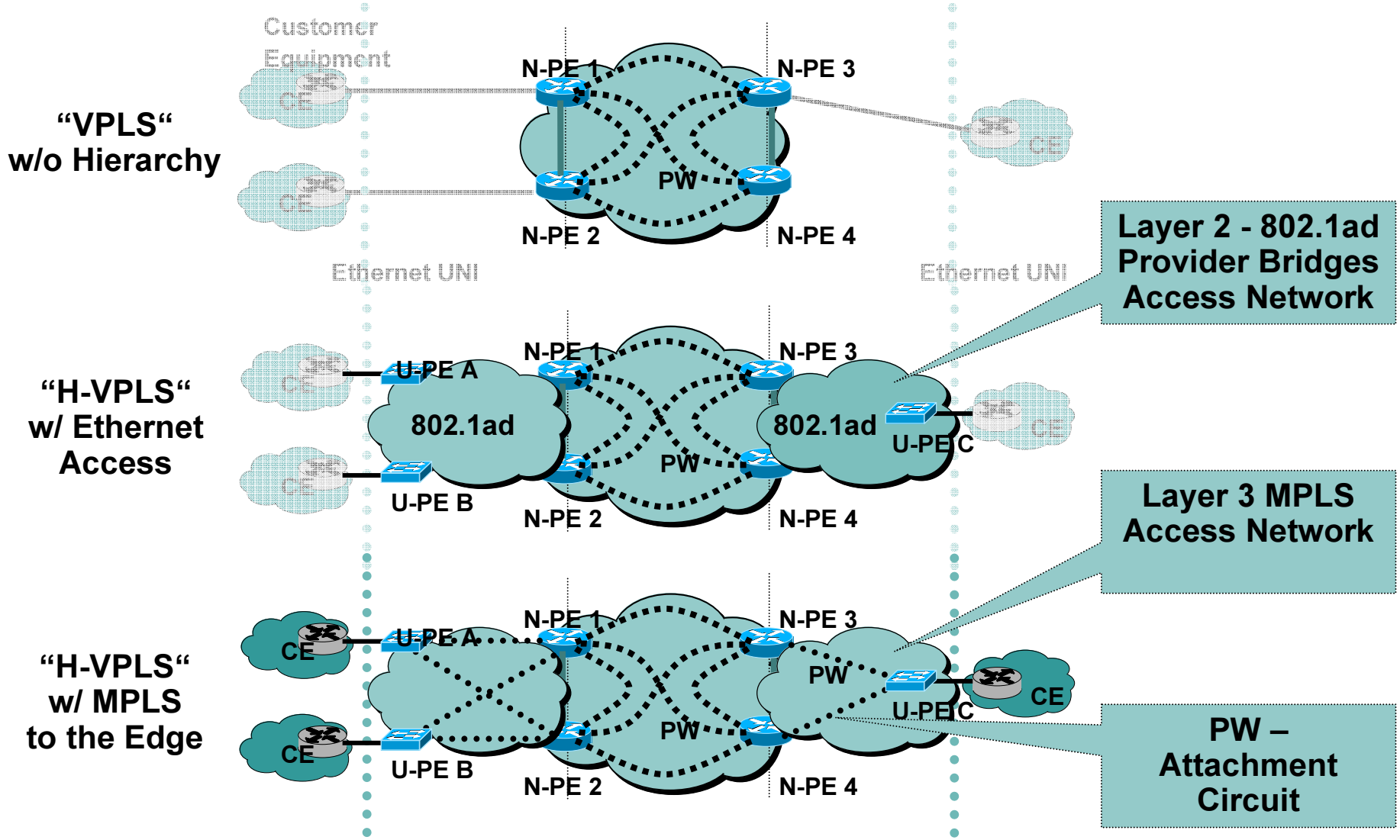
Virtual Private LAN Service

- **VPLS Overview**
- **VPLS Architectures**

VPLS Architectures

- **VPLS defines two Architectures**
  - **Non-Hierarchical (Single PE)**
  - **Hierarchical (Distributed PE)**
    - **802.1ad (aka QinQ) Access**
    - **MPLS Access**
- **Each Architecture has different scaling characteristics**

Way to Build a L2 Core:
VPLS—Virtual Private LAN Services



VPLS Architecture: Characteristics - Direct Attachment (Flat)

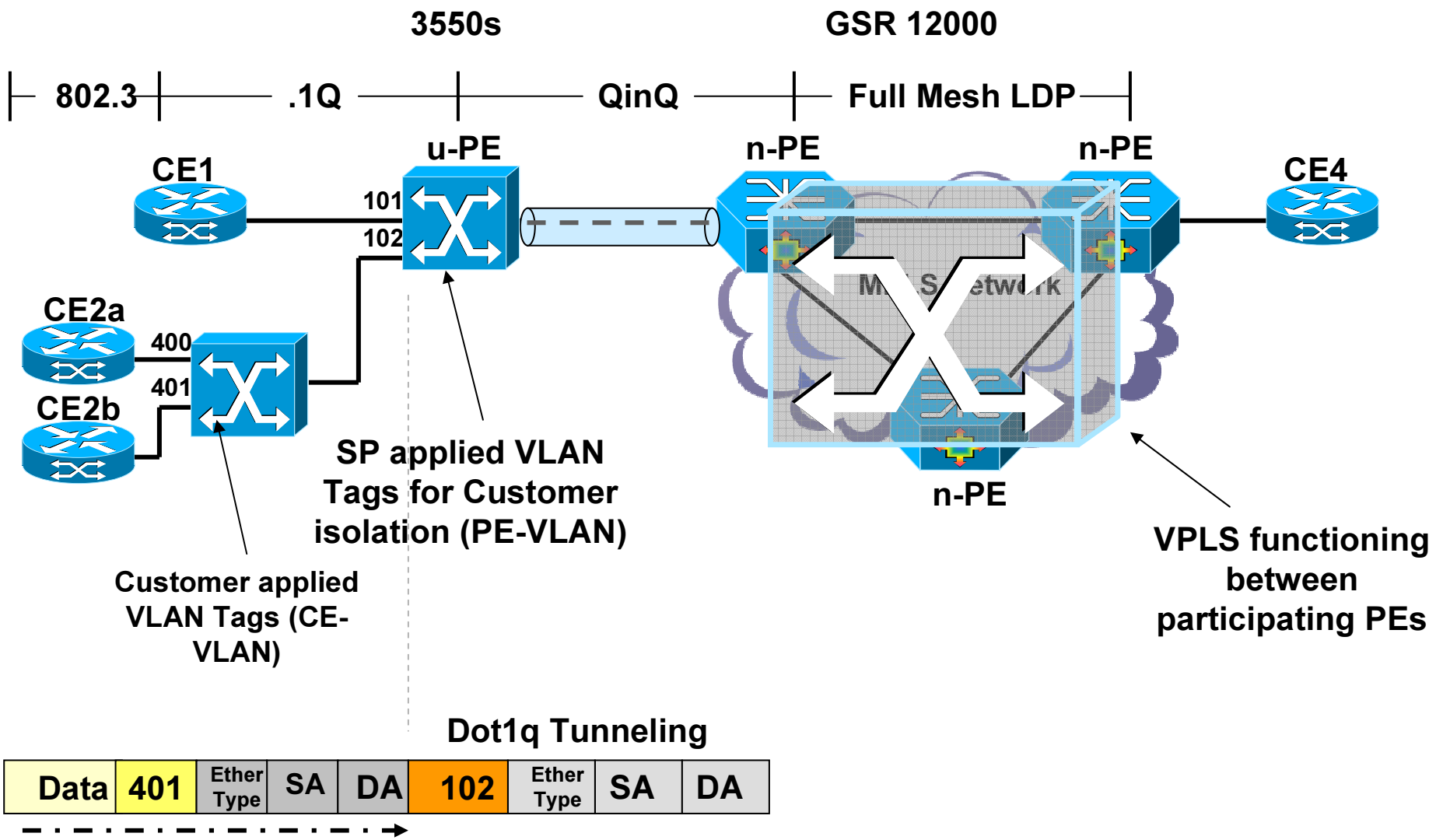
Overview:

