Multiprotocol Label Switching (MPLS) – TE usage

Engenharia de Computadores e Telemática
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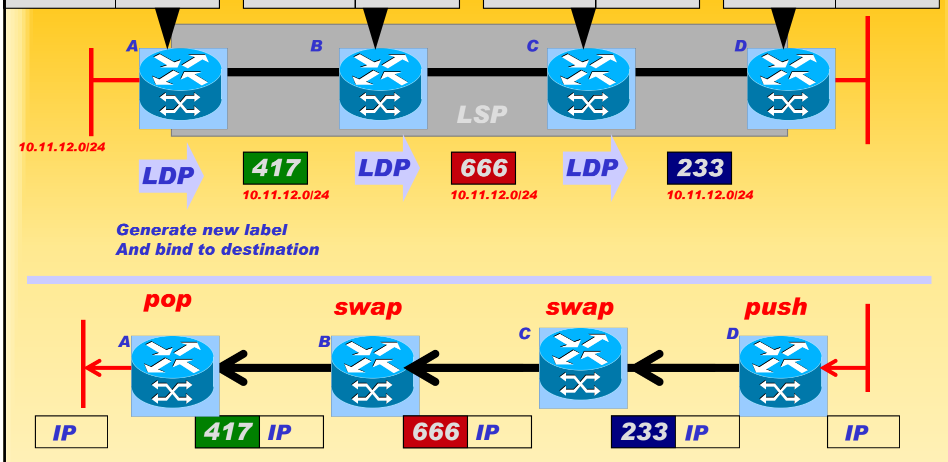
LDP and Hop-by-Hop routing

network	next-hop
10.11.12.0/24	direct

network	next-hop
10.11.12.0/24	A

network	next-hop
10.11.12.0/24	B

network	next-hop
10.11.12.0/24	C



Constrained based Routing

- A cost is associated to each link
- Each link has a further set of attributes that represent performance metrics

The routing objective is to determine the lowest cost path that does not violate the restrictions that were assigned

- Restrictions can be associated to a set of performance characteristics, like for example, bandwidth, delay, priority, etc.
  - For the bandwidth case, the restriction that is imposed to the routing algorithm is that the path must have, on each connection it traverses, a bandwidth higher than a certain threshold.
  - In this case, the connection attribute used is the available bandwidth.

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Constraint Based Routing?

Basic components

Problem here:
OSPF areas hide information for scalability. So these extensions work best only within an area…

1.Specify path constraints
2.Extend topology database to include resource and constraint information — ***Extend Link State Protocols (IS-IS, OSPF)***
3.Find paths that do not violate constraints and optimize some metric
4.Signal to reserve resources along path
5.Set up LSP along path (with explicit route) — ***Extend RSVP or LDP or both!***
6.Map ingress traffic to the appropriate LSPs

Note: (3) could be offline (e.g. network operational center – NOC - systems) or online (perhaps an extension to OSPF)

Problem here:
what is the "correct" resource model for IP services?

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Resource Reservation + Label Distribution

Two emerging/competing/dueling approaches:

Add label distribution and explicit routes to a resource reservation protocol

RSVP-TE

RSVP

CR-LDP

LDP

Add explicit routes and resource reservation to a label distribution protocol

Constraint-Based LSP Setup using LDP
draft-ietf-mpls-cr-lpd-05.txt

RSVP-TE: Extensions to RSVP for LSP Tunnels
draft-ietf-mpls-rsvp-lsp-tunnel-08.txt

As of February 2003, the IETF MPLS working group deprecated CR-LDP and decided to focus purely on RSVP-TE.

RFC 3468: The Multiprotocol Label Switching (MPLS) Working Group decision on MPLS signalling protocols

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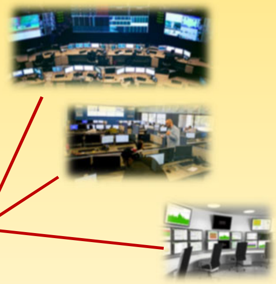
LSPs establishing protocols

- RSVP-TE (*Resource Reservation Protocol – Traffic Engineering*)
  - Extension of the RSVP protocol
- CR-LDP (*Constrained based Routing – Label Distribution Protocol*)
  - Extension of the LDP protocol, deprecated
- Both protocols enable:
  - The specification of a route to a LSP
  - To chose the labels on each link of the route
  - To make resources reservation for the LSP
- Routes are previously determined:
  - By management (Traffic engineering), in a NOC
  - By a *Constrained based Routing* type protocol



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RSVP-TE vs. CR-LPD

RSVP-TE

- ***Soft state periodically refreshed***
- ***IntServ QoS model***

CR-LDP

- ***State maintained incrementally***
- ***New QoS model derived from ATM models***

And the QoS model determines the additional information attached to links and nodes and distributed with extended link state protocols…

And what about that other Internet QoS model, diffserv?

