Segment Routing

Network Infrastructures A.A. 2020/21

Outline

- Introduction to Segment Routing
- Segment Routing Policy
- SRv6 and Segment Routing extension Header
- Network Programming

Outline

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SR overview

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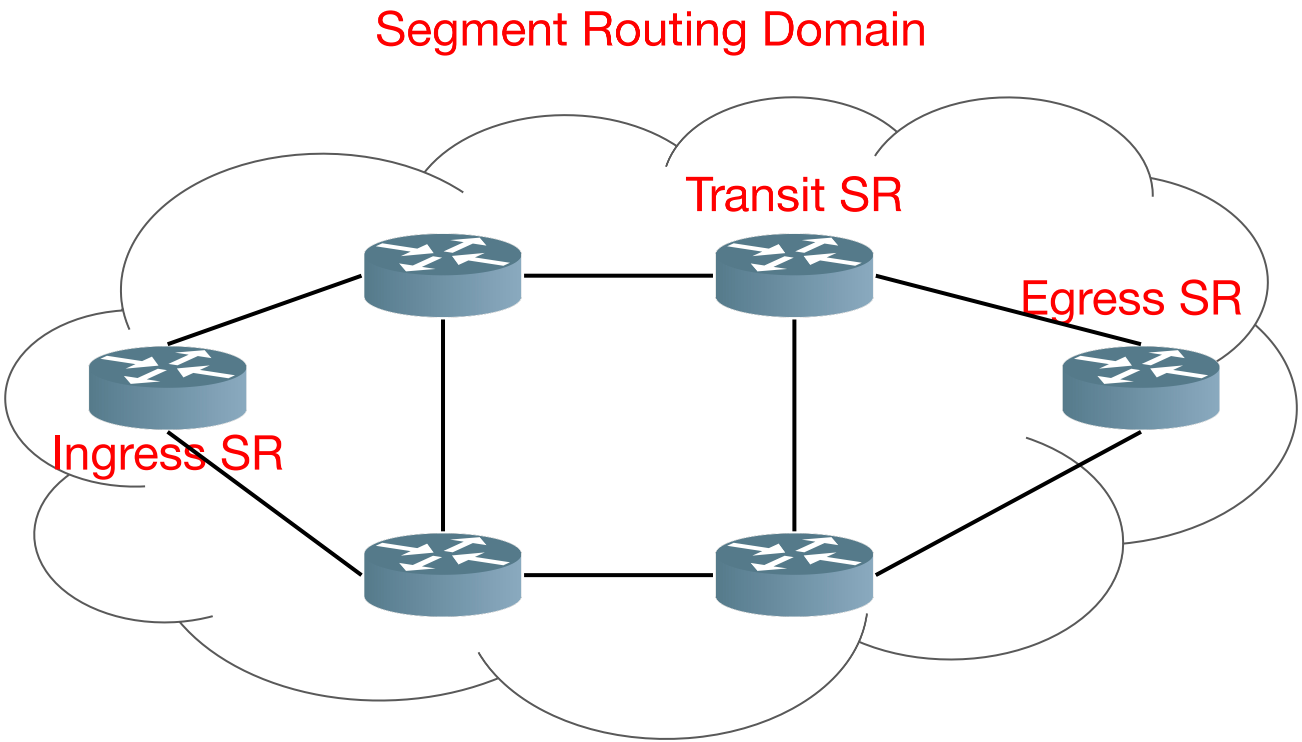
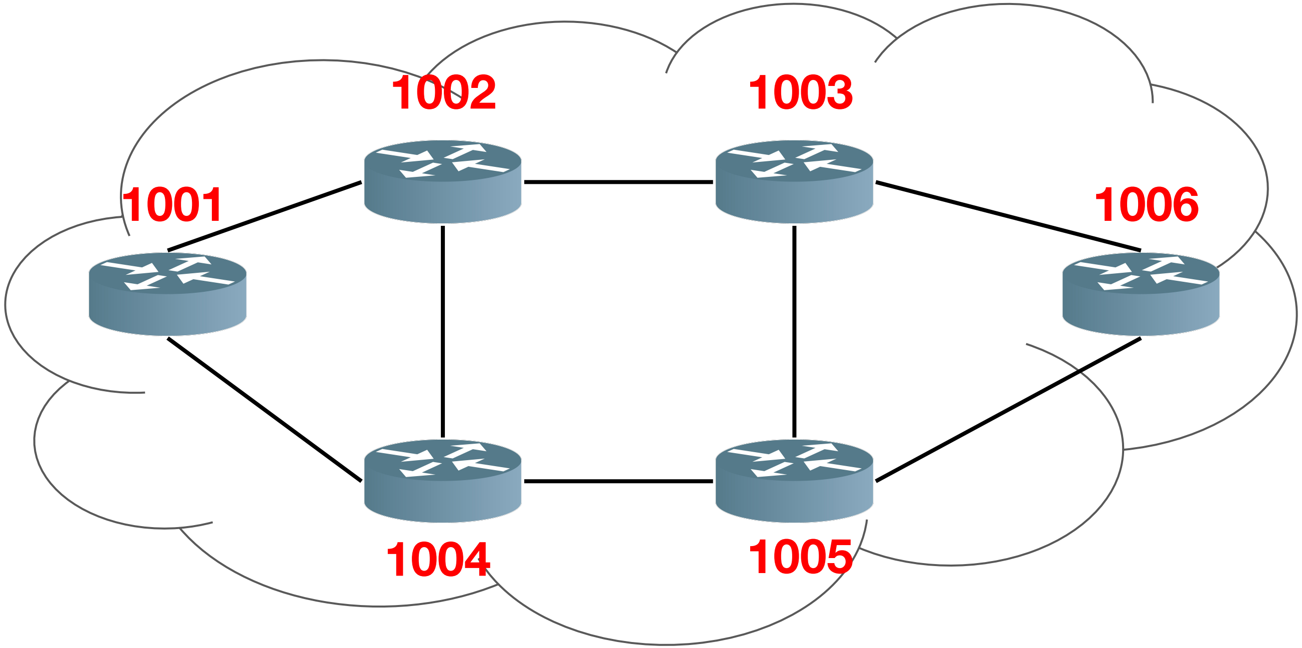
- Segment Routing (SR) leverages the source routing paradigm
- A node steers a packet through an ordered list of instructions, called segments
- A segment can represent any instruction, topological or service-based
- A segment can have a semantic:
    - local to an SR node
    - global within an SR domain
- SR allows to enforce a flow through any topological path while maintaining per-flow state only at the ingress nodes to the SR domain

SR terminology



SR idea



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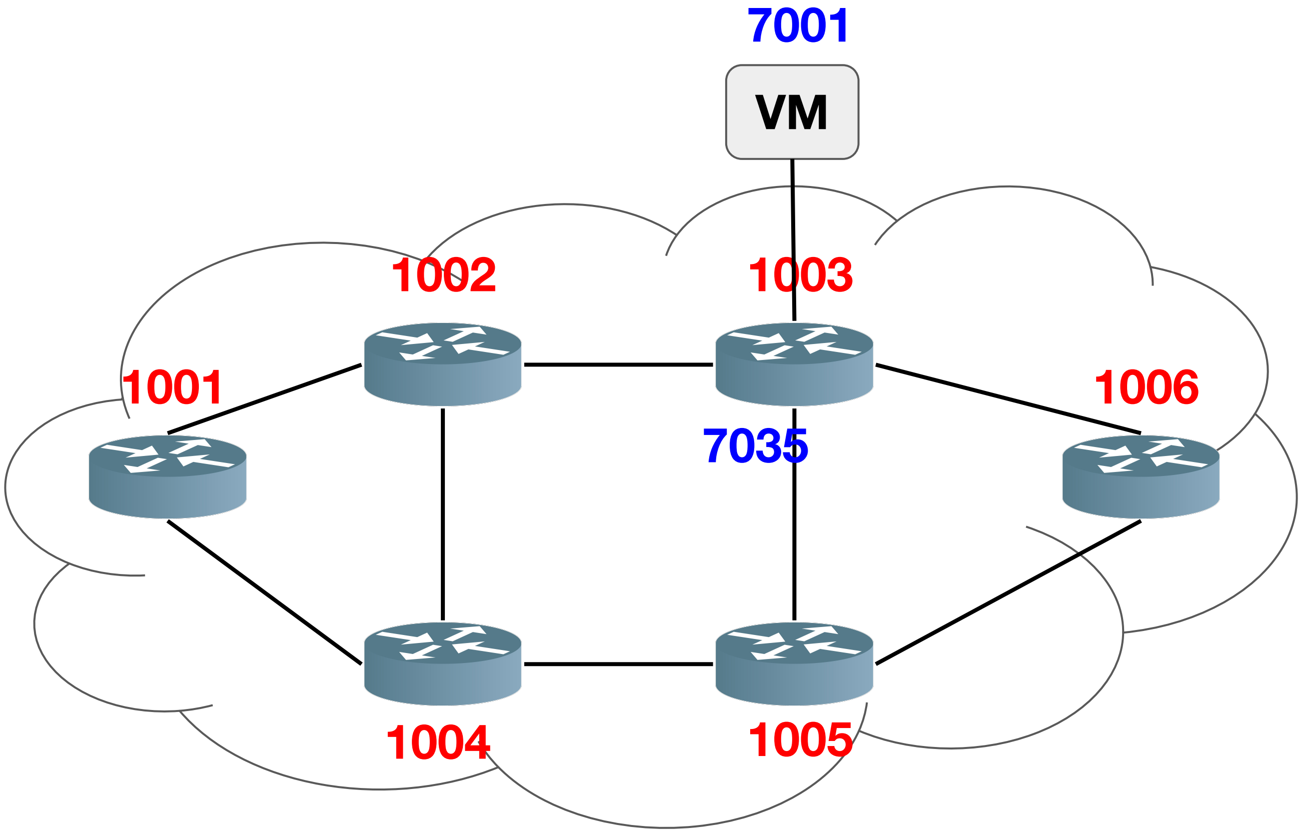

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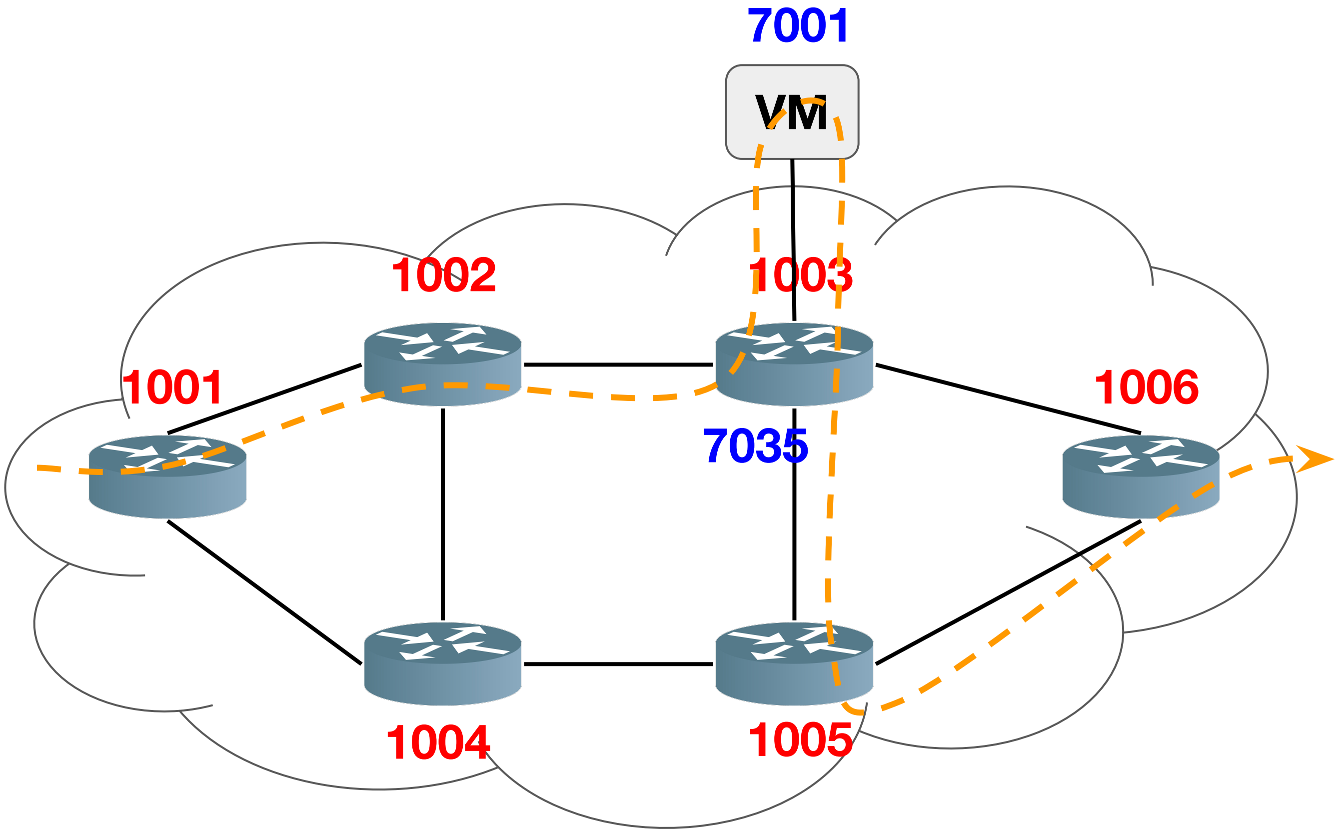

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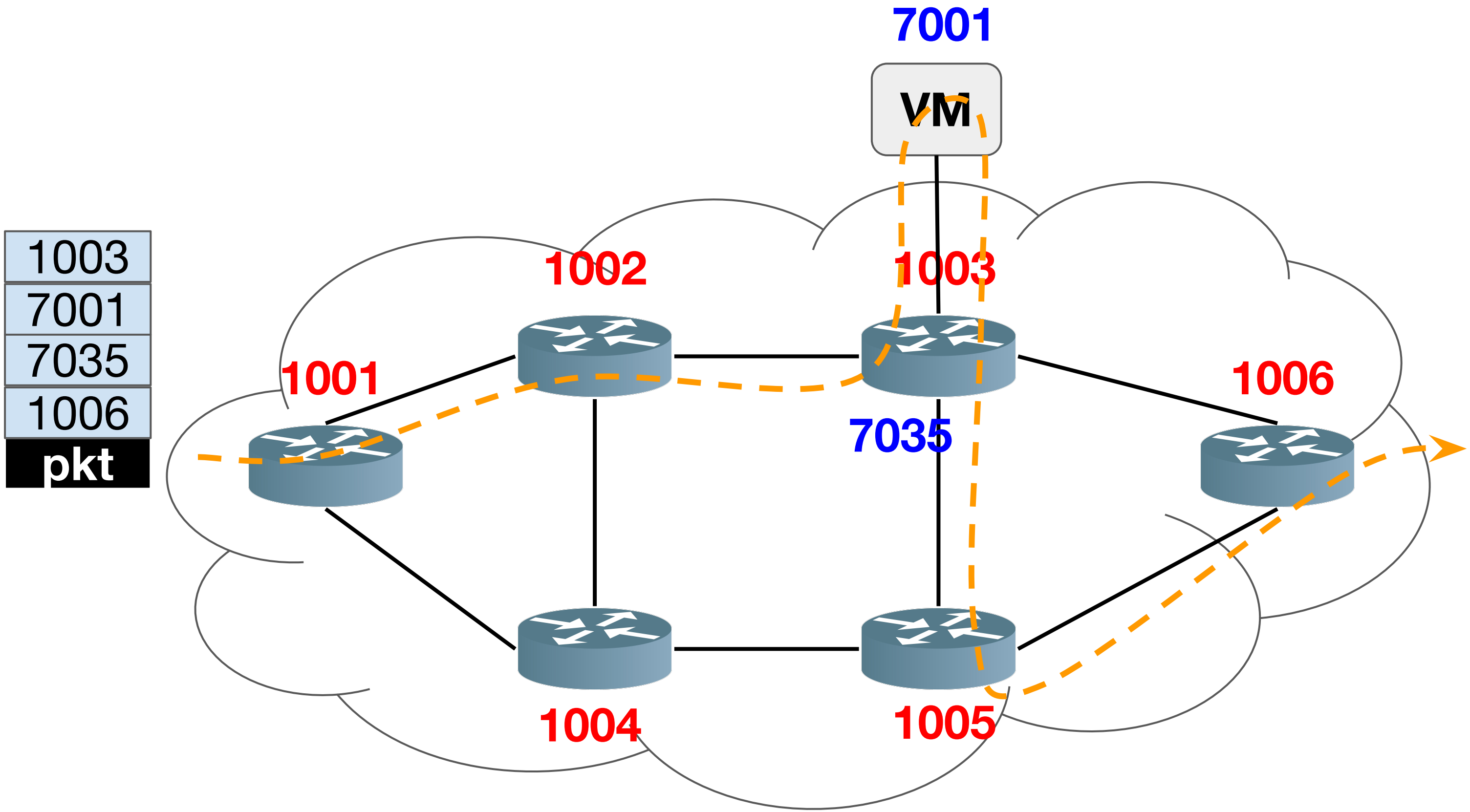
1003
7001
7035
1006
pkt
7001
VM
1002
1003
1001
7035
1006
1004
1005

