CHAPTER 4

HYBRID ADAPTIVE LOAD SHIFTING APPROACH FOR
FAULT RECOVERY IN OPTICAL WDM NETWORKS

4.1 INTRODUCTION

WDM networks play a significant role in telecommunication systems to face the demand for wider bandwidths. Technological growth and the emergence of new advents in WDM technologies require wavelength-routed channel, which will implement high bit rate applications in the network transport layer. Several researches were carried out and possible technologies were implemented to improve the performance in WDM networks. Based on the impact, failures are classified into Wavelength level failures and Fiber level failures. Wavelength level failures affect the light-path transmission quality, whereas, Fiber level failures have an impact on all the light-paths of an individual fiber.

It is very important to have survivable networks, which are able to prevent failures and reduce the data loss in the network caused by failures. The primary light-paths are solely responsible for transmitting information and hence more traffic during normal operation in survivable WDM networks. If there is any failure in primary light-path, then the traffic is rerouted to a new light-path called as backup light-path. Various protection and restoration methods are used to avoid such failures. The reported works (Saleh et al 2012 and Vladica Tintor et al 2012) have concentrated on wavelength capacity requirements, routing and wavelength assignment, and
protection-switching time requirements for path protection and link protection schemes.

Fault-tolerance is a mechanism that facilitates a network to carry on its operation, in-spite of any failures in the network. The motivation for this study is offered by prior studies devoted on the survivability problems (Ratnam et al 2006, Song Dong et al 2006, Sahu 2006 and Achille Pattavina 2006). The techniques for fault-management are static (or) protection fault management and dynamic (or) restoration fault management scheme. In static fault management scheme, backup route and wavelength are reserved during call setup. In dynamic fault management scheme, backup route and wavelength are dynamically discovered during call setup.

Generally, dynamic fault management schemes are more efficient in utilizing the capacity due to sharing of spare capacities, while static fault management scheme have a faster restoration time and provide guarantee on the recovery. The restoration time taken by the static scheme is much less compared to the dynamic scheme. The dynamic scheme cannot assure 100% restoration guarantee, since the resources are not reserved for a backup light-path. Though the static scheme has faster recovery time and assures restoration, it involves high overhead and blocking probability.

After careful investigation of the existing works, it is observed that the problems addressed above have not been suggested with proper solution. Thus, the objective of this work is to develop an algorithm, which provides a combined solution for the above problems. In this chapter, a hybrid adaptive load shifting algorithm for fault recovery is presented. Positive effects of protection and restoration schemes have been combined to reduce the link failures in the network. The overall goal of this approach is to attain minimum blocking probability and delay thereby increasing the channel utilization and throughput.
4.2 RELATED STUDY

Laxman Sahasrabuddhe et al (2002) developed fault management techniques for IP-over-WDM networks and they can be classified into two schemes namely IP Protection (Backup light-path and wavelength are preconfigured) and IP Restoration (Backup light-path and wavelength are discovered dynamically). They showed through simulation that the recovery time for WDM shared-path protection is much faster than the recovery time for IP restoration.

Path protection/restoration and Link protection/restoration are the two basic survivability approaches examined by Ramamurthy et al (2003). From the simulation, it has been showed that shared-path protection achieves better capacity utilization over dedicated-path and shared-link protection schemes. Also, it is proved that the path restoration survivability approach has better restoration efficiency than the link restoration approach.

Xuetao Wei et al (2008) developed an improved survivable light-path allocation algorithm after analyzing the survivability techniques for light-path allocation in single-link failure of optical WDM networks. The improved algorithm has better performance in the number of average interrupt light-paths with enhanced resource utilization ratio.

In optical networks, packet-oriented routing and switching results in packet loss and packet arrival delay at end systems. To overcome the problems addressed, He and Simeonidou (2005) presented a flow oriented routing and switching method. Results revealed that the suggested method achieves good throughput comparing with packet-switching routers.

A new heuristic algorithm called Shared Multi-sub backup-paths Reprovisioning (SMR) was implemented by Lei Guo (2007) to overcome the
problem of multiple failures in WDM networks. The reported SMR algorithm has the ability to recover from multiple failures.

Tzanakaki et al (2008) have studied the use of dynamic WDM network environment in core optical networks with focus on resilience issues and addressed the problem of efficiently provisioning light-paths with different protection requirements. Based on the survivability requirement of the network, various routing and wavelength assignment schemes are combined in their approach to enhance the spare capacity utilization and considerable decrease in the blocking probability of high priority traffic.

