Segment Routing

Network Infrastructures A.A. 2020/21

Outline

SAPIENZA
UNIVERSITÀ DI ROMA

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

Outline

SAPIENZA
UNIVERSITÀ DI ROMA

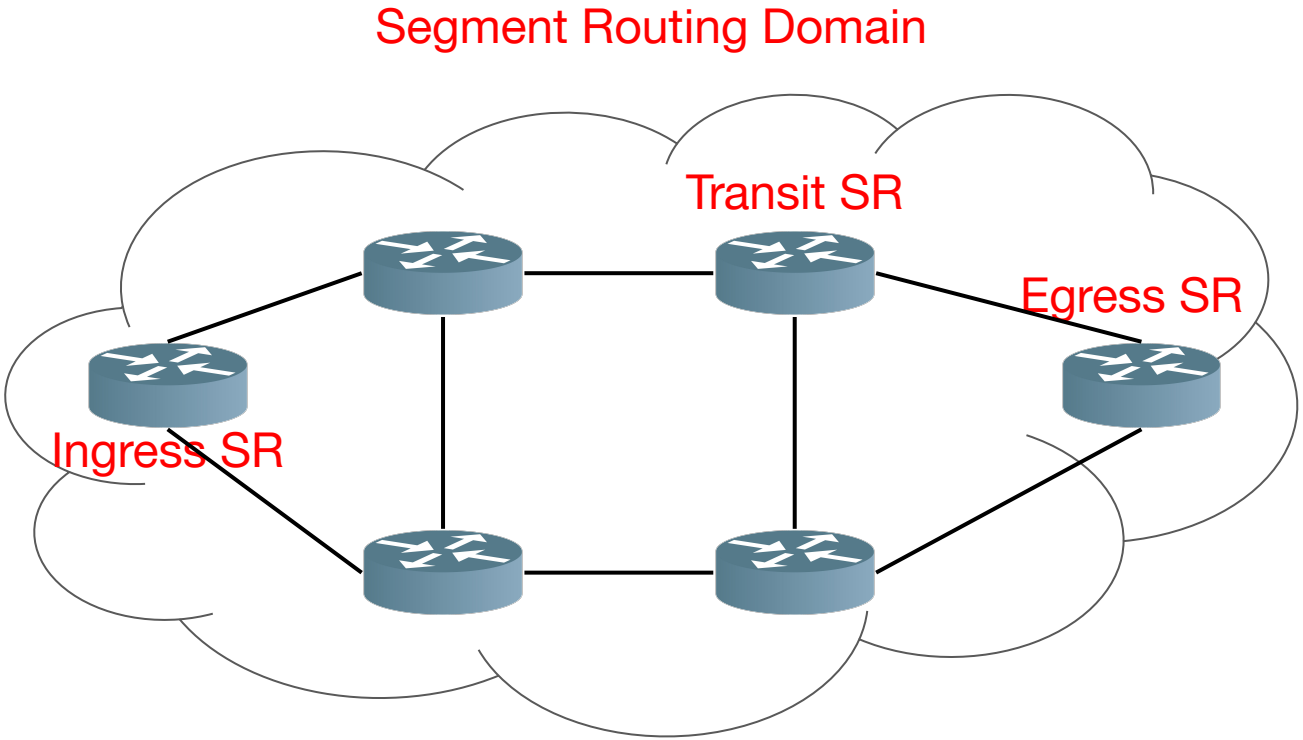
- Introduction to Segment Routing
- Segment Routing Policy
- SRv6 and Segment Routing extension Header
- Network Programming

SR overview

SAPIENZA
UNIVERSITÀ DI ROMA

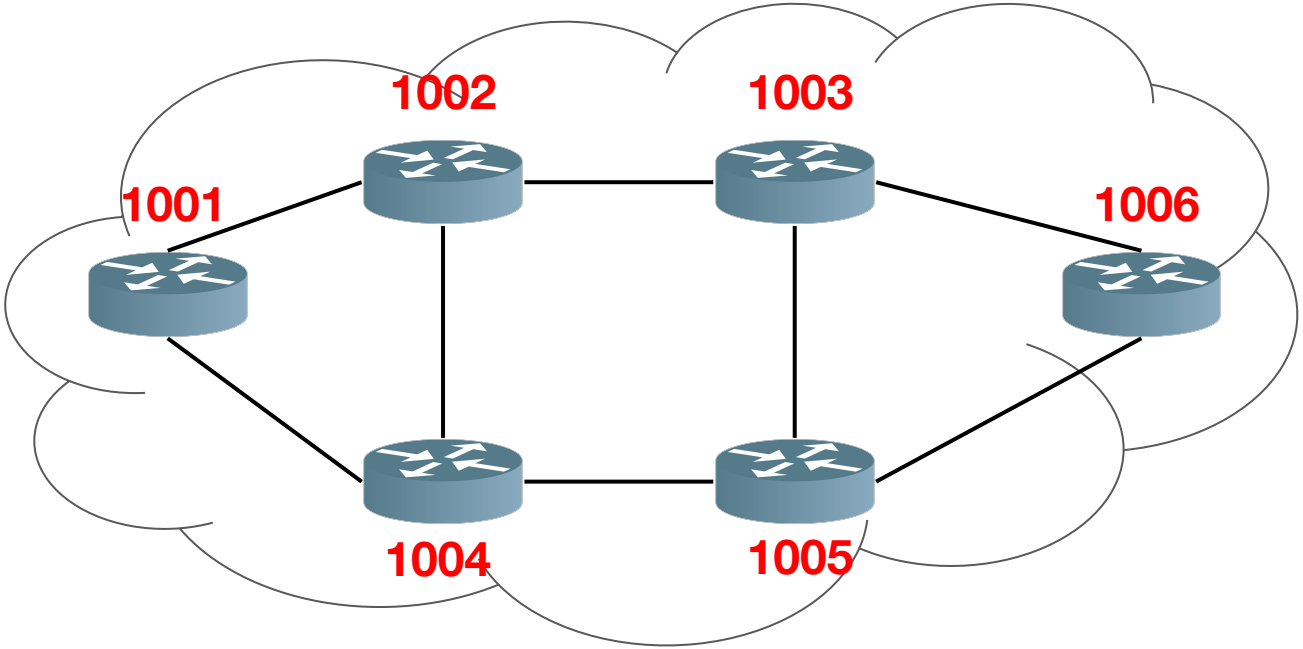
- Segment Routing (SR) leverages the source routing paradigm
- A node steers a packet through an ordered list of instructions, called segments
- A segment can represent any instruction, topological or service-based
- A segment can have a semantic:
  - local to an SR node
  - global within an SR domain
- 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



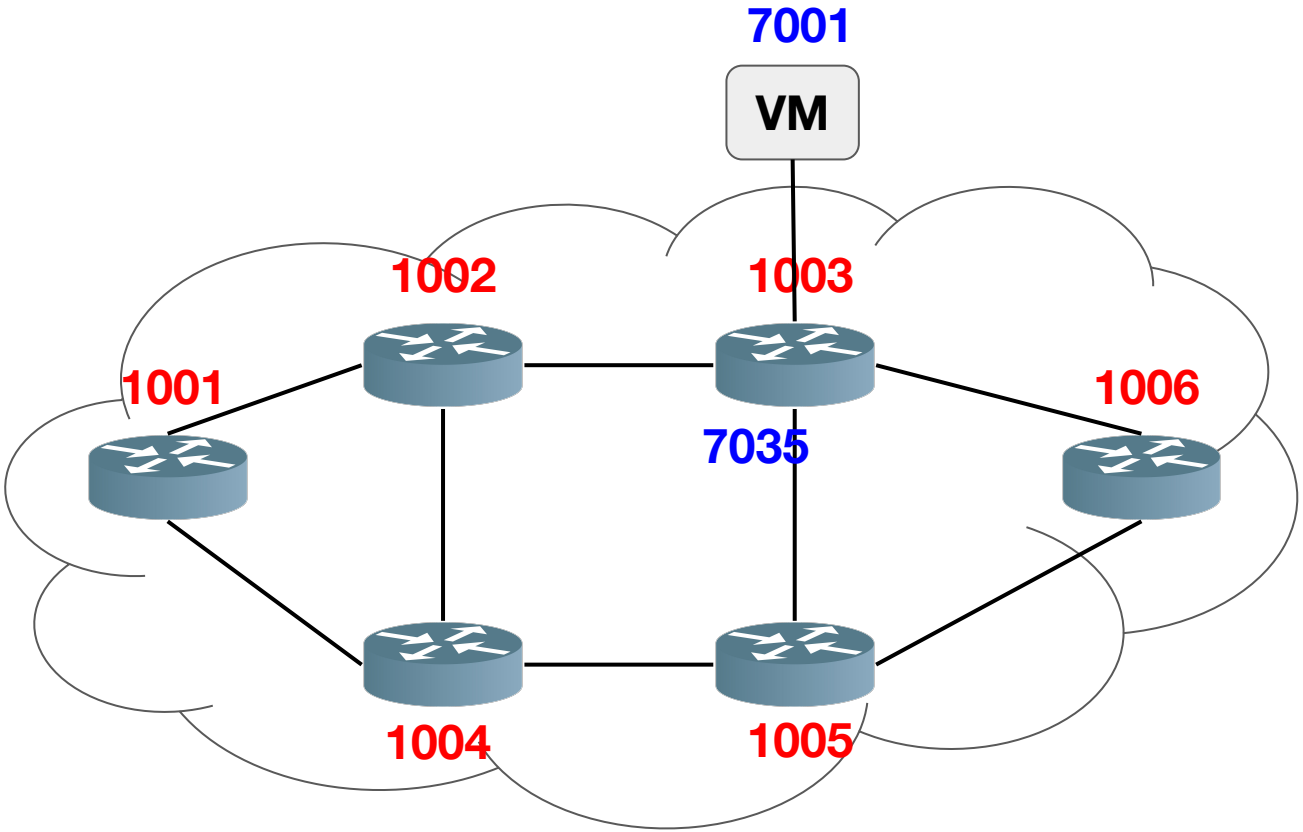
SR idea

SAPIENZA
UNIVERSITÀ DI ROMA



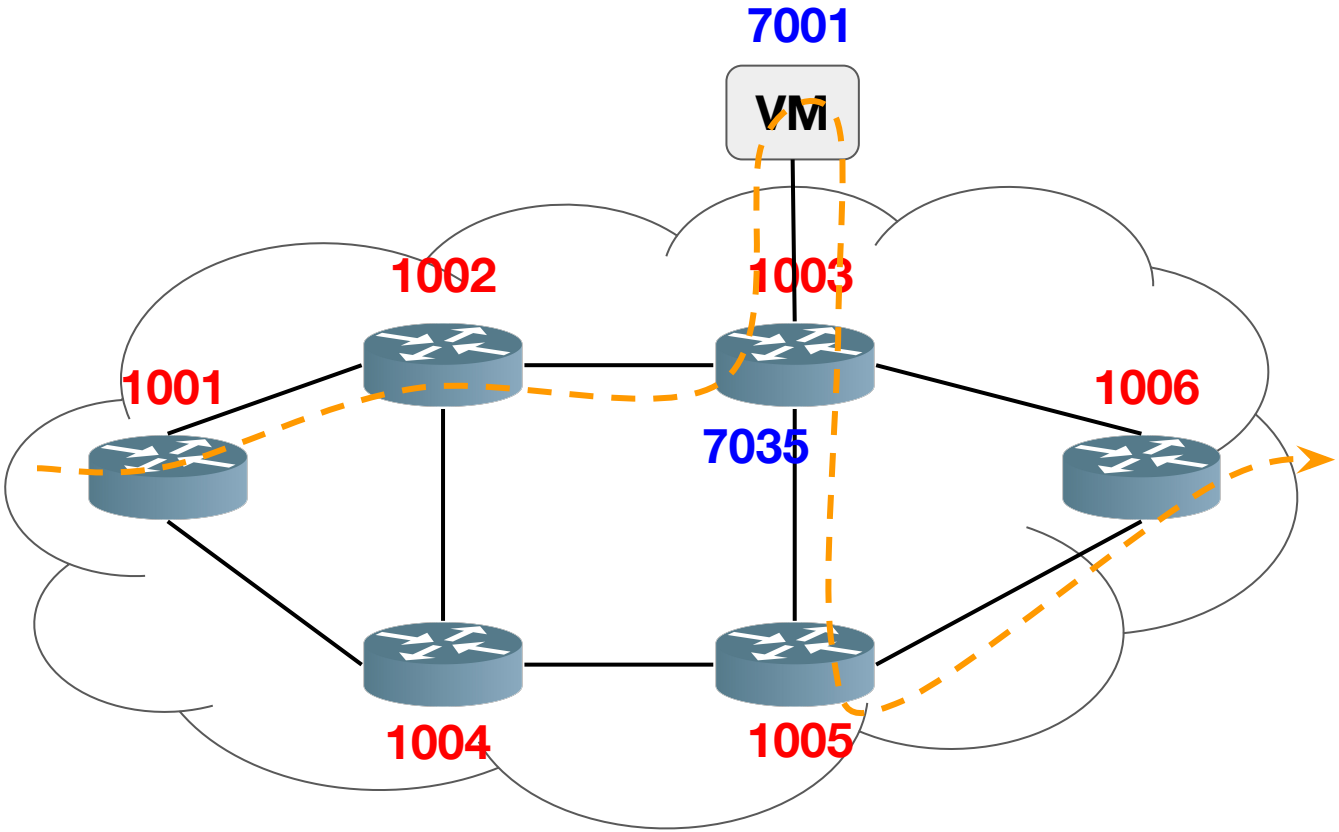
SR idea

SAPIENZA
UNIVERSITÀ DI ROMA

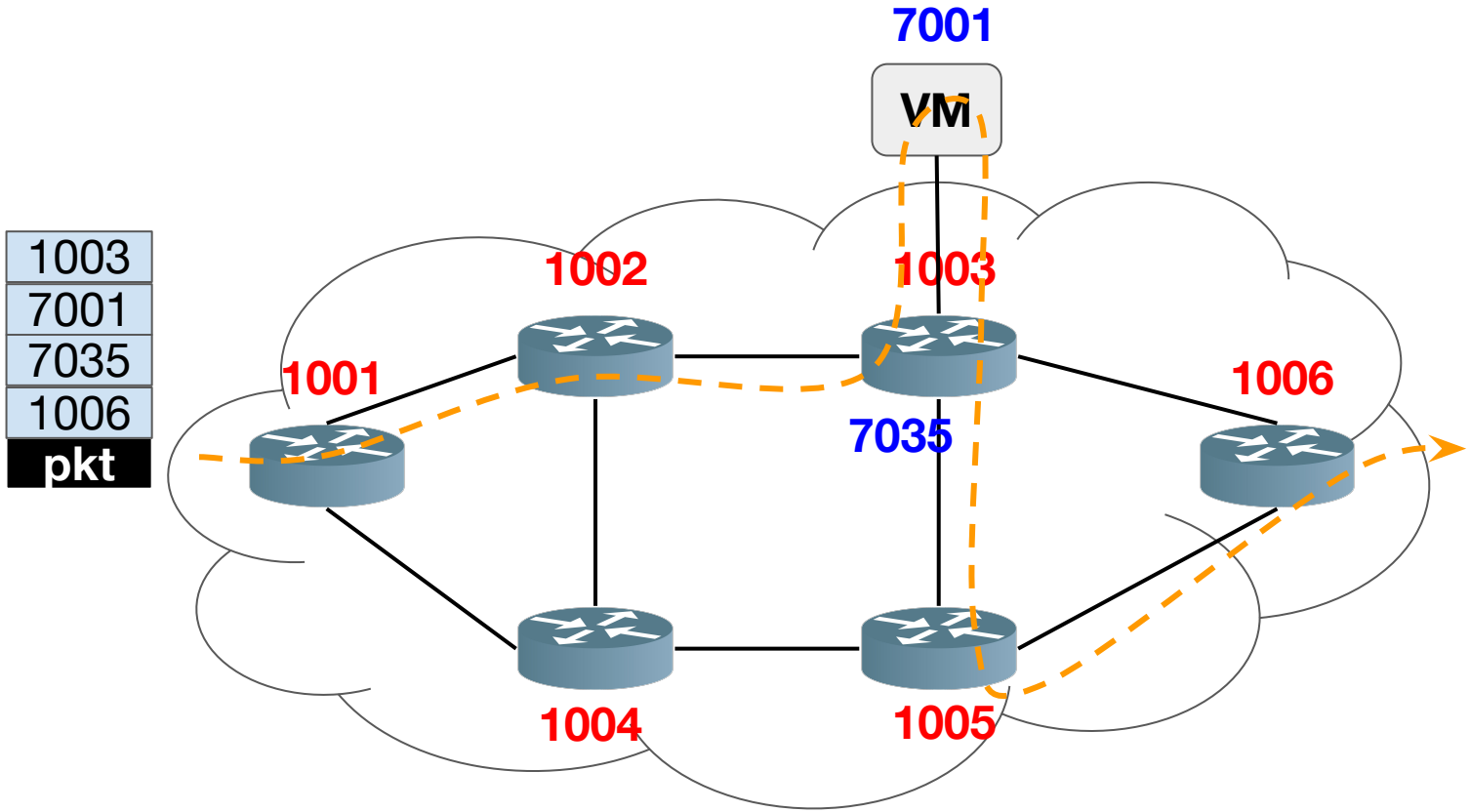


SR idea

SAPIENZA
UNIVERSITÀ DI ROMA



SR idea


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

SR control plane

SAPIENZA
UNIVERSITÀ DI ROMA

- 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

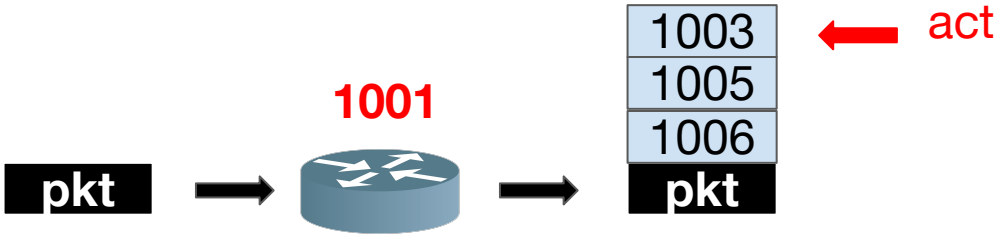
SAPIENZA
UNIVERSITÀ DI ROMA

- 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

SAPIENZA
UNIVERSITÀ DI ROMA

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

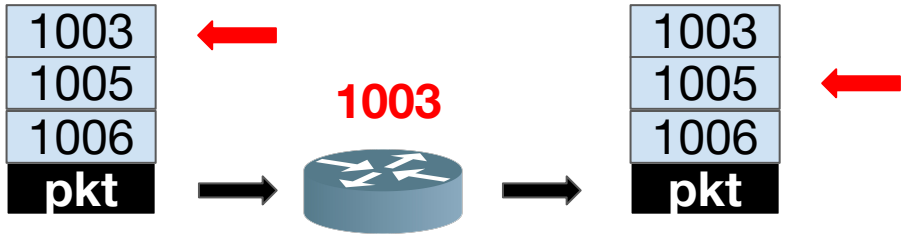


- Three different operations:
  - PUSH: the instruction consisting of the insertion of a segment at the top of the segment list

