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Protecting multicast services in optical internet backbones ☆

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ABSTRACT

Many applications in the future Internet will use the multicasting service mode. Since many of these applications will generate large amounts of traffic, and since users expect a high level of service availability, it is important to provision multicasting sessions in the future Internet while also providing protection for multicast sessions against network component failures. In this paper we address the multicast survivability problem of using minimum resources to provision a multicast session and its protection paths (trees) against any single-link failure. We propose a new, and a resource efficient, protection scheme, namely, Segment-based Protection Tree (SPT). In SPT scheme, a given multicast session is first provisioned as a primary multicast tree, and then each segment on the primary tree is protected by a multicast tree instead of a path, as in most existing approaches. We also analyze the recovery performance of SPT and design a reconfiguration calculation algorithm to compute the average number of reconfigurations upon any link failure. By extending SPT to address dynamic traffic scenarios, we also propose two heuristic algorithms, Cost-based SPT (CB_SPT) and Wavelength-based SPT (WB_SPT). We study the performance of the SPT scheme in different traffic scenarios. The numerical results show that SPT outperforms the best existing approaches, optimal path-pair-based shared disjoint paths (OPP_SDPs). SPT uses less than 10% extra resources to provision a survivable multicast session over the optimal solution and up to 4% lower than existing approaches under various traffic scenarios and has an average number of reconfigurations 10–86% less than the best cost efficient approach. Moreover, in dynamic traffic cases, both CB_SPT and WB_SPT achieves overall blocking probability with 20% lower than OPP_SDP in most network scenarios.

1. Introduction

The future Internet is a high performance communication network, that is capable of supporting large amounts of individual and aggregate traffic, in order to meet the explosive increase in bandwidth demand in the Internet, and to support a greater variety of network applications. For this reason, the optical fiber is the physical medium of choice in both the access and distribution networks of the future Internet. Wavelength-division multiplexing (WDM) technology is used on optical fibers in order to allow an aggregate traffic on the order of Tbps to be carried on a single fiber, with each wavelength carrying traffic in the tens of Gbps order. Many of the applications that will be supported by the future Internet will employ the multicasting service mode [2]. These include high-definition video distribution, online gaming, e-Science applications, etc. To implement multicasting, a node should have the capability to replicate an incoming packet into multiple copies. In the context of optical networks, there are two ways to implement the multicast function at a node, unicast and multicast. In unicast mode, traffic duplication can only be implemented in the electronic domain, whereas in multicast mode, traffic duplication can be done

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in the optical domain by using optical splitters [6]. If a multicast session is provisioned as a tree in the optical domain, it is called a "light-tree" which originates at a source node and delivers the same data to a number of destination (leaf) nodes [4].

As the capacity of fibers keeps on increasing, a fiber cut caused by an accident or a failure of a switch port or a node interface may lead to loss of tremendous amounts of data. In the scenario of multicasting service, data loss on one fiber may cause the disruption of delivery to multiple nodes. Since users expect a high level of network and service availability, protection of multicast session against network component failures must be provided. The most common type of failures in optical networks is the link failures, and this is why a number of strategies have been proposed in the literature to provide this type of protection. One approach that was proposed in [3] is to find two light trees, where both of them start from the source and end at the destination nodes, but they are routed in a link disjoint manner. It is clear that this method is not capacity efficient since it is not always possible to find two link disjoint trees in a network. In [5], the authors introduced a number of protection schemes: link-based, segment-based and path-based. In link-based and segment-based approaches, a multicast session is routed first to construct a multicast tree, and then each link or segment on the tree is protected by a path starting at the tail node and finishing at the head node of the link or segment it protects. Alternatively, a path-based protection scheme, named optimal path-pair-based shared disjoint paths (OPP_SDPs) algorithm, achieves the best result in terms of network resource consumption in [5] by self-sharing primary and spare capacity [7]. The idea is to find two shortest link disjoint paths for each source and destination pair. Recently, a couple of new technologies were applied to the survivability problem, *p*-cycle [9] and network coding [10]. These techniques do have some nice features such as the fast recovery of *p*-cycles or high bandwidth utilization of network coding. However, *p*-cycle-based schemes are not efficient and flexible to protect dynamic traffic, especially multicast traffic, while network coding introduces extra computational cost as well as O-E-O conversion since network coding can only be performed in the electronic domain in current optical networks, which may introduce an additional expense.

A path-based scheme, called multicast protection through spanning paths (MPSP), proposed in [7], outperforms OPP_SDP under both static and dynamic traffic patterns. It first provisions a primary multicast tree and then establishes a number of paths to protect each path between any pair of leaf nodes on the primary tree, called spanning path. Each path is link disjoint from the spanning path it protects. However, this scheme relies on the assumption that wavelengths reserved in a fiber can be used in two opposite directions by reconfiguring the switches at two end nodes. However, this feature cannot be achieved in practice. Between two connected nodes, there are usually two physical fibers set up and each of them works in one direction. The switches at end nodes use input and output ports to connect incoming and outgoing fibers, respectively [4,5]. Reserved capacity (wavelength) in a fiber cannot be used in both directions by simply reconfiguring the switches at end nodes due to the fixed switching ports. One way to enable this feature is to change the physical infrastructure by deploying a pair of circulators between two nodes as shown in Fig. 1. The fiber is connected to the circulators instead of switching ports on the switches. The circulators connect to both input and output ports on the nearby switches and can configure the fiber to connect to either input port or output port. Only changing the configuration of both switches and circulators will make the transmission in both directions on the same fiber possible such that one unit of capacity reserved in a directed link can be shared by primary and protection paths in MPSP scheme. Due to the infrastructure of current Internet backbone networks, the lack of support for this functionality and the restrictions this imposes on other modes of communication, we do not take this assumption into consideration in our proposed scheme.

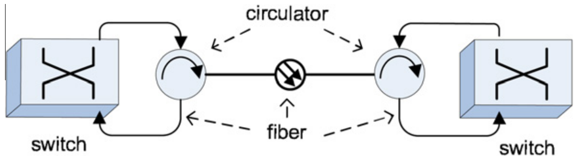

Fig. 1. Additional depolyment of circulators enables capacity sharing in opposite directions of a fiber.

A tree-based protection scheme, Segment-based Protection Tree (SPT) algorithm, is proposed in this paper to provision a multicast request and protect it against any single link failure. We first provision the multicast session on a light tree and then construct protection multicast trees instead of paths to protect the primary light tree. Each protection tree, similar to primary tree, is rooted at the source and reaches every destination in the session. Each segment on the primary tree is protected by a protection tree. A protection tree can share any link with the primary tree as well as other protection trees. The uniqueness of our schemes is that each protection tree is a complete multicast tree from source to destinations. It does not have to traverse the end nodes of a segment it protects. In this case, multiple segments may share one protection tree, which potentially improves the efficiency of the bandwidth utilization.

The rest of this paper is organized as follows. In Section 2, we present the assumptions and statement of the problem addressed. The proposed scheme, SPT, will be introduced in Section 3. The method of computing the average number of reconfigurations will be presented in Section 4. We further study the dynamic multicast cases by proposing two heuristic algorithm extended from SPT in Section 5. Numerical results will be presented and explained in Section 6. Finally, we conclude this paper in Section 7.

2. Preliminaries

In this section, we first describe multicast protection problem addressed in the paper with the corresponding