Multi-Protocol Label Switching

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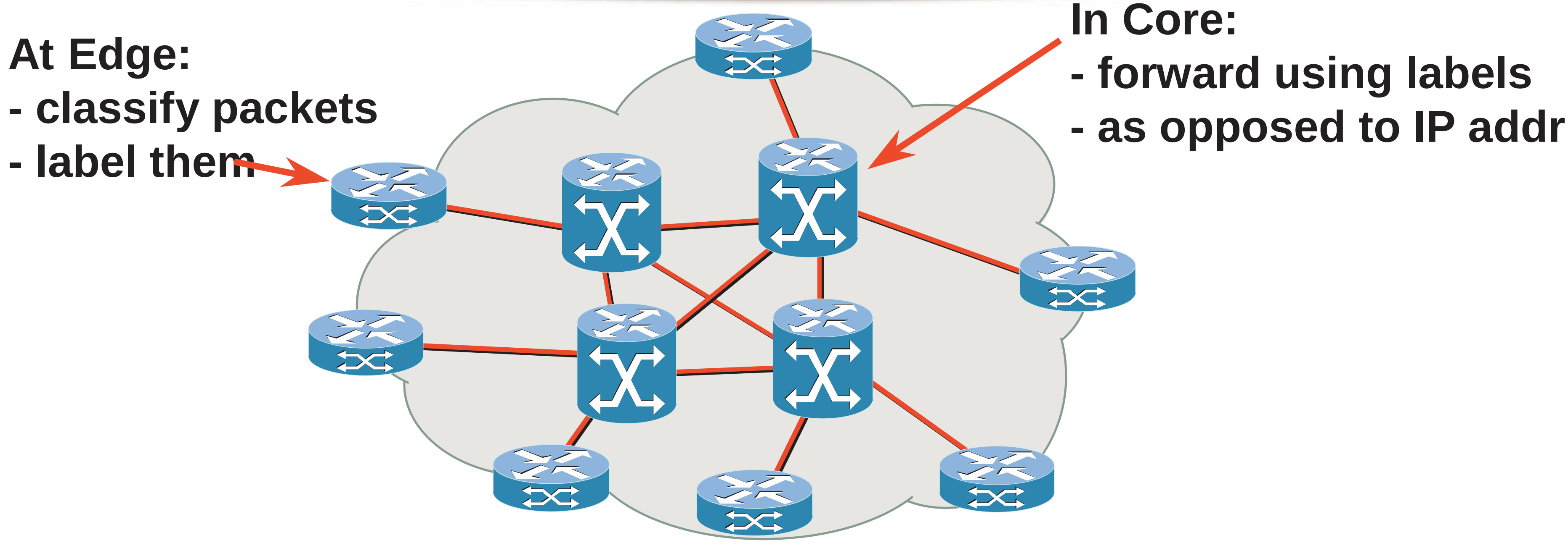
Agenda

- Introduction to MPLS
- MPLS forwarding
- Label Distribution Protocol
- Traffic Engineering
- MPLS VPN
- MPLS QoS

MPLS Concept



- Enable ATM switches to act as routers
- Create new IP capabilities via flexible classification

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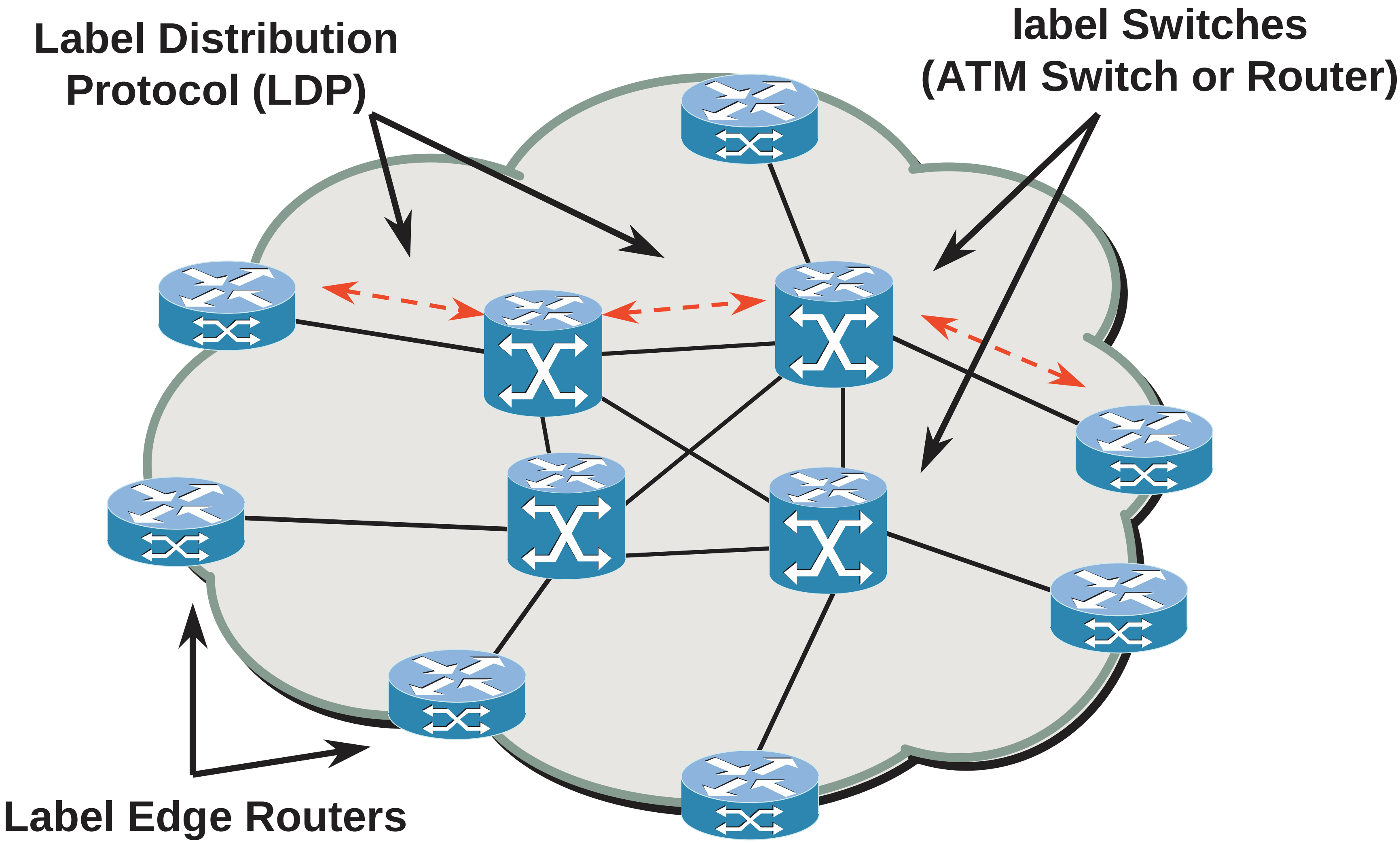
MPLS Overview

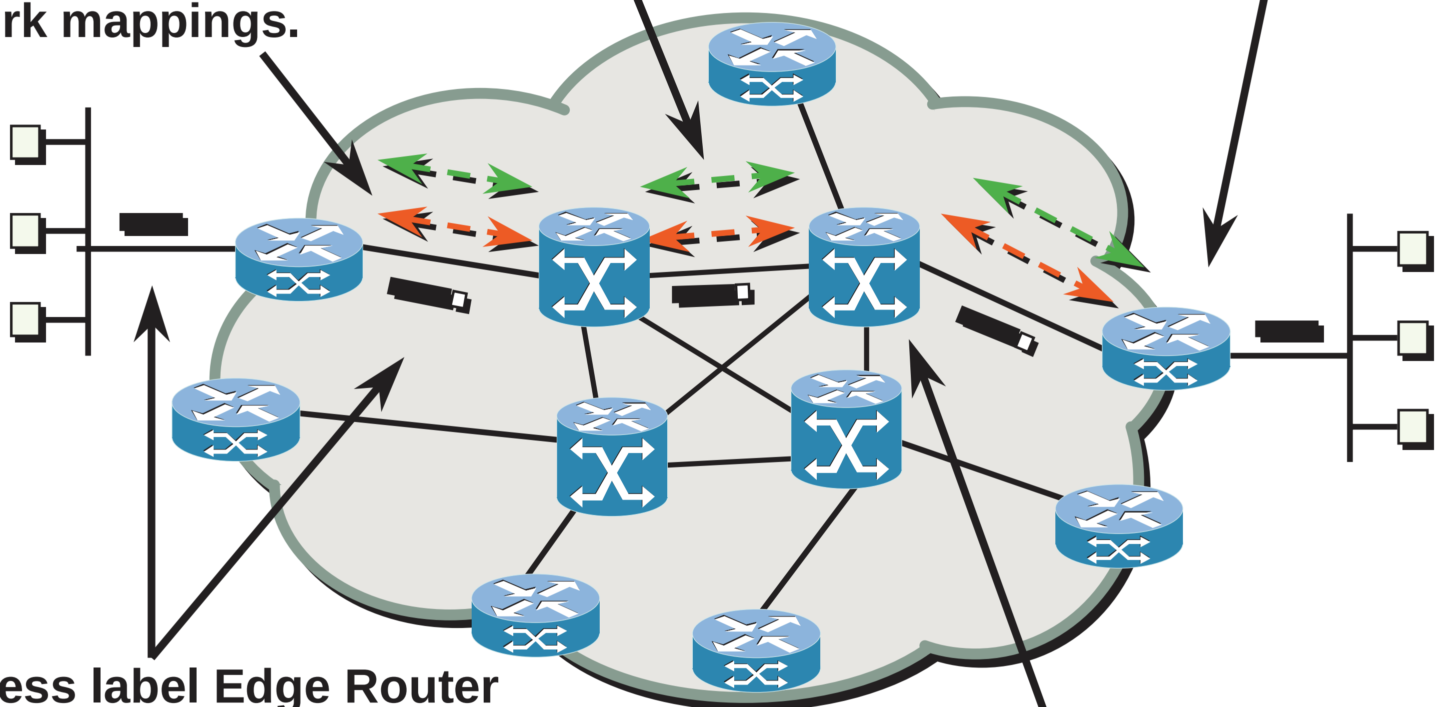


MPLS Operation

1a. Existing routing protocols (e.g. OSPF, IS-IS) establish reachability to destination networks

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

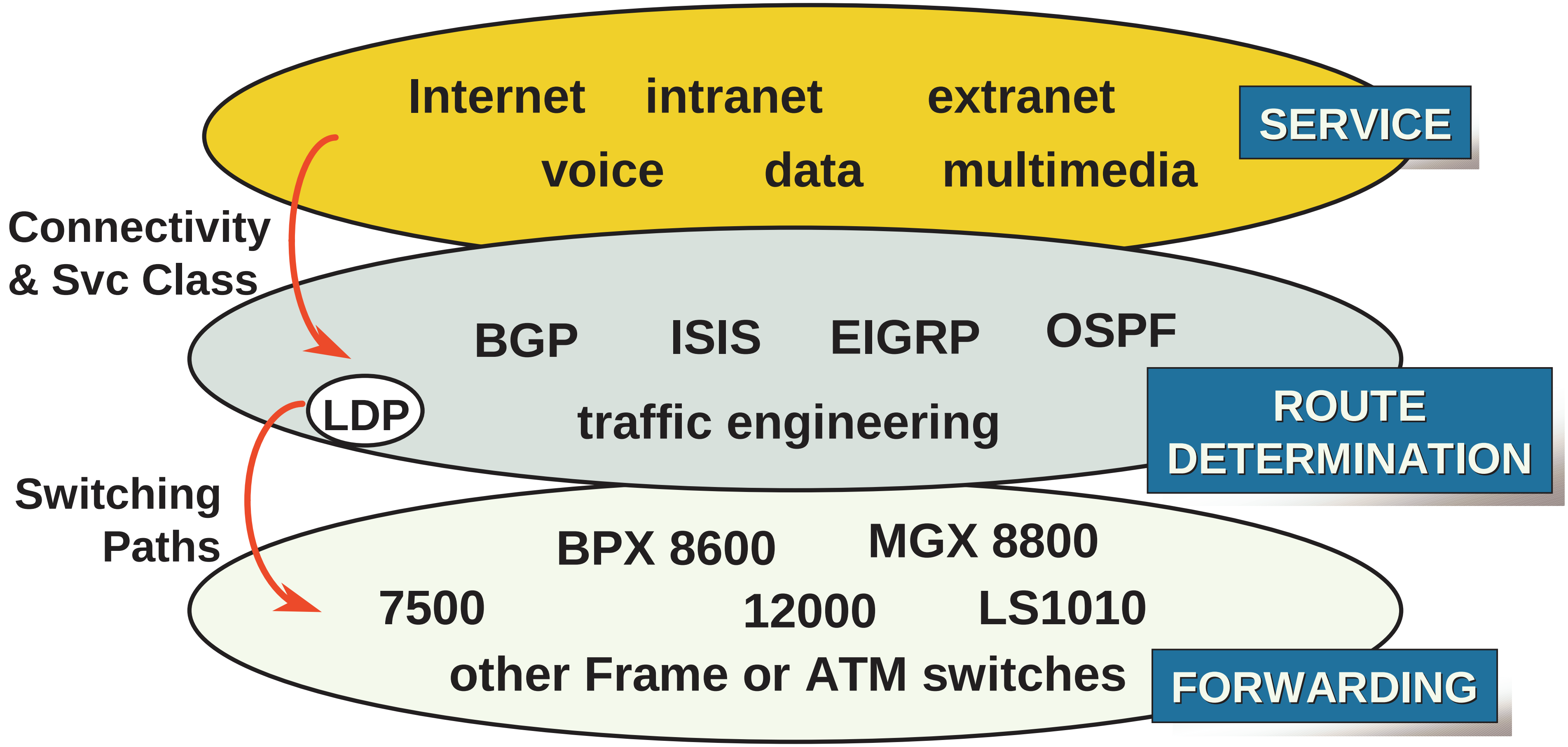
4. Label Edge Router at egress removes tag and delivers packet



2. Ingress label Edge Router receives packet, performs Layer 3 value-added services, and “MPLS” packets

3. Label Switches switch labelged packets using label swapping

Control Planes in MPLS



Advanced MPLS

- Basic label switching: destination-based unicast
- Many additional options for assigning tags
- The Key: separation of routing and forwarding

Destination-based Unicast Routing	IP Class of Service	Resource Reservation (eg RSVP)	Multicast Routing (PIM v2)	Explicit & Static Routes	Virtual Private Networks
Label Forwarding Information Base (TFIB)					
Per-Label Forwarding, Queuing, and Multicast Mechanisms					

Encapsulations

ATM Cell Header

GFC	VPI	VCI	PTI	CLP	HEC	DATA

Label Info Header

PPP Header (Packet over SONET/SDH)

