Segment Routing

Setting the scene...

Dhruv Dhody
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Why Segment Routing (SR)?

- Ability for a node to specify a path
  - So that apart from the usual shortest-path, another path can be taken up!
  - Basically Source Routing!
    - In contrast to the usual hop-by-hop destination-based routing!
    - *But what happened to source routing in the past?*
      - *Significant security concerns for IP in the open Internet and thus was deprecated!*
- No state in the network
  - Everything needed is in the packet header *(no signaling protocols)*
  - Highly Scalable
- Simplify Network Operations
  - Agile and flexible Traffic Engineering
  - Better resource utilization
  - Network Operations and Management

What is Segment Routing (SR)?

- A modern variant of source-routing!
- No state on the transit routers, instead it is part of the packet header, injected at the ingress.
- Some concepts
  - SR Domain: the set of nodes participating in the SR-based routing model
  - SR Path: an ordered list of **segments** that connects an SR ingress node to an SR egress node
  - SR Segment: an instruction a node executes on the incoming packet (e.g., forward packet through a specific interface, or forward via shortest path to the destination).
  - SID: a segment identifier
  - Two dataplanes are supported : SR-MPLS & SRv6

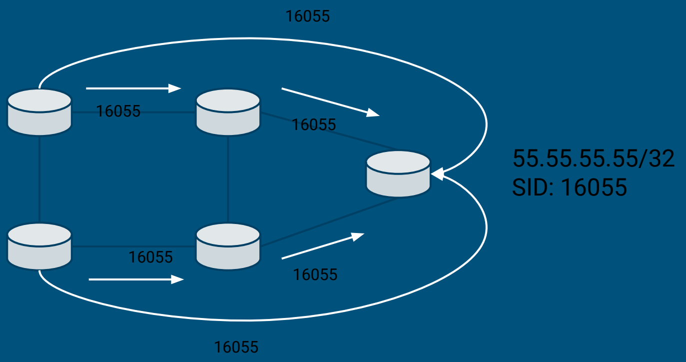
SR Forwarding & Control Planes

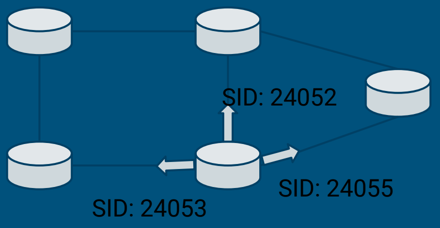
- SR Forwarding Plane
  - SR-MPLS
    - an ordered list of segments is represented as a stack of MPLS labels
    - No change in MPLS header and dataplane
    - Segment represented as MPLS label and SR Path as label stack
  - SRv6
    - an ordered list of segments is encoded in a routing extension header (SRH)
    - More later on…

- SR Control Plane
  - The “brains” of the whole operation!
  - IGP / BGP-LS
    - Distribute the SR information such as SIDs
  - PCEP
    - When a centralized Path Computation Element (PCE) is used to compute SR Paths
  - SR Path/Policy
    - a framework that enables the instantiation of an ordered list of segments on a node for the steering of traffic for a specific purpose
    - Distributed via BGP/PCEP/YANG

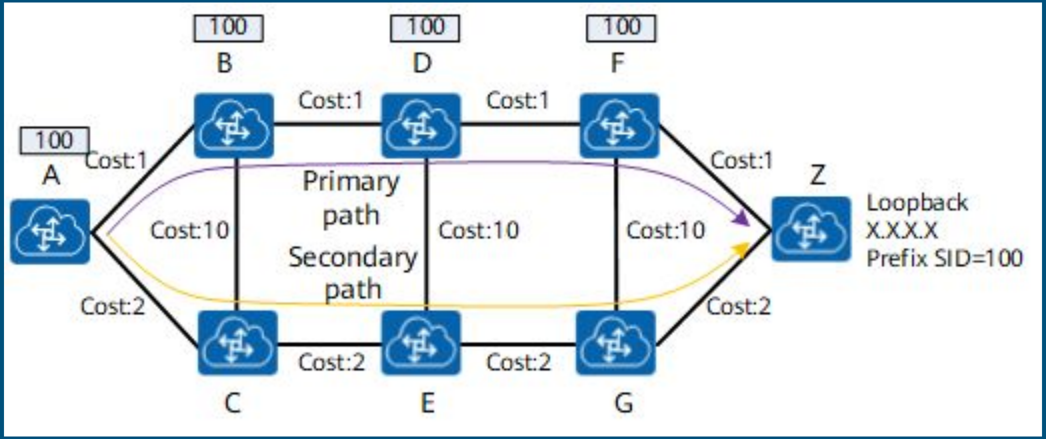
Segments / SIDs

- Prefix/Node SID - Globally unique segment identifier represent ECMP-aware shortest route to the prefix/node.
- Adjacency SID - Local segment identifier for an adjacency
- Others
  - Anycast SID
  - Binding SID
  - Egress Peer Engineering (EPE) Segments

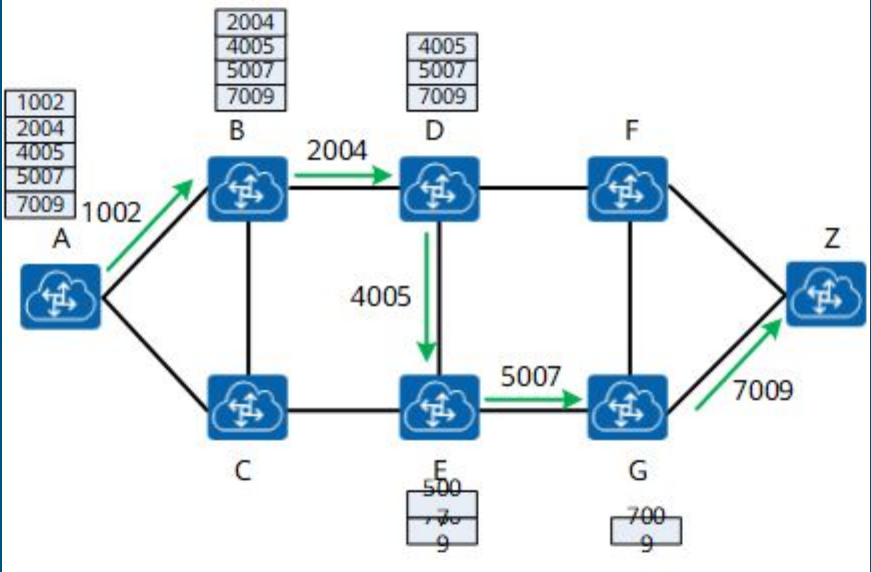




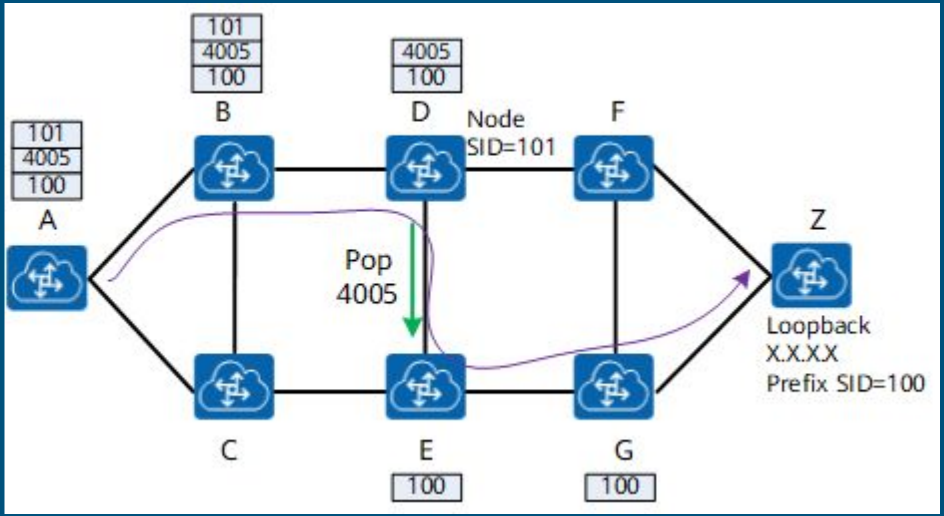
Prefix SID Example



Adjacency SID Example



Mixed Example



Our focus is on the SR on IPv6 (SRv6) dataplane today!

Introduction to SRv6

Darren Dukes ddukes@cisco.com

INTC/IIESoc Webinar – March 9, 2023

SRv6 is IETF Proposed Standard

Architecture

- Segment Routing Architecture RFC 8402
- Source Packet Routing in Networking (SPRING) Problem Statement and Requirements RFC 7855
- IPv6 Segment Routing Header (SRH) RFC 8754
- Segment Routing over IPv6 (SRv6) Network Programming RFC 8986

Use-cases

- SRv6 based overlay services RFC9259
- IGP Flexible Algorithm RFC9350
- Topology Independent Fast Reroute using Segment Routing (WG Draft)

Protocol Extensions

ISIS

- IS-IS Extensions for SRv6 RFC 9352

OSPF

- OSPFv3 Extensions for SRv6 (WG Draft)

BGP

- BGP Link State Extensions for SRv6 (WG Draft)

PCEP

- PCEP Extensions for SRv6 (WG Draft)

OAM

- OAM In SRv6 Networks 9259

Performance Measurement

- A Two-Way Active Measurement Protocol (TWAMP) RFC 5357
- Simple Two-Way Active Measurement Protocol RFC 8762
- Enhanced Performance Measurement Using Simple TWAMP in Segment Routing Networks (Draft)
- Performance Measurement Using Simple TWAMP (STAMP) for Segment Routing Networks (WG Draft)
- Simple TWAMP (STAMP) Extensions for Segment Routing Networks (WG Draft)
- Simple Two-Way Direct Loss Measurement Procedure (Draft)

Up-to-date list on https://segment-routing.net/ietf

SRv6
Network Programming
Introduction

Segment Routing

- Source Routing
  - the topological and service (NFV) path is encoded in packet header
- Scalability
  - the network fabric does not hold any per-flow state for TE or NFV
- Simplicity
  - automation: TILFA sub-50msec FRR
  - protocol elimination: LDP, RSVP-TE, VxLAN, NSH, GTP, ...
- End-to-End
  - DC, Metro, WAN

Two dataplane instantiations

Segment Routing

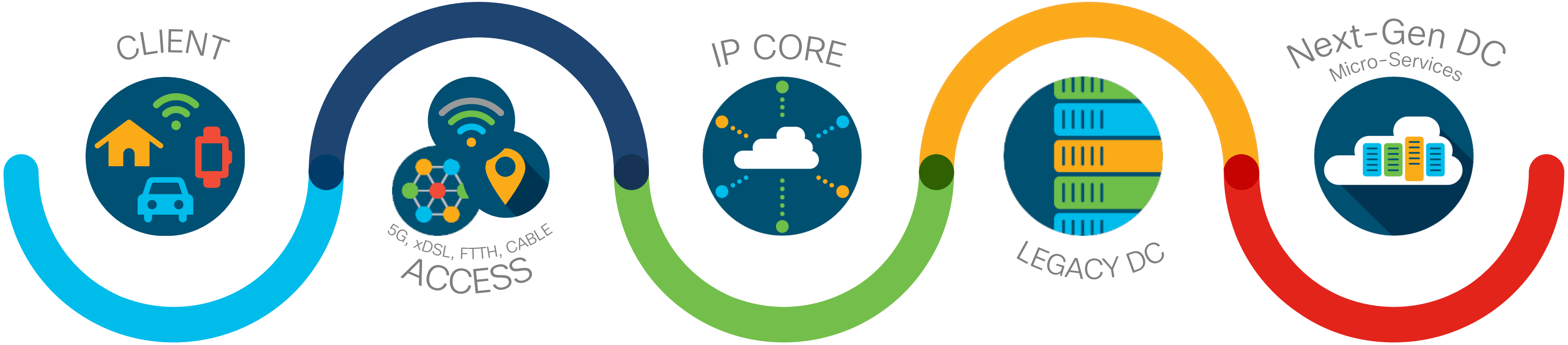
MPLS

- leverage the mature MPLS HW with only SW upgrade
- 1 segment = 1 label
- a segment list = a label stack

