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A multi-domain control scheme for diffserv QoS and energy saving consideration in software-defined flexible optical networks

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ABSTRACT

The software-defined networking has emerged as an efficient network technology. It is capable of supporting the dynamic nature of future network functions and intelligent applications to provide the customized services. However, the physical impairments are still the main factor affecting the transmission quality of the signal. Meanwhile, the future network design should also take the growing energy consumption into account. To address the above issues, we first present an impairment-energy aware control plane for single domain management based on the extended OpenFlow protocol in software-defined flexible optical networks. Then, a service-oriented multi-domain control scheme is designed for the network scalability requirement. To implement our scheme, a multi-domain quality of transmission (QoT) and energy aware routing and spectrum assignment (RSA) algorithm is proposed for the diffserv quality of service (QoS) and energy saving consideration. The experimental works validate that our proposed RSA scheme makes a better balance between the QoT and the energy efficiency and also improves the spectrum resources utilization with the acceptable average set up delay.

1. Introduction

The emergence of bandwidth hungry Internet services and multimedia applications results to insatiable bandwidth demand in the core networks with speeds of 100 Gb/s and beyond [1]. To support bandwidth demand and efficiently utilize the spectrum resources, the spectrum-sliced elastic optical (SLICE) network, also called the flexible optical network, has been considered to be a promising solution to adaptively allocate optical bandwidth to an end-to-end optical path. Note that the complexity of network topology has also been increased with the network scale expansion. Therefore, the distributed multi-domain provisioning needs to be addressed. Simultaneously, the concept of programmable networks, such as software-defined networks (SDN) in which the control plane is extracted from the data plane, has been introduced. It can dramatically simplify network management, allowing network operators to flexibly manage routers and switches using software running on external servers. Software-defined networking can allow transport networks in different domains to be intelligently interconnected. They can also be managed by dynamically controlled multi-domain and multi-layer network capabilities to meet service needs. In SDN, a software-based controller is responsible for managing the forwarding information of one or more switches. The hardware only handles the traffic according to the rules set by the controller [2] through an open protocol, such as OpenFlow. OpenFlow switch specification is proposed by the Open Networking Foundation (ONF) to make an open standards-based approach to SDN implementation.

In light of the above, the research on the software-defined optical networks (SDON) has been attracted extensive attention recently. In [3], an OpenFlow-based elastic lightpath provisioning in flex-grid optical networks was first presented and experimentally demonstrated. Some new features of OpenFlow enabling technologies were considered, including bandwidth-variable optical switch and the extension of flow entry and so on. For elastic optical networks with direct-detection optical orthogonal frequency division multiplexing (DDO-OFDM) transmission, an extended OpenFlow-based control plane was designed and deployed in [4]. The two-phase routing and spectrum assignment (RSA) algorithm was also implemented considering the bit error rate (BER) limitation. Liu et al. [5] successfully demonstrated a dynamic transparent optical network employing flexible transmitters and receivers. Note that the flexible transceivers were controlled by an OpenFlow-stateless path computation element (PCE) communication protocol.

In SDON, the impact of physical impairments on the transmission performance cannot be ignored for that they may affect the quality of transmission (QoT) seriously. In addition, it is

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estimated that energy consumption of backbone network infrastructures, such as routers and switches, will consume approximately to 20% of the total Internet energy usage by 2020 [6]. The physical impairments and also the energy-consuming issues should be considered during the RSA process to achieve energy efficiency with the impairment constraints. However, there is little focus on the routing and resource allocation considering the physical impairments and energy consumption in SDON. A BER-adaptive wavelength switched optical network (WSON) employing the multiformat and multirate transmitter/receiver is successfully demonstrated for the first time in [7]. The receiver can detect the optical signal and send the BER information to an OpenFlow controller via extended OpenFlow protocols. Authors in [8] developed an OpenFlow translation agent. It can collect the optical signal-to-noise ratio (OSNR) as the metric of quality of transmission (QoT) and translate them into OpenFlow protocol for the controller. Wang et al. [9] presented a SDN control plane based on an overlay Generalized Multi-Protocol Label Switching (GMPLS) model. This model made it possible to collect the energy related information and the types of the traffic flows which can be used for end-to-end quality of service (QoS) provision.

Furthermore, in SDN, the separation of control plane and data plane makes it a suitable candidate for an integrated control plane supporting multi-domain technologies. Yet, there is very little research on multi-domain SDON. The architecture of a SDN enabled optical network control plane based on OpenFlow was proposed in [10,11]. The unified control plane is mainly designed for multi-domain packets over fixed/flexible grid optical networking. In [10], to implement the proposed architecture, the bandwidth variable optical cross connect (BV-OXC) and bandwidth variable optical transponder (BVT) were supported in the extended OpenFlow protocol. Its extensions for flexible grid transport technology along with the integration with fixed grid and layer-2 packet switching were verified and experimentally demonstrated.

