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The bridge to possible

Segment Routing MPLS Introduction: Follow the Labels

Luc De Ghein –Technical Leader CX

BRKENT-2005

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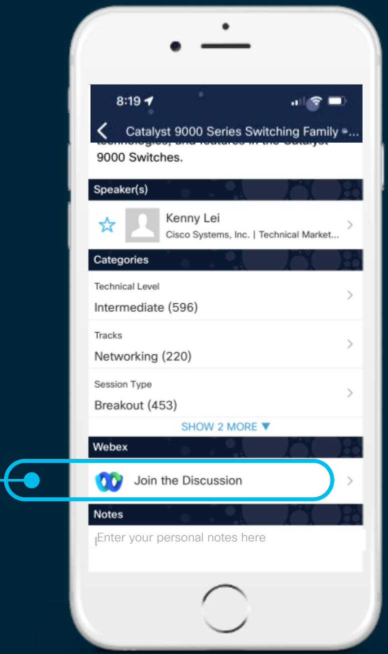

8:19

Catalyst 9000 Series Switching Family •...

9000 Switches.

Speaker(s)

Kenny Lei
Cisco Systems, Inc. | Technical Market...

Categories

Technical Level
Intermediate (596)

Tracks
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Agenda

- Introduction
- The Labels
- MPLS Forwarding
- Ti-LFA
- SR Policy
- On Demand Next Hop (ODN)
- SR Operations, Administration, and Maintenance (OAM)
- Key Takeaways

Introduction

Stay Up-To-Date

http://www.segment-routing.net/

https://www.linkedin.com/groups/8266623

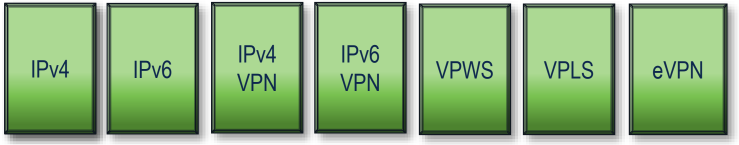
https://twitter.com/SegmentRouting

https://www.facebook.com/SegmentRouting/

Before We Get Started

- This session in on SR MPLS

- The services you are used, still work



IPv4

IPv6

IPv4 VPN

IPv6 VPN

VPWS

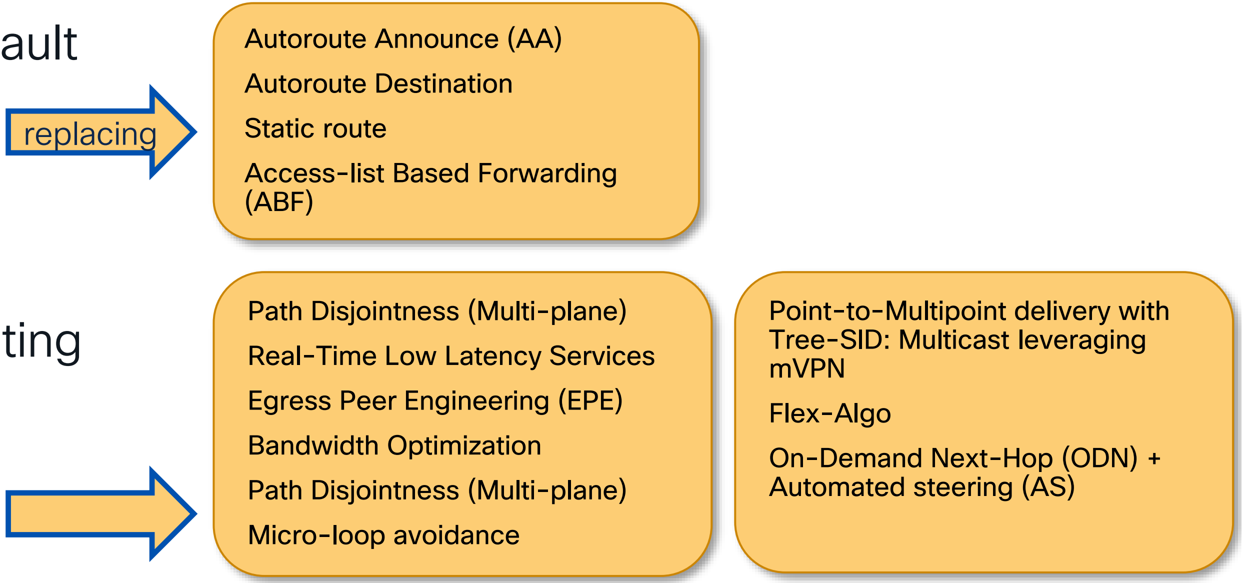
VPLS

eVPN

Including Inter-AS Option A, B, and C

Why SR?

- No LDP
  - But interworking is still possible
- No RSVP-TE
- Load balancing by default
- Simplified forwarding
  - Based on color
  - Automated steering
- Simplified troubleshooting
- Better protection
- Many new features



Autoroute Announce (AA)

Autoroute Destination

Static route

Access-list Based Forwarding (ABF)

Path Disjointness (Multi-plane)

Real-Time Low Latency Services

Egress Peer Engineering (EPE)

Bandwidth Optimization

Path Disjointness (Multi-plane)

Micro-loop avoidance

Point-to-Multipoint delivery with Tree-SID: Multicast leveraging mVPN

Flex-Algo

On-Demand Next-Hop (ODN) + Automated steering (AS)

In a Nutshell

Source Routing paradigm

Stateless IP fabric

Data Plane

MPLS
(segment labels)

IPv6
(+ SR extension header)

Control Plane

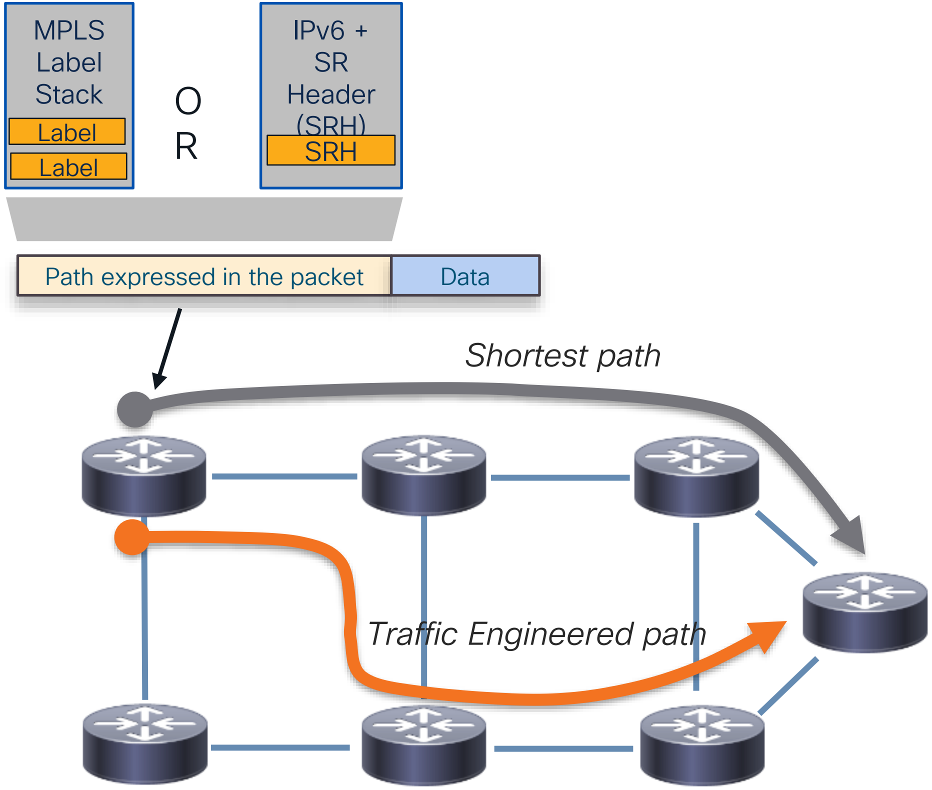
Routing protocols with extensions
(IS-IS, OSPF, BGP)