SR forwarding

SAPIENZA
UNIVERSITÀ DI ROMA

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

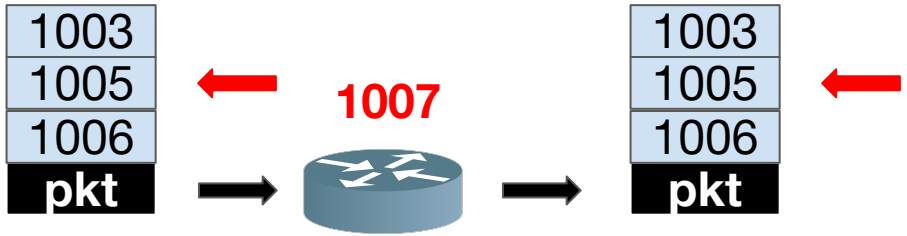


- Three different operations:
  - PUSH: the instruction consisting of the insertion of a segment at the top of the segment list
  - NEXT: when the active segment is completed, NEXT is the instruction consisting of the inspection of the next segment

SR forwarding

SAPIENZA
UNIVERSITÀ DI ROMA

- 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
  - 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

SAPIENZA
UNIVERSITÀ DI ROMA

- **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

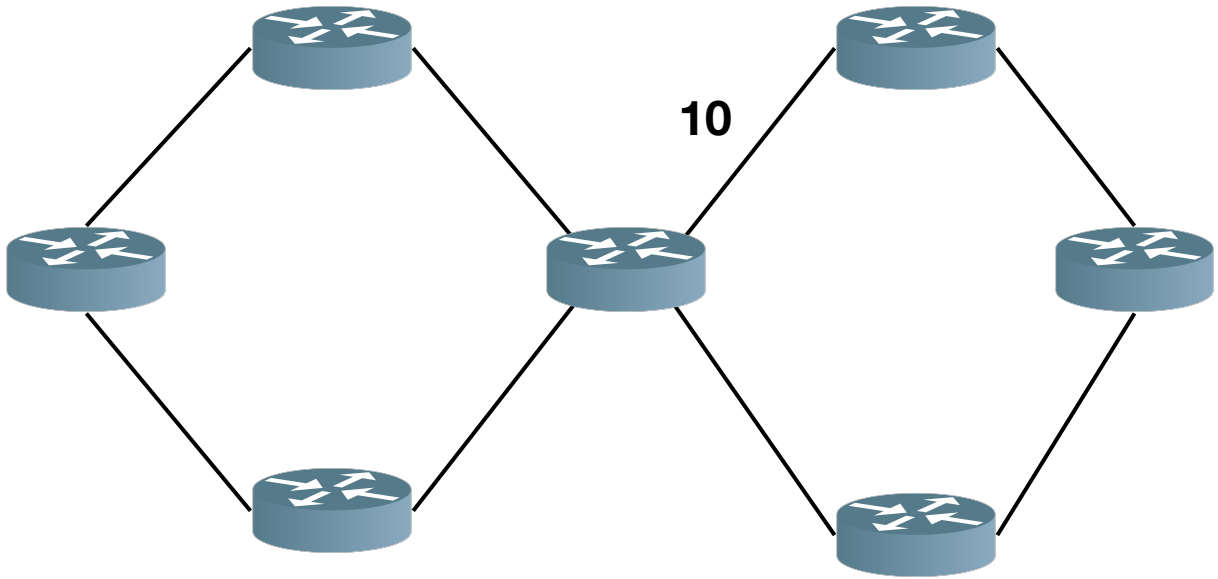
Type of segments

SAPIENZA UNIVERSITÀ DI ROMA

- 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)

