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Hierarchical Service Function Chaining (hSFC)

Abstract

Hierarchical Service Function Chaining (hSFC) is a network architecture allowing an organization to decompose a large-scale network into multiple domains of administration.

The goals of hSFC are to make a large-scale network easier to design, simpler to control, and supportive of independent functional groups within large network operators.

Status of This Memo

This document is not an Internet Standards Track specification; it is published for examination, experimental implementation, and evaluation.

This document defines an Experimental Protocol for the Internet community. This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Not all documents approved by the IESG are candidates for any level of Internet Standard; see Section 2 of RFC 7841.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at https://www.rfc-editor.org/info/rfc8459.

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1. Introduction

Service Function Chaining (SFC) is a technique for prescribing differentiated traffic-forwarding policies within an SFC-enabled domain. The SFC architecture is described in detail in [RFC7665] and is not repeated here.

This document focuses on the difficult problem of implementing SFC across a large, geographically dispersed network, potentially comprised of millions of hosts and thousands of network-forwarding elements and which may involve multiple operational teams (with varying functional responsibilities). We recognize that some stateful Service Functions (SFs) require bidirectional traffic for transport-layer sessions (e.g., NATs, firewalls). We assume that some Service Function Paths (SFPs) need to be selected on the basis of transport-layer coordinate (typically, the 5-tuple of source IP address, source port number, destination IP address, destination port number, and transport protocol) stickiness to specific stateful SF instances.

Difficult problems are often made easier by decomposing them in a hierarchical (nested) manner. So, instead of considering a single SFC control plane that can manage (create, withdraw, supervise, etc.) complete SFPs from one end of the network to the other, we decompose the network into smaller domains operated by as many SFC control plane components (under the same administrative entity). Coordination between such components is further discussed in this document.

Each subdomain may support a subset of the network applications or a subset of the users. Decomposing a network should be done with care to ease monitoring and troubleshooting of the network and services as a whole. The criteria for decomposing a domain into multiple SFC-enabled subdomains are beyond the scope of this document. These criteria are deployment specific.

An example of simplifying a network by using multiple SFC-enabled domains is further discussed in [USE-CASES].

We assume the SFC-aware nodes use the Network Service Header (NSH) [RFC8300] or a similar labeling mechanism. Examples are described in Appendix A.

The SFC-enabled domains discussed in this document are assumed to be under the control of a single organization (an operator, typically), such that there is a strong trust relationship between the domains. The intention of creating multiple domains is to improve the ability

to operate a network. It is outside of the scope of this document to consider domains operated by different organizations or dwell on interoperator considerations.

We introduce the concept of an Internal Boundary Node (IBN) that acts as a gateway between the levels of the hierarchy. We also discuss options for realizing this function.

1.1. Experiment Goals

This document defines an architecture that aims to solve complications that may be encountered when deploying SFC in large networks. A single network is therefore decomposed into multiple subdomains, each treated as an SFC-enabled domain. Levels of hierarchy are defined, together with SFC operations that are specific to each level. In order to ensure consistent SFC operations when multiple subdomains are involved, this document identifies and analyzes various options for IBNs to glue the layers together (Section 4.1).

Because it does not make any assumptions about (1) how subdomains are defined, (2) whether one or multiple IBNs are enabled per subdomain, (3) whether the same IBN is solicited at both the ingress and egress of a subdomain for the same flow, (4) the nature of the internal paths to reach SFs within a subdomain, or (5) the lack of deployment feedback, this document does not call for a recommended option to glue the SFC layers together.

Further experiments are required to test and evaluate the different options. A recommendation for hSFC might be documented in a future specification when the results of implementation and deployment of the aforementioned options are available.

It is not expected that all the options discussed in this document will be implemented and deployed. The lack of an implementation might be seen as a signal to recommend against a given option.

2. Terminology

This document makes use of the terms defined in Section 1.4 of [RFC7665] and Section 1.3 of [RFC8300].

The following terms are defined:

- Upper-level domain: the entire network domain to be managed.
- Lower-level domain: a portion of the network (called a subdomain).
- Internal Boundary Node (IBN): is responsible for bridging packets between upper and lower levels of SFC-enabled domains.

3. Hierarchical Service Function Chaining (hSFC)

A hierarchy has multiple levels: the topmost level encompasses the entire network domain to be managed, and lower levels encompass portions of the network. These levels are discussed in the following subsections.

3.1. Upper Level

Considering the example depicted in Figure 1, a top-level network domain includes SFC data plane components distributed over a wide area, including:

- Classifiers (CFs)
- Service Function Forwarders (SFFs)
- Subdomains

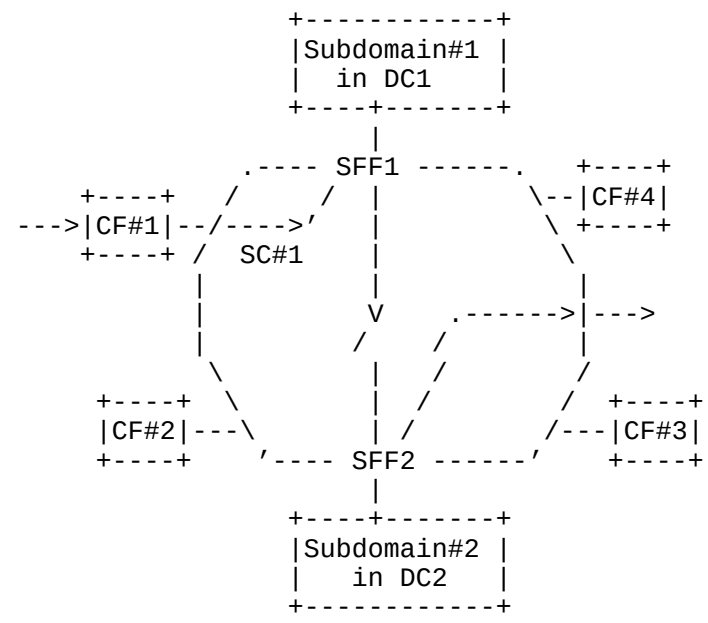


Figure 1: Network-Wide View of Upper Level of Hierarchy

One path is shown from edge classifier (CF#1) to SFF1 to Subdomain#1 (residing in Data Center 1) to SFF1 to SFF2 (residing in Data Center 2) to Subdomain#2 to SFF2 to network egress.

For the sake of clarity, components of the underlay network are not shown; an underlay network is assumed to provide connectivity between SFC data plane components.

Top-level SFPs carry packets from classifiers through a set of SFFs and subdomains, with the operations within subdomains being opaque to the upper levels.

We expect the system to include a top-level control plane having responsibility for configuring forwarding policies and traffic-classification rules.

The top-level Service Chaining control plane manages end-to-end service chains and associated service function paths from network edge points to subdomains. It also configures top-level classifiers

at a coarse level (e.g., based on source or destination host) to forward traffic along paths that will transit across appropriate subdomains.

Figure 1 shows one possible service chain passing from the edge through two subdomains to network egress. The top-level control plane does not configure traffic-classification rules or forwarding policies within the subdomains.

At this network-wide level, the number of SFPs required is a linear function of the number of ways in which a packet is required to traverse different subdomains and egress the network. Note that the various paths that may be followed within a subdomain are not represented by distinct network-wide SFPs; specific policies at the ingress nodes of each subdomain bind flows to subdomain paths.

Packets are classified at the edge of the network to select the paths by which subdomains are to be traversed. At the ingress of each subdomain, packets are reclassified to paths directing them to the required SFs of the subdomain. At the egress of each subdomain, packets are returned to the top-level paths. Contrast this with an approach requiring the top-level classifier to select paths to specify all of the SFs in each subdomain.

It should be assumed that some SFs require bidirectional symmetry of paths (see more in Section 5). Therefore, the classifiers at the top level must be configured with policies ensuring outgoing packets take the reverse path of incoming packets through subdomains.

3.2. Lower Levels

Each of the subdomains in Figure 1 is an SFC-enabled domain.

Figure 2 shows a subdomain interfaced with an upper-level domain by means of an Internal Boundary Node (IBN). An IBN acts as an SFC-aware SF in the upper-level domain and as a classifier in the lower-level domain. As such, data packets entering the subdomain are already SFC encapsulated. Also, it is the purpose of the IBN to apply classification rules and direct the packets to the selected local SFPs terminating at an egress IBN. Finally, the egress IBN restores packets to the original SFC shim and hands them off to SFFs.

Each subdomain intersects a subset of the total paths that are possible in the upper-level domain. An IBN is concerned with upper-level paths, but only those traversing its subdomain.

Each subdomain is likely to have a control plane that can operate independently of the top-level control plane, managing classification, forwarding paths, etc., within the level of the subdomain, with the details being opaque to the upper-level control elements. Section 4 provides more details about the behavior of an IBN.

The subdomain control plane configures the classification rules in the IBN, where SFC encapsulation of the top-level domain is converted to/from SFC encapsulation of the lower-level domain. The subdomain control plane also configures the forwarding rules in the SFFs of the subdomain.

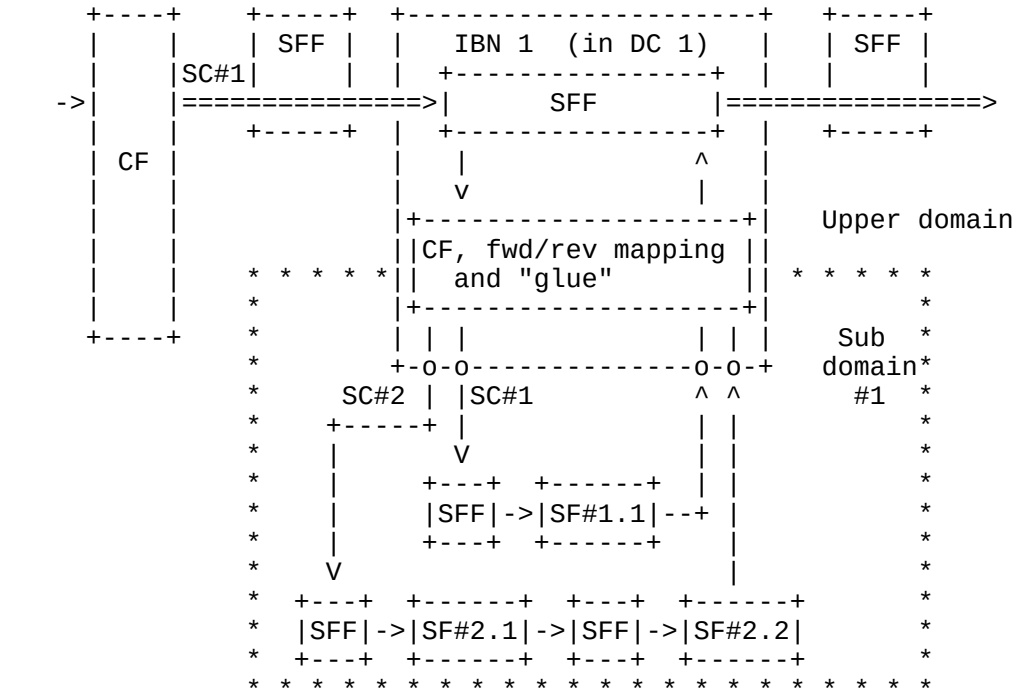


Figure 2: Example of a Subdomain within an Upper-Level Domain

If desired, the pattern can be applied recursively. For example, SF#1.1 in Figure 2 could be a subdomain of the subdomain.