SDN controller
(BGP, PCEP, NETCONF/YANG)

Path Options

Dynamic
(Optimized CSPF computation)

Explicit
(expressed in the packet)



The Labels

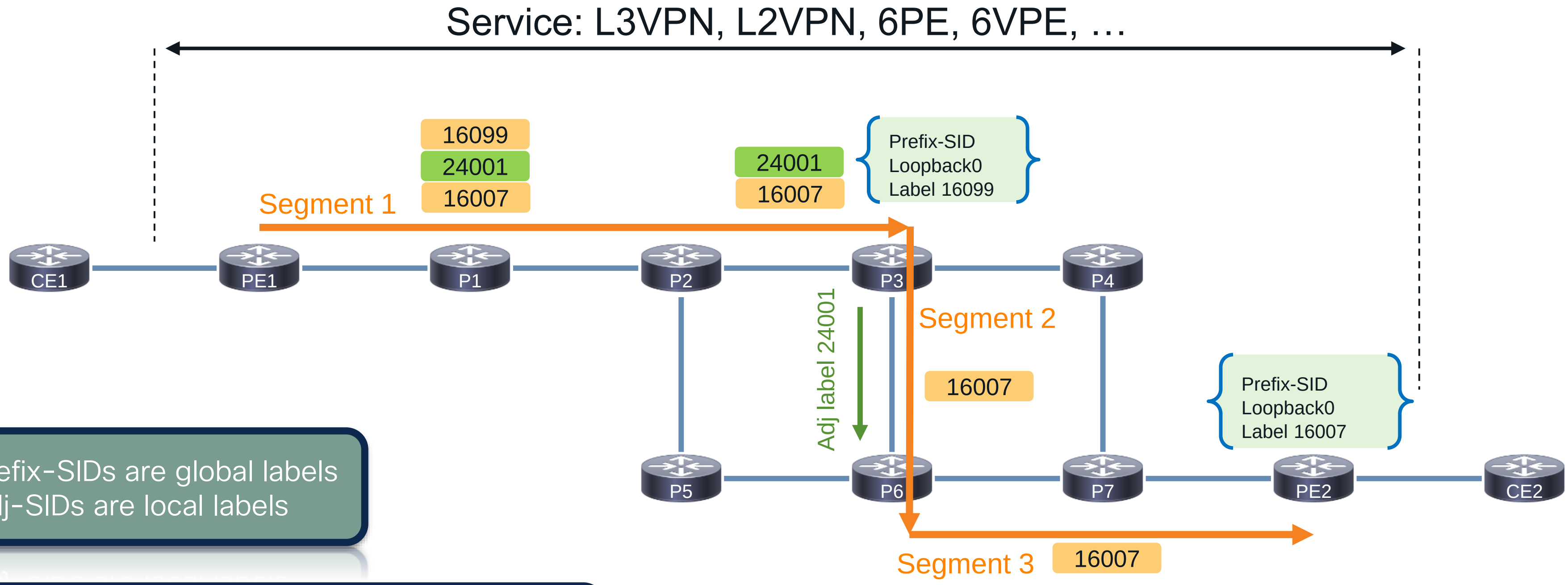
A Segment

- A segment is an instruction
  - with MPLS forwarding: segment = label
- Link-state routing protocol is needed to advertise
  - Segments (Prefix-SID, Adjacency-SID)
  - MPLS Label
- Removing the signaling and state (no LDP/ no RSVP-TE)
- Controller/SDN can be used if/when needed

*SID = Segment Identifier

All Together

24001	→	Adj-SID label
16007	→	Prefix-Sid label



Prefix-SIDs are global labels
Adj-SIDs are local labels

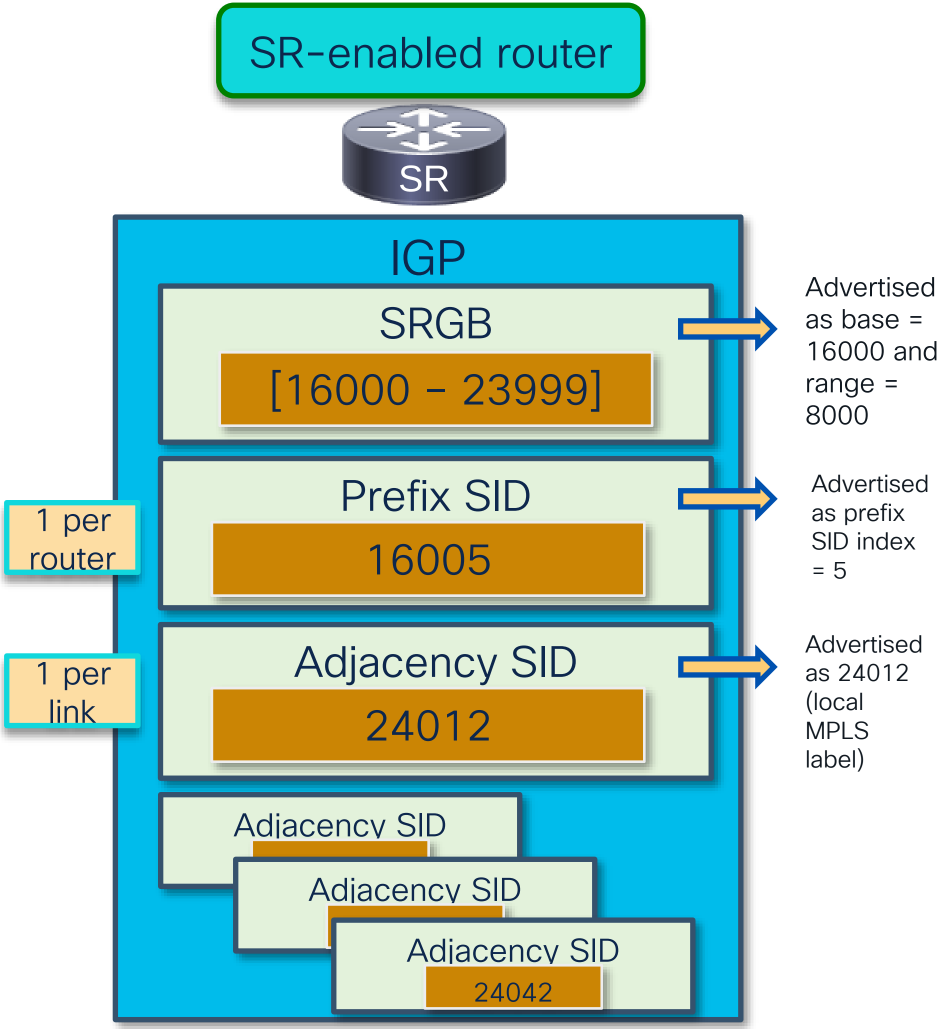
Deviate from shortest path – Source Routing:
Traffic Engineering based on SR

Default: PHP at each segment

MPLS Forwarding

SIDs

- Prefix SID
  - SID encoded as an index
  - Index represents an offset from SRGB base
  - Index globally unique
  - SRGB may vary across LSRs
  - SRGB (base and range) advertised with router capabilities
- Adjacency SID
  - SID encoded as absolute (i.e. not indexed) value
  - Locally significant
  - Automatically allocated for each adjacency
  - From label range [24,000-max] used for dynamic label allocation



SR-enabled router

SR

IGP

SRGB

[16000 – 23999]