PPP Header	Label Info Header	Layer 3 Header

LAN MAC Label Header

MAC Header	Label Info Header	Layer 3 Header

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Generic Label Header Format

```
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, 3 bits
S = Bottom of stack, 1bit
TTL = Time to live, 8 bits

- **Generic: can be used over Ethernet, 802.3, PPP links, Frame Relay, ATM PVCs, etc.**
- **Uses 2 new Ethertypes/PPP PIDs/SNAP values/etc.**
  - one for unicast, one for multicast
- **4 octets (per tag level)**

ATM MPLS

- VPI/VCI field is used as a ‘tag’
- Label is applied to each cell, not whole packet
- Label swapping = ATM switching

Carrying Labels on Ethernet Links

- Extra four bytes might lead to fragmentation of 1492-byte packets
- Path MTU discovery will detect need to fragment (MTU discover packets will be sent tagged)
- But: many Ethernet links actually support 1500 or 1508-byte packets
- And: most packets will normally be carried over ATM, or PPP/SDH links, not Ethernet

MPLS Basics: Summary

- MPLS puts IP routing functions on ATM switches. This provides better IP and ATM integration and better scaling.
- On non-ATM equipment, MPLS simplifies the forwarding operation and introduces 'lightweight virtual circuits'. This allows advanced features like MPLS Traffic Engineering.

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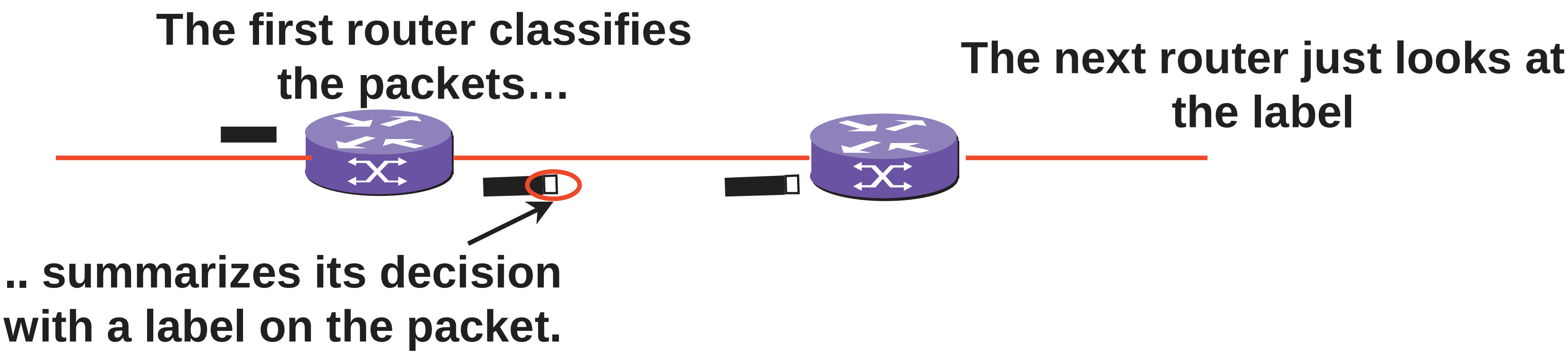
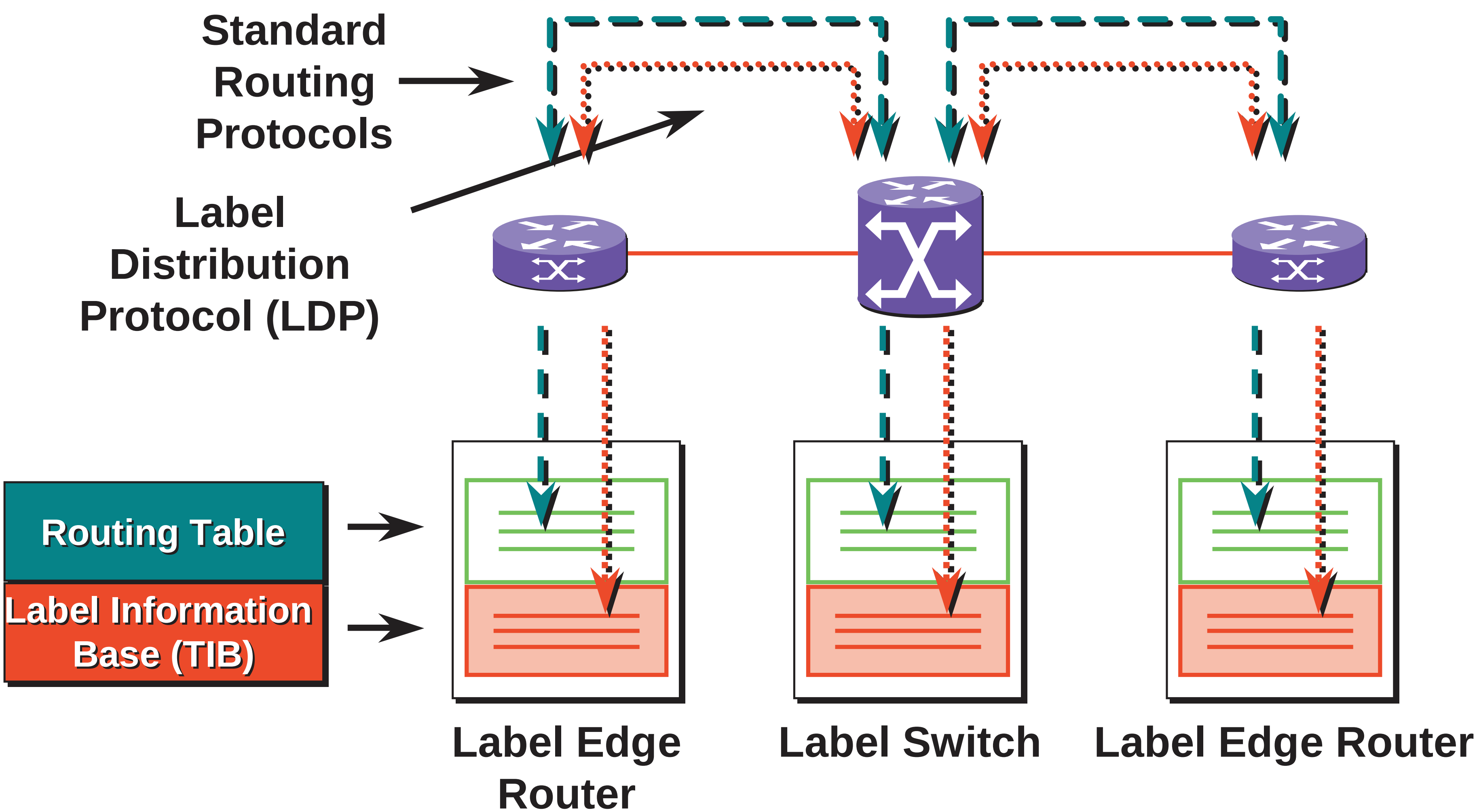
MPLS: Forwarding

- A pair of routers handle a class of packets with similar parameters

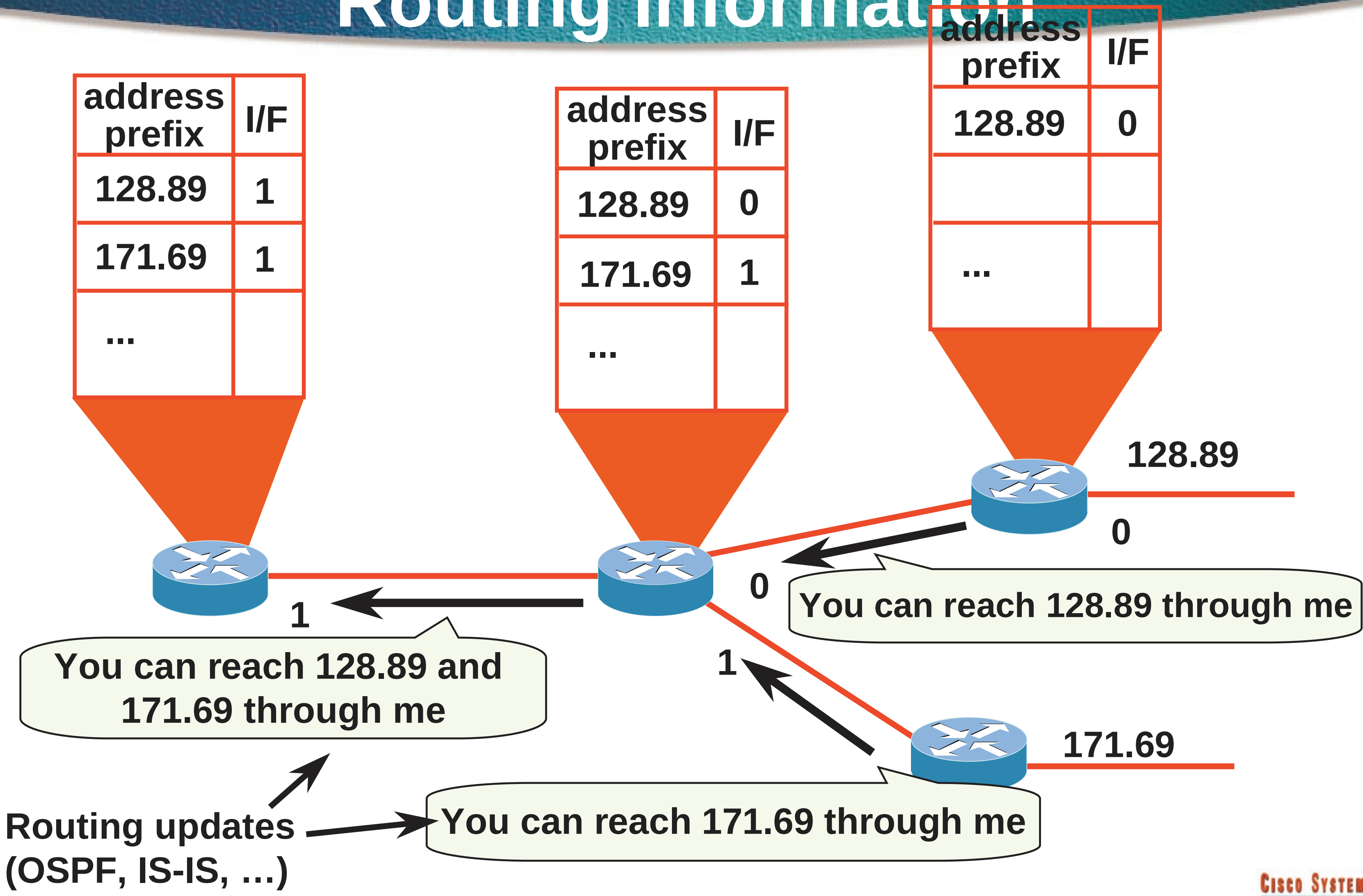


- MPLS simplifies forwarding, pushes packet classification back towards the edge

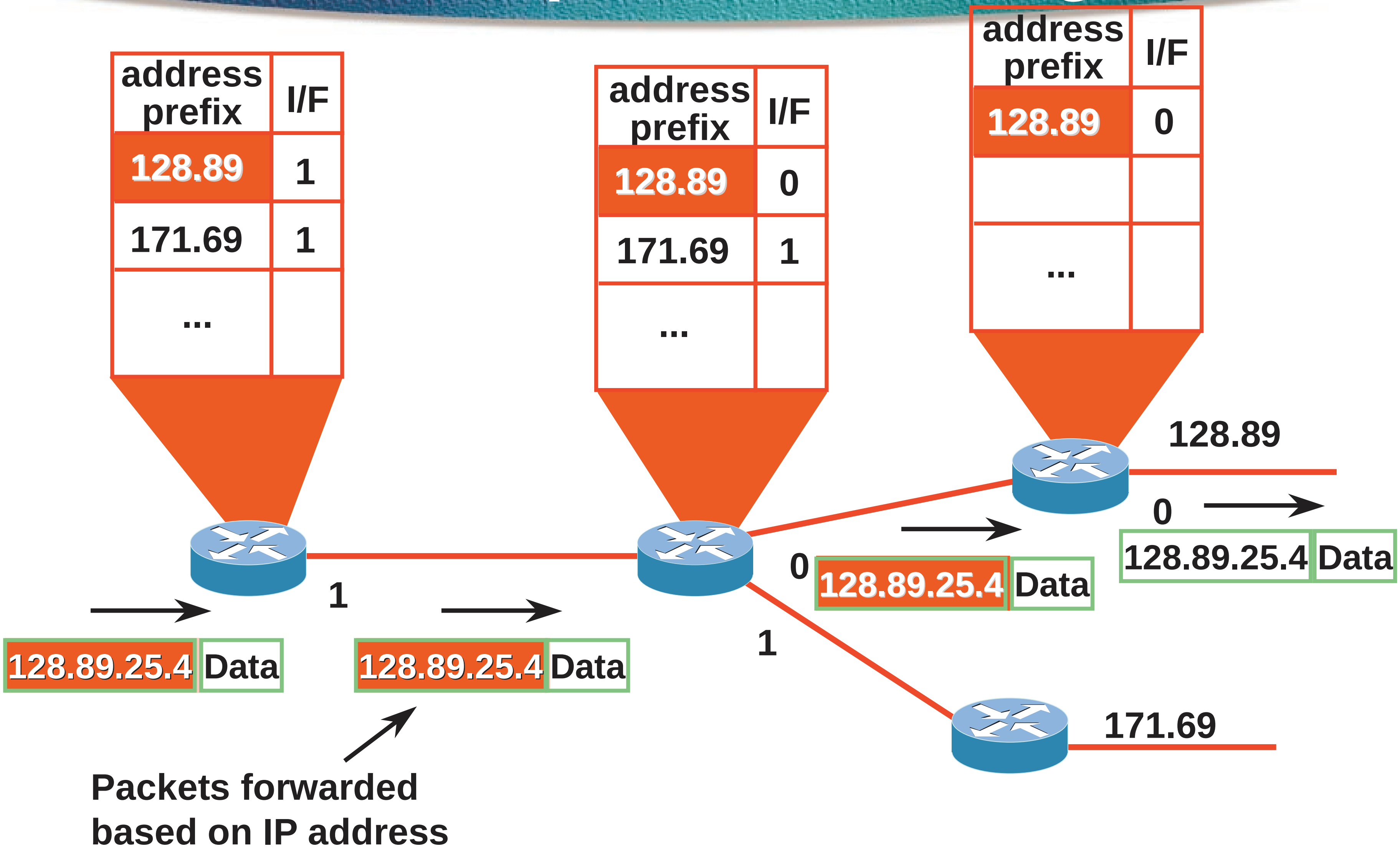
Label Distribution Protocol



Router Example: Distributing Routing Information



Router Example: Forwarding Packets



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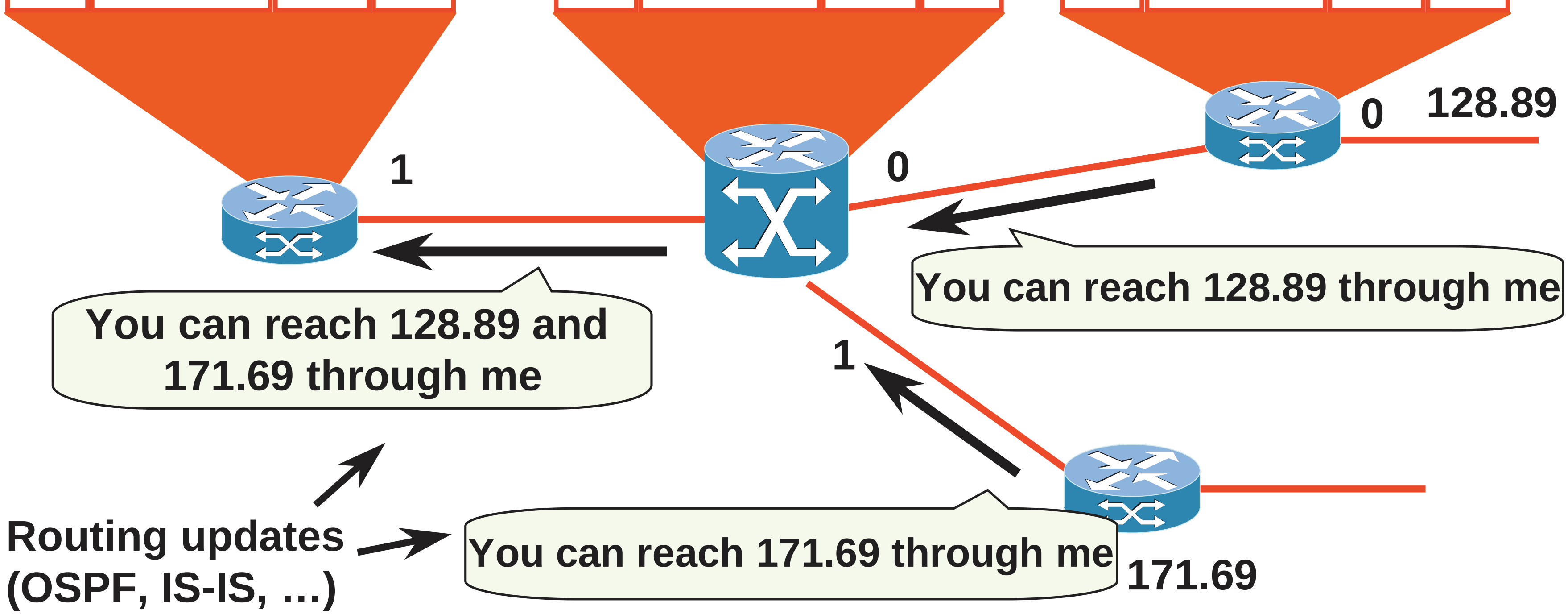
MPLS Example: Routing Information

In Tag	Address Prefix	Out I'face	Out Tag
	128.89	1	
	171.69	1	
	...	...	

In Tag	Address Prefix	Out I'face	Out Tag
	128.89	0	
	171.69	1	
	...	...	

In Tag	Address Prefix	Out I'face	Out Tag
	128.89	0	
	...	...	

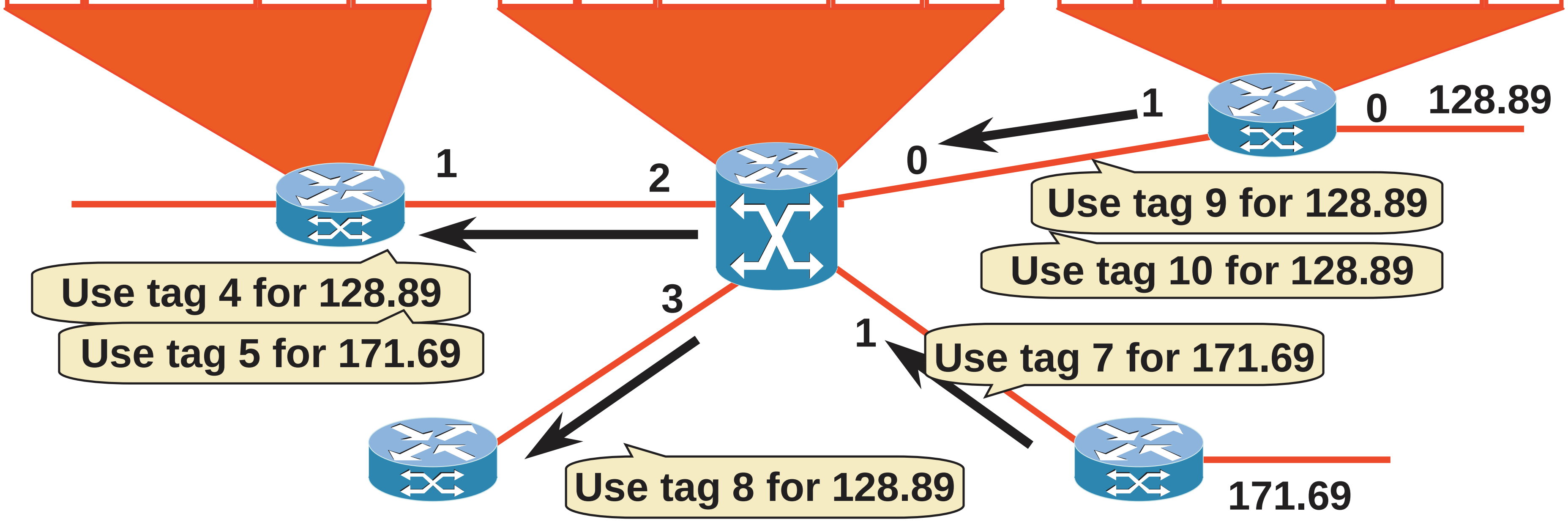


ATM MPLS Example: Assigning Labels

In Tag	Address Prefix	Out I'face	Out Tag
-	128.89	1	4
-	171.69	1	5
	...	...	

In Tag	In I/F	Address Prefix	Out I'face	Out Tag
4	2	128.89	0	9
8	3	128.89	0	10
5	2	171.69	1	7

In Tag	In I/F	Address Prefix	Out I'face	Out Tag
9	1	128.89	0	-
10	1	128.89	0	-
		...	...	

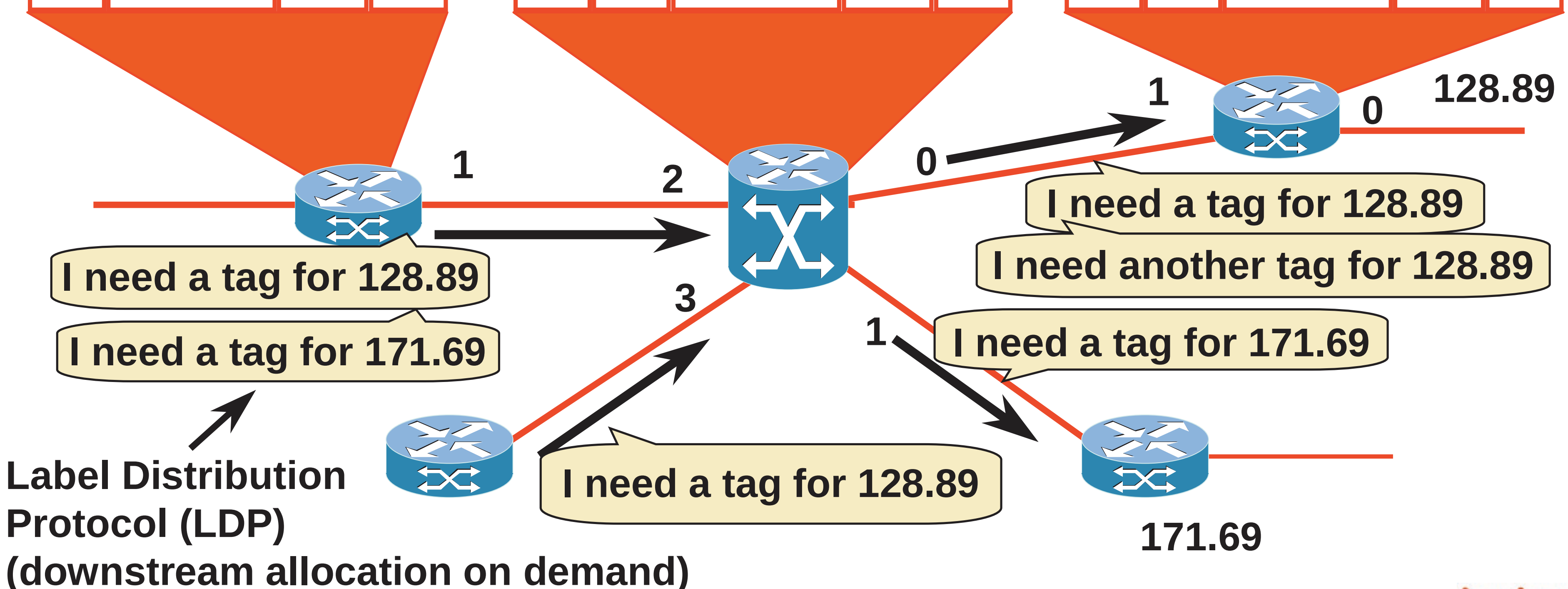


ATM MPLS Example: Requesting Labels

In Tag	Address Prefix	Out I'face	Out Tag
	128.89	1	
	171.69	1	
	...	...	

In Tag	In I/F	Address Prefix	Out I'face	Out Tag
