Computer Networks 129 (2017) 105–116

Contents lists available at ScienceDirect

Computer Networks

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

Online assignment of non-SDN virtual network nodes to a physical SDN

Amin Ghalami Osgouei*, Amir Khorsandi Koohanestani, Hossein Saidi, Ali Fanian

Department of Electrical and Computer Engineering, Isfahan University of Technology, Isfahan 84156-83111, Iran

ARTICLE INFO

Article history:
Received 15 August 2016
Revised 4 March 2017
Accepted 6 September 2017
Available online 12 September 2017

Keywords:
Virtual network embedding
Software defined networks
Online algorithms
Competitive analysis

ABSTRACT

Network virtualization is a promising solution to increase utilization of communication resources in data center networks. On the other side, software defined networks (SDNs) gather great attention from industry and academia to be used as the networking solution for data centers. Virtualizing SDNs and providing suitable virtual network embedding (VNE) techniques, paves the path for designing highly configurable virtualized cloud data centers. Considering the challenges which are arisen by using the SDNs as the substrate network for hosting non-SDN virtual networks, it is desired to develop an online VNE technique with a bounded competitive ratio as well as polynomial execution time in terms of problem size. To achieve this goal, this work is a primary step which solves the embedding problem with releasing the capacity constraints of physical network links. So, to the best of our knowledge, the problem of online virtual node assignment to physical nodes of SDNs with limited capacity of in-node and on-controller processing powers is presented for the first time in this work. Furthermore an online mapping algorithm is provided for the mentioned problem with poly-logarithmic competitive ratio. This can be considered as an online algorithm for general node assignment problem with batch arrivals of the requests and also can be used as a solution for online virtual machine allocation problem with batch arrivals of the requests.

1. Introduction

Software defined networks (SDN) are proposed based on separating control plane and data forwarding plane of computer networks [1]. This separation creates great opportunities in terms of facilitating network management tasks, resource slicing process and gathering network statistics. Due to numerous benefits of SDNs in facilitating network management, using SDNs as communication backbone of data centers can be a promising solution for better resource utilization in data center networks.

The most fundamental architectural attribute of SDN is using simplified routers as the forwarding nodes of the data plane. These simplified forwarding nodes require deploying a logically centralized controller which hosts the network control functions that are excluded from the forwarding nodes. The excluded controlling functions are replaced by a flow table on each data forwarding node. These data flow tables must be managed by a controller. Proposing appropriate controller architecture which fits the requirements and design goals of the network, has got a great attention from the research community [2,3].

The requirement of devising network wide consistent decisions, imposes a logically centralized architecture for SDN controller. On the other side, placing a physically centralized controller in a large network, may lead to emergence of network single point of failure and also network performance bottleneck. So, in order to mitigate the challenges of using physically centralized controller in a SDN, several distributed architectures have been proposed where several physical controllers collaboratively form a logically centralized controller [3]. In this way, each physical controller is responsible for managing a subset of SDN data forwarding nodes. As a consequence, the central performance bottleneck will be reduced through devising local decisions by physical controllers.

Separation of network control functions from the data forwarding nodes in SDNs, makes the process of slicing network nodes easier. Some network virtualization solutions have been proposed to address the network slicing process in SDNs [4,5]. Although the proposed virtualization solutions provide required slicing functions for virtualizing SDNs, but they don't deal with the process of mapping virtual network resources to the substrate SDN. The mapping process of virtual networks to physical networks is known as Virtual Network Embedding (VNE) and got great attention in industry and academia [6]. The overall process of mapping virtual networks

* Corresponding author.
E-mail addresses: a.ghalami@ec.iut.ac.ir, amin.oskuii@gmail.com (A. Ghalami Osgouei), a.khorsandi@ec.iut.ac.ir (A. Khorsandi Koohanestani), hsaidi@cc.iut.ac.ir (H. Saidi), a.fanian@cc.iut.ac.ir (A. Fanian).

http://dx.doi.org/10.1016/j.comnet.2017.09.004
1389-1286/

to the substrate network, involves the joint mapping of both virtual nodes and virtual links to the appropriate resources of the substrate network. The quality of the mapping generated by VNE process, has great impact on the resource utilization of the substrate network.

Network virtualization is an extension of the server virtualization idea which necessitates the performance and functionality isolation between the tenant virtual networks and providing transparency for the users of tenant virtual network. The processing demands of virtual nodes must be addressed separately in two different categories of data forwarding and controlling tasks. Data forwarding tasks of virtual nodes will be delegated to hosting physical nodes and network control functions will be hosted by physical controllers. On the other side, it is very possible to face with some virtual tenants which are not designed based on the SDN paradigm. Therefore, the network controlling functions of non-SDN virtual network must be offloaded to physical controllers.

Any algorithm which makes decision about mapping non-SDN virtual nodes to SDN nodes must check the available space both on the physical node and its corresponding controller.

