Dynamic Preemptive Multi-class Routing Scheme Under Dynamic Traffic in Survivable WDM Mesh Networks

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Abstract. A large-scale optical network will carry various traffic classes with different fault-tolerance requirements. Several previous papers suggest a preemptive multi-class routing scheme. They have proposed Integer Linear Programming (ILP) formulations to implement this routing scheme and simulate it under the assumption that the traffic holding on the network will not depart. However, in the real world, most of the traffic is the dynamic traffic: the traffic holding on the network will leave at the end of connection holding time. In this paper, we propose a detailed algorithm for Dynamic Preemptive Multi-class Routing (DPMR) scheme under dynamic traffic pattern. Furthermore, we compare DPMR scheme with DPP (Dedicated Path Protection) and SPP (Shared Path Protection), and evaluate their performances from resource utilization ratio and blocking probability. In addition, we propose a modified link cost function for Dynamic Preemptive Multi-class Routing scheme to find the routes.

1 Introduction

The growth in internet traffic has led to a tremendous demand for bandwidth. Wavelength-division -multiplexing (WDM) technology can meet this demand and is deployed in the next generation network infrastructures [1]. Due to per fiber bandwidths of the order of several hundred gigabits-per-second (Gb/s), enormous data loss may be experienced in the event of network failures such as node, link, or channel faults. So it is critical to consider networks survivability and design survivable WDM networks [2].

Survivability mechanisms proposed for wavelength routed WDM networks are typically classified as preplanned protection mechanisms and dynamic restoration mechanisms. In [3] and [5], the authors have introduced conventional protection and restoration schemes, and discussed the benefits of different survivable approaches. For example, path protection scheme (dedicated path protection and shared path protection[5]) which will assign a backup path to its primary path can provide quick and guaranteed recovery, but does not use resources efficiently. Correspondingly, the restoration scheme which will not assign backup resources

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to its primary path can use resources efficiently, but does not guarantee 100% recovery when resources are inadequate for recovery path allocation.

In these studies [3,5], the researchers have focused their attention on a single class of traffic. In practical network services, different connections will have different service level requirements [4]. For example, critical applications, such as emergency applications and banking institution transactions, will coexist with non-critical applications like Internet radio, file transfer, web browsing and e-mail Therefore, it is greatly necessary to differentiate different services and meet different customers' demands in finite network resources. Papers [6,7,8] have suggested differentiated reliability in mesh networks with shared path protection. They assign different backup resources to primary paths according to the primary path's different reliability requirements. It is an efficient approach to meet customer's different requirements using finite network resources. However, they do not consider that certain traffic's primary paths can share resources with high priority traffic's backup path which will save more resources. Papers [9,10] just differentiate priority of traffic and suggest that high priority traffic's backup path can share resources with low priority traffic's working path. But they just propose Integer Linear Programming (ILP) formulations to implement the routing scheme and simulate it under the assumption that the traffic holding on the network will not depart at all.

However, the fact is that more and more connection requests from customers will change from time to time, so the simulation assumption in [9,10] may result in low resource utilization and less flexibility [11,12]. Because of the mentioned reasons before, the investigation of dynamic network behavior for WDM optical networks becomes much more essential and important to us. In addition, general link cost function used to compute the shortest paths is designed to increase the degree of wavelength sharing. Due to the definition of preemptive multi-class routing scheme-low priority traffic primary paths can share resources with high priority traffic's backup paths-link cost function for it will be modified.

This paper is organized as follows: Section 2 presents three schemes: DPP, SPP and DPMR. Section 3 introduces link cost function and network model. Section 4 details algorithms for DPP, SPP and DPMR under dynamic traffic. Section 5 analyses the simulation and compares the performances. Section 6 concludes.

2 Scheme Description

In this section, we will describe three routing schemes: Dedicated Path Protection, Shared Path Protection and Dynamic Preemptive Multi-class Routing schemes. Detailed description will be shown in the following.

