International Journal of Multimedia and Ubiquitous Engineering
Vol.9, No.8 (2014), pp.233-240
http://dx.doi.org/10.14257/ijmue.2014.9.8.20

Robust Network Design using Topology Characteristics

Hoyoung Hwang and Seungcheon Kim[**]

Department of Multimedia Engineering, Hansung University, Korea
Department of Information Communication Engineeging, Hansung University, Korea
(hyhwang, sckim)@hansung.ac.kr

Abstract

This paper studies robust network recovery method using logical ring architecture embedded in network topology. We present topology information based capacity provisioning methods for WDM optical networks which are widely used as a backbone architecture of current Internet. The efficiency of spare capacity provisioning is a key issue in survivable network design. In the methods, the spare wavelengths are reserved to perform optical link protection using only topology information of a network without need to calculate the amount of on-going traffic of the network, thus provide simple and efficient spapre capacity planning. The basic idea of the topology information based methods is embedding virtual cycles to perform recovery on the network topology graphs. We compare the proposed scheme with other topology information based schemes. We provide performance analysis of the topology information based schemes by the numerical calculation using cut-sets of the topology graphs, and compare it with computer simulation results.

Keywords: *spare capacity, robust, topology, cycle, cut-set*

1. Introduction

The requirements for network recovery methods include speed of recovery, efficiency in resource utilization, robustness against multiple failures, and etc. The resource efficiency can be obtained by sharing spare resources needed for network recovery. To improve the sharing of spare resources in WDM networks, methods to share backup paths as well as spare capacity together should be studied since the routing and the capacity assignment are tightly coupled in WDM networks via wavelength channels.

In this paper, we studied simple and fast network recovery methods using only the topology information of networks. We proposed a cycle-based recovery method for WDM optical mesh networks. The proposed method centers around multiple ring-cover where each network link is included in number of m backup cycles and each cycle protects $1/m$ of the link capacity. Distributed link restoration is performed using preplanned cycles, and both the backup paths and the spare capacity can be shared. The pre-configuration of the cycles and the spare capacity placement are derived directly from the network topology in off-line, which is independent of the working traffic status or its dynamic changes over time. The proposed method provides efficiency and simplicity to survivable network design and management.

We first examine several topology information based network recovery methods. Then we present the provisioning of backup paths and the recovery procedure for the proposed method. The performance of the proposed method is presented by computer simulations and also by calculation using the concept of cut-set. The

---

[**] Corresponding author is Seungcheon Kim

Copyright ⓒ 2014 SERSC

performance results show that the proposed topology information based method provides improved resource efficiency and robustness.

2. Topology Information based Recovery Methods

The basic idea of the topology information based methods is embedding virtual cycles to perform recovery on the network topology graphs. The motivation behind a cycle-based backup configuration in mesh networks is that only cycles that include the primary path can contribute to find alternative paths in a graph that represents a network topology. Cycles can provide backup paths that are independent of the routing of primary connections, and show simple and fast recovery operation. In addition, carefully designed cycles can provide backup paths sharing and spare capacity sharing together to the links included in the cycle. One of the important features of WDM networks is the tightly-coupled route and capacity relationship based on wavelength channels, in contrast to packet based networks such as IP or ATM networks where the routing function and the capacity allocation function are separated. Therefore, sharing of backup paths as well as sharing of spare capacity is an important requirement for an efficient recovery method in WDM networks. Cycle-based backup configuration is a promising approach to meet the requirement of resource sharing for WDM networks.

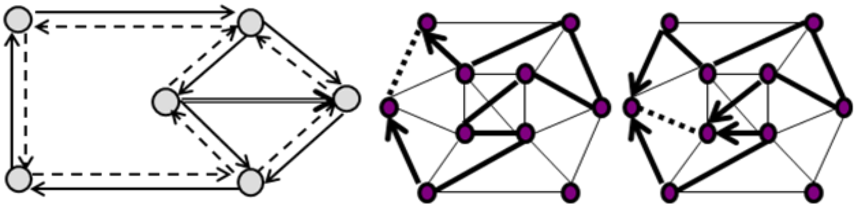


Figure 1. Topology Information Embedded Cycles: Generalized Loopback (left) and p-cycle (right)

Configuration of rings such that each link is included in at least one ring is called ring-cover or single ring-cover, and several approaches to use a ring-cover as a backup path configuration method were studied[1, 2]. The drawback of single ring-cover is the high spare capacity redundancy which is more than 100% in protection techniques and also very high in shared restoration techniques as will be presented in this paper.

