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An MPLS-Based Forwarding Plane for Service Function Chaining
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Abstract

Service Function Chaining (SFC) is the process of directing packets through a network so that they can be acted on by an ordered set of abstract service functions before being delivered to the intended destination. An architecture for SFC is defined in [RFC7665](#).

The Network Service Header (NSH) can be inserted into packets to steer them along a specific path to realize a Service Function Chain.

Multiprotocol Label Switching (MPLS) is a widely deployed forwarding technology that uses labels to identify the forwarding actions to be taken at each hop through a network. Segment Routing is a mechanism that provides a source routing paradigm for steering packets in an MPLS network.

This document describes how Service Function Chaining can be achieved in an MPLS network by means of a logical representation of the NSH in an MPLS label stack.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [\[RFC2119\]](#).

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[1.](#) Introduction

Service Function Chaining (SFC) is the process of directing packets through a network so that they can be acted on by an ordered set of

abstract service functions before being delivered to the intended destination. An architecture for SFC is defined in [[RFC7665](#)].

When applying a particular Service Function Chain to the traffic selected by a service classifier, the traffic needs to be steered through an ordered set of Service Functions (SF) in the network. This ordered set of SFs is termed a Service Function Path (SFP), and the traffic is passed between Service Function Forwarders (SFFs) that are responsible for delivering the packets to the SFs and for forwarding it onward to the next SFF.

In order to steer the selected traffic between SFFs and to the correct SFs the service classifier needs to attach information to each packet. This information indicates the SFP on which packet is being forwarded and hence the SFs to which it must be delivered. The information also indicates the progress the packet has already made along the SFP.

The Network Service Header (NSH) [[I-D.ietf-sfc-nsh](#)] has been defined to carry the necessary information for Service Function Chaining in packets. The NSH can be inserted into packets and contains various information including a Service Path Indicator (SPI), a Service Index (SI), and a Time To Live (TTL) counter.

Multiprotocol Label Switching (MPLS) [[RFC3031](#)] is a widely deployed forwarding technology that uses labels to identify the forwarding actions to be taken at each hop through a network. In many cases, MPLS will be used as a tunneling technology to carry packets through networks between SFFs.

Segment Routing [[RFC7855](#)] introduces a source routing paradigm into packet switched networks. The application of Segment Routing in MPLS networks is described in [[I-D.ietf-spring-segment-routing-mpls](#)].

This document describes how Service Function Chaining can be achieved in an MPLS network by means of a logical representation of the NSH in an MPLS label stack. This approach is applicable to both classical MPLS forwarding (where labels are looked up at each hop, and swapped for the next hop [[RFC3031](#)]) and MPLS Segment Routing (where labels are looked up at each hop, and popped to reveal the next label to action [[I-D.ietf-spring-segment-routing-mpls](#)]). The mechanisms described in this document are a compromise between the full function that can be achieved using the NSH, and the benefits of reusing the existing MPLS forwarding paradigms.

It is assumed that the reader is fully familiar with the terms and concepts introduced in [[RFC7665](#)] and [[I-D.ietf-sfc-nsh](#)].

2. Choice of Data Plane SPI/SI Representation

While [[I-D.ietf-sfc-nsh](#)] defines the NSH that can be used in a number of environments, this document provides a mechanism to handle situations in which the NSH is not ubiquitously deployed. In this case it is possible to use alternative data plane representations of the SPI/SI by carrying the identical semantics in MPLS labels.

In order to correctly select the mechanism by which SFC information is encoded, it may be necessary to configure the capabilities and choices either within the whole Service Function Overlay Network, or on a hop by hop basis. It is a requirement that both ends of a tunnel over the underlay network know that the tunnel is used for SFC and know what form of NSH representation is used. A control plane signalling approach to achieve these objectives is provided using BGP in [[I-D.ietf-bess-nsh-bgp-control-plane](#)].

Note that the encoding of the SFC information is independent of the choice of tunneling technology used between SFFs. Thus, an MPLS representation of the logical NSH (as defined in this document) may be used even if the tunnel between a pair of SFFs is not an MPLS tunnel. Conversely, MPLS tunnels may be used to carry other encodings of the logical NSH (specifically, the NSH itself).

