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Dynamic multicast traffic grooming in WDM networks

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Abstract Dynamic multicast traffic grooming in wavelength division multiplexing (WDM) networks was analyzed to minimize networkwide costs and to increase the network resource utilization. A network model was developed for dynamic multicast traffic grooming with resource constraints and an algorithm that can provide quality of service (QoS) was proposed. The QoS is measured by the maximum number of lightpaths passing between the source and the destinations. The blocking probability of the algorithm was assessed in simulations. The results show that a higher QoS requirement results in higher blocking probability, and when the QoS requirement is low, changes in the QoS requirements have only small effects on the blocking probability.

Keywords optical communication, traffic grooming, WDM, dynamic multicast traffic

1 Introduction

In WDM network, each wavelength is capable of huge bandwidth, from 622 Mb/s, 2.5 Gb/s to 10 Gb/s, even the emerging 40 Gb/s. Yet the bandwidth requirement of a connection request is always less than the bandwidth of a wavelength. If all bandwidth of a wavelength is assigned to a connection request, enormous bandwidth will be wasted. At the same time, because of the constraint of network resource and cost, it is impossible to assign a bandwidth to every connection. In WDM networks, traffic grooming can efficiently multiplex/demultiplex a set of low-rate traffic streams into/from one high-speed lightpath in order to minimize networkwide cost and to increase network resource utilization efficiency. Dutta [1] presents a review of WDM network traffic grooming research. Traffic grooming for static connections has been researched in many papers [2, 3].

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With the development of multimedia technology and the increasing demand of multimedia service, there is more and more multicast service emerging, such as network video conference, video on demand (VoD) and so on. Traffic grooming for multicast traffic is becoming more and more important in traffic grooming research [4].

At the same time, the developing network intelligence can provide customers with capability of dynamic real-time connection setup and release, increasing network resource utilization. Wen [5] presents a set of algorithms for dynamic unicast traffic grooming. To our knowledge, there is no paper focusing on dynamic multicast traffic grooming. Dynamic multicast traffic grooming is researched in this paper. Section 2 presents a network model for dynamic multicast traffic grooming and a new traffic grooming algorithm is proposed in Sect. 3. Section 4 and Sect. 5 show and discuss the simulation results. Finally, Sect. 6 concludes the paper.

2 Network model for dynamic multicast traffic grooming

Network physical topology is denoted with $G_p = (N, E)$. Here N is the set of network nodes, and E is the set of network links. Node i has T_i optical transceivers. $\Lambda = \{\lambda_0, \lambda_1, \dots, \lambda_{W-1}\}$ is the set of wavelength on a link, the bandwidth of which is C . There are W wavelengths on each link.

Customers' connection requests arrive dynamically, denoted with $G = \{s, d_1, d_2, \dots, d_F, b\}$. s is the source node and d_i is the sink nodes of the connection, bandwidth requirement of which is b . When the number of sink node $F = 1$, the connection request becomes a unicast connection request. Customers can release their connections at any time.

In grooming network, the routing of a connection may pass several lightpaths from source to sinks and electronic cross connections are used to connect these lightpaths; so the delay of a connection comprises lightpath transport delay and electronic cross connection delay. With the constraint of the electronic cross connection speed, the electronic connection occupies the main part of the whole delay. In order to

decrease the connection delay and improve QoS, H_{\max} is denoted as the maximum number of lightpaths passed from the source to all sinks. Hence, the maximum number of electronic cross connections from the source to all sinks is $H_{\max} - 1$. Customers can set H_{\max} according to QoS requirement, thereby controlling the delay of the connection.

In our network model, each node is capable of traffic grooming and electronic cross connection, but none has the capability of optical multicast cross connection and wavelength conversion. The lightpath should be compliant to wavelength continuity constraint.

3 Algorithm for dynamic multicast traffic grooming

Our traffic grooming algorithm is divided into two parts: connection setup and connection release.

When setting up a new connection, in order to utilize the unused bandwidth of built lightpaths, an auxiliary graph $G_1(N, E_1)$ is constructed according to the present network state. N is the set of physical network nodes. The set of links E_1 is inserted based on the following rules: if there are any built lightpaths between node i and j , and the unused bandwidth is not less than bandwidth requirement b , $(i, j) \in E_1$; if link $(i, j) \in E$ and there is at least one unused wavelength on link (i, j) , $(i, j) \in E_1$.

For routing a multicast connection, a multicast tree Q from the source to all sinks is needed. The algorithm generates the multicast tree iteratively. At the beginning, there is only one node, source node s , on the tree Q , namely, $Q = \{s\}$. Set D includes all sinks. At each iteration, a node d_i is selected from the set D and added to the multicast tree Q . In order to utilize the electronic cross connection capability of network nodes and decrease traffic transporting on same links, the nodes with electronic cross connection on the path from Q to d_i are also added to the multicast tree Q . Now $Q = Q + \{t_0, t_1, \dots, t_j, d_i\}$ (t_i is electronic cross connection node), $D = D - \{d_i\}$. When $D = \emptyset$, it means all sinks are on the multicast tree and the connection has been set up, or continues to the next iteration.

