Optimized Dynamic Traffic Grooming for Multicast Traffic in Optical WDM Networks

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Abstract: The dynamic traffic-grooming problem in wavelength routed networks is generally a two-layered routing problem in which traffic connections are routed over light paths in the virtual topology layer and light paths are routed over physical links in the physical topology layer. Traffic grooming for multicast communication in WDM networks has received very little attention to date. In this paper, we investigate the problem of grooming multicast traffic in WDM networks. We develop an optimized dynamic traffic grooming algorithm to address the traffic grooming problem in mesh networks in the multicast scenario for maximizing the resource utilization as well as minimizing the blocking probability. By simulation results, we show that our proposed algorithm achieves better throughput and bandwidth utilization with reduced blocking probability.

Key words: WDM Networks, multicast traffic, resource utilization, blocking probability, dynamic traffic grooming.

1. INTRODUCTION

1.1. Wavelength-Division-Multiplexing (WDM) Networks

The need for on-demand provisioning of wavelength routed channels with service differentiated offerings within the transport layer has become essential due to the recent emergence of high bit rate IP network applications. Diverse optical transport network architectures have been proposed in order to achieve the above requirements. This approach is determined by the fundamental advances in the wavelength division multiplexing (WDM) technologies. Due to the availability of ultra long-reach transport and all-optical switching, the deployment of all-optical networks has been made possible [1].

The concurrent transmission of multiple streams of data with the assistance of special properties of fiber optics is called as wavelength division multiplexing (WDM). The WDM network provides the capability of transferring huge amount of data at high speeds by the users over large distance [2].

For the future generation internet, WDM is considered as a backbone which is the most talented technology. The data is routed through optical channels called light paths in WDM all optical networks. The light path establishment requires same wavelength and it should be used along the entire route of the light path without wavelength conversion. This is commonly considered to the wavelength continuity constraint [3].

1.2. Multicasting in WDM Networks

A network technology which is used for the delivery of information to a group of destinations is called as multicast addressing. This simultaneously uses the most efficient strategy to deliver the message over each link of the network only once. Moreover, it creates the copies only when the links to the multiple destinations split [4].

In recent years, multicast communication is turning out to be vital due to its efficient resource usage and the increasing popularity of the point-to-multipoint multimedia applications. Usually, a source and a set of destinations are included in a multicast session. In conventional data networks, in order to allow a multicast session, a multicast tree which is rooted at the source is constructed with branches spanning all the destinations [5].
Recently, multicast routing in optical networks has been researched which is related to the design of multicast-capable optical switches. For multicast in WDM networks, the concept of light-trees was introduced. Reducing the distance of network-wide hop and the total number of transceivers used in the network are the objective of setting up the light trees. Nowadays, there are several network applications which require the support of QoS multicast such as multimedia conferencing systems, video on demand systems, real-time control systems, etc. [6].

1.3. Dynamic Traffic Grooming in Multicast

Generally, the dynamic traffic grooming problem in a wavelength routed networks is a two-layered problem. The traffic connections are routed over light paths in the virtual topology layer and light paths are routed over physical links in the physical topology layer in this network. In a wavelength routed network (WRN), a set of OXC nodes are connected by fiber links in the physical topology. A wavelength path may cover several fiber links in the physical topology and it is referred as lightpaths. On each fiber link, a lightpath uses a wavelength along its path and all the light paths collectively form the virtual topology which carries the multi-granularity sub wavelength connections. A connection may pass through several light paths along its path by using a fraction of the bandwidth [7].

There are two major resource constraints in an optical grooming network due to the wavelength and the transceivers. The traffic grooming algorithm uses a route with the shortest physical length to satisfy a connection and to save wavelength resources. Similarly, in order to save transceiver resources and to satisfy a connection, the traffic grooming algorithm uses a route with the least number of virtual hops (light paths) because each lightpath uses a transmitter/receiver pair. The number of transceiver resources increases, if the number of lightpaths in the route increases [8].

In future, the part traffic of WDM networks will be in multicast but most of the existing works on traffic grooming have assumed only the unicast traffic. Though a number of researchers are examining in the field of the multicast communication in the WDM networks, till now, very less attention has been received in the traffic grooming for the multicast communication in WDM networks [16].

