Service Function Chaining
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Hierarchical Service Function Chaining
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Abstract

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

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

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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1. Introduction

Service Function Chaining (SFC) is a technique for prescribing differentiated traffic forwarding policies within the SFC domain. SFC is described in detail in the SFC architecture document [I-D.ietf-sfc-architecture], and is not repeated here.

In this document we consider the difficult problem of implementing SFC across a large, geographically dispersed network comprised of millions of hosts and thousands of network forwarding elements, involving multiple operational teams (with varying functional responsibilities). We expect asymmetrical routing is inherent in the

network, while recognizing that some 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 application-specific data visible to the network, with transport-layer coordinate (typically, 5-tuple) stickiness to specific Service Function instances.

Note: in this document, the notion of the "path" of a packet is the series of SF instances traversed by a packet. The means of delivering packets between SFs (the forwarding mechanisms of the underlay network) is not relevant to the current discussion.

Difficult problems are often made easier by decomposing them in a hierarchical (nested) manner. So instead of considering an omniscient 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 sub-domains. Each sub-domain may support a subset of the network applications or a subset of the users. The criteria for determining decomposition into SFC-enabled sub-domains are beyond the scope of this document.

Note that decomposing a network into multiple SFC-enabled domains should permit end-to-end visibility of Service Functions and Service Function Paths. Decomposition should also be implemented with special care to ease monitoring and troubleshooting of the network as a whole.

An example of simplifying a network by using multiple SF domains is further discussed in [I-D.ietf-sfc-dc-use-cases].

We assume the SF technology uses NSH [I-D.ietf-sfc-nsh] or a similar labeling mechanism.

The "domains" discussed in this document are assumed to be under control of a single organization, 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 the document to consider domains operated by different organizations.

1.1. 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 RFC 2119 [RFC2119].

2. Hierarchical Service Function Chaining (hSFC)

A hierarchy has multiple levels. The top-most level encompasses the entire network domain to be managed, and lower levels encompass portions of the network.

2.1. Top Level

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

- classifiers (CFs),
- Service Function Forwarders (SFFs) and
- Sub-domains.

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

Top-level service function paths carry packets from classifiers through a series of SFFs and sub-domains, with the operations within sub-domains being opaque to the higher levels.

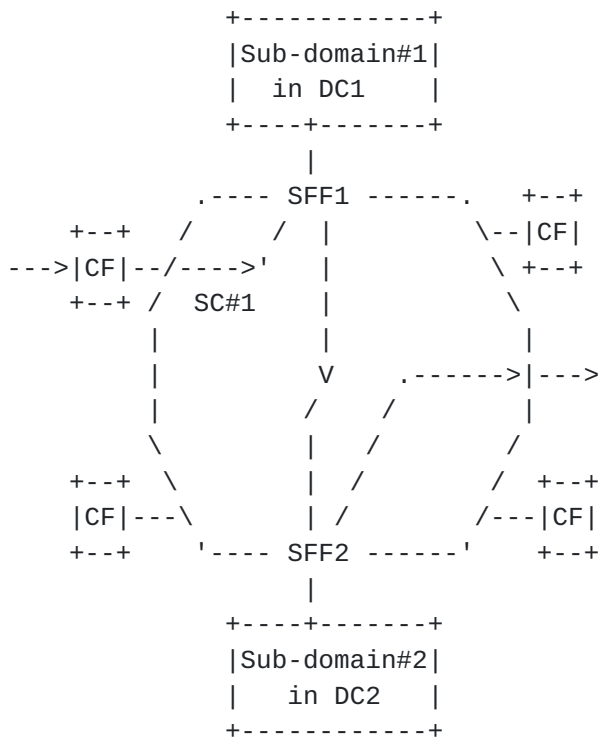
We expect the system to include a top-level control-plane having responsibility for configuring forwarding and classification. The top-level Service Chaining control-plane manages end-to-end service chains and associated service function paths from network edge points to sub-domains and configuring top-level classifiers at a coarse level (e.g., based on source or destination host) to forward traffic along paths that will transit appropriate sub-domains. The figure shows one possible service chain passing from edge, through two sub-domains, to network egress. The top-level control plane does NOT configure classification or forwarding within the sub-domains.

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 sub-domains and egress the network. Note that the various paths which may be taken within a sub-domain are not represented by distinct network-wide SFPs; specific policies at the ingress nodes of each sub-domain bind flows to sub-domain paths.

Packets are classified at the edge of the network to select the paths by which sub-domains are to be traversed. At the ingress of each sub-domain, paths are reclassified to select the paths by which SFs in the sub-domain are to be traversed. At the egress of each sub-domain, 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 sub-domain.

