

Network Working Group  
Internet Draft  
Intended status: Standards Track  
Expires: April 2018

C. Filsfils, Ed.  
S. Previdi, Ed.  
A. Bashandy  
Cisco Systems, Inc.  
B. Decraene  
S. Litkowski  
Orange  
R. Shakir  
Google  
October 27, 2017

**Segment Routing with MPLS data plane**  
**draft-ietf-spring-segment-routing-mpls-11**

Abstract

Segment Routing (SR) leverages the source routing paradigm. A node steers a packet through a controlled set of instructions, called segments, by prepending the packet with an SR header. In the MPLS dataplane, the SR header is instantiated through a label stack. This document specifies the forwarding behavior to allow instantiating SR over the MPLS dataplane.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [BCP 14](#) [[RFC2119](#)] [[RFC8174](#)] when, and only when, they appear in all capitals, as shown here.

Status of this Memo

This Internet-Draft is submitted in full conformance with the provisions of [BCP 78](#) and [BCP 79](#).

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at <http://datatracker.ietf.org/drafts/current/>.

Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any

time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."

This Internet-Draft will expire on April 27, 2009.

## Copyright Notice

Copyright (c) 2017 IETF Trust and the persons identified as the document authors. All rights reserved.

This document is subject to [BCP 78](#) and the IETF Trust's Legal Provisions Relating to IETF Documents (<http://trustee.ietf.org/license-info>) in effect on the date of publication of this document. Please review these documents carefully, as they describe your rights and restrictions with respect to this document. Code Components extracted from this document must include Simplified BSD License text as described in Section 4.e of the Trust Legal Provisions and are provided without warranty as described in the Simplified BSD License.

## Table of Contents

<a href="#">1.</a>	<a href="#">Introduction.....</a>	<a href="#">3</a>
<a href="#">2.</a>	<a href="#">MPLS Instantiation of Segment Routing.....</a>	<a href="#">3</a>
<a href="#">2.1.</a>	<a href="#">Supporting Multiple Forwarding Behaviors for the Same Prefix .....</a>	<a href="#">4</a>
<a href="#">2.2.</a>	<a href="#">SID Representation in the MPLS Forwarding Plane.....</a>	<a href="#">4</a>
<a href="#">2.3.</a>	<a href="#">Segment Routing Global Block and Local Block.....</a>	<a href="#">5</a>
<a href="#">2.4.</a>	<a href="#">Mapping a SID Index to an MPLS label.....</a>	<a href="#">6</a>
<a href="#">2.5.</a>	<a href="#">PUSH, CONTINUE, and NEXT.....</a>	<a href="#">6</a>
<a href="#">2.5.1.</a>	<a href="#">PUSH.....</a>	<a href="#">6</a>
<a href="#">2.5.2.</a>	<a href="#">CONTINUE.....</a>	<a href="#">7</a>
<a href="#">2.5.3.</a>	<a href="#">NEXT.....</a>	<a href="#">7</a>
<a href="#">2.6.</a>	<a href="#">MPLS Label downloaded to FIB corresponding to Global and Local SIDs.....</a>	<a href="#">7</a>
<a href="#">2.7.</a>	<a href="#">Active Segment.....</a>	<a href="#">7</a>
<a href="#">2.8.</a>	<a href="#">Forwarding behavior for Global SIDs.....</a>	<a href="#">8</a>
<a href="#">2.8.1.</a>	<a href="#">Forwarding Behavior for PUSH and CONTINUE Operation for Global SIDs.....</a>	<a href="#">8</a>
<a href="#">2.8.2.</a>	<a href="#">Forwarding Behavior for NEXT Operation for Global SIDs.....</a>	<a href="#">9</a>
<a href="#">2.9.</a>	<a href="#">Forwarding Behavior for Local SIDs.....</a>	<a href="#">10</a>
<a href="#">2.9.1.</a>	<a href="#">Forwarding Behavior Corresponding to PUSH Operation on Local SIDs.....</a>	<a href="#">10</a>
<a href="#">2.9.2.</a>	<a href="#">Forwarding Behavior Corresponding to CONTINUE Operation for Local SIDs.....</a>	<a href="#">10</a>
<a href="#">2.9.3.</a>	<a href="#">Outgoing label for NEXT Operation for Local SIDs.....</a>	<a href="#">11</a>



