International Journal of Computer Applications (0975 – 8887)
Volume 57– No.11, November 2012

Dynamic Traffic Grooming in WDM Optical Networks with Full Wavelength Conversion and Grooming Devices on Max-Connectivity Nodes

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ABSTRACT

Traffic grooming is applied to WDM optical networks with the intent of provisioning lower rate connection requests onto lightpaths with higher rate. Traffic grooming problem is an optimization problem which mainly focuses on minimization of network cost through minimizing the devices used in the network. Our work focuses on dynamic traffic grooming with full wavelength conversion. In this paper, we propose a heuristic approach to solve dynamic GRWA problem in WDM optical mesh networks with grooming devices only on Max-connectivity nodes. We provide first fit wavelength assignment procedure. We have compared our results with other grooming schemes and succeeded in showing that Max-connectivity grooming is more cost effective with similar blocking probability than other grooming schemes.

Keywords: WDM optical networks, Dynamic traffic, Wavelength assignment, Traffic grooming.

1. INTRODUCTION

Huge transmission bandwidth of optical networks makes them attractive for current transport networks. Traffic in present day communication networks increases due to the emerging application of IP-TV, VOIP, video conferencing, video-on demand, internet data etc. Optical networks can meet this ever-increasing demand with the implementing of dense wavelength division multiplexing (DWDM). In WDM technology, multiple optical channels are transmitted through a single fiber and hence a single fiber can support several hundred tera-bit per second bandwidth. However, the data rate required for individual connection request is much lower than a single wavelength channel. Hence, for efficient utilization of network resources, traffic grooming technique has been preferred in current networks where low speed traffic requests are groomed into high speed wavelength channel. In the present paper, we investigate the cost issue and the blocking probability in WDM mesh networks with connectivity grooming under dynamic traffic conditions.

Traffic grooming problem has been addressed by several group of workers for both WDM ring networks and WDM mesh networks [1-8]. Initially, it was focused on WDM ring networks and afterwards, to overcome its limitations towards scaling, rapid and bandwidth provisioning, research shifted on WDM mesh networks. Several researchers reported traffic grooming in WDM mesh networks under different traffic scenarios e.g. static , incremental or dynamic[9-14]. In static traffic grooming, traffic matrices are fixed and known in advance and it is required to set up lightpaths for known traffic demand only, where as in dynamic traffic grooming connection requests change with time. The situation is much more complex in the later case, as it is required to decide whether the current lightpaths would be used or how to reconfigure the lightpaths on the arrival of connection requests, to optimal use of network resources.

In the present context, we focus on dynamic traffic grooming in WDM mesh networks with full wavelength conversion. Earlier, in [11], the authors demonstrated a dynamic traffic grooming algorithm based on an auxiliary graph in a WDM mesh network. They proposed four different grooming policies by assigning different weights at the edges of the auxiliary graph. Also, they presented an adaptive grooming policy for better performance. In [12], a joint routing algorithm (RA) was proposed based on three routing graphs for dynamic traffic grooming in WDM mesh networks with wavelength continuity constraints. However in JRA, since all the new lightpath segments in a path use the same wavelength, it is difficult to find a path all the time. In [13], the author studied dynamic traffic grooming in optical networks with sparse wavelength conversion. An adaptive traffic load based heuristic algorithm was developed for converter placement. It has less computation complexity and almost similar performance with greedy heuristic.

A cost effective dynamic traffic grooming approach was proposed in [14], where grooming resources were distributed at the edges of the network. The most contiguous algorithm was used to evaluate blocking performance for dynamic traffic in a 16-nodes WDM mesh network. In [15],an integer linear programming(ILP) was formulated for dynamic traffic grooming to study the blocking probability in medium size WDM mesh networks .For larger networks, the authors proposed heuristic approach to meet the blocking probability requirements. However, their work was limited to single hop dynamic traffic grooming. In [16], a simulation based optimization approach was used to minimize the grooming resources in WDM networks. In their work, first utilization statistics of grooming devices are collected and then, the distribution of the grooming devices is made depending on the utilization statistics.

In the present work, we propose a heuristic procedure using max-connectivity grooming for solving GRWA problem with dynamic lightpath requests. We have shown that max-connectivity grooming uses minimal number of grooming devices and thus effectively reduces the network cost compared to other grooming schemes. We focus on the formulation of grooming, routing and wavelength assignment (GRWA) problem in WDM mesh networks with dynamic traffic under the constraints of the number of grooming devices used and wavelength continuity.

Our proposed scheme tries to keep the blocking performance as low as possible with optimal number of grooming and wavelength conversion resources. The proposed algorithm is simple to implement and is very efficient in performance. Our simulation results show that distribution of grooming resources on the nodes having maximum connectivity results in better blocking performance than other grooming schemes. We have compared our simulation results with edge grooming and all grooming for 16-node and 20-node mesh networks with wavelength conversion.

In section 2, the problem definition of GRWA problem with dynamic traffic requests has been presented. Section 3 includes the heuristic approach to solve dynamic traffic grooming problem with grooming resources on the nodes having maximum connectivity. Section 4, discusses the performance of our proposed heuristic approach with different lightpath requests and cost comparison for three different grooming techniques. Section 5 includes the conclusion of the work.

