Sparse Traffic Grooming in Survivable Optical Wavelength Division Multiplexing Mesh Networks

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Mostly survivability in optical Mesh network is major topic of discussion as failure in the high speed network will affect the services. Wavelength Division Multiplexing (WDM) technology has made it possible to use the large capacity of an optical fiber. In a WDM Network, survivability is a major area of concern as a WDM network carries a large amount of data. The failure of a network element could result in a large amount of data loss. The goal of survivability is to maintain connectivity and services after a failure. The proposed method is based on Survivable Traffic Grooming to address the gap between bandwidth capacity of wavelength and bandwidth requirement of a connection and also to provide fault tolerance. This method focuses on a sparse grooming network, where only a few network nodes have the traffic grooming capability. The objective is to provide a fault tolerant network while minimizing the network cost and maximize the network throughput as reducing the utilized number of wavelengths. We have compared the result of our system with Multicast traffic grooming with survivability in WDM mesh networks.

Keywords: Survivability, Sparse Traffic Grooming, Optical Network, WDM, Fault Tolerance.

1. INTRODUCTION

Internet traffic has been growing at a rapid rate for many years. Increased traffic in communication networks resulted in changes in the telecommunication industry. The most important factor in these changes is the bandwidth requirement. As the demand for bandwidth increases, we need to have high-speed networks. Optical networks provide efficient bandwidth capacity. The high bandwidth capacity of an optical network can be used as per the requirement of the user. This results in a flexible network to fulfill the demand of users. An Optical Network provides Tbps capacity, which is divided into small capacity channels with a capacity equal to STS-1. A single STS-1 is OC-1 (51.84 Mbps) and an optical fiber with OC-n, where the value of n varies. OC-192 has a capacity 10 Gbps.

Bandwidth is assigned using Wavelength Division Multiplexing (WDM) technology. Each wavelength has a high bandwidth capacity. As compared to this capacity of each wavelength band, the connection requests coming to it are of lower rates. Lower rate requests coming to such wavelengths with high bandwidth wastes its bandwidth capacity. Therefore, instead of using a complete channel or wavelength for the requests of lower data rate, the traffic grooming method is used. In traffic grooming, a number of requests may allow transferring the data through the same channel or wavelength. Each channel is carrying a large amount of data. Any failure to the network of such a high-capacity, high-speed network leads to data loss. So we need to have a fault tolerant network which is called as a survivable WDM network.

A groomed network requires its nodes with the grooming capability to have extra hardware and software configurations. Due to this the cost of the network is high and providing cost-effective solutions is not possible. So it is recommended by the literature to use sparse traffic grooming where few nodes have the grooming capability. Sparse traffic grooming with the fault tolerant system, i.e., Survivable Sparse Traffic Grooming is one of the new approaches focused in this paper.

Even in the case of failure of node or link, the connectivity is maintained in survivable sparse traffic grooming. The traffic grooming improves the use of wavelength. Achieving survivability over a sparse traffic grooming network will lead to optimization of wavelength utilization, a cost effective solution, and a fault tolerant network.

The organization of the paper is as follows: Section 2 provides related work in the literature on traffic grooming...
and survivability. In Section 3, describes the details of our proposed algorithms. Section 4 presents the simulated results of the proposed algorithm on NSFNET network and test their performance by comparing the results with a Full Grooming algorithm. Section 5 concludes this paper.

2. RELATED WORK
An Optical Network provides terabits of bandwidth; this will help to create multicast applications. Traffic grooming increases the cost of the network, so sparse traffic grooming is recommended to reduce this cost. Most of the work in the literature addresses the problem of reducing the number of Add-Drop Multiplexers (ADMs). Some of them also address the problem of reducing the use of wavelengths. Light trees can be used for multicast connections in a WDM network. From source to destinations the data transmission takes place like the light trees. The majority of the literature in traffic grooming focuses on increasing the efficiency of the network while minimising the cost. Mohammad introduce two novel approximation algorithms for the many-to-many traffic grooming problem. The algorithm is based on light path and has an approximation ratio of complexity.