		128.89	0	
		171.69	1	
		...	...	

In Tag	In I/F	Address Prefix	Out I'face	Out Tag
		128.89	0	
		...	...	

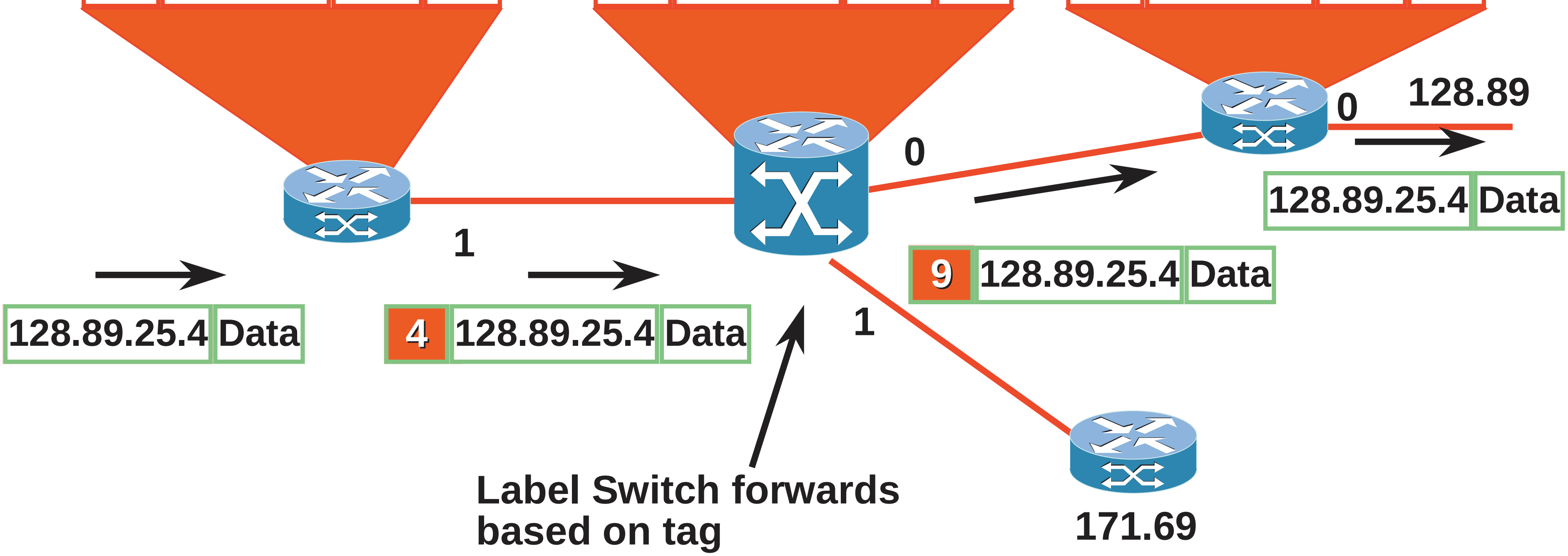


MPLS Example: Forwarding Packets

In Tag	Address Prefix	Out I'face	Out Tag
-	128.89	1	4
-	171.69	1	5
...	...	...	...

In Tag	Address Prefix	Out I'face	Out Tag
4	128.89	0	9
5	171.69	1	7
...	...	...	...

In Tag	Address Prefix	Out I'face	Out Tag
9	128.89	0	-
...	...	...	...

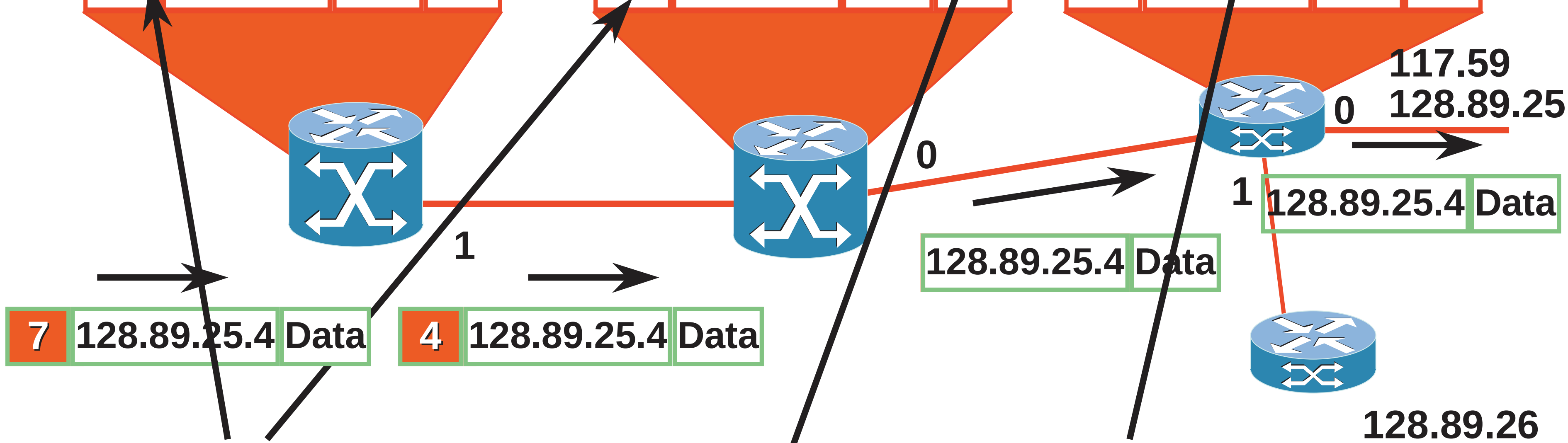


MPLS Example: More Details

In Tag	Address Prefix	Out I'face	Out Tag
7	128.89	1	4
2	171.69	1	5
7	117.59	1	4

In Tag	Address Prefix	Out I'face	Out Tag
4	128.89	0	X
5	171.69	1	7
4	117.59	0	9

In Tag	Address Prefix	Out I'face	Out Tag
X	128.89.25	0	-
X	128.89.26	1	-
...	...	...	...



Prefixes that share a path can share tag

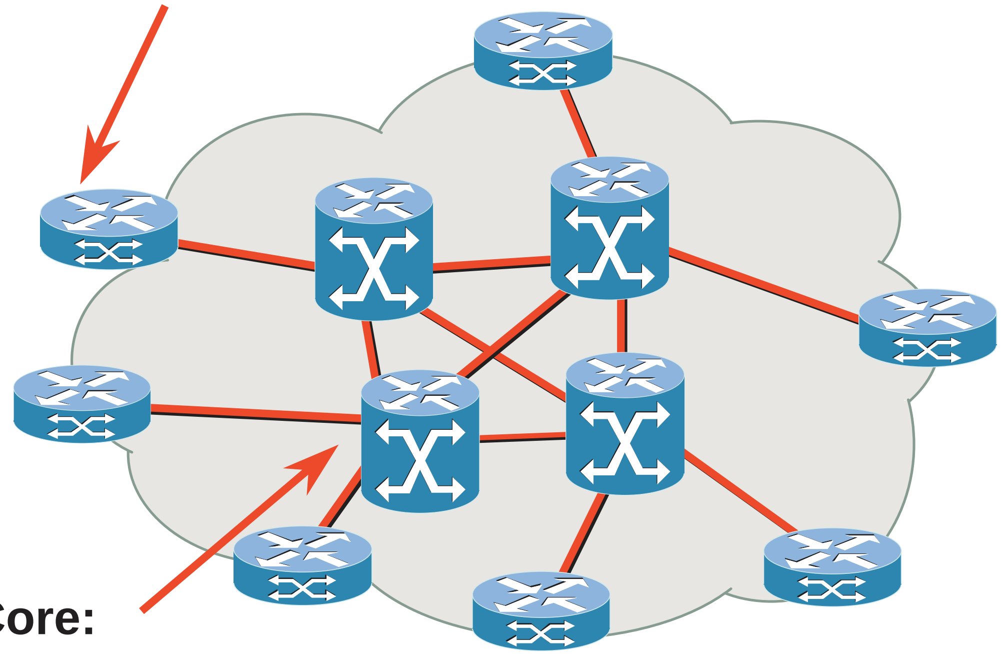
Remove tag one hop prior to de-aggregation point

De-aggregation point does L3 lookup

Internet IGP Labelling

- **Apply labels to IGP routes**
  - Conserves labels
- **Shields core from BGP routes**
  - No BGP route flaps in core
  - Smaller tables
  - Faster convergence

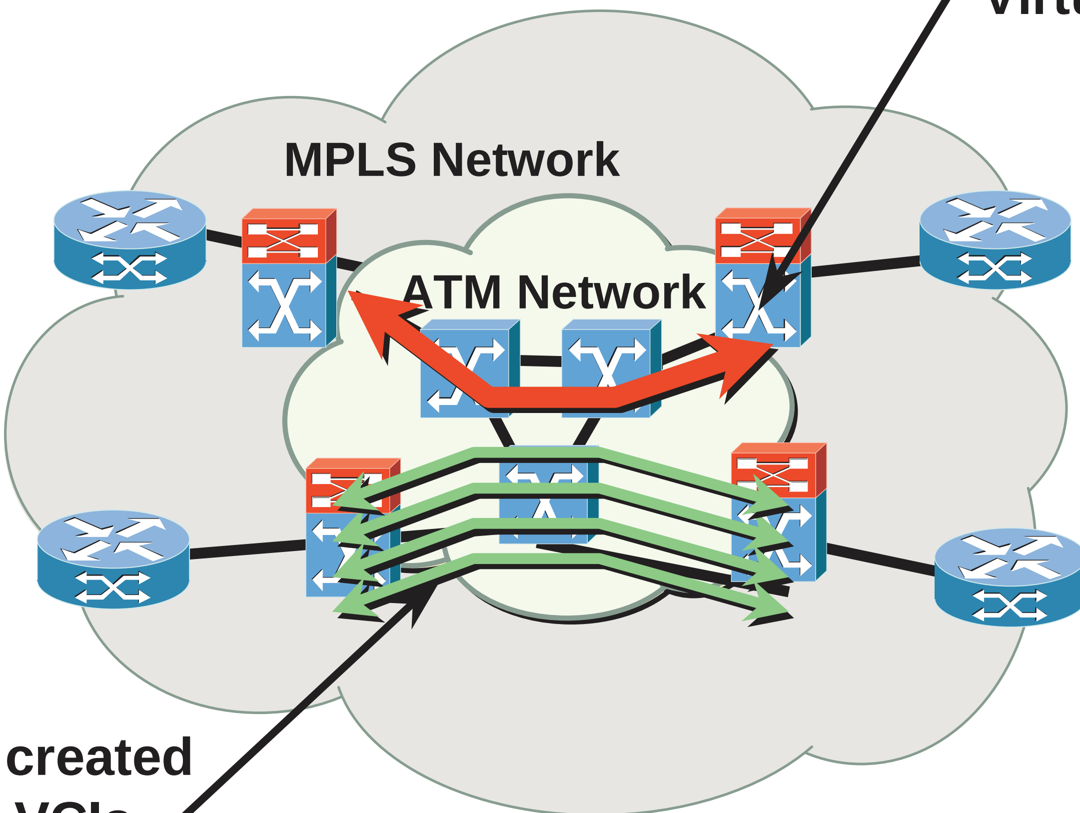
At Edge:
- Look up IP address, find BGP next hop
- Look up BGP next hop, find IGP route & label
- apply IGP label, forward



In Core:
- forward using labels
- labels assigned to IGP routes only

MPLS Across Non-MPLS ATM Networks

Labelled cells transported in Virtual Path



ATM SVCs created as needed; VCIs mapped to tags

Label Forwarding: Summary

- **Helps routing scale: analyze packets only at edge**
- **Makes full-featured routing feasible**
  - **Labelling on destination, source, ToS, (RSVP)**
  - **Multicast labelling, other modes**
- **Will run on any MAC layer**
- **Basic mechanism is extensible to traffic engineering, multicast**

Agenda

- Introduction to MPLS
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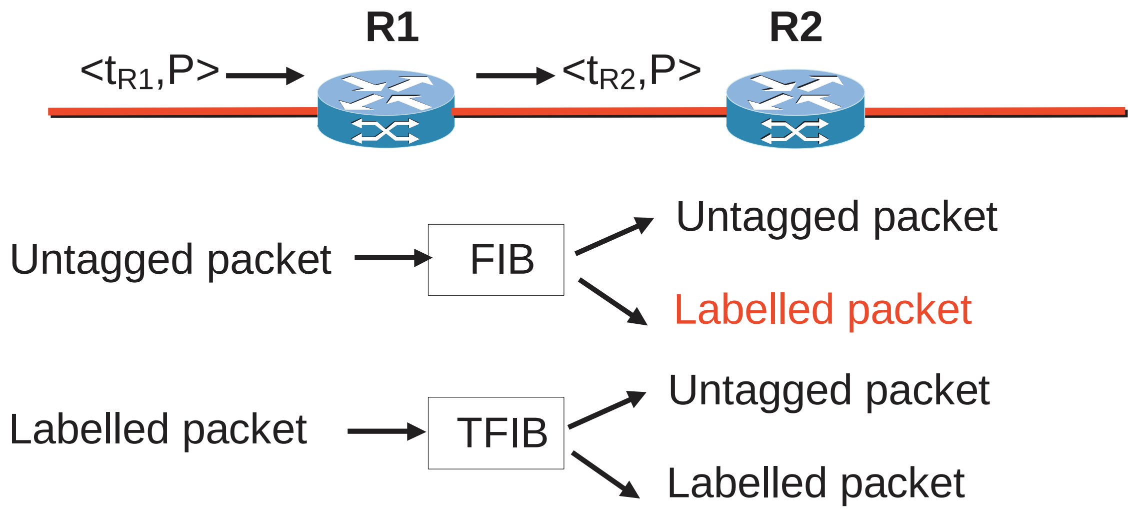
- Label Distribution Protocol
- Traffic Engineering
- MPLS VPN
- MPLS QoS

MPLS control plane



- **FIB: for unlabelled packets**
  - **New function: outgoing labelled packet**
- **TFIB: for incoming labelled packets**

TIB and TFIB

Tag Information Base (TIB)

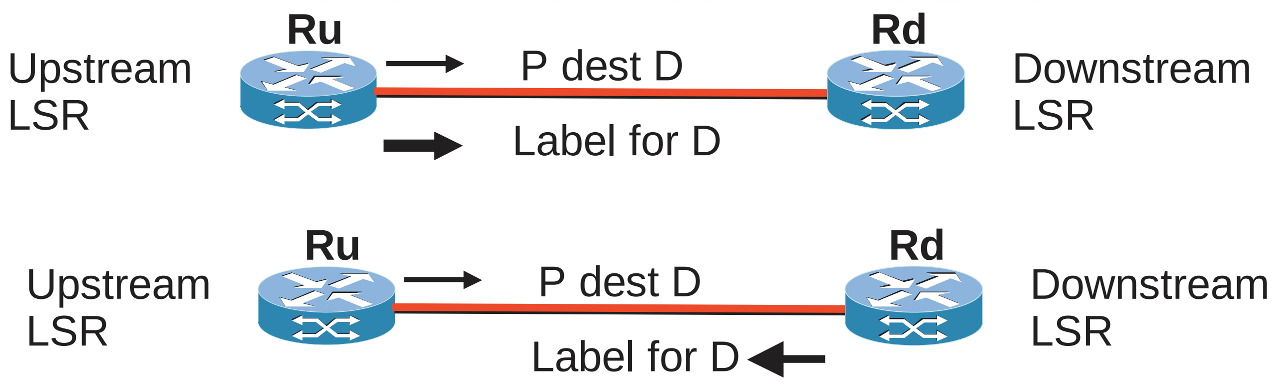
Destination	Incoming tag	(Peer, Outgoing tag)
D	tR1	(R2:0,tR2)

Tag Forwarding Information Base (TFIB)

Incoming tag	Outgoing tag	Interface
tR1	tR2	i3

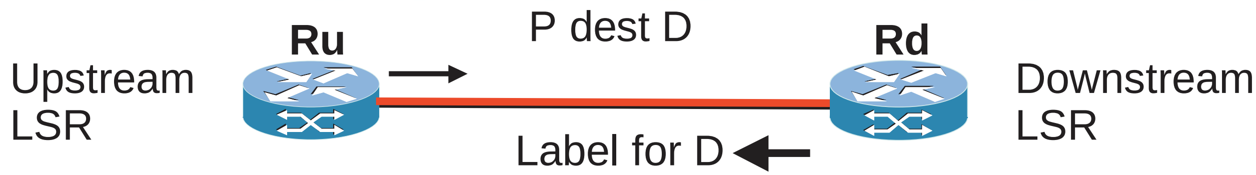
- **TIB is populated by LDP/TDP**
- **TFIB is derived from TIB and used for packet forwarding**

Label distribution



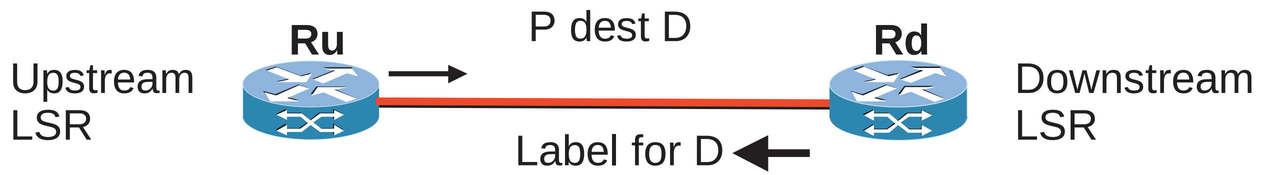
- **Upstream tag distribution**
  - **when tag is assigned (based on destination) by upstream router**
