WDM 망에서 QoS 제약 조건을 고려한 p-Cycle 적용 방안

(Adaptation of p-Cycle considering QoS Constraints in WDM Networks)

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요 약 본 논문은 WDM(Wavelength Division Multiplexing) 망에서 서비스 품질에 따른 제약조건을 고려하였을 때 장애 복구에 적용될 수 있도록 개선된 p-cycle(preconfigured protection cycle) 기법을 제안한다. 기존의 p-cycle에서는 양방향으로 동일한 대역폭을 가지는 연결만을 고려하기 때문에 단방향 멀티캐스팅이나 양방향으로 서로 다른 대역폭을 사용하는 경우에는 적용하기 어려운 문제점이 있다. 또한 대체 경로의 서비스 품질은 고려하지 않으므로 장애 발생 시 대체 경로에서 서비스 품질을 만족시킬 수 없을 수 있다는 문제점이 있다.

본 논문에서는 단방향 멀티캐스팅이나 양방향 비대칭 대역폭을 사용하는 광대역 멀티미디어 통신에서 사용되는 단방향 연결의 장애복구를 효율적으로 구현할 수 있도록 p-cycle 기법을 개선하였다. 또한 장애 복구를 위한 대체 경로의 p-cycle에서 서비스 품질을 보장할 수 있도록 하기 위해서 p-cycle 선정을 위한 새로운 절차를 제안한다. 단방향 연결 개념을 사용한 p-cycle을 적용함으로서 비대칭적인 대역폭을 사용하는 통신환경에서 장애 복구를 위해 요구되는 대역폭을 줄일 수 있었으며, 제안된 p-cycle 선정 절차에 의해 구성된 대체 경로가 서비스 품질을 보장할 수 있는지의 여부를 시험하기 위해서 미국 시험망에 적용하고 그 결과를 분석하였다.

키워드 : 자동복구, p-cycle, 네트워크 장애복구

Abstract In this paper, we propose an enhanced p-cycle (preconfigured protection cycle) scheme for WDM mesh networks with QoS constraints. In the previous researches on p-cycle, it is assumed that user's connection has a bi-directional connectivity and the same bandwidth on both direction. Therefore it is difficult to apply p-cycle based link protection to uni-directional connections for multicasting or asymmetric broadband multimedia communications with bi-directional connectivity. And it didn't consider QoS of backup path.

We enhanced the p-cycles to accomodate uni-directional connections for multicasting or asymmetric bandwidth communications with bi-directional connectivity. And we propose a selection procedure of p-cycle to assure QoS of backup path. We were able to reduce a required backup bandwidth by applying a uni-directional p-cycle concept to asymmetric broadband multimedia communication environment. The proposed p-cycle selection procedure is applied to the U.S. sample network to evaluate whether the configured p-cycles can support QoS constraint of working path and backup path.

Key words : Automatic restoration, p-cycle, Network fault restoration

1. Introduction

Various protection & restoration schemes have been developed for ring-based or mesh-based network topologies [1,2]. The ring-based protection mechanisms, such as UPSR (uni-directional path-switched ring), use a simple switching mechanism that permits restoration in about 50~60ms, but they require at least 100% of redundant resource for

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hot-standby backup. Even though ring protection mechanisms are fast, they are intrinsically poor in resource utilization. The mesh-based restoration mechanisms provide better resource utilization because any spare capacity in each link can be reusable by other restoration paths. Since the restoration involves complex distributed signalings, mesh restoration is not expected to be as fast as the ring protection[1].

The p-cycle (preconfigured protection cycle) based fault restoration scheme offers an alternative approach[3,4] which is distinct from both ring and mesh concepts; it permits ring-like fast protection switching speeds (because only two nodes perform the real-time protection switching actions), and also provides optimized network capacity utilizations which are virtually as efficient as mesh-based span restorations[5].

The previous researches on p-cycle[3-6], however, have not considered sufficiently the uni-directional connection and asymmetric bandwidth requirements in bi-directional connectivity. The p-cycle concept is basically based on undirected graph and provides bi-directional alternate path having the same bandwidth in both directions for a span failure. This assumption is impractical in real network environment. In many bi-directional broadband connections, bandwidth requests are different according to the transmission direction and sometimes uni-directional connections are used (e.g. uni-directional multicasting and asymmetric broadband multimedia communication); a span may have different bandwidth requirement in each direction (or each link). Therefore the concept of the p-cycle should be modified to support uni-directional connections.