2. GENERAL PROBLEM STATEMENT AND ASSUMPTIONS

In dynamic traffic grooming, traffic is not uniform and the nodes are allowed to have dynamically changing connections. We formulate the GRWA problem with dynamic traffic using a simple heuristic procedure explained later in the paper. In the formulation we consider wavelength assignment and wavelength conversion, including routing and grooming. In this study, we consider all grooming, edge grooming and max-connectivity grooming. The physical topologies involved in dynamic traffic grooming consists of two mesh WDM optical networks, as illustrated in Figs. 3(a) and 3(b).The following assumption have been considered to solve the GRWA problem:

Assumptions:

i. All links in the network are bidirectional.
ii. Traffic demands are dynamic. Traffic requests vary with time.
iii. The transceivers in a network node are tunable to any wavelength on the fiber.
iv. Number of wavelengths available per fiber is limited.
v. Any node can provision lightpath requests maximum up to the number of transceivers installed on that node.
vi. Network nodes have wavelength conversion capability. So, a lightpath may use different wavelength along its path from source node to the destination node.

2.1 Network Cost and Other Formulations

Network cost is comprised of the number of devices (Grooming and wavelength conversion) and hop count used for connection establishment. We have considered WDM networks with full wavelength conversion and no wavelength conversion. In the network with no wavelength conversion, wavelength continuity constraint is fulfilled. With full wavelength conversion wavelength continuity constraint is avoided. The network with wavelength conversion increases the cost but also increases the throughput which is highly desired. The performance comparison between wavelength conversion and no wavelength conversion is shown in results and discussion section. In the following, we present the cost formulation under full wavelength conversion and no wavelength conversion. Total cost includes the cost of wavelengths used to establish lightpath request from source to destination node plus the cost of all wavelength convertors and traffic grooming devices used by the lightpath requests.

i. Full wavelength conversion:

$$\text{Total Cost} = \sum_{i=0}^{N} \{(\alpha_i * CG) + (\beta_i * CW)\} + \sum_{i=0}^{L} H_i \ldots\ldots\ldots\ldots\ldots (1)$$

ii. No wavelength conversion:

$$\text{Total Cost} = \sum_{i=0}^{N} \{(\alpha_i * CG)\} + \sum_{i=0}^{L} H_i \ldots\ldots\ldots\ldots\ldots (2)$$

where,

N is number of nodes present in the given mesh network,
L is the number of requested connections,
CG is the grooming cost and **CW** is the cost associated to wavelength conversion,
α_i is the number of grooming devices used at the i[th] node,
β_i is the number of wavelength conversion resources used at the i[th] node,
H_i is the number of hops used by the i[th] connection request.

The general cost function given by Eq. (1) and Eq. (2) are subject to the following constraints:

i. One lightpath corresponds to a single wavelength between two nodes,

$$\sum_{i,j}^{w} p_{i,j}^{w} \leq b(i,j) \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where,

w : is the particular wavelength used between node i and node j,
$p_{i,j}^{w}$ implies that wavelength w has been assigned to the lightpath from node i to node j,
variable $b(i,j)$ shows whether lightpath from node i to node j exists or not.

ii. Grooming and wavelength conversion capability of each node depends on number of grooming devices placed on that node.

iii. Grooming state of each grooming device can not exceed the maximum capacity of the fiber link,

$$\sum_{r,w} y_{i,j}^{c} \leq C_{max} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where,

$r \in$ L(lightpath requests),
c = [1, 3, 12.... C_{max}],
C_{max} is the maximum capacity of the fiber link.
$y_{i,j}^{c}$ is the lightpath request between node i and j with bandwidth c.

We have also presented formulations for determining average hop count and the blocking probability. Average hop count for each grooming policy is determined using the following equation:

$$\text{Average hop count} = \frac{\sum_{i=0}^{T} H_i}{T} \ldots\ldots\ldots\ldots (5)$$

where,

T is the number of successfully established lightpath requests,
H_i is the number of hops used by the i[th] connection request.

Blocking probability is determined as follows:

$$\text{Blocking Probability} = \frac{(L-T)}{L} * 100 \ldots\ldots\ldots\ldots (6)$$

where,

L is the total number of lightpath requests,
T is the number of successfully established lightpath requests.

Our goals are to determine the following.

1) Blocking probability in the network with minimal usage of grooming resources. In this study, we have considered full wavelength conversion mesh network and focused on maximizing the throughput on the expense of grooming resources.
2) Total cost of the network given by Eq. (1).

2.2 Illustrative Example

In the following example, we have shown how placement of wavelength conversion devices with grooming devices can reduce the blocking probability. Figs. 1 (a) and 1 (b) show two optical mesh networks having two wavelengths (λ_1, λ_2) available in each link and all the links are bidirectional. Nodes in Fig. 1 (a) also have wavelength conversion capability. In Fig. 1(b) nodes do not have wavelength conversion capability

