Demystifying Segment Routing (SR-MPLS)

AUSNOG 2022

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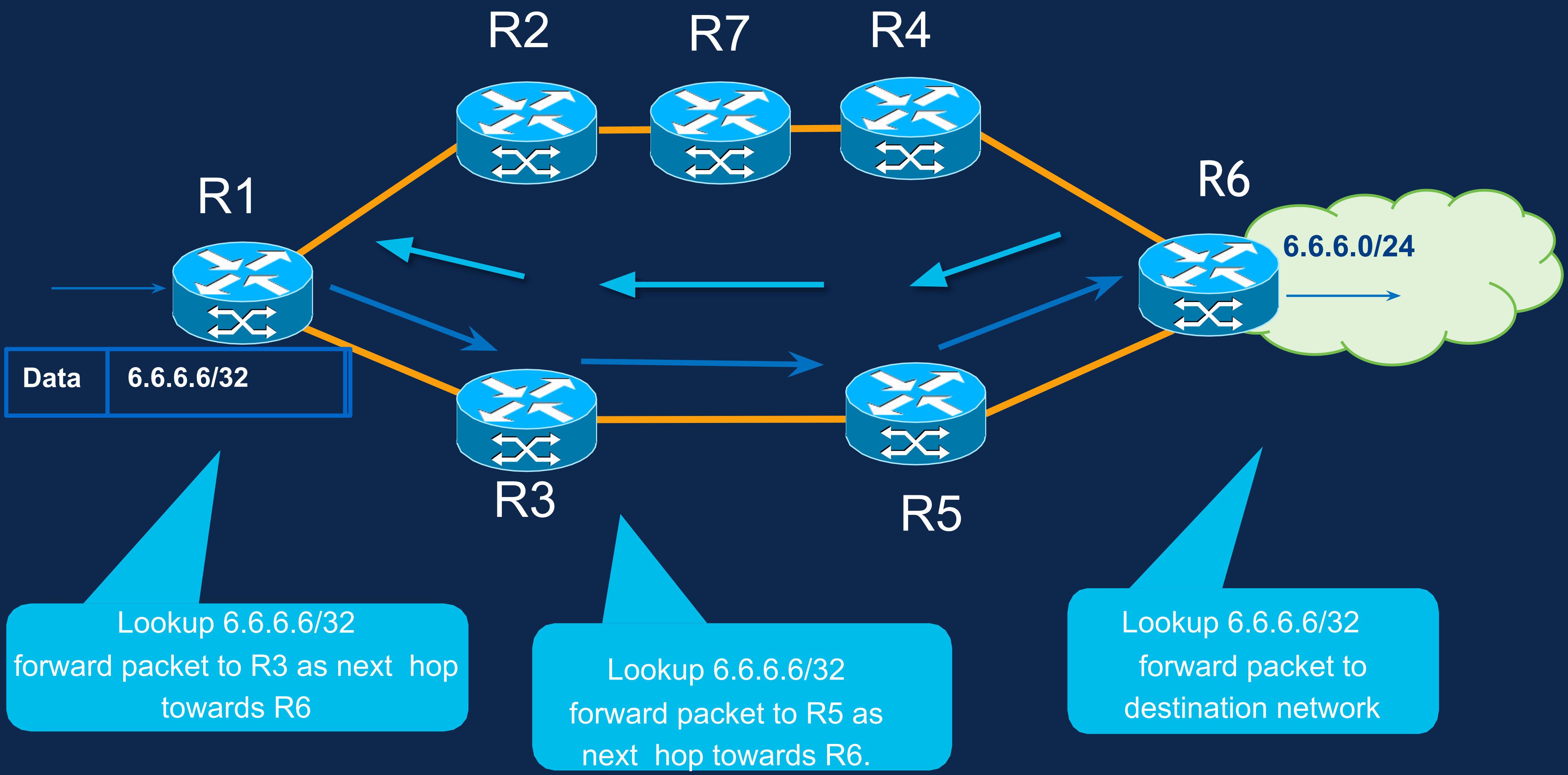
Cisco Systems

Routing Protocols, Destination Based Data Flow



MPLS Brief History

Original drivers towards label switching

- Designed to make router faster.
  - Routers were originally built to handle forwarding in the software on a single CPU.
  - ATM switches were faster than routers.
  - MPLS allows the device to do same job as router with performance of ATM switch.
- Late 1996, proprietary multilayer solutions emerged with integrated ATM switching and IP routing:
  - IP Switching—Ipsilon/Nokia
  - Tag Switching—Cisco Systems
  - Cell Switching Router (CSAggregate Route-Based IP Switching (ARIS)—IBM

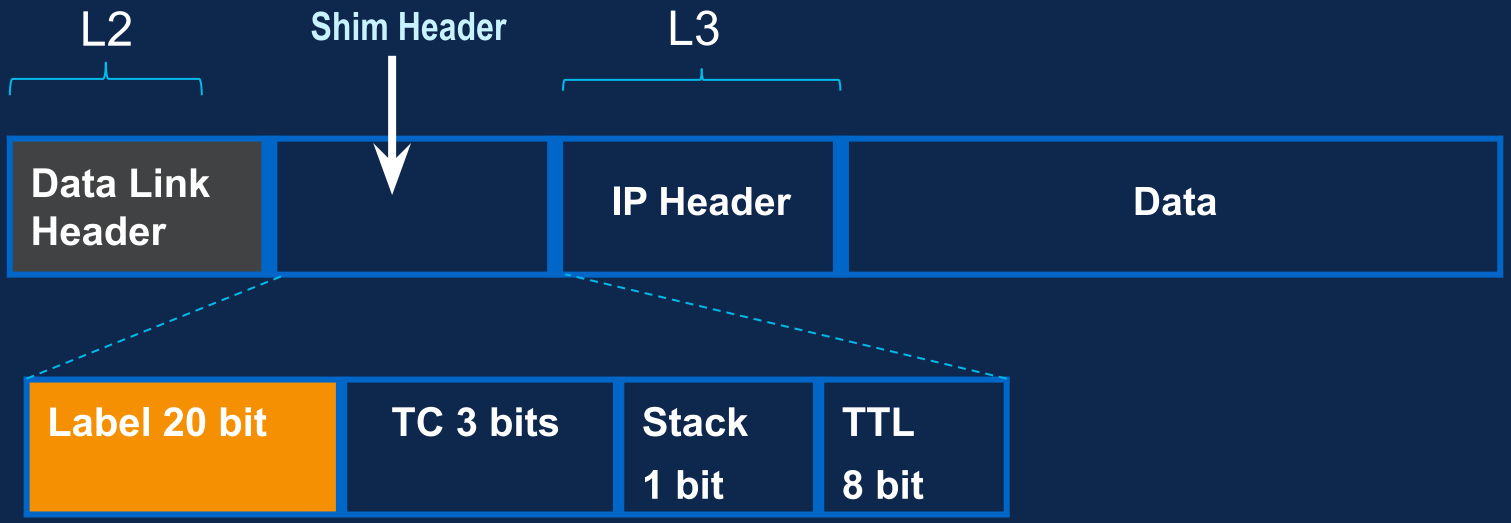
These were all similar technologies but were NOT interoperable.

- IETF worked to standardize the solutions and develop MPLS:-
  - First IETF RFC on MPLS published in Jan 2001
    - ❖ RFC 3031 specifies "MPLS Architecture" (https://tools.ietf.org/html/rfc3031)
    - ❖ RFC 3032 specify "Label Stack Encoding"(https://tools.ietf.org/html/rfc3032)

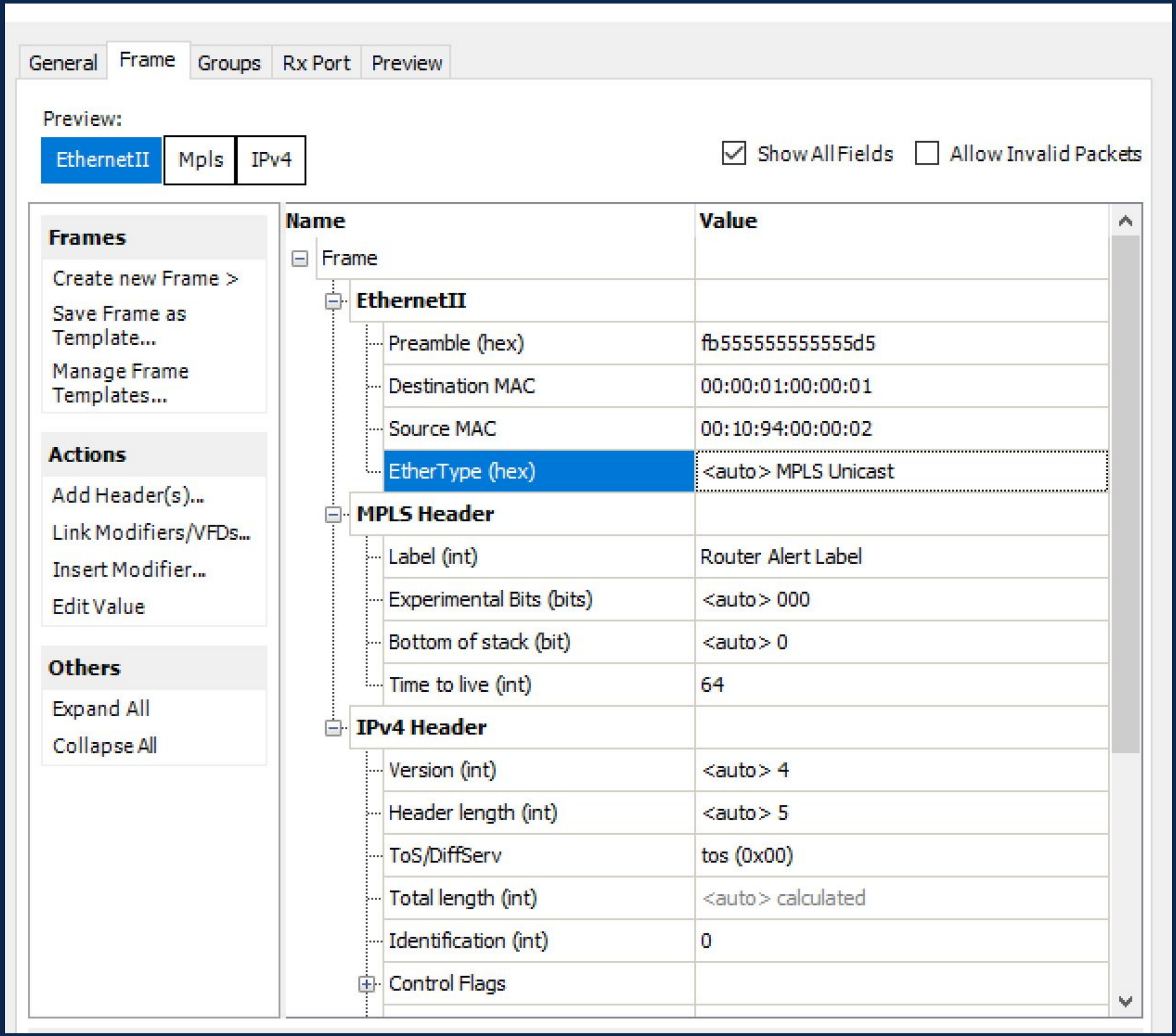
MPLS Data Plane

- It's a simple encapsulation at "layer 2.5"
- MPLS forwards packets by switching labels [push, pop] based on a forwarding database.
- Forwarding is based on simple look-up.

{incoming interface, incoming label} {outgoing interface, outgoing label}



MPLS FRAME


General
Frame
Groups
Rx Port
Preview
Preview:
EthernetII
Mpls
IPv4
Show All Fields
Allow Invalid Packets
Frames
Create new Frame >
Save Frame as Template...
Manage Frame Templates...
Actions
Add Header(s)...
Link Modifiers/VFDs...
Insert Modifier...
Edit Value
Others
Expand All
Collapse All
Name
Value
Frame
EthernetII
Preamble (hex)
fb555555555555d5
Destination MAC
00:00:01:00:00:01
Source MAC
00:10:94:00:00:02
EtherType (hex)
<auto> MPLS Unicast
MPLS Header
Label (int)
Router Alert Label
Experimental Bits (bits)
<auto> 000
Bottom of stack (bit)
<auto> 0
Time to live (int)
64
IPv4 Header
Version (int)
<auto> 4
Header length (int)
<auto> 5
ToS/DiffServ
tos (0x00)
Total length (int)
<auto> calculated
Identification (int)
0
Control Flags

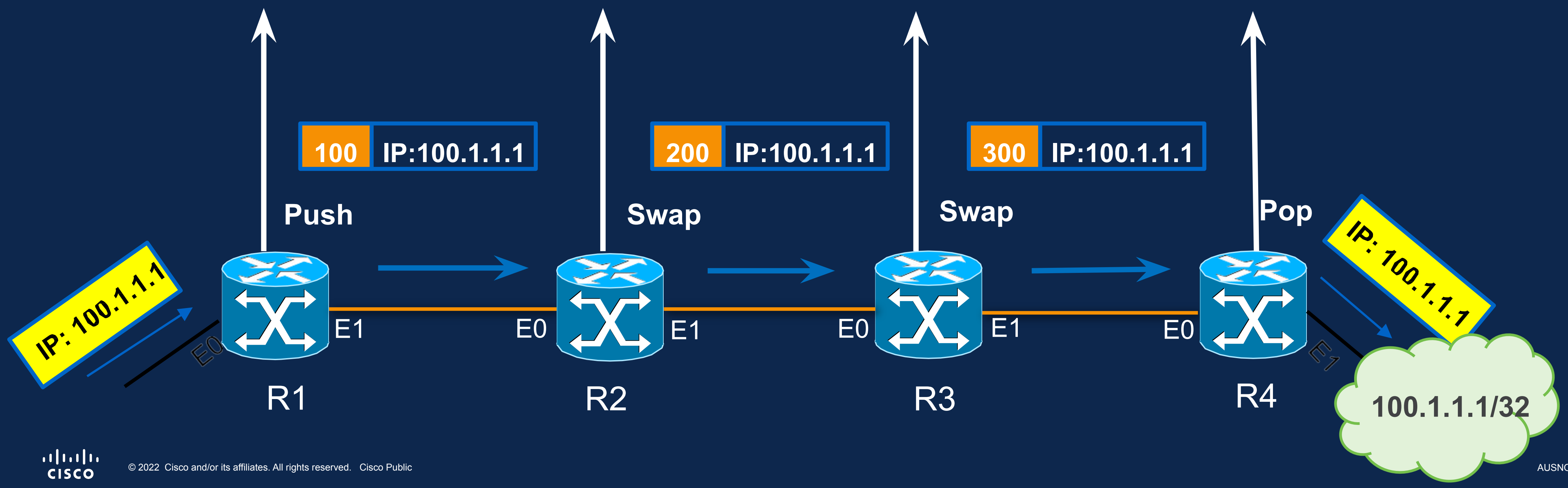
MPLS Forwarding Plane Operations

Prefix: 100.1.1.1/32	
Local Label	Null
Out Interface	E1
Out Label	100
Operation	Push

