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A Multi-Backup Path Protection scheme for survivability in Elastic Optical Networks

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ABSTRACT

Two important challenges in designing a survivable optical network are minimizing backup spectrum allocation and ensuring spectrum assignment constraints. Allocating backup spectrum is one important approach for survivable optical network design. Connection requests which are rejected due to the unavailability of a single backup path can be survived using multiple backup routes. Multiple backup routes not only increase connection acceptance rate, but also improve backup resource sharing. In this paper, we present a strategy for survivability which optimizes primary and backup spectrum allocations and multiple backup route assignments for surviving a connection request. In our strategy, named as Backup Spectrum Reservation with MultiPath Protection (BSR-MPP), multiple backup routes are searched over advance reserved backup resources when an optical connection is concerned. Simulation results show that confinement of backup resources result in higher resource sharing and assignment of multiple backup lightpaths. It can also be observed that BSR-MPP has lower Bandwidth Blocking Probability and higher spectrum efficiency as compared to conventional Shared Path Protection (SPP) and MultiPath Protection (MPP) strategies.

1. Introduction

Advancement of the optical network technology from the rigid Wavelength Division Multiplexing (WDM) to the flexible spectrum allocation has paved the way for higher utilization of the optical fiber bandwidth. In an optical network, bandwidth demand may vary from a few Gbps to hundreds of Gbps [1]. Spectrum sliced elastic optical path network (SLICE) architecture [1] leads to spectrum efficiency by incorporating unused spectrum, taking from sub-channel to super-channel, which is not employed in conventional WDM architectures. A network based on SLICE architecture is also known as flexible optical network or Elastic Optical Network (EON).

In EON, a network node has the ability to assign wide range of bandwidth when user data demand arrives from the upper client layers. Connection request provisioning in an EON is based on the Routing, Modulation, and Spectrum Assignment (RMSA) [2,3] approach. In RMSA, spectrum requirement is computed based on the length of an optical route. For shorter route, higher level of Modulation Format (MF) is used in order to ensure lower usage of spectrum. EON architecture is mainly based on Sliceable Bandwidth Variable Transponder (SBVT) and Bandwidth Variable cross Connect (BV-WXC).

SBVT can generate signals of variable spectrum demand based on transmission distance. SBVT consists of laser sources, electronic processing domain, and Photonic Integrated Circuit (PIC). Laser sources generate signals based on bandwidth demand, whereas electronic processing domain filters optical signals. PIC, on the other hand, helps in switching optical signals to the optical multiplexer. Different types of MFs can be used by the laser sources for transmission of optical signals. Modulation formats can be Binary Phase Shift Keying (BPSK), Quadrature Phase-Shift Keying (QPSK), 8-Quadrature Amplitude Modulation (8-QAM), or 16-Quadrature Amplitude Modulation (16-QAM) in EONs. Lower MF supports higher distance of transmission by compromising spectrum efficiency. A detailed architecture of SBVT can be found in [4–6].

The implementation of BV-WXC, used for cross connection of input signals to output signals, is relied on Bandwidth Variable Spectrum Selective Switches (BV-SSSs) that function like add-drop of signals based on optical routes/lightpaths. BV-SSS is made of Liquid Crystal on Silicon (LCoS) or Micro Electro-Mechanical System (MEMS) [4].

As link failure in an optical network results in data as well as revenue losses, designing a survivable network is of prime importance. Network survivability is the ability to reroute the data of a

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failed link over an alternate route. Several strategies have been proposed in literature to incorporate survivability in the context of EONs. The survivable strategies can be classified in two types, *protection* and *restoration*. In protection or pre-planned mechanism, alternate routes are reserved in advance before the beginning of a communication. In contrast, restoration is the process of recovering the connection after a failure. In EONs, the issue of survivability becomes more compelling due to the enforcement of spectrum continuity and contiguity constraints.

Spectrum continuity constraint requires assignment of the same numbered Frequency Slots (FSs) on all links of a route while enforcing the selection of consecutive FSs [2]. Both primary and backup routes, in EONs, must satisfy continuity and contiguity constraints for all links of an optical route. Hence, spectrum constraints increase design complexity of survivable EONs than conventional WDM architectures.

In this paper, we present Backup Spectrum Reservation with MultiPath Protection (BSR-MPP) scheme which efficiently utilizes network capacity for backup routes and provides more resources for primary routes. Remaining of this paper is organized as follows. Existing literature related to the survivability in the context of EONs is covered in Section 2. Our proposed BSR-MPP strategy, in Section 3, is then explained. Section 4 describes survivability in EONs and compares the performance of our proposed approach with existing strategies namely Shared Path Protection (SPP) and MultiPath Protection (MPP). Finally, we conclude our paper in Section 5.