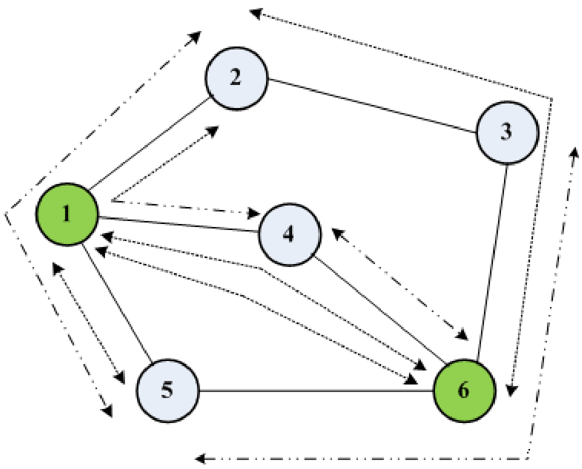


Fig.1 (a) Network with wavelength conversion resources. Max-Connectivity nodes are 1 & 6

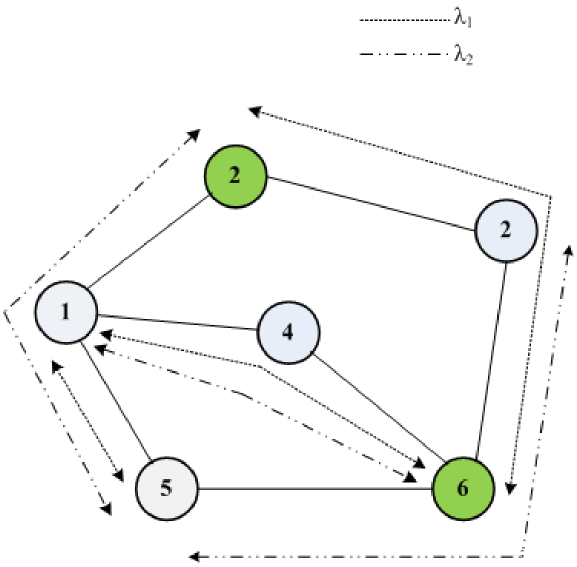


Fig.1 (b) Network without wavelength conversion resources. Node 2 & 6 are randomly selected for placing grooming devices

Suppose we have eight connection requests of OC-3 as described in table 1.

s-d	No. of connections requests	Wavelength assignment for Fig. 2(a)	Wavelength assignment for Fig. 2(b)
1→6	2	λ_1	$\lambda_1, \lambda_2,$
6→4	1	λ_2	-
2→6	1	λ_1	λ_1
3→5	1	λ_2	λ_2
5→1	1	λ_1	λ_1
5→2	1	λ_2	λ_2
4→2	1	λ_1, λ_2	-

Table 1. Connection requests and wavelength assignment to each request

For two mesh networks shown in Figs. 1 (a) and 1(b), we have assigned wavelengths to the connection requests as depicted in table 1. We can see that using wavelength conversion devices with grooming devices in Fig. 1(a) all the requests have been successfully established. In Fig. 1(b), where we have not used wavelength conversion requests 6→4 and 4→2 are blocked. So, with proper placement of grooming devices with wavelength conversion resources blocking probability in the network can be minimized.

3. HEURISTIC APPROACH TO SOLVE DYNAMIC TRAFFIC GROOMING PROBLEM

Several researchers have proposed solutions to dynamic traffic grooming problem earlier [10-16]. Most of them have considered a full grooming network with no wavelength conversion, sparse wavelength conversion and full wavelength conversion. We have solved dynamic traffic grooming problem using full wavelength conversion network with grooming devices on the nodes having maximum connectivity. We have proposed a simple heuristic approach with first fit wavelength assignment to solve dynamic traffic grooming problem in WDM optical mesh networks. In this section, we have presented the proposed heuristic approach used to solve GRWA problem with dynamic traffic.

In dynamic scenario, traffic arrives in the network and releases after a certain time period. The complexity in dynamic traffic grooming increases due to the random arrival and departure of individual connection demands. The offered network load for a certain time period is given by the following equation [14]:

$$\mathbf{L} = \boldsymbol{\lambda} * \mathbf{H} \dots\dots\dots\dots (7)$$

Where,
L is the offered load in Erlang,
λ is number of lighpath request per hour,
H is average holding time in hours.

