VLAN-based Traffic Steering for Hierarchical Service Function Chaining

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***Abstract*—Along the increasing demands for complex networking services, big networking infrastructures, and network service providers aim to provide customized services to the users. Complex services require a composition of intermediate networking Service Functions (SFs). Service Function Chaining (SFC) is a networking concept enabling to compose and force the order of invoking SFs. New technologies such as Software Defined Networking and Network Function Virtualization promote the SFC dynamic composition and management. However, it is still challenging to implement flexible and scalable SF chains in large networking infrastructures. In this paper, we discuss the concept of hierarchical SFC and show its ability to enhance the network scalability and to simplify SFC management. Moreover, we propose a novel traffic steering method to implement hierarchical SFC without requiring data plane components modification. Our proposed approach enhances the scalability of hierarchical SFC and eases its deployment.**

I. INTRODUCTION

Large-scale infrastructures involve massive networking devices and resources. Along with the growing demands for networking services, the customers require increasingly advanced and customized services. Security services, as a complex service example, require composing a set of elementary Service Functions (SFs) to satisfy the technical clauses depicted in service level agreements. Security policies as such, can vary depending on the traffic types, customer preferences, network state. Yet, it is a tedious task to stitch SFs together to compose added value services.

Service Function Chaining (SFC) is the networking concept aiming to compose ordered lists of SFs. Service chains can be statically created by identifying traffic types using, for example, VLANs or tunnels. Nowadays, SFC is a hot industrial and research topic where several problems are being discussed. Recently, important research efforts have been made to propose dynamic SFC schemes [1], [2]. Moreover, standardization bodies such as the European Telecommunications Standards Institute (ETSI) and the Internet Engineering Task Force (IETF) published relevant standards such as the RFC 7665 [3].

To fulfil the need for flexible and programmable service chains, networking technologies such as Software Defined Networking (SDN) and Network Function Virtualization (NFV) can be designed to make use of SFC. As a reminder, SDN is the networking technology separating the data plane from the control plane. It uses a centralized control and programming by dedicated interfaces and protocols of communication to the data plane networking devices. NFV is a trending network virtualization framework that enables the development of virtual network service functions that are able to run on commodity hardware.

Besides the recent SFC advancement, the issue of implementing service chains in large scale networks, especially deployed in wide geographic areas is a complex task [1]. The configuration of a large number of network devices in a centralized way raises some concerns. It provides some end-to-end visibility on service chains but complicates the management tasks. It might not be feasible nor scalable for boundary nodes to maintain a detailed characterization of a large number of service functions. The hierarchical SFC presents an architectural approach to extend the scalability and simplify SFC management. Hierarchical SFC is an architectural concept that can be deployed by the SFC solutions and it is agnostic to the data plane SFC forwarding schemes. It aims to reduce the number of SFC forwarding paths and simplify management tasks through the decomposition of SFC domain into multiple sub-domains

In this paper, we discuss hierarchical service function chaining along with its benefits and limits. Moreover, we propose a traffic forwarding technique to implement hierarchical SFC without requiring data plane components modification. Our proposed approach enhances deployment flexibility and scalability of hierarchical SFC.

The remainder of this paper is organized in the following fashion. Section II presents the related work. Section III describes the SFC concept. Section IV presents the concept of hierarchical SFC, the benefits and limits of deploying the hierarchical SFC. In Section V, we propose a traffic steering method for hierarchical SFC. Finally, Section V concludes the paper and presents some future research work.

II. RELATED WORK

The early contributions to SFC started in IETF and ETSI working groups (WG), primarily the IETF SFC WG and ETSI NFV WG. IETF recently published RFC 7665 [3] to describe the SFC architecture components and concepts. Later, several encapsulation methods for SFC information were published including the Network Service Header (NSH) [4]. Many other forwarding methods have been published; for instance, the SFC forwarding based on VLANs [5], MPLS [6] and Mac addresses [7][8].