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Resource Reservation Protocol with Traffic Engineering (RSVP-TE)

- Evolution of RSVP
  - RFC 3209: RSVP-TE: Extensions to RSVP for LSP Tunnels. (12/2001)
  - RFC 5151: Resource Reservation Protocol-Traffic Engineering (RSVP-TE) Extensions. (2/2008)
- To map traffic flows onto the physical network topology through label switched paths, resource and constraint network information are required
  - Provided by Extend Link State Protocols (IS-IS or OSPF with TE extensions).
    - RFC 3630: Traffic Engineering (TE) Extensions to OSPF Version 2. (9/2003)
    - RFC 5305: IS-IS Extensions for Traffic Engineering. (10/2008)

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RECALL:
ReSerVation Protocol (RSVP)

- ReSerVation Protocol (RSVP) was developed to communicate resource needs between hosts and network devices
  - Associated to the Intserv QoS model
- RSVP allows:
  - The source to describe the characteristics of the IP packets flow.
  - Destinations to describe the reservation they want.
  - Routers to know how to process the packets flow in order to fulfil the requested reservation.
- Encapsulated on IP (protocol type = 46 (0x2E))
- Signalling is based on PATH and RESV messages.
  - PATH announces the traffic characteristics at the sender.
  - RESV achieves reservations that were initiated by the receivers.
  - If the reservation is not possible, a RESV ERR message is sent.
- The routers reservation states have to be periodically refreshed (soft states).

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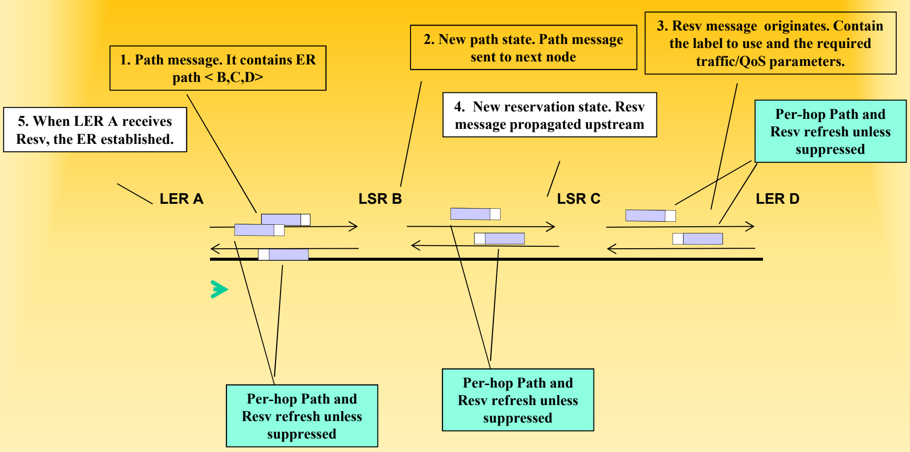
Establishment of a LSP with the RSVP-TE protocol



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REFERENCE:
Extensions to RSVP for LSP Tunnels

- The SENDER_TEMPLATE (or FILTER_SPEC) object together with the SESSION object uniquely identifies an LSP tunnel (flow).
- LSP Tunnel related new objects
  - Explicit Route
    - Carried in PATH and contains a series of variable-length data items called sub-objects.
    - Possible sub-objects: IPv4 prefix, IPv6 prefix, and autonomous system number.
  - Label Request
    - Carried in PATH requesting a label for a specific tunnel/flow.
    - Request cab be without label range, with an ATM label range, or with an Frame Relay label range.
  - Label
    - Carried in RESV messages and contain a single label for a specific tunnel/flow.
  - Record Route
    - Carried in PATH and RESV, used to collect detailed path information and useful for loop detection and diagnostics.
  - Session Attribute
    - Carried in PATH, used to define the type and name of the session/tunnel/flow, also used to define priority values.
- LSP Tunnel related new object types
  - Session object new types
    - LSP_TUNNEL_IPv4 and LSP_TUNNEL_IPv6
  - Sender Template object new types
    - LSP_TUNNEL_IPv4 and LSP_TUNNEL_IPv6
  - Filter Specification object new types
    - LSP_TUNNEL_IPv4 and LSP_TUNNEL_IPv6

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REFERENCE:
Traffic Engineering Extensions to OSPF

- RFC 3630: Traffic Engineering (TE) Extensions to OSPF Version 2. (9/2003)
- OSPF Traffic Engineering (TE) extensions are used to advertise TE Link State Advertisements (TE-LSAs) containing information about TE-enabled links.
  - Traffic Engineering LSA is a type 10 Opaque LSAs, which have an area flooding scope.
- TE-LSA contains one of two possible top-level Type Length Values (TLVs)
  - **Router Address**: specifies a stable IP address of the advertising router that is always reachable if there is any connectivity to it; this is typically implemented as a "loopback address";
  - **Link**: describes a single link with a a set of sub-TLVs (Link type, Link ID, Local interface IP address, Remote interface IP address, Traffic engineering metric, Maximum bandwidth, Maximum reservable bandwidth, Unreserved bandwidth, and Administrative group.
- The information made available by these extensions can be used to build an extended link state database
  - Can be used to:
    - Monitoring the extended link attributes;
    - Local constraint-based source routing;
    - Global traffic engineering.

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LSPs priorities

When:

- A new LSP requires resources that are not available on the network, or
- On failure situations (on a link, for example)

The operator can establish different priorities to avoid the "most important" traffic from becoming blocked by the "less important" traffic.