- Okay for small customer implementations
- Simple provisioning
- Full mesh of directed LDP sessions required between participating PEs
- VLAN and Port level support (no QinQ)

Drawbacks:

- No hierarchical scalability
- Scaling issues:
  - PE packet replication
  - Full mesh causes classic - N*(N-1) / 2 concerns

VPLS Architecture:
Architecture – Ethernet Edge H-VPLS



VPLS Architecture: Characteristics – H-VPLS

Benefits:

- Best for larger scale deployment
- Reduction in packet replication and signaling overhead on PEs
- Full mesh for core tier (Hub) only
- Attachment VCs “virtual switch ports” effected through Layer 2 tunneling mechanisms (MPLS PW, L2TPv3, QinQ)
- Expansion affects new nodes only (no re-configuring existing PEs)

Drawbacks:

- More complicated provisioning
- MPLS Edge H-VPLS requires MPLS to u-PE
  - Complex operational support
  - Complex network design
  - Expensive Hardware support

DEMO

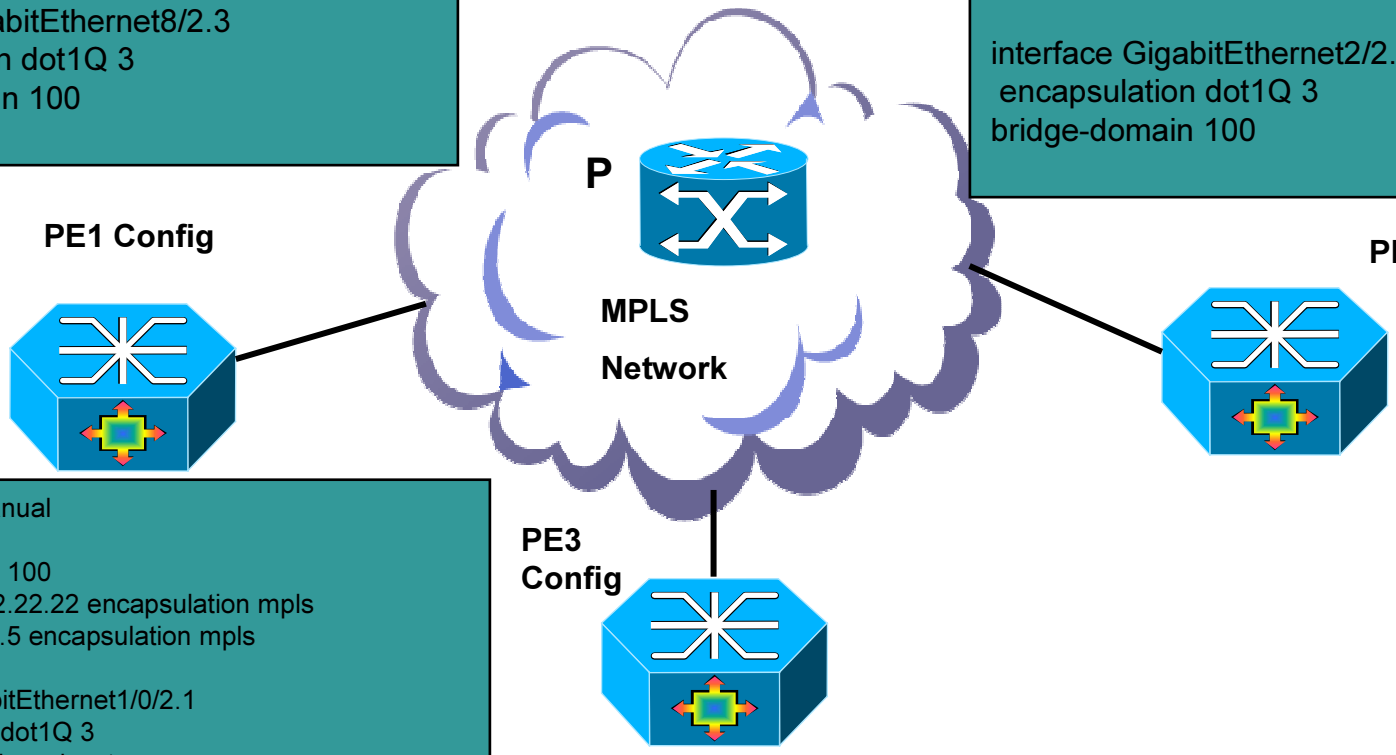
VPLS with Dot1q ACs

```
l2 vfi sanog manual
 vpn id 100
 bridge-domain 100
 neighbor 21.21.21.21 encapsulation mpls
 neighbor 22.22.22.22 encapsulation mpls

interface GigabitEthernet8/2.3
 encapsulation dot1Q 3
 bridge-domain 100
```

PE1 Config

```
l2 vfi sanog manual
 vpn id 100
 bridge-domain 100
 neighbor 21.21.21.21 encapsulation mpls
 neighbor 5.5.5.5 encapsulation mpls

interface GigabitEthernet2/2.2
 encapsulation dot1Q 3
bridge-domain 100
```