4. Internal Boundary Node (IBN)

As mentioned in the previous section, a network element termed an "Internal Boundary Node" (or IBN) is responsible for bridging packets between upper and lower layers of SFC-enabled domains. It behaves as an SF to the upper level (Section 3.1) and looks like a classifier and end of chain to the lower level (Section 3.2).

To achieve the benefits of hierarchy, the IBN should be applying fine-grained traffic-classification rules at a lower level than the traffic passed to it. This means that the number of SFPs within the lower level is greater than the number of SFPs arriving to the IBN.

The IBN is also the termination of lower-level SFPs. This is because the packets exiting lower-level SFPs must be returned to the upper-level SFPs and forwarded to the next hop in the upper-level domain.

When different metadata schemes are used at different levels, the IBN has further responsibilities: when packets enter the subdomain, the IBN translates upper-level metadata into lower-level metadata; and when packets leave the subdomain at the termination of lower-level SFPs, the IBN translates lower-level metadata into upper-level metadata.

Appropriately configuring IBNs is key to ensuring the consistency of the overall SFC operation within a given domain that enables hSFC. Classification rules (or lack thereof) in the IBN classifier can, of course, impact upper levels.

4.1. IBN Path Configuration

The lower-level domain may be provisioned with valid upper-level paths or allow any upper-level paths.

When packets enter the subdomain, the Service Path Identifier (SPI) and Service Index (SI) are re-marked according to the path selected by the (subdomain) classifier.

At the termination of an SFP in the subdomain, packets can be restored to an original upper-level SFP by implementing one of these methods:

1. Saving the SPI and SI in transport-layer flow state (Section 4.1.1).

2. Pushing the SPI and SI into a metadata header (Section 4.1.2).

3. Using unique lower-level paths per upper-level path coordinates (Section 4.1.3).

4. Nesting NSH headers, encapsulating the upper-level NSH headers within the lower-level NSH headers (Section 4.1.4).

5. Saving the upper level with a flow identifier (ID) and placing an hSFC Flow ID into a metadata header (Section 4.1.5).

4.1.1. Flow-Stateful IBN

An IBN can be flow aware, returning packets to the correct upper-level SFP on the basis, for example, of the transport-layer coordinates (typically, a 5-tuple) of packets exiting the lower-level SFPs.

When packets are received by the IBN on an upper-level path, the classifier parses encapsulated packets for IP and transport-layer (TCP, UDP, etc.) coordinates. State is created, indexed by some or all transport coordinates (typically, {source-IP, destination-IP, source-port, destination-port, and transport protocol}). The state contains, at minimum, the critical fields of the encapsulating SFC header (SPI, SI, MD Type, flags); additional information carried in the packet (metadata, TTL) may also be extracted and saved as state. Note that some fields of a packet may be altered by an SF of the subdomain (e.g., source IP address).

Note that this state is only accessed by the classifier and terminator functions of the subdomain. Neither the SFFs nor SFs have knowledge of this state; in fact they may be agnostic about being in a subdomain.

One approach is to ensure that packets are terminated at the end of the chain at the same IBN that classified the packet at the start of the chain. If the packet is returned to a different egress IBN, state must be synchronized between the IBNs.

When a packet returns to the IBN at the end of a chain (which is the SFP-terminating node of the lower-level chain), the SFC header is removed, the packet is parsed for flow-identifying information, and state is retrieved from within the IBN using the flow-identifying information as index.

State cannot be created by packets arriving from the lower-level chain; when state cannot be found for such packets, they must be dropped.

This stateful approach is limited to use with SFs that retain the transport coordinates of the packet. This approach cannot be used with SFs that modify those coordinates (e.g., NATs) or otherwise create packets for new coordinates other than those received (e.g., as an HTTP cache might do to retrieve content on behalf of the original flow). In both cases, the fundamental problem is the inability to forward packets when state cannot be found for the packet transport-layer coordinates.

In the stateful approach, there are issues caused by having state, such as how long the state should be maintained as well as whether the state needs to be replicated to other devices to create a highly available network.

It is valid to consider the state to be disposable after failure, since it can be recreated by each new packet arriving from the upper-level domain. For example, if an IBN loses all flow state, the state is recreated by an endpoint retransmitting a TCP packet.

If an SFC domain handles multiple network regions (e.g., multiple private networks), the coordinates may be augmented with additional parameters, perhaps using some metadata to identify the network region.

In this stateful approach, it is not necessary for the subdomain’s control plane to modify paths when upper-level paths are changed. The complexity of the upper-level domain does not cause complexity in the lower-level domain.

Since it doesn’t depend on NSH in the lower-level domain, this flow-stateful approach can be applied to translation methods of converting NSH to other forwarding techniques (refer to Section 7).

