Computer Networks 93 (2015) 492–505

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Network service chaining with optimized network function embedding supporting service decompositions

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ARTICLE INFO

Article history:
Received 27 February 2015
Revised 10 August 2015
Accepted 19 September 2015
Available online 22 October 2015

Keywords:
Network service chaining (NSC)
Network Function Virtualization (NFV)
Software-Defined Networking (SDN)
Network function decomposition
Embedding

ABSTRACT

The rise of Software-Defined Networking (SDN) and Network Function Virtualization (NFV) introduce opportunities for service providers to reduce CAPEX/OPEX and to offer and quickly deploy novel network services. In particular, SDN and NFV enable the flexible composition of network functions, a generic service concept known as network service chaining (NSC).

However, the control of resources, management and configuration of network service chains is challenging. In particular, there typically exist multiple options on how an abstract network service can be decomposed into more refined, inter-connected network functions. Moreover, efficient algorithms have to be devised to allocate the network functions. The underlying algorithmic problem can be seen as a novel generalization of the Virtual Network Embedding Problem (VNEP), where there exist multiple realization options. The joint optimization of decomposition and embedding has not been studied in the literature before.

This paper studies the problem of how to optimally decompose and embed network services. In particular, we propose two novel algorithms to map NSCs to the network infrastructure while allowing possible decompositions of network functions. The first algorithm is based on Integer Linear Programming (ILP) which minimizes the cost of the mapping based on the NSCs requirements and infrastructure capabilities. The second one is a heuristic algorithm to solve the scalability issue of the ILP formulation. It targets to minimize the mapping cost by making a reasonable selection of the network function decompositions. The experimental results indicate that considering network function decompositions at the time of the embedding significantly improves the embedding performance in terms of acceptance ratio while decreasing the mapping cost in the long run in both optimal and heuristic solutions.

1. Introduction

Network service chaining (NSC) is a service concept which has gained much interest from both practitioners and researchers. NSC promises increased flexibility and cost-efficiency for future carrier networks. NSC is enabled by Software-Defined Networking (SDN) and Network Function Virtualization (NFV). Employing SDN and NFV developments simplifies the service chain provisioning significantly and enables the introduction of new services. Traditionally, a service composed of several functions is implemented by middleboxes and traffic should flow through these middleboxes in a given order. A service chain is an abstraction to define high-level services in a more generic way. The service is

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http://dx.doi.org/10.1016/j.comnet.2015.09.035
1389-1286/

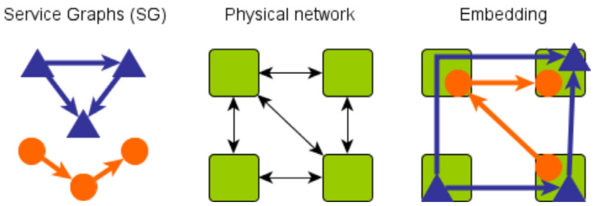

Fig. 1. Network function embedding concept.

composed of a chain of high-level Network Functions (NFs) with pre-defined parameters referred to as Service Graph (SG). Different aspects of service chaining, its limitations and existing challenges are investigated by different activities and research projects such as: (i) a dedicated working group (Service Function Chaining Working Group) in IETF which focuses on the service chaining architecture, (ii) the Network Functions Virtualization (NFV) group within ETSI which investigates software-based telecommunications services to be run in virtualized environment instead of special purpose appliances, (iii) UNIFY, a EU-funded FP7 project, which focuses on developing an automated, dynamic service creation architecture based on a dynamic fine-granular service chaining model leveraging Cloud virtualization techniques and SDN.

An NF can be decomposed in multiple ways to several less abstract, more refined NFs, and thus an SG composed of several high-level NFs can be realized through multiple options referred to as service decompositions. To be more precise, NF decomposition refers to (i) translation of a high-level/abstract NF (e.g., Firewall) to more refined NFs (e.g. an OpenFlow- or an iptables-based Firewall) or (ii) decomposing a compound NF into multiple NFs which can potentially be abstract and are interconnected in a graph (e.g. a load-balanced Firewall can be decomposed into any number of Firewalls preceded by a number of load balancers).