An important consideration in p-cycle must be the QoS of backup path. A p-cycle protects all links on the cycle and straddling links at the same time[3]. When the links protected by a cycle require different QoS constraints (such as delay), then the protection cycle should satisfy the QoS constraints of all working links protected by it. The end-to-end SLA (Service Level Agreement) should also be taken into consideration. As the p-cycle length becomes long, the better efficiency ratio is achieved[5,6]. But delay time also becomes longer as the cycle length becomes longer. In most case of link failures, the backup path has longer length then the working path/link in p-cycle, because the backup path traverses protection cycle except the failed link. Therefore delay time becomes longer with growing cycle length; long delay time in backup path may cause deteriorated QoS with increased end-to-end delay. An example is illustrated in Figure 1, where one of the preconfigured protection cycles (p-cycles) is displayed as a dotted line. When a link failure occurs between node 14 and 15, the traffic through this link is detoured along path 14-8-5-1-2-3-4-6-7-9-10-11-16-17-18-19-20 -15. This detour path has significantly longer length compared with the working path, and the longer delay of backup path may affect the end-to-end quality of user services.

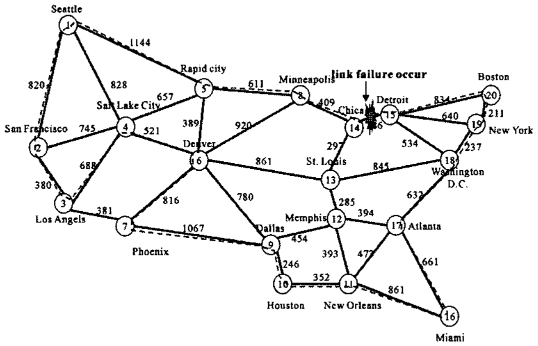


Figure 1 p-Cycle backup path of very long length

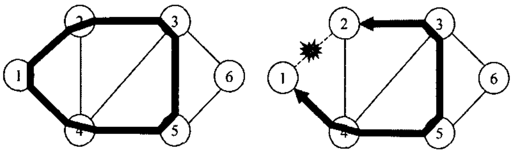
In our previous work [7], we enhanced the p-cycles to accommodate uni-directional connections to be used in uni-directional multicasting or asymmetric broadband multimedia communications with bi-directional connectivity. We were able to reduce the required backup bandwidth by applying a uni-directional p-cycle concept to asymmetric broadband multimedia communication environment. However, it still didn't consider the QoS of backup path. In this paper, we propose an enhanced p-cycle concept for QoS-guaranteed fast restoration in WDM optical mesh network[8-10]. We propose a selection procedure of p-cycle to assure QoS. We applied it to the WDM network, and analyzed the simulation result.

The rest of this paper is organized as follows. In section 2, we describe the related works for p-cycles and analyze their characteristics. In section 3, we extend the p-cycles with directed graph for uni-directional connections. In section 4, QoS problem of p-cycles in WDM network is studied. In section 5, we evaluate and analyze the proposed uni-directional p-cycle for WDM optical networks. Finally we make conclusion in section 6.

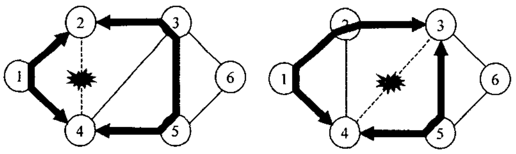
2. p-Cycle based restorations

2.1 The p-Cycle concept

Cycle-oriented pre-configuration of spare capacity for restoration of mesh network[3] is based on the formation of preconfigured p-cycles. The p-cycle protects both on-cycle failure and off-cycle straddling span failures. Figure 2(a) shows an example of a pre-configured protection cycle (a p-cycle). In Figure 2(b), when a span on the cycle becomes fault status, the surviving arc of the p-cycle is used to detour the traffic flow. Furthermore, the p-cycle can protect off-cycle straddling spans, which have p-cycle nodes as endpoints as shown in Figure 2(c) and (d) where the same p-cycle is used as the restoration path for the straddling spans l_{2-4} and l_{3-4}. Thus, the spare capacity on a p-cycle is more highly shared for restorations than in conventional ring protections.