- Each LSP has two priorities assigned: "*setup Priority*" and "*holding Priority*"
- There are 8 different priority levels
- A established LSP can "steal" network resources from the already established LSPs that have a lower "*holding Priority*" than its "*setup Priority*"

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REVIEW: MPLS - Major Drivers

- Provide IP VPN Services *"the leased line"*
  - Scalable IP VPN service – Build once and sell many
  - Managed Central Services – Building value added services and offering them across VPNs
- Managing traffic on the network using MPLS Traffic Engineering
  - Providing tighter SLA/QoS (Guaranteed BW Services)
  - Protecting bandwidth - Bandwidth Protection Services
- Integrating Layer 2 & Layer 3 Infrastructure
  - Layer 2 services such as ATM (or Frame Relay) over MPLS
  - Mimic layer 2 services over a highly scalable layer 3 infrastructure

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MPLS QoS

DiffServ over MPLS

- MPLS doesn’t define a new QoS architecture
  - Actually one of the issues between CR-LDP vs RSVP-TE
- Most of the work on MPLS QoS has focused on supporting current IP QoS architectures
- Same traffic conditioning and Per-Hop behaviors as defined by DiffServ

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Label Header for Packet Media

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
```

Label	EXP	S	TTL

Label	20 bits
EXP	Experimental Field, 3 bits (Class of service information)
S	Bottom of Stack, 1 Bit
TTL	Time to Live, 8 Bits

Shim Header (may or may not exist)

- Can be used over other layer-2 technologies, avoiding its formal existence
- Contains all information needed at forwarding time
- One 32-bit word per label
- EXP field size limitation by standards

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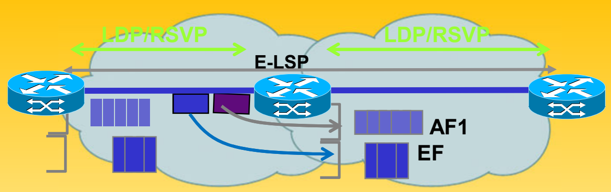
Diff-Serv Support Over MPLS



- DiffServ is supported today over MPLS
  - RFC3270
- "plain old" Diff-Serv just over MPLS
- Example above illustrates support of EF and AF1 on single E-LSP
- EF (Expedited Forwarding) and AF1 (Assured Forwarding) packets travel on single LSP (single label)

…. but are queued into different queues (different EXP values)

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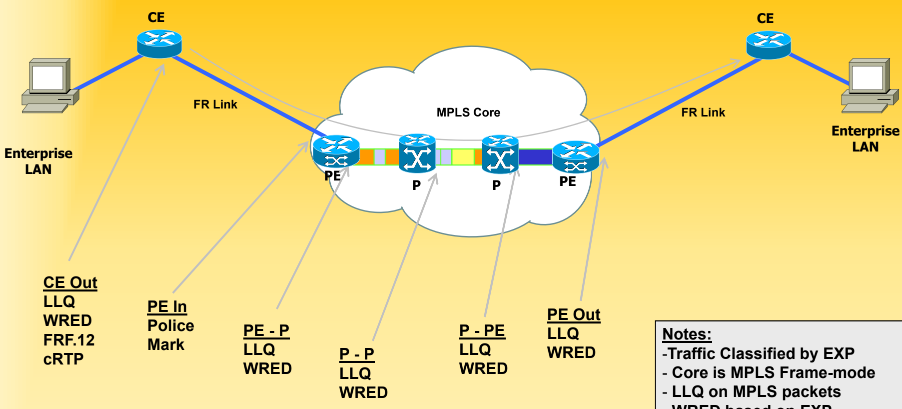
EXAMPLE:
DiffServ MPLS QoS Implementation(s)



LLQ – Low Latency Queing

Notes:
- Traffic Classified by EXP