3. Basic Unit of Representation

When an MPLS label stack is used to carry a logical NSH, a basic unit of representation is used. This unit comprises two MPLS labels as shown below. The unit may be present one or more times in the label stack as explained in subsequent sections.

In order to convey the same information as is present in the NSH, two MPLS label stack entries are used. One carries a label to provide context within the SFC scope (the SFC Context Label), and the other carries a label to show which service function is to be actioned (the SF Label). This two-label unit is shown in Figure 1.

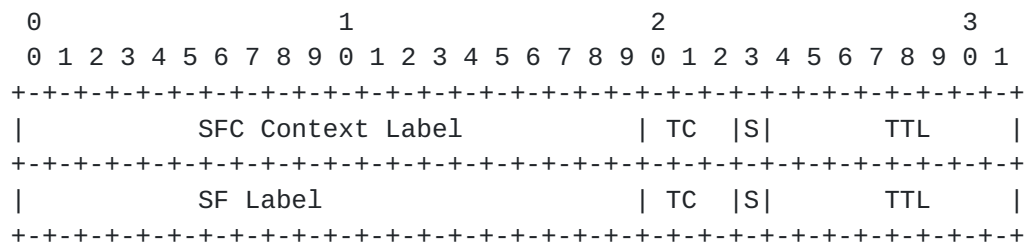


Figure 1: The Basic Unit of MPLS Label Stack for SFC

The fields of these two label stack entries are encoded as follows:

Label: The Label fields contain the values of the SFC Context Label and the SF Label encoded as 20 bit integers. The precise semantics of these label fields are dependent on whether the label stack entries are used for MPLS swapping (see [Section 4](#)) or MPLS-SR (see [Section 5](#)).

TC: The TC bits have no meaning. They SHOULD be set to zero in both label stack entries and MUST be ignored.

S: The bottom of stack flag has its usual meaning in MPLS. It MUST be clear in the SFC Context label stack entry and MAY be set in the SF label stack entry depending on whether the label is the bottom of stack.

TTL: The TTL field in the SFC Context label stack entry SHOULD be set to 1. The TTL in SF label stack entry (called the SF TTL) is set according to its use for MPLS swapping (see [Section 4](#)) or MPLS-SR (see [Section 5](#)) and is used to mitigate packet loops.

The sections that follow show how this basic unit of MPLS label stack may be used for SFC in the MPLS label swapping case and in the MPLS-SR case. For simplicity, these sections do not describe the use of metadata: that is covered separately in [Section 8](#).

4. MPLS Label Swapping

This section describes how the basic unit of MPLS label stack for SFC introduced in [Section 3](#) is used when MPLS label swapping is in use. As can be seen from Figure 2, the top of the label stack comprises the labels necessary to deliver the packet over the MPLS tunnel between SFFs. Any MPLS encapsulation may be used (i.e., MPLS, MPLS in UDP, MPLS in GRE, and MPLS in VXLAN or GPE), thus the tunnel technology does not need to be MPLS, but that is shown here for simplicity.

An entropy label ([\[RFC6790\]](#)) may also be present as described in [Section 7](#)

Under these labels (or other encapsulation) comes a single instance of the basic unit of MPLS label stack for SFC. In addition to the interpretation of the fields of these label stack entries provided in [Section 3](#) the following meanings are applied:

SPI Label: The Label field of the SFC Context label stack entry contains the value of the SPI encoded as a 20 bit integer. The semantics of the SPI is exactly as defined in [\[I-D.ietf-sfc-nsh\]](#).

Note that an SPI as defined by [[I-D.ietf-sfc-nsh](#)] can be encoded in 3 octets (i.e., 24 bits), but that the Label field allows for only 20 bits and reserves the values 0 through 15 as 'special purpose' labels [[RFC7274](#)]. Thus, a system using MPLS representation of the logical NSH MUST NOT assign SPI values greater than $2^{20} - 1$ or less than 16.

SI Label: The Label field of the SF label stack entry contains the value of the SI exactly as defined in [[I-D.ietf-sfc-nsh](#)]. Since the SI requires only 8 bits, and to avoid overlap with the 'special purpose' label range of 0 through 15 [[RFC7274](#)], The SI is carried in the top (most significant) 8 bits of the Label field with the low order 12 bits set to zero.

TC: The TC field is as described in [Section 3](#).

