A Distributed Priority Based Routing Algorithm for Dynamic Traffic in Survivable WDM Networks

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Summary
Dynamic routing of a restorable connection necessitates the presence of a pair of link-disjoint primary and backup lightpaths online once a connection request arrives at the network. Diverse traffic classes are processed by a large-scale optical network with dissimilar fault tolerance requirements. Several previous work recommend a preemptive multi-class routing scheme, without considering the varying loads of dynamic traffic. This paper proposes a new distributed priority based routing algorithm intended for a variety of traffic classes, which employs the concept of load balancing to establish the primary and backup lightpaths. The proposed algorithm calculates the cost metric on the basis of the load on the links. The dynamic traffic can be classified into high and low priority. The routing of high priority traffic is performed over the lightly loaded links, in such a manner that the links with lighter loads are chosen instead of links with heavier-loads whilst routing the primary and backup paths. In addition, the resources can be shared between the high priority traffic's backup path and low priority traffic. Based on the simulation results, it has bee shown that the distributed priority based routing algorithm reduces the blocking probability and latency by means of increased throughput and channel utilization.
Keywords: *Multi-class Routing, Link Cost, Distributed, Priority, Load Balancing*

1. Introduction

The recent emergence of high-bit-rate IP network applications creating the need for on-demand provisioning of wavelength-routed channels with service-differentiated offerings within the transport layer. In order to accomplish the above requirements, diverse optical transport network architectures have been proposed, driven by fundamental advances in wavelength division multiplexing (WDM) technologies. The deployment of *all-optical networks* [1] has been made possible due to the availability of ultra long-reach transport and all-optical switching.

In general, the Wavelength-Division-Multiplexing (WDM) is considered as the most promising technology for the backbone of future next-generation internet [2]. In case of WDM all-optical networks, the data are routed in optical channels called lightpaths. In the absence of wavelength conversion capability, the establishment of a lightpath requires the usage of same wavelength along entire route of the lightpath, which is known as the wavelength continuity constraint [3].

In view of the fact that each lightpath can carry a huge amount of traffic, failures in such networks may seriously damage end-user applications. In accordance with the scale of their effect, failures in all-optical WDM networks can be classified into two categories [5]. One category is a wavelength-level failure which affects the quality of transmission of every individual lightpath. The other category is a fiber-level failure which impacts all the lightpaths on an individual fiber. As each lightpath is expected to operate at a rate of several gigabytes per second, a failure can lead to a severe data loss.

Therefore, it is very important to have networks that are capable of preventing such failures; these are known as survivable networks [6]. In survivable WDM networks, the lightpath known as primary lightpath carries traffic during normal operations. In case a primary lightpath fails, the traffic is rerouted over a new lightpath known as the backup lightpath. The protection and/or restoration schemes can be used to protect the network against failures.

1.1 The Routing and Wavelength Assignment (RWA) Problem

This section addresses the static routing and wavelength assignment (RWA) problem, also known as the Static Lightpath Establishment (SLE) problem. In case of SLE, lightpath requests are known in advance, and the routing and wavelength assignment operations are performed off-line. The intention is to minimize the number of wavelengths required to set up a certain set of lightpaths for a given physical topology.

In adaptive routing, the selection of the route from a source node to a destination node is performed dynamically, on the basis of the network state [13]. The set of all connections that are currently in progress determine the state of the network. One form of adaptive routing is adaptive shortest-cost-path routing, which is well-matched for use in wavelength-converted networks. In this approach, each of the unused links, used links and wavelength-converter links in the network has a cost of 1,

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∞, c units respectively. In the absence of wavelength conversion, $c = \infty$. Once a connection arrives, the shortest-cost path between the source node and the destination node is computed. In case of multiple paths with the same distance, any one path is selected at random.

Centralized Algorithm (CA): In the centralized scenario, when a demand arrives at the source node, the demand information is sent to a network management system (NMS) by the source node. The NMS runs a centralized routing algorithm for the determination of a primary/backup path pair for the demand [12]. Subsequently the determined routes are sent back to the source node. Then a signaling procedure is carried on by the source node in order to set up the primary lightpath and reserve backup channels along the backup path.

