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Restoration optimization strategy for multifiber optical networks

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Abstract

Resource optimization is a very important issue related with restoration in optical networks. In the proactive restoration, backup lightpaths are established along with the primary light paths. In this paper, we have proposed a strategy for resource optimization, which works with proactive restoration. The performance of the proposed strategy is evaluated by applying on the sample network.

Keywords: Multifiber networks; Proactive; Path-based restoration; Wavelength; Provisioning

1. Introduction

Multifiber networks are those optical networks in which a link between two nodes consists of more than one fiber. If there are n fibers in the link and each fiber has m wavelengths, then functionally it is equivalent to a fiber with $n \times m$ wavelengths. It can be used for high bandwidth, survivability, rerouting and reduction in wavelength converters at the cost of some complexity. A single link can carry n messages on the same wavelength simultaneously, each on a different fiber [1,2]. Each lightpath is categorized by the fiber on the link and the wavelength. Disjoint layers are made from these lightpaths. Each layer may have more than one lightpath, but these lightpaths should be link disjoint with each other. Each route is categorized by the fiber and the wavelength. Provisioning in multifiber networks deals with the allocation of resources such as fibers and wavelengths for data transmission with the objective of minimum resource requirement. Provisioning and restoration are very important issues in WDM optical networks. Provisioning is important due to the factor that deals with resource allocation, but the aim should be that the resource requirement is as minimum as possible. The resource required depends upon the resource allocation strategy i.e. provisioning.

In this paper, one very efficient provisioning strategy for proactive restoration has been proposed. In proactive restoration, all resources for recovering from the failure(s) are reserved in advance. To achieve full protection and fast recovery times backup paths should be determined and centrally computed in advance before the occurrence of failure. When failure(s) occurs the system can immediately shift to the recovery paths. Also, the proposed algorithm will obey the wavelength continuity constraint i.e. the data for a source destination pair will be transmitted on the same wavelength. Reactive restoration is another scheme in which the backup lightpaths (recovery paths) are searched only when a failure occurs. Proactive restoration can be further categorized into two ways depending on the

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provisioning scheme. These types are dedicated backup path and the backup multiplexing. In dedicating backup path, every primary light path has separate backup lighpath i.e. no resource sharing is there between the backup lighpaths. In backup multiplexing, resources can be shared between more than one backup lightpaths. It can handle single fiber/node failure only. But with dedicated lightpaths, the system is able to recover from multiple failures.

This paper is organized as follows. Section 2 introduces the restoration in optical networks. Section 3 describes an existing restoration strategy in optical networks. In Section 4, we propose an optimization restoration strategy to reduce the resources required for connection establishment. Section 5 evaluates the performance of the proposed strategy by taking a single-mode multifiber network. Conclusions are given in Section 6.

2. Restoration in optical networks

Providing resilience against failure is an important requirement for high-speed networks. The amount of disruption caused by a network-related outage becomes more significant because these networks carry more and more data. A single outage can disrupt millions of users and results in millions of dollars of lost revenue to users and operators of the networks [3]. Survivability is the ability of the network to continue providing service in the presence of failure. It is greatly affected by provisioning. The restoration techniques can be categorized in various ways. They can be categorized as link based and path based [4]. In link-based restoration, a new path is selected between end nodes of failed link only. In path-based restoration, a new path is searched between the source and the destination. The path-based restoration can be further categorized as failure dependent and failure independent. In the failure-dependent method, associated with each failure, a backup lightpath is there. The backup lightpath need not to be link and node disjoint with the primary lightpath. In the failure-independent approach, there is only one backup lightpath. In it, both lightpaths need to be link and node disjoint. The survivability approach can be static or dynamic in nature. If the survivability approach becomes affected by the network situation e.g. link utilization, number of wavelengths required, neighborhood information of a node or link, etc., then it is dynamic in nature otherwise it is static. Many terms are associated with restoration such as blocking probability, degree of survivability, resource utilization and restoration time [5]. Blocking probability is the ratio of number of connections rejected and total number of connection requests [6]. Degree of survivability is the ratio of traffic affected that has been restored by the amount of the total traffic affected. Resource utilization gives the degree of utilized resources out of the given resources. Restoration time is the time taken by the system for restoration after failure.