IPv6

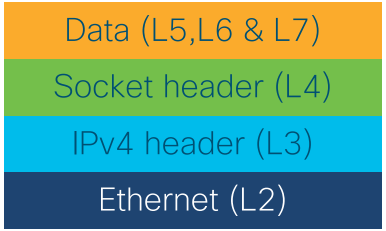
- leverages RFC8200 provision for source routing extension header
- 1 segment = 1 address
- a segment list = an address list in the SRH (RFC8754)

IPv6 provides reachability



IPv4 limitations & work-arounds

- × Limited address space
- × No engineered Load Balancing
- × No VPN
- × No Traffic Engineering
- × No Service Chaining



IPv4 limitations & work-arounds

- × Limited address space → NAT
- × No engineered Load Balancing → MPLS Entropy Label, VxLAN UDP
- × No VPN → MPLS VPN's, VxLAN
- × No Traffic Engineering → RSVP-TE, SR-TE MPLS
- × No Service Chaining → NSH

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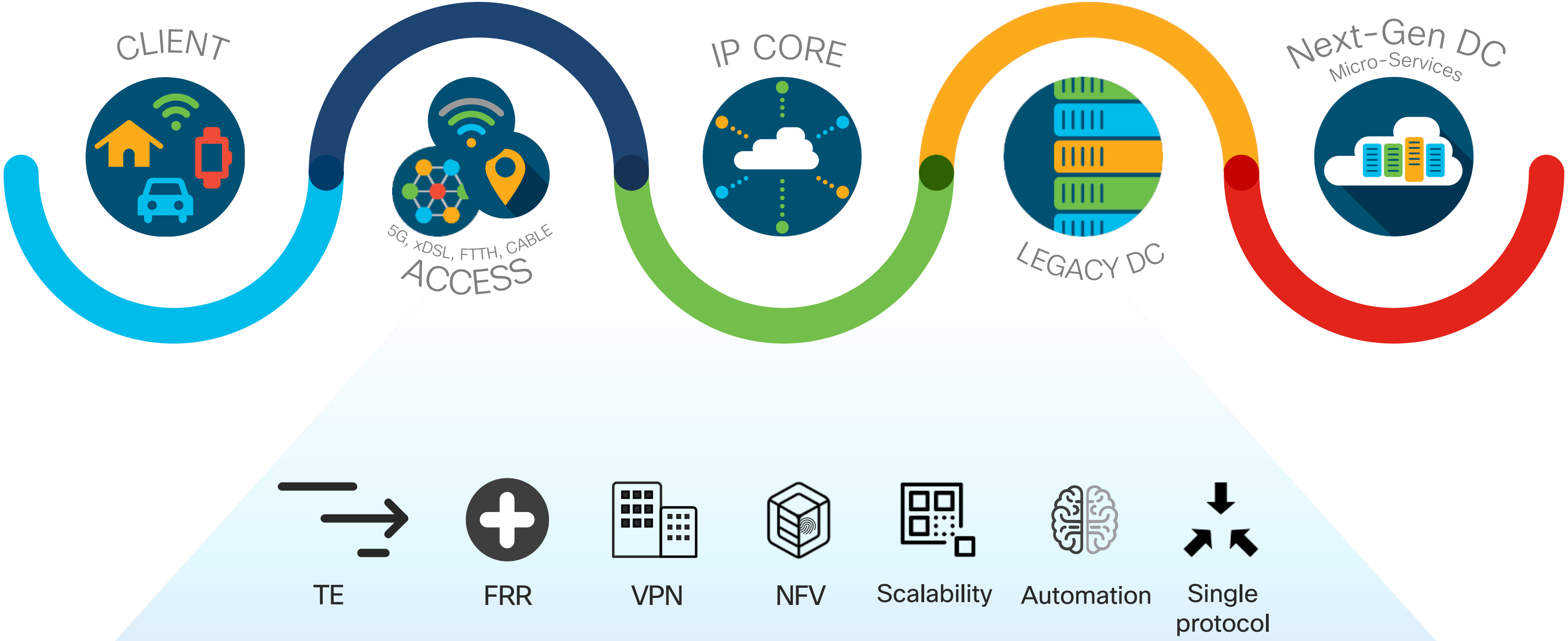
Data (L5,L6 & L7)
Socket header (L4)
IPv4 header (L3)
Ethernet (L2)

Simplicity (back to the OSI model)

Data (L5,L6 & L7)
Socket header (L4)
IPv4 header (L3)
NSH
VxLAN (+ IP and UDP)
MPLS
Ethernet (L2)

SRv6 unleashes IPv6 potential



SR for anything:
Network as a Computer

Network instruction

- 128-bit SRv6 SID
  - Locator: routed to the node performing the function
  - Function: any possible function
    either local to NPU or app in VM/Container
  - Flexible bit-length selection

Network instruction

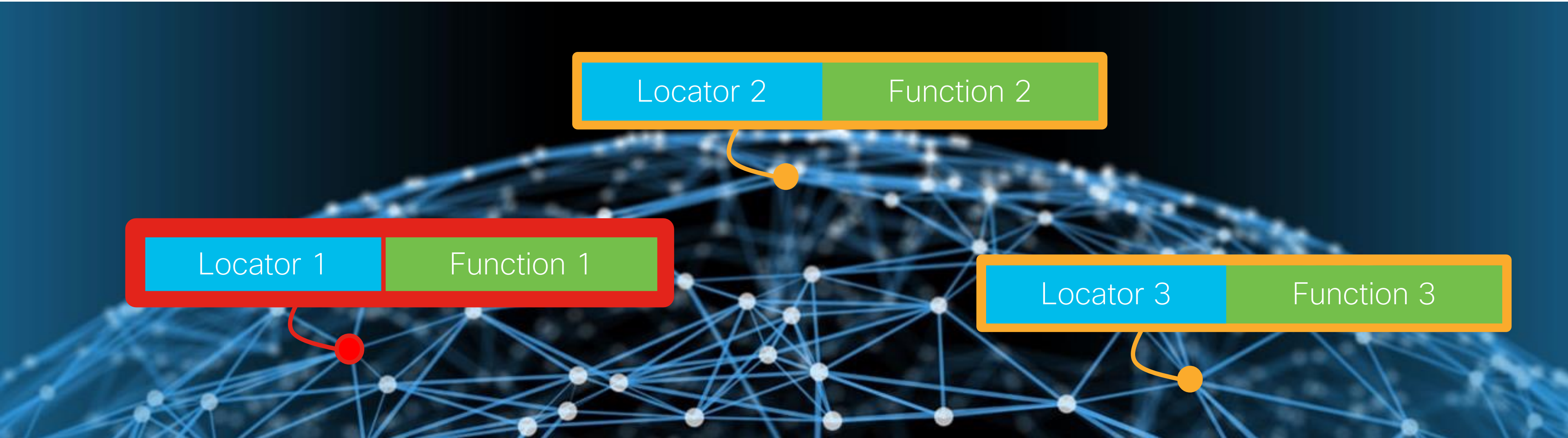
- 128-bit SRv6 SID
  - Locator: routed to the node performing the function
  - Function: any possible function

    either local to NPU or app in VM/Container
  - Arguments: optional argument bits to be used only by that SID
  - Flexible bit-length selection

Network Program

Active Segment →

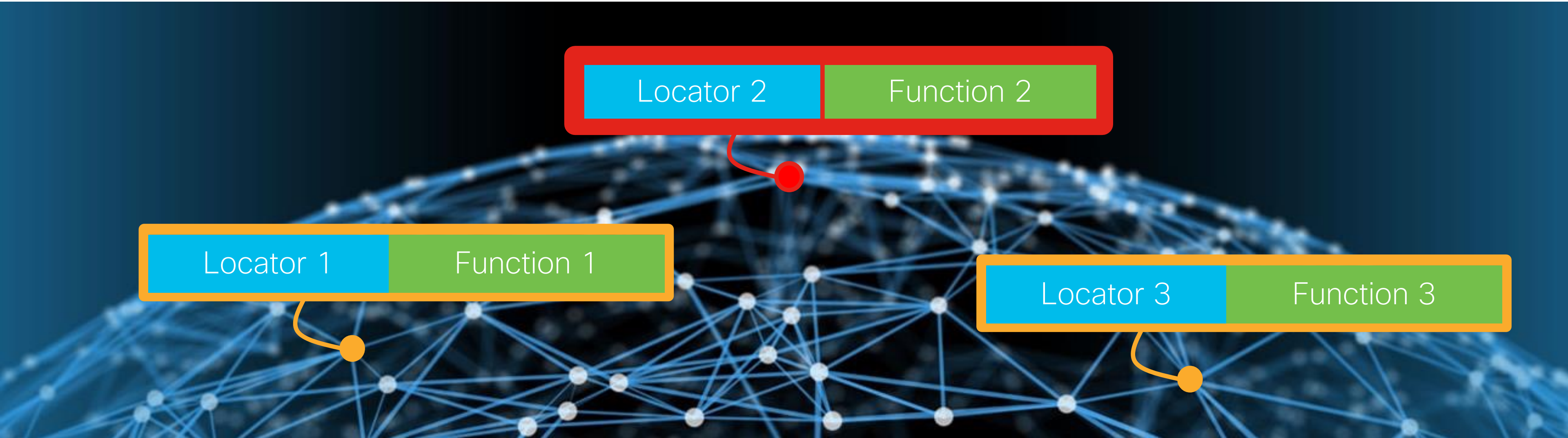
Locator 1	Function 1
Locator 2	Function 2
Locator 3	Function 3