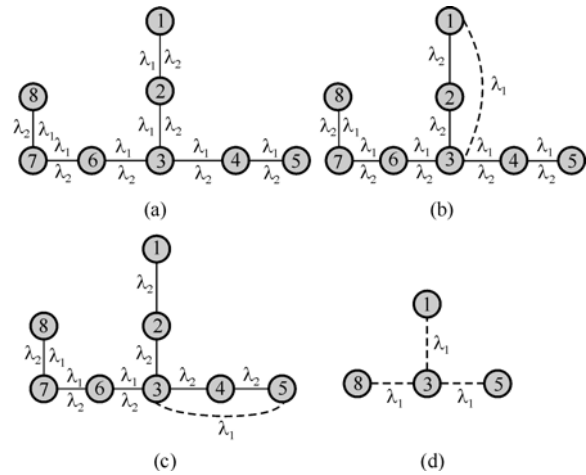
In order to select the node d_i is added to the multicast tree, auxiliary graph $G_1(N, E_1)$ is updated first according to the network state. For each node pair in set $\{(i, j) | i \in Q, j \in D\}$, k -shortest paths on the auxiliary graph should be calculated. All paths must be sorted according to path length compliant to non-decreasing rule and a sorted table must be obtained. Path p_{ij} ($i \in Q, j \in D$) is picked up from head of the sorted table for wavelength assignment. If p_{ij} passes any built lightpaths, use the built lightpath, or assign wavelength according to first-fit rule. The wavelength assignment should meet the following requirements:

- 1) the number of lightpaths passed from source s to node j should be no more than H_{\max} .
- 2) the two end nodes of new lightpaths should have enough optical transceivers.

If wavelength assignment for path p_{ij} succeeds, node j is added to the multicast tree. At the same time, electronic cross connection nodes on path p_{ij} are also added to the multicast tree. Unused bandwidth on built lightpaths should be updated. If new lightpaths are needed, new lightpaths must be set up.

If wavelength assignment fails, the next path from the sorted table for wavelength assignment should be considered. If wavelength assignment for all paths in sorted table fails, it means it is impossible to set up a multicast tree for the connection request and it means that that the routing is unsuccessful.

The following example demonstrates the process to set up a multicast connection. As Fig. 1(a) shows, there are 8 nodes in the star network, 2 wavelengths on each link, 4 optical transceivers on each node. Assume that there is a lightpath $L_{13}=(1, 2, 3)$ between node 1 and 2 using wavelength λ_1 with unused bandwidth $C/2$. Now a new connection request arrives with source 1, sinks $\{5, 8\}$, and bandwidth requirement of $C/2$, $H_{\max}=3$. For simple, set $k=1$.



(Unused wavelength and wavelength used by lightpaths are indicated in the figure. Dash lines in (b) and (c) indicate lightpaths with enough unused bandwidth. Dash lines in (d) indicate lightpaths that the multicast tree passes.)

Fig. 1 Multicast traffic grooming example. (a) Physical network; (b) Auxiliary graph at the first iteration; (c) Auxiliary graph at the second iteration; (d) Multicast tree

At the beginning of the setup process, $Q = \{1\}$, $D = \{5, 8\}$. The auxiliary graph is generated according to current network state, shown as Fig. 1(b). Calculate k -shortest ($k=1$) paths for node pair (1, 5) and (1, 8), and get path (1, 3, 4, 5), (1, 3, 6, 7, 8). Path (1, 3, 4, 5) is shorter and wavelength is assigned to the path. On segment (1, 3), the path can use the built lightpath L_{13} ; on segment (3,4, 5), a new lightpath $L_{35} = (3, 4, 5)$ is set up by using wavelength λ_1 . The number of

lightpaths from source 1 to sink 5 is 2, which is no more than H_{\max} . So node 5 is added to the multicast tree. The path passes lightpath L_{13} and L_{35} , and node 3 is electronic cross connection node, so node 3 is also added to the tree. The first iteration finished, and now $Q = \{1, 3, 5\}$, $D = \{8\}$. The auxiliary graph for the second iteration (Fig. 1(c)) is updated. The k -shortest paths for node pair is calculated (1, 8), (3, 8), (5, 8), and paths (1, 2, 3, 6, 7, 8), (5, 3, 6, 7, 8), (3, 6, 7, 8) are obtained. Path (3, 6, 7, 8) is shortest the and it is to assign wavelength for the path. A new lightpath $L_{38} = (3, 6, 7, 8)$ should be set up with wavelength λ_1 . The number of lightpath from node 1 to node 8 is 2, which is no more than H_{\max} . Node 8 is added to the multicast tree. Now $Q = \{1, 3, 5, 8\}$, $D = \emptyset$. Since $D = \emptyset$, the connection has been set up. The multicast tree is shown as Fig. 1(d). The multicast traffic sets out from node 1 and reaches node 3 through lightpath L_{13} . At node 3, after electronic cross connection, traffic arrives in node 5 and 8 through lightpath L_{35} and L_{38} , respectively.