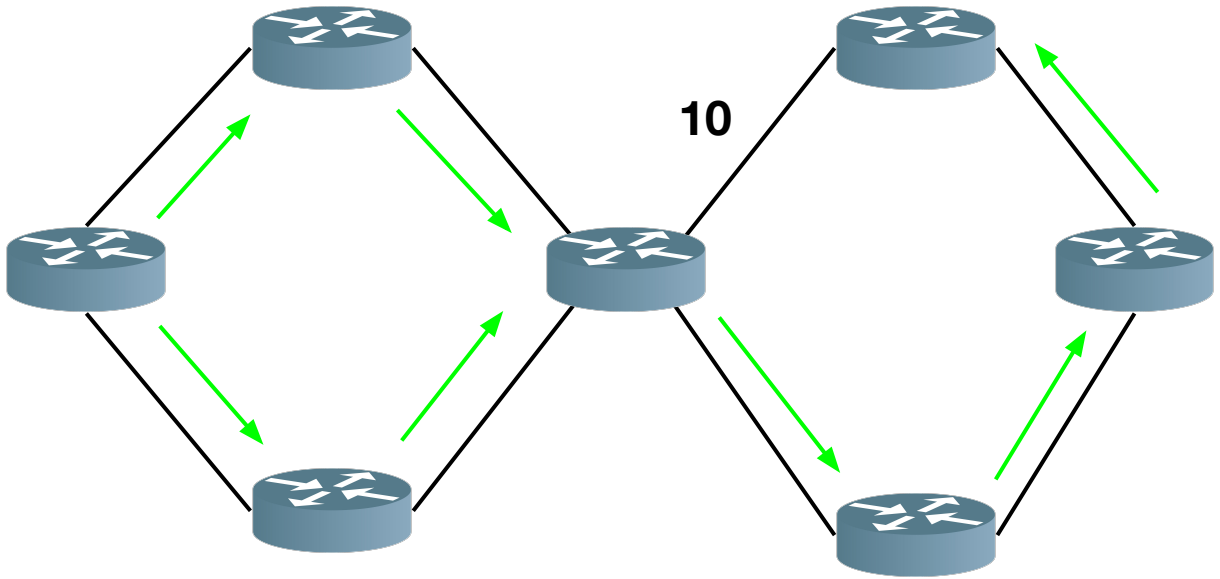
Type of segments: some examples

SAPIENZA
UNIVERSITÀ DI ROMA



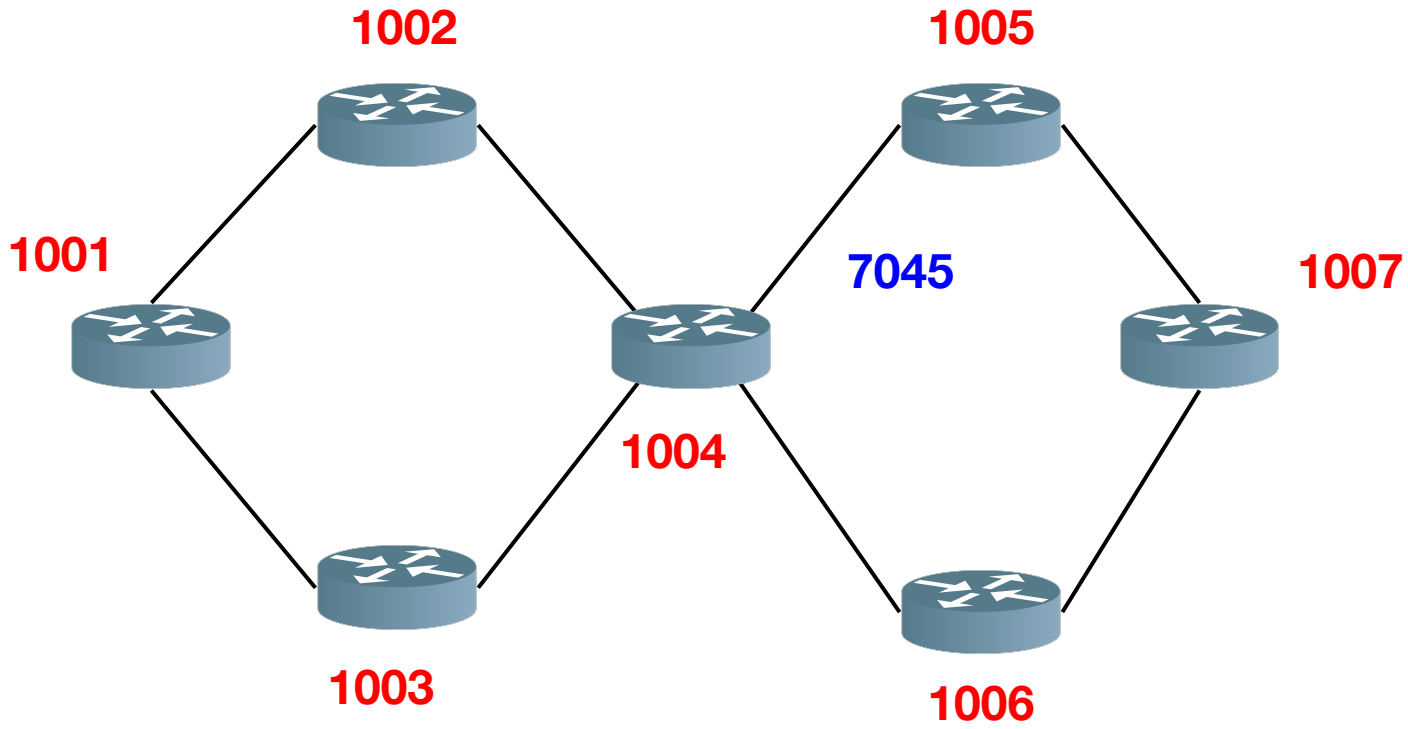
Type of segments: some examples

SAPIENZA
UNIVERSITÀ DI ROMA



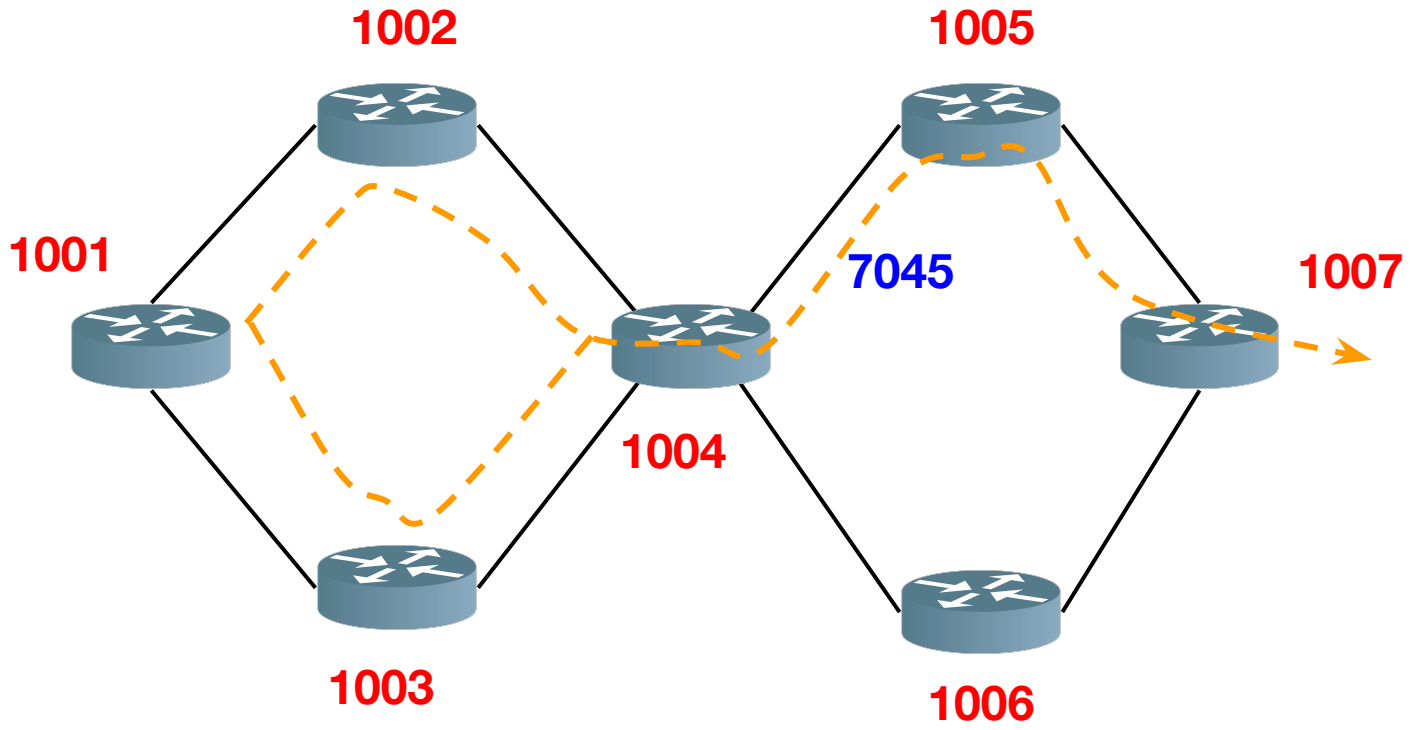
Type of segments: some examples

SAPIENZA
UNIVERSITÀ DI ROMA



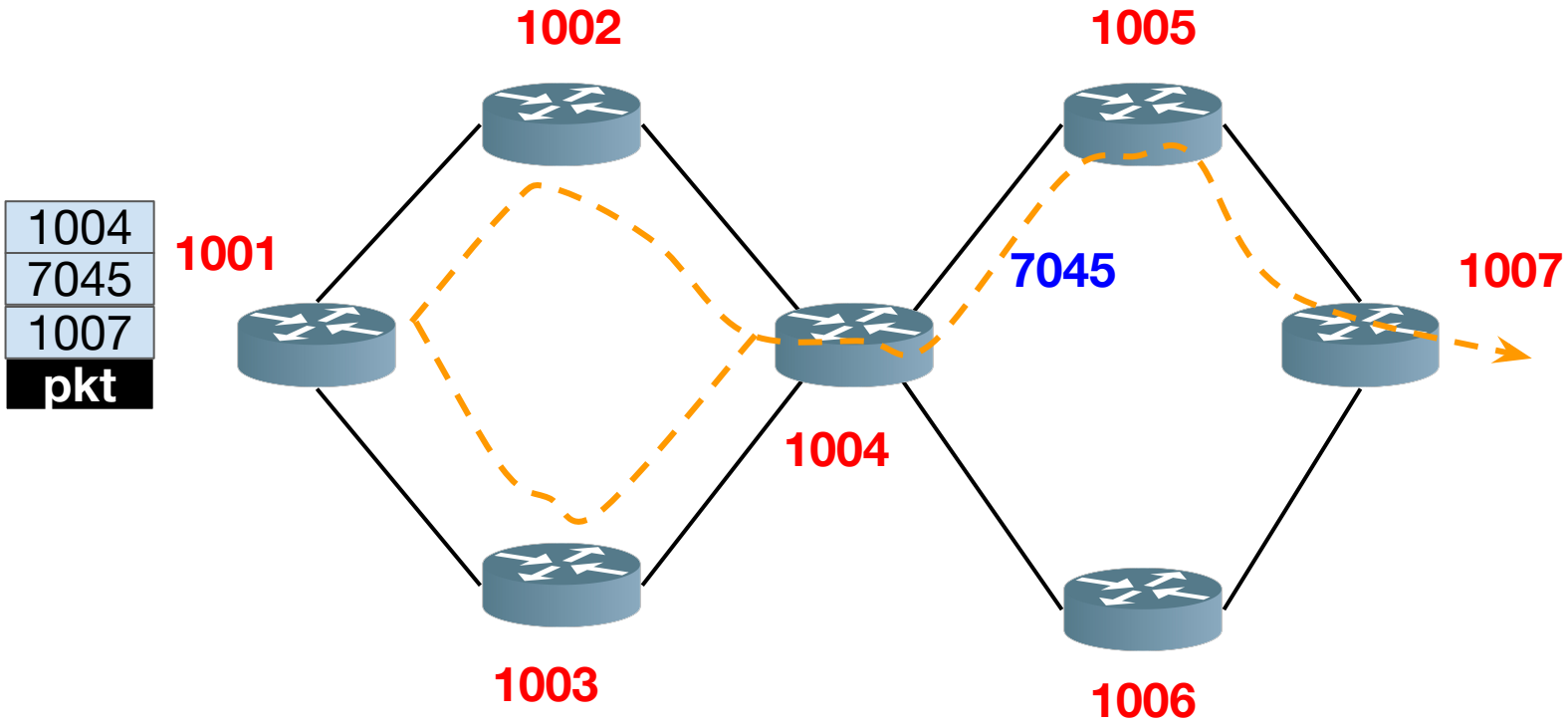
Type of segments: some examples

SAPIENZA
UNIVERSITÀ DI ROMA



Type of segments: some examples

SAPIENZA
UNIVERSITÀ DI ROMA



Outline

SAPIENZA
UNIVERSITÀ DI ROMA

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

SR Policy

SAPIENZA
UNIVERSITÀ DI ROMA

- 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

SAPIENZA
UNIVERSITÀ DI ROMA

- 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

SAPIENZA
UNIVERSITÀ DI ROMA

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

SAPIENZA
UNIVERSITÀ DI ROMA

- 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

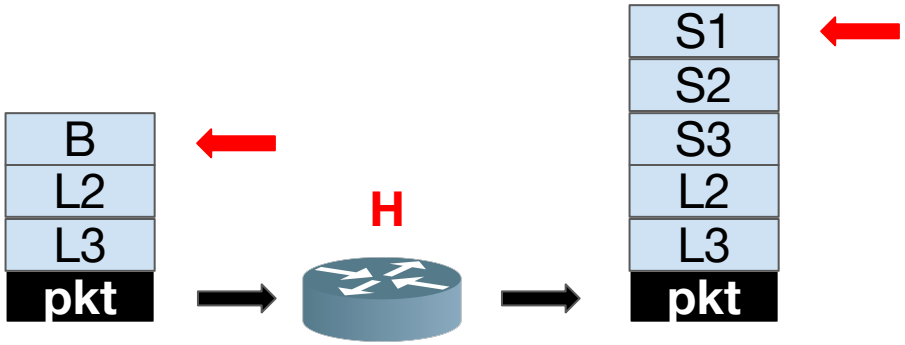
SAPIENZA
UNIVERSITÀ DI ROMA

- A dynamic candidate path is specified as an optimization objective and constraints
  - eg. minimize delay avoiding link I
- 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

SAPIENZA
UNIVERSITÀ DI ROMA

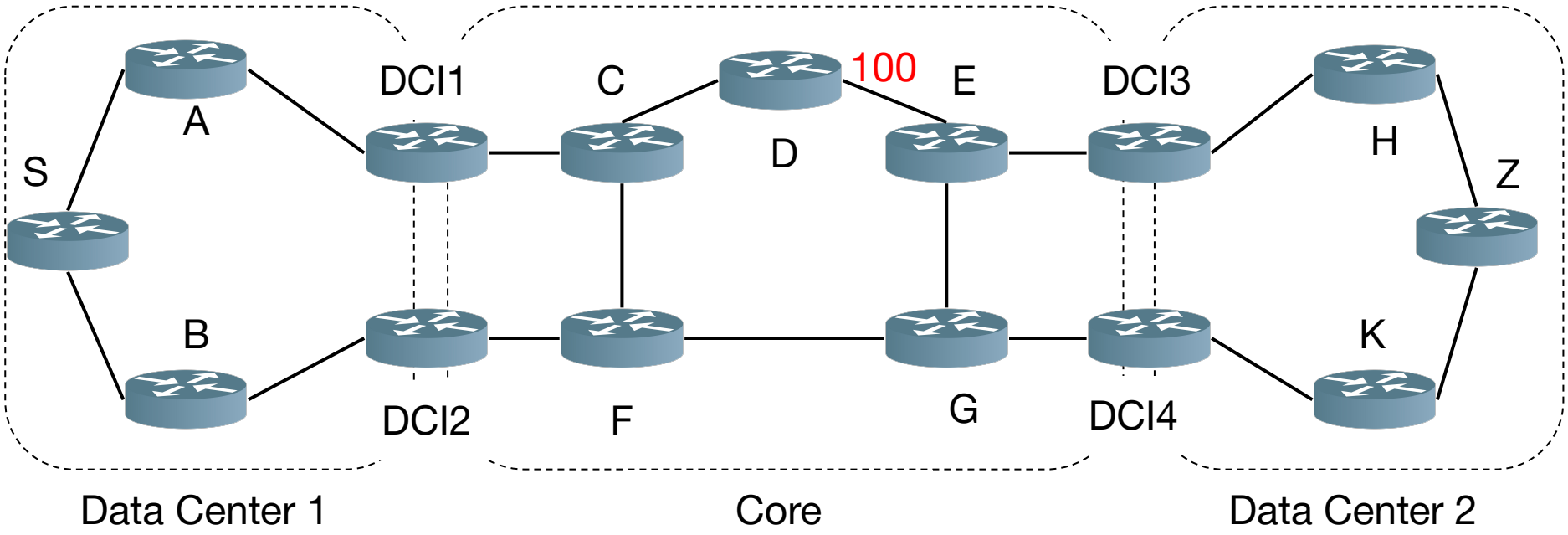
- An SR Policy installs a **BSID** entry in the forwarding plane with the action of steering the packets matching this entry to the selected path
- Let us assume that headend **H** has a valid SR Policy **P** of SID-List **<S1, S2, S3>** and BSID **B**



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

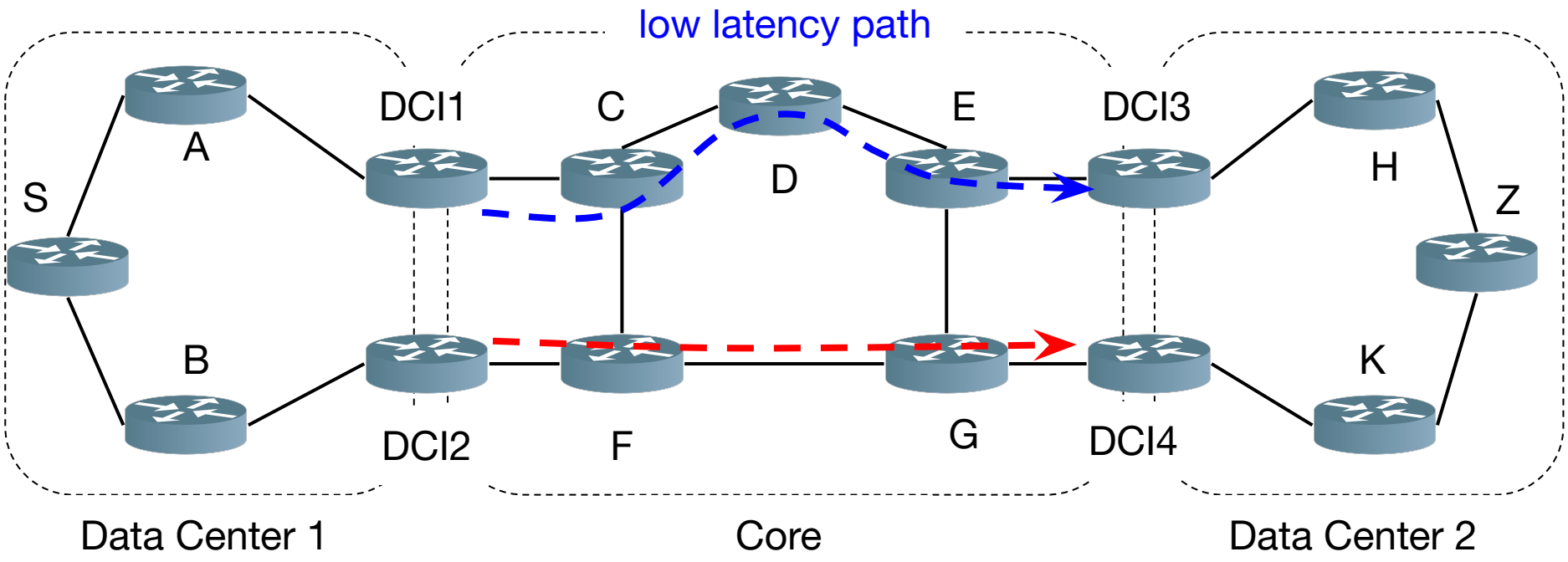
SRTE Policy: an example

SAPIENZA
UNIVERSITÀ DI ROMA



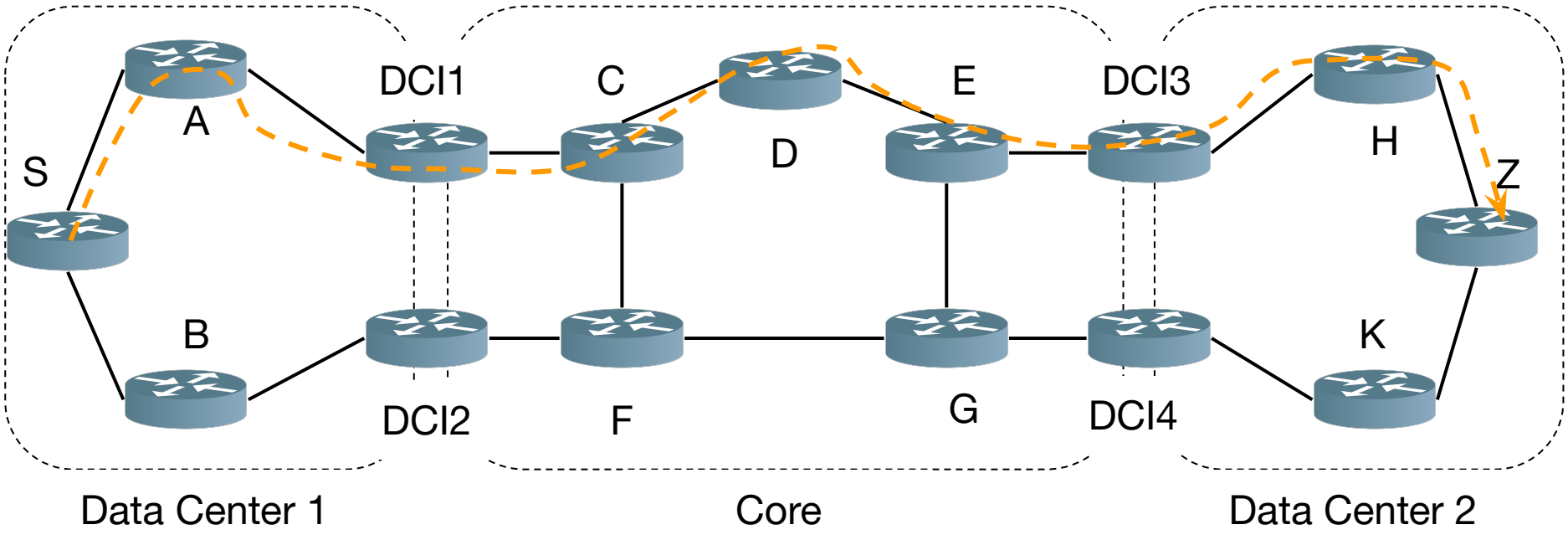
SRTE Policy: an example

SAPIENZA
UNIVERSITÀ DI ROMA



SRTE Policy: an example

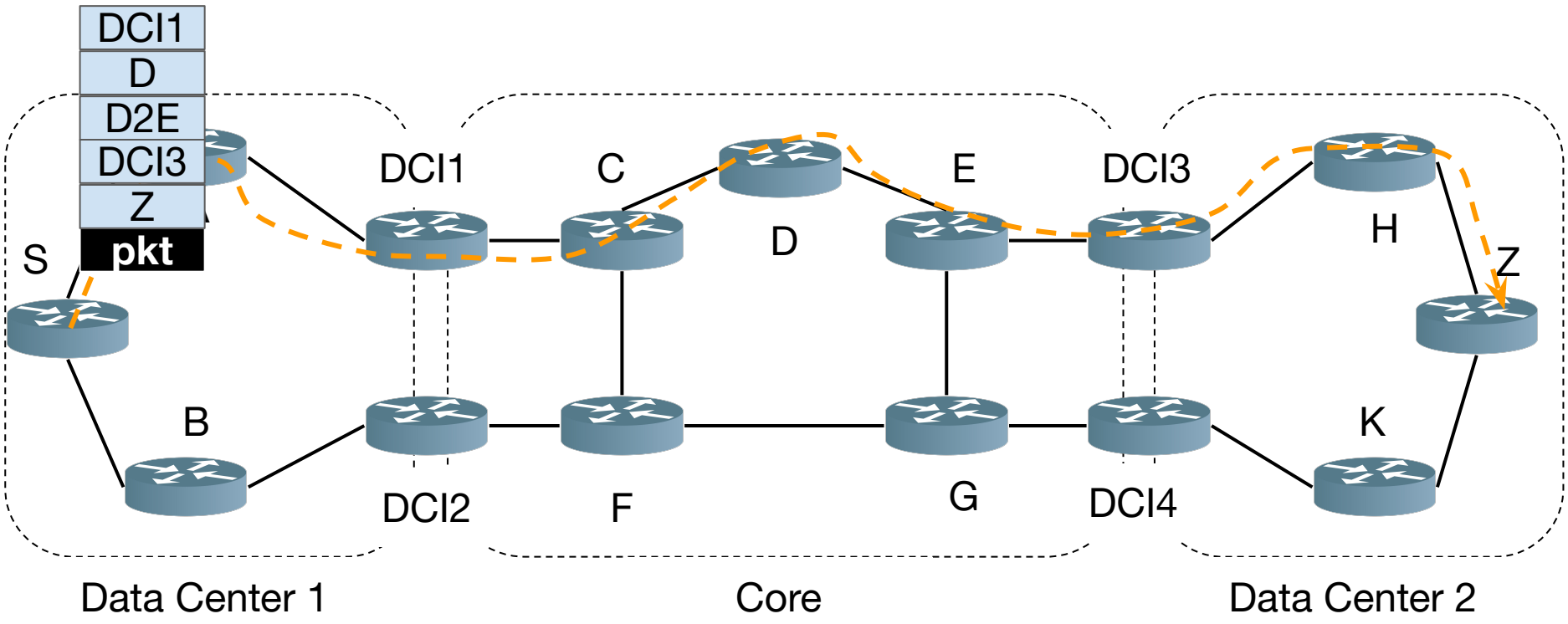
SAPIENZA
UNIVERSITÀ DI ROMA



SRTE Policy: an example

SAPIENZA
UNIVERSITÀ DI ROMA

option 1

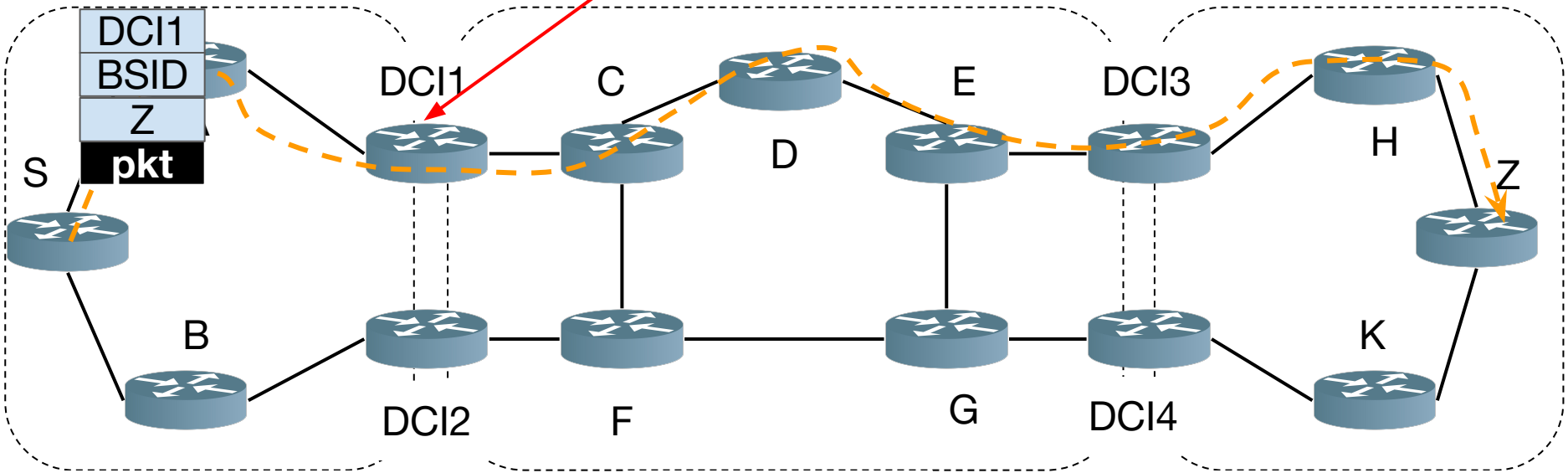


SRTE Policy: an example

SAPIENZA
UNIVERSITÀ DI ROMA

option 2

install BSID: <D,D2E,DCI3>
advertise BSID in data center 1 as “low latency policy”