An alternative method is that using cyclic-double-cover (CDC) conjecture. The CDC is a well-known conjecture in graph theory: a set of cycles exists in a two-connected graph G that each edge of G is included exactly two of the cycles. A protection technique using CDC conjecture has been proposed which performs fiber protection with 100% of spare capacity redundancy[3]. A problem on the CDC configuration is that some cycles may be too long in a large network. A long backup cycle needs more spare capacity and time to complete restoration than shorter one, thus decreases the QoS of restored connections and also the robustness in the event of multiple failures.

A protection cycle configuration method using generalized loopback is studied[4], and the tradeoff between spare capacity and robustness has been observed. This method requires less than 100% of spare capacity redundancy for single link failure, since it is possible that not all the links are included in the protection cycles, however, which results in decreased robustness against multiple failures. A strong point of this configuration method is that it does not need to be globally reconfigured for a small change of a network topology.

As another alternative to ring covers, p-cycle configuration has been proposed[5]. This method can provide efficient spare capacity redundancy which is very close to optimal spare capacity placement for local link restoration. However, this method may also suffer from long protection cycles.

In this paper, we present another cycle-based recovery method using only topology information. Objectives of the proposed method include simple design and management of robust network, as well as efficient spare resource utilization.

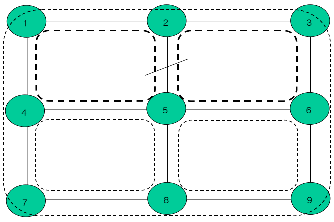


Figure 2. An Example of Virtual Backup Cycles (*m*=2)

3. Multiple Ring Covers

Figure 2 presents a configuration of multiple backup cycles. In this case, the number of backup cycles per link (m) is 2. In the figure, physical links are shown as solid lines and five shared backup cycles have been found shown as dashed lines. Each network link is assigned two backup cycles, and each cycle is responsible for restoration of half (1/2) of the link capacity. Primary capacity of a link, i.e., the available wavelengths of a link are partitioned into two even restoration units so that one restoration unit covers half of the link capacity. Then, each unit can be restored by one backup cycle as preconfigured. For example, if link (2-5) failed, one restoration unit on link (2-5) can be restored using the backup path (2-1-4-5), and the other restoration unit can be restored using another backup path (2-3-6-5), as preconfigured by the backup cycles. It is obvious that this basic idea can be easily extended to other values of m, *i.e.*, the number of backup cycles and the number of restoration units per link can be 1, 3, 4, or more.

The pre-configuration of the backup paths and placement of spare capacity is performed at network design phase. The multiple backup cycles are found by searching k-shortest paths between the end nodes of a link with preference of disjoint shortest paths, and joining them with the target link. Backup cycles are determined only once for a given network topology $G=(N, E)$, where N is the set of nodes and E is the set of edges. Our first goal is to find a set of cycles that covers each link at least m times to configure m backup cycles per link. To perform efficient spare capacity planning, the backup cycles of a link should have the least number of shared links which would reduce the sharability of spare capacity. Therefore, the first goal should be updated to reflect this fact that each link should be included in m cycles that have the least number of shared links. If we consider the restoration speed and the QoS of restored connections, short backup cycles are preferred to long backup cycles.

The proposed method has some potential advantages. First, it provides simple backup network design and management. A group of logical cycles embedded in the physical network topology perform restoration, and they can be preconfigured at network design phase without concerning the working traffic status changing over time. Moreover, the proposed mechanism performs link restoration that recovers the whole primary capacity of a failed link including currently unused wavelengths, not just the working wavelength channels which are passing through the failed link.

Therefore, the failed link can be assumed to be virtually exists even after failure as if no failure has happened, and additional optical channel setup requirements can be accepted on the restored virtual link without consideration of network topology update.

Second, it provides simple and efficient spare capacity utilization since the restoration unit to be reserved on the backup paths is 1/*m* of a link capacity, not all the link capacity nor individual wavelength. This granularity of restoration unit can provide more efficient spare capacity sharing compared with the link-based restoration schemes where a restoration unit is a fiber, since the average amount of spare capacity required per link can be reduced. In addition, it can provide simpler backup management and operation compared with the wavelength-based restoration schemes where one backup path should be managed per individual wavelength channel.

Third, the proposed method provides a different point of view on the robustness against multiple failures. In single ring-cover protection or restoration techniques, if two links included in a same cycle failed together, it may be impossible to recover any of the working capacity on the two links. With multiple ring-covers, on the other hand, there are still possibilities that part of the capacity on the failed links can be restored using other safe backup cycles, if the *m* backup cycles of a link are disjoint one another. This fact enables multi-level survivability services according to the priority of traffic. Therefore, the survivability of 'some' working traffic against double failures can be improved, which will have favorable effect on network services providing multiple reliability levels.