Simple Distributed Algorithm (SDA): In the distributed scenario, the computation of the primary and backup paths for an arriving demand is the responsibility of the source node [12]. As it is impossible for each node to maintain the complete network status information, only limited network status information is maintained by each node. This limited information is used for the path computation. According to the simple distributed algorithm, each node only knows whether each link has a free channel. The primary path is computed as in the case of the centralized algorithm. However in the backup path computation, the links along the chosen primary path and the links with no free channels are excluded by the algorithm, which then computes the shortest path in the graph as the backup path.

The following section discusses the other existing works on this routing problem.

The objective of the dynamic routing algorithm is the acceptance of maximum possible demands under the network resource constraint. This objective is fulfilled by CA by means of identification of a primary/backup lightpath pair that employs the minimum number of free channels for the current demand. Hence more network resources are left for the future demands. However, CA is not scalable to large networks due to its centralized nature. The failure of the NMS can bring down the entire network. Alternatively, even though there is no scalability problem and the single point of failure problem of CA in SDA, the performance of SDA in terms of the number of demand blocking is much worse than that of CA.

This paper developes a new distributed routing algorithm that can achieve a performance close to that of CA. The proposed algorithm employs the concept of load balancing to establish the primary and backup lightpaths, which achieves a blocking performance equal to that of a centralized algorithm.

The proposed algorithm determines the cost metric on the basis of the load of the links. The dynamic traffic is classified as high and low priority. The routing of high priority traffic is performed over the lightly loaded links, in such a manner that the links with lighter loads are chosen instead of links with heavier-loads whilst routing the primary and backup paths. In addition, the resources can be shared between the high priority traffic's backup path and low priority traffic.

This paper is organized as follows. Section 2 gives the detailed related work done in WDM. Section 3 presents the distributed QOS based routing algorithm. Section 4 gives the experimental results and section 5 concludes the paper.

2. Related Work

Harsha V. Madhyastha and N. Balakrishnan [6] have considered the problem of Routing and Wavelength Assignment (RWA) in Virtual-Wavelength-Path (VWP) routed networks and took up the novel approach of not only minimizing the network cost, in terms of number of wavelengths and number of wavelength converters, but also maximizing the resource utilization, measured by the average weighted hop count. They discuss a heuristic algorithm for routing which not only tries to minimize the number of wavelengths required (NWR) but also minimizes the average number of hops taken up by a lightpath. They have also discussed a wavelength assignment procedure which minimizes the number of wavelength converters required.

Mohan et al. [7] have discussed different methods for the pro-active fault-tolerant routing problem. The discussed methods differ in their complexity and performance. All the discussed methods employ backup multiplexing technique to efficiently use the wavelength channels, which improve the network performance. All the discussed methods were evaluated through extensive simulation experiments on different networks with different connectivity.

Maciej Kurant, Patrick Thiran [8] have extended all the theoretical results in to the presence of multiple link failures.

Arun K. Somani et al[9] have studied the performance of source based routing algorithms with partial information routing. According to them, due to the dependency on the partial information for making dynamic routing decisions, the capacity redundancy in the network is high. They suggested a dynamic routing algorithm that employs a simple segmented path protection scheme as a means to improve capacity efficiency. They performed a comparison of the performance of partial information routing algorithm with and without segmented path protection through simulation studies.

Lei Guo [10], have performed a study on the problem of surviving multiple failures in WDM networks, and discussed a new heuristic algorithm called SMR. A comparison with previous algorithms reveals that the survivable performance of SMR can be significantly improved.

Barbato et al. [11] have considered the future scenario of WDM networks designed and optimized for static traffic and then employed to provide lambda-connection service on demand, which leads dynamic low-priority optical connections to co-exist together with static high-priority connections on the same optical network. They have discussed and tested an advanced routing algorithm able to reduce blocking of future connections in different ways. By means of dynamic traffic simulations they illustrate the performance improvement of the advanced routing algorithm compared to other well-known classical solutions.

3. The Distributed QOS Based Routing Algorithm

In this algorithm, link loads are taken into consideration in the establishment of lightpaths. (ie) We consider the links with lesser loads than the links with heavy loads, for primary and backup path routing, since considering load balancing in demand routing can improve the demand blocking performance. Initially we classify the traffic flows as Class-I and Class-II flows, depending on their priority. Thus most important data with high priority is considered as Class-I flows and remaining data with least priority, is considered as Class-II flows. Furthermore, high priority traffic's backup path can share resources with low priority traffic. So we will modify the general link cost function to improve wavelength resource sharing.