Network Program

Locator 1	Function 1
Locator 2	Function 2
Locator 3	Function 3

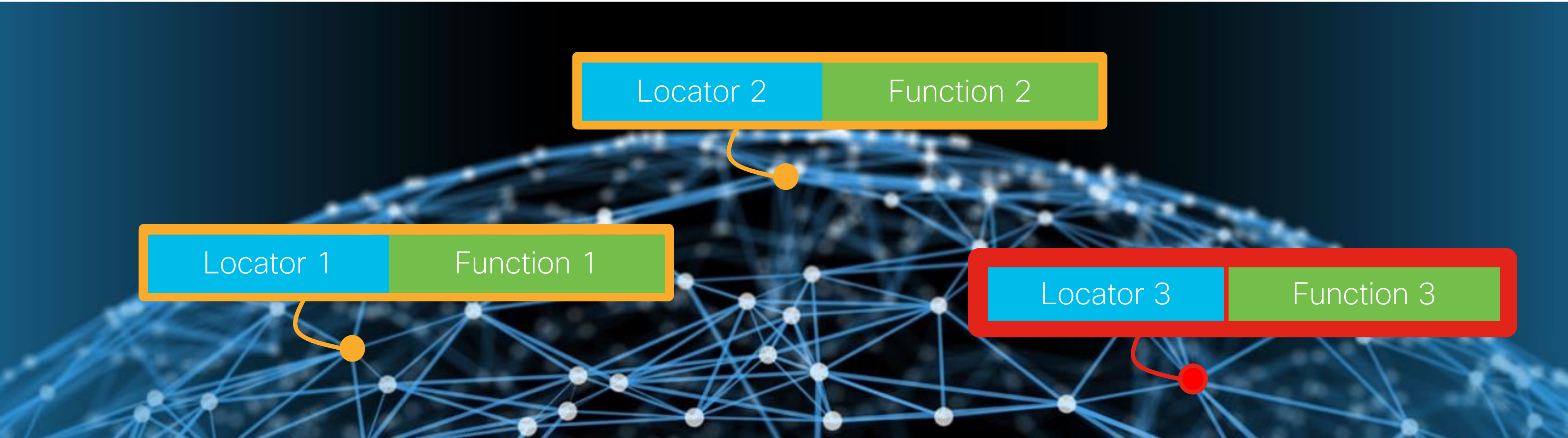
Active Segment → Locator 2 | Function 2



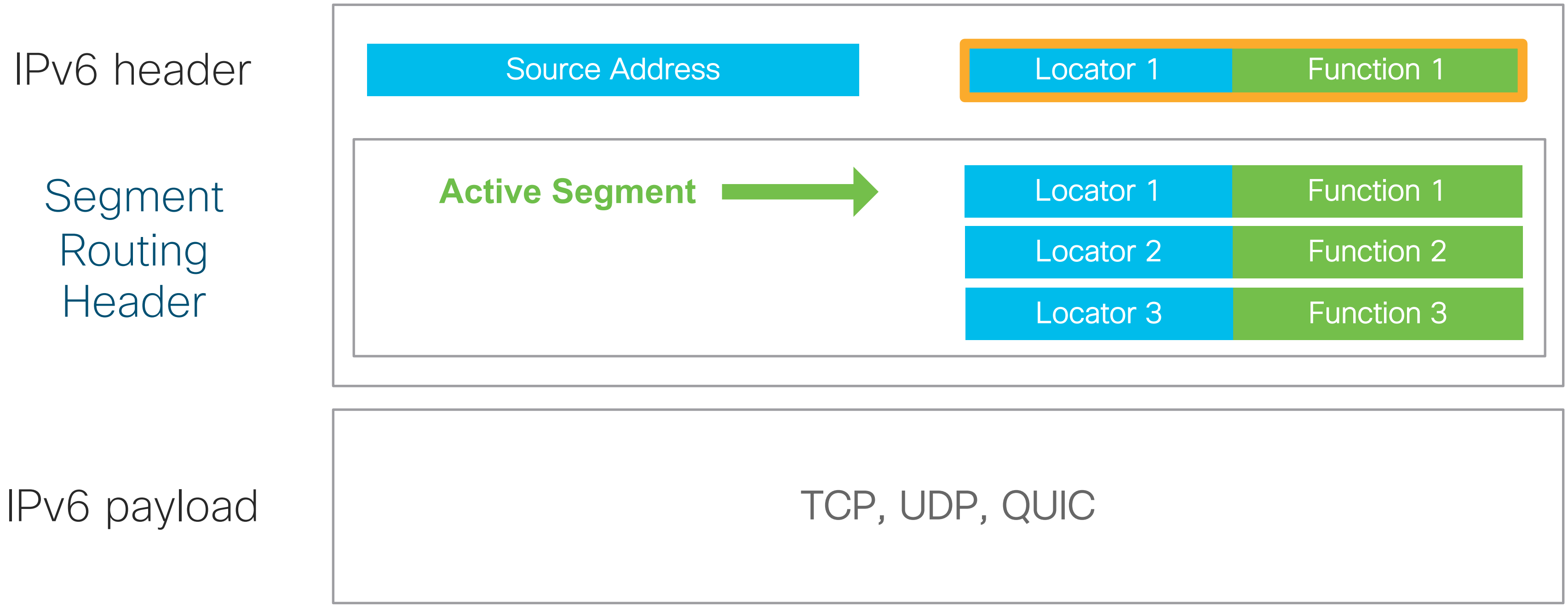
Network Program

Locator 1	Function 1
Locator 2	Function 2
Locator 3	Function 3

Active Segment → Locator 3 | Function 3



Network Program in the Packet Header



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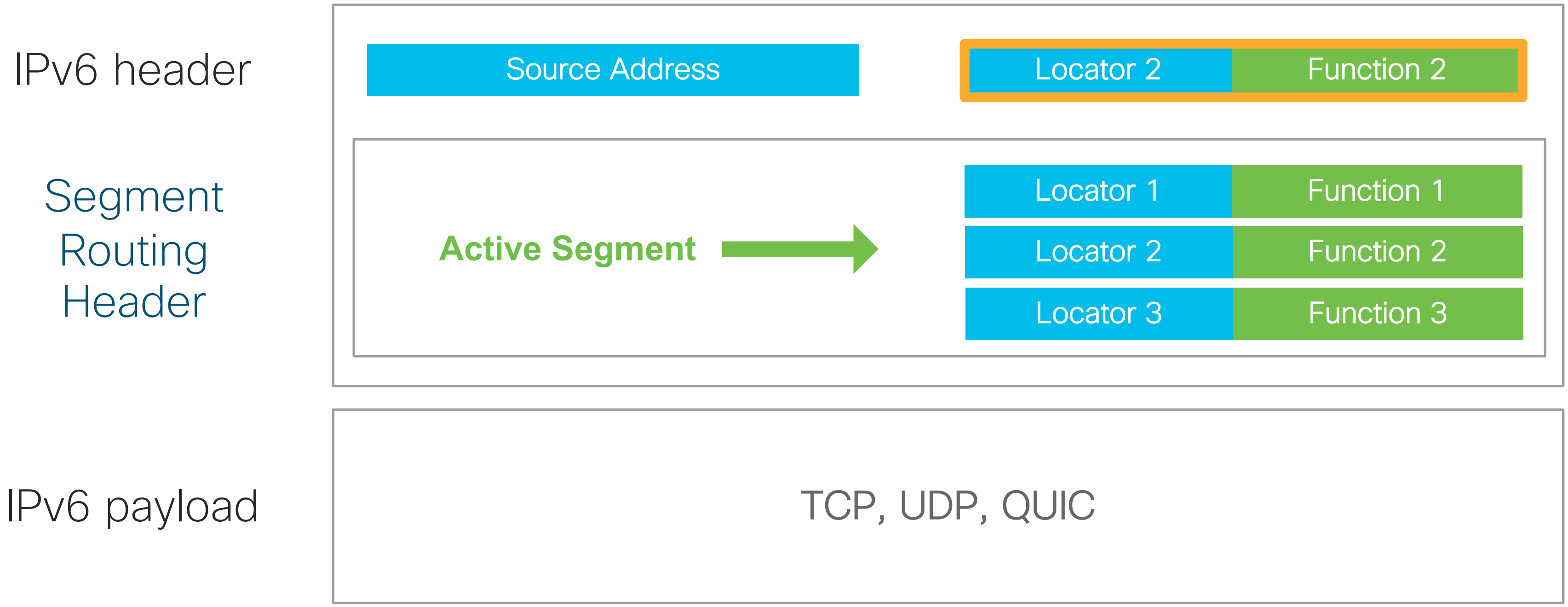

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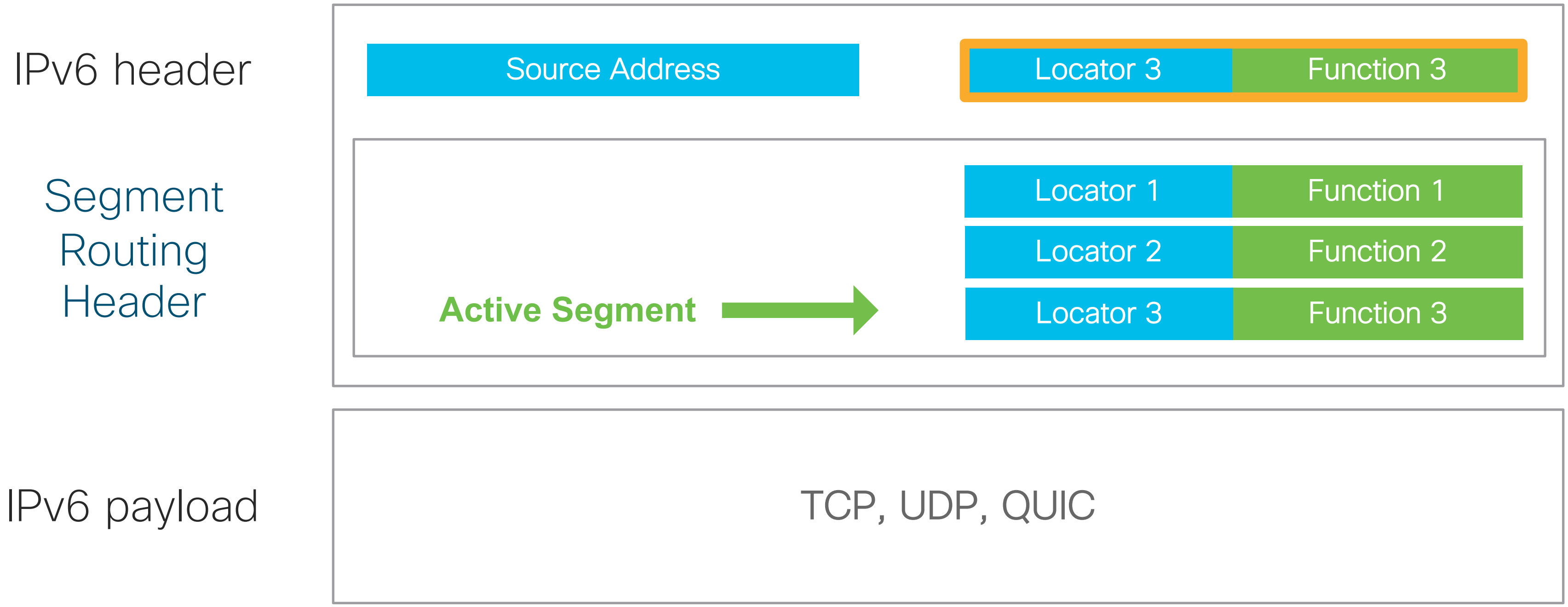
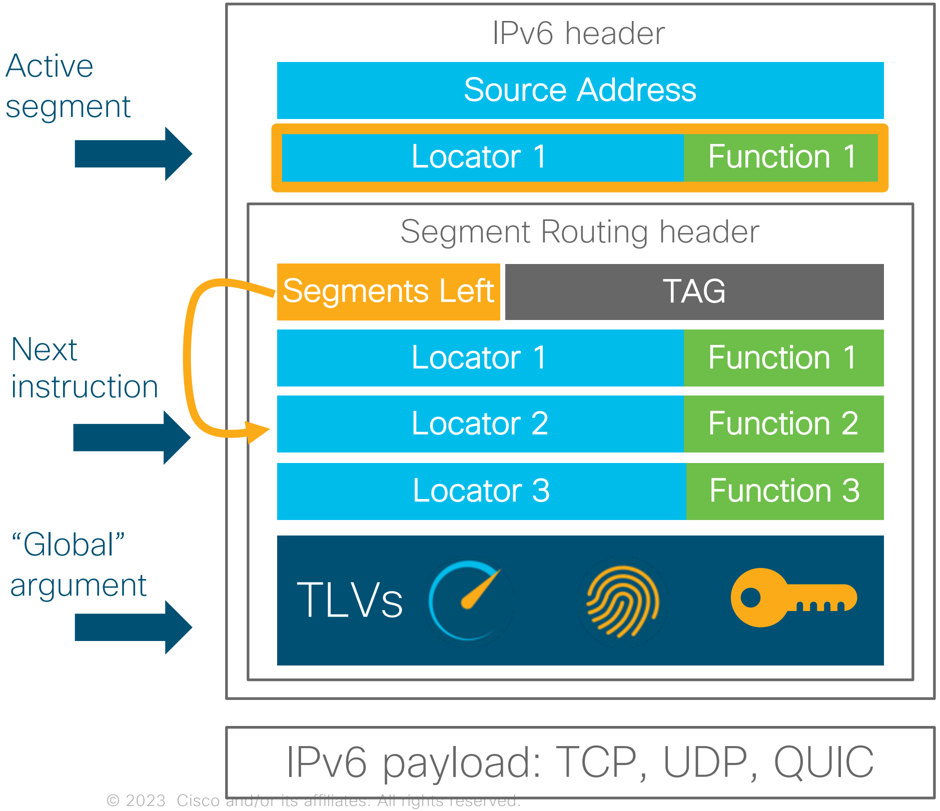
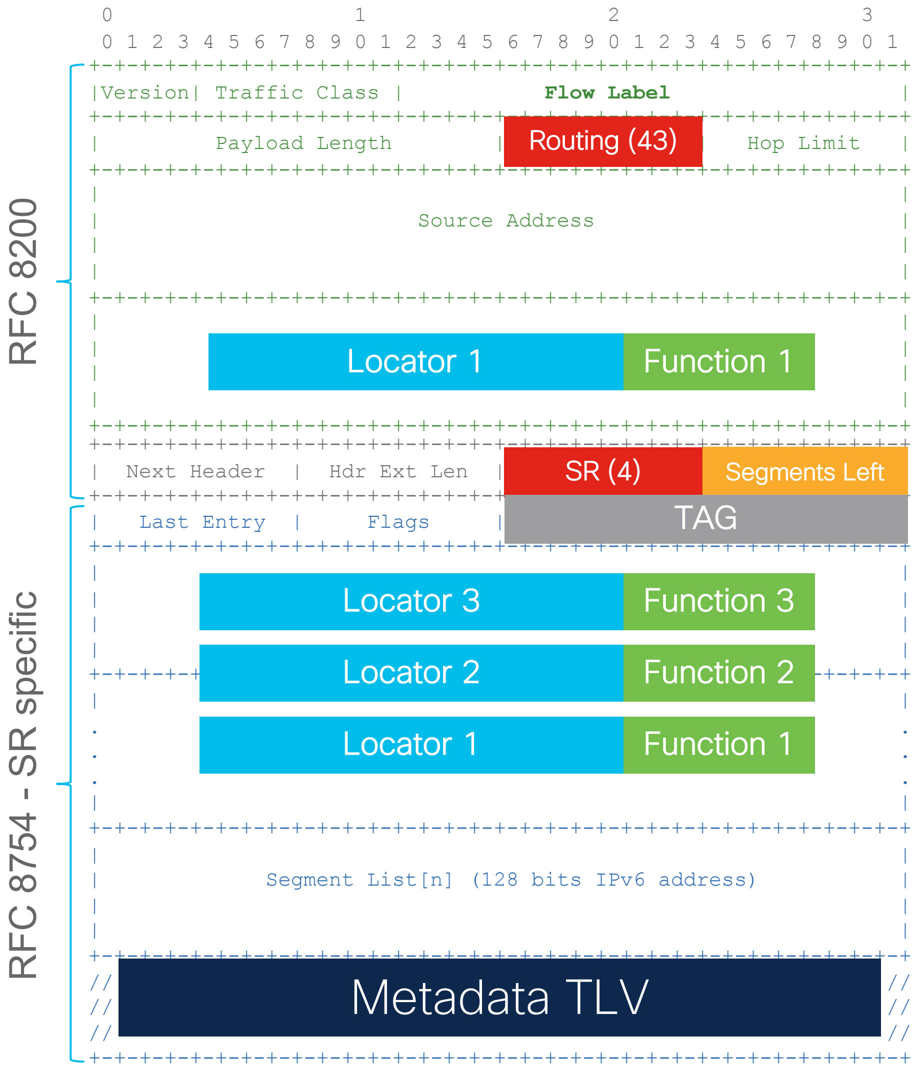