In academia, several solutions have been presented recently to tackle SFC challenges in different research areas. Yet,

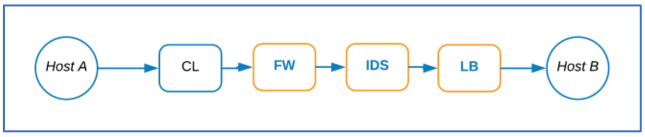


Figure 1: Example of a Service Function Chain composed by a firewall, intrusion detection system and a load balancer. The chain is delimited by classifiers.

related to hierarchical SFC, few works are published. Recently, Vu et al. [9] present the implementation of hierarchical service function chaining in the OpenDaylight SDN platform. They tackle the challenge of saving the higher level SFC path information when traffic enters the subdomains and restore it at the exit. By encoding the higher level SFC path information in the NSH metadata field, they could save the information while traversing the lower level domains. At the exit of the subdomains, the metadata is retrieved to set the appropriate header fields for the top-level domain. Compared to our approach, this implementation relies on NSH that is not widely supported by the SFs today. For the purpose of ease of flexibility, we based our approach on Vlans. Moreover, our approach links lower level chains with higher level chains via the Internal Boundary Node (IBN) and reclassification, coping with the need for transferring the higher level SFC path information in the subdomains.

III. Service Function Chaining

SFC refers to steering the traffic through an ordered list of SFs [8]. For example, a service chain (or service function chain) can be represented as {Firewall, IDS, Load Balancer} (Figure 1). Network traffic for this chain once sent from "host A" to the target "host B", is classified at the ingress of the SFC domain, then intercepted by the firewall, later, the traffic is steered to an Intrusion Detection System (IDS) that will forward it to the Load Balancer.

SFC can be statically achieved by stitching SFs together in the network topology. Such techniques are known to be error-prone, expensive and inflexible [10]. Recently, some flexible SFC techniques are proposed: achieving SFC using VLANs, MPLS tags or by encoding the SFC information in existing packet header fields such as Mac address or IP option field, or defining new headers to encode SFC metadata ((e.g., NSH [4], SFCEH [11]). Such metadata reflect the SFC instructions to be applied by SFC elements while forwarding traffic through a Service Function Path (SFP) and invoking the required SFs.

Typically, nodes at the edges of an SFC domain contain a function for traffic classification (classifier, CL) to filter different traffic types and bind them to the accurate service chains (see Figure 2). Then, Service Function Forwarders (SFF) direct traffic from and to SFs. In some cases, the SFs are not able to decode the SFC information; proxies are used in this case to decode and forward SFC traffic from the SFF to the SF and vice versa.

IV. Hierarchical Service Function Chaining

A. The concept of hierarchical SFC

The concept of hierarchical SFC has been introduced in [12] and further discussed in [13]. Hierarchical SFC permits the decomposition of network architecture into multiple sub-domains. It is beneficial for large scale networks to simplify SFC control. Mainly hierarchical SFC extends the infrastructure's capacity to support fine granular policies, increased number of service functions while reducing the forwarding state. Moreover, by managing SFC sub-domains independently, the management complexity is reduced.

Hierarchical SFC consists of two levels of SFC, a top level and a lower level. The top-level domain network consists of SFC data plane elements (the classifier, forwarder, and service