Prefix: 100.1.1.1/32	
Local Label	100
Out Interface	E1
Out Label	200
Operation	Swap

Prefix: 100.1.1.1/32	
Local Label	200
Out Interface	E1
Out Label	300
Operation	Swap

Prefix: 100.1.1.1/32	
Local Label	300
Out Interface	--
Out Label	--
Operation	POP



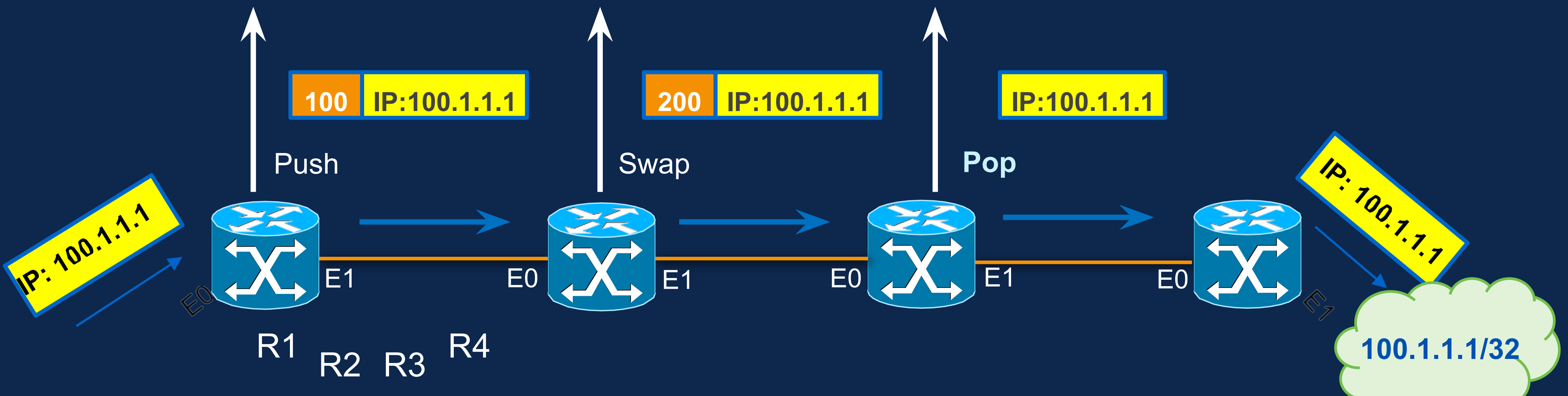
MPLS: Penultimate hop popping (PHP)

Prefix: 100.1.1.1/32	
Local Label	Null
Out Interface	E1
Out Label	100
Operation	Push

Prefix: 100.1.1.1/32	
Local Label	100
Out Interface	E1
Out Label	200
Operation	Swap

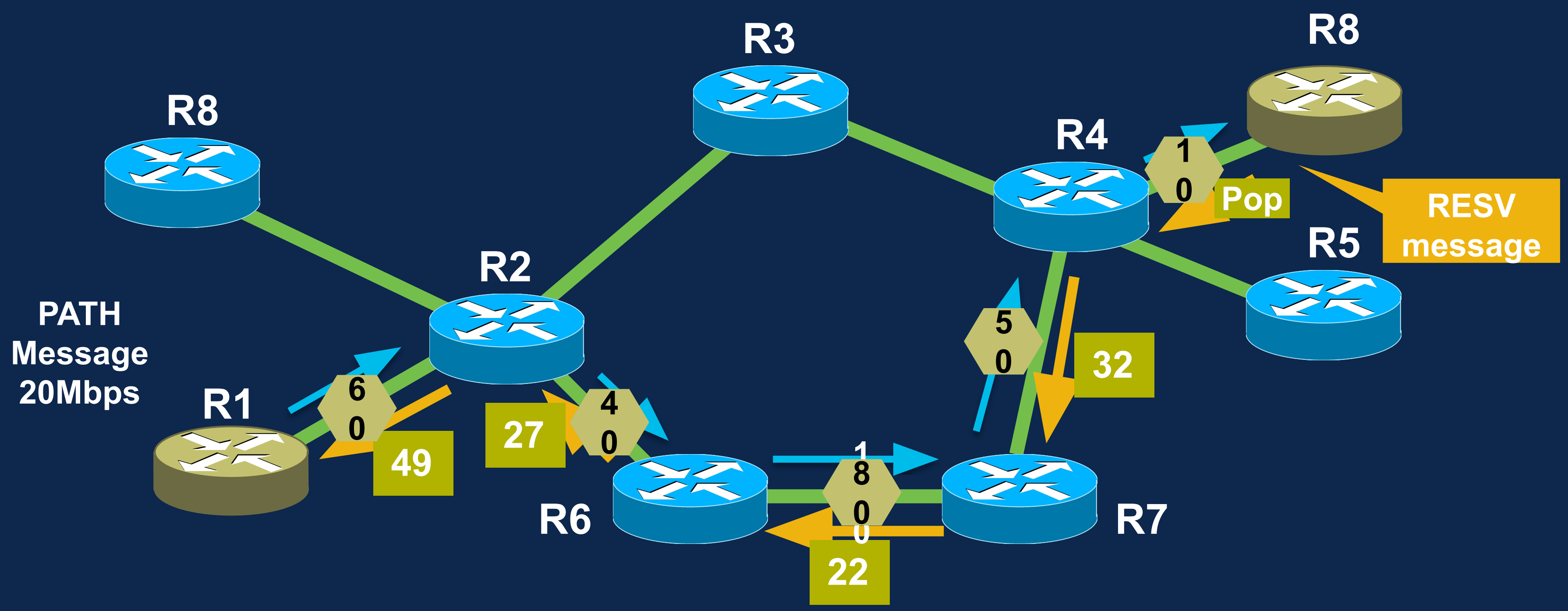
Prefix: 100.1.1.1/32	
Local Label	200
Out Interface	E1
Out Label	imp-null
Operation	Pop

Prefix: 100.1.1.1/32	
Local Label	imp-null
Out Interface	--
Out Label	--
Operation	--



* label with a value of 3 signifies an implicit NULL

RSVP – TE CONTROL PLANE



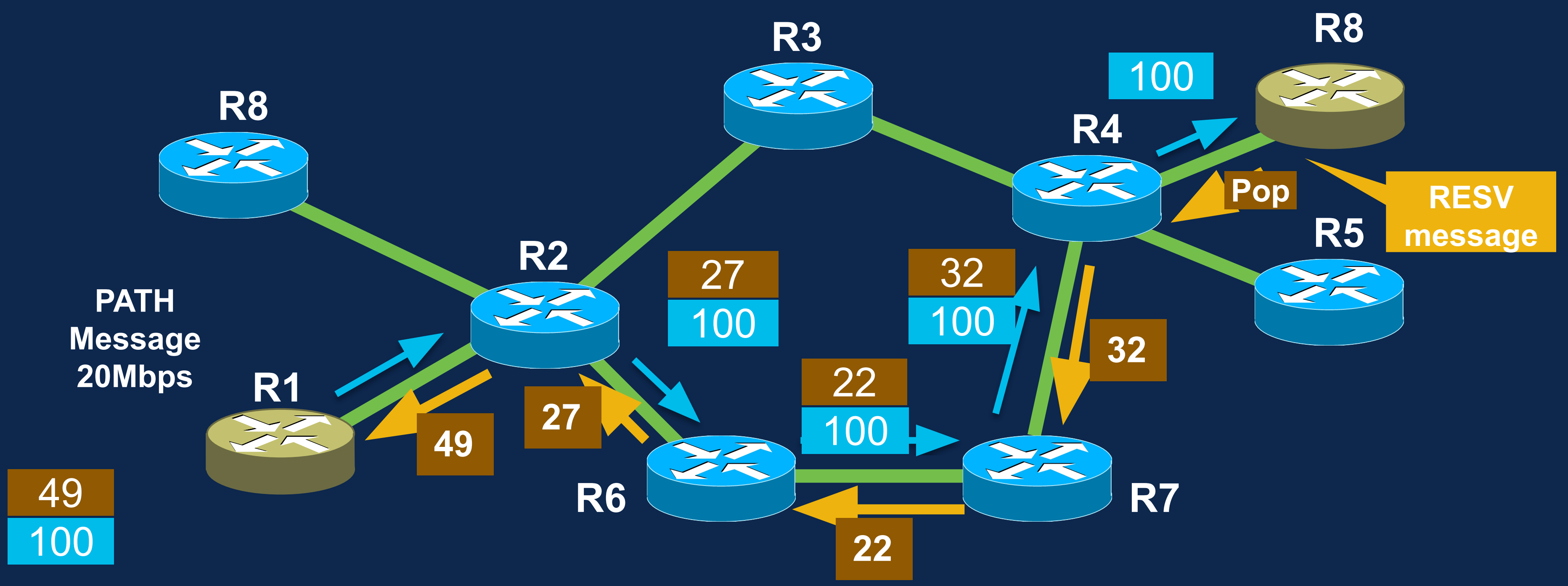
RSVP PATH: { R1 □ R2 □ R6 □ R7 □ R4 □ R9 }

RSVP RESV: Returns labels and reserves bandwidth on each link

Bandwidth available

Re ed label via RESV message

RSVP – TE DATA PLANE



Explicit Route Object { R1 □ R2 □ R6 □ R7 □ R4 □ R9 }

RSVP RESV: Returns labels and reserves

Service Label

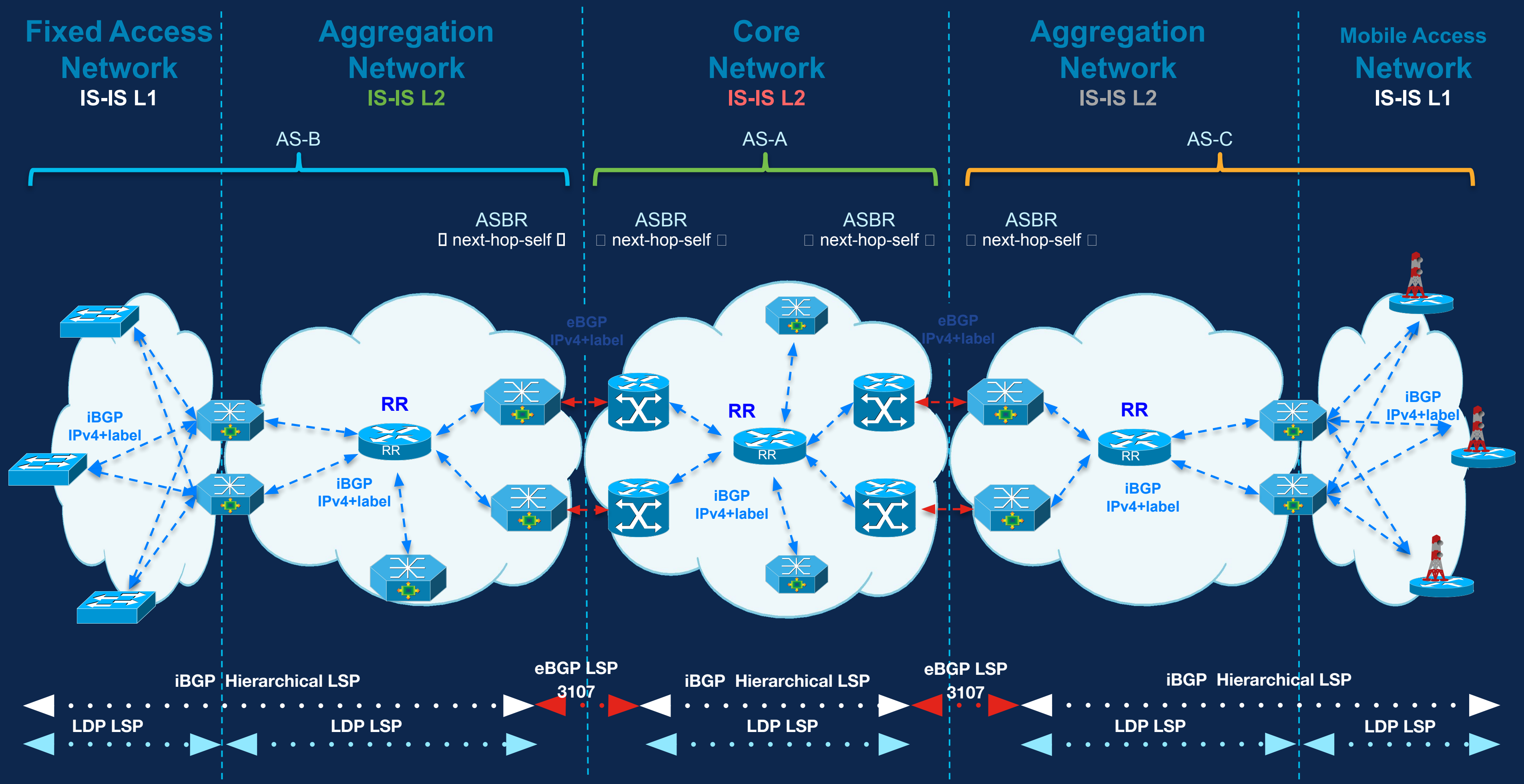
100

49

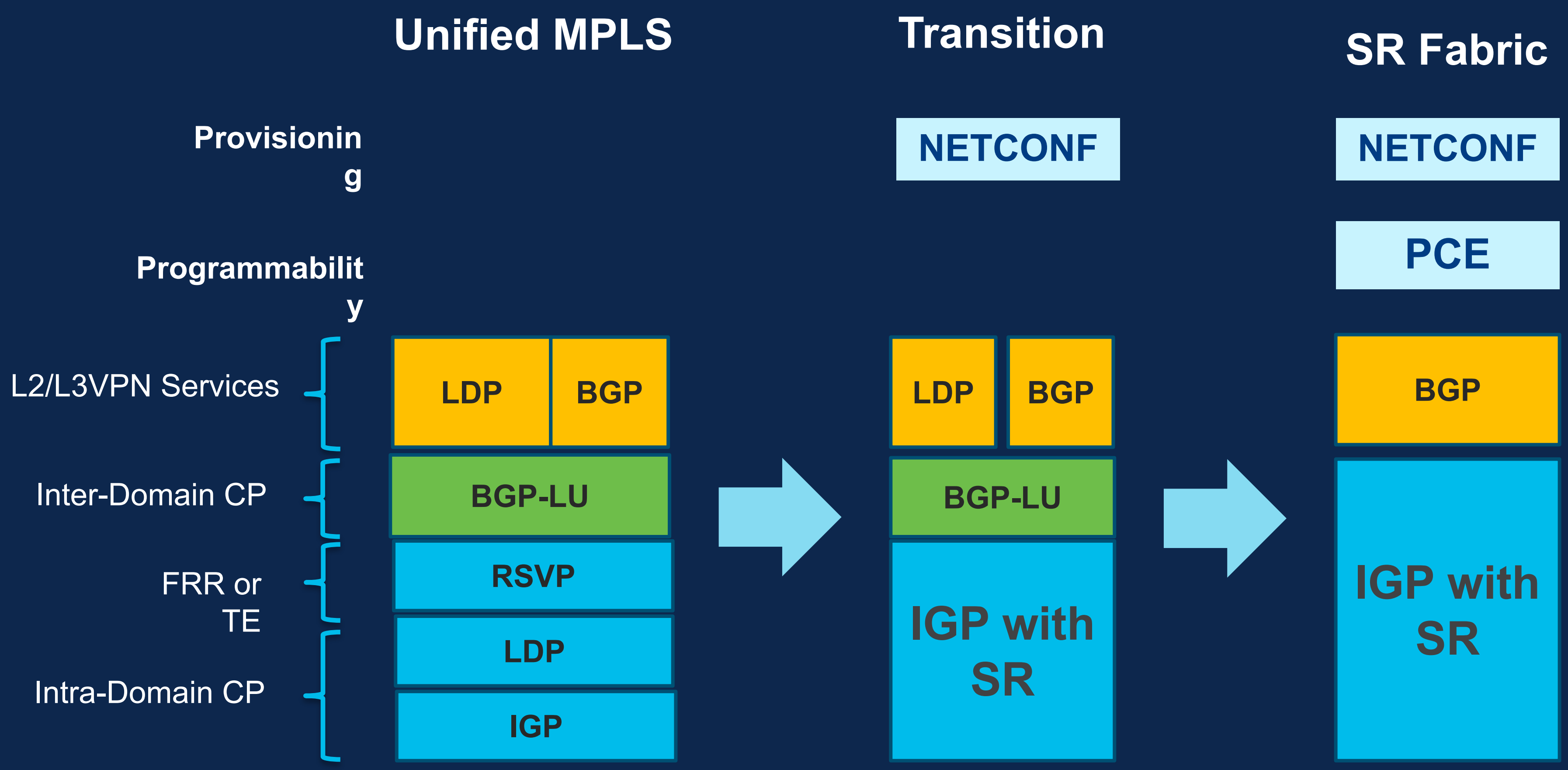
(y LDP, BGP etc.)