It should be assumed that some service functions in the network require bidirectional symmetry of paths (see more in Section 4). Therefore the classifiers at the top level must be configured with policies ensuring server-to-client packets take the reverse path of client-to-server packet through sub-domains. (Recall the "path" denotes the series of service functions; the precise physical network path within the underlay network is not relevant here.)



One path is shown from edge classifier to SFF1 to Sub-domain#1 (residing in data-center1) to SFF1 to SFF2 (residing in data-center 2) to Sub-domain#2 to SFF2 to network egress.

Figure 1: Network-wide view of top level of hierarchy

2.2. Lower Levels

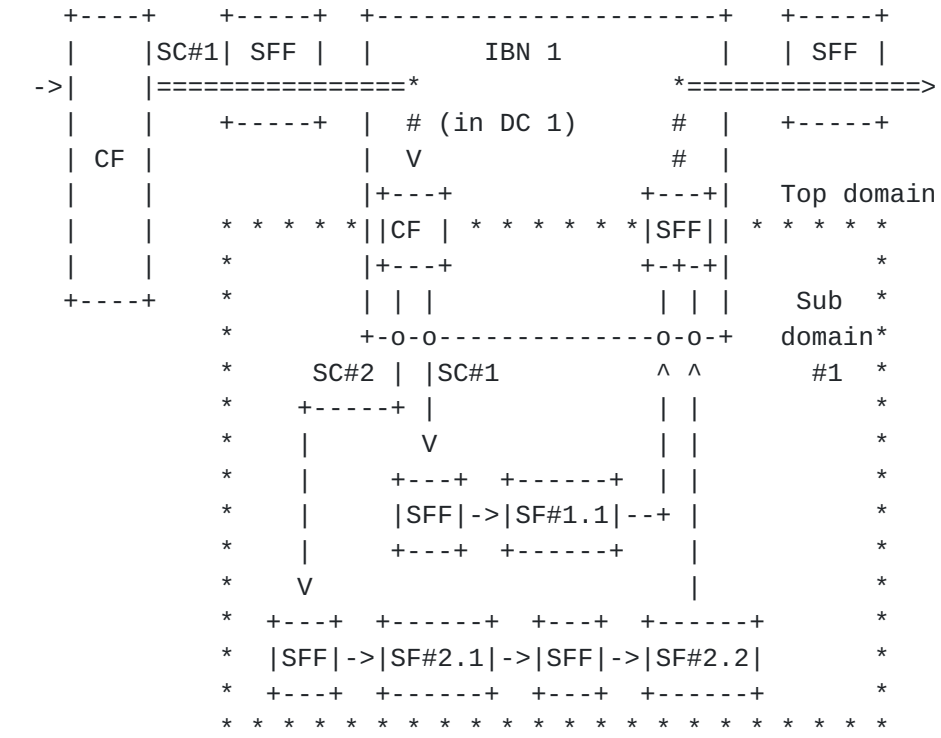
Each of the sub-domains in Figure 1 is an SFC domain.

Unlike the top level, however, data packets entering the sub-domain are already encapsulated within SFC transport. Figure 2 shows a sub-domain interfaced with a higher-level domain by means of an Internal Boundary Node (IBN). It is the purpose of the IBN to remove packets from the SFC encapsulation, apply Classification rules, and direct

the packets to the selected local service function paths terminating at an egress IBN. The egress IBN finally restores packets to the original SFC transport and hands them off to SFFs.

Each sub-domain intersects a subset of the total paths that are possible in the higher-level domain. An IBN is concerned with higher-level paths, but only those traversing the sub-domain. A top-level controller may configure the IBN as an SF (the IBN plays the SF role in the top-level domain).

We expect each sub-domain to have a control-plane that can operate independently of the top-level control-plane. The sub-domain control-plane configures the classification and forwarding rules in the sub-domain. The classification rules reside in the IBN, where packets are moved from SFC encapsulation of the top-level domain to and from SFC encapsulation of the lower-level domain.



*** Sub-domain boundary; === top-level chain; --- low-level chain.

Figure 2: Sub-domain within a higher-level domain

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

3. Internal Boundary Node (IBN)

A network element termed "Internal Boundary Node" (IBN) bridges packets between domains. It looks like an SF to the higher level, and looks like a classifier and end-of-chain to the lower level.

To achieve the benefits of hierarchy, the IBN should be applying more granular traffic classification rules at the lower level than the traffic passed to it. This means that the number of SF Paths within the lower level is greater than the number of SF Paths arriving to the IBN.

