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Placement of Sparse Grooming Resources in WDM Mesh Network under Dynamic Traffic

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Abstract - Optical networks based on WDM technology offer the promise to satisfy the bandwidth requirements of the Internet infrastructure, and provide the bandwidth needs of future applications in the local and wide area networks. The network performance is now mainly limited by the processing capability of the network elements, which are mainly electronic. Traffic streams from users generally (in Mbps) have a data-rate that is far less than bandwidth of optical fibers (in Tbps) or that of a light-path in optical fibers. This mismatch of bandwidths between user needs and wavelength capacity makes it clear that some multiplexing should be done to use the wavelength capacity efficiently, which will result in reduction on the cost of line terminating equipment (LTE). Multiplexing low bandwidth traffic request onto high capacity wavelength channel is called as traffic grooming. Unlike full grooming, in which each node is capable of grooming (called as G-node), sparse grooming employs only a few grooming nodes in the network without a significant reduction in performance. Traffic grooming in particular sparse grooming optimizes the cost and reduces the network complexity by reducing the grooming hardware with optimal network performance. Here, we present some heuristic algorithms to perform G-node selection and grooming in a WDM optical network using dynamic traffic along with load balancing. We show by our simulation results that network throughput (or blocking probability) almost as same as full grooming can be achieved using sparse grooming. We also compare the performance of the proposed algorithm with the earlier available approaches and our simulation results show that our algorithm provides performance as good as the present approaches.

Keywords - *Line Terminating Equipment (LTE) SONET/SDH, Synchronous Optical Network (SONET)/Synchronous Digital Hierarchy (SDH), Dense Wavelength Division Multiplexing (DWDM) Integer Linear Programming (ILP), NSF-NET.*

1. Introduction

In the past few decades, computer and telecommunication networks have experienced dramatic growth. With the growth of the Internet technology, there is a huge demand for network bandwidth. This demand is aggravated by the advent of new bandwidth hungry applications, such as multimedia communications e.g. voice mails, video on demand and high data traffic on Internet. The unprecedented growth of internet traffic and rapid advancements in the optical transport technologies have fueled the Internet transport infrastructure to evolve towards a model of high speed IP routers interconnected by intelligent optical networks.

1.1 Optical Transport Network

Optical transport networks are high-capacity telecommunications networks based on optical technologies and components that provide routing, grooming, and restoration at the wavelength level as well as wavelength-based services. Optical networks, based on the emergence of the optical layer in transport networks, provide higher capacity (in Tbps) and reduced costs for new applications such as the Internet, video and multimedia interaction, and advanced digital services. Optical networks are also being used widely nowadays in backbone networks that spans long distances, e.g., each link could be a few hundreds to a few thousands of kilometers in length., due to their high relatively low cost. The backbone network can be set up to provide nationwide or global coverage. Most telecom backbone networks are deployed today as an interconnection of "stacked" SONET/SDH rings, in which the fibers support multiple wavelengths using WDM transmission equipment. Ring networks, however, are inefficient in using the expensive bandwidth resources of the network. Thus, mesh networks, which consist of an arbitrary interconnection pattern, are being deployed as the backbone of choice for our future telecom networks.

1.2 Optical WDM Network

With the advancement of Dense Wavelength Division Multiplexing (DWDM) technology, the bandwidth of a fiber has significantly increased. Recent studies indicate that up to 360 DWDM wavelength channels can be sent through a single fiber. Similarly each wavelength channel can also carry up to 100 Gbps, with the advancements in switching equipments, tunable lasers and photo detectors. Even though fibers can offer very high bandwidth, user requests that come to optical fiber networks are of lower bandwidth. The capacity requirement of these low-rate traffic connections can vary in range from STS-1(51.84 Mbps or lower) up to full wavelength capacity. This requires efficient grouping of individual connections onto the same wavelength as dedicating a unique wavelength for each demand will lead to huge wastage of bandwidth. Intelligent grouping is also required because each wavelength has to be dropped at the source and destination of each of the connections assigned to it. Dropping a wavelength at any node involves conversion from optical to electronic domain, and the equipment for performing this is the main contributor towards the cost of the network. This grouping of connections and assigning wavelengths to these groups, so as to optimize on some objective such as throughput or network cost, is termed as "traffic grooming".