- **Downstream tag distribution**
  - **current LDP/TDP implementation**

Label Distribution



- **Downstream label distribution**
  - **Downstream LSR (Rd) distributes all tags to upstream neighbors (Ru)**
  - **Used for frame interfaces**
  - **When downstream LSR is ready to forward labelled packets for destination D, it assigns a label and distribute it to all upstream neighbors**

Label Distribution



- **Downstream on demand label distribution**
  - **Downstream LSR distribute part of its label space**
  - **Based on upstream neighbors requests**
  - **Used for ATM interfaces**
  - **When upstream LSR is ready to forward packets for destination D, it requests a tag for D from the next-hop (Rd)**

Label Distribution

- **Protocol enhancements in order to carry labels**
  - **BGP**

    Used to distribute labels for external destinations (MPLS-VPN)
  - **RSVP**

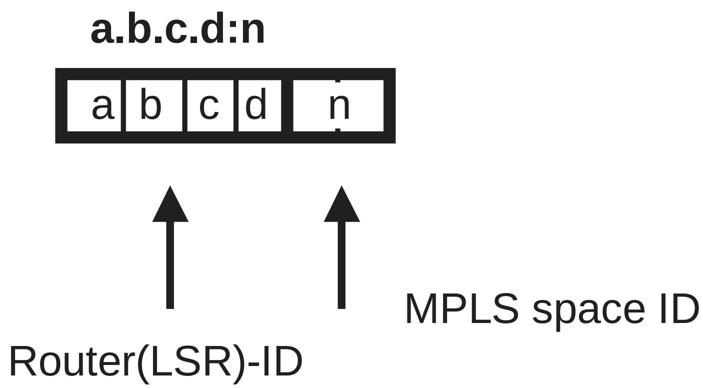
    Used for LSP tunnels (Traffic Engineering)
  - **PIMv2**

    Used to distribute labels for (S,G) or (*,G) entries in multicast state table

LDP transport

- LDP uses TCP as transport layer
- Well-known TCP port 711
- One TCP session per LDP session
  - No multiplexing at this stage
  - when label is assigned (based on destination) by upstream router

LDP Identifier



- **Identifies label space for**
  - **The router**
  - **The interface**
- **Exchanged during LDP session set up**
- **6 bytes**

LDP neighbor discovery

- Discovery is done through Hello packets
  - Hello are periodically sent via UDP
  - Hello are sent on all label-enabled interfaces
  - Source address is the outgoing interface
  - Hellos packets contain

    LDP Identifier

    Label space

LDP Session

- Once discovery is done the LDP session is established over TCP
- LSRs send periodically keepalive LDP packets to monitor the session

LDP Identifiers and Next-Hop addresses

Tag Information Base (TIB)

Dest	In tag	(Peer, Out tag)
D	tR1	(R2:0,tR2)

Routing Table

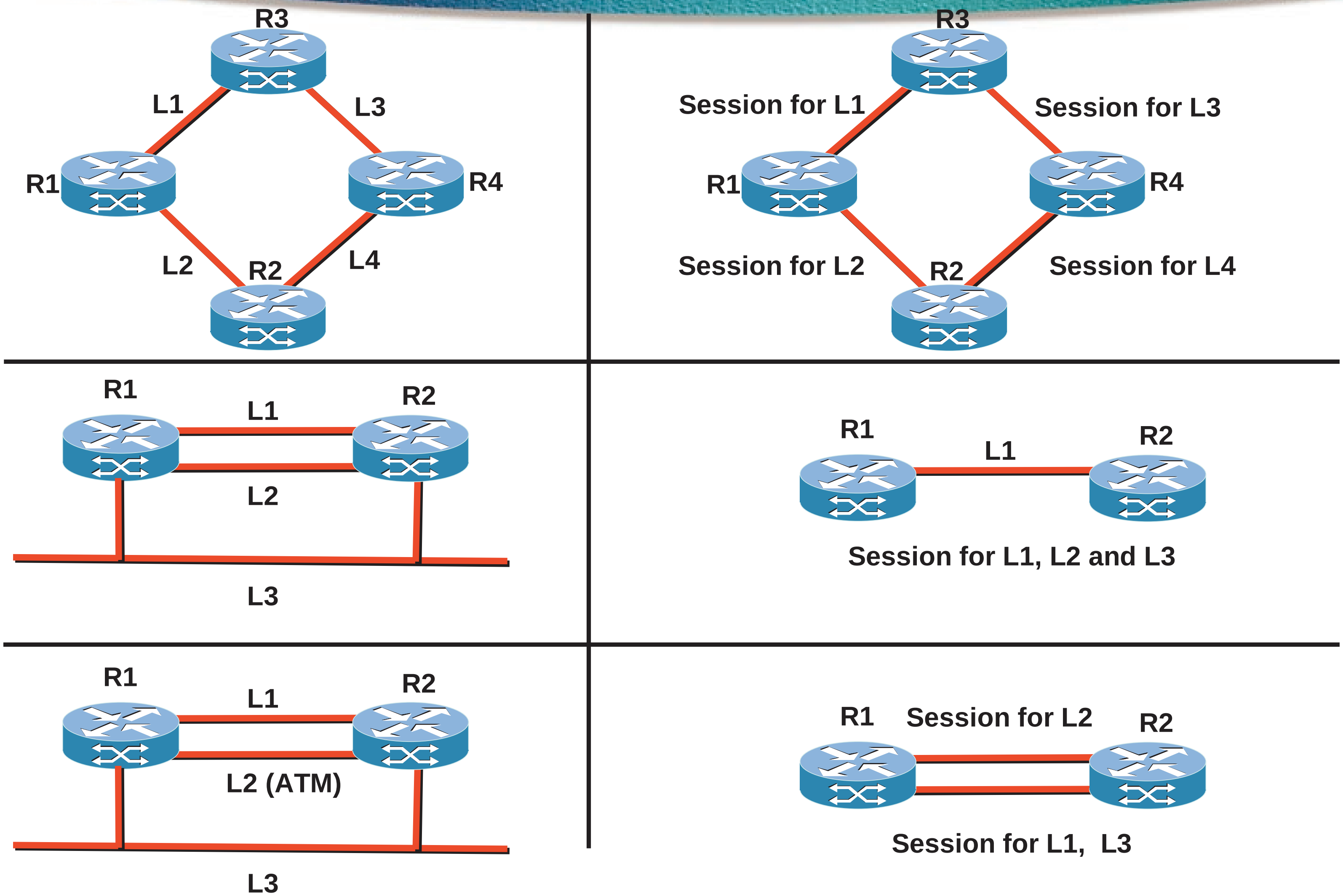
Dest	Next-Hop	Int	Pctl	Metric
D	a.b.c.d	e0	OSPF	10

- **Tag Information Base (TIB):**
  - **Stores tags with peer LDP Identifier**
- **Routing Information Base (RIB)**
  - **Maintains next-hop IP addresses**

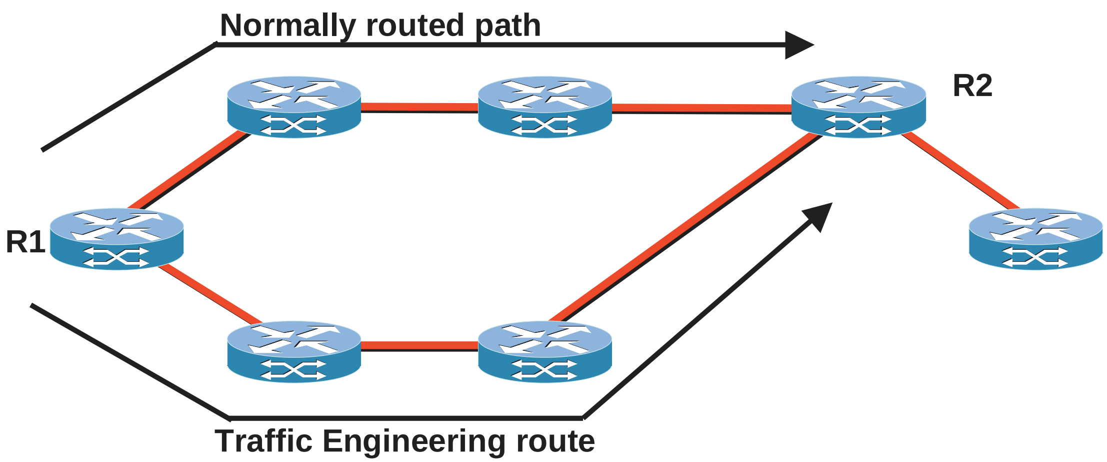
LDP Identifiers and Next-Hop Addresses

- **TFIB requests labels assigned by next-hop to destination**
- **LDP maps next-hop address into peer LDP Identifier in order to retrieve a label**
- **LSRs advertise interface addresses via LDP**
- **LSRs map peer LDP ID to addresses**
    - **Using learned addresses**

LDP Sessions



LDP Sessions between non directly connected LSRs



- LDP session is established between R1 and R2
  - End of tunnel is BGP next-hop for destination
