Combiner Queues for Survivability in Optical WDM Mesh Network

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Abstract —Survivability is the major problem in Wavelength Division Multiplexed (WDM) Optical network. Also, the selection of grooming node is another important issue in the Optical Mesh Network. Most of the work in the field of the optical network is focused of sparse traffic grooming and survivability as a separate issue. We here presented a novel approach for providing survivability to sparse traffic grooming. This survivability on sparse traffic grooming is considered for the failure of a link on sparse grooming network. When we have sparse grooming network and a link failure occurs then we are providing a solution of shared link using combiner queues. We have proved that the combiner queues help to reduce the blocking probability and also reduce the number of call dropping. We have presented the queuing model which helps to calculate the total requests at a node or in the entire network. The presented combiner queuing model is useful for the calculation of probabilities, as m server queuing system.

Index Terms—Survivability, fault tolerance, sparse traffic grooming, WDM, optical network, combiner queue

I. Introduction

The requirement of the bandwidth for the transfer of data goes on increasing. To fulfil the demand of bandwidth hungry society, use of optical fiber is increased. The availability of the bandwidth in each optical fiber is in Tbps. Though the requirement has increased a user will not utilize Tbps bandwidth. These fibers have n number of channels in each fiber. The most common channel is OC-192 of the capacity of STS-1*192. The capacity of STS-1 is 51.84MBps [1]. Therefore each such a channel provides Gbps of bandwidth and a single fiber is of Tbps capacity.

This optical fiber is connected to the nodes at the backbone. Each node will be connected to some other nodes to form an irregular mesh in the network. At each node different requests are arrived to get the service. Any such a single request will not require such a large bandwidth. Therefore needs to use the multiplexing techniques at the nodes. There are different multiplexing techniques such as time division multiplexing, space division multiplexing, frequency division multiplexing, and packet division multiplexing. The frequency division multiplexing (FDM) over optical fiber is wavelength division multiplexing (WDM).

Routing and Wavelength Assignment will be done at the nodes, but due to the availability of more bandwidths than the requirement we need to multiplex low-speed traffic. This traffic will be multiplexed on high capacity channels. This is known as traffic grooming. To provide the capability of traffic grooming at the node, the node must be configured by some special hardware or software like add/drop multiplexer (ADM), Optical-ADM (OADM), optical cross connects (OXC). This requirement increases the cost of the network. Therefore to reduce the cost of the network is one of the problems. To reduce the cost of the network traffic grooming is provided to few number of nodes in the network. This is called as sparse traffic grooming.

When we use sparse traffic grooming then as compare to full grooming the performance of the network degrades. Now it is very important to have a near optimal performance by sparse traffic grooming when we try to reduce the cost of the network.

Now the most important event about the backbone network is a natural disaster. Due to some natural disasters like earthquake, flood, etc the backbone network is get affected. Not only the natural disasters but some manmade activities also lead to damaging the backbone network. This damage may be a failure of node or link. A network must survive in any such situations without affecting network service. This is survivability of the network.

To provide the survivability to the network there are various methods used one is protection and other is restoration as shown in Fig. 1. These survivability techniques are used for fault management. In restoration there are path and link restoration whereas the protection method is either a dedicated or shared protection. This dedicated and shared protection also applies to path protection and link protection like restoration.

In restoration the failure of the link or path is detected and restored. The time of restoration is the concern in this scheme, but will restore the link or path over the best route. The protection method provides an alternate arrangement for the path failure or link failure. In

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dedicated path protection or the link protection a dedicated alternate path is provided. If a failure occurs in the network, the alternative arrangement made through the protection mechanism is useful to complete the call. In shared protection a common shared path between multiple link or path is made available to serve as an alternative for the failure.

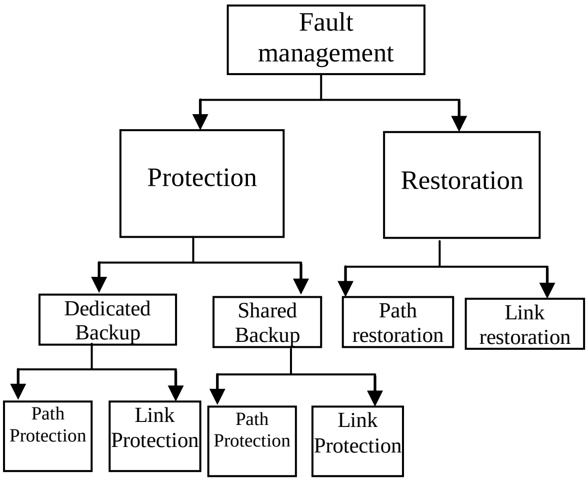

Fig. 1. Fault management methods.