Optical multicasting using “light-tree” may be a good solution for traffic grooming in WDM networks. Multiple multicast sessions can be groomed to share the capacity on the same wavelength channel because each wavelength will have capacity up to OC-192. In this case, the lightpaths or the light-trees can be established to accommodate multicast requests, which have lower capacity requirement than the bandwidth of a wavelength [17].

In our previous paper [19], we have proposed to develop a resource efficient multicast routing protocol. In this protocol, the incoming traffic is sent from the multicast source to a set of intermediate junction nodes and then, from the junction nodes to the final destinations. The traffic is distributed to the junction nodes in predetermined proportions that depend on the capacities of intermediate nodes ingress traffic and the capacity of junction nodes.

In this paper, we investigate the problem of grooming multicast traffic in WDM networks. We address the traffic grooming problem in mesh networks in the multicast scenario with traffic engineering objective as maximizing the resource utilization as well as minimizing the blocking probability. We also present an algorithm to integrate the multicast traffic grooming and load balancing with the aim of maximizing the request acceptance of future incoming connections.

2. RELATED WORK

Steven S. W. Lee et al. [9] have considered one light-path based and two light-tree based traffic grooming schemes for supporting IP multicast services. They have made performance comparisons for call blocking probability and bandwidth blocking probability on those schemes. Their simulation results revealed that the light-path scheme has lower blocking probability and less consumes bandwidth consumption as IP demand volumes are small (i.e., several Megabit/sec).

Neal Charbonneau et al. [10] have introduced and motivated the static multicast advance reservation (MCAR) problem for all-optical wavelength-routed WDM networks. They have investigated the static MCAR problem where the set of advance reservation requests is known ahead of time. They have shown that the problem is NP-complete and formulated the problem mathematically as an integer linear program and developed three efficient heuristics, seqRWA, ISH,
and SA, to solve the problem for practical size networks. They have also introduced a theoretical lower bound on the number of wavelengths required.

Javier E. Sierra et al. [11] have proposed a novel architecture named S/G Light-tree for supporting unicast/multicast connections. Their architecture allows traffic dropping and aggregation in different wavelengths without performing OEO conversions. An on-line heuristic that routes traffic demands minimizing blocking probability by taking advantage of their proposed architecture. Their simulation result shows that their proposed architecture improves blocking probability and minimizes the number of used wavelengths when compared to light-trees.

Ahmed E. Kamal [12] has presented an account of recent advances in the design of optical networks for multicast traffic grooming in WDM mesh networks. He addressed the network design and session provisioning under both static and dynamic multicast traffic. Under static traffic conditions, his objective is to accommodate a given set of multicast traffic demands, while minimizing the implementation cost. He also presented the optimal and heuristic solution techniques for mesh network topologies. Under dynamic traffic conditions, he also explained the techniques for dynamic routing and session provisioning of multicast sessions, whose objective is to minimize session blocking probabilities.

Der-Rong Din [13] has considered the Optimal Multiple Multicast Problem (OMMP) on wavelength division multiplexing (WDM) ring networks without wavelength conversion. He has proposed a genetic algorithm to solve the formulation of OMMP. His experimental results have indicated that GA is robust for this problem.

3. OPTIMIZED DYNAMIC TRAFFIC GROOMING

3.1. Node Design for Multicast Traffic Grooming

In order to support multicast traffic in general, data must be copied and duplicated using special hardware, which may be electronic, optical or a combination of both. When multicast traffic grooming is involved, it may happen that at a node in the network, some of the tributaries aggregated on a certain wavelength need to be duplicated, while others need not be duplicated. In this case, it is natural to use an approach in which the optical signal is terminated at a Line Terminating Equipment (LTE), and the tributaries are accessed. Tributaries that need to be copied are then duplicated in the electronic domain. The LTE in Fig. 1 performs this operation. In this figure an example is shown in which the traffic to be duplicated is received on wavelength $\lambda_2$, and is then duplicated in the electronic domain, before being routed back through the digital cross-connects to the two LTEs which transmit this traffic on $\lambda_1$ and $\lambda_2$, and on two different outgoing Optical Cross Connects (OXC) ports. A copy of the traffic may also be dropped at the considered node for delivery to attached end users, if needed. It is to be noted that the traffic duplication hardware may also include buffering and regeneration circuitry. The traffic duplication hardware may not be required if the traffic is transmitted multiple times from the same digital cross-connect input port to multiple outputs, but this will introduce an added delay, which may result in bandwidth wastage, or more complex synchronization [12].