SR control plane

- The SR architecture supports any type of control-plane: distributed, centralized or hybrid.
- In a **distributed scenario**:
  - the segments are allocated and signaled by OSPF or BGP
  - a node individually decides to steer packets on a source-routed policy
  - a node individually computes the source-routed policy
- In a **centralized scenario**:
  - the segments are allocated and instantiated by an SR controller
  - the SR controller decides which nodes need to steer which packets on which source-routed policies
  - the SR controller computes the source-routed policies
- A **hybrid scenario** complements a base distributed control-plane with a centralized controller
  - for example, when the destination is outside the IGP domain, the SR controller may compute a source-routed policy on behalf of an IGP node

SR data plane

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- The SR architecture can be instantiated on various dataplanes
  - SR over MPLS (SR-MPLS)
  - SR over IPv6 (SRv6)
- Segment Routing can be directly applied to the MPLS architecture with no change on the forwarding plane
- Segment Routing can be applied to the IPv6 architecture with a new type of routing header called the SR header (SRH)

SR forwarding

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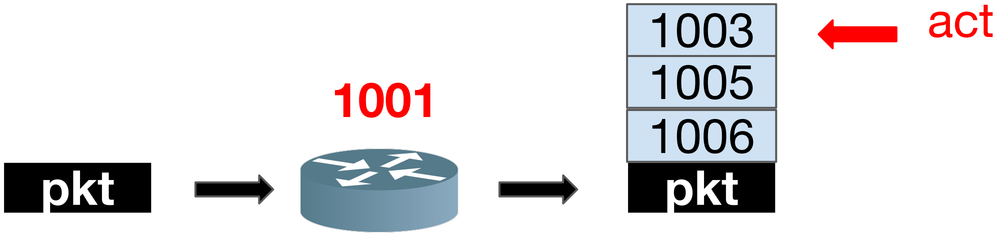
- SR nodes have a forwarding table that specifies the operation to perform on a received packet



- Three different operations:
  - PUSH: the instruction consisting of the insertion of a segment at the top of the segment list

SR forwarding

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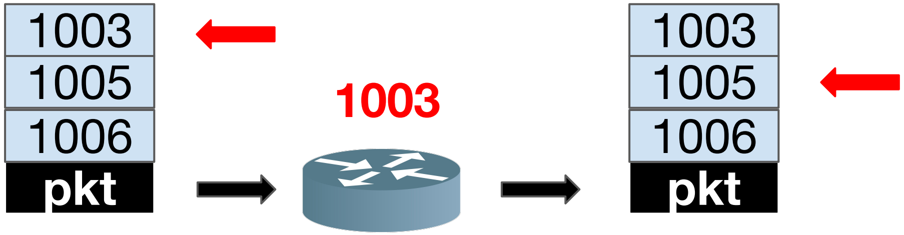

- Three different operations:
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SR forwarding

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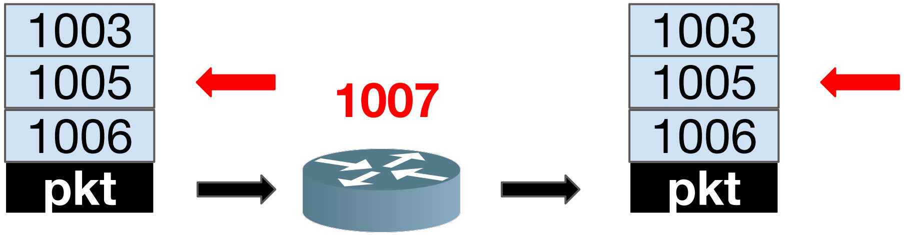

- Three different operations:
  - PUSH: the instruction consisting of the insertion of a segment at the top of the segment list
  - NEXT: when the active segment is completed, NEXT is the instruction consisting of the inspection of the next segment
  - CONTINUE: the active segment is not completed and hence remains active

Global and Local segments

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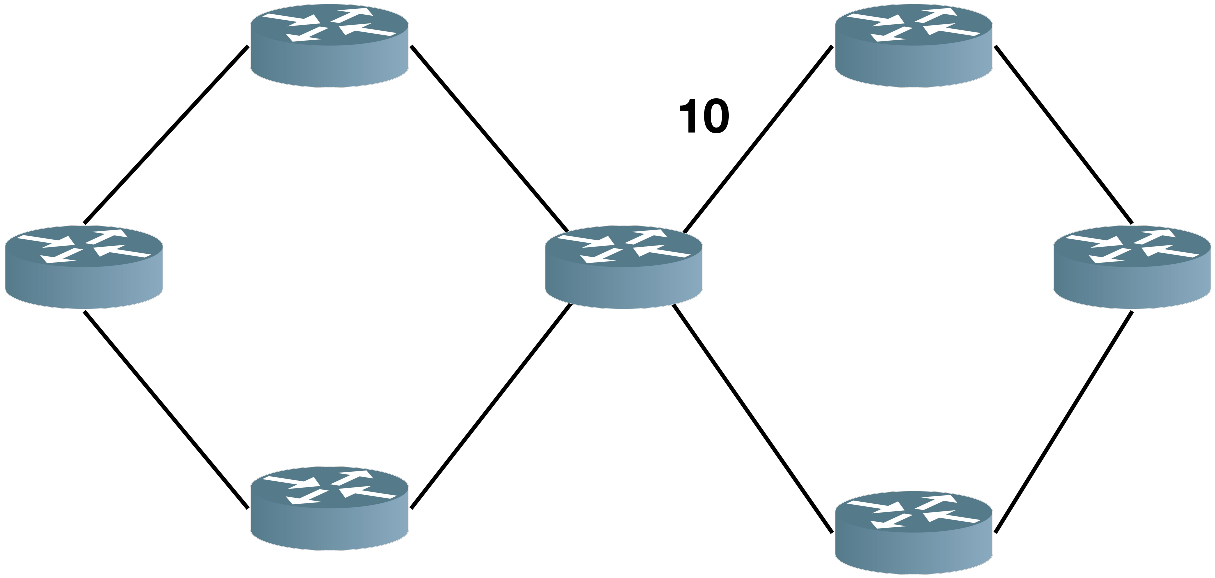
- **SR Global Block** (SRGB): the set of global segments in the SR Domain
- **SR Local Block** (SRLB): local property of an SR node
- Global Segment
  - the instruction associated to the segment is defined at the SR Domain level
  - a topological shortest-path segment to a given destination within an SR domain is a typical example of a global segment
- Local Segment
  - the instruction associated to the segment is defined at the node level

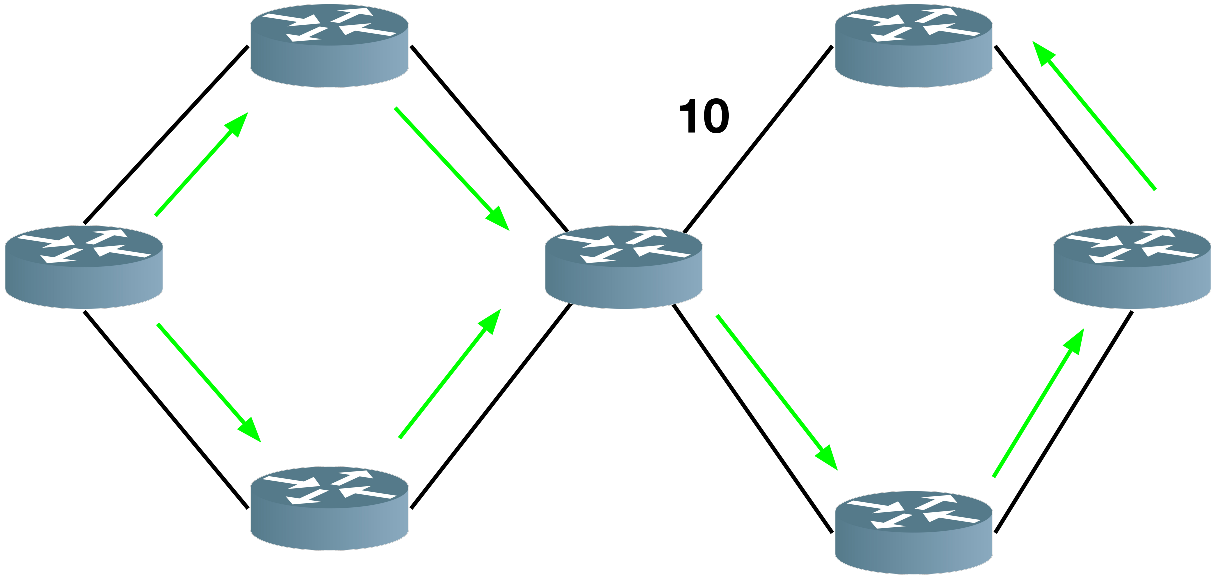
Type of segments

- Segments are generally advertised in the network by means of an IGP protocol
- IGP-Prefix segment
  - forward the packet along the path computed using the routing algorithm
- IGP-Node segment
  - is an IGP-Prefix Segment which identifies a specific router
- IGP-Adjacency segment
  - forward the packet over a unidirectional adjacency (local segment)

Type of segments: some examples



Type of segments: some examples



Type of segments: some examples

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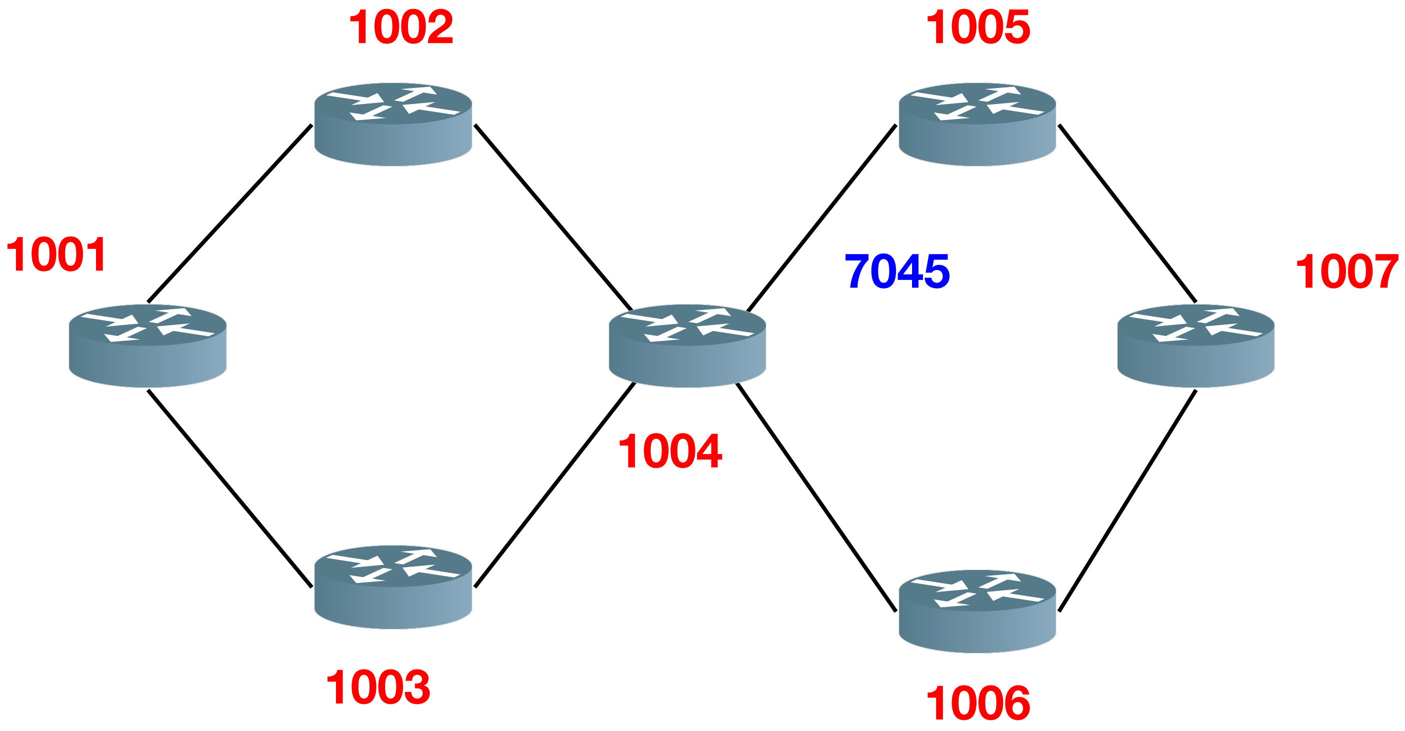
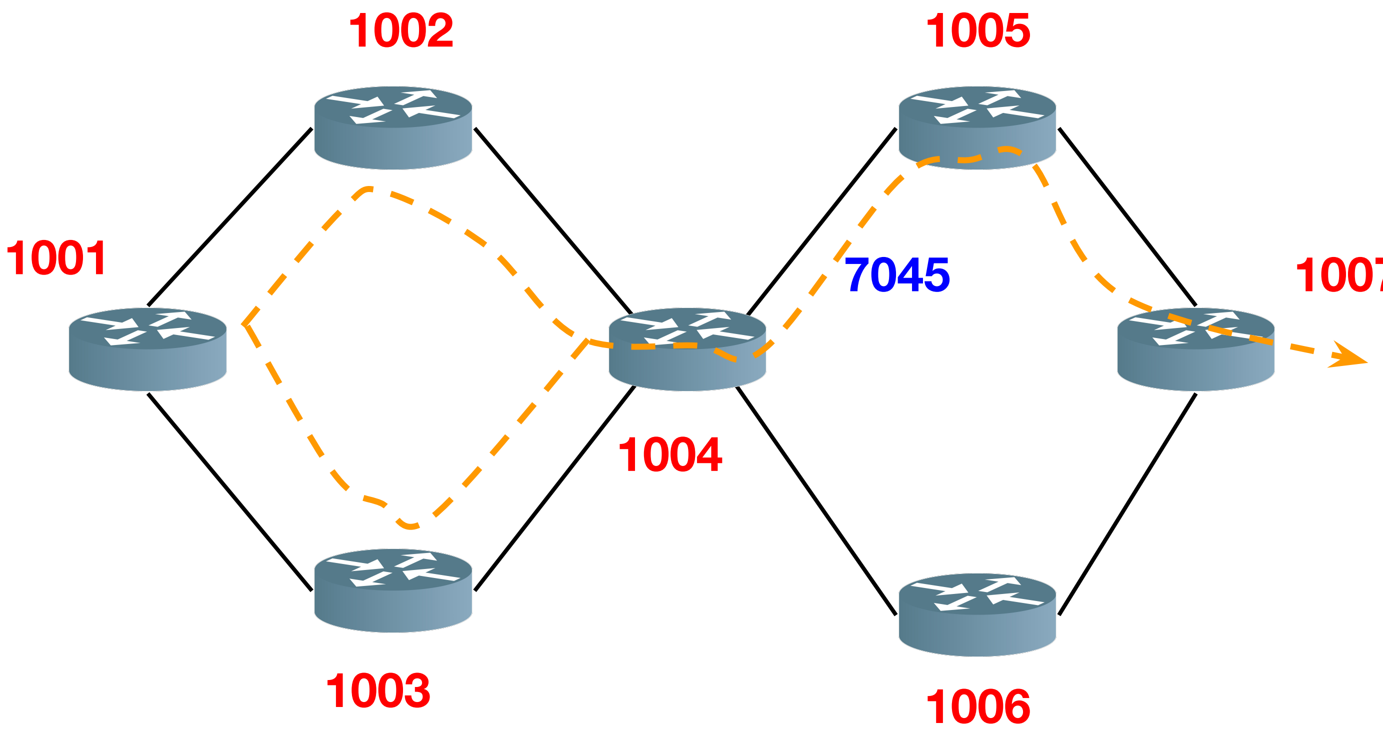
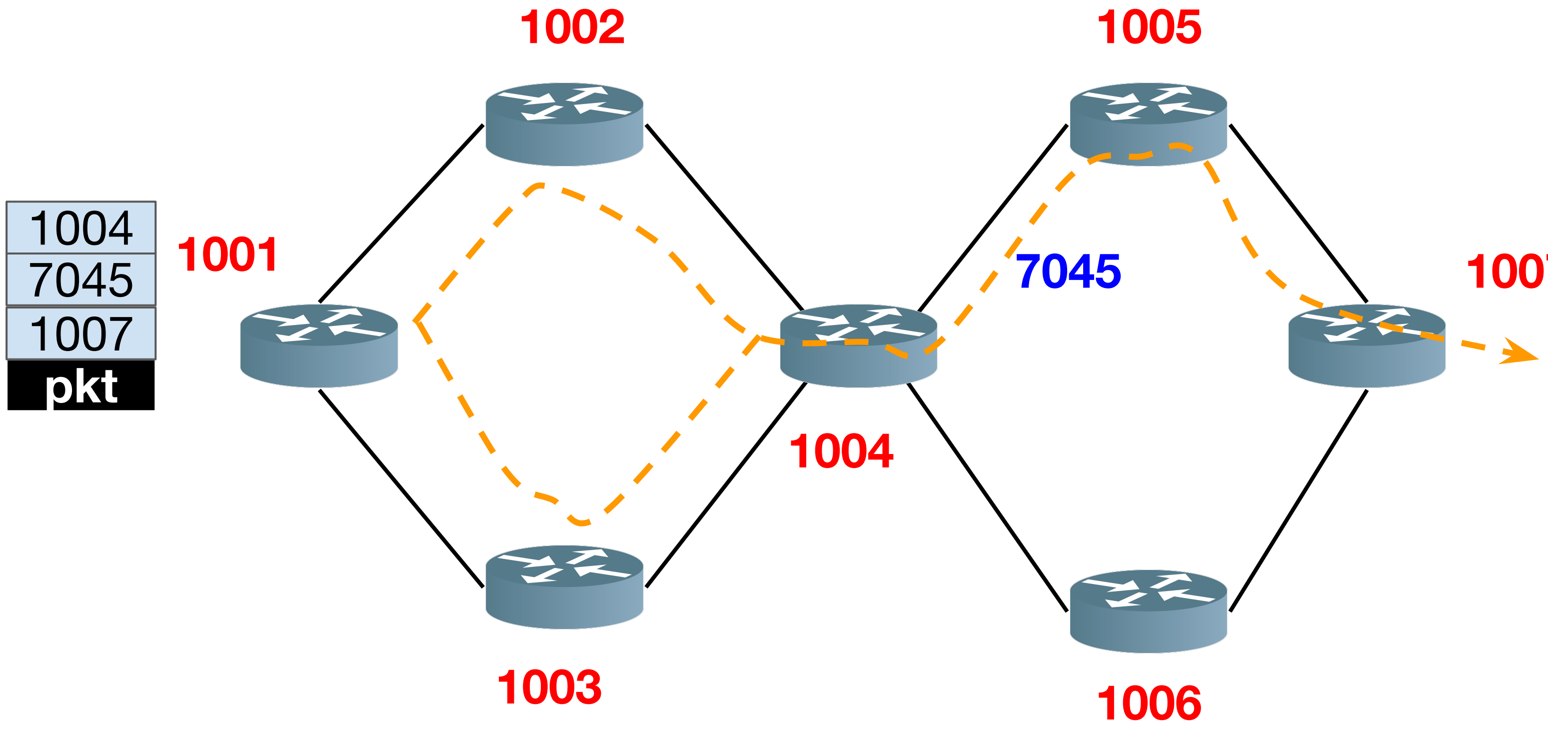


