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An optimization method of VON mapping for energy efficiency and routing in elastic optical networks

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A B S T R A C T

To improve resources utilization efficiency, network virtualization in elastic optical networks has been developed by sharing the same physical network for difference users and applications. In the process of virtual nodes mapping, longer paths between physical nodes will consume more spectrum resources and energy. To address the problem, we propose a virtual optical network mapping algorithm called genetic multi-objective optimize virtual optical network mapping algorithm (GM-OVONM-AL), which jointly optimizes the energy consumption and spectrum resources consumption in the process of virtual optical network mapping. Firstly, a vector function is proposed to balance the energy consumption and spectrum resources by optimizing population classification and crowding distance sorting. Then, an adaptive crossover operator based on hierarchical comparison is proposed to improve search ability and convergence speed. In addition, the principle of the survival of the fittest is introduced to select better individual according to the relationship of domination rank. Compared with the spectrum consecutiveness-opaque virtual optical network mapping-algorithm and baseline-opaque virtual optical network mapping algorithm, simulation results show the proposed GM-OVONM-AL can achieve the lowest bandwidth blocking probability and save the energy consumption.

1. Introduction

Compared with traditional wavelength division multiplexing networks which operate at the coarse granularity of a wavelength [1,2], elastic optical networks (EONs) improve the bandwidth resource utilization by operating at the finer granularity of a frequency slot and selecting difference modulation format according to the transmission distance [3,4]. Meanwhile, the sustained growth of date traffic with a huge amount of emerging applications requires a high efficiency and flexible basic network, such as video conference, high-definition television, cloud computing and date center. To accommodate to the diversity of infrastructure network, researchers have proposed network virtualization as a solution [5,6]. Through network virtualization, multiple virtual optical networks (VONs) can coexist on the same substrate infrastructures [7,8].

In general, a VON is composed of several virtual nodes (VNs) and virtual links. The substrate nodes provide computing resources for virtual nodes and the substrate fiber links offer bandwidth resources for virtual links. The process of constructing VONs is called virtual optical network mapping.

Many studies VON mapping have been carried out in EONs. In terms of survivability and security, because multiple VONs can share the same substrate infrastructures (i.e., Data centers (DCs) and fiber links), the blind VN mapping operation might bring down the services. This would be catastrophic in optical inter-DC networks, since the DCs (i.e., substrate nodes) and fiber links usually carry massive date and live communications. Hence, survivable VON mapping is challenging. The researchers in [9] studied the availability-aware survivable virtual network embedding problem and designed efficient heuristics to satisfy the availability requirement of each virtual network. In [10], a novel risk assessment model to identify risky virtual machines was designed and a novel risk-aware virtual network embedding heuristic algorithm was proposed by the researchers to perform the physical isolation between risky and safe virtual machines. Survivable mapping of VONs are not considered in this paper.

In terms of resource consumption, the study in [11] investigated an efficient heuristic algorithm based on node-ranking approach to maximize resource utilization. The paper in [12] proposed a load balancing algorithm based on key-link and resources contribution degree for VONs mapping in EONs.

Meanwhile, the growth of network traffic has certainly promoted the increasing of the energy consumption in network. The rapid growth of network energy consumption will restrict the sustainable development of national information industry. The problem of the energy

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consumption has been attracting more and more attention [13–15]. Therefore, in the processing of virtual optical network mapping, the joint optimization of spectrum resources consumption and the energy consumption is an urgent problem that need to be solved.

In order to reduce the spectrum resources consumption, in [16], the researchers presented the multicast service-oriented virtual nodes mapping problem over OFDM-based EONs. The work in [17] introduced one baseline mapping approach named LCLC (the largest computing resource requirement versus the largest computing resource provisioning). The investigation in [18] studied the opaque virtual optical network mapping problem in EONs based on the concept of spectrum consecutiveness (SC) of links or paths. The authors of [19] proposed a dynamic efficient VON mapping algorithm over EONs, which considers both switching capability of optical nodes and fragmentation degree loss of optical links. In [20], the authors proposed a novel virtual node embedding algorithm called alignment and consecutiveness-aware virtual network embedding (ACT-VNE) for EONs. The work in [21], authors studied algorithms for both transparent VON and opaque VON, then considered the continuity and consecutiveness of substrate fiber links. However, In [19–21], the node mapping does not take the distribution of the substrate nodes into account and result in more spectrum resources consumption.

In order to consider the distance among substrate nodes, the authors in [22] proposed two heuristic algorithms with a layered-graph. In [23], the authors proposed a VON mapping algorithm called resource and load aware algorithm based on ant colony optimization. However, the algorithms does not take the energy consumption into account. The work in [24] developed the power-aware virtual links mapping approach and the power-aware virtual nodes mapping approach to reduce power consumption for static VON requests. But the paper only considers the energy consumption and ignores the spectrum resources consumption.

Therefore, in order to jointly optimize the energy consumption and spectrum resources consumption, in [25], the authors proposed an Integer Linear Programming (ILP) model to reduce the energy consumption so as to reduce the bandwidth consumption. The authors in [26] presented ILP model to achieve the purpose of consumption optimization in the terms of energy and bandwidth. However, ILP model is not suitable for large scale networks [27]. In addition, the optimal resource allocation problem in virtualization network is proved to be a NP-hard problem [28,29]. Many studies have shown that intelligent optimization algorithm is an effective way to solve such NP-hard problem.