SRv6 Header

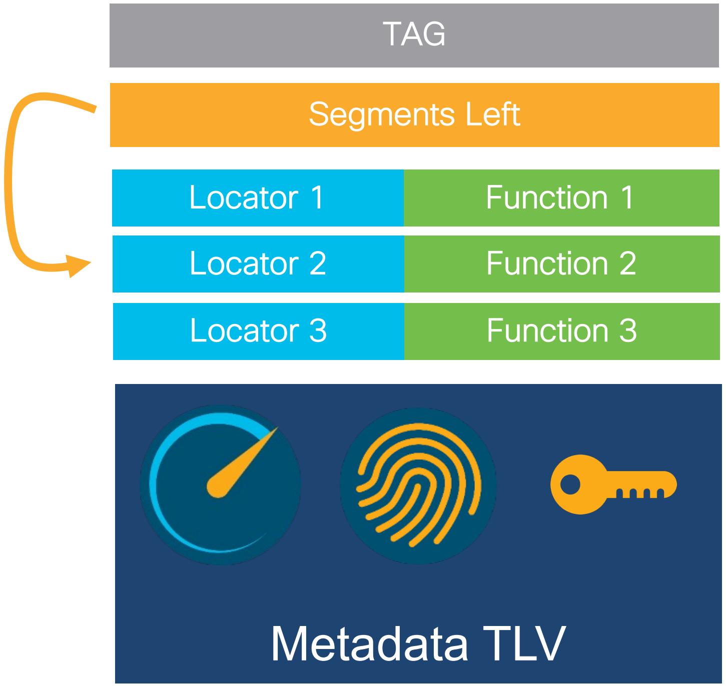


Active segment
Next instruction
"Global" argument
IPv6 header
Source Address
Locator 1
Function 1
Segment Routing header
Segments Left
TAG
Locator 1
Function 1
Locator 2
Function 2
Locator 3
Function 3
TLVs
IPv6 payload: TCP, UDP, QUIC



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
RFC 8200
|Version| Traffic Class |
Flow Label
Payload Length
Routing (43)
Hop Limit
Source Address
Locator 1
Function 1
Next Header
Hdr Ext Len
SR (4)
Segments Left
Last Entry
Flags
TAG
RFC 8754 - SR specific
Locator 3
Function 3
Locator 2
Function 2
Locator 1
Function 1
Segment List[n] (128 bits IPv6 address)
Metadata TLV

SRv6 for anything



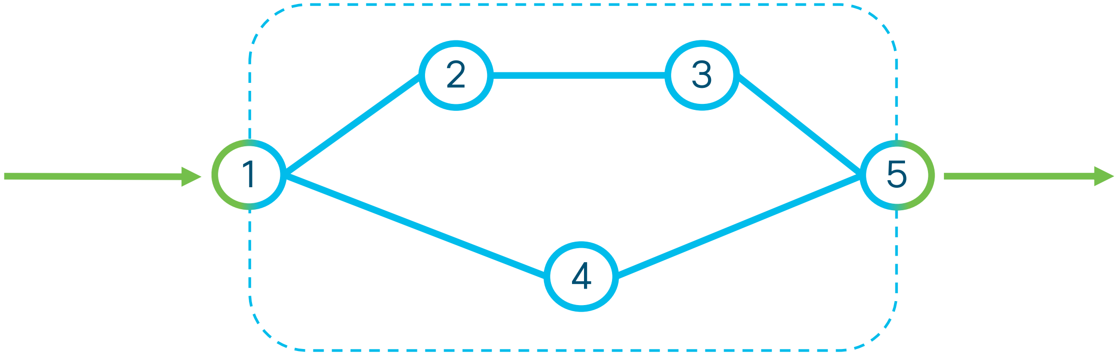
Optimized for HW processing
e.g. Underlay & Tenant use-cases

Optimized for SW processing
e.g. NFV, Container, Micro-Service

SRv6 Domain

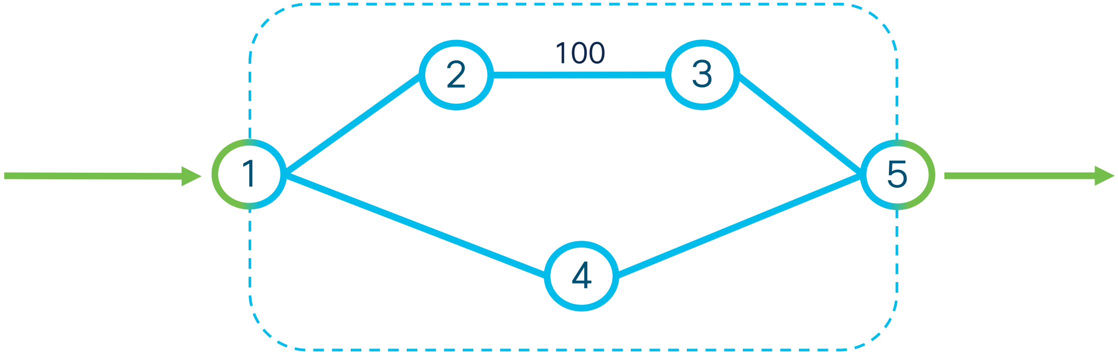
IPv6 enabled provider infrastructure

SR Domain



Encapsulation at the Domain ingress

- IPv4, IPv6 or L2 frame is encapsulated within the SR Domain
- Outer IPv6 header includes an SRH with the list of segments

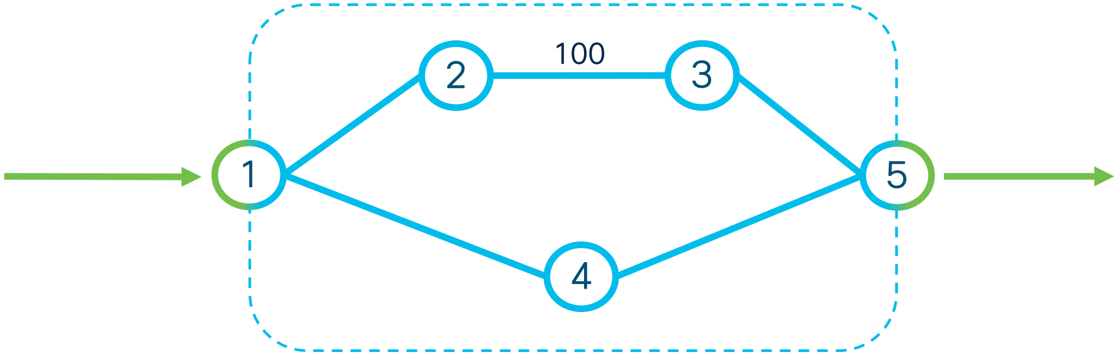


IPv4	SA = A.A.A.A, DA = B.B.B.B
Payload	

IPv6	SA = A:1::, DA = B:0:0:2:C3::
SR	(B:0:0:5:DB::) SL=1
IPv4	SA = A.A.A.A, DA = B.B.B.B
Payload	

SRH of the outer IPv6 encapsulation

- Domain acts as a giant computer
- The network program in the outer SRH is executed



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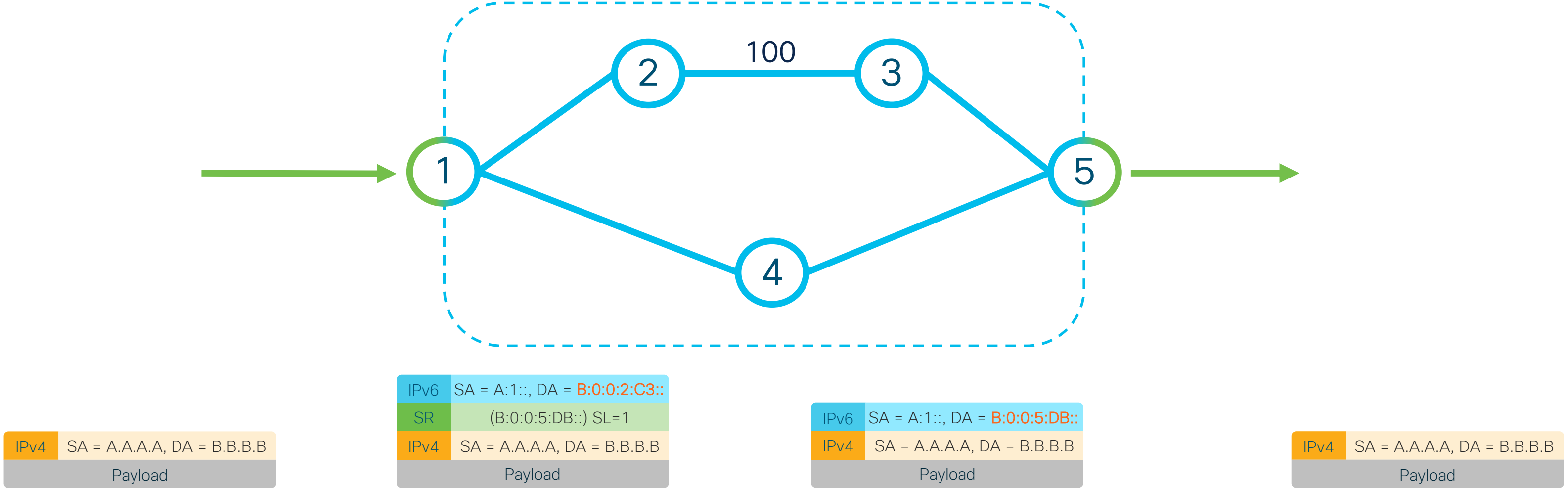
Payload	