Here we are focusing on the use of combiner queues at each node for providing survivability over sparse traffic grooming in optical WDM Mesh Network. The focus of the paper is to get the optimal performance even after the failure of a link. Also, we are providing cost effective solution using sparse grooming. In the literature, most of the work on survivability is for full grooming. In case of full grooming survivability, network node fails or link fails then the request get survived but the cost of the network is not optimum. But in sparse grooming, the cost is reduced and the same sparse grooming network is made survivable.

Paper is arranged as Section II elaborates the literature review, Section III presents the proposed Combiner Queue method and its implementation. The results and conclusions are preceded in the next section.

II. Literature Review

Traffic grooming is widely studied by the researchers and different views about the use of bandwidth and shaping the traffic was proposed. Traffic grooming and all its aspects are studied by Mukherjee [1]. The main focus of earlier research was on full traffic grooming where all the nodes in the network have grooming capability. If a node is grooming node then it will multiplex low-speed connections to high-speed connection. The add-drop multiplexer called ADM is used at a node to add or drop the request. Due to wavelength division multiplexing (WDM), numbers of wavelengths are available on a single fiber. Each wavelength needs an ADM for multiplexing of traffic. As fiber optic communication is widely used in the backbone network the requirement of ADM or OADM increases.

Due to increased cost of the network in the full grooming researchers has moved towards the sparse traffic grooming. In the sparse traffic grooming very few nodes have traffic grooming capabilities. This reduction in the number of grooming nodes reduces the requirement of ADM or optical add-drop multiplexers (OADM). Therefore it is very important to select the best grooming nodes so that with the fever number of grooming nodes network must give the best performance. This must be compared with the full grooming. For sparse traffic grooming, there are various methods proposed in the literature. We have compared so many methods for grooming node (G-node) selection. Madushanka Nishan Dharmaweera [2] proposed a scheme for traffic grooming and multipath routing that all together improves the performance of the network. Chengying Wei [3] proposed smallest cost highest degree method for selection of the grooming nodes. Shengfeng Zhang [4] proposed some traffic partitioning strategies over sparse traffic grooming to improve the results. Sandip Shinde [5] proposed a heuristics method. This method proposed for sparse traffic grooming. The main concept was to use nodal degree and maximum total traffic for the selection of the G-node. A node out of two nodes with the same nodal degree is considered for selection as grooming node. The node with greater weight count has the maximum probability to be selected as grooming node. Also, Sandip Shinde [6] proposed a modified multiobjective meta heuristics based on the heuristics proposed in [5]. The method proposed in [5], [6] are proved to be the best for reducing the blocking probability and improve the network performance for sparse traffic grooming.

This high-speed network is considered to be the best network if it provides service without break. But due to natural disasters or some hardware failure or some unavoidable circumstances, the failures in such a large network leads to loss of large data and may lead to some economic losses which may not be recovered. So it is important to have survivability in the given network. Ashok Kumar Pradhan [7] proposed a method for survivability which is for multicast protection and also on the grooming. They are used shared segment protection for multicast protection. Sandip R. Shinde [8] proposed fault tolerant system. This system is providing survivability over sparse grooming. Also, the combiner queues are used for the selection of the G-node.

There are two type of failures in the network. One is a failure of a link and other is a failure of a node. Most of the work gives a solution to the link failure. There are methods to resolve these problems called as protection and restoration [1]. In the protection scheme some dedicated resources are allocated to work alternately when the failure occurs at some time. But in restoration, there are no dedicated resources allocated. The available resources after utilization to the regular traffic at that node will be used as a spare capacity resource. There are dedicated and shared protection schemes available. These are either path protection or link protection. Therefore we have dedicated path and link protection or shared path or link protection. Canhui (Sam) Ou [9] proposed PAL, MPAC, SPAC approaches for Survivable Traffic Grooming with shared protection. Menglin Liu [10], discusses elastic networks. In elastic networks, instead of following the traditional fixed ITU-T wavelength grid, optical transponders are capable of properly tuning their rates, and consequently their spectrum occupation. Authors have proposed a shared protection, elastic separate-protection-at-connection (ESPAC) where an overlap factor OVLP is been set. It allows spectrum overlap between adjacent backup wavelengths leads to significant gain on spectrum saving.