3.1 Network Model

The network topology is denoted as $G(N, L, W)$ for a given survivable meshed WDM optical network, where N is the set of nodes, L is the set of bi-directional links, and the W is the set of available wavelengths per fiber link. $|N|, |L|$, and $|W|$ denote the node number, the link number and the wavelength number, respectively. We assume each required bandwidth is a wavelength channel and each node has the O/E/O wavelength conversion capacity. Simply, a standard shortest path algorithm (e.g., Dijkstra algorithm) can be used to find the connection's primary path and link-disjoint backup path. After finding the shortest primary path, the links traversed by the primary path will be removed. In the residual graph, the shortest backup path is selected by a standard shortest path algorithm.

3.2 Computing Primary and Backup Paths for Class-I (High Priority) Flows

A. Computing Primary Path

The link cost function for primary path computation is designed based on the following steps:

1) For each link L_i , $i = 1,2,3,\cdots$ calculate the load index of the link L_i as

$$Load(L_i) = Ch_f / Ch_n \qquad (1)$$

Where Ch_f is the number of free channels in that link and Ch_n is the total no. of channels in that link.

2) The link cost function $C(L_i)$ is then defined as

$$\begin{aligned} C(L_i) &= 1 - Load(L_i), \text{ if } Load(L_i) > L_{thr} \\ &= 1 + Load(L_i) \text{ , if } Load(L_i) > 0 \\ &\quad \text{and } Load(L_i) <= \mathrm{L}_{\mathrm{thr}} \\ &= \infty, if\ Load\ (L_i) = 0 \qquad (2) \end{aligned}$$

Where L_{thr} is the load threshold.

3) After we assign each link a cost using the above formula, Dijkstra's shortest path algorithm is then used to compute the least-cost path as the primary path. If the least-cost path has a cost of infinity, then the demand is blocked; otherwise a backup path is computed using the method given in the next subsection.

B. Computing Backup Path

In the backup path calculation, the link cost function is selected based on the no. of free channels as well as the no. of backup channels in a link.

1) For each link L_i, $\mathrm{i} = 1,2,3,.....$ calculate the load index of the link Li as

$$Load(L_i) = (Ch_f + Ch_b) / Ch_n \qquad (3)$$

Where Ch_f is the no. of free channels, Ch_b is the no. of backup channels and Ch_n is the total no. of channels in that link.

2) The link cost function $C(L_i)$ is then defined as

$$C(L_i) = \infty \text{, if } Load(L_i) = 0 \ = \ 1 - Load(L_i), \text{ Otherwise} \qquad (4)$$

After we assign each link a cost using the above formula, Dijkstra's shortest path algorithm is then used to compute the least-cost path as the backup path. If the least-cost path has a cost of infinity, then the demand is blocked; otherwise, the demand is admitted.

3.3 Computing Primary and Backup Paths for Class-II (Low Priority) Flows

A. Computing Primary Path

We will adopt the general link cost function to compute the low priority traffic's primary path.

General Link Cost Function. We will define the link cost function in the following which will be used for computing the primary and backup paths to implement the wavelengths sharing.

The capacity of link L_i, $i = 1,2,3,.....$ can be divided into three types:

1. Free capacity (f_i): the free capacities that can be used by the following primary or backup paths.

2. Reserved capacity (RC_i): the reserved capacities of some backup paths.

3. Working capacity (W_i): the working capacities of some primary paths and can not be used for any other purpose until the corresponding primary path is released.

The link cost function $C(L_i)$ for finding a primary path with requested bandwidth (*RB*) is calculated as

$$C(L_i) = \infty \text{ if } f_i < RB$$
$$= c_i \text{ , if } f_i > RB \quad (5)$$

Where c_i is the basic cost of link L_i that is decided by physical length of the fiber link, the expense of fiber link installation, and so on.

B. Computing Backup Path

Because the high priority traffic's backup path can share resources with low priority traffic, so we must consider the factor into the link cost function for low priority traffic's backup path. With the requested bandwidth (*RB*) and the found low priority traffic's primary path, the reserved capacity $R_C(L_i)$ along link L_i can be further divided into three types:

(b) Non-sharable capacity $(N_C(L_i))$: the capacities reserved by some protected path(s) and is not shared by $FHPP_S$, where the "high priority traffic's protected path(s)" should not be link-disjoint with $FHPP_S$.

(c) High priority traffic's capacity $H_C(L_i)$: the capacity reserved by high priority traffic's backup path(s) and is shared by low priority traffic's backup path(s).