<a href="#">3.</a>	<a href="#">IGP Segments Examples.....</a>	<a href="#">11</a>
<a href="#">3.1.</a>	<a href="#">Example 1.....</a>	<a href="#">12</a>
<a href="#">3.2.</a>	<a href="#">Example 2.....</a>	<a href="#">13</a>
<a href="#">3.3.</a>	<a href="#">Example 3.....</a>	<a href="#">14</a>
<a href="#">3.4.</a>	<a href="#">Example 4.....</a>	<a href="#">14</a>
<a href="#">3.5.</a>	<a href="#">Example 5.....</a>	<a href="#">14</a>
<a href="#">4.</a>	<a href="#">IANA Considerations.....</a>	<a href="#">15</a>
<a href="#">5.</a>	<a href="#">Manageability Considerations.....</a>	<a href="#">15</a>
<a href="#">6.</a>	<a href="#">Security Considerations.....</a>	<a href="#">15</a>
<a href="#">7.</a>	<a href="#">Contributors.....</a>	<a href="#">15</a>
<a href="#">8.</a>	<a href="#">Acknowledgements.....</a>	<a href="#">16</a>
<a href="#">9.</a>	<a href="#">References.....</a>	<a href="#">16</a>
<a href="#">9.1.</a>	<a href="#">Normative References.....</a>	<a href="#">16</a>
<a href="#">9.2.</a>	<a href="#">Informative References.....</a>	<a href="#">17</a>

## [1.](#) Introduction

The Segment Routing architecture [[I-D.ietf-spring-segment-routing](#)] can be directly applied to the MPLS architecture with no change in the MPLS forwarding plane. This document specifies the forwarding plane behavior to allow Segment Routing to operate on top of the MPLS data plane. This document does not address the control plane behavior. Control plane behavior is specified in other documents such as [[I-D.ietf-isis-segment-routing-extensions](#)], [[I-D.ietf-ospf-segment-routing-extensions](#)], and [[I-D.ietf-ospf-ospfv3-segment-routing-extensions](#)].

The Segment Routing problem statement is described in [[RFC7855](#)].

Co-existence of SR over MPLS forwarding plane with LDP [[RFC5036](#)] is specified in [[I-D.ietf-spring-segment-routing-ldp-interop](#)].

Policy routing and traffic engineering using segment routing can be found in [[I.D. filsfiles-spring-segment-routing-policy](#)]

## [2.](#) MPLS Instantiation of Segment Routing

MPLS instantiation of Segment Routing fits in the MPLS architecture as defined in [[RFC3031](#)] both from a control plane and forwarding plane perspective:



- o From a control plane perspective, [[RFC3031](#)] does not mandate a single signaling protocol. Segment Routing makes use of various control plane protocols such as link State IGPs [I-D.ietf-isis-segment-routing-extensions], [I-D.ietf-ospf-segment-routing-extensions] and [[I-D.ietf-ospf-ospfv3-segment-routing-extensions](#)]. The flooding mechanisms of link state IGPs fits very well with label stacking on ingress. Future control layer protocol and/or policy/configuration can be used to specify the label stack.
- o From a forwarding plane perspective, Segment Routing does not require any change to the forwarding plane because Segment ID (SIDs) are instantiated as MPLS labels and the Segment routing header instantiated as a stack of MPLS labels.

We call "MPLS Control Plane Client (MCC)" any control plane entity installing forwarding entries in the MPLS data plane. IGPs with SR extensions [[I-D.ietf-isis-segment-routing-extensions](#)], [I-D.ietf-ospf-segment-routing-extensions], [I-D.ietf-ospf-ospfv3-segment-routing-extensions] and LDP [[RFC5036](#)] are examples of MCCs. Local configuration and policies applied on a router are also examples of MCCs.

### **[2.1. Supporting Multiple Forwarding Behaviors for the Same Prefix](#)**

The SR architecture does not prohibit having more than one SID for the same prefix. In fact, by allowing multiple SIDs for the same prefix, it is possible to have different forwarding behaviors (such as different paths, different ECMP/UCMP behaviors,...,etc) for the same destination.