Considering all these literature published we have proved that use of queues at each wavelength is useful to groom the traffic efficiently and also the combiner queues will help to reduce blocking probability.

III. Combiner Queues for Survivability

Combiner Queues for Survivability (CQS) provides fault tolerance over sparse traffic grooming in an optical network. We are using the NSFNET topology for the simulation. NSFNET topology is an irregular mesh and is the 14-node network. So many Rings at the backbone connects together to from the irregular mesh. First of all, CQS method recommends selecting the grooming node so that the network becomes sparse grooming. Here CQS selected the G-node using combiner queues (CQ). The method which we used for selection of the G-node is

Algorithm: *G-node selection by CQ Algorithm*

Initialize the weight (w) to zero
Assign the weight to each node
Calculate the nodal degree(nd) of the each node
For nodal degree nd=1
    weight has to be incremented w=w+1
Initialize the traffic at each node
Traffic requests must be Poisson process at each node
    For each request at node increase the weight
If the capacity C of CQ is full at some node
    then declare the node as G-node
If two nodes with same nodal degree then compare the queue capacity of these nodes
    node with max weight count is selected as G-node
If number of G-nodes are not optimum
    then sort the nodes according to a nodal degree
    select the highest nodal degree node as G-node.

In the given algorithm the selection of grooming node depends upon the blocking probability. Initially one node is selected as grooming node then performance is calculated and compared with non-grooming network. Every time the number of grooming nodes will be increased by one. And the performance will be compared with non-grooming and full grooming network. The process will be continued till we get the optimum results. Our implementation has proved that 5 node grooming in NSFNET topology will give us the near optimal performance. We have tested the results for the six nodes grooming which reduce blocking probability but the variation is negligible. Therefore for further implementation, we fix the grooming node to 5. The NSFNET topology used in the simulation is as shown in Fig. 2.

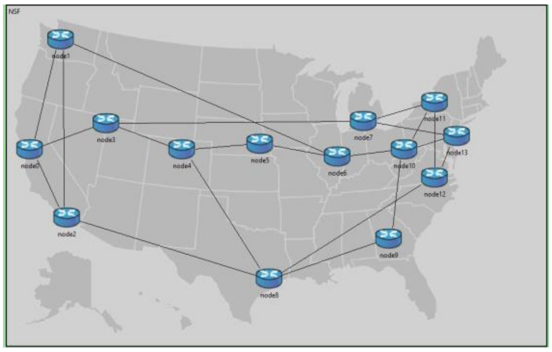

Fig. 2. NSFNET Topology.

After selection of the G-node, the network is converted into sparse grooming network. In this network, only G-node has the capacity to multiplex low-speed connections on high-speed channel.

Survivability is implemented in this sparse grooming network. CQS is providing survivability for the failure of the link. Shared protection is used to provide survivability if the link failure occurs. Due to shared protection, only spare capacity of the other links will be used in case of the failure. This will help to reduce the cost of the survivable network as any extra resources are not used. The main task of our implementation is the use of combiner queues for traffic grooming network.

A. Combiner Queue

At each node, there is a use of a queue for each wavelength. The network is using WDM which divides a channel into n small wavelengths. If we divide wavelengths into more wavelengths then it makes more wavelengths available for assignment at each node. But an increase in number of wavelengths increases the requirement of ADM or OADM. Therefore dividing the channel into 3 or 4 wavelengths will give optimum results and the requirement of ADM or OADM will be reduced. So in the given network, we have combined these queues of different wavelengths as one queue at a node. This will help to reschedule the wavelength assignment at that node. This is mathematically represented as

T be the total time we required for the simulation. As the scope of the paper, we are considering that time for mathematical representation of data.

$\lambda 1, \lambda 2, \lambda 3$ be the arrival rate of the queue 1, 2, and 3 respectively.

λ_i be the arrival at the i^{th} combiner queue which is the sum of all its sub-queues.

$$\lambda_i = \lambda 1 + \lambda 2 + \lambda 3 \quad (1)$$

Total number of requests at one queue for time T is

$$\mathrm{N}_i = \lambda_i T \quad (2)$$

Now the total number of packets arrive at a node *d* is given by sum of all packets in all queues

$$\mathrm{N}_d = N_i + N_{i+1} + N_{i+2} \quad (3)$$

Therefore

$$\mathrm{T}_d = \frac{\mathrm{N}_d}{\sum_{d} \sum_{i=1}^{l} \lambda_i} \quad (4)$$

where *l* is the number of fiber links at that node which is a nodal degree of the node. As the nodal degree of each node is different the number of requests served by every node at the *T* moment of time is different and therefore total number of requests served by the network is given by

$$\mathrm{N} = \mathrm{N}_1 + N_2 + N_3 + \ldots\ldots + N_{14} \quad (5)$$

And the total time spend by the request in the queue is given by

$$\mathrm{T} = \frac{N : \sum_{j=1}^{14} \mathrm{N}_j}{\lambda : \sum_{i=1, j=1}^{nl, j} \lambda_i} \quad (6)$$

