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Survivable virtual optical network embedding with probabilistic network-element failures in elastic optical networks

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ABSTRACT

The elastic optical networks can elastically allocate spectrum tailored for various bandwidth requirements. In addition, different virtual optical networks (VONs) formed by different applications or service providers need to be embedded on the common physical optical network, it brings virtual optical network embedding (VONE) problem. There is no precise standard to measure the survivability of VON from the failure probability view and take minimum VON failure probability as an objective in a VONE problem. In this paper, we investigate a survivable VONE problem from a new perspective. Considering probabilistic physical network-element failures, a novel metric, named virtual optical network failure probability (VON-FP), is introduced to evaluate the survivability of VONs in elastic optical networks. Moreover, a failure-probability-aware virtual optical network embedding (FPA-VONE) algorithm is proposed to deploy VONs on the physical network elements with small failure probability, and finally to decrease the VON-FP and enhance the spectrum utilization effectively.

1. Introduction

Due to the rapid growth of cloud-based application and high-bitrate services, network virtualization is researched to overcome the ossification of current network architectures. To deliver these services by many geographically distributed data centers, virtual data centers (VDCs) coexisting over a shared physical network can flexibly dispatch a huge number of computing resources and large volumes of data by network virtualization technology [1]. Meanwhile, the emergence of high bandwidth and high burstiness connecting requests, especially for the sub-wavelength and super-wavelength applications, has been stimulating the improvement of optical transmission technologies. Elastic optical network (EON), which can offer flexible data line rate, are deemed as a promising technology to support these services [2,3]. Additionally, as a special form of multicarrier modulation, orthogonal frequency division multiplexing (OFDM) is used to split single data stream into a number of lower rate orthogonal sub-carriers, which can be partially overlapping in the spectrum domain [4]. The enabling technologies, such as OFDM-based bandwidth-variable wavelength cross-connects (BV-WXC) and bandwidth-variable transponder (BV-Transponder) have turned the elastic optical network into reality [5–9].

In addition, since different virtual optical networks (VONs) formed by different applications or service providers need to be embedded on the common physical network, it brings virtual optical network embedding (VONE) problem, which is how to deploy network resources and application resources on the physical network by node mapping and link mapping [10,11]. Many virtual optical network requests with high quality of service need physical network to provide high survivability network resources to resist multiple link failures. To survive a physical network link or node failure, many survivable VONE algorithms pre-compute alternative paths or facility nodes and reserve free spectrum or application resource on them [12,13]. In [14], Zhang et al. propose resource orchestration schemes in overlay networks enabled by optical network virtualization, which can provision the fewest data centers to guarantee K-connect survivability. In [15], Xie et al. study the problem of survivable impairment-aware virtual optical network mapping in flexible-grid optical networks (SIA-VONM). Its objective is to minimize the total cost of transponders, regenerators, and shared infrastructure for a given set of virtual optical networks. The authors also propose integer linear program (ILP) and heuristic algorithm for comparison in [16]. In [17], Gong et al. present a novel dynamic transparent virtual network embedding

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(VNE) algorithm, which considers node mapping and link mapping jointly, for network virtualization over optical orthogonal frequency-division multiplexing (O-OFDM) based elastic optical infrastructures. In [18], Meixner et al. investigate the disaster-resilient and post-disaster-survivable VN mapping problem using a probabilistic model to reduce the expected VN disconnections and capacity loss, while providing an adaptation to minimize VN disconnections by any post-disaster single-physical-link failure. Besides, the authors in [19] introduced probabilistic link failure model to address multiple link failure problem, and proposed that minimizing the end-to-end failure probability is equal to improving the survivability of a connection request. However, there is no precise standard to measure the survivability of VON from the failure probability view and take minimum VON failure probability as an objective in a VONE problem.

In this paper, we investigate a survivable VONE problem from a new perspective. Considering probabilistic physical network-element failures, a novel metric, named virtual optical network failure probability (VON-FP), is introduced to evaluate the survivability of VONs in elastic optical networks. Moreover, a failure-probability-aware virtual optical network embedding (FPA-VONE) algorithm is proposed to deploy VONs on the physical network elements with small failure probability, and finally to decrease the VON-FP and enhance the spectrum utilization effectively.

The rest of this paper is organized as follows. In Section 2, we propose the network model for our algorithm and VON failure probability is also introduced in this section. The VON embedding algorithm is discussed in Section 3. The simulation and numerical analysis are presented in Section 4, and last Section gives the conclusions.

2. Network model and VON failure probability

In this section, we describe the network modeling in terms of virtual optical network and physical infrastructure firstly. Then the VON failure probability is introduced from failure probability view for the estimation.

