Availability-Aware SRLG Failure Protection in Survivable WDM Mesh Networks

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Abstract: With the increase of SRLGs, availability of shared-path protection deteriorates significantly. We propose availability-aware SRLG failure protection and heuristics by satisfying availability requirements while minimizing spare capacity usage.

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1. Introduction

Shared risk link groups (SRLG) in wavelength-division multiplexing (WDM) networks refers to situations where links share a common physical attribute, for example, cable, conduit, or duct. Links in the group have a shared possibility to fail simultaneously. For 100% survivability against single SRLG failures, backup path and working path must satisfy SRLG-disjoint constraints [1], [2]. Apart from SRLG-disjoint constraints, it is important to consider availability in working and backup paths establishment. Availability and survivability are among the most important parameters in the Service Level Agreement (SLA) between a network service provider and its service subscribers. Availability is the probability that the connection will be found in the operating state at a random time in the future [3]–[5]. Availability-aware share-path protection for differentiated services has been extensively studied in recent years by using link-disjoint one or multiple paths [3]–[6].

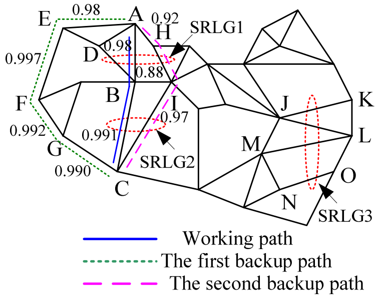


Fig. 1. Illustrative example of availability-aware SRLG failure protection. There are 3 SRLGs, 1 working path and two backup paths. The availability of the connection is 0.9997.

With the increase of size or number of SRLGs, availability of shared-path protection deteriorates significantly since the SRLG-disjoint constraint makes the working path and especially the backup path much longer. We argue that the existing availability-aware share-path protection using multiple paths may not work well with SRLGs since capacity efficiency of shared-path protection has already be a concern due to SRLG constraints [1]. If more spare capacity is used to enhance availability, capacity efficiency of availability-aware SRLG failure protection becomes much poorer. Furthermore, proposing an efficient share-path protection heuristic satisfying both SRLG-disjoint constraint and availability requirements within reasonable computational complexity is another challenge. Therefore, *it is a challenge to provide availability-aware SRLG failure protection while minimizing the usage of spare capacity*. To the best of our knowledge, the problem of availability-aware SRLG failure protection in WDM mesh networks has not been studied.

2. Problem analysis

Let $SRLGs = \{A_1, A_2, \cdots, A_k, \cdots, A_M\}$, where $A_k = \{l_{i,j}\}$ is the set of links belonging to the k th SRLG and M represents the total number of SRLGs in the network. S denotes the size of an SRLG and for simplification. For simplification, we always assume the size of each SRLG is equal. Thus we use $[S \times M]$ to denote a network with M SRLGs and each SRLG contains S links. Let r denote the survivability of a connection, which is the probability of the connection to survive arbitrary single SRLG failures. As there are M SRLGs, there are M kinds of failures. Assume D of the M failures will fail the connection. Thus survivability of the connection can be calculated as $r = 1 - D/M$. In 100% single SRLG failure protection, two backup paths can share a wavelength on a common link if and only if their working paths are SRLG- disjoint. If we know the mean time to failure (MTTF) and mean time to repair (MTTR) of a component, link, or connection, its availability can be calculated as $a = MTTF/(MTTF + MTTR)$. Let a_i denote the availability of link i along path P_k . The availability of path k can be calculated as $A_k = \prod_{i \in P_k} a_i$. To calculate the most available path with the shortest-path (SP) algorithm, e.g. Dijkstra's algorithm, we can use

$-\log(A_k) = -\log(a_1) + \cdots - \log(a_i) + \cdots, i \in P_k$. In other words, we add weights on links of networks, and thus apply the shortest-path algorithm for computing the most available path. Note that *the most available path (MAP) is defined as a path with the highest availability from the source to the destination of a connection request*. For dedicated-path protection where there is only one backup path and sharing is disallowed, the availability is $A = 1 - (1 - A_w) \times (1 - A_b) = A_w + (1 - A_w) \times A_b$, where A_w is the availability of the working path and A_b is the availability of the backup path. Similarly, if there are N backup paths and they do not share wavelengths with other connections, the availability can be calculated as $A = 1 - (1 - A_w) \times (1 - A_p) \times \cdots \times (1 - A_N)$. Calculation of availability of shared-path protection is more complex [3]. Generally, the more sharing of backup resources, the less the availability will be. *The problem of availability-aware SRLG failure protection is NP-complete* because a special case of the problem that providing shared-path protection against SRLG failures proves to be NP-complete [1].