ed label via RESV message

and that got us here ..Unified MPLS Transport Model



SP Network - Simplification Journey



What is a “Segment” ?

“Segment”

“an instruction a node executes on the incoming packet”

Internet Engineering Task Force (IETF)
Request for Comments: **8402**
Category: Standards Track
ISSN: 2070-1721

C. Filsfils, Ed.
S. Previdi, Ed.
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Cisco Systems, Inc.
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Orange
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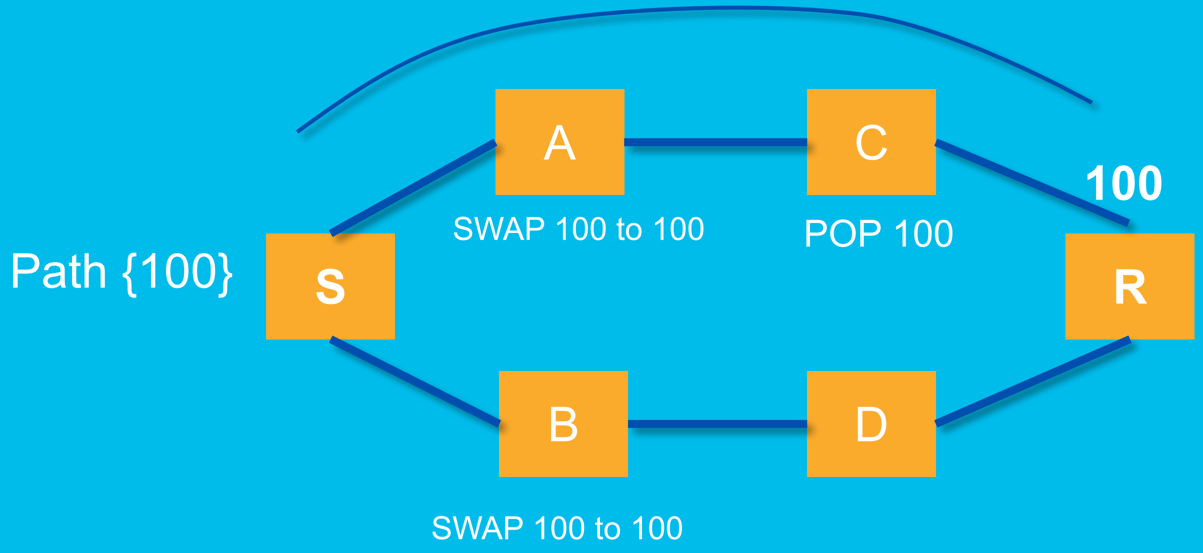
Google, Inc.
July 2018

Segment Routing Architecture

Abstract

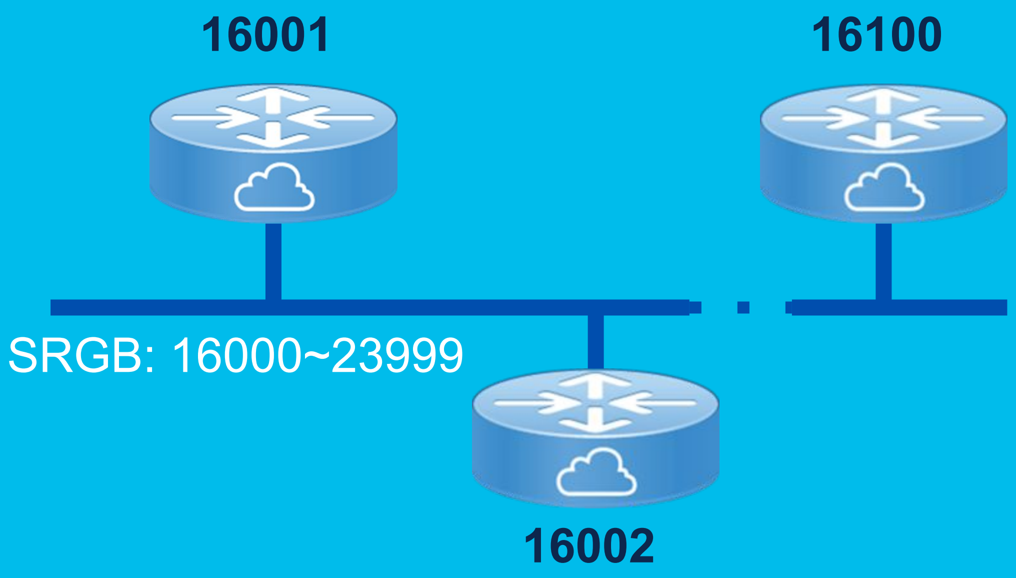
Segment Routing (SR) leverages the source routing paradigm. A node steers a packet through an ordered list of ***instructions***, called **"segments"**. A segment can represent any **instruction**, ***topological*** or ***service based***.

SRGB, IGP-Node Segment and IGP-Prefix Segment



IGP PREFIX SEGMENT

- Signaled by ISIS/OSPF
  - Minor extensions to existing link-state routing protocols
- Shortest-path to IGP prefix
  - Equal Cost Multipath (ECMP)-aware
- Global significance in SR domain
- **Label = SRGB + Index**
  - SRGB = Segment Routing Global Block
  - Default SRGB: 16,000 – 23,999
  - Advertised as index



Constructs of Segment Routing - SRGB and Prefix SID – Control Plane

```
RP/0/RP0/CPU0:PTT-5504-1#show isis database  verbose | i "SRGB"
Wed Aug 10 01:55:53.556 UTC
   Segment Routing: I:1 V:0, SRGB Base: 16000 Range: 8000
   Segment Routing: I:1 V:0, SRGB Base: 16000 Range: 8000
   Segment Routing: I:1 V:0, SRGB Base: 16000 Range: 8000
```

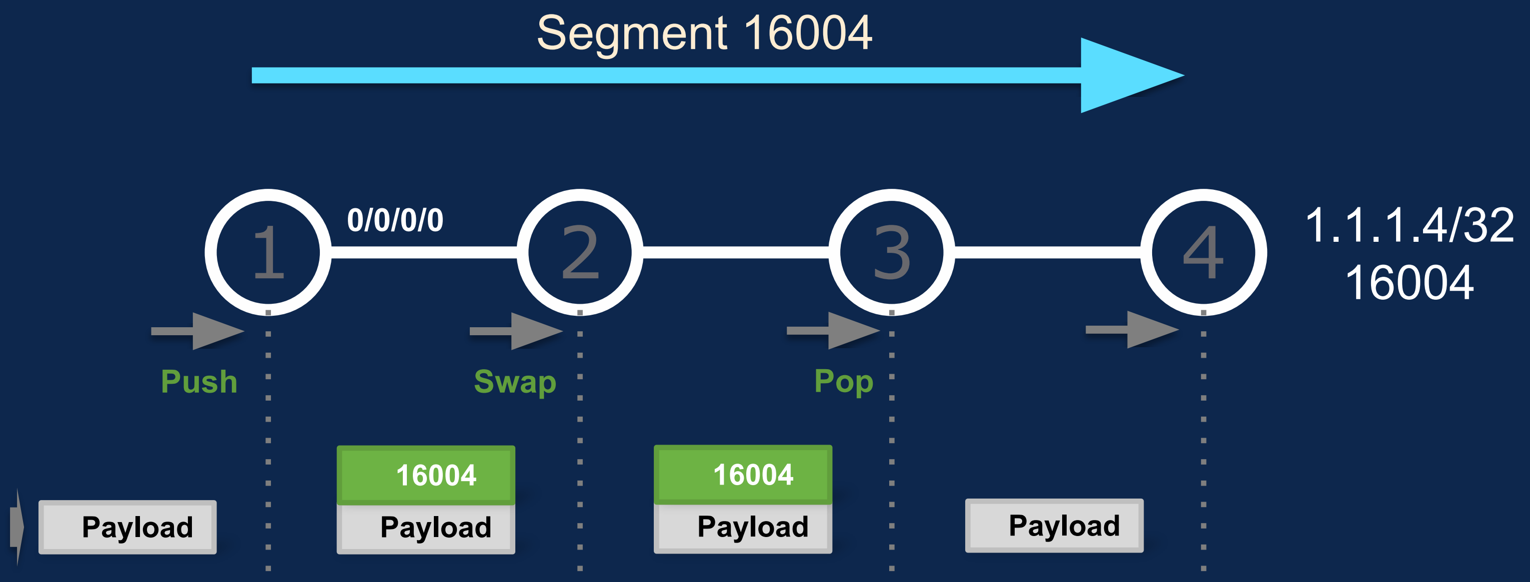
```
RP/0/RP0/CPU0:PTT-5504-1#show isis database  verbose | i "Prefix-SID Index:"
Wed Aug 10 01:58:28.622 UTC
   Prefix-SID Index: 1, Algorithm:0, R:0 N:1 P:0 E:0 V:0 L:0
   Prefix-SID Index: 801, Algorithm:128, R:0 N:1 P:0 E:0 V:0 L:0
   Prefix-SID Index: 901, Algorithm:129, R:0 N:1 P:0 E:0 V:0 L:0
   Prefix-SID Index: 2, Algorithm:0, R:0 N:1 P:0 E:0 V:0 L:0
   Prefix-SID Index: 802, Algorithm:128, R:0 N:1 P:0 E:0 V:0 L:0
   Prefix-SID Index: 902, Algorithm:129, R:0 N:1 P:0 E:0 V:0 L:0
   Prefix-SID Index: 3, Algorithm:0, R:0 N:1 P:0 E:0 V:0 L:0
   Prefix-SID Index: 803, Algorithm:128, R:0 N:1 P:0 E:0 V:0 L:0
   Prefix-SID Index: 903, Algorithm:129, R:0 N:1 P:0 E:0 V:0 L:0
```

```
router isis core

 flex-algo 128
 !
 flex-algo 129
 !
 address-family ipv4 unicast
  metric-style wide
  segment-routing mpls

 interface Loopback0
  passive
  address-family ipv4 unicast
   prefix-sid absolute 16003
   prefix-sid algorithm 128 absolute 16803
   prefix-sid algorithm 129 absolute 16903
```

SR – DATA PLANE OPERATION




```
RP/0/0/CPU0:Node1#show cef 1.1.1.4/32
1.1.1.4/32, version 277, internal 0x4004001 0x0 (ptr 0xacce39a4) [1], 0x0 (0xaccde760), 0x450 (0xacd8b8)
 local adjacency 10.0.0.2
 Prefix Len 32, traffic index 0, precedence n/a, priority 1
   via 99.1.2.2, GigabitEthernet0/0/0/0, 5 dependencies, weight 0, class 0 [flags 0x0]
    path-idx 0 NHID 0x0 [0xacbb3bf0 0x0]
    next hop 99.1.2.2
    local adjacency
     local label 16004      labels imposed {16004}
```

IGP-Adjacency SID

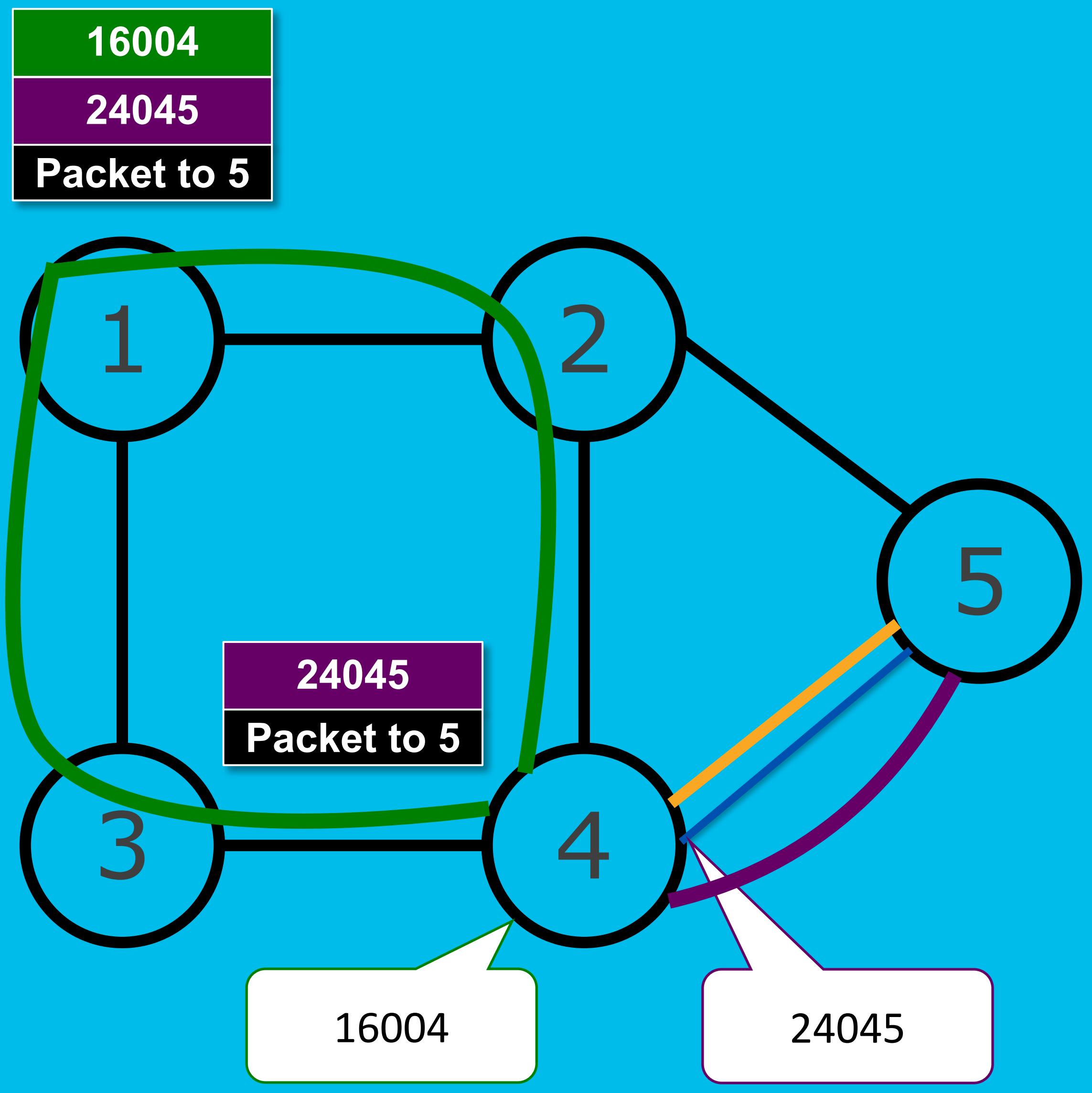
Steer traffic on any path through the network