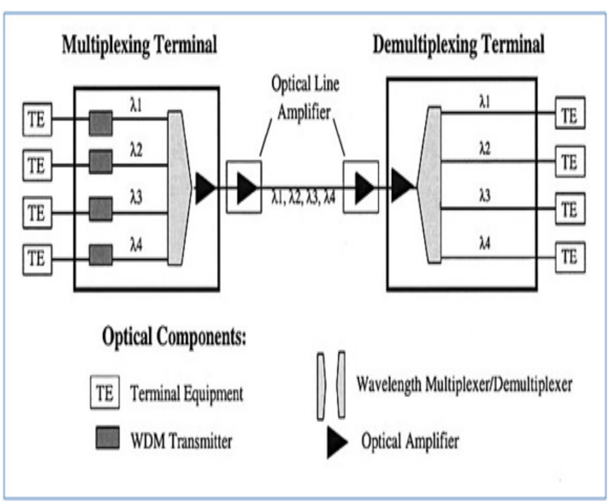

Fig.1: Optical Multiplexing

1.3 Traffic Grooming

1.3.1 Static Traffic Grooming

Static grooming is based on known long term traffic demands and the objective is to route all these traffic demands while minimizing the overall network cost. It is essentially an optimization problem that can be seen as a dual problem from different perspectives. One perspective is that, for a given traffic demand, satisfy all traffic requests as well as minimize the total network cost. The dual problem is that, for given resource limitation and traffic demands, maximize network throughput, i.e., the total amount of traffic that is successfully carried by the network.

1.3.2 Dynamic Traffic Grooming

The traffic request can be dynamic in nature, measured by the arrival rate and the holding time statistics of a connection request. In dynamic grooming algorithms are developed to groom and route the traffic request as they arrive in real time and the future traffic is unknown.

1.3.3 Sparse Traffic Grooming

Sparse grooming is an alternative in which, a selected subset of nodes are equipped with the grooming facilities and we call them G-nodes as in [Reference Num for G-node]. Research done in sparse grooming attempts to find the location of grooming sites.

2. Related Work

The majority of research on traffic grooming in the optical domain is focused on Synchronous Optical Network (SONET)/Synchronous Digital Hierarchy (SDH) over WDM ring topology with the objective of minimizing the number of Add/Drop multiplexer (ADM). As backbone network topology shifted from a ring to a mesh, research on traffic grooming was done in general network topologies. Traffic grooming problem on general topologies is NP-hard [1]. Early research focused on developing an integer linear programming (ILP) formulation and solving it for networks with a few nodes. While this method provides near optimal solutions for small networks, when the number of nodes increases the method becomes computationally intractable [1]. Over the period of time many researcher have proposed various heuristics algorithms and compare their performance in terms of blocking probability. Heuristic methods are capable of producing near optimal solutions in acceptable time. Most of the previous work done in grooming on backbone network assumes a full grooming network, in which all switching nodes in the network are assumed to have traffic grooming capabilities [1]. Research done in sparse grooming, attempts to find the locations of grooming sites [2]-[10]. They often require the number of grooming nodes as an input parameter. In our work, we select the number of nodes for performing traffic grooming as well as their placement. This approach is more reasonable due to cost considerations. Sparse node selection can be either based on topological information or finding the grooming nodes using simulations on the network topology. Several approaches based on network topology information like highest nodal degree for sparse node or G-node se- lection was proposed in [2]. Simple other heuristics like random and nodes with highest bypass traffic were chosen for grooming [2] and have been shown that optimal performance near to full grooming can be achieved using sparse grooming in the same network keeping the other resources like wavelengths etc. constant. Several of the approaches discussed here assumes two types of traffic request either static call arrival [2] [8] [10] or dynamic call arrival according to poison process with call holding time following exponential distribution [3] [4] [5]. In dynamic call arrival process each node in the network gets an equal chance of being a source and destination using uniform distribution, traffic or bandwidth request were also generated uniformly. Minimum dominating set (MDS) of a graph based approach was applied in [3] under dynamic traffic consideration. K-WMDS finds the set of nodes which are at distance k or less than k from the nodes in dominating set. Performance comparison for different values of k shows that as value of k increases the throughput decreases rapidly. The main drawback of the algorithm in [3] was that of selecting the nodes for grooming. Also it has been shown in [11] that how proper choice of routing and wavelength assignment algorithm contributes to the network performance.

