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An efficient mechanism for dynamic survivable multicast traffic grooming

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ABSTRACT

Recent advances in wavelength division multiplexing (WDM) networks have helped enhance the popularity of multicasting services. However, as a single network failure may disrupt the information transmission to multiple end-users, protecting multicast requests against network failures becomes an important issue in network operation. This paper investigates the sub-wavelength level protection for dynamic multicast traffic grooming. A new method named lightpath-fragmentation based segment shared protection (LF-SSP) scheme is proposed. By carefully splitting primary/backup lightpaths into segments to improve resource sharing for both traffic grooming and protection, LF-SSP aims to minimize the network resources allocated for request protection. Extensive simulations are carried out to compare the performance of LF-SSP to some existing approaches, on sub-wavelength-level as well as wavelength-level multicast protections in different cases. Results show that LF-SSP steadily outperforms these existing methods as long as the network resources are not too limited. Influences of the add/drop port resources and the average number of destinations per connection request on the LF-SSP performance are also evaluated.

1. Introduction

The increasing bandwidth demands over the past decades have driven wavelength-division-multiplexing (WDM) networks to become the dominant infrastructure for backbone networks [1]. In such networks, data is transmitted through all-optical wavelength channels, referred to as *lightpaths* [2], using optical-cross-connects (OXCs). A lightpath may span several physical links. If all OXCs are not equipped with any wavelength converter, the lightpath has to be served using the same wavelength along its route, which is known as the *wavelength continuity constraint* [3].

Multicast involves the delivery of a message from a single source to a group of destinations simultaneously. As WDM networking technologies become mature, and bandwidth intensive multicast applications, such as interactive distant learning, high-definition-television (HDTV), live-video conferencing, etc., become increasingly popular, it is widely believed that a large portion of the future Internet traffic will be multicast in nature. To support the physical-layer multicasting, various methods utilizing either lightpath, or *light-tree* [4], or both have been proposed.

For many multicast sessions, the bandwidth they require is usually less than $OC-3(155\ \text{Mb/s})$, which is much lower as compared to the capacity that can be provided by a single wavelength channel in today's WDM networks, e.g., $OC-192(10\ \text{Gb/s})$. To efficiently utilize wavelength capacity, *traffic grooming* [5] is usually adopted to pack multiple sub-wavelength granularity requests into a single wavelength channel for transmission. Multicast traffic grooming has received considerable attention, and the early-stage work has been mainly focusing on the static problems, wherein the network resources and all the traffic demands are known a priori [5–7]. In recent years, however, as more and more agile components are developed and widely deployed in optical networks, multicast traffic tends to show its dynamic nature and consequently, dynamic multicast traffic grooming is becoming increasingly important. With the requests arriving and leaving the networks dynamically, studies on dynamic multicast traffic grooming problem mainly focus on algorithm design for minimizing request blocking probability or maximizing network throughput, e.g., [7–9].

Optical networks are vulnerable to various component failures, and a single failure may cause massive information losses and serious service interruptions. In networks supporting a large number of bandwidth-intensive multicast applications, influences of network failures could be even more devastating. Having proper

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survivability mechanisms to protect multicast sessions against network failures is therefore of essential importance. Generally speaking, the network survivability methods can be classified into two categories: *restoration* [10] and *protection* [11]. While restoration is reactive with efficient resource utilization, protection is proactive and recovers more quickly after the failures. In high-speed WDM backbone networks, protection is usually regarded as a more favorable option as it guarantees full recovery and faster restoration speed [12].

A number of multicast protection mechanisms have been proposed in literature [13–19]. According to whether backup resources can be shared or not, such protection mechanisms can be classified into *dedicated* or *shared* protections; while according to how the backup route is calculated, they can be classified into five categories [17]: *tree*-based, *ring*-based, *path*-based, *segment*-based, and *cycle*-based. Results in [18,19] showed that the tree- and ring-based methods are not resource efficient, while the cycle-based ones are not flexible enough for dynamic request protection, especially for the dynamic multicast requests. Between the path-based and segmented-based schemes, the latter one is reported to achieve better blocking performance, faster restoration speed and higher resource efficiency in protecting wavelength-level multicast requests [19].

Compared to the extensive research efforts dedicated towards wavelength-level multicast request protection, sub-wavelength-level multicast request protection, which is also known as survivable multicast traffic grooming (SMTG), has received rather limited attention: though two methods, which will be reviewed in Section 2.3, have been proposed in [20] for SMTG, some assumptions adopted therein may not necessarily be valid in modern optical communication networks. Specifically, as pointed out in [18], in current backbone networks, the capacity reserved for protection within a fiber cannot be utilized in two opposite directions by simply reconfiguring the switches at its two end nodes. Therefore, we do not adopt such assumptions in our proposed scheme.