The service rate μ at each node will vary as utilization of the network is

$$\rho = \frac{\lambda}{\mu} \quad (7)$$

From above queuing theory, it is easy to calculate the blocking probability at a node. The blocking probability of the network is

$$P\{block\} = \begin{cases} p_0 \dfrac{m^m \rho^n}{m!} & n > m \\ 0 & otherwise \end{cases} \quad (8)$$

where *n* is total arrived calls and *m* is the total available channels.

The architecture of the combiner queue is as shown in Fig. 3. In this Fig. 3 we see that the combiner queue has infinite capacity. But due to life of call request and real time data the infinite capacity is not considered in the implementation. So we are considering the buffer available at queue is twice that of the carrying capacity at that node. This will help to reduce the waiting time as compared to the infinite buffer case of combiner queues. In any network infinite buffer is not the solution. Due to the consideration of buffer capacity equals to twice the carrying capacity at that node, transfer of data to its destination is possible in the time period less than the RTT (round trip time). As optical fiber provides a capacity of Tbps this buffer capacity which we considered is appropriate and is proved by the results.

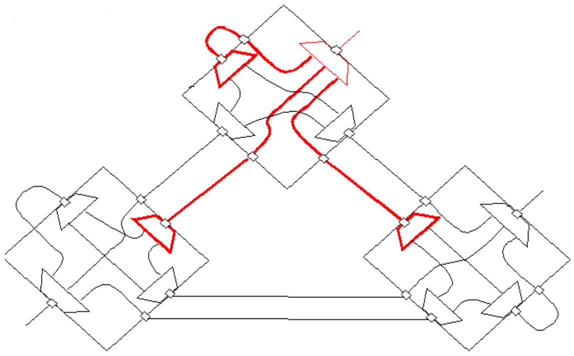

Fig. 3. Architecture of combiner queue.

B. Path Protection

In the fault tolerant system when a fault occurs at any link or link fails due to some disasters then there is a need to provide survivable solution to the situation. For the failure survivability the schemes which provide the solution is protection and restoration. There is shared protection and dedicated protection. In the dedicated protection scheme there is a dedicated alternate path or link is made available if the failure occurred. Whereas in shared protection the protection to the path or the link is provided as a shared resource between the two or more paths or link. If the dedicate resource is provided the cost of the network is increased while shared resource reduce the cost in comparison with dedicated protection.

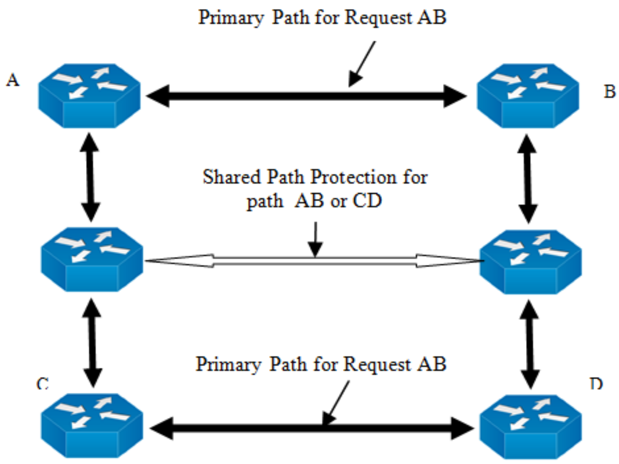

Fig. 4. Shared path protection for two different routes

We are using the shared protection to the link failure. The number of calls on the failure link will be transmitted to other link. The queue which is used at the failure link will use other queues at that node and reschedule the assignment. The queues help to buffer the request for some Δt time and assign the wavelengths available. So the number of queues available in the network to provide service remains same. And the call blocking probability will not be affected. If the protection is not used then all the calls coming to the link will not get served and the number of dropped calls increases due to failure of that link. The protection of the link also has the combiner queues. The shared protections are as shown in Fig. 4. In this figure there are two links one is from node A to node

B and other is from node C to node D. These links are the primary roots of the network. To these routes one shared protection is provided which is common for both link A-B and link C-D. One can have n request over these links and these may be routed differently as load changes but the protection is shared and gives optimal performance as discussed in the result section. When this shared protection is used and a link fails no change in the performance has observed. Whereas if two or more links fails which is using the same shared protection then there is small increase in the call block and call drop. This call blocking probability is negligible. The occurrence of two or more link failure at a time for the links which share a common protection is rare.