2. Related work

There are a few existing literature related to the survivability in EONs. In survivable strategies, backup routes are either pre-planned or post computed after a failure. In pre-planned (protection) strategy, backup resources are reserved in advance of connection establishment. On the other hand, in restoration, backup routes are computed online after a failure solely based on the status of the network. Survivability is addressed in a few literature when EONs are concerned.

In [7], authors presented a comparison between a conventional Shared Backup Path Protection (SBPP) and Dedicated Path Protection (DPP) schemes using Integer Linear Programming (ILP) optimization approach under static traffic scenario. Mixed Integer Linear Programming (MILP) optimization for DPP proposed, in [8], at different levels of backup bandwidth squeezing. Authors of [9] compared an ILP model for SBPP with 1 + 1 protection at different levels of squeezing. In [10], authors proposed a minimum free spectrum block consumption algorithm with a tradeoff between spectrum block and joint failure probability. Elastic Separate Protection At Connection (ESPAC), presented in [11], was based on spectrum assignment (i.e., first-fit for primary and last-fit for backup routes). The ILP model in [12] showed spectrum efficiency of MultiPath Provisioning than traditional SPP with the recovery of partial as well as full bandwidth protections at static traffic scenarios.

In [13,14], the concept of Bandwidth Squeezed Restoration (BSR) was proposed to minimize the bandwidth utilization of a network. The scheme showed spectral efficiency and recovered many connections when failure was concerned, for the best effort and bandwidth guaranteed traffic. In [15], authors proposed After Failure Repair Optimization (AFRO) strategy based on rerouting of existing lightpaths from the highly loaded link to the restored link that resulted in uniform distribution of load and better utilization of the repaired links. A dynamic OpenFlow based lightpath restoration mechanism presented in [16] and its performance tested on the Global Environment for Network Innovations (GENI) testbed. In [17], authors presented a multipath restoration strategy. The advantage of multipath routing based schemes relied on the easiness of availability of small spectrum chunks satisfying spectrum continuity and contiguity constraints. However, survivability achieved at the cost of redundant guard bands and differential delay between various chunks received at the destination. Restoration of multi-link failure recovery based on traffic-aware load balancing discussed in [18]. For concurrent failures of primary and reserved backup routes, a survival traffic cognition algorithm presented in [19].

In the following section we discuss a novel strategy, Backup spectrum Reservation with MultiPath Protection (BSR-MPP), which can efficiently address survivability when an EON is concerned.

3. Backup Spectrum Reservation with MultiPath Protection (BSR-MPP)

In Backup Spectrum Reservation with MultiPath Protection (BSR-MPP), available spectrum is split into two parts, primary spectrum and backup spectrum, which are utilized for connection establishment. When a connection request arrives, a primary route is first searched over the primary spectrum. If a primary route is available, then searching is initiated for the respective backup route which is confined only to the advance reserved spectrum. If the connection request is not survived by a single backup route, then a second backup route is assigned to the request. Reservation of spectrum ensures continuity as well as contiguity of all similar-indexed Frequency Slots (FSs) for all links; hence, sharing of FSs is increased because of the removal of spectrum conflict between primary and backup lightpaths. However, this situation is not obvious when SPP and MPP are concerned. In order to minimize the effect of guard bands, searching of a second backup lightpath comes into consideration only when spectrum is not available on the first backup lightpath. Our BSR-MPP algorithm, where first-fit spectrum assignment strategy is used for primary and backup routes, is presented in Algorithm 1.

Algorithm 1. Backup Spectrum Reservation with MultiPath Protection (BSR-MPP)

1: $P_{s,d}$: Primary route with source s and destination d
2: $B^{j}_{s,d}$: j^{th} backup route with source s and destination d
3: **Input:** A connection request $R(s,d,k)$ where s, d, and k represent the source node, the destination node, and the demanded bandwidth (in GHz)
4: Set Request_Accepted_Flag = 0
5: $BW^{\max}_{p} \leftarrow$ Maximum available bandwidth (in GHz) for $P_{s,d}$
6: **if** ($BW^{max}_{p} < k$) **then**
7: **goto** step 18 ▸ **Bandwidth is not available for primary route**
8: **end if**
9: $BW^{max}_{B,1} \leftarrow$ Maximum available bandwidth (in GHz) for $B^{1}_{s,d}$
10: **if** ($BW^{max}_{B,1} \geqslant k$) **then**
11: Request_Accepted_Flag = 1
12: **goto** step 18 ▸ **If the request is survived by single backup route**
13: **end if**
14: $BW^{max}_{B,2} \leftarrow$ Maximum available bandwidth (in GHz) for $B^{2}_{s,d}$