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Continuity Aware Spectrum Allocation Schemes for Virtual Optical Network Embedding in Elastic Optical Networks

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A B S T R A C T

Optical network virtualization has been studied as a promising technique for optical network resources provisioning. In the virtualization context of Elastic Optical Network (EON), Virtual Optical Network Embedding (VONE) is investigated as a key issue for allocating spectrum resources to VON requests. This paper discusses the continuity constraint for the VONE problem in EONs, and presents three continuity-aware spectrum allocation schemes according to strict and relaxed continuity constraints. We have demonstrated the proposed schemes on emulated testbed to verify the feasibility of composing VON with discontiguous spectrum resources. Additionally, the performances of the proposed schemes are compared via simulation in terms of blocking probability, spectrum resource utilization and discontinuity degree.

1. Introduction

With the evolution of cloud computing and high performance network-based applications (e.g., virtual machine migration, video conference, etc.), the data traffic in transport networks tends to be diversified and dynamic. In this case, the concept of virtualization has been introduced into optical networks as a promising manner to provision optical network resources flexibly and efficiently [1,2].

In network virtualization scenario, network operator allows multiple Virtual Optical Networks (VON) which are managed by different network customers to coexist on the same infrastructures [3]. To allocate multiple VONs from the shared physical network, many works have investigated the virtualization techniques in Elastic Optical Network (EON) to support network resource partition and aggregation. At device level, enabled by multi-flow transponder (MF-TP) and an elastic regenerator (ER), the capability of optical network elements can be sliced into heterogeneous pieces for different users/tenants [4]. At networking level, the bandwidth and switching capacity can be virtualized through partition and aggregation of spectrum resources [5]. Based on these sliceable equipment and spectrum resources, it is a key issue to embed/map virtual network requests to physical network infrastructures. The problem of Virtual Optical Network Embedding (VONE) in EONs has been addressed in [6,7]. In particular, a Layered-Auxiliary-Graph (LAG) approach is proposed to help link mapping and node mapping [6]. There are also many works that have considered the VONE issue from various perspectives to compose VON with different optimization objectives (e.g., cost, survivability, etc.) [8–11]. The survivable VON mapping problem in EONs is discussed in [8,9], and especially the spectrum and modulation format convertible regenerators are considered to minimize the blocking of VON requests for lacking of spectrum and regenerator resources in [8]. An energy-efficient VON design scheme is discussed in IP over Elastic Optical Networks [10]. The VONE problem which considers the mixed transparent and translucent virtual links is discussed in [11]. Continuity is one of the most important constraints in EONs, and it has been investigated widely with various considerations (e.g., fragmentation) [12,13]. However, few studies have discussed the continuity constraint specifically in the context of VON. All the above works have mentioned the problem of spectrum allocation for VONE, but they all obey the continuity constraint obviously or acquiescently. Actually, allocating spectrum resources for VON is not totally the same with that for end-to-end lightpath. The allocated spectrum for one end-to-end lightpath is used to setup one single optical channel, while the spectrum for one VON may usually be used to setup multiple channels as users require. Consequently, it is meaningful to re-consider the continuity constraint for the VONE problem in EONs. To the best of our knowledge, this is the first work which considers the

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continuity constraint in spectrum resources allocation strategies for VONE.

This paper discusses the continuity constraint for the VONE problem in EONs, and defines the concept of sub-network to describe the continuity on network level. Based on sub-network, three continuity-aware spectrum allocation schemes are proposed to assign spectrum resources for the VON requests with differentiated continuity requirements. Contiguous Spectrum from One Sub-network (CSOS) allocates contiguous spectrum resources from one sub-network according to the strict continuity constraint. Discontiguous Spectrum from One Sub-network (DSOS) is designed to allocate discontiguous spectrum resources from one sub-network. Discontinuity Spectrum from Multiple Sub-network (DSMS) enables network provider to compose spectrum resources for one VON from multiple sub-networks. Demonstration results show that it is feasible to provision VON with discontiguous spectrum resources. Simulation results show that DSOS and DSMS can accommodate more VONs on the same infrastructure and improve spectrum consumption ratio, while they would introduce spectrum gaps into VONs and result in certain limitations for setting up super channels.

2. Continuity-aware spectrum allocation schemes for VONE in EONs

In this work, two kinds of resources are considered for the problem of VONE. One is the spectrum resources in fiber links, and the other is the computing resources which correspond to optical nodes. We formulate the physical network as a graph $G_p(V_p, E_p)$, where V_p is a set of physical nodes N_p and E_p is a set of physical links L_p. For a given $N_p \in V_p$, it is associated with its computing resources C_n, and for a given $L_p \in E_p$, it corresponds to its spectrum resources S_l. To simplify the resource model, we consider the spectrum resources in terms of Frequency Slots (FS) instead of bitrates. In other words, modulation format is not concerned in this paper.

