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Provisioning for restorable WDM optical networks

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Abstract

Restoration is a very critical issue in WDM optical networks. Provisioning also plays a great role in the networks because it deals with resource allocation. In this paper, we have presented two provisioning strategies for restorable networks: unity link weight strategy and varying link weight strategy. The strategies are implemented for critical applications which require 100% degree of survivability. The simulation is done using different proportionate of resources for working and restoration lightpaths. The simulated results show that the performance of the unity link weight strategy is much better than the varying link weight strategy in terms of resource requirement and blocking probability.

Keywords: Restorable networks; Blocking probability; WDM; Provisioning

1. Introduction

WDM optical networks are an attractive candidate for next-generation applications. They may be used for local, metropolitan, and wide area networks. In wide area wavelength routed backbone environments, the network is composed of routers connected by WDM links. Restoration is one very important issue. It deals with reconfiguring and re-establishment of the affected connections after a failure [1]. Re-establishing in restoration is data transmission over another route or path if the existing lightpath is not able to transmit the data due to any component failure. It becomes more important to have an effective restoration scheme in optical networks because they are high-speed networks and the disruption in service even for a short time results in a huge amount of data loss. So, it is required to re-establish the affected connections almost immediately after the occurrence of failure for critical applications. If the resources are allocated in advance to handle the failure occurrence, then it requires more resources. A network with restoration capability is known as a restorable network.

Provisioning is the process of assigning the resources to the connections. The main aim in provisioning is to allocate the resources efficiently so that more number of connections can be accommodated with available resources or the resource requirement is as few as possible to accommodate all the connection requests. Lightpath is a connection in all optical networks, which is totally optical except at the end nodes. There are two types of lightpaths: working lightpath and restoration lightpath. Working lightpaths are those lightpaths upon which data transmission takes place under normal conditions. Restoration lightpaths are those lightpaths

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that carry the data when the working lightpath cannot be used due to failure occurrence. A restorable network requires resources for restoration lightpaths also. As provisioning deals with resource allocation and restoration requires the resources, these are related terms [2]. A connection is called restorable if the resources are allocated for its restoration lightpath also. A restorable network has restorable connections. Provisioning makes available the resources for restoration lightpaths to make the connections restorable. So, in a restorable network, an efficient provisioning strategy is desirable.

The restoration techniques can be categorized as proactive and reactive techniques. Proactive techniques are those techniques in which the resources for restoration lightpath are reserved, when the connection request arrives. Reactive techniques are those techniques in which restoration lightpaths are searched after failure occurrence. Restoration techniques can be categorized as link based and path based [3]. In link-based restoration, a new path is selected between end nodes of a failed link only. In path-based restoration, a new path is searched between the source and the destination. Path-based restoration can be further categorized as failure dependent and failure independent. In the failure-dependent method, associated with each failure, a restoration lightpath is there. The restoration lightpath need not be link and node disjoint with the working lightpath. In the failure-independent approach, there is only one backup lightpath. In it, both lightpaths need to be link and node disjoint. The provisioning strategies presented in this paper are based on proactive path-based failure-independent restoration and support the single link/node failure model. The proactive approach is used because the backup lightpath is to be established along with the primary lightpath to avoid time delays in searching the alternate path for affected traffic after failure to avoid data loss. The lightpaths established will be wavelength continuous.

Many terms are associated with restoration such as blocking probability, degree of survivability, and resource requirement. Blocking probability is the ratio of the number of connections rejected and the total number of connection requests [4]. Degree of survivability is the ratio of traffic affected that has been restored by the amount of the total traffic affected. Resource requirement gives the minimum resources required to accommodate all the connection requests. Blocking probability and resource requirement are directly related to each other. If the blocking probability decreases with any strategy then the resource requirement decreases. In this paper, resource requirements have been measured in terms of minimum number of wavelengths required to accommodate all the connection requests.

This paper is organized as follows: In Section 2, we present problem definition and two provisioning strategies: Varying Link Weight (VLW) and Unity Link Weight (ULW) strategies for restorable WDM networks. The ULW strategy uses the minimum possible number of channels to establish a lightpath leading to a reduction in resource requirement and blocking probability. The VLW strategy may or may not choose a lightpath that uses the minimum possible number of channels. There is non-symmetric distribution of data in VLW. But in the ULW strategy, each link is given equal priority. So, it tries to balance the load over the links leading to efficient utilization of links. It directly reduces the resource requirement and blocking probability. Section 3 focuses on results and discussion, which show simulation results by taking an example of realistic NSFNET and EON networks. The results are taken for various proportions of resources for working and restoration lightpaths and clearly show that the minimum numbers of wavelengths required to accommodate all the connection requests, i.e. the resource requirements and blocking probability, are less with the ULW strategy as compared to the VLW strategy. Conclusions are given in Section 4.

2. Provisioning strategies for restorable WDM networks

2.1. Problem definition

The ability of the network to reconfigure and re-establish the connections upon failure is known as restoration. Provisioning deals with resource allocation. When the network is restorable, then the provisioning has to allocate the resources for working lightpaths as well as restoration lightpaths. There will be two indexed lists of wavelengths: one for working lightpaths and another for restoration lightpaths according to the proportion of resources.

Given a network with physical topology represented by a graph G (A, B, L). Here, A is the set of vertices or nodes in the network. The total number of nodes in the network is $|A| = n$, and is numbered from 0 to $n-1$. B is the set of links in the network. These are the physical links connecting the nodes and assumed to be undirected. L is the set of weights associated with the links. This weight is used for computing the route with the shortest path algorithm. The set of connection requests is C. $|C| = I$ indicates the total number of connection requests. Let N be the set of wavelengths required to establish all the connection requests to achieve 100% degree of survivability in the event of failure.

The objective is to minimize the blocking probability and total number of wavelengths required to accommodate all the connection requests. The following constraints have been considered:

1. It is assumed that there is no wavelength converter in the network. So, *wavelength continuity* constraint is to be observed.
2. A link cannot be used by both primary and backup lightpaths of a connection request because primary and backup lightpaths are link disjoint.
3. The weight of the primary lightpath according to the links along the route and the link weights will never be greater than the weight of the backup lightpath as the shortest path algorithm is applied and the shortest path according to the weight is taken as the route for the primary lightpath.

Two provisioning strategies for restorable networks are given in the next subsections.

2.2. VLW strategy

In the VLW strategy, the weights assigned to the links can be any positive number. The different links may have different link weights. The shortest path algorithm is applied on the network to find the route for the working path based on the weights of the links for a connection request. The shortest path algorithm computes a route with minimum weight and results in efficient utilization of resources. Now a network is considered that is similar to the original network except that it does not have the links and the intermediate nodes used by the working lightpath. Again, the shortest path algorithm is applied on the network considered in the previous step to find the route for restoration lightpath. In this way, the routes for both the lightpaths, working and restoration lightpaths, of a connection request will be node and link disjoint with each other and node/link failure can be handled. The same procedure is followed for all the *s–d* pairs. The working route will never have weights higher than the restoration lightpath. It is done because mostly the data are to flow over the working lightpath and it should be optimum as compared to the restoration lightpath. The wavelengths along the routes for working and restoration lightpaths are allocated according to the first-fit strategy [5]. The wavelengths