(a) p-cycle (b) protection of on-cycle failure



(c) protection of off-cycle straddling span failure(1) (d) protection of off-cycle straddling span failure(2)

Figure 2 Use of p-cycles in restoration

2.2 p-Cycles for WDM networks

D.A. Schupke et al. extended the p-cycle concept to be used in WDM mesh networks with and without wavelength conversion[6]. They divided the WDM network into two types: i) VWP(Virtual Wavelength Path) network with no restriction in wavelength conversion, and ii) WP(Wavelength Path) network with no wavelength conversion. A unidirectional link interconnecting the WDM nodes is a fiber dedicated to the transmission in one direction. If the nodes in VWP WDM networks provide full wavelength conversion, lightpaths can be switched to an outgoing fiber if there is any free wavelength channel. Therefore optimization model for the cycle configuration can be used with definition of the connection granularity of a single capacity as lambda.

If the nodes in WP WDM networks do not have any wavelength converters at all, the nodes can switch a lightpath to an outgoing fiber only if the wavelength of lightpath is free. WP networks can be treated as VWP networks with additional wavelength constraints in the fibers and wavelength continuity constraints in the nodes. Since wavelength conversion is not possible in this case, there may be situations where working paths and p-cycles should have different wavelengths in both directions. If the wavelengths of the working path are different in both directions and the p-cycles have complementary wavelengths, the two p-cycles can protect the bi-directional on-cycle working link only. Thus working paths and p-cycles are considered as unidirectional, but bandwidth usage on each span is still symmetric.

3. Enhanced p-Cycles for directed graph

3.1 p-Cycle with directed graph

The p-cycle concept is basically based on undirected graph. In other words, links in each span are treated as bi-directional connection with the same bandwidth. To choose an optimal configuration, elementary cycles without directional distinction are used and p-cycles don't consider direction, although Johnson's algorithm[11] can be used to generate the set of all elementary circuits that have directional distinction from the network graph. The p-cycle that protects on-cycle spans and straddling spans, provides a bi-directional alternate path having the same bandwidth in both directions for a span failure.

This assumption is impractical in real network environment. In many bi-directional connections, bandwidth requests are different according to the transmission direction and sometimes uni-directional connections are used. Also GMPLS (Generalized

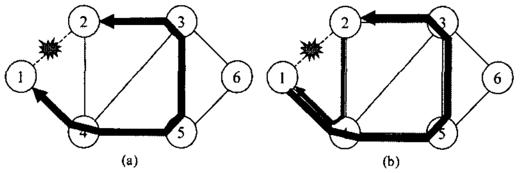


Figure 3 Restoration by uni-direction cycle

Multi-Protocol Label Switching) supports uni-directional LSP (Label Switched Path)[8]. Thus a span has different bandwidth consumption in each direction (or each link). Therefore the concept of the p-cycle should be modified to support uni-directional connection. If uni-directional p-cycle is used, different restoration path (cycle) may be used at a span failure. In Figure 3, the span l_{1-2} may has asymmetric bandwidth usage. Lets assume that the bandwidth used by edge $E_{1,2}$ is larger than $E_{2,1}$. If bi-directional p-cycles are used, only a bi-directional p-cycle that has the same bandwidth in both directions is provided. If uni-directional p-cycles are used, two p-cycles are provided: one is passing over 1→4→5→3→2→1 and has large bandwidth to protect edge $E_{1,2}$, the other is passing over 2→4→1→2 and has small bandwidth to protect edge $E_{2,1}$.

3.2 Enhanced p-Cycles for directed graph

Each span in the network is consisted of a pair of counter-directional edges, which contains one or more optical fibers. The network is modeled as a directed graph $G=(V, E)$ where V represents the set of nodes and E represents the set of directional edges. P is the set of all p-cycles (or elementary cycles) in the network. s_j and w_j are the number of spare and working links on edge j, respectively. n_i is the number of unit-capacity copies of cycle i in the p-cycle design. $x'_{i,j}$ is the number of paths that a single unit-capacity copy of p-cycle i provides for failed edge j. $p_{i,j}$ is the number of spare links required on edge j to build a unit-capacity copy of p-cycle i. c_j is the cost of edge j.