S: The S field is as described in [Section 3](#).

TTL: The TTL field in the SPI label stack entry SHOULD be set to 1 as stated in [Section 3](#). The TTL in SF label stack entry is decremented once for each hop in the SFP, i.e., for each SFI executed, and so mirrors the TTL field in the NSH.

The following processing rules apply to the Label fields:

- o When a Classifier inserts a packet onto an SFP it sets the SPI Label to indicate the identity of the SFP, and sets the SI Label to indicate the first SF in the path.
- o When a component of the SFC system processes a packet it uses the SPI Label to identify the SFP and the SI Label to determine to which SFF or SFI to deliver the packet. Under normal circumstances (with the exception of branching and reclassification - see [[I-D.ietf-bess-nsh-bgp-control-plane](#)]) the SPI Label value is preserved on all packets. The SI Label value is modified by and SFFs and through reclassification to indicate the next hop along the SFP.

The following processing rules apply to the TTL field of the SF label stack entry:

- o When a Classifier places a packet onto an SFP it MUST set the TTL to a value between 1 and 255. It SHOULD set this according to the expected length of the SFP (i.e., the number of SFs on the SFP), but it MAY set it to a larger value according to local configuration.

- o When an SFF receives a packet from any component of the SFC system (Classifier, SFI, or another SFF) it MUST discard any packets with TTL set to zero. It SHOULD log such occurrences, but MUST apply rate limiting to any such logs.
- o An SFF MUST decrement the TTL by one each time it sends the packet to an SFI (local or remote), but not when it sends the packet to another SFF.
- o If an SFF decrements the TTL to zero it MUST NOT send the packet, and MUST discard the packet. It SHOULD log such occurrences, but MUST apply rate limiting to any such logs.
- o SFIs MUST ignore the TTL, but MUST mirror it back to the SFF unmodified along with the SI (which may have been changed by local reclassification).
- o If a Classifier along the SFP makes any change to the intended path of the packet including for looping, jumping, or branching (see [[I-D.ietf-bess-nsh-bgp-control-plane](#)]) it MUST NOT change the SI TTL of the packet. In particular, every component of the SFC system MUST NOT increase the SI TTL value.

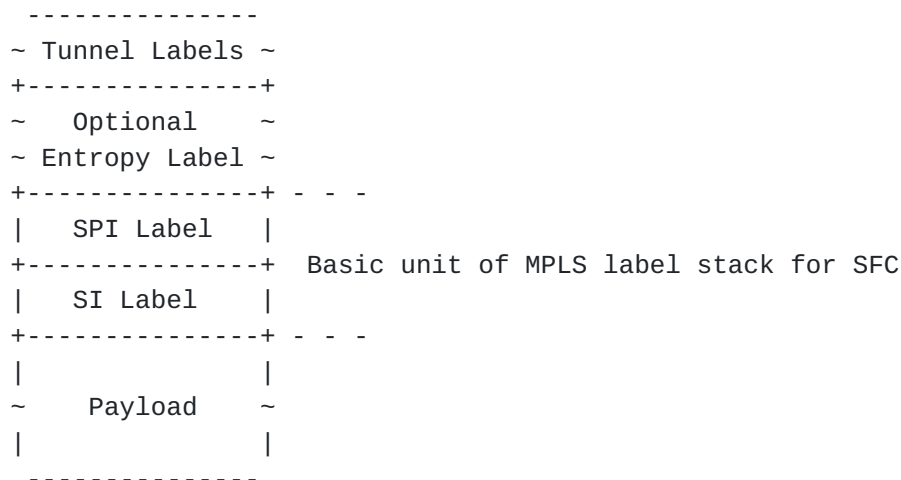


Figure 2: The MPLS SFC Label Stack

5. MPLS Segment Routing

This section describes how the basic unit of MPLS label stack for SFC introduced in [Section 3](#) is used when MPLS-SR. As can be seen Figure 3, the top of the label stack comprises the labels necessary to deliver the packet over the MPLS tunnel between SFFs. Any MPLS

encapsulation may be used and the tunnel technology does not need to be MPLS or MPLS-SR, but MPLS-SR is shown here for simplicity.