During the iterations, if the electronic cross connection node 3 has not been added to the multicast tree, viz. $Q = \{1, 5\}$, $D = \{8\}$. At the second iteration, k -shortest paths for node pair (1, 8), (5, 8) are calculated and the paths (1, 2, 3, 6, 7, 8), (5, 3, 6, 7, 8) are obtained. Path (5, 3, 6, 7, 8) is the shorter one and it is to assign wavelength for the path. On segment (5, 3), the built lightpath L_{35} is used, and on segment (3, 6, 7, 8), it sets up a new lightpath. The traffic sets out from node 1 and arrives at node 5 through L_{13} and L_{35} , then reaches node 8 through L_{35} and L_{58} . As seen, if node 3 has not been added to the multicast tree, the traffic passes lightpath L_{35} twice, so bandwidth $C/2$ on link (3, 4) and (4, 5) is wasted.

If customers want to release any connection, the bandwidth of all lightpaths that the connection passes should be released. When any lightpath is used only by the released connection, the lightpath and transceivers on both end nodes of the lightpath should be released. Figure 2 presents the algorithm's flow chart.

4 Simulation model

The connection blocking probability of the proposed grooming algorithm is simulated. Only when all sinks have been added to the multicast tree does it mean that the connection has been set up successfully. Connection requests arrive with Poisson distribution with average arrival rate λ . Duration of connections is compliant with exponential distribution with average $1/\mu$. Since the network load is decided by ratio λ/μ , let $\mu=1$ and λ should be adjusted according to different network loads. Number of sinks in a connection is compliant with uniform distribution in interval $[2, |N|]$ and bandwidth requirement is compliant with uniform

distribution in interval $[1, R]$ in which R is the maximum bandwidth requirement.

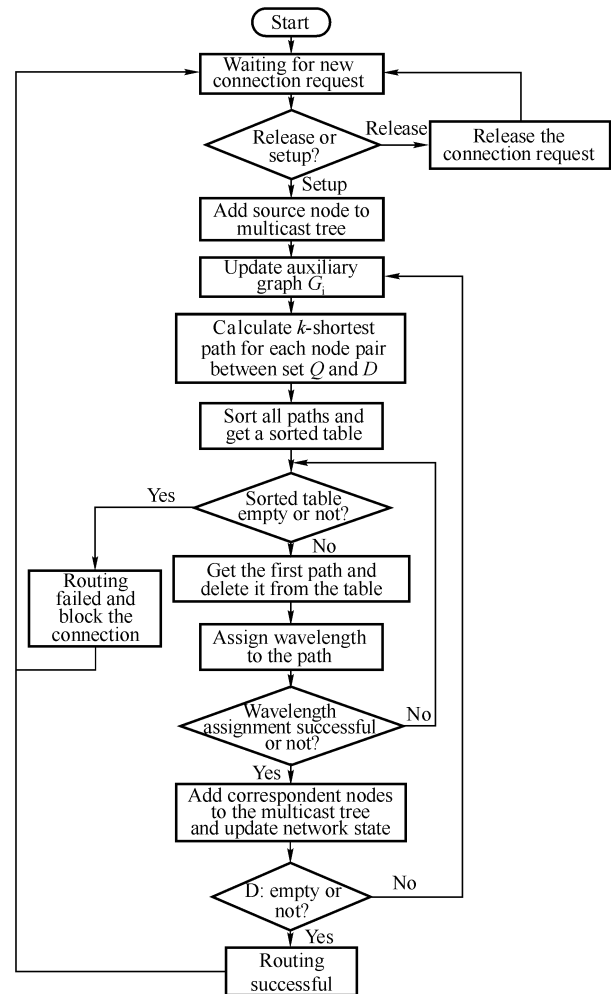


Fig. 2 Algorithm's flow chart

5 Simulation results

This section simulates connection blocking probability of the proposed grooming algorithm on European optical network (EON), the topology of which is shown as Fig. 3.