The objective function is:

$$Minimize \sum_{j=1}^{|E|} c_j s_j \qquad (1)$$

subject to :

$$s_j = \sum_{i=1}^{|P|} p_{i,j} n_i \qquad \forall j \in E \qquad (2)$$

$$w_j \le \sum_{i=1}^{|P|} x'_{i,j} n_i \qquad \forall j \in E \qquad (3)$$

$$n_i \ge 0 \qquad \forall i \in P \qquad (4)$$

Equation (1)-(4) are similar to [3] that defines conditions for directed graph. The coefficients $x'_{i,j}$ and $p_{i,j}$ are evaluated for each cycle contained in the cycle set P. $p_{i,j}$ is 1 if cycle i passes over span j, otherwise it is 0. $x'_{i,j}$ can be either 0 or 1. In contrast to [3], we use uni-directional p-cycles, and the condition of $x'_{i,j}$ is different from the $x_{i,j}$ in [3]. Furthermore, it is different from [6] which considers working paths and p-cycles as unidirectional to apply WP networks. If either end node of the failed edge is not on the cycle, $x_{i,j}$ is 0. If both end nodes of the edge are on the cycle, it can be subdivided into two cases: (case 1) end nodes are not adjacent to one another on the cycle, and (case 2) end nodes are adjacent to each other on the cycle.

Case 1: $x'_{i,j}$ is 1.

Case 2: $x'_{i,j}$ is 1 if cycle i passes over edge j', otherwise 0. (j' is the opposite directional edge of edge j)

If the end nodes are not adjacent to each other on the cycle, $x'_{i,j}$ is 1. Since we are using uni-directional p-cycle, off-cycle straddling span can be protected in one p-cycle direction only. It can't be protected in counter direction with the same p-cycle. If the end nodes are adjacent to one another along the cycle and cycle i passes over edge j', $x_{i,j}$ is 1; otherwise 0. Edge j' is on the same span with edge j, but has opposite direction. This condition has not been considered in [3] and [6]. Figure 4 shows that edge j can be protected by cycle i which passes over edge j'. When a failure occurs on edge j, data traffic from node A to node B should be detoured at node A using path A-C-B. This path constructs a cycle i and can protect edge j. But cycle i passes over edge j', not edge j. A protection cycle passing over edge j (A-B-C) can protect edge j', but can't protect edge j. Therefore Schupke's model [6] for the configuration of p-cycles in WDM network should

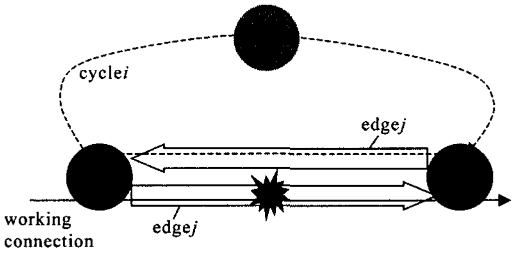


Figure 4 Restoration by opposite direction cycle

be modified.

4. QoS constraints of p-Cycle

The p-cycle is span-based restoration scheme, therefore the restoration is performed for each span (or link) against a link failure and not performed for each end-to-end path. In span restoration like p-cycle, we don't require information of each path on working links and don't know about the connections that pass through the link. End-to-end lightpath connections, which pass through the same fiber, may have different QoS classes with one another. However, since restoration is performed per fiber when a link failure occurs, all lightpaths on a failed fiber are treated in the same manner. It causes QoS problem on end-to-end lightpath connection. Sometimes QoS of a preconfigured protection cycle cannot satisfy users end-to-end lightpath connection.

Usually QoS includes bandwidth, delay, jitter and bit/packet error-ratio. In restoration of WDM network, the bandwidth constraint is not a critical issue, because restoration is performed per lambda that usually has fixed bandwidth. To make the problem simple, we assume that every wavelength has same error-ratio. Then the error is determined by length of the optical link. Since, the error-ratio in optical layer is significantly low, nowadays, we think that the difference of length between working link and backup-path does not affect seriously on the error-ratio constraints. In transparent WDM optical network where O-E-O conversion is not used, the wavelength is translated without buffering at all-optical(O-O-O) OXC node. Therefore jitter is zero or very low value, and we can neglect the effect of jitter. Consequently the delay is the most important QoS parameter in the WDM network. In this paper we focus our attention on the delay constraints to guarantee the QoS of end-to-end lightpath.

4.1 Selection of p-cycle with permitted delay time

There are two limits in the selection of p-cycle with permitted delay time: i) propagation delay time along the cycle, ii) number of hop of the cycle. When the geographical size of network is small, the propagation delay of optical layer along the path is short. Delay time of the end-to-end lightpath is dominated by the processing time at nodes, and the number of hop is a good criteria. However, when the geographical size of network is large, the delay time of the end-to-end lightpath is dominated by the end-to-end propagation delay. Therefore we should consider the delay time with the propagation delay of the lightpath.