![Figure 1: Multicast Traffic Duplication in the Electronic Domain](image)
which implements both electronic and optical
duplication, based on need and cost. Such nodes
are known as translucent nodes [12].

\[ RC_{ij} = \frac{AC_{ij} - BW}{GF} \]  

(1)

Where \( AC_{ij} \) is an available capacity on wavelength
\( w \), \( BW \) is the bandwidth requirement of the session
on this link and \( GF \) is the grooming factor.

The minimum \( RC \) on all wavelengths is
calculated assuming that the session is provisioned,
and the routing that yields the maximum over these
minima is used.

It is assumed that residual capacity graph for
each wavelength \( w \) is formed for each session. The
current such graph is referred to as \( G_w \) and the new
graph, \( G'_w \), is formed for each session by applying
equation (1) on all links of the graph using the
session requirement. After deciding on the routing
and wavelength assignment of the session, only \( G_w \)
on which the session is routed is updated by
discounting the allocated link capacities.

3.3. Optimized Dynamic Traffic Grooming
(ODTG) Algorithm

Let \{MSCd\} be the set of multicast sessions,
\( d = 1, 2, \ldots x \) Let \( R_m \) be the multicast receiver for
the multicast source \( S \), where \( m = 1, 2, 3 \ldots k \)

Let \{\( C_{gi} \)\} be the candidate routes from \( S \) to \( R_m \) in
\( G'_w \) where \( i = 1, 2, 3 \ldots n \)

\{\( H_{ji} \)\} = hops in each \( C_{gi} \) where \( j = 1, 2, 3 \ldots n \)

\{\( BW_{ji} \)\} = bandwidth on each hop

**CR** = Connection Route

1. For each \( \{MSCd\} \)
   2. For each \( w \)
       Find the residual capacity graph \( G'_w \)
   3. End For
4. End For
5. For each \( \{C_{gi}\} \), \( i = 1, 2, 3 \ldots n \)
6. Let **CR** = \( C_{gi} \)
7. For each \( \{H_{ji}, i\} \) on \( C_{gi} \)
   8. If (\( RC > \max(\text{RC}) \)), then
       Repeat from 3
   9. Else
       **CR** = \( \Phi \)
       Break
10. End if
11. End for
12. If (\( CR > 0 \)) Then
    Establish route **CR**
13. End if
14. Return **CR**
15. End for
16. End
3.4. Selection of Best Route

As the number of candidate routes increases exponentially with the number of hop within a path, it is unfeasible to search all the candidate routes in a large network. In order to reduce the number of candidate routes, we selectively search some candidate paths, instead of exhaustively searching all possible routes. The set of connection routes are selected from traffic grooming algorithm. A Broken Route ($R_B$) is a hop in a route where there is no lightpath exists. A route may contain many such hops and the sum of the length of all such hops gives the total length ($L$) of a $R_B$. The route checks whether there is any existing light path in each hop. It evaluates all the candidate routes continuously until it finds a set of routes $\{R\}$ with minimum number of $R_B$s and minimum number of cost. If both the hops have the same value, the length of the hop with the shortest distance will be chosen as a route.

3.5. Route Selection Algorithm

Let $\{C_{R_i}\}, i = 1, 2, 3 \cdots n$ be the set of connection routes selected from the previous algorithm.

1. For each $\{CR_i\}, i = 1, 2, 3 \cdots n$
2. For each hop $\{H_i\}$
   3. If (light path exists) Then
      Continue
   4. Else
      $R_B C_i = R_B C_i + 1$
      $R_B l_i = \text{length of } H_i$
      $\text{TotR}_B l_i = \text{TotR}_B l_i + R_B l_i$
   5. End if
3. End for
4. Find $\{C_{R_j}\}$ such that $R_B C_j = \min (R_B)$
5. For each $C_{R_j}$
   6. $\text{TotR}_B l_j = \min(\text{TotR}_B l_j)$
   7. Select the route $C_{R_j}$
6. End if
7. End for
8. End for