Along with topological information like degree a new sequential simulation based approach for sparse node selection was presented in [4] which directly aim at reducing the blocking probability in the network. Here each node of the network is assumed to be a grooming node one by one and corresponding average blocking probability is evaluated, based on their average blocking probability nodes are added or selected for grooming. Nodes with lowest blocking performance are given preference over others. Two grooming algorithms Path Independent Connect through Node (PI-CTN) and Path Dependent Connect through Node (PD-CTN) are also proposed in [4] to exploit efficiently the sparse grooming capability existing in the network. Here each node has a dedicated grooming node which is nearer to the source and hence routing in done in similar manner. But as we all know sequentially selecting a single node for grooming is computationally complex because for each simulation step suppose we are formulating T request with a network of N nodes the complexity of the algorithms becomes O(N*T) for selecting a single grooming node. As proposed in [11] that proper choice of routing strategy along with suitable choice of wavelength assignment affects the throughput performance of the network under consideration. Random G-node selection using random wavelength assignment and single pair shortest path algorithm for routing is given in [5]. In [5] wavelength continuity constraint was considered, so that the same wavelength should be used to setup light path from source to destination.

If the same wavelength is not available on all links the call is blocked or an alternate path can be searched for wavelength assignment and routing. But in [5] only single pair shortest path is evaluated for a traffic request. So the request in here is blocked permanently if the resources are not available. Genetic algorithm based approach was applied first time in [6] for solving the problem of traffic grooming with sparse grooming resources. The traffic pattern considered in [6] was relatively static and the Most Contiguous Heuristics algorithm for RWA was presented but the algorithm does not guarantee that it will always find the wavelength assignment with the lowest possible number of traffic grooming and wavelength conversion devices. Also in [6] enumeration tables for all assignment of source to destinations were generated and chromosomes were selected for mutation out of large enumeration tables. It has been shown in the literature that the GRWA problem can be solved either independently or separately. Solving the GRWA has several advantages like modularity and optimized algorithms can be applied to each problem separately. In [6] how the sparse grooming nodes and how many nodes to be selected is not given. Also it is difficult to define the fitness function for genetic algorithm and how many crossovers should be done to generate new offspring. In [7] a new methodology was presented to place the grooming nodes at the edge of the network rather than distribute them throughout the optical network domain. Most Contiguous heuristic from [6] is used for GRWA problem solving. Hence it carries several drawbacks from [6] as it is. In [7] the call arrival or traffic request is dynamic according to poison arrival and call holding times are exponentially distributed with mean 1/H where H is average call holding time in hours. The performance comparison in [7] is done in terms of offered load in erlangs vs. blocking probability. Blocking probability can be simply calculated as the ratio of calls blocked to total calls generated in the network. Hierarchical traffic grooming is efficient and effective framework for WDM network for general topology and is presented in [8]. In [8] the network is divided into clusters and each cluster is viewed as a virtual star; one node in each cluster is designated as hub of the cluster. The hub of each cluster forms another cluster; cluster may correspond to independent administrative entities (e.g. autonomous systems). Static traffic pattern is chosen in [8] to perform grooming and RWA. Popular clustering algorithm K-Center is used in [8] to from first level cluster and decide hub node of that cluster. As we all know K-Center itself is a NP-Complete problem hence a heuristic algorithm for clustering is presented in [8]. As hub carry or groom traffic from cluster to cluster a specialized hierarchical routing algorithm is required. Also intra-cluster and inter-cluster traffic increases load on the hub node. It is a question of importance that how many hub nodes or how many clusters should be formed over a network topology, so that optimal performance can be achieved using minimum network cost and resources. In [9] a simple network topological information based algorithm is given to select sparse grooming nodes with the objective of maximizing the overall throughput.