Path is specified by list of segments in packet header, a stack of labels

No path is signalled

No per-flow state is created

Single protocol: IS-IS or OSPF



ANYCAST SID

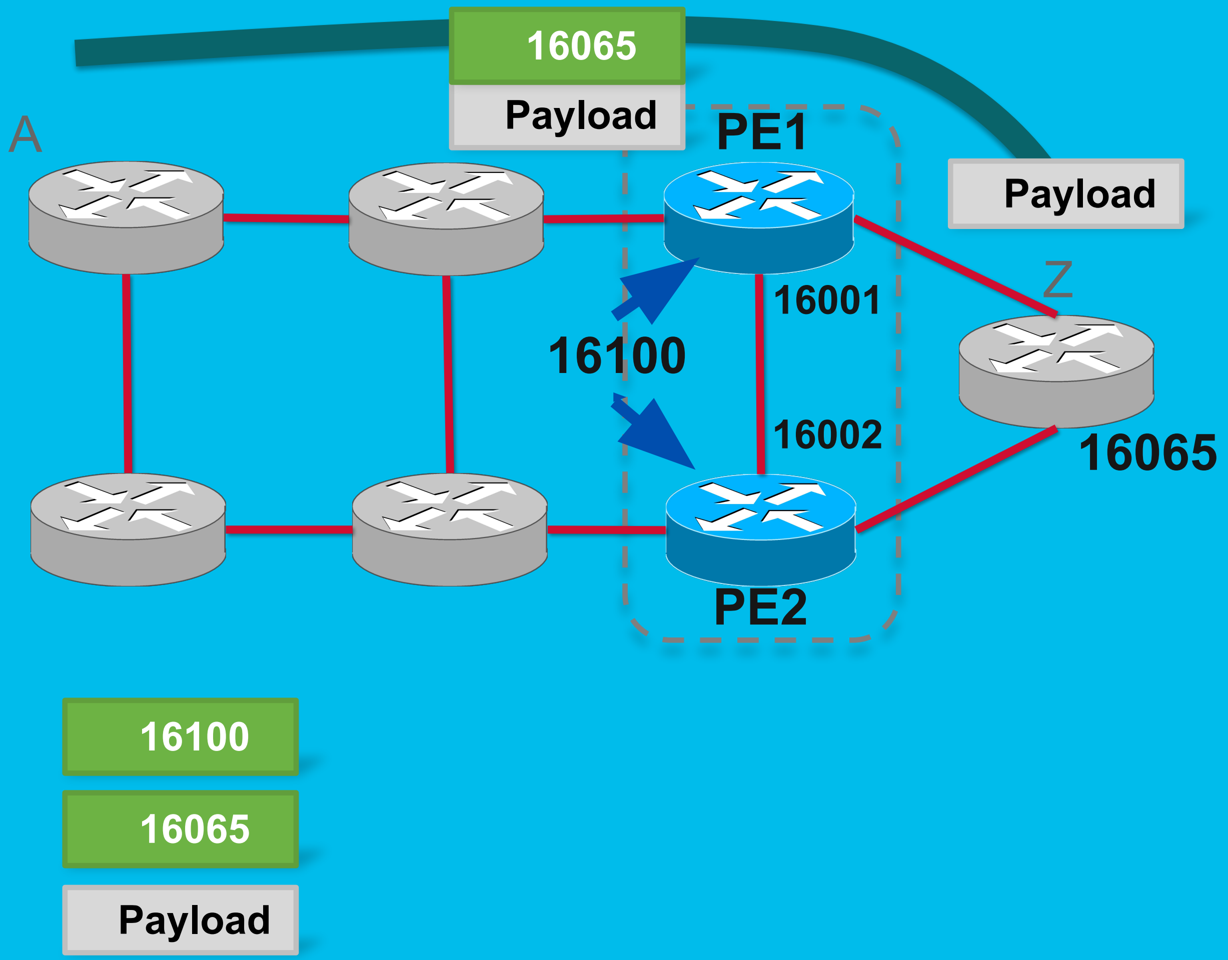
Anycast prefixes: same prefix advertised by multiple nodes

Anycast prefix-SID: Same prefix-SID for the same prefix!

Traffic is forwarded to one of the Anycast prefix-SID originators, **based on best IGP path**

If primary node fails, traffic is auto re-routed to the other node

Note: *nodes advertising the same Anycast prefix-SID must have the same SRGB*



ANYCAST SID

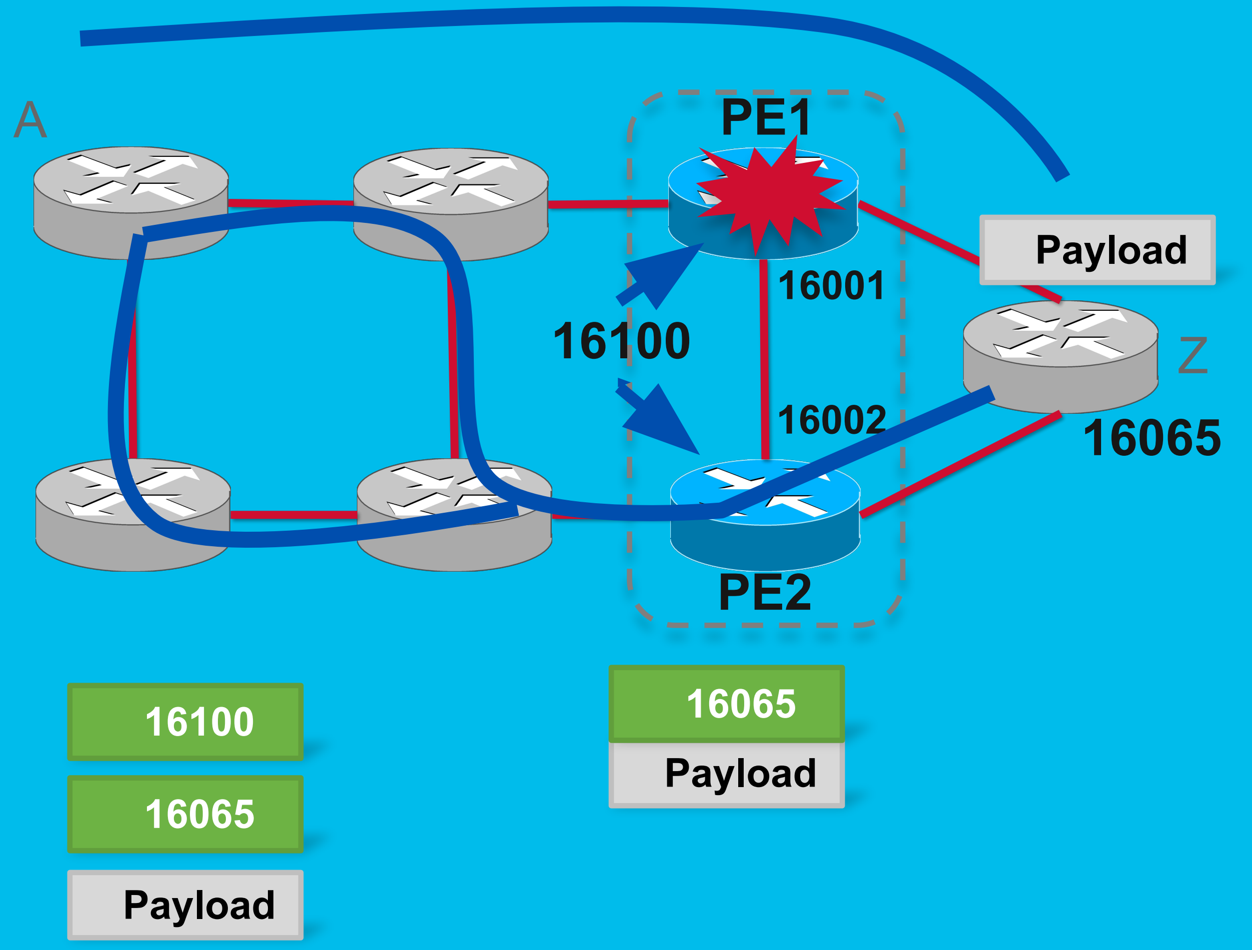
Anycast prefixes: same prefix advertised by multiple nodes

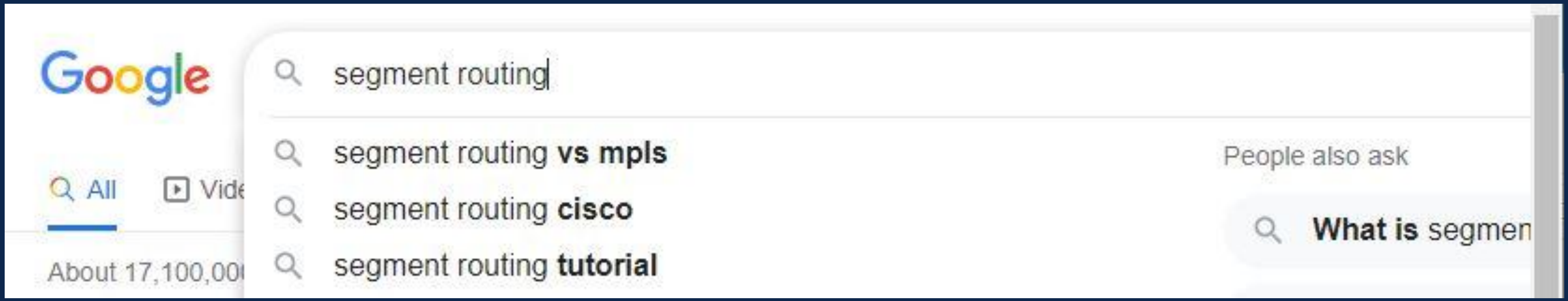
Anycast prefix-SID: prefix-SID associated with anycast prefix - Same prefix-SID for the same prefix!

Traffic is forwarded to one of the Anycast prefix-SID originators **based on best IGP path**