3. Existing restoration strategy

The existing strategy uses the shortest path algorithm both for primary and backup lightpaths. Disjoint layers are made from these lightpaths. Each layer may have more than one lightpath, but these lightpaths should be node and link disjoint to ensure restoration after failure occurrence. The primary and backup lightpath for a particular source destination pair should be in different layers.

Algorithm.

1. *Find the route(s) for the primary lightpaths for all source destination pairs.*
2. *Now, disjoint layers are made from these routes for the lightpaths. Every lightpath is present in only one layer. Each layer can have more than one lightpath. All lightpaths need to be link disjoint.*
3. *Optimize the layers by reducing the number of layers. A layer should contain the maximum light paths that it can have i.e. if a lightpath can be adjusted in any of the existing layer, then no new layer should be added for it.*
4. *Number these layers from 1 to N, if there are N layers.*
5. *If there are W wavelengths in each fiber, assign floor(x/W)th fiber to the x layer.*
6. *Assign (x mod W)th wavelength to layer x.*
7. *Find the routes for the backup lightpath for all source destination pairs. Try to adjust these lightpaths in already existing layers. For all those lightpaths that cannot be adjusted in existing layers, make new layers. (The primary and backup lightpath for a particular source destination pair need to be in different layers.)*
8. *Number these layers from N+1 to M (if M–N new layers are formed in Step 7) and assign fibers and wavelengths to these layers as in Steps 5 and 6.*

4. The proposed restoration strategy for optimization

The following steps can be applied on the results generated by the above-mentioned existing strategy to optimize the resource requirements i.e. to minimize the number of fibers per link. The proposed optimization strategy with restoration in multifiber networks works in the following steps:

1. Find the number of fibers used on each link and calculate the average (avg).
2. Let the highest numbered layer be f on which any connection is established.

3. Put all the layers from avg + 1 to f in an array.
4. Repeat the following steps for $i = f$ to avg + 1.
5. Fail the ith fiber on all the links and find all the affected lightpaths.
6. For all affected primary lightpaths do the following steps:
   a. Make the backup lightpaths as primary lightpaths.
   b. Try to find and adjust the alternate backup lightpaths in 1 to $i-1$ layers. If not successful for all the lightpaths and if $i >$ avg + 1, cancel all the reconfigurations, otherwise go to Step 8.
7. Find all affected backup lightpaths and do the following steps:
   c. Try to find and adjust the alternate backup lightpaths from 1 to $i-1$ layers.
   d. If successful for all the lightpaths, delete layer i from the array.
   e. If not successful for all the lightpaths, cancel all the reconfigurations done in this Step and Step 6.
   f. If $i >$ avg + 1, go to Step 4.
8. Take the entries one by one from the array and renumber those starting from avg + 1.

5. Results and discussion

Consider the network shown in Fig. 1 having seven nodes with 10 links as sample network. Each link may consist of more than one fiber, but every link has the same number of fibers. Single-mode fibers are taken for connection establishment. The system assumes centralized control for calculating the primary lightpaths, backup lightpaths, assigning layers to lightpaths and doing the optimizations.

Following source destination (*s–d*) pairs for connection establishment have been taken:

(2−3), (5−6), (7−4), (2−5), (4−6), (1−4),
(6−3), (1−7) and (3−4).

By applying the existing and proposed strategies on the sample network with the given *s–d* pairs, the results are shown in Tables 1 and 2, respectively. In these tables, the first column shows the *s–d* pairs, the second column shows the primary route for these *s–d* pairs, the third column indicates the layer on which the primary route will be established, the fourth column shows the backup route and the last column indicates the layer for this backup route.