Instantiating Segment routing over the MPLS forwarding plane fits seamlessly with this principle. An operator may assign multiple MPLS labels or indices to the same prefix and assign different forwarding behaviors to each label/SID. The MCC in the network downloads different MPLS labels/SIDs to the FIB for different forwarding behaviors. The MCC at the entry of an SR domain or at any point in the domain can choose to apply a particular forwarding behavior to a particular packet by applying the PUSH action to that packet using the corresponding SID.

### **[2.2. SID Representation in the MPLS Forwarding Plane](#)**

When instantiating SR over the MPLS forwarding plane, a SID is represented by an MPLS label or an index [I-D.ietf-spring-segment-routing].



A global segment MUST be a label, or an index which may be mapped to an MPLS label using the SRGB of the node installing the global segment in its FIB/receiving the labeled packet. [Section 2.4](#) specifies the procedure to map a global segment represented by an index to an MPLS label within the SRGB.

The MCC MUST ensure that any label value corresponding to any SID it installs in the forwarding plane follows the following rules:

- o The label value MUST be unique within the router on which the MCC is running. i.e. the label MUST only be used to represent the SID.
- o The label value MUST NOT be identical to or within the range of any reserved label value or range [[reserved-MPLS](#)], respectively.

### **[2.3. Segment Routing Global Block and Local Block](#)**

The concepts of Segment Routing Global Block (SRGB) and global SID are explained in [[I-D.ietf-spring-segment-routing](#)]. In general, the SRGB need not be a contiguous range of labels.

For the rest of this document, the SRGB is specified by the list of MPLS Label ranges  $[Ll(1), Lh(1)]$ ,  $[Ll(2), Lh(2)]$ , ...,  $[Ll(k), Lh(k)]$  where  $Ll(i) \leq Lh(i)$  and the ranges do not overlap.

The following rules apply to the list of MPLS ranges representing the SRGB

- o The list of label ranges MUST only be used to instantiate global SIDs into the MPLS forwarding plane
- o Every range in the list of ranges specifying the SRGB MUST NOT cover or overlap with a reserved label value or range [[reserved-MPLS](#)], respectively.

Local segments MAY be allocated from the Segment Routing Local Block (SRLB) [[I-D.ietf-spring-segment-routing](#)] or from any unused label as long as it does not use a reserved label. The SRLB consists of the range of local labels reserved by the node for certain local segments. In a controller-driven network, some controllers or applications MAY use the control plane to discover the available set of local SIDs on a particular router [[I.D. ietf-spring-segment-routing-policy](#)]. Just like SRGB, the SRLB need not be a single contiguous range of label, except the SRGB MUST only be used to instantiate global SIDs into the MPLS forwarding plane. Hence it is specified the same way and follows the same rules SRGB is specified above in this sub-section.





## 2.4. Mapping a SID Index to an MPLS label

This sub-section specifies how the MPLS label value is calculated given the index of a SID. The value of the index is determined by an MCC such as ISIS [[I-D.ietf-isis-segment-routing-extensions](#)] or OSPF [[I-D.ietf-ospf-segment-routing-extensions](#)]. This section only specifies how to map the index to an MPLS label. The calculated MPLS label is downloaded to the FIB, sent out with a forwarded packet, or both.

Consider a SID represented by the index "I". Consider an SRGB as specified in [Section 2.3](#). The total size of the SRGB, represented by the variable "Size", is calculated according to the formula:

$$\text{size} = \text{Lh}(1) - \text{Ll}(1) + 1 + \text{Ll}(2) - \text{Ll}(2) + 1 + \dots + \text{Lh}(k) - \text{Ll}(k) + 1$$

The following rules MUST be applied by the MCC when calculating the MPLS label value corresponding the SID index value "I".