In addition to the node and controller processing powers, the size of data flow tables and the bandwidth of physical links are other resource constraints of SDNs. The table size constraints are mostly dependent on the available technology, which does not seem to be a hard constraint today.

In contrast, the bandwidth constraints of the physical links affect the process of finding feasible mappings of virtual networks on the SDN substrate. The ideal approach is to develop an algorithm which considers all constraints and devises a single shot decision about the desired mapping. But, doing so is a very complex task. In other words, embedding a virtual network on a physical network is a special version of sub-graph isomorphism problem [7] which is NP-complete [8]. Several researchers proposed two steps VNE techniques to deal with the complexity of this problem [9–11].

In a two steps VNE, the process of embedding virtual networks is done through separation of two tasks: mapping of nodes and mapping of links. At the first step, a mapping of virtual nodes will be found and then based on the outcome of this step, the virtual links will be mapped to physical paths. Using two steps VNE techniques does not necessarily lead to the best solution of the problem, but provides a tool to develop a practical VNE technique.

The node mapping part of two steps VNE technique is also a complex task in which, mapping each virtual network is considered as a *request* which may be fulfilled if all of its demands can be satisfied; otherwise, it will be dropped. It is also assumed that the nodes of a single request can't be clustered on a single physical node. In other words, upon arriving a request, its nodes must be served in way that no two of them be assigned to the same physical node.

This problem can be considered under two different assumptions. First, assuming that all the requests are known in advance and the algorithm must find the optimal mapping based on a specific objective function. This configuration is called offline version of the problem. By assigning a color to each request, this problem can be considered as a version of "*All-or-nothing Generalized Assignment Problem*" which has been studied in [12].

The second assumption leads to the online version of the problem in which, requests arrive one by one and no new request will arrive until the algorithm makes its irrevocable decision about the current request. Each arriving request in this problem is the node set of a virtual network. This case differs from the previously studied online bipartite matching [13] or online generalized assignment [14,15] in which the requests contain just one node or item.

This paper only deals with the problem of online node assignment of several non-SDN virtual networks to a physical SDN in which an online mapping algorithm is proposed with poly-logarithmic competitive ratio. In contrast to other VNE methods which are generally based on heuristic techniques [16,17], the effectiveness of the proposed algorithm is proven by using analytical competitive ratio techniques. It is also assumed that non-SDN requests are generated randomly in advance and arrive independent of algorithm outcome.

The solution proposed in this paper is also applicable to other contexts. For instance the problem of task scheduling in a virtualized cloud data center can benefit from this method. To explain more, regard the situation, in which some tasks with specific processing and communication demands must be assigned to some virtual machines. Each virtual machine has a limited processing power and communication capacity. The assignment of the tasks to these VMs is just similar to the node assignment problem where VMs and their intercommunication links play the same role as physical nodes and physical controllers respectively.

The main contributions of this paper can be summarized as follows:

- Addressing the node assignment challenges in the mapping of non-SDN virtual networks to physical SDN;
- Developing an online admission control and mapping strategy for all or nothing node assignment problem;
- Competitive analysis and experimental evaluation of the proposed algorithm;

The remainder of this paper is organized as follows. The second section is dedicated to the related researches. The formal definition of the problem is provided in the third section. The proposed algorithm, assumptions and its competitive analysis are presented in Section 4. Additionally, a lower bound for the competitive ratio of any solution to this problem is presented in this section. The simulation results are provided in Section 5. Finally, Section 6 contains future directions of the research and conclusions.

2. Related works

SDN as a new network architecture paradigm has been proposed for the first time in [1]. A comprehensive survey of issues and technical advances related to SDN is provided in [18].

An offline version of VNE has been proposed in [19]. An offline version of VNE for embedding virtual SDNs over the physical SDN which is based on a heuristic method, is provided in [20]. Authors of [21] and [6] provide two comprehensive surveys in the field of network virtualization and VNE algorithms respectively.

On the other side, online algorithms constitute a great stream of research in the field of algorithm design. A survey on different issues and techniques regarding online algorithms is provided in [22]. As stated there, online algorithms deal with a sequence of requests, $\sigma = \sigma(1), \ldots, \sigma(m)$. The algorithm must serve each request without any knowledge about the future possible requests. Serving each request, imposes a cost to the algorithm and the objective is to minimize the total cost.

The main criteria for evaluating the performance of an online algorithm is "*competitive ratio*" which was first proposed in [23]. Let $A(\sigma)$ and $OPT(\sigma)$ to be the cost of serving a sequence of requests σ by a deterministic algorithm A and the optimal offline algorithm respectively. According to Sleator and Tarjan [23], the algorithm A is called to be C-competitive if there is a constant a such that (1) holds for all sequences of requests σ.

$$A(\sigma) \leq C.OPT(\sigma) + a \tag{1}$$

An online virtual circuit routing algorithm with the objective function of maximizing the revenue is provided in [24]. The competitive ratio achieved there, is $O(\log n)$ where n is the size of host network. In [25], another online virtual circuit routing algorithm