An entropy label ([\[RFC6790\]](#)) may also be present as described in [Section 7](#)

Under these labels (or other encapsulation) comes one of more instances of the basic unit of MPLS label stack for SFC. In addition to the interpretation of the fields of these label stack entries provided in [Section 3](#) the following meanings are applied:

SFC Context Label: The Label field of the SFC Context label stack entry contains a label that delivers SFC context. This label may be used to indicate the SPI encoded as a 20 bit integer using the semantics of the SPI is exactly as defined in [\[I-D.ietf-sfc-nsh\]](#) and noting that in this case a system using MPLS representation of the logical NSH MUST NOT assign SPI values greater than $2^{20} - 1$ or less than 16. This label may also be used to convey other context-specific semantics. Alternatively this label may be used to provide other SFC context such as indicating, perhaps with a node SID (see [\[I-D.ietf-spring-segment-routing\]](#)), how to interpret the SF Label.

SF Label: The Label field of the SF label stack entry contains a value that identifies the next SFI to be actioned for the packet. This label may be scoped globally or within the context of the preceding SFC Context Label and comes from the range $16 \dots 2^{20} - 1$.

TC: The TC field is as described in [Section 3](#).

S: The S field is as described in [Section 3](#).

TTL: The TTL field in the SFC Context label stack entry SHOULD be set to 1 as stated in [Section 3](#). The TTL in SF label stack entry is set according to the norms for MPLS-SR.

The following processing rules apply to the Label fields:

- o When a Classifier inserts a packet onto an SFP it adds a stack comprising one or more instances of the basic unit of MPLS label stack for SFC. Taken together, this stack defines the SFs to be actioned and so defines the SFP that the packet will traverse.
- o When a component of the SFC system processes a packet it uses the top basic unit of label stack for SFC to determine to which SFI to next deliver the packet. When an SFF receives a packet it examines the top basic unit of MPLS label stack for SFC to

determine where to send the packet next. If the next recipient is a local SFI, the SFC strips the basic unit of MPLS label stack for SFC before forwarding the packet.



Figure 3: The MPLS SFC Label Stack for Segment Routing

6. Control Plane Considerations

In order that a packet may be forwarded along an SFP several functional elements must be executed.

- o Discovery/advertisement of SFIs.
- o Computation of SFP.
- o Programming of Classifiers.
- o Advertisement of forwarding instructions.

Various approaches may be taken. These include a fully centralized model where SFFs report to a central controller the SFIs that they

support, the central controller computes the SFP and programs the Classifiers, and (if the label swapping approach is taken) the central controller installs forwarding state in the SFFs that lie on the SFP.

Alternatively, a dynamic control plane may be used such as that described in [[I-D.ietf-bess-nsh-bgp-control-plane](#)]. In this case the SFFs use the control plane to advertise the SFIs that they support, a central controller computes the SFP and programs the Classifiers, and (if the label swapping approach is taken) the central controller uses the control plane to advertise the SFPs so that SFFs that lie on the SFP can install the necessary forwarding state.

7. Use of the Entropy Label

Entropy is used in ECMP situations to ensure that packets from the same flow travel down the same path, thus avoiding jitter or re-ordering issues in a flow.

Entropy is often determined by hashing on specific fields in a packet header such as the "five-tuple" in the IP and transport headers. However, when an MPLS label stack is present, the depth of the stack could be too large for some processors to correctly determine the entropy hash. This problem is addressed by the inclusion of an Entropy Label as described in [[RFC6790](#)].

When entropy is desired for packets as they are carried in MPLS tunnels over the underlay network, it is RECOMMENDED that an Entropy Label is included in the label stack immediately after the tunnel labels and before the SFC labels as shown in Figure 2 and Figure 3.

If an Entropy Label is present in a packet received by an SR-capable node (at the end of a tunnel across the underlay network), it is RECOMMENDED that the value of that label is preserved and used in an Entropy Label inserted in the label stack when the packet is forwarded (on the next tunnel) to the next SFF.

If an Entropy Label is present in an MPLS payload, it is RECOMMENDED that the initial Classifier use that value in an Entropy Label inserted in the label stack when the packet is forwarded (on the first tunnel) to the first SFF. In this case it is not necessary to remove the Entropy Label from the payload.