Type of segments: some examples



Type of segments: some examples



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SR Policy

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- An SR Policy is identified through the tuple

<headend, color, endpoint>

- The headend is the node where the policy is instantiated/implemented
- The endpoint indicates the destination of the policy
  - headend and endpoint are specified as an IPv4 or IPv6 address
- The color is a 32-bit numerical value that associates the SR Policy with an intent (e.g., low-latency)

Candidate Path and Segment List

- An SR Policy is associated with one (or more) candidate path
- A candidate path is itself associated with a Segment-List (SID-List)
  - a SID-List represents a specific source-routed way to send traffic from the head-end to the endpoint of the corresponding SR policy
- A candidate path is either dynamic or explicit
- A headend may be informed about a candidate path for an SR Policy by various means including:
  - local configuration
  - PCE

SR Policy: summary

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SR policy POL1 <headend, color, endpoint>

Candidate-path CP1

Preference 200

Weight W1, SID-List1 <SID11...SID1i>

Weight W2, SID-List2 <SID21...SID2j>

Candidate-path CP2

Preference 100

Weight W3, SID-List3 <SID31...SID3i>

Weight W4, SID-List4 <SID41...SID4j>

SR Database

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- An SR headend maintains the Segment Routing Traffic Engineering Database (SRTE-DB)
- The SRTE-DB is used to validate explicit candidate paths and compute dynamic candidate paths
- It includes the following information:
    - Regular IGP information (topology, IGP metrics)
    - Extended TE Link attributes (such as latency, loss, TE metric)
    - Inter-Domain Topology information
    - Segment Routing information (such as SRGB, Prefix-SIDs, Adj-SIDs, Peering SID SRv6 SID)

Dynamic Candidate Path

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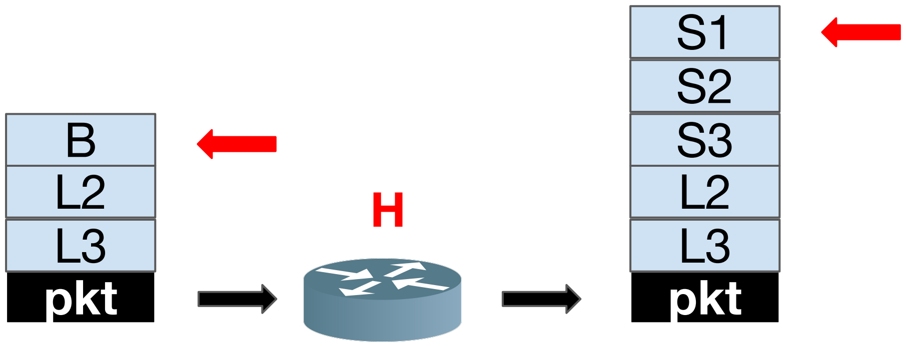
- A dynamic candidate path is specified as an optimization objective and constraints
  - eg. minimize delay avoiding link l
- The headend of the policy leverages its SRTE-DB to compute a SID-List that fits this optimization problem
  - re-computes any time the inputs to the problem change
- When local computation is not possible, the head-end may send path computation request to a PCE

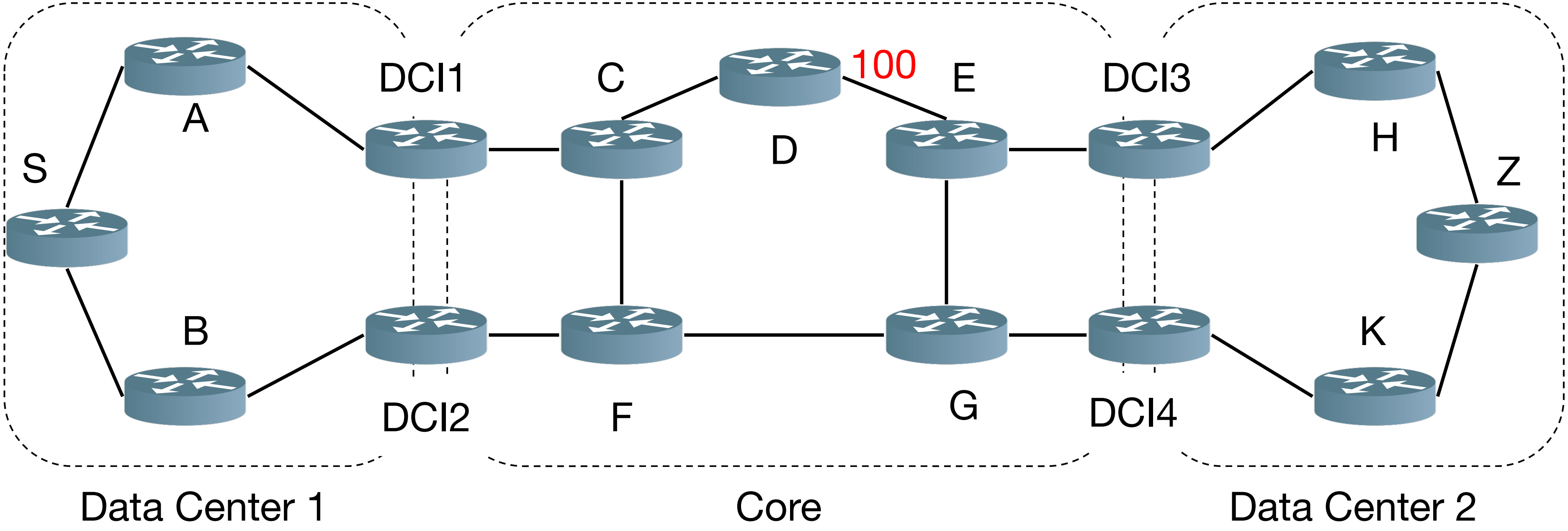
Binding SID

- An SR Policy installs a **BSID** entry in the forwarding plane with the action of steering the packets matching this entry to the selected path
- Let us assume that headend **H** has a valid SR Policy **P** of SID-List **<S1, S2, S3>** and BSID **B**

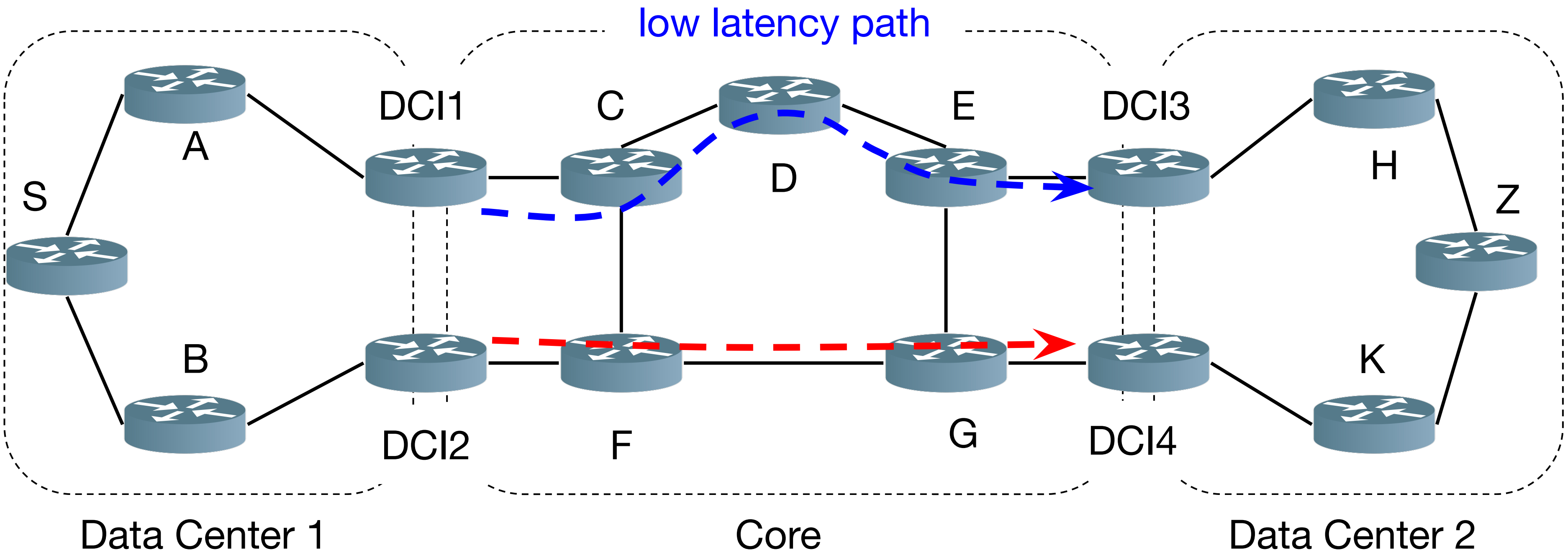


- **H** has steered the packet in the SR policy **P**

SRTE Policy: an example



SRTE Policy: an example



SRTE Policy: an example

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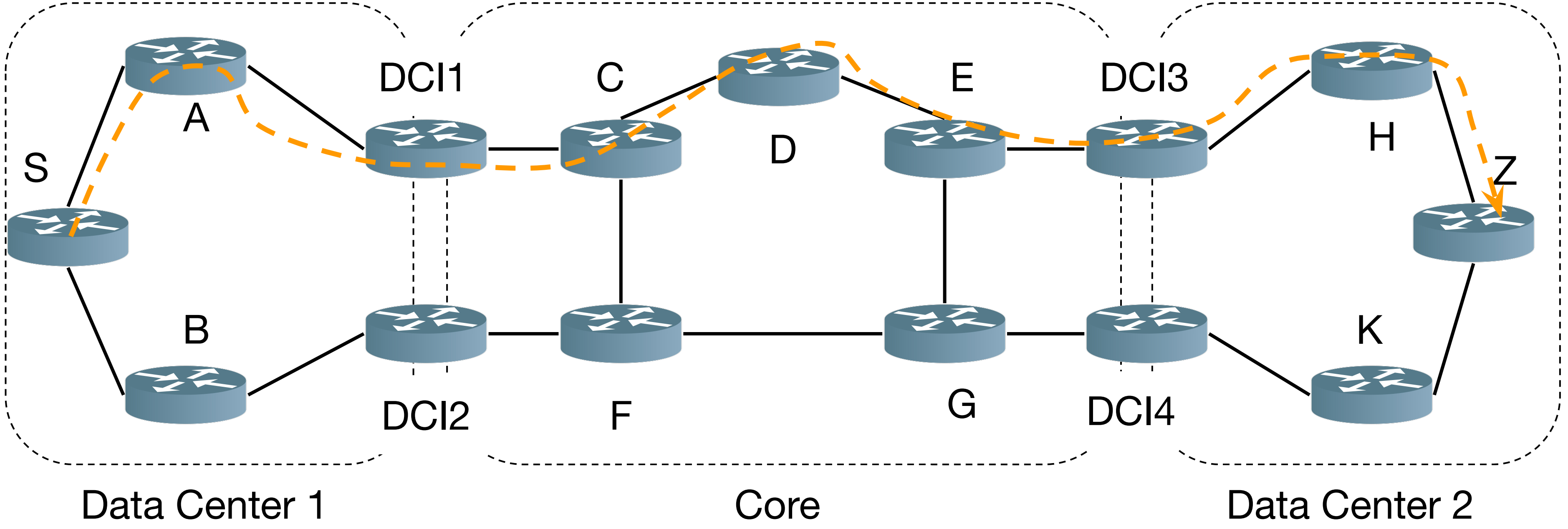
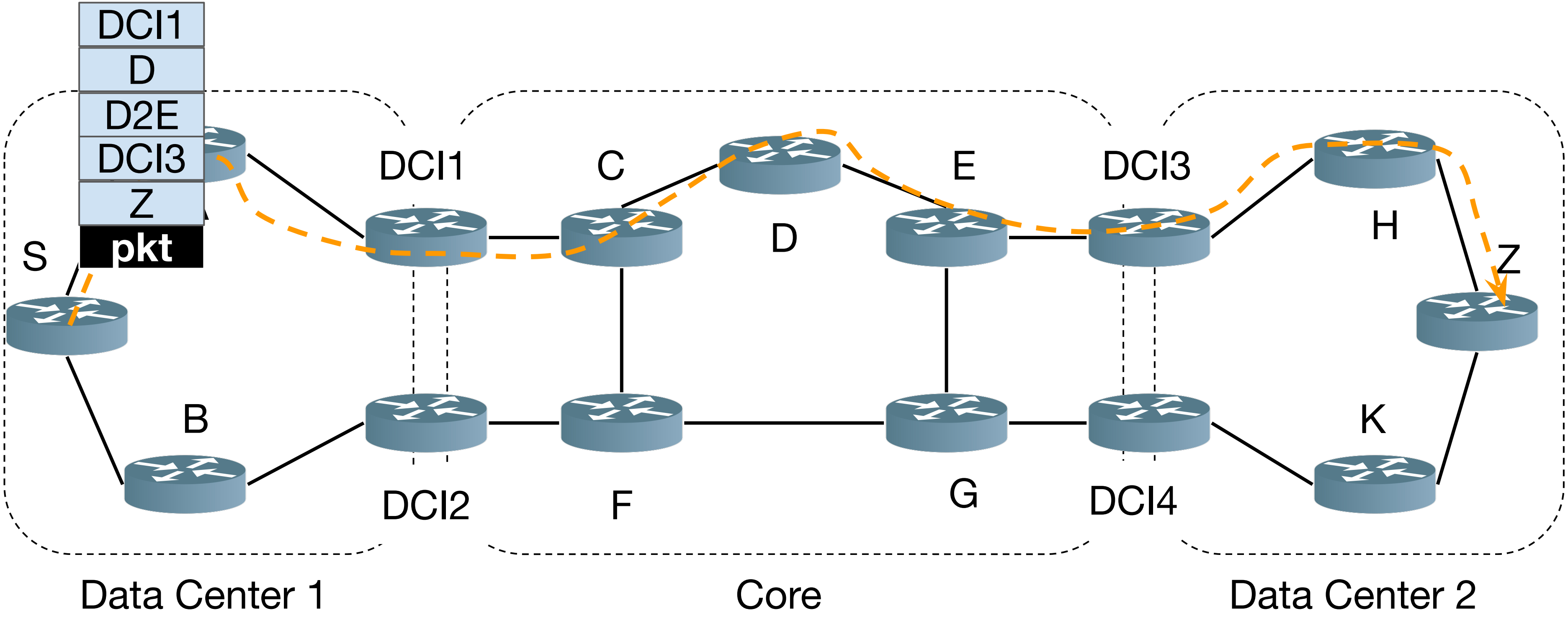