- Hello mechanism is different
  - Direct Hello packets

Label Distribution Protocol (LDP)

- **Run in parallel with routing protocols**
- **Distributes <tag,prefix> bindings**
- **Incremental updates over TCP**
- **Other tag distribution mechanisms can run in parallel with it**

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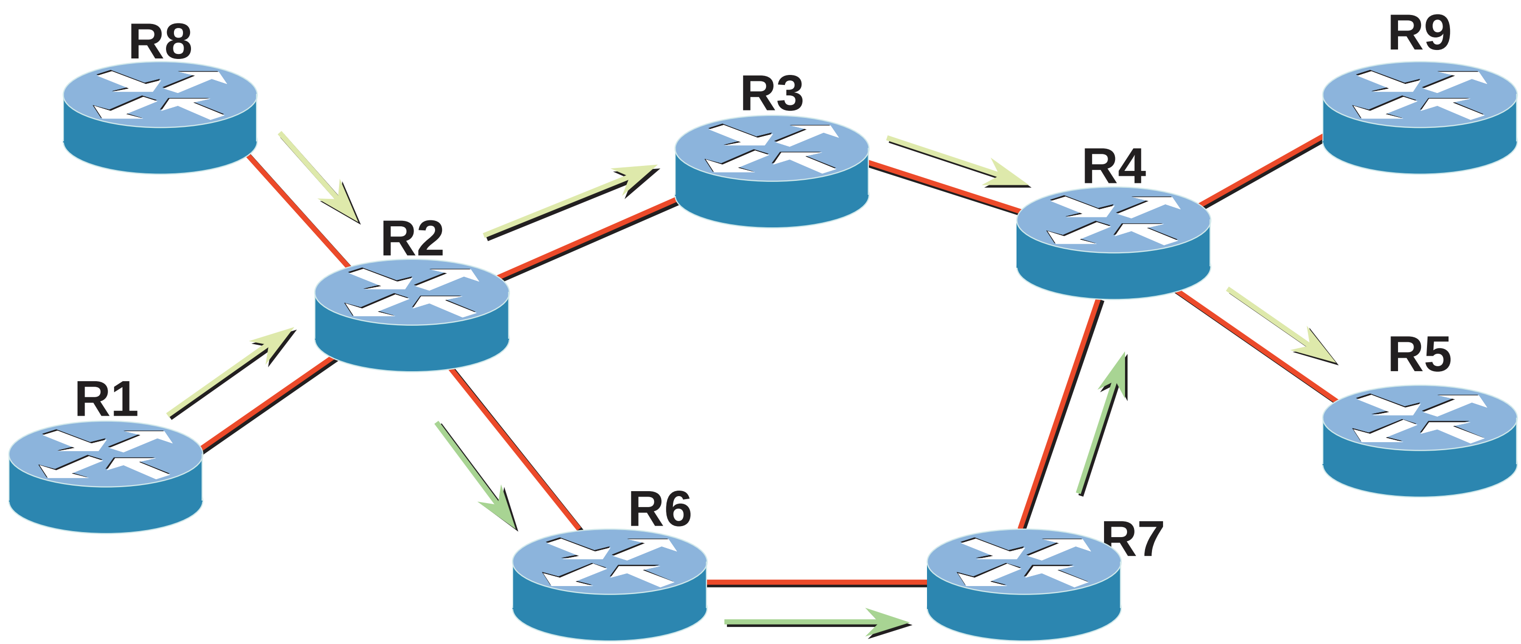
- Label Distribution Protocol
- Traffic Engineering
- MPLS VPN
- MPLS QoS

Traffic Engineering Motivation

- “For a given **network topology** and **traffic load**, where should my traffic go and how do I make it go there ?”

Traffic Engineering Motivation

- Link not available
- Economics
- Size of pipes
- Failure scenarios
- Unanticipated growth
- Class of service routing



IP (Mostly) Uses Destination-Based Least-Cost Routing
Flows from R8 and R1 Merge at R2 and Become Indistinguishable
From R2, Traffic to R3, R4, R5, R9 Use Upper Route

Alternate Path Under-Utilised

LSP tunnels

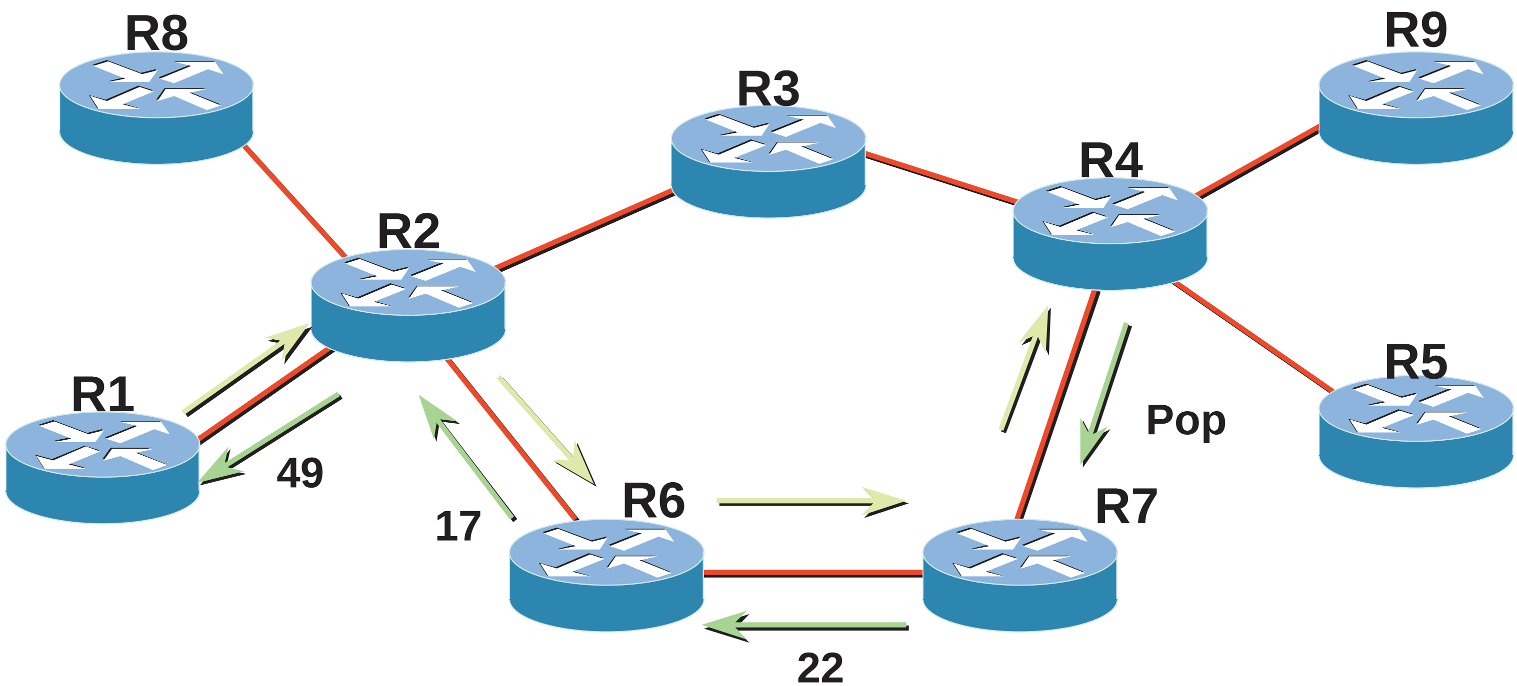
- **Labelled packets are forwarded based on tag, not IP destination**
- **In conjunction with signaling mechanism. Label forwarding can be used to create a multi-hop LSP tunnel: TE tunnel**
- **LSP tunnel is used to reach BGP next-hop**

LSP tunnel setup via RSVP

- RSVP extensions
- Initiated at source router
- Complete path in forward messages
- Label established by reply messages
- Rapid tear down on link failure

LSP tunnel setup via RSVP

- **Possible future resource capabilities**
- **Unidirectional data flow**
- **May traverse ATM LSR, but not begin or end there**

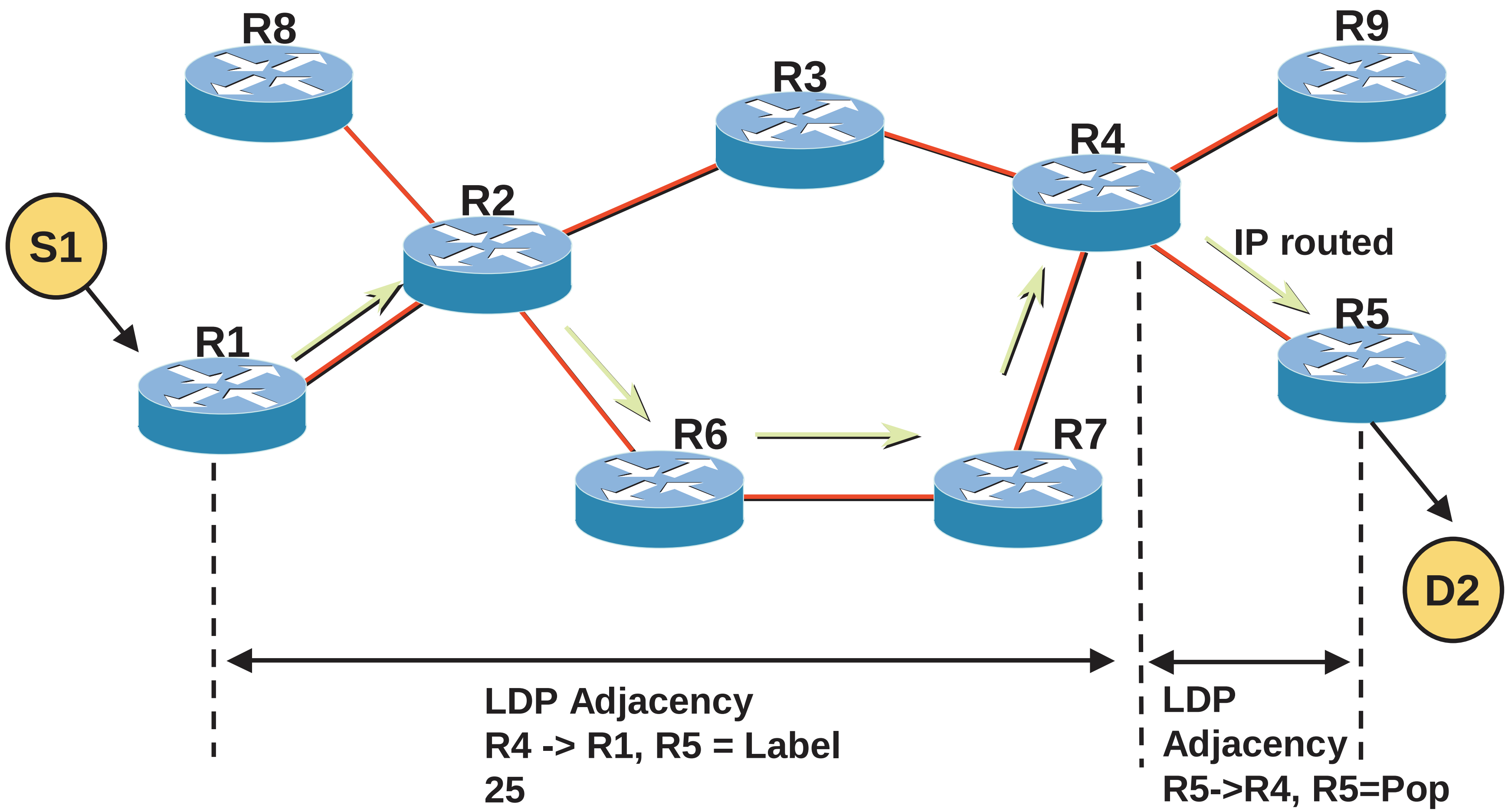


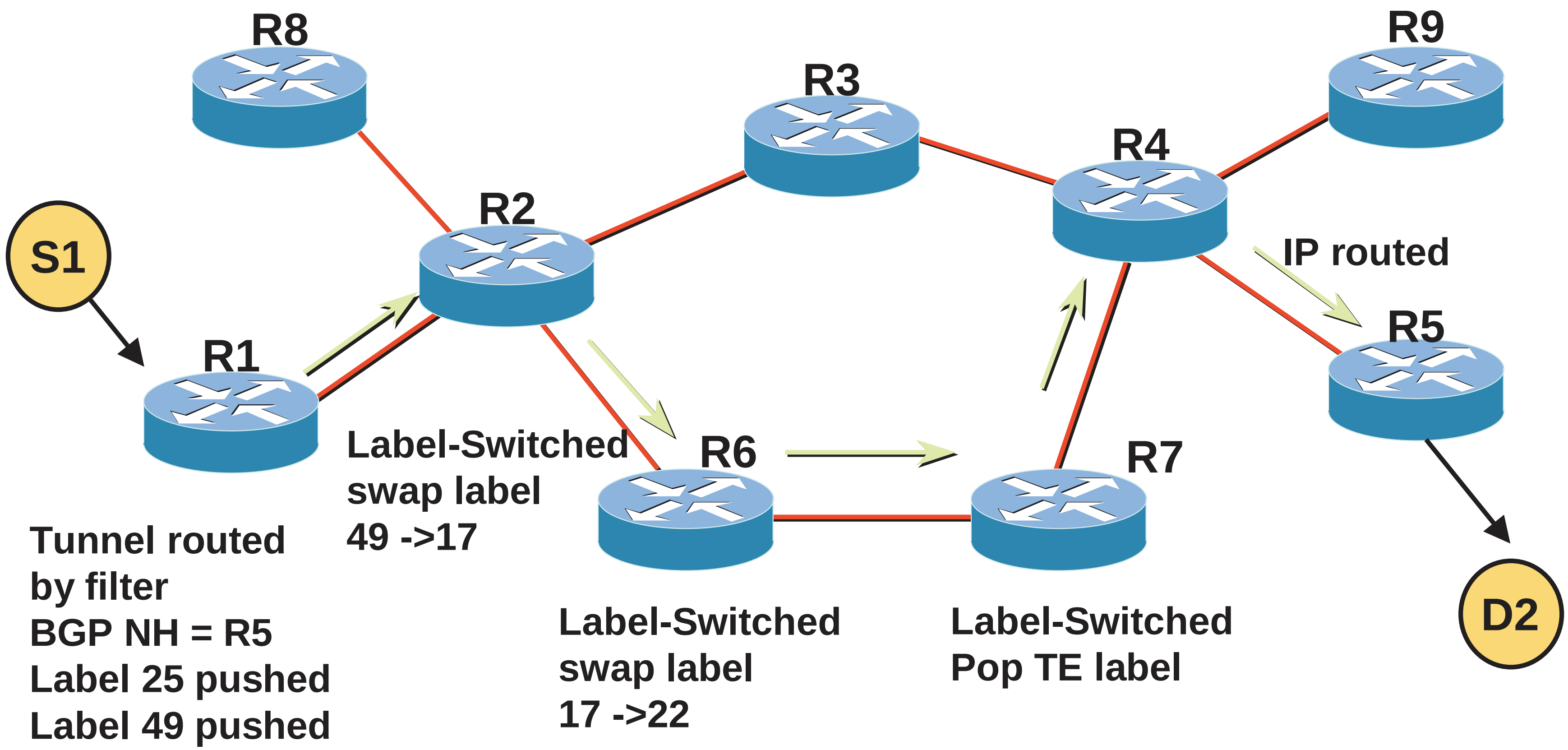
Setup: Carries Path (R1->R2->R6->R7->R4) and Tunnel ID

Reply: Communicates Labels and Establishes Label Operations

LSP tunnel configuration

- **IOS tunnel interface with tag-switching encapsulation (not GRE)**
- **Source route**
  - **Specified as the sequence of IP addresses**
- **Configured only at the head of the tunnel**


R8
R3
R9
R4
R2
S1
IP routed
R5
R1
R6
R7
D2
LDP Adjacency
R4 -> R1, R5 = Label
25
LDP
Adjacency
R5->R4, R5=Pop


R8
R3
R9
R4
R2
S1
IP routed
R5
R1
Label-Switched
swap label
49 ->17
R6
R7
Tunnel routed
by filter
BGP NH = R5
Label 25 pushed
Label 49 pushed
Label-Switched
swap label
17 ->22
Label-Switched
Pop TE label
D2

LSP Tunnels forwarding

- Build around CEF
- At head

    uses CEF (IP-->tag)

    TFIB (tag->tag)

- At midpoint uses TFIB (tag->tag)
- MPLS performance

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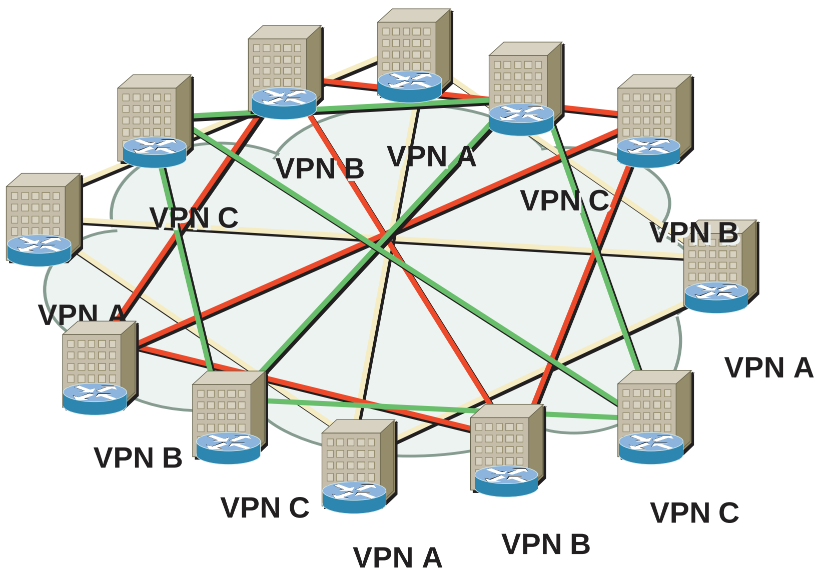
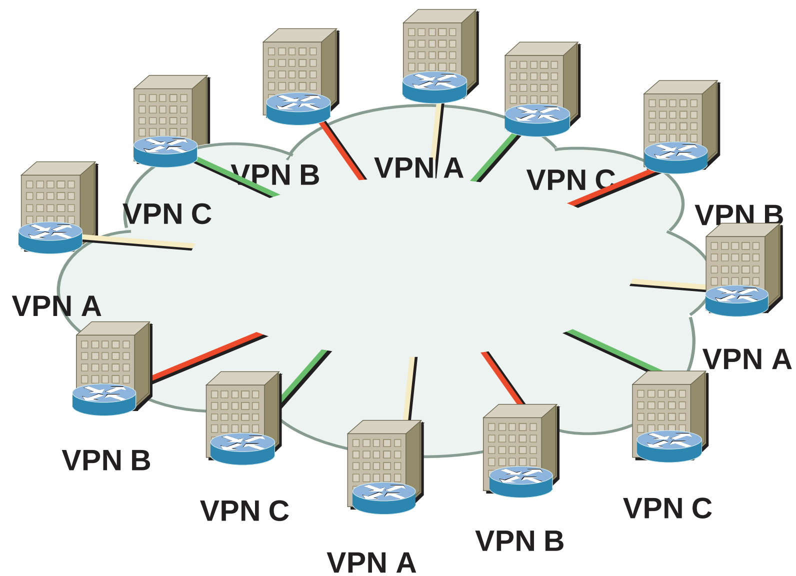
Benefits of Internet-Scale VPNs



Connection-Oriented
VPN Topology