Delay time of backup-path consists of propagation time and processing time at nodes[12]. Propagation time is calculated from the path length divided by the speed of light. In p-cycle, backup-path is preconfigured and there is no processing delay in all-optical OXC transit nodes. Therefore we can ignore the processing time at node.

$$T_{delay} = T_{path\ propagation} + T_{node\ processing} \qquad (5)$$

In fact, the limiting delay time along a cycle does not exactly reflect the delay time of the backup-path when a failure occurs. In Figure 1 if a failure occurs at the link between node 14 and 15, the backup-path of this failed link traverses almost overall part of the cycle, and the delay time along the cycle is almost same as the delay time of the backup-path. But, if a failure occurs at the link between node 1 and 4, the backup-path of this failed link uses only part of the cycle (1→2→3→4). In this case the delay time along the cycle does not represent the delay time of the backup-path. Although some link protected by this cycle may use only a part of cycle with short delay, the other links protected by the same cycle may use most of the cycle with a long delay. Furthermore, we don't know which connections using the links tolerate longer backup-path delay, and which connections require short backup-path delay. In order to make the problem simple, we assumed that the delay time along a cycle represents the upper limit delay time of the backup-path.

4.2 Delay distribution of sample network

We analyzed the delay time distribution of cycles in real networks, and analyzed the effect of network size to the delay time constraint. In real time applications, interactive service users want to receive responses within 250ms, and user's data must be arrived at the destination terminal within 125ms. Even if we don't know about the QoS requirement of each end-to-end user connection, it is important to guarantee the end-to-end delay time within 125ms for interactive communications.

We analyzed the delay time distribution in sample network of USA with 20 nodes and 35 bi-directional links (70 uni-directional links) as shown in Figure 1. The U.S. sample network has near mesh topology. The distance of the longest link is 1,114 miles and the shortest link is 211 miles.

Figure 5 illustrates the delay time distribution of cycles of the U.S. sample network. In this experiment, we set the processing time as 1ms at each node and 2.5×10^5Km/sec as a propagation speed of light signal through fiber link. In p-cycle, the restoration is performed at physical layer (optical level), and the 1ms of node processing time is long enough. From the graph, we know that most cycles satisfy the limited delay time. The 86% of cycles have a delay time within 80ms and 95% of cycles within 85ms. We may allow the backup-path with delay time about 80ms in networks of the equivalent size of the sample U.S. network. In the U.S. sample network, one of the longest paths is between Seattle and Miami. The propagation delay time between the two end nodes is 23ms through the shortest path. We suppose that working paths are routed along the shortest path. Therefore, although we add additional backup-path delay time (80ms), it does not exceed 110ms, and it is within the limit of 125ms for interactive communications.

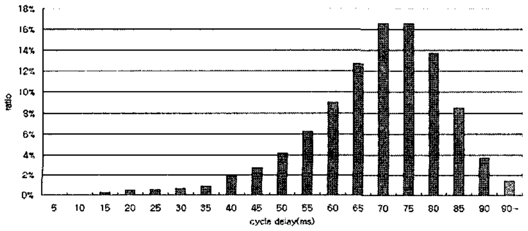


Figure 5 Cycle delay distribution of the U.S. sample network

Some cycles with very long delay, should be excluded from p-cycle configuration. Throughout the analysis of the ratio of cycles excluded, we found that the exclusion of p-cycles with very long delay must be treated depending upon the network environment. In case of a network with small size as in Korea, the longest cycle delay time is only 23ms, while the propagation delay of the longest path is only 7ms[13]. Thus, there is no necessity for excluding any elementary cycles. In case of the U.S. sample network, the longest cycle delay time is 96ms and some cycles with long delay must be excluded. If working path is routed using the shortest path, a cycle with the longest delay time can be accepted. But if working path is not routed using shortest path, this cycle can't be used. Moreover if applications at the end node require some processing time, the ratio of excluded cycles should be increased. In case the worldwide network, a lot of cycles will be excluded because of the strict delay time constraint. Therefore an algorithm for configuration of p-cycle within permitted delay time is required.

4.3 Selection procedure of p-cycle

There are two approaches in selecting cycles that guarantees the required delay time. First approach is the selection of all cycles that allow the limited delay time from elementary cycles before solving MIP(Mixed Integer Program) problem. In this case, a cycle extracting step for QoS should be added. However, MIP problem is solved quickly, because through the cycle extracting step the number of candidate cycles is reduced compared with the number of elementary cycles. The other approach is adding constraint expression for delay without adding more steps. It looks simpler than first approach, but it makes MIP problem to be more complex.