The link cost function $C(L_i)$ for finding a backup path for low priority traffic's primary path with requested bandwidth (RB) is calculated as

$$= \infty \text{ if } H_C(L_i) + N_C(L_i) < RB$$

$$C(L_i) = \frac{RB - H_c(L_i) - N_c(L_i)}{f_i}, \text{ if } H_c(L_i) + N_c(L_i) \geq RB \quad (6)$$

3.4 Distributed Algorithm

Step1: Wait for a request,

1.1 if the request is high priority traffic, then
  1.1.1 go to step 2;
1.2 if the request is low priority traffic, then
  1.2.1 go to step4;
1.3 otherwise, update the network state.

Step2: Compute the primary path for this high priority connection according to (1),

2.1 If the primary path is found, then
  2.1.1 record routes information and wavelength assignment.
  2.1.2 Update the network state and link cost function,
  2.1.3 goto step 3.
2.2 If either the primary path or available wavelengths is not found, then
  2.2.1 go to step 5.

Step3: Compute the backup path for this high priority connection according to (4),

3.1 If the backup path is found, then r
  3.1.1 record routes information and wavelength assignment.
  3.1.2 Update the network state and link cost function,
  3.1. 3 go to step 1.
  3.2 If either the backup path or available wavelengths is not found, then
  3.2.1 go to step 5.

Step4: Compute the working path for this low priority connection according to (3),

4.1 If the working path is found, then
  4.1.1 record routes information and wavelength assignment.

4.1.2 Update the network state and link cost function,
4.1.3 go to step 1.
4.2 If either the working path or available wavelengths is not found, then
4.2.1 go to step 5.

Step5: block this request and go to step 1.

3.5 Control Mechanism

After a pair of primary and backup paths is computed by RLBH, signaling procedures need to be carried out to setup the primary lightpath and reserve wavelength channels for the backup lightpath.

For primary lightpath setup, a reservation message is sent along the primary path. Each intermediate node reserves one free channel using first-fit wavelength assignment (i.e., the first free channel is reserved). After the destination receives the reservation message, it sends an acknowledgment message (ACK) back to the source node. Each intermediate node configures its cross-connect upon receiving the ACK and forward the message to the next node toward the source.

In parallel with primary lightpath setup, a similar procedure is carried out for backup lightpath reservation. For each link on the backup path, first-fit wavelength assignment is used to choose a backup channel or a free channel for the backup lightpath.

Unlike primary lightpath setup, the cross-connects in the nodes along the backup path cannot be configured at this time due to backup sharing. The configurations are done when the backup lightpath needs to be activated to restore traffic after the primary lightpath fails.

4. Simulation Results

In this section, we examine the performance of our new distributed OoS aware priority based routing algorithm with an extensive simulation study based upon the ns-2 network simulator. We use the Optical WDM network simulator (OWNs) patch in ns2, to simulate a NSF network (Fig.1) of 14 nodes. Various simulation parameters as given in table 1.

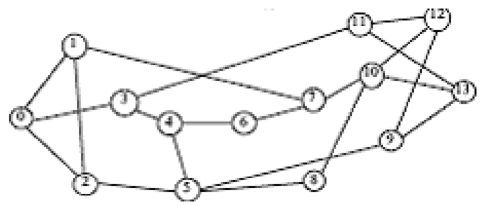

Fig.1 NSF network with 14 nodes

Table1: Simulation Parameters

Topology	Mesh
Total no. of nodes	14
Link Wavelength Number	8
Link Delay	10ms
Wavelength Conversion Factor	1
Wavelength Conversion Distance	8
Wavelength Conversion Time	0.024
Link Utilization sample Interval	0.5
Traffic Arrival Rate	0.5
Traffic Holding Time	0.2
Packet Size	200
No. of Session-traffics	5
Max Requests Number	50

In our experiments, we use a dynamic traffic model in which connection requests arrive at the network according to an exponential process with an arrival rate r (call/seconds). The session holding time is exponentially distributed with mean holding time s (seconds). The connection requests are distributed randomly on all the network nodes. In all the experiments, we compare the results of DPBR with that of the standard SDA scheme.