PE2 Config

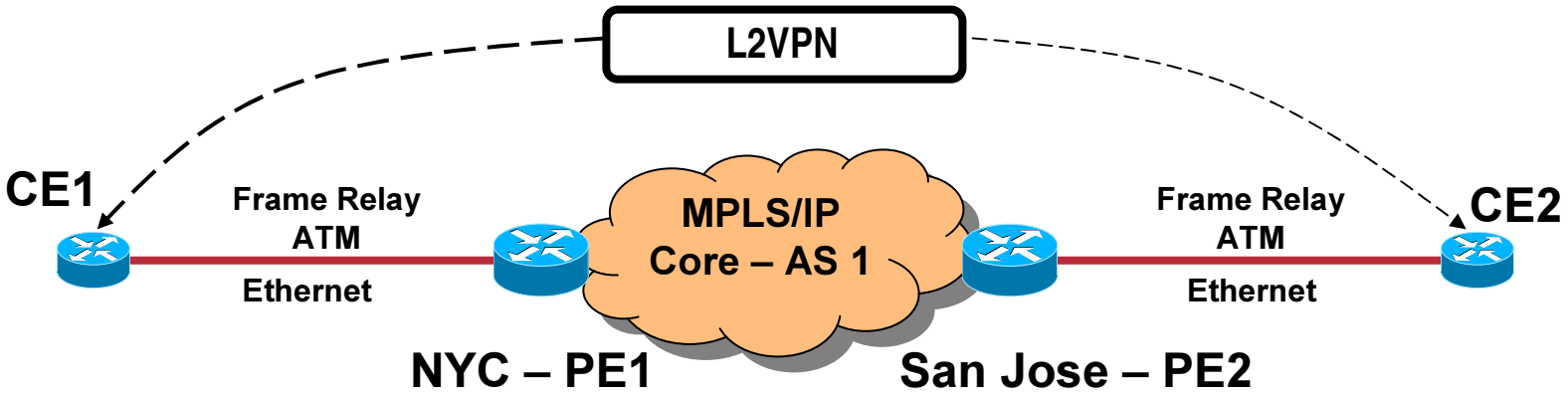



```
l2 vfi sanog manual
 vpn id 100
 bridge-domain 100
 neighbor 22.22.22.22 encapsulation mpls
 neighbor 5.5.5.5 encapsulation mpls

interface GigabitEthernet1/0/2.1
 encapsulation dot1Q 3
 no ip directed-broadcast
 bridge-domain 100
```

PE3 Config

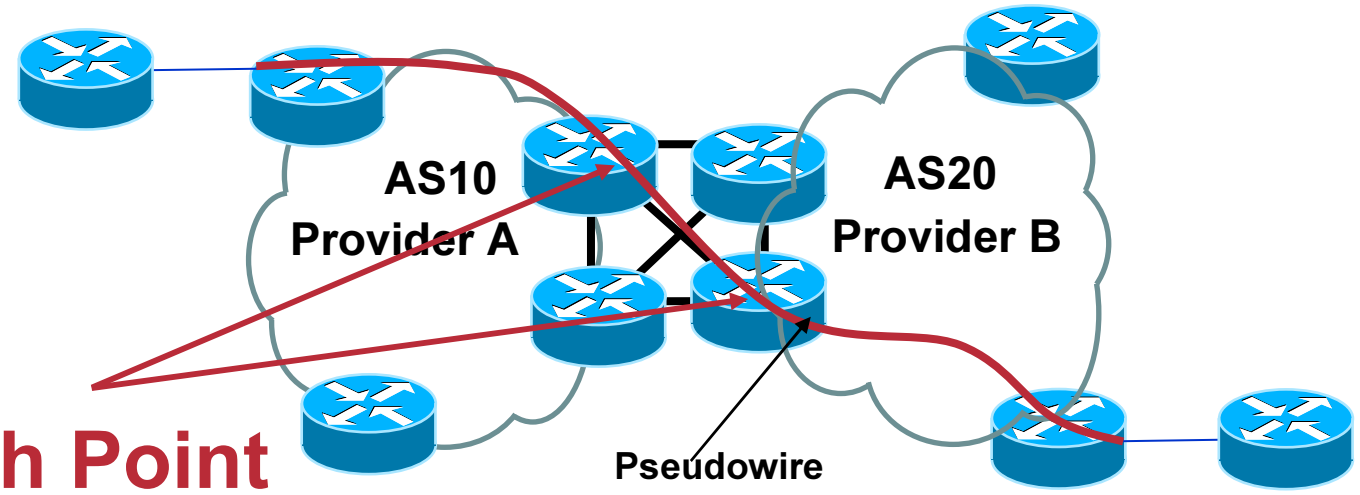
Pseudo Wire Stitching

Pseudo Wire Extensibility Limitation



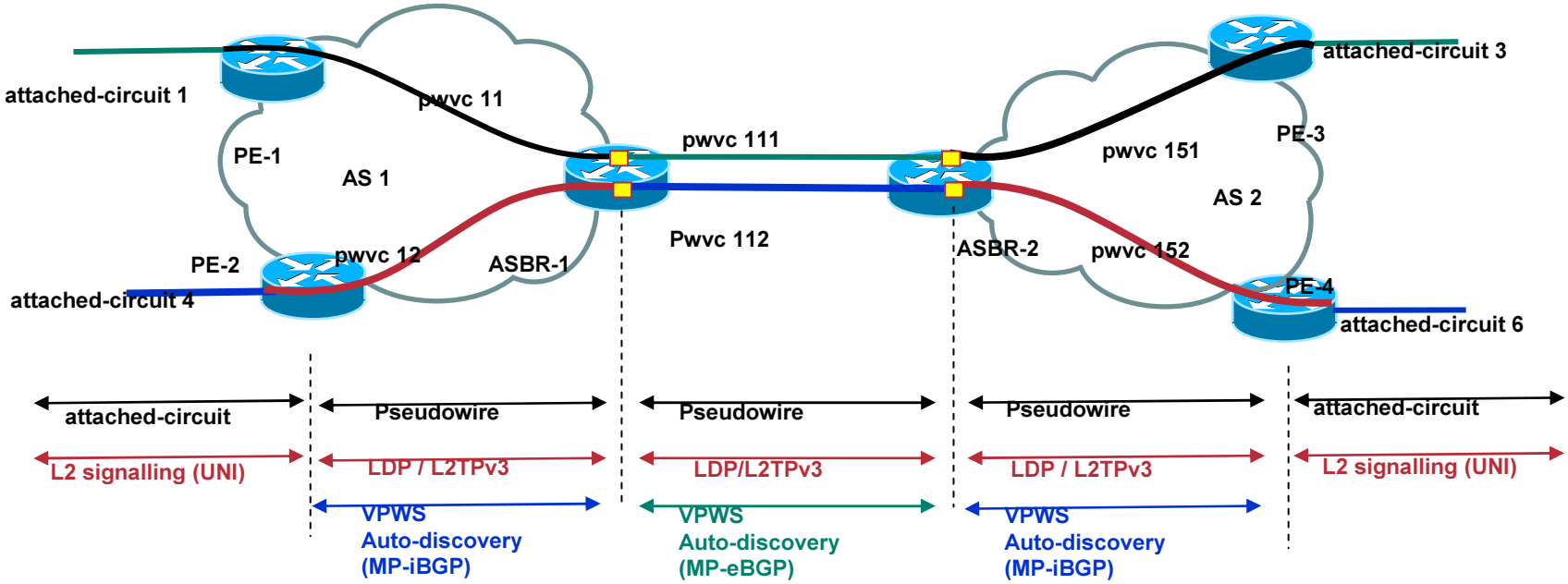
- What is the Problem?
  - L2VPNs are created by inter-connecting 2 attachment circuits using a Pseudo Wire (AToM and L2TPv3) to provide an end to end L2 connection but in 1 BGP AS
  - End to end L2VPN deployment not possible across multiple ASes
  - Changes in the control and data plane code are required for inter-working them across multiple ASes

