Fast-Recovery p-Cycle Protection in WDM Networks Using Straddling Segments

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Abstract: The path-segment-protecting p-cycle (or "flow p-cycle") contributes more saving on spare capacity than conventional link-protecting p-cycle. However, this technique fundamentally requires signaling at all nodes on the restoration paths. This paper presents a new approach on routing the light-paths of node pairs in order to boost the amount of traffic traversing straddling segments in opposite directions so that both end nodes of each segment can detect any link failure on the segment and perform protection switching around a p-cycle. The work in the present paper is to optimize the spare capacity of p-cycles by using an ILP formulation. Numerical results indicate that the proposed approach of using straddling segments can improve the performance of spare capacity allocation network compared to the baseline of link-protecting p-cycle.

Keywords-- **survivability, WDM, p-cycle, protection and restoration, flow p-cycle**

1. Introduction

Nowadays, Wavelength Division Multiplexing (WDM) network is an effective technology to serve as backbone for Wide Area Network(WAN), because the growth in the population of Internet users and number of applications has been creating a growing demand for bandwidth [1]. As the data capacity of fiber optic systems increases, a failure of single link can lead to huge data loss [2]. Therefore, network recovery is required to offer rapid response to network failures. Recovery mechanisms can be classified into two general categories: Protection and Restoration. Most studies in the field of resilient network design are dedicated to protection rather than restoration because it provides fast and assured failure recovery [3]. Generally, network protection schemes are evaluated on the basis of their speed and capacity. Initially, two common schemes which are ring protection and mesh protection. The search for improving recovery switching time and reducing capacity redundancy leads to the discovery of preconfigured protection cycle (p-cycle), introduced by W. D. Grover and D. Stamatelakis [4]. The p-cycle performs switching as fast as ring protection (50-60 msec) and capacity efficient approximately like mesh protection.

Importantly, mostly studies so far on p-cycle have considered link-protecting p-cycle, which operate as shown in Fig. 1. The dotted line presents the considered cycle (1-2-3-4-6-1). This p-cycle does not only protect links that are part of itself (links (1-2), (2-3), (3-4), (4-6), (6-1)) as ring protection, but also protects links that directly straddle the respective p-cycle (link (2-4)) as the advantage of p-cycle. However, in Fig. 1 links (1-5) and (5-4) are close to being straddling link but cannot actually be link-protected by the cycle shown. That was the motivation of applying path-based protection on p-cycle to offer such a kind of recovery function [3].

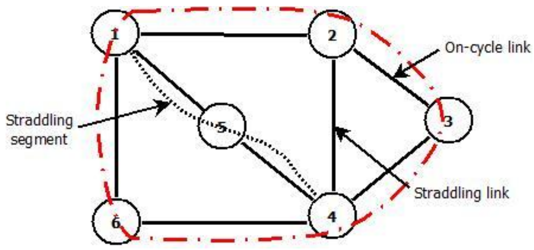

Fig. 1: Physical topology of test network

One effort at extending p-cycle to path oriented framework leads to *path-segment protecting p-cycle* [5] also called "flow p-cycle". Flow p-cycle provides more efficiency spare capacity for protecting network than link-protecting p-cycle because they allow protection of arbitrarily defined path segments, as opposed to just links. However, they do not have the property of requiring only simple end-node fault detection and switchover activation [5]. In other words, it fundamentally requires signaling to cross-connections at all nodes on the restoration path. More recently, [6] also proposed a different approach to extend the potential of basic p-cycle concept to path protection called failure-independent path-protecting (FIPP) p-cycle which retains two main benefits: fast restoration and capacity efficiency. On the contrary, FIPP has a limitation of needing both source and destination nodes to be on cycle for protection. It was natural to ask with which kind of flow p-cycle scenarios we can keep the beauty of p-cycle on fast recovery, but also achieve the spare capacity efficiency.

2. Concept of fast-recovery p-cycle protection using straddling segments

The problem of network survivability can be stated under two sub-problems which are routing of light-paths and spare capacity allocation.

2.1 Routing of light-paths

One of the greatest challenges in WDM networks is to develop efficient algorithms to establish light-paths. Routing in optical networks has been under investigation in a number of studies to minimize the cost of working capacity. Fixed path routing is the simplest approach to find a light-path for each source-destination pair. Typically this path is computed off-line in advance using standard shortest path algorithm (such as Dijkstra) to determine the shortest path in terms of the number of hops (assuming that all links have the same weight) [7], [8].

