

Consolidation of Optical Networks with 1:1 Protection

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Abstract

A 1:1 protection scheme for consolidating two identical networks is proposed and we show that a set of the protection links with the same number of the working links is sufficient and necessary.

1. Introduction

In the past few years, merge and acquisition are often in the telecommunications industry after the telecom bubble. Carriers and operators need to reduce their investment and operation cost by efficient utilization of network resources. Optimizing network configurations to suspend the use of various network elements including fibers, backbone routers and optical cross-connects, etc. is critical to save operation cost. We have considered the consolidation of two optical networks to use a minimum number of working fibers for the traffic between any network nodes [2-4]. Data traffic can take alternative routes when interconnection links are installed between the two networks. Operation cost can be dramatically reduced. This is an ideal case which will only work if all the resultant fiber links are able to work properly at every second for a long period of time. Practically, such network faces high risk of losing large amount of data due to link failures [1]. Therefore, operators have to use backup or redundant network resources to protect the network from possible failures. Since efficient utilization of network resources is among the top priorities for operators, they need to use a minimum number of redundant resources for the protection purpose. In this paper, we investigate and propose a 1:1 protection scheme for an arbitrary link failure of an optical network that was consolidated from two identical networks with additional interconnection links. Constraints on the number of backup operational fiber links required for the protection of the consolidated network, which is operating with minimum links, are discussed.

2. Protection of the consolidated network

In the previous investigation of the consolidation of two optical networks which share the same topology and geographical coverage, we considered only the connected networks and modeled the existing networks as directed planar graphs. We assume that there are two separate links of opposite directions connecting two nodes if there is a physical link between these two nodes. The nodes and fiber links of the two networks are all co-located [2-4]. Each network is fully connected before optimization, meaning each node in one network can find a routing path to any other node in that network.

The interconnection links are installed at some strategic locations (cities) to connect the nodes in the two networks with a minimum number of the operational fiber links in [2-4]. When the cost of deploying interconnection links varies, the amount of interconnection links to be employed for the

consolidation purpose will also vary because of cost considerations. Thus the variation of the interconnection build cost will result in different required number of the operational fiber links. Lower interconnection build cost implies that larger amount of interconnection links can be introduced, which results in a smaller number of operational fiber links required.

To simplify the problem and derive some insightful analytical results, we considered two extreme scenarios of different interconnection cost. First, we considered the merging with negligible cost for the construction of interconnection links [3]. Under this assumption, all co-located nodes are installed with interconnections. Secondly, we assumed a very high interconnection build cost. In this case, only two interconnection links with reverse directions shall be installed. The optimal locations of the two interconnection links to achieve maximum saving in operational fiber links are given [4].

These studies were concentrating on the minimum requirement of operational fiber links to provide connectivity for any two nodes of the two networks. In this paper, we will take into account of some practical considerations and investigate the protection issues of the merged network. As mentioned, service providers have to use backup resources to protect their networks against link failures. But at the same time they need to reduce expenses by using minimum redundant resources [1,5]. Single fiber cut is the most common failure scenario in fiber optics networks [5]. We will provide single fault protection schemes for the two cases discussed in the studies in [3] and [4], respectively.

a) Full-interconnection case

When the interconnection build cost is assumed to be negligible, it is reasonable to install interconnection links at all co-located nodes. We have derived that the minimum number of links required after consolidation for the full interconnection case is $L_{\min}$ (i.e. $L_{\min}$ is the minimum number of links required after the merging of two identical networks when interconnection build cost is negligible) [3]. Suppose we are now operating the merged network using the minimum $L_{\min}$ fiber links. All the $L_{\min}$ links are in one network and all the co-located nodes are installed with two interconnection links of reverse directions. We can provide protection for any single link failure of the $L_{\min}$ fiber links by turning on the corresponding $L_{\min}$ links in the second network. It is obvious that when any single link failure happens in the original $L_{\min}$ links, traffic can take alternative route through the interconnection links and the corresponding mirror link in the second network. Since all the corresponding links are available in the second network for the protection purpose, it provides 1:1 protection for the merged network. Thus it is a sufficient condition. We will prove in the following that all the $L_{\min}$ protection links are necessary to be lit up.

The notations in Fig. 1 are stated as follows.

N^A_i, N^B_i – two co-located nodes i of network A and network B respectively.

$l^A(i, j), l^B(j, i)$ – the link for the traffic from node i to node j in network A and the corresponding mirror link for that of node j to node i in network B .

l^{AB}_i – interconnection link installed at node i and supports traffic from network A to network B .