If primary node fails, traffic is auto re-routed to the other node

Note*: nodes advertising the same Anycast prefix-SID must have the same SRGB*





Segment Routing is not a mpls replacement

VPNv4

VPNv6

VPWS

VPLS

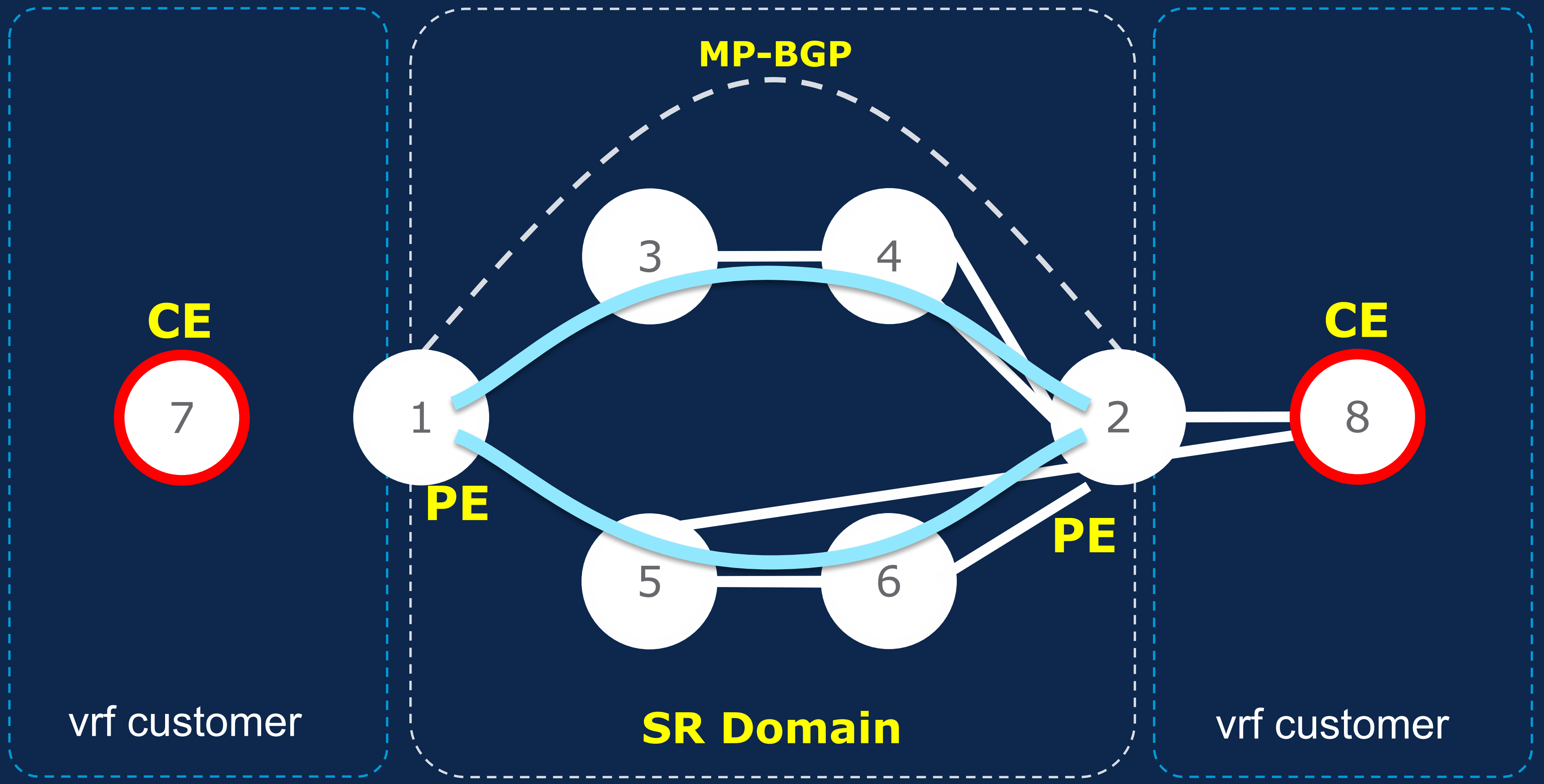
EVPN

Everything Used to Work with LDP

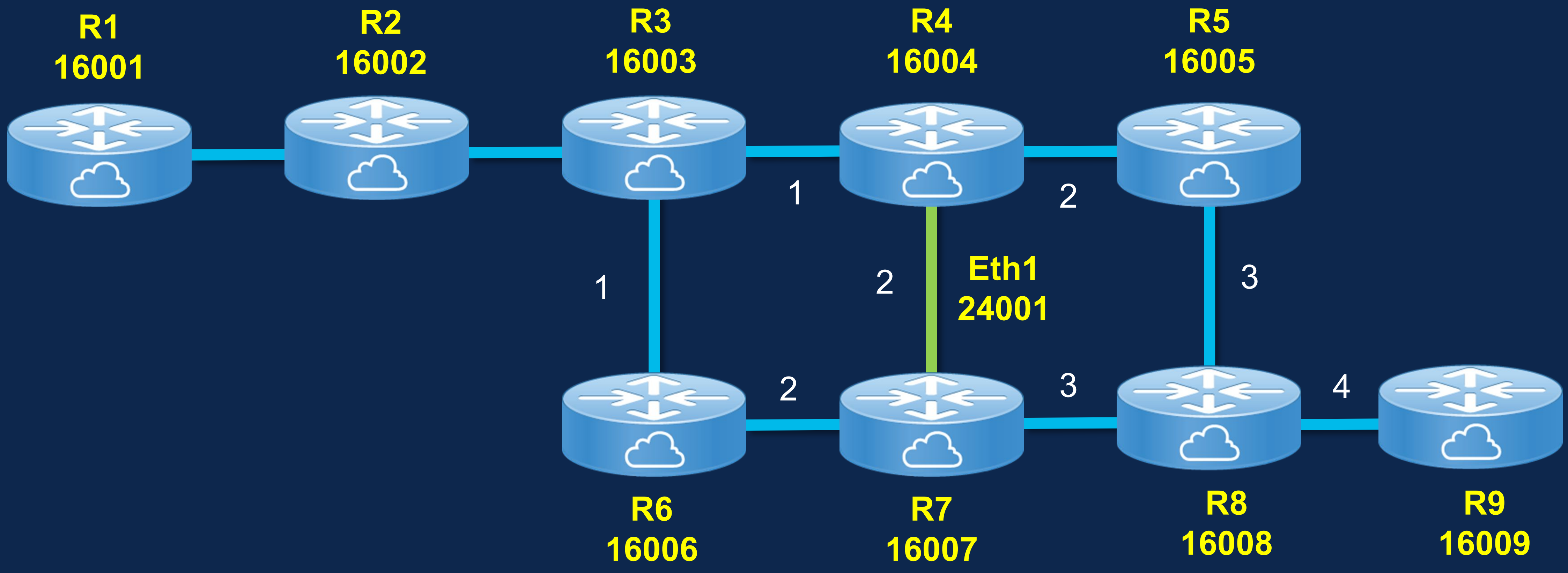
The overlay services will work as usual, including Inter-AS Options 1,2,3

OVERLAY SERVICE UNDERPINNED BY SR CORE

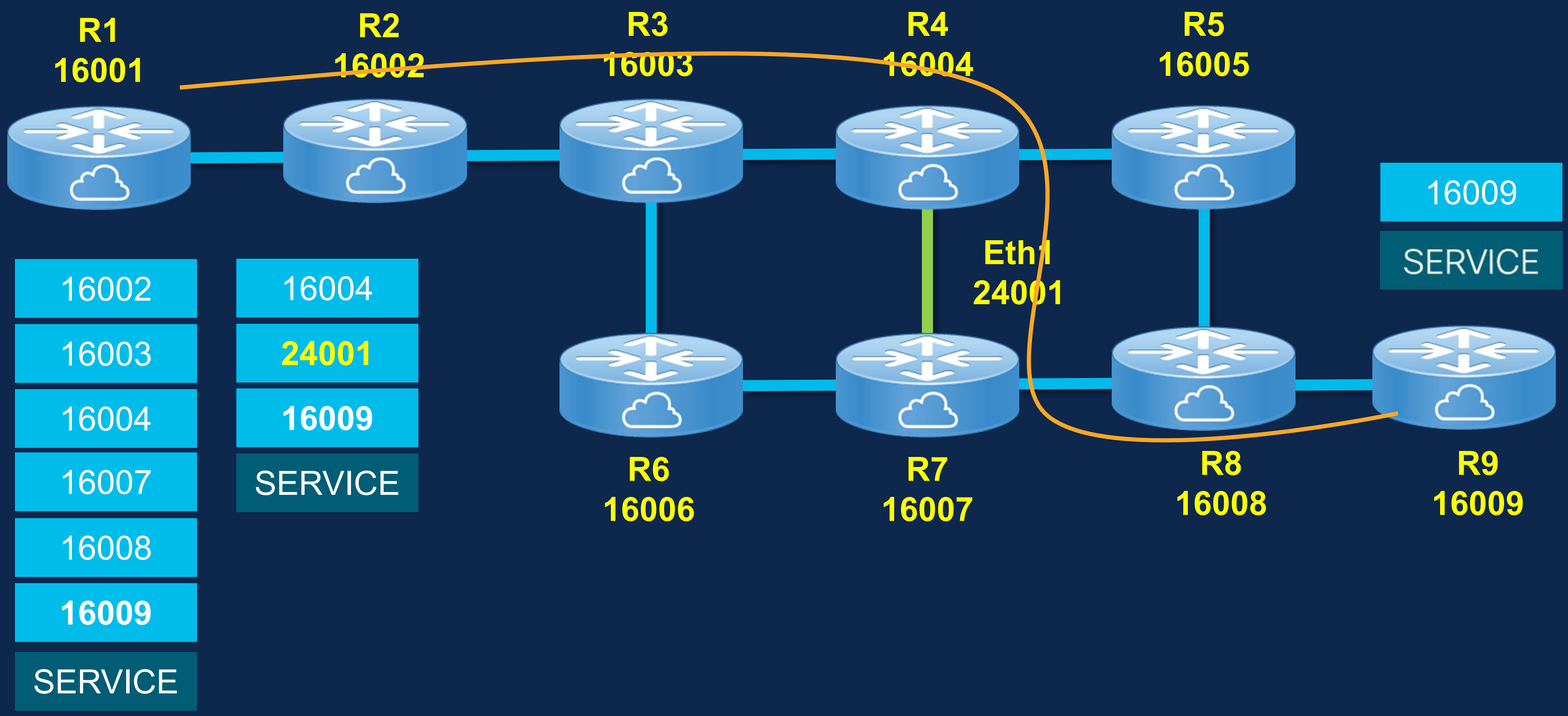
- MPLS services ride on prefix segments
- Simple, one less protocol to operate (LDP)



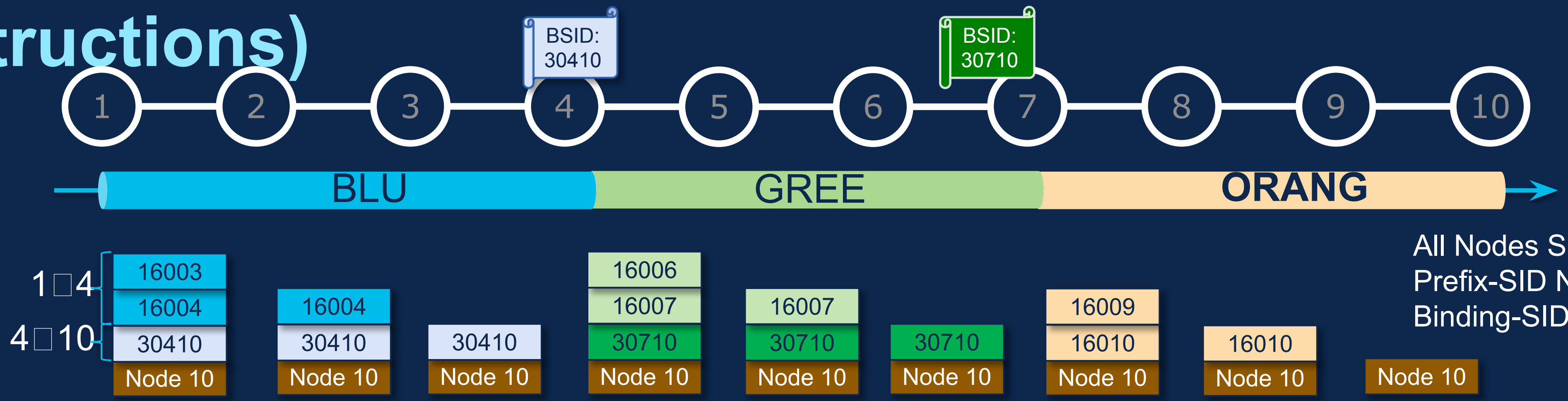
LABEL DEPTH ISSUES



LABEL DEPTH ISSUES



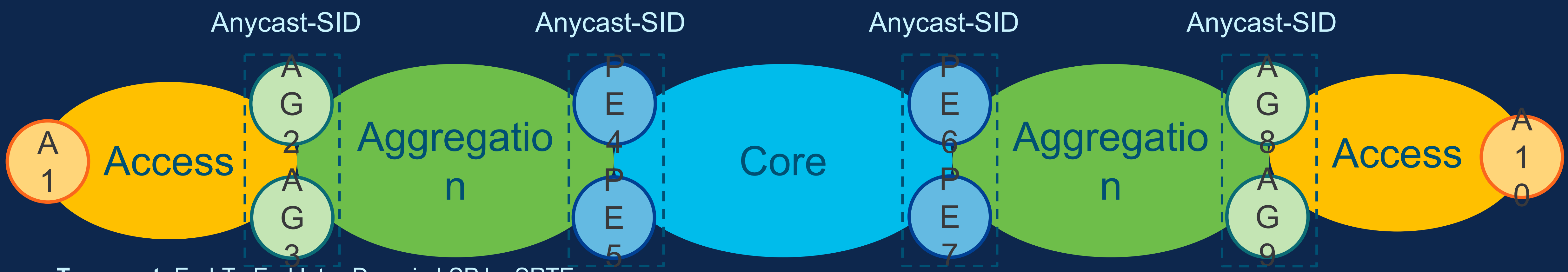
Binding-SID, Stitching Segments (Topological Instructions)



All Nodes SRGB [16,000-23,999]
Prefix-SID NodeX: 1600X
Binding-SID X□Y: 300XY

- Assume Node1 can’t push 8 labels to go to Node10
  - “compress” label stack by stitching SRTE Policies:
    - Node1 pushes:
      - 2 labels to go to Node4
      - Binding-SID (30410) to go to Node10
    - Node4 pops Binding-SID and pushes:
      - 2 labels to go to Node7
      - Binding-SID (30710) to go to Node10
    - Node7 pops Binding-SID and pushes 2 labels to go to Node10

Inter-Domain LSP - Data Plane



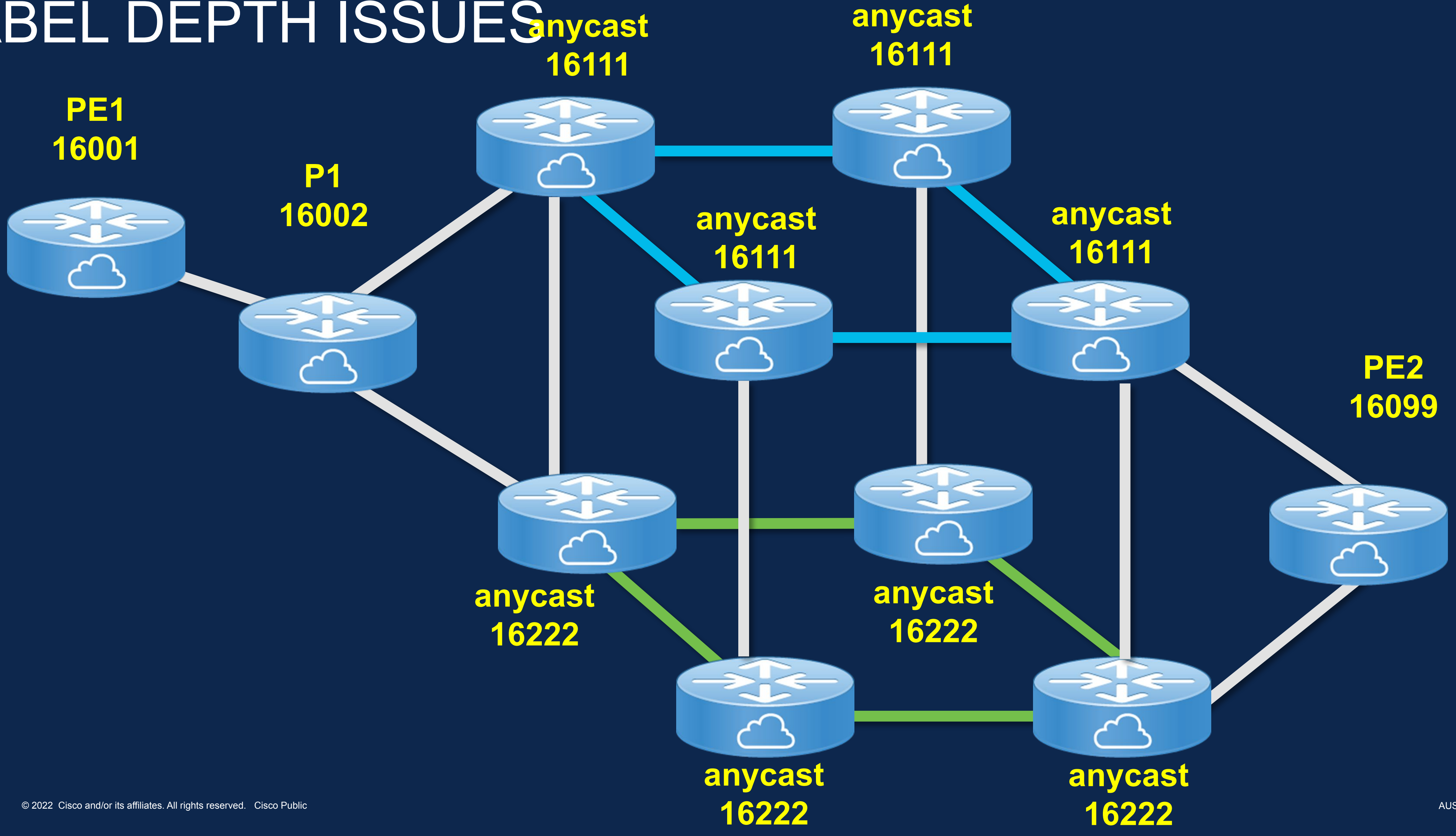
Transport: End-To-End Inter-Domain LSP by SRTE