SRTE Policy: an example

option 1



SRTE Policy: an example

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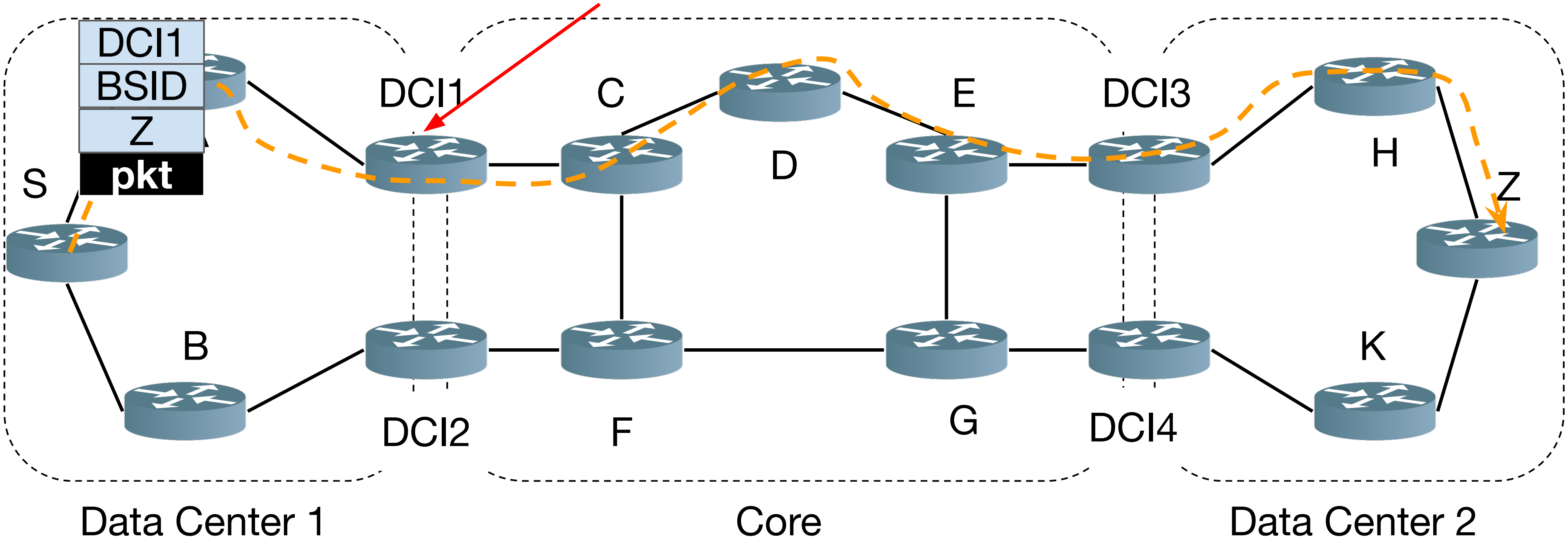
install BSID: <D,D2E,DCI3>

option 2

advertise BSID in data center 1 as “low latency policy”



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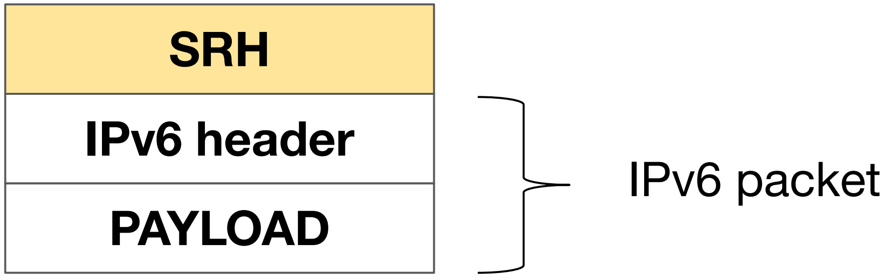
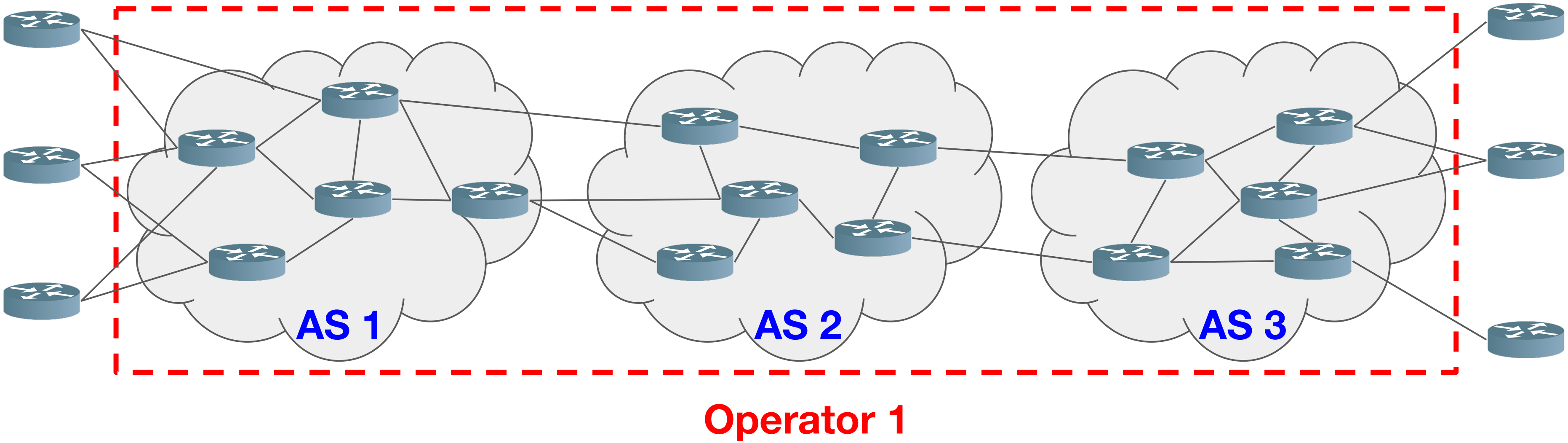
SRH instantiation

- The source based routing model in case of SR over IPv6 dataplane (SRv6) is realized through the instantiation of the Segment Routing Header (SRH)
- The SRH is added to the packet by its source:
  - At the node originating the packet (host, server)
  - At the ingress node of an SR domain

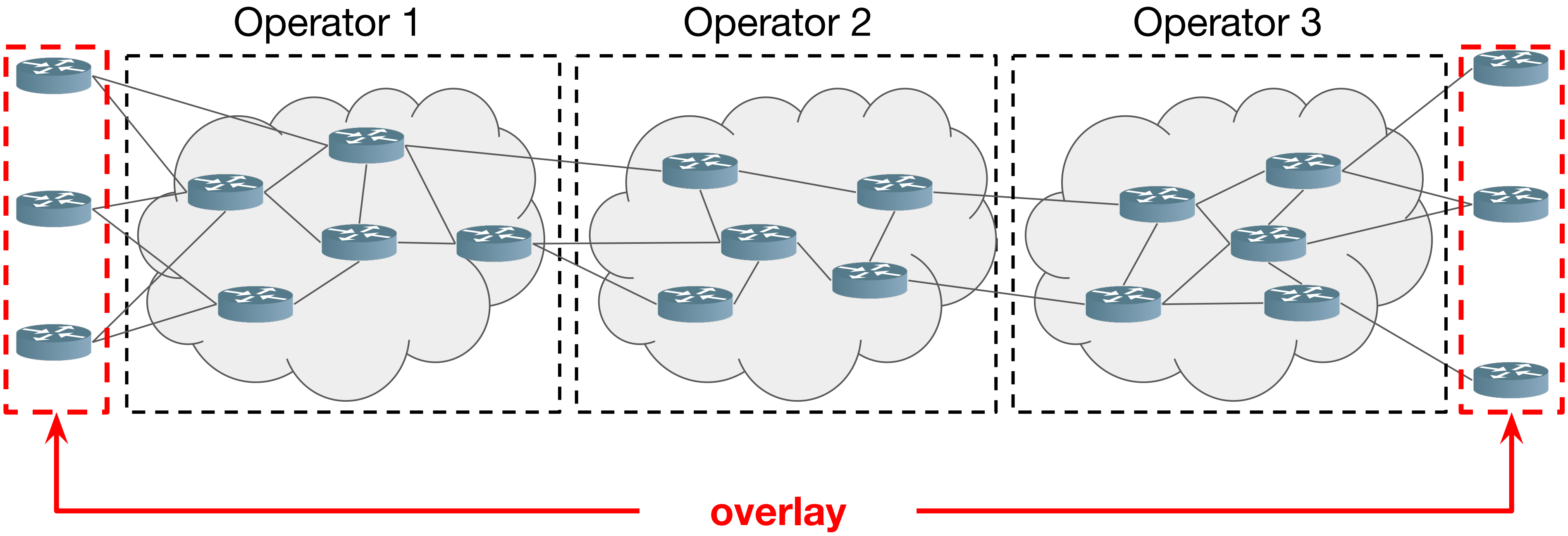


Examples of SRv6: Service Provider Network



- an IPv6 packet received at ingress, is:
  - classified according to network operator policies
  - encapsulated with an outer header with an SRH applied to the incoming packet

Examples of SRv6: Overlay Network



- The SRH originated by the overlay can only contain address/segment under the administration of the overlay

Segment Routing Extension Header (SRH)

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- A new type of the Routing Header is defined
  - the Segment Routing Header (SRH)

next header	hdr ext len	routing type	segments left
last entry	flags	tag	
segments list [0] (128 bit IPv6 address)			
……. .			
segments list [n] (128 bit IPv6 address)			
optional type length value objects (variable)			

Segment Routing Extension Header (SRH)

- **Next Header**: Identifies the type of header immediately following the SRH
- **Hdr Ext Len**: length of the SRH header in 8-octet units
- **Routing Type**: TBD, to be assigned by IANA (suggested value: 4)
- **Segments Left**: it contains the index, in the Segment List, of the next segment to inspect
  - Segments Left is decremented at each segment
- **Last Entry**: contains the index, in the Segment List, of the last element of the Segment List
- **Flags**: 8 bits of flags
- **Tag**: tag a packet as part of a class or group of packets (packets sharing the same set of properties)
- **Segment List[n]**: 128 bit IPv6 addresses representing the nth segment in the Segment List
- **Type Length Value** (TLV)

SRH TLVs

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- Type Length Value (TLV) contain optional information that may be used by the node identified in the DA of the packet
  - Multiple TLVs may be encoded in the same SRH
- The following TLVs are defined:
  - **Ingress Node TLV**: identifies the node this packet traversed when entered the SR domain
  - **Egress Node TLV**: identifies the node this packet is expected to traverse when exiting the SR domain
  - **NSH Carrier TLV**

SRH processing

- For the SRH holds the following property:
  - Only the router whose address is in the DA field of the packet header MUST inspect the SRH
- Segment Routing in IPv6 networks implies that the segment identifier is moved into the DA of the packet

- The DA of the packet changes at each segment termination/completion

My Local SID Table

- An SRv6-capable node N maintains a MyLocalSID Table
- This table contains all the local SRv6 segments explicitly instantiated at node N
- N is the parent node for these SID's
- Every SRv6 local SID instantiated has a specific instruction bounded to it

MyLocalSID Table

SID	instruction
...	...

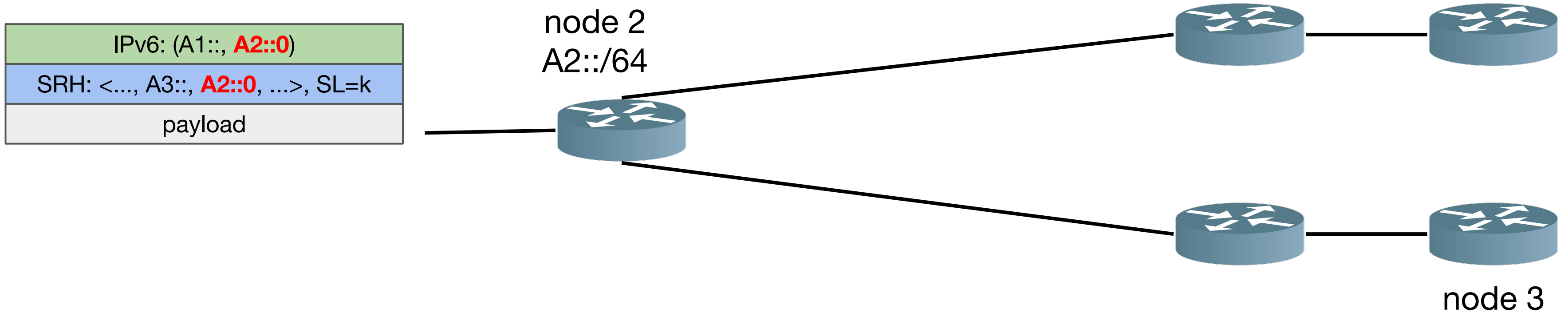
SRH Functions

- Segment Routing architecture defines a segment as an instruction or, more generally, a set of instructions (function)
- Two SRv6 basic functions are:
  - **End**
    - the endpoint (End) function is the base of the source routing paradigm
    - it consists of updating the DA with the next segment and forward the packet accordingly
  - **End.X**
    - the endpoint layer-3 cross-connect function

Endpoint Function (End)

- When a node receives a packet destined to DA "S" and:
  - S is an entry in the MyLocalSID table
  - the function associated with S is "End"

1. **IF** SegmentsLeft > 0 **THEN**
2. decrement SL
3. update the IPv6 DA with SRH[SL]
4. FIB lookup on updated DA
5. forward accordingly to the matched entry
6. **ELSE**
7. drop the SRH