IPv6	SA = A:1::, DA = B:0:0:5:DB::
IPv4	SA = A.A.A.A, DA = B.B.B.B
Payload	

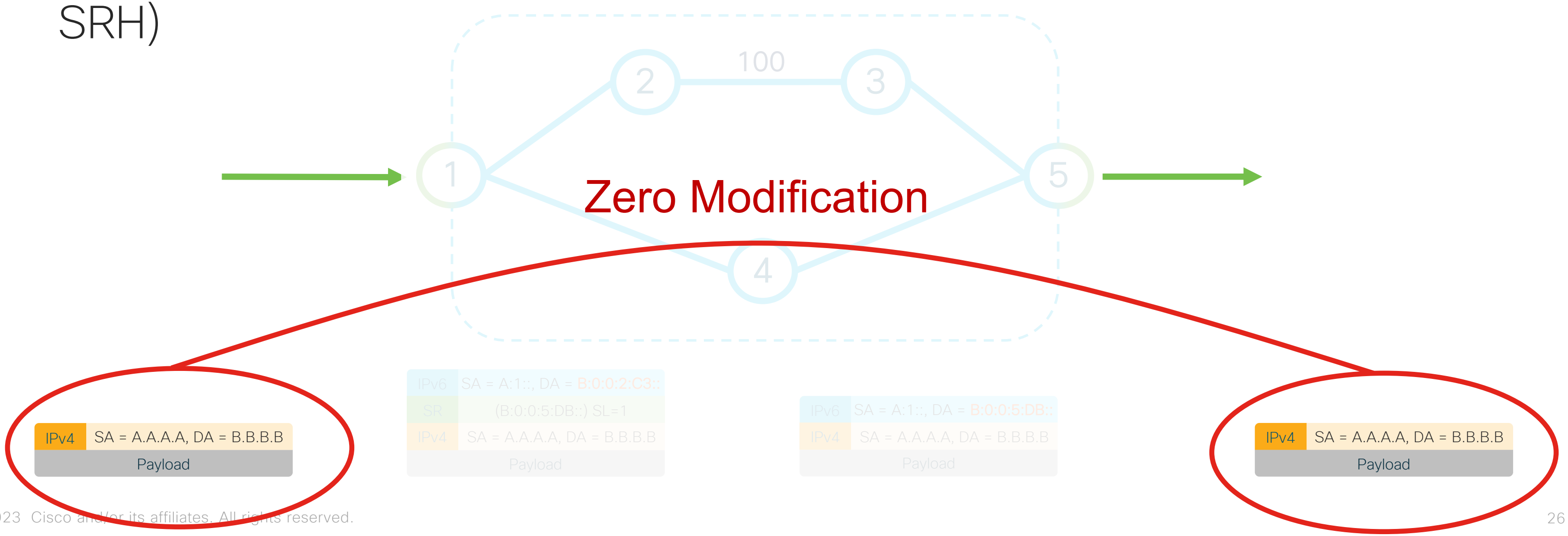
Decapsulation at Domain Egress

- Egress PE removes the outer IPv6 header as the packet leaves the SR domain



End-to-End Integrity

- End-to-end integrity principle is strictly guaranteed
  - Inner packet is unmodified
  - Same as SR-MPLS (MPLS stack is replaced by IPv6 outer header and SRH)

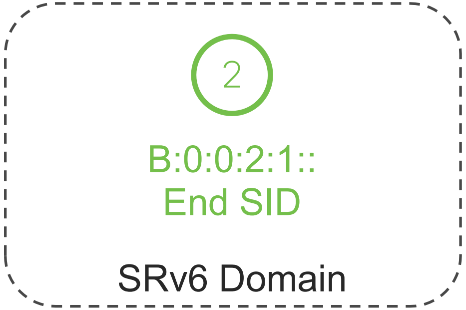


End and End.X SID behaviors

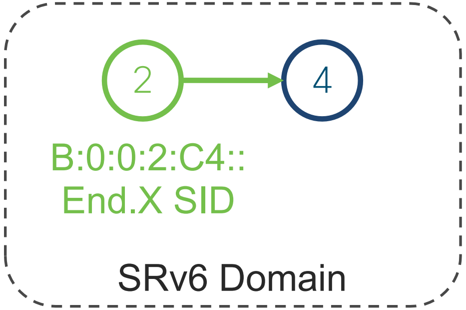
Illustration convention:

- IPv6 address of node k is **A:<k>::**
- SRv6 SID of node k is **B:0:0:<k>:<function>::**

- End – Default endpoint behavior
  - shortest-path to the SID's endpoint
  - endpoint updates DA with next SID
  - endpoint forwards according to updated DA

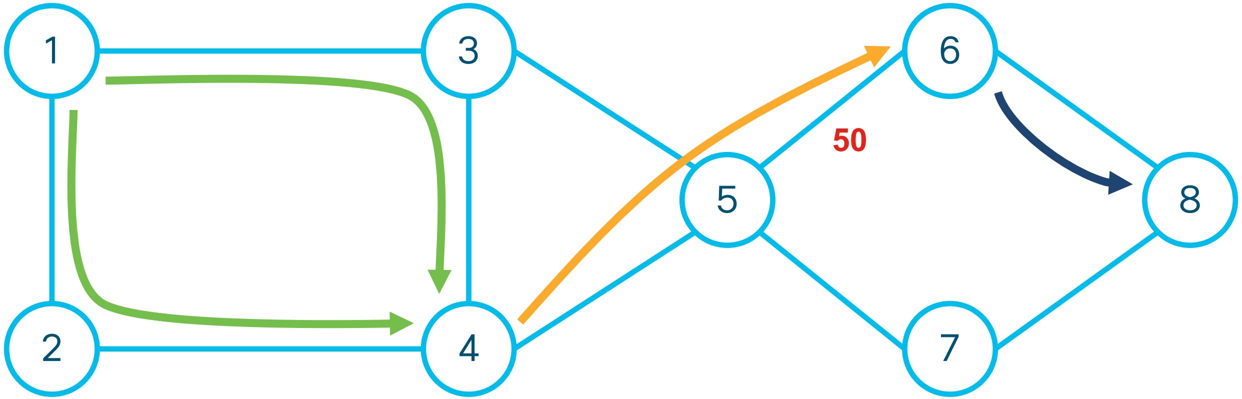


- End.X – Endpoint with cross-connect
  - shortest-path to SID's endpoint
  - endpoint updates DA with next SID
  - endpoint forwards to interface associated with SID



Endpoint behaviors illustration

SR: 〈 B:0:0:4:1::, B:0:0:5:C6::, A:8:: 〉



Default metric 10

- B:0:0:4:1:: shortest path to node 4
- B:0:0:5:C6:: shortest path to node 5, then cross-connect towards 6
- A:8:: regular IPv6 address of node 8

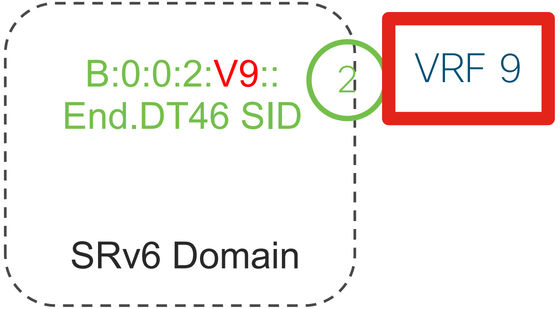
Usecase

End.DT46 Behavior

Illustration convention:

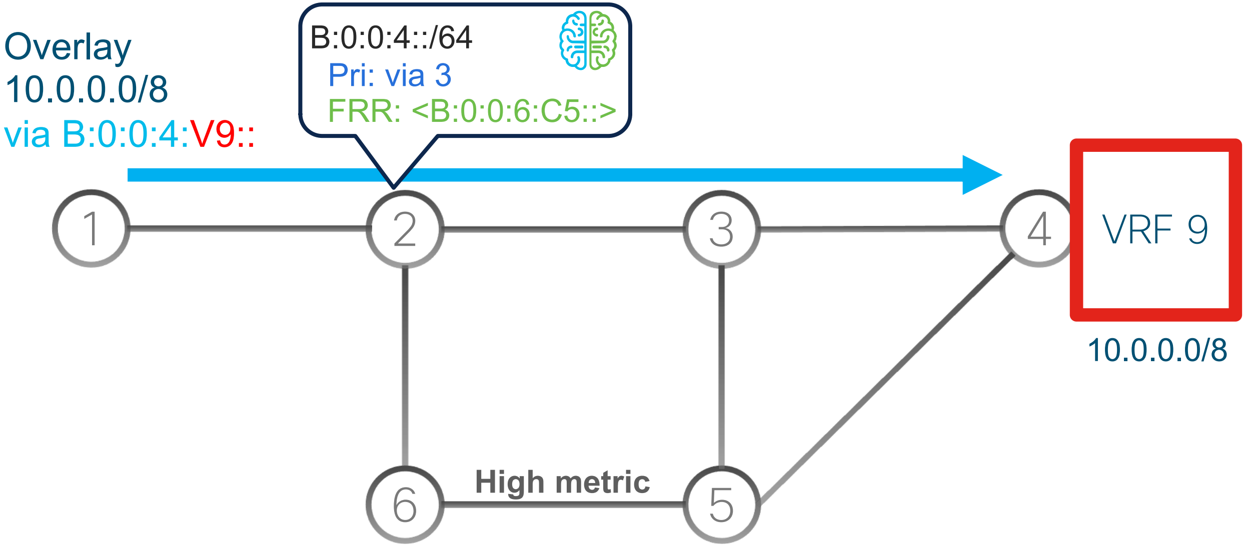
- IPv6 address of node k is **A:<k>::**
- SRv6 SID of node k is **B:0:0:<k>:<function>::**

- End.DT46 – Endpoint with decapsulation to a table
  - shortest-path to SID's endpoint
  - endpoint decapsulates outer IPv6 header
  - forwards to the new destination via a VRF
    - *IPv4 or IPv6 table associated with the VRF*



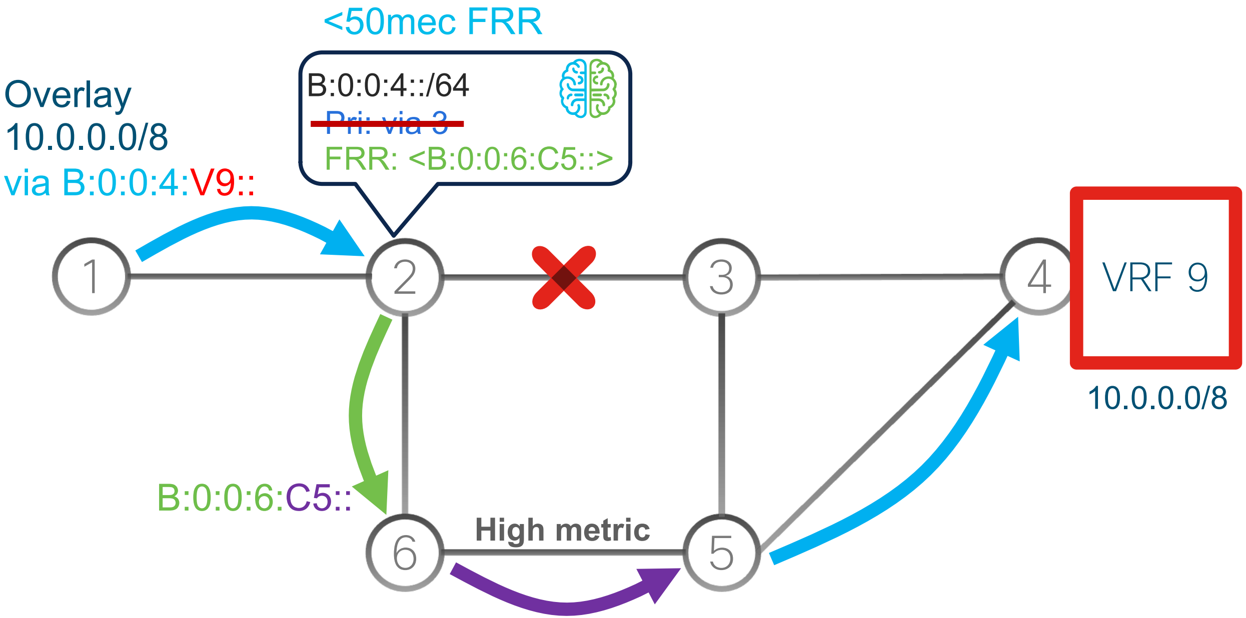
RFC8986 SRv6 SID Behaviors

TI-LFA



- 50msec Protection upon local link, node or SRLG failure
- Simple to operate and understand
  - automatically computed by the router's IGP process
  - 100% coverage across any topology
  - predictable (backup = post-convergence)
- Optimum backup path
  - leverages the post-convergence path
  - avoid any intermediate flap via alternate path
- Incremental deployment
- Distributed and Automated Intelligence