- Core is MPLS Frame-mode
- LLQ on MPLS packets
- WRED based on EXP
- No need for inbound policy in Core
- LLQ for Min B/W guarantee

Unmanaged Customer Equipment (CE) example shown

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Relationship between MPLS TE and MPLS Diff-Serv

• Diff-Serv specified independently of Routing/Path Computation
• MPLS Diff-Serv (RFC3270) also specified independently of Routing/Path Computation

• MPLS TE designed as tool to improve backbone efficiency independently of QoS:
– MPLS TE compute routes for aggregates across all Classes
– MPLS TE performs admission control over "global" bandwidth pool for all Classes (i.e., unaware of bandwidth allocated to each queue)
• MPLS TE and MPLS Diff-Serv:
– can run simultaneously
– can provide their own benefit (i.e. TE distributes aggregate load, Diff-Serv provides differentiation)
– are unaware of each other (TE cannot provide its benefit on a per class basis such as CAC and constraint based routing)

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DiffServ aware Traffic Engineering (DS-TE)

- DS-TE is more than MPLS TE + MPLS DiffServ
- DS-TE makes MPLS TE aware of DiffServ:
  - DS-TE establishes separate tunnels for different classes
  - DS-TE takes into account the "bandwidth" available to each class (e.g. to queue)
  - DS-TE takes into account separate engineering constraints for each class
    - e.g. I want to limit Voice traffic to 70% of link max, but I don't mind having up to 100% of BE traffic.
    - e.g I want overbook ratio of 1 for voice but 3 for BE
- DS-TE ensures specific QoS level of each DiffServ class is achieved

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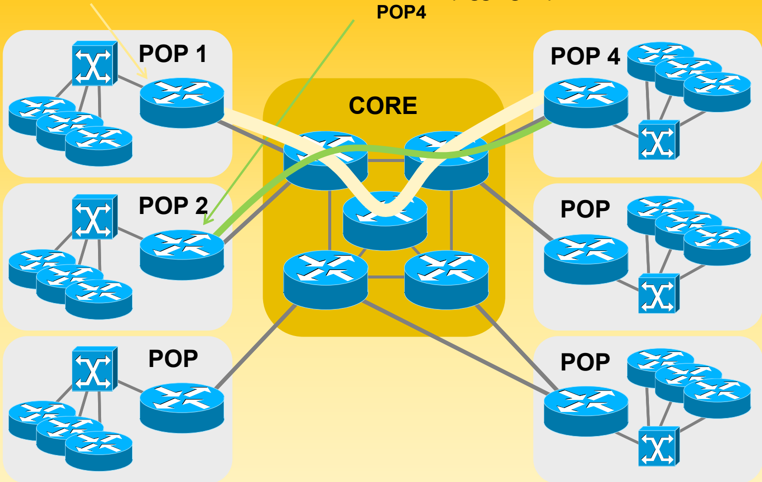
MPLS TE with Best Effort Network

Find Route and Set-Up Tunnel for 20 Mb/s (Aggregate) From POP1 to POP4

Find Route and Set-Up Tunnel for 10 Mb/s (Aggregate) From POP2 to POP4



No priority in network, selection of path by LSP

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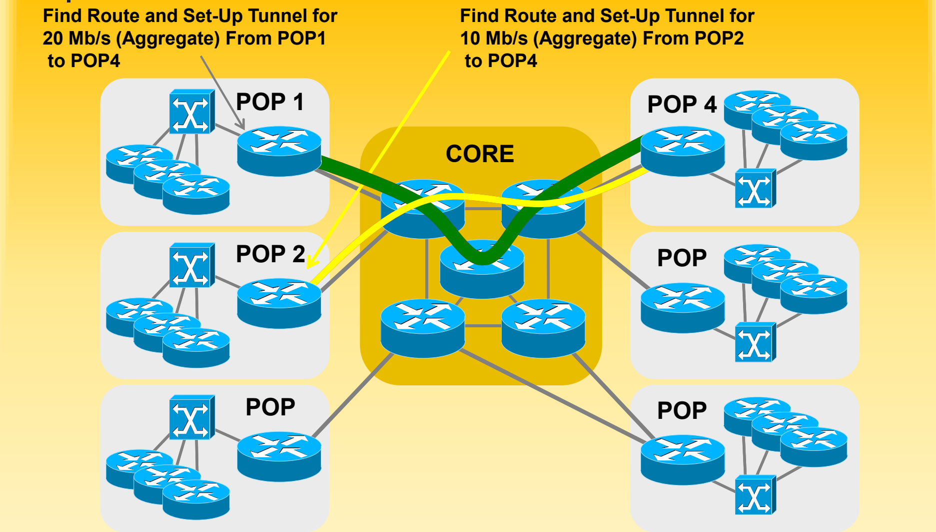
MPLS TE with DiffServ Network



Priority in network, selection of path by LSP, priority in the routers inside each tunnel

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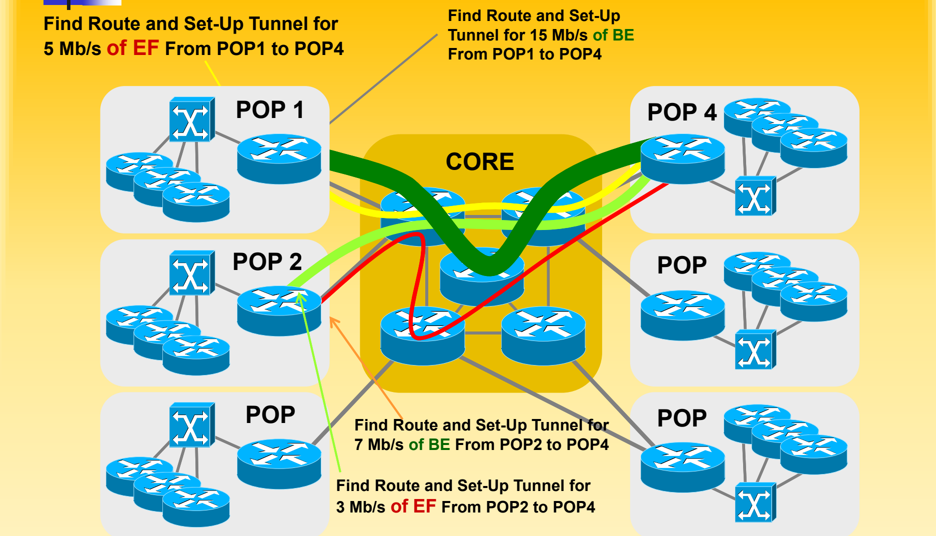
MPLS DS-TE with DiffServ Network



Priority in network, selection of path by LSP **and** priority, priorities in the core may lead to repositioning of the tunnels.

