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Spectrum–block consumption for shared-path protection with joint failure probability in flexible bandwidth optical networks

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ABSTRACT

We address the problem of providing shared-path protection for a set of connection requests in a flexible bandwidth optical network under the constraint that the joint failure probability of the primary path and backup path of each request is below a given maximum joint failure probability threshold. The overall objective of the problem is to minimize spectrum consumption while meeting the maximum joint failure probability requirements. We propose the minimum free spectrum–block consumption algorithm (MFSB) for providing shared-path protection with joint failure probability requirements in flexible bandwidth optical networks, and we introduce two additional algorithms, named the conventional shared spectrum–block (CSSB) consumption algorithm and the maximum shared spectrum–block (MSSB) consumption algorithm, for comparison. Simulation results show that MFSB not only achieves better performance in terms of blocking probability, spectrum consumption, spectrum redundancy, and hop counts compared to the CSSB and MSSB algorithms, but also guarantees a joint failure probability that is lower than the MSSB algorithm. Furthermore, the spectrum efficiency of these three algorithms increases with the growth of the maximum shared degree, especially for the MFSB algorithm. Therefore, the MFSB algorithm provides a better tradeoff between the minimum spectrum–block consumption and the average joint failure probability.

1. Introduction

To support the flexible bandwidth demands of emerging next-generation dynamic high-bandwidth applications, a novel network architecture named SLICE [1–4] has been proposed. The SLICE architecture employs coherent optical orthogonal frequency-division multiplexing (CO-OFDM) to flexibly allocate a variable number of spectrum slices or blocks for variable-bandwidth channels [5] in order to increase spectral efficiency. In addition to spectrum efficiency, another important issue in flexible bandwidth optical networks is network survivability, particularly in the case of multiple failures. Since multiple failures will result in tremendous traffic loss without effective survivable protection schemes, minimizing the joint failure probability between a primary path and its backup path is critical.

Many current works on flexible bandwidth optical networks focus on improving spectral efficiency. The performance of OFDM-modulated signals, filtering characteristics, and guard bands have been investigated in spectrum-sliced elastic optical path networks, and such networks have been shown to have increased spectral efficiency over

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current WDM networks [6]. Simultaneously, the blocking performance of spectrum efficient super-channels has been analyzed in dynamic flexible grid networks [7], and such super-channels have also been shown to provide high spectral efficiency. Furthermore, algorithms that utilize distance-adaptive frequency allocation schemes for maximizing spectrum efficiency have been proposed in elastic optical path networks and are proven to provide high spectrum efficiency [8]. However, these studies only address the problem of spectrum efficiency and do not consider network survivability.

Another key problem in flexible bandwidth optical networks is the routing and spectrum allocation (RSA) problem. To efficiently minimize the spectrum consumption, both an integer linear programming (ILP) model and an effective RSA algorithm have been proposed in [9], and have been shown to provide better results than traditional algorithms. Simultaneously, another RSA model with ILP formulations and two efficient heuristic algorithms has been proposed in [10,11] with different optimization objectives. Considering the effect of different modulation levels on the routing and spectrum allocation, Christodoulopoulos et al. have proposed a dynamic and elastic bandwidth allocation scheme in flexible OFDM-based optical networks, and introduced the routing, modulation level and spectrum allocation (RMLSA) problem [12,13]. In transparent flexible optical WDM (FWDM) networks [14,15], routing, wavelength assignment, and spectrum allocation have been investigated, in which both spectrum efficiency and cost are improved compared to fixed grid networks. Moreover, to improve the performance of blocking probability, a dynamic routing and spectrum assignment algorithm has been proposed by ant colony optimization in flexible bandwidth optical networks, which achieves a lower blocking probability with high adaptability to the traffic rate variation [16]. However, the above references do not consider protection or restoration.

Survivability in flexible bandwidth optical networks is critical in order to guarantee high service level assignment; hence, protection or restoration mechanism needs to be considered. Compared to traditional shared protection in WDM networks, shared-path protection is more complex in flexible bandwidth optical networks, since a single wavelength assignment is transformed to the assignment of several contiguous frequency slots in the frequency domain. In [17], we consider shared-path protection and dynamic load balancing with multi-link failure restoration in spectrum-elastic optical path networks. To overcome the spectrum insufficiency, a novel restoration scheme named bandwidth squeezed restoration (BSR) [18], has been proposed for supporting best-effort recovery when the available bandwidth resources are insufficient. The authors in [19] proposed an efficient survivable flexible optical WDM network (FWDM) design algorithm, but shared protection was not investigated. Simultaneously, the work in [20] evaluated conservative and aggressive backup sharing in OFDM-based optical networks. In addition, previous studies [21–23] have demonstrated the spectral efficiency of shared backup flexible bandwidth optical networks. Also, survivable traffic grooming problem has been investigated in order to improve the bandwidth efficiency and guarantee the high quality of service [24]. However, these references do not consider the effect of the link failure probability on shared-path protection, particularly the joint failure probability between primary path and backup path. Furthermore, the relationship between minimum spectrum–block consumption and the link failure probability was not investigated. Therefore, in this paper, we focus on the problem of minimizing spectrum–block consumption with a constraint on the joint failure probability.

Obviously, how to evaluate the failure probability of lightpaths plays an important role in order to ensure high network survivability. In this paper, we focus on the effect of the failure probability on network performance, especially for the joint failure probability of primary and backup paths, which is the probability that both paths fail at the same time. Lee et al. investigated networks with probabilistic failures and developed diverse routing schemes for dealing with multiple and possibly correlated failures [25,26]. In particular, they took a probabilistic view of network failures where multiple failures events may occur simultaneously. Moreover, they also developed a novel probabilistic shared risk link group (SRLG) framework for modeling correlated failures, and they formulated the problem of finding two paths with minimum joint failure probability. In order to maximize survivability under multiple failures, the authors in [27–29] investigated the problem of finding two link-disjoint paths and addressed the issues of how reliable two-path protection can be and how to achieve the maximum reliability in mesh networks. To improve the service availability against network failures, Zhang et al. developed a mathematical model to analyze the availabilities of connections with different protection strategies [30]. Based on the analytical model, they developed provisioning strategies for a given set of connection demands and proposed an ILP model and heuristic approaches to provision the connections cost effectively while satisfying the connections' availability requirements. Xia et al. investigated the problem of risk-aware provisioning in WDM mesh networks, where path selection is dictated by service-level agreement (SLA) violation risk and focused on devising an efficient scheme of computing paths that are likely to accommodate the SLA-requested availability [31]. In [32] we proposed an ILP model and a rescaled failure-probability-aware algorithm to minimize the spectrum resource consumption under failure probability constraints in flexible bandwidth optical networks, and in [33], we developed a survivable traffic cognition algorithm considering joint failure probability.

Decreasing the potential failure probability is an important task for network service providers. Therefore, the failure probability is an important factor to be considered in the research of flexible bandwidth optical networks. However, computing the exact joint failure probability between primary and backup paths is difficult since it is a nonlinear problem. A low failure probability for each link can be considered in order to linearize the failure probability calculation.

The main contribution of our paper is to identify the relationship between the spectrum consumption and the joint failure probability of primary and backup paths. We propose the minimum free spectrum–block consumption algorithm for providing shared-path protection with