Cross-layer shared protection strategy towards data plane in software defined optical networks

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**A R T I C L E   I N F O**

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**A B S T R A C T**

In order to ensure reliable data transmission on the data plane and minimize resource consumption, a novel protection strategy towards data plane is proposed in software defined optical networks (SDON). Firstly, we establish a SDON architecture with hierarchical structure of data plane, which divides the data plane into four layers for getting fine-grained bandwidth resource. Then, we design the cross-layer routing and resource allocation based on this network architecture. Through jointly considering the bandwidth resource on all the layers, the SDN controller could allocate bandwidth resource to working path and backup path in an economical manner. Next, we construct auxiliary graphs and transform the shared protection problem into the graph vertex coloring problem. Therefore, the resource consumption on backup paths can be reduced further. The simulation results demonstrate that the proposed protection strategy can achieve lower protection overhead and higher resource utilization ratio.

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1. Introduction

With the rapid deployment of cloud computing, the traffic demand in networks has increased rapidly, and this growth will continue in the foreseeable future [1]. To accommodate the increased burstiness of high-volume traffic, optical transport networks which have the advantages of large capacity, high bandwidth and low latency may be the best option nowadays. However, cloud computing promises to provide on-demand computing, storage and bandwidth resource, which requires network operators to evolve their infrastructures to be more intelligent and agile in resource orchestration [2].

As a promising centralized control architecture, the software defined networking (SDN) based on OpenFlow protocol has been introduced into optical transport networks [3–5]. Such network is called as software defined optical networks (SDON), which could make a vital contribution to solve the above challenge. SDON allows network operators to control the network using software running on a network operating system, thus leading to a more flexible control manner. Therefore, SDON enables the network operators and service providers to customize their infrastructure dynamically according to application requirements [6–8]. Meanwhile, SDON divides the network into control plane and data plane. The survivability is an important issue in the SDON, and the authors in Refs. [9,10] had discussed the survivable strategies for the data plane. In this paper, we just focus on the survivability of the data plane. The data plane mainly performs transmission function, which aggregates traffic from tens of thousands of users. Since a tremendous amount of data is loaded through the data plane, so it is significant to study and design survivable strategy for the data plane of SDON [11].

According to whether the backup resource is reserved for link failure, the survivable strategies could be divided into two categories: protection and restoration [12]. Because the resource is reserved for backup path before failure occurs, so the whole recovery time of protection is very short. Therefore, protection becomes more popular survivability technology in the SDON. For instance, the authors in Ref. [13] proposed a link protection scheme using the group table concept of OpenFlow. In this scheme, the flow entries related to backup path and working path were installed in the switches with different priorities and the recovery action was added in the switches themselves. When a link failed, the backup path could be exploited without the intervention of the controller. Therefore, the total recovery time was less than 50ms. Nevertheless, this scheme adopted 1:1 path protection method, which would result in low bandwidth efficiency. To enhance the bandwidth efficiency, an OpenFlow-based segment protection (OSP) scheme was described in Ref. [14]. Unlike traditional protection schemes, the OSP only allocated backup resource to the vital links based on the entire network state. Compared with setting individual protection path for each

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service, the OSP could guarantee efficient network resource utilization. However, the recovery time of OSP was barely satisfactory. Aiming at this problem, authors in Refs. [15,16] researched the protection strategies in SDON, which guaranteed a short recovery time and improved the resource utilization ratio by allocating spectrum resource and IT resource from an integrated perspective.

Traditionally, the aforementioned protection strategies were merely applied on the IP layer or the optical layer. Since lacking interaction between IP layer and optical layer, it is difficult to achieve cross-layer resource optimization. What are worse, the protection strategies on different layers may cause excessive resource consumption or strategy conflict, and the result will turn out to be just the opposite of our wish. Hence, the protection strategies tend to be IP and optical integrated to meet the growing requirement of network performance. Researches in the past years had studied the cross-layer protection strategies based on GMPLS control technology. The authors of Ref. [17] introduced a protection approach taking advantage of GMPLS. By incorporating network state information from both layers, the approach could provide integrated end-to-end survivability. Simulation results showed that this protection approach could efficiently improve the network utilization while guaranteeing the reliability of services. To further enhance the network utilization, an efficient protection scheme was proposed in Ref. [18] to dynamically allocate restorable bandwidth-guaranteed paths in integrated IP over WDM networks. Benefited from GMPLS technology, this scheme could reduce the blocking probability and the times of optical–electrical–optical conversions. To take full advantage of the cooperation between the layers, Ref. [19] proposes an inter-layer mixed resource sharing (ILMRS) scheme. The ILMRS strategy allows the wavelength link occupied by the working path can be shared with the inter-layer backup label switched paths (LSPs) and the wavelength link occupied by the backup path can be shared with the inter-layer working LSPs when the corresponding constrains can be satisfied. But due to strictly following the fixed ITU-T wavelength grids and spacing, optical network allocates bandwidth resource in a coarse granularity manner, which will lead to lower network utilization ratio.