C. Heuristics for Link Failure Survivability

This heuristic algorithm for link failure provides protection to the link if failure occurs\. Initially the network works at normal situation and generates the Poisson traffic. Each request originated at a node as source node has destination node address and the size of bandwidth required by the request. This size helps to find out the required wavelength capacity for that request. The node runs the wavelength assignment algorithm and routes the request using the routing algorithm. A protection to the link is provided in the advance. If any failure is detected then heuristic will help to complete the call.

Algorithm: Heuristics for Link Failure Survivability

1. *Generate the Poisson traffic with source S and destination D of size S*
2. *Assign wavelength W_i as per best-fit wavelength assignment algorithm*
3. *Route package P through wavelength W_i*
4. *PROTECTION [] [] // stores alternate route*
5. *For every Package P*

N_i = Current Node
N_x = Next Node in the route of package P
N_{f1} = failed link endpoint 1 //Null if no failed link
N_{f2} = failed link endpoint 2 //Null if no failed link
IfLink failure occurs
N_{f1} = failed link endpoint 1
N_{f1} = failed link endpoint 2
Request will be rescheduled by combiner queue
Set FAIL_FLAG = true
If FAIL_FLAG = True
If (N_i = N_{f1} AND N_x = N_{f2}) OR (N_i = N_{f2} AND N_x = N_{f1})
Then send "Route Failed" message & use the protection link.
N_x=PROTECTION[i][D]
Forward the request package P in the queue connected to N_x
Assign wavelength W_i as per best-fit wavelength assignment algorithm
Route package P through wavelength W_i

IV. Results

We have used combiner queues for the selection of the G-node. Not only the selection of grooming node is done with the use of combiner queue but also we have used these queues for reducing the call blocking probability. This is mathematically represented as shown in equation 1 to equation 8. The call blocking probability for the selection of G-node is as shown in Fig. 5. These nodes which have proved less blocking probability at the selection of the G-node will be considered and the other nodes are non grooming nodes. The failure of the link may occur between any two nodes. These nodes may be a pair of grooming nodes or one grooming and one non grooming node or two non grooming nodes. The combiner queues at these nodes are used to work on the failure of the link. If the particular link will fail then all the requests on that link will use the link protection method. Using this method the alternate link is made available for the transfer of the request. These calls will be served on the given protection link. All virtual paths will be established through the given link.

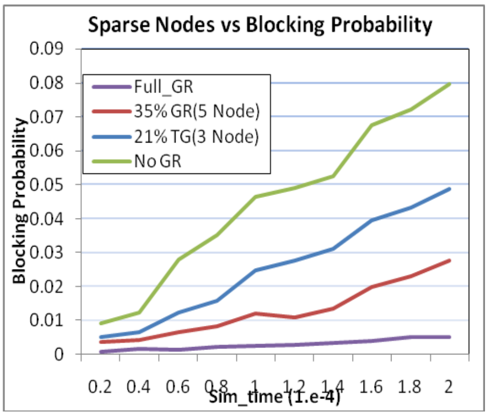

Fig. 5. Blocking probability Vs time for different grooming schemes.

As the arrival of call request is Poisson process, the rate of arrival is very large and the arrival rate varies from node to node. This arrival also varies from channel to channel at the same node. This is also represented in the given mathematical representation.

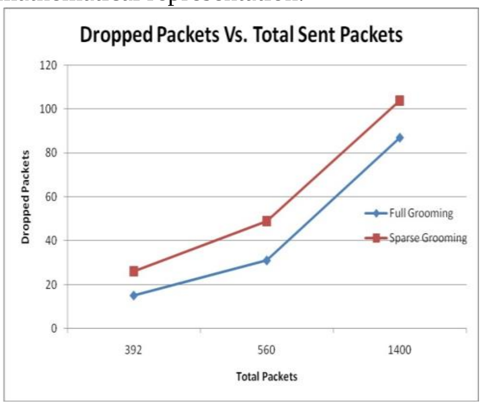

Fig. 6. No. of calls dropped Vs arrival rate when link failure.