Advertised as base = 16000 and range = 8000

1 per router

Prefix SID

16005

Advertised as prefix SID index = 5

1 per link

Adjacency SID

24012

Advertised as 24012 (local MPLS label)

Adjacency SID

Adjacency SID

Adjacency SID

24042

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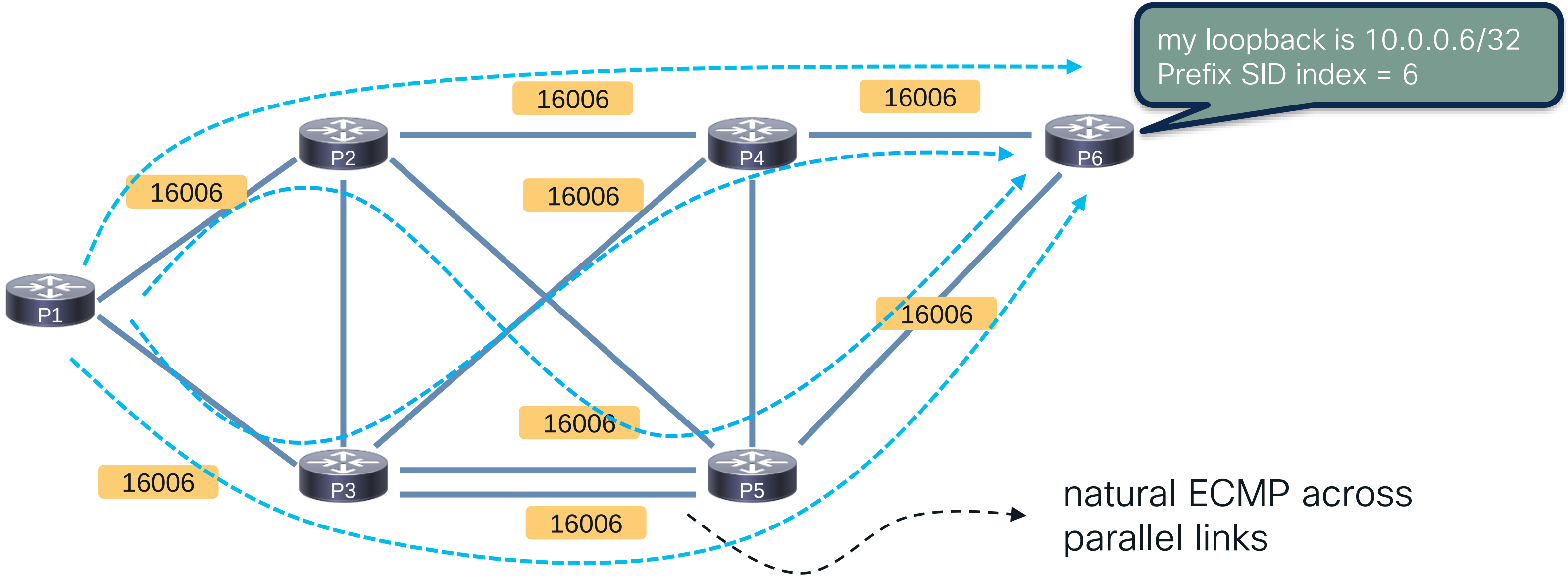
Global Labels

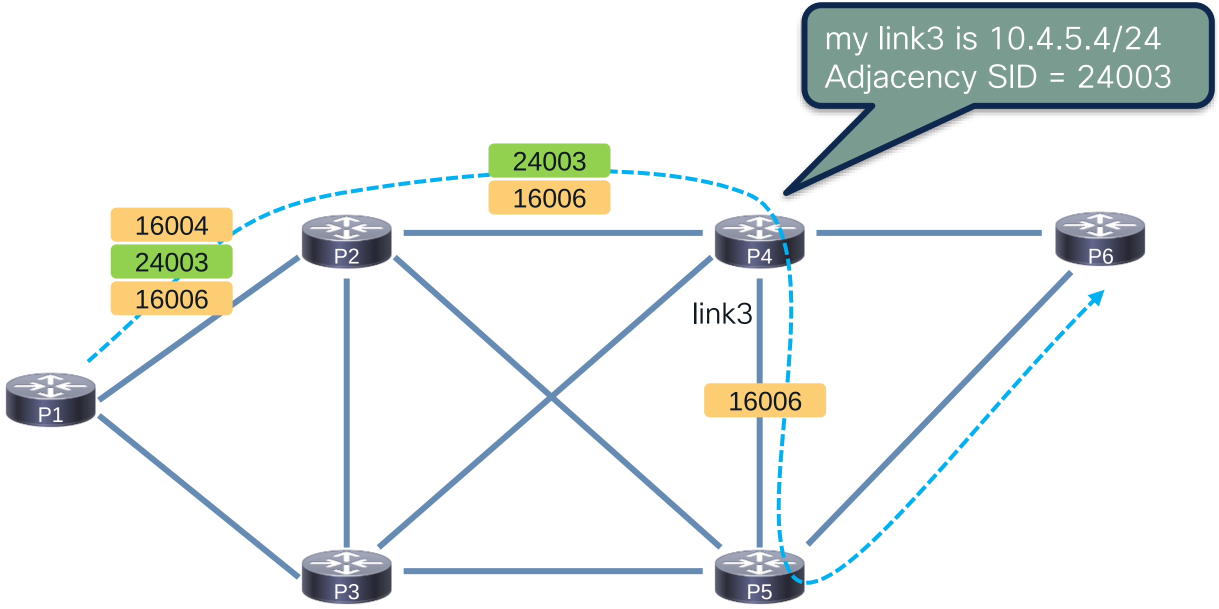
- Recommended same SRGB on all routers
- ‘Node’ label = get the traffic to me, by shortest route, possibly with ECMP
- A packet injected anywhere with top label 16006 will go to R6