8. Metadata

Metadata is defined in [[RFC7665](#)] as providing "the ability to exchange context information between classifiers and SFs, and among

SFs." [I-D.ietf-sfc-nsh] defines how the context information can be directly encoded in fields that form part of the NSH encapsulation.

The next two sections describe how metadata is associated with user data packets, and how metadata may be exchanged between SFC nodes in the network.

8.1. Indicating Metadata in User Data Packets

Metadata is achieved in the MPLS realization of the logical NSH by the use of an SFC Metadata Label which uses the Extended Special Purpose Label construct [RFC7274]. Thus, three label stack entries are present as shown in Figure 4:

- o The Extension Label (value 15)
- o An extended special purpose label called the Metadata Label Indicator (MLI) (value TBD1 by IANA)
- o The Metadata Label (ML).

```
-----  
| Extension = 15 |  
+-----+  
|      MLI      |  
+-----+  
| Metadata Label |  
-----
```

Figure 4: The MPLS SFC Metadata Label

The Metadata Label value is an index into a table of metadata that is programmed into the network using in-band or out-of-band mechanisms. Out-of-band mechanisms potentially include management plane and control plane solutions (such as [I-D.ietf-bess-nsh-bgp-control-plane]), but are out of scope for this document. The in-band mechanism is described in [Section 8.2](#)

The SFC Metadata Label (as a set of three labels as indicated in Figure 4) may be present zero, one, or more times in an MPLS SFC packet. For MPLS label swapping, the SFC Metadata Labels are placed immediately after the basic unit of MPLS label stack for SFC as shown in Figure 5. For MPLS-SR, the SFC Metadata can be present zero, one, or more times and are placed at the bottom of the label stack as shown in Figure 6.

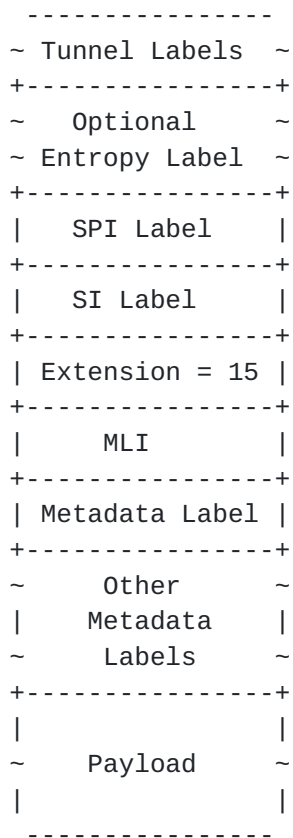


Figure 5: The MPLS SFC Label Stack for Label Swapping with Metadata Label

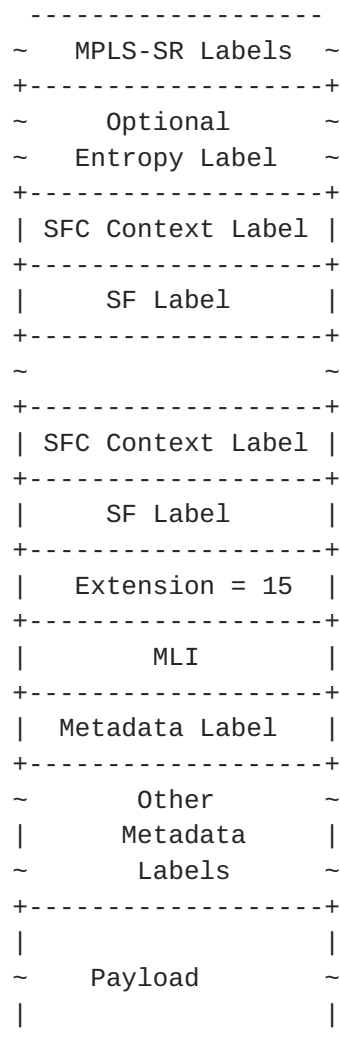


Figure 6: The MPLS SFC Label Stack for MPLS-SR with Metadata Label

8.2. Inband Programming of Metadata

A mechanism for sending metadata associated with an SFP without a payload packet is described in [[I-D.farrel-sfc-convent](#)]. The same approach can be used in an MPLS network where the NSH is logically represented by an MPLS label stack.