The Sub-Path strategy presented in [9] quantifies the grooming potential of a node based on a set of pre-calculated shortest paths to be used for traffic delivery. The proposed scheme in [9] only uses topological network information but results show that it closely matches the performance of the Bypass- Traffic strategy presented in [2]. The Sub-Path strategy in [9] determines the set of all pre-calculated shortest paths for all pairs of nodes in the network and selects the nodes which fall into the shortest paths of the earlier precalculated shortest paths. Along with sub-path scheme nodal degree and bypass traffic is also presented. Integer linear Programming formulation and heuristics results both are presented in [9] for dynamic traffic scenario. But the consideration of Grooming OXC in [9] is a little different; here they assume a coarse granular OXC which can groom the traffic which is less than the total capacity of wavelength channel. Sparse grooming in all-optical network under static traffic demand is presented in [10]. An iterative greedy heuristics based on least light-path usage under static traffic consideration for sparse grooming node placement is given in [10]. It uses Dijkstra's single pair shortest path algorithm for routing and least used scheme for wavelength assignment. In least used scheme, all wavelengths are numbered and the wavelength which is lest used is selected for assignment. Since the G-node selection in [10] is sequential it is very time consuming and complex. Fixed-alternate routing and adaptive routing provide significant benefits over fixed-shortest-path routing, and often, these routing approaches even provide improved performance over wavelength conversion [11]. It is critical to choose a wavelength-assignment scheme, not based solely on its blocking performance relative to other wavelength- assignment schemes, but also based on its compatibility with the chosen routing protocol. Existing research demonstrates that an effective routing, wavelength assignment and a proper grooming node placement algorithm are the primary vehicle for improving the blocking performance of the networks. Considering the above presented methodologies each one of them has several pros and cons. In the following chapter we propose our methodology for sparse G-node selection along with solution to the GRWA problem under dynamic traffic scenario and try to overcome earlier approaches.

3. Proposed Methodology

We are going to propose new algorithm for sparse traffic grooming. Proposed algorithm will select set of grooming nodes from the set of nodes present in the mesh topology. The grooming node will perform full duplex multiplexing as well as wavelength conversion. For the formulation of proposed algorithm it is necessary to implement existing non traffic grooming and full traffic grooming algorithms.

Objectives:

1. Reduce the cost as compare to full traffic grooming.
2. Select optimal number of grooming nodes.
3. Increase network throughput.
4. Reduce blocking probability.
5. Compare proposed method with the best existing method to prove the results.

Assumptions:

1. Request arrives according to poisson distribution.
2. Topology : NSF-NET
3. To find shortest path Dijkstra’s k alternate shortest path algorithm will be used.
4. For wavelength assignment First Fit and Best Fit technique will be used.
5. On grooming node multiplexing is assumed on both directions.
6. Full wavelength conversion is considered because it reduces blocking probability.

