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An efficient mechanism for dynamic multicast traffic grooming in overlay IP/MPLS over WDM networks

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ABSTRACT

This paper proposes an efficient overlay multicast provisioning (OMP) mechanism for dynamic multicast traffic grooming in overlay IP/MPLS over WDM networks. To facilitate request provisioning, OMP jointly utilizes a data learning (DL) scheme on the IP/MPLS layer for logical link cost estimation, and a lightpath fragmentation (LPF) based method on the WDM layer for improving resource sharing in grooming process. Extensive simulations are carried out to evaluate the performance of OMP mechanism under different traffic loads, with either limited or unlimited port resources. Simulation results demonstrate that OMP significantly outperforms the existing methods. To evaluate the respective influences of the DL scheme and the LPF method on OMP performance, provisioning mechanisms only utilizing either the IP/MPLS layer DL scheme or the WDM layer LPF method are also devised. Comparison results show that both DL and LPF methods help improve OMP blocking performance, and contribution from the DL scheme is more significant when the fixed routing and first-fit wavelength assignment (RWA) strategy is adopted on the WDM layer. Effects of a few other factors, including definition of connection cost to be reported by the WDM layer to the IP/MPLS layer and WDM-layer routing method, on OMP performance are also evaluated.

1. Introduction

As wavelength division multiplexing (WDM) networks are taking over the dominant role in the Internet backbone [1], it is widely believed that IP over WDM networks will be a key component of the next-generation Internet [2,3]. The emerging networking technologies, such as Multi-Protocol Label Switching (MPLS) [4], Generalized MPLS (GMPLS) [5], User Network Interface (UNI) [6], and path computation element (PCE) [7], are also paving the way for such network revolution.

An IP/MPLS over WDM network has two different layers. The IP/MPLS layer consisting of label switching routers (LSRs) and label switched paths (LSPs) is the carrier network, and it delivers requests between its end users; the WDM layer consisting of optical-cross-connects (OXCs) and fiber links is the transport network, and it provides dynamic connectivity services to the upper-layer client (s) in the form of *lightpaths* [8]. A lightpath may span several optical links, and it has to be assigned the same wavelength along its route if all OXCs do not have wavelength conversion capability.

For the interconnection between the IP/MPLS layer and the WDM layer networks, three architectural alternatives, namely, overlay, peer and augmented models, have been proposed [9]. In the overlay model, the two network layers are independent of each other, and the only information exchange between them is for service requests and responses. While in the peer model, a unified control plane is maintained, in charge of all network control and management. The augmented model tries to make a compromise between the two by allowing certain information to be shared between the two layers; however, there is still no consensus on what kind of information should be shared. Adapting a peer-model approach allows the network transmission provisioning problem to be conveniently mapped into a network flow problem with complete topology and capacity information on both layers. In practice, however, since the IP-layer and the WDM layer networks are usually owned by different network operators, overlay model is widely accepted as the most practical one for near-term deployment [9]. The emergence of service oriented optical networks further demonstrates the feasibility of such model [10]. While extensive work has been done on transmission provisioning in peer model networks [11–16], studies on overlay network model are still relatively limited, and mostly only for handling unicast traffic [17–20].

Multicast is an efficient way of disseminating information from one source to multiple destinations simultaneously [21]. In recent

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years, as Internet applications, such as multi-player gaming, video conferencing and interactive distance learning, are becoming increasingly popular, multicasting becomes one of the essential capabilities in modern networks. In the traditional IP networks, multicast is realized relying on the IP router's copying capability; while in WDM networks, it relies on the OXCs' light-splitting capability. To support physical-layer multicasting in WDM networks, a generalized lightpath concept, named *light-tree*, was proposed [22].

The bandwidth required for a typical multicast session is on the order of megabits per second (Mbps), which is much smaller compared to the 2.5–40 gigabits per second (Gbps) capacity that can be steadily provided by a single wavelength channel in today's WDM networks. To efficiently utilize the wavelength capacity, several multicast sessions are usually packed together onto wavelength channels for transmission. Such a process is known as *multicast traffic grooming* [23].

The early-stage work on multicast traffic grooming mainly focused on the static scenario where traffic is known a prior [24–26]. As more agile networking technologies are being adopted in optical networks, however, multicast traffic tends to show its dynamic nature. Hence dynamic multicast traffic grooming problem becomes an important research issue. Different algorithms utilizing either lightpath, or light-tree, or both for dynamic multicast traffic grooming have been proposed [27–37].

