Dynamic Multicast Traffic Grooming in WDM Networks with Reconfigurable Light-trees

Xiaodong Huang[†], Farid Farahmand[‡], Tao Zhang[†], and Jason P. Jue[†]

[‡]*Department of Electrical Engineering, The University of Texas at Dallas, Richardson, TX 75083*

[†]*Department of Computer Science, The University of Texas at Dallas, Richardson, TX 75083*

{*xxh020100, ffarid, txz021000, jjue*}@utdallas.edu

Abstract: We address the traffic grooming problem in WDM mesh networks with dynamic multicast traffic. We develop a grooming algorithm in which light-trees can dynamically be reconfigured when a new route is established.

OCIS codes: (060.4250) Networks

1 Introduction

An important feature of next generation high-speed optical networks is multicasting (one-to-many or many-to-many communications). In order to effectively implement multicasting in WDM circuit-switched networks, *light-trees* can be established in the network. A light-tree is a wavelength channel that can reach more than one destination all-optically [1].

Generally, the bandwidth requirement of an individual user is only a fraction of the light-tree capacity. Therefore, dedicating an entire light-tree to a few individual users results in low channel efficiency. One approach to improve the network efficiency is to pack several sub-wavelength unicast and multicast traffic requests into a single light-tree. The problem of multiplexing and routing low-speed traffic requests over light-trees, as well as determining the routing and wavelength assignments of light-trees is known as the *traffic grooming problem*.

In this paper, we address the multicast traffic grooming problem in WDM mesh networks with dynamic multicast traffic. Our study is based on employing a multicast-capable node architecture in which an incoming light-tree can be terminated, split, or extended to the next node, optically. Under this assumption, we introduce a new grooming algorithm called *reconfigurable light-tree*, ReLT. The basic underlying principle in ReLT is that established light-trees can dynamically be reconfigured in order to reach new destinations and hence, satisfy new requests. The simulation results indicate that, under a multicast traffic scenario, ReLT has better performance than constructing individual lightpaths when transceivers are limited due to cost constraints.

2 Node architecture

Fig. 1(a) shows a multicast-capable grooming optical crossconnect (MCG-OXC) with drop and branch capability. In this architecture, traffic grooming capability is offered by the electronic layer, which allows the multiplexing of low speed traffic into high-speed channels as well as the demultiplexing of incoming high-speed traffic. The demultiplexed traffic can be fully dropped and switched to local clients or partially aggregated with other incoming and local traffic to be retransmitted optically to the next hop. Multicast-capable optical cross-connects, residing in the photonic layer of the MCG-OXC, perform optical power splitting and optical switching. One approach to realize the multicasting capability is to employ a splitter-and-delivery (SaD) switch architecture [3], shown in Fig. 1(b). In SaD-based cross-connects, each incoming wavelength goes through an optical power splitter and can be sent to any number of output ports. The strictly non-blocking characteristic of SaD-based cross-connects ensures that no existing connection will be interrupted as light-trees change dynamically.

3 Problem formulation and description of grooming algorithms

The general multicast grooming problem can be formulated as follows. *Given* the network physical topology, the number of wavelengths in each fiber, the number of transmitters and receivers at each node, the existing established light-trees and lightpaths, the existing traffic on light-trees and lightpaths, and an incoming multicast traffic request with a specified source, set of destinations, and bandwidth requirement, *find* the routing for the incoming request in order to minimize the request blocking probability. We assume that each node is an MCG-OXC with full splitting and full grooming capability with no wavelength converters and that requests are multicast with sub-wavelength bandwidth demand. Under our assumed network, the routing of a request could be single-hop over a single new or existing light-tree, or could be multihop over multiple new or existing light-trees.

The basic idea in ReLT is that initial multicast requests are satisfied by establishing a shortest-path light-tree between a source and multiple destinations. Once a light-tree is established, it can be shared and reconfigured by other new low-speed multicast requests. For example, the leaves of the light-tree can be extended beyond the original ending nodes or new leaves can be established on the existing light-tree. Furthermore, new multicast requests can utilize an existing light-tree and be dropped on one of the intermediate nodes on the light-tree. Fig. 2 demonstrates