Algorithm to find path:
Function Find Path (Request R, topology T)

holding time(ht)=file size/bandwidth
i=1
k= Number of alternate paths considered
while ($i \leq k$) **do**
find shortest path with Dijkstra's algorithm with propagation delay link cost
if a path is found **then**
if slot in wavelengths are available for the duration of ht
then
Assign slot in wavelengths, update all tables
return
else
Remove the busiest link during the window from topology
i ++
end if
end if
end while
end function

Time Complexity:
Let w=number of wavelengths in a optical link
t = number of instances
n= average number of requests per instance
For no traffic grooming (NTG) first fit is used for wavelength assignment hence;
Worst case: O(n*t*w*k)
Best case: O(n*t*k)
For traffic grooming (TG) best fit technique is used for wavelength assignment hence;
O(n*t*w*k)

Proposed Algorithm:
This algorithm is good mixture of topology based and traffic based algorithms. As literature shows that nodal degree algorithm (topology based) gives better results for sparse node selection. Hence we will consider nodal degree algorithm for the design of proposed algorithm.
In proposed algorithm following steps have been carried out:

1) Allo_TG: Traffic grooming algorithm is carried out; if the node is considered in the shortest path then it's cost is incremented by 1 and nodes are sorted in decreasing order. A set is prepared for top 60% nodes.
2) Wave_NTG: Non traffic algorithm is carried out; while assigning the request if the wavelength conversion is performed then cost of the node is incremented by 1 and nodes are sorted in decreasing order. A set is prepared for top 60% nodes.
3) Block_NTG: Non traffic grooming algorithm is carried out; while assigning the request if request is blocked at a node then cost of that node is incremented by 1 and nodes are sorted in decreasing order. A set is prepared for top 60 % nodes.
4) Nodal: Nodes are sorted according to nodal degree in decreasing order and top 60% nodes are selected in a set.
5) Intersection of Allo_Tg, Wave_NTG and Block_NTG is perfomed if node count is not 60% then remaining nodes are taken fro, nodal set.

Time Complexity:
Let
k = number of shortest paths
w = number of wavelengths
t = number of instances
n= Avg. number of requests per instance
Proposed algorithm need to perform both non traffic grooming and traffic grooming.
Time complexity for non traffic grooming:
O(n*t*k*w/2)
Time complexity for traffic grooming
O(n*t*k*w)
Time complexity for proposed algorithm:
O(n*t*k*w + n*t*k*w/2)

4. Performance Analysis and Result

We have conducted simulation experiments on 14-node NSF-NET topology with 42 uni-directional links as shown in Figure 2. We assume 10 wavelengths of 10 Gbps(OC-192) on each link and full wavelength conversion at each node. Each node is capable of multiplexing and de-multiplexing. Each node packs low bandwidth requests on a single wavelength i.e.TG. We assumed that requests arrive in the system in Poisson fashion. The source and destination for the requests are generated randomly using Poisson uniform distribution. Call arrival at a node is according to Poisson process with rate and each call is equally likely to be destined to any of the remaining nodes in the network. The call holding time is exponentially distributed with parameter: average blocking probability = number of blocked calls / total number of calls.

We compare the performance of different grooming policies on the network topology shown in Fig. 2, which has 19 nodes and 31 links. All the nodes have grooming capability but no wavelength-conversion capability. Each link is bidirectional with W = 16 wavelengths in each direction and each wavelength have a capacity of OC-192. The traffic arrival is a Poisson process and the connection holding time is exponentially distributed (whose average value is normalized to unity in our studies reported here). The traffic is uniformly distributed among all node pairs. There are four types of connection requests: OC-3, OC-12, OC-48, and OC-192, and the proportion of the number of these connections is 6:6:6:1. For a connection request Ts, d, g, m), m, the amount of the traffic in unit of g, is uniformly distributed between 1 and 32, 1 and 16, 1 and 8, and 1 and 2 for OC-3, OC-12, OC-48, and OC-192 types of connections, respectively. We simulate 100,000 connection requests to obtain the network performance under a certain scenario and a grooming policy. We ran our simulation experiments on a Linux PC with a 1.5-GHz Pentium IV processor and 512-MB memory. Each data point reported in the illustrations in this section took between 6-9 minutes of running time on this computer. Traffic Blocking Ratio represents the percentage of the amount of blocked traffic over the amount of bandwidth requirement of all traffic requests during the entire simulation period. Connection Blocking Probability represents the percentage of the total number of blocked connection requests over the number of all traffic requests during the entire simulation period. The connections with different bandwidth requirements may experience different connection.