4.3 HYBRID ADAPTIVE LOAD SHIFTING APPROACH FOR FAULT RECOVERY

In optical network, quick detection and isolation of faults is essential for the robustness and reliability of both the network and services carried over it. An ANN based algorithm was developed to predict the failures and to guarantee proactive fast re-routing of these networks. In this section, Protection and restoration approaches are combined and implemented for recovering the network from failures. Srikanth et al (2009) developed a fault recovery algorithm which addresses the multi-path routing and fault recovery mechanism. However, it failed to address the adaptive load shifting mechanism. The suggested fault recovery algorithm addresses all the three issues and comprises of three phases:

1. Multi-path Routing: Based on the current load and blocking probability, multiple light-paths are established.

2. Hybrid fault recovery mechanism: Here, the advantages of the protection and restoration schemes are combined in which the light-
paths are sorted based on minimum load and blocking probability (Srikanth et al 2009).

3. Adaptive Load shifting: Heavy load is shifted effectively to other light-paths based on dynamic load changes in the network.

4.3.1 Algorithm to determine multiple shortest paths

**Step 1:** For every link \((l_i, L)\),

\[ C_i = BP + G; \]  \hspace{1cm} (4.1)

where, \(BP\) is the blocking probability, \(G\) is the current load of \(l_i\) and \(C_i\) is the link cost function.

**Step 2:** Find minimum-cost path between the source and destination using Dijkstra’s algorithm.

**Step 3:** Find the shortest paths \(P_i, i=1,2,\ldots,k\) such that \(C_i < C_o\), where \(C_o\) is the lower bound of the cost function \(C\).

4.3.2 Hybrid adaptive algorithm

**Step 1:** At time \(t_o\), let \(\{BLP\}\) is the set of light-paths with

\[ Load_{BLP(o)} = Load_{MAX}, \]

where \(Load_{BLP(o)}\) is the total traffic load of \(\{BLP\}\) at \(t_i\) and \(Load_{MAX}\) is the maximum load in the network.

**Step 2:** At the time of call setup, find a pair of fiber-disjoint backup path and a primary path.
2.1: A vector \( \{LP\} \) contains a sorted list of all the light-paths in virtual topology. The light-paths are arranged such that the light-path with minimum load and blocking probability will be the first element in the list.

while \( \{LP\} \) is not empty

Remove the first element \( LP_i \) of \( \{LP\} \);

Reroute the traffic again at time \( t_j \);

if \( \text{Load}_{B_{LP_{i,0}}} > \text{Load}_{B_{LP_{i,1}}} \), then

Restore the path \( LP_i \);

else

Repeat 2.1;
endif
end while.

2.2: Choose the first successful path \( LP_i \) from the list \( \{LP\} \) for routing the primary light-path. In case of any failures, choose the first successful path among the remaining alternate light-paths for routing the backup light-path.

Step 3: Wavelengths are reserved for the chosen backup path. If the wavelength cannot be reserved for the path, the next available path from the list \( \{LP\} \) is selected as backup path. Reroute the traffic over this backup path.

Step 4: Information about the topology and load changes in the network are updated by sending LSA messages by the routing protocol. Then by executing the steps 1 and 2 of the algorithm, primary and backup paths are once again calculated.
4.3.3 Adaptive Load shifting algorithm

Step 1: Let \( LP_1, LP_2, \ldots, LP_k \) be the set of light-paths for a given pair of source and destination sorted by their load and blocking probability. Let \( LP_1 \) be the primary light-path and other paths \( LP_i, i=2,\ldots,k \) are the alternate paths.

Step 2: Let \( \text{Load}_{LP_i} \) be the total load on the primary path \( LP_1 \) at time \( t \).

Step 3: Let \( \text{Load}_{\text{max}LP_i} \) be the maximum threshold value of the total load on the primary path, given by \( \text{Load}_{\text{max}LP_i} = CP_{\text{tot}LP_i} \);

where, \( CP_{\text{tot}LP_i} \) is the total available channel capacity of the path \( LP_i \).

Step 4: Let \( \text{Load}_{\text{shift}} \) be the load to be shifted from the overloaded path to least loaded alternate path.

4.1: If \( \text{Load}_{LP_i} > \text{Load}_{\text{max}LP_i} \), then

i) \( dp = \text{Load}_{LP_i} - \text{Load}_{\text{max}LP_i} \); \hspace{1cm} (4.2)

ii) \( \text{Load}_{\text{shift}} = \left( \frac{\text{Load}_{LP_i}}{2} \right) + dp \); \hspace{1cm} (4.3)

iii) \( \text{Load}_{LP_i} = \text{Load}_{LP_i} - \text{Load}_{\text{shift}} \); \hspace{1cm} (4.4)

iv) \( \text{Load}_{LP_i} = \text{Load}_{LP_i} + \text{Load}_{\text{shift}} \); \hspace{1cm} (4.5)

v) if \( \text{Load}_{LP_i} > \text{Load}_{\text{max}} \), then

Repeat 4.1;

vi) end if;

4.2: end if.
4.4 SIMULATIONS

The experiments are carried out to simulate a NSFNET under different traffic conditions and different link capacities. In addition to the hybrid adaptive load shifting algorithm, the performances of both static and dynamic fault management schemes are presented for comparison. For the experimental setup, various simulation parameters have been considered viz., number of nodes, link bandwidth, link delay, traffic arrival rate, traffic holding time, number of session traffics, packet size and maximum request.