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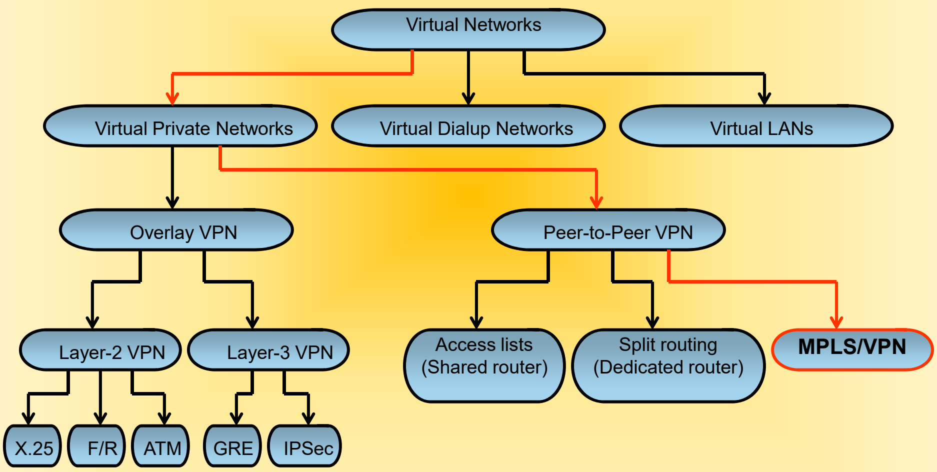
MPLS Layer 3 VPNs

Virtual Network Models



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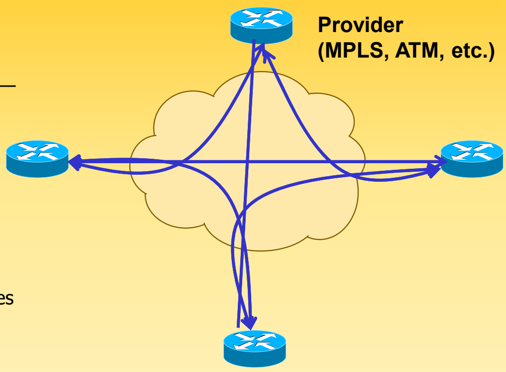
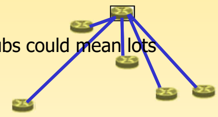
Overlay Network

- Provider sells a circuit service
  - customer wants to deploy its own network over those services
- Customers purchases circuits to connect sites, runs IP
  - N sites, (N*(N-1))/2 circuits for full mesh—expensive
- scalability issue because of routing peers in mesh approach
  - N sites, each site has N-1 peers
- Hub and spoke with static routes is simpler,
  - still buying N-1 circuits from hub to spokes
  - suffers from the same N-1 number of routing peers
  - Spokes distant from hubs could mean lots of long-haul circuits





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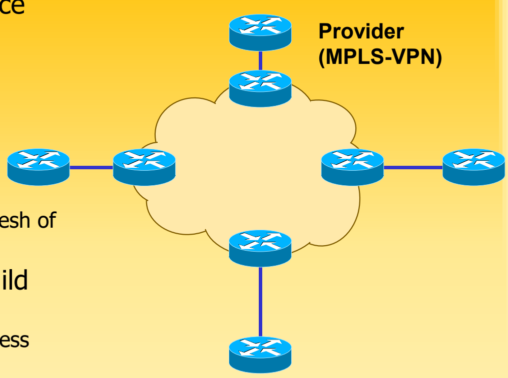
Peer Network

- Provider sells an MPLS-VPN service
- Customers purchases circuits to connect sites, runs IP
  - N sites, N circuits into provider
  - Access circuits can be any media at any point (FE, POS, ATM, T1, dial, etc.)
  - Full mesh connectivity without full mesh of L2 circuits
- Hub and spoke is also easy to build
  - Spokes distant from hubs connect to their local provider's POP, lower access charge because of provider's size



The Internet is a large peer network!

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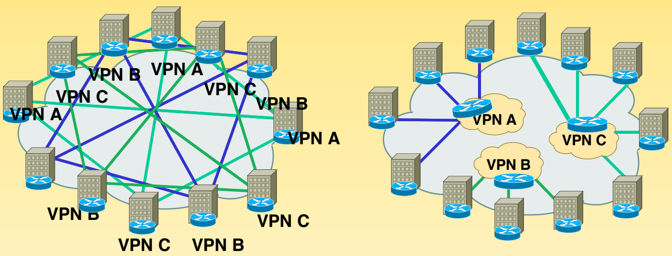
IP/MPLS Applications

MPLS-based VPNs

- MPLS L3VPN – VPN-IP over MPLS
  - VPN is a secure IP-based network between geographically dispersed sites that can communicate securely over a shared backbone;
  - MPLS VPNs provides the capability to deploy and administer scalable Layer 3 VPN backbone services to business customers
- MPLS L2VPN – Any Technology (AT) or Transport over MPLS (e.g.: EoMPLS)
  - AT over MPLS transport Layer2 packets over MPLS network;
  - Allow the use of MPLS network to provide connectivity between customer sites with existing Layer2 networks;
- MPLS-TE
  - Extends existing IP protocols and makes use of MPLS forwarding capabilities to provide TE
  - Brings explicit routing capabilities to MPLS networks

MPLS L3 VPNs using BGP (RFC2547)

- End user perspective
  - Virtual Private IP service
  - **Simple routing – just point default to provider**