2.1. Definition of sub-network

With customers' VON requests coming and leaving, the FSs in fiber links may be reserved alternately by multiple users, as depicted by the physical network view in Fig. 1. In this case, the unoccupied FSs are still available to be assigned to new coming connections or VONs. In order to address the continuity constraint for VONE more clearly, the concept of sub-network is introduced to describe the FS occupation status at network level instead of at one single link level. For a given physical network graph $G_p(V_p, E_p)$, we denote each of its sub-network as a new graph $G_s(V_s, E_s)$, where V_s is a set of nodes and E_s is a set of links of this sub-network. As illustrated by the sub-network view in Fig. 1, the concept of sub-network is defined as follows:

(1) From topology perspective, the sub-network topology $G_s(V_s, E_s)$ is a part of or whole of the physical network topology $G_p(V_p, E_p)$. More specifically, the sub-node set V_s and the sub-link set E_s are the subsets of the physical node set V_p and physical link set E_p respectively (i.e., $V_s \subseteq V_p$, $E_s \subseteq E_p$). As depicted in Fig. 1, the topology of Sub-Network 1–3 is parts of the physical topology, while Sub-Network 4 has the same topology with physical network.

(2) From spectrum perspective, the available FSs of a sub-link L_s are part of or whole of the unoccupied FSs of corresponding physical link L_p (i.e., $S_{L_s} \subseteq S_{L_p}$). For instance, the link A–B on Sub-Network 1 has the same available FSs with that on physical link A–B, and the available FSs of link A–C on Sub-Network 1 are part of that on physical link A–C.

(3) The FSs on each link of a sub-network should be consistent. In other words, the FSs of a sub-network G_s are the common unoccupied slots of all the links of this sub-network (i.e., $S_{G_s} = S_{L_a} \cap S_{L_b} \forall L_a,\ L_b \in E_s$). For instance, FS {1,8} are unoccupied on link (A–C) of physical network in Fig. 1, but they are not available on sub-link (A–C) of Sub-Network 1. That is because they are not consistent with the same slots on link (A–B), which is another sub-link of Sub-Network 1.

It is concluded that a sub-network represents a spectrum resources subset of the physical network from both the topology and the spectrum perspectives. Precisely, one sub-network represents all the available consistent FSs on the corresponding sub-topology, while a different sub-network represents another consistent FS set on a different sub-topology.

2.2. Continuity-aware spectrum allocation schemes

In the scenario of optical network virtualization, multiple VONs, which are managed by different customers, may coexist on the same infrastructures. However, different customers deploy different applications on their own VONs and they may have different performance requirements for their VONs. For instance, on EON substrate, some users need the ability to manage super channel on their VONs as if they were operating a real physical EON, while some customers may just need to use their VON as traditional Wavelength Division Multiplex (WDM) networks. In this paper, we focus on the continuity constraint for VON embedding in EONs, and we classify the VON requests into two classes according to the requirement for continuity. The first one is the *continuity-aware* VON request, which requires strict continuity for each of its virtual link. Therefore, a set of FSs with spectrum gaps would not be accepted by this kind of users. The second one is the *continuity-unaware* VON request, which requires the best-effort continuity. It means that this kind of users do not require continuity strictly, and the FSs with certain gaps would also be accepted when contiguous FSs are not sufficient.

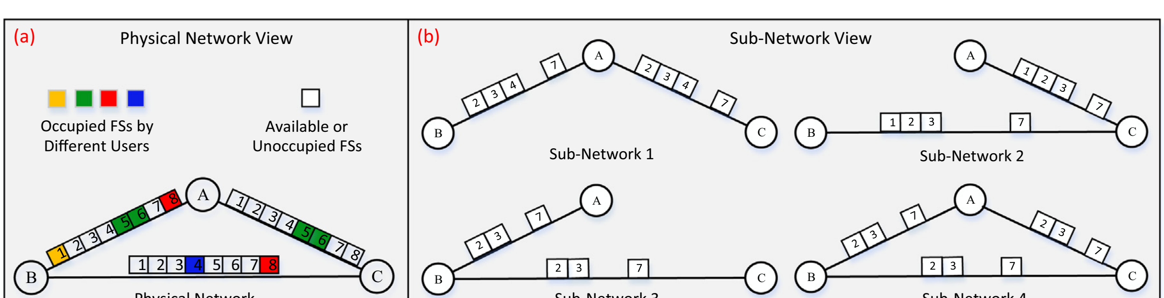

Fig. 1. Definition of sub-network.