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Two-layer optimization of survivable overlay multicasting in elastic optical networks

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ABSTRACT

Elastic optical network (EON) architectures are considered as a very promising approach for future optical transport networks, since they efficiently use the spectrum resources and provide high bandwidth scalability and granularity. At the same time, the multicast transmission technique is widely used to provide increasingly popular streaming services in computer networks. In this paper, we focus on optimization of lightpath connections in EONs supporting bandwidth-demanding multicast-capable applications. Since multicasting in the optical layer is still not deployed in most of real-world backbone networks, we propose to provision the application-layer multicasting in an overlay network. To this end, we study a two-layer optimization problem that combines the optimization of multicasting in the overlay network (application layer) and the optimization of lightpaths in the EON. What is more, we address our problem with the survivability assumptions and we propose several survivability scenarios that can be applied in the network (in both the overlay network and the optical layer) to provide the required protection against failures. In the overlay network, we propose to protect the data stream by a dual homing scheme, wherein in the optical layer, we apply a dedicated path protection scheme. Moreover, in both layers we consider a scenario with no protection. We perform numerical experiments to compare different protection scenarios and to evaluate potential benefits of using multicasting instead of a typical unicast transmission. We use several comparison criteria (metrics) that affect the considered elastic optical network, namely, network deployment cost, power consumption and spectrum usage. The obtained results show that the values of these metrics significantly depend on the applied protection scenario. Eventually, we can see that multicasting brings significant savings in terms of all defined metrics when compared to unicast transmission.

1. Introduction

Recently, we are witnessing a rapid growth in popularity of different kind of multimedia streaming services in the Internet. To emphasize the growing popularity of various video streaming services, we need to quote [1] where the authors claim that Video on Demand traffic will triple and Internet TV will be increased 17 times by 2015. The total share of all forms of video (already mentioned) and peer-to-peer (P2P) applications will grow continuously to make up approximately 90 percent of all global consumer traffic in the next three years. Services like IP

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Television (IPTV), Content Delivery Network (CDN) data distribution, transmission of scientific data (e.g., large hadron collider data), and big data transmission (e.g., meteorology and environmental data) have high bandwidth requirements of up to 10–200 Gbps. The provisioning of these upper-layer services can be costly [2] and should be carried over an underlying optical transport network, as only the optical fiber is capable of providing high bandwidth over long distances.

In our work, for the underlying optical network, we apply the concept of Elastic Optical Networks, which allow for efficient and flexible allocation of spectrum resources in optical fiber links and on-demand bandwidth provisioning [3]. To this end, EONs make use of advanced single-carrier and multi-carrier modulation techniques as well as they can operate within flexible frequency grids. We also choose a multicasting transmission approach, defined as one to many communication, as it is the most effective technique (in terms of cost and performance) to provide data streaming in computer networks. Since all-optical multicasting is not a widely used approach in real optical networks according to the high complexity and large costs of the required hardware (i.e., multicast-capable wavelength-routing switches) [4], we implement the multicast transmission in an overlay approach in the application layer. The overlay network is a virtual network, realized in the application layer, on top of an underlying physical network, which, in our case, corresponds to the optical network. Nodes of the overlay network can be considered as being connected by virtual or logical links, each of which corresponds to a path, possibly through many physical links, in the underlying physical network [5]. Thanks to that independence from the physical layer, overlay networks are flexible, scalable and robust. Moreover, it is comparatively easy to design and implement new overlay communication protocols and environments. Because of those advantages, overlay networks are used in many popular services like cloud computing [6], grid computing [7] and various streaming services.

In this paper, we focus on optimization of a two-layer network in which the overlay network realizes the multicast transmission and the underlying transport network is implemented as an elastic optical network. In Fig. 1, we illustrate our general approach to optimizing this network. First, with given multicast sessions defined by a root (source), set of receivers (clients) and bandwidth requirement (bit-rate), we create overlay trees in the upper (application) layer in an efficient manner in respect of different metrics (objective functions). Therefore, an upper-layer optimization algorithm is applied and the algorithm generates a matrix of aggregated unicast traffic demands. The matrix is used as an input data for the second stage of optimization process performed for the lower (optical) layer. At the optical layer, we look for a set of optical path (lightpath) connections to support these upper-layer traffic demands. In EONs, a lightpath is determined by a routing path, which connects the end nodes of a demand, and a segment of spectrum allocated on this path. Thus, we run an optical-layer optimization algorithm to solve the Routing and Spectrum Allocation (RSA) problem. As a result, by solving RSA, we find a set of lightpaths supporting the overlay multicast transmission.

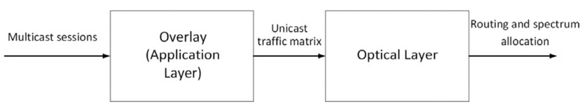

Fig. 1. Two-layer optimization.

Currently, the data streaming is used in the Internet in a wide spectrum of services and applications. In some cases, the streaming needs to be protected according to the significance of the transmitted data (e.g., financial information, critical updates in large IT systems, video signal related to security issues) or according to the business needs. Therefore, in this paper we propose several survivability scenarios that can be applied in the network to provide the required protection. We combine protection methods that can be used both in an application (overlay) layer as well as an optical layer and protect the network against single link failures in the application layer and the optical layer, respectively. In the former case, we propose to protect the streaming against access link failures by dual homing and double multicast trees [8–10]. In the latter case, we protect the EON against optical fiber link failures by a Dedicated Path Protection (DPP) method [11]. Moreover, as a reference scenario we also consider a network with no protection (NP). Consequently, combining all possible protection methods in both layers, we obtain six various survivability scenarios that are analyzed and compared in this paper. As the performance metrics applied to compare the survivability scenarios, we use the following metrics related to the EON performance, namely: network deployment cost including both CAPEX and OPEX factors, power consumption, and frequency spectrum usage, similarly as in [12].

The main goal and contribution of the paper is to compare different protection scenarios applied in both overlay network and optical layer using the EON-related performance metrics. Namely, in the overlay network, dual homing and double trees protection methods are used, while in the optical layer the DPP method is applied. Since even a single-layer optimization problem of either the overlay network or the optical network is *NP*-hard [11,13], we consider a decomposition of our two-layer network optimization problem on two sub-problems, related to each layer, for which optimization is performed. To model each of the sub-problems, we formulate them as ILP (Integer Linear Programming) problems. Since these ILP models can be solved only for small networks, we develop and run effective heuristic methods for larger problem instances. We want to stress that this article is not focused mainly on the optimization issues and, therefore, the ILP models and heuristic algorithms are presented briefly without deep mathematical investigations. Also, it should be underlined that the novelty of this paper follows from the use of the EON approach in the optical layer, which to the best of our knowledge has not been studied in a survivable overlay multicasting scenario so far.

The rest of the paper is organized in the following way. In Section 2, we review previous works on elastic optical networks and two-layer optimization. Section 3 introduces the concepts of overlay multicasting, elastic optical networks, and survivability scenarios that we consider in this paper. Section 4 focuses on optimization of the overlay