Optics Communications 402 (2017) 26–35

Contents lists available at ScienceDirect

Optics Communications

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

Virtual optical network mapping and core allocation in elastic optical networks using multi-core fibers

Hejun Xuan [a], Yuping Wang [a,*], Zhanqi Xu [b], Shanshan Hao [a], Xiaoli Wang [a]

[a] School of Computer Science and Technology, Xidian University, Xi'an, 710071, China
[b] State Key Lab of Integrated Service Network, Xidian University, Xi'an, 710071, China

ARTICLE INFO

Keywords:
Virtual optical networks mapping
Core allocation
Elastic optical network
Multi-cores

ABSTRACT

Virtualization technology can greatly improve the efficiency of the networks by allowing the virtual optical networks to share the resources of the physical networks. However, it will face some challenges, such as finding the efficient strategies for virtual nodes mapping, virtual links mapping and spectrum assignment. It is even more complex and challenging when the physical elastic optical networks using multi-core fibers. To tackle these challenges, we establish a constrained optimization model to determine the optimal schemes of optical network mapping, core allocation and spectrum assignment. To solve the model efficiently, tailor-made encoding scheme, crossover and mutation operators are designed. Based on these, an efficient genetic algorithm is proposed to obtain the optimal schemes of the virtual nodes mapping, virtual links mapping, core allocation. The simulation experiments are conducted on three widely used networks, and the experimental results show the effectiveness of the proposed model and algorithm.

1. Introduction

In recent years, more and more new services, such as mobile data, online gaming, cloud computing, and file sharing, are growing exponentially, leading to a far more than many times increment compared to the increment in system capacity [1]. Traditional wavelength division multiplexing networks can only provide the coarse granularity of a single wavelength and cannot suit for different bandwidth connection requirements adaptively, especially in the case of the requested bandwidth being only fractional bandwidth of a wavelength. The continuous growth of various applications requires an efficient networking infrastructure [2,3]. The recent elastic optical networks can provide the flexible and variable bandwidth allocation to each connection request and get higher spectrum utilization [4,5]. Elastic optical networks allow the optical spectra to be allocated at the granularity of a few gigahertz or even lower, which facilitates agile spectrum management in the optical layer. Therefore, elastic optical networking has been considered as a promising enabling technology for the physical infrastructure of the next generation internet [2]. In addition, network virtualization has been suggested as a fundamental diversifying attribute of the future network that can allow some heterogeneous/homogeneous network architectures to coexist on a shared physics network [6]. With network virtualization, the role of internet service providers includes two parts: infrastructure provider, which own physical networks, and service provide, which can use physical resources from infrastructure provider to build virtual networks for users [7–9]. Based on the concept of infrastructure as a service, elastic optical network virtualization promotes the sharing of physical infrastructure among different users and applications, and enables network operators to efficiently offer their network resources as a service [10].

Optical network virtualization has many advantages and can help virtual networks with different topologies. What is more, it enables network operators to operate different virtual optical networks that share a common physical network, simplifies optical layer resource management, provides flexible spectrum assignment scheme, and offers secure application services [11]. Since optical network virtualization can improve the energy efficiency and spectrum efficiency, it has been paid much attention to both academia and industry. An important research field on virtualization technology is to design and develop the future network architecture, such as virtual optical networks mapping algorithms, virtual optical networks-based control and management, etc. [12]. A much more challenge is how to map a set of virtual optical networks to the physical network while arriving at some goals, such as minimizing energy consumption, utilizing frequency slots resource most efficiently [13,14]. In recent years, more and more researches focus on

* Corresponding author.
E-mail address: ywang@xidian.edu.cn (Y. Wang).