natural ECMP across parallel links

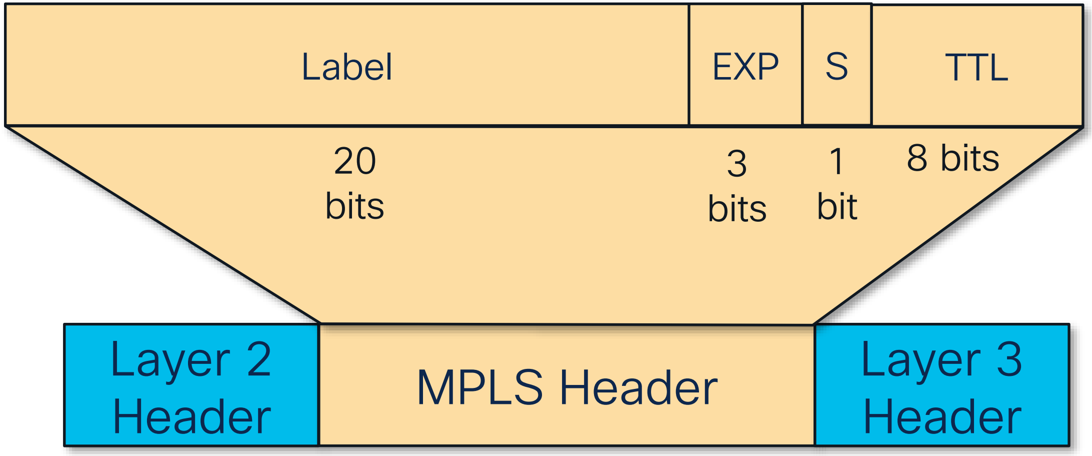
Local Adjacency SID Labels

- Force the packet to take a link at a router


my link3 is 10.4.5.4/24
Adjacency SID = 24003

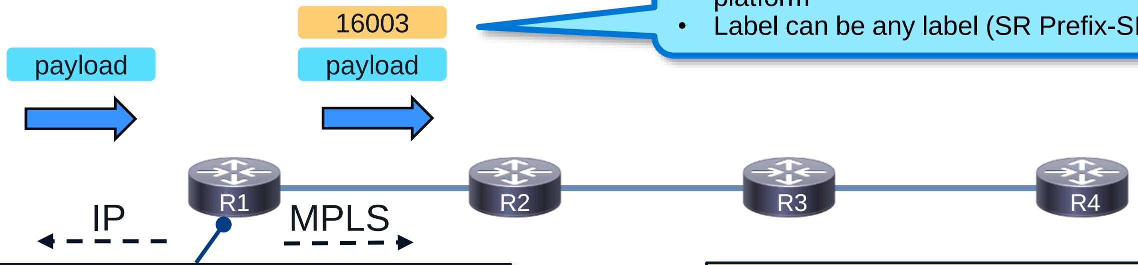
No Change in MPLS Forwarding

- MPLS label operations:
  - Push, Pop, and Swap
- We have, as before, …
  - Special labels {0 - 15}
    - PHP (default behavior, also for SR)
    - explicit-null for IPv4 and IPv6
  - QOS propagation (EXP bits)
    - Still uniform model, pipe, and short pipe model
  - TTL propagation as usual
  - Load balancing as before
    - FAT label support



MPLS Label Operation: Push Label(s)

- Push can occur at ingress of MPLS domain
  - MPLS label stack added in CEF (FIB) table
  - Top label is SR label; other labels can be service labels (MPLS VPN, BGP-LU, etc.)
- Push can occur at intermediate MPLS (P) router
  - MPLS label(s) added in LFIB (active protection)



- Label stack added can be up to size supported by the platform
- Label can be any label (SR Prefix-SID, Adj-SID label, …)

```
RP/0/0/CPU0:R1# show route 10.100.1.3/32

Routing entry for 10.100.1.3/32
  Known via "isis 1", … , labeled SR, …
   Routing Descriptor Blocks
    10.1.15.5, from 10.100.1.3, via GigabitEthernet0/0/0/0
      Route metric is 60
```

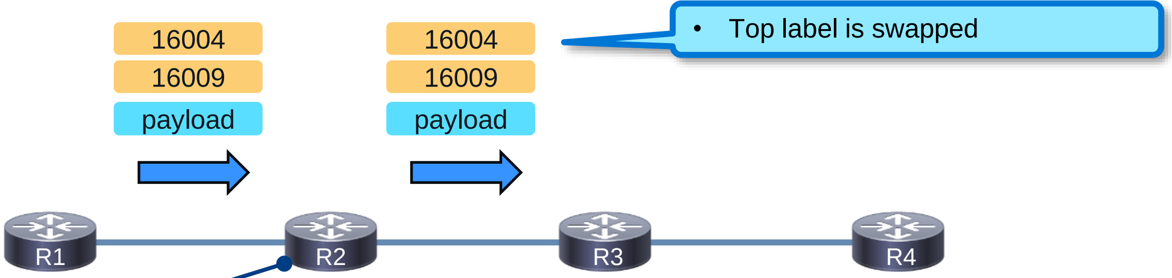
```
RP/0/0/CPU0:R1# show cef 10.100.1.3/32

10.100.1.3/32, …  labeled SR, …

 via 10.1.12.2/32, GigabitEthernet0/0/0/1,…
 local label 16003      labels imposed {16003}
```

MPLS Label Operation: Swap Label(s)

- Swap occurs at intermediate MPLS (P) router
  - Only top label is swapped
  - MPLS label is swapped in LFIB
  - Other labels are not touched (EXP bits, TTL)
  - Within one SR segment, top label is swapped with same label



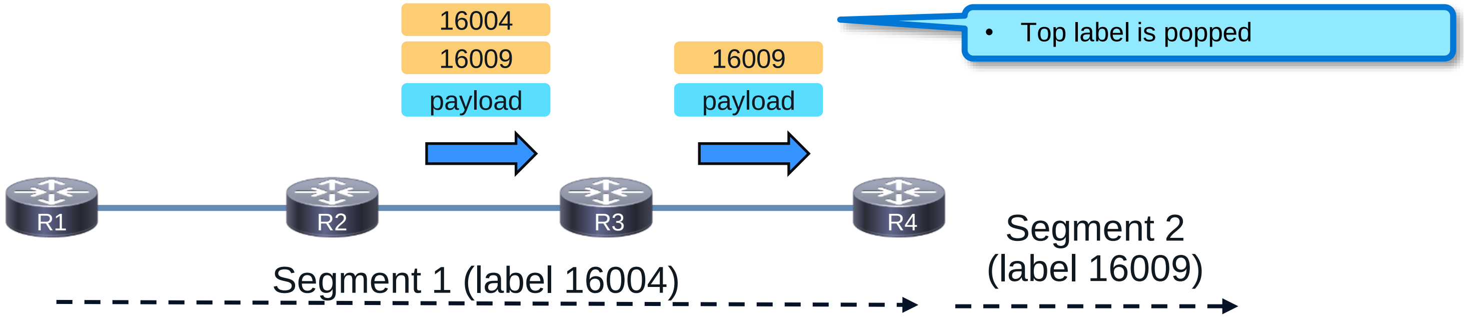
- Top label is swapped

```
RP/0/0/CPU0:R2# show mpls forwarding labels 16004

Local  Outgoing    Prefix             Outgoing     Next Hop        Bytes
Label  Label       or ID              Interface                    Switched
------ ----------- ------------------ ------------ --------------- ------------
16004  16004       SR Pfx (idx 4)     Gi0/0/0/1    10.1.59.9       1420
```

MPLS Label Operation: Pop Label(s)

- Pop occurs at intermediate MPLS (P) router: top label is removed
- By default on penultimate router of one SR segment
  - Label stack could become unlabeled
  - Label stack can still have other labels
    - e.g. when packet is moved from one SR segment to another SR segment