Outline

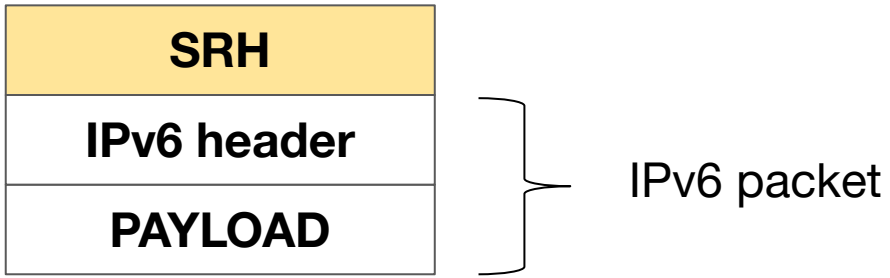
SAPIENZA
UNIVERSITÀ DI ROMA

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

SRH instantiation

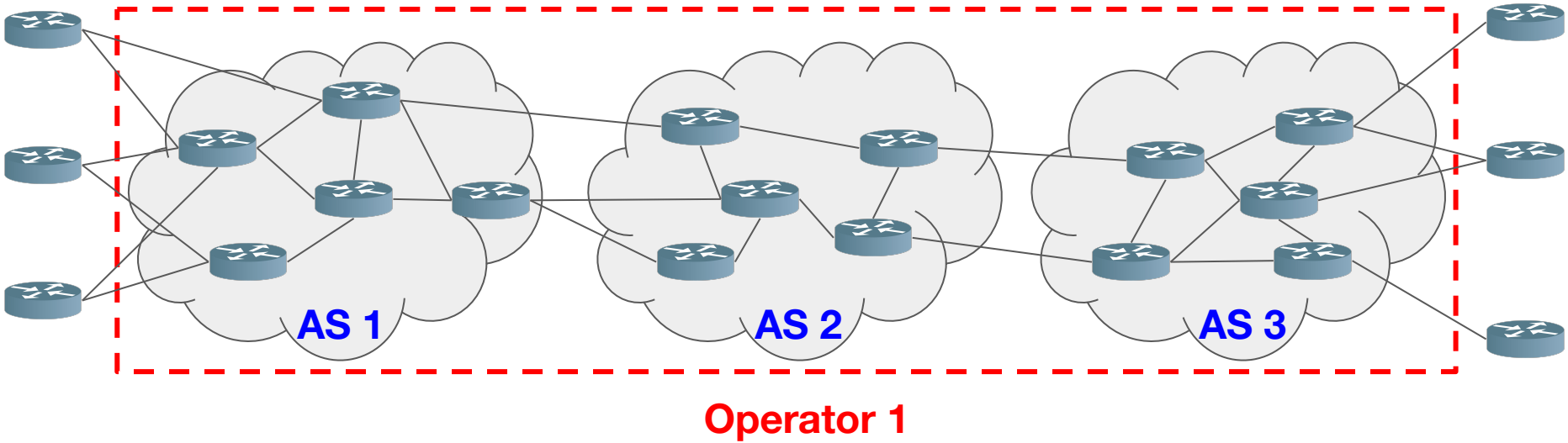
SAPIENZA UNIVERSITÀ DI ROMA

- 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

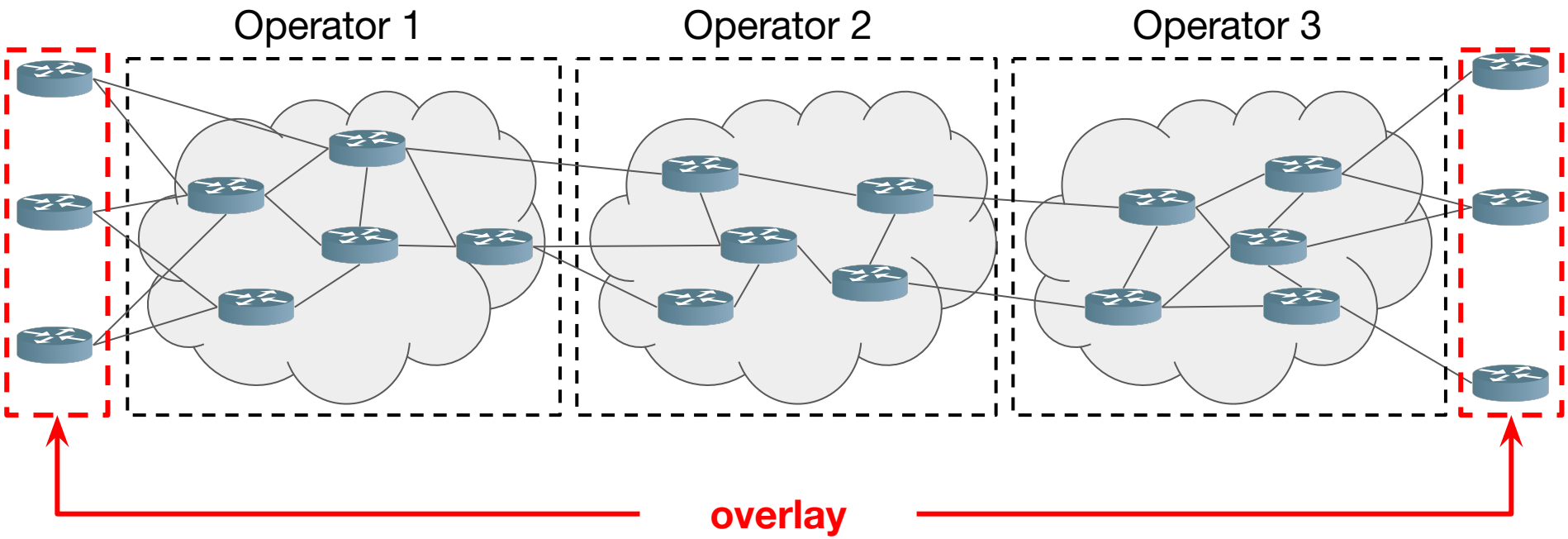
SAPIENZA UNIVERSITÀ DI ROMA



- 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

SAPIENZA
UNIVERSITÀ DI ROMA

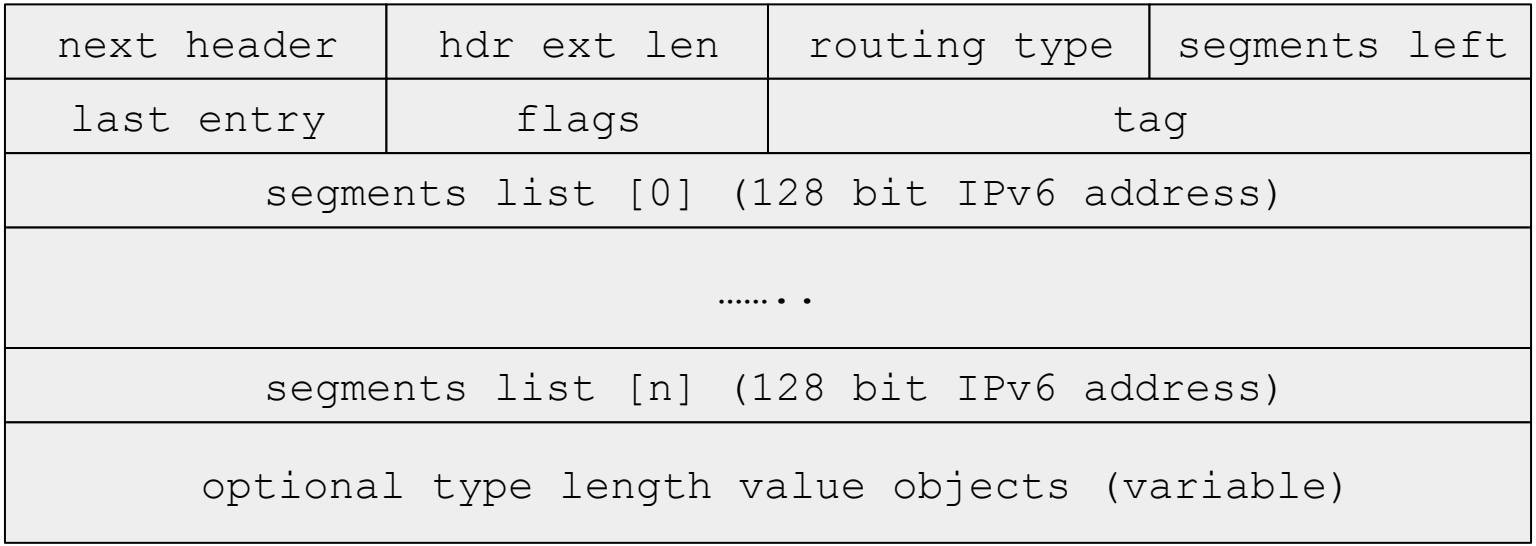


- The SRH originated by the overlay can only contain address/segment under the administration of the overlay

Segment Routing Extension Header (SRH)

SAPIENZA UNIVERSITÀ DI ROMA

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



Segment Routing Extension Header (SRH)

SAPIENZA UNIVERSITÀ DI ROMA

- **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

SAPIENZA
UNIVERSITÀ DI ROMA

- 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

SAPIENZA
UNIVERSITÀ DI ROMA

- 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

SAPIENZA
UNIVERSITÀ DI ROMA

- 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

SAPIENZA
UNIVERSITÀ DI ROMA

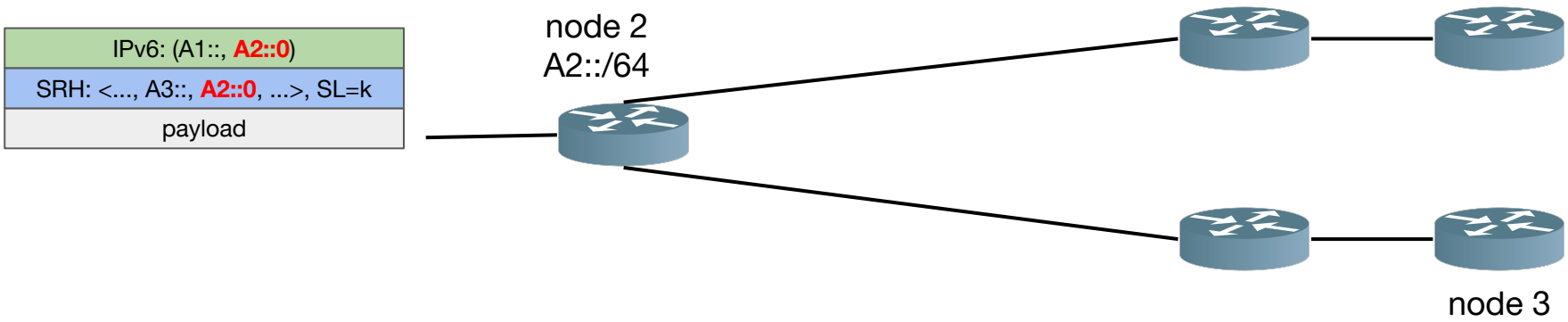
- Segment Routing architecture defines a segment as an instruction or, more generally, a set of instructions (function)
- Two SRv6 basic functions are:
  - **End**
    - the endpoint (End) function is the base of the source routing paradigm
    - it consists of updating the DA with the next segment and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

Endpoint Function (End)

SAPIENZA UNIVERSITÀ DI ROMA

- 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

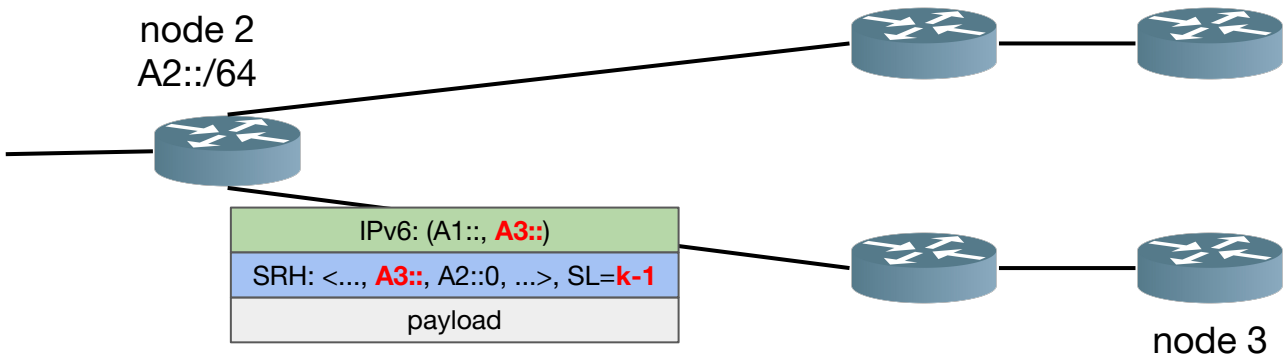


Endpoint Function (End)

SAPIENZA UNIVERSITÀ DI ROMA

- 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

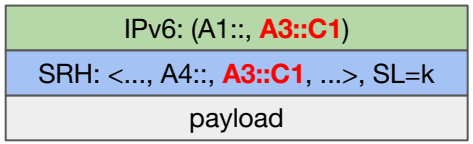


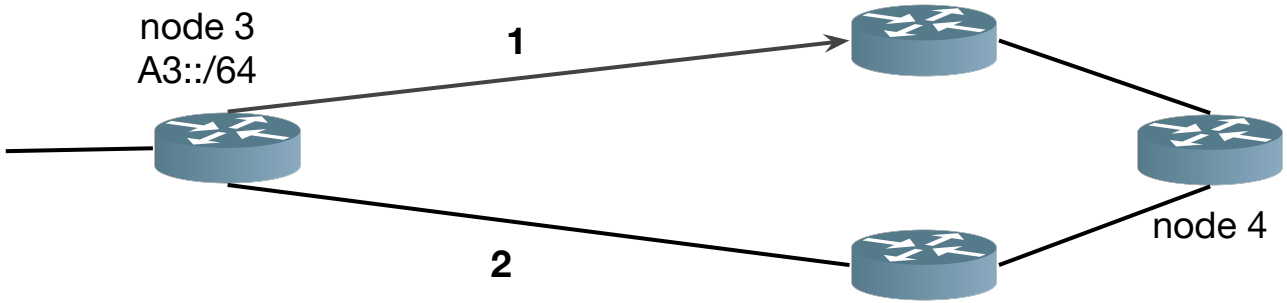
Endpoint with Layer-3 cross-connect (End.X)

SAPIENZA UNIVERSITÀ DI ROMA

- 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.X"

1. **IF** SegmentsLeft > 0 **THEN**
2. decrement SL
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



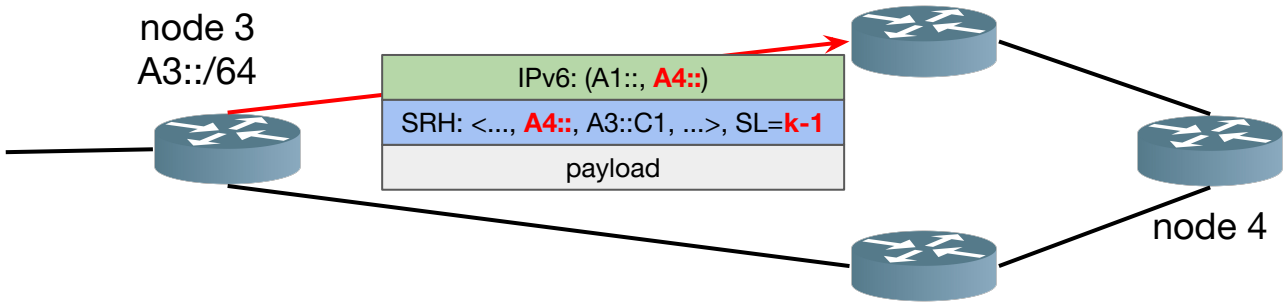


Endpoint with Layer-3 cross-connect (End.X)