- o  $0 \leq I < \text{size}$ . If the index "I" does not satisfy the previous inequality, then the label cannot be calculated.
- o The label value corresponding to the SID index "I" is calculated as follows
  - o  $j = 1$  ,  $\text{temp} = 0$
  - o While  $\text{temp} < I$ 
    - .  $\text{temp} = \text{temp} + \text{Lh}(j) - \text{Ll}(j) + 1$
    - .  $j = j + 1$
  - o  $\text{label} = I - \text{temp} + \text{Ll}(j)$

## 2.5. PUSH, CONTINUE, and NEXT

PUSH, NEXT, and CONTINUE are operations applied by the forwarding plan. The specifications of these operations can be found in [[I-D.ietf-spring-segment-routing](#)]. This sub-section specifies how to implement each of these operations in the MPLS forwarding plane.

### 2.5.1. PUSH

PUSH corresponds to pushing one or more labels on top of an incoming packet then sending it out of a particular physical interface or virtual interface, such as UDP tunnel [[RFC7510](#)] or L2TPv3 tunnel



[[RFC4817](#)], towards a particular next-hop. Sections [2.8](#) and [2.9](#). specify additional details about forwarding behavior.

### **[2.5.2. CONTINUE](#)**

In the MPLS forwarding plane, the CONTINUE operation corresponds to swapping the incoming label with an outgoing label. The value of the outgoing label is calculated as specified in Sections [2.8](#) and [2.9](#).

### **[2.5.3. NEXT](#)**

In the MPLS forwarding plane, NEXT corresponds to popping the topmost label. The action before and/or after the popping depends on the instruction associated with the active SID on the received packet prior to the popping. For example suppose the active SID in the received packet was an Adj-SID [[I-D.ietf-spring-segment-routing](#)], then on receiving the packet, the node applies NEXT operation, which corresponds to popping the top most label, and then sends the packet out of the physical or virtual interface (e.g. UDP tunnel [[RFC7510](#)] or L2TPv3 tunnel [[RFC4817](#)]) towards the next-hop corresponding to the adj-SID.

## **[2.6. MPLS Label downloaded to FIB corresponding to Global and Local SIDs](#)**

The label corresponding to the global SID "Si" represented by the global index "I" downloaded to FIB is used to match packets whose active segment (and hence topmost label) is "Si". The value of this label is calculated as specified in [Section 2.4](#).

For Local SIDs, the MCC is responsible for downloading the correct label value to FIB. For example, an IGP with SR extensions [I-D.ietf-isis-segment-routing-extensions, I-D.ietf-ospf-segment-routing-extensions] allocates and downloads the MPLS label corresponding to an IGP-adjacency-SID [[I-D.ietf-spring-segment-routing](#)].

## **[2.7. Active Segment](#)**

When instantiated in the MPLS domain, the active segment on a packet corresponds to the topmost label on the packet that is calculated according to the procedure specified in Sections [2.8](#) and [2.9](#). When arriving at a node, the topmost label corresponding to the active SID matches the MPLS label downloaded to FIB as specified in [Section 2.6](#).



## **2.8. Forwarding behavior for Global SIDs**

This section specifies forwarding behavior, including the outgoing label(s) calculations corresponding to a global SID when applying PUSH, CONTINUE, and NEXT operations in the MPLS forwarding plane.

This document covers the calculation of outgoing label for the top label only. The case where outgoing label is not the top label and is part of a stack of labels that instantiates a routing policy or a traffic engineering tunnel is covered in other documents such as [I.D.filsfils-spring-segment-routing-policy].

### **2.8.1. Forwarding Behavior for PUSH and CONTINUE Operation for Global SIDs**

Suppose an MCC on a router "R0" determines that PUSH or CONTINUE operation is to be applied to an incoming packet whose active SID is the global SID "Si" represented by the global index "I" and owned by the router Ri before sending the packet towards a neighbor "N" directly connected to "R0" through a physical or virtual interface such as UDP tunnel [[RFC7510](#)] or L2TPv3 tunnel [[RFC4817](#)].

The method by which the MCC on router "R0" determines that PUSH or CONTINUE operation must be applied using the SID "Si" is beyond the scope of this document. An example of a method to determine the SID "Si" for PUSH operation is the case where ISIS [I-D.ietf-isis-segment-routing-extensions] receives the prefix-SID "Si" sub-TLV advertised with prefix "P/m" in TLV 135 and the destination address of the incoming IPv4 packet is covered by the prefix "P/m".