Based on the above mentioned analysis, a VON mapping algorithm called genetic multi-objective optimization virtual optical network mapping algorithm (GM-OVONM-AL) is proposed to jointly optimize the energy consumption and spectrum resources consumption. In GM-OVONM-AL, a vector function is designed to balance the energy consumption and spectrum resources consumption by optimizing population classification and crowding distance sorting. At the same time, in order to improve the search ability and convergence speed of the algorithm, an adaptive crossover operator based on hierarchical comparison is proposed. In addition, the mechanism of survival of the fittest is introduced to select the individual. Finally, we evaluate our solutions in terms of bandwidth blocking probability, energy consumption and spectrum utilization.

The remainder of this paper is organized as follows. We describe the problem in Section 2 and propose the GM-OVONM-AL in Section 3. Meanwhile, in Section 4, the performance evaluation is presented and finally we conclude the paper in Section 5.

2. Problem statement

A VON request is abstracted as the set of virtual nodes (VNs) and virtual optical links (VOLs). Each VN has a certain request for computing resource, and each VOL has bandwidth request. Each VN can be mapped onto any substrate node in the substrate network that satisfies its computing resource. A VOL may be mapped onto one or more substrate fiber links (SFLs) on the substrate network. Thus there will be a variety of substrate network resource allocation schemes for any VON request.

2.1. Problem description

In this study, the substrate EONs are modeled as an undirected graph $\boldsymbol{G^s}(\boldsymbol{V^s},\boldsymbol{E^s})$, where $\boldsymbol{V^s}$ is the set of substrate nodes, and $\boldsymbol{E^s}$ represents the set of SFLs. Each substrate node $v^s \in \boldsymbol{V^s}$ has computing resource of $c^s_{v^s}$, we assume that each SFL $e^s \in \boldsymbol{E^s}$ can accommodate B^s frequency slots (FSs).

Similar to the substrate network, a VON request can also be modeled as an undirected graph $\boldsymbol{G^r}(\boldsymbol{V^r},\boldsymbol{E^r})$, where $\boldsymbol{V^r}$ is the set of VNs, and $\boldsymbol{E^r}$ represents the set of VOLs. Each VN $v^r \in \boldsymbol{V^r}$ associates with computing resource requirement $c^r_{v^r}$, while the bandwidth requirement of each VOL $e^r \in \boldsymbol{E^r}$ is $bw^r_{e^r}$ (in terms of Gb/s). In this study, we consider both node mapping and link mapping in the mapping process. In the process of node mapping, each VN from a VON request is mapped onto a unique substrate node that has sufficient computing resource. The link mapping is essentially a special routing and spectrum assignment (RSA) operation. Specifically, the RSA sets up a lightpath in the substrate network for each VOL to satisfy its bandwidth requirement under the spectrum non-overlapping, continuity and contiguous constraints.

A VON request with 3 VNs interconnected via 3 VOLs is depicted in Fig. 1(a) where the numbers over VOLs represent the required bandwidth and the numbers at VNs indicate the required computing resource. Fig. 1(b) illustrates a NSFNET network with 14 substrate nodes. The available computing resource and the distance between the substrate nodes are shown. For example, the VNs A, B, C in VON request are mapped onto substrate nodes 0, 4, 11 that meet the required computing resource of VONs, and the VOLs (A, B), (A, C) and (B, C) are mapped onto SFLs (0-1-3-4), (0-7-8-11) and (2-6-7-8-11) in Fig. 2.

2.2. Problem model

In the mapping process of VON request, reducing the energy consumption quite often compromises the quality of service provisioning due to lower transmission rates and longer paths adopted. Therefore, in this paper, the objective function is to minimize the energy

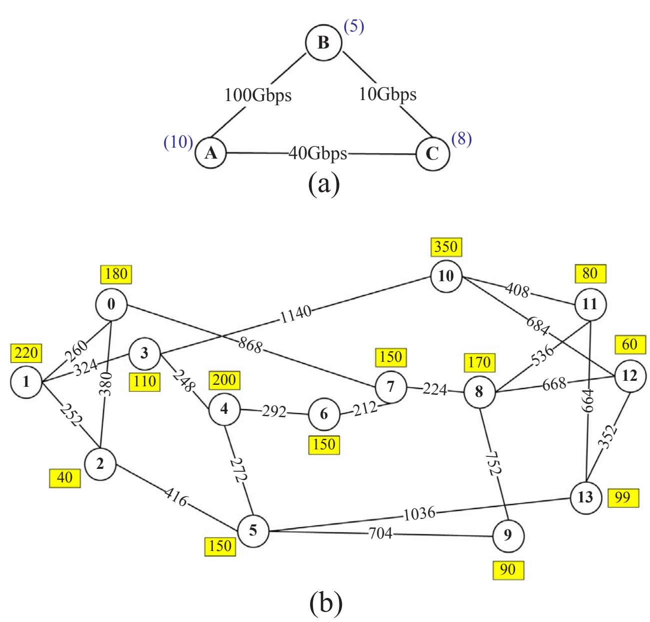

Fig. 1. (a) Virtual optical network. (b) Substrate network.