4.1.2. Encoding Upper-Level Paths in Metadata

An IBN can push the upper-level SPI and SI (or encoding thereof) into a metadata field of the lower-level encapsulation (e.g., placing upper-level path information into a metadata field of the NSH). When packets exit the lower-level path, the upper-level SPI and SI can be restored from the metadata retrieved from the packet.

This approach requires the SFs in the path to be capable of forwarding the metadata and appropriately attaching metadata to any packets injected for a flow.

Using a new metadata header may inflate packet size when variable-length metadata (NSH MD Type 0x2) is used.

It is conceivable that the MD Type 0x1 Fixed-Length Context Header field of the NSH is not all relevant to the lower-level domain. In this case, 32 bits of the Fixed-Length Context Header field could be repurposed within the lower-level domain and restored when leaving.

If flags or TTL (see Section 4.4) from the original header also need to be saved, more metadata space will be consumed.

In this metadata approach, it is not necessary for the subdomain's control element to modify paths when upper-level paths are changed. The complexity of the upper-level domain does not increase complexity in the lower-level domain.

4.1.3. Using Unique Paths per Upper-Level Path

This approach assumes that paths within the subdomain are constrained so that an SPI (of the subdomain) unambiguously indicates the egress SPI and SI (of the upper domain). This allows the original path information to be restored at subdomain egress from a look-up table using the subdomain SPI.

Whenever the upper-level domain provisions a path via the lower-level domain, the lower-level domain control plane must provision corresponding paths to traverse the lower-level domain.

A downside of this approach is that the number of paths in the lower-level domain is multiplied by the number of paths in the upper-level domain that traverse the lower-level domain. That is, a subpath must be created for each combination of upper SPI/SI and lower chain. The number of paths required for lower-level domains will increase exponentially as hierarchy becomes deep.

A further downside of this approach is that it requires upper and lower levels to utilize the same metadata configuration.

Furthermore, this approach does not allow any information to be stashed away in state or embedded in metadata. For example, the TTL modifications by the lower level cannot be hidden from the upper level.

4.1.4. Nesting Upper-Level NSH within Lower-Level NSH

When packets arrive at an IBN in the top-level domain, the classifier in the IBN determines the path for the lower-level domain and pushes the new NSH header in front of the original NSH header.

As shown in Figure 3, the Lower-NSH header used to forward packets in the lower-level domain precedes the Upper-NSH header from the top-level domain.

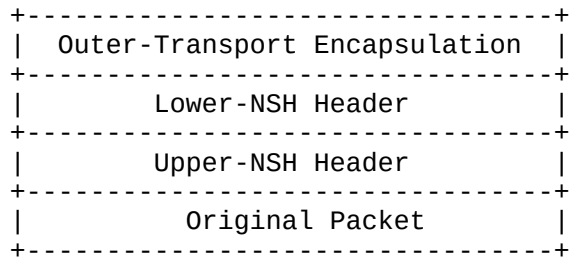


Figure 3: Encapsulation of NSH within NSH

The traffic with this stack of two NSH headers is to be forwarded according to the Lower-NSH header in the lower-level SFC domain. The Upper-NSH header is preserved in the packets but not used for forwarding. At the last SFF of the chain of the lower-level domain (which resides in the IBN), the Lower-NSH header is removed from the packet, and then the packet is forwarded by the IBN to an SFF of the upper-level domain. The packet will be forwarded in the top-level domain according to the Upper-NSH header.

With such encapsulation, Upper-NSH information is carried along the extent of the lower-level chain without modification.

A benefit of this approach is that it does not require state in the IBN or configuration to encode fields in metadata. All header fields, including flags and TTL, are easily restored when the chains of the subdomain terminate.

However, the downside is that it does require SFC-aware SFs in the lower-level domain to be able to parse multiple NSH layers. If an SFC-aware SF injects packets, it must also be able to deal with adding appropriate multiple layers of headers to injected packets.

By increasing packet overhead, nesting may lead to fragmentation or decreased MTU in some networks.

4.1.5. Stateful/Metadata Hybrid

The basic idea of this approach is for the IBN to save upper domain encapsulation information such that it can be retrieved by a unique identifier, termed an "hSFC Flow ID".

The hSFC Flow ID is placed, for example, in the NSH Fixed-Length Context Header field of the packet in the lower-level domain, as shown in Figure 4. Likewise, hSFC Flow ID may be encoded as a Variable-Length Context Header field when MD Type 0x2 is used.

When packets exit the lower-level domain, the IBN uses the hSFC Flow ID to retrieve the appropriate NSH encapsulation for returning the packet to the upper domain. The hSFC Flow ID Context Header is then stripped by the IBN.

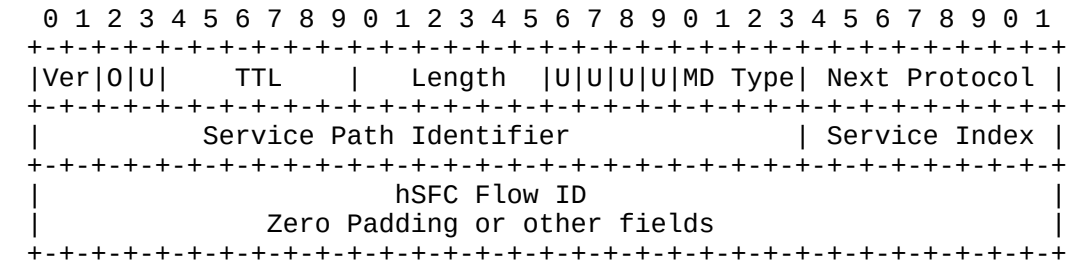


Figure 4: Storing hSFC Flow ID in Lower-Level NSH Fixed-Length Context Header Field ([RFC8300], Section 2.4)

Advantages of this approach include:

- It does not require state to be based on a 5-tuple, so it works with SFs that change the IP addresses or port numbers of a packet, such as NATs.
- It does not require all domains to have the same metadata scheme.
- It can be used to restore any upper-domain information, including metadata, flags, and TTL, not just the service path.
- The lower-level domain only requires a single item of metadata regardless of the number of items of metadata used in the upper domain.
- The SFC-related functionality required by this approach in an SFC-aware SF is able to preserve and apply metadata, which is a requirement that was already present in [RFC8300].

