Shared Protection of Lightpath with Guaranteed Switching Time over DWDM Networks

Yen-Wen Chen and I-Hsuan Peng

Abstract: **Survivability is a very important requirement for the deployment of broadband networks because out of service links can affect volumes of traffic even if it is a very short time. And the data paths of broadband networks, which are critical for traffic engineering, are always necessary to be well protected. The procedure of protection or restoration for a path is initiated when failure is detected within the working path. In order to minimize the influence on transmission quality caused by the failure of links and to provide a definite time for the recovery from the failure, the protection switching time (PST) should be carefully considered in the path arrangement. Several researches have been devoted to construct the protection and restoration schemes of data paths over dense wavelength division multiplexing (DWDM) networks, however, there was rare research on the design of data paths with guaranteed protection switching time. In this paper, the PST-guaranteed scheme, which is based on the concept of short leap shared protection (SLSP), for the arrangement of data paths in DWDM networks is proposed. The proposed scheme provides an efficient procedure to determine a just-enough PST-guaranteed backup paths for a working path. In addition to selecting the PST-guaranteed path, the network cost is also considered in a heuristic manner. The experimental results demonstrate that the paths arranged by the proposed scheme can fully meet the desired PST and the required cost of the selected path is competitive with which of the shared path scheme.**

Index Terms: **Dense wavelength division multiplexing (DWDM), path protection, protection switching time.**

I. INTRODUCTION

Recently, services and applications of networks have had a remarkable growth and the demand of bandwidth has increased accordingly. The dense wavelength division multiplexing (DWDM), which can support terabit bandwidth and the virtual optical path (through the technique of wavelength conversion), has been recognized as the most convincing technology for the provisioning of the broadband backbone and interconnections among enterprises [1]. As a great volume of traffic is transmitted on the links of DWDM network, the reliability of the lightpaths arranged in the DWDM network becomes a very important issue in network planning. No matter which kind of network topology is used, a well-designed protection or restoration scheme is required to avoid a huge data loss caused by the unexpected link fault. The restoration based scheme is designed to search for a backup path after the failure is detected on a working path. And this always causes a long time to recover the transmission. On the other hand, the protection based scheme can arrange the backup path in advance and the traffic can be switched to the pre-assigned backup path quickly when the working path suffers a failure. Basically, the restoration-based schemes can arrange the network resources (e.g., links and wavelength) with more flexibility, however, more switching time is required. The switching time required for the restoration based scheme includes the time to search for the backup path. And it is unpredictable whether the backup path can be found or how long the time is required for the search. On the other hand, the switching time required for the protection-based schemes is the summation of the time to detect the failure and the time to inform the partner the use of the backup path and it is more predictable. Hence, the protection-based scheme is more suitable to be used in the arrangement of data paths requiring deterministic switching time. Several researches of path/link protection in various DWDM-based network topologies have been studied recently [2]–[6]. The integral technologies such as error correction, bandwidth management and protection switch, were proposed in [2] and [3]. In [4] and [5], the protection and restoration schemes for DWDM networks were studied by considering the dedicated and shared links approaches. The protection scheme was applied to the assignment of reliable label switch paths over multiprotocol label switching (MPLS) networks in [7]. For the protection and restoration of data paths considered in the network, it can also be classified into link oriented and path oriented approaches. Link oriented protection/restoration approach has the advantage of short response time because the occurring failure on a link can be immediately detected by the two end nodes of the link. However, this approach is costly comparing with path oriented approach because the resources required for protection/restoration are on the basis of per link. In addition, path oriented approach has lower cost and longer response time. Therefore, in [8] and [9], the concept of short leap shared protection (SLSP) was proposed to make tradeoff between the above two approaches. Although lots of works have been devoted for the path protection in DWDM network, the issue of path protection with guaranteed switching time is rarely studied. How to guarantee the protection switching time (PST) for data paths is a very crucial issue in the management and planning of broadband transport like DWDM networks. Thus, in addition to providing the quality of services (QoS) in the network, the broadband transport should also be able to support the quality of reliability (QoR) for the paths with different reliability requirements. Recently, the issue of service level agreement (SLA) [11], [12] has been regarded as an essential statement in providing services, and the reliability of leased lines is usually a mandatory statement. The QoR mechanism should be able to arrange the working path and its associated backup path. In this