4. Spare Capacity Provisioning Using Cut-set

The set of links to be eliminated to make partition of a topology graph into two separated parts is called cut-set. A cut-set may have various numbers of links as shown in Figure 3. A cut-set with n links is denoted as CS(n). In multiple ring covers, the spare capacity needed to restore a communication link is distributed to *m* backup cycles. To have *m* disjoint backup routes, a link should be included in a cut-set with more than m+1 links; CS(*m*+1). If one of the link in CS(*m*+1) has failed, then the capacity on the failed link can be restored using the other *m* links included in *m* disjoint backup cycles, and each link restore 1/*m* of the required spare capacity.

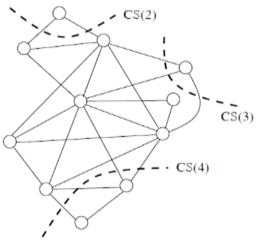


Figure 3. Cut-sets in a Network Topology

For example, if a link in CS(4) has failed when the backup cycle multiplicity *m*=3, then the remaining three links can accommodate 1/3 of the failed capacity respectively. If a link in CS(3) has failed, however, one of the two remaining links should restore 2/3 of the failed capacity while the other remaining link restore 1/3 of the failed capacity. If a link in CS(2) has failed, then the only remaining link should restore all of the failed capacity. The failed capacity of a link in CS(1) cannot be restored.

Copyright ⓒ 2014 SERSC

Table 1. Spare Capacity Assignment for *m* and Cut-sets

Cut-Set	$M=1$	$M=2$	$M=3$	$M=4$	$M=5$
CS(1)	X	X	X	X	X
CS(2)	1+1	1+1	1+1	1+1	1+1
CS(3)	$\cdots$	$\frac{1}{2}\times 3$	$\frac{2}{3}\times 2+\frac{1}{3}\times 1$	$\frac{2}{4}\times 3$	$\frac{3}{5}\times 2+\frac{2}{5}\times 1$
CS(4)		$\cdots$	$\frac{1}{3}\times 4$	$\frac{2}{4}\times 2+\frac{1}{4}\times 2$	$\frac{2}{5}\times 3+\frac{1}{5}\times 1$
CS(5)			$\cdots$	$\frac{1}{4}\times 5$	$\frac{2}{5}\times 1+\frac{1}{5}\times 4$
CS(6)				$\cdots$	$\frac{1}{5}\times 6$

The spare capacity assignment for given number of *m* and the type of cut-set are presented in Table 1. This means that we can calculate the spare capacity requirement using only the topology information such as cut-sets. For example, in the topology graph G(100, 180) shown in Figure 4, there are 8 links included in 4 CS(2) type cut-sets. Thus if *m*=2, the 8 links should accommodate 100% of link capacity while other 172 links accommodate 1/2 of the link capacity, assuming all the links have the same wavelength capacity. In the next section, we will compare the calculation results using cut-sets with the computer simulation results.

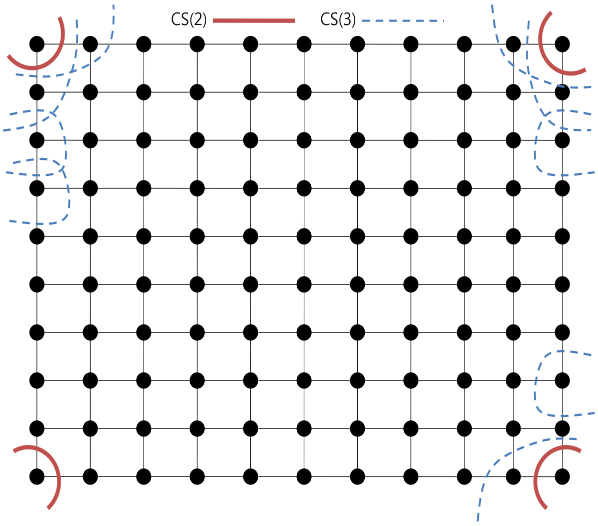
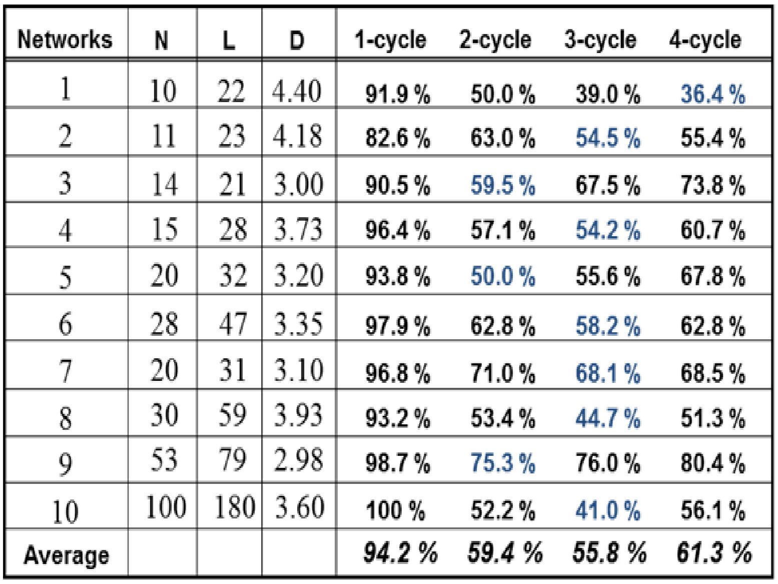