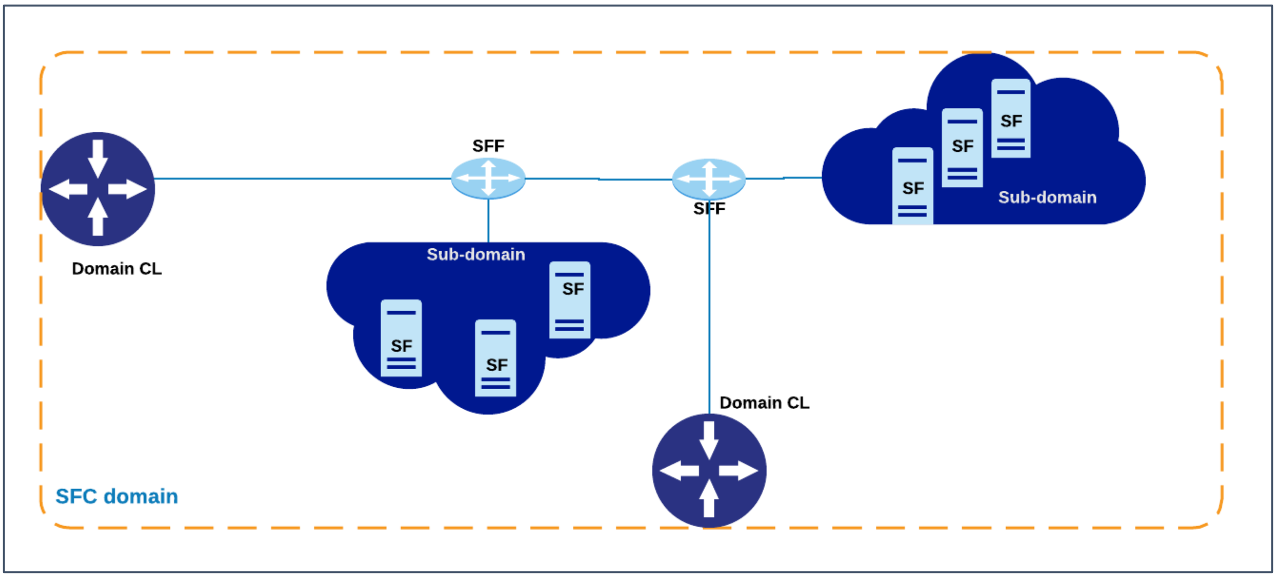


Figure 2: An example of Service Function Chaining Architecture, where the SFs in the sub-domain are visible to the SFC domain's SFFs.

functions) that are connected over a wide network area. The lower level domain is a sub-domain of the SFC domain. The sub-domain is a smaller SFC domain that contains SFC elements as well.

The main difference between the top-level SFC domain and lower level SFC sub-domain is that, the first exchanges SFC information known in the SFC domain while the lower level exchanges SFC information that is local to the sub-domain. The traffic going through a sub-domain is considered by the top domain as reaching an SF. The SFC elements in the sub-domain are not aware of the top-level SFC elements (CL, SFFs). The link between the two levels is realized by the IBN. The IBN is seen as an SF by the top-level, while it is seen as an SFC classifier by the lower sub-domain (Figure 3).

B. *Benefits of hierarchical SFC*

1) Expanding the number of service chains

Service Function Chaining can be achieved in different ways: by exchanging forwarding information in dedicated headers, using tags or by re-classification at each hop. Exchanging SFC information, especially the service chain identifier or service path identifier in a field of small length, e.g., using VLAN can allow for 2^{12} of different combinations of service chain identifiers. Having two levels of chains, a global chain identifier in the top-level domain and a local chain identifier in the lower level sub-domain can expand the number of chain identifiers. A top-level service chain might be combined with multiple lower-level or local service chain identifiers.

2) Supporting fine granularity

As stated in [13], hierarchical SFC can be beneficial when the lower level achieves fine granularity policies. The sub-domain classifier has to achieve more specific path control compared to the top-level classifier. The fine granularity is a required standing point for SFC and a real need in large-scale networks where the granularity can be limited by the SFC protocols used and by the scale and subscribers demands [7].

3) Reducing the forwarding state

By using two levels of SFC, a high-level classification and a lower level traffic binding, the forwarding state is split. The global domain classification is realized on the higher level, while the local and more granular path binding is realized in sub-domains. The decomposition of classification considerably reduces the number of Service Function Paths (SFPs) and the resulted forwarding state that will need to be maintained at higher level.

4) Scalability

As stated in the previous sub-sections, hierarchical SFC allows to expand the number of service chains, supports fine granularity, and reduces the forwarding state. These factors influence the network operator's ability to extend the number of service functions, users, and granular policies.

5) Reducing management complexity

Hierarchical SFC decomposes the SFC domain into independent SFC sub-domains. Typically, these sub-domains can be hosted in distinct data-centers. The later can be managed independently and each sub-domain can have an independent controller that programs the SFC data-plane elements. This approach reduces management complexity.