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

3.1. IBN Path Configuration

An operator of a lower-level SF Domain may be aware of which high-level paths transit their domain, or they may wish to accept any paths.

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

After exiting a path in the sub-domain, packets can be restored to an original upper-level SF path by these methods:

1. Saving SPI and SI in transport-layer flow state,

2. Pushing SPI and SI into metadata,

3. Using unique lower-level paths per upper-level path coordinates.

3.1.1. Flow-Stateful IBN

An IBN can be flow-aware, returning packets to the correct higher-level SF path on the basis of the transport-layer coordinates (typically, a 5-tuple) of packets exiting the lower-level SF paths.

When packets are received by the IBN on a higher-level path, the encapsulated packets are parsed for IP and transport-layer (TCP, UDP...) coordinates. State is created, indexed by these coordinates (a 5-tuple of {source-IP, destination-IP, source-port, destination-port and transport protocol} in a typical case). The state contains

critical fields of the encapsulating SFC header (or perhaps the entire header).

The simplest approach has the packets return to the same IBN at the end of the chain that classified the packet at the start of the chain. This is because the required transport-coordinates state is rapidly changing and most efficiently kept locally. If the packet is returned to a different IBN for egress, transport-coordinates state must be synchronized between the IBNs.

When a packet returns to the IBN at the end of a chain, the SFC header is removed, the packet is parsed for IP and transport-layer coordinates, and state is retrieved from them. The state contains the information required to forward the packet within the higher-level service chain.

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., as done by a NAT) 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 (it MUST time out eventually), 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 re-created by each new packet arriving from the higher-level domain. For example, if an IBN loses all flow state, the state is re-created by an end-point 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 sub-domain's control-plane to modify paths when higher-level paths are changed. The complexity of the higher-level domain does not cause complexity in the lower-level domain.

3.1.2. Encoding Upper-Level Paths in Metadata

An IBN can push the upper-level Service Path Identifier (SPI) and Service Index (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 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 new metadata may inflate packet size when variable-length metadata (type 2 from NSH [I-D.ietf-sfc-nsh]) is used.

It is conceivable that the MD-type 1 Mandatory Context Header fields of NSH [I-D.ietf-sfc-nsh] are not all relevant to the lower-level domain. In this case, one of the metadata slots of the Mandatory Context Header could be repurposed within the lower-level domain, and restored when leaving.

In this metadata approach, it is not necessary for the sub-domain's controller to modify paths when higher-level paths are changed. The complexity of the higher-level domain does not cause complexity in the lower-level domain.

3.1.3. Using Unique Paths per Upper-Level Path

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

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

A down-side of this approach is that the number of paths in the lower-level domain is multiplied by the number of paths in the higher-level domain that traverse the lower-level domain. I.e., a sub-path must be created for each combination of upper SPI/SI and lower chain.

3.2. Gluing Levels Together

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

In some cases the meanings of the various path IDs and metadata must be coordinated between domains.

One approach is to use well-known identifier values in metadata, communicated by some organizational 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 sub-domain classifier could have a policy, "if pathID=classA then chain packet to path 1234"; the higher-level controller would be expected to configure the concrete higher-level pathID for classA.

4. Sub-domain Classifier

Within the sub-domain (referring to Figure 2), after the IBN removes higher-level encapsulation from incoming packets, it sends the packets to the classifier, which selects the encapsulation for the packet within the sub-domain.

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 SFs 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 in and scaling out service functions. All of the complexities of load-balancing among multiple SFs can be handled within a sub-domain, under control of the classifier, allowing the higher-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 sub-domain to be received by the same classifier or a coordinated cluster of classifiers. There are both stateful and stateless approaches to ensuring bidirectional symmetry.

5. Control Plane Elements

Controllers have been mentioned in this document without much explanation. Although control protocols have not yet been standardized, from the point of view of hierarchical service function chaining we have these expectations:

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

- Each control-plane is agnostic about other levels of hierarchy. This aspect allows humans to reason about the system within a single domain and allows control-plane algorithms to use only domain-local inputs. Top-level control does not need visibility to sub-domain policies, nor does sub-domain control need visibility to higher-level policies.

- Sub-domain control-planes are agnostic about control-planes of other sub-domains. This allows both humans and machines to manipulate sub-domain policy without considering policies of other domains.

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

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

6. Acknowledgements

The concept of Hierarchical Service Path Domains was introduced in draft-homma-sfc-forwarding-methods-analysis-01 [I-D.homma-sfc-forwarding-methods-analysis] as a means to improve scalability of service chaining in large networks.