We also calculated the number of dropped call for which there was no channel available in time. When the number of requests goes on increasing the call drop ratio is as shown in Fig. 6. The call drop is only for the situations in the full grooming and sparse grooming when a link failure occurs. It also applies to the multiple failure of the link as the shared protection is available for the failure. If the two links for which the protection is shared will fail then there is increase in the call drop.

We also calculated the blocking probability for each node against the number of requests generated at that node when a link is failed. The result of blocking at each node against the total traffic is as shown in fig. 7. This failure of the link also affects the call blocking probability. When there is increase in arrival rate the call blocking probability goes on increasing. But when the traffic in the network is too high the call blocking in sparse traffic grooming is nearly equal to the call blocking probability in full grooming even after the failure of link.

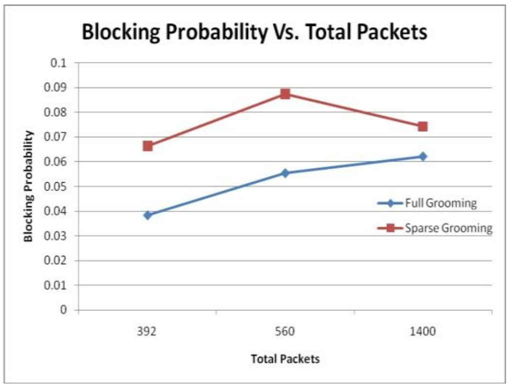

Fig. 7. Call blocking probability Vs arrival rate at each node.

V. Conclusions

Combiner queues will be useful for the selection of the G-nodes. The network of these G-nodes which is sparse grooming network when used for fault tolerance will give a good performance. The network using survivability that is when a link fails then CQS achieve optimal results in terms of call blocking probability and call drops. Therefore we conclude here that the use of combiner queues not only helps for the sparse grooming but also helps for the survivability. The queue holds the request in it which helps to re-route the call request when a link failure occurs. Shared link scheme used for survivability helps to reduce the cost of the network.

References

[1] B. Mukherjee, *Optical WDM Networks*; New York: Springer, 2006.

[2] M. N. Dharmaweera, J. Zhao, L. Yan, M. Karlsson, and E. Agrell, "Traffic-grooming- and multipath-routing-enabled impairment-aware elastic optical networks," *IEEE/OSA J. of Optical Communications and Networking*, vol. 8, no. 2, pp. 58-70, Feb. 2016.

[3] C. Wei, Q. Shen, H. Liu, and Y. Chen, "A grooming nodes optimal allocation method for multicast in WDM networks," *Advances in OptoElectronics*, 2016.

[4] S. Zhang, H. Peng, M. Sui, and H. Liu, "A multicast sparse-grooming algorithm based on network coding in WDM networks," *Journal of Optical Communications*, vol. 36, no. 1, pp. 17-23, Jan. 2016.

[5] S. R. Shinde and S. Patil, "Heuristics for sparse traffic grooming in dynamic WDM optical mesh networks," in *Proc. International Conference on Computing Communication Control and Automation (ICCUBEA)*, Pune, 2015, pp. 159-163.

[6] S. R. Shinde, S. H. Patil, and M. Gulwani, "Modified multiobjective metaheuristics for sparse traffic grooming in optical WDM mesh networks," *Elsevier Proc Comp. Sci. J.* vol. 57, pp. 980-987, 2015.

[7] A. K. Pradhan, S. Ghose, and T. De, "Multicast protection and grooming scheme in survivable WDM optical networks," *J. Optical Switching and Networking*, vol. 19, no. 2, pp. 42-57, January 2016.

[8] S. R. Shinde, S. H. Patil, S. E. Roslin, and A. S. Shinde, "Fault tolerant system for sparse traffic grooming in optical WDM mesh networks using combiner queue," *IJACSA International Journal of Advanced Computer Science and Applications*, vol. 7, no. 3, pp. 176-180, 2016.

[9] C. (Sam) Ou, K. Zhu, H. Zan, L. H. Sahasrabuddhe, and B. Mukherjee, "Traffic grooming for survivable WDM networks—shared protection," *IEEE Journal on Selected Areas in Communications*, vol. 21, no. 9, November 2003.

[10] M. Liu, M. Tornatore, and B. Mukherjee, "Survivable traffic grooming in elastic optical networks—shared protection," *Journal of Lightwave Technology*, vol. 31, no. 6, March 15, 2013.

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