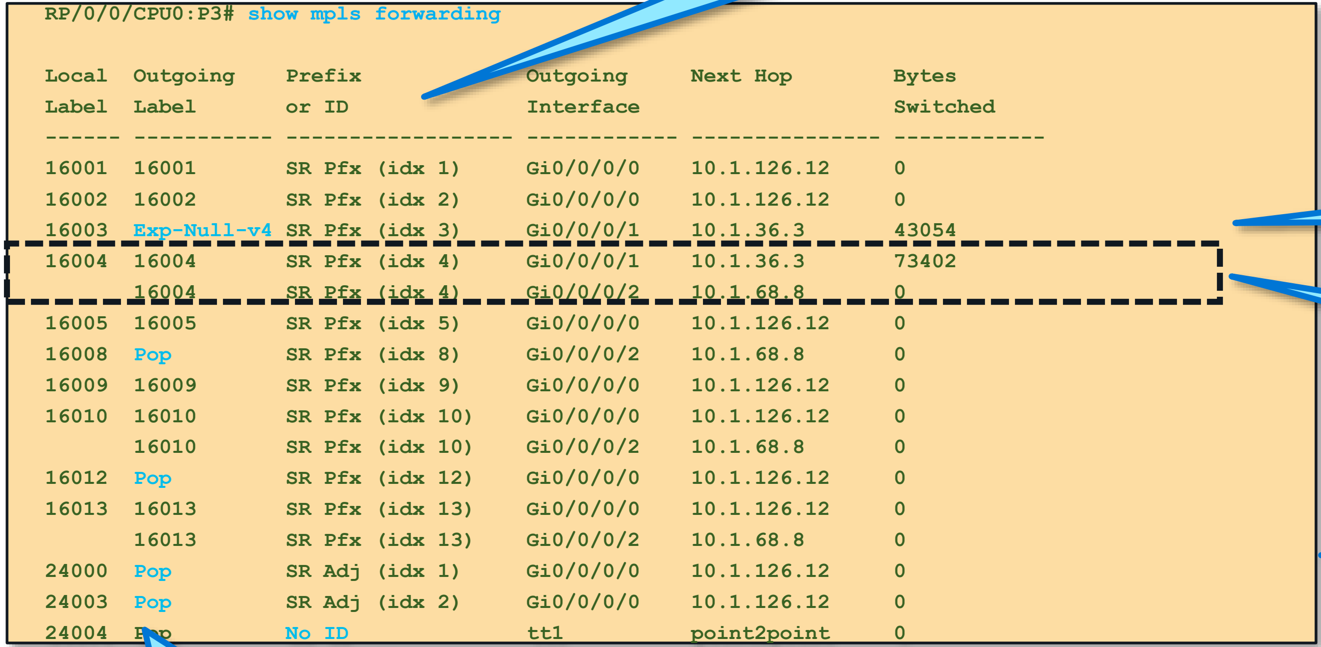


- Top label is popped

```
RP/0/0/CPU0:R3# show mpls forwarding labels 16004

Local  Outgoing    Prefix             Outgoing     Next Hop        Bytes
Label  Label       or ID              Interface                    Switched
------ ----------- ------------------ ------------ --------------- ------------
16004  Pop         SR Pfx (idx 4)     Gi0/0/0/3    10.1.46.4       1880280
```

LFIB



```
RP/0/0/CPU0:P3# show mpls forwarding

Local  Outgoing    Prefix             Outgoing     Next Hop        Bytes
Label  Label       or ID              Interface                    Switched
------ ----------- ------------------ ------------ --------------- ------------
16001  16001       SR Pfx (idx 1)     Gi0/0/0/0    10.1.126.12     0
16002  16002       SR Pfx (idx 2)     Gi0/0/0/0    10.1.126.12     0
16003  Exp-Null-v4 SR Pfx (idx 3)     Gi0/0/0/1    10.1.36.3       43054
16004  16004       SR Pfx (idx 4)     Gi0/0/0/1    10.1.36.3       73402
       16004       SR Pfx (idx 4)     Gi0/0/0/2    10.1.68.8       0
16005  16005       SR Pfx (idx 5)     Gi0/0/0/0    10.1.126.12     0
16008  Pop         SR Pfx (idx 8)     Gi0/0/0/2    10.1.68.8       0
16009  16009       SR Pfx (idx 9)     Gi0/0/0/0    10.1.126.12     0
16010  16010       SR Pfx (idx 10)    Gi0/0/0/0    10.1.126.12     0
       16010       SR Pfx (idx 10)    Gi0/0/0/2    10.1.68.8       0
16012  Pop         SR Pfx (idx 12)    Gi0/0/0/0    10.1.126.12     0
16013  16013       SR Pfx (idx 13)    Gi0/0/0/0    10.1.126.12     0
       16013       SR Pfx (idx 13)    Gi0/0/0/2    10.1.68.8       0
24000  Pop         SR Adj (idx 1)     Gi0/0/0/0    10.1.126.12     0
24003  Pop         SR Adj (idx 2)     Gi0/0/0/0    10.1.126.12     0
24004  Pop         No ID              tt1          point2point     0
```

- SR Prx or SR Adj

- Special labels {0-15} are still used

- ECMP, can only be Prefix-SID

- Data plane makes no distinction between Prefix-SID and Adj-SID

- Any Adj-SID will have pop operation

- Binding entry (used with SR-TE)

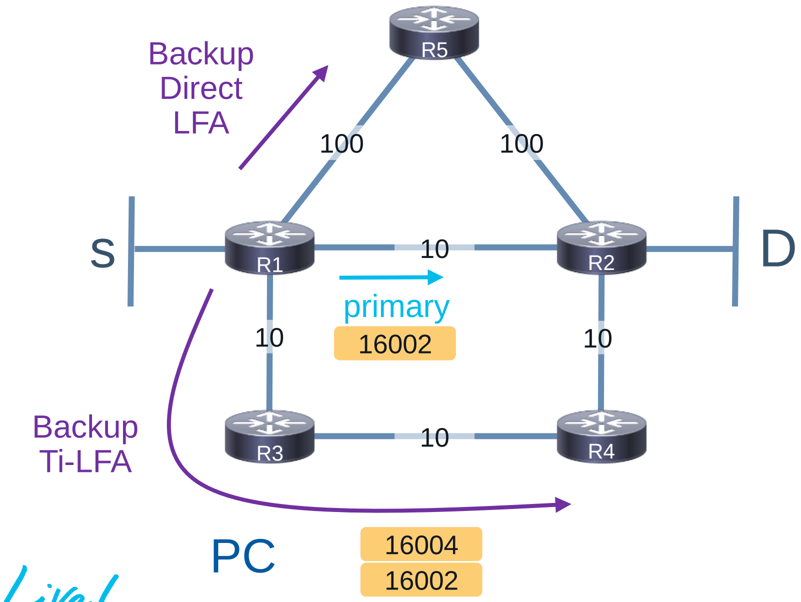
Ti-LFA

Ti-LFA

- It is LFA+
- No Signaling
- Link or node protection
- Protects IP and MPLS traffic
- Repair path can consist of Global Labels, and Adjacency SID Labels
- Makes LFA Topology Independent (Ti)
  - Algorithm, with similar tiebreakers
  - Using segments to force traffic over backup path
    - 100% coverage
  - Protected traffic is on Post-Convergence (PC) path
    - Avoiding another path move at regular convergence after failure
    - Not available with LFA

Ti-LFA Example

- Link State routing provides full topology view
- MPLS label stack can force the traffic to go anywhere
  - Without risk of (micro-)loop



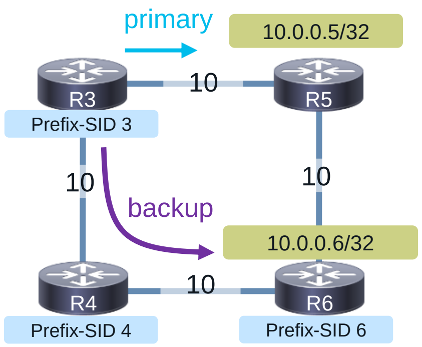
Ti-LFA protection always works by pushing extra MPLS labels

- Any number; rarely more than 2
- Any combination of Prefix SID or Adjacancy SID labels

With Ti-LFA:
Ti-LFA uses PC path

Ti-LFA Example

Single-Segment Example



RIB

```
RP/0/RP0/CPU0:R3# show route 10.0.0.5/32

Routing entry for 10.0.0.5/32
  Known via "isis 1", distance 115, metric 10, labeled SR, type level-2
  Installed Apr 26 13:59:29.323 for 3d00h
  Routing Descriptor Blocks
    10.3.4.4, from 10.0.0.5, via GigabitEthernet0/0/0/2, Backup (TI-LFA)
      Repair Node(s): 10.0.0.6
      Route metric is 30
    10.3.5.5, from 10.0.0.5, via GigabitEthernet0/0/0/1, Protected
      Route metric is 10
  No advertising protos.
```

IP route, but MPLS forwarding entries are also protected

ISIS

```
RP/0/RP0/CPU0:R3# show isis fast-reroute 10.0.0.5/32

L2 10.0.0.5/32 [10/115]
     via 10.3.5.5, GigabitEthernet0/0/0/1, R5, SRGB Base: 16000, Weight: 0
       Backup path: TI-LFA (link), via 10.3.4.4, GigabitEthernet0/0/0/2 R4, SRGB Base: 16000, Weight: 0, Metric: 30
         P node: R6.00 [10.0.0.6], Label: 16006
         Prefix label: 16005
         Backup-src: R5.00
```

one additional label

FIB

```
RP/0/RP0/CPU0:R3# show cef 10.0.0.5/32
10.0.0.5/32, version 212, labeled SR
 remote adjacency to GigabitEthernet0/0/0/1
 Prefix Len 32, traffic index 0, precedence n/a, priority 1
   via 10.3.4.4/32, GigabitEthernet0/0/0/2, 17 dependencies, weight 0, class 0, backup (TI-LFA) [flags 0xb00]
    path-idx 0 NHID 0x0 [0xf1244a0 0x0]
    next hop 10.3.4.4/32, Repair Node(s): 10.0.0.6
     local label 16005      labels imposed {16006 16005}
   via 10.3.5.5/32, GigabitEthernet0/0/0/1, 17 dependencies, weight 0, class 0, protected [flags 0x400]
    path-idx 1 bkup-idx 0 NHID 0x0 [0xf29e070 0xf29d0b0]
    next hop 10.3.5.5/32
     local label 16005      labels imposed {ImplNull}
```

repair node

one additional label

SR Policy

What is an SR Policy?