TI-LFA



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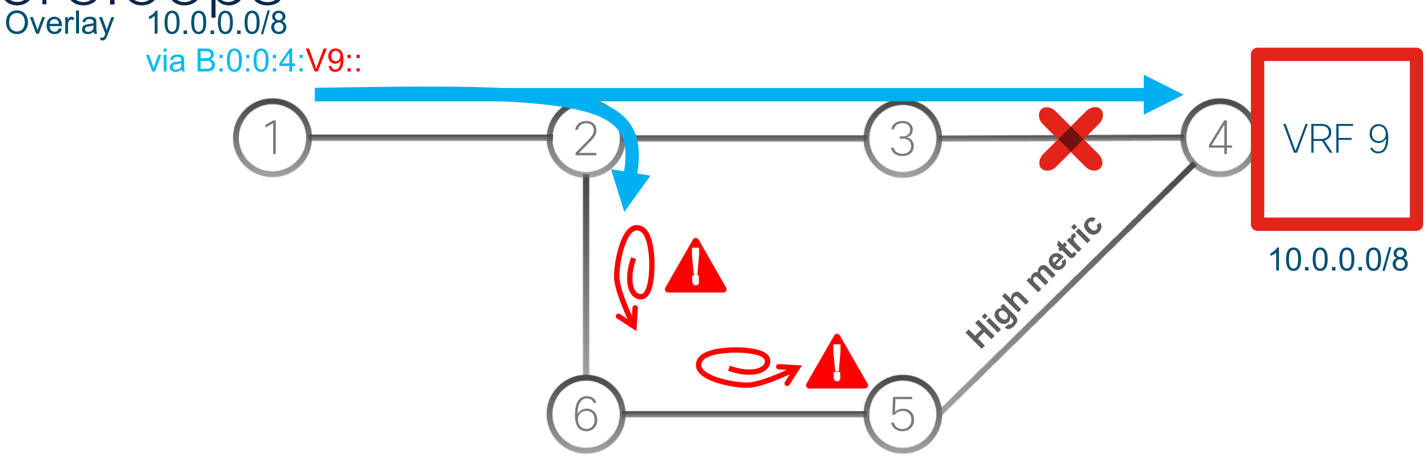
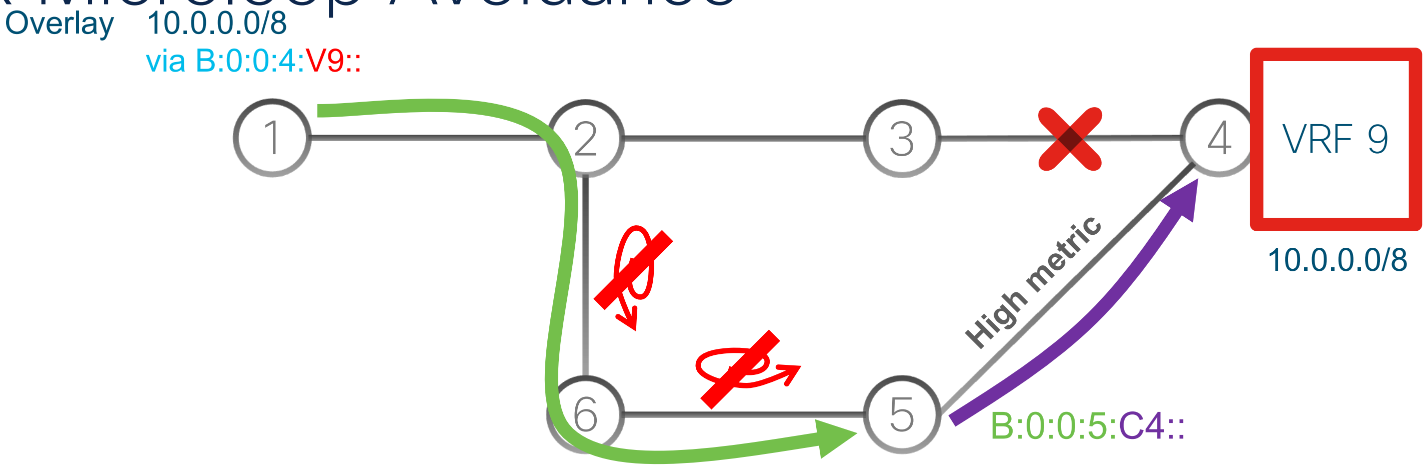
Microloops



- Microloops are a day-one IP drawback
  - Unsynchronized distributed convergence and IP hop-by-hop routing can cause transient packet loops after a topology change
- Microloops cause packet loss and out-of-order packets

SR Microloop Avoidance

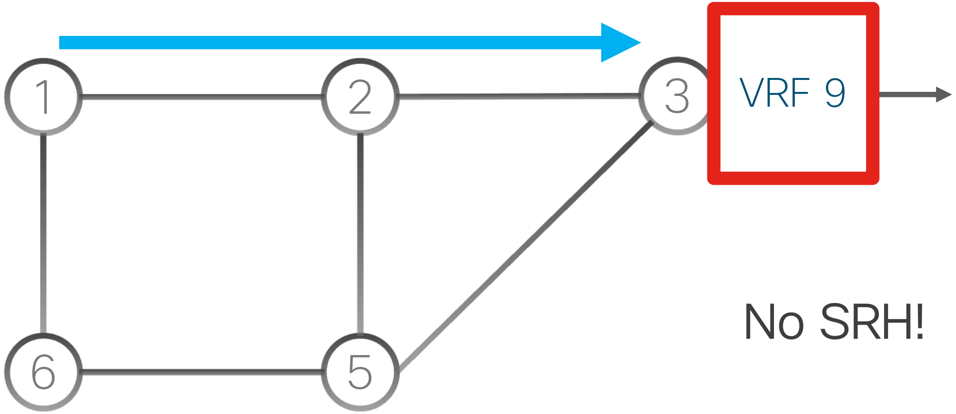


- SR Microloop Avoidance temporarily steers traffic on the loop-free post-convergence paths using SR Policies
- After the network has converged the SR Policies are deactivated

VPN over Best-Effort Slice

Network Program: B:0:0:3:V9::

B::/40 locator block is associated with ISIS base algo (Low Cost, Best Effort)

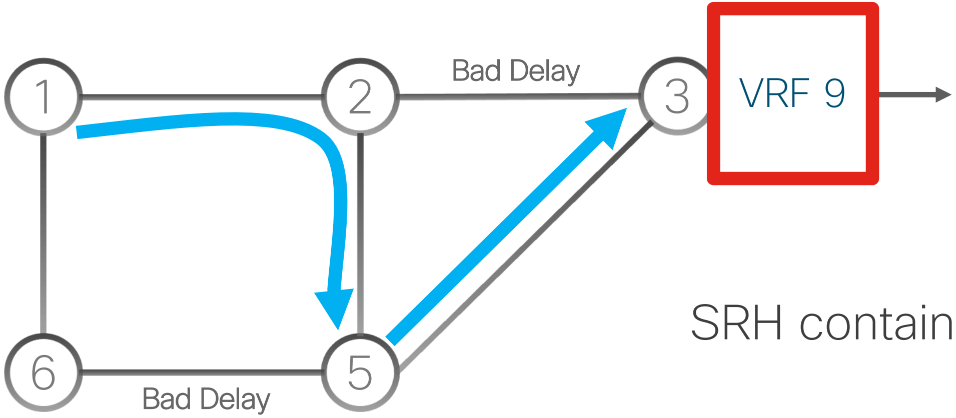


No SRH!

VPN with Low-Delay Slice – SR-TE Option

Network Program: B:0:0:2:C5:: then B:0:0:3:V9::

B::/40 locator block is associated with ISIS base algo (Low Cost)

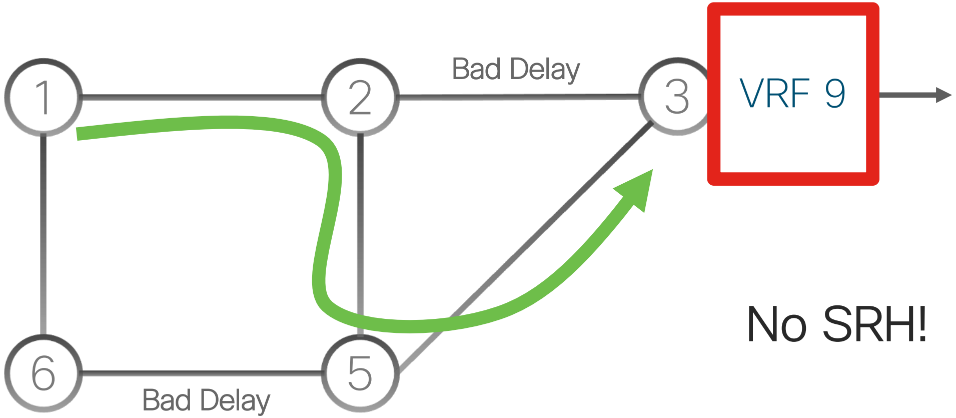


SRH contains 1 single SID

VPN with Low-Delay Slice – Flex-Algo Option

Network Program: D:0:0:3:V9::

D::/40 locator block is associated with Low Delay Flex-Algo

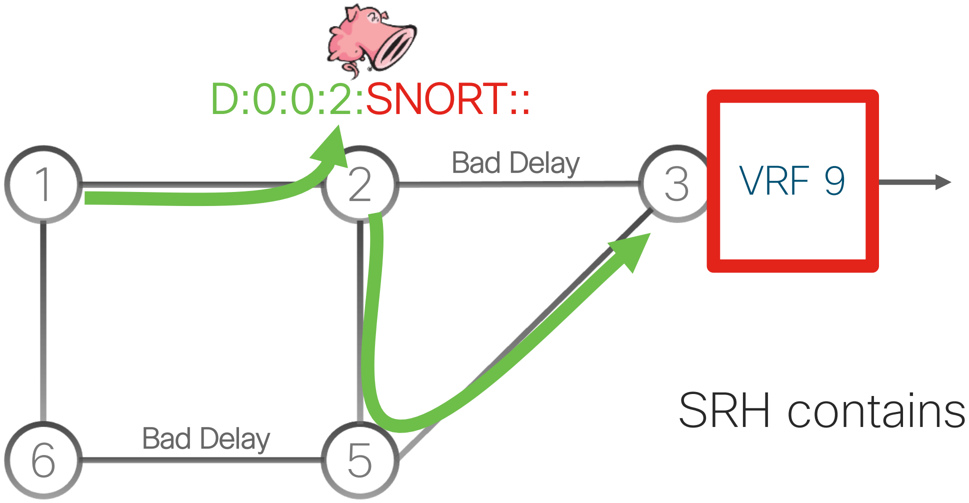


No SRH!

Snort Firewall, VPN & Low-Delay Slice

Network Program: D:0:0:2:SNORT:: then D:0:0:3:V9::

D::/40 locator block is associated with Low Delay Flex-Algo

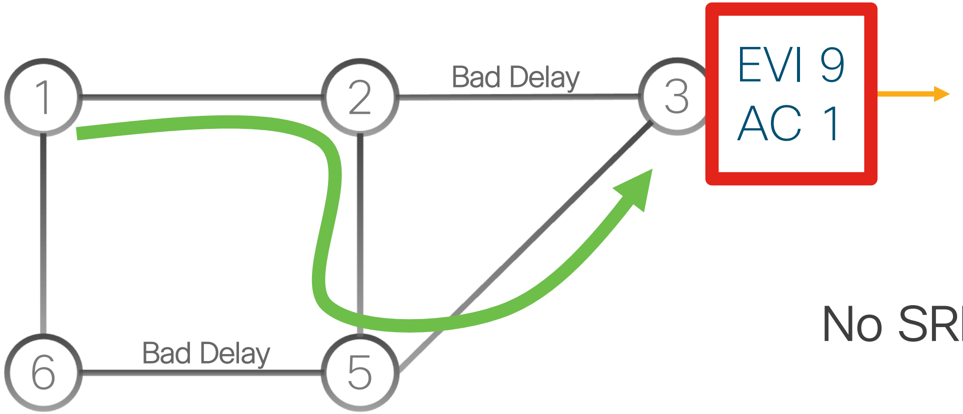


SRH contains 1 Single SID

EVPN VPWS Single-Home & Low-Delay Slice

Network Program: D:0:0:3:X1::

D::/40 locator block is associated with Low Delay Flex-Algo

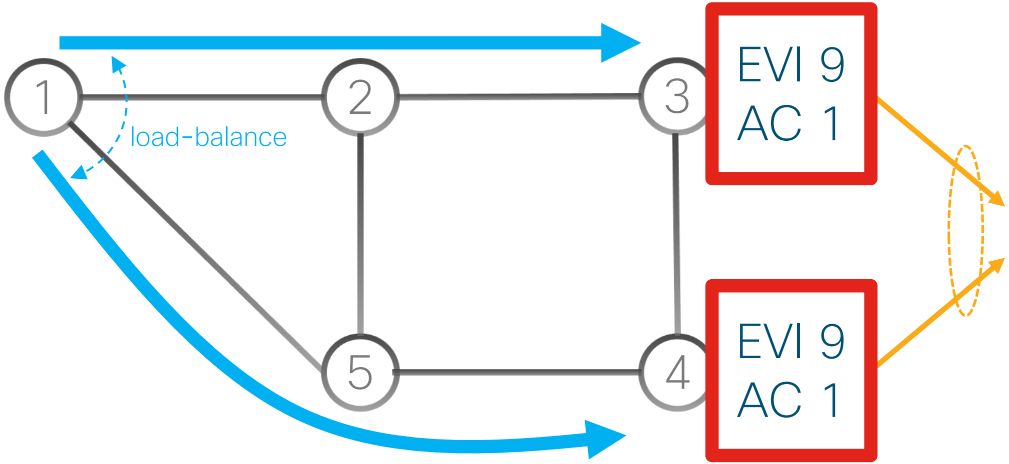


No SRH!

