ABSTRACT

While services benefit from distributed cloud centers running in isolation, allowing multiple centers to cooperate on implementing services unlocks the full power of distributed cloud computing. Distributed cloud services are typically set up by chaining together a number of functions that are specified with an implicit order. They can incorporate complex structures, e.g., include functions that classify and forward flows over distinct branches and functions that are traversed by certain types of flows but skipped by others. These requirements need specification techniques more powerful than existing graph-based ones. We present a context-free grammar for abstract description of service function chaining structures and a concrete syntax based on the YANG data modeling language that can easily be translated into an explicit configuration of service functions. Finally, we present examples of using our models for complex services within common use cases of service function chaining.

1. INTRODUCTION

According to a cloud-readiness study published in the latest Cisco Global Cloud Index [3], in the coming years, cloud computing operators are expected to be prepared for a wide range of cloud services including video and music streaming in different qualities, communication via text/voice/video, medical and safety applications, stock trading, and personal content storage. Some of these services have very strict requirements that should be considered in all stages of service design, implementation, deployment, and maintenance. Distributed cloud computing divides the burden of fulfilling these requirements over multiple cloud centers. Network Function Virtualization (NFV), in turn, aims at designing efficient architectures and solutions and reducing the complexity of service provisioning in cooperating distributed cloud centers [4].

By applying NFV in large-scale networks, a service can be defined as a composition of multiple service functions that should be traversed by network flows in a specific order [5]. The simplest case for such a service is a linear chain of at least one service function between two specific endpoints in the network. Inserting functions that can split network flows over different paths makes the structure of a service more complicated than a simple chain. Such services can be modeled as directed graphs consisting of service functions as nodes and the connections between pairs of service functions as edges of the graph. These graphs are known as forwarding graphs in ETSI NFV terminology [3].

For resource allocation and network optimization purposes, network operators need precise and compact representations for the graphs that model the structure and requirements of a service. As long as the order of traversing the functions is fixed and given, traditional graph representations (e.g., adjacency lists and matrices) can be used for modeling the services. But these representations can quickly become ineffective when the exact order of traversing the functions is not specified or not relevant for the functionality of the service. For example, when there are no direct dependencies between two functions that should be applied to a flow, the network can benefit from a flexible service representation that allows the operator to compose the required services in the most efficient way. We have addressed this problem by introducing a context-free grammar in a previous work [11]. In this paper, we present an enhanced version of our service description grammar that can express more service structures compared to its earlier version. Based on this grammar, we propose an extension to the YANG [1] data model for service function chaining, published as a working draft [12] by the IETF Service Function Chaining (SFC) group. With this extension, complex and flexible service compositions can be defined, configured, and reused.

This paper is organized as follows: after a brief overview of related work in Section 2, we describe our models in Section 3. To highlight the value of our proposed service specification models, we present examples of complex chains from common service function chaining use cases in Section 4 before we conclude the paper in Section 5.

2. RELATED WORK

Sun et al. [12] have published a survey of cloud computing description languages. Our model differs from the existing models in the sense that we focus on a flexible description for expressing how the components of a distributed cloud service are chained and composed to set up a service. In our previous work [11], we have elaborated on the importance and influences of the service structure on different metrics concerning the network operators, service providers, and users. In this paper, we extend our previous description model with more features making it capable of describing more complex structural requirements. In a similar approach to flexibility in service description, Keller et al. [7] propose modeling a cloud application as a generic graph template that can be modified and adapted during and after deployment.
3. FLEXIBLE SERVICE SPECIFICATION

The initial version of our context-free grammar \[1\] can specify a flexible description for the way service functions are chained together to build a service. In this section, we present an enhanced and more powerful version of this grammar and a YANG data model based on the new grammar. The grammar and the data model both describe a service as an arrangement of different compositions of service functions. For simplicity, we assume all the functions that build up a service are virtualized, and we use VNFs and service functions interchangeably in this paper. A composition in the simplest case is a single VNF or an endpoint of a service flow but it can also be complex like a multi-branch structure.