Figure 4. Cut-sets in a 10x10 Grid Network Topology

5. Performance Analysis

We performed simulations to estimate the performance of the proposed method with 10 example network topologies. We assumed that each fiber contains 60 wavelengths and all the network links have the same number of fibers. Table 2 presents the spare capacity overhead versus *m*. In this paper, the spare capacity overhead is defined as the ratio of the amount of required spare capacity to the amount of total primary capacity for 100% restoration of any single link failure. As we can see in each row, the spare capacity ratio can be substantially improved by using multiple backup cycles compared with that of the fiber or link-based single backup cycle (*m*=1). We can also realize that the spare capacity overheads of dense networks are better than that of sparse networks.

Table 2. Spare Capacity Overhaed of Multiple Ring-covers



Networks	N	L	D	1-cycle	2-cycle	3-cycle	4-cycle
1	10	22	4.40	91.9 %	50.0 %	39.0 %	36.4 %
2	11	23	4.18	82.6 %	63.0 %	54.5 %	55.4 %
3	14	21	3.00	90.5 %	59.5 %	67.5 %	73.8 %
4	15	28	3.73	96.4 %	57.1 %	54.2 %	60.7 %
5	20	32	3.20	93.8 %	50.0 %	55.6 %	67.8 %
6	28	47	3.35	97.9 %	62.8 %	58.2 %	62.8 %
7	20	31	3.10	96.8 %	71.0 %	68.1 %	68.5 %
8	30	59	3.93	93.2 %	53.4 %	44.7 %	51.3 %
9	53	79	2.98	98.7 %	75.3 %	76.0 %	80.4 %
10	100	180	3.60	100 %	52.2 %	41.0 %	56.1 %
Average				***94.2 %***	***59.4 %***	***55.8 %***	***61.3 %***

Table 3 shows the spare capacity calculation results for network 2 and network 10, when m=2, 3 respectively. The calculation results are the same as the simulation results shown in Table 2 for the same network topology and *m*. Therefore, we can see that the spare capacity ratio calculated using only topology information can be feasible and high accuracy.

Table 3. Spare Capacity Calculation Using Cut-sets

Network Topology	Spare Capacity Calculation	
	2-cycles (*m*=2)	3-cycles (*m*=3)
Net. 2 (11, 23)	(1×6) + (1/2×17) = 14.5 (spare capacity) 14.5/23 = **63.04%**	(1×6) + (2/3×3) + (1/3×14) = 12.66 (spare capacity) 12.66/23 = **55.07%**
Net. 10 (100, 180)	(1×8) + (1/2×172) = 94 (spare capacity) 94/180 = **52.22%**	(1×8) + (2/3×28) + (1/3×144) = 74.66 (spare capacity) 74.66/180 = **41.48%**

Figure 5 shows the relationship between the spare capacity redundancy and the robustness against double link failure for network 2. This graph depicts that the robustness is normally decreased as *m* increases while the spare capacity efficiency is improved, due to the fact that the size of network region affected by double-link failure becomes larger as the number of backup cycles per link increases. Therefore, an appropriate value of *m* should be determined to reflect the preferable relationship between the spare capacity redundancy and the robustness of a target network.