Disadvantages include those of other stateful approaches, including state timeout and synchronization, mentioned in Section 4.1.1.

There may be a large number of unique NSH encapsulations to be stored, given that the hSFC Flow ID must represent all of the bits in the upper-level encapsulation. This might consume a lot of memory or

create out-of-memory situations in which hSFC Flow IDs cannot be created or old hSFC Flow IDs are discarded while still in use.

4.2. Gluing Levels Together

The SPI or metadata included in a packet received by the IBN may be used as input to reclassification and path selection within a lower-level domain.

In some cases, the meanings of the various path IDs and metadata must be coordinated between domains for the sake of proper end-to-end SFC operation.

One approach is to use well-known identifier values in metadata, maintained in a global registry.

Another approach is to use well-known labels for chain identifiers or metadata, as an indirection to the actual identifiers. The actual identifiers can be assigned by control-plane systems. For example, a subdomain classifier could have a policy, "if pathID = classA then chain packet to path 1234"; the upper-level controller would be expected to configure the concrete upper-level "pathID" for "classA".

4.3. Decrementing Service Index

Because the IBN acts as an SFC-aware SF to the upper-level domain, it must decrement the Service Index in the NSH headers of the upper-level path. This operation should be undertaken when the packet is first received by the IBN, before applying any of the strategies of Section 4.1, immediately prior to classification.

4.4. Managing TTL

The NSH base header contains a TTL field [RFC8300]. There is a choice:

a subdomain may appear as a pure service function, which should not decrement the TTL from the perspective of the upper-level domain, or

all of the TTL changes within the subdomain may be visible to the upper-level domain.

Some readers may recognize this as a choice between "pipe" and "uniform" models, respectively [RFC3443].

The network operator should be given control of this behavior, choosing whether to expose the lower-level topology to the upper layer. An implementation may support per-packet policy, allowing some users to perform a layer-transcending trace route, for example.

The choice affects whether the methods of restoring the paths in Section 4.1 restore a saved version of the TTL or propagate it with the packet. The method of Section 4.1.3 does not permit topology hiding. The other methods of Sections 4.1.1, 4.1.2, 4.1.4, and 4.1.5 have unique methods for restoring saved versions of the TTL.

5. Subdomain Classifier

Within the subdomain (referring to Figure 2), as the classifier receives incoming packets, the upper-level encapsulation is treated according to one of the methods described in Section 4.1 to either statefully store, encode, or nest header information. The classifier then selects the path and metadata for the packet within the subdomain.

One of the goals of the hierarchical approach is to make it easy to have transport-flow-aware service chaining with bidirectional paths. For example, it is desired that for each TCP flow, the client-to-server packets traverse the same SF instances as the server-to-client packets, but in the opposite sequence. We call this "bidirectional symmetry". If bidirectional symmetry is required, it is the responsibility of the control plane to be aware of symmetric paths and configure the classifier to chain the traffic in a symmetric manner.

Another goal of the hierarchical approach is to simplify the mechanisms of scaling SFs in and out. All of the complexities of load-balancing among multiple SFs can be handled within a subdomain, under control of the classifier, allowing the upper-level domain to be oblivious to the existence of multiple SF instances.

Considering the requirements of bidirectional symmetry and load-balancing, it is useful to have all packets entering a subdomain be received by the same classifier or a coordinated cluster of classifiers. There are both stateful and stateless approaches to ensuring bidirectional symmetry.

6. Control Plane Elements

Although SFC control protocols have not yet been standardized (as of 2018), from the point of view of hierarchical service function chaining, we have these expectations:

- Each control-plane instance manages a single level of the hierarchy of a single domain.

- Each control plane is agnostic about other levels of the hierarchy. This aspect allows humans to reason about the system within a single domain and control-plane algorithms to use only domain-local inputs. Top-level control does not need visibility to subdomain policies, nor does subdomain control need visibility to upper-level policies. (Top-level control considers a subdomain as though it were an SF.)

