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Novel P-Cycle protection strategy for asymmetric traffic in mesh optical networks

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Abstract A novel prefigured-cycle (P-Cycle) algorithm was proposed to improve the protection success ratio for asymmetric traffic in mesh optical networks. The proposed algorithm was simulated in a Pan-European COST239 network environment under an asymmetric dynamic traffic model. The experimental results show that the proposed algorithm has lower capacity redundancy and higher utilization rate of configured resources than traditional P-Cycle methods. Network performance can be improved when implementing this algorithm under single-link failure circumstances. The system behavior is analyzed under different traffic volumes and the configuration strategy is also investigated for the heavy-load and light-load networks respectively.

Keywords mesh optical network, P-Cycle, survivability, protection

1 Introduction

There are several protection/restoration approaches for optical mesh networks. Further development of an optical network and investment on network infrastructure make the survivability more important. Protection and restoration are mainly based on mesh or ring topology. Optical cross-connect (OXC) systems are now considered commercial equipment – a status that mesh topology is expected to achieve in the future. Professor W. D. Grover first proposed the concept of a P-Cycle [1,2]. The primary disadvantage of the standard survivability configuration is restoration speed when there is failure. However, with the design of the preconfigured cycle, the

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ring-like protection speed and mesh-like efficiency can be easily achieved [1,3]. As the P-Cycle protects not only the on-cycle link but also the straddle link, it can significantly improve the utilization ratio of the network resource. However, traditional single-link P-Cycle protection wastes more resources to prevent the failure, which most likely happens in a short time frame. It can also fail to fulfill the requirement of a protection target.

In this paper, we propose a P-Cycle protection model for the asymmetric environment to fight against excessive resource waste. Based on the restriction discussed above, the network model and a heuristic algorithm called CBM, which can be used in the asymmetric environment, are introduced. Unlike the previous protection method, it is easy to implement with higher efficiency in an asymmetric environment. The performance of the proposed mechanism is investigated.

2 Restrictions of P-Cycles in asymmetric environment

For the asymmetric dynamic traffic environment, service requests are based entirely on the distribution of a traffic matrix. It can be regarded as the superposition of several independent random processes. Each request occurs within a finite service time. After the service is over, it is torn down by the signaling procedure and corresponding resources are released. The dynamic characters are generally referred to as an undetermined distribution. Existing studies of the P-Cycle are focused on the bidirectional capacity configuration. For the static traffic model, the actual working capacity is not very large so that the configured P-Cycle can meet the requirement of network operators [4]. However, since the configured resource cannot be fully specified for protection for the dynamic traffic environment, it wastes more resources for pre-configuration.

As shown in Fig. 1(a), there are two units of working capacity between B and E , which can be fully protected by unit protection capacity in the protection cycle: $A-B-C-D-$

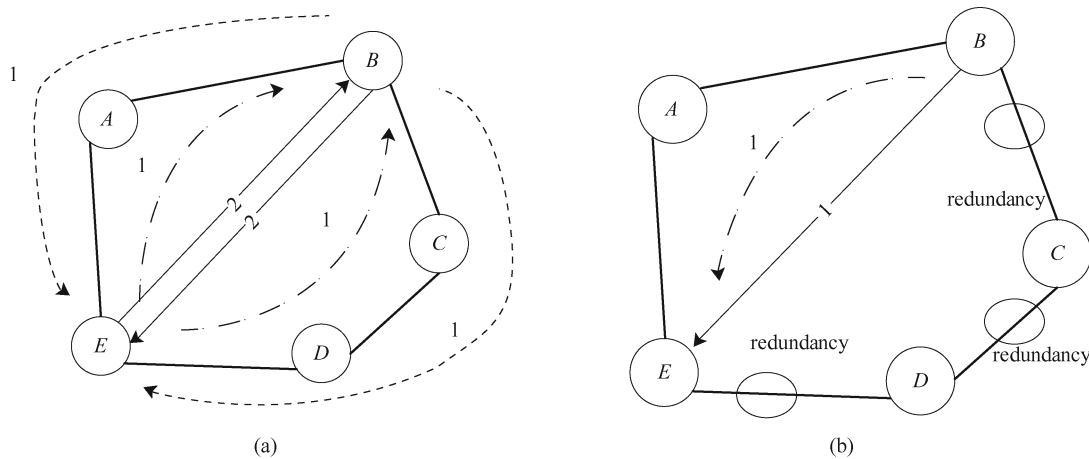


Fig. 1 Symmetric/asymmetric protection capacity. (a) Symmetric capacity distribution; (b) asymmetric capacity distribution