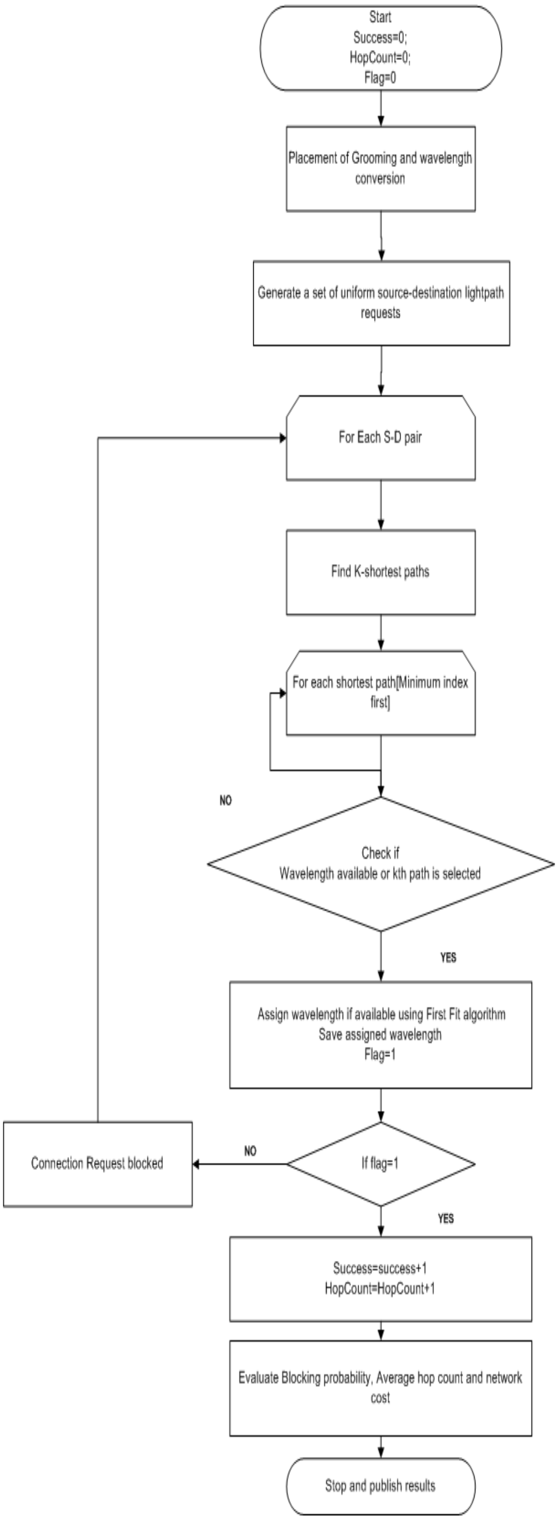


Fig. 2. Flowchart for Heuristic Procedure

Our proposed heuristic tries to improve the blocking performance with the minimal use of grooming resources

However, the procedure focuses on the successful establishment of connection requests as much as possible on the expense of wavelength conversion and grooming devices reducing the blocking probability in the network.

Fig. 2 shows a flowchart of the proposed heuristic. The proposed scheme is simple and has good performance. Heuristic procedure for dynamic traffic provisioning is presented below.

Outline of the heuristic procedure used:

- Generate a set of uniform source-destination lightpath requests
- Populating the network with traffic [Traffic formation]
- Deploying Grooming and wavelength conversion resources
- Success=0 , Flag=0;
- For each lightpath request:
  - Find K-shortest path.
    - Calling shortest path algorithm (dijkstra-shortest-path)
    - HopCount = 0;
    - For i=1 : k
      - IF (Assign_wavelength())
      - Wavelength assignment using first fit algorithm.
      - Flag=1.
      - Success=Sucess+1.
      - HopCount=HopCount+1.
      - break();
      - Else Flag=0;
    - If (Flag == 0)
    - Connection Blocked.
  - Return number of successfully established lightpath request and the devices used.
  - Evaluate Blocking probability, Network cost and Average hop count.

3.1 Wavelength Assignment Heuristic

The complexity in GRWA problem arises from the fact that routing and wavelength assignment are subject to these two constraints.

- Wavelength Continuity constraint: A light path must use the same wavelength on all the links along its path from source to destination edge node.
- Distinct wavelength constrained: All light paths using the same link must allocate distinct wavelengths

In the absence of the wavelength conversion, it is required that the lightpath occupy the same wavelengths over all the fiber links it uses. This requirement is

referred to as the wavelength continuity constraint. However, this may result in the inefficient utilization of WDM channels. Alternatively, the routing nodes may have limited or full conversion capability, whereby it is possible to convert an input wavelength to a subnet of the available wavelengths in the network.
The wavelength continuity constraint restricts a connection to occupy the same wavelength on every link of a chosen path from source to destination. It could result in rejecting a connection request even though the required capacity is available on all the links of the path but not on the same wavelength. The reason for rejecting a request is due to the inability of intermediate nodes to switch the connection from one wavelength to another on two consecutive links.

Once the route has been determined for lightpath request, wavelength assignment is to be done for each lightpath. Wavelength assignment can be done using several approaches. We have used a simple approach called first fit (FF) wavelength assignment [14]. All the available wavelengths are numbered. When wavelength is to be assigned, a lower numbered wavelength is considered before a higher numbered wavelength. The lowest numbered wavelength available is then assigned to the lightpath. First fit wavelength assignment scheme tries to pick the wavelength from lowest numbered side so that no free wavelength is left. Now, we have presented the first fit wavelength assignment procedure that we have used in our simulation results. This procedure also returns the hop count traversed by successfully established connection request.

Outline of the wavelength assignment procedure:

Assign_wavelength(Path[], WL_Matrix[])
Start Procedure
- HopCount=0
- Success=0
- Begin=1
- Current_node=1
- N=length (Path [])
- HopCount=N-1
- WL=length(WL_Matrix)
- while(Begin<=WL)
- Current_WL=WL_matrix[Begin]
- while (Current_node <= Hopcount)
- If(WL_available(Current_WL))
- Current_node=Current_node+1
- Success=1
- else
- Success=0
- break
- End If
- End while
- Begin=Begin+1
- If (Current_node==Hopcount && Success==1)
- Save_assigned_WL(Path)
- return Hopcount
- return true
- break
- else
- Success=0
- end If
- end while
- If (Success==0)
- return false;
- end If

End Procedure

4. RESULTS AND DISCUSSION

Simulations have been carried out to investigate the performance of the proposed heuristic procedure considering the network topologies illustrated in Figs. 3(a) and 3(b).In our simulations, 16-nodes and 20-nodes mesh network topologies were chosen for solving GRWA problem with dynamic traffic load.