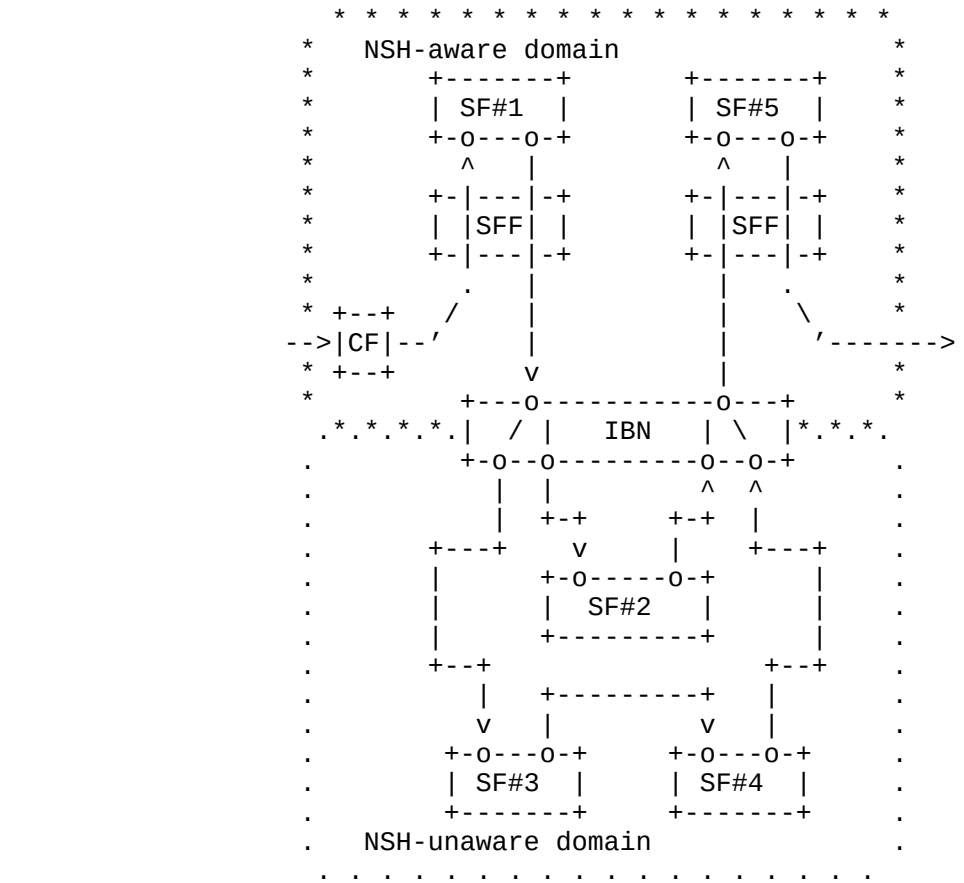
- Subdomain control planes are agnostic about the control planes of other subdomains. This allows both humans and machines to manipulate subdomain policy without considering policies of other domains.

Recall that the IBN acts as an SFC-aware SF in the upper-level domain (receiving SF instructions from the upper-level control plane) and as a classifier in the lower-level domain (receiving classification rules from the subdomain control plane). In this view, it is the IBN that glues the layers together.

These expectations are not intended to prohibit network-wide control. A control hierarchy can be envisaged to distribute information and instructions to multiple domains and subdomains. Control hierarchy is outside the scope of this document.

7. Extension for Adapting to NSH-Unaware Service Functions

The hierarchical approach can be used for dividing networks into NSH-aware and NSH-unaware domains by converting NSH encapsulation to other forwarding techniques (e.g., 5-tuple-based forwarding with OpenFlow), as shown in Figure 5.



SF#1 and SF#5 are NSH aware; SF#2, SF#3, and SF#4 are NSH unaware. In the NSH-unaware domain, packets are conveyed in a format supported by SFs that are deployed there.

Figure 5: Dividing NSH-Aware and NSH-Unaware Domains

7.1. Purpose

This approach is expected to facilitate service chaining in networks in which NSH-aware and NSH-unaware SFs coexist. Some examples of such situations are:

- In a period of transition from legacy SFs to NSH-aware SFs
- Supporting multitenancy

7.2. Requirements for an IBN

In this usage, an IBN classifier is required to have an NSH conversion table for applying packets to appropriate lower-level paths and returning packets to the correct upper-level paths. For example, the following methods would be used for saving/restoring upper-level path information:

- Saving SPI and SI in transport-layer flow state (refer to Section 4.1.1)
- Using unique lower-level paths per upper-level NSH coordinates (refer to Section 4.1.3)

Using the unique paths approach would be especially good for translating NSH to a different forwarding technique in the lower level. A single path in the upper level may be branched to multiple paths in the lower level such that any lower-level path is only used by one upper-level path. This allows unambiguous restoration to the upper-level path.

In addition, an IBN might be required to convert metadata contained in the NSH to the format appropriate to the packet in the lower-level path. For example, some legacy SFs identify subscribers based on information about the network topology, such as the VLAN ID (VID), and the IBN would be required to create a VLAN to packets from metadata if the subscriber identifier is conveyed as metadata in upper-level domains.

Other fundamental functions required for an IBN (e.g., maintaining metadata of upper level or decrementing Service Index) are the same as in normal usage.

It is useful to permit metadata to be transferred between levels of a hierarchy. Metadata from an upper level may be useful within a subdomain, and a subdomain may augment metadata for consumption in an upper domain. However, allowing uncontrolled metadata between domains may lead to forwarding failures.

> In order to prevent SFs of lower-level SFC-enabled domains from supplying (illegitimate) metadata, IBNs may be instructed to only permit specific metadata types to exit the subdomain. Such control over the metadata in the upper level is the responsibility of the upper-level control plane.

To limit unintentional metadata reaching SFs of lower-level SFC-enabled subdomains, IBNs may be instructed to only permit specific metadata types into the subdomain. Such control of metadata in the lower-level domain is the responsibility of the lower-level control plane.

8. IANA Considerations

This document has no IANA actions.

9. Security Considerations

hSFC makes use of service chaining architecture; hence, it inherits the security considerations described in the architecture document [RFC7665].

Furthermore, hSFC inherits the security considerations of the data-plane protocols (e.g., NSH) and control-plane protocols used to realize the solution.