Tunnel Stitching at ASBR – Stitch Point



- Tunnel stitching solves this problem by inter-connecting pseudo wires belonging to different autonomous systems and thus providing an end-2-end path
- Tunnel stitch point refers to the ASBR where tunnel stitching is performed
- Achieved through inter-working of data and control planes at the stitch point

Pseudo Wire Stitching Reference Model

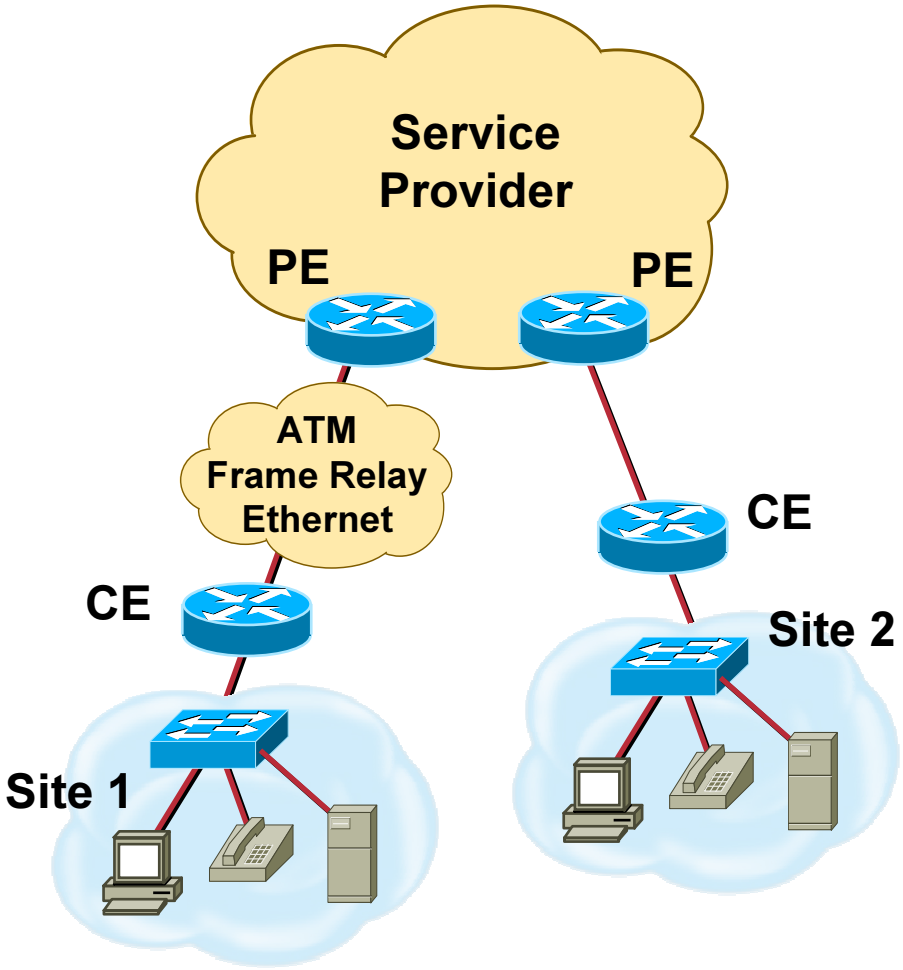


- Each pseudo wire segment can independently employ draft-martini or L2TPv3 signaling and encapsulations
- The ASBRs are responsible for "cross-connecting" the pseudowire control channels and pseudowire data planes
- Easy provisioning and Scalable
- In the end-2-end L2VPN path, you can have 1 or multiple stitch point

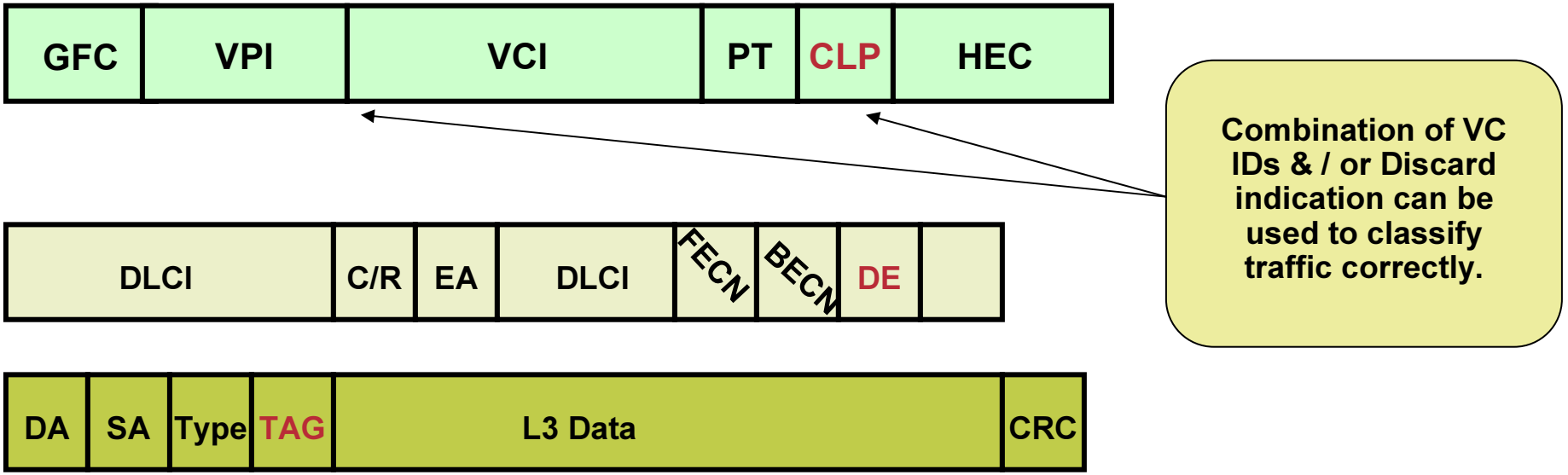
Quality of Service

L2VPN Deployment –
The Layer-2 Service Level Agreement (SLA)

- Point to point guarantees are the basis for the SLA
  - Delay
  - Delay Variation
  - Loss
- In a port trunking environment the FR / ATM / Ethernet access network may enforce SLA
  - Marking, Policing
  - Queuing, Shaping, etc.
- Pay-as-you-grow services can be implemented for many service encaps
- Service Provider Equipment is transparent to the Customer