4.4.1 Performance Metrics

The performance of hybrid adaptive load shifting algorithm is evaluated mainly, according to the following metrics:

1. Blocking Probability: It is the ratio of number of connection requests rejected to the total number of requests sent in the network.

2. Average end-to-end Delay: Sum of delay experienced by each packet with respect to the number of surviving packets from source to destination.

3. Packets Received: It is the average number of packets successfully received per unit time (seconds).

4. Channel Utilization: It is the ratio of bandwidth received into total available bandwidth for a traffic flow.

4.4.2 Results and discussions

In this section, the performance of the hybrid adaptive load shifting algorithm is compared with the existing static and dynamic fault management
algorithms. Traffic load of the network is compared with different performance metrics viz., blocking probability, end-to-end delay, packets received and channel utilization. The simulation is performed using a varying traffic load from 2MB to 14 MB in increments of 2 MB.

Figure 4.1 Variation of Blocking probability with load

Blocking probability with traffic load is depicted in Figure 4.1 for the suggested hybrid adaptive load shifting algorithm compared with the existing static and dynamic algorithms. It is clearly observed from the figure 4.1 that the blocking probability for hybrid adaptive load shifting algorithm is significantly lesser than the existing algorithms. The improvement is due to the selection of backup paths with least blocking probability and load. For example, when the load is 8 MB, the blocking probability for the hybrid
algorithm is only 0.2, whereas for static and dynamic algorithms, the blocking probabilities are 0.41 and 0.6 respectively.

![Figure 4.2 Variation of End-to-end delay with load](image)

**Figure 4.2 Variation of End-to-end delay with load**

Figure 4.2 shows the variation of average end-to-end delay with load for the static, dynamic and the suggested hybrid algorithm. It is seen from the figure 4.2 that hybrid algorithm has lesser delay than the existing algorithms. When a traffic load is 8 MB, the average end-to-end delay for the hybrid algorithm is 560ms. For static and dynamic algorithms, end-to-end delay is 1340ms and 2620ms respectively. This reduction in delay is due to
the recovery time involved in the dynamic fault management algorithm and is minimized to a greater extent in the hybrid adaptive load shifting algorithm.

Figure 4.3 Variation of Packet received with load

The variation of packet received with load is given in Figure 4.3 for hybrid algorithm compared with static and dynamic algorithms for various loading conditions. For a network load of 8 MB, it is observed that the number of packets received by the hybrid algorithm is 10300, whereas static and dynamic algorithms receive only 7012, 2995 packets respectively. The higher packet receiving capacity of the hybrid adaptive load shifting algorithm is due to the selection of primary and backup paths with least load.
Figure 4.4  Variation of Channel utilization with load

Figure 4.4 shows the utilization of channel by hybrid algorithm compared with the existing algorithms. For a traffic load of 8 MB, the figure 4.4 shows that the hybrid adaptive load shifting algorithm achieves utilization as 0.27 Mbps, whereas static and dynamic algorithms achieve 0.177 Mbps, 0.22 Mbps respectively. From Figure 4.4, it is proved that hybrid algorithm achieves comparatively better channel utilization than other algorithms, since it achieves load balancing by load shifting mechanism.
Figure 4.5 Variation of Blocking probability with nodes

Figure 4.5 shows the variation of blocking probability with number of nodes for the suggested hybrid algorithm compared with static and dynamic algorithms. Here, the number of nodes is varied from 2, 4, 6...14. Obviously, as the number of nodes increases, the blocking probability of hybrid adaptive load shifting algorithm is significantly lesser than the existing static and dynamic algorithms.
Figure 4.6 Variation of Blocking probability with time

Figure 4.6 presents the variation of blocking probability with time for the static, dynamic compared with the suggested hybrid algorithm. Here, the time is varied from 3, 6, 9,...21secs. It is clearly observed that the blocking probability of hybrid adaptive load shifting algorithm is significantly lesser than the existing algorithms, as time increases.

4.5 CONCLUSION

In this chapter, a hybrid adaptive load shifting algorithm for fault recovery in survivable WDM networks was discussed which combines the positive effects of protection and restoration approaches. Initially, multiple shortest light-paths are established based on the current load and blocking
probability. The first successful path is chosen as primary light-path for routing. When failure occurs, the backup path is selected as the first successful path among the alternate light-paths, and wavelengths are reserved for the backup path. If that wavelength cannot be reserved, the next available path from the list is selected as a backup path. Also, loads are adaptively shifted to alternate resource-efficient light-paths, based on the dynamic load changes. From the simulation results, it is shown that the suggested algorithm achieves reduced blocking probability and delay with increased channel utilization and throughput. After fault diagnosis in an optical network, network topology information changes have to be updated to maintain the correct light-path decision.