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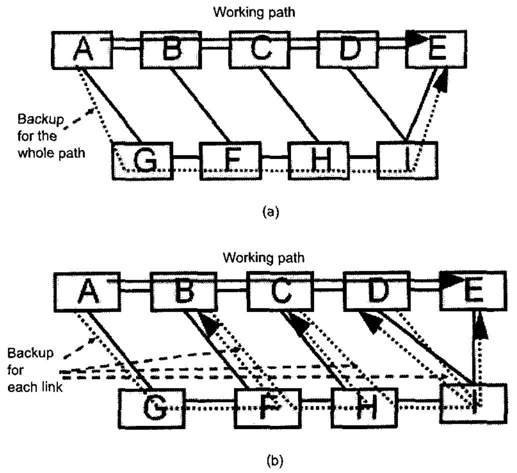

Fig. 1. Path and link protection schemes: (a) Path protection, (b) link protection.

way, the traffic can be switched to the backup path within the expected switching time when failure occurs. If the switching time of the path can be designed in advance, then the volume of lost data can be estimated in case of occurring failure and some prearrangement procedures to reduce loss can be performed. In this paper, we propose a PST-guaranteed scheme for the protection of lightpath over DWDM networks. The proposed scheme is based on the concept of SLSP [8], [9] to provide a just-enough protection switching time for the planned paths, and the required cost can also be minimized.

This paper is organized as follows. The schemes of path protection are briefly described in the next section. The PST-guaranteed scheme is proposed in Section III. The calculations of PST and the cost of the path, which are applied during path arrangement, are also explained in this section. In Section IV, the effectiveness of the proposed scheme is examined and is compared with other schemes through experimental examples. The conclusions are provided in the last section.

II. OVERVIEW OF PATH PROTECTION APPROACHES

As mentioned in the previous section, the protection-based scheme has the advantage of short switching time as comparing to the restoration based approaches. Therefore, it is more suitable to be applied in the PST-guaranteed protection scheme. Generally speaking, the protection-based approach can be further classified into path oriented protection and link oriented protection [4], [6]. In the path oriented protection scheme, a separate path from the source to destination is predetermined as the backup path in advance. And in order to increase the reliability, the links of working path and its associated backup path are selected to be mutually exclusive as shown in Fig. 1(a). If the links are designed to be shared by more than one backup path (i.e., shared links), then the constraint of the shared risk link group (SRLG) [6], [7] shall be satisfied. The defect of path oriented scheme is that the required switching time is dependent of the number of hops that the working path and the backup path travel. The reason is that the switching procedure is initiated by the source node after it is informed of a fault and the occurrence of link failure is propagated to the source node through each hop. In order to reduce the switching time, the link oriented protection was proposed to localize the fault on the link by link basis as shown in Fig. 1(b). The link oriented protection can have shorter response time than that of the path oriented scheme because the occurrence of a link failure needs only to be notified by the end nodes of this link. However, the link oriented scheme requires more network resources for the protection than that of the path oriented scheme.

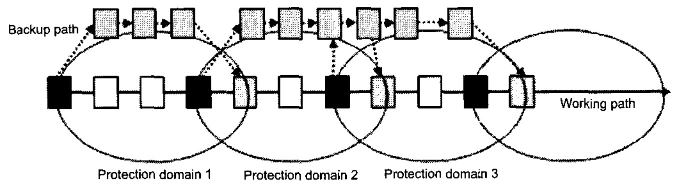

Fig. 2. SLSP based protection scheme.

In [8] and [9], SLSP scheme was a compromise between the above two extremes. Instead of link oriented protection, the basic concept of SLSP is to define two or more than two consecutive links (hops) as a protection domain or segment. Each protection domain is regarded as a "virtual link" so that the link oriented protection concept is performed. And the path oriented protection concept is applied to each segment as shown in Fig. 2. In order to prevent the failure of nodes, there is overlap of protection between segments. If the protection domain is set to be one link and the whole path, respectively, then it can be regarded as the link oriented protection and the path oriented protection.