The incoming signal on an input port is split into a number of components light trees which are realized by optical splitters. This splitting is all-optical and these components are independently routed. Mohammad proposed a light-tree based ILP formulation. To achieve scalability, Sub-Light-Tree Saturated Grooming (SLTSG) is proposed. Using a light tree the logical links are established with multiple destinations. SLTSG is the heuristic with an objective to minimize the network cost. The network cost is associated with ADM, Optical ADM (OADM) and a number of wavelengths used.

For connections is known in advance, transfer of data from source to destination a light path is set up. A wavelength is assigned to each connection and request is routed to the light path. This process of setting the light path is known as Routing and Wavelength Assignment (RWA) problem. There are several algorithms discussed by Chu. There is two algorithms Fixed-Alternate Routing (FAR) algorithm, other is the Least-Loaded Routing (LLR) algorithm. The wavelength converter placement problem is one of the objectives of Chu. Proactive protocol for RWA problem is proposed using the concept of ant colony optimization. This proactive protocol updates the changes in the network. The ants are controlled agents and find the optimal light path. In the RWA protocol for establishing the light path, the wavelengths used between the links have to be same along the entire path which is called Wavelength Continuity Constraint (WCC). These WCC constraints will be avoided by wavelength converters. ACORWA algorithm was proposed using the ant colony optimization.

Yao et al. 7 discussed sparse traffic grooming in heterogeneous multi-vendor optical WDM networks. In sparse traffic grooming, we consider that there are \( n \) nodes in the network and \( m \) nodes are with grooming capabilities. It means that these \( m \) nodes have special hardware and software required for grooming. Therefore, \( (n-m) \) nodes are there in the network without grooming capability in the sparse grooming network. All these nodes are optical cross-connects (OXC). Such a network is called a sparse grooming network. They proposed the Maximize-Light Path Sharing Multi-Hop (MLS-MH) algorithm supporting dynamic traffic grooming in sparse grooming networks.

Using WDM technology the wavelength assignment will be done efficiently. Also, due to efficient solutions of traffic grooming, terabytes of data flows through the single optical fiber at large speed. Therefore, the demand for a fault tolerant network system is increasing. There are two basic methods of fault recovery to ensure optical network survivability. The first method is a protection scheme based on dedicated resources, which are provided for the protection of the path. The other method is dynamic restoration, which leads to restoration of systems.

PAL, MPAC, SPAC approaches are proposed for Survivable Traffic Grooming with shared protection. It explores different ways of backup, sharing, and the trade-off between wavelengths and grooming ports. To protect the individual connection SPAC gives the best performance. This performance is best when the number of grooming ports is sufficient for requests arrived. The authors have proposed a shared protection, Elastic Separate-Protection-At-Connection (ESPAC) where an overlap factor (OVLP) is set. It allows spectrum overlap between adjacent backup wavelengths. This leads to a significant gain in spectrum saving.

In literature, the Survivable traffic grooming problem is studied over a full groomed network to provide fault tolerance. In all the above methods, it is observed that the method which analyses sparse traffic grooming and survivability together is not implemented. This leads to our proposed method discussed in the next section. The fault tolerant system is implemented using a Combiner Queue for Sparse Traffic Grooming which focuses on the performance improvement of the network. It also talks about the reduction in blocking probability. The blocking probability is reduced due to the use of Combiner queues. The bandwidth utilization is improved because of this method. This work uses the survivability over sparse grooming in the optical WDM mesh network. This is the initial attempt of combining survivability over sparse grooming.

In the paper, Modified Multi-objective Metaheuristic for Sparse Traffic Grooming in Optical WDM Mesh Networks...
Networks\textsuperscript{14} the authors have modified multi-objective Metaheuristics for sparse traffic grooming. The network performance improves with this method but the method does not work for faults.

