An Efficient Approach for Lightpath Restoration in WDM Networks

S. M. Humayun Kabir, Van Su Pham, and Giwan Yoon, *Member, KIMICS*

Abstract—WDM is an incredibly promising technique in which multiple channels are operated along a single fiber, providing the facilities of terabit per second bandwidth. Thus, the survivability of WDM networks becomes critical for the success of the next generation internet architecture. Despite the fact that the path-based proactive restoration scheme guarantees 100% restoration as it computes a backup light path while the primary light path is being set up, this method results in additional capacity consumption. In this paper, an ideal technique is proposed that modifies the active multi-backup paths method and results in a better restoration scheme. Based on a theoretical analysis, a new method is shown to reduce the number of hopes as well as the restoration time.

Index Terms—Lightpath, Wavelength Division Multiplexing (WDM)

I. INTRODUCTION

Networks using wavelength division multiplexing (WDM) are considered to be a promising candidate for the future wide-area backbone networks. WDM divides the tremendous bandwidth of a fiber into many non-overlapping wavelengths (or wavelength channels) which can operate simultaneously, with the fundamental requirement that each of these channels operates at different wavelengths. As the network failure in a system may seriously impair the service continuity to its end users, the survivability has become an important issue in the case of WDM networks. Light path can be defined as the optical communication channel between two nodes in a network. It is established by allocating a particular wavelength channel. Although WDM may provide larger amount of bandwidth to its user it also has some critical problems. As the fiber carries a huge amount of traffic a single link failure can cause a serious damage in WDM system.

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II. RESTORATION SCHEME

A number of restoration methods for WDM optical networks have been employed [1] [3] [5]. At the first step, the restoration scheme can be classified into two broad categories that are reactive and proactive. In the first case of reactive restoration scheme, the backup light path is searched after the working light path fails. As the searching technique is applied after the link failure this method does not provide 100% recovery as there may not be available backup path due to the lack of available network resources and spare capacity of the network. The reactive restoration scheme is the easiest way of recovering a failure. To overcome the limitations of reactive method, a proactive method is introduced. In the case of the proactive method, a backup light path is recognized at the time of the establishment of the primary lightpath. The backup path takes the place of the failed primary lightpath. As the backup lightpath is searched before the failure of the primary lightpath, the proactive method ensures 100% recovery when the failure occurs.

The proactive and reactive methods are either *link-based* or *path-based* [6]. The link-based method employs *local detouring* whereas the path based method employs *end-to-end detouring*. The link-based method reroutes traffic around the failed component. When a link fails, a new path is selected between the end nodes of the failed link. This path along the working segment of the primary path will be used as the backup path. This method has some basic limitations such as the limitations of the backup path; the length of the backup path is usually longer. The most fundamental issue is that the wavelength assignment that is the backup path has to use the same wavelength of the primary light path as the working segment of the primary lightpath is retained [6].

On the other hand, in the path-based restoration method a backup path does not need to retain the working segment of the primary light path. In this case, the backup path can use any wavelength, except for the one used by the corresponding primary light path.

A. Path-Based Method

In path-based method, the FNM (Failure Notification Message) is sent from the first node next to the failure to the destination node along the primary path, notifying it that a failure has occurred. The following figure illustrates this technique.