Connectionless
VPN Topology

VPN Aware Network :
VPNs are "built-in" rather than "overlaid"

VPN Models - The Overlay model

- **Private trunks over a TELCO/SP shared infrastructure**
  - **Leased/Dialup lines**
  - **FR/ATM circuits**
  - **IP (GRE) tunnelling**
- **Transparency between provider and customer networks**
- **Optimal routing requires full mesh over the backbone**

VPN Models - The Peer model

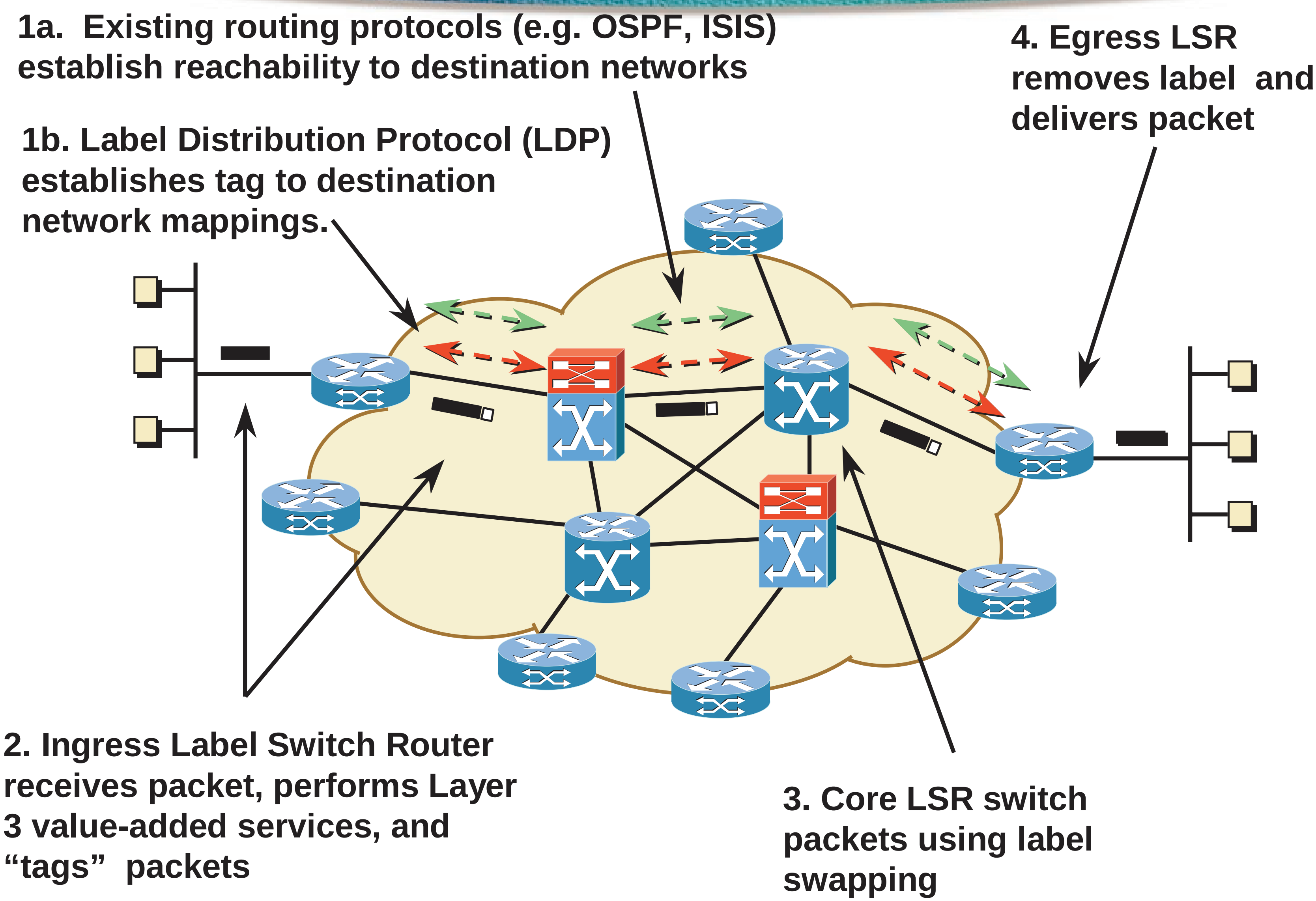
- **Both provider and customer network use same network protocol**
- **CE and PE routers have a routing adjacency at each site**
- **All provider routers hold the full routing information about all customer networks**
- **Private addresses are not allowed**
- **May use the virtual router capability**

  Multiple routing and forwarding tables based on Customer Networks

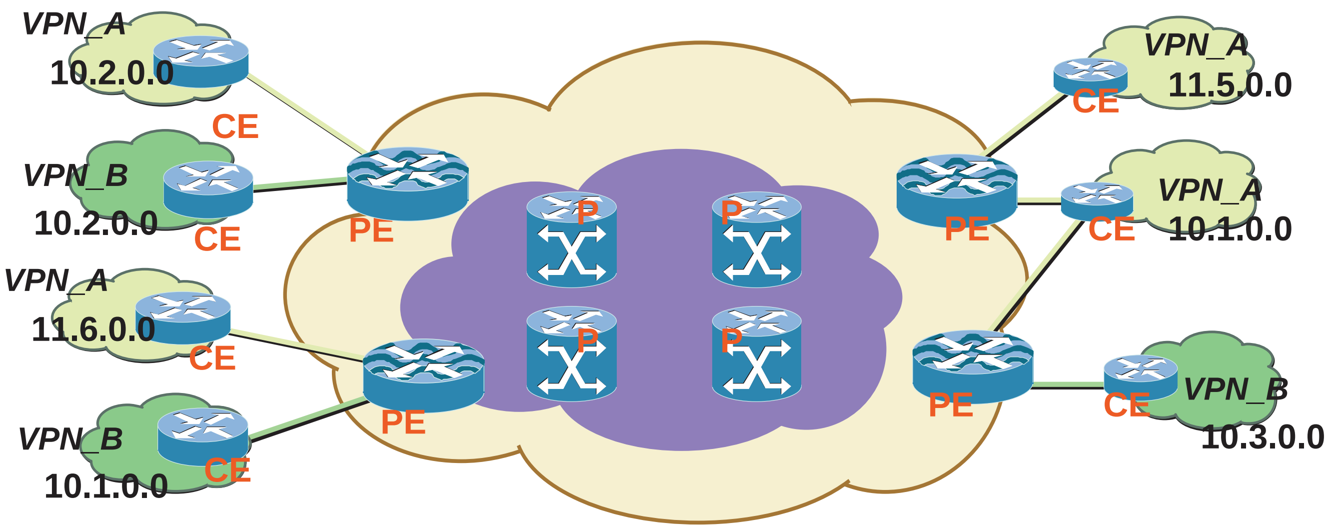
VPN Models - MPLS-VPN: The True Peer model

- **Same as Peer model BUT !!!**
- **Provider Edge routers receive and hold routing information only about VPNs directly connected**
- **Reduces the amount of routing information a PE router will store**
- **Routing information is proportional to the number of VPNs a router is attached to**
- **MPLS is used within the backbone to switch packets (no need of full routing)**

MPLS Operation

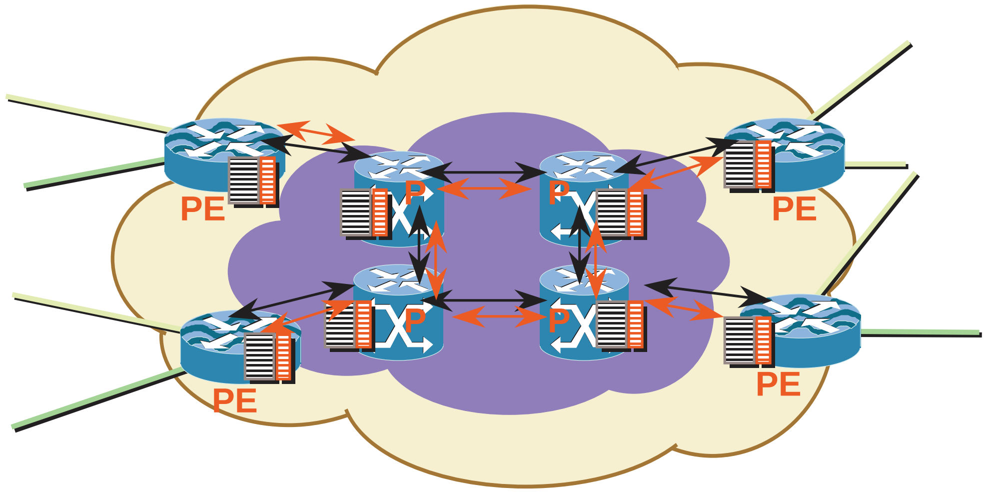


MPLS VPN
Routing Architecture



- P router = Provider Router (Core LSR)
- PE router = Provider Edge router (Edge LSR)
  knows which VPN each CE belongs to (by sub-interface)
- CE router = Customer Edge router
- RD (Route Distinguisher) = uniquely identify a VPN (AS#,VPN_ID)
- IPv4 Addresses are unique within VPN
- IPv4 Addresses might overlap across VPN's

MPLS VPN
Internal Reachability and Label

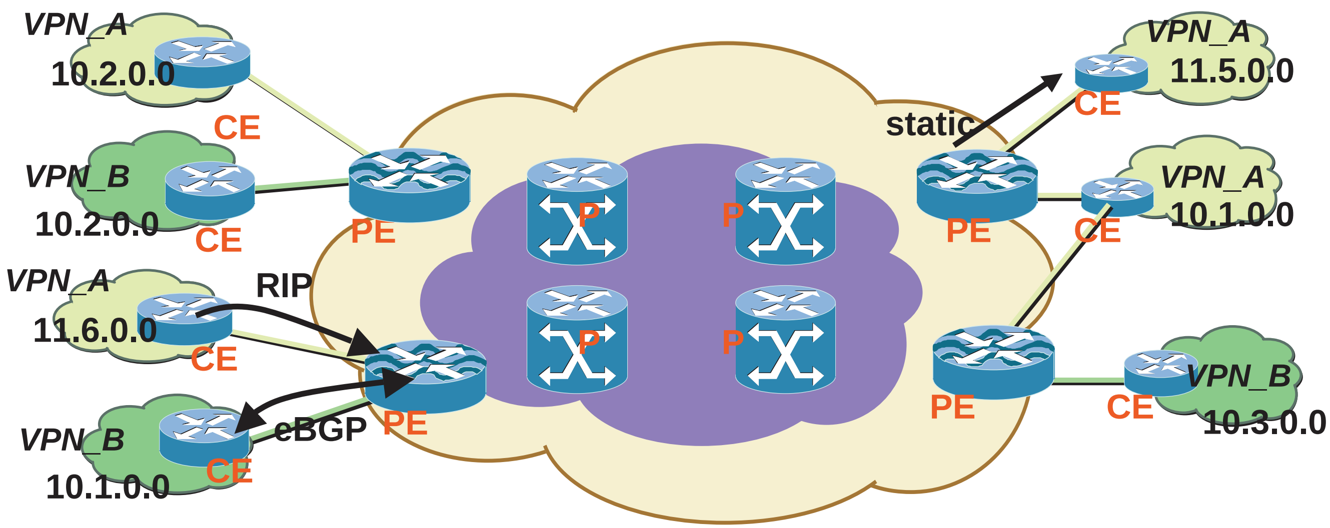


- **Each P routers, including PE has to maintain Internal Routes reachability and associated internal Labels.**

- **The FIB is populated by an IGP (I-ISIS, OSPF, EIGRP)**

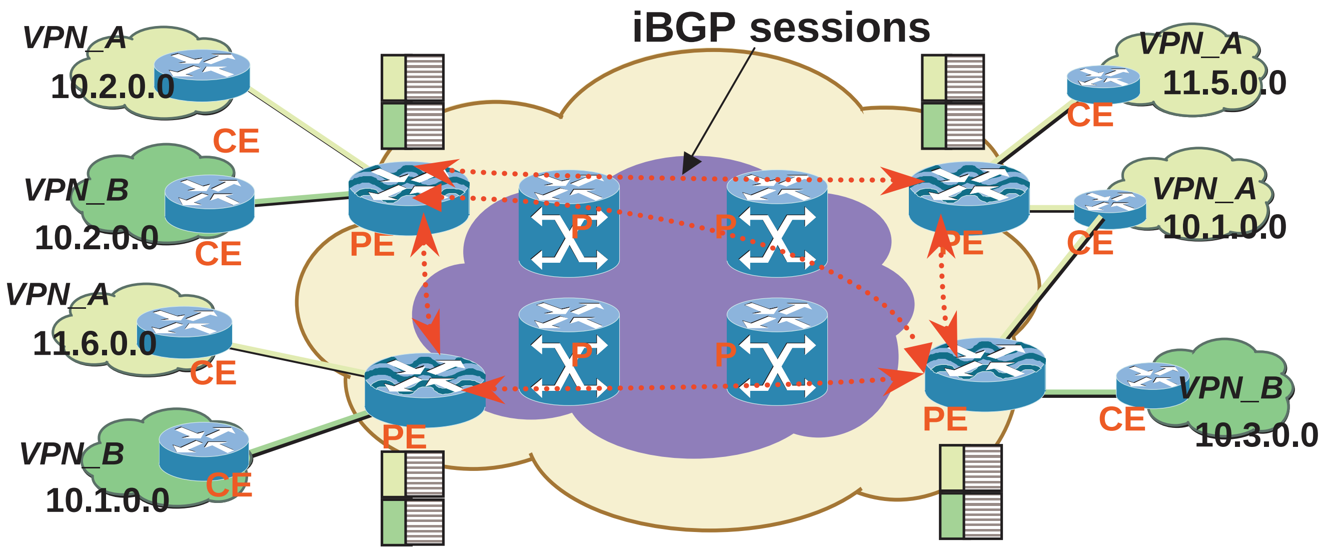
- **TFIB populated by LDP**

MPLS VPN
VPN-IPv4 Addresses



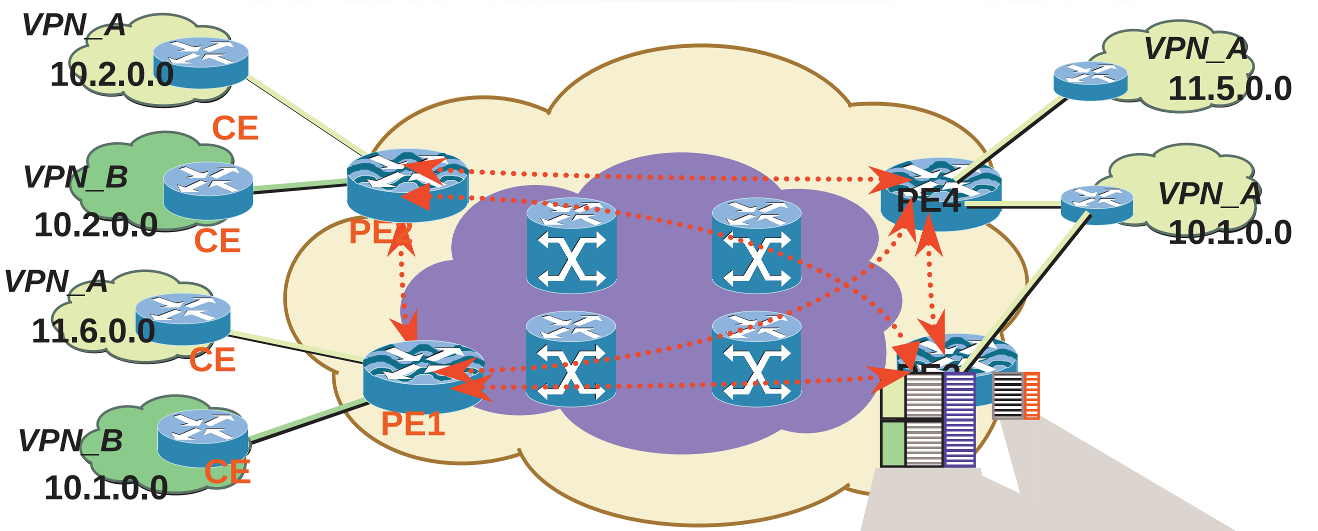
- **Ingress PE routers, learns routes from CE**
    - Static routing, eBGP or RIPv2
- **In order to guarantee the uniqueness of the customer address, the ingress PE router converts IPv4 address into a globally unique "*VPN-IPv4*" address**
- **A 64 bits "Route Distinguisher" is prepended to the customer IPv4 address and propagated via BGP to the egress PE's (BGP Multiprotocol Extension)**

Per VPN FIB (Forwarding Information Base)



- ***VPN-IPv4*** **address are propagated together with the associated** ***Label*** **in "*BGP multi-protocol extension"* (NLRI field)**