Pradhan et al.\textsuperscript{15} proposed a survivable heuristic model for multicastr traffic grooming (MTGS). They used static traffic over the optical mesh network. The main focus of this paper is to when a path failure occurs then the path protection is provided. This protection is also groomed.

3. PROPOSED METHODS

The problem statement is as follows: given a network with \( N \) nodes, the traffic load between each node pair and the number of grooming nodes is to be placed in the network. The objective is to design a fault tolerant network with survivable traffic grooming and to save network equipment cost by sparse groomed network. For this purpose, we propose a Survivable Sparse Traffic Grooming algorithm. It provides Traffic grooming on sparse grooming network nodes to avoid a bandwidth mismatch between the capacities of the optical network and user demands. This is not provided by the MTGS. In the literature, all the methods are using traffic grooming and providing the survivability to it. Whereas in the proposed method, we are using survivability over sparse traffic grooming.

The methodology starts with designing a network topology \( G(V,E) \), where \( V \) is the number of nodes and \( E \) are the connecting links. On this network topology, Wavelength Division Multiplexing (WDM) technology is applied. It divides each fiber into four wavelength channels. These four channels have different bandwidth capacities, i.e., OC-3, OC-12, OC-48, and OC-192, respectively. Whenever a connection request comes for routing, the Best Fit method is applied to assign the wavelength channel.

Algorithm (Survivable Sparse Grooming Algorithm).

For network topology \( G(V,E) \)
1. Perform the shortest path routing using Dijkstra’s algorithm.
2. Perform Wavelength Division Multiplexing.
3. Select sparse grooming nodes having a maximum nodal degree.
4. If request arrives on grooming node (multiplexing)
   a. If capacity available on queue, insert the request into a queue and assign 1 \( \mu \)s delay.
   b. Else if the queue capacity has reached OC-192 or if there is timeout
      i. Generate a grooming request of all queued data and go to Step 9.
      ii. If arrived request is not after the timeout, go to Step 4. a.
      iii. Else return.
5. Else If a request arrives on grooming node (demultiplexing), extract requests from groomed request and go to Step 9.


6. Else if request arriving at the non-grooming node, go to Step 9.
7. If a timeout event occurs, Repeat Step 4. b.
8. If a link fails, apply link restoration and route the request on an alternate path.
9. Assign wavelength channel using Best Fit method.
10. If a channel is available, Route request through a selected wavelength channel on the shortest path.
11. Else block the request and calculate blocking probability.
12. End.

For sparse grooming node selection, we have used a Maximum Nodal Degree algorithm. In this algorithm, the grooming capability is allocated to the first \( M \) nodes with the largest nodal degree. The number of sparse nodes giving optimized value for blocking probability over the network cost will be chosen. Dijkstra’s shortest path routing is used to route connection requests. The connection will be routed to the appropriate wavelength channel.

If a request comes across a grooming node, then it will follow the Grooming algorithm. Every node has a queue of different data requests according to the node’s respective links. Every queue has a maximum capacity of OC-192. Here multiplexing and demultiplexing of requests will be performed. When the request arrives, if the respective queue can accommodate the requested bandwidth, then this request is inserted in the respective queue. A delay of 1 \( \mu \)s is applied to that request. After 1 \( \mu \)s delay, a trigger event will occur and then a groomed request will be formed with all the requests residing in the queue. This groomed request is then routed further.

For achieving survivability, a link Restoration algorithm is used. If a link fails, then it dynamically finds the backup path. Then the request is routed to its destination through the backup path. It helps in maintaining services and connections after a failure. The MTGS method uses path protection and there is a separate link for the protection of each link. This increases the cost of the network. In our method, the link restoration method is there which helps to reduce the cost. Also, helps to increase the utilization of wavelengths.

The proposed method is using the dynamic traffic at each node for every wavelength request. The MTGS method is for the static traffic. Therefore we say that the proposed method is more dynamic and reduces the cost of the network as compared to MTGS. We also say that the blocking probability is less in the proposed method as compared with MTGS.