http://dx.doi.org/10.1016/j.optcom.2017.05.065
Received 5 December 2016; Received in revised form 12 May 2017; Accepted 23 May 2017
0030-4018/

the virtual optical network mapping problem (including virtual nodes mapping problem and virtual links mapping problem) and spectrum assignment problem. To address the virtual optical network mapping problem, a mixed integer programming formulation is established [15], and a traffic-matrix-based mapping algorithm is designed to obtain the optimal solutions. The role of dynamic optical networks is addressed in cloud computing environments [16]. To provide effective and optimal virtual infrastructures services to users and satisfy users' requirements, an effective virtual optical network mapping algorithm is presented. Also, an integer linear programming model addressing the virtual optical network mapping problem is set up and an algorithm based on layered-auxiliary-graph (LAG) that decomposes the physical infrastructure into several layered graphs according to the bandwidth requirement of a virtual optical network request is presented [17]. In addition, some researches are focusing on the virtual optical network embedding problem with survivable considered. To satisfy the availability requirement of each virtual link or virtual node, the availability of a virtual link or a virtual node based on the availabilities of the substrate link and node is analyzed, and an integer linear programming model for the A-SVNE problem is proposed [14]. To solve FD-EVN design and the enhanced virtual network embedding problem, a binary quadratic programming formulation and a mixed integer linear programming formulation are presented [18]. Literature [19] established an integer linear programming formulation and proposed a heuristic algorithm based on dedicated protection for the 1+1-Protected virtual network embedding problem. In general, the resource of spectrum is an important resource for the elastic optical network. To overcome the spectrum lacking problem of elastic optical network using single-core fiber, elastic optical networks using multi-core fibers is an important method. At the same time, elastic optical networks using multi-core fibers will bring some other challenges, such as core allocation, crosstalk. So, we must investigate the elastic optical networks using multi-core fibers. However, existing works almost formulated the virtual optical network with one fiber core mapping problem as an integer linear programming model.

There are some researches focusing on space-division multiplexed elastic optical networks using multi-core fibers [20–22]. To reduce both the crosstalk and fragmentation elastic optical networks using multi-core fibers, an on-demand spectrum and core allocation method is proposed [22]. Two heuristic algorithms are presented to solve routing, spectrum assignment problem [23], and to trade-off between spectral efficiency and amount of transmission devices. Fujii, et al. [24] proposed a spectrum assignment and core allocation algorithm based on spectrum region which is related with corresponding building modules in space-division multiplexed elastic optical networks using multi-core fibers. Optical white box and optical black box networks are investigated, and an effective algorithm is proposed to solve the routing, modulation, spectrum, and core allocation problem [25]. There are also some similar works for the space-division multiplexed elastic optical networks using multi-core fibers [26,27]. However, the existing works almost focused on elastic optical network in physical-layer, and optical network virtualization has not been investigated.

We investigate a static (off-line) virtual optical network mapping problem, where virtual connection requests are known in advance. In addition, we assume that the system resource is sufficient. That is to say, all the virtual connection requests can be served. Different from the existing works, we investigate virtual optical network mapping problem on the elastic optical networks using multi-core fibers. What is more, cross-talk among the fiber cores is taken into account. We establish a constrained optimization model with the maximum index of the used frequency slots to be minimized, which is used to determine an optimal optical network mapping (including virtual nodes mapping and virtual links mapping), core allocation and spectrum assignment scheme. To solve the model effectively, a specifically designed genetic algorithm with three populations is proposed.

The rest of this paper is organized as follows. Section 2 describes the problem formulation, and establishes the optimization model. To solve the optimization model effectively, we propose a genetic algorithm with tailor-made operators in Section 3. To evaluate the algorithm proposed, simulation experiments are conducted, and the experimental results are analyzed in Section 4. The paper is concluded with a summary in Section 5.