In light of this, in this paper we propose a novel protection strategy towards data plane (PSDP) based on the SDON architecture with hierarchical structure of data plane. Firstly, the SDON architecture with hierarchical structure of data plane is established to redesign the structure of the data plane. Based on SDN control technology, the data plane is divided into four layers for getting fine-grained bandwidth resource. On the basis of the SDON architecture with hierarchical structure of data plane, the SDN controller performs the cross-layer routing and resource allocation algorithm, which can allocate bandwidth resource to working path and backup path in a fine-grained manner. Finally, by designing a shared protection method based on vertex coloring (SPVC) to support PSDP, the resource consumption on backup paths can be reduced further.

The rest of the paper is organized as follows. Section 2 describes the network architecture. The protection strategy towards data plane is presented in Section 3. We describe the simulation environment and present the numeric results and analysis in Section 4. A final conclusion is provided in Section 5.

2. Network architecture

In traditional IP over optical transport networks architecture, the minimum bandwidth resource allocation granularity on optical layer is wavelength. Therefore, a request will consume a wavelength at least, no matter how much bandwidth resource the request demands. For example, if a request demands 1 Gbps bandwidth and the capacity of a wavelength is 10 Gbps. In extreme cases, the request will occupy a wavelength entirely, and the remainder bandwidth on the wavelength cannot be used by other requests. It will cause the resource utilization ratio deteriorate seriously. To this end, it is important to redesign the traditional architecture for allocating bandwidth resource in a fine-grained manner. In this section, we define the SDON architecture with hierarchical structure of data plane based on the architecture proposed in the Ref. [20]. In this network architecture, the bandwidth allocation granularity can be reduced. Therefore, the bandwidth resource can be utilized efficiently.

The SDON architecture with hierarchical structure of data plane is illustrated in Fig. 1. The whole network is divided into the control plane and the data plane. The data plane is controlled by the SDN controller through extended OpenFlow protocol. In order to realize the centralized control functionality of the controller, the network nodes on the underlying data plane should be composed of OpenFlow router (OF-router) and OpenFlow enabled bandwidth variable optical switch (OF-BVOS). The OF-router receives flow table messages from the controller, and then translates it into the logical language, which the underlying hardware devices can understand, and then controls the cross connection process of the underlying OF-BVOS. In order to allocate bandwidth resource in a fine-grained manner, we introduce a hierarchical structure of data plane [21]. And this structure is according to the realistic network architecture. Actually, the data plane is a multivendor heterogeneous network (e.g., IP/MPLS, SDH/SONET, ATM and WDM optical network). Therefore, the four-layer model is based on the multiplexing capabilities of the node interfaces [22,23]. In this paper, we mainly focus on the protection algorithm for optical networks. Therefore, for simplicity we do not go deep into technology-specific properties and just start from more generalized abstractions. With adding a network abstraction module, the SDN controller divides the data plane into four layers: the wavelength layer, the time division multiplexing (TDM) layer, the light-path layer and the IP layer. And from the bottom up, the bandwidth allocation granularity is decreasing. When a new request comes, the protection module will apply protection strategy and set up the working path and backup path according to the bandwidth resource on all layers. Finally, the configuration commands are issued to complete the protection operation in parallel by the SDN controller through the extended OpenFlow protocol [24].

To achieve the function of the proposed architecture described above, the controller has to be extended in order to provide the protection strategy functions. The functional building blocks of SDN controller are shown in Fig. 2. The SDN controller consists of six modules, i.e., network abstraction module, multi-layer resource information database (MRID) module, topology management module, protection control module, path computing entity (PCE) and plug-in module and resource management module. The network abstraction module can interact with the OF-Router module to collect bandwidth resource information of the underlying data plane, and then abstract them into four layers as described above. The MRID module contains the real-time resource information of the underlying data plane, including the resource availability status of the four layers. According to the entire bandwidth resource information from the MRID module, topology management module is mainly used for the generation of network topology. When a request comes, the protection control module decides to apply the protection strategy to guarantee the survivability of the request. The PCE and plug-in module is responsible for computing the working path and backup path. And then the resource management module allocates resource for the working path and backup path according to the information database.

3. Protection strategy towards data plane (PSDP)

On the basis of the SDON architecture with hierarchical structure of data plane, a protection strategy towards data plane (PSDP) is proposed. Firstly, the procedure of traffic grooming in multi-layer network architecture is presented to allocate and recycle bandwidth resource efficiently. Subsequently, the procedure of the cross-layer routing and resource allocation (RRA) is described. With the help of cross-layer RRA, the controller can allocate bandwidth for the working path and backup path in an economical manner. Finally, we design a shared
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