In Fig. 2a with traffic direction from A to D, when link (A-B) fails, end nodes A and D will detect loss of light and then perform protection without any signaling. On the other hand, extra time for recovery is needed in the situation when link (B-C) fails in Fig. 2b since node A cannot be aware that a failure is happening. In order to overcome this kind of difficulty, we utilize the role of bi-directional traffic which makes two end nodes sensible to failure at any link on the segment. For example, in Fig. 1c wherever a failure happens on the straddling segment, nodes A and D will know they need to do switching instantaneously.

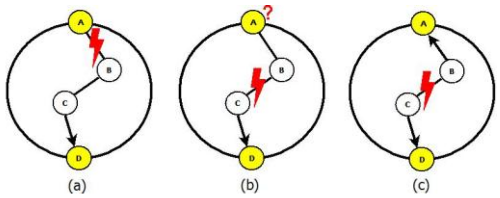

Fig. 2: Example of (a) failure is detected instantly (b) failure is not detected instantly (c) any failure is detected instantly

In this paper, opaque networks (with opto-electronic conversion) are considered. Transparent networks will be considered in future work. We assume that there are 2 candidate paths for each node pair chosen by the shortest path algorithm. Other given information is a set of candidate cycles together with their corresponding straddling segments. Traffic demands are assumed to be symmetric, i.e., the same number of light-paths in the opposite directions for each node pair. Routing for each node pair is assumed to be symmetric, with the same light-path used in opposite directions. In order to decide which light-path will be selected to be primary working light-path, we consider all 3 possible cases as follow:

- There is no light-path traversing any straddling segment: the shortest path would be selected.
- There is only one light-path traversing any straddling segment: the mentioned light-path would be selected.
- Both two light-paths traverse any straddling segment: there are two options:
  - If the two traversed straddling segments have the same hop count: the shortest path would be selected.
  - If the two traversed straddling segments have different number of hop count: the light-path contained longer segment would be selected.

2.2 Spare capacity allocation

The ILP (Integer Linear Programming) model has been used for solving spare capacity allocation problem with single link failure.

The parameters of our model are:

S is the set of links (set of all links between 2 adjacent nodes) in the network.

D_i The set of end node pairs of paths affected by failure of link i.

P is set of all candidate cycles.

c_k Cost of adding a unit capacity to link k. The costs are pre-computed constants

d^r Number of demand units on node pair r.

$\gamma_{i,j}^r$ It denotes the basic topological relationships between each link failure i with respect to the protection relationship cycle j provide for paths on demand pair r. In particular, it takes the value zero if flow r cannot be protected by cycle j upon link failure i, 1 if link i is in an on-cycle relationship, and 2 otherwise.

$\delta_{j,k}$ Takes the value of one if cycle j includes link k, otherwise, 0.

Variables:

n_j Number of unit capacity copies of cycle j to build in design.

s_k Number of spare capacity units required on link k to support the set of p-cycle used.

$n_{i,j}^r$ Number of copies of cycle j that are needed for protection of path r against failure i.

The given formulation [5] optimizes the spare capacity placement of a flow p-cycle network with 100% link failure protection given fixed working capacity design. The objective function is to minimize the total spare capacity cost. Although the ILP formulation is the same as in [5], there is a difference in considering backup capacities. In this paper, some links are protected even though they are neither an on-cycle link nor a straddling link.

Minimize: $$\sum_{k \in S} c_k s_k \qquad (1)$$

Subject to:

$$\sum_{j\in P}\gamma_{i,j}^{r}n_{i,j}^{r} \geq d^{r} \quad \forall i \in S; \forall r \in D_i \quad (2)$$

$$n_j \geq \sum_{r\in D_i} n_{i,j}^{r} \quad \forall i \in S; \forall j \in P \quad (3)$$

$$s_k \geq \sum_{j\in P} n_j \delta_{j,k} \quad \forall k \in S \quad (4)$$

Equation (2) asserts that affected working flow upon a link failure must be fully restored. Equation (3) says that the number of copies of cycle j to build is set by the largest failure-specific simultaneous use for unit copies of cycle j. Equation (4) says that the spare capacity on link k must be enough to support the number of copies of each p-cycle that overlies the link.