Delay constraint has trade-off relationship with the efficiency of the backup bandwidth utilization. If we apply strict delay constraint with short delay limit, many cycles of long length would be

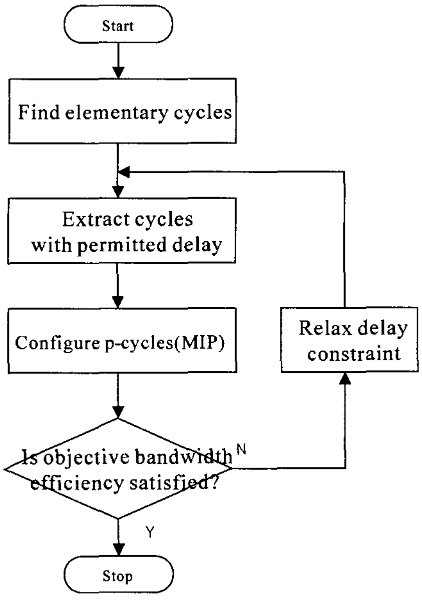


Figure 6 Selection procedure of p-cycle

eliminated in the cycle extracting step, causing decreased backup bandwidth-sharing ratio. We expect that the objective backup bandwidth efficiency should be achieved somehow, although longer delay time required. Therefore we propose a selection procedure of p-cycle as shown in Figure 6.

5. Simulation result

In this section, we analyze and evaluate the proposed uni-directional p-cycle concept for WDM optical network. MS Visual C++ 6.0 program has been used to find elementary circuits and to calculate the required coefficients of Section 3. To solve MIP, CPLEX 7.5 has been used. The test network (Figure 2) is consisted of 6 nodes and 9 bi-directional spans (18 edges). We considered WDM network, and used lambda as the granularity of capacity. First, we assigned working capacity (lambda) on each span symmetrically, and then we made asymmetric working capacity on each span by reducing the assigned working capacity of one side of edge only.

Figure 7 shows the simulation result. Asymmetric ratio means the difference of assigned working capacity between each edge pairs. By increasing the asymmetric ratio, the total working capacity of the network is decreased, and the required spare capacity decreases in uni-directional p-cycle method. But in the case of undirected(bi-directional) p-cycle method, the required spare capacity is not decreased.

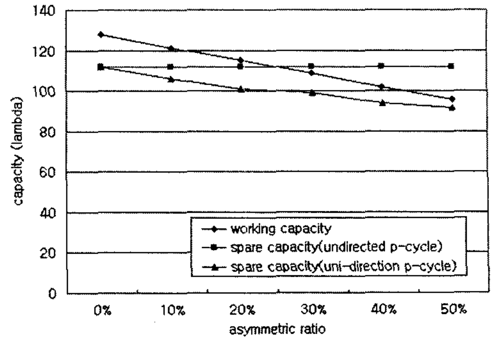


Figure 7 Required spare capacity over the asymmetric ratio

When we use the undirected(bi-directional) p-cycle method, the total spare capacity required to construct p-cycles for 100% restoration against one edge failure is not changed regardless of the asymmetric ratio. When we use the uni-directional p-cycle method, however, the required spare capacity is reduced. This result is reasonable, because the undirected(bi-directional) p-cycle assumes that bandwidths used on each direction in a span are identical and provides protection cycles having the same bandwidth on two directions. Although the bandwidth used by one edge is reduced, the undirected p-cycle can't reflect it properly. Therefore it should provide the protection cycle that can accommodate the bigger bandwidth between two edges. But the uni-directional p-cycle, that is proposed in this paper, can treat the asymmetric bandwidth properly and requires smaller spare bandwidth than undirected approach.

6. Conclusion

In this paper, we enhanced the p-cycle restoration scheme to be used in the directed graph. We modified the object function of p-cycle to accommodate the directed graph, and showed that the uni-directional p-cycle method is more useful than the existing undirected(bi-directional) p-cycle method when each span has asymmetric bandwidth and the established optical path has asymmetric bandwidth on each direction. From the simulation results, we could verify that the enhanced p-cycle with uni-directional graph provides better utilization than the p-cycle with undirected graph.

To assure the QoS of the backup-path, we suggested selection procedure of p-cycle. Delay is the most important QoS parameter of backup-path in WDM networks, but there is trade-off between the delay constraint and the backup bandwidth utilization efficiency. Thus we proposed a selection procedure of p-cycle with permitted delay time.

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