TI-LFA	TI-LFA	TI-LFA	TI-LFA	TI-LFA
TI-LFA	TI-LFA	TI-LFA	TI-LFA	TI-LFA
AG2/3	PE4/5	PE6/7	AG8/9	A10
PE4/5	PE6/7	AG8/9	A10	
PE6/7	AG8/9	A10		
AG8/9	A10			
A10				

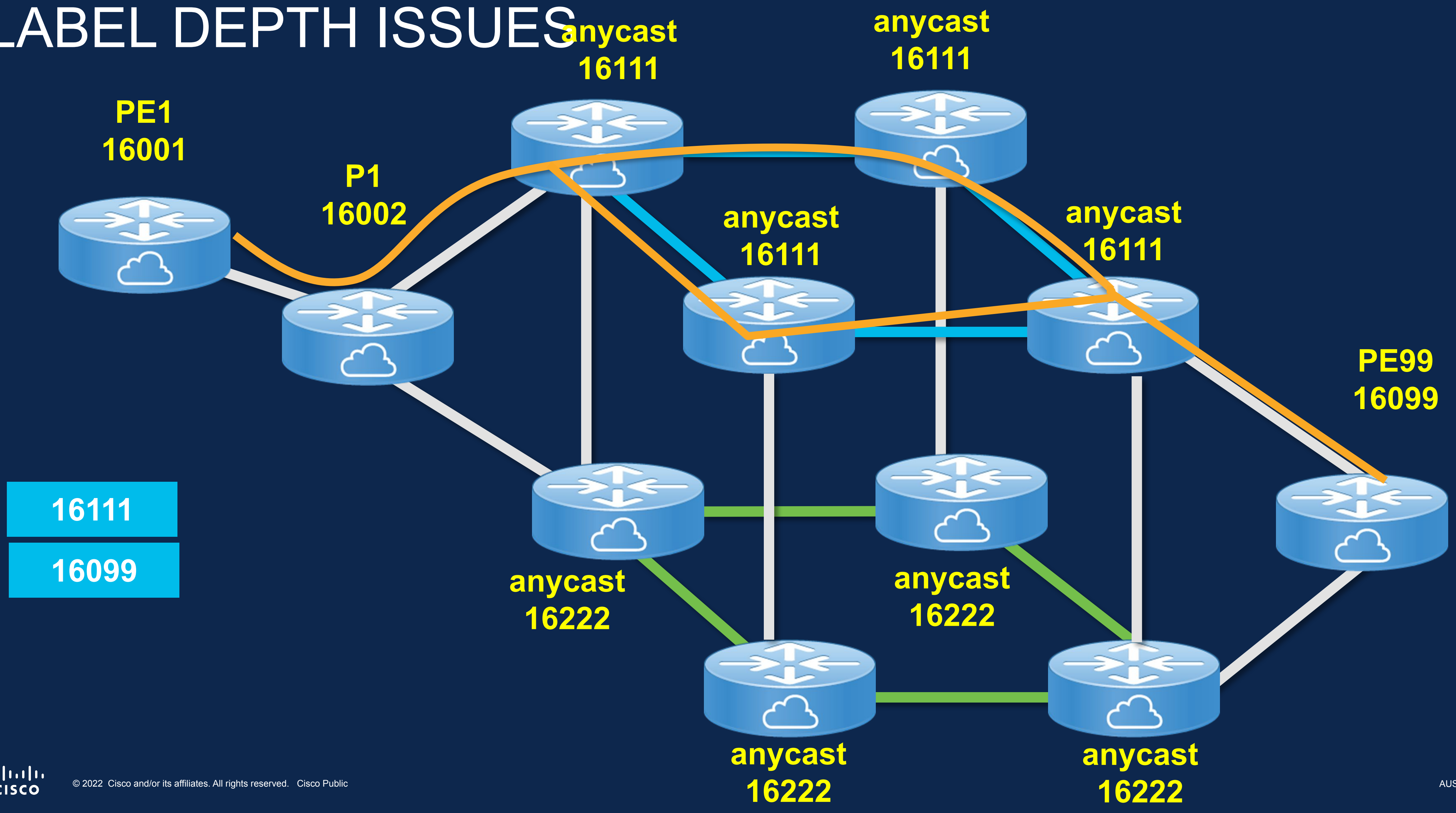
Label Stack must be optimized!
Service label(s) need to be considered!

CHALLENGES

LABEL DEPTH ISSUES



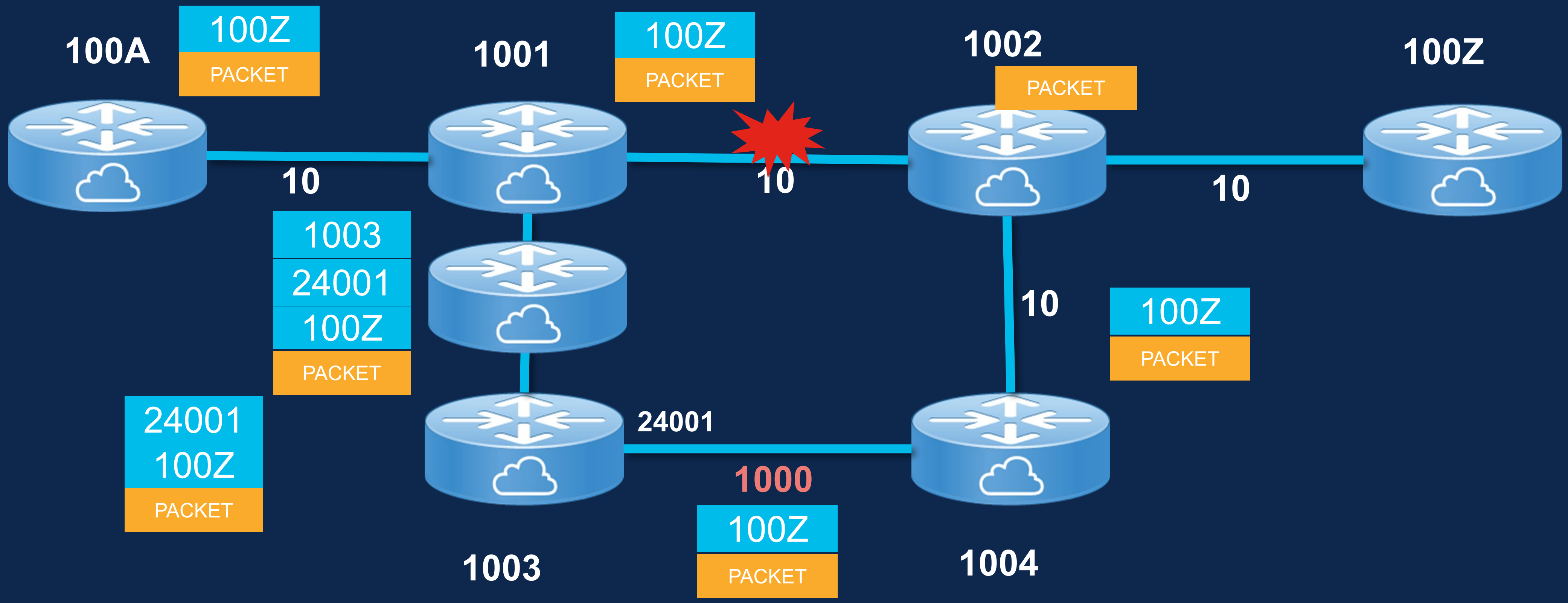
LABEL DEPTH ISSUES



What is TI-LFA

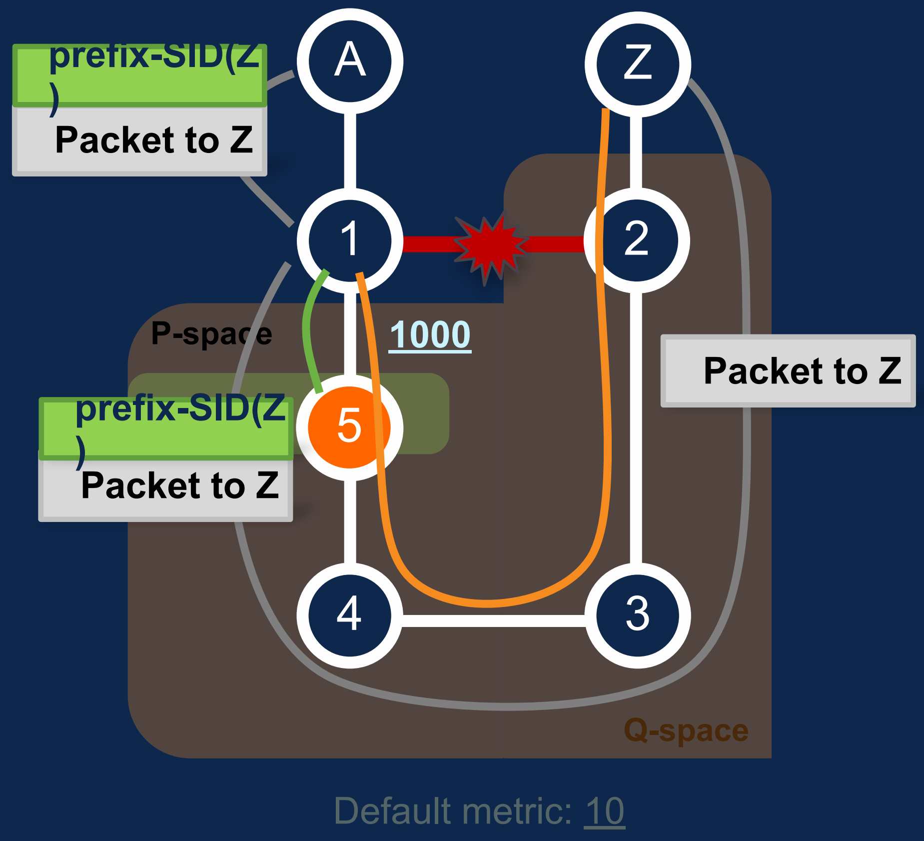
- ✔ **Extremely simple to configure**
- ✔ **Works on any topology (Topology Independent)**
- ✔ **Under 50ms restoration**
- ✔ **No Signaling**
- ✔ **Link or Node Protection**
- ✔ **Using Segments to force traffic over backup path**

TI-LFA Operation



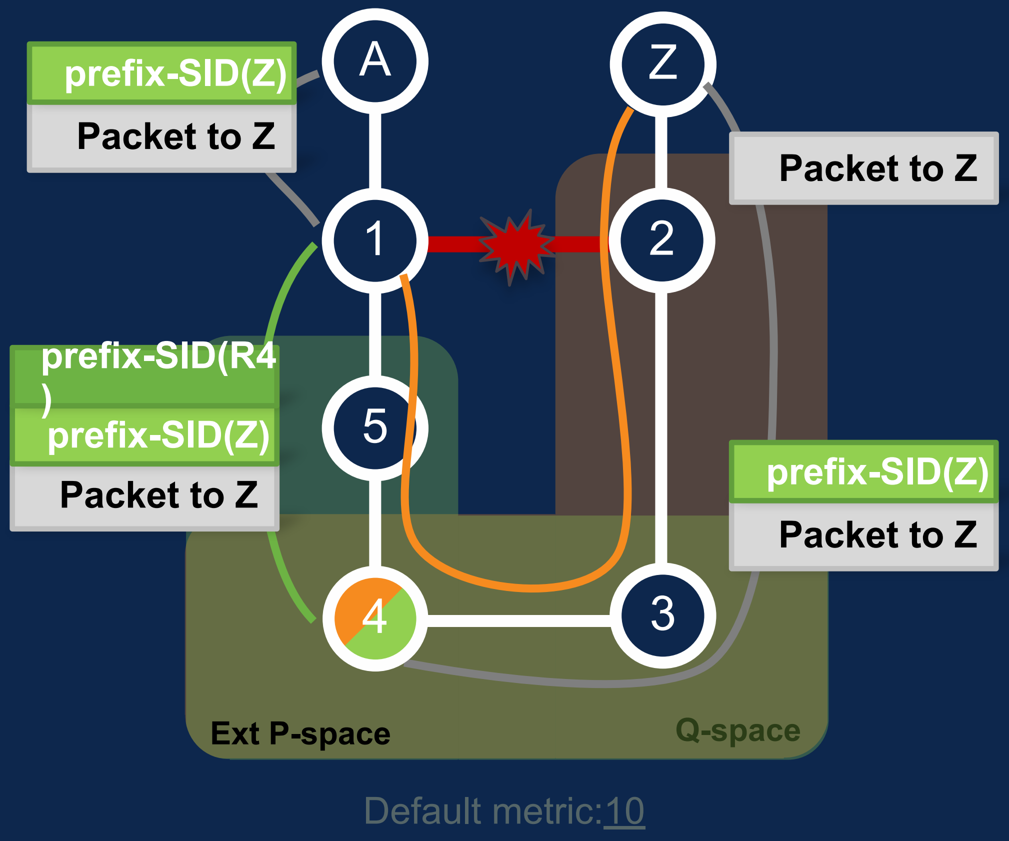
TI-LFA – zero-segment example

- To steer packets on TI-LFA backup path:
  - “forward packet to R5 without any additional segment”