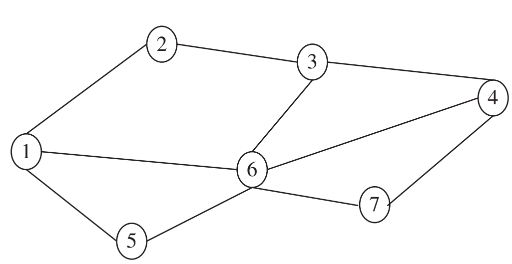

Fig. 1. The 7-node 10-link network.

Table 1. Results without optimization strategy for proactive survivability

s–d Pairs	Primary route	Layer	Backup route	Layer
2–3	2–3	1	2–1–6–3	3
5–6	5–6	1	5–1–6	4
7–4	7–4	1	7–6–4	3
2–5	2–1–5	1	2–3–6–5	2
4–6	4–6	1	4–3–6	4
1–4	1–6–4	2	1–2–3–4	5
6–3	6–3	1	6–4–3	6
1–7	1–6–7	1	1–2–3–4–7	7
3–4	3–4	1	3–6–7	5

Table 2. Results with proposed optimization strategy for proactive survivability

s–d Pairs	Primary route	Layer	Backup route	Layer
2–3	2–3	1	2–1–6–3	3
5–6	5–6	1	5–1–6	4
7–4	7–4	1	7–6–4	3
2–5	2–1–5	1	2–3–6–5	2
4–6	4–6	1	4–3–6	4
1–4	1–6–4	2	1–2–3–4	5
6–3	6–3	1	6–7–4–3	2
1–7	1–6–7	1	1–5–6–4–7	5
3–4	3–4	1	3–6–7	5

In the sample network and for the given *s–d* pairs, a total of 35 channels are required as per Table 1. The network has a total of 10 links. So, the average number of layers per link comes out to be 3.5 (whole number value 4). But with the existing strategy, the number of layers required is 7, so there is need to minimize the number of layers required starting from layer 7 (maximum) to layer 5 (avg + 1) if possible. Put numbers 5, 6 and 7 in the array. Starting with layer 7, there is no primary route established on this layer. Nothing is required to be done for primary route reconfiguration. This layer has one backup route corresponding to the *s–d* pair (1–7), so this route needs adjustment for optimization. The alternative route for backup is 1–5–6–4–7, and this is adjusted on layer number 5. Now, there is no need for layer number 7 and delete the entry corresponding to it from the array. It is the turn for the optimization of layer number 6. No primary route is established on this layer. There is one backup route (6–4–3) corresponding to the *s–d* pair (6–3) on this layer. This is adjusted on layer number 2 on the route 6–7–4–3. Hence, there is now no route on this layer and its entry should be deleted from the array. The last layer that needs optimization is layer number 5. It has backup lightpaths corresponding to *s–d* pairs (1–7), (3–4) and (1–4) established on it. Coming to the alternate backup route (1–5–6–7–4) for the (1–4) *s–d* pair, it cannot be adjusted in the first four layers, so this layer cannot be optimized. System requirement has reduced from 7 layers to 5 layers. If we use the single-mode multifiber system the requirement has reduced from 7 fibers per link to 5 fibers per link.

6. Conclusions

In this paper, we have discussed the survivability problem in multifiber optical networks. Then we explained the existing strategy for connection establishment. This paper presents a strategy that reduces the resources (number of fibers in this case) required. The existing strategy uses the shortest path both for the primary and backup connection establishment. It provides good results as it uses the shortest path. The proposed strategy optimizes the results by reducing the number of fibers needed by calculating the average number of fibers required per link. Then it tries to adjust the path calculated on layers above the minimum layers required into the calculated average number of layers. The proposed optimization strategy is based on the path-based restoration and uses dedicated backup lightpaths. As it is proactive in nature, it ensures high degree of survivability.

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