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Multipath routing with topology aggregation for scalable inter-domain service provisioning in optical networks

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ABSTRACT

In this paper, we propose to use static virtual topology for a scalable inter-domain optical service provisioning, while addressing the resource efficiency issue by using multipath routing. To this end, we discuss methods for virtual topology aggregation with consideration of inter-domain routing, and propose two heuristic algorithms for two representative applications, referred to as real-time streaming and bulk data transfer. We consider specific requirements of each application, including transmission deadline and jitter, and evaluate the impact of differential delay issue of multipath routing on the performance of proposed algorithms. Numerical results show that the proposed multipath routing algorithms yield a low blocking ratio of inter-domain connections even on the static virtual topology, which is known for poor blocking performance otherwise. The resulting differential delay is sufficiently small for the studied applications, and can be compensated with relatively small buffers. We show that a scalable inter-domain service provisioning in optical networks can be achieved by using a combination of static virtual topology and multipath routing.

1. Introduction

In recent years, carriers have witnessed an ever-growing bandwidth demand, driven by the emerging high performance applications in e-science, cloud computing, high-definition visualization, and many more. The global nature of such applications created a pressing need for service provisioning across multiple heterogeneous domains. While optical networks have emerged as the best candidate in serving data-intensive applications, practical approaches to provisioning optical services in multi-domain settings remain a challenge. The demarcation of the domains, either administratively or technically, limits the visibility to the domains to obtain a detailed view of the whole network, challenging the applicability of single-domain Routing and Wavelength Assignment (RWA) algorithms in multi-domain scenarios. Scalability is another issue in inter-domain service provisioning, due to the amount of domain–internal information that needs to be exchanged and updated among domains participating in the end-to-end provision.

To address these challenges, topology aggregation techniques have been proposed, which abstract domain–internal information and advertise information to other domains in a limited, and therefore more scalable fashion. For example, OIF proposed three topologies to be adopted in topology aggregation: *Abstract Node, Abstract Link* and *Pseudo-node*, which represent *Single Node, Full mesh* and *Symmetric Star*, respectively. To guarantee the resource availability to inter-domain connections, the virtual topologies can be created based on transit tunnels that are set up in advance between border nodes of a domain,

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which is referred to as a *static virtual topology* in this paper. The tunnels are typically over-provisioned in order to avoid high blocking ratio of inter-domain traffic. The static virtual topology with over-provisioned transit tunnels, while scalable and effective for inter-domain scenarios, is not resource efficient and often results in excess capacity reserved for inter-domain traffic.

In this paper, we propose a trade-off solution, which utilizes the transit tunnels in each domain to create a static virtual topology for scalability, while overcoming the need to over-provision the tunnels with multipath routing. We propose that each domain computes paths between each pair of border nodes as transit tunnels for inter-domain traffic. Instead of over-provisioning the tunnel created, we propose to use multipath routing to aggregate bandwidth when the tunnels are not sufficient for the dynamic connection demand using single path routing. The aggregated domain information is exchanged between domains only once, based on which a domain chain (path) is computed upon connection request. In this way, we limit the overall amount of information exchanged, and decrease the frequency of the exchange. The end-to-end path computation can be then facilitated by either a Routing Area Leader (RAL), proposed by ITU-T [1], or the Path Computation Element (PCE) proposed in IETF [2].

To study the value of the proposed approach, we present two heuristic algorithms for two representative applications, referred to as real-time streaming and bulk data transfer. In contrast to our previous studies on optimal solutions, which was limited to small networks, heuristics carry potential for practical deployment, on realistic-size networks. Here, we study application-specific requirements, such as transmission deadline and jitter. We consider the differential delay issue of multipath routing and investigate the effectiveness of multipath routing in addressing resource inefficiency of the static virtual topology. We also investigate the performance of multipath routing regarding load balancing by defining the maximum utilization of the available bandwidth on the static virtual topology. Numerical results show that optical networks can yield scalability by the usage of static virtual topology in inter-domain service provisioning, while resolving the resource inefficiency through multipath routing. The proposed heuristic algorithms for both applications can achieve low blocking ratio despite of the static virtual topology, while the resulting differential delay is sufficiently small, and thus can be compensated with small buffers. We also show that splitting traffic on multiple paths for load balancing does not necessary lead to performance improvement regarding the blocking ratio when static virtual topology is used.

The rest of the paper is organized as follows: Section 2 presents the related work and our contribution. Section 3 describes the proposed inter-domain provisioning framework which includes topology aggregation for inter-domain multipath routing and a discussion on the differential delay issue of multipath routing. This section also includes the proposed algorithms for two applications, i.e., bulk data transfer and real-time streaming. Section 4 evaluates the performance of the proposed inter-domain multipath routing on the static virtual topology. Finally, Section 5 draws conclusions.

2. Related work and our contribution

Various methods have been presented for multi-domain optical service provisioning using topology aggregation, with primary focus on lightpath provisioning. For example, a stochastic model is presented in [3] to estimate the effective number of available wavelengths along inter-domain paths, based on which an RWA strategy can successfully set up an end-to-end connection. The ASON hierarchical routing model was discussed by ITU-T and OIF which presented a comprehensive hierarchy to multi-level routing [4,5]. The domains are abstracted by means of virtual topologies which are then used to compute the end-to-end path [1,5]. Here, the interface between the domains, referred to as External Network to Network Interface (E-NNI) was defined to facilitate the information exchange between domains.

Static virtual topology has been proposed to ensure the availability of network resource before traffic arrives, eliminating the need of dynamic set up and tear down of lightpaths. As a consequence, the information exchanged between domains is reduced to the bandwidth availability on the transit tunnels, which significantly reduces the amount of inter-domain information exchange since the domain–internal resource information does not need to be exchanged [6]. However, to ensure a low blocking probability of inter-domain requests, transit tunnels are usually over-provisioned, which in such scenarios with static virtual topology typically results in a poor resource utilization. In this paper, we propose a novel approach to use multipath routing to counter this issue, which, instead of over-provisioning of transit tunnels, can aggregate bandwidth from multiple paths.

However, multipath routing carries a challenge of the differential delay, which is caused by the diversity of paths used between a source and destination pair. The differential delay can affect the quality of services, especially for the real-time applications which have strict requirements of the jitter and delay. Research efforts have been focused on solving the differential delay issue for multipath routing, with primary focus on single domain scenarios. Ahuja et al. [7] studied the problem of minimizing the differential delay in the context of Ethernet over SONET; proposed algorithms select a path for a *Virtually Concatenated Group* (VCG) which has the minimum differential delay [7]. Chen et al. [8] proposed to use multipath routing in the inter-domain service provisioning in circuit switching networks. In [8], the multipath routing solution was derived on the aggregated multi-domain virtual topology, which was formulated as an Integer Linear Programing (ILP) model, where the optimal solutions were tailored to satisfy the connection demands with extremely high bandwidth requirements. The complexity issue of the ILP has been observed in [8], therefore the heuristics targeting different applications are necessary. As a follow-up of this work, we here investigate only the heuristics on inter-domain multipath routing in optical networks, which have a greater potential for practical applicability.