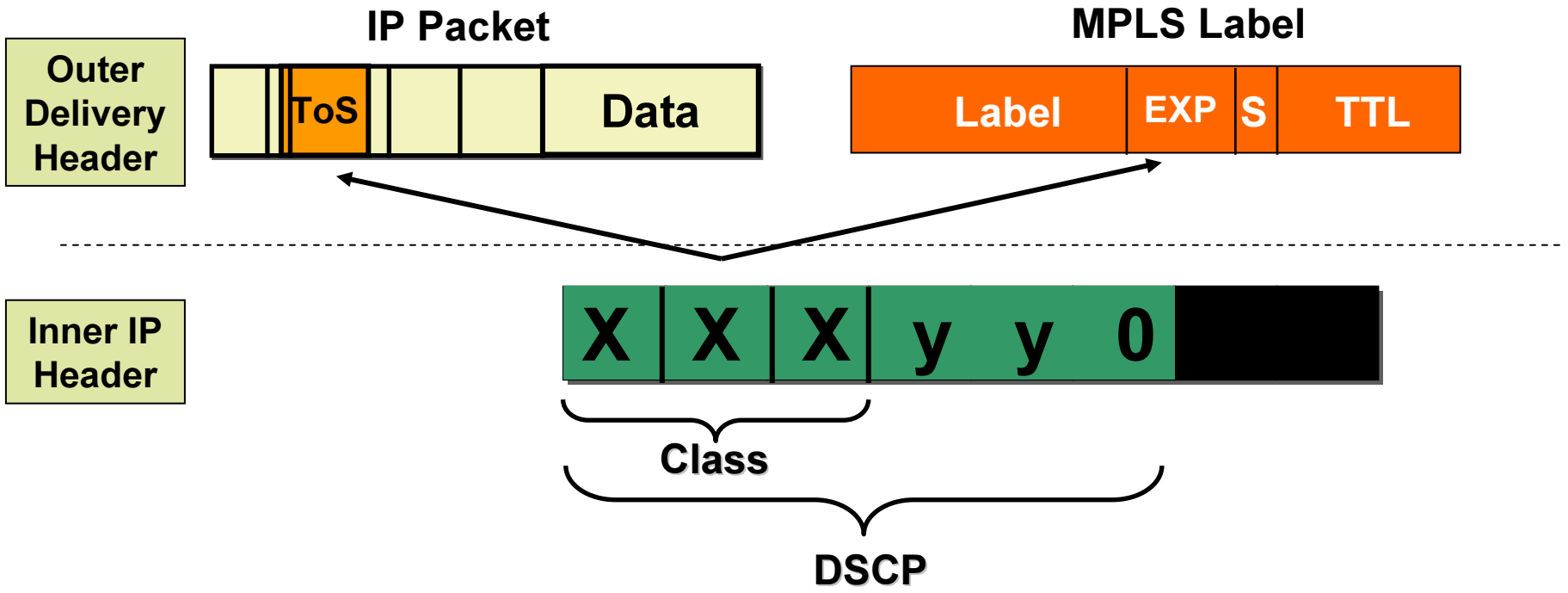


L2VPN Deployment –
How does an SP prioritize traffic?



- Provide Service on Port, Layer 2 or Layer 3 Info
- Enforcing sub-rate leased line access
- L2 PDUs provide options for setting frame priority (ex: CLP, DE, 802.1p)
- L2 PVC or Inner L3 Precedence (e.g. ATM VP 10 = CBR VCs)

L2VPN Deployment –
Precedence Equivalence: MPLS / IP



- IP Precedence is the most often used in determining different traffic priorities (0 – 7) (Customer set, SP optionally enforces)
- Most SPs implement 3 – 5 traffic classes (Best Effort → Mission Critical)
- Enforce policies through shaping, marking, policing

L2VPN QoS Deployment

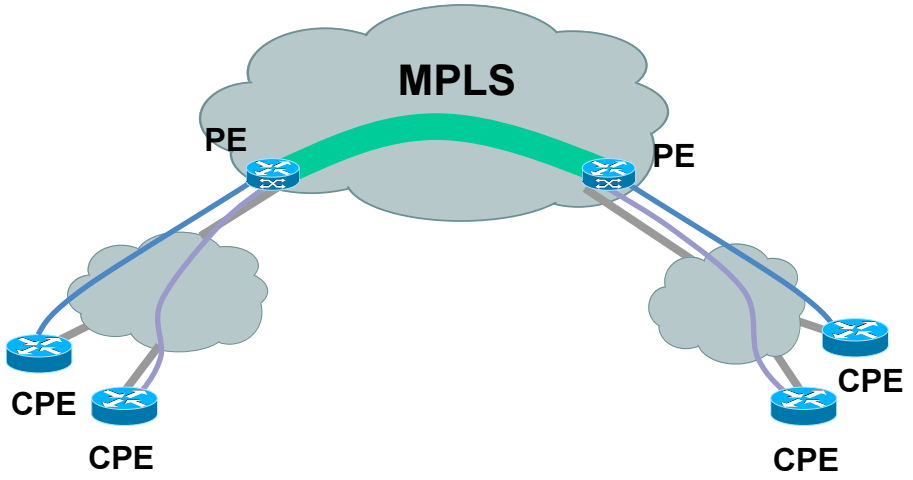
L2 QoS Functions:

- **Shaping –** When transmit rates are higher than expected buffering or queuing is used delay excess traffic, opposite of policing
- **Marking –** The ability to differentiated packets by setting properties within the Layer 2 or Layer 3 header like the IP precedence, or L2 Class of Service or drop priority.
- **Policing –** Used to drop or remark with a lower priority IP Precedence or MPLS EXP bits in traffic that is in excess of contract.
- **Queuing –** Congestion management by giving correct priority to traffic classes one can manage time-sensitive applications without penalizing lower priority traffic. (CBWFQ)