2. Problem formulation

2.1. Physical elastic optical network description

Let us use a undirected graph $G = (V, E)$ to denote a network, where $V = \{v_1, v_2, \ldots, v_N\}$ is the set of the network nodes with N being the number of nodes and v_i the ith optical node, respectively. $E = \left\{l_{ij} | v_i, v_j \in V\right\}$ represents a set of optical fiber links with $|E|$ being the number of links in a network and l_{ij} the link between node v_i and node v_j in the network topology. The number of virtual machines (VMs) at node v_i is denoted by $c(v_i)$. Different from the previous related works, we consider the elastic optical networks using multi-core fibers. So, l_{ij} can be denoted as $l_{ij} = \left\{l_{ij}^1, l_{ij}^2, \ldots, l_{ij}^c, \ldots, l_{ij}^{N_{core}}\right\}$, where N_{core} and l_{ij}^c are the number of fiber cores and the sth fiber core on link l_{ij}, respectively. Let $F = \{f_1, f_2, \ldots, f_{|F|}\}$ be a set of available frequency slots in each fiber core, and $|F|$ be the number of frequency slots. Like the existing works [28,29], we assume that each frequency slot has the same bandwidth C_{fs}, and the capacity of a frequency slot is $ML \times C_{fs}$, where ML is the bits per symbol in a specific modulation level. ML can be assigned as 1, 2, 3, and 4 for different modulation levels of BPSK, QPSK, 8QAM and 16QAM.

2.2. Virtual optical network description

We use $VON = \left\{VON^1, VON^2, \ldots, VON^M\right\}$ to denote the set of the virtual optical networks (VON) on physical network G, where VON^m is the mth virtual optical network and M is the number of the virtual optical networks. $V^m = \left\{v_1^m, v_2^m, \ldots, v_{N_m}^m\right\}$ denotes the set of the virtual nodes in virtual optical network VON^m, where N_m is the number of the virtual nodes in virtual optical network VON^m. In general, we have $N_m \le N$. Let $N' = \sum_{m=1}^{M} N_m$ denote the total number of the virtual nodes in all virtual optical networks. Each virtual node $v_n^m (v_n^m \in V^m)$ has a set Ω_n^m of the candidate physical nodes, and the physical nodes in Ω_n^m are all adjacent to each other. That is to say, v_n^m can only be mapped to the physical nodes in Ω_n^m. When a virtual node is mapped to physical node v_i, a virtual machine on v_i will be occupied by the virtual node. So, the number of virtual nodes, which have been mapped to physical node v_i, should not be greater than $c(v_i)$. Let $R^m = \left\{r_1^m, r_2^m, \ldots, r_{|R^m|}^m\right\}$ denote a series of virtual connection requests in VON^m, where $|R^m|$ is the number of virtual connection requests in VON^m, and $r_k^m (r_k^m \in R^m)$ is the kth virtual connection request in VON^m which can be described as $r_k^m = (s_k^m, d_k^m, T_k^m)$, where $s_k^m, d_k^m (s_k^m, d_k^m \in V^m)$ and T_k^m are the virtual source node, virtual destination node and required capacity, respectively. If a virtual connection request $r_k^m = (s_k^m, d_k^m, T_k^m)$ exists, there is a virtual link between virtual nodes s_k^m and d_k^m.

2.3. Virtual optical network mapping

In the existing works, virtual optical network mapping has two models, i.e., pipe model [17,30] and hose model [31]. We adopt the former one in our work. To serve a virtual connection request, the virtual nodes mapping scheme should be determined, i.e., two virtual nodes of a virtual connection request should be mapped to two different physical nodes. For a specific virtual connection request $r_k^m = (s_k^m, d_k^m, T_k^m)$, if virtual nodes s_k^m and d_k^m are mapped to physical nodes $s_{k'}$ and $d_{k'} (s_{k'}, d_{k'} \in V)$, the virtual connection request r_k^m will be translated to a physical connection request $r_{k'} = (s_{k'}, d_{k'}, T_{k'})$, where $T_{k'} = T_k^m$. When all virtual nodes are mapped to physical nodes, all the virtual connection requests will be translated to physical connection requests(briefly connection requests throughout this paper). Let $R' = \{r_1, r_2, \ldots, r_{|R'|}\}$ denote the