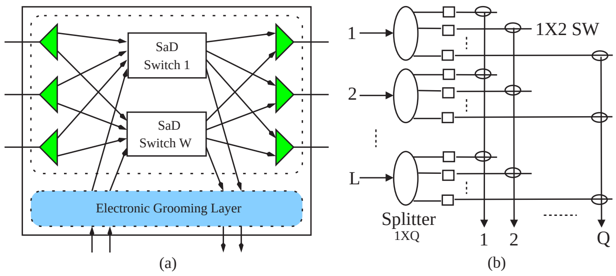


Fig. 1. (a) The MCG-OXC node architecture; (b) The SaD switch.

these concepts. Fig. 2(a) shows a case in which a new request sharing an existing light-tree is dropped on intermediate nodes, b and c, on the light-tree. Fig. 2(b) shows the case where the existing light-tree is split in order to reach new destination nodes, d and f. Finally, Fig. 2(c) shows the case when the existing light-tree is reconfigured and extended beyond its ending node, g.

In order to realize the ReLT grooming algorithm, we use an auxiliary graph model representing the state of the network. Details of this graph model can be found in [4]. The basic concept of the graph model is as follow. The physical network can be represented by G_0 = (V_0, E_0). There are w wavelengths on each fiber. We will generate an auxiliary graph GG = (V, E), which has w + 1 layers: w wavelength layers and one grooming layer. Wavelength layers are used to map the network state on each wavelength.

We define three types of vertices to abstract the capability of an MCG-OXC: Grooming Vertex (GVT): representing the grooming capability of an MCG-OXC; Transmitting Vertex (TVT): abstracting a transmitting port for a specific wavelength on an MCG-OXC; Receiving Vertex (RVT): abstracting a receiving port for a specific wavelength on an MCG-OXC. The RVT is connected to a remote TVT on a neighbor node according to the physical network topology. There are w RVTs in GG for each receiving port on a node, one for each wavelength.

The auxiliary graph GG is initially generated as follows. *Step 1:* Generate a wavelength layer for each wavelength. This involves three basic operations. (1) For each node on G_0, add a TVT and a RVT to the layer for each transmitting and receiving port, respectively. (2) For each node on G_0, add a *pass-through* edge from each RVT to each TVT within the node. (3) For each fiber link on G_0, add a wavelength link edge from the TVT at a node to the RVT at the neighboring node. *Step 2:* Generate the grooming layer. For each node on G_0, add a GVT to the layer. Note that there are no edges between GVTs. *Step 3:* Connect wavelength layers and the grooming layer. Within each node, add an *Adding Edge* from the GVT to the TVTs at each layer. Also, add a *Dropping Edge* from the RVTs at each layer to the GVT.

In our graph model, an edge is either used by a light-tree or is freely available. Each edge has an associated *weight*, *capacity*, and *residual capacity*. The weight will be assigned according to the routing policy (e.g. minimizing the number of physical hops on the light-tree). The capacity is the maximum traffic an edge can carry. All edges, except the wavelength link edge, have unlimited capacity. The residual capacity is the available capacity of an edge which can be used to carry new traffic. The wavelength link is the only edge type that has limited residual capacity which is initially equal to the channel capacity and changes dynamically.

After the initial construction of the auxiliary graph, GG, is completed, the *ReqSetup* routine in the ReLT is executed each time a new request arrives. We describe the basic steps of *ReqSetup* for a new request, $Req(s, M, B)$, where s is the source, M is the set of destination nodes in the multicast group, and B is the bandwidth demand of the request. *Step 1:* Check the residual capacity of each wavelength link on each layer and delete it if its residual capacity is less than B. *Step 2:* Search the shortest-path tree on GG from the GVT at the source node to the all GVTs corresponding to the destination nodes in multicast group M. If no such a tree exists, discard the request. Otherwise, continue. *Step 3:*Iterate through each edge on the shortest path tree to establish the route for all nodes in M. That is, for each optical hop (starting with and ending at a GVT), if none of TVTs and RVTs is on any light-tree, set up a new light-tree along the vertices on the optical hop. On the other hand, if some of TVTs and RVTs are on a light-tree, extend the existing light-tree to cover the remaining vertices.

In the ReLT algorithm, selecting the shortest-path tree in order to reach all destination nodes in a multicast group depends on the weight assignment of edges in the auxiliary graph. Such weight assignment in turn depends on the routing policy. A routing policy is a criterion used to select the best possible route. In this paper we only consider minimizing the total number of physical hops on the light-tree. Hence, the weight for all edges on the light-tree is the same as the sum of all physical hops on the light-tree.