2.1. Network modeling

2.1.1. Virtual optical network

Note that, the virtual optical network is a VDC-based VON request, including the required computing resources (CRs) on virtual nodes (VNs) and bandwidth requirement (BR) on virtual links (VLs). $G^v(N^v, L^v, R^v_n, R^v_l)$ indicates a set of VONs, where N^v, L^v, R^v_n and R^v_l denote a set of VNs, a set of VLs, the required CRs at each VN, and the BR on each VL, respectively, in Fig. 1(a).

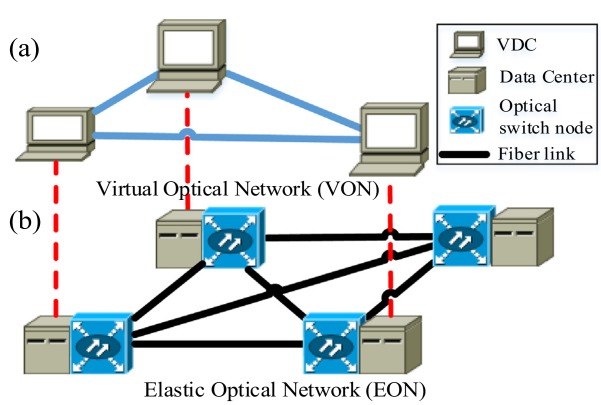

Fig. 1. The illustration of (a) a VON request and (b) physical infrastructure.

2.1.2. Physical infrastructure

To satisfy the large CRs' requirement and high BR services, the physical infrastructure consists of DCs and EONs. Different fixed-line-rates (FLRs) and mixed-line-rate (MLR) are considered to better carry the services with arbitrary BR. In EONs, 40/100/400 Gbps is carried by one spectrum channel with different spectrum widths, where a pair of optical transponders (OTPs) is placed on the both end-nodes of the channel. Line rate combination (LRC) is indicated as a line rate triple (x,y,z), where x, y and z denote the number of OTPs for 400, 100 and 40 Gbps. In a physical network, a physical node (PN) denotes optical equipment interconnecting with a DC and a physical link (PL) denotes a fiber link which can provide contiguous frequency slots (FSs). A graph $G^p(N^p, L^p, A^p_n, A^p_l)$ denotes a physical network, where N^p, L^p, A^p_n and A^p_l represent a set of PN, a set of PL, the available CRs at each PN and the available number of FSs on each PL, respectively, in Fig. 1(b).

2.2. VON failure probability (VON-FP)

Based on the network modeling, we investigate the survivability of VONs from failure probability view, regardless of how many failure events simultaneously occurring in EONs. Since VLs of VONs are embedded in physical paths of EONs, the failure probability of VLs are obtained by the failure probability of the embedded physical paths, in Fig. 2. BR on a VL can be divided into different line rates, and these line rates are carried by different spectrum channels. Since we assume that optical signal pass through all the intermediate nodes (IN) and links without OEO conversion except the OTPs on the source node and destination node, a physical path occupies n^t spectrum channels and $2n^t$ OTPs. We assume each link (m,n) and each OTP in EONs are potential to fail with probability $p_{m,n}$ and p_t, respectively. For a spectrum channel passing through a PL (m,n), the failure probability of this channel on link (m,n) is $p_{m,n}$. All the failure events for both a channel on a link and an OTP on end-nodes are considered as mutually independent events. For a spectrum channel on PL (m,n) is reliable with the probability (1-$p_{m,n}$) and an OTP is reliable with the probability (1-p_t). The physical path x is survivable when all the spectrum channels and OTPs of this path are available. Therefore, the failure probability of a VL FP^{vl} can be formulated as follows, where (m,n) is a PL on the physical path x which is mapped by this VL.

$$FP^{vl}_i = 1 - \prod_{(m,n)\in x} (1 - p_{m,n})^{n_t} (1 - p_t)^{2n_t} \tag{1}$$

In order to improve survivability for a VON embedding, dedicated-path protection scheme (a primary path p and a link-disjoint backup path b) is applied in EONs to protect a virtual link of a VON request. Thus, the failure probability of a VL is written as follows, where (m,n) and (p,q) are the PLs on primary path p and backup path b mapped by this VL.

$$FP^{vl}_i = \left[1 - \prod_{(m,n)\in p} (1-p_{m,n})^{n_t} (1-p_t)^{2n_t}\right] * \left[1 - \prod_{(p,q)\in b} (1-p_{p,q})^{n_t} (1-p_t)^{2n_t}\right] \tag{2}$$

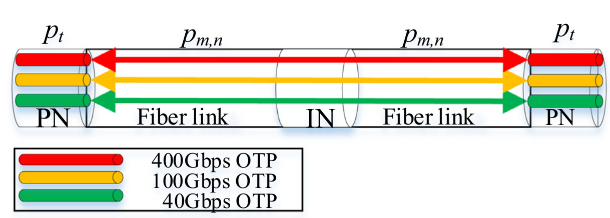

Fig. 2. The illustration of a virtual link failure probability.