EVPN VPWS MH All-Active & Best-Effort Slice

Network Program: B:0:0:3:X1:: or B:0:0:4:X1::

B::/40 locator block is associated with ISIS base algo (Low Cost)



No SRH!

Load-balancing

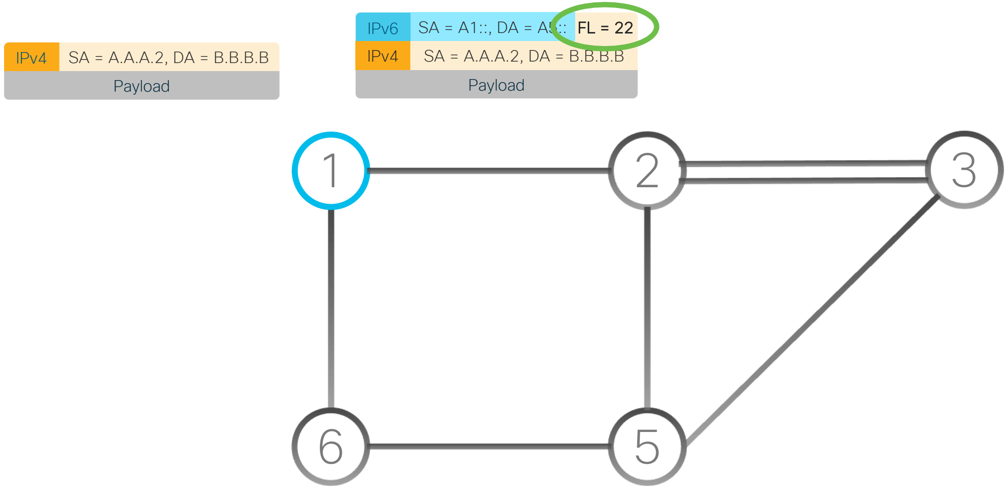
- 20-bit entropy
- No additional protocol
  - infamous mpls entropy label

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version| Traffic Class |           Flow Label                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Payload Length        |  Next Header  |   Hop Limit   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                         Source Address                        |
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                      Destination Address                      |
|                                                               |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Load-balancing

- Action at the ingress of SRv6 domain

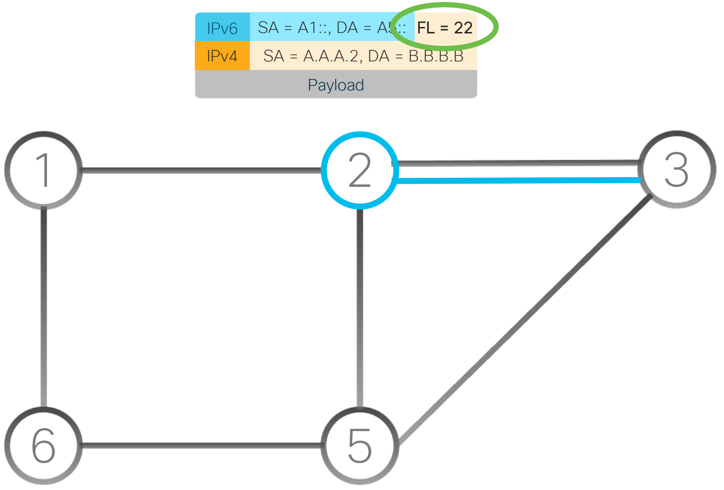
Flow Label is the result of the hash of the inner packet



Load-balancing

- Action at a transit node

Outer Flow Label used for hashing

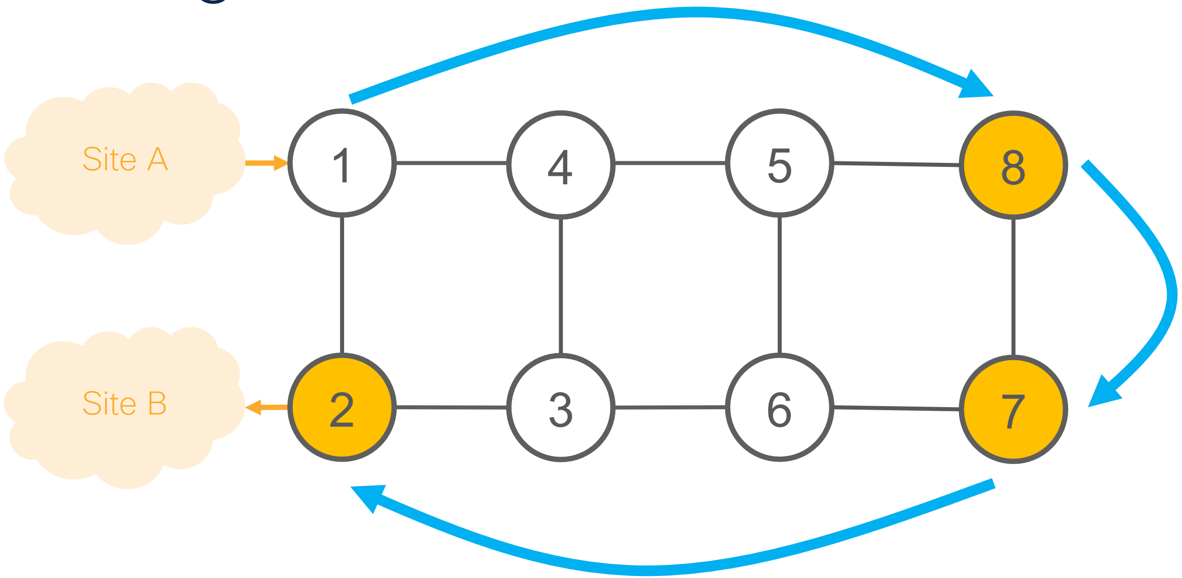


SRv6 SRH compression

draft-ietf-spring-srv6-srh-compression
NEXT and REPLACE C-SID flavors

- Program
  - list of instructions contained in DA/SRH
- Instruction
  - SRv6 SID
- C-SID Container
  - SRv6 SID that contains a list of C-SIDs
- C-SID
  - The locator-node and function bits of a SID that supports compressed encoding of SIDs

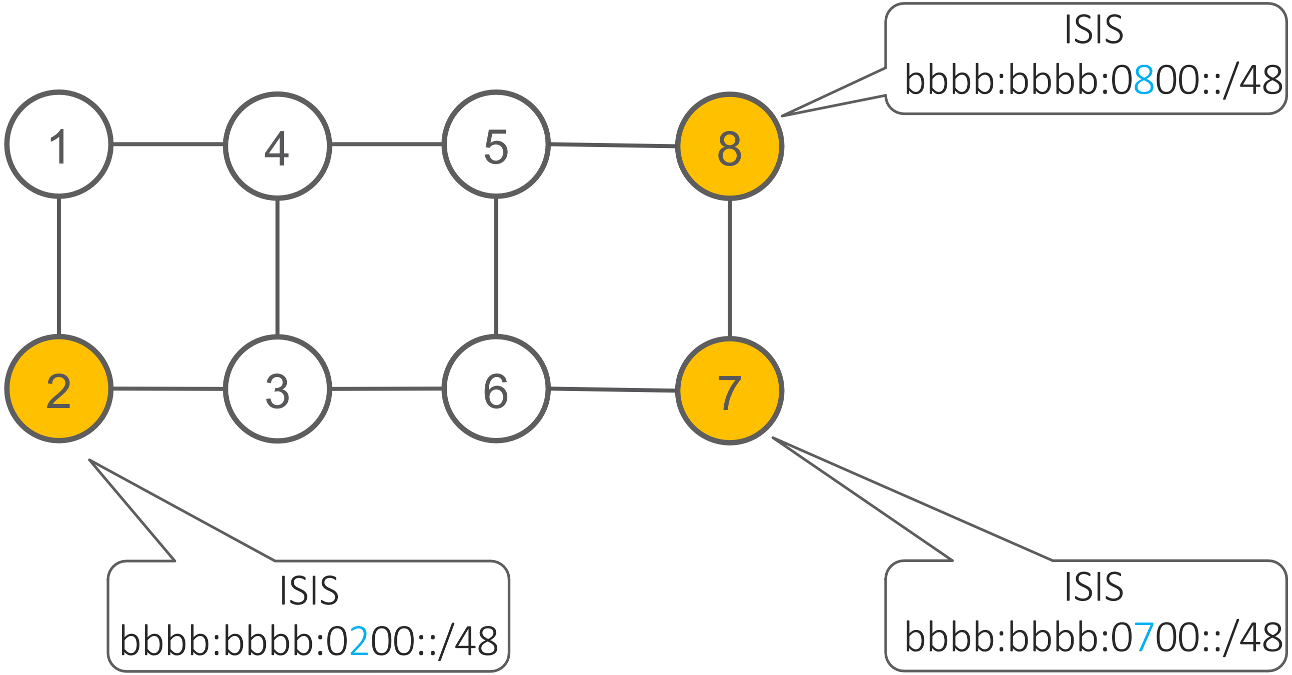
Illustration: go to 8 then 7 then 2 and decaps



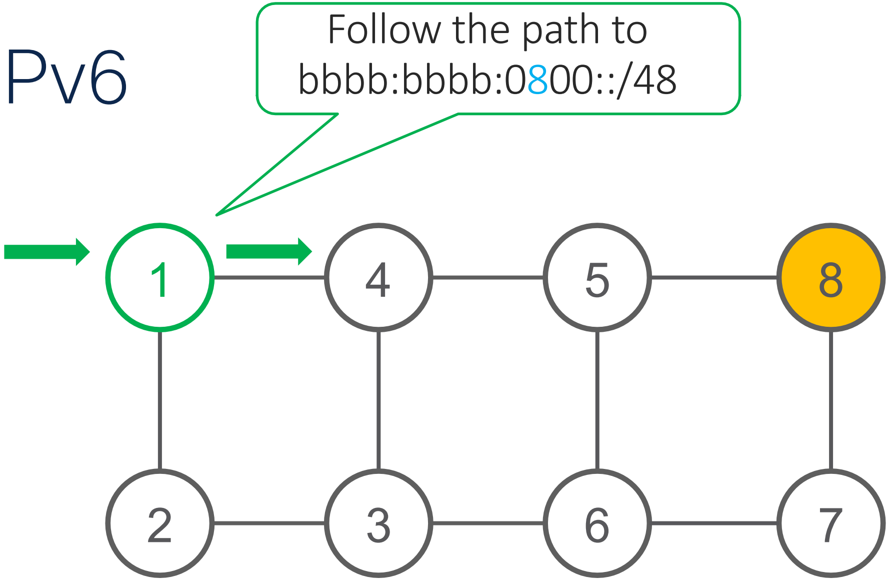
One single NEXT C-SID container in the DA is enough