In this paper, we address the problem of protecting sub-wavelength-level multicast requests in dynamic traffic grooming process. A novel mechanism, named lightpath-fragmentation based segment shared protection (LF-SSP) scheme, is proposed to protect multicast requests at the connection level. The primary objective of the algorithm design is to protect requests against any single link failure while minimizing the network's bandwidth blocking ratio (BBR), which is defined as

$$\mathrm{BBR} = \frac{\sum \text{Blocked request bandwidth}}{\sum \text{Bandwidth of all requests}}$$

By adopting the lightpath fragmentation (LF) method to fragment new lightpaths into shorter segments to improve resource sharing for both traffic grooming and request protection, the LF-SSP scheme attempts to minimize the network resources allocated to protect each request. To evaluate the performance of LF-SSP, extensive simulations are carried out. We firstly compare the LF-SSP scheme against an existing method for sub-wavelength-level multicast request protection, and then extend the comparison to a few existing methods for wavelength-level request protection. Simulation results demonstrate that LF-SSP outperforms the existing methods in different cases as long as the network resources are not too limited. In addition, the effects of a few factors, including the redundancy level of add/drop port resources and the average number of destinations per multicast session, are also evaluated.

The remainder of this paper is organized as follows. Section 2 defines the network model and the problem to be addressed, followed by a brief description of related work. Section 3 describes the proposed LF-SSP scheme for dynamic SMTG. The simulation results are presented and discussed in Section 4. Section 5 concludes the paper.

2. Network model and problem definition

2.1. Network model

We consider dynamic multicast traffic grooming problem in wavelength-routed WDM networks. The network is represented by a directed graph $G = (V, E)$, where V and E denote the sets of network nodes and fiber links, respectively. Specifically, we assume that the physical-layer topology of the network is a set of nodes interconnected by fiber links. Each fiber link is composed of two fibers in opposite directions, each of which carrying W wavelengths. The capacity of each wavelength is B units. Each network node is equipped with a grooming-capable optical cross-connect (GC-OXC) [7] as shown in Fig. 1. Each GC-OXC is equipped with a certain number of add/drop ports, which generally equals the number of transceiver pairs on the node. As both the add/drop ports and the transmitters/receivers are high-cost components, a network node is usually equipped with a limited number of ports shared by all wavelengths going through it. In this paper, we define the *add/drop ratio* r $(0 < r \leqslant 1)$ as the ratio of the number of add/drop port pairs over the total number of wavelengths passing-through the OXC. We refer to a network node with $r < 1$ as a port-limited node; and a port-unlimited one otherwise.

To support multicasting services, a lightpath-based scheme is adopted in this paper: as demonstrated in our previous study [9], the lightpath-based approaches steadily outperform the light-tree based ones in achieving better bandwidth blocking performance for dynamic multicast traffic grooming. A lightpath occupies a wavelength along its route, a transmitter at its source node, and a receiver at its destination node, whereas a multicast request may traverse several lightpaths along its route, and consumes a portion of the bandwidth provided by each lightpath it traverses.

2.2. Problem statement

The dynamic SMTG problem in WDM networks can be formulated as follows. Upon the arrival of each multicast request

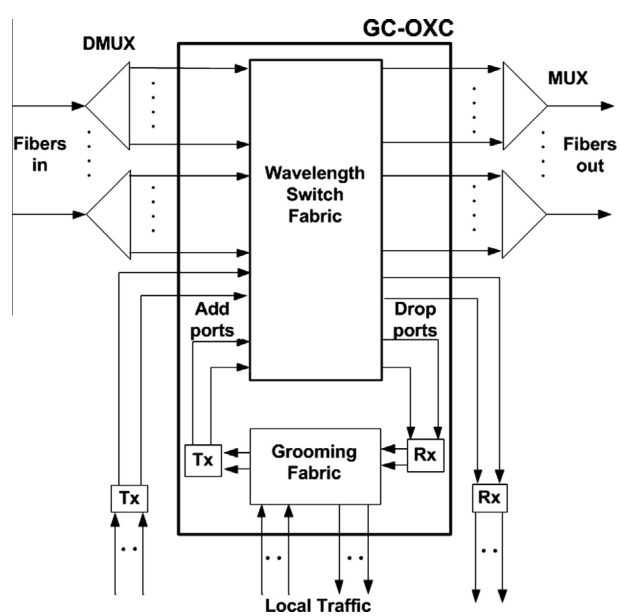

Fig. 1. A typical grooming-capable OXC architecture.