3. Proposed heuristics for availability-aware SRLG failure protection

As both 100% survivability against SRLG failures and availability guarantee need to be taken into account simultaneously, we may design the protection with two steps. First, to satisfy 100% SRLG failure protection, SRLG-disjoint working path and backup path (We call it *the first backup path* hereafter) needs be established first. However, it may not satisfy availability requirements. So we may consider another backup path (*the second backup path* hereafter) to enhance availability. As single SRLG failure protection has been guaranteed, this path only needs to be link disjoint with the working path and the first backup path. We do not consider the scenario of more than two backup paths. Our heuristics will be based on working path first [1], [2], dynamic routing of working path and backup path(s), and first-fit for wavelength assignment. Working path first means that the working path will be computed first, followed by the first backup path and then the second backup path. Note that the second backup path will be considered only after the working path and the first backup path cannot satisfy the availability requirement. If its availability is less than *the minimal availability requirement (MAR)* or no SRLG-disjoint backup path can be found, decline the request. Fig. 1 shows an illustrative example. To reduce computational complexity we motivate to compare the following three heuristics:

Heuristic 1 (the shortest path only): Always use the shortest path for the working path, the first backup path and the second backup path if necessary.

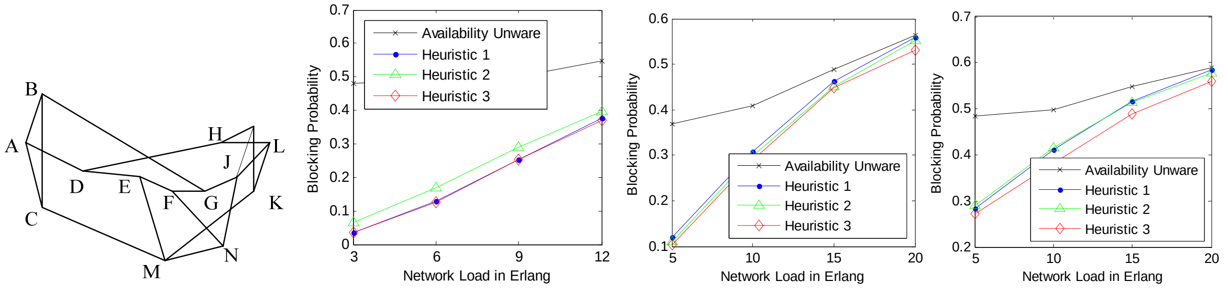
Heuristic 2 (the most available path only): Always use the most available path for the working path, the first backup path and the second backup path if necessary.

Heuristic 3 (the intelligent hybrid scheme): use the shortest path for the working path. The first backup path and the second backup path always use the shortest path to try first, and if its availability cannot satisfy the availability requirement, use the most available path to try. The motivation of the heuristic 3 is to get the benefits from the shortest path and the most available path by trying to minimize spare capacity usage for availability.

4. Performance evaluation

We compare the proposed three heuristics as well as the *traditional availability-unaware SRLG failure protection*, where only one backup path is established, and working path and backup path are computed iteratively using the shortest path. The arrival of request to the network follows Poisson distribution with λ connection requests per unit time and connection-holding time is exponentially distributed with a mean value of μ. Thus, network $load = \lambda / \mu$ (Erlang). An arrival session is equally likely to be arrived at and destined to any node in the network. SRLGs are randomly selected and one fiber may belong to several SRLGs. The availability of link is uniformly distributed from 0.9 to 1, i.e., $0.9 < a_i < 1$. The simulation program was written with Matlab and the final result of blocking probability at each load is the average result of at least 20000 connection requests.

First, we quantitatively compare the performance under the 14-node topology (8 wavelengths per fiber and wavelength is unconvertible), as shown in Fig. 2 (a). Fig. 2(b) - Fig. 2(d) plot simulation results. We observe that as expected, with the decrease of MAR, blocking probability improves. Fig. 2(b) shows if the availability requirement is very high (e.g. MAR=0.99), all the proposed heuristics will significantly outperform availability-unaware protection. This is because the second backup path has to be used for further enhancement of availability in most cases. Fig. 2(c) shows if the availability requirement (e.g. MAR=0.98) is easier to be satisfied, availability-unaware SRLG failure protection, heuristic 1 and heuristic 3 have similar blocking probability. This is because in this scenario, usually a pair of working path and backup path is enough to satisfy almost all availability requirements. Fig. 2(d) demonstrates that, with the increase of the number of SRLGs, as expected, the blocking probability increases, and heuristic 3, generally, outperforms others in blocking probability.

