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An optimization approach for survivable lightpath provisioning in multi-domain optical networks

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ABSTRACT

This paper proposes an optimization approach for survivable lightpath provisioning that allows traffic splitting in multi-domain optical networks to minimize the cumulative cost of a set of paths. The proposed approach, called two-phase hierarchical optimization, employs an integer linear programming (ILP) formulation based on hierarchical path computation with full-mesh topology abstraction. There are two phases in the approach. The first phase solves the ILP problem on an inter-domain topology and then feeds the results as intra-domain requests. The second phase solves the ILP problem in each related domain. Finally, we concatenate all the intra-domain solutions along routing sequences. Three different protection strategies, namely same domain sequence (SDS), link disjoint (LD), and domain disjoint (DD) are considered with varying degrees of primary and backup route separation. Furthermore, we evaluate our approach from two points: the effect of traffic demands and the effect of link capacity. The results show that the LD strategy gives notably better performance than the other strategies in both points.

1. Introduction

Survivability is a key design issue in optical networks due to the huge loss of data and revenue once a failure occurs. For multi-domain optical networks, many existing survivability studies have focused on survivability issues under various conditions [1]. In general, these studies can be classified along the traditional lines of pre-configured protection and post-fault restoration. Pre-configured protection schemes provide faster recovery and single-failure resiliency guarantees by employing the pre-assigned capacity to ensure survivability. Meanwhile, post-fault restoration schemes re-route the affected traffic after failure occurrence by using available capacity. Therefore, protection schemes are superior to restoration alternatives if the service requires high reliability.

In multi-domain optical networks, the network domains can be delineated by administrative ownership (intra-carrier level and inter-carrier level), vendor or technology type, and geographic. Therefore, there are more complexities than single-domain ones, since the detailed domain-internal topology and resource information are not propagated across domain boundaries due to scalability and privacy concerns [2,3]. This makes it difficult to design protection schemes for multi-domain optical networks. More recently, researchers have started to implement a range of multi-domain protection schemes based on partial global state information [4–6]. These strategies rely on distributed path computation and signaling to resolve complete end-to-end primary and backup path pairs [7–10]. However, within the multi-domain context, protection schemes can be further delineated as per the availability of global diversity state, i.e., per-domain protection or end-to-end path protection. We focus on end-to-end path protection schemes, which have been designed to achieve better domain diversity between primary and backup routes than the per-domain protection schemes. These schemes assume some type of global skeleton view of the network, typically via hierarchical inter-domain routing protocols [11,12]. The topology abstraction approach, which is adopted to hide internal domain states so as to resolve routing scalability and security issues, can affect the accuracy of the routing state information. The work in [6] presented two topology abstraction approaches. First, the simple node abstraction condenses a domain into a single virtual node and provides no intra-domain visibility. Second, the full-mesh topology abstraction provides better intra-domain visibility by reducing a domain to its border nodes inter-connected by an appropriate set of abstract links. The full-mesh topology abstraction approach provides more accurate intra-domain usage state than the simple node approach [11].

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Several works have recently focused on this line of work [4–6]. The work in [4] presented an enhanced abstraction of the network domain topologies to compute link-disjoint primary and backup routes. However, this enhanced abstraction introduces significant routing overhead which implies significant scalability issues. The work in [5] presented a path protection scheme and showed that the utilization of partially overlapped domain sequences guarantees the most effective utilization of network resources. The work in [6] presented a mechanism for computing a pair of link-disjoint paths considering the wavelength continuity constraint. The primary and backup routes are allowed to traverse the same domain sequence or partially overlapped domain sequences. The work in [13] presented several approaches based on an enhanced abstraction with intra-domain disjointness information to find a pair of disjoint end-to-end routes. The primary and backup routes may traverse multiple domains from source to destination and result in minimum total cost.

Nevertheless, these existing multi-domain protection solutions are heuristic algorithms, and use graph-theoretic approaches to compute intra-domain and inter-domain route sequences with dated or inaccurate routing information. Recently, the work in [14] presented an optimization design for multi-domain protection considering only link disjointness. Furthermore, to handle various types of traffic demands, which may occur in the case of very high demand or insufficient capacity, a survivable lightpath provisioning scheme should effectively accommodate the incoming traffic by splitting them into multiple paths at the same time. To the best of our knowledge, however, no studies have addressed the support of various types of traffic demands.