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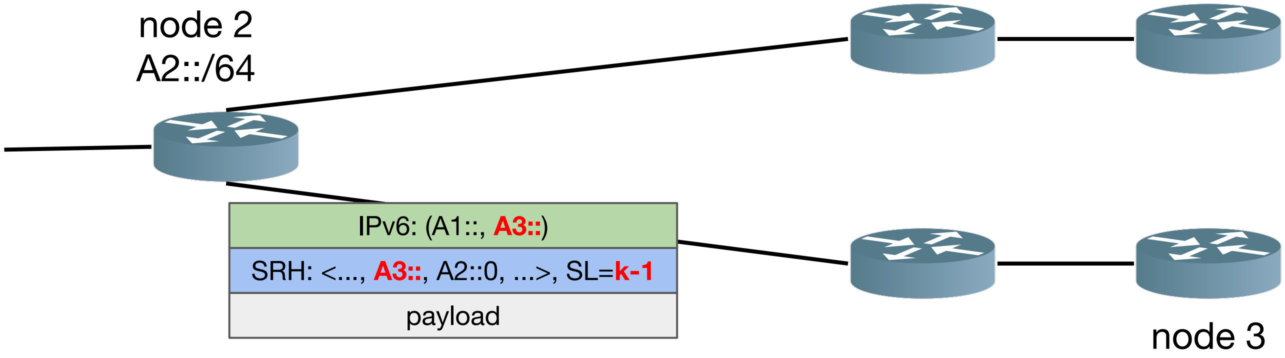

Endpoint with Layer-3 cross-connect (End.X)

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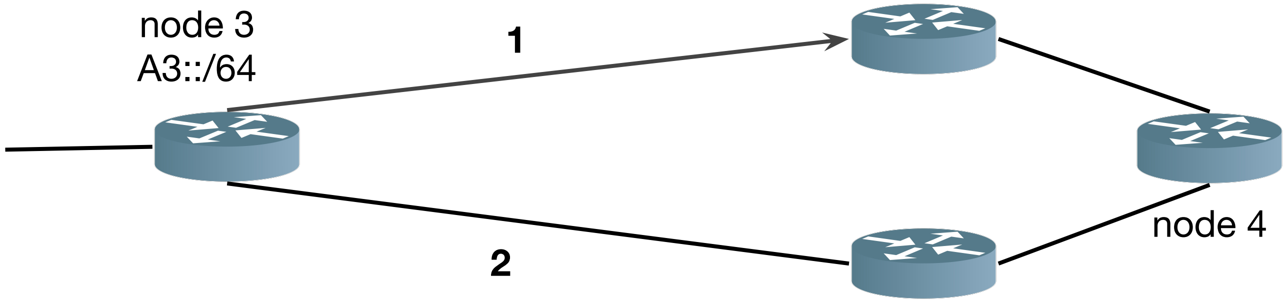
3. update the IPv6 DA with SRH[SL]
4. forward to layer-3 adjacency bound to the SID "S"
5. **ELSE**
6. drop the SRH

IPv6: (A1::, **A3::C1**)
SRH: <..., A4::, **A3::C1**, ...>, SL=k
payload



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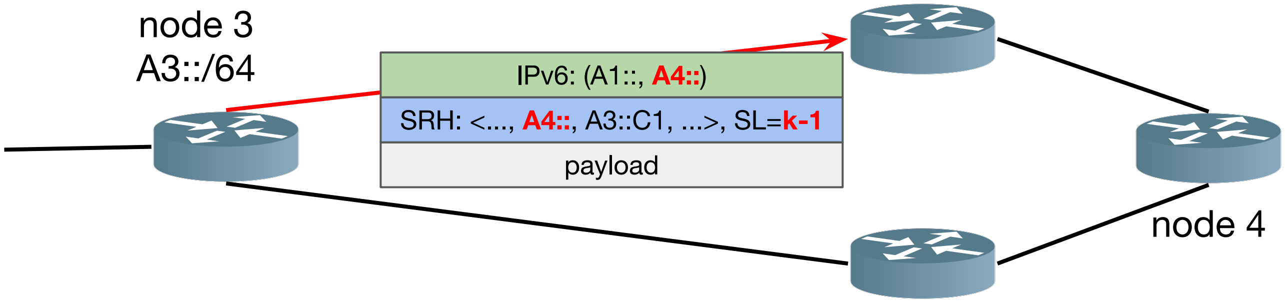
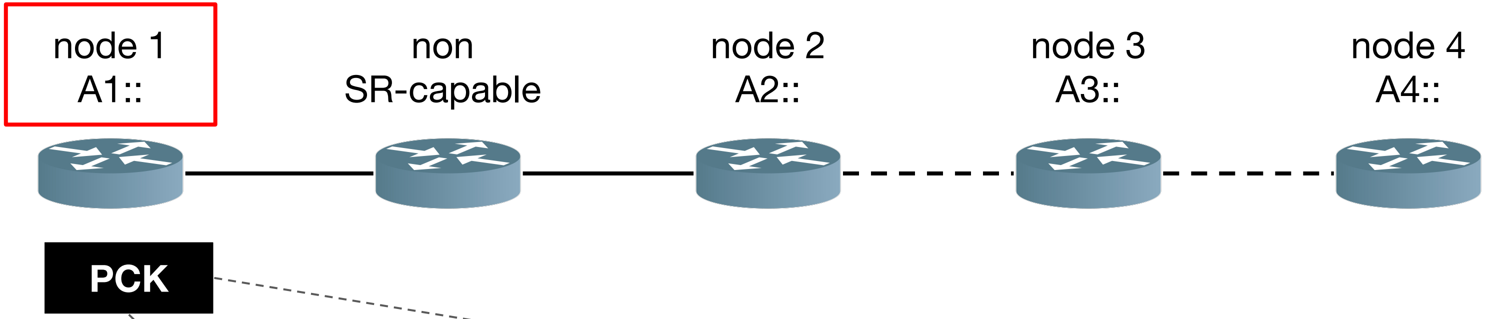


Source Node

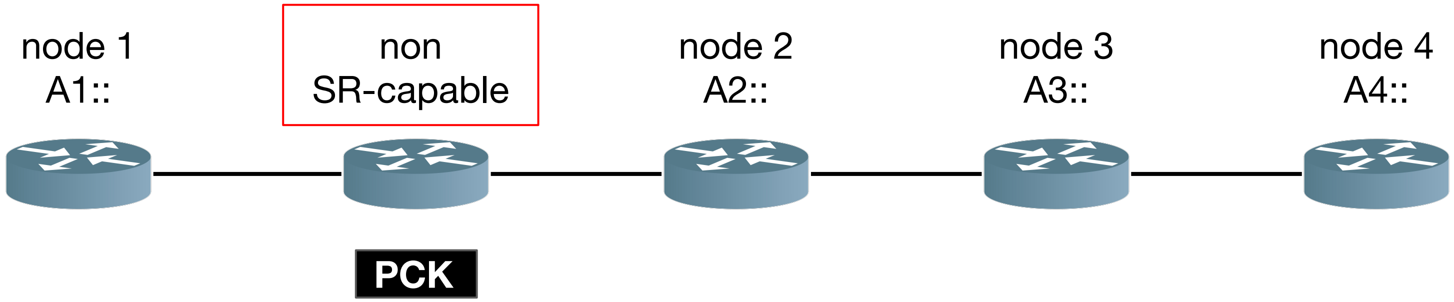
- Source Node is SR-capable
- SRH is created with:
  - Segment List in reversed order of the path
    - Segment List [0] is the **LAST** segment
    - Segment List [n-1] is the **FIRST** segment
    - Segment left is set to **n-1**
    - First segment is set to **n-1**
- IP DA is set to the first segment
- Packet is sent according to the IP DA
  - Normal IPv6 forwarding

Source Node



payload length		next = 43	hop limit
source address = A1::			
destination address = A2::			
next header	len = 6	type = 4	**SL = 2**
First = 2	flags	tag	
segments list [0] = A4::			
segments list [1] = A3::			
segments list [2] = A2::			

Non-SR Transit Node



- Plain IPv6 forwarding
- Solely based on IPv6 destination address
- No SRH inspection or update

SR Segment Endpoints

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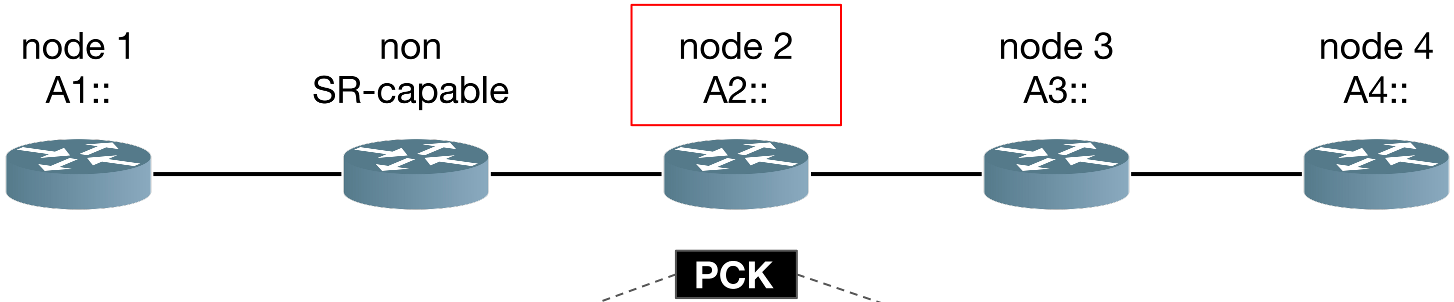
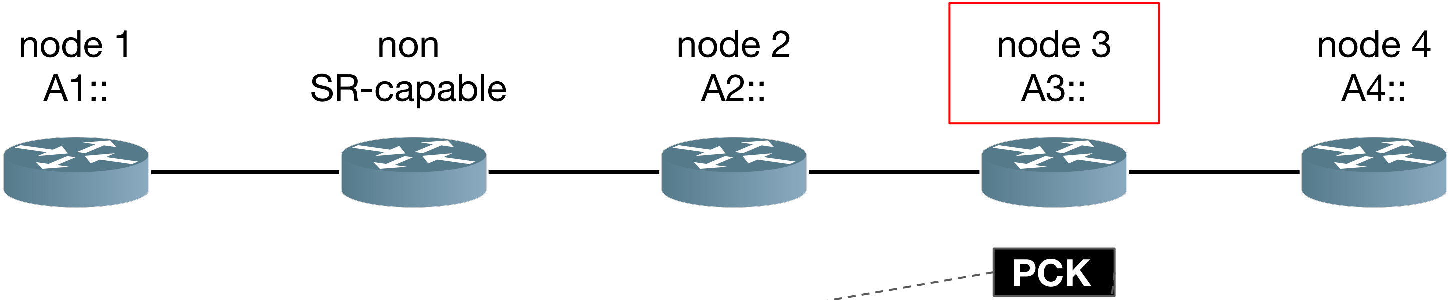
- **SR Endpoints**: SR-capable nodes whose address is in the IP DA
- SR Endpoints inspect the SRH and do:
  - IF Segments Left > 0, THEN
    - Decrement Segments Left (-1)
    - Update DA with Segment List [Segments Left]
    - Forward according to the new IP DA

SR Segment Endpoints



vers	traffic class	flow label	
payload length		next = 43	hop limit
source address = A1::			
destination address = A3::			
next header	len = 6	type = 4	**SL = 1**
first = 2	flags	tag	
segments list [0] = A4::			
segments list [1] = A3::			
segments list [2] = A2::			
Payload			

SR Segment Endpoints

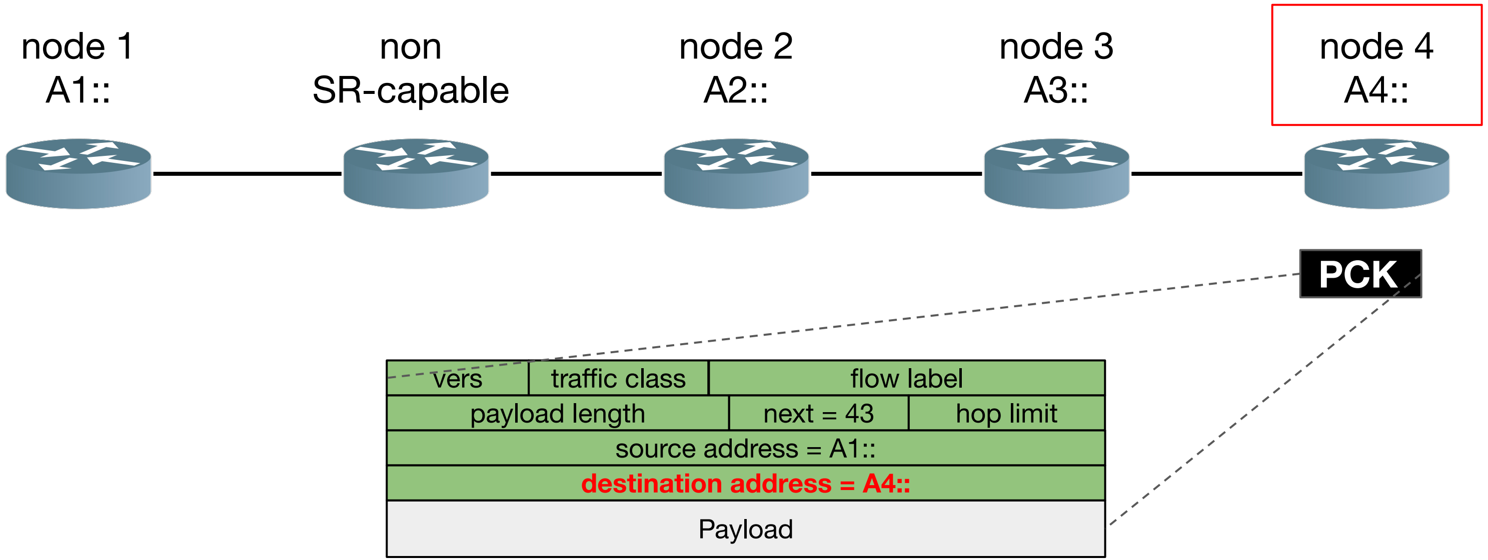


vers	traffic class	flow label	
payload length		next = 43	hop limit
source address = A1::			
destination address = A4::			
next header	len = 6	type = 4	**SL = 0**
first = 2	flags	tag	
segments list [0] = A4::			
segments list [1] = A3::			
segments list [2] = A2::			
Payload			

SR Segment Endpoints

- SR Endpoints: SR-capable nodes whose address is in the IP DA
- SR Endpoints inspect the SRH and do:
  - IF Segments Left > 0, THEN
    - Decrement Segments Left (-1)
    - Update DA with Segment List [Segments Left]
    - Forward according to the new IP DA
  - ELSE (Segments Left = 0)
    - Remove the IP and SR header
    - Process the payload

SR Segment Endpoints



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SRv6 Segment Format

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locator	*function*	*argument*
1111:2222:3333:4444:	5555:6666:	7777:8888

- An SRv6 local SID is logically represented as LOC:FUNCT
  - LOC is the L most significant bits
  - FUNCT is the 128-L least significant bits
- L is called the locator length and is flexible
- Most often the LOC part of the SID is routable and leads to the node which owns that SID
- The FUNCT part of the SID is an opaque identification of a local function bound to the SID
- A function may require additional arguments
  - the SRv6 Local SID will have the form LOC:FUNCT:ARGS

SRv6 Functions

- Each entry of the MyLocalSID Table indicates the function associated with the local SID
- In practice, any function can be attached to a local SID
  - a node N can bind a SID to a local VM which can apply any complex function on the packet
- Some examples:
  - End
  - End.X
  - End.B6

End.B6

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- Endpoint bound to an SRv6 Policy
- When N receives a packet destined to S and S is a local End.B6 SID, N does:

```
IF NH=SRH and SL > 0
    do not decrement SL nor update the IPv6 DA with SRH[SL]
    insert a new SRH
    set the IPv6 DA to the first segment of the SRv6 Policy
    forward according to the first segment of the SRv6 Policy
ELSE
    drop the SRH
```