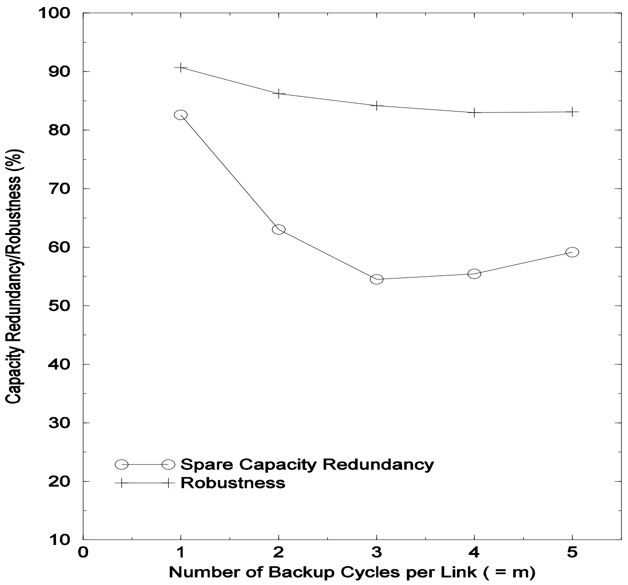


Figure 5. Spare Capacity Redundancy Versus Robustness for Double Failure

6. Conclusion

In this paper, a cycle-based backup path provisioning method is presented for WDM optical mesh networks. The proposed cycle configuration design can be derived directly from the network topology. We can calculate the spare capacity ratio of a network using only the topology information, and the results shows high accuracy and similarity compared with computer simulation results.

The proposed cycle configuration is applicable to networks with arbitrary two-connected topologies, and provides simple self-healing network design method. The spare capacity efficiency is improved by using multiple ring-covers by partitioning the working capacity of a link into several even restoration units, which is under 60% of redundancy for guaranteed restoration for single link failure. Considering the trade-off between the capacity redundancy and the robustness, two or three backup cycles per link is appropriate for most practical mesh networks. In addition, multiple ring-covers can provide layered reliability based on priorities of traffic and can assure survivability of high-priority traffic in case of multiple-link failure, although the overall robustness against multiple failures may not be improved.

Acknowledgement

This work was financially supported by Hansung University

References

[1] S. Ahn, “A Fast VP Restoration Scheme using Ring-Shaped Sharable Backup VPS”, Proceedings of Globecom'97, **(1997)** Nov. 1997, Arizona, USA, pp. 1383-1387.

[2] L. M. Gardner, M. Heydari, J. Shah, I. H. Sudborough, I. G. Tollis and C. Xia, “Techniques for Finding Ring-Covers in Survivable Networks, Proceedings of Globecom'94, pp. 1862-1866, **(1994)** November 1994, San Francisco, USA.

[3] G. Ellinas, A. G. Hailemariam and T. E. Stern, “Protection Cycles in Mesh WDM Networks, IEEE Journal on Selected Areas in Communications, vol. 18, no. 10, **(2000)**, pp. 1924-1937.

[4] S. Lummetta, M. Medard and Y. C. Tseng,” Capacity versus Robustness: A tradeoff for link restoration in mesh networks”, Journal of Lightwave Technology, vol. 18, no. 12, **(2000),** pp. 1765-1775.

[5] W. D. Grover and D. Stamatelakis, “Cycle-oriented distributed preconfiguration: Ring-like speed with mesh-like capacity for self-planning network restoration”, Proceedings of ICC98, pp. 537-543, **(1998)** June 1998, Atlanta, USA.

[6] S. Chaudhuri, G. Hjalmtysson and J. Yates, "Control of Lightpaths in an Optical Networks", In Optical Internetworking Forum OIF **(2000)** January.

[7] M. Bakri and M. Koubaa, "A. Bouallegue, An iterative Partial Path Protection-based approach for routing static D-connections in WDM transparent networks with SRLG constraints", Proceedings of ICOIN2012, **(2012)** February, Kuala Lumpur, Malaysia.

[8] H. Hwang and S. Lim, "WDM Optical Network Restoration and Spare Resource Planning using Multiple Ring-Cover", Journal of Korea Information Processing Society, vol. 12-C, no. 6, **(2005)** October.

[9] S. Jang and D. Kang, "A Wire/Wireless Convergence System for Ubiquitous network using Optical WDM-PON", Proc. of Summer Conference of Korea Institute of Information Technology, **(2006)** June.

Authors

Hoyoung Hwang, he received the BS, MS, and Ph.D. degree in computer engineering from Seoul National University, Korea. In 2007, he joined the department of Multimedia Engineering, Hansung University now serving as an associate professor. His research interests include optical networks, mobile ad-hoc networks, and frequency issues.

Seungcheon Kim, he received the BS, MS, and Ph.D. degree in electronics engineering from Yonsei University, Korea. He worked as a senior researcher in LG electronics. He is now an associate professor in the department of information communications engineering, Hansung University. His research interests include wireless networks and ubiquitous sensor networks. *corresponding author

Copyright ⓒ 2014 SERSC