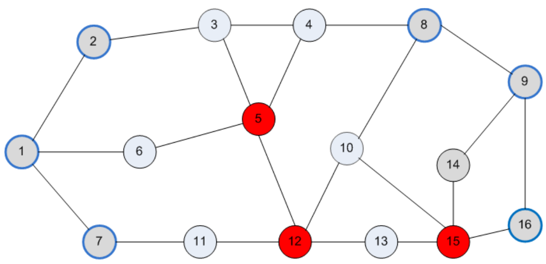


Fig. 3(a). 16-node Mesh network (Edge nodes – 1, 2, 7, 8, 9 and 16. Max-connectivity – 5, 12 and 15)

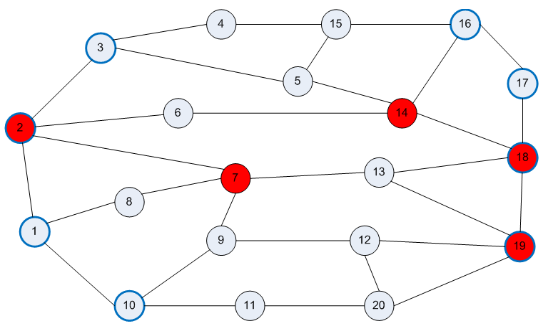


Fig. 3(b). 20-node Mesh network (Edge nodes – 1,2,3,10,16,17,18,19 and 20. Max-connectivity nodes- 2,7,14,18 and 19)

We have compared our results of max-connectivity grooming with edge grooming and all grooming.we have found that it is efficient and cost effective to deploy grooming and wavelength resources on the nodes having maximum connectivity instead of placing resources randomly over the network. Our heuristic approach uses first-fit wavelength assignment algorithm presented in section 3. We have also investigated the variation in the throughput (Blocking probability) using variable number of wavelengths per fiber. Each fiber link can carry upto 10 OC-48 wavelength channels. Each connection request is assumed to be of OC-3 and the average holding time for each request is 10 minutes. Offered load in the network is computed using Eq. (7) depicted in section 3.

In Fig. 4, we have considered two types of network configuration, network having full wavelength conversion capability and the network having no wavelength conversion resources. Each link is assumed to carry maximum of 10 wavelengths. The network having no wavelength conversion capability will follow wavelength continuity constraint. Wavelength continuity is an important aspect of WDM optical networks, this is already been discussed in section 3. To avoid wavelength continuity constraint, we deploy wavelength convertors in the WDM optical networks. Using wavelength convertors in the network significantly reduces blocking probability as shown in Fig. 4. In Fig. 4, 16-node mesh network is considered and we can observe that the use of wavelength conversion with max-connectivity grooming effectively improves performance of the network with comparison to other grooming policies.