- Simple, automated, and scalable
  - No core state: state in the packet header
  - Traffic engineered “SR Policy”
  - No headend a-priori configuration: on-demand policy instantiation
  - No headend a-priori steering: on-demand-steering
- Dynamic or explicit path
  - Explicit-path is defined as list of segments:
    - All hops are IP addresses (link/node = loopback)
    - All hops are MPLS labels
    - Mix of IP addresses/MPLS labels
- PCE/PCC is possible (multi-domain)

No signaling protocol

No bandwidth without controller

Protection is Ti-LFA

ECMP used

Definition of a SR Policy

- An SR Policy is identified through the following tuple:
  - The head-end where the policy is instantiated/implemented
  - The endpoint (i.e.: the destination of the policy)
  - The color (an arbitrary numerical value)
- At a given head-end, an SR Policy is fully identified by the <color, endpoint> tuple
- An endpoint can be specified as an IPv4 or IPv6 address
- SR Policy can be defined on the head end or on the SR-PCE

SR Policy Breakdown

- Candidate path with preference
  - Higher preference is preferred, default = 100
- Explicit or dynamic path
  - Dynamic = calculated by PCC or PCE
  - Explicit = segment-list (labels) defined on PCC or PCE!
- Metric
  - Type = IGP, hopcount, latency, TE
  - Margin
- Constraints
  - Affinity
  - Disjoint-path
  - Bounds (cumulative metric)
  - Segments (protection type or SID algorithm)

SR Policy Examples

```
segment-routing
 traffic-eng
  logging
   policy status
  !
  segment-list explicit-to-ABR-1
   index 5 address ipv4 10.1.3.3
   index 10 mpls label 16007
   index 20 mpls label 16009
   index 30 mpls label 16005
  !
  policy to-ABR1
   binding-sid mpls 1000
   color 1000 end-point ipv4 10.0.0.5
   candidate-paths
    preference 100
     dynamic
      metric
       type igp
      !
     !
    !
    preference 200
     explicit segment-list explicit-to-ABR-1
```

```
segment-routing
 traffic-eng
 !
 policy policy-1
   color 1000 end-point ipv4 10.0.0.2
   candidate-paths
    preference 100
     dynamic
      pcep
      !
      metric
       type te
```

```
segment-routing
 traffic-eng
  policy policy-1
   candidate-paths
    preference 100
     dynamic
      metric
       sid-limit 5
       margin absolute 100
```

```
segment-routing
 traffic-eng
  logging
   policy status
  !
 policy to-PE2-PCE
   binding-sid mpls 1234
   color 3000 end-point ipv4 10.0.0.2
   candidate-paths
    preference 100
     dynamic
      pcep
      !
      metric
       type igp
```

```
segment-routing
 traffic-eng
  policy POLICY_1
   end-point ipv4 1-.1.1.3 color 1
    candidate-paths
     preference 50
      dynamic mpls pce
       unprotected
       invalidation drop
```

```
segment-routing
 traffic-eng
  policy test
   candidate-paths
    preference 100
     constraints
      disjoint-path group-id 100 type {link | node| srlg | srlg-node}
```

```
segment-routing
 traffic-eng
  policy test
   candidate-paths
    preference 100
     constraints
      affinity {exclude-any | exclude-group | exclude-item | include-all| include-any}
```

```
segment-routing
 traffic-eng
  policy test
   candidate-paths
    preference 100
     constraints
      bounds cumulative type {hopcount | igp | latency | te}
```

Binding-SID

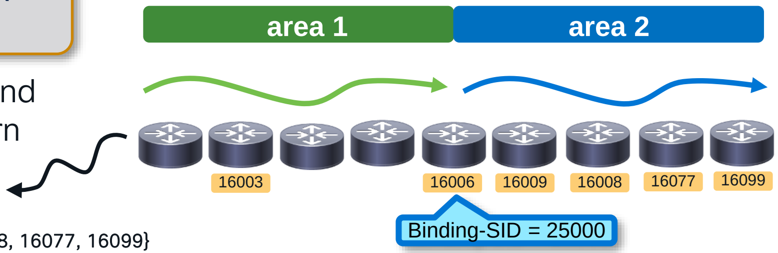
- Head end receives a packet with Binding Segment label and steers packet into SR policy
- Binding-SID is incoming label in LFIB
- Binding SID is automatically associated with every SR policy (overwritten if configured)

```
segment-routing
 global-block 16000 23999
 traffic-eng
  logging
   policy status
  !
  policy to-ABR1
   binding-sid mpls 1000
   color 1000 end-point ipv4 10.0.0.5
   candidate-paths
   …
```

```
FIB @ headend
Incoming label: 1000
Action: pop and push <label stack of policy>
```

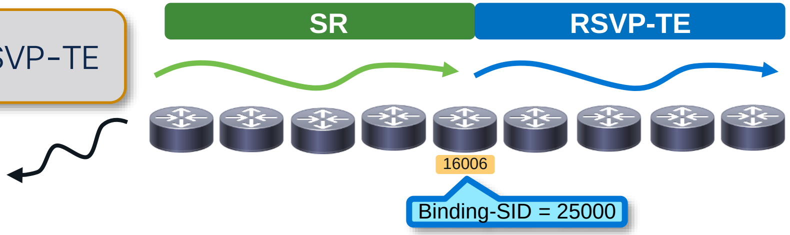
Hierarchy of SR Policies

Shorter SID list and isolation of churn



{16003, 16006, 25000}
instead of
{16003, 16006, 16009, 16008, 16077, 16099}

SR Policy to RSVP-TE



{16006, 25000}

Automated Steering

per-destination

automatically steers service routes on their matching (color + endpoint) SR Policy

- Static into policy is possible

```
segment-routing
 traffic-eng
  policy c100
   color 100 end-point ipv4 10.0.0.3
   candidate-paths
    preference 100
     dynamic
      metric
       type igp
      !
```

Matching color and endpoint

```
router static
 address-family ipv4 unicast
  10.0.0.12/32 sr-policy srte_c_100_ep_10.0.0.6
```

per-flow

automatically steers service routes on their matching (color + endpoint) SR Policy per Forward Class