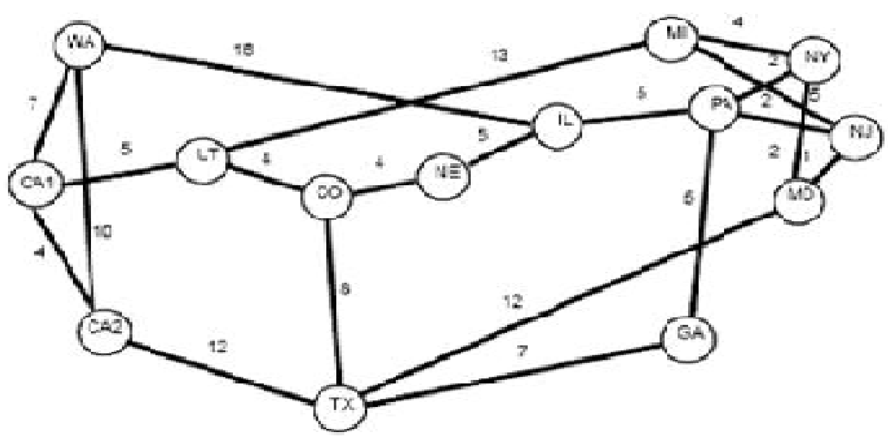

Fig. 2: NSF-NET Topology

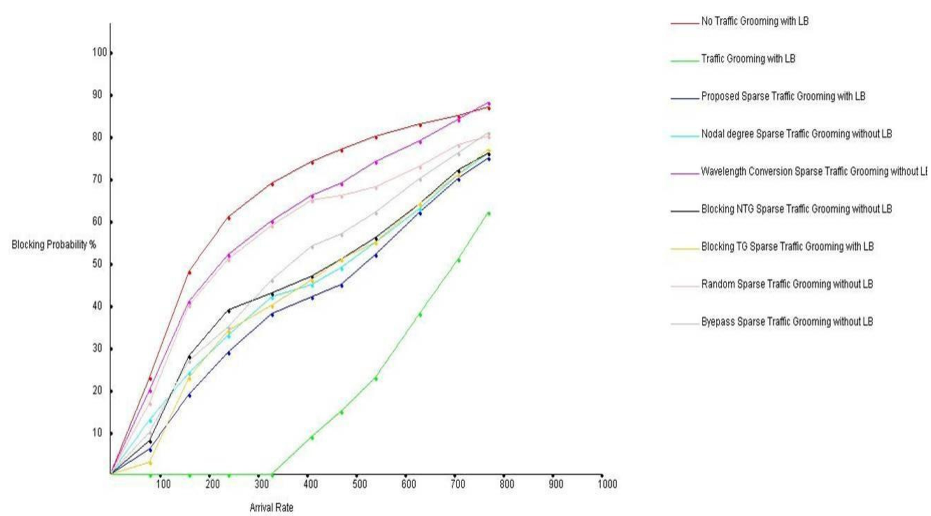

Fig 3: Comparison of NTG, TG

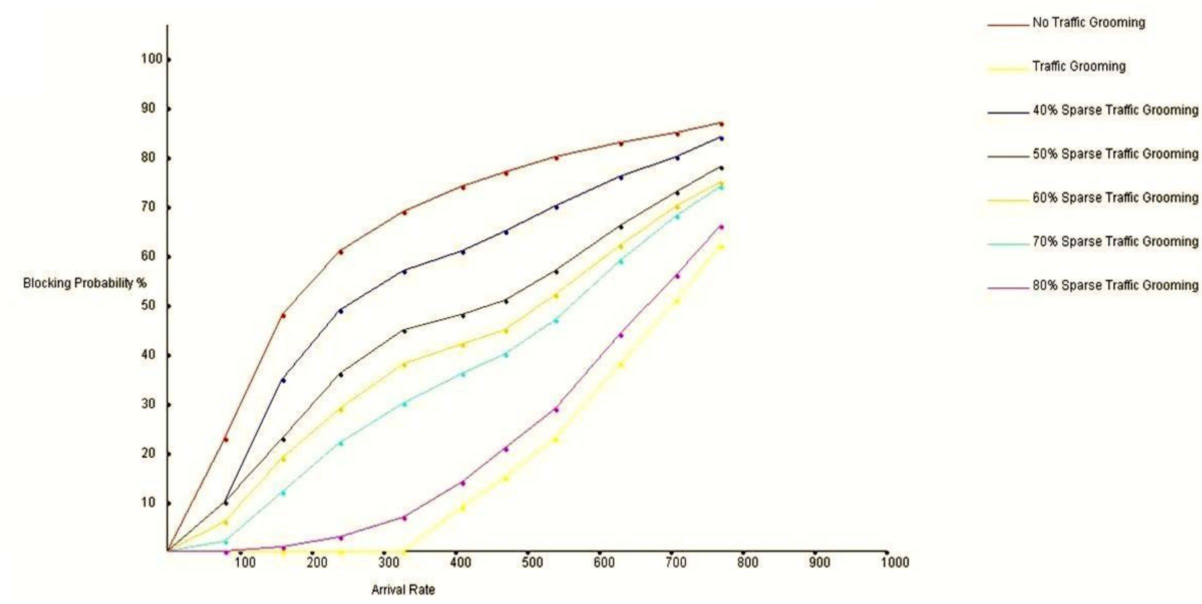

Fig. 4 Comparison of Proposed vs Existing STG techniques

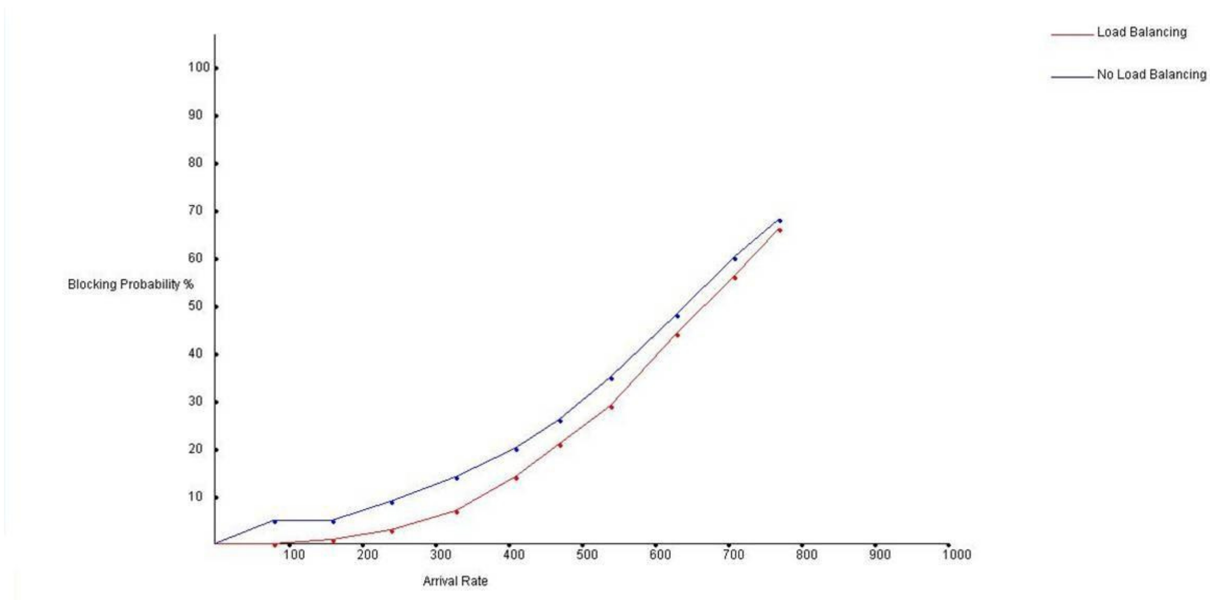

Fig. 5 STG with and without load-balancing

5. Conclusions and Future Work

Optical wavelength-division multiplexing is a promising technology to accommodate the explosive growth of Internet and telecommunication traffic in wide-area, metro-area, and local-area networks. While a single fiber strand has over a terabit-per second bandwidth and a wavelength channel has over a gigabit-per-second transmission speed, the network may still be required to support traffic connections at rates that are lower than the full wavelength capacity. Typically, the cost of a nation-wide optical network is dominated by optical transponders and optical amplifiers. If one assumes that the fiber routes are fixed, then the amplifier cost is constant, in which case one should concentrate on minimizing the number of transponders in the network. Though the number of transponders has been used as an objective function in many studies on ring networks, it has not been considered at all for mesh networks. The objective functions that have been considered for mesh networks so far include: the blocking probability, the total number of wavelengths required, and the total route distance.

Traffic grooming can be used to increase the utilization of light-paths in an optical network and reduce the network complexity. Unfortunately, the resulting ILP problem is usually very hard to solve computationally, in particular for large networks. In this paper, we presented a heuristic algorithm to perform sparse grooming in an all-optical network to increase the utilization of light-paths. We