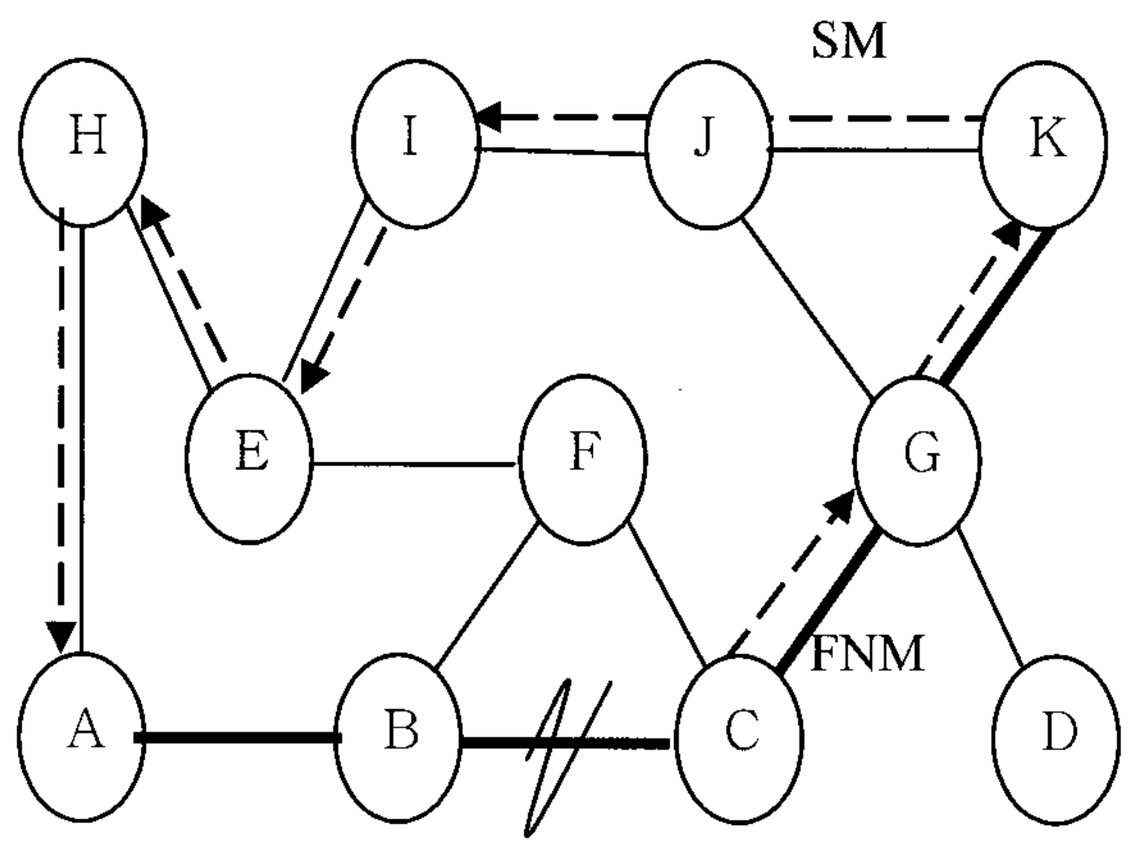

Fig. 1 Path-based method

Fig. 1 represents the example of path-based method. When the link failure between node B and node C occurs along the primary path A-B-C-G-K, the first node next to the failure, C sends an FNM to destination node K. Node K then sends a SM(Setup Message) to source node A using the link disjoint backup path K-J-I-E-H-A to configure the cross-connects in that path. Then node A, the source node resends the lost traffic through backup path A-H-E-I-J-K. Hops need to restore the path is 1 (for FNM) + 5 = 6.

B. Multi-Backup Method

In the multi-backup method, a backup path from each node along the working path to the source node is calculated. The backup path must be link-disjointed with the working path. Hence, some nodes might not have backup paths to the source node; these nodes are called as unsupported nodes and the nodes which have a backup path to the source node are called as the supported node [1]. The network in Fig. 2 illustrates the mechanism of multi-backup method.