IPv6: (A1::, **A4::20**)
SRH: <..., A5::, **A4::20**, ...>, SL=k
payload

node 4
A4::/64

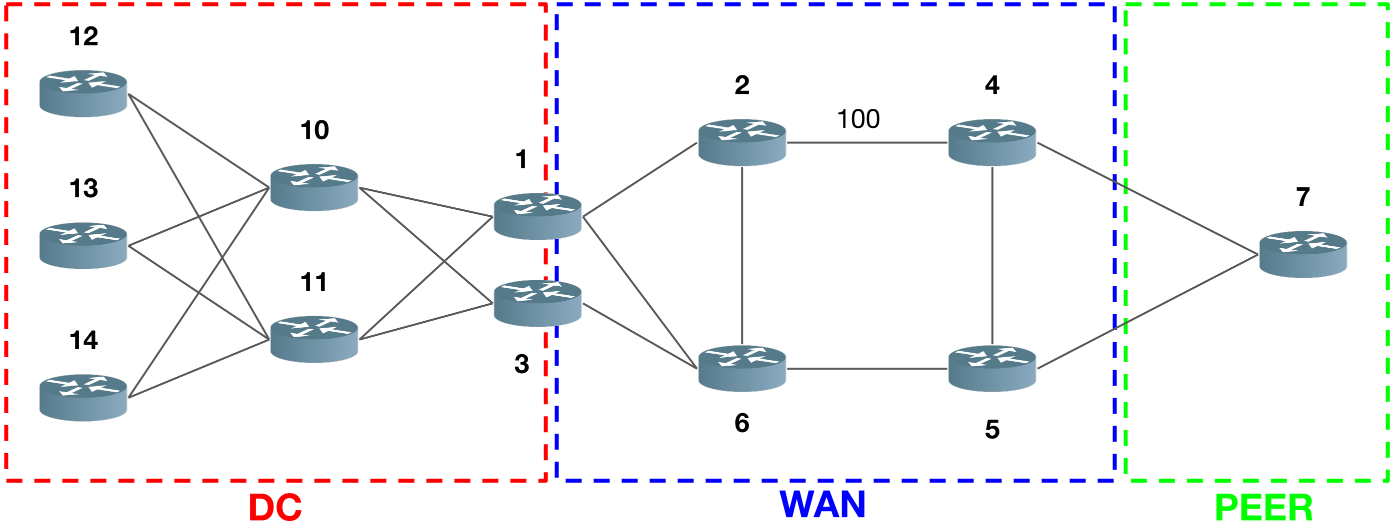
IPv6: (A1::, **S1**)
SRH: <S3, S2, **S1**>, SL=2
SRH: <..., A5::, A4::20, ...>, SL=k
payload

MyLocalSID Table

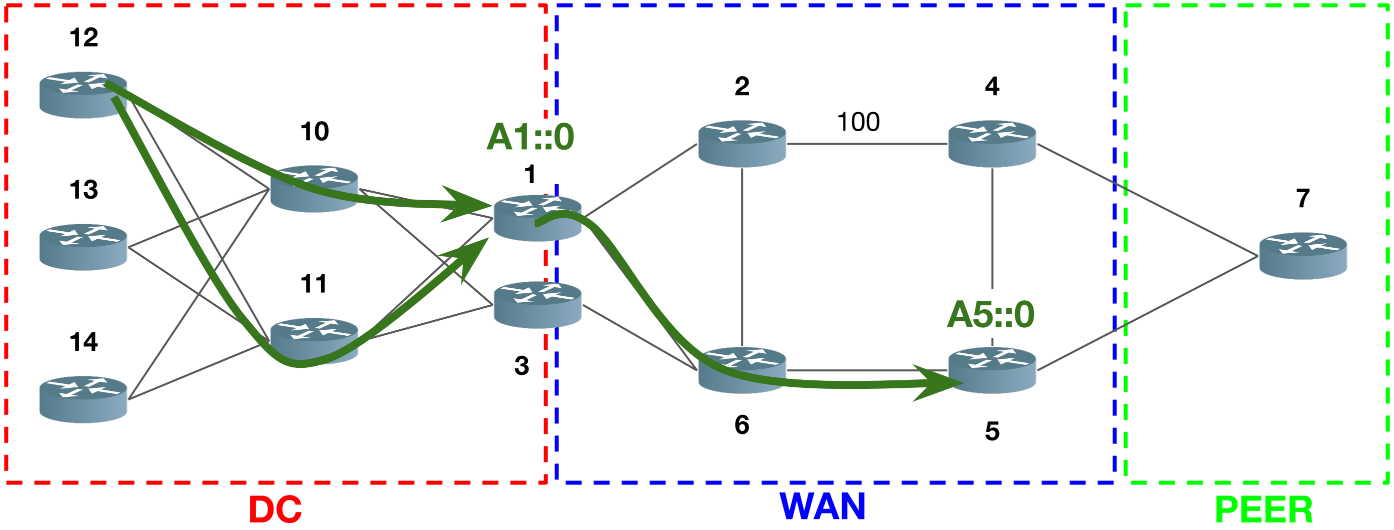
SID	instruction
...	...
A4::20	End.X <S1, S2, S3>
...	...

SID allocation for illustration purpose

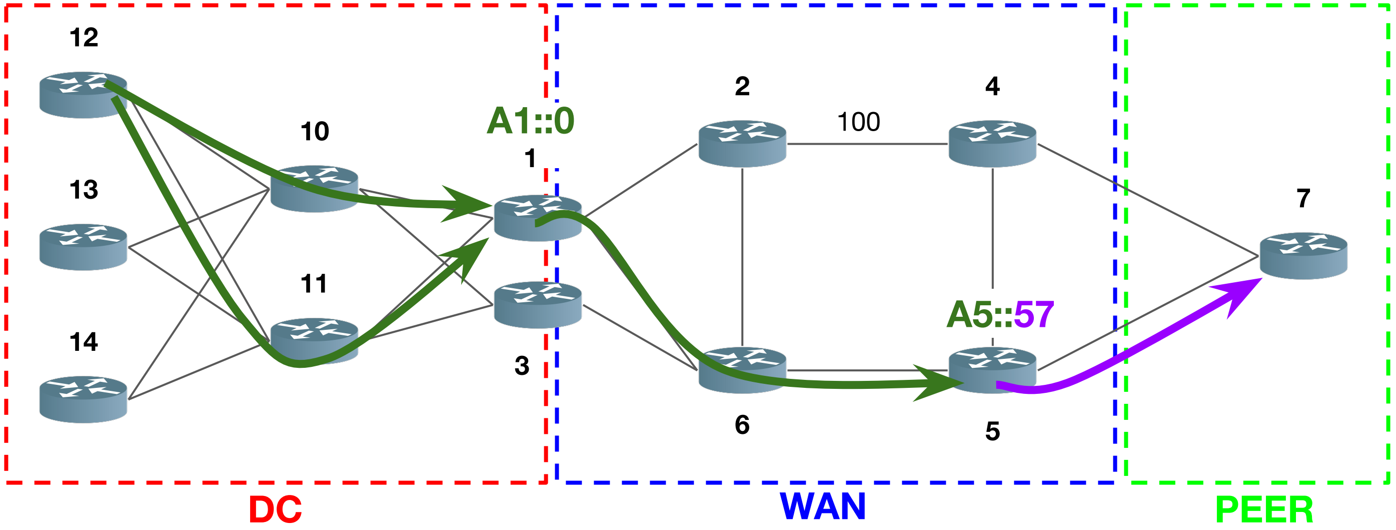
- Node K advertises prefix AK::/64
- The function is encoded in the last 64 bits
  - **0** denotes the **End** function
  - **CJ** denotes the **End.X** function on **link CJ**



