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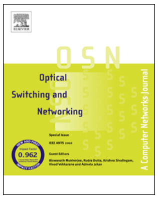

Software-defined adaptive survivability for elastic optical networks

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ABSTRACT

Cloud computing is dominating Internet services and would continue to expand in the foreseeable future. It is very challenging for network operators to evolve their infrastructures to be more intelligent and agile in resource orchestration. Nowadays, the optical networks term denotes high-capacity telecommunications networks based on optical technologies and components that can provide capacity, provisioning, routing, grooming, or restoration at the wavelength level. The proposed Elastic Optical Networks (EONs) technology is expected to mitigate this problem by adaptively allocating spectral resources according to client traffic demands. In this paper, we focus on survivability problems in dynamic routing in EONs. We propose Adaptive Survivability (AS) approach to achieve the best trade-off between the efficiency of path protection and cost of routing. Moreover, we propose entirely new Routing, Spectrum and Modulation Assignment (RMSA) algorithm to optimize both anycast and unicast traffic flows. Finally, we evaluate the performance of RMSA algorithms and assess the effectiveness of AS approach under various network scenarios. The main conclusion is that using AS approach results in significant improvement of network performance.

1. Introduction

Over the past few years, the Internet consolidated itself as a very powerful platform. It has changed our means of communication and has given a “globalized” dimension to the world. We may observe the impact of the progression of social media in our life. Web services such as Facebook, Google+, etc., break records in the number of users. For example, on August 27, 2015, a billion users of Facebook were online, which represents 1/7 of the world's population. Shortly after, What's App announced that it has 900 million active users. The first widely available measurement from December 1995, revealed 16 million registered Internet users (0.4% of world population). Since then, the number of people connected to a global network has multiplied more than 200 times.

Communication networks have to accommodate the inflation of clients. Elastic Optical Networks (EONs), based on the optical orthogonal frequency-division multiplexing (O-OFDM) technology [1], have attracted intensive research interests as it may significantly improve the spectral efficiency of the optical layer with flexible bandwidth allocation [2,3]. According to a definition of EONs included in ITU-T recommendation (G.694.1) [4], the spectrum is divided into narrow frequency segments (called slices). A lightpath required to serve a network request is defined by a routing path and an optical channel. These consist of a flexibly assigned subset of slices around a nominal central frequency. Failure of an optical network element (e.g., a fiber cut) may cause huge data loss, resulting in the failure of several lightpaths. This problem becomes additionally challenging, when lightpaths are upgraded to high bit rates (e.g. 100 Gbps, 400 Gbps and more). Subsequently, survivability in optical networks is a basic issue [5,6].

In this paper, we focus on the Routing, Modulation and Spectrum Allocation (RMSA) problem with survivability constraints in the context of dynamic routing of anycast and unicast traffic. Anycasting – defined as one-to-one-of-many transmission – is a very effective way to serve network services provisioned in data centers (DCs) including popular cloud computing and content-oriented services. The anycast request is defined by a client node, where the request is issued and two demands (connections) are required to serve the request, namely, an upstream demand (from the client node to the DC) and a downstream demand (from the DC to the client node). These two demands that realize the same anycast request are called *associated*. For more details on modeling of anycast traffic refer to [7,8].

By breaking the fixed-grid spectrum allocation limit of conventional Wavelength Division Multiplexing (WDM) networks, EONs increase the flexibility in the connection provisioning. As a matter of fact, the available Routing and Wavelength Assignment

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(RWA) proposals for WDM networks are no longer directly applicable in EONs. In EONs, routing concerns establishment of lightpaths for individual connection requests. The process is accompanied by solving the problem of Routing and Spectrum Allocation (RSA), which concerns finding a routing path and a contiguous segment of spectrum subject to the constraint of no frequency overlapping in network links [9]. The RMSA problem is to determine three elements for a lightpath: a routing path, a contiguous segment of spectrum subject to the constraint of no frequency overlapping in network links, and a modulation format (MF) [10,11].

Focusing on the survivability in EONs, the following methods should be mentioned [5,6]. The first technique is called the Dedicated Path Protection (DPP). It implies that each demand is served by a working (primary) path and a backup path, which is link-disjoint with the working path. The DDP method requires a large amount of extra capacity for protection purposes, keeping protection resources idle when there is no failure. The second way of obtaining survivability in optical networks is Shared Backup Path Protection (SBPP). It allows different backup paths to share spectrum resources on the overlapping portion if the corresponding working paths are link-disjoint. SBPP utilizes capacity more efficiently than DPP, but in some cases may not provide 100% protection. For e.g., there can be multiple-link failures in the network, which concurrently affect several demands that share the same resources on the backup paths. Another technique of ensuring network survivability in EONs is Squeezed Path Protection (SPP) [12]. The key idea of SPP is the use of bandwidth squeezing after a link failure, i.e., only a part (e.g. 25%) of the traffic on the working path is to be protected (or restored). Therefore, the backup path requires much less spectrum resources compared to the working path. Moreover, similar to the SBPP technique, the SPP method allows different backup paths to share spectrum on the overlapping portion if the corresponding working paths are link-disjoint. The concept of SPP guarantees a Service Level Agreement (SLA) while simultaneously the network does not need to reserve so much bandwidth as in conventional dedicated protection. The backup path bandwidth is reduced to the required minimum amount, which enables cost-effective restoration in terms of spectral resource utilization.