  - Full site-site connectivity without the usual drawbacks (routing complexity, scaling, configuration, cost)
- Major benefit for provider – scalability



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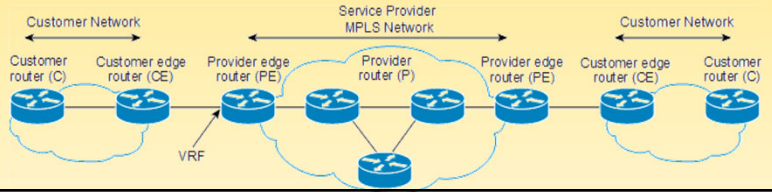
MPLS VPN Terminology

- Customer router (C) is connected only to other customer devices.
- Customer Edge (CE) router peers at Layer 3 to the Provider Edge (PE).
  - The PE-CE Interface runs either a dynamic routing protocol (eBGP, RIPv2, EIGRP, or OSPF) or has static routing (Static, Connected).
- Provider (P) router, resides in the core of the provider network.
  - Participates in the control plane for customer prefixes. The P router is also referred to as a Label Switch Router (LSR), in reference to its primary role in the core of the network, performing label switching/swapping of MPLS traffic.
- Provider Edge (PE) router, sits at the edge of the MPLS SP network.
  - In an MPLS VPN context, separate VRF routing tables are allocated for each user group.
  - Contains a global routing table for routes in the core SP infrastructure.
  - The PE is sometimes referred to as a Label Edge Router (LER) or Edge Label Switch Router (ELSR) in reference to its role at the edge of the MPLS cloud, performing label imposition and disposition.



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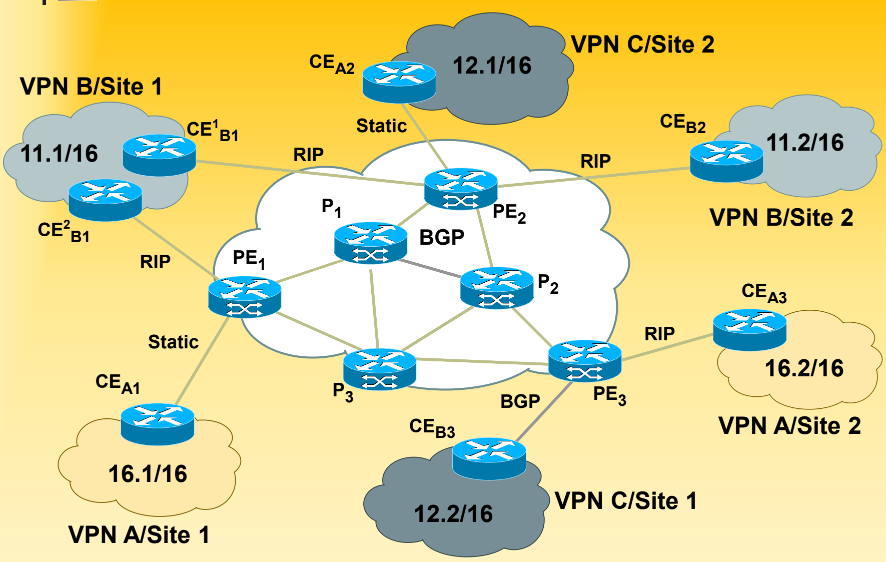
EXAMPLE: MPLS VPN Topology



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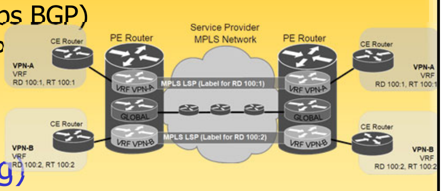
VPN Routing and Forwarding Instance (VRF)

- PE routers maintain separate routing tables.
  - Virtual Routing and Forwarding (VRF) instance is separate from the global routing table that exists on PE routers
- – Global routing table
  - Contains all PE and P routes (perhaps BGP)
  - Populated by the VPN backbone IGP



- – VRF (VPN routing and forwarding)
  - Routing and forwarding table associated with one or more directly connected sites (CE routers)
  - VRF is associated with any type of interface, whether logical or physical (e.g. sub/virtual/tunnel)
  - Interfaces may share the same VRF if the connected sites share the same routing information
  - Routes are injected into the VRF from the CE-PE routing protocols for that VRF and any MP-BGP announcements that match the defined VRF.

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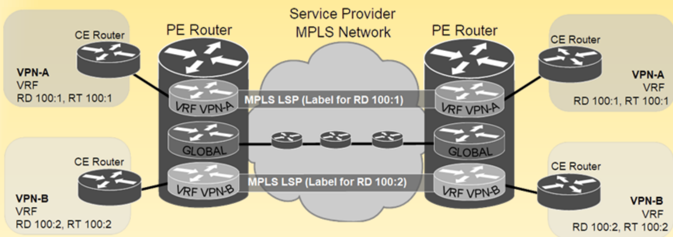
Route Distinguisher