The packet header is formed exactly as previously described in this document so that the packet will follow the SFP through the SFC network. An Extended Special Purpose Label is used to indicate that metadata is present. Thus, three label stack entries are present:

- o The Extension Label (value 15)

- o An extended special purpose label called the Metadata Present Indicator (MPI) (value TBD2 by IANA)
- o The Metadata Label (ML) that is associated with this metadata on this SFP and can be used to indicate the use of the metadata as described in [Section 8](#).

The SFC Metadata Present Label, if present, is placed immediately after the last basic unit of MPLS label stack for SFC. The resultant label stacks are shown in Figure 7 for the MPLS label swapping case and Figure 8 for the MPLS-SR case.

```

-----
~ Tunnel Labels ~
+-----+
~ Optional ~
~ Entropy Label ~
+-----+
| SPI Label |
+-----+
| SI Label |
+-----+
| Extension = 15|
+-----+
| MPI |
+-----+
| Metadata Label|
+-----+
| Metadata |
~ ~
|
-----

```

Figure 7: The MPLS SFC Label Stack Carrying Metadata

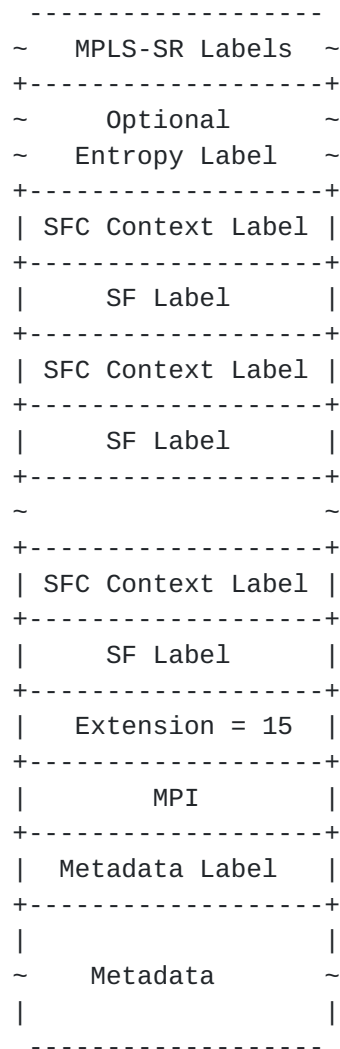


Figure 8: The MPLS SFC Label Stack for MPLS-SR Carrying Metadata

In both cases the metadata is formatted as a TLV as shown in Figure 9.

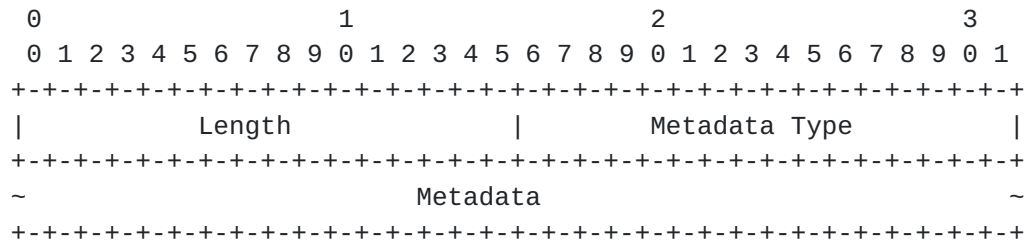


Figure 9: The Metadata TLV

The fields of this TLV are interpreted as follows:

Length: The length of the metadata carried the Metadata field in octets not including any padding.

Metadata Type: The type of the metadata present. Values for this field are taken from the "MD Types" registry maintained by IANA and defined in [[I-D.ietf-sfc-nsh](#)].

Metadata: The actual metadata formatted as described in whatever document defines the metadata. This field is end-padded with zero to three octets of zeroes to take it up to a four octet boundary.

9. Worked Examples

Consider the simplistic MPLS SFC overlay network shown in Figure 10. A packet is classified for an SFP that will see it pass through two Service Functions, SFa and SFb, that are accessed through Service Function Forwarders SFFa and SFFb respectively. The packet is ultimately delivered to destination, D.

Let us assume that the SFP is computed and assigned the SPI of 239. The forwarding details of the SFP are distributed (perhaps using the mechanisms of [[I-D.ietf-bess-nsh-bgp-control-plane](#)]) so that the SFFs are programmed with the necessary forwarding instructions.