E. However, it cannot work so efficiently if the bidirectional working capacities between *B* and *E* are not the same. The residual capacity will be held in cycle *A-B-C-D-E* and cannot exhibit the predominance of the P-Cycle. Conversely, more than half a cycle of the protection capacity is wasted. Based on the restriction discussed above, an efficient P-Cycle protection model is proposed for the single link failure that can be used under asymmetric environments. The network capacity can be significantly improved without distorting performance of the protection success ratio, thus leading to a higher utilization ratio of the network resource.

3 CBM heuristic algorithm

Unidirectional configuration of the P-Cycle protection model is rather complex compared with generic situations in terms of computation time, stored memory, and other factors [5]. The computational speed to some extent can influence network survivability. As the dynamic properties increase, it cannot fulfill the requirement of real-time application. Therefore, the quality of service (QoS) is distorted. We proposed a heuristic algorithm that can perform well in an asymmetric dynamic environment called combination of BP and MP (CBM), where BP is the basic P-Cycle protection model and MP is the extended protection model called meshed P-Cycle. With the hybrid protection model, the candidate P-Cycle set can be rapidly calculated and configured.

Assume that the generic asymmetric traffic model partitions a common traffic element into two parts: the asymmetric part and the symmetric part. Each part takes a different protection strategy.

There are two directions for each network link: positive and negative. The working capacity on the positive direction is $y_1, y_2, y_3, \dots, y_L$, and that on the negative direction is $q_1, q_2, q_3, \dots, q_L$, where L is the total number of links in the network topology.

The i th traffic element Tr_i can be divided as

$$Tr_i = Tr_{symi} + Tr_{asymi}, \quad (1)$$

where, $i = 1, 2, \dots, 2L$, and Tr can be either q or y . Tr_{symi} and Tr_{asymi} are the symmetric part and the asymmetric part respectively.

The symmetric part of a common traffic element can be expressed as

$$Tr_{symi} = \min\{y_i, q_i\}. \quad (2)$$

And the asymmetric part can be expressed as

$$Tr_{asymi} = \max\{y_i, q_i\} - \min\{y_i, q_i\}. \quad (3)$$

Through Eqs. (2) and (3), any traffic element can be simply divided into two parts. The principle of the CBM algorithm is to utilize the straddle link algorithm (SLA) to calculate the candidate P-Cycle set for the symmetric part, and the asymmetric part with protection of the mesh cycle. Although the basic P-Cycle often has a longer cycle length, it at least contains a straddle link. A mesh cycle often employs less network resources, but cannot ensure a straddle link. The P-Cycle has higher resource efficiency due to the straddle link, and it is useless if the P-Cycle is selected without a straddle link. One unit protection capacity can protect double working capacity on a straddle link, but only one unit working capacity for an on-cycle link.

Sorting the symmetric traffic element before configuring the protection resource yields:

$$\{Tr_{sym_new1}, Tr_{sym_new2}, \dots, Tr_{sym_newL}\},$$

where working capacity on each link obeys:

$$\lceil Tr_{sym_new1} \rceil \geq \lceil Tr_{sym_new2} \rceil \geq \dots \geq \lceil Tr_{sym_newL} \rceil.$$

Configure the protection capacity first for the heaviest load link since there are not enough resources to be configured for that link. After dealing with the link, deduct Tr_{sym_newi}

from the traffic element list. When all the symmetric parts of each traffic element are configured, there are no longer enough resources in the network to support that link. The unidirectional work capacity shall be protected with mesh cycles.

