Optical Switching and Networking 14 (2014) 233–240

Contents lists available at ScienceDirect

Optical Switching and Networking

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

Cost efficient virtual network mapping across multiple domains with joint intra-domain and inter- domain mapping ☆

Hongfang Yu [a], Tao Wen [a], Hao Di [a], Vishal Anand [b], Lemin Li [a]

[a] *Key Lab of Optical Fiber Sensing and Communications (Ministry of Education), University of Electronic Science and Technology of China, Chengdu, China*

[b] *Department of Computer Science, The College at Brockport, State University of New York, USA*

ARTICLE INFO

Article history:
Received 15 February 2014
Received in revised form
15 April 2014
Accepted 13 May 2014
Available online 8 July 2014

Keywords:
Domain-level graph
Multiple domains
Network virtualization
Virtual network mapping

ABSTRACT

Network virtualization allows the coexistence of multiple virtual networks on a shared substrate optical network, which interconnects the geo-distributed data centers. A virtual network (VN) typically spans across multiple domains, which may be managed by different infrastructure providers (InPs). The topology and resource information on each domain is confidential and kept private by the InP. However, a domain-level (global) view is required to achieve cost efficient VN mapping across multiple domains. In this paper, we present a framework for the cost efficient VN mapping across multiple domains with joint intra-domain and inter-domain mapping. In the framework, the VN mapping is accomplished by the mapping manager that is the broker between the SPs and the InPs. The mapping manager collects the mapping candidates for the VN request from the InPs, and then establishes the abstracted domain-level graph. Finally the candidates are selected on the domain-level graph with cost and quality of services (QoS) consideration. We formulate the problem of candidate selection as an mixed integer linear programming (MILP), and then relax the integer constraints to obtain a linear program to solve it. The simulation results show that our proposed framework can achieve low resource allocation cost and good QoS performance for the VN request.

1. Introduction

To improve the quality of experience (QoE) and quality of service (QoS) using cloud computing, cloud service providers are building geo-distributed networks of data centers [1,2]. This multi-datacenter system cannot only reduce latency but also increase survivability in the presence of outages affecting an entire site or its connections to the outside world. Thus, the substrate network, which interconnects multiple data centers (each with a large number of computing physical server) with networks, is deployed to support a variety of distributed applications and services. *Optical network* [3] is a natural choice for the substrate network because of its high speed, enormous bandwidth and protocol transparency.

With the increasingly popular virtualization of both computing and networking resources in a geo-distributed optical networks of data centers (called a physical substrate), multiple

☆ This research was partially supported by the National Grand Fundamental Research 973 Program of China under Grant (No. 2013CB329103), Natural Science Foundation of China grant (Nos. 61271171 and 61001084), Program for Changjiang Scholars and Innovative Research Team (PCSIRT) in University and the 111 Project B14039.

The research of Dr. Vishal Anand is supported in part by the Provost Fellowship and Scholarly Incentive Grant at the College at Brockport, SUNY.

E-mail addresses: yuhf@uestc.edu.cn (H. Yu), winterwentao@gmail.com (T. Wen), dihao@uestc.edu.cn (H. Di), vanand@brockport.edu (V. Anand), lml@uestc.edu.cn (L. Li).

http://dx.doi.org/10.1016/j.osn.2014.05.020
1573-4277/

virtual networks (VNs) can share the physical resources of the underlying substrate [4–6]. Using virtualization multiple heterogeneous network architectures can cohabit on a shared substrate network. Virtualization technology is also a business enabler that allows agile deployment of various applications and services with increased flexibility while optimizing the use of infrastructure resources as well as reducing the cost of maintaining them.

Each request in a virtualized network environment is modeled as a virtual network (VN), consisting of virtual nodes interconnected by virtual links. It is essential to address the VN mapping problem for enabling network virtualization. The VN mapping problem is the allocation of substrate network resources to satisfy the constraints of the virtual nodes and links of the VN, e.g., satisfying the required computing resources on the virtual nodes and the bandwidth resources of the virtual links.