This paper presents an optimization approach for survivable lightpath provisioning that allows traffic splitting in multi-domain optical networks to minimize the cumulative cost of a set of paths. It is an extended version of our previous work presented in [15]. To handle dated or inaccurate routing information, we focus on the full-mesh topology abstraction approach, since it provides better performance than the alternatives. We formulate an integer linear programming (ILP) model based on hierarchical path computation. There are two phases in the proposed approach. The first phase solves the ILP problem on the inter-domain topology and then feeds the results as intra-domain requests. The second phase solves the ILP problem in each related domain. Finally, we concatenate all the intra-domain solutions along routing sequences. Three different protection strategies, namely same domain sequence (SDS), link disjoint (LD), and domain disjoint (DD), are considered with varying degrees of primary and backup route separation. Furthermore, to support various types of traffic demands, we evaluate our approach for two different numbers of requested wavelengths. In the first case, the number of requested wavelengths is less than link capacity. The link capacity is defined as the number of wavelengths on each link. In the second case, the number of requested wavelengths is greater than link capacity. For the latter case, the proposed approach allows traffic splitting among feasible primary and backup routes.

We extend our work with various additions. The extension parts are mainly described as follows. We extensively discuss the ongoing researches on an optimization approach for survivable lightpath provisioning in three different protection strategies. We extend the performance evaluation of our proposed approach in different networks, especially the network with more connected links, to clarify the performance of each protection strategy. Furthermore, the performance of our proposed approach is extensively evaluated from two points: the effect of traffic demands and the effect of link capacity.

The rest of the paper is organized as follows. Section 2 surveys related work on multi-domain survivability. Section 3 then describes the optimization approach for survivable lightpath provisioning. Performance analysis results are presented in Section 4, followed by conclusions in Section 5.

2. Related works

A pair of paths are domain-diverse if they do not transit any of the same domains [12]. Therefore, multi-domain protection schemes can be delineated as per the level of domain diversity between primary and backup routes, as shown in Fig. 1. Some end-to-end protection strategies have been advanced to improve resiliency and load distribution by increasing domain diversity between primary and backup routes. These solutions assume a global inter-domain state and use two-step distributed path computation. Namely, a loose route (LR) pair is computed over the higher-level inter-domain topology to determine end-to-end primary and backup domain sequences. These LRs are then expanded using distributed signaling, i.e., explicit route (ER) expansion. Note that these schemes can be implemented using Internet Engineering Task Force (IETF) path computation element (PCE) [16,17] and resource reservation protocol (RSVP-TE) standards.

In this way, the work in [18] presented a dedicated inter-domain path selection solution using breadth-first search [19]. Specifically, a constrained set of k-shortest paths (k-SP) is computed and searched for a subset of least-cost diverse routes using an ILP formulation. Findings showed competitive route selection success ratios as compared to ideal global ILP formulations. However, since

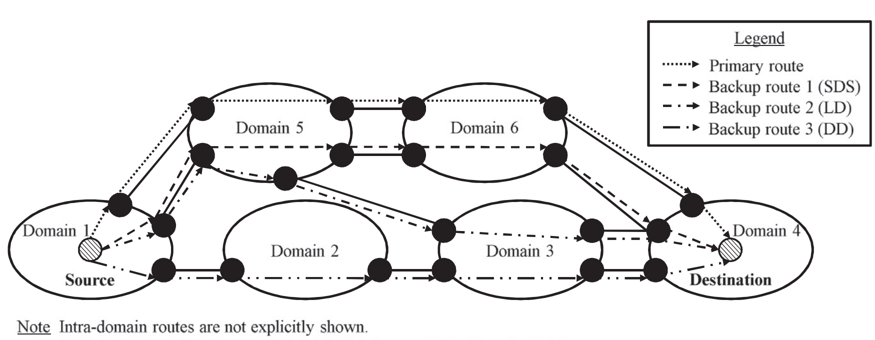

Fig. 1. Primary and backup skeleton routes with different domain-diversity requirements.