Assume that the residual resource on the i th link is $Tr_{sym_res_i}$, $i = 1, 2, \dots, L$. Then,

$$Tr_{asym_i} = Tr_{asym_i} + 2Tr_{sym_res_i}. \quad (4)$$

The CBM algorithm generates a candidate cycle set as

$$CBMP = \{CBMP_1, CBMP_2, CBMP_3, \dots, CBMP_Z\}.$$

It can be proven that the cycle number generated by CBMP satisfies $3|L| \geq Z > 0$, where $|L|$ is the total number of links in the network. As for the unidirectional P-Cycle, the traditional criterion is not feasible anymore due to the protection without the use of a straddle link. The cycle length is the only criterion for unidirectional link configuration.

Detailed steps of the CBM are given as follows:

Step 1 Calculate the basic P-Cycle (BP) sets with SLA. Sort each P-Cycle based on the working capacity, then construct the candidate cycle set with the mesh P-Cycle generating algorithm. The sorting criterion is with the amended capacity efficiency [1] for the symmetric part and the cycle length for the asymmetric part.

Step 2 Based on the traffic distribution of the dynamic service request, calculate the pre-calculated routing path with the Dijkstra algorithm, then obtain the working capacity of each directional link.

Step 3 Divide the working capacity into the symmetric part and the asymmetric part (See Eq. (1)). Resort the working link with available capacity to yield $Tr_{sym_new_i} = \max_{i \leq j \leq L} \{Tr_{sym_j}\}$ (optional) (Eqs. (2) and (3)).

Step 4 For heavy load scenarios, some working capacities cannot obtain the working resource; these parts shall be re-allocated during unidirectional configuration (see Eq. (4)). Use mesh cycle protection until all the working capacities have been configured with a protection capacity, and then the algorithm ends. Even without any resource to be configured, the algorithm ends.

With the Pan-European COST239 topology in the down-triangle traffic distribution, the traffic intensity is assumed to be 10 erlang. The performance is calculated and shown in Table 1, where CBMTRS is the unidirectional configuring model with working capacity as the sorting criterion; CBMNTRS is the unidirectional configuring model without sorting; CBMNTRD is the configuring method in Ref. [4] and CBMTRD is the configuring strategy for protection capacity in Ref. [4]. It can be seen that CBMNTRS has the lowest redundancy, configuring ratio of the whole network and the least cycle number. Since CBMNTRS does not proportion service upon each cycle, its configured cycle number is the lowest, and it also has the longest cycle length. The average cycle length is about 4.692 hops.

In Table 1, PCN, SWCN, AL, RD, and RUR denote the physical cycle number, the single wavelength cycle number, the average length, the redundancy, and the resource utilization ratio respectively.

Table 1 Performance of different algorithms

	PCN	SWCN	AL	RD	RUR
CBMTRS	22	25	3.909	2.011	0.207
CBMNTRS	13	13	4.692	0.779	0.080
CBMTRD	28	38	4.535	2.348	0.242
CBMNTRD	32	41	4.562	2.476	0.256

4 Numerical results

To investigate the performance of the proposed algorithm, we construct a simulation platform in an OPNET simulation environment with the Pan-European COST239 simulation topology. The network topology is shown in Fig. 2. During simulation, the dynamic traffic model follows a random distribution, and the traffic matrix is generated with a pseudo-random algorithm. The traffic intensity grows from 80 to 180 erl. The performance of resource redundancy, protection success ratio, traffic restoring time and the resource utilization ratio of the network are investigated. The simulation is compared with the configured strategy in Ref. [4].

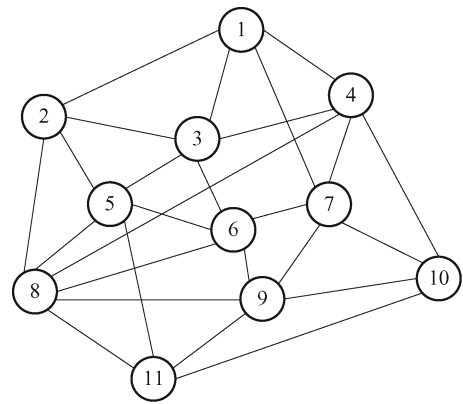


Fig. 2 Network topology

Figure 3 gives the network resource utilization ratio for different traffic volumes. We can easily establish that the resource utilization ratio increases with traffic volumes. With different numbers of service requests, the bearing service uses more wavelengths for support. To ensure continuous traffic growth, more protection resources shall be configured so that the network resource utilization ratio grows. As the traffic load grows to some extent, the working capacity and the protection capacity reaches the maximum, and a peak value appears. As the traffic load becomes heavier, idle resources can no longer be configured for protection. Therefore, the network