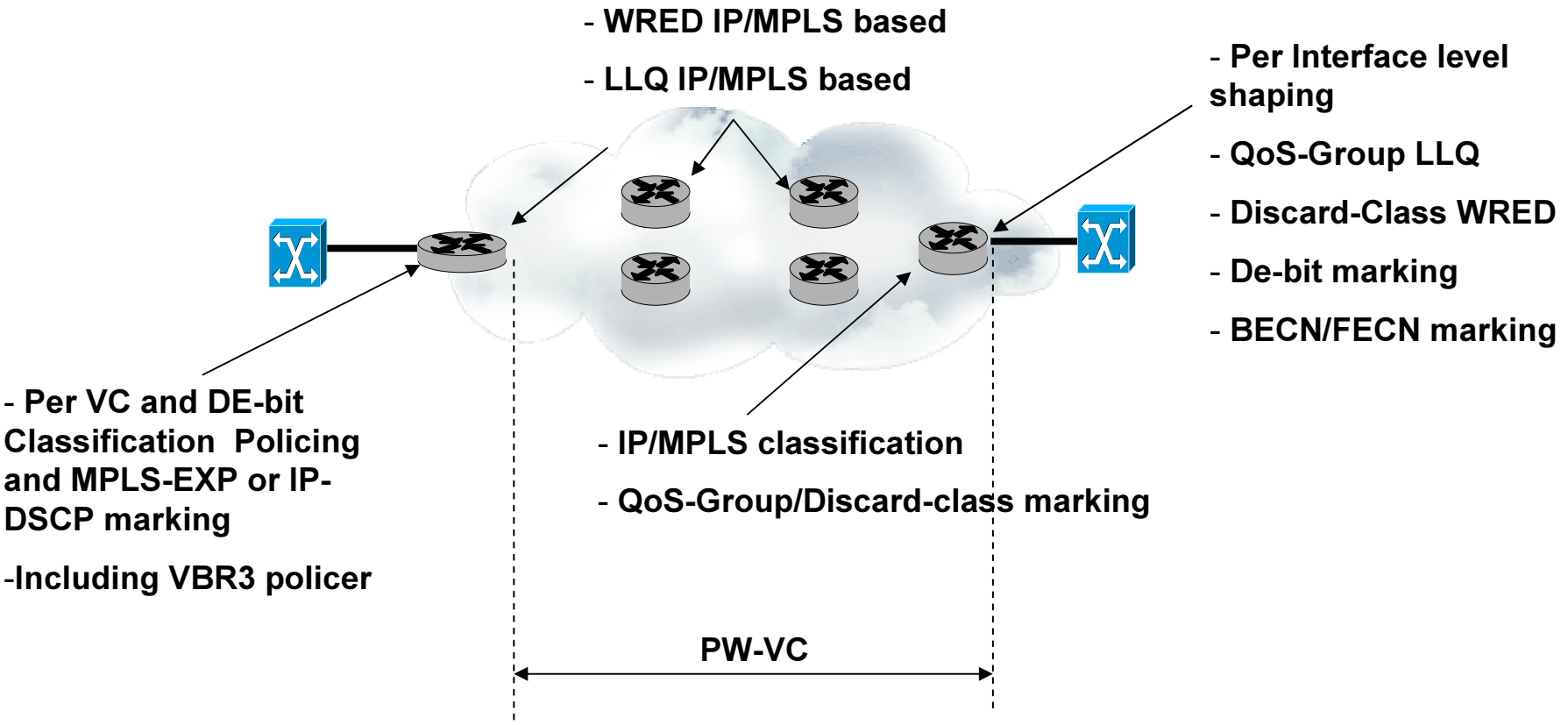
L2 Tunnel Selection

- Tunnel defined as preferred path in pseudo-wire class
- Pseudo-wire class applied to attachment circuit xconnect
- Fallback can be disabled if TE tunnel unreachable

L2 Service Transported over a TE Tunnel (Point-to-Point Tight SLA)