The packet progresses as follows:

- a. The Classifier assigns the packet to the SFP and imposes two label stack entries comprising a single basic unit of MPLS SFC representation:
 - * The higher label stack entry contains a label carrying the SPI value of 239.
 - * The lower label stack entry contains a label carrying the SI value of 255.

Further labels may be imposed to tunnel the packet from the Classifier to SFFa.

- b. When the packet arrives at SFFa it strips any labels associated with the tunnel from the Classifier. SFFa examines the top labels and matches the SPI/SI to identify that the packet should be forwarded to SFa. The packet is forwarded to SFa unmodified.
- c. SFa performs its designated function and returns the packet to SFFa.

- d. SFFa modifies the SI in the lower label stack entry (to 254) and uses the SPI/SI to look up the forwarding instructions. It sends the packet with two label stack entries:
- * The higher label stack entry contains a label carrying the SPI value of 239.
 - * The lower label stack entry contains a label carrying the SI value of 254.
- Further labels may be imposed to tunnel the packet from the SFFa to SFFb.
- e. When the packet arrives at SFFb it strips any labels associated with the tunnel from SFFa. SFFb examines the top labels and matches the SPI/SI to identify that the packet should be forwarded to SFb. The packet is forwarded to SFb unmodified.
- f. SFb performs its designated function and returns the packet to SFFb.
- g. SFFb modifies the SI in the lower label stack entry (to 253) and uses the SPI/SI to lookup up the forwarding instructions. It determines that it is the last SFF in the SFP so it strips the two SFC label stack entries and forwards the payload toward D using the payload protocol.

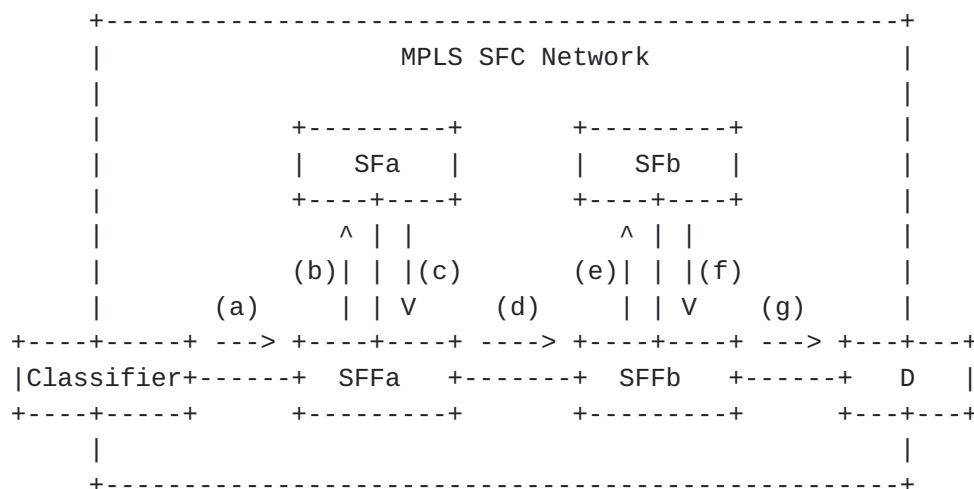


Figure 10: Service Function Chaining in an MPLS Network

Alternatively, consider the MPLS SFC overlay network shown in Figure 11. A packet is classified for an SFP that will see it pass

through two Service Functions, SF1 and SF2, that are accessed through Service Function Forwarders SFF1 and SFF2 respectively. The packet is ultimately delivered to destination, D.

Let us assume that the SFP is computed and assigned the SPI of 239. However, the forwarding state for the SFP is not distributed and installed in the network. Instead it will be attached to the individual packets using MPLS-SR.

The packet progresses as follows:

1. The Classifier assigns the packet to the SFP and imposes two basic units of MPLS SFC representation to describe the full SFP:

- * The top basic unit comprises two label stack entries as follows:
 - + The higher label stack entry contains a label carrying the SFC context.
 - + The lower label stack entry contains a label carrying the SF indicator for SF1.
- * The lower basic unit comprises two label stack entries as follows:
 - + The higher label stack entry contains a label carrying the SFC context.
 - + The lower label stack entry contains a label carrying the SF indicator for SF2.