SAPIENZA UNIVERSITÀ DI ROMA

- 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.X"

1. **IF** SegmentsLeft > 0 **THEN**
2. decrement SL
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



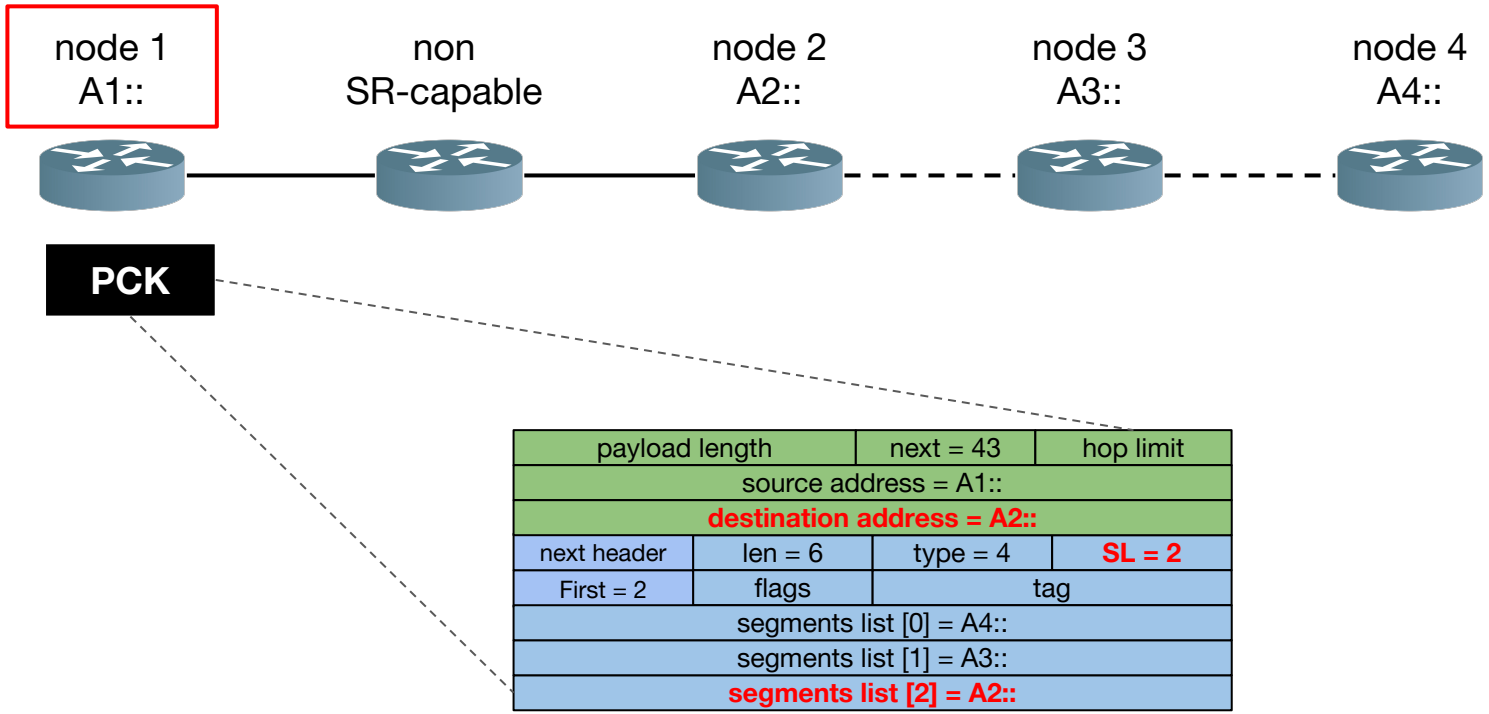
Source Node

SAPIENZA
UNIVERSITÀ DI ROMA

- 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

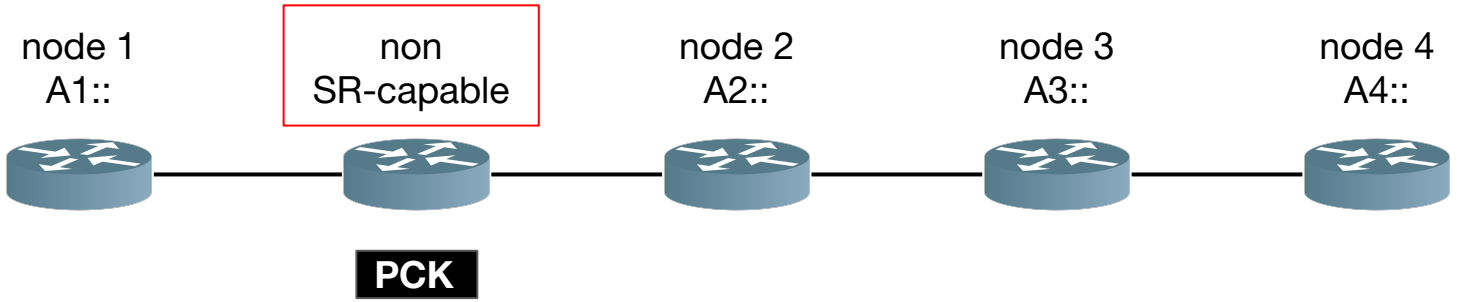
Source Node

SAPIENZA
UNIVERSITÀ DI ROMA



Non-SR Transit Node

SAPIENZA
UNIVERSITÀ DI ROMA



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

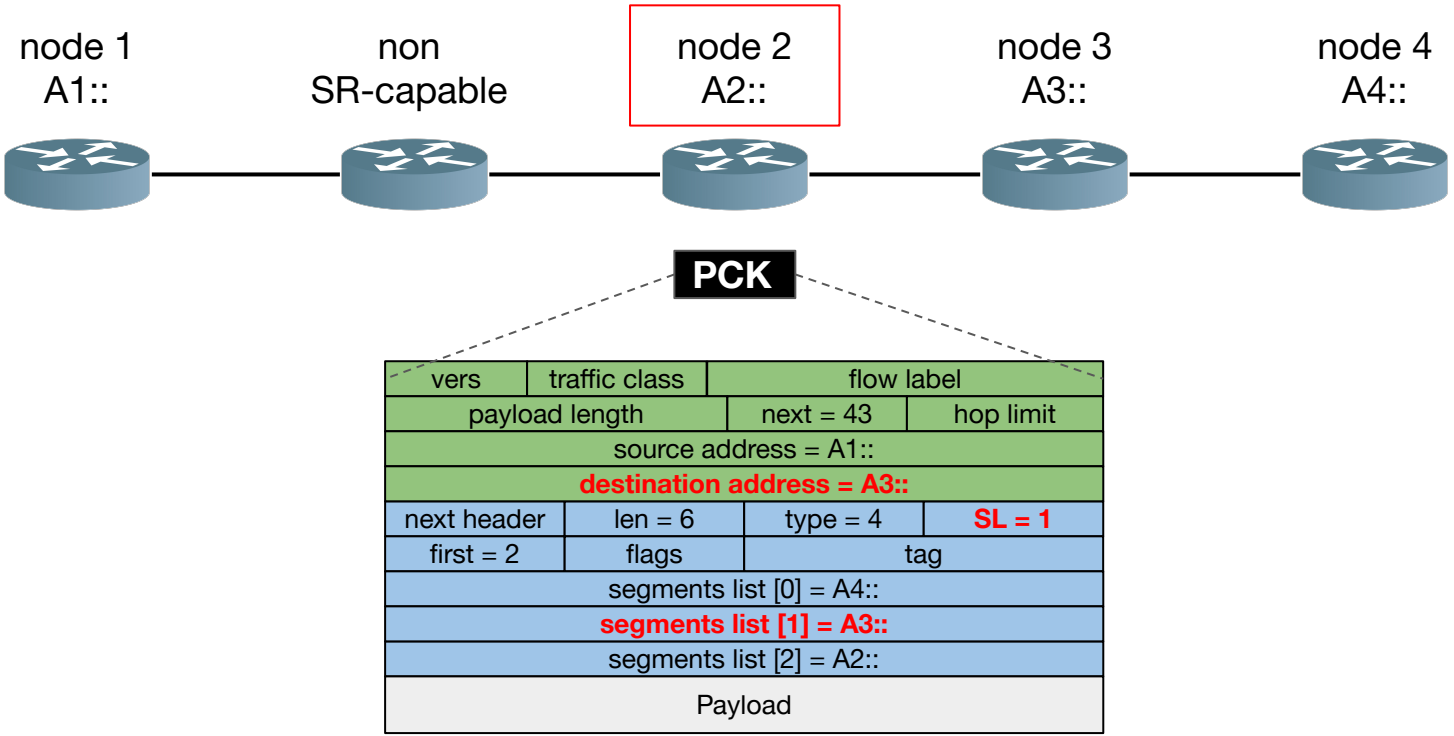
SR Segment Endpoints

SAPIENZA
UNIVERSITÀ DI ROMA

- **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

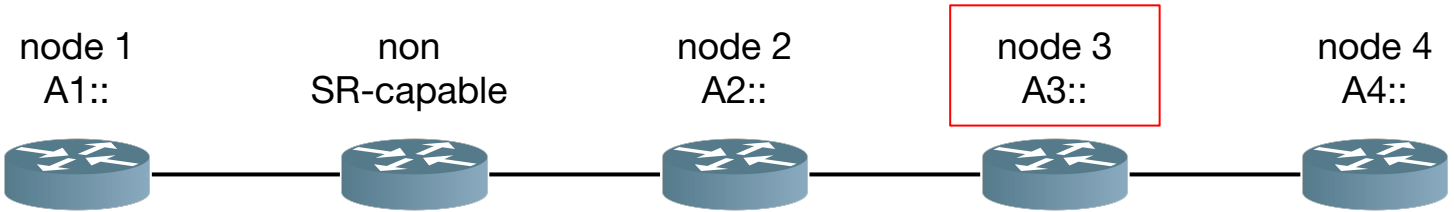
SR Segment Endpoints

SAPIENZA
UNIVERSITÀ DI ROMA



SR Segment Endpoints

SAPIENZA
UNIVERSITÀ DI ROMA



PCK

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			

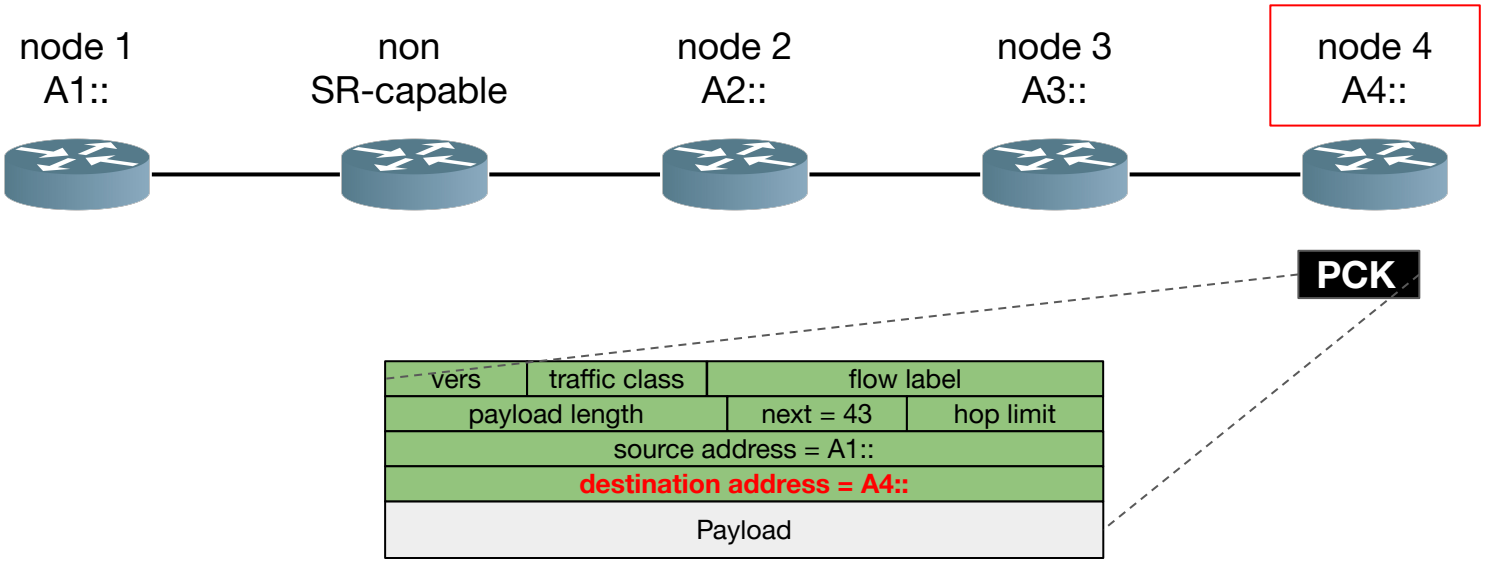
SR Segment Endpoints

SAPIENZA
UNIVERSITÀ DI ROMA

- 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

SAPIENZA
UNIVERSITÀ DI ROMA



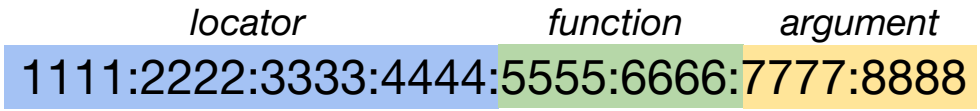
Outline

SAPIENZA
UNIVERSITÀ DI ROMA

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

SRv6 Segment Format

SAPIENZA UNIVERSITÀ DI ROMA



- 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

SAPIENZA
UNIVERSITÀ DI ROMA

- 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

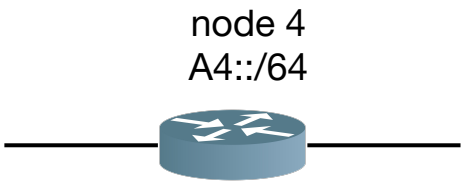
End.B6

SAPIENZA UNIVERSITÀ DI ROMA

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

1. **IF** NH=SRH **and** SL > 0
2. do not decrement SL nor update the IPv6 DA with SRH[SL]
3. insert a new SRH
4. set the IPv6 DA to the first segment of the SRv6 Policy
5. forward according to the first segment of the SRv6 Policy
6. **ELSE**
7. drop the SRH

