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An intelligent inter-domain routing scheme under the consideration of diffserv QoS and energy saving in multi-domain software-defined flexible optical networks

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ABSTRACT

Large scale multi-domain software-defined optical networks (SDON) provisioning has become a key area with increased scalable bandwidth services across wider network regions. Although distributed schemes could achieve lightpath routing by the ergodic process of domain boundary nodes, it increases the complexity of the signaling procedure and deployment of the interface. Moreover, the physical impairments are always the main factor of the infrastructure layer in SDON, which affect the transmission quality of the signal. Meanwhile, with increasing energy consumption of the Internet, it is imperative to design energy-efficient networks. To address the above issues, in this paper, an intelligent inter-domain routing scheme, which is supported by hierarchical control plane architecture, is presented based on sub-topology graph under the consideration of diffserv quality-of-service (QoS) and energy saving. The proposed scheme could achieve multi-domain quality of transmission (QoT), energy aware routing and spectrum assignment (RSA). We explore the scenarios where the multi-domain SDON achieve energy efficiency on the basis of meeting the QoT requirement. The blocking, energy consumption and average set up delay performances of the proposed schemes are estimated. The results indicate that the introduction of sub-topology in multi-domain RSA scheme has the better performance comparing with the distributed scheme.

1. Introduction

Future and emerging Internet applications are becoming cloud-based applications with the common requirement for a high capacity flexible optical network infrastructure, such as cloud computing and geographical service distribution for better customer experience, high definition video streaming, and data backup services. Flexible optical transport networks also called elastic optical networks (EON) could provide long-reach optical transport to meet the big data rates beyond 100 Gb/s [1] and the required flexible transport capacity at the backbone networks. It can allocate an appropriate optical spectrum range and modulation format to an end-to-end optical path according to the client (e.g. IP) traffic demand and path attributes (e.g., physical impairments or the demand of QoS). For large scale multi-domain optical networks, different domains are actually managed by different vendors, diverse signaling message formats, transmission technology and switching technology increase the negative influence on the intelligent inter-domain connection provisioning between different domains. Limited resource visibility will increase the difficulty of inter-domain routing. How to improve the efficiency of the end-to-end, QoS guaranteed cross-domain connections has become one of the attractive research in the trend of large scale, multi-domain development.

Software Defined Networking (SDN) with OpenFlow Protocol (OFP) [2], which allows operators to control the network using software running on the network operating system within an external controller, provides the maximum flexibility and high scalability for the operators to control the optical networks, and matches the carrier's preferences with its centralized architecture, simplicity and manageability. To meet the requirements of various services, flexible optical network technologies are moving toward more efficient, flexible and scalable solutions. With the virtues of vertical architecture and centralized abstraction, SDN makes it possible to design a successful flexible optical networks control plane framework, resulting in flexible networks ability in the deployment of new services and protocols, better QoS, lower energy consumption, and higher revenue [3]. Thus, software defined optical network (SDON) which could deliver dynamic end-to-end service across multi-domain networks has shown a continuous growth of data traffic demand as a trend to solve the issue of cross-domain connections,

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especially for the intelligently providing inter-domain connections.

Plenty of work has been done in applying SDON. Originally, the research of SDON mainly focuses on a single administrative domain to improve manageability of networks [4,5], and reviews are provided in [6,7] of the benefits, challenges in SDN's optical extension and the requirement of new devices to enable SDON. These works have shown that the introduction of SDN in optical network is necessary to meet the intelligent development. In recent years, with the continuous expansion of the optical network, the inter-domain service which is easy to be blocked for more resource consumption attracts more and more attention. Intelligently providing inter-domain connections across multi-domain optical networks to complete routing and spectrum assignment (RSA) becomes a focus of research [8,9]. Different concrete multi-domain RSA schemes for inter-domain routing in multi-domain SDON have investigated integration [10,11]. Those schemes have one thing in common, that is considering collaboration between controllers under information isolation.

However, for the issue discussed above, the network architecture in multi-domain SDON which determines global optimization ability of path planning is essential. Detail descriptions have been provided in [12–14] of new architectures based on a broker designed to coordinate inter-domain networking across the administrative domains. These provide the reference to the hierarchical control plane architecture presented in this paper. A bit additional, it should be noted that the application layer of SDON is weak, Network function virtualization (NFV) could make up for this shortcoming by slicing and restructuring of a shared physical resources. NFV combined with SDON is applied to provide partition, abstraction, flexibility, with an acceptable performance penalty and lower operating expense [15]. Some previous work has shown the potential of SDON such as integrated virtualized EON resource provisioning [16].