For CONTINUE operation, an example of a method to determine the SID "Si" is the case where ISIS [I-D.ietf-isis-segment-routing-extensions] receives the prefix-SID "Si" sub-TLV advertised with prefix "P" in TLV 135 and the top label of the incoming packet matches the MPLS label in FIB corresponding to the SID "Si" on the router "R0".

The forwarding behavior for PUSH and CONTINUE corresponding to the SID "Si"

- o If the neighbor "N" does not support SR or "I" does not satisfy the inequality specified in [Section 2.4](#) for the SRGB of the neighbor "N"



- o If it is possible to send the packet towards the neighbor "N" using standard MPLS forwarding behavior as specified in {[RFC3031](#)} and [[RFC3032](#)], then forward the packet. The method by which a router decides whether it is possible to send the packet to "N" or not is beyond the scope of this document. For example, the router "R0" can use the downstream label determined by another MCC, such as LDP [[RFC5036](#)], to send the packet.
- o Else if there are other useable next-hops, then use other next-hops to forward the incoming packet. The method by which the router "R0" decides on the possibility of using other next-hops is beyond the scope of this document. For example, the MCC on "R0" may chose the send an IPv4 packet without pushing any label to another next-hop.
- o Otherwise drop the packet.
- o Else
  - o Calculate the outgoing label as specified in [Section 2.4](#) using the SRGB of the neighbor "N"
  - o If the operation is PUSH
    - . Push the calculated label according the MPLS label pushing rules specified in [[RFC3032](#)]
  - o Else
    - . swap the incoming label with the calculated label according to the label swapping rules in [[RFC3032](#)]
  - o Send the packet towards the neighbor "N"

### **[2.8.2](#). Forwarding Behavior for NEXT Operation for Global SIDs**

As specified in [Section 2.5.3](#) NEXT operation corresponds to popping the top most label. The forwarding behavior is as follows

- o Pop the topmost label
- o Apply the instruction associated with the incoming label prior to popping





The action on the packet after popping the topmost label depends on the instruction associated with the incoming label as well as the contents of the packet right underneath the top label that got popped. Examples of NEXT operation are described in [Section 3](#).

## **[2.9](#). Forwarding Behavior for Local SIDs**

This section specifies the forwarding behavior for local SIDs when SR is instantiated over the MPLS forwarding plane.

### **[2.9.1](#). Forwarding Behavior Corresponding to PUSH Operation on Local SIDs**

Suppose an MCC on a router "R0" determines that PUSH operation is to be applied to an incoming packet using the local SID "Si" before sending the packet towards a neighbor "N" directly connected to R0 through a physical or virtual interface such as UDP tunnel [[RFC7510](#)] or L2TPv3 tunnel [[RFC4817](#)].

An example of such local SID is an IGP-Adj-SID allocated and advertised by ISIS [[I-D.ietf-isis-segment-routing-extensions](#)]. The method by which the MCC on "R0" determines that PUSH operation is to be applied to the incoming packet is beyond the scope of this document. An example of such method is backup path used to protect against a failure using Ti-LFA [[I.D.bashandy-rtgwg-segment-routing-ti-lfa](#)].

As mentioned in [[I-D.ietf-spring-segment-routing](#)], a local SID is specified by an MPLS label. Hence the PUSH operation for a local SID is identical to label push operation [[RFC3032](#)] using any MPLS label. The forwarding action after pushing the MPLS label corresponding to the local SID is also determined by the MCC. For example, if the PUSH operation was done to forward a packet over a backup path calculated using Ti-LFA, then the forwarding action may be sending the packet to a certain neighbor that will in turn continue to forward the packet along the backup path