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



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

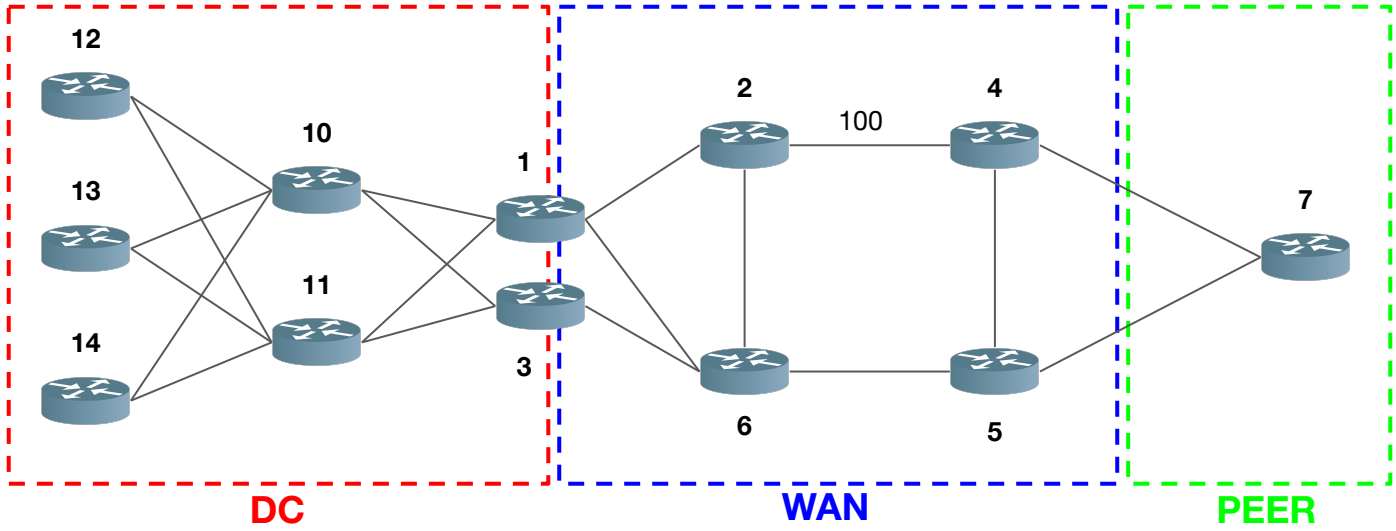
MyLocalSID Table

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

SID allocation for illustration purpose

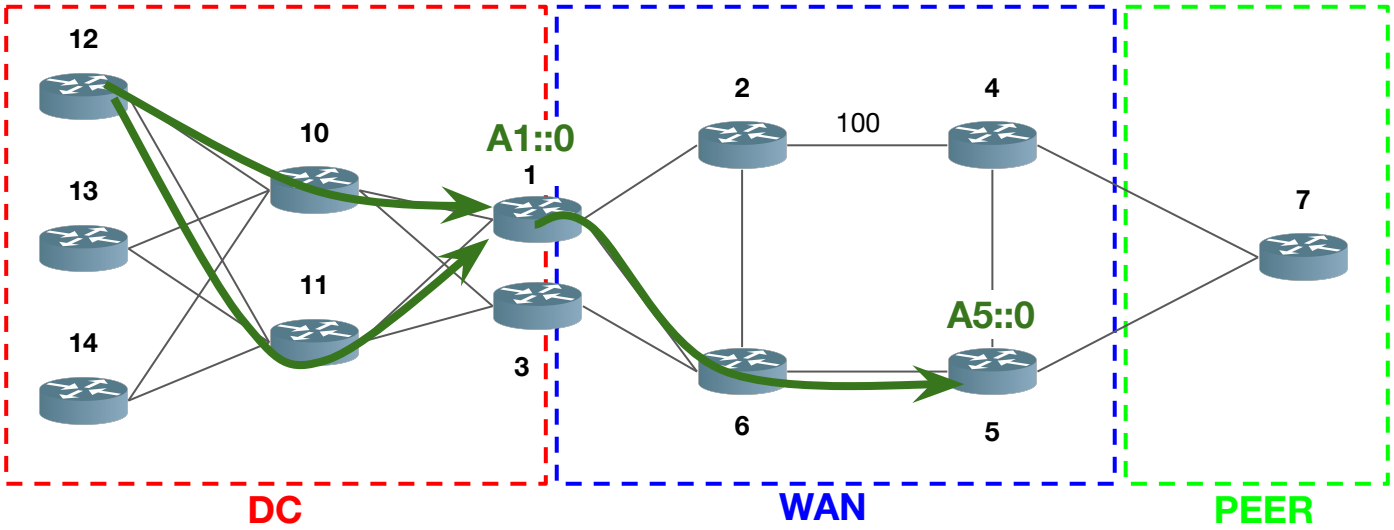
SAPIENZA UNIVERSITÀ DI ROMA

- 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**

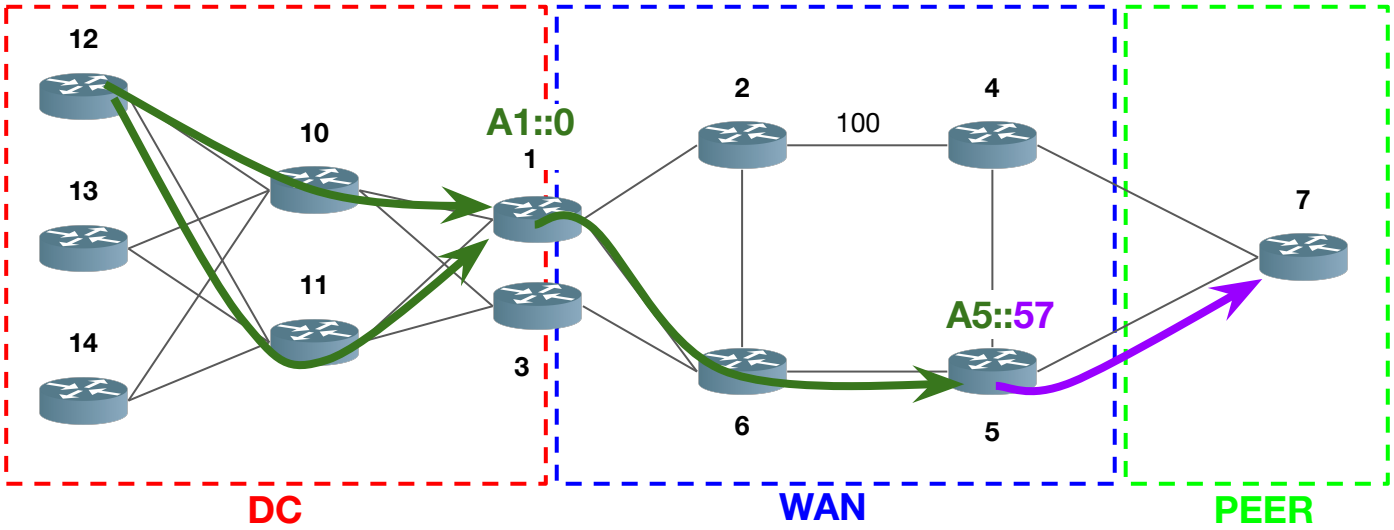


A1::0 and then A5::0

SAPIENZA
UNIVERSITÀ DI ROMA



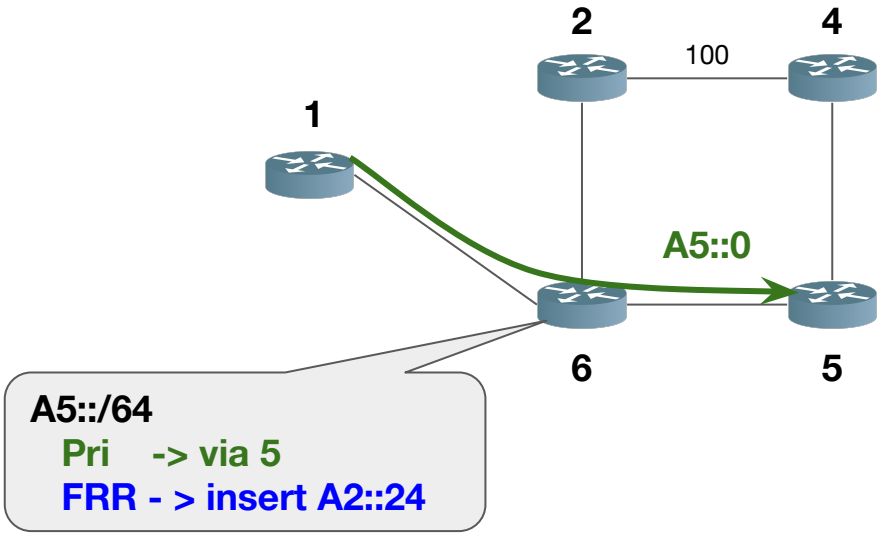
A1::0 and then A5::57



TILFA

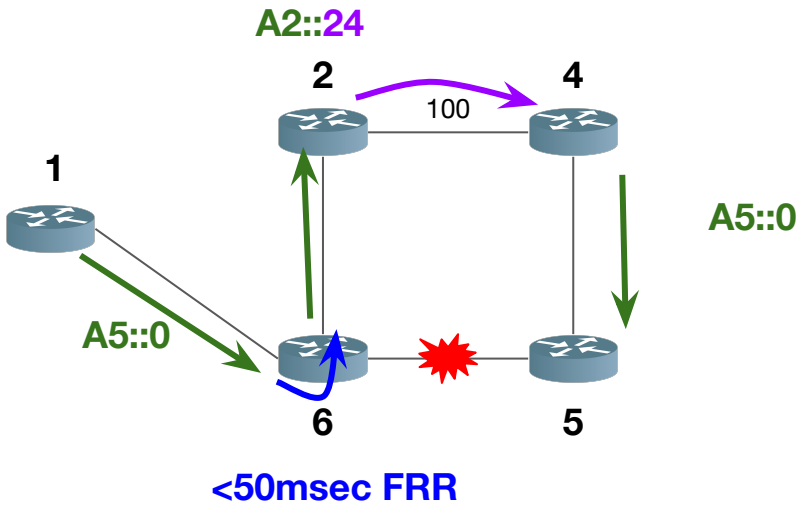
SAPIENZA
UNIVERSITÀ DI ROMA

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

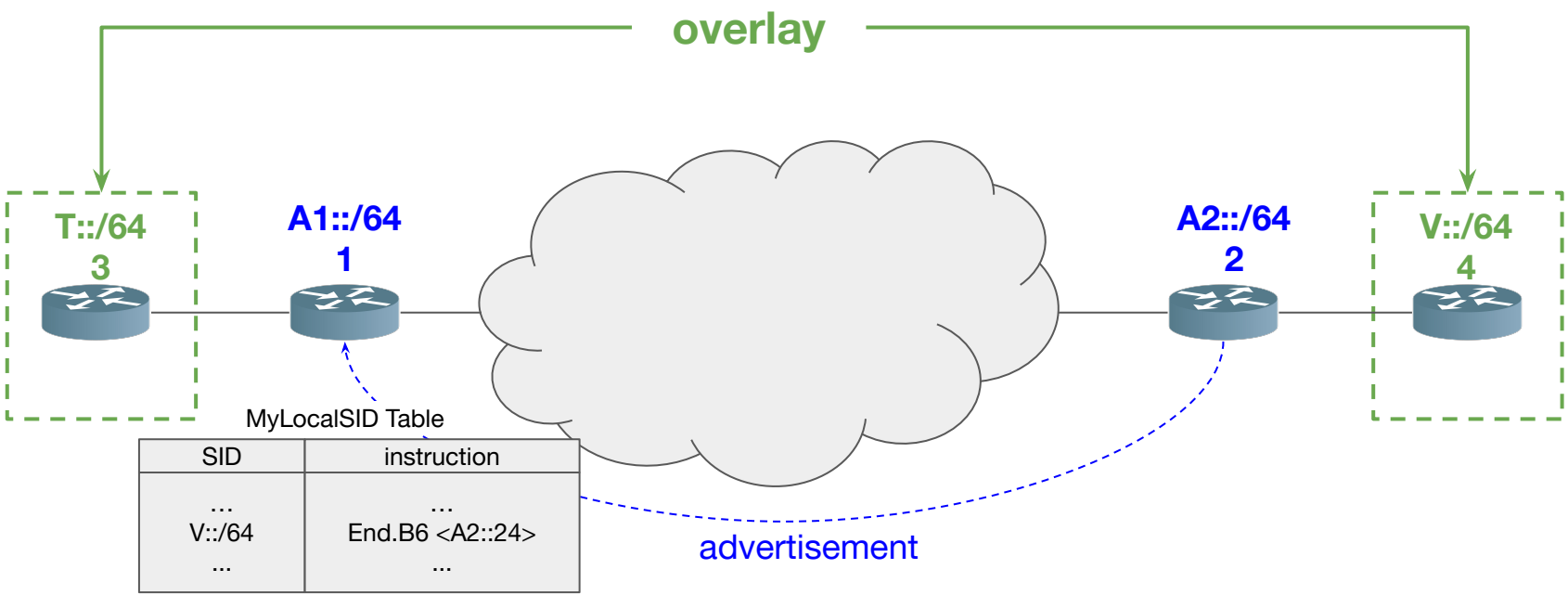


TILFA

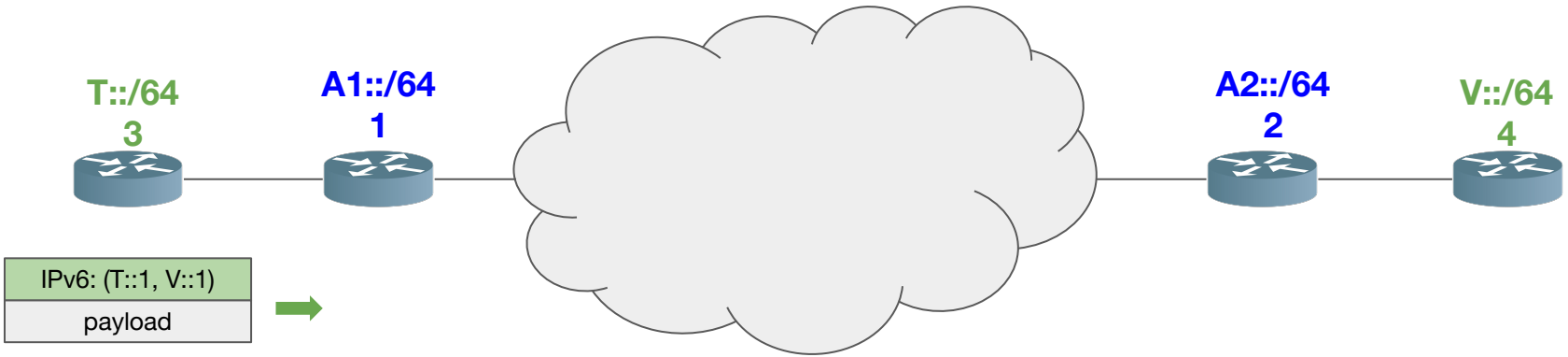
- 50 msec protection upon local link, node or SRLG failure



Overlay

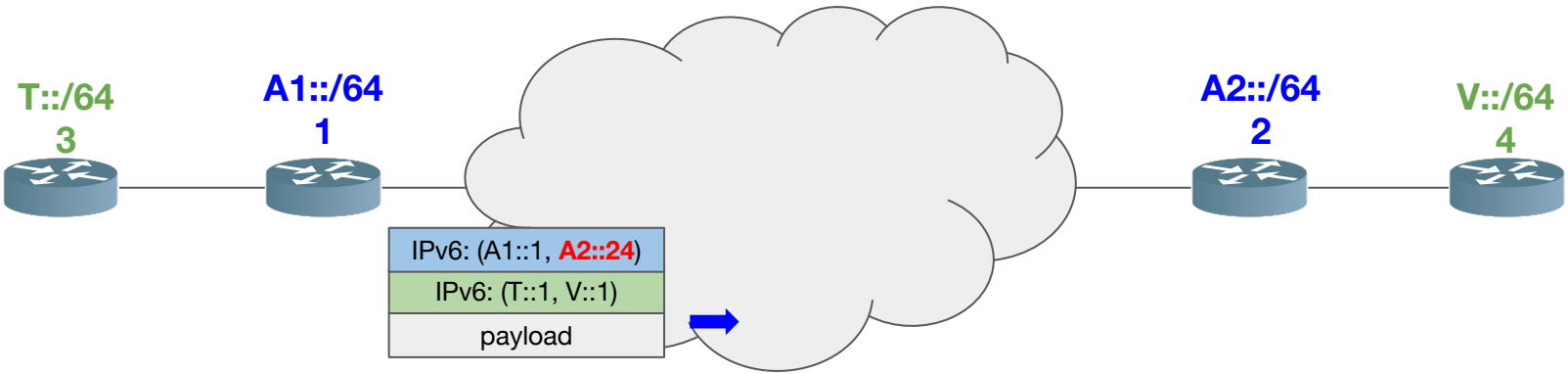

overlay
T::/64
3
A1::/64
1
A2::/64
2
V::/64
4
MyLocalSID Table
SID
instruction
...
V::/64
...
...
End.B6 <A2::24>
...
advertisement