- Dedicated Path Protection
    - only single class traffic is considered.
    - every traffic will be assigned two link-disjoint paths: primary path and backup path.
    - backup paths can not share resources with each other.

- Shared Path Protection
  - only single class traffic is considered.
  - every traffic will be assigned two link-disjoint paths: primary path and backup path.
  - backup paths can share resources with each other.
- Dynamic Preemptive Multi-Class Routing
  - multi-class traffic is considered.
  - not every traffic will be assigned two link-disjoint paths: primary path and backup path; only high priority traffic will have backup paths.
  - high priority traffic's backup paths can share resources each other.
  - high priority traffic's backup paths can share resources with low priority traffic's working paths.

3 Link Cost Function and Network Model

3.1 Link Cost Function

In this section, we will discuss two link cost functions: general link cost function and modified link cost function. General link cost function is used by Dedicated Path Protection scheme and Shared Path Protection scheme. Due to the difference of Dynamic Preemptive Multi-class Routing (DPMR) with DPP and SPP, we will modify the general link cost function to implement it into DPMR scheme.

General Link Cost Function. A large degree of wavelength resource sharing is the advantage of shared protection. In order to achieve this goal, 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 i 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 CP for finding a primary path with requested bandwidth (RB) is calculated as

$$CP_i = \begin{cases} +\infty & f_i < RB \\ c_i & f_i \geq RB \end{cases} \tag{1}$$

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

In order to find a backup path for the primary path, we should define the corresponding link cost function firstly. Concerning the requested bandwidth (RB) and the found primary path, the reserved capacity (RC_i) on link i can be further divided into two types:

1. Sharable capacity (sc_i): the capacities reserved by some protected path(s) and is shared by the found primary paths, where the "some protected path(s)" should be link-disjoint with the found primary paths.
2. Non-Sharable capacity (none-sc_i): the capacities reserved by some protected path(s) and is not shared by the found primary paths, where the "some protected path(s)" should not be link-disjoint with the found primary paths.

Obviously, $RC_i = sc_i +$ none-sc_i. Fig.1 shows the capacity along link i.

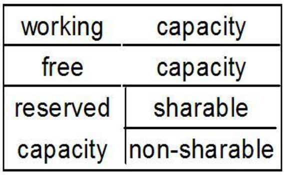

Fig. 1. Capacity along link i

The link cost function CB for finding a backup path for protected path with requested bandwidth (RB) is calculated as

$$CB_i = \begin{cases} \varepsilon & RB \le sc_i \\ \varepsilon + \alpha \cdot \frac{RB - sc_i}{f_i} & sc_i < RB \le sc_i + f_i \\ +\infty & sc_i + f_i < RB \end{cases} \qquad (2)$$

where ε is a adequately small positive constant, for instance, 0.001 or 0.0001; α is a parameter that is a positive constant (In the simulation of this paper, set $\varepsilon = 0.001$ and $\alpha = 1$). In our algorithm, if there is enough sharable capacity available along the link, the backup path will take the sharable capacity on a link firstly. The value of link cost will have two cases: 1) If there is enough sharable capacities to meet the requested bandwidth (RB), then the sharable capacities will be reserved for the backup path of the new request without needing to allocate new wavelength resource, thus we make the cost of link i be a adequately small positive constant ε; 2) If there isn't enough sharable capacity along the link, then certain free capacities will be occupied and the link cost will be determined by how many free capacities will be taken. If the summation of the sharable and free capacities is less than the RB, then the link is unavailable for the backup path, so we make the link cost be infinite. Therefore, in (2), we can observe that those links with enough reserved capacities will have smaller link cost. If the backup paths traverse these links, then we do not need to reserve new backup wavelengths. Thus, the resource utilization ratio will be improved.

Modified Link Cost Function. Because in Dynamic Preemptive Multi-class Routing scheme, there has multi-class traffic: high priority traffic and low priority traffic. 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.