### **[2.9.2](#). Forwarding Behavior Corresponding to CONTINUE Operation for Local SIDs**

A local SID on a router "R0" corresponds to a local label such as an IGP adj-SID. In such scenario, the outgoing label towards a next-hop "N" is determined by the MCC running on the router "R0" and the forwarding behavior for CONTINUE operation is identical to swap operation [[RFC3032](#)] on an MPLS label.





```

+-----+
| IP address allocated by the operator:                |
|               192.0.2.1/32 as a loopback of R1      |
|               192.0.2.2/32 as a loopback of R2      |
|               192.0.2.3/32 as a loopback of R3      |
|               192.0.2.4/32 as a loopback of R4      |
|               192.0.2.5/32 as a loopback of R5      |
|               192.0.2.8/32 as a loopback of R8      |
| 198.51.100.9/32 as an anycast loopback of R4        |
| 198.51.100.9/32 as an anycast loopback of R5        |
| SRGB defined by the operator as 1000-5000           |
| Global IGP SID indices allocated by the operator:    |
|               1 allocated to 192.0.2.1/32           |
|               2 allocated to 192.0.2.2/32           |
|               3 allocated to 192.0.2.3/32           |
|               4 allocated to 192.0.2.4/32           |
|               8 allocated to 192.0.2.8/32           |
|               1009 allocated to 198.51.100.9/32      |
| Local IGP SID allocated dynamically by R2           |
|               for its "north" adjacency to R3: 9001 |
|               for its "north" adjacency to R3: 9003 |
|               for its "south" adjacency to R3: 9002 |
|               for its "south" adjacency to R3: 9003 |
+-----+

```

Figure 2: IGP Address and Segment Allocation - Illustration

### 3.1. Example 1

Suppose R1 wants to send an IPv4 packet P1 to R8. In this case, R1 needs to apply PUSH operation to the IPv4 packet.

Remember that the SID index "8" is a global IGP segment attached to the IP prefix 192.0.2.8/32. Its semantic is global within the IGP domain: any router forwards a packet received with active segment 8 to the next-hop along the ECMP-aware shortest-path to the related prefix.

R2 is the next-hop along the shortest path towards R8. By applying the steps in [Section 2.6](#) the local label downloaded to R1's FIB corresponding to the global SID index 8 is 1008 because the SRGB of R2 is [1000,5000] as shown in Figure 2.



Because the packet is IPv4, R1 applies the PUSH operation using the label value 1008 as specified in 2.8.1. The resulting MPLS header will have the "S" bit [[RFC3032](#)] set because it is followed directly by an IPv4 packet.

The packet arrives at router R2. Because the top label 1008 corresponds to the IGP SID "8", which is the prefix-SID attached to the prefix 192.0.2.8/32 owned by the R8, then the instruction associated with the SID is "forward the packet using all ECMP/UCMP interfaces and all ECMP/UCMP next-hop(s) along the shortest path towards R8". Because R2 is not the penultimate hop, R2 applies the CONTINUE operation to the packet and sends it to R3 using one of the two links connected to R3 with top label 1008 as specified in [Section 2.8.1](#).

R3 receives the packet with top label 1008. Because the top label 1008 corresponds to the IGP SID "8", which is the prefix-SID attached to the prefix 192.0.2.8/32 owned by the R8, then the instruction associated with the SID is "send the packet using all ECMP interfaces and all next-hop(s) along the shortest path towards R8". Because R3 is the penultimate hop, R3 applies NEXT operation then sends the packet to R8. The NEXT operation results in popping the outer label and sending the packet as a pure IPv4 packet to R8. The

In conclusion, the path followed by P1 is R1-R2--R3-R8. The ECMP-awareness ensures that the traffic be load-shared between any ECMP path, in this case the two north and south links between R2 and R3.

### [3.2](#). Example 2

Suppose the right most router R0 wants to send a packet P2 to R8 over the path <R2, (north link between R2 and R3)>. In that case, the router R0 needs to use the SID list <2, 9001, 8>. Using the calculation techniques specified in [Section 2.8](#) and 2.9 the resulting label stack starting from the topmost label is <1002, 9001, 1008>.

The MPLS label 1002 is the MPLS instantiation of the global IGP segment index 2 attached to the IP prefix 192.0.2.2/32. Its semantic is global within the IGP domain: any router forwards a packet received with active segment 1002 to the next-hop along the shortest-path to the related prefix.

The MPLS label 9001 is a local IGP segment attached by node R2 to its north link to R3. Its semantic is local to node R2: R2 applies NEXT operation, which corresponding to popping the outer label, then





switches a packet received with active segment 9001 towards the north link to R3.