The underlying substrate optical network typically consists of multiple administrative domains provided by Infrastructure Providers (InPs). Each InP deploys and manages the physical network resources in its domain and offers their resources to the Service Providers (SPs). Each SP leases the resources from multiple InPs to create and deploy the VN for end users [4]. An InP can map the VN request in its administrative domain using the intra-domain algorithms proposed in [7–16] as the InP has the complete knowledge of its domain. However, when the VN request is mapped across multiple domains (e.g., to satisfy location, resource efficiency constraints) there is no global view of the underlying substrate as InPs in different domains do not expose or share their topology and resource information with each other. In this work we propose a scheme that uses a broker between the InPs and the SPs to enable the InPs to cooperate and accomplish the VN mapping across multiple domains.

So far, there have been only very limited works on virtual network mapping across multiple domains [17–19]. The work in [17] proposes a side-by-side framework to address VN mapping across multiple domains. The VN request firstly is partitioned into several VN sub-graphs, and each sub-graph is mapped by an InP in its domain. Meanwhile, the works in [18,19] propose a sequent VN mapping framework. An InP partially maps the VN request and forwards the residual part to other InPs in a recursive manner. These works can map the VN request across multiple domains without knowing the topology and resource information of the individual domains. However, separation of inter-domain mapping and inter-domain mapping restricts the solution space, and may result in the poor performance and low resource utilization.

In this paper we present a framework of cost efficient VN mapping across multiple domains, called MD-VNM. The framework determines the intra-domain and inter-domain mapping in the same phase, and also considers the QoS performance. In our framework, the mapping manager receives the VN request from the SP, and cooperates with the InPs to find the VN mapping. In each domain the InP finds the candidates for mapping the virtual nodes and links while considering the intra-domain QoS performance. The InPs then offer the intra-domain candidates to the mapping manager, bidding for the virtual nodes and links in the VN request, and cooperate with the mapping manager to find inter-domain link candidates that interconnect intra-domain node candidates. The mapping manager collects these candidates and pricing provided by InPs to establish a domain-level graph and selects the candidates from the graph with (intra-domain and inter-domain) cost and QoS consideration, i.e., intra-domain and inter-domain VN mapping is determined in the same phase. The rest of the paper is organized as follows. The related work is introduced in Section II. Section III formulates the multi-domain cost efficient VN mapping problem. Section IV describes our framework for cost efficient VN mapping across multiple domains. Section V presents the MILP and the integer-relaxed algorithm for candidate selection. Section VI presents the simulation results, and Section VII concludes the paper.

2. Related work

Some heuristics for VN mapping in single domain under different objectives and constraints have been proposed recently [7–16]. Based on shortest path, *k*-shortest paths and multi-commodity flow algorithms, the work in [7] presented two-stage simple approaches to relax the tight coupling between node mapping in the first stage and link mapping in the second. However, separating node and link mapping stages may result in poor performance. The work in [8–12] developed integer linear programming (ILP) optimization, column generation, heuristics and meta-heuristics by coordinating the node and link mapping phases, and introduced better correlation between the two phases. Quality of Service (QoS) constraint during VI mapping is considered in [13].The works in [14–16] consider the special constraints of optical networks, such as wavelength continuity, transmission impairments and sub-carrier slot continuity.

More recent works [17–19] have considered virtual network mapping across multiple domains, where papers [17,18] focus on the general networks, and paper [19] focuses on the optical network. In [17], the VN request is partitioned into several VN sub-graphs, and each sub-graph is mapped by an InP in its domain. Finally, the inter-domain virtual links interconnecting the VN sub-graphs (in different domains) are mapped onto inter-domain paths. In [18], the VN request is sent to all InPs. InPs do the mapping in sequence. The first InP partially maps the received VN request and forwards the residual part to other InPs in a recursive manner. After the mapping of virtual nodes is determined in different domains, the inter-domain virtual links are mapped. These current works do well in distributed environment. However, separation of intra-domain and inter-domain mapping is hard to achieve the global-view optimization and meet the end-to-end QoS requirements. The authors in [19] investigated dynamic virtual network mapping over multiple-domain SDN networks and proposed an efficient VN request scheduling mechanism.

3. Problem statement

In this section we formulate the problem of cost efficient VN mapping across multiple domains WDM network with the QoS consideration.