A1::0 and then A5::0

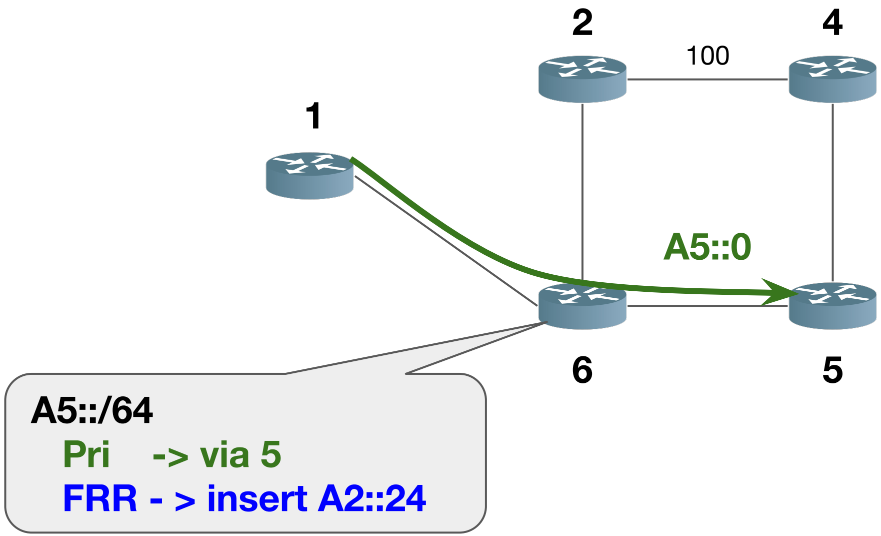


A1::0 and then A5::57



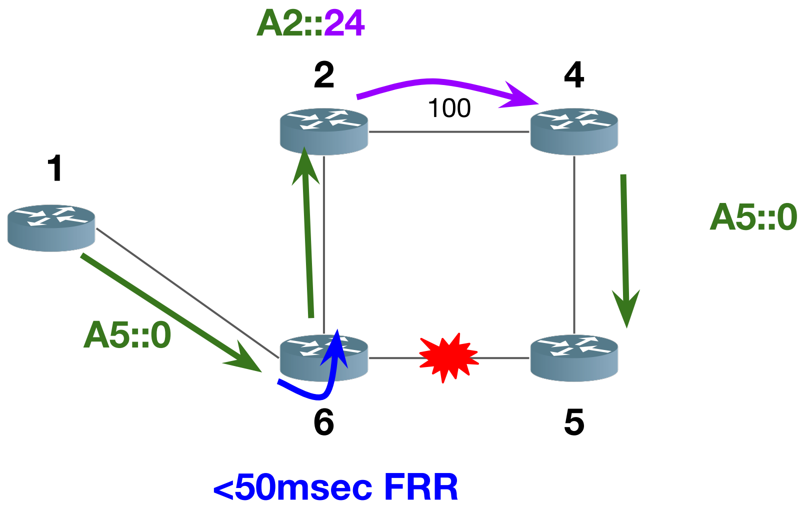
TILFA

- 50 msec protection upon local link, node or SRLG failure

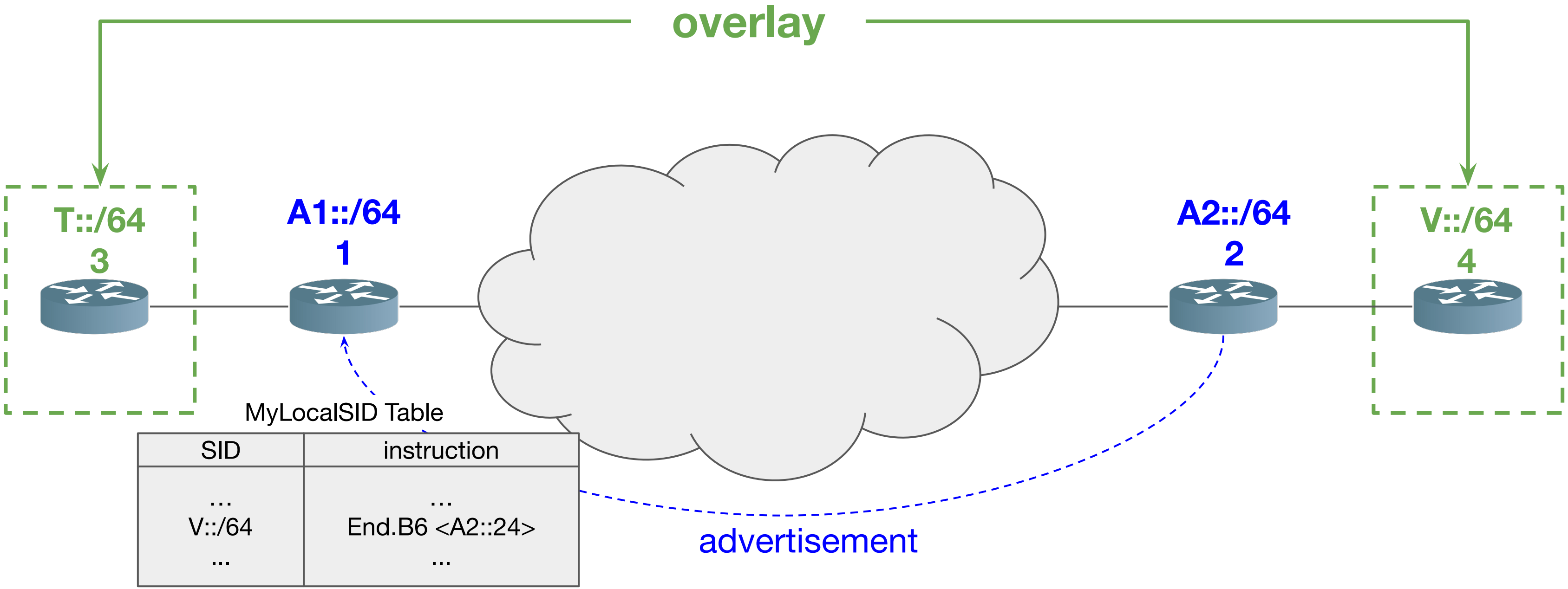


TILFA

- 50 msec protection upon local link, node or SRLG failure

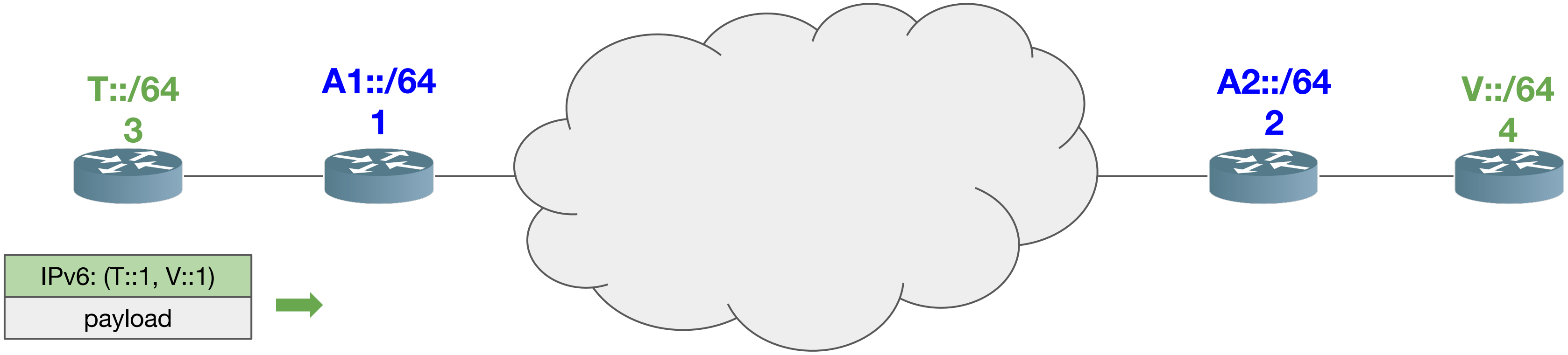


Overlay

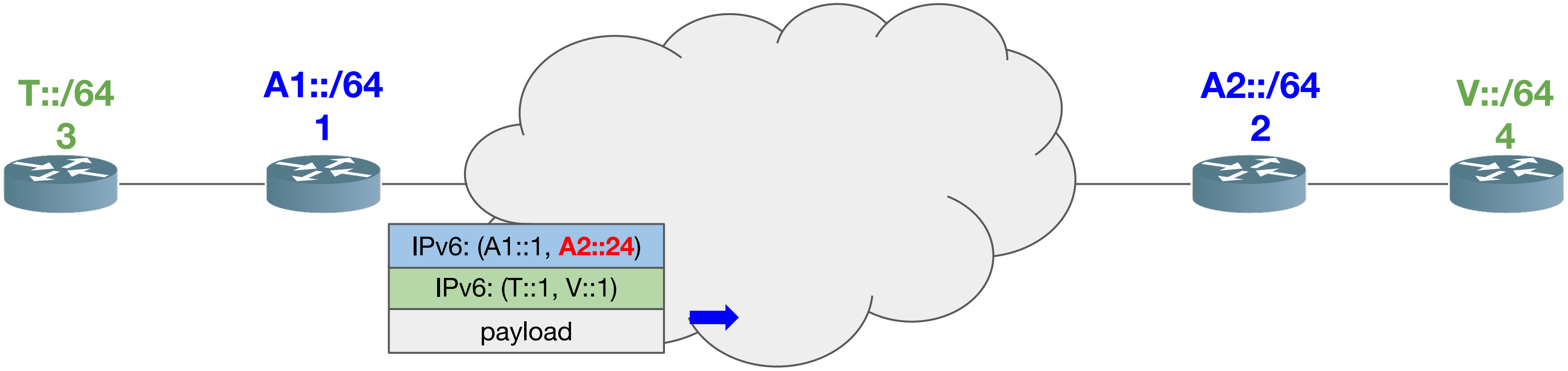


SID	instruction
…	…
V::/64	End.B6 <A2::24>
…	…

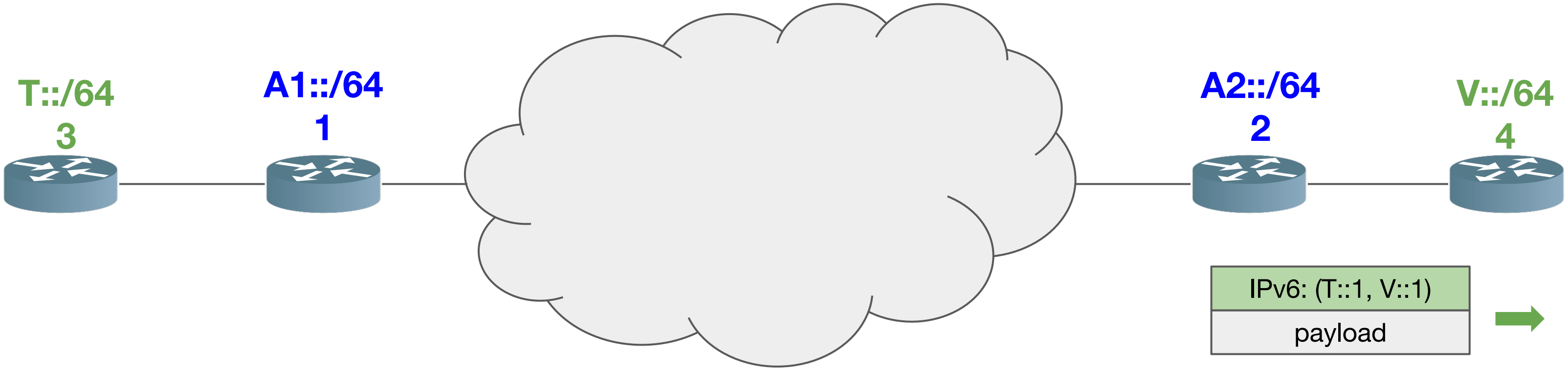
Overlay



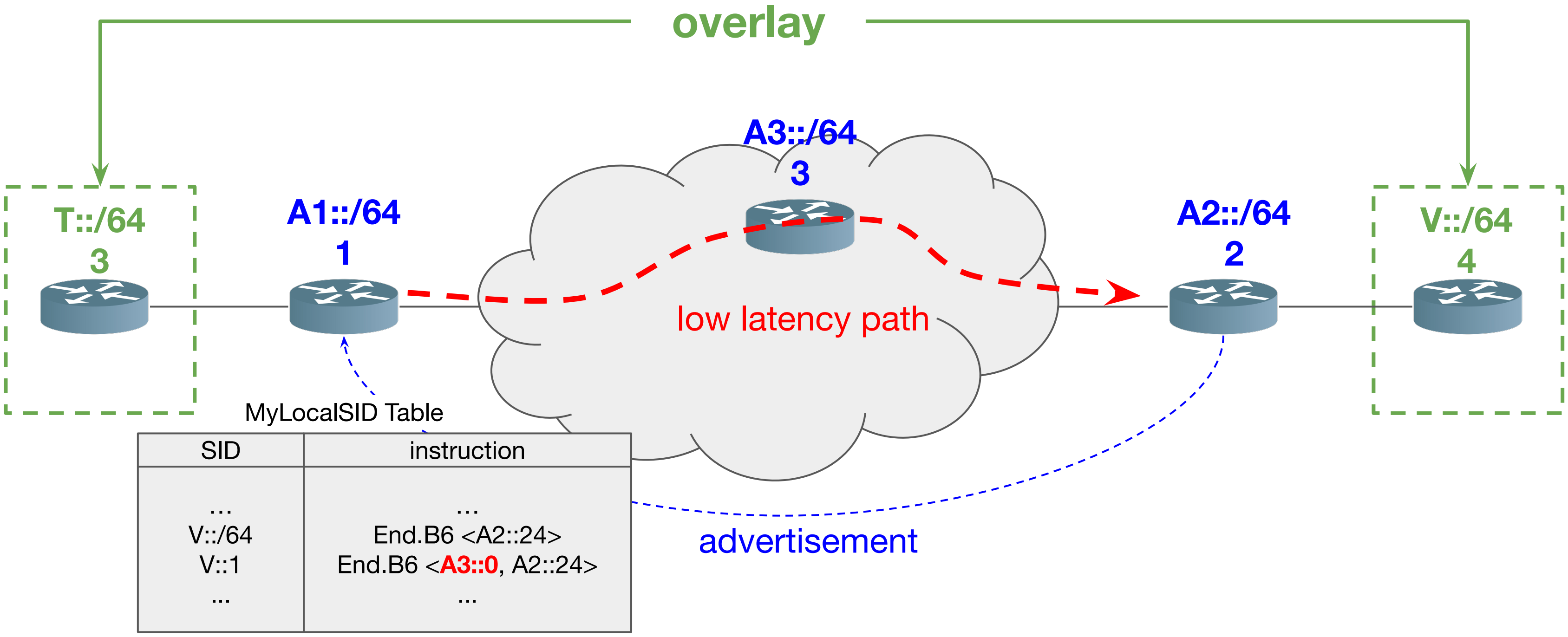
Overlay



Overlay



Overlay with underlay SLA



SID	instruction
...	...
V::/64	End.B6 <A2::24>
V::1	End.B6 <A3::0, A2::24>
...	...

Overlay with underlay SLA

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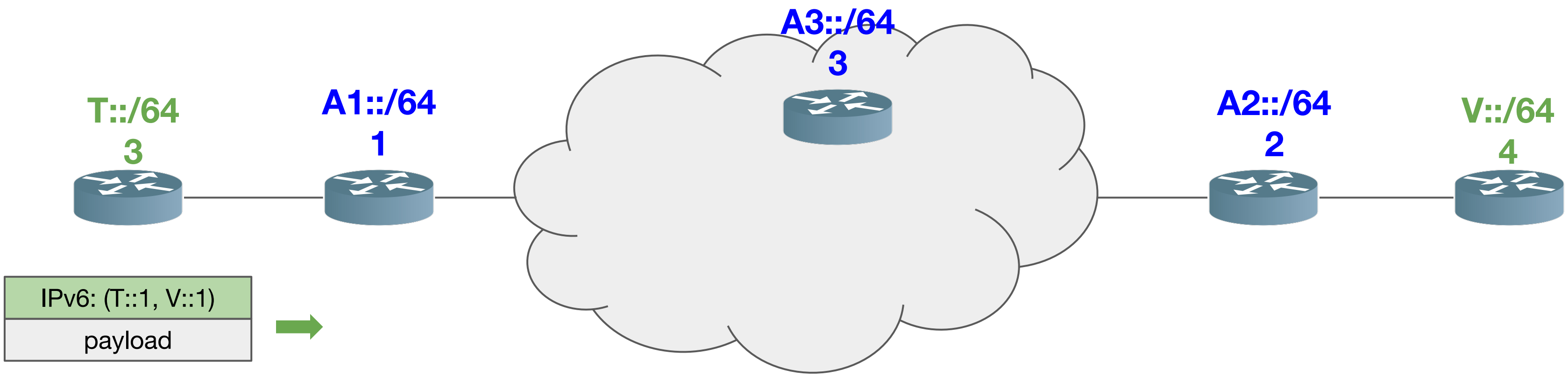
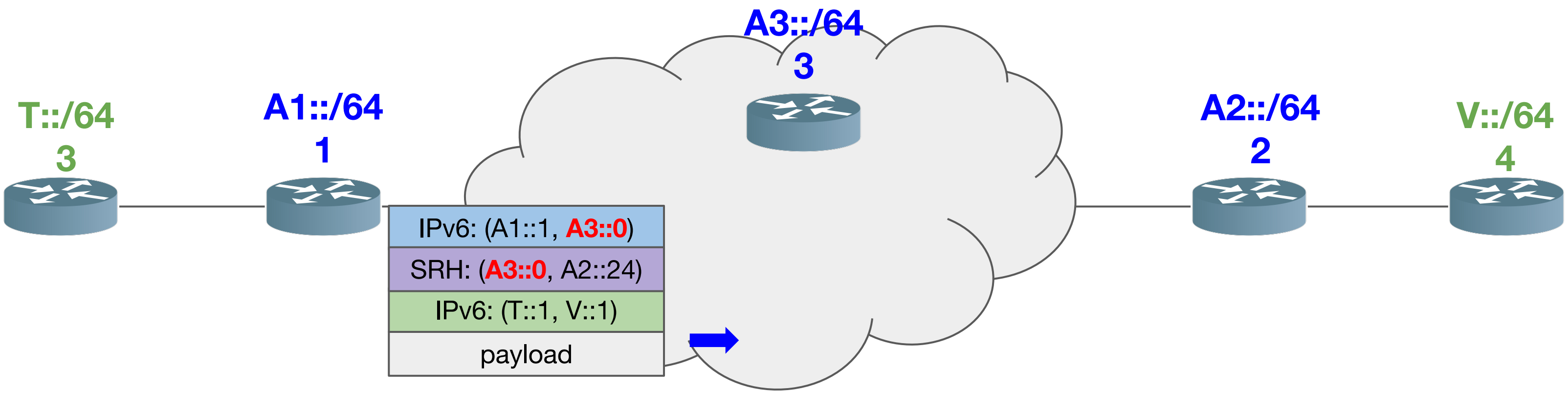
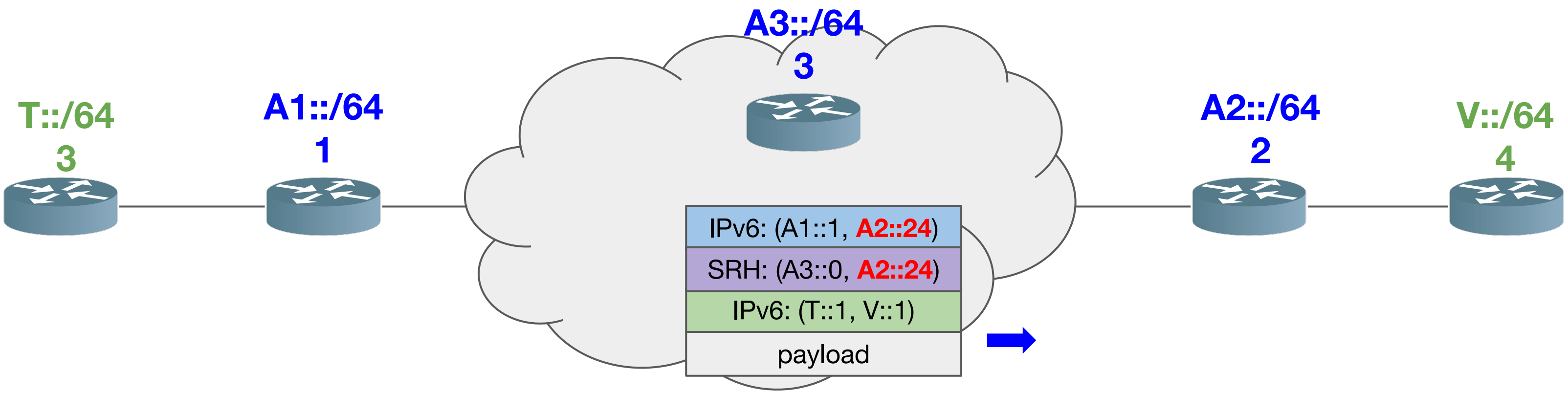