1. Link cost function for low priority traffic's path(s)

$$CP_i^* = \begin{cases} +\infty & f_i < RB \\ c_i & f_i = RB \\ c_i \cdot (1 - \frac{f_i - 1}{|W|}) & f_i > RB \end{cases} \tag{3}$$

   where c_i,f_i,W and RB are the same meaning with the notations in the last subsection. We can observe that the link cost reduces as the free wavelength links increase. The shortest path algorithm will favor fiber links that have much more free wavelength links. Therefore, the low priority traffic's working capacities will be distributed to all the links, and the load will be more balanced. The load balancing may lead to more low priority traffic's paths link disjoint and result in more spare capacities to be shared by high priority traffic's backup path(s)[13].
2. Link cost function for high priority traffic's primary path
   We will still adopt (1) in general link cost function (see the last subsection) to compute the high priority traffic's primary path.
3. Link cost function for high priority traffic's 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 high priority traffic's backup path. With the requested bandwidth (RB) and the found high priority traffic's primary path(FHPP), the reserved capacity(RC_i^*) along link i can be further divided into three types:
   (a) Sharable capacity (sc_i^*): the capacities reserved by high priority traffic's protected path(s) and is shared by FHPPs, where the "high priority traffic's protected path(s)" should be link-disjoint with FHPPs.
   (b) Non-sharable capacity (none-sc_i^*): the capacities reserved by some protected path(s) and is not shared by FHPPs, where the "high priority traffic's protected path(s)" should not be link-disjoint with FHPPs.
   (c) Low priority traffic's capacity (lc_i): the capacity reserved by low priority traffic's working path(s) and is shared by high priority traffic's backup path(s).

   Obviously, $RC_i^* = sc_i +$ none-$sc_i^* + lc_i$. Fig.2 shows the capacity along link i.

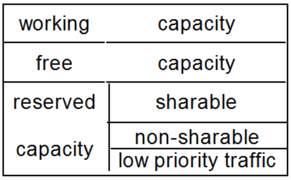

Fig. 2. Capacity along link i

The link cost function CB_i^* for finding a backup path for high priority traffic's primary path with requested bandwidth (RB) is calculated as

$$CB_i^* = \begin{cases} \varepsilon^* & RB \le sc_i^* + lc_i \\ \varepsilon^* + \alpha^* \cdot \frac{RB - sc_i^* - lc_i}{f_i} & sc_i^* + lc_i < RB \le sc_i^* + lc_i + f_i \\ +\infty & sc_i^* + lc_i + f_i < RB \end{cases} \tag{4}$$

where ε^* is also a sufficient small positive constant comparing with ε in the last subsection, such as 0.001 or 0.0001; α^* is a parameter that is a positive constant (in the simulation of this paper, set $\varepsilon^* = 0.001$ and $\alpha^* = 1$). The similar explanation process of (4) which has explained in the last subsection will present in the following. In our algorithm, the high priority traffic's backup path will take the sharable capacity and low priority traffic's capacity along a link firstly if there are enough sharable capacity and low priority traffic's capacity available on the link. If there are enough sharable capacities and low priority traffic's capacity to meet the requested bandwidth (RB), then the sharable capacities and low priority traffic's capacity would be reserved for the backup path of the new high priority traffic's request without allocating new wavelength, so we let the cost of link i to be a sufficient small positive constant ε^*. If there isn't enough sharable capacity and low priority traffic's capacity along the link, then certain free capacities will be taken and the link cost will be determined by how many free capacities will be taken. If the summation of the sharable, free and low priority traffic's capacities is less than the RB, the link is unavailable for the backup path, so we make the link cost to be infinite. From (4), we can observe that these links with enough reserved capacities will have smaller link cost. If the backup paths traverse these links, then we do not need to reserve new backup wavelengths. Thus, the resource utilization ratio will be improved.

3.2 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. In some simple method, such as in [14], 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.