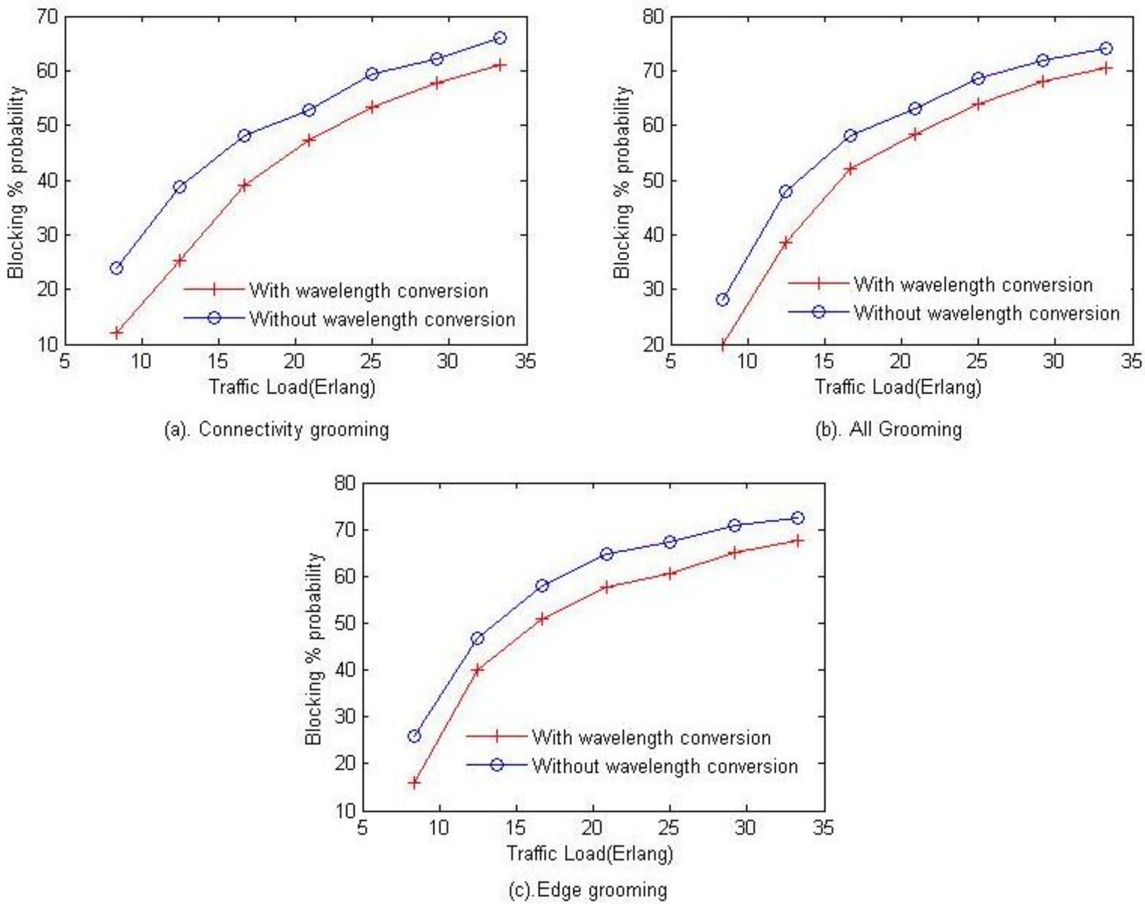


Fig. 4. Blocking % probability vs. Traffic load (For full wavelength conversion and no wavelength conversion networks.

In Fig. 5, blocking probability for three different grooming policies (i.e. all grooming, edge grooming, max-connectivity grooming) is plotted with dynamic traffic load (Erlang). Simulation results have been shown for 16-node and 20-node networks depicted in Figs. 3(a) and 3(b).

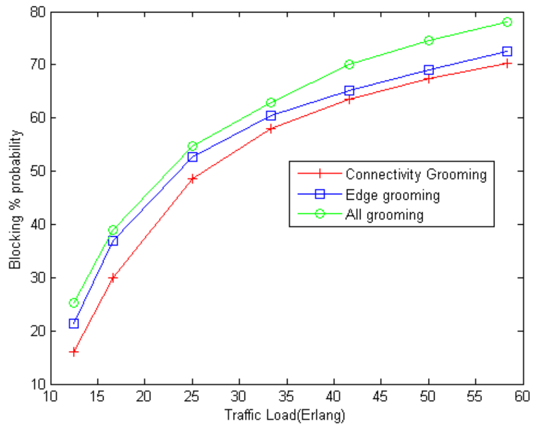


Fig. 5(a). Blocking % probability vs. Traffic load (Erlang) for the 16-node network.

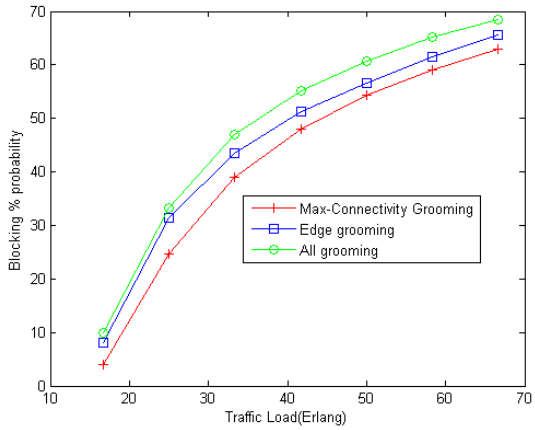


Fig. 5(b). Blocking % probability vs. Traffic load (Erlang) for the 20-node network.

In this evaluation, the resources placed on the nodes are fixed and then for each grooming policy the results are compared. Also, we have assumed that all the nodes in the network will have wavelength conversion capability and each fiber supports 10 wavelengths. We have placed 5 grooming devices in all the grooming schemes. Our results show that placing the grooming resources on the nodes having maximum connectivity is more efficient than placing the grooming resources on the edges or on randomly chosen nodes.

Fig. 6 shows a comparison between the results obtained for three grooming policies from our heuristic procedure for the 16-node and 20-node networks. For fairness in the results, the comparison for three grooming policies is conducted for constant traffic load of 20 Erlang and 10 wavelengths available per fiber. In our heuristic approach to solve the GRWA problem, the grooming devices are increased additively and the resultant blocking probability is examined. As the grooming devices are increased in the network the number of successfully established connection requests also increases and hence improves the blocking probability. Our results show that the performance of the max-connectivity grooming is better than edge and all grooming policy.

As the grooming resources are increased in the network, the blocking probability reduces significantly. It is certain that when almost all the nodes in the network are equipped with grooming resources the blocking probability will be less. It can be observed from Fig. 6 that all grooming policy shows better performance than other grooming policies when almost all the nodes are equipped with grooming devices.