Overlay



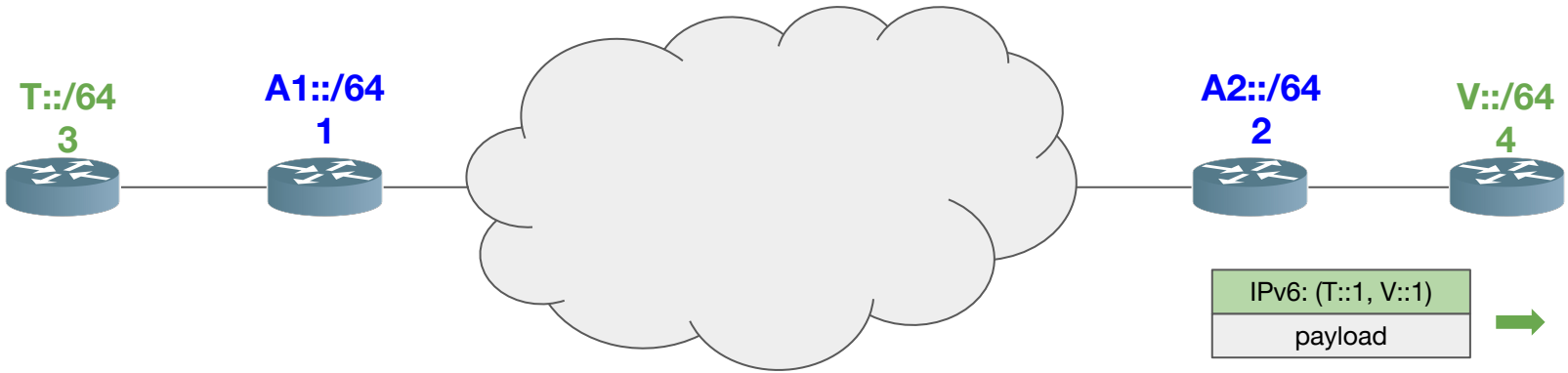
Overlay

SAPIENZA
UNIVERSITÀ DI ROMA



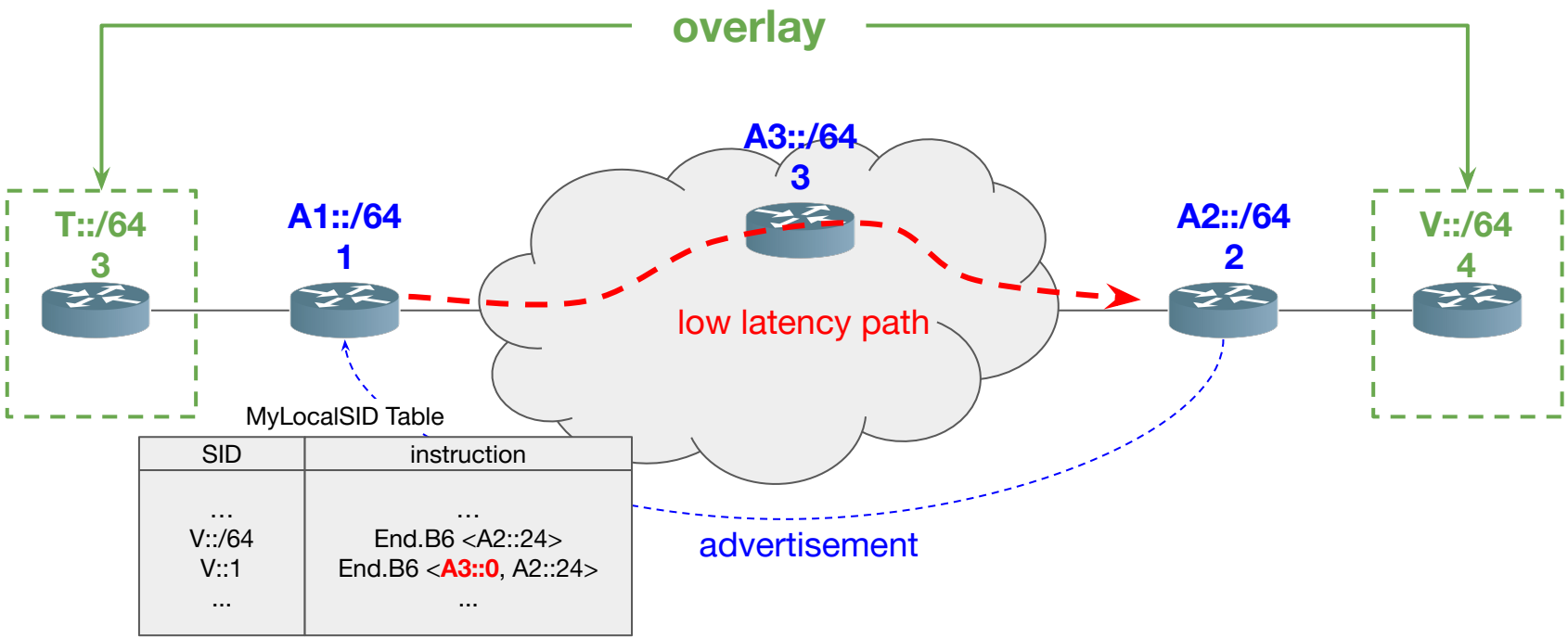
Overlay

SAPIENZA
UNIVERSITÀ DI ROMA



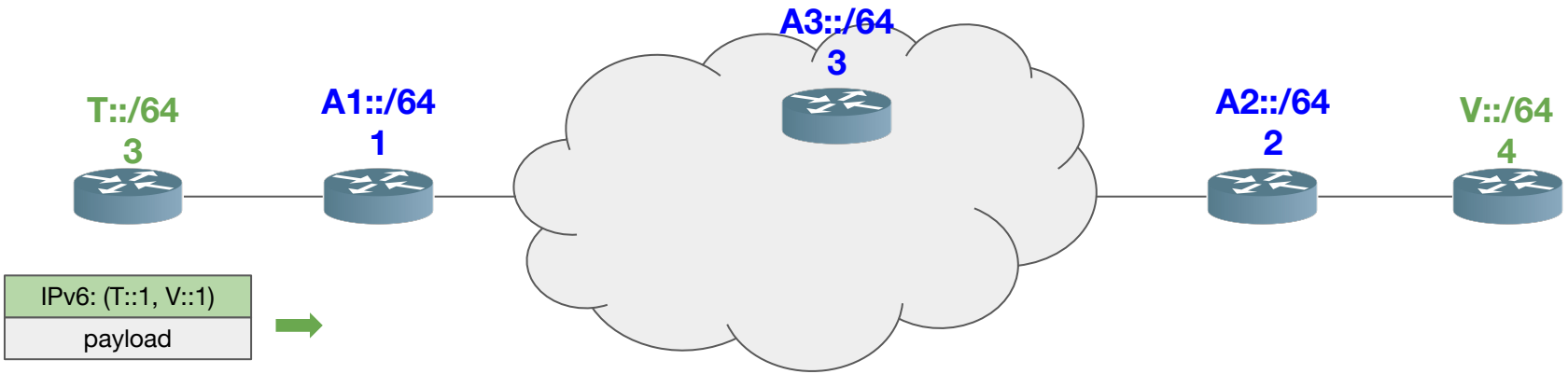
Overlay with underlay SLA

SAPIENZA
UNIVERSITÀ DI ROMA



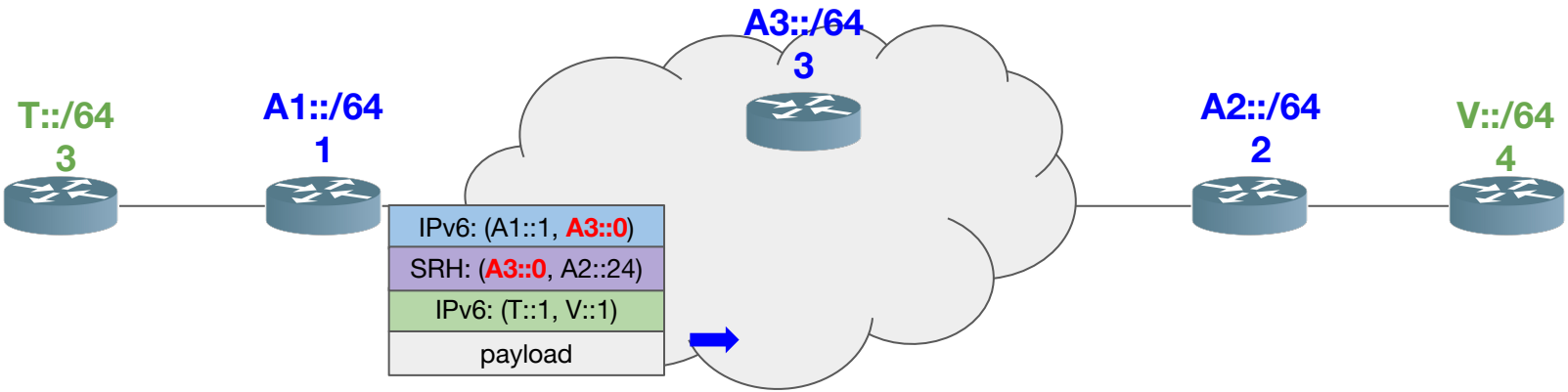
Overlay with underlay SLA

SAPIENZA
UNIVERSITÀ DI ROMA



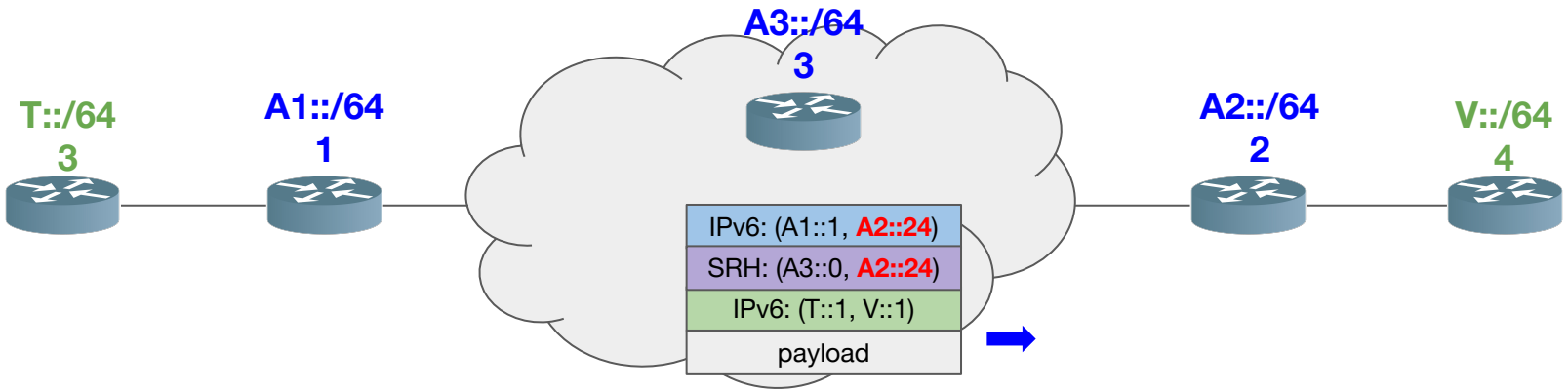
Overlay with underlay SLA

SAPIENZA
UNIVERSITÀ DI ROMA



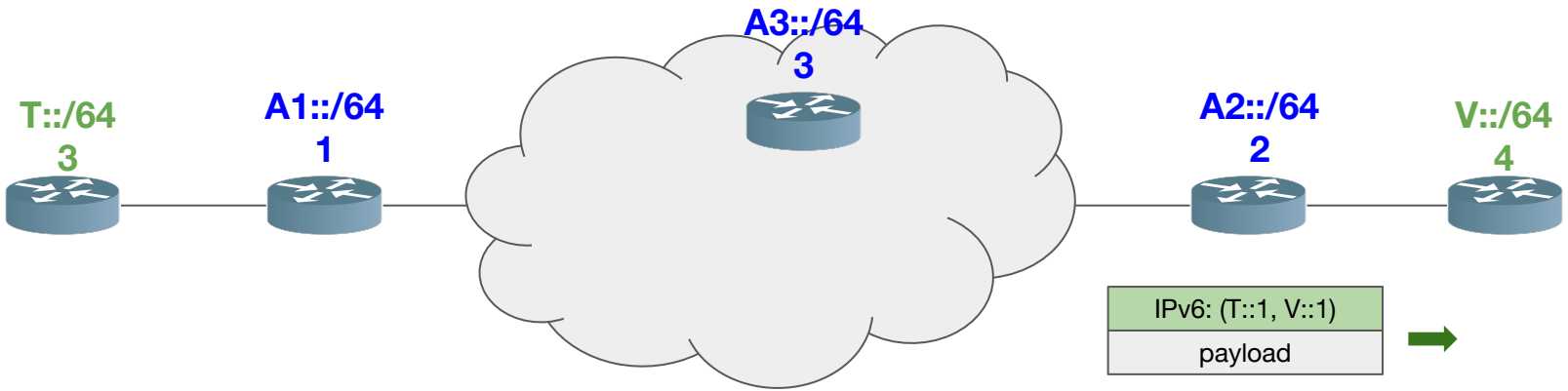
Overlay with underlay SLA

SAPIENZA
UNIVERSITÀ DI ROMA



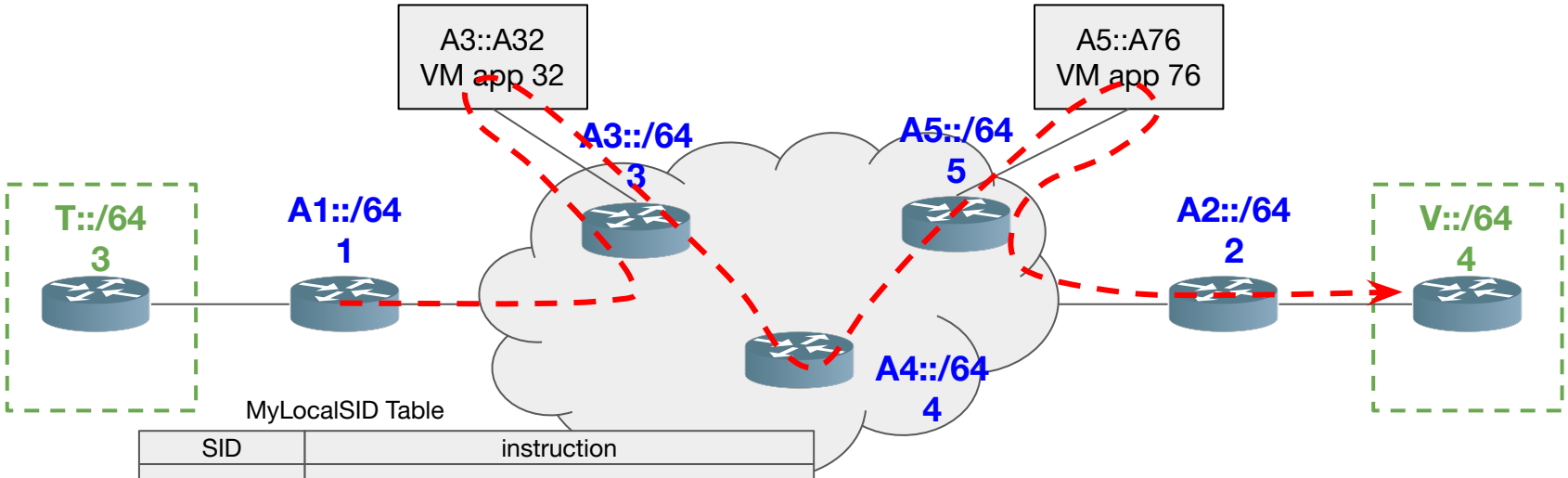
Overlay with underlay SLA

SAPIENZA
UNIVERSITÀ DI ROMA



Integrated NFV

SAPIENZA
UNIVERSITÀ DI ROMA

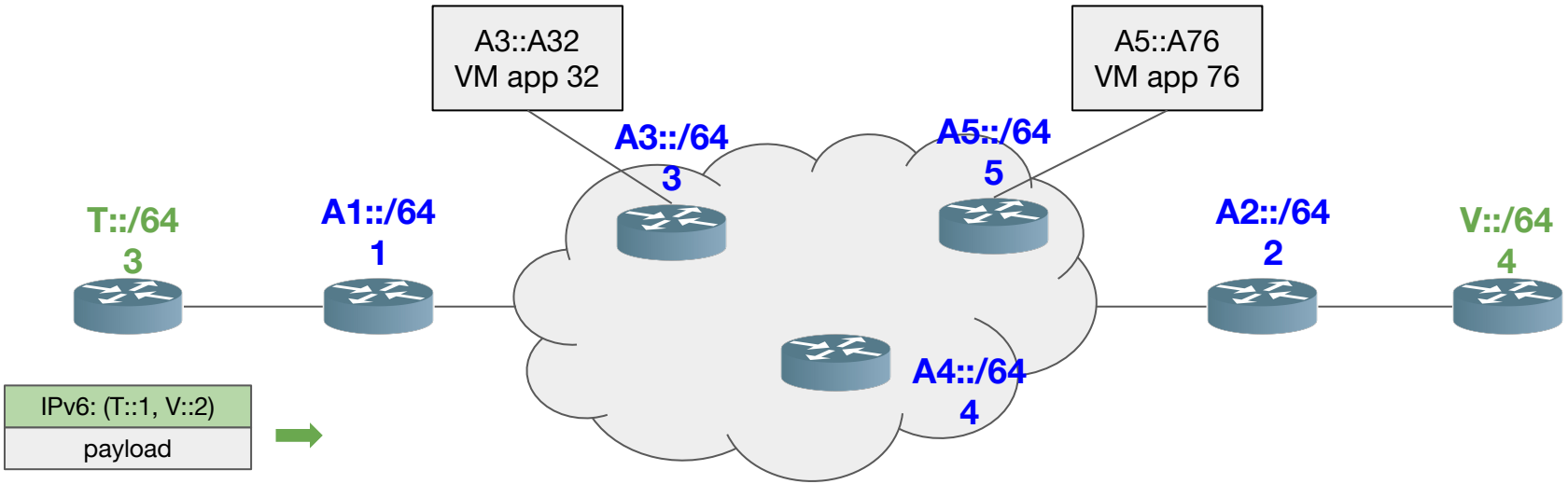


MyLocalSID Table

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

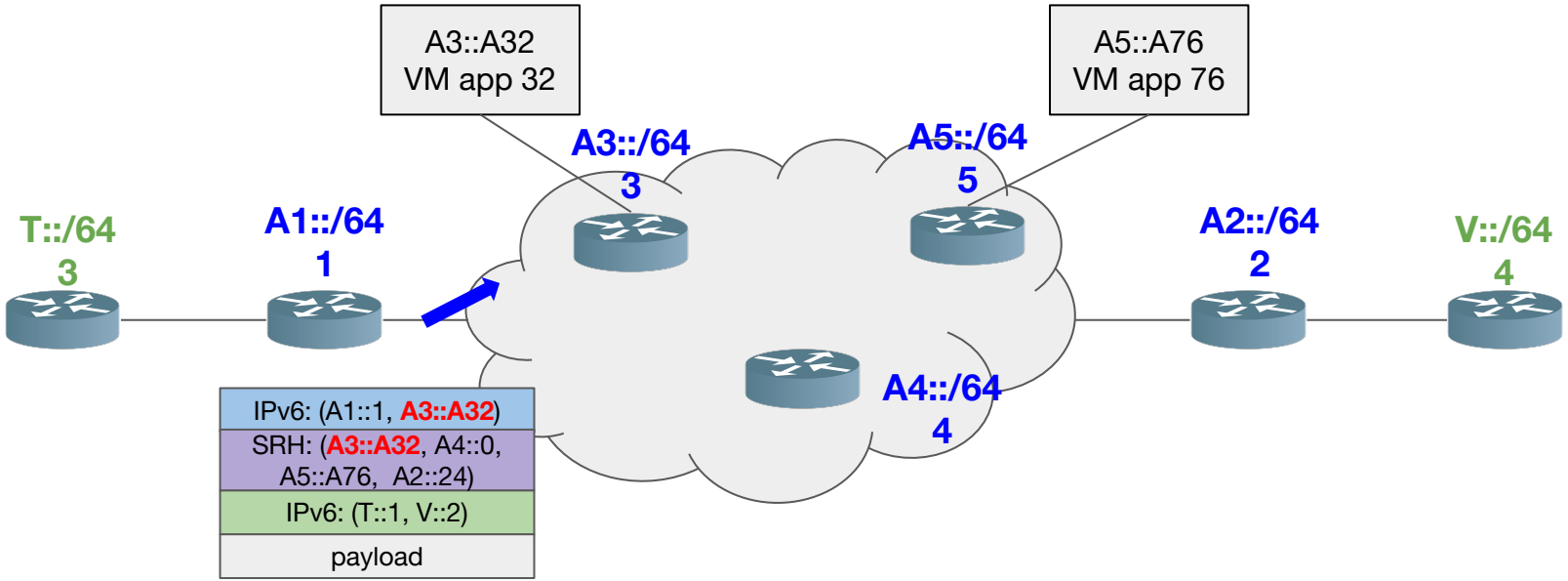
Integrated NFV

SAPIENZA
UNIVERSITÀ DI ROMA



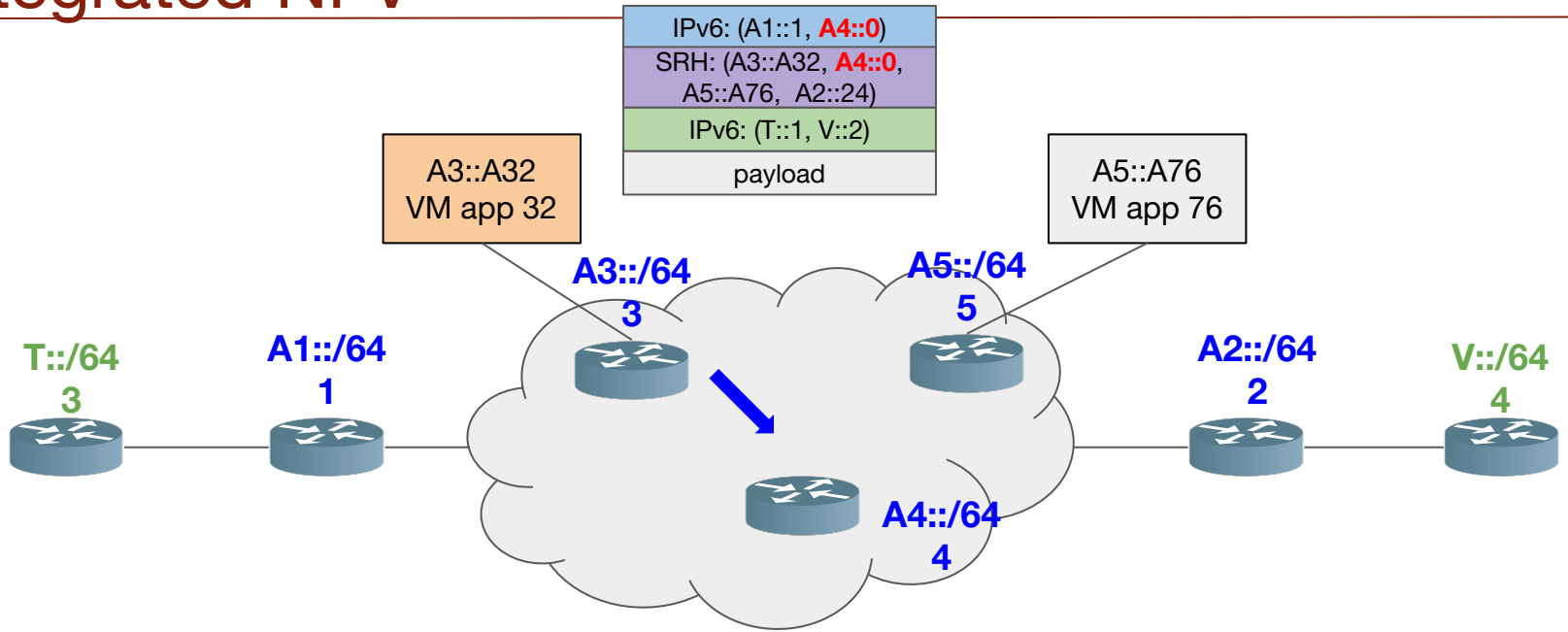
Integrated NFV

SAPIENZA
UNIVERSITÀ DI ROMA