4 Algorithms Description for DPP, SPP and DPMR Under Dynamic Traffic

4.1 Algorithm for DPP

- **Input:** the network graph $G(N, L, W)$ and the connection request will be routed, whose source node is s and destination node is d. The required bandwidth is a wavelength channel.
- **Output:** one primary path and one dedicated protected backup path for the connection request
- **Step1:** wait for a request, if one request comes, then go to step 2 , else update the network state.
- **Step2:** compute the primary path for this connection according (1) firstly, if the primary path is found, then record routes information and wavelength assignment. Update the network state and link cost function, go to step 3. If either the primary path or available wavelengths is not found, go to step 4.
- **Step3:** compute the backup path for this connection according to (1), if the backup path is found, then record routes information and wavelength assignment. Update the network state and link cost function, go to step 1. If either the backup path or available wavelengths is not found, go to step 4.
- **Step4:** block this request and go to step1.

4.2 Algorithm for SPP

- **Input:** the network graph $G(N, L, W)$ and the connection request will be routed, whose source node is s and destination node is d. The required bandwidth is a wavelength channel.
- **Output:** one primary path and one shared protected backup path for the connection request.
- **Step1:** wait for a request, if one request comes, then go to step 2 , else update the network state
- **Step2:** compute the primary path for this connection according to (1), if the primary path is found, then record routes information and wavelength assignment. Update the network state and link cost function, go to step 3. If either the primary path or available wavelengths is not found, go to step 4.
- **Step3:** compute the backup path for this connection according to (2), if the backup path is found, then record routes information and wavelength assignment. Update the network state and link cost function, go to step 1. If either the backup path or available wavelengths is not found, go to step 4.
- **Step4:** block this request and go to step 1.

4.3 Algorithm for DPMR

- **Input:** the network graph $G(N, L, W)$ and the connection request will be routed, whose source node is s and destination node is d. The required bandwidth is a wavelength channel.

- **Output:** one primary path and one shared protected backup path for the connection request.
- **Step1:** wait for a request, if the request is high priority traffic, then go to step 2; if the request is low priority traffic, then go to step4; otherwise, update the network state.
- **Step2:** compute the primary path for this high priority connection according to (1), if the primary path is found, then record routes information and wavelength assignment. Update the network state and link cost function, go to step 3. If either the primary path or available wavelengths is not found, go to step 5.
- **Step3:** compute the backup path for this high priority connection according to (4), if the backup path is found, then record routes information and wavelength assignment. Update the network state and link cost function, go to step 1. If either the backup path or available wavelengths is not found, go to step 5.
- **Step4:** compute the working path for this low priority connection according to (3), if the working path is found, then record routes information and wavelength assignment. Update the network state and link cost function, go to step 1. If either the working path or available wavelengths is not found, go to step 5.
- **Step5:** block this request and go to step 1.

5 Simulation Results and Analysis

All simulations have been performed on the 24 nodes USANET topology as shown in Fig.3, Each node pair is interconnected by a bi-directional fiber link and each fiber link has 8 wavelengths. We assume all nodes have full O/E/O wavelength convertible capacity. All connection requests are arriving by Poisson process and uniformly distributed among all resource-destination pairs. The holding time of each connection is normalized to unity and follows a negative exponential distribution. We simulate arrivals and departures of 100000 connections. Two main parameters: blocking probability and resource utilization will be performed.

5.1 Performance Parameters

Two main parameters: blocking probability and resource utilization.

1. Blocking probability
$$BP = B/A$$
   Blocking probability is the ratio of the total number of blocked connections (B) and the total number of arrivals (A). Obviously, the small value of BP means the small blocking probability.
2. Resource utilization
$$RU = H/CW$$