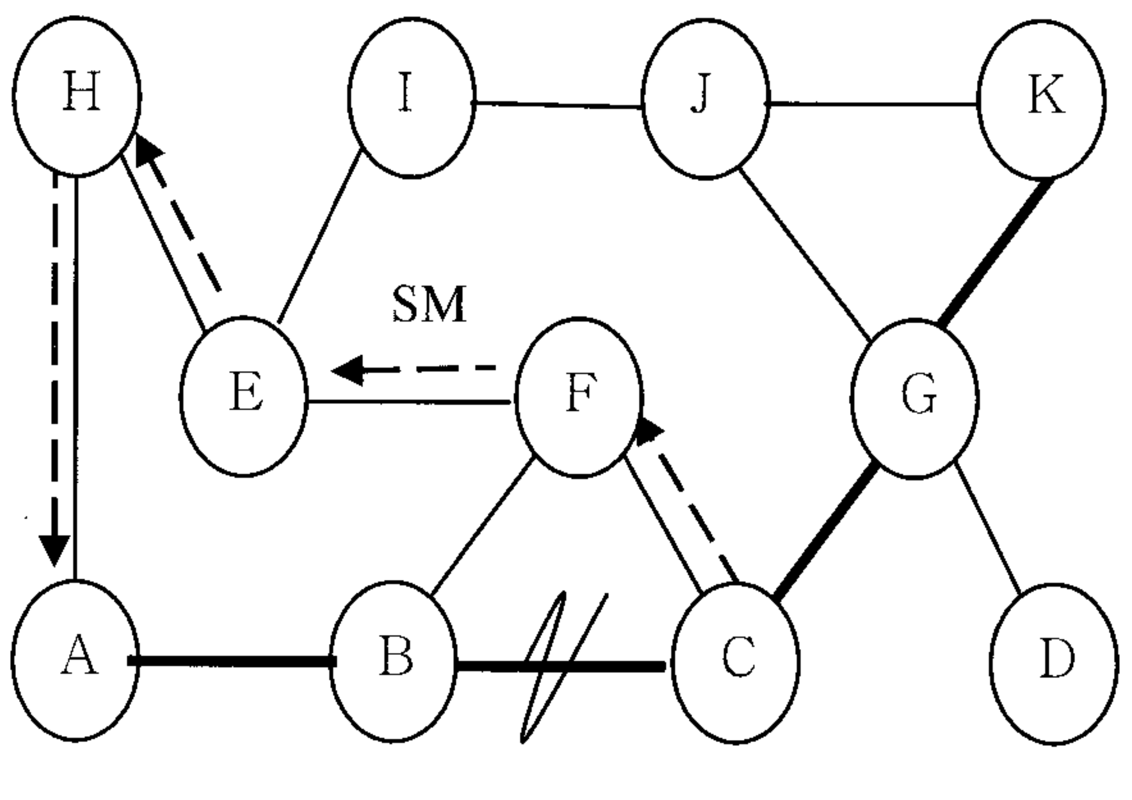

Fig. 2 Multi-backup method

From Fig. 2, when the link failure between node B and node C occurs along the primary path A-B-C-G-K, the first node next to the failure, C, as it is a directly connected to the source with a link disjoint backup path is called as the supported node, sends the Setup Message to the source node A using the path C-F-E-H-A to configure the cross connects along the path. Then, the node A resends the lost traffic through the path A-H-E-F-C and the rest of the working links of the primary light path C-G-K. Thus, the hops is needed to restore the path are 4.

III. PROPOSED METHOD

This paper proposes an improved method for light path restoration in WDM networks. In this case, when a link failure happens in a network, the next node to the failed link will identify that a failure has occurred in the network. Now if the node is not supported, then it will send the FNM (*Failure Notification Message*) to its next node until a supported node is not found. If the supported node is not found throughout the destination, the destination node then accepts the FNM and sends the SM (*setup message*) to the source node, then the source node sends the remaining data to the destination using the same path used for sending SM. In other case, if the node immediately after the failure link gets a supported node through the working path or the node itself is a supported node, then it sends the SM to the source using the shortest path to that node and the source node. The shortest path is calculated using Dijkstra's shortest path algorithm. It is noted that the working primary light path can be a part of this shortest path. Therefore it is considered that the wavelength cannel is available. When the source node gets the SM, it then sends the remaining data through the path used for sending SM to the node of the failure link. This node then forwards the data towards the destination using the working path of the primary lightpath. When any link failure will happen in a network the first node will continue to send the data to the next node of the filed link until a backup lightpath is not established to continue the data flow of the network.