Proof: Assume one of the $L_{\min}$ links for the single failure protection case above can be removed and only $(L_{\min}-1)$ protection links are needed. Suppose an arbitrary protection link $l^B(m, n)$ can be removed. Then the traffic from N^A_m to N^A_n and that from N^B_m to N^B_n can not be supported if the single link failure happens at $l^A(m, n)$. If there is still a path that can provide the connection for the traffic from N^A_m to N^A_n , $l^A(m, n)$ should have been suspended in the prior optimization of network A , as discussed in the proof of Theorem 1 in [4]. This proves our claim that all the $L_{\min}$ protection links are necessary for the 1:1 protection scheme.

For the full-interconnection case, turning on a set of protection links with the number equal to that of the working links and located at the same locations (but in the second network) is sufficient to protect any arbitrary link failure of the consolidated network operating with minimum fiber links. When it is the case, all the $L_{\min}$ protection links are necessary to be lit up.

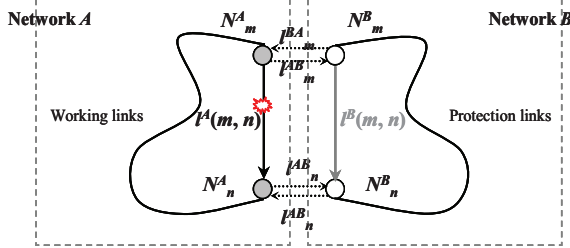


Fig. 1. Protection scheme for the full-interconnection case when interconnection build cost is negligible.

b) Two-interconnection case

For the two-interconnection case in 4, the merged network consists of three parts, namely the two interconnection links, the remaining fiber links in network A and those in network B . The resultant fiber links in network A and B are located at the same places but with reverse directions. To protect single fiber cut of this merged network, we can turn on a set of protection links in network A and B and make sure that all the protection links in network A (network B) are identical to the working links of network B (network A). Also, two more interconnection links shall be installed at the same locations as the working interconnections but with reverse directions. This provides a simple single failure protection scheme for the merged network, and there is no redundant protection link in this scheme. The proof is quite straightforward and thus is omitted here. But the problem is that there may not be additional fiber links available to be turned on at some locations for the protection purpose as the merged network is already using both links of opposite direction as working links. For these situations, we claim that no protection scheme for single failure of an arbitrary fiber link is available. For better illustration, consider the consolidation of two

networks in Fig. 2(a). The original two identical tree networks with 8 nodes and 14 links for each network in Fig. 2(a) are optimized to be the network in Fig. 2(b) with two interconnection links (the dotted links). The optimized network operates with 20 fiber links, whereas 28.6% ($= 8/28$) of the fiber links are saved. It is not able to provide arbitrary single link failure protection scheme for this network since there are no more fiber links available at some places when fiber link failure happens. For instance, if a single link failure happens at any double lines (any one of the two reversely directed links) of Fig. 2(b), no additional protection link is available from the two original networks. But we can still protect the single failure at any links denoted as single line in Fig. 2(b). It is illustrated in Fig. 2(c), the dashed links are available from the original network and can be turned on for protection purpose. It shall be noted that typically only those branch links in tree-structured networks or alike have this limitation of unable to be protected from single failure.

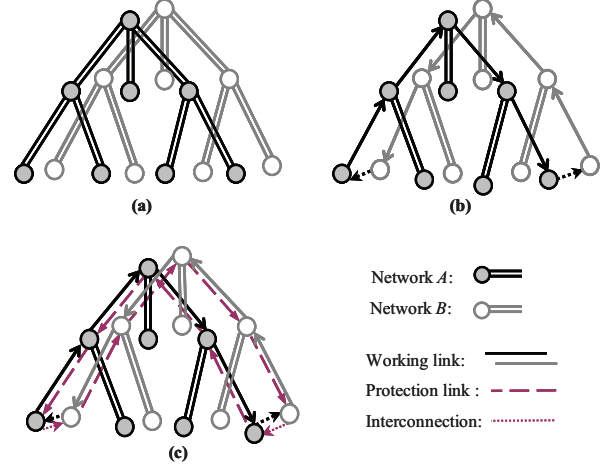


Fig. 2. The consolidation of two identical tree networks with 1:1 protection. (a) two identical networks: double line means two operational fiber links with reverse directions. (b) the merged network with two interconnection links installed at two most apart articulation nodes. (c) protection for single link failure at some locations.

3. Summary

We provided a 1:1 protection scheme for the consolidation of two identical optical networks under two circumstances of different interconnection numbers. We claim that a set of the protection links with the same number and locations as the working links is sufficient for both cases to protect any arbitrary link failure of the consolidated network. All the protection links are necessary to be turned on in this protection scheme.

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