find the optimum number of light-paths using the percentage reduction in light-paths. We also show that our algorithms will produce solutions that are more robust to changes in traffic pattern and random variation in the traffic matrix than even an optimal solution for either objective, when such an optimal solution is produced by an algorithm that is unaware of this duality of objectives (e.g., by simply solving an ILP model). Our algorithms can be extended to cope with more complicated network topologies.

Recently, there have been e orts to extend studies of this kind to cases of dynamic traffic. However, this area is still comparatively new, and most of the proposed approaches ignore the optical routing maximization aspect in favor of simply considering blocking probability. For larger sized networks, decomposition approaches can be applied to break them into small pieces, and use the star approach to solve each piece hierarchically. Dynamic traffic must be considered because the traffic grooming locations are envisaged to be extending from core networks to metropolitan area networks and even further to end users. At such points, traffic demands are more likely to be much less than the capacity of a lightpath, and variations in them are less likely to be smoothed out by aggregation. It's a challenging problem to groom the traffic dynamically at network nodes.

Survivability is an important area to explore further because a loss of single wave-length channel can lead to very expensive and high amount of data loss in WDM optical networks. Since it is not always possible to monitor the status of a large network using centralized controller, distributed approaches are the best way to deal with such problems. Survivable traffic grooming in distributed environment is an interesting problem to solve. This study was devoted to the traffic-grooming problem in a WDM mesh network. We studied the architecture of a node with grooming capability. We presented the ILP formulation for traffic-grooming in such a WDM mesh net- work.

We compared the performance of the single-hop grooming approach, blocking probability, and resource efficiency. We observed that employing more grooming capacity can help a network operator to improve the network performance and the utilization of the link capacity. However, this may also increase the network cost since more electronic processing is needed. We verified the blocking performance unfairness between connections of different bandwidth-granularity classes due to resource-usage characteristics. We also observed that the unfairness problem can become more severe when a network has more grooming capability. This may lead to an interesting research topic in the future.

This study was devoted to the problem of designing a WDM mesh backbone network with sparse traffic-grooming capability. The mathematical formulations (ILPs) for two design objective functions were presented. Due to the large computational complexity of ILPs, three heuristic algorithms were also proposed to solve large instances of the problem. Our results from both the mathematical formulations and heuristics show that, by employing a limited number of grooming nodes, the network capacity can be used more efficiently and the network performance can be improved significantly. We also showed that it is possible to nd a balance between the number of wavelength channels and the number of grooming nodes used in the network. This balance will eventually reduce the network cost. Further study is needed on the effect of sparse grooming on dynamic traffic, and more intelligent heuristic algorithms could also be developed.

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