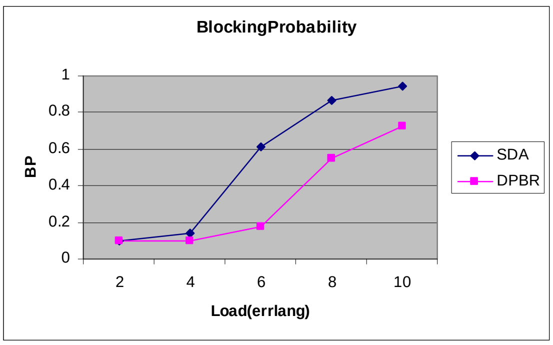

Fig2: Load Vs Blocking Probability

Fig.2 shows the blocking probability obtained with our DBPR algorithm compared with standard SDA scheme. It shows that the blocking probability is significantly less than the SDA scheme, as load increases

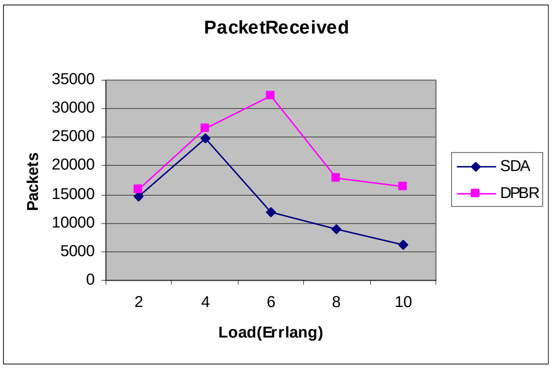

Fig3: Load Vs Throughput

The throughput for the 2 schemes, by varying the load are given in Figure 3. We can see that the packet received is more for the DPBR scheme than the SDA scheme.

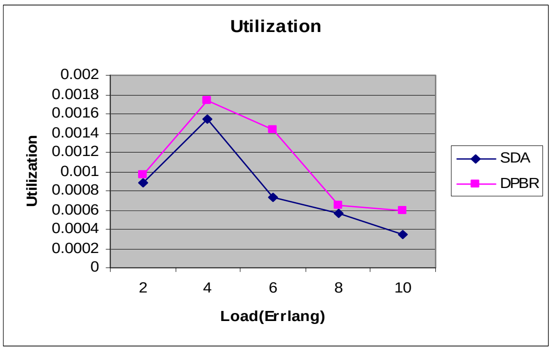

Fig4: Load Vs Utilization

Fig.4 shows the channel utilization obtained for various loads . It shows better utilization than the DPBR scheme.

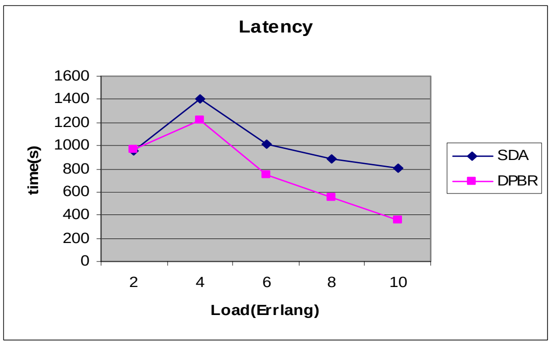

Fig5: Load Vs Latency

Fig.5 shows the end-to-end latency occurred for various loads. It shows that the latency of DPBR is significantly less than the SDA scheme.

5. Conclusion

A variety of traffic classes with different fault-tolerance requirements is carried by a large-scale optical network. A study on various related works suggest a preemptive multi-class routing scheme, without the consideration of the varying loads of dynamic traffic. In this paper, a new distributed priority based routing algorithm has been developed for various traffic classes, which employs load balancing to establish the primary and backup lightpaths. In this algorithm, the computation of the cost metric is performed on the basis of the load of the links. On the basis of the priority, the traffic flows are classified as Class-I and Class-II flows. Therefore most important data with high priority is considered as Class-I flows and remaining data with least priority is considered as Class-II flows. The lightly loaded links are employed to route the high priority traffic. Consequently, the links with lighter loads are selected for high priority traffic instead of links with heavier-loads when routing the primary and backup paths. In order to achieve this, the link cost function is modified for both primary and backup path calculation. In addition, the resources can be shared among the high priority traffic's backup path and low priority traffic. On the basis of the simulation results, it can be observed that the distributed priority based routing algorithm has reduced blocking probability and latency by means of increased throughput and channel utilization.

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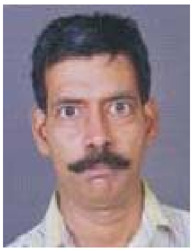

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