The protection switching time of the SLSP scheme is determined by the size of the protection domain and the length of backup path selected for that protection domain. The size of protection domain reflects the time to detect the fault, while the length of its backup path determines the time to notify the switching on the path. If the protection domain is with n hops and its associated backup path is with m hops, then the required switching time is the summation of the propagation delay through $(n-1)$ hops (assuming that fail occurred on the farthest link) and the $2m$ propagation delay (round trip delay between the two end nodes of the backup path for notification and acknowledgement). Thus, the SLSP based scheme can support the arrangement of the protection domain and this is helpful in the design of PST-guaranteed path in DWDM networks.

III. PST-GUARANTEED PATH ARRANGEMENT

In [8] and [9], the size of the protection domain is selected as fixed and the paths are determined by the minimum cost of the paths found. The advantage of this approach is that the decision of the backup path for each segment is independent to each other and the backup paths of segments can be searched in parallel. Although the SLSP scheme provides a very good idea in compromising the link protection and path protection schemes, the PST can not be guaranteed. Theoretically, the protection switching time can be adapted by choosing the protection domain properly. If the protection domain is selected small then a faster switching time can be achieved, however, more network resources (e.g., λ and link) will be reserved. This is because a smaller protection domain means more protection domains are needed for a specific path and it is more close to link protection. (e.g., in Fig. 1(b)., the number of links of backup path in path protection is 5, and it is 11 in link protection). Therefore, for the allocation of paths with different QoR, it is more cost effective to arrange the paths with the minimum cost, and the desired PST can also be satisfied. The allocation of backup paths can be planned as dedicated or shared. The dedicated path approach has the advantage of fast switching time, however, the network resources (wavelengths) shall be reserved for each backup path exclusively. For the shared path approach, the wavelengths can be shared with all possible backup paths and, therefore, the network resources can be allocated effectively and the cost can also be reduced.

As mentioned in previous sections, PST includes the time to detect the fault and the time to switch the path. Let T_{pst} be the maximum PST of the designed path, we have

$$T_{pst} = T_{detect} + T_{switch} \tag{1}$$

and

$$T_{detect} = T_f + (n-1)T_p + nT_{node\_w}$$
$$T_{switch} = 2[(m+1)T_{node\_b} + mT_p]$$

where T_{detect} and T_{switch} are the time to detect the fault and the time to inform/acknowledge the peer node for the switching of path, respectively. T_f is the time required to detect the fault and T_p is the propagation delay on each link. This is because the propagation time of light is very fast. For simplicity, we assume that the difference of the lengths of links is not significant and the propagation times of all links are the same. In fault detecting, if the fault occurs in the first or the final hop of working path, the notification message must be transported in $n-1$ hops. In switching, the propagation time of informing and acknowledgement message is $2mT_p$ because each message shall be propagated in m hops. The values of n and m denote the number of hops of the working path and backup path; the parameters T_{node_w} and T_{node_b} are the time required for the nodes within the working path and the backup path to process the messages of notification and switching, respectively. In fault detecting, the notification message must be processed by n nodes. In switching, the informing and acknowledgement message must be processed by $m+1$ nodes. Here, for simplicity, we assume the values of T_{node_w} and T_{node_b} are the same (i.e., $T_{node\_w} = T_{node\_b} = T_{node}$), and (1) becomes

$$T_{pst} = (T_f + 2T_{node} - T_p) + (2m+n)(T_{node} + T_p). \tag{2}$$

If T_f, T_{node}, and T_p are all with constant values, then the protection switching time can be determined through the selection of m and n (i.e., the size of the protection domain and the number of hops of its backup path). Let the required PST be T_{pst_G}, and

$$T_{pst} \leq T_{pst\_G}$$

we have

$$(2m+n) \leq \frac{T_{pst\_G} - T_f - 2T_{node} + T_p}{T_{node} + T_p}. \tag{3}$$

The PST can then be confined to T_{pst_G} if the values of m and n can satisfy (3).