4. SIMULATION RESULTS

4.1. Simulation Settings

In this section, we examine the performance of our optimized dynamic traffic grooming (ODTG) algorithm with an extensive simulation study based upon the ns-2 network simulator [18]. We use the Optical WDM network simulator (OWNs) patch in ns2. Various simulation parameters are given in table 1.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Simulation Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topology</td>
<td>Mesh</td>
</tr>
<tr>
<td>Total no. of nodes</td>
<td>14</td>
</tr>
<tr>
<td>Link Wavelength Number</td>
<td>8</td>
</tr>
<tr>
<td>Link Delay</td>
<td>10ms</td>
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<tr>
<td>Wavelength Conversion Factor</td>
<td>1</td>
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<tr>
<td>Wavelength Conversion Distance</td>
<td>8</td>
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<tr>
<td>Wavelength Conversion Time</td>
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<tr>
<td>Link Utilization sample Interval</td>
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<tr>
<td>Traffic Arrival Rate</td>
<td>0.5</td>
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<tr>
<td>Traffic Holding Time</td>
<td>0.2</td>
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<tr>
<td>Packet Size</td>
<td>200</td>
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<tr>
<td>No. of Receivers</td>
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<tr>
<td>Max Requests Number</td>
<td>50</td>
</tr>
<tr>
<td>Load</td>
<td>2, 4, 6, 8 and 10Mb</td>
</tr>
</tbody>
</table>

In our experiments, we use an exponential traffic model with an arrival rate 0.5 (call/seconds). The session holding time is 0.2s (seconds). The connection requests are distributed randomly on all the network nodes. In all the experiments, we compare the results of our Optimized Dynamic Traffic Grooming (ODTG) with that of the Static Traffic Grooming and S/G Light tree [11].

4.2. Performance Metrics

The performance is evaluated mainly, according to the following metrics.

- **Blocking Probability**: It is the ratio of number of rejected requests to the total number of requests sent.
- **Throughput**: It is the average number of packets received successfully.
- **Bandwidth Utilization**: It is the ratio of bandwidth received into total available bandwidth for a traffic flow.

4.3. Results

(A) Varying the Number of Hops

In our initial experiment, we vary the number of hops as 0, 1, 2, 3 and 4.
Fig. 3 shows the blocking probability obtained with our ODTG scheme compared with the static and S/G light tree schemes. It shows that the blocking probability of ODTG scheme is significantly less than the static and S/G schemes, as number of hops increases.

The throughput in terms of packets received for the ODTG scheme by varying the number of hops is given in Fig 4. We can see that the throughput is more for the ODTG scheme than the other two schemes.

Fig. 5 shows the bandwidth utilization obtained for various numbers of hops. It shows better utilization for the ODTG than the static and S/G light tree schemes.

(B) Varying the Load
In our next experiment, we vary the traffic rate as 2, 4, 6, 8 and 10Mb.

Fig. 6 shows the blocking probability obtained with our ODTG scheme compared with static and S/G light tree schemes. It shows that the blocking probability of ODTG scheme is significantly less than the static and S/G schemes.

The throughput in terms of packets received for the ODTG scheme by varying the load is given in Fig 7. We can see that the throughput is more for the ODTG scheme than the other two schemes.

Fig. 8 shows the bandwidth utilization obtained for various loads. It shows better utilization for the ODTG than the static and S/G schemes.

5. CONCLUSION
In this paper, we have investigated the problem of grooming multicast traffic in WDM networks. We have addressed the traffic grooming problem in mesh networks in the multicast scenario with traffic
engineered objective as maximizing the resource utilization as well as minimizing the blocking probability. We have used the maximizing bandwidth capacity algorithm to increase resource utilization, and to minimize the blocking probability for future arriving requests. This is done by using paths which will maximize the bandwidth capacity left after routing a multicast tree. We have also designed a route selection algorithm based on the lightpath availability, to select a set of best routes from the established connection routes. The dynamic traffic grooming algorithm can be used for both single-hop traffic grooming and multi-hop traffic grooming. By simulation results, we have shown that our proposed scheme has reduced blocking probability with increased throughput and bandwidth utilization.

REFERENCES


[18] Network Simulator: www.isi.edu/nsnam/ns