Still, there are important research challenges to be addressed in multi-domain SDON, such as the design and implementation of the control mechanism for the QoS consideration and how to achieve the energy efficiency. In multi-domain SDON, the routing will become increasing sophisticated due to the number of domains and the cross-domain routing process for considering physical impairments evaluation and the energy consumption assessment. In order to reduce the energy consumption and also provide different QoS supports in multi-domain SDON, we first propose a software-defined flexible optical network architecture based on the OpenFlow protocol. Then, an impairment-energy aware control scheme and also a service-oriented multi-domain control strategy are presented. Based on this, we design a multi-domain QoT and energy aware RSA scheme for the best attempt to consider the QoT requirements and also the energy efficiency.

The rest of the paper is structured as follows. Section 2 describes our presented OpenFlow-based flexible optical networks, including the network architecture, the impairment-energy aware control plane design, and the service-oriented multi-domain control strategy, etc. Based on the previous work in Section 2, a multi-domain RSA scheme, in which the physical impairments and energy consumption are all considered, is proposed in Section 3. The performance evaluation of the scheme is presented in Section 4. Finally, conclusions are given in Section 5.

2. Openflow-based software-defined flexible optical networks

2.1. Network architecture

SDN is an emerging architecture that is manageable, dynamic and cost-effective, making it much suitable for the high-bandwidth and dynamic nature of the applications. This architecture decouples the control plane and the data plane. The network intelligence is logically centralized and the underlying infrastructure is abstracted from the applications and network services. Meanwhile, the control layer and the application layer are tightly coupled, enabling multi-type of service to be supported by the transport network. A logical view of the SDN architecture has been depicted in [12] as shown in Fig. 1. The SDN controllers maintain a global view of the network. The control plane communicates with the application layer through the unified Application Programming Interface (API), which greatly simplifies the network design and operation. The control layer can control the network devices centrally, also simplifying the network devices themselves. They no longer need to understand and process complicated protocol standards but merely execute the act set from the controllers [12].

In this paper, we present a simple but classical OpenFlow-based flexible optical network architecture as shown in Fig. 2. The OpenFlow enabled bandwidth variable wavelength cross-connects (OF-BV-WXC) and the OpenFlow enabled bit rate/bandwidth variable transponder (OF-BR/BV-transponder) are deployed. The OpenFlow controller can be NOX or Beacon, implemented by C++ and Java [2]. According to the OpenFlow Switch Specification 1.4.0 [13], the switch may establish communication with a single controller or multiple controllers.

The communication between the OF-BV-WXC and the OpenFlow controller is through the OpenFlow channel, which is the interface used to exchange OpenFlow message between the switch and the controller. The controller configures and manages the switch, receives events from the switch, and sends packet out the switch through the OpenFlow channel [13]. The flow table and the group table are both used to perform packet matching and action handling. An OpenFlow switch may have one OpenFlow channel to a single controller, or multiple channels for reliability, each to a different controller.

2.2. Impairment-energy aware control plane design

For the SDON, the control layer should have the ability to monitor the transmission performance of the infrastructure layer flexibly, including some transmission parameters, such as the physical impairments and energy related factors, for the QoS evaluation and the energy efficiency assessment. In view of this, we first present a impairment-energy aware control scheme as shown in Fig. 3 to make a better network transmission performance for the SDON.

In our proposed scheme, only transmission-controlled OpenFlow controller is considered, responsible for the related

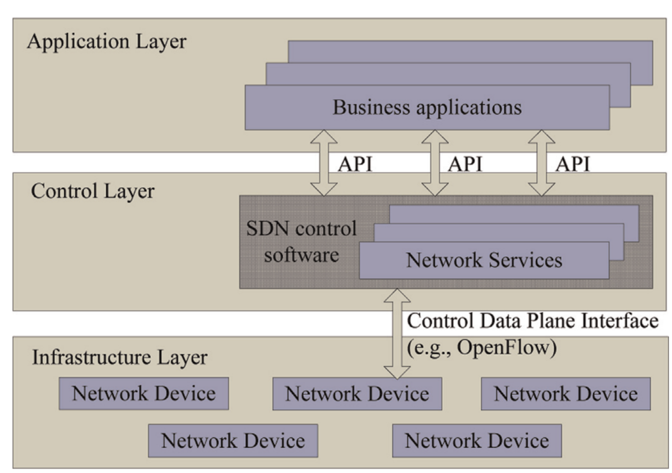

Fig. 1. SDN architecture [12].