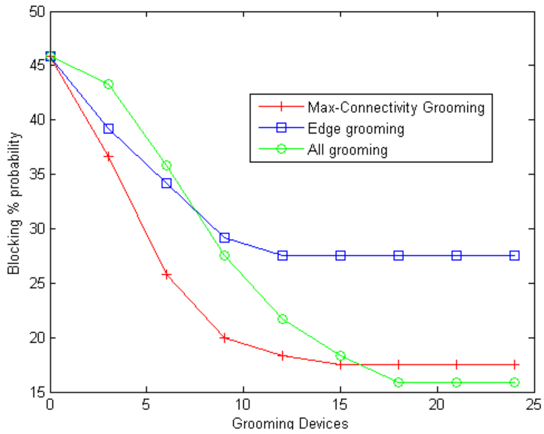


Fig. 6(a). Blocking % probability vs. Grooming devices for 16-node network

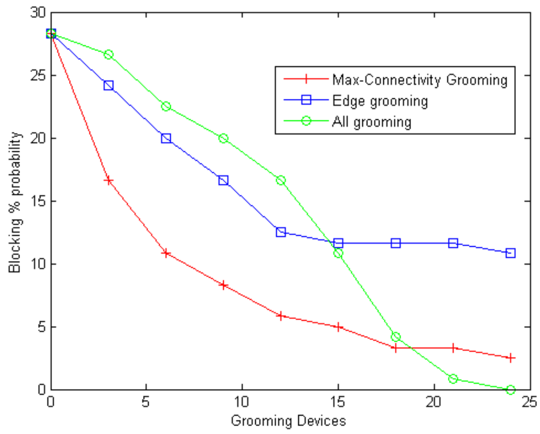
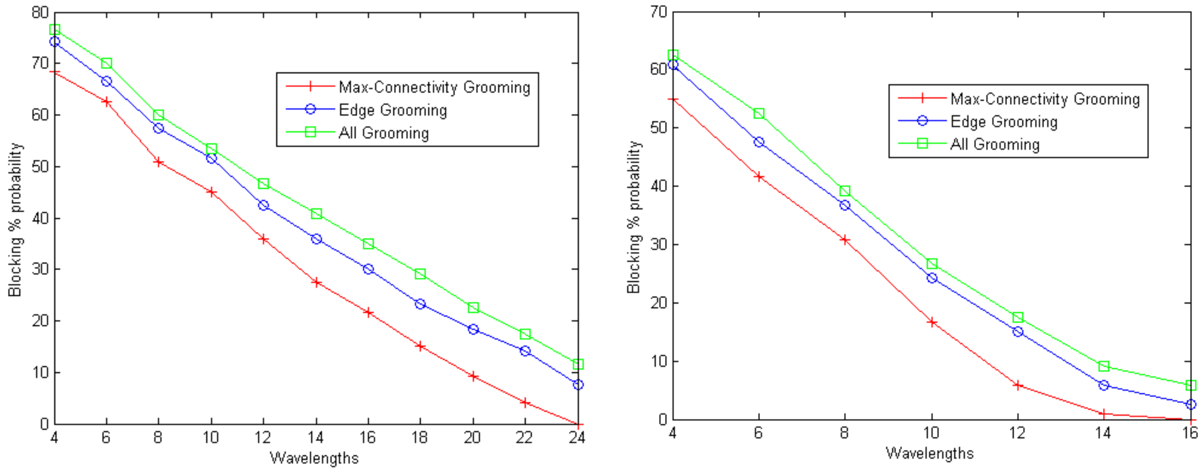


Fig. 6(b). Blocking % probability vs. Grooming devices for 20-node network

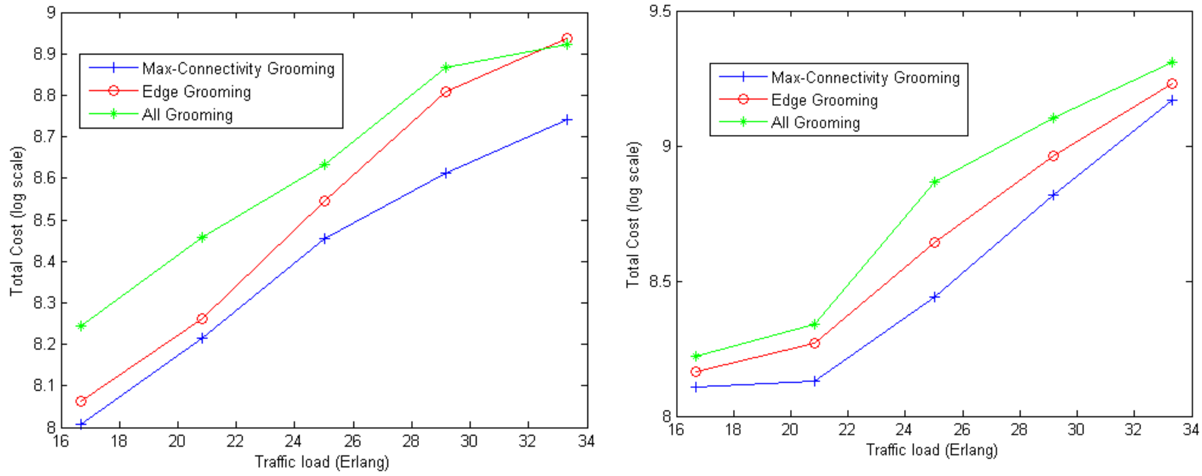
In Fig. 7, we have shown the performance of our heuristic approach with respect to additively increasing number of wavelengths used per fiber. It is certain that using less number of wavelengths per fiber in a network will result in more blocking probability than the network using more number of wavelengths per fiber. We have investigated the performance of our heuristic approach for fixed traffic load of 20 Erlang and 3 grooming devices for all three grooming schemes. It can be observed that max-connectivity grooming produces better result. The blocking percentage probability for max- connectivity grooming is much better than other grooming techniques. Also, it can be noticed from Figs. 7(a) and 7(b) that with 24 and 16 wavelengths per fibre for 16-node and 20-node mesh network respectively, max-connectivity grooming results in zero blocking probability.