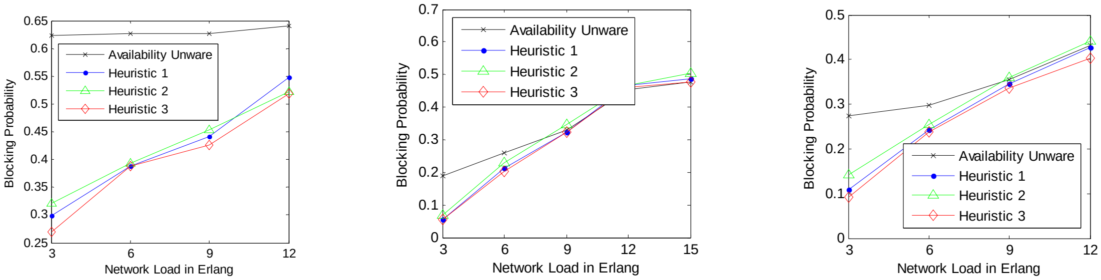


(a) 14-node topology. (b) SRLG=[3x4] and MAR=0.99. (c) SRLG=[3x4] and MAR=0.98. (d) SRLG=[3x12] and MAR=0.98.

Fig. 2. 14-node NSFnet topology and simulation results.

Second, we use a much larger network, i.e., the 28-node topology (4 wavelengths per fiber and wavelength is unconvertible), as shown in Fig. 1. Obviously, the average working or backup path(s) in the 28-node topology is longer than that in the 14-node topology, which will affect the average availability of a connection. Similarly, Fig. 3(b) shows if the MAR is high (e.g. MAR=0.98), our proposed scheme performs significantly better than the availability-unaware protection. Fig. 3(c) **-** Fig. 3(d) demonstrate that with the increase of number of SRLGs, heuristic 3 performs even better than others in blocking probability.

In summary, some observations from our extensive simulations are: 1) Blocking probability increases with the increase of the MAR. Our proposed scheme does even better with high MAR. 2) If the MAR is very low, generally, one working path and one backup path using the shortest path is enough, so the heuristic 3 performs the same as the traditional availability-unaware protection. 3) Despite the increase of numbers of SRLGs, heuristic 3 always outperform other two heuristics in blocking probability. Therefore, *the proposed availability-aware SRLG failure protection performs better than traditional availability-unaware SRLG failure protection in satisfying both survivability and availability requirements. Furthermore, heuristic 3 can make the best balance in survivability, availability and capacity efficiency*.



(a) SRLG=[4x8] and MAR=0.98. (b) SRLG=[4x8], and MAR=0.95. (c) SRLG=[4x20] and MAR=0.95.

Fig. 3. simulation results with the 28-node WDM network topology.

5. Conclusion

We have presented availability-aware SRLG failure protection and a heuristic that intelligently uses the shortest path and the most available path for its spare capacity, which can make a good balance among availability, survivability and capacity efficiency.

6. References

[1] D. Xu, Y. Xiong, C. Qiao, and G. Li, “Failure protection in layered networks with shared risk link groups,” *IEEE Network*, May-June 2004, Vol. 18, pp. 36–41.

[2] X. Shao, Y. K. Yeo, Y. Bai, J. Chen, L. Zhou, and L. H. Ngoh, "Backup Reprovisioning after Shared Risk Link Group (SRLG) Failures in WDM Mesh Networks", *IEEE/OSA Journal of Optical Communications and Networking (JOCN)*, Vol. 2, Issue 8, Aug. 2010, pp. 587-599.

[3] J. Zhang, K. Zhu, H. Zang, N. S. Matloff, and B. Mukherjee, “Availability-aware provisioning strategies for differentiated protection services in wavelength-convertible WDM mesh networks.” *IEEE/ACM Trans. Netw.*, vol. 15, pp. 1177-1190, Oct. 2007.

[4] L. Song, J. Zhang, and B. Mukherjee, “Dynamic provisioning with availability guarantee for differentiated services in survivable mesh networks.” *IEEE J. Sel. Areas Commun.*, vol. 25, pp. 35-43, April, 2007.

[5] Y. Huang, J.P. Heritage, B. Mukherjee, and W. Wen, “Availability-guaranteed service provisioning with shared-path protection in optical WDM networks,” in *Proc. OFC’2004*, Vol. 1, Feb. 2004.

[6] X. Cheng, X. Shao, Y. Wang, and Y. K. Yeo, "Differentiated Resilient Protection against Multiple-Link Failures in Survivable Optical Networks", in *Proc. OFC’2008*, JWA100, Feb. 2008, San Diego, California, USA.