On the other hand, for the multi-domain SDON, physical layer impairments in the infrastructure layer of the SDON have always been the utmost important factor for the quality of the signal transmission. Especially in the case where the bandwidth channels occupy large bandwidths (>100 GHz). In addition, with the emergence of new, developing Internet applications, network traffic has been showing an explosive growth, and the telecommunications network along with energy consumption is showing a growing trend with a rate of 10% per year. Accordingly, the issues including physical impairments evaluation and energy consumption assessment should be considered in multi-domain RSA to meet the QoT requirements and also the energy efficiency. Above all, on the basis of hierarchical control plane architecture, we propose an intelligent inter-domain routing scheme based on the sub-topology graph under the consideration of diffserv QoS and energy saving. The aim of the scheme is to improve the performance of the entire network by reducing the consumption of inter-domain resource.

Overall, the paper is organized as follows. Section 2 describes presented OpenFlow-based multi-domain SDON, including FlowBroker architecture, the application of path computation element (PCE) under the consideration of impairment-energy, and the service-oriented hierarchical control strategy, etc. Based on the previous work in Section 2, the proposed multi-domain RSA scheme, in which the physical impairments and energy consumption are all considered, is described in detail in Section 3. The performance evaluation of the scheme such as blocking probability, the results of energy consumption and set up delay are introduced in Section 4. Section 5 is the tag section, which is summaries and extensions of this paper.

2. OpenFlow-based multi-domain software-defined flexible optical networks

2.1. FlowBroker architecture based on OpenFlow

Although more mature and intelligent, a GMPLS-based distributed control plane may not be an ideal solution for the requirement of unified control functionality in optical networks, which need end-to-end high capacity connectivity between users and geographically distributed remote data centers traversing multiple network domains. In contrast, the expanded OFP has been proposed to serve for the unified control plane of the SDON [17], enabling the possibility of SDON to be flexibly and dynamically provisioned and reconfigured by providing the maximum flexibility. The SDON could arguably match carriers' preference giving its simplicity and manageability with the expanded OFP, and provide a new vendor agnostic framework for evolving carrier grade networks.

However, despite massive progress, an OpenFlow-based unified control plane for multi-domain multi-vendor SDON is still under study since key issues such as resource abstract, dynamic restoration, transponder control, and multi-vendor interoperability, openness have not been solved well so far, and the topology information may not be willing to share between different domains in the ordinary course of events. These problems result in the absence of a control entity to collect and update the information of the global network topology. But NFV enables physical infrastructure providers to partition, abstract, and compose their physical resources into multiple independent slices with each virtual resource resulting in the same functionality of the actual physical resource, with an acceptable performance penalty. Dynamic multi-domain virtual optical network deployment has been proved in [18], thus providing us an effective way to solve the problem that lack of considering collaboration between controllers under information isolation in SDON.

Optical FlowBroker and multi-domain resource broker have been designed to coordinate inter-domain networking across administrative domains in [12], which take into account the collaboration between controllers under information isolation to serve for the RSA of the whole network. In this paper, we present a new FlowBroker architecture based on OpenFlow by combining both the advantages of SDN and NFV as Fig. 1 shown. The multi-domain resource FlowBroker (MRFB) architectural model defines a domain as a set of OpenFlow switches with a single controller, managing the flow tables of all switches within that domain. As conveyed in Fig. 1, controllers in different domains periodically collect the information of topology, link state, domain etc and store them in the local traffic engineering database (TED) to serve for local events; and the essential global information will be stored in the global TED of the MRFB to deal with global event and prepare for the STG-RSA algorithm (details will be presented below) to determine domain forwarding decisions on a per-flow basis. The architecture could provide a mechanism for virtualizing transport nodes and links. It allows the composition of end-to-end virtual transport infrastructures across different transport technologies as well as end-to-end network service provisioning. This needs multiple OF-controlled EON virtualization visors to complete the composition of virtual optical networks (VONs) across multi-vendor's transport and control plane technologies and thus we can achieve the interconnection of multi-vendor network. The proposed MRFB shall not be understood as a broker within the classical understanding, but as a network entity able to satisfy different network virtualization requirements, within the heterogeneous network control domains.

Fig. 2 presents a simple, classical and improved OpenFlow-based initial simulation multi-domain topology which utilizes the