```
!
ip vrf red
rd 1:1
route-target export 1:1
route-target import 1:1
```

- To differentiate 10.0.0.0/8 in VPN-A from 10.0.0.0/8 in VPN-B
  - 64-bit quantity
- Configured as ASN:YY or IPADDR:YY
  - ASN is the most common
- Purely to make a route unique
  - Unique route is now RD:Ipaddr (96 bits) plus a mask on the IPAddr portion
  - So customers don't see each others routes




```
!
ip vrf VPN-A
rd 100:1
route-target export 100:1
route-target import 100:1
```

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Route Target

```
!
ip vrf red
rd 1:1
route-target export 1:1
route-target import 1:1
```

- Creates or adds to a list of VPN extended communities used to determine which routes are imported by a VRF
- To control policy about who sees what routes
- 64-bit quantity (2 bytes type, 6 bytes value)
- Carried as an extended community
  - Typically written as ASN:YY
- Each VRF 'imports' and 'exports' one or more RTs
  - Exported RTs are carried in VPNv4 BGP
  - Imported RTs are local to the box
- A PE that imports an RT installs that route in its routing table
- Example: Each VRF in VPN A has the same route target in their import list and export list. Each VPN A VRF accepts only received routes that have this route target attached. Because this route target is attached to each route advertised by VPN A VRFs, every site in VPN A accepts routes only from other sites in VPN A.

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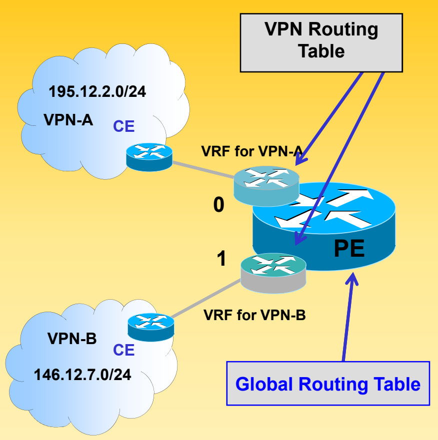
Virtual Routing and Forwarding Interface definition

- Define a unique VRF for interface 0
- Define a unique VRF for interface 1
  - Packets will never go between interfaces 0 and 1
- Uses VPNv4 to exchange VRF routing information between PE's



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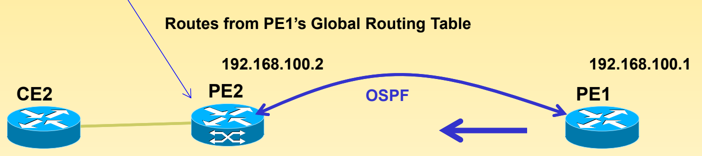
PE Router – Global Routing Table Output

```
PE2#sh ip route

Gateway of last resort is not set

C    192.168.1.0/24 is directly connected, Ethernet0/0
     192.168.100.0/32 is subnetted, 3 subnets
O       192.168.100.1 [110/11] via 192.168.1.1, 00:04:27, Ethernet0/0
C       192.168.100.2 is directly connected, Loopback0
O       192.168.100.3 [110/11] via 192.168.1.3, 00:04:27, Ethernet0/0
```



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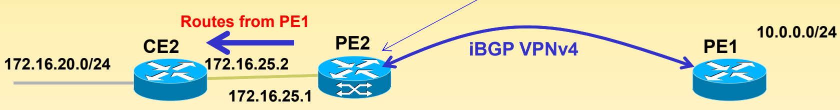
PE Router – VRF Routing Table Output