In conclusion, the path followed by P2 is R0-R1-R2-north-link-R3-R8.

### **3.3. Example 3**

R0 may send a packet P3 along the same exact path as P2 using a different segment list <2,9003,8> which corresponds to the label stack <1002, 9003, 1008>.

9003 is a local IGP segment attached by node R2 to both its north and south links to R3. Its semantic is local to node R2: R2 applies NEXT operation, which corresponds to popping the top label, then switches a packet received with active segment 9003 towards either the north or south links to R3 (e.g. per-flow loadbalancing decision).

In conclusion, the path followed by P3 is R0-R1-R2-any-link-R3-R8.

### **3.4. Example 4**

R0 may send a packet P4 to R8 while avoiding the links between R2 and R3 by pushing the SID list <4,8>, which corresponds to the label stack <1004, 1008>.

1004 is a global IGP segment attached to the IP prefix 192.0.2.4/32. Its semantic is global within the IGP domain: any router forwards a packet received with active segment 1004 to the next-hop along the shortest-path to the related prefix.

In conclusion, the path followed by P4 is R0-R1-R2-R4-R3-R8.

### **3.5. Example 5**

R0 may send a packet P5 to R8 while avoiding the links between R2 and R3 and still benefiting from all the remaining shortest paths (via R4 and R5) by pushing the SID list <1009, 8> which corresponds to the label stack <2009, 1008> using the steps specified in Sections [2.8](#) and 2.9.

1009 is a global anycast-SID [[I-D.ietf-spring-segment-routing](#)] attached to the anycast IP prefix 198.51.100.9/32. Its semantic is global within the IGP domain: any router forwards a packet received with top label 2009 (corresponding to the active segment 1009) to the next-hop along the shortest-path to the related prefix.



In conclusion, the path followed by P5 is either R0-R1-R2-R4-R3-R8 or R0-R1-R2-R5-R3-R8.

#### **4. IANA Considerations**

This document does not make any request to IANA.

#### **5. Manageability Considerations**

This document describes the applicability of Segment Routing over the MPLS data plane. Segment Routing does not introduce any change in the MPLS data plane. Manageability considerations described in [I-D.ietf-spring-segment-routing] applies to the MPLS data plane when used with Segment Routing.

#### **6. Security Considerations**

This document does not introduce additional security requirements and mechanisms other than the ones described in [I-D.ietf-spring-segment-routing].

#### **7. Contributors**

The following contributors have substantially helped the definition and editing of the content of this document:

Martin Horneffer  
Deutsche Telekom  
Email: Martin.Horneffer@telekom.de

Wim Henderickx  
Nokia  
Email: wim.henderickx@nokia.com

Jeff Tantsura  
Email: jefftant@gmail.com  
Edward Crabbe  
Email: edward.crabbe@gmail.com

Igor Milojevic  
Email: milojevicigor@gmail.com

Saku Ytti  
Email: saku@ytti.fi

## **8. Acknowledgements**

The authors would like to thank Les Ginsberg and Shah Himanshu for their comments on this document.

This document was prepared using 2-Word-v2.0.template.dot.

## **9. References**

### **9.1. Normative References**

- [I-D.ietf-spring-segment-routing] Filsfils, C., Previdi, S., Decraene, B., Litkowski, S., and R. Shakir, "Segment Routing Architecture", [draft-ietf-spring-segment-routing-12](#) (work in progress), June 2017.
- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", [BCP 14](#), [RFC 2119](#), DOI 0.17487/RFC2119, March 1997, <<http://www.rfc-editor.org/info/rfc2119>>.
- [RFC3031] Rosen, E., Viswanathan, A., and R. Callon, "Multiprotocol Label Switching Architecture", [RFC 3031](#), DOI 10.17487/RFC3031, January 2001, <<http://www.rfc-editor.org/info/rfc3031>>.