C. *Limits of hierarchical SFC*

Hierarchical SFC is a network architecture that can be combined with SFC forwarding protocols such as Network Service Header [14], Service Chain Header [15], and IPv6 Extension Header for SFC[11]. Thus, limits can vary depending on the underlying traffic steering protocols, while

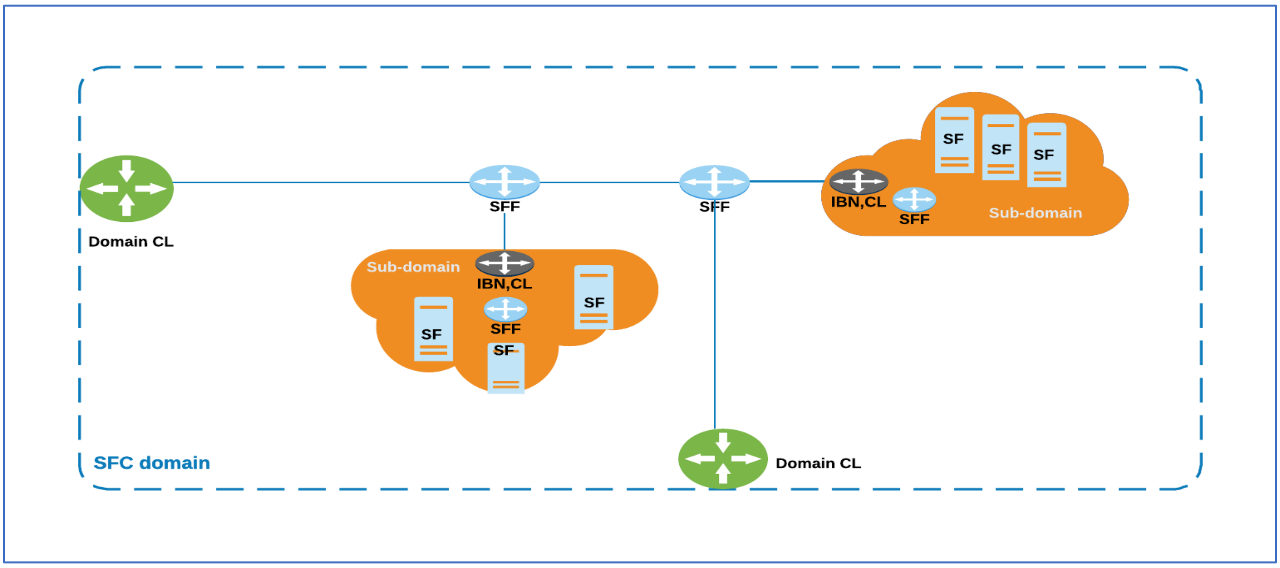


Figure 3: Architecture of Hierarchical SFC, where the SFC sub-domains are seen as single SFs to the higher SFC domain.

some limits can be common.

The IBN node's role is to tie together the low-level and top-level SFC. As a result, the IBN acts as a proxy, classifier and can act as a forwarder. Each traffic crossing the sub-domain should pass through the IBN. Hence there is a risk for a single point of failure: traffic entering and exiting the sub-domain is queued in the IBN. The IBN translates each top-level SFC packets to lower-level SFC (and vice versa for the outgoing traffic) depending on the traffic steering protocols used. Moreover, a re-marking of the incoming traffic may be required by the IBN. In order to prevent a single point of failures, multiple IBN instances may be enabled within a sub-domain.

Moreover, we noticed that the hierarchical SFC paths require more hops and SFC elements (IBNs, forwarders) compared to the flat SFC. Also, the traffic passing several SFC elements, top-level and lower-level SFC proxies can cause a queuing delay.

V. THE PROPOSED TRAFFIC STEERING METHOD

In this section, we present an SFC traffic steering method, based on VLANs and describe the related operations. The terms, traffic steering and forwarding technique, are used interchangeably in this paper, to refer to the set of steps, protocols and elements involved in the delivery of traffic according to the accurate service chain. Specifically, we focus on a forwarding technique that considers the hierarchy of SFC: the set of operations, protocols and devices to enable the SFC communication between the lower-level and higher-level SFC.

A. Traffic steering method for HSFC based on Vlans

Different forwarding techniques can be used to steer traffic between HSFC layers. They are essentially based on saving the transport-layer flow state by the IBN, or by transmitting the SFP information as a meta-data between the higher-level and lower level [13].

In our forwarding technique, we combine two methods: saving the transport-layer flow state and transmitting the SFP information. For the traffic coming from the higher-level domain, the IBN saves the flow state, restores the packet's header before returning to the higher-level. For the second method of transmitting the SFC information as metadata, we mark packets with a chain identifier. This prevents the SFFs from reclassifying packets each time they traverse them. Thus, the chain Id is transferred with packets to simplify the chaining, while saving the flow-state at the ingress of sub-domains (precisely, by the IBN) allows for the separation between the two levels, and the ability to restore the traffic at the egress of the sub-domain.