Compared to the extensive interests received in peer model networks, dynamic multicast traffic grooming in overlay IP over WDM networks, however, has not received much attention in the past years. Since the two layers of the network are managed by independent owners with very limited information exchanges in between, routing decisions made on one layer may lead to inefficient resource utilizations on the other layer. To the best of our knowledge, up till now only two methods have been proposed for tackling this problem. Both methods, which will be reviewed in Section 2, are easy to be implemented, yet not free from the inherent limits caused by limited information exchanges between the two layers.

Our previous study [20] on *unicast* traffic grooming in overlay networks shows that, by letting the two layers agree on a definition of the cost for setting up a new lightpah and allowing the IP/MPLS-layer operator to keep record of the recent service requests that have been supported by the WDM layer network, the IP/MPLS-layer owner can make better routing decisions and improve network performance significantly [20]. To extend such results to multicast traffic grooming, however, requires nontrivial work. The issues to be studied include the definition of the cost for setting up new connections (not necessarily new lightpaths), the routing method, and more. Further, how to improve the efficiency of WDM-layer network resource sharing is also an important issue.

This paper addresses the dynamic multicast traffic grooming problem in overlay IP/MPLS over WDM networks. To help relax the constraint imposed by limited information exchanges in overlay networks while improving resource sharing in traffic grooming process, an efficient overlay multicast provisioning (OMP) mechanism is proposed. By jointly utilizing a historical data learning (DL) scheme on the IP/MPLS layer for link cost estimation, and a lightpath fragmentation (LPF) based method on the WDM layer for improving resource sharing, OMP aims to minimize the *bandwidth blocking ratio* (BBR), which is defined as

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

Extensive simulation results show that OMP significantly outperforms the existing methods under different traffic loads, in networks with limited or unlimited optical port resources. It is also found that the IP-layer DL contributes more to improve network performance than the WDM-layer LPF method. Effects of other factors, including definition of new connection cost and WDM-layer routing method, on OMP performance are also evaluated.

The remainder of the paper is organized as follows. Section 2 presents the network model, the definition of the problem, and some most closely related existing results. Section 3 describes the proposed OMP mechanism. Performance evaluations are carried out in Section 4. Section 5 concludes the paper.

2. Network models, previous work and problem statement

2.1. Overlay IP/MPLS over WDM network model

A typical overlay IP/MPLS over WDM network as shown in Fig. 1 is considered in the paper. With the overlay architecture, the operations and management of the two layers' networks are independent of each other; the IP/MPLS layer is an integrated service provider (ISP) delivering the service requests between its end users, while the WDM layer is the bandwidth provider providing the required connectivity services to its upper layer client(s).

In such an overlay network, the operator of each layer keeps all the information of its own layer, and sends its management commands to all its network elements via a centralized control system. Based on their service contracts, the two operators can also work cooperatively to provide the desired service fulfilling each arriving request. Specifically, upon the arrival of a multicast request, the IP-layer ISP firstly tries to find a route tree for it using only the existing logical links with sufficient residual bandwidths. If such effort fails, it then figures out the LSR pairs between which new lightpaths may need to be set up, and enquires the WDM layer operator for the costs of setting up such lightpaths. After receiving the set up costs reported by the WDM layer, the IP-layer ISP finally decides the lightpaths to be purchased. Note that whether to enquire the WDM layer for lightpath set up costs is decided by the IP layer operator, while whether a new lightpath can be set up or not is decided by the WDM layer operator. In the cost enquiring process, the necessary information exchanges between the two layers are performed through well-defined network interfaces, i.e., UNIs, but not necessarily through the information exchange channels as shown in Fig. 1.

In this paper, we assume that there is only one ISP, and it has exact information of the IP/MPLS-layer network. We also reasonably assume that such IP-layer ISP can keep records of the lightpaths that have been supported by the WDM layer, their corresponding setup costs, as well as the time when such costs were reported. We extend the historical data learning (DL) scheme proposed in [20] from unicast to multicast case.

On the WDM layer network, we assume that the fixed minimum hop routing and first-fit wavelength assignment policy is adopted for lightpath routing. Note that a lightpath route could be very long and the long lightpaths may degrade resource sharing in traffic grooming process. As our previous results showed that splitting long lightpaths into shorter ones helps improve resource sharing in dynamic traffic grooming process [34], we assume that a lightpath fragmentation (LPF) based method is adopted in the lightpath routing process. With the LPF method, long lightpaths may be fragmented into shorter ones upon set up. We also assume that an established lightpath with ongoing transmission cannot be fragmented or rerouted.

Detailed DL scheme and the LPF method will be presented later in Section 3.

2.2. Node architecture

A typical network node in overlay IP/MPLS over WDM networks is an OXC interconnected with zero, one or more LSRs through UNI