DA = bbbb:bbbb:0800:0700:0200:FDT4:0000:0000

Basic IP Routing: no new extension

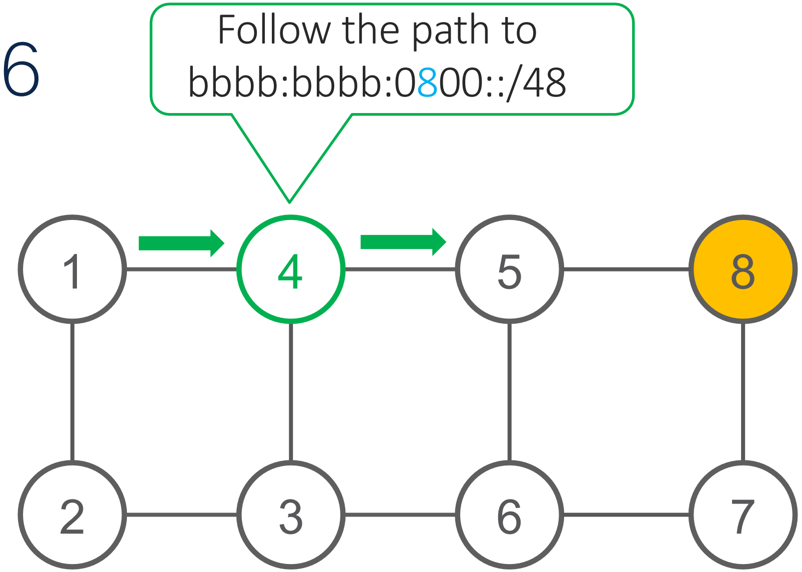


@1: basic IPv6



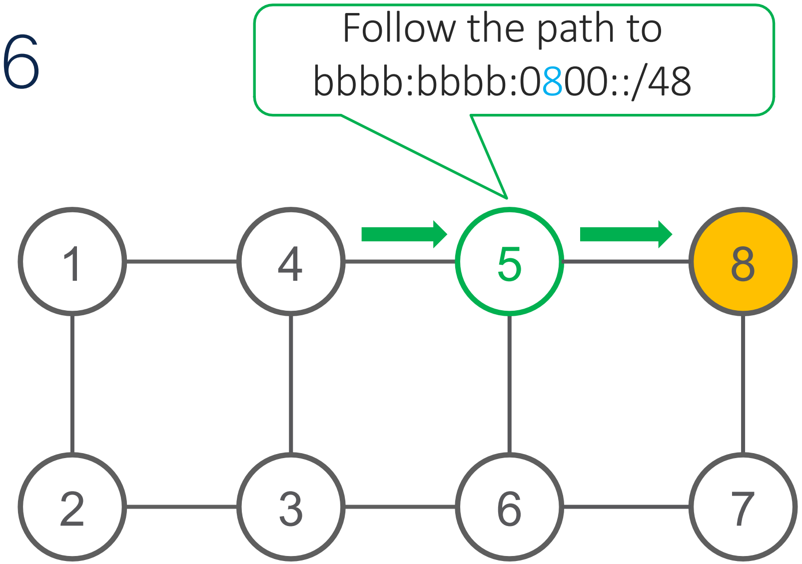
DA = bbbb:bbbb:0800:0700:0200:FDT4:0000:0000

@4: basic IPv6



DA = bbbb:bbbb:0800:0700:0200:FDT4:0000:0000

@5: basic IPv6



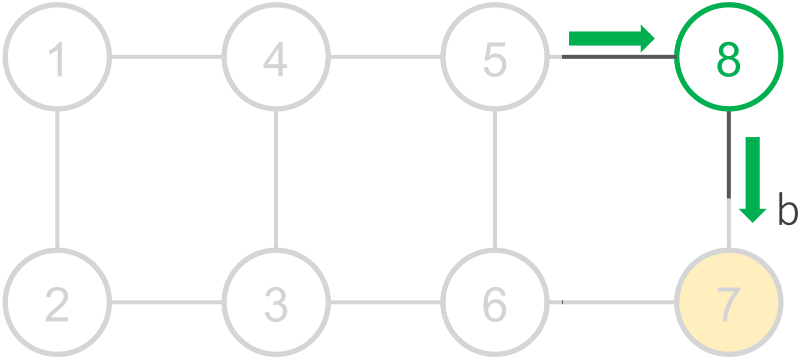
DA = bbbb:bbbb:0800:0700:0200:FDT4:0000:0000

@8: Copy Args and Forward

Rx'd DA: bbbb:bbbb:0800:0700:0200:FDT4:0000:0000

SHIFT << 16

Tx'd DA: bbbb:bbbb:0700:0200:FDT4:0000:0000:0000

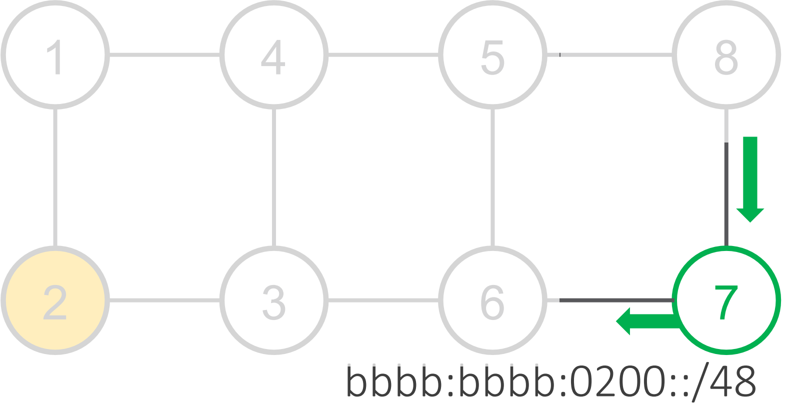


bbbb:bbbb:0700:

:/48

```
FIB Longest-Match bbbb:bbbb:0800::/48 → SRv6 function:
        Copy arguments into current function
        Set last remaining bits to 0
        Lookup the updated DA and forward
```

@7: Copy Args and Forward



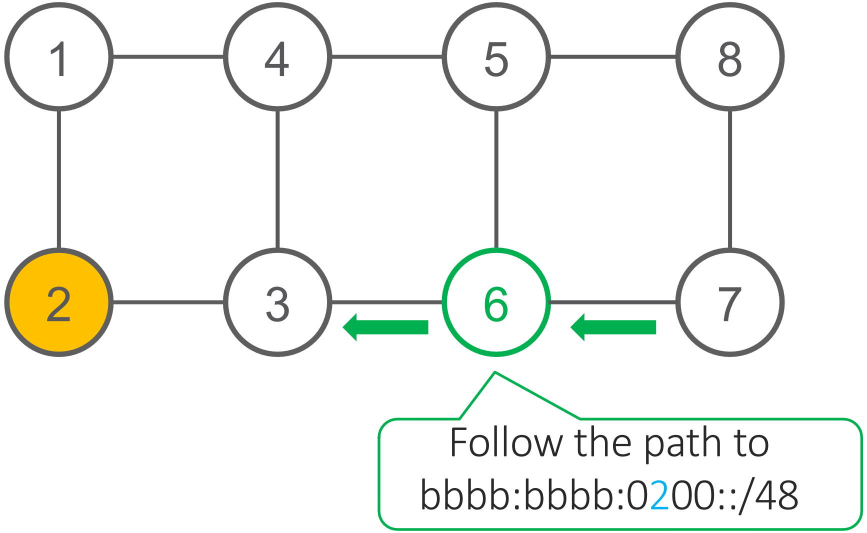
Rx'd DA: bbbb:bbbb:0700:0200:FDT4:0000:0000:0000

SHIFT << 16

Tx'd DA: bbbb:bbbb:0200:FDT4:0000:0000:0000:0000

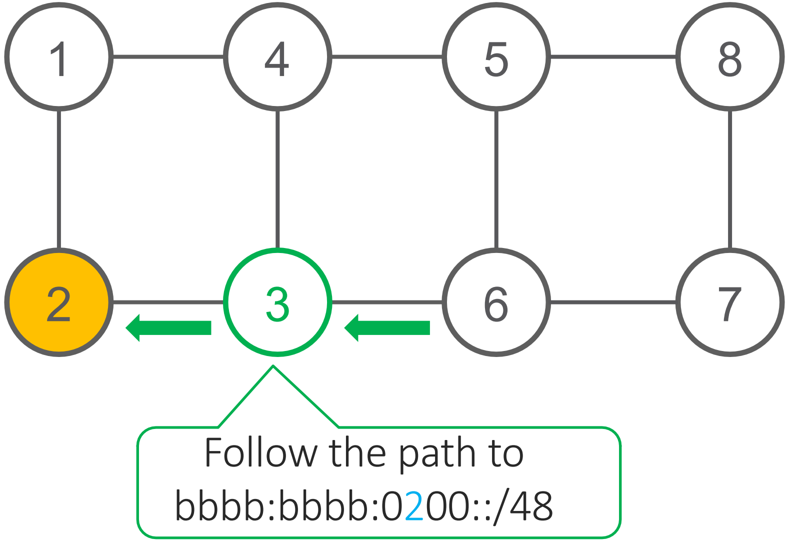
```
FIB Longest-Match bbbb:bbbb:0700::/48 → SRv6 Function:
        Copy arguments into current function
        Set last remaining bits to 0
        Lookup the updated DA and forward
```

@6: basic IPv6



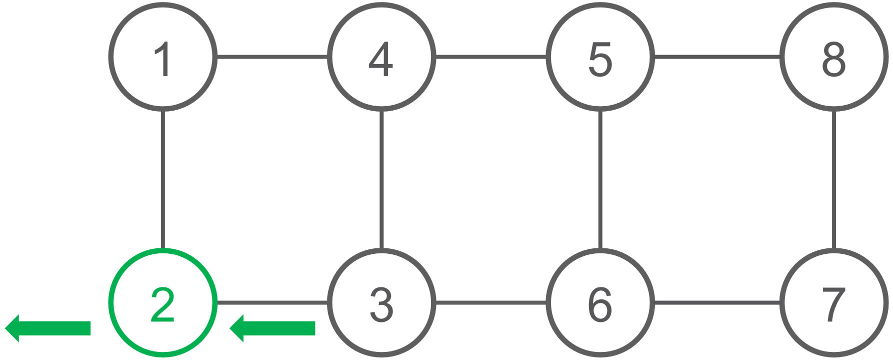
DA = bbbb:bbbb:0200:FDT4:0000:0000:0000:0000

@3: basic IPv6



DA = bbbb:bbbb:0200:FDT4:0000:0000:0000:0000

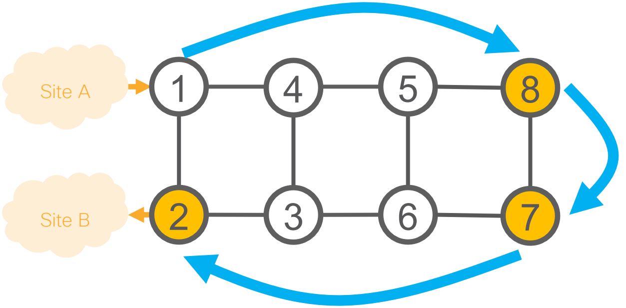
@2: SRv6 End.DT4 behavior



Rx'd DA: bbbb:bbbb:0200:FDT4:0000:0000:0000:0000

```
FIB Longest-Match bbbb:bbbb:0200:FDT4::/64 → SRv6 function:
  Decapsulate and forward inner IPv4 packet to Site B
```

Recap



- @1: inner packet P encapsulated with outer DA
  bbbb:bbbb:0800:0700:0200:FDT4:0000:0000
- @4 & @5: classic IP forwarding, outer DA unchanged
- @8: SRv6 NEXT behavior: copy args and forward, outer DA becomes
  bbbb:bbbb:0700:0200:FDT4:0000:0000:0000
- @7: SRv6 NEXT behavior: copy args and forward, outer DA becomes
  bbbb:bbbb:0200:FDT4:0000:0000:0000:0000
- @6 & @3: classic IP forwarding, outer DA unchanged
- @2: SRv6 End.DT4: Decapsulate and forward inner packet

SRv6

- IETF proposed standard
- Network Programming: RFC8754, RFC8986
- Use cases: TILFA, any VPN
- Compression: Working group draft

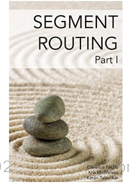
Resources / Stay Up-To-Date

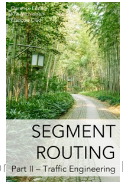
http://www.segment-routing.net/

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

https://twitter.com/SegmentRouting

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





Segment Routing, Part I / II - Textbooks