Instead of encoding the chain Id, as a metadata field, we opt for VLAN Ids as chain identifiers. We distinguish between top chains, used in the higher level, and lower chains used in lower domains. The lower chains are included in the top chains, yet the chains are agnostic to each other. The Ids can be reused, as the top-level chains are agnostic to lower-level chains, and the subdomains are also agnostic to each other. This allows using the full range of Ids possible inside each domain. The range of 4094 possible identifiers in a VLAN field (i.e. 12 bits field size allows for more than 4094 possible VLAN Ids) can be used in each sub-domain or top domain (see Figure 4).

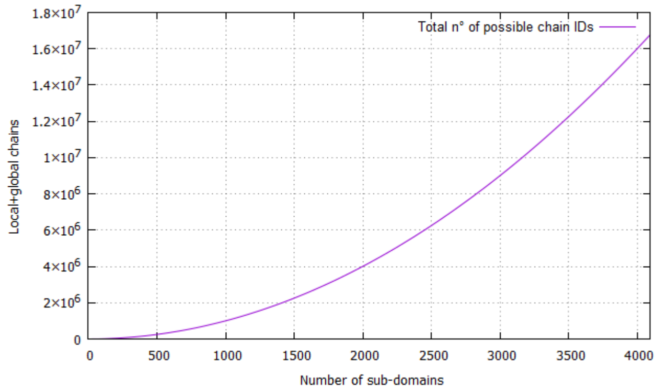


Figure 4: Total number of possible chain IDs for H SFC based on the capacity of VLAN Id field and the proposed Traffic steering method.

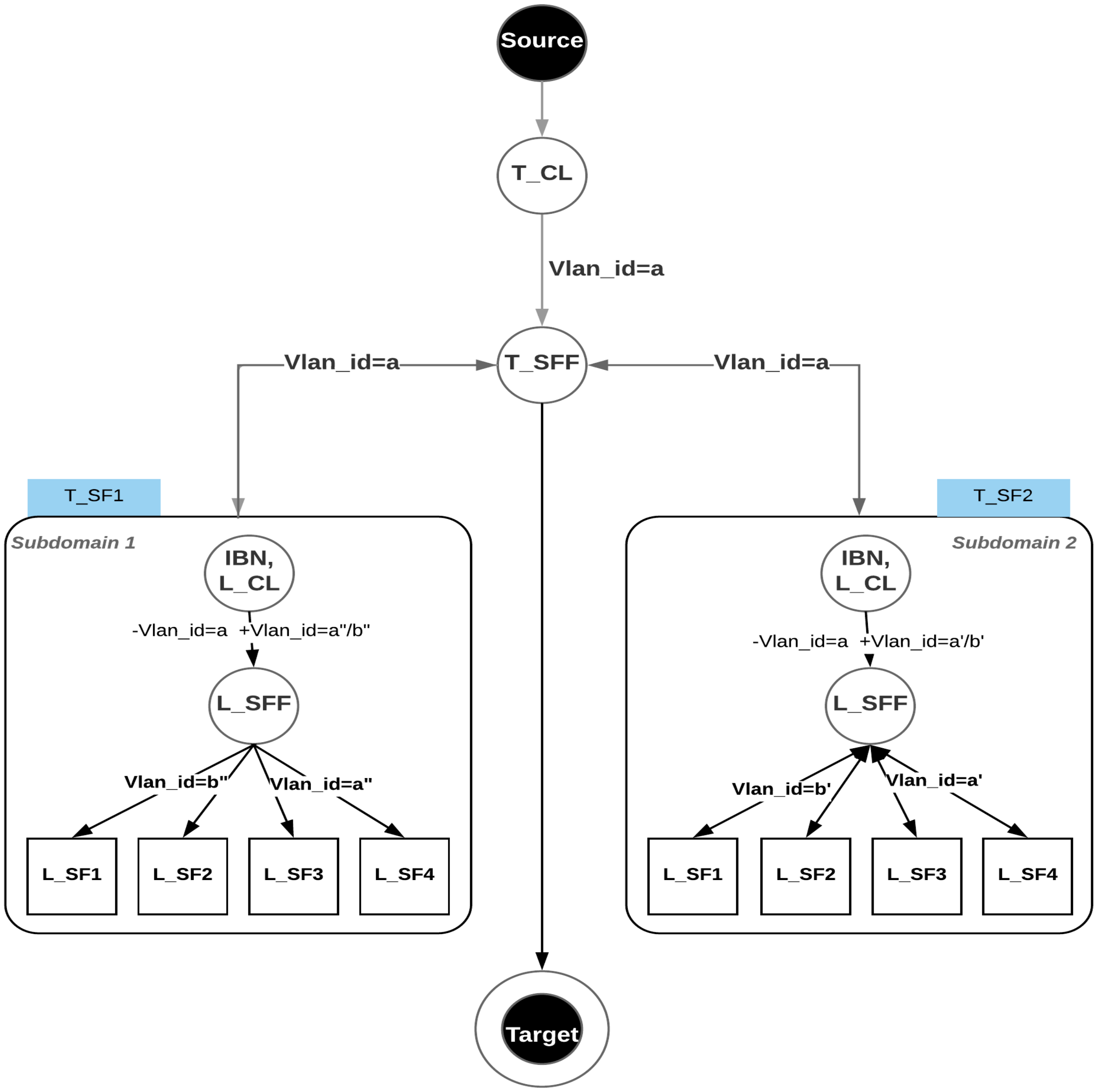
The proposed forwarding method relies on a peer of VLAN Ids and directions, to differentiate between the higher and lower-level chains. The direction is extracted from the source and destination of the traffic. This forwarding method permits a flexible HSFC implementation. Using VLANs, this solution can be integrated into the controllers without modifying the SFs and switches. Moreover, reusing the VLAN Ids in each domain allows for a very high number of chains, including high-level and low-level chains (Figure 4). The reclassification is only achieved at the ingress of a subdomain, at the IBN and CL.