So far, there have been several solutions proposed for survivable EONs in the literature. Survivable RSA algorithms under single-link failure for DDP have been studied in [13–15]. Concurrently, offline problems for SBPP have been proposed in [16,17]. Eventually, dynamic survivable EON scenarios have been studied in [18]. All these solutions assure network survivability under single link failures. Algorithm for multi-link failure has been proposed in [19].

This paper is an extended version of our conference paper [20]. The extension concerns mainly: a new algorithm for network survivability problems under multi-link failures in EONs; enhanced comparison of path protection techniques in various scenarios of link failures that occur in the network rendering to a parameter ∂ described in the Section 3. According to the best of our knowledge, this extended paper is the first one that addresses the issues of multi-link survivability problems with traffic classes aware in dynamic routing in EONs with the ability to change MF between nodes. Note that in this paper, we continue our research on dynamic routing in EONs, as started in our previous papers [10,20,21].

The rest of the paper is divided into five sections. In Section 2, survivability and RMSA problems are defined. Furthermore, we introduce traffic classes' support in our algorithm. In Section 3, we proceed to describe simulation setup. In Section 4 results are presented. Finally, Section 5 contains conclusions.

2. Dynamic routing modulation and spectrum assignment problem with network survivability

In this section, we formulate the problem of a dynamic RMSA in survivable EONs with both unicast and anycast requests. The objective is to minimize Bandwidth Blocking Probability (BBP), defined as the volume of rejected traffic divided by the volume of all traffic offered to the network, while enabling network survivability. In addition, in Paragraph C, we introduce the concept of traffic classes in EONs.

2.1. Notation

We use similar notations as in [10]. The physical network is modeled as graph $G(V, E, B, L)$ where V denotes a set of nodes, E is a set of fiber links, each fiber link may accommodate B frequency slices (slots) at most, and $L = [l(1),l(2),\ldots,l(|E|)]$ represents link lengths for each $e\in E$. We assume that R data centers are already located at some nodes of the network. In addition, we assume that data centers (DCs) are equally connected to network nodes, to which are connected to, which means that we do not take the physical connection between the server and the backbone network node. Furthermore, we assume that each anycast request may be assigned to each DC, because DCs provide the same service of content.

Each request d may be of two types: unicast (*one-to-one*) or and anycast (*one-to-one of many*). The unicast request is described by the following: source node $s(d)$, destination node $t(d)$, capacity (bitrate) $c(d)$. The anycast request described by: source (client) node $s(d)$, downstream capacity $c\_down(d)$, upstream capacity $c\_up(d)$.

Let $l(p) = \Sigma_{e\in p} l(e)$ denote length of path p calculated as the sum of link lengths included in the path. Let $P(s, t)$ denote a set of k-shortest paths for node pair (s, t). Notice that in the case of a unicast request, the set of candidate paths include exactly k paths. Concerning anycast requests, the situation is different, i.e., for each downstream (upstream) request the set of candidate paths contains of $k|R|$ paths, since each DC node $r\in R$ is considered. For instance, in the case of a downstream request d the set of candidate paths $P\_down(d)$ will include all paths from sets $P(r, t)$ for each $r\in R$. For the sake of simplicity, we assume that paths included in each set $P(s, t)$, $P\_down(d)$, and $P\_up(d)$ are sorted according to increasing values of the path length.

We assume that various MFs may be used in the EON. Let M denote a set of available MFs. According to the considered physical model, for each MF $m\in M$ and bit-rate c there is a constant $dist(m, c)$ that denotes the maximum distance that a particular modulation may support for bit-rate c. Additionally, let $nn(c(d), p, m)$ represent the number of slices required to serve request d with bitrate $c(d)$ using path p and modulation m for primary path and analogously let $nn'(c(d), p, m)$ denote the number of slices required for backup path. Without a loss of generality, we assume that the greater the MF is, then a higher spectral efficiency is achieved. Since regenerators are costly, we assume that the selection of a MF is made in order to minimize the number of regenerators placed in the network. Finally, we do not allow grooming of the regenerators, therefore one regenerator serves one request at a time.

2.2. Problem description

Considering the physical topology discussed above, our goal is to find a route, assign a MF and allocate spectrum for each connection request such that the average BBP is minimized. The solution to the problem is subject to the following constraints:

- Spectrum contiguity, spectrum continuity and slice opacity: in EONs, continuous spectrum resources to the specific demand

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