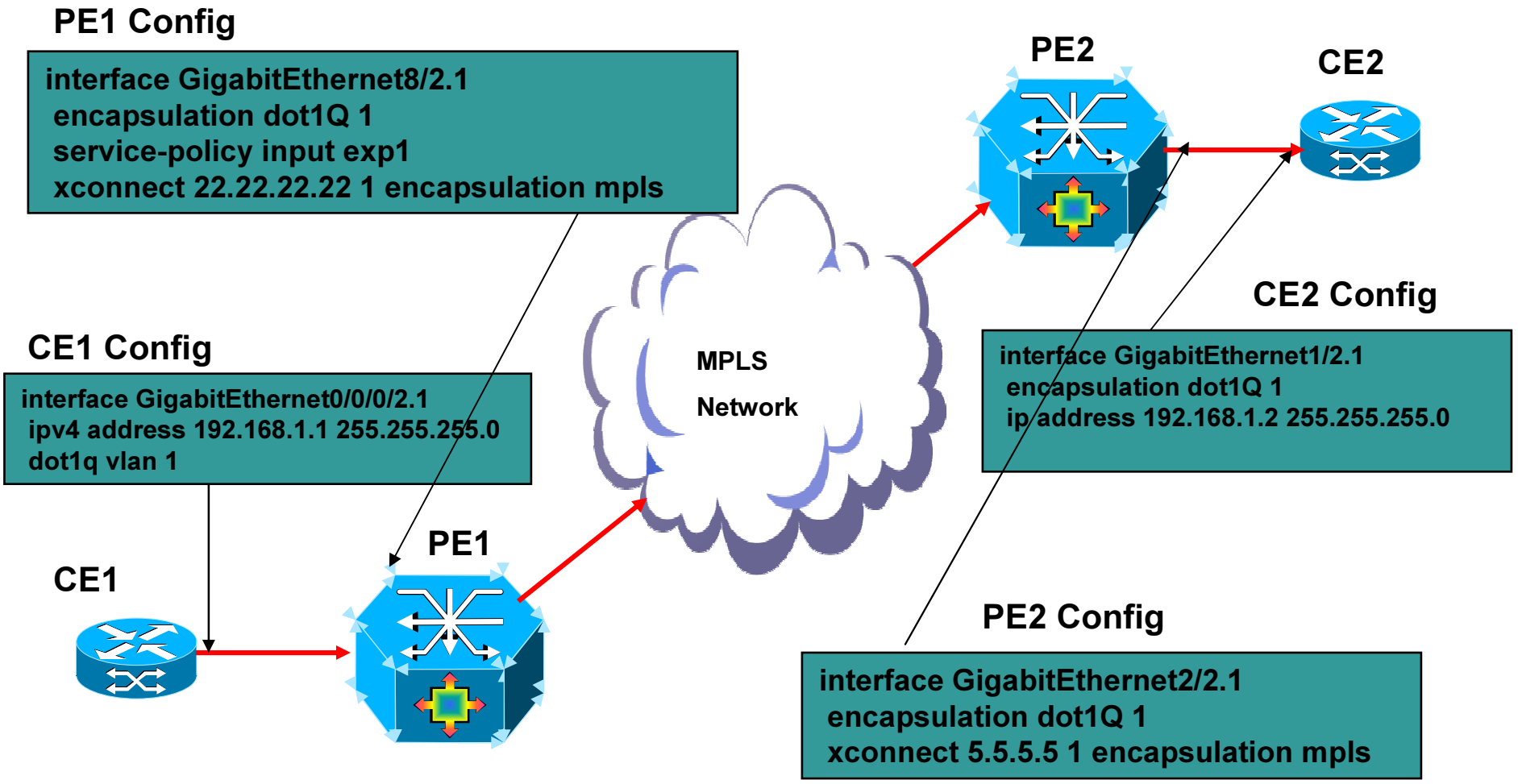


The Complete Picture



DEMO

QoS on Point to Point VLAN over MPLS

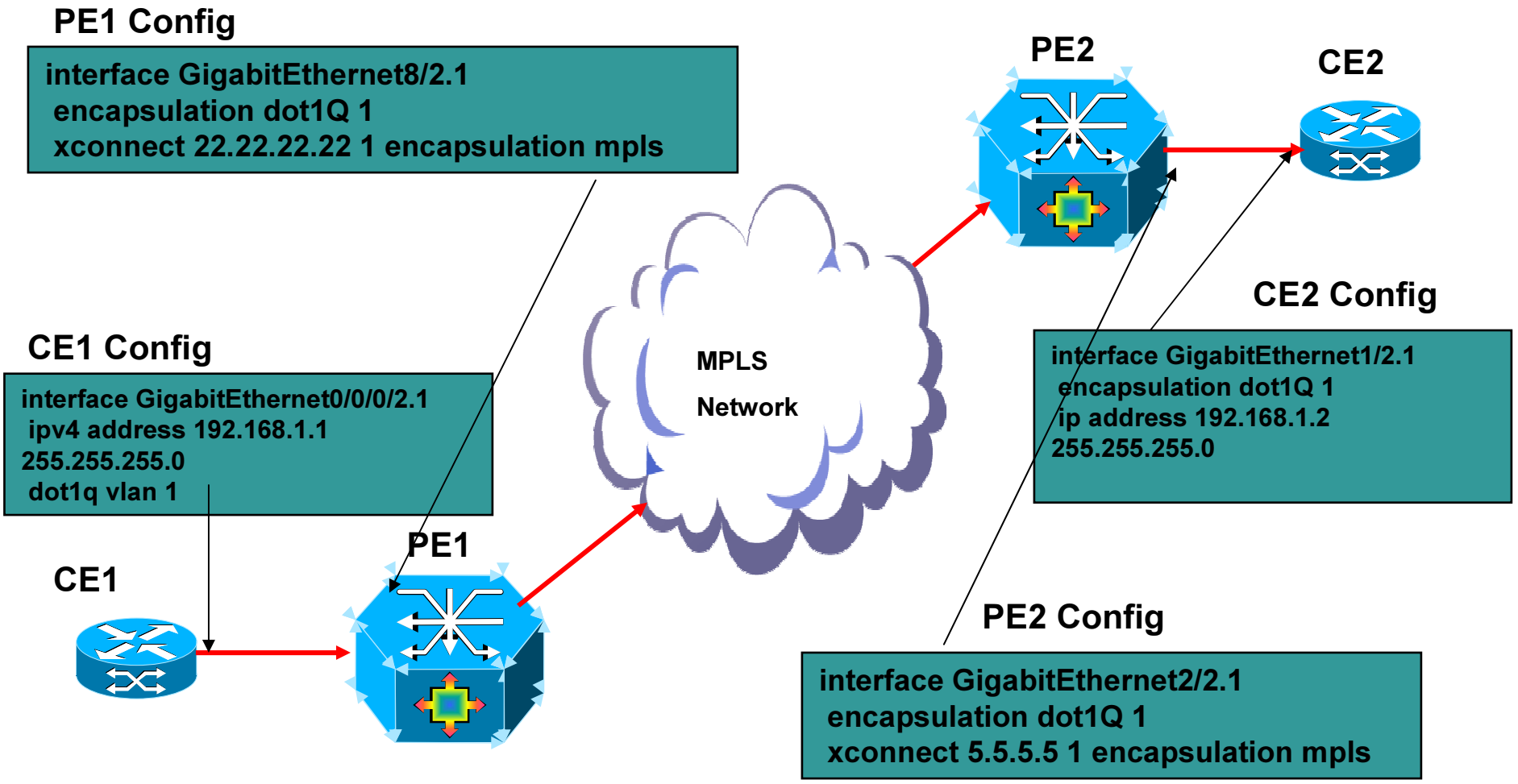


Questions & Answers

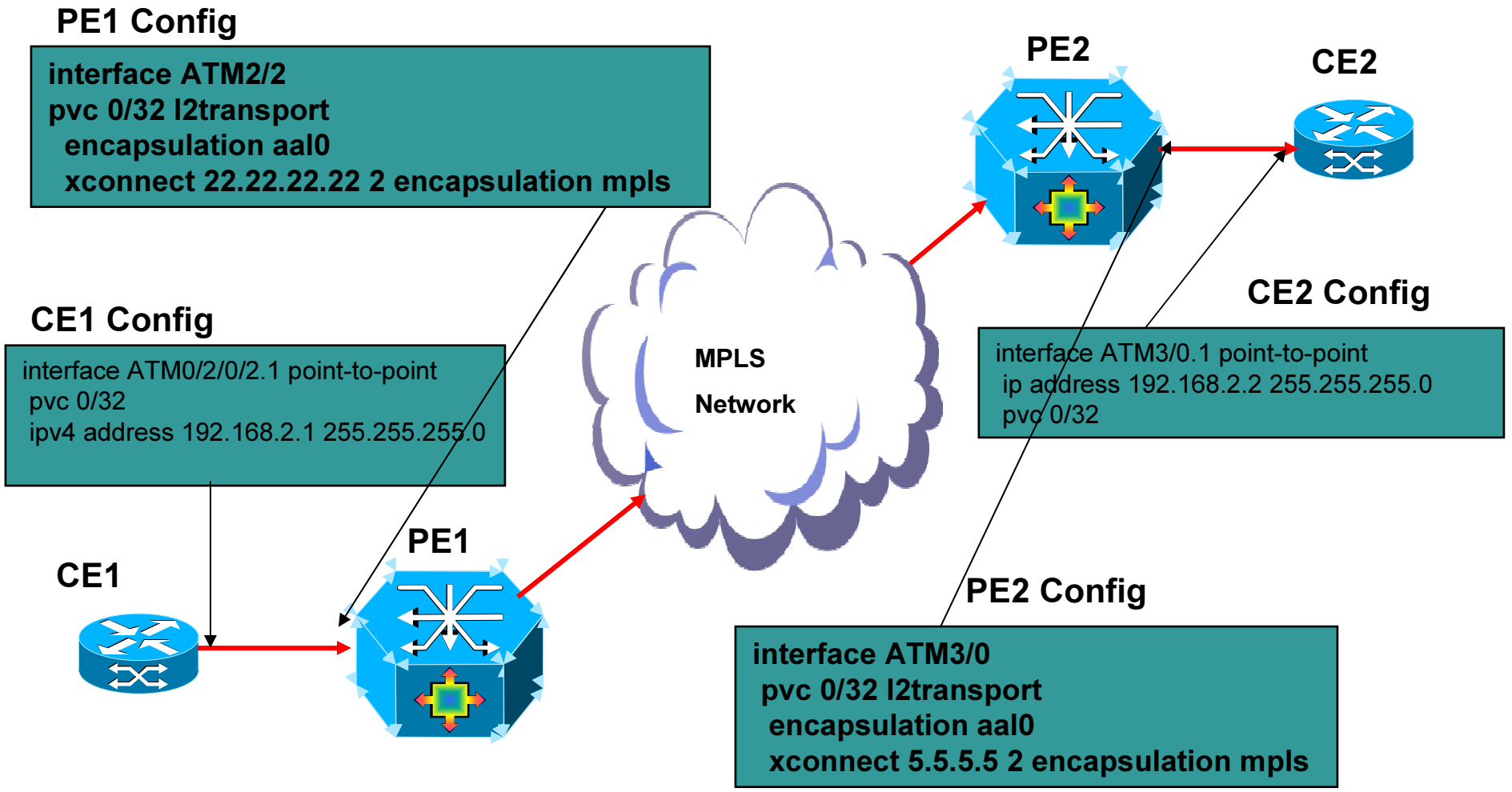
Backup

DEMO

Point to Point
VLAN over MPLS



Point to Point
Cell Relay over MPLS