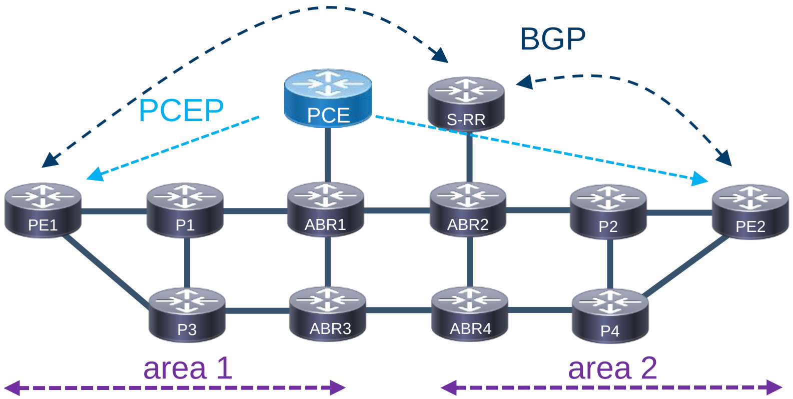
- Forward Class is internal to router
- COS can be mapped to FC
- Up to 8 ways

```
segment-routing
 traffic-eng
  policy c100
   color 100 end-point ipv4 10.0.0.3
   candidate-paths
    preference 100
     dynamic
      metric
       type igp
      !
policy c101
   color 101 end-point ipv4 10.0.0.3
   candidate-paths
    preference 100
     dynamic
      metric
       type hopcount
!
policy c1000
   color 1000 end-point ipv4 10.0.0.3
   candidate-paths
    preference 100
     per-flow
      forward-class 0 color 100
      forward-class 1 color 101
```

Each color is separately defined for same endpoint

On Demand Next Hop (ODN)

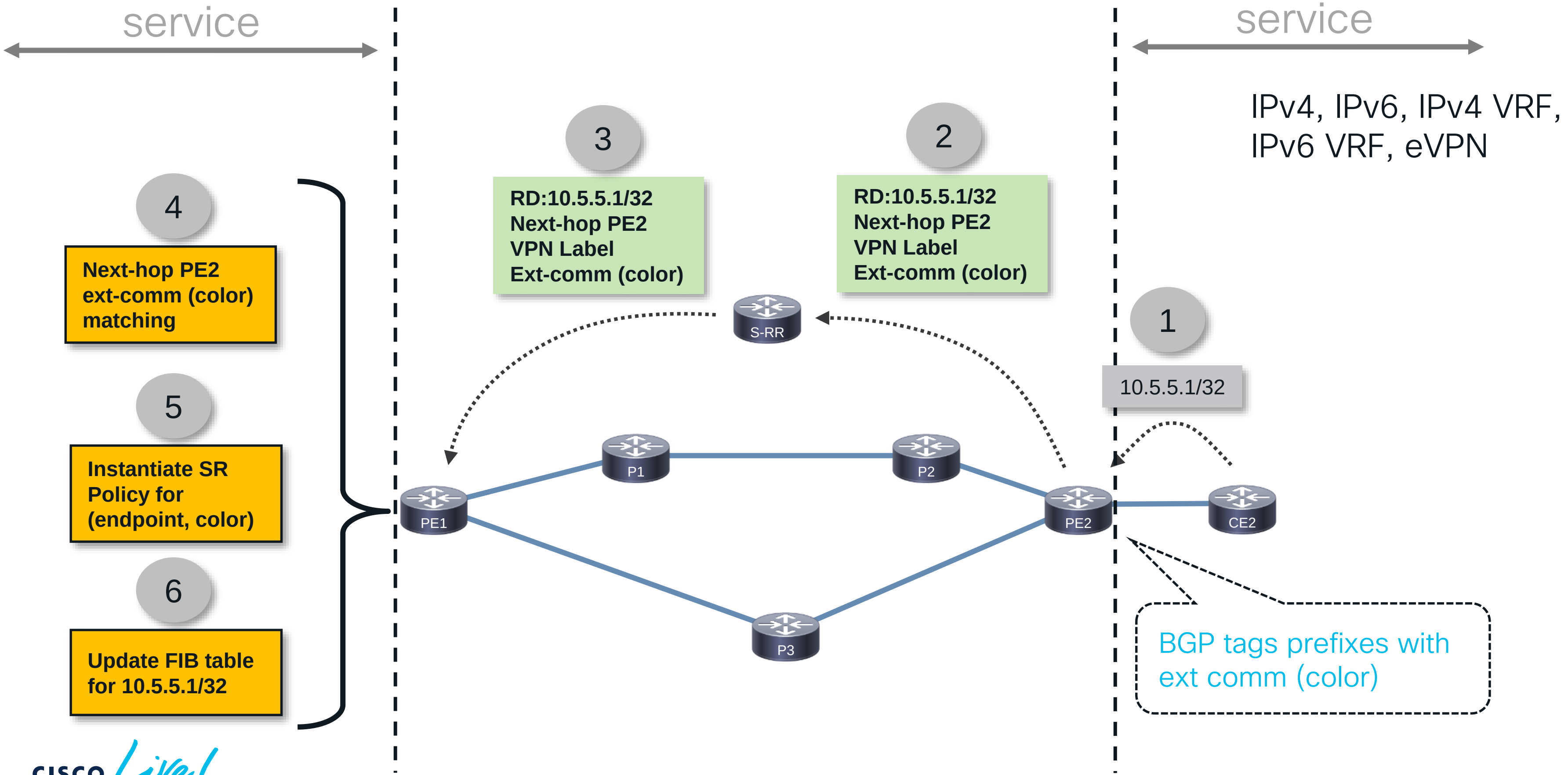
ODN



Automated SR Policy
Inter-AS & Seamless MPLS: no need for BGP-LU (RFC3107)
SLA-aware BGP service

- On-demand Next-hop automates and simplifies the service head end configuration
  - No SR Policy config on the head end router
  - No complex/explicit steering on the service head end for the service
    - For example: no autoroute-announce, no static routes
  - No need for full path knowledge on head end router is SR-PCE is used
- The SR Policies deployed when needed
  - The learning of the service route, initiates the SR Policy, and traffic-to-SR Policy mapping
  - Example of a service route: vpnv4 route

ODN Behavior



IPv4, IPv6, IPv4 VRF, IPv6 VRF, eVPN

1

10.5.5.1/32

BGP tags prefixes with ext comm (color)

2

RD:10.5.5.1/32
Next-hop PE2
VPN Label
Ext-comm (color)

3

RD:10.5.5.1/32
Next-hop PE2
VPN Label
Ext-comm (color)