4. RESULTS

Simulations were conducted on 14 Node NSFNET networks. In this network, each link is divided into four wavelength channels of capacity OC-3, OC-12, OC-48, and OC-192. On the grooming node, we have designed
a queue for each physical link. The capacity for each queue is OC-192. In each queue, incoming requests will be inserted and by combining these requests, a grooming request will be formed. The performance of the proposed Survivable Sparse Traffic Grooming algorithm is compared with an existing full grooming algorithm. This comparison is done with parameters like blocking probability and wavelength utilization.

Figure 1 shows the comparison of blocking probabilities by varying the number of grooming nodes. For the selection of the grooming node in sparse traffic grooming network the maximum nodal degree algorithm is used. A number of sparse nodes used are five. This is selected by conducting simulations with a different number of grooming nodes as shown in Figure 1.

The observations are that with five grooming nodes, the minimum blocking probability over network cost can be achieved.

The 6 node grooming gives the lowest blocking and network cost is reduced to 50%. It is observed that with 5 grooming nodes, the blocking probability is nearly equal to the blocking of the 6 grooming node method but the network cost is reduced to 65%. Therefore, it is optimal to choose the number of grooming nodes as five.

Figure 2 shows the graph plotted of increasing simulation time. It shows the comparison between proposed method, Full Grooming and non-grooming method on the basis of blocking probability. Full grooming algorithm has low blocking probability. With our proposed system, we have tried to achieve lower blocking probability while minimizing the network cost. From Figure 2, it is observed that, as a No-Grooming method has large blocking, in comparison, the proposed method achieves to reduce the blocking.

Figure 3 gives detailed graphical representation for the various methods. When the survivability is provided over the optical network then our proposed method gives better results than MTGS. The MTGS is not using dynamic traffic. If we implement the proposed method for the static traffic then the results will give more difference and our method will outperform than MTGS. It is also observed that sparse traffic grooming gives better results but that is when there is link failure in the proposed method. Due to failure, it will require some resources to restore the link. Then the performance is varying. In terms of full grooming as all nodes have grooming capability performance is very good but the cost of the network is very high as every grooming node requires some special hardware and software. This adds more cost of the network.

Figure 4 shows the wavelength utilization on a non-grooming node. The graph in blue color shows the bandwidth request that incoming connections have requested. The graph in red color shows the capacity of a wavelength channel on which the subsequent request is routed. For instance, a connection request for bandwidth OC-78 and OC-192 wavelength channel is used which gives 40% of wavelength utilization. It is observed from the graph that there is a large amount of wastage of bandwidth in case of non-grooming nodes. The graph depicts that if the nodes are not groomed for survivability, then bandwidth
utilization is less. So we may say that wavelengths are underutilized.

Figure 5 shows the graph of wavelength utilization in the case of a grooming node. Here incoming requests are first groomed and then forwarded on the wavelength channel. For instance, a groomed request with total OC-172 bandwidth is routed on the OC-192 wavelength channel. It gives almost 90% of wavelength utilization. It is observed from the graph that, the grooming node gives maximum wavelength utilization as compared to utilization in the non-grooming node as shown in Figure 4.

5. CONCLUSIONS
The use of WDM technology leads to the proper availability of wavelength bands to serve the request. Due to the best grooming of traffic, a fiber channel can transfer terabytes of data. This data will get transferred with a speed of light. The proposed algorithm is based on Sparse Traffic grooming in WDM network for Survivability. The existing full grooming methods give the lowest blocking probability for connection requests but with higher network cost. Also, the existing MTGS is using full grooming though implemented survivability. With our proposed system, we achieved lower blocking probability nearer to the lowest blocking of full grooming and the network cost is significantly reduced as survivability is used over sparse traffic grooming. Due to less number of grooming nodes, the hardware and software requirement will be reduced which reduces the cost of the network. With sparse grooming nodes, it reduces the number of resources used and hence the network cost. The proposed algorithm also implements survivability which makes the network fault tolerant. It also gives maximum wavelength utilization avoiding wastage of bandwidth.

References
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