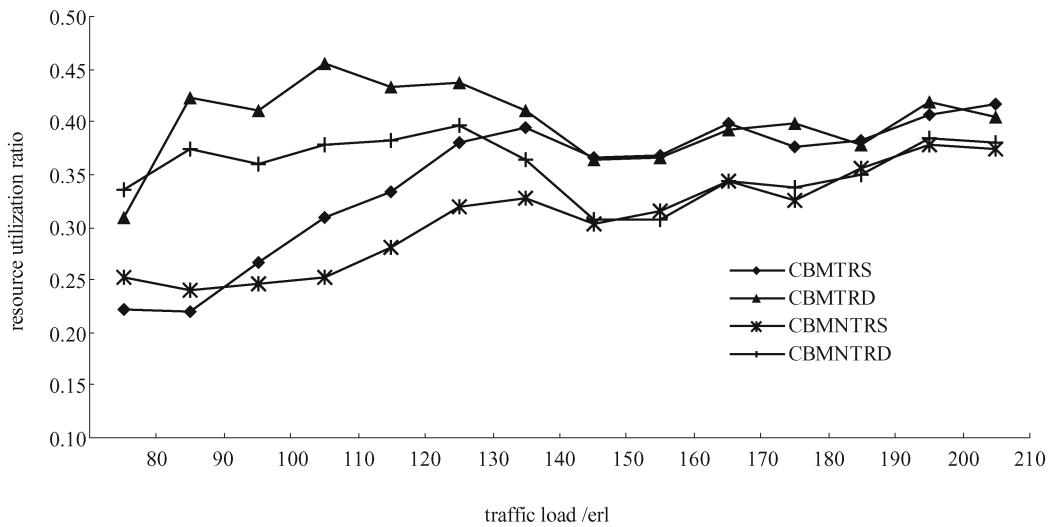


Fig. 3 Comparison of resource utilization ratio for different protection models

resource utilization ratio decreases slightly. When the network load reaches a new higher value, the total number of the wavelength grows, and the resource utilization ratio increases again. Furthermore, because the bidirectional protection approach needs a maximum of capacity on two directions, more resources must be configured compared to the directional configuration model, and the sorted protection cycle is often much better than the unsorted one. Since a more efficient cycle often has a higher length, the occupied resource is more than others.

Figure 4 shows the comparisons of the redundancy for different configured protection models. Under a light network load, CBMNTRS has the lowest redundancy, followed by CBMTRS. In an asymmetric environment, the bidirectional configured method wastes much more protection resources than the unidirectional one, and no sufficient resource can be configured when the traffic load grows heavy enough. Therefore, CBMNTRS and CBMTRS are better than CBMNTRD and CBMTRD respectively. As the traffic load grows continuously, no

sufficient resource can be configured even for CBMNTRS and CBMTRS, and the resource redundancy gradually becomes the same.

Figure 5 shows the performance of the protection success ratio for different configured methods. Protection success ratio is one of the most important parameters to evaluate network survivability. It can be easily seen that the CBMTRS algorithm performs the best. When the traffic volume reaches 210, it can still provide a protection success ratio of about 93%. The algorithm proposed in Ref. [4] was distorted when the traffic volume reached 120. When no full protection can be provided, CBMTRS performs better than CBMNTRS. Sorting traffic elements in the traffic list can generate a better performance than the unsorted one. The link with the heaviest traffic loads can be protected due to the priority of serving in the candidate cycle sets. The working capacity is dispatched onto several cycles for protection.