In addition to providing the guaranteed switching time, we should also properly determine the protection domain and the backup path so that the cost can be minimized. Normally, the cost of a path with protection can be divided into the resources required for the working path and its protection path. Consider that a working path is divided into several protection domains and each protection domain may consist of different number of links (i.e., the protection domains may be with different sizes). Let $CW_{l,j}$ and $CB_{l,j}$ be the costs of the l-th link of the j-th protection domain of the working path and backup path, respectively. And, in the proposed method, the links used by working paths should not be shared with its backup path for the consideration of reliability, and the links of the backup paths may allow to be shared with other backup paths. Then it is reasonable that the cost of the path traveling on this link shall consider the number of the wavelength R_λ used at the link and the number of paths, which also travel the same link and shared wavelengths. Therefore, the costs of the link used for the working path and for the backup path are dealt with different considerations due to different allocation policies. We have

$$CW_{l,j} = \frac{C_{l,j} R_\lambda}{\lambda_{l,j}}. \tag{4}$$

And $CB_{l,j}$ is the cost of the l-th link of the j-th protection domain of the backup path, which can be obtained as

$$CB_{l,j} = \sum_{i=1}^{R_\lambda} \frac{C_{l,j}}{\lambda_{l,j} k_i} \tag{5}$$

where $C_{l,j}$ and $\lambda_{l,j}$ are the cost and the number of wavelengths of the l-th link of the j-th segment, respectively. And k_i is the number of paths that share with the link and whose number of shared wavelengths is no less than i. An example for calculating the cost is illustrated in Fig. 3 which depicts the j-th segment of working path P1. And link AB is shared by the backup paths of P1, P2, and P3. The numbers of wavelengths required for P1, P2, and P3 are 4, 3, and 2, respectively. Assuming that the cost of AB link is C_{AB} and the number of wavelengths is 15. Then the $CB_{AB,j}$ of P1 can be obtained according to (5) as

$$CB_{AB,j} = \sum_{i=1}^{4} \frac{C_{AB}}{15k_i} = \frac{C_{AB}}{15*3} + \frac{C_{AB}}{15*3} + \frac{C_{AB}}{15*2} + \frac{C_{AB}}{15*1}.$$

The total cost of the path, C, can then be calculated by the summation of $CW_{l,j}$ and $CB_{l,j}$ as

$$C = \sum_j \left(\sum_l CW_{l,j} + \sum_l CB_{l,j}\right). \tag{6}$$

Based on the above descriptions, the proposed algorithm is illustrated in the following three steps:

Step 1 :

<*i*> Determine the working path with the minimum cost according to (4);

<*ii*> Set the diameter of protection domain to maximal hops (i.e., $H_{pst}-2$)(i.e., $m=1$) but not larger than the hops of entire working path.

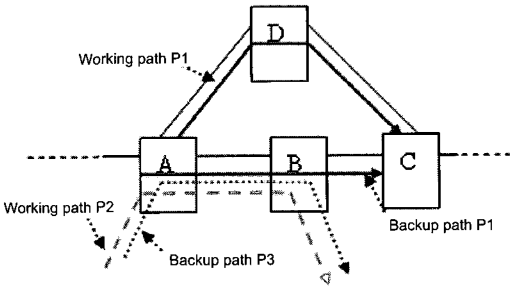

Fig. 3. An example of backup path cost.

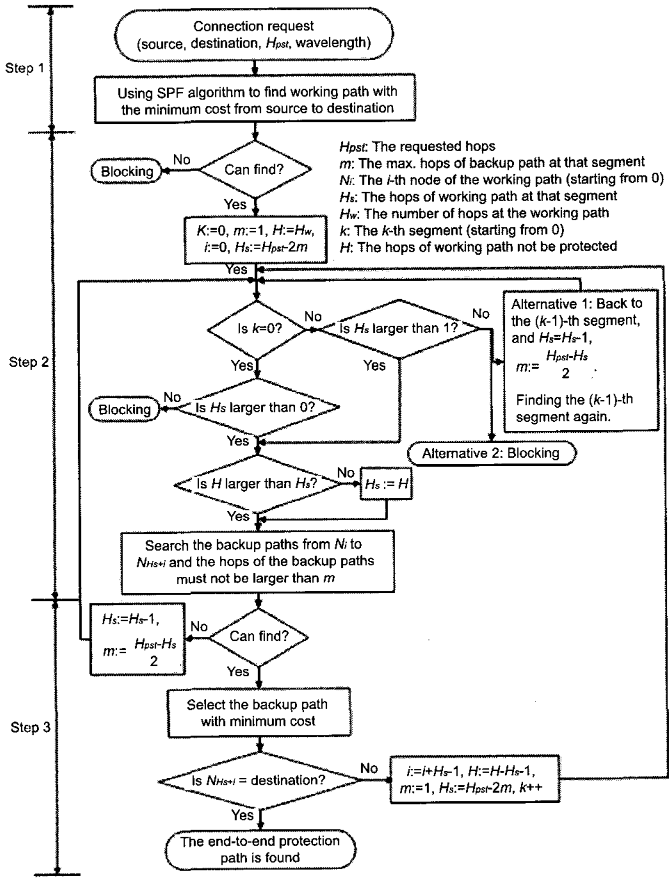

Fig. 4. Procedures of the proposed algorithm.