```
PE2#sh ip route vrf RED
Routing Table: RED

Gateway of last resort is 192.168.100.1 to network 0.0.0.0

     172.16.0.0/16 is variably subnetted, 8 subnets, 3 masks
C       172.16.25.0/30 is directly connected, Serial4/0
C       172.16.25.2/32 is directly connected, Serial4/0
B       172.16.20.0/24 [20/0] via 172.16.25.2, 00:07:04
     10.0.0.0/24 is subnetted, 1 subnets
B       10.0.0.0 [200/307200] via 192.168.100.1, 00:06:28
B*    0.0.0.0/0 [200/0] via 192.168.100.1, 00:07:03
```



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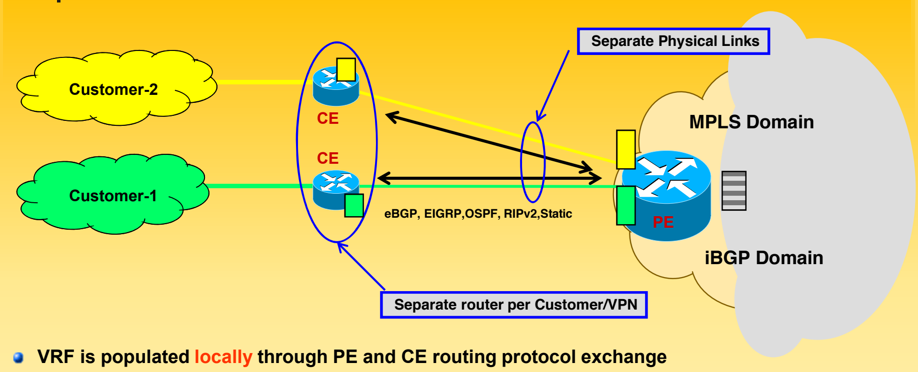
VRF Route Population



- **VRF is populated locally through PE and CE routing protocol exchange**
  - RIP Version 2, OSPF, BGP-4, EIGRP, & Static routing
  - “connected” is also supported (i.e. Default-gateway is PE)
- **Separate routing context for each VRF**
  - routing protocol context (BGP-4 & RIP V2)
  - separate process (OSPF)

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Carrying VPN Routes in BGP

- VRFs by themselves aren’t all that useful
  - Need some way to get the VRF routing information off the PE and to other PEs
  - This is done with BGP
- Additions to MP-BGP to Carry MPLS-VPN Info
  - RD: Route Distinguisher
  - RT: Route Target
  - VPNv4 address family
  - MPLS Label

```
Border Gateway Protocol - UPDATE Message
 Marker: ffffffffffffffffffffffffffffffff
 Length: 91
 Type: UPDATE Message (2)
 Withdrawn Routes Length: 0
 Total Path Attribute Length: 68
▿Path attributes
 ▹Path Attribut - ORIGIN: INCOMPLETE
 ▹Path Attribut - AS_PATH: empty
 ▹Path Attribut - MULTI_EXIT_DISC: 0
 ▹Path Attribut - LOCAL_PREF: 100
 ▿Path Attribut - EXTENDED_COMMUNITIES
  ▹Flags: 0xc0: Optional, Transitive, Complete
   Type Code: EXTENDED_COMMUNITIES (16)
   Length: 8
  ▿Carried extended communities: (1 community)
   ▹Community Transitive Two-Octet AS Route Target: 200:1
 ▿Path Attribut - MP_REACH_NLRI
  ▹Flags: 0x80: Optional, Non-transitive, Complete
   Type Code: MP_REACH_NLRI (14)
   Length: 33
   Address family: IPv4 (1)
   Subsequent address family identifier: Labeled VPN Unicast (128)
  ▹Next hop network address (12 bytes)
   Subnetwork points of attachment: 0
  ▿Network layer reachability information (16 bytes)
   ▹Label Stack=24 (bottom) RD=200:1, IPv4=192.1.1.0/25
```

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MPLS/VPN Packet Forwarding

- Between PE and CE, regular IP packets (currently)
- Within the provider network—label stack
  - Outer label: "get this packet to the egress PE"
  - Inner label: "get this packet to the egress CE"
- Remember: MPLS nodes forward packets based on TOP label
  - any subsequent labels are ignored
  - Penultimate Hop Popping procedures used one hop prior to egress PE router

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VPNv4

- In BGP for IP, 32-bit address + mask makes a unique announcement
- In BGP for MPLS-VPN, (64-bit RD + 32-bit address) + 32-bit mask makes a unique announcement
- Since the route encoding is different, need a different address family in BGP

  VPNv4 = VPN routes for IPv4
  - As opposed to IPv4 or IPv6 or multicast-RPF, etc…
- VPNv4 announcement carries a label with the route
  - "If you want to reach this unique address, get me packets with this label on them"

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Terminology

Terminology, 1/2

- RR—Route Reflector
  - A router (usually not involved in packet forwarding) that distributes BGP routes within a provider's network
- PE—Provider Edge router
  - The interface between the customer and the MPLS-VPN network; only PEs (and maybe RRs) know anything about MPLS-VPN routes
- P—Provider router
  - A router in the core of the MPLS-VPN network, speaks LDP/RSVP but not necessarily VPNv4
- CE—Customer Edge router
  - The customer router which connects to the PE; does not know anything about labels, only IP (most of the time)
- LDP—Label Distribution Protocol
  - Distributes labels with a provider's network that mirror the IGP, one way to get from one PE to another
- LSP—Label Switched Path
  - The chain of labels that are swapped at each hop to get from one PE to another

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Terminology, 2/2

- VPN—Virtual Private Network
  - A network deployed on top of another network, where the two networks are separate and never communicate
- VRF—Virtual Routing and Forwarding instance
  - Mechanism in IOS used to build per-interface RIB and FIB
- VPNv4
  - Address family used in BGP to carry MPLS-VPN routes
- RD
  - Route Distinguisher, used to uniquely identify the same network/mask from different VRFs (i.e., 10.0.0.0/8 from VPN A and 10.0.0.0/8 from VPN B)
- RT
  - Route Target, used to control import and export policies, to build arbitrary VPN topologies for customers

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