- **Additional community fields (64 bits Extended Community attribute) are associated to VPN-IPv4 address, to build a per VPN FIB :**
  - **"Target VPN" (list of), "VPN of Origin" , Site of Origin**
- **Filters (route-maps) are applied to tightly control *intra-VPN* and *inter-VPN* connectivity**
- **Creation of a per VPN RIB and FIB**

Label Binding to VPN-IPv4 addresses



- iBGP (Multiprotocol Extension) has distributed the Label associated with <*VPN-IPv4*> . Filters are applied on extended community attributes
- LDP has distributed the Label associated with Interior routes (*BGP next hop* add)
- Recursive lookup
  For each customer address the PE does a recursive lookup to find the path to the "*BGP next hop", * and build its TFIB
- Each <*VPN-IPV4 address* > is assigned, an Interior Label AND an Exterior Label

TFIB

<VPN_B,10.1> , iBGP next hop PE1	T1	T7
<VPN_B,10.2> , iBGP next hop PE2	T2	T8
<VPN_B,10.3> , iBGP next hop PE3	T3	T9
<VPN_A,11.6> , iBGP next hop PE1	T4	T7
<VPN_A,10.1> , iBGP next hop PE4	T5	TB
<VPN_A,10.4> , iBGP next hop PE4	T6	TB
<VPN_A,10.2> , iBGP next hop PE2	T7	T8

PE1, next hop	T7
PE2, ""	T8
PE3, ""	T9
PE1, ""	Ta
PE4, ""	Tb

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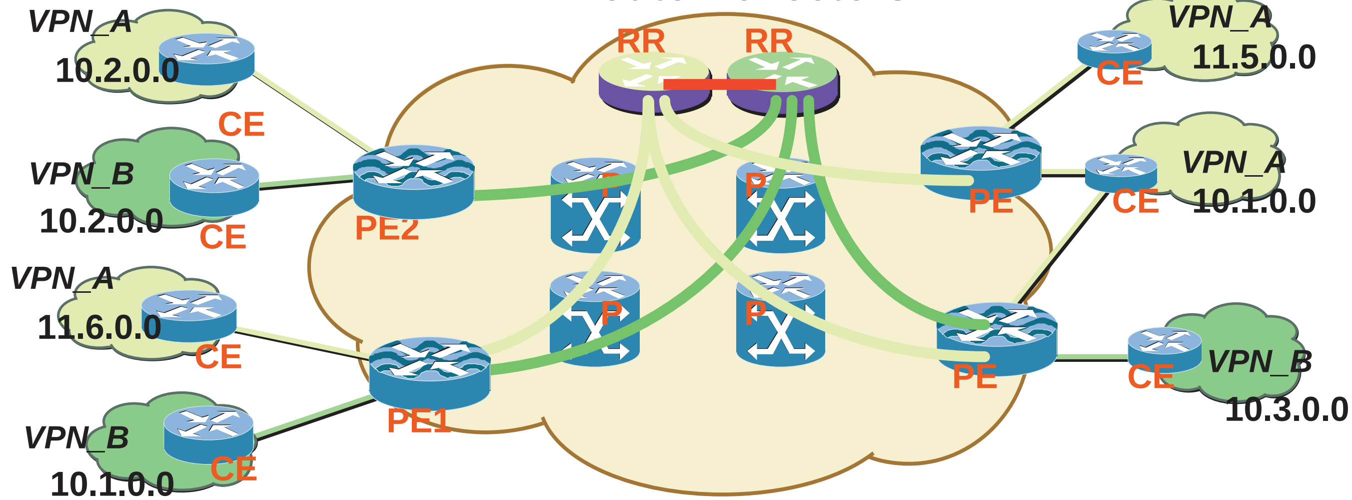
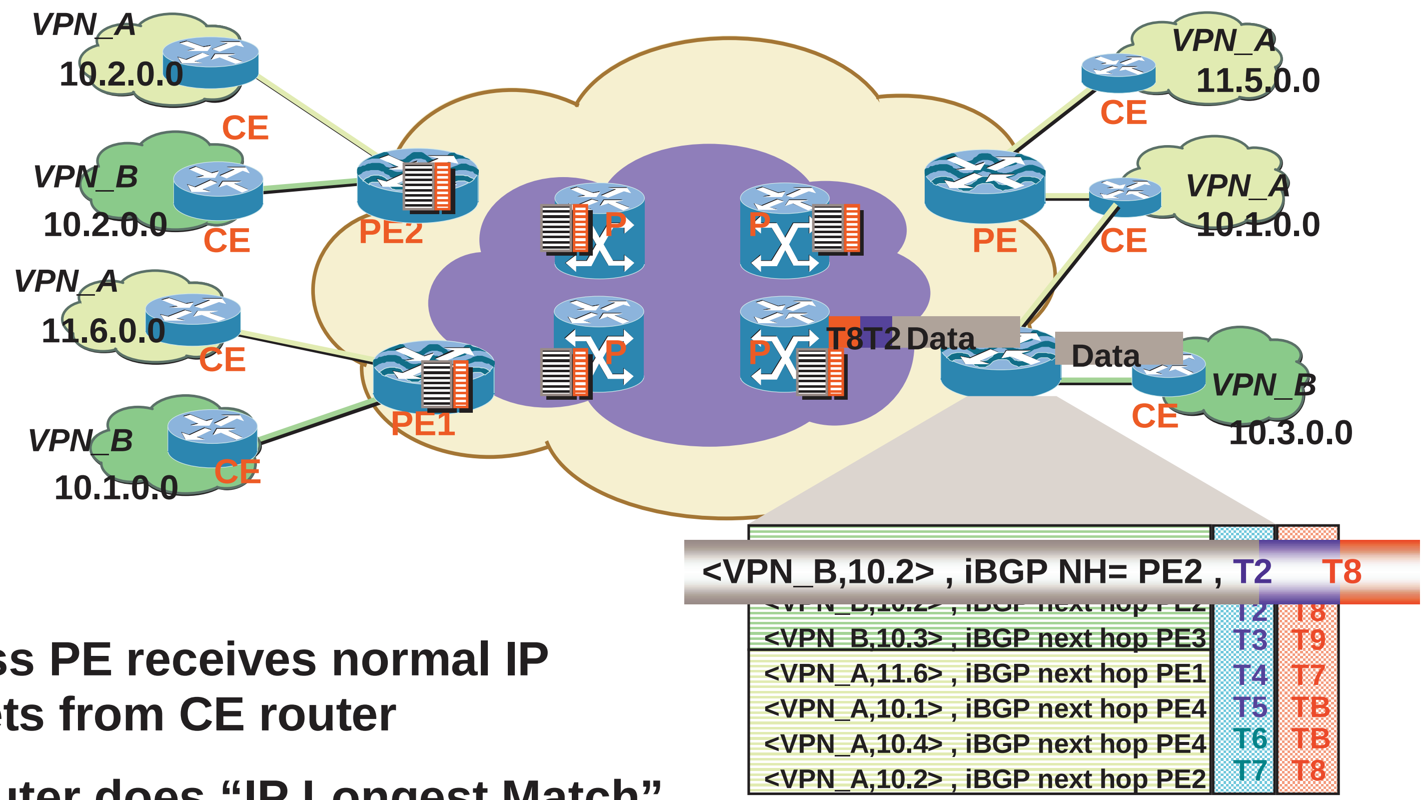
Scaling : BGP Hierarchical Architecture



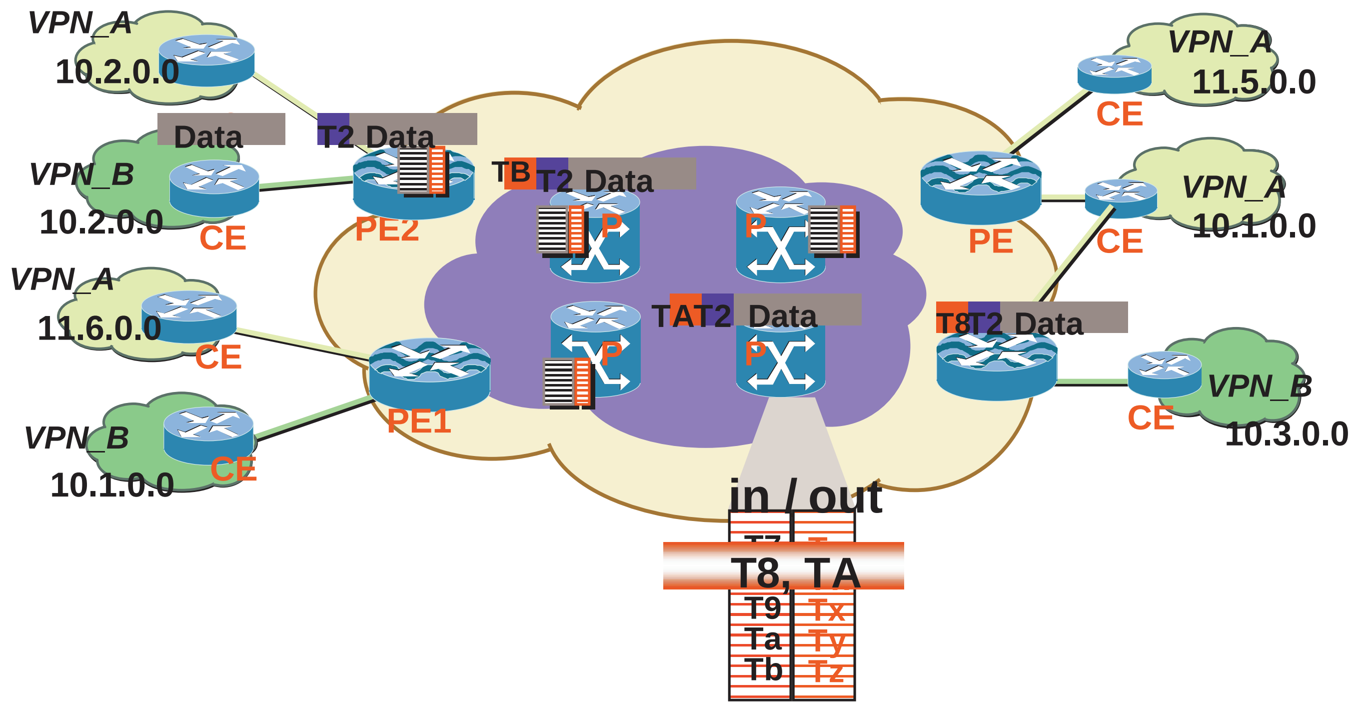
- Full mesh of BGP peers => scalability issues for Very Large *VPN's*
- Use of *BGP Route Reflector* to scale the VPN BGP peering
- for resiliency peers "multiple VPN PE" to multiple VPN RR
- PE needs to have the routing information only for the VPN's it is connected to.
- peer RR together to allow inter VPN communications

Forwarding and Isolation: Stacks of Label



- Ingress PE receives normal IP Packets from CE router
- PE router does "IP Longest Match" from VPN_B FIB , find iBGP next hop PE2 and *impose a stack of Labels's :* exterior Label T2 + Interior Label T8

Forwarding and Isolation: Stack of Label



- All Subsequent P routers do switch the packet **Solely on Interior Label**
- Egress PE router, removes **Interior Label**
- Egress PE uses **Exterior Label** to select which VPN/CE to forward the packet to.
- **Exterior Label** is removed and packet routed to CE router

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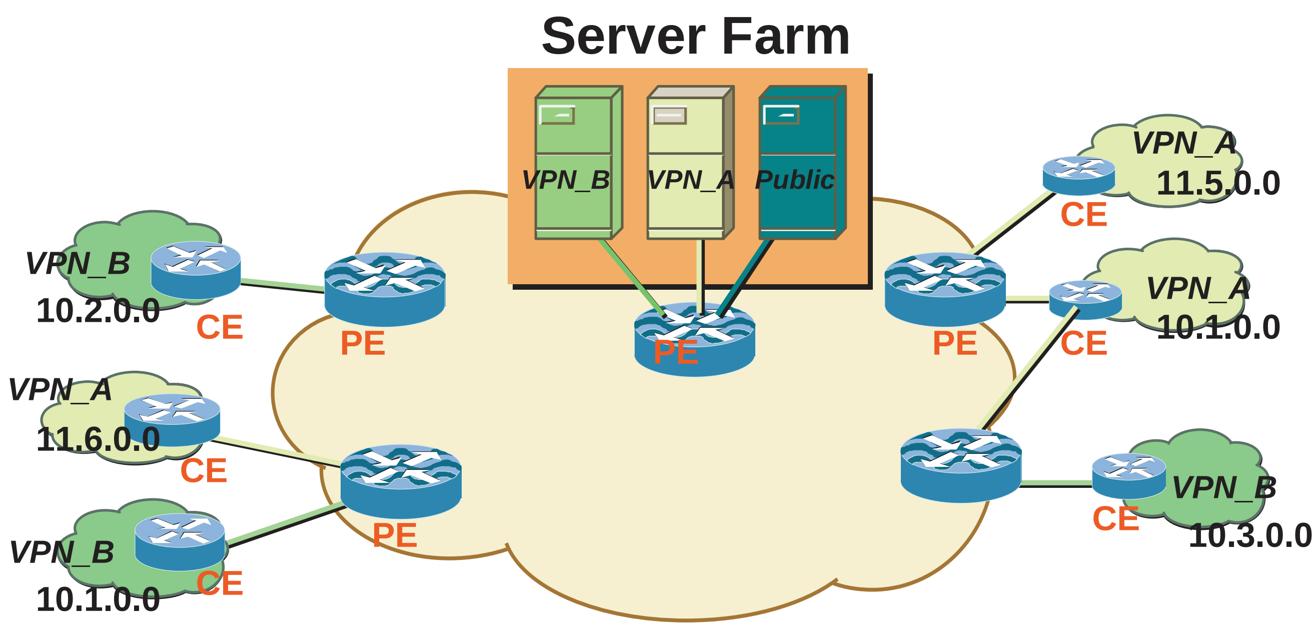
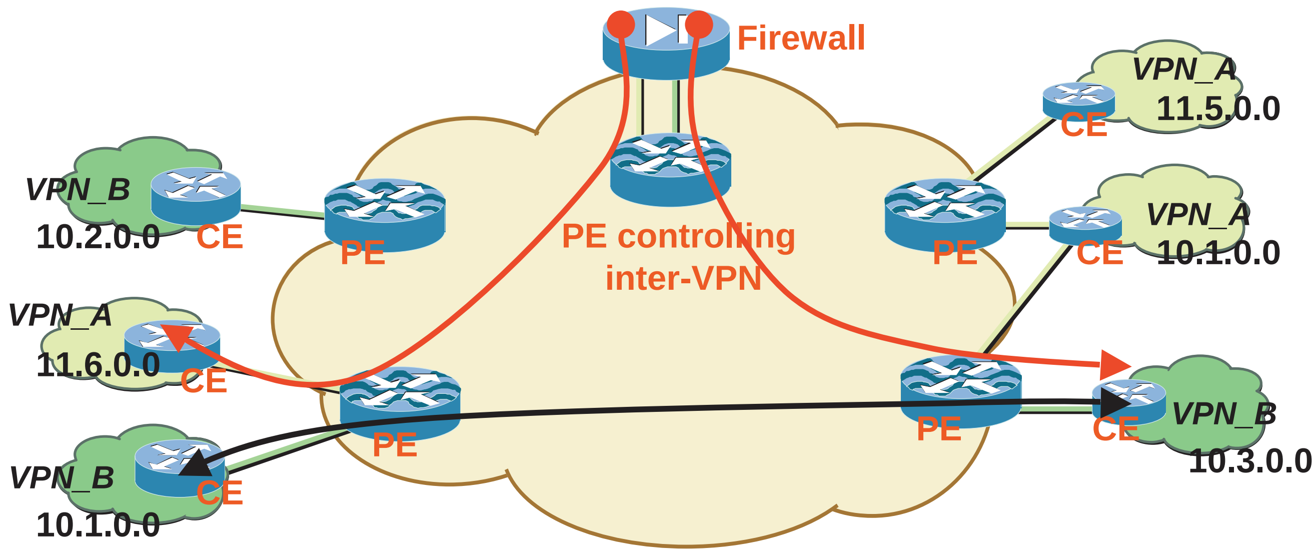
Closed User Group Servers



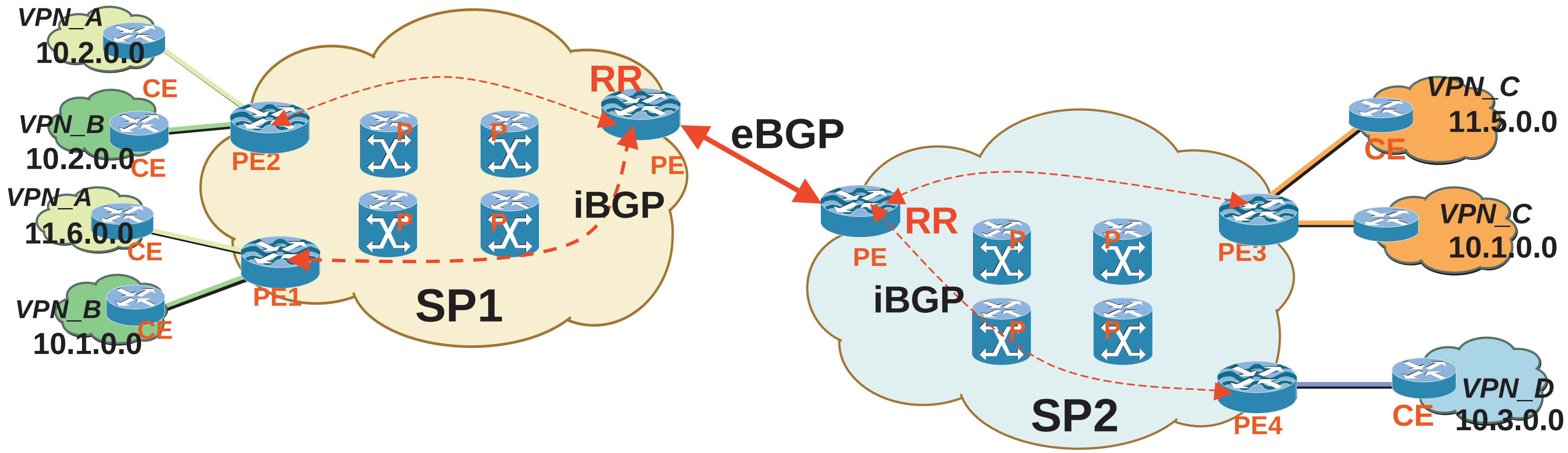
- Green VPN customers access to Green Server only
- There may be “public” servers in a common public “VPN”
- Server IPv4 address is advertised only in the VPN it belongs to.
- VLAN are used to isolate per VPN servers, in the “server farm”