Further labels may be imposed to tunnel the packet from the Classifier to SFF1.

2. When the packet arrives at SFF1 it strips any labels associated with the tunnel from the Classifier. SFF1 examines the top labels and matches the context/SF values to identify that the packet should be forwarded to SF1. The packet is forwarded to SF1 unmodified.
3. SF1 performs its designated function and returns the packet to SFF1.
4. SFF1 strips the top basic unit of MPLS SFC representation revealing the next basic unit. It then uses the revealed context/SF values to determine how to route the packet to the

next SFF, SFF2. It sends the packet with just one basic unit of MPLS SFC representation comprising two label stack entries:

- * The higher label stack entry contains a label carrying the SFC context.
- * The lower label stack entry contains a label carrying the SF indicator for SF2.

Further labels may be imposed to tunnel the packet from the SFF1 to SFF2.

5. When the packet arrives at SFF2 it strips any labels associated with the tunnel from SFF1. SFF2 examines the top labels and matches the context/SF values to identify that the packet should be forwarded to SF2. The packet is forwarded to SF2 unmodified.
6. SF2 performs its designated function and returns the packet to SFF2.
7. SFF2 strips the top basic unit of MPLS SFC representation revealing the payload packet. It forwards the payload toward D using the payload protocol.

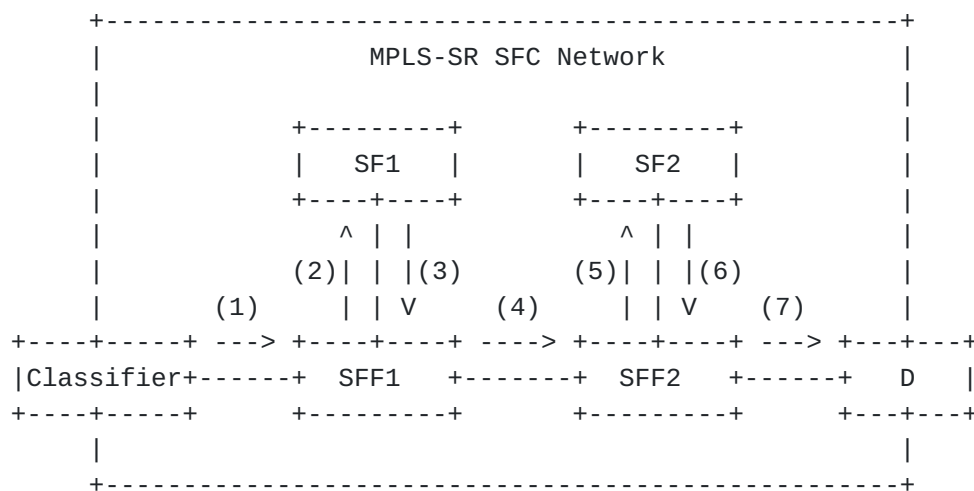


Figure 11: Service Function Chaining in an MPLS-SR Network

10. Security Considerations

Discussion of the security properties of SFC networks can be found in [RFC7665]. Further security discussion for the NSH and its use is present in [I-D.ietf-sfc-nsh].

It is fundamental to the SFC design that the classifier is a trusted resource which determines the processing that the packet will be subject to, including for example the firewall. It is also fundamental to the Segment Routing design that packets are routed through the network using the path specified by the node imposing the SIDs. Where an SF is not encapsulation aware the packet may exist as an IP packet, however this is an intrinsic part of the SFC design which needs to define how a packet is protected in that environment. Where a tunnel is used to link two non-MPLS domains, the tunnel design needs to specify how it is secured. Thus the security vulnerabilities are addressed in the underlying technologies used by this design, which itself does not introduce any new security vulnerabilities.

11. IANA Considerations

This document requests IANA to make allocations from the "Extended Special-Purpose MPLS Label Values" subregistry of the "Special-Purpose Multiprotocol Label Switching (MPLS) Label Values" registry as follows:

Value	Description	
-----+-----+-----		
TBD1	Metadata Label Indicator (MLI)	[This.I-D]
TBD2	Metadata Present Indicator (MPI)	[This.I-D]

12. Acknowledgements

This document derives ideas and text from [\[I-D.ietf-bess-nsh-bgp-control-plane\]](#).

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13. References

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