Step 2 : Search for the backup paths of the protection domains which satisfy the required PST.

Step 3 :

<*i*> If there is no backup path satisfying the required PST in Step 2, then, reduce the protection domain by one hop and return to Step 2. Else, select the backup paths of the protection domain with the minimum cost according to (5).

<*ii*> Repeat Steps 2 and 3 until the destination node is reached.

In Step 2, although the proposed scheme is not the optimal solution, the size of the protection domain is selected from the largest one to the smallest one so that the path with smaller cost can be found in a greedy manner. The sizes of protection domains are variable and are independent to each other. The detailed procedure of the proposed scheme is depicted in Fig. 4.

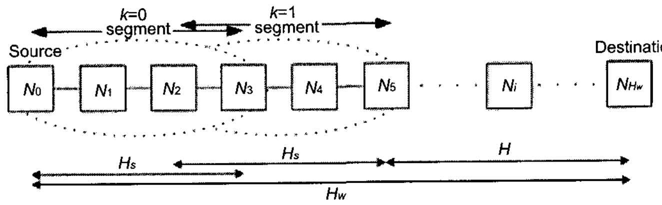

Fig. 5. Parameters used in the proposed algorithm.

The parameter H_{pst} is the maximum number of the required hops for the connection to switch to a backup path. The value of H_{pst} is regarded as $2m + n$ according to (3). And the meanings of other major parameters used in Fig. 4 are also indicated in Fig. 5. The proposed scheme performs the guarantee of PST for the path arranged in Step 2 and determines the path by considering the cost in Step 3. Because the protection domain is initially set to be with maximal hops (in Step 1) and is decreased by one hop if the PST can not be satisfied (in Step 3), the cost of the path can be minimized. In a special case, the cost of the path is the same as the shared path approach if the PST is satisfied for the protection domain covering the whole path. And blocking may occur when PST can not be satisfied by the requirement of the path or when the network resource (e.g., wavelength) is exhausted.

It is noted that there are two alternatives in Step 2. The alternative 1 allows the search procedure in Step 2 to be processed recursively so that the blocking rate can be reduced if there is no qualified backup path found. Alternative 2 does not perform the recursive process and has lower computation complexity. The computation complexity of the proposed scheme is mainly in Step 2. In alternative 2, for the worst case, the working path is divided into H_{pst} segments and the diameter of each protection domain is set and tested from the amount hops of the working path to one hop, therefore, for the worst case, the diameter is one hop (i.e., H_{pst} trials are needed). And each trial requires the complexity of $O(N^2)$ to search for the shortest path within one segment. Therefore, the complexity of the proposed scheme is $O({H_{pst}}^2 \times N^2)$. And for the worst case of alternative 1, the backtrack procedure needs H_{pst} times to seek for all possible segment sizes, and its complexity becomes $O({H_{pst}}^3 \times N^2)$.

IV. Experimental Results

In order to examine the efficiency of the proposed scheme, we assume a DWDM based core network topology with 13 nodes and 21 links (Fig. 6) is applied in simulation. We assume that each node of the topology has the capability of wavelength conversion and the number of wavelengths for each link ranges from 8 to 256. The number of wavelengths a and the cost b of each link are denoted by the parenthesis (a, b) within each link. Each path request is generated with 5 parameters: Source node, destination node, required number of wavelength, desired PST (i.e., T_{pst_G}), and lifetime of the path. Each parameter is randomly and uniformly generated within its range. One path is generated in each time unit. During the simulation, the required wavelengths of the working path and the backup path, if the desired PST can be guaranteed, are reserved for each path request and

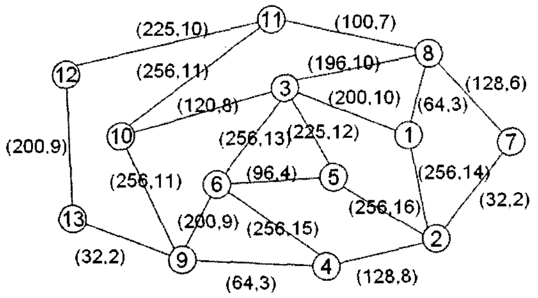

Fig. 6. The experimental topology.