To give an example, consider that a user requests a service including a parental control NF. The functionality of this NF can be decomposed to (i) Traffic Classifier, (ii) Web Proxy and (iii) Firewall NFs. Each of these NFs can be realized through more refined NFs, e.g. a Firewall can be implemented as (i) iptables-based Firewall or (ii) OpenFlow-based Firewall. These NFs should be traversed in a given order and the logical connectivity between them is as follows: Traffic Classifier → Web Proxy → Firewall. This connectivity can be represented by a graph which is referred to as a Network Function Graph NFG. Service decomposition is defined as a mapping of each NF into a set of NFGs: $NF_i \rightarrow \{NFG_1^i, NFG_2^i, \ldots\}$.

Having multiple decomposition options for service realization, a challenging task is to find an optimal placement of the NFs within the service to the components of an infrastructure. We refer to this problem as the Network Function Embedding Problem (NFEP) and Fig. 1 illustrates its general idea. As we see in this figure, given multiple SGs composed of NFs and a common physical network, we look for a placement of NFs/logical links to the nodes/links of the physical network. In this figure, only one decomposition is depicted for each SG. However, as explained earlier, an SG can be realized through multiple decompositions. This problem can be seen as a generalization of the Virtual Network Embedding Problem (VNEP) in which virtual networks are mapped to a common infrastructure without having multiple realization options.

The literature is rich on algorithmic proposals to solve the VNEP [1]. However, no work considered to decompose and embed an SG at the same time.

Our contribution. The decompositions of an SG need to reflect required hardware resources and capabilities (e.g. requirement for iptables-based Firewall). Selecting a decomposition independently of available resources in the infrastructure may yield mapping solutions far from optimal. We accordingly present algorithms (optimal and heuristic) for the NFEP which take the SG decomposition opportunities into account. This would certainly improve the performance of the embedding as a reasonable decomposition is selected which corresponds to the existing resources and thus leads to a better placement of the NFs.

To the best of our knowledge, the joint optimization of SG decomposing and its embedding has not been investigated in prior work.

We first propose an Integer Linear Programming (ILP) model to solve the NFEP. This model considers SG decomposition options as the input of the embedding problem. The objective is to minimize the cost of the mapping based on the SG requirements and infrastructure capabilities. We define the cost of mapping an SG as the cost of the total substrate resources allocated to that SG which is calculated based on: (i) the cost of each unit of CPU, memory and storage in a physical node (ii) the cost of each unit of bandwidth in a physical link and (iii) the resource usage of the given SG. The cost per unit of capacity (i, ii) is determined by the infrastructure provider (InP). The algorithm maps the NFs within an SG to the components of the physical network in such a way that the resource consumption is minimized and the QoS requirements of the SG are satisfied. This is equivalent to maximizing the number of service requests which are accepted and thus the acceptance ratio in the long run is increased. One of the main constraints in this mapping is that NFs in an SG can be of different types (e.g. a VM image, a process in a container or a hardware appliance). However, not all types, e.g., iptables-based and OpenFlow-based Firewalls, are supported by all infrastructure nodes.

Solving the VNEP is NP-hard in most of the cases [2] and allowing for all possible SG decompositions generally increases the complexity drastically. As a result, finding the optimal solution might not be feasible in large-scale scenarios. We therefore propose a heuristic algorithm to overcome the scalability limitation of the ILP solution. In this scheme, first a reasonable decomposition is selected for the SG and then NFs of the selected decomposition are placed on physical network components based on a backtracking mechanism. This algorithm was briefly presented in [3] as a short paper, without any thorough evaluation. We use the proposed ILP-based approach to benchmark the heuristic algorithm. Therefore, this paper extends the work in [3] by providing an ILP model and a thorough evaluation of the proposed scheme. These evaluations should enable more accurate conclusions regarding the performance of the heuristic-based approach compared to the optimal solution.

The proposed approaches are evaluated thoroughly and compared in an extensive computational evaluation. The experimental results indicate that employing SG