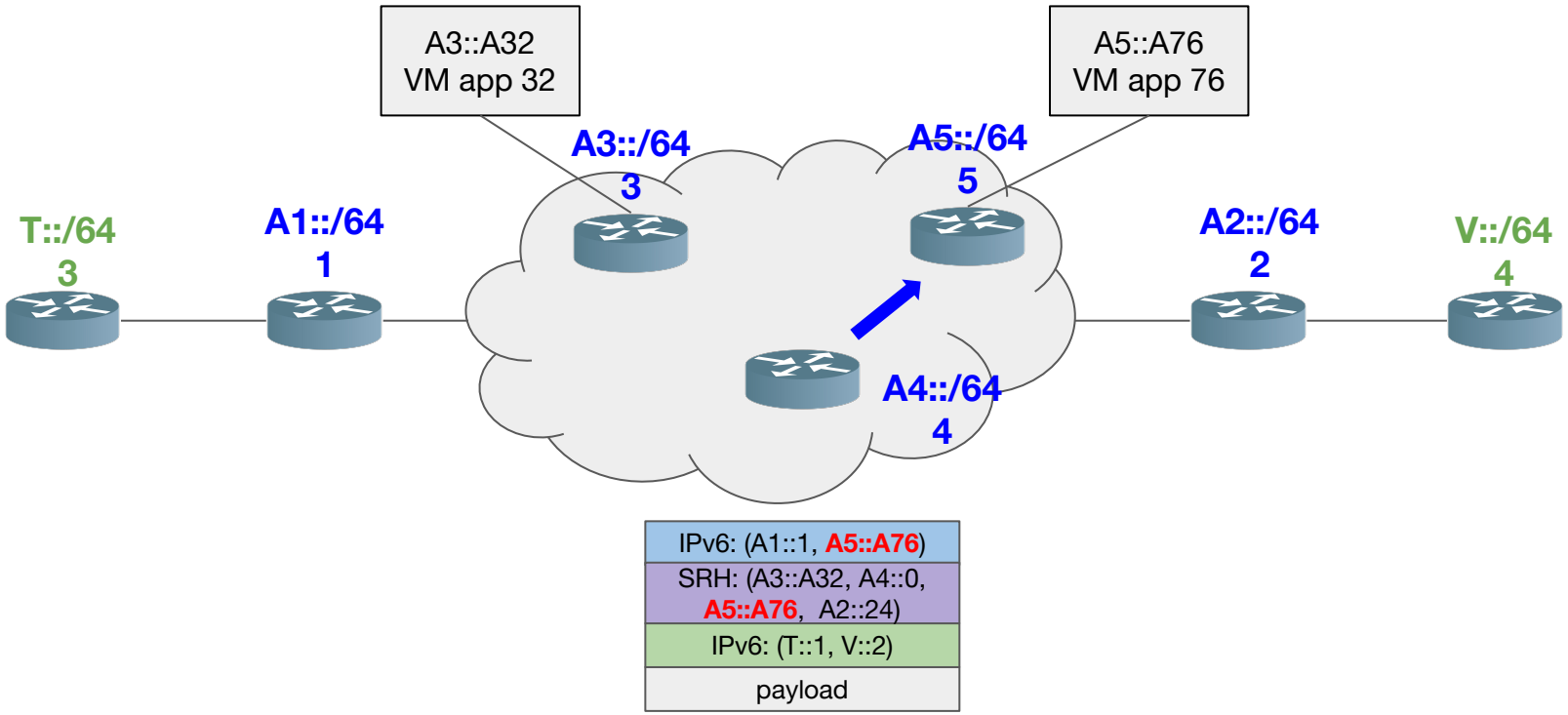
Integrated NFV

SAPIENZA
UNIVERSITÀ DI ROMA

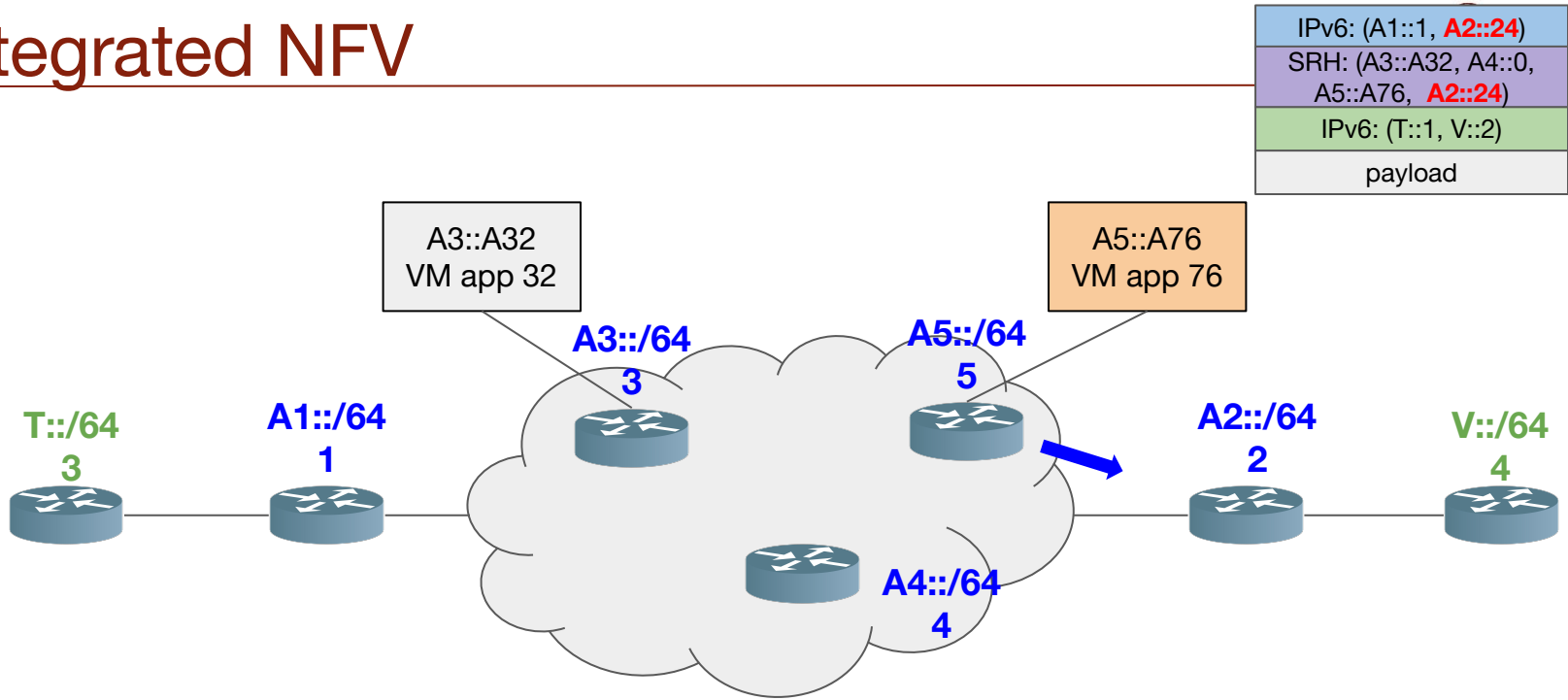


Integrated NFV

SAPIENZA
UNIVERSITÀ DI ROMA

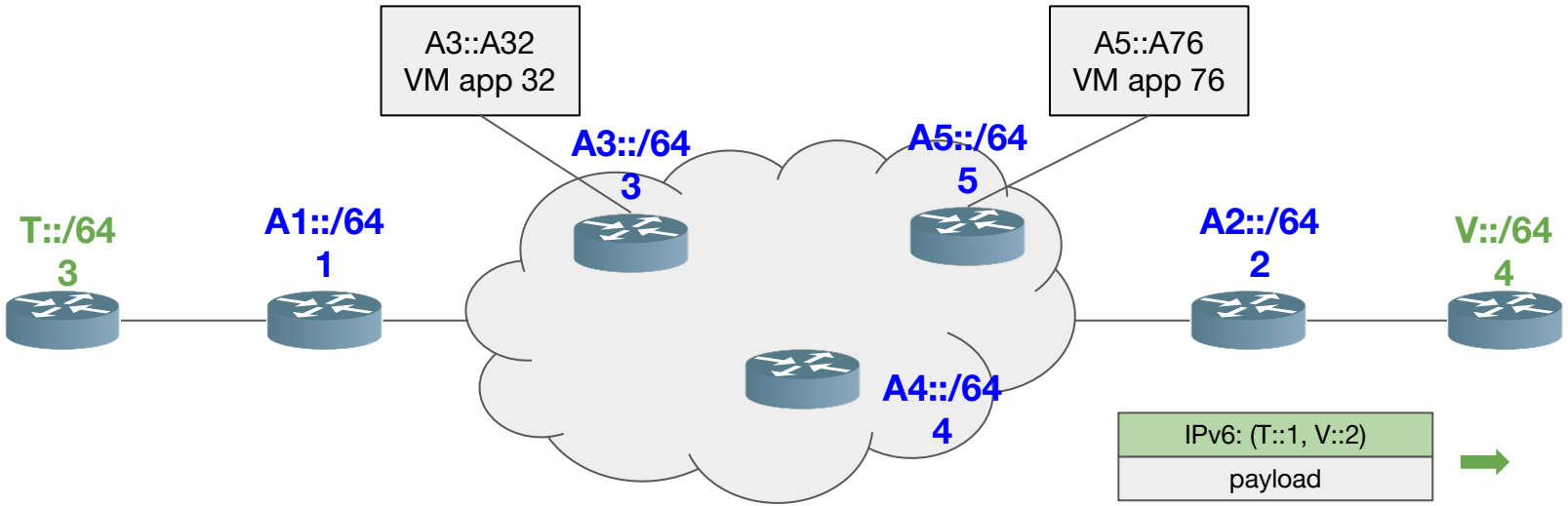


Integrated NFV



Integrated NFV

SAPIENZA
UNIVERSITÀ DI ROMA



References

SAPIENZA
UNIVERSITÀ DI ROMA

- James F. Kurose and Keith W. Ross. 2012. Computer Networking: A Top-Down Approach (6th Edition) (6th ed.). Pearson.
- http://www.segment-routing.net/
- C. Filsfils, N. K. Nainar, C. Pignataro, J. C. Cardona and P. Francois, "The Segment Routing Architecture," *2015 IEEE Global Communications Conference (GLOBECOM)*, San Diego, CA, 2015, pp. 1-6.
- Segment Routing Architecture, draft-ietf-spring-segment-routing-14
- Segment Routing Policy for Traffic Engineering, draft-filsfils-spring-segment-routing-policy-04.txt
- IPv6 Segment Routing Header (SRH), draft-ietf-6man-segment-routing-header-07
- SRv6 Network Programming, draft-filsfils-spring-srv6-network-programming-03