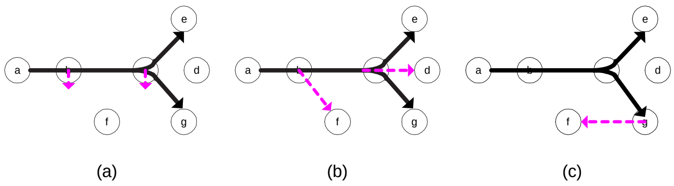
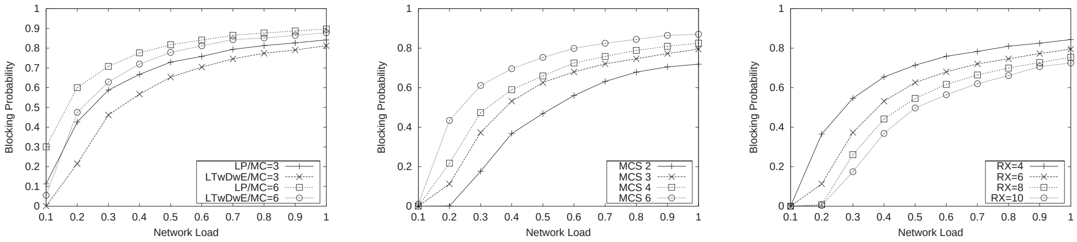


Fig. 2. Basic operations supported by the ReLT algorithm.



(a) (b) (c)

Fig. 3. ReLT performance in terms of blocking probability (a) compared to the lightpath-based approach; (b) for various multicast group sizes; (c) using different number of receivers per node.

A clear advantage of ReLT algorithm is its ability to reduce average number of logical hops that each request must go through. This is due to the fact that light-trees can be reconfigured to optically reach new destinations. However, allowing light-trees to reach too many destination nodes can result in blocking many intermediate nodes from directly accessing the wavelength channel. One way to minimize such cases is to impose a *hop constraint* in terms of the number of nodes that can lie on a light-tree. Another important issue in implementing the ReLT is that a light-tree can go through many splitters and hence, experience excessive power loss. One way to address this problem is by imposing a constraint on the number of times a light-tree can be split in order to satisfy new multicast requests.

4 Simulation results

We have chosen the NSFNet backbone with 14 nodes as our test network. We assume traffic arrival is Poisson process and all incoming requests have the same multicast group size, MCS. We also assume the number of transmitters and receivers per node are 3 and 6, respectively.

Fig. 3(a) shows the performance of the ReLT algorithm in terms of satisfying the number of multicast requests, compared the lightpath based approach for when MCS is set to 3 and 6. Note that the blocking improvement decreases from 10 to 6 percent, as the multicast group size becomes larger. This is due to the fact that when MCS is moderately large, more resources are utilized. This figure also suggests that, in general, the ReLT algorithm utilizes transmitters more efficiently, and therefore, when a limited number of transmitters are used, better performance can be expected compared to the lightpath approach. Fig. 3(b) shows the performance of the ReLT when the size of the multicast group increases from 2 to 6. Fig. 3(c) examines the performance of the ReLT as the number of receivers per node changes between 4 and 10. This plot indicates that as the number of receivers per node increases, the blocking probability improves. Such improvement becomes less apparent as the number of receivers continues to increase beyond 8.

5 Conclusion

In this paper, we have presented a grooming algorithm, ReLT, for the traffic grooming problem in WDM mesh networks supporting multicast requests. This algorithm adopts dynamically reconfigurable light-trees as its building block. Simulation results indicate that under a multicast traffic senario, ReLT outperforms the lightpath-based approach in terms of blocking probability.

References

1. L.H. Sahasrabuddhe and B. Mukherjee, “Light trees: optical multicasting for improved performance in wavelength routed networks,” *Communications Magazine*, IEEE , vol. 37, issue: 2, pp. 67-73, Feb. 1999.
2. C. Qiao and M. Yoo, “Optical Burst Switching (OBS) - A New Paradigm for an Optical Internet,” *Journal of High Speed Networks*, vol. 8, no.1, pp.69-84, Jan. 1999.
3. W.S. Hu and Q.J. Zeng, “Multicasting optical cross connects employing splitter-and-delivery switch,” *Photonics Technology Letters*, IEEE, vol. 10, issue: 7, pp. 970-972, July 1998.
4. X. Huangy, F. Farahmand, and J. P. Jue, “An Algorithm for Traffic Grooming in WDM Mesh Networks with Dynamically Changing Light-Trees,” *Proceedings, GLOBECOM’ 04*, Dallas, TX, Nov. 29, 2004, (to appear).