The authors would like to thank the following individuals for taking the time to read and provide valuable feedback:

Ron Parker

Christian Jacquenet

Jie Cao

7. IANA Considerations

This memo includes no request to IANA.

8. Security Considerations

Hierarchical service function chaining makes use of service chaining architecture, and hence inherits the security considerations described in the architecture document.

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

The systems described in this document bear responsibility for forwarding internet traffic. In some cases the systems are responsible for maintaining separation of traffic in private networks.

This document describes systems within different domains of administration that must have consistent configurations in order to properly forward traffic and to maintain private network separation. Any protocol designed to distribute the configurations must be secure from tampering.

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

9. References

9.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <http://www.rfc-editor.org/info/rfc2119>.

9.2. Informative References

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Appendix A. Examples of Hierarchical Service Function Chaining

The advantage of hierarchical service function chaining 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

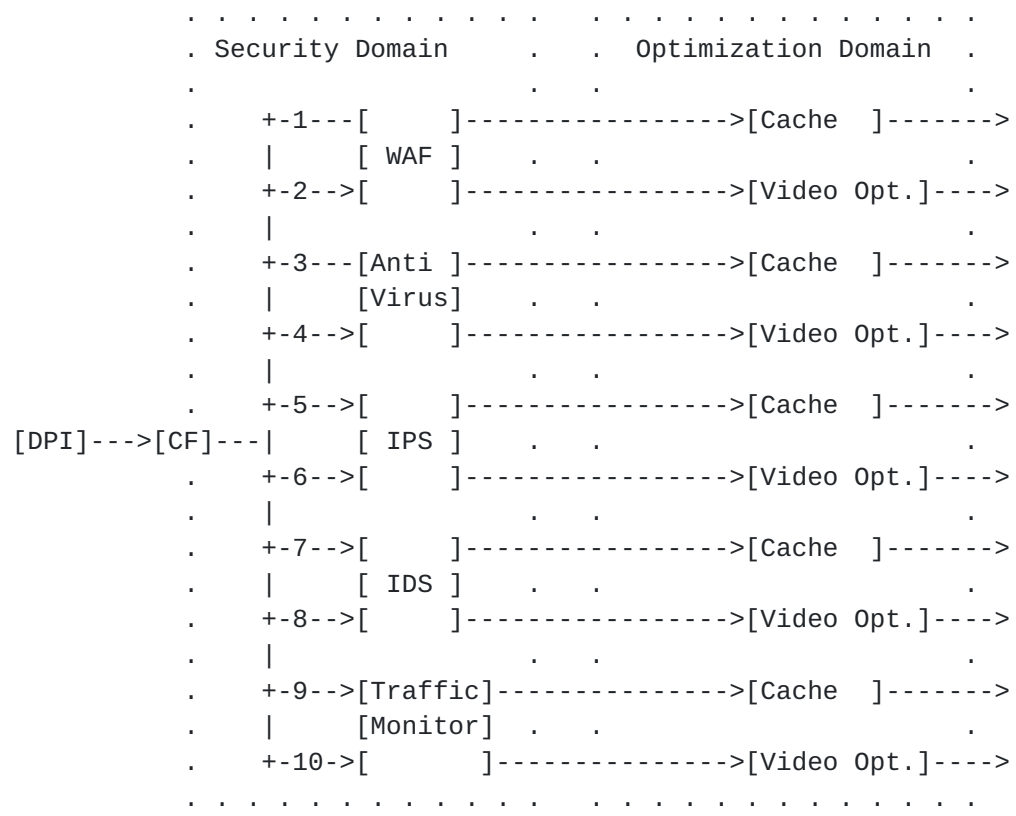
In this case, hierarchical service function chaining is used to simplify service function chaining management by reducing the number of Service Function Paths.

As shown in Figure 3, there are two domains, each with different concerns: a Security Domain that selects Service Functions based on network conditions and an Optimization Domain that selects Service Functions 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 hierarchical SFC, only 5 SFPs in Security Domain and 2 SFPs in Optimization Domain will be required, as shown in Figure 4.

In the flat model, the number of SFPs is the product of the number of functions in all of the domains. In the hSFC model, the number of SFPs is the sum of the number of functions. For example, adding a "bypass" path in the Optimization Domain would cause the flat model

to require 15 paths (5 more), but cause the hSFC model to require one more path in the Optimization Domain.