- [RFC3032] Rosen, E., Tappan, D., Fedorkow, G., Rekhter, Y., Farinacci, D., Li, T., and A. Conta, "MPLS Label Stack Encoding", [RFC 3032](#), DOI 10.17487/RFC3032, January 2001, <<http://www.rfc-editor.org/info/rfc3032>>.
- [reserved-MPLS] "Special-Purpose Multiprotocol Label Switching (MPLS) Label Values", <<https://www.iana.org/assignments/mpls-label-value>>

## 9.2. Informative References

- [I-D.ietf-isis-segment-routing-extensions] Previdi, S., Filsfils, C., Bashandy, A., Gredler, H., Litkowski, S., Decraene, B., and j. jeffrant@gmail.com, "IS-IS Extensions for Segment Routing", [draft-ietf-isis-segment-routing-extensions-13](#) (work in progress), June 2017.
- [I-D.ietf-ospf-ospfv3-segment-routing-extensions] Psenak, P., Previdi, S., Filsfils, C., Gredler, H., Shakir, R., Henderickx, W., and J. Tantsura, "OSPFv3 Extensions for Segment Routing", [draft-ietf-ospf-ospfv3-segment-routing-extensions-09](#) (work in progress), March 2017.
- [I-D.ietf-ospf-segment-routing-extensions] Psenak, P., Previdi, S., Filsfils, C., Gredler, H., Shakir, R., Henderickx, W., and J. Tantsura, "OSPF Extensions for Segment Routing", [draft-ietf-ospf-segment-routing-extensions-16](#) (work in progress), May 2017.
- [I-D.ietf-spring-segment-routing-ldp-interop] Filsfils, C., Previdi, S., Bashandy, A., Decraene, B., and S. Litkowski, "Segment Routing interworking with LDP", [draft-ietf-spring-segment-routing-ldp-interop-08](#) (work in progress), June 2017.
- [RFC7855] Previdi, S., Ed., Filsfils, C., Ed., Decraene, B., Litkowski, S., Horneffer, M., and R. Shakir, "Source Packet Routing in Networking (SPRING) Problem Statement and Requirements", [RFC 7855](#), DOI 10.17487/RFC7855, May 2016, <<http://www.rfc-editor.org/info/rfc7855>>.
- [RFC5036] Andersson, L., Acreo, AB, Minei, I., Thomas, B., " LDP Specification", [RFC5036](#), DOI 10.17487/RFC5036, October 2007, <<https://www.rfc-editor.org/info/rfc5036>>



- [RFC7510] Xu, X., Sheth, N., Yong, L., Callon, R., and D. Black, "Encapsulating MPLS in UDP", [RFC 7510](#), DOI 10.17487/RFC7510, April 2015, <<https://www.rfc-editor.org/info/rfc7510>>.
- [RFC4817] Townsley, M., Pignataro, C., Wainner, S., Seely, T., Young, T., "Encapsulation of MPLS over Layer 2 Tunneling Protocol Version 3", [RFC4817](#), DOI 10.17487/RFC4817, March 2007, <<https://www.rfc-editor.org/info/rfc4817>>
- [I-D.ietf-idr-segment-routing-te-policy] Previdi, S., Filsfils, C., Mattes, P., Rosen, E., Lin, S., " Advertising Segment Routing Policies in BGP", draft-ietf-idr-segment-routing-te-policy-00 (work in progress), July 2017
- [I.D. filsfils-spring-segment-routing-policy] Filsfils, C., Sivabalan, S., Raza, K., Liste, J. , Clad, F., Voyer, D., Lin, S., Bogdanov, A., Horneffer, M., Steinberg, D., Decraene, B. , Litkowski, S., " Segment Routing Policy for Traffic Engineering", [draft-filsfils-spring-segment-routing-policy-01](#) (work in progress), July 2017



## Authors' Addresses

Clarence Filsfils (editor)  
Cisco Systems, Inc.  
Brussels  
BE

Email: cfilsfil@cisco.com

Stefano Previdi (editor)  
Cisco Systems, Inc.  
Italy

Email: stefano@previdi.net

Ahmed Bashandy  
Cisco Systems, Inc.  
170, West Tasman Drive  
San Jose, CA 95134  
US

Email: bashandy@cisco.com

Bruno Decraene  
Orange  
FR

Email: bruno.decraene@orange.com

Stephane Litkowski  
Orange  
FR

Email: stephane.litkowski@orange.com

Rob Shakir  
Google

Email: robjs@google.com