Our results show that max-connectivity grooming results in better performance than other grooming schemes with the increasing number of wavelengths per fiber.



(a) (b)

Fig. 7. Blocking % probability vs. Number of wavelengths, (a) using 16-node network, (b) using 20-node network



(a) (b)

Fig. 8. Total cost (log scale) vs. Traffic load (Erlang), (a) using 16-node network, (b) using 20-node network

Fig. 8 shows the comparison of cost for three different grooming policies for 16-node and 20-node irregular mesh networks depicted in Fig. 3. For unbiasedness in the results we have evaluated the performance for a constant blocking probability (i.e. 20 %) for all the grooming policies. The result shows that placing the devices on the nodes with maximum connectivity significantly improves the cost factor. Here, we can see that the cost increases with the increase in traffic load in the network. As the traffic load increases, the resources available over the network must also be increased to satisfy as much as light path requests possible. As a result the number of wavelengths and the grooming devices used is also increased and more importantly it increases the cost factor. In Fig. 8 (a) and 8 (b), it is depicted that to achieve the blocking probability of 20% for different traffic load max-connectivity grooming policy is most cost effective than the other policies.

To best understand the behaviour of different grooming techniques, we measure the average hop count. Fig. 9 depicts the difference between average number of hops used by the lightpaths established. The results shown in Fig. 9 are evaluated for the 16-node and 20-node mesh networks depicted in Fig. 3 with full wavelength conversion capability. We have considered that 8 wavelengths are available per fiber and tests are performed using 6 grooming devices. The figure shows that difference between the three grooming policies is very small. This means that the max-connectivity grooming and wavelength assignment heuristic can achieve a better cost than the other grooming techniques without hindering the average number of hops.

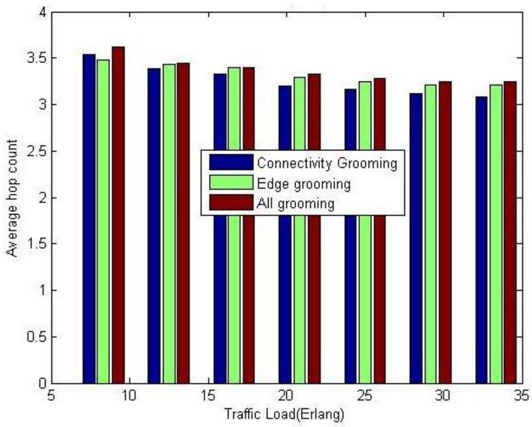


Fig. 9(a). Average number of hops vs. Traffic load using 16-node network

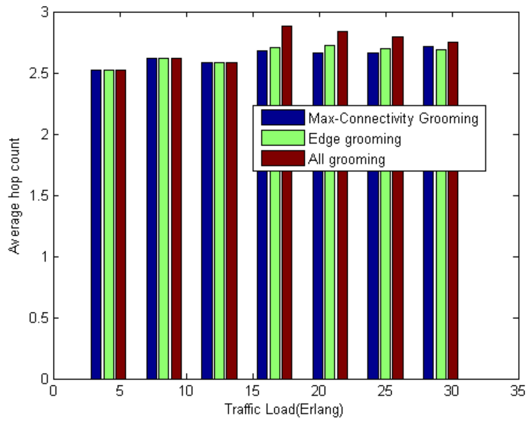


Fig. 9(b). Average number of hops vs. Traffic load using 20-node network

In Table 2, average route length for different grooming techniques in 16-node mesh network is compared. The result shown in the table are evaluated for a constant load of 30 Erlang, with 8 wavelengths available per fiber using 6 grooming devices. It can be seen that the average hop count for max-connectivity grooming less for both wavelength conversion capable and without wavelength conversion capable mesh network. Also, very less difference can be seen in max-connectivity grooming for wavelength conversion and without wavelength conversion network in comparison to other grooming techniques. It shows that we can achieve better cost using max-connectivity grooming than other grooming policies. In Table 3, results are shown for same network configuration with 20-node mesh network with 30 bidirectional links and 8 wavelengths available per link. As the number of links in the network increases, it also increases the alternate paths for lightpath establishment. In this scenario, average hop count increases, but our max-connectivity grooming scheme for the placement of grooming devices on the nodes shows better results than other grooming techniques.

Table 2. Average route length in 16 node mesh network.

	Full wavelength conversion	No Wavelength conversion
All grooming	3.19	3.24
Edge grooming	3.16	3.21
Max-connectivity grooming	3.14	3.12

Table 3. Average route length in 20 node mesh network.

	Full wavelength conversion	No Wavelength conversion
All grooming	2.81	2.58
Edge grooming	2.77	2.57
Max-connectivity grooming	2.60	2.55

5. CONCLUSION

In this paper, under the constraint of limited wavelength per fiber link, we have developed a heuristic procedure for dynamic traffic grooming in WDM optical mesh networks with grooming devices on max-connectivity nodes. Based on this heuristic, we have presented the simulation results for different grooming schemes and have found that placement of grooming devices on maximum connectivity nodes is efficient and cost effective than other grooming schemes. We have also shown the results under wavelength continuity constraint and compared it with the network having wavelength conversion capability. The network with full wavelength conversion capability shows much better performance in terms of blocking probability.

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