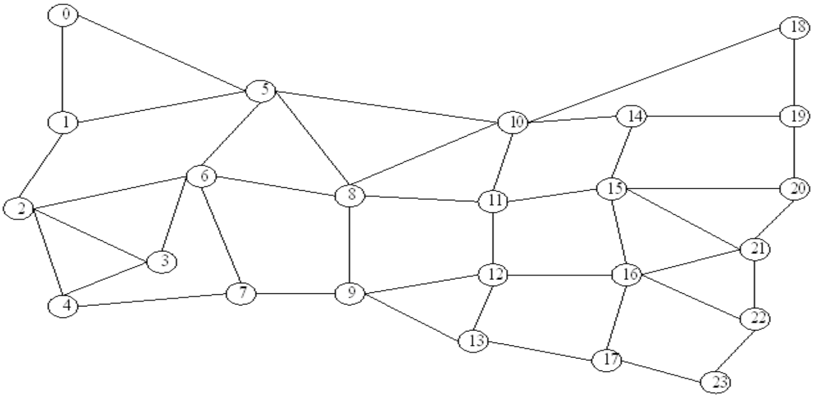

Fig. 3. USANET

Resource utilization is the ratio of the connections that are holding on the network (H) and the consumed wavelengths (CW). When the value of RU is big, the resource utilization ratio is high.

5.2 Analysis

We compare the performances of DPMR to SPP (Shared Path Protection) and DPP (Dedicated Path Protection). In Fig.4, we find that DPMR has larger values than DPP and SPP, and it means that resource utilization of DPMR is higher than that of DPP and SPP. The reason for this is that high priority traffic's backup paths can share resources of low priority traffic, thus DPMR can save more resources. As the network load increases, the value of DPMR increases which means the much higher resource utilization. It is because the chances of share resource between high priority traffic's backup paths and low priority traffic increase when more connections arrive in the network under much higher traffic intensity.

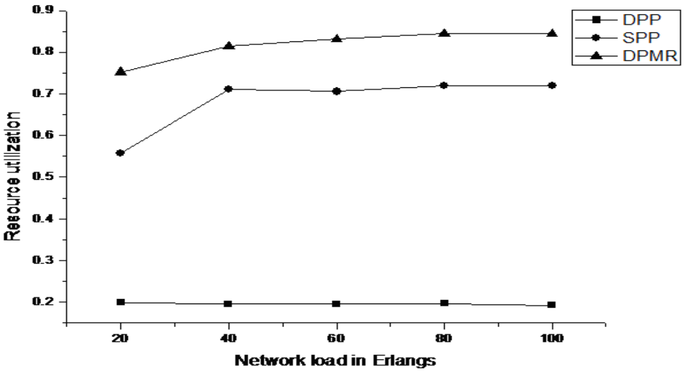

Fig. 4. Resource utilization vs. network load in Erlangs in USANET

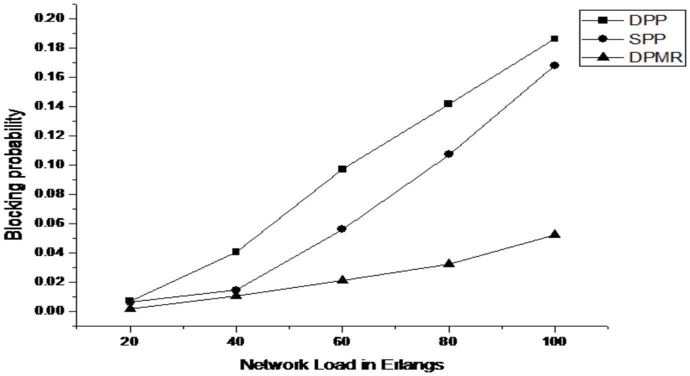

Fig. 5. Blocking probability vs. network load in Erlangs in USANET

In Fig.5, we also find that blocking probability of DPMR is much lower than that of DPP and SPP. The reason is that DPMR can save more wavelength resources as mentioned before. Then the network will have more resources to support the incoming connections and establish them successfully. When the network load increases, the advantage of DPMR is more significant.

6 Conclusions

In this paper, we have proposed an algorithm DPMR under dynamic traffic. We also have modified the general link cost function according to Dynamic Preemptive Multi-Class Routing scheme and used it to find the routes. Then, we have evaluated the performances from resource utilization and blocking probability. Simulations show that DPMR is better than DPP and SPP in resource utilization and blocking probability

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