3.1 Context-Free Grammar

We express our context-free grammar in Extended Backus-Naur Form (EBNF) as shown in Figure 1. Terminals of the grammar are given in bold font. (vnf) and (endpoint) correspond to the set of available VNFs and the set of points in the network where the service flows start or end.

This grammar can be used for specifying a set of totally ordered VNFs to be chained together in the given order (simple sequence) and a set of partially ordered VNFs to be chained together in the most efficient order according to the optimization objectives in the network (best-binding). Extending our previous grammar, a set of VNFs can now be specified to be chained together in a way that all possible permutations of them are traversable (all-bindings), i.e., a full mesh of paths has to be built among the VNFs. A complex branching structure for splitting the flows over different branches (split) can also be expressed. This composition consists of:

- a VNF that can classify and split the flows over different branches, specified as the first (func) in the split composition,
- an optional best-binding composition to be traversed before the flows reach the branches \[11\],
- branches that can consist of a single VNF or endpoint, a composition of multiple VNFs, or can be an empty branch (pass) that can be used for skipping a part of the service structure. In case the branches are identical, they need to be specified only once together with the number of required replications.

Existence of partially ordered sets of VNFs in a service structure turns the deployment request for the service into a flexible request that can be translated into the best possible forwarding graph depending on requirements of the service and available resources in the network.

3.2 YANG Data Model

Based on the context-free grammar shown in Figure \[1\], we define a YANG model for services. YANG data models can be used for defining configuration and runtime state of different data elements. Services and the network functions which composed them can be abstracted as reconfigurable data elements with certain attributes, e.g., required link capacity and computational resources. In a dynamic cloud computing environment, where requirements of services and availability of network resources are changing over time, the structure of a service can also be considered as a (re)configurable attribute of the service. In the IETF SFC YANG data model draft \[12\], no model has been specified for expressing complex service structures besides simple sequence of functions. To fill this gap, we propose extending the IETF SFC model...
with our definitions. We present the tree representation of our YANG module (effectively, the grammar) for flexible specification of complex services in Figure 2 and omit the detailed definition of the module because of space limitations.

We have created the tree representation using pyang[1], an open-source tool for validating YANG modules. Within this tree, each leaf node that represents a data element is specified by a name and a type, e.g., identifier of type string. A list of leaf nodes is specified by \(<name>\)* and type of the leaves, e.g., the list sequence-functions defines a set of service-functions. Lists that consist of non-leaf nodes are specified by \(<name>\)* and a key written as \([<name>]\) that is unique among all items of the list, e.g., in the list of compositions each item has a unique composition-identifier. Description of the list elements follows as children of the node. To express a choice among different options, the node name is written as \((<name>)\)? and the possible choices are represented as its child nodes with the format : \((<name>)\). Optional data items are represented as \(<name>\)?, e.g., number of replications can be optionally specified for a branch if outgoing branches from a splitter function are identical.

We use service-function for referring to the service function type defined in the latest IETF draft of a YANG model for SFC [12]. This type corresponds to the VNFs and endpoints in our grammar description.

Consistent with the context-free grammar, the YANG module also contains all of the composition types described in Section 5.1 sequence, best-binding, all-bindings, split, and single function.

In our flexible service specification module, the service specification consists of a list of service-components, which is a list of at least one composition of service functions. Definition of components is required for defining complex services, e.g., nested compositions and branching structures. Such structures can only be expressed using path references within the module, as in the YANG data modeling language [1] recursive structures are not allowed. For this purpose, we define a reference to component-identifier as a new type called component-ref and use it for referring to defined components within other compositions. For referring to the starting point of the service among all defined components, we use the starting-component reference.

With this model, services can be defined from scratch using the available types of functions in the network. Additionally, the operator can keep a catalog of pre-composed services that a tenant can request as a standalone service or for using it as part of a more complex service structure. Existing services can easily be referenced within a service structure using the composition type link-to-composition.