4

Next-hop PE2 ext-comm (color) matching

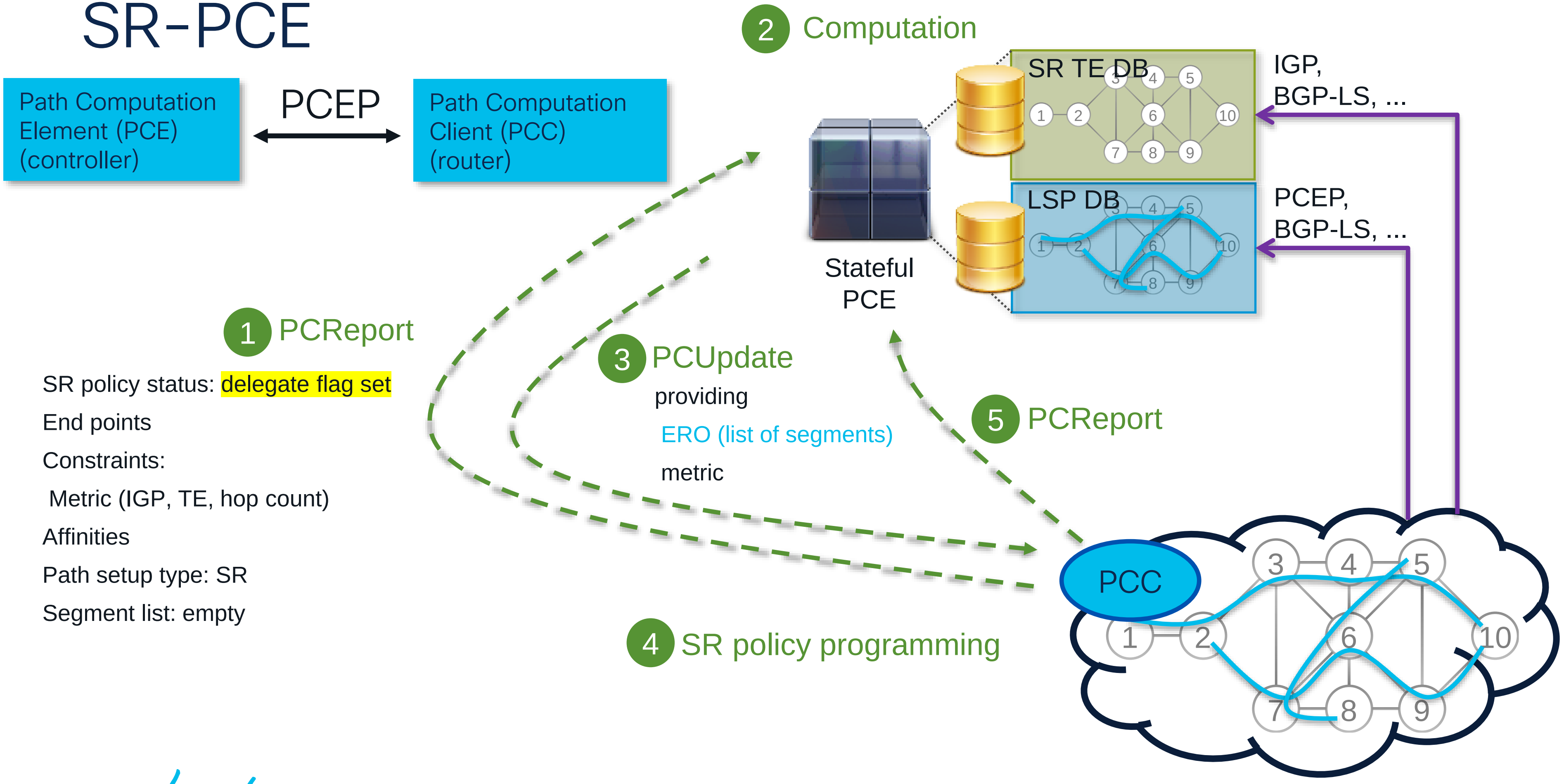
5

Instantiate SR Policy for (endpoint, color)

6

Update FIB table for 10.5.5.1/32

SR-PCE



Path Computation Element (PCE) (controller)

PCEP

Path Computation Client (PCC) (router)

2 Computation

SR TE DB

IGP, BGP-LS, ...

LSP DB

PCEP, BGP-LS, ...

Stateful PCE

1 PCReport

SR policy status: delegate flag set

End points

Constraints:

Metric (IGP, TE, hop count)

Affinities

Path setup type: SR

Segment list: empty

3 PCUpdate

providing

ERO (list of segments)

metric

5 PCReport

4 SR policy programming

SR Operations, Administration, and Maintenance (OAM)

SR MPLS OAM

- Ping, traceroute for Prefix SIDs and Adj-SIDs for IGP
- Regular MPLS OAM works for SR
- OAM gives you extra (above normal ping and traceroute):
  - Consistency check
  - Path discovery
  - MPLS traffic black hole
  - Path divergence detection
  - Premature IP header exposition
  - Can detect inconsistencies between control plane and forwarding
- OAM was expanded with SR OAM
  - Only prefix-SID for now
  - Only new Target FEC Stack TLV for SR is added

```
ping mpls ipv4 10.1.1.1/32
traceroute mpls ipv4 10.1.1.1/32
```

```
ping mpls ipv4 10.1.1.1/32 fec-type generic
traceroute mpls ipv4 10.1.1.1/32 fec-type
generic
```

```
ping sr-mpls 10.1.1.1/32 fec-type igp
<isis/ospf>
traceroute sr-mpls 10.1.1.1/32 fec-type igp
<isis/ospf>
```

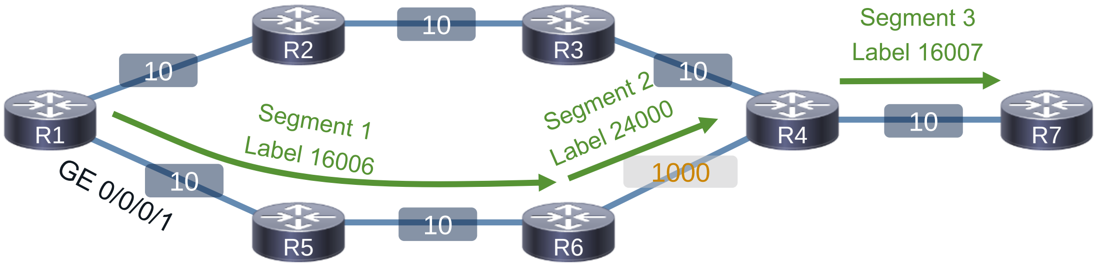
```
RP/0/RP0/CPU0:PE1# trace sr-mpls policy ?
  binding-sid  Specify the binding-sid of the SR
policy
  name         Specify the name of the SR policy
```

NIL-FEC

- Nil FEC (defined in RFC4379), specifies that no explicit FEC (Control Plane) is associated with the label
- Typically used to carry labels in reserved range (explicit-null or router alert) for diagnostic purpose
- Ping and traceroute
- But very powerful tool to check any combination of segments on any path!
- Does not carry any information to identify the intended target
  - The packet may be forwarded wrongly somewhere, but still make it
  - No control plane validation is performed at originator or responder
- This was an interim solution
- Can force traffic over non-least cost path

NIL-FEC Example

User specifies:
- Outgoing label stack (one or more labels)
- Outgoing interface
- Next-hop interface address



Specify outgoing interface and next hop

Specify segments as list of labels in comma separated list (first label is top label)

24000 is adj-SID label from R6 to R4

```
RP/0/0/CPU0:R1# trace mpls nil-fec labels 16006,24000,16007 output interface gigabitEthernet 0/0/0/1 nexthop 10.1.5.5

Tracing MPLS Label Switched Path with Nil FEC with labels [16006,28097,16007], timeout is 2 seconds

Codes: '!' - success, 'Q' - request not sent, '.' - timeout,
  'L' - labeled output interface, 'B' - unlabeled output interface,
  'D' - DS Map mismatch, 'F' - no FEC mapping, 'f' - FEC mismatch,
  'M' - malformed request, 'm' - unsupported tlvs, 'N' - no rx label,
  'P' - no rx intf label prot, 'p' - premature termination of LSP,
  'R' - transit router, 'I' - unknown upstream index,
  'X' - unknown return code, 'x' - return code 0

Type escape sequence to abort.

 0 10.1.5.1 MRU 1500 [Labels: 16006/24000/16007/explicit-null Exp: 0/0/0/0]
L 1 10.1.5.5 MRU 1500 [Labels: implicit-null/24000/16007/explicit-null Exp: 0/0/0/0] 12 ms
L 2 10.5.6.6 MRU 1500 [Labels: implicit-null/16007/explicit-null Exp: 0/0/0] 19 ms
L 3 10.4.6.4 MRU 1500 [Labels: implicit-null/explicit-null Exp: 0/0] 13 ms
! 4 10.4.7.7 41 ms
```

Key Takeaways

- SR is simpler and easier to troubleshoot than LDP or RSVP-TE
- No changes in MPLS forwarding
- Ti-LFA
  - Built from same fundaments as LFA
  - But much better and much easier
- SR Policy (SR-TE) is simpler than RSVP-TE
- Controller

Technical Session Surveys

- Attendees who fill out a minimum of four session surveys and the overall event survey will get Cisco Live branded socks!
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