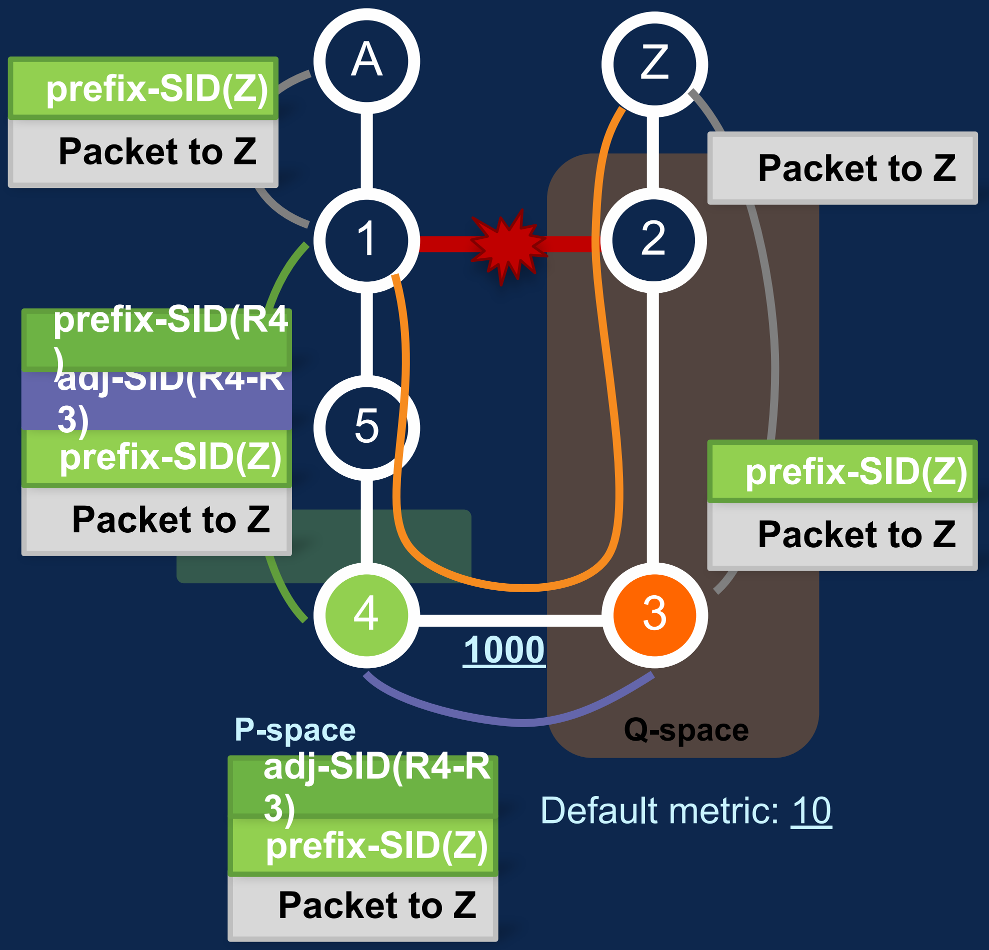
TI-LFA – single-segment example

- To steer packets on TI-LFA backup path:
  - “forward packet on interface to R5
  - push segment {prefix-SID(R4)}”



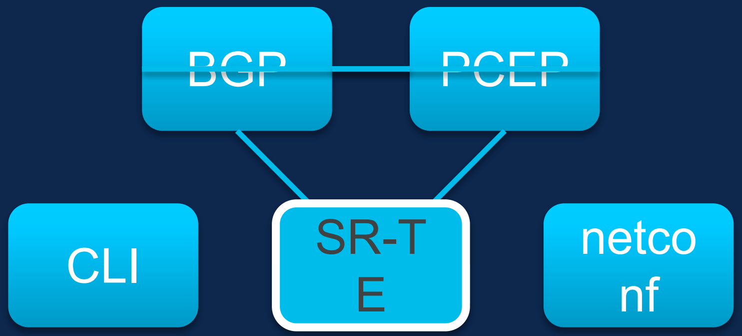
TI-LFA – double-segment example

- To steer packets on TI-LFA backup path:
  - forward packet on interface to R5
  - push segments {prefix-SID(R4) and adj-SID(R4-R3)}"



Traffic Engineering with Segment Routing

- Automated On-Demand Policy
  - No core state: state in the packet header
  - Automated steering: BGP prefix coloring
  - No tunnel interface: on-demand policy instantiation
- CLI or Controller Based Policy
  - Support constraint-based routing
  - CLI is just one way, more programmable ways
  - Support controller based BGP sr-policy instantiation
- Centralized Multi-Domain Policy
  - SR Path Compute Element (SR-PCE) for path compute
  - Binding-SID (BSID) for traffic steering and scale
  - Supports centralized policy via PCEP provision
- 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 colour (an arbitrary numerical value)



No Signaling Protocol

Protection is Ti-LFA

ECMP by native

SR Policy CLI Configuration

```
segment-routing
 global-block 16000 23999
 traffic-eng
  logging
   policy status
  !
  segment-list explicit-to-ABR-1
   index 5 address ipv4 10.1.3.3
   index 10 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
```

SRTE

Explicit-path definition

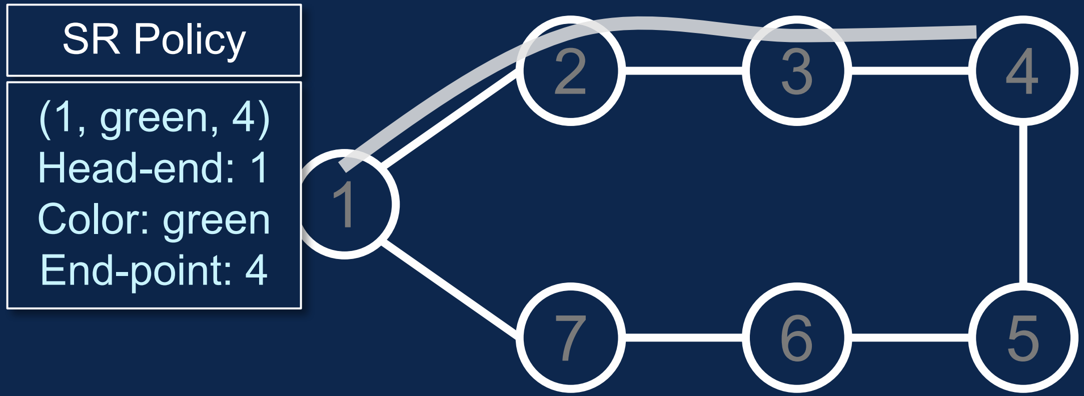
SR Policy

Dynamic path

Explicit path

candidate-paths with higher preference wins, if the path is valid

Examples of SR – POLICY usage



Configuring Binding SID

```
segment-routing
 traffic-eng
  policy AUSNOG-BSID
   binding-sid mpls 1000
   color 1000 end-point ipv4 1.1.1.4
   candidate-paths
    !
```

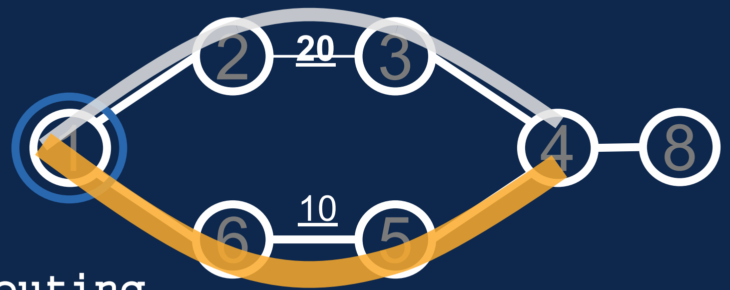
Static Route to an SR-POLICY

```
router static
 address-family ipv4 unicast
  1.1.1.4/32 sr-policy AUSNOG
 !
!
```

Per-Flow steering

```
policy per-flow-r4
 color 103 end-point ipv4 1.1.1.4
 candidate-paths
  preference 100
   per-flow
    forward-class 0 color 101
   !
```

SR Ping – Referencing a Policy



R1#ping sr-mpls policy name <POLICY1>
[lsp-end-point <1.1.1.8>]

Policy is referenced by its name.

User may optionally overwrite FEC value used in Ping.

R1#ping sr-mpls policy
color <20> end-point ipv4 <1.1.1.4>
[lsp-end-point <1.1.1.8>]

Policy is referenced by its color and end-point

R1#ping sr-mpls policy binding-sid 1000
[lsp-end-point <1.1.1.8>]

Policy is referenced by the binding SID.

The policy may be instantiated by configuration, netconf, PCEP or BGP-TE.

On Node1:

```
segment-routing
 traffic-eng
  policy POLICY1
   color 20 end-point ipv4 1.1.1.4
   binding-sid mpls 1000
   candidate-paths
    preference 200
     explicit segment-list SIDLIST1
      weight 1
     dynamic pce
      weight 4
    preference 300
      explicit segment-list SIDLIST2
      dynamic mpls
  segment-list name SIDLIST1
   index 10 mpls label 16002
   index 20 mpls label 24123
   index 30 mpls label 16004
  !
 segment-list name SIDLIST2
   index 10 address ipv4 1.1.1.4
```

Path Computation for Inter-Area

What is the solution?

- Centralized computation model using SR-PCE (Segment-Routing Path Computation Element)
- SR-PCE will compute & download path to Head-end or PCC (Path Computation Client)
- PCEP (Path Computation Element Protocol) is used to/from PCE and PCC or between PCEs

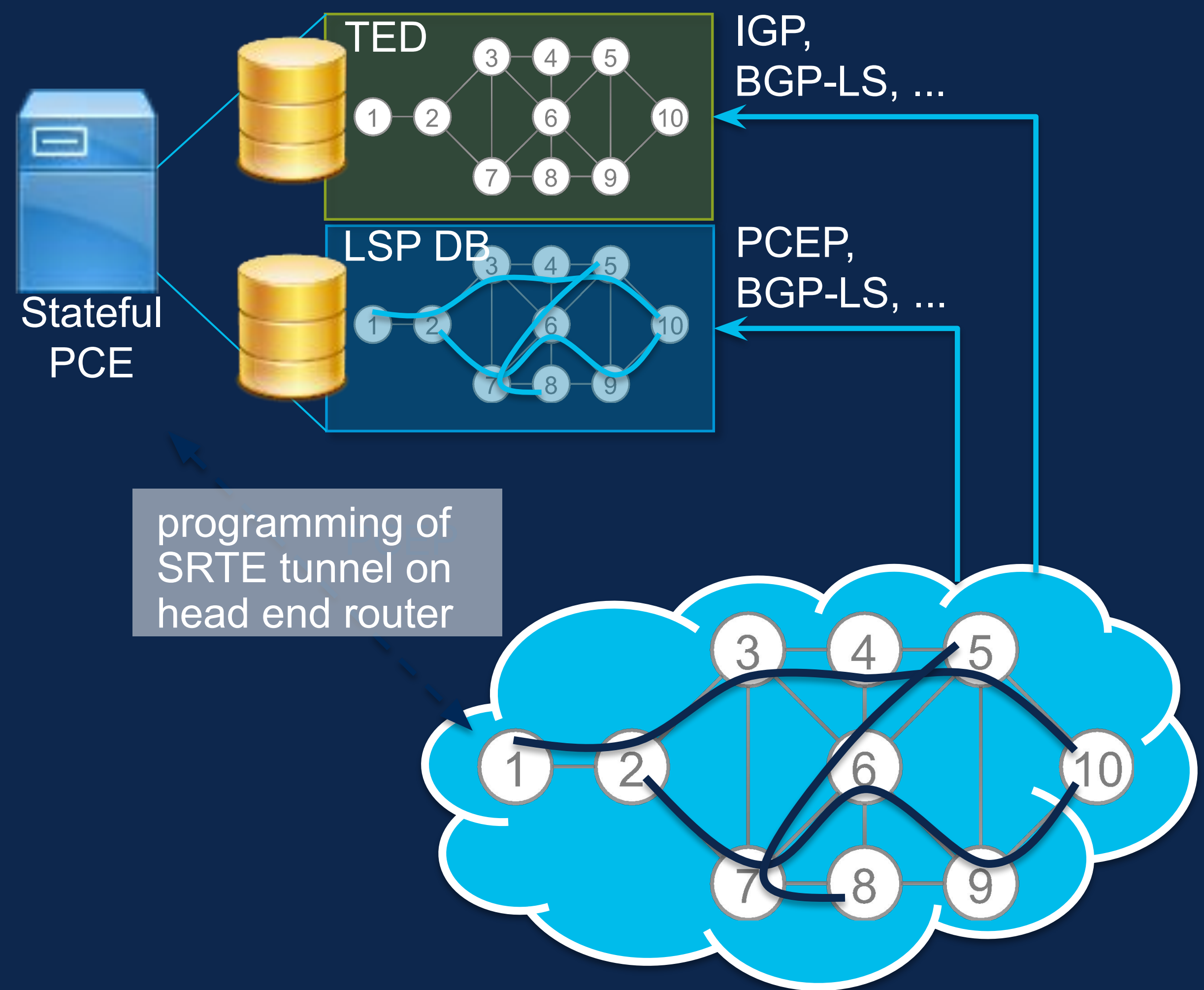
Path Computation Element

TED = IGP Topology + TE link attributes + SIDs + SRGB

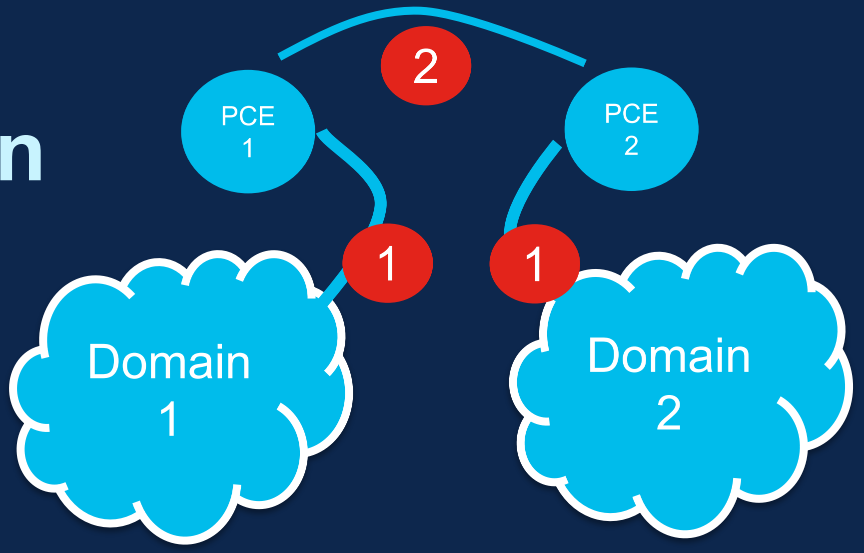
SRTE Policy path

TED = Traffic Engineering Database

- Path computation
- Large, multi-domain and multi-layer networks
- Path computation element (**PCE**)
  - ❖ Computes network paths (topology, paths, etc.)
  - ❖ Stores TE topology database (synchronized with network)
  - ❖ May initiate path creation
  - ❖ Stateful - stores path database included resources used (synchronized with network)
- Path computation client (**PCC**)
  - ❖ May send path computation requests to PCE
  - ❖ May send path state updates to PCE
- Used between head-end router (PCC) and PCE to:
  - ❖ Request/receive path from PCE subject to constraints
  - ❖ State synchronization between PCE and router
  - ❖ Hybrid CSPF



At a glance: SR-PCE Configuration




```
interface Loopback 0
 ip address 10.0.0.11
pce
 address ipv4 10.0.0.11
 segment-routing
  traffic-eng
   peer ipv4 10.0.0.1
   !
...
router ospf 1
 distribute link-state instance-id 3[x]
```