Based on the discussion above, in actual network planning, CBMNTRS can be used when the network has a light

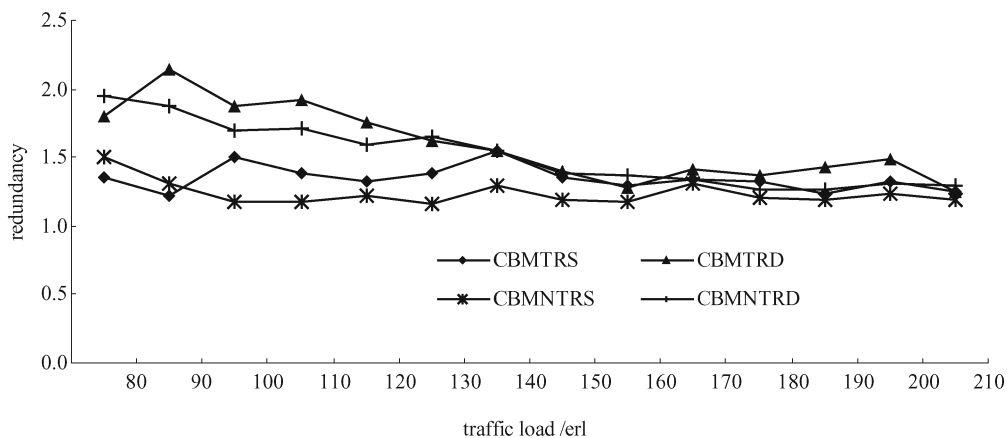


Fig. 4 Comparison of redundancy for different protection models

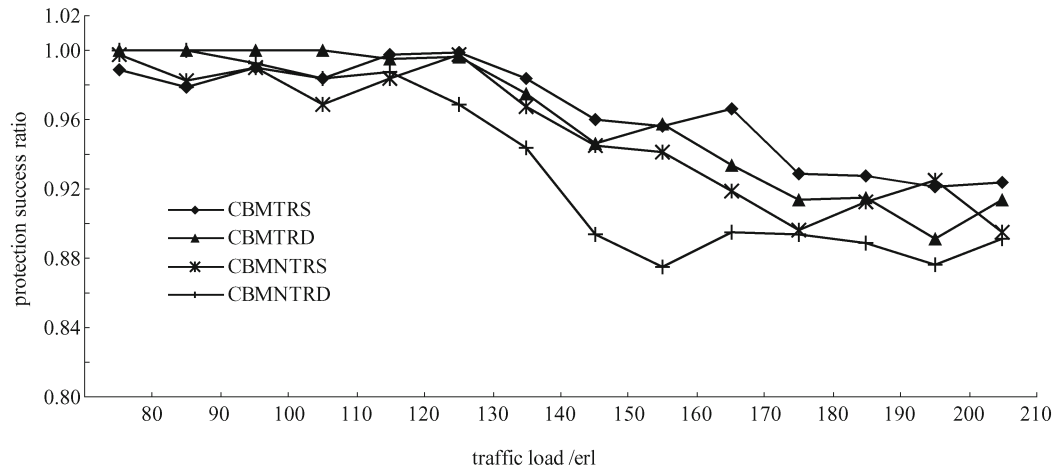


Fig. 5 Comparison of protection success ratio for different protection models

load (less than 130 erl). CBMNTRS can save parts of the resource to be pre-configured. But for the network with a heavy load (more than 130 erl), the CBMTRS algorithm can be used to improve the protection success ratio performance at a relatively small resource cost. Even the configured algorithm in Ref. [4] can be improved by introducing a simple strategy of sorting under a heavy traffic load. In an asymmetric dynamic traffic environment, a CBM-configured algorithm can yield a better performance and the network performance can be significantly improved.

5 Conclusions

Using the principle of a traditional P-Cycle, this paper proposes an asymmetric configuration model for a dynamic environment under a single link failure scenario. The study extends the simulation platform and compares the results with a previous configured model. The protection resource efficiency and protection speed are advanced compared with other protection methods. The restoring and switching operation needs coordination between the controlling message and actual device in future intelligent optical networks. Since an optimal protection cycle often has a longer cycle length that leads to a slow restoration when failure happens, the real-time application cannot be suitable for bearing. A further study shall focus on the reasonable trade-off

between the protection resource utilization ratio and the restoring time to fulfill services with different QoS levels and traffic types.

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