3. Results and discussion

We used the test network model as shown in Fig. 1. First, we managed randomly traffic demand of network in the range of (1-10) units up to (1-40) units to observe the effect of traffic demand or choosing primary light-path on the total cost (working and back up light-paths) of proposed fast recovery flow p-cycle. The average amounts of working and spare capacities of test network using conventional p-cycle and fast-recovery flow p-cycle are shown in Table 1. In general, with same amount of working capacity, proposed approach always support much less spare capacity compared with basic p-cycle.

Table 1: Working and spare capacity of test network for basic p-cycle and proposed flow p-cycle with different range of traffic demands

Range of traffic (units)	1-10	1-25	1-20	1-25	1-30	1-35	1-40
Working capacity	161	228	290	399	502	539	609
Spare capacity with basic p-cycle	259	364	484	635	847	811	1100
Spare capacity with proposed flow p-cycle	32	63	64	63	95	111	112

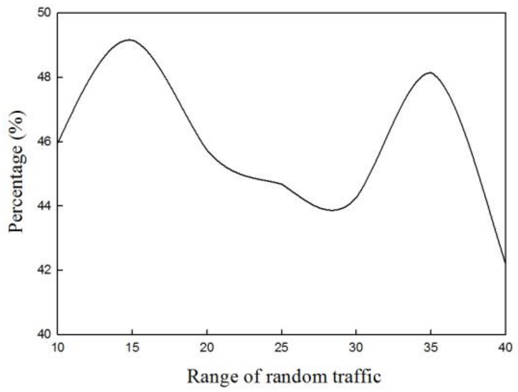

Fig. 3: The proportion of total cost of test network using fast recovery path-segment p-cycle and conventional p-cycle with different ranges of traffic.

Fig.3 reported the total cost of test network using proposed technique and basic p-cycle when routing of light-path only choose the shortest path as a primary light-path for every node pair. The percentage of these two total costs fluctuated between 42-47% when we change the range of random traffic from 10 to 40 units. This implies that the amount of traffic demand do have the significant effect on total cost of network. In comparison, the total cost of network using proposed technique still lower than using flow p-cycle without routing of light-path (around 3-20%) [5]. In other words, with this kind of scenario, fast-recovery p-cycle protection using straddling segments can greatly reduce the spare capacity allocated.

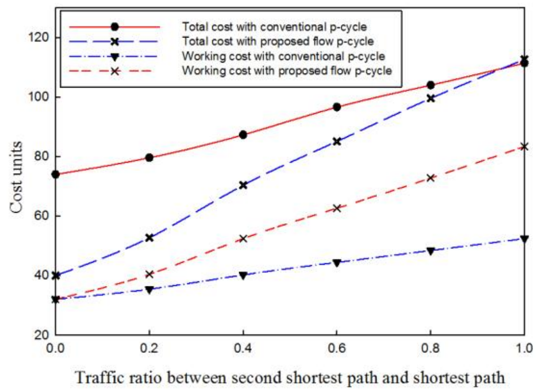

Fig. 4: Total cost of proposed method and conventional p-cycle with changing distribution of traffic demand on two candidate paths

Fig. 4 showed that once again traffic demand has effect on total cost of network. Furthermore, both basic p-cycle and proposed flow p-cycle reach the optimal solution when test network uses only shortest path for every node pair. The cost for working light-paths of proposed flow p-cycle boosted dramatically when changing the traffic ratio between second shortest path and shortest path, while that number of basic p-cycle increased slightly. It is because the more traffic traverses longer path, the more cost we have to pay. However, choosing more second shortest path makes more used straddling segments which can helps proposed flow p-cycle has modest back up cost compared with conventional one. Fig. 4 also presented the gap between these two methods is narrowed when the amount of traffic traversed second shortest path increase.

4. Conclusion

“Flow p-cycle” is known as a different and effective solution to solve the survivability problem by using path-segment protecting approach compared with conventional p-cycle in the view of minimizing spare capacity. Nevertheless, fast recovery time is not preserved since the requirement on signaling at every node of network. This paper was introduced with the aim of keeping the benefit about fast recovery time whereas investigate the impact of traffic allocation on the changing of total cost of network. By implying a new technique in routing of light-path which helps pair up the light-paths to cross straddling segments as much as possible, the capacity optimization model shows that only 42-47% of basic p-cycle's total cost is required for working and back up light-path in case of proposed flow p-cycle. This paper also demonstrates the type of traffic scenarios where proposed technique can get the optimal cost solution. This paper has not solved an absolute joint optimal problem but it is interesting work in future for our next paper.

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