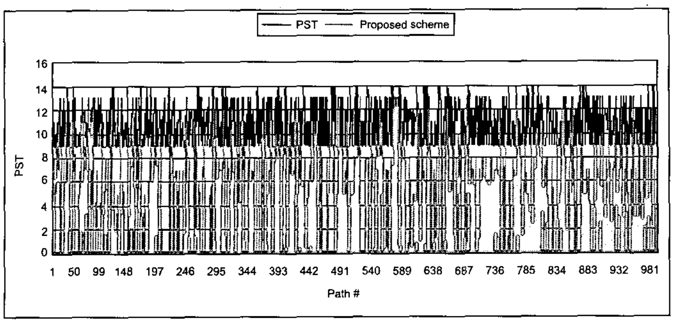

Fig. 7. PST of 1000 experimental paths.

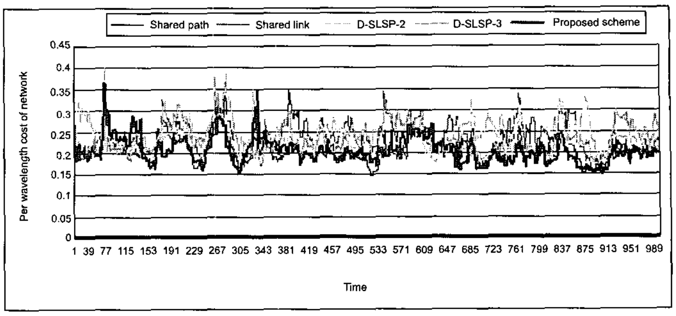

Fig. 8. Per wavelength cost of protection schemes.

they are released when the lifetime is expired. In Fig. 7, 1000 paths are randomly generated to examine whether the proposed scheme can guarantee the required PST or not. The black line indicates the required PST of each path and the gray line indicates the actual PST obtained from the proposed scheme. It is noted that the path, if its PST can not be satisfied during the establishment, is regarded as blocking and its actual PST is set to be zero in Fig. 7. It demonstrates that the actual PST of each "accepted" path is always less than its desired PST. Thus, the proposed scheme can effectively guarantee the protection switching time of the paths.

The performance of the proposed scheme is also compared with other schemes such as shared link, shared path, and the dynamic SLSP (D-SLSP) [8], [9]. Two different sizes of protection domains, 2 and 3, are adopted for SLSP during the simulation. Because all schemes, except the proposed scheme, do not support the capability of guaranteed PST, the path arrangements are all based on the minimum cost approach. The simulation results in Fig. 8 show the cost of different schemes. It is noted that the cost is calculated on the basis of per wavelength (i.e., per wavelength cost = (costs of working and backup paths)/(number of requested wavelength in the path)) of the accepted paths. Thus, the unaccepted connection requests are not taken into account for average. The cost is estimated on per wavelength basis not per path because paths may have different requirement of the number of wavelengths. The simulation results show that the cost of the proposed scheme is relatively small when comparing with other schemes.