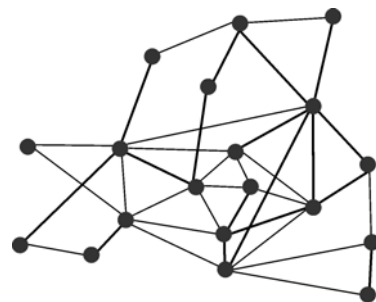


Fig. 3 Network topology of EON

Figure 4 shows the connection blocking probability under different network loads when $|\Lambda|=16$, $k=2$, $|T|=20$, $R=C/2$, $H_{\max}=2, 3, 4, 5$.

Figure 5 is similar with Fig. 4, with the only difference being $R=C$.

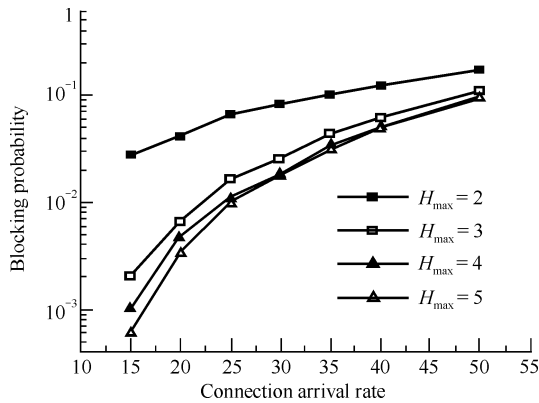


Fig. 4 Blocking probability ρ vs. connection arrival rate λ ($R=C/2$)

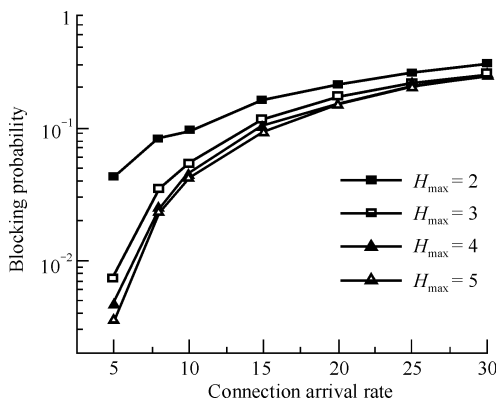


Fig. 5 Blocking probability ρ vs. connection arrival rate λ ($R=C$)

From Fig. 4 and Fig. 5, it can be concluded that different QoS requirements result in different connection blocking probabilities; the higher the QoS requirement, the higher is the blocking probability. It can also be seen that the gap between curve $H_{\max}=2$ and $H_{\max}=3$ is relatively larger; the gap between curve $H_{\max}=3$ and $H_{\max}=4$ is relatively smaller. Yet curve $H_{\max}=4$ and $H_{\max}=5$ are very close. From the network topology, it can be found that the minimum distance between the node pair with maximum distance is 4. Most connection requests can be routed in 4 hops, so curve $H_{\max}=4$ and $H_{\max}=5$ are very close. H_{\max} is a controllable variable closely related to the network topology.

Compared with Fig. 4, the gaps between curves in Fig. 5 are smaller than that in Fig. 4. This is because when $R=C$, bandwidth of connection request is relatively large, there are more connections that cannot share the built lightpaths and new lightpaths have to be set up. The effect of H_{\max} becomes weaker, so the gap of curves in Fig. 5 becomes

smaller.

Figure 6 shows the connection blocking probability under different optical transceivers on each node when $|\Lambda|=16$, $k=2$, $\lambda=30$, $R=C/2$, $H_{\max}=2, 3, 4, 5$. Because of the cost of network nodes, when the number of transceiver is far less than the number of ideal transceivers $|\Lambda|$ (node's degree $\times |\Lambda|$), the number of transceivers has relatively a strong effect on the network blocking probability.

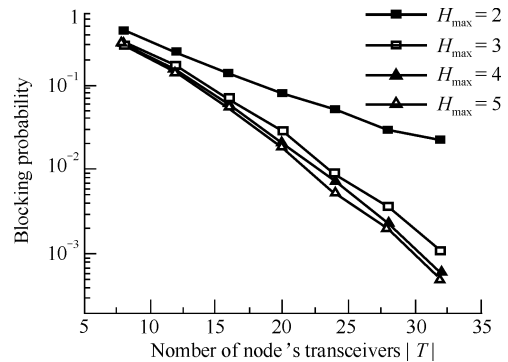


Fig. 6 Blocking probability ρ vs. number of node's optical transceivers $|T|$

6 Conclusions

In this paper, the problem of dynamic multicast traffic grooming is studied for WDM mesh networks. A network model of dynamic multicast traffic grooming under resource constraint is presented and an algorithm with QoS capability is proposed. Block probability of the algorithm is assessed through simulation. Simulation results show that higher QoS requirement results in higher block probability. Customers can explore trade-off between QoS and block probability. In present network cost architecture, node's resource is the main constraint in network performance.

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