To keep the descriptions compact, we have only included structural attributes in the YANG model shown here. Different requirements and specifications of services and their components can be included in the model, e.g., as described in the IETF SFC YANG data model draft [12].

4. USAGE SCENARIOS

For delivering a service, different VNFs need to be deployed in the network and corresponding flows need to be routed through them in a specific order, resulting in different service compositions (described in Section 3). In this section, we give an overview of these compositions occurring in common cloud services. We show examples from use cases of service function chaining [2, 6, 8, 9] in fixed and mobile broadband networks and data center networks, where distributed cloud services can be integrated. We show sample forwarding graphs and how the graphs can be compactly described using our grammar. Every abstract service description expressed by the context-free grammar described in Section 3.1 can also be expressed using corresponding YANG definitions shown in Section 3.2.

A simple example of service function chaining in fixed broadband networks consists of a Broadband Network Gateway (BNG) and a Network Address Translator (NAT) as endpoints of service flows between the customer premises network and public Internet. Assuming that all network flows need to traverse these two functions, Figure 3(a) shows the structure of this service. Using a simple sequence from our model, the abstract description of this service is:

\[
\text{service}\{\text{BNG, NAT}\}
\]

Depending on the requirements of the service, this description can be interpreted as a symmetric service, i.e., the functions are traversed by flows in both directions between the Internet and the customer network, or it can describe an asymmetric service to be applied only to flows going from the customer network towards the Internet.

In case the order of traversing the functions does not affect the functionality of the service, describing the service using a “best-binding” composition instead of a simple sequence of functions allows the operator to order the functions in the most beneficial way for the network and the service, e.g.,:

\[
\text{service}\{\text{best-binding}\{\text{BNG, NAT}\}}\}
\]

Now we assume that HTTP traffic is detected and sent through an HTTP filter function and non-HTTP traffic is routed directly between BNG and NAT. The corresponding graph for this service is shown in Figure 3(b). This service can be expressed as follows using our “split” composition:
type comprising a branch type “pass” to enable skipping the HTTP filter function for some flows:

\[
\text{service{split\{BNG; HTTP-Filter; pass\}, NAT}}
\]

The first function in the “split” composition (BNG) is the splitter function and the HTTP-Filter and the “pass” keyword each correspond to one outgoing branch.

As a more complex example, we look at a scenario in a mobile broadband network in Figure 3d. This is a symmetric service between the Internet and a Packet Gateway (PGW) where the user equipments are connected via the access network. Firewall (FW) and Deep Packet Inspector (DPI) are applied to all flows and later on the flows are divided over three branches. TCP flows need to traverse a TCP optimizer function, flows belonging to a certain video streaming service go through a Lawful Interception (LI) and a video optimizer function, and other flows need to go through a header enrichment function. This structure can be expressed as follows, using a “split” composition:

\[
\text{service{PGW, FW, split\{DPI; Header-Enr; LI, Video-Opt; TCP-Opt\}}} \}
\]

As a last example, we look at a service chaining scenario in a data center network, shown in Figure 3d. Different flows need to traverse different subsets and different permutations of the set of functions, including a Web Optimization Controller (WOC), a firewall responsible for external threats (EdgeFW), a network and application monitoring function (MON), an Application Delivery Controller (ADC), and an application-specific firewall (AppFW). This complex structure can be compactly described using an “all-bindings” composition:

\[
\text{service{all-bindings\{WOC, EdgeFW, MON, ADC, AppFW\}}} \}
\]

These examples confirm the existence of complex chaining structures in networks. Our models facilitate the flexible and compact description of possible chaining scenarios.

5. CONCLUSION

The grammar presented in this paper provides a powerful tool for abstract specification of complex service structures that can be used as a basis for defining specification languages and models. The YANG model we have defined based on this grammar extends the structural aspects of existing YANG definitions for service function chaining that are under development by standardization bodies. These definitions and various use case documents prove the existence of service structures that are more complicated than a linear and totally ordered set of functions, which makes our model an important contribution towards flexible specification of complex structures in distributed cloud services.

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