In order to further examine the efficiency of the proposed scheme, we also study the cases with strict and loose PST requirements, respectively. The required protection switching times of the strict and loose cases are set to be within the range of 3~8 and 15~20 time units, respectively. As shown in Table 1, the proposed scheme can guarantee the desired PST for all of the established paths. On the other hand, the other schemes do not support the capability of guaranteed PST and, therefore, can not differentiate the QoR of the paths established. The blocking is mainly occurred when the network resource (wavelength) is insufficient or the PST can not be satisfied. It shall be noted that although the blocking rate of the proposed scheme is higher than other schemes, it is not fair in this case. This is because all paths established by the proposed scheme satisfy the required PST, while the other schemes do not. In order to compare the blocking rate fairly, we loosen the requirement of PST so that all schemes can have the same base in calculating the blocking rate. Table 2 shows the simulation results of the case with loose PST requirement. It indicates that the paths established by all schemes can almost satisfy the required loose PST. D-SLSP scheme may be regarded as an optimal method in decreasing blocking rate. This is because of the D-SLSP method uses the exhaustive search to find more than one working path (not only the shortest path, maybe all the S-D pairs in the network topology) in its procedure. And the backup path for each S-D pair is chosen by considering the lowest cost summation of the working path and its associated backup path. Although the blocking rate of D-SLSP scheme is the lowest, the complexity is the highest and the PST is the longest. The blocking rate of the proposed scheme is close to the D-SLSP scheme and the average cost is close to which of the shared path scheme (which is the lowest one among these schemes). This phenomenon can also explain that the blocking rate of the proposed scheme in Table 1 is mainly caused by the unsatisfied PST, because the proposed scheme has the similar blocking rate with other schemes for loose PST requirement. The proposed scheme can achieve 100% PST satisfaction in both cases when comparing to other schemes. The higher blocking rate of our scheme shown in Table 1 is mainly due to insufficient network resources. Because that our scheme has very similar performance when comparing to other schemes in loose case (Table 2). Thus, if PST is insensitive (loose case), our scheme is not inferior to other schemes. Thus, the proposed scheme is superior to the other schemes in its guaranteed PST and acceptable complexity and average cost.

The above results are experimented by using the alternative 2. We have also tried the using of alternative 1 to examine its efficiency. However, the result is not significant when comparing to

Table 1. Experimental results of strict PST requirement.

	Schemes	Blocking rate	PST Average	PST Satisfaction (%)	Average cost per λ
Required PST range: 3~8	Shared path	0.535	8.942	59.4%	0.209
	Shared link	0.576	8.307	63.4%	0.235
	D-SLSP-2	0.517	9.091	57.3%	0.237
	D-SLSP-3	0.458	9.044	52.7%	0.233
	Proposed scheme	0.879	6.025	100%	0.174

Table 2. Experimental results of loose PST requirement.

	Schemes	Blocking rate	PST Average	PST Satisfaction (%)	Average cost per λ
Required PST range: 15~20	Shared path	0.535	8.942	99.6%	0.209
	Shared link	0.576	8.307	99.6%	0.235
	D-SLSP-2	0.517	9.091	99.4%	0.237
	D-SLSP-3	0.458	9.044	98.6%	0.233
	Proposed scheme	0.528	8.945	100%	0.212

alternative 2. The reason may be that the recursive procedure is helpful for a large value of H_{pst}, and the larger the H_{pst} value is, the longer the PST is required. And according to our results in Table 1, most paths can be successfully found and the blocking rate of the proposed scheme is close to the other schemes. It means that the reason for blocking is mainly due to the insufficient wavelength and, therefore, the recursive procedure is not necessary.

V. CONCLUSION

In this paper, we point out that the quality of reliability is an important issue in deploying DWDM in broadband transport especially when SLA is an essential requirement for the provisioning of network services. Like the differential services provided in QoS networks, the networks should also provide differential QoR for different reliability needs. And as the path is provided with a specific PST, this path shall be guaranteed to be switched within the specific PST when the network fault occurs. In this paper, we proposed a PST-guaranteed protection scheme for DWDM networks. The basic concept of the proposed scheme is to provide the just-enough PST while maintaining the minimum cost for the path. This scheme demonstrates a 100% guaranteed PST for the allocation of DWDM paths with various PST requirements according to our experimental results. We also provide a cost function to fairly calculate the cost of the paths found. And the blocking rate is minimized by the flexible adjustment of the size of the protection domain. The experimental results also illustrate that the proposed scheme can achieve a relatively

we consider the protection of lightpaths at physical (optical) layer, further study may focus on the protection of routing paths at IP layer by considering the reliability of lightpaths in IP over DWDM architecture. Furthermore, the issues of mean time between failure (MTBF) and mean time to repair (MTTR) of links are not considered this paper, which are also the main factors of path reliability. More effort could be devoted for the achievement of high reliable DWDM transport.

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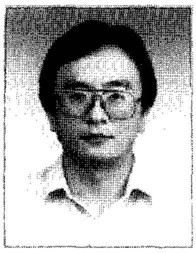

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