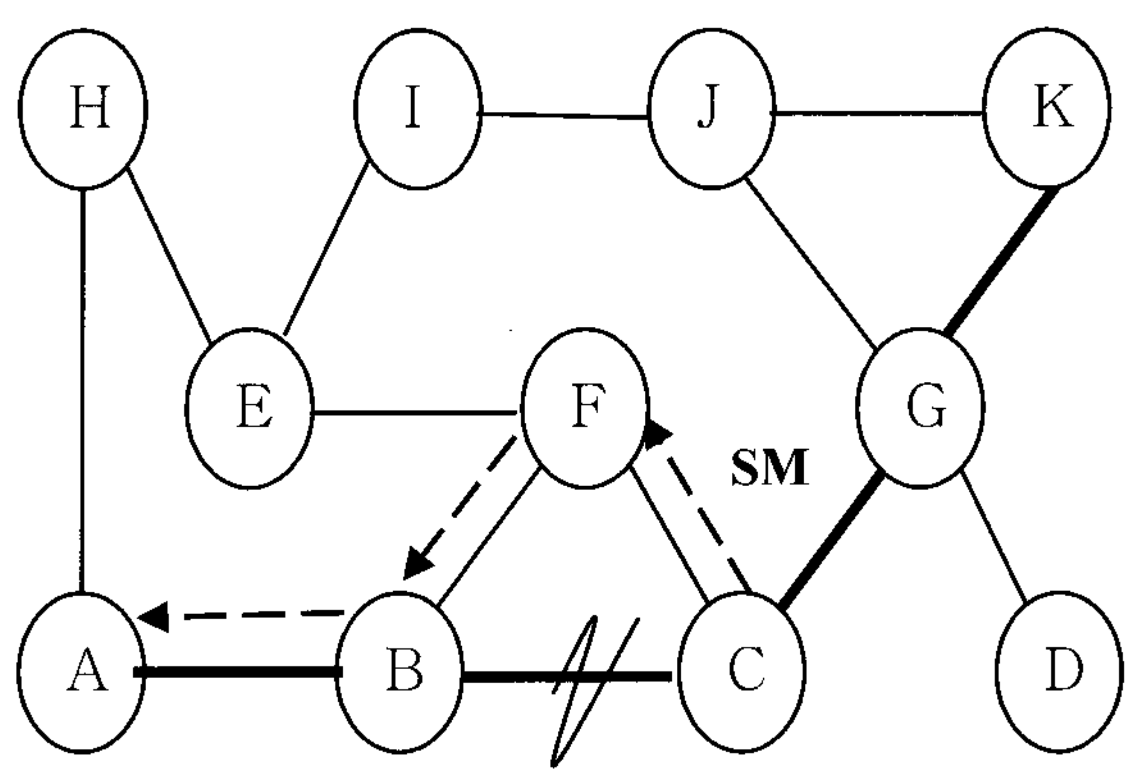

Fig.3 Proposed method

In Fig. 3 the proposed method is shown. When the link failure between node B and node C occurs along the primary path A-B-C-G-K, the first node next to the failure, C, as it is a directly connected to the source with a link disjoint backup path is called as the supported node, sends the Setup Message to the source node A using the path C-F-B-A to configure the cross connects along the path. After that, the node A resends the lost traffic through the path A-B-F-C and the rest of the working links of the primary light path C-G-K. Thus, the hops is needed to restore the path are 3.

A. Proposed Algorithm

1. Let total number of links be **P**
2. Select the foremost node next of the failed link from **P** and call it as **testNode**
3. repeat
   if(**testNode** is supported or **destNode**)
      Apply Dijkstra's Shortest Path algorithm between the **testNode** and the **sourceNode** and send SM to this path.
   else
      Send the FNM to the next available supported node.
   untill **testNode** is supported or **destNode**

4. Send data using the calculated path at step 3
5. Terminate

IV. EXPERIMENTAL RESULTS

A. Test Networks

The performance of the improved method has been compared with that of the active multi backup method. Two different networks have been taken out for the simulation result. The considered characteristics of the test networks are the number of nodes, number of links and average nodal degree. For comparison, two distinctive networks are taken; topology network 3 in [4] and the test network in [7] are used for the theoretical analysis.