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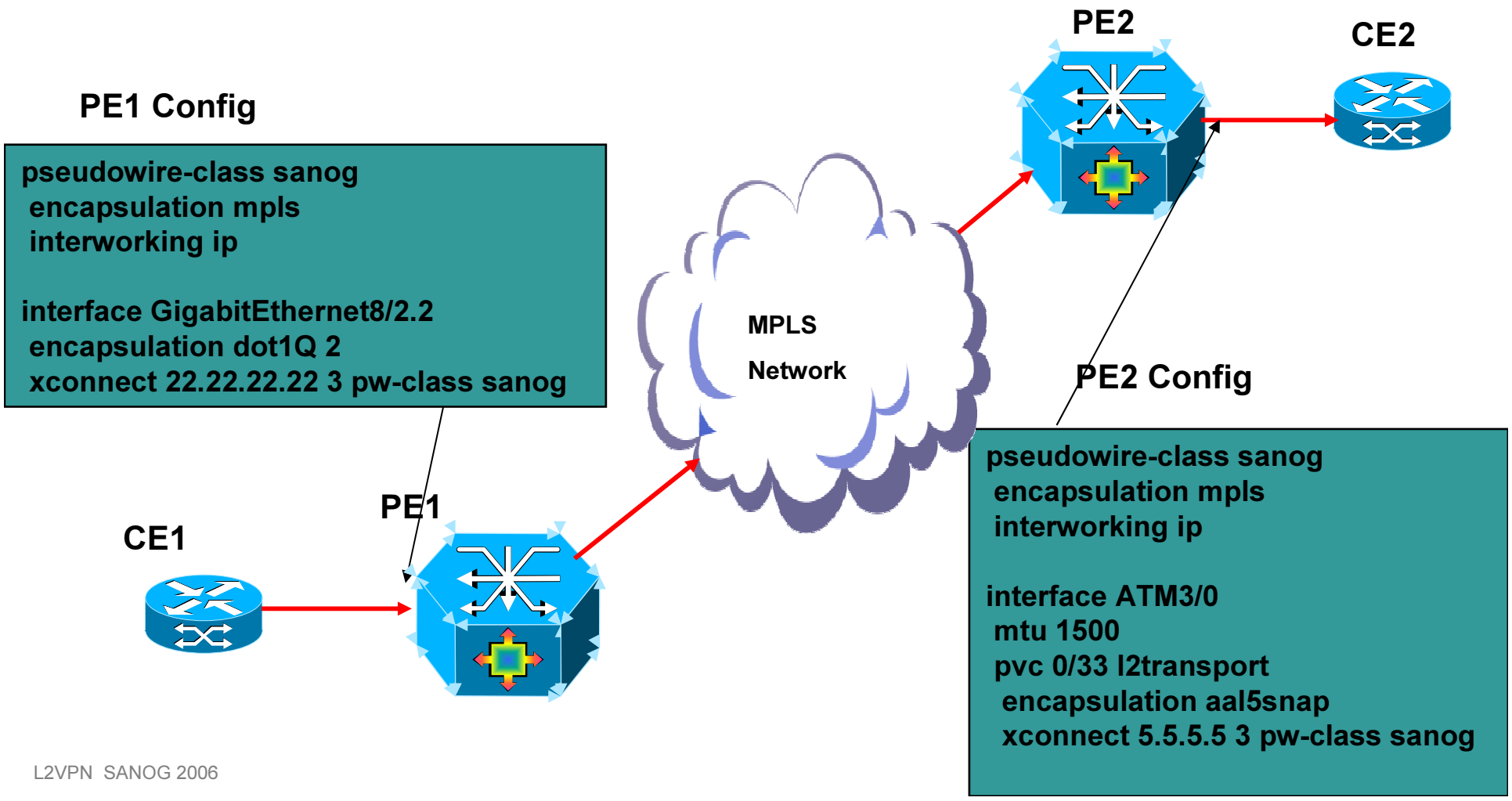

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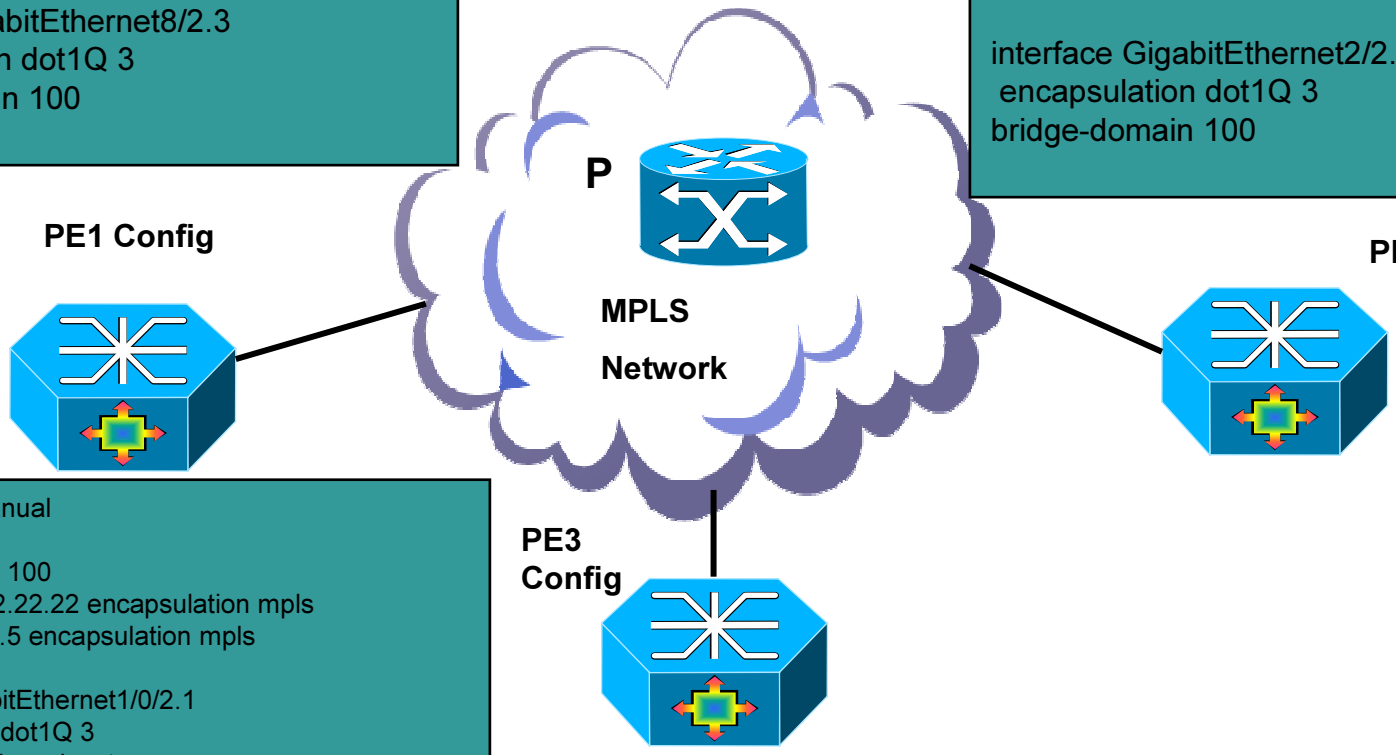

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QoS on Point to Point VLAN over MPLS