Distribute IGP LS info into BGP-LS 1

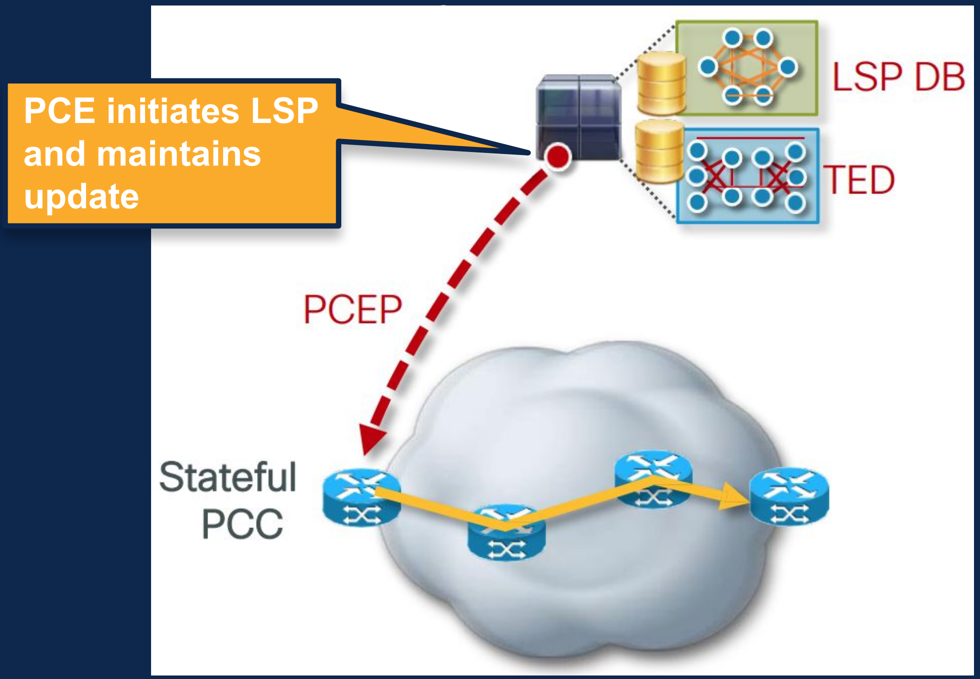
instance-id needed for multi-domain (one instance ID per domain)

```
router bgp 65000
 address-family ipv4 unicast
 !
 address-family link-state link-state
 !
 neighbor 10.0.0.22
  address-family link-state link-state
```

BGP-LS peering 2

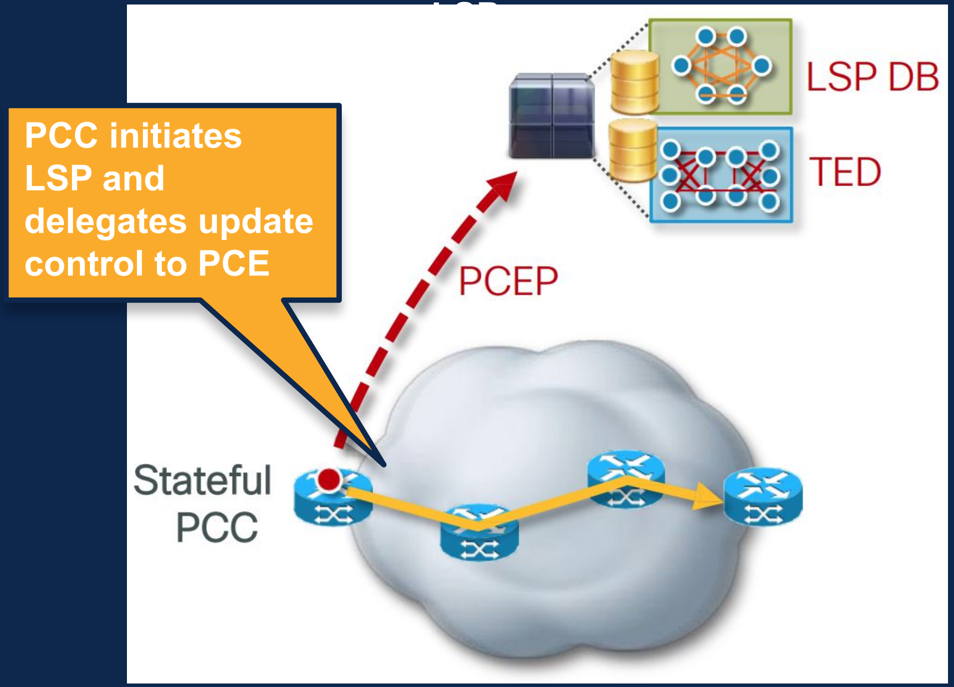
PCE-Initiated and PCC-Initiated LSP

PCE-Initiated



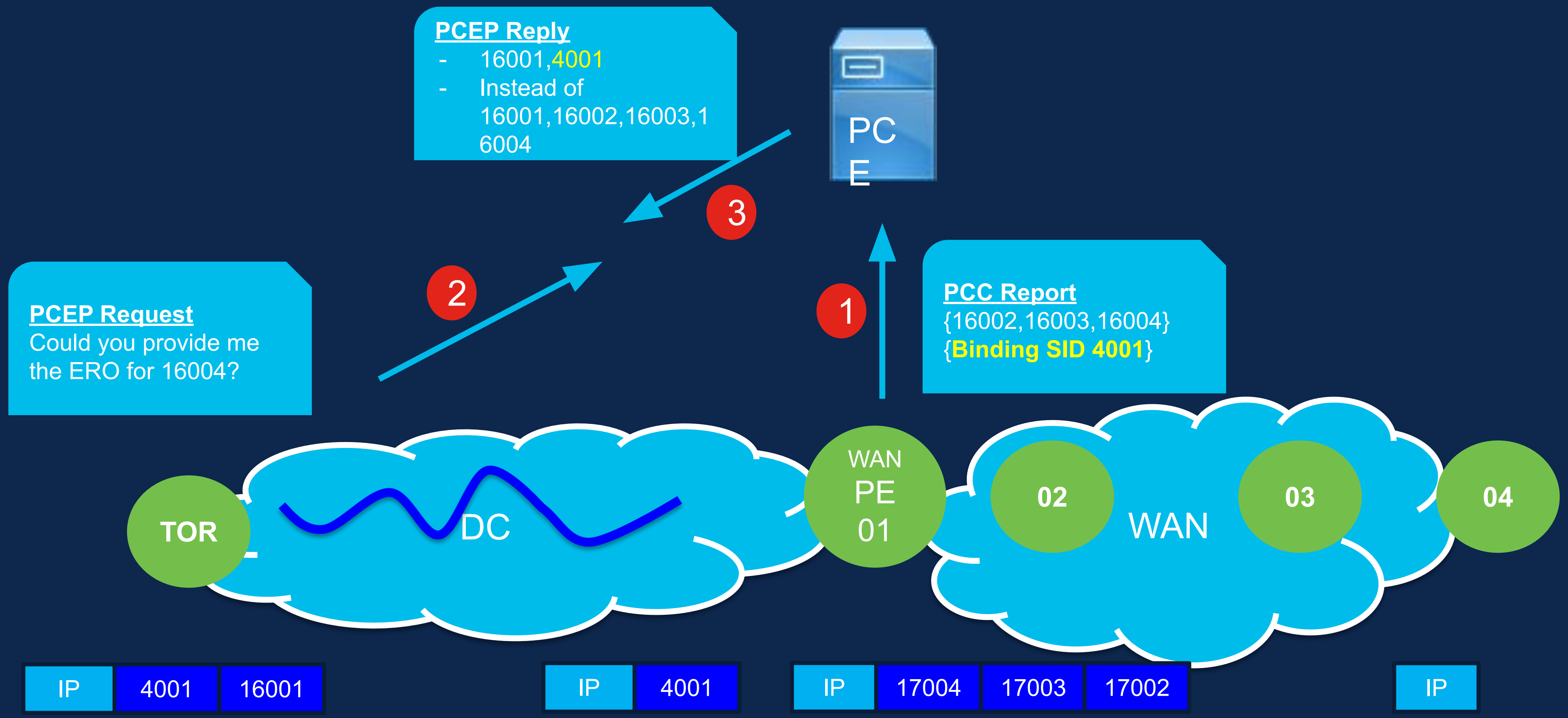
- PCE part of controller managing full path lifecycle
- Tighter integration with application demands

PCC-Initiated

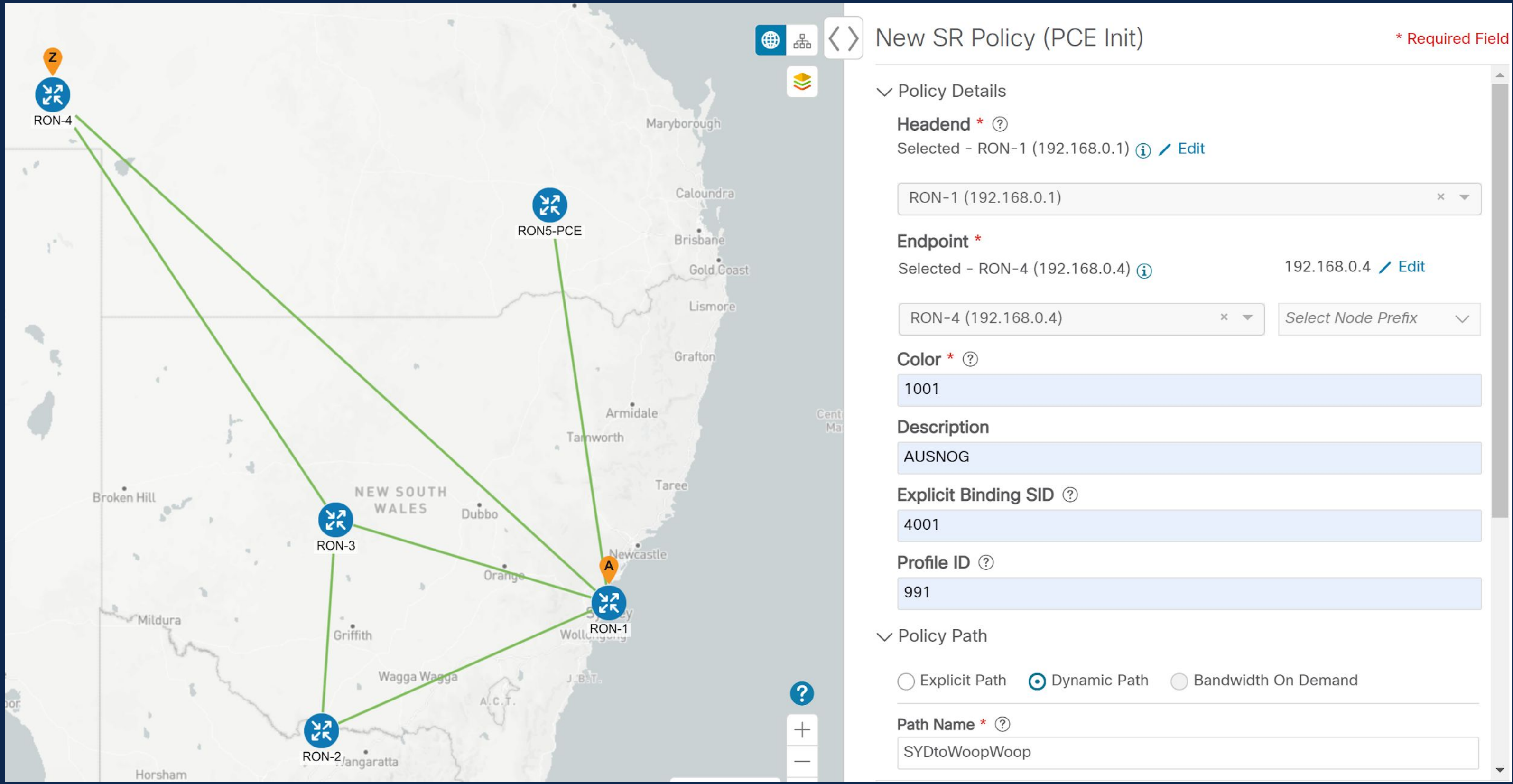


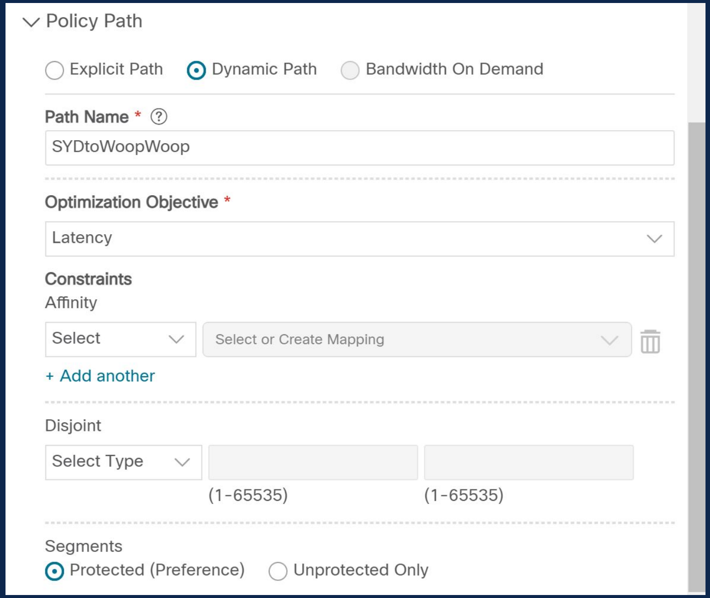
- PCC initiate path setup based on distributed network state
- Can be used in conjunction with PCE-initiated paths

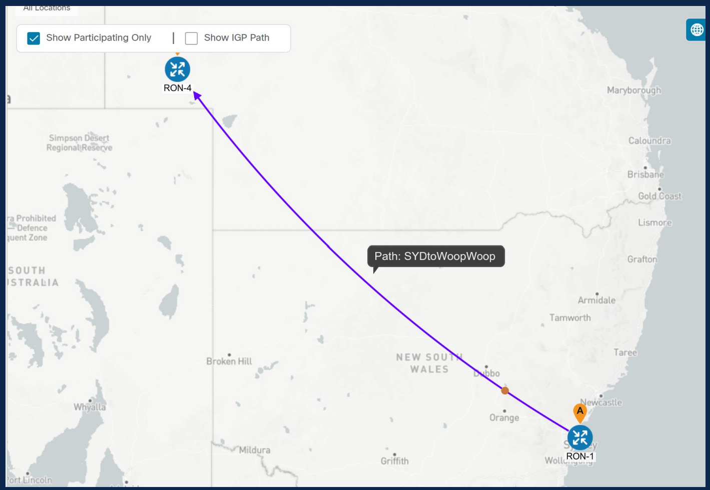
Binding-SID use-case examples



True Programmability







Desire from the Network

- **Simplicity**
  Less numbers of protocols to operate & troubleshoot
  Less numbers of protocol interactions to deal with
  Deliver automated FRR for any topology

- **Scale**
  Avoid thousands of labels in LDP database
  Avoid thousands of MPLS Traffic Engineering LSP’s in the network
  Avoid thousands of tunnels to configure

- **Leverage all services supported over MPLS today (L3/L2 VPN, TE, IPv6)**
  Requires evolution and not revolution

- **Bring the network closer to the applications**

THANK YOU

CISCO

The bridge to possible