Table I: The characteristics of test networks

Test Network	No of Nodes	No of Links	Average Nodal Degree
1	53	76	3
2	50	125	5

B. Numerical Results

Table II: The improvement of the path length in new method over the active multi-backup method for network 1.

	Improvement of the Path Length using Primary Working Path		
Method	2	3	4
Improved Method	25	25	24
ActiveMulti-Backup	27	29	30
Improvement (%)	11.11	13.79	20

First row of the above table depicts the improvement of the path length using primary working path. The second and third row shows the average number of hops for the path in improve method over the active multi-backup method. Finally, in the fourth row, the improvement percentage is shown.

Table III: The improvement of the path length in new method over the active multi-backup method for network 2.

	Improvement of the Path Length using Primary Working Path		
Method	2	3	4
Improved Method	26	27	28
ActiveMulti-Backup	30	32	35
Improvement (%)	10	15.62	20

First row of the above table depicts the improvement of the path length using primary working path, second and third row shows the average number of hops for the path in improved method over the active multi-backup method. Finally in the fourth row the improvement percentage is shown.

V. DISCUSSION

In an improved method for lightpath restoration, before failure the primary path calculation, based on the iteration of the Dijkstra algorithm, has the complexity of $O(n^2)$ for each primary path, where n is the total number of nodes in the network. After failure, the algorithm provides better restoration time. In this paper, the performance of the proposed restoration algorithm depends on the location of the failure. In the worst case, the time complexity of the proposed algorithm is $O(n)$, where n is the total number of the nodes in the network. The worst case is the case when the failure occurs just before the destination and the setup message needs to travel the nodes almost equal to the number of nodes in the primary path before the failure. So, this complexity is insignificant as compared to when the Dijkstra algorithm twice or active restoration method are applied.

The improved method reduces the number of hops and thus results in a better performance than the active multi-backup method.

VI. CONCLUSION

The proposed method shows better performance over the active multi-backup method. It is a new restoration scheme, reducing the backup path length, and hence the restoration time is also reduced. In this method, the backup path is chosen when a failure occurs, depending on the routing table of the adjacent nodes of the node next to the failure. For different networks, theoretical analysis, simulation, and comparison between the active multi-backup method and the proposed new method have been made. As a result, it seems clear that the new method can significantly reduce the restoration path and time.

ACKNOWLEDGMENT

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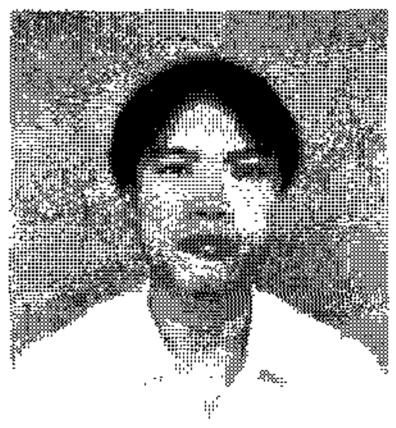

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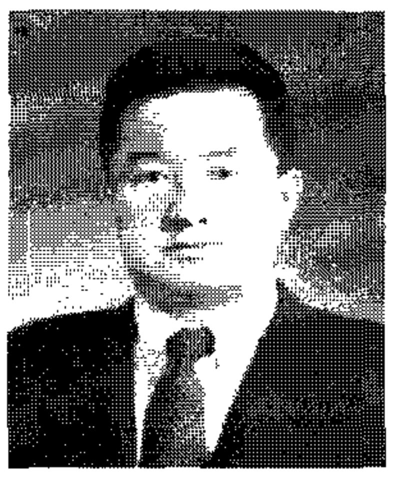

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