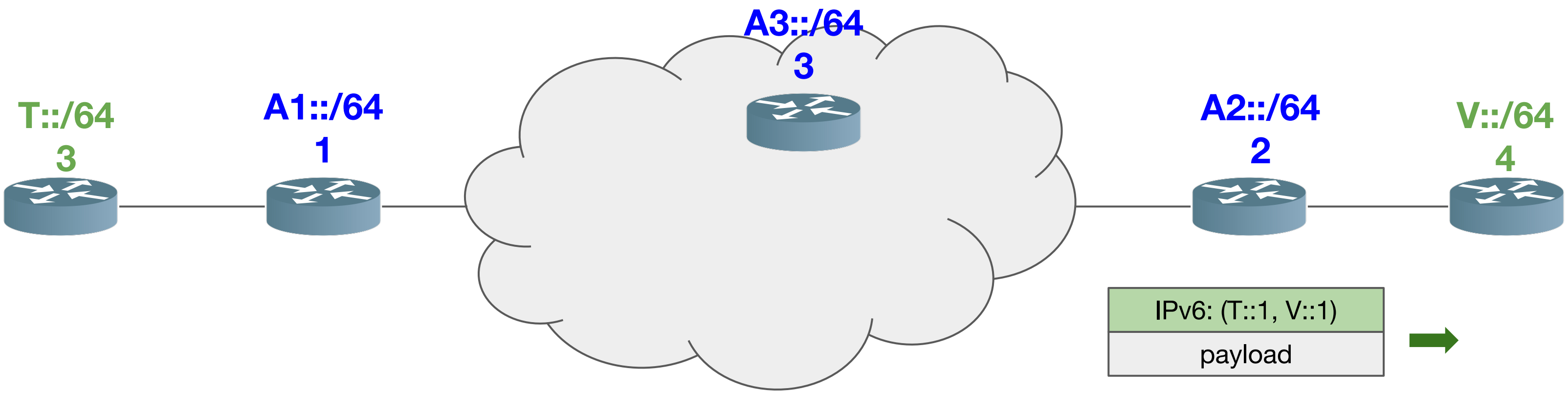
Overlay with underlay SLA



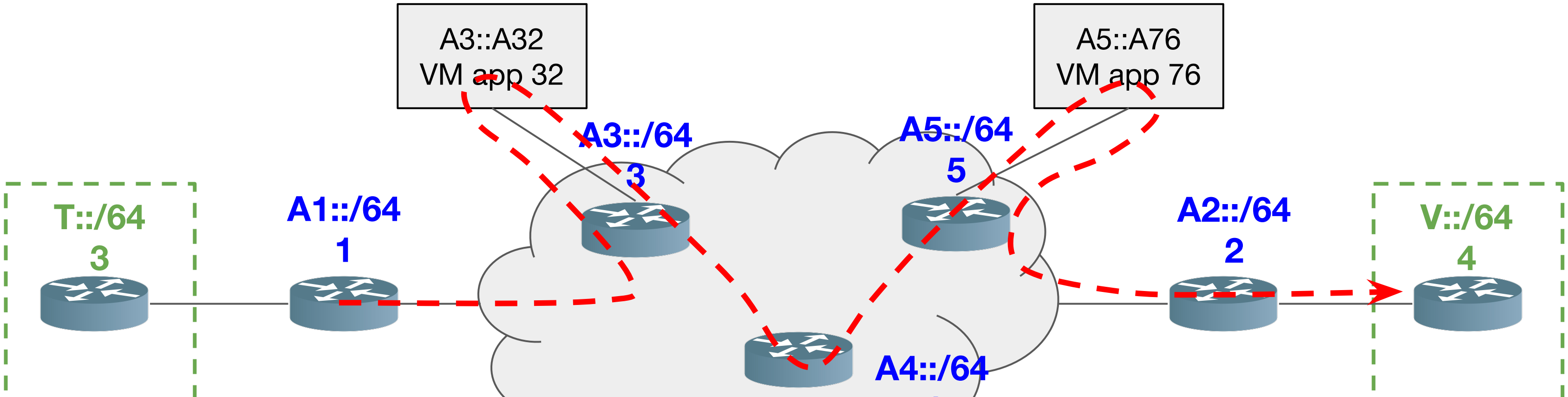
Overlay with underlay SLA



Overlay with underlay SLA



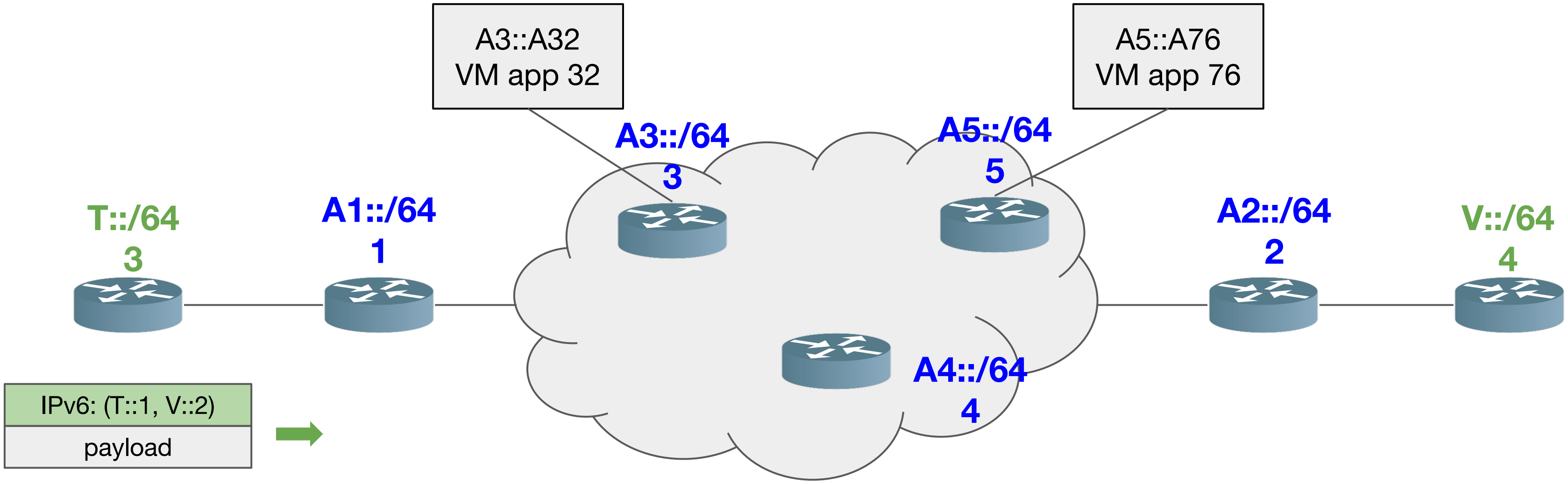
Integrated NFV



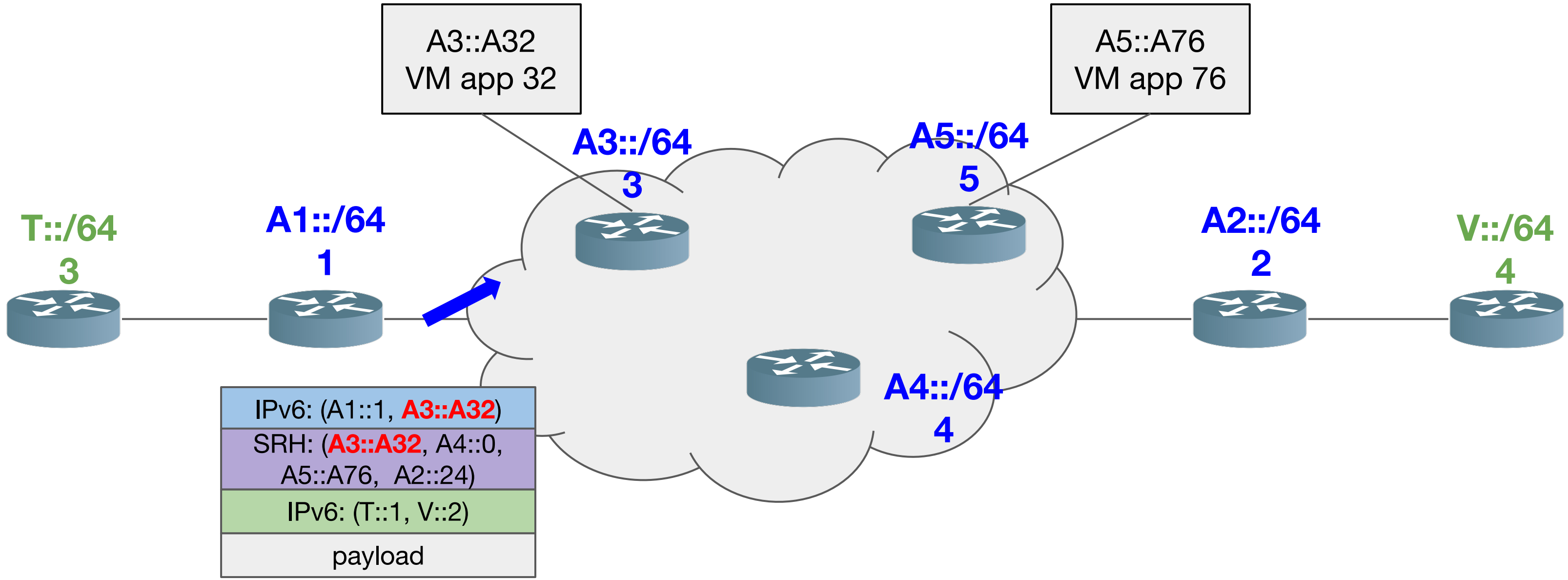
MyLocalSID Table

SID	instruction
…	…
V::/64	End.B6 <A2::24>
V::1	End.B6 <A3::0, A2::24>
V::2	End.B6 <A3::A32, A4::0, A5::A76, A2::24>
…	…

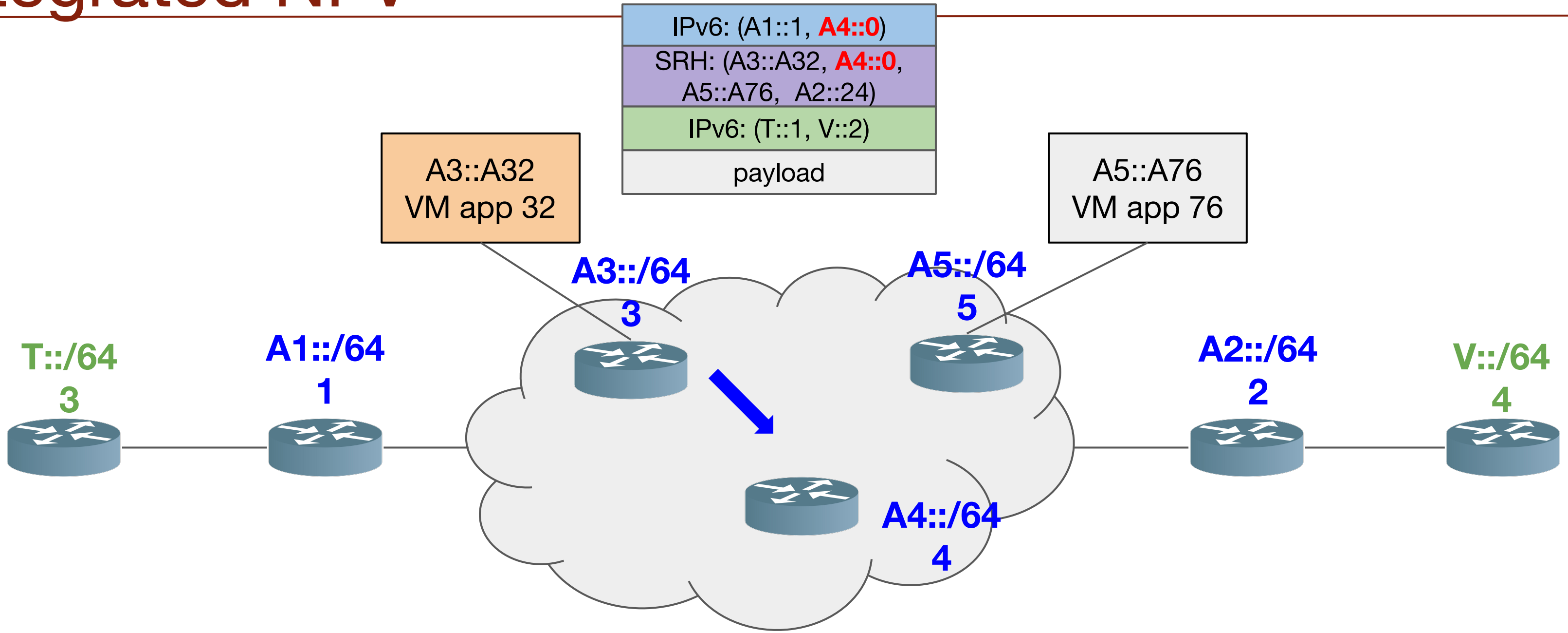
Integrated NFV



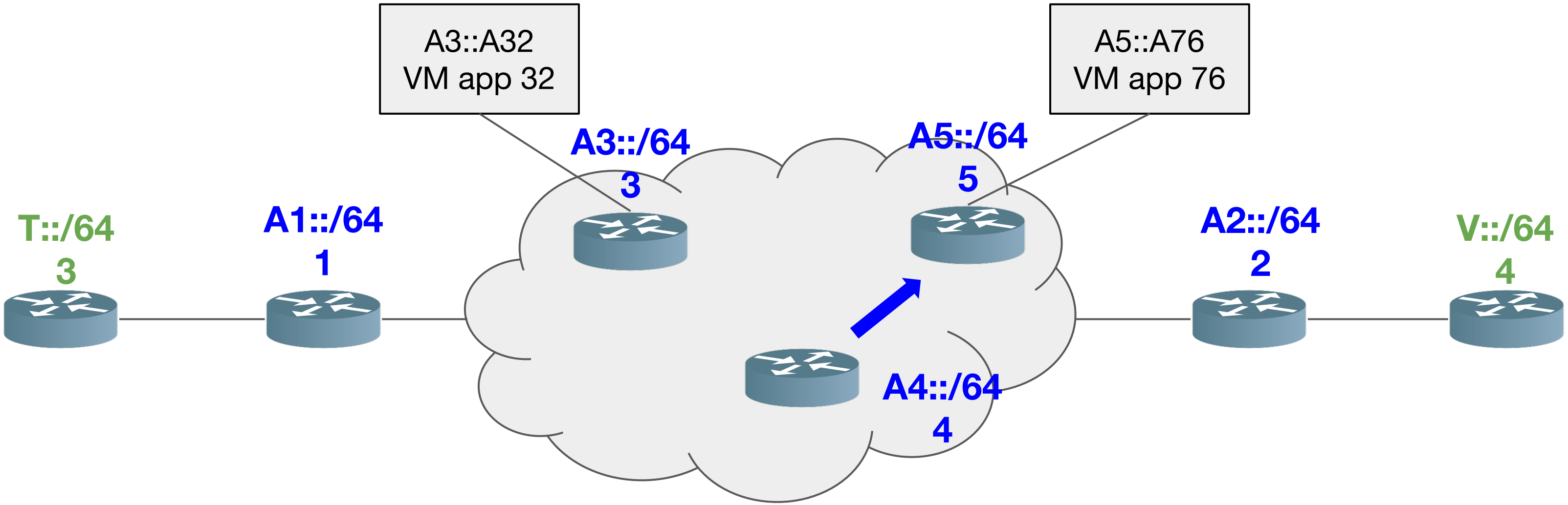
Integrated NFV



Integrated NFV



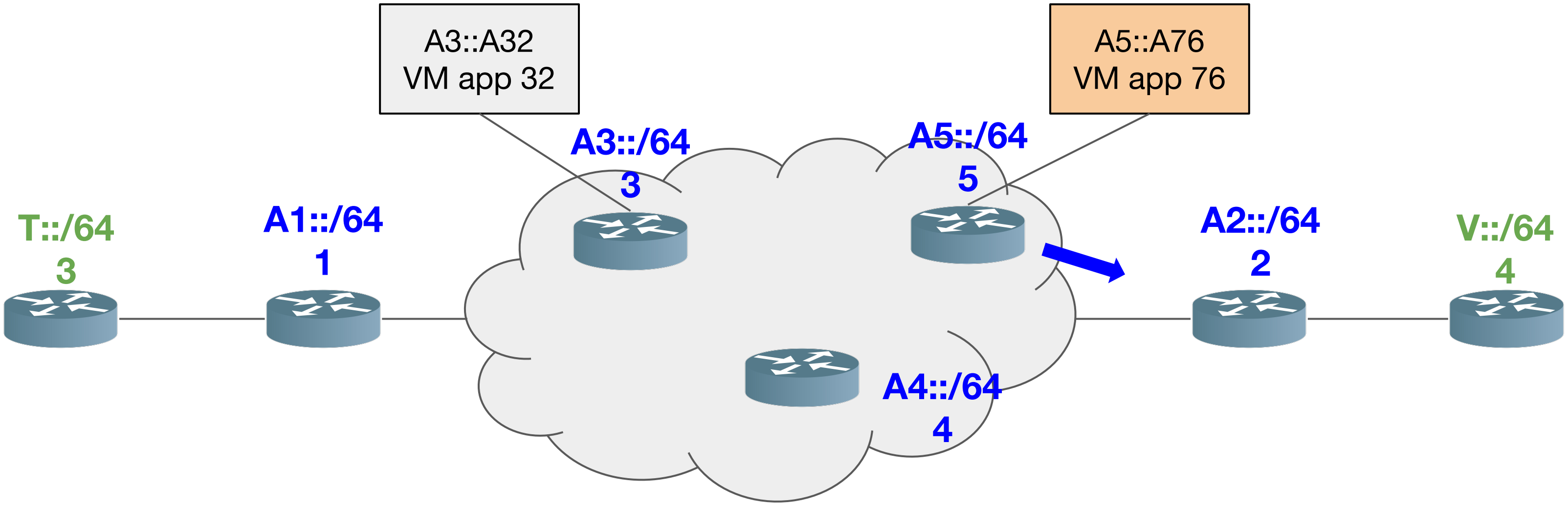
Integrated NFV



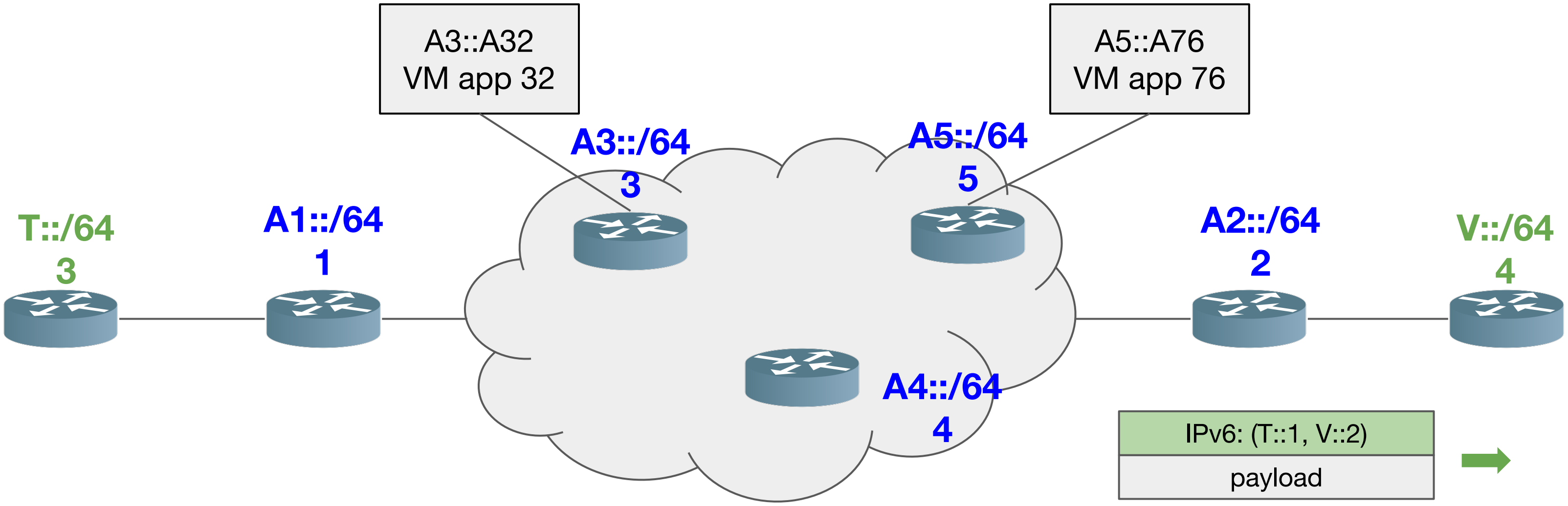
IPv6: (A1::1, **A5::A76**)
SRH: (A3::A32, A4::0, **A5::A76**, A2::24)
IPv6: (T::1, V::2)
payload

Integrated NFV

IPv6: (A1::1, A2::24)
SRH: (A3::A32, A4::0, A5::A76, A2::24)
IPv6: (T::1, V::2)
payload



Integrated NFV



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