B. Traffic steering operation

Figure 5 describes the proposed traffic steering operation. We refer in Figure 5 to top and lower level SFC elements and chains only for clarification. There is no difference between the type of CLs, SFFs and chains in the actual network. The top-level elements including T_CL and T_SFF deal with top-level chains, while L_CL and L_SFF deal with lower level chains.

At the ingress of the top-level domain, the T_CL classifies traffic and pushes the accurate VLAN id to the chain. The T_SFFs look to the VLAN id and forward traffic according to the list of SFs in the T_chain. The subdomains are seen as SFs to the Top domain.

The IBN, acting as a proxy between the top domain and the subdomain, glues the levels together. The IBN and CL can coexist in the same device. The IBN retrieves the VLAN Id corresponding to the top chain and links it to a lower chain Id. At the egress of the subdomain, the IBN retrieves the top domain chain Id. The CL classifies packets, pops the T_chain Id and pushes the L_chain Id. At the egress of the lower domain, the IBN retrieves the T_chain Id according to the L_chain Id and direction of the traffic.



- **T_CL**: Top domain Classifier
- **L_CL**: Low domain Classifier
- **T_SFF**: Top domain Service Function Forwarder
- **L_SFF**: Low domain Service Function Forwarder
- **T_SF**: Top domainService Function
- **L_SF**: Low domainService Function
- **IBN:** Internal Boundary Node
- **T_chain**: Top level chain
- **L_chain:** Low level Chain

- T_chain **a**: T_SF1->T_SF2
- L_chain **a'**: L_SF4->L_SF3
- L_chain **b'**: L_SF1->L_SF2
- L_chain **a''**: L_SF4->L_SF3
- L_chain **b''**: L_SF1->L_SF2

Figure 5: State diagram for data plane components and operations involved in the proposed HSFC traffic steering method.

CONCLUSION

In this paper, we have characterized the benefits and limits of deploying the hierarchical SFC concept. Moreover, we proposed a traffic steering method. By decomposing SFC into a top and lower levels, the infrastructure capacity can be extended to support increasing numbers of service functions and more granular policies, thus promoting the SFC scalability. Moreover, the discussed approach presents less complexity in managing an SFC domain by managing sub-domains and the global domain apart. Our next step is to implement hierarchical SFC along with our traffic steering method in the MeDICINE framework [16] to assess its performance.

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