Inter VPN's communications



- Inter VPN's communication is controlled by mean of "Community filtering" (VPN of Origin, Target VPN)
- VPN Leakage point control the inter-VPN point (may be multiple)
- *intra-VPN* can be any to any while *inter-VPN* can be hub and spoke
    - Central Firewall control
- Internet Connectivity can be provided in the same manner

VPN Spanning multiple domains



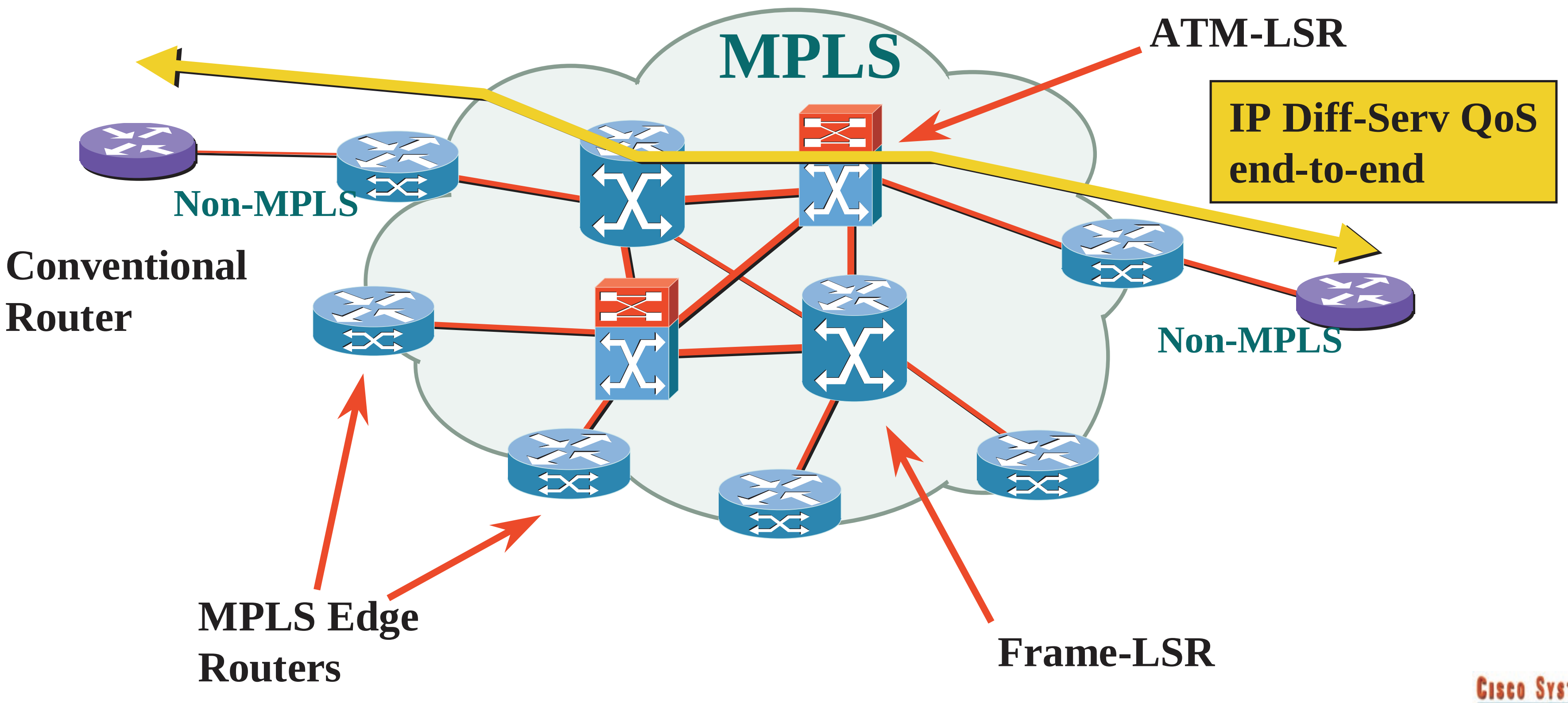
- VPN Membership can be extended across SP boundaries
- Private BGP peering
- *Multi-Protocol extension* and *community* attributes are carried through the external BGP private peer.
- *RD's* are affected independently by both SP
- Reachability is controlled by both BGP peers (VPN of Origin, Target VPN)

Agenda

- Introduction to MPLS
- Label forwarding
- Label Distribution Protocol
- Traffic Engineering
- MPLS VPN
- MPLS QoS

What is Label/MPLS QoS ?

Support of Consistent IP Diff-Serv Classes of Service end-to-end when part of the network is running MPLS



MPLS QoS: 3 Steps

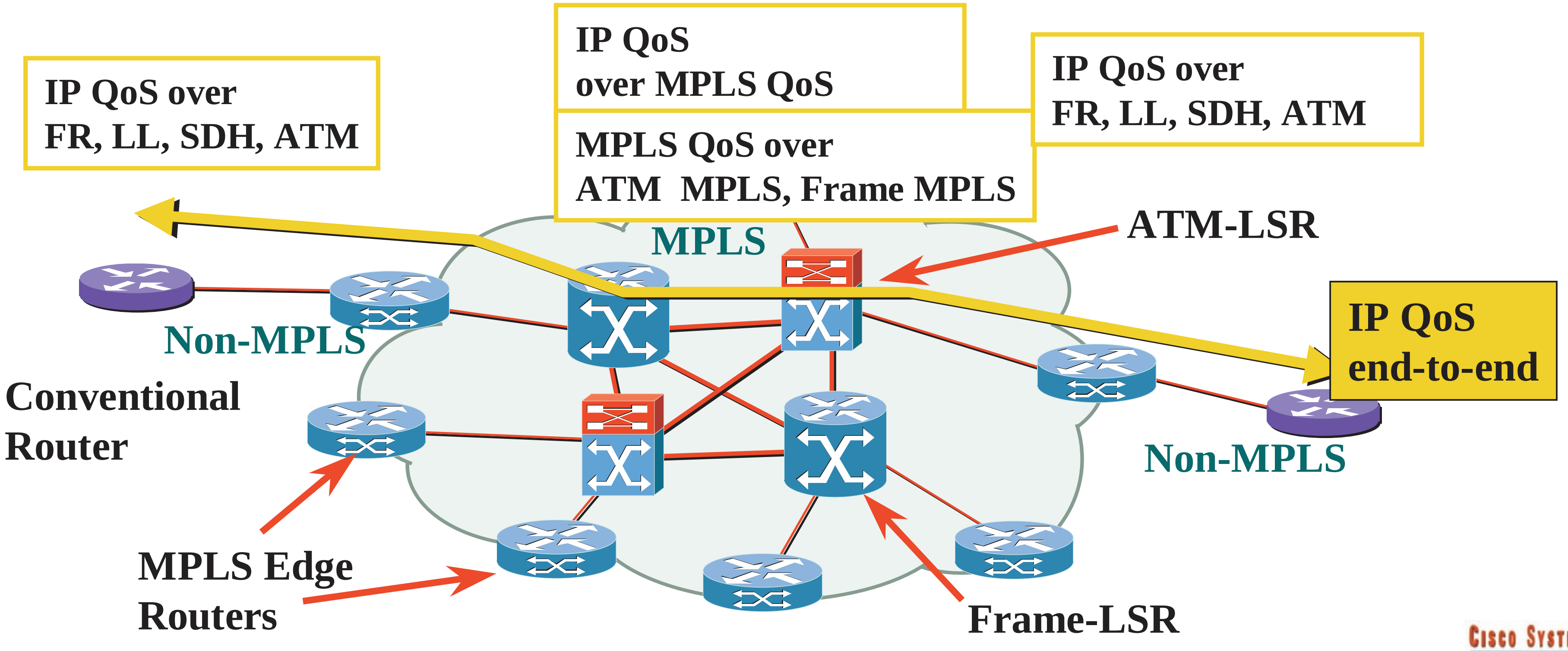
1) in non-MPLS part :

existing IP mechanism (CAR) to mark IP DS-byte

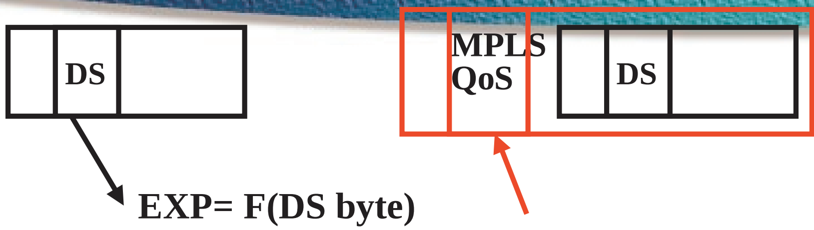
existing IP Mechanisms (WRED/WFQ) for service differentiation

2) Mapping IP DS-byte into EXP field on MPLS Edge

3) Supporting Differentiation based on EXP field in MPLS Backbone

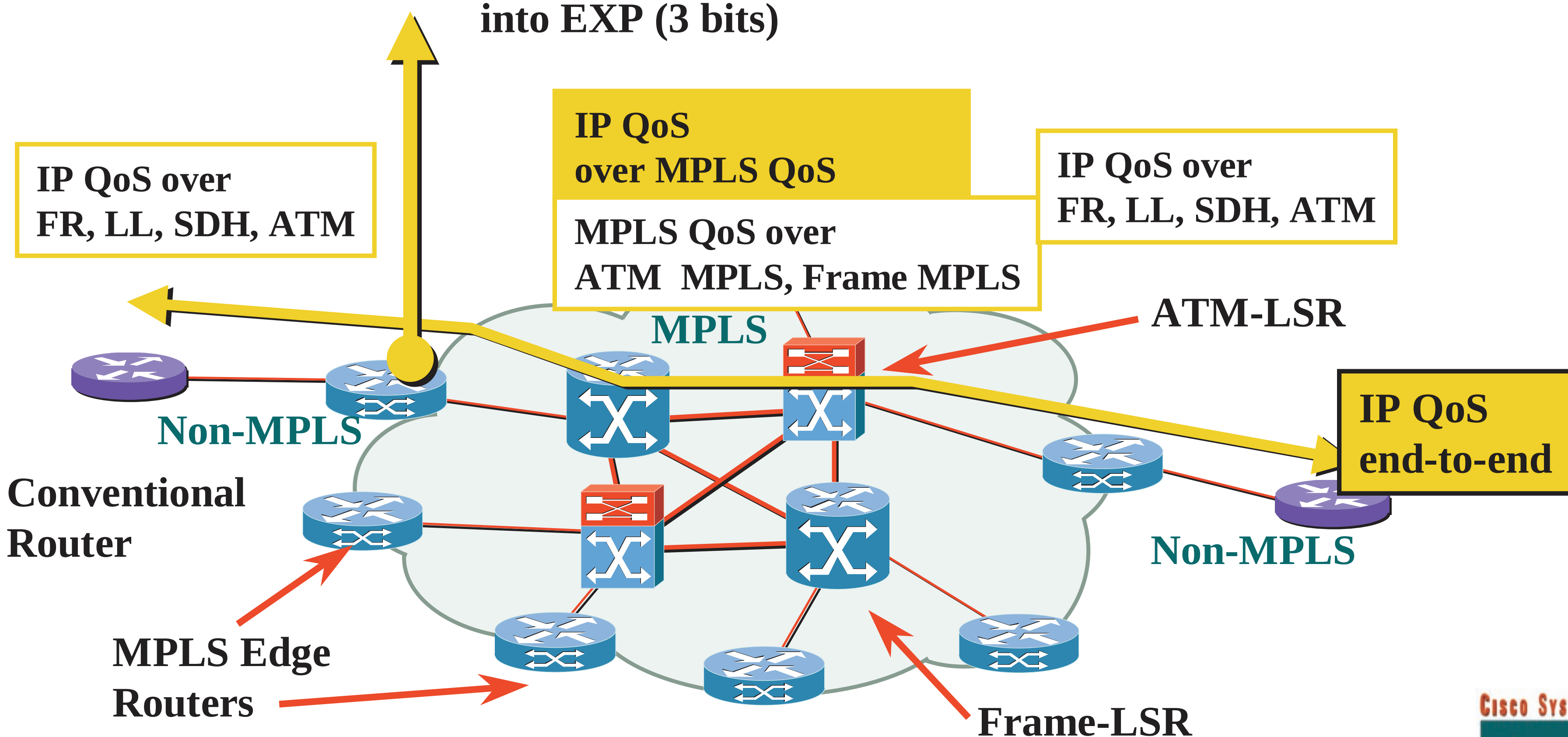


Mapping IP QoS into EXP



ATM LSR= ATM Switch running MPLS

At MPLS Imposition: DS-Byte (initially Precedence) mapped into EXP (3 bits)



Supporting MPLS QoS over non-ATM MPLS

- On MPLS Frame Interface (ie non-ATM), it's simple:
  - Every MPLS packet has explicit indication of QoS in MPLS Header
  - Use EXP field to trigger Selective Scheduling (WFQ) and Selective Discard (WRED) ; exactly like use of IP DS-byte in non-MPLS
- Net result is end-to-end QoS indistinguishable from non-MPLS network

Supporting MPLS QoS over ATM MPLS

- Main challenges:
  - No QoS field in ATM cell header
  - No WRED in switches
- Two modes:
  - Single `VC' ABR
  - Multi-`VC' TBR
    (closer to Frame QoS)
  - Each has advantages and drawbacks

TBR= Tag Bit Rate
ATM Service Category better suited to IP

Single-ABR and Multi-TBR

- Multi-VC TBR Mode:
  - Congestion managed directly at every hop (IP and ATM hops)
  - Possible Discard at every hop
  - Resource Allocation per QoS per link; does not have to concern itself with topology and geography
- Single-VC ABR:
  - No Loss in the ATM fabric
  - Discard possible only on the Edge performed by Routers
  - Resource Allocation optionally per Pair of Edge Routers. Sharing of bandwidth across QoS indirect via WRED profiles

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