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 3: Flat SFC (normal branching)

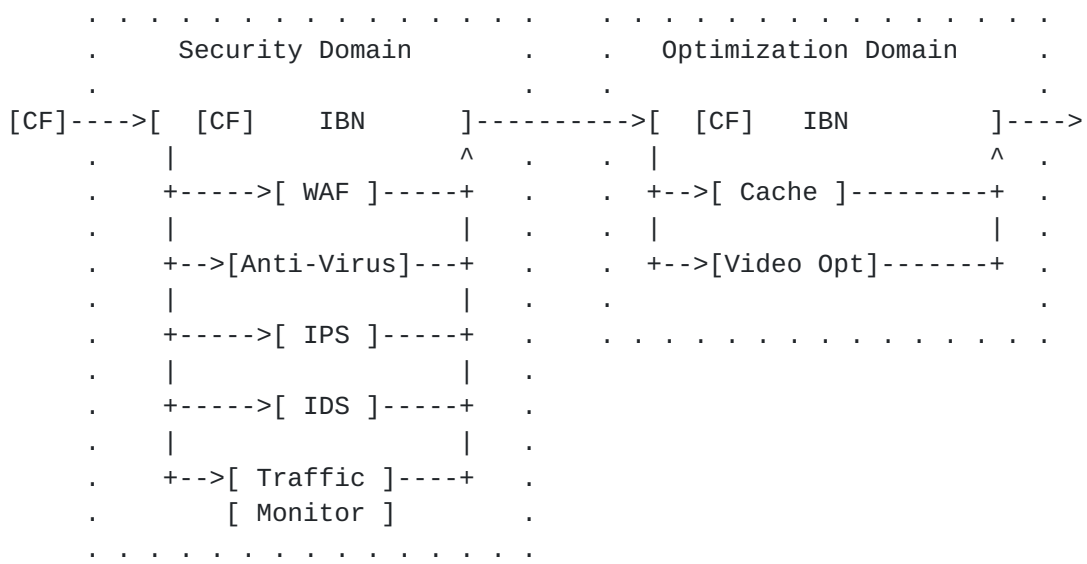


Figure 4: Simplified path management with Hierarchical SFC

A.2. Managing a Distributed Data-Center Network

Hierarchical service function chaining can be used to simplify inter-data-center SFC management. In the example of Figure 5, shown below, 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 service functions are deployed as dedicated hardware appliances, and there is a desire to lower the cost (both CAPEX and OPEX) of deploying such service functions in all data centers.

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

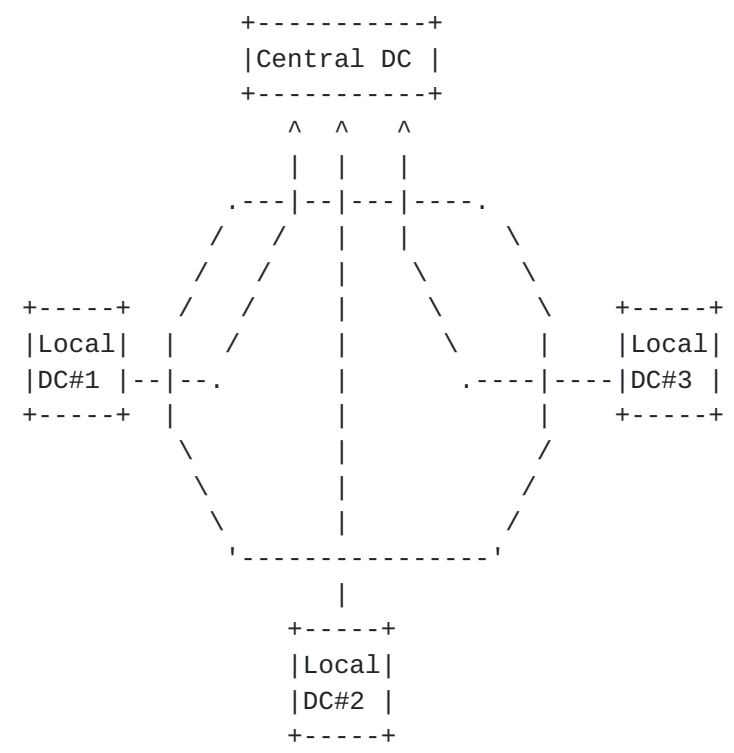


Figure 5: Simplify inter-DC SFC management

For large data center operators, one local DC may have tens of thousands of servers and hundred 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 large scale data center, using flat SFC is very complex, requiring a super-controller to configure all data centers. For example, any changes to Service Functions or Service Function Paths in the central DC (e.g., deploying a new SF) would require updates to all of the Service Function Paths 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 data center can be managed independently to significantly reduce management complexity. Service Function Paths between data centers can represent abstract notions without regard to details within data centers. Independent controllers can be used for the top level (getting packets to pass the correct data centers) and local levels (getting packets to specific SF instances).

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