This document describes systems that may be managed by distinct teams that all belong to the same administrative entity. Subdomains must have consistent configurations in order to properly forward traffic. Any protocol designed to distribute the configurations must be secure from tampering. The means of preventing attacks from within a network must be enforced. For example, continuously monitoring the network may allow detecting such misbehaviors. hSFC adheres to the same security considerations as [RFC8300]. Those considerations must be taken into account.

The options in Sections 4.1.2 and 4.1.5 assume the use of a dedicated context header to store information to bind a flow to its upper-level SFP. Such a context header is stripped by the IBN of a subdomain before exiting a subdomain. Additional guards to prevent leaking unwanted context information when entering/exiting a subdomain are discussed in Section 7.2.

All of the systems and protocols must be secure from modification by untrusted agents.

9.1. Control Plane

Security considerations related to the control plane are discussed in the corresponding control specification documents (e.g., [BGP-CONTROL], [PCEP-EXTENSIONS], or [RADIUS]).

9.2. Infinite Forwarding Loops

Distributing policies among multiple domains may lead to forwarding loops. NSH supports the ability to detect loops (as described in Sections 4.3 and 4.4 of [RFC8300]), but the means of ensuring the consistency of the policies should be enabled at all levels of a domain. Within the context of hSFC, it is the responsibility of the Control Elements at all levels to prevent such (unwanted) loops.

10. References

10.1. Normative References

[RFC7665] Halpern, J., Ed. and C. Pignataro, Ed., "Service Function Chaining (SFC) Architecture", RFC 7665, DOI 10.17487/RFC7665, October 2015, <https://www.rfc-editor.org/info/rfc7665>.

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Appendix A. Examples of Hierarchical Service Function Chaining

The advantage of hSFC compared with normal or flat service function chaining is that it can reduce the management complexity significantly. This section discusses examples that show those advantages.

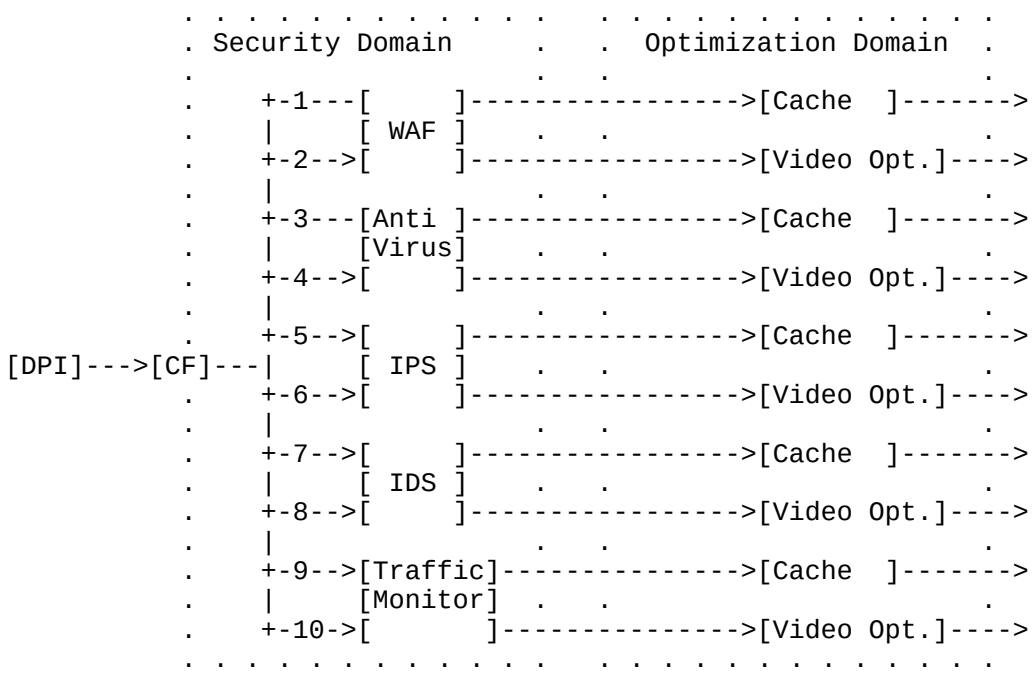
A.1. Reducing the Number of Service Function Paths

In this case, hSFC is used to simplify service function chaining management by reducing the number of SFPs.

As shown in Figure 6, there are two domains, each with different concerns: a Security Domain that selects SFs based on network conditions and an Optimization Domain that selects SFs based on traffic protocol.

In this example, there are five security functions deployed in the Security Domain. The Security Domain operator wants to enforce the five different security policies, and the Optimization Domain operator wants to apply different optimizations (either cache or video optimization) to each of these two types of traffic. If we use flat SFC (normal branching), 10 SFPs are needed in each domain. In contrast, if we use hSFC, only five SFPs in Security Domain and two SFPs in Optimization Domain will be required, as shown in Figure 7.

In the flat model, the number of SFPs is the product of the number of SFs in all of the domains. In the hSFC model, the number of SFPs is the sum of the number of SFs. For example, adding a "bypass" path in the Optimization Domain would cause the flat model to require 15 paths (five more) but cause the hSFC model to require one more path in the Optimization Domain.



Legend:
IDS: Intrusion Detection System
IPS: Intrusion Prevention System
WAF: Web Application Firewall
DPI: Deep Packet Inspection

The classifier must select paths that determine the combination of Security and Optimization concerns. 1:WAF+Cache, 2:WAF+VideoOpt, 3:AntiVirus+Cache, 4:AntiVirus+VideoOpt, 5:IPS+Cache, 6:IPS+VideoOpt, 7:IDS+Cache, 8:IDS+VideoOpt, 9:TrafficMonitor+Cache, 10:TrafficMonitor+VideoOpt

Figure 6: Flat SFC (Normal Branching)

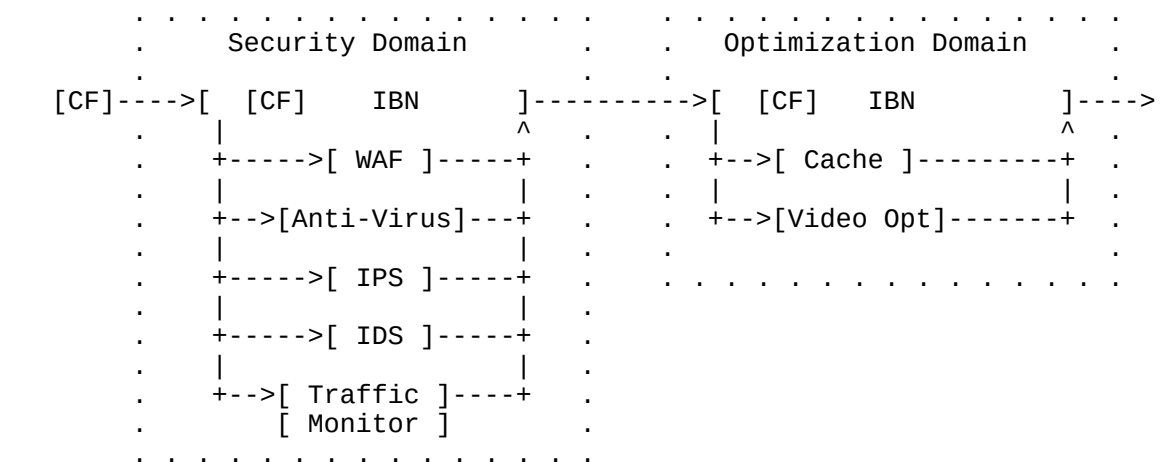


Figure 7: Simplified Path Management with hSFC

A.2. Managing a Distributed DC Network

Hierarchical service function chaining can be used to simplify inter-DC SFC management. In the example of Figure 8, there is a central data center (Central DC) and multiple local data centers (Local DC#1, #2, #3) that are deployed in a geographically distributed manner. All of the data centers are under a single administrative domain.

The central DC may have some service functions that the local DC needs, such that the local DC needs to chain traffic via the central DC. This could be because:

- Some SFs are deployed as dedicated hardware appliances, and there is a desire to lower the cost (both CAPEX and OPEX) of deploying such SFs in all data centers.

- Some SFs are being trialed or introduced, or they otherwise handle a relatively small amount of traffic. It may be cheaper to manage these SFs in a single central data center and steer packets to the central data center than to manage these SFs in all data centers.

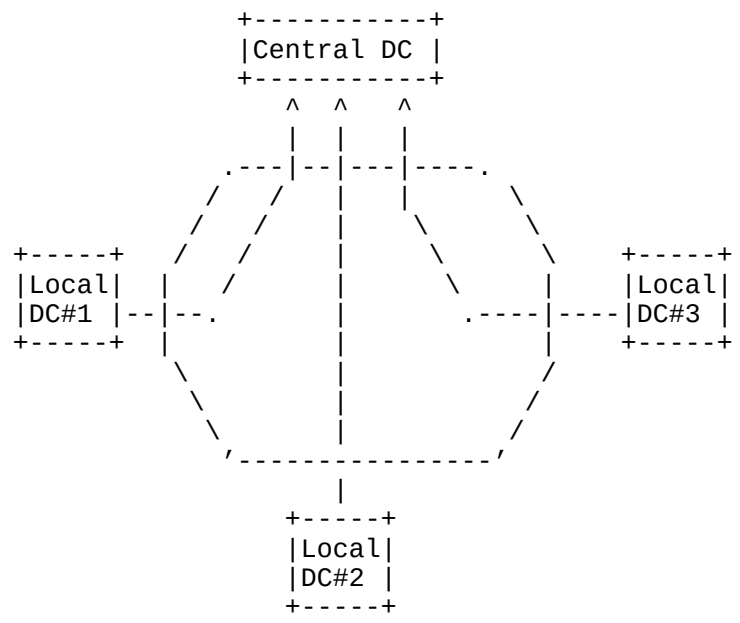


Figure 8: Simplify Inter-DC SFC Management

For large DC operators, one local DC may have tens of thousands of servers and hundreds of thousands of virtual machines. SFC can be used to manage user traffic. For example, SFC can be used to classify user traffic based on service type, DDoS state, etc.

In such a large-scale DC, using flat SFC is very complex, requiring a super controller to configure all DCs. For example, any changes to SFs or SFPs in the central DC (e.g., deploying a new SF) would require updates to all of the SFPs in the local DCs accordingly. Furthermore, requirements for symmetric paths add additional complexity when flat SFC is used in this scenario.

Conversely, if using hierarchical SFC, each DC can be managed independently to significantly reduce management complexity. SFPs between DCs can represent abstract notions without regard to details within DCs. Independent controllers can be used for the top level (getting packets to pass the correct DCs) and local levels (getting packets to specific SF instances).

Acknowledgements

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The concept of nesting NSH headers within lower-level NSH was contributed by Ting Ao. The concept originally appeared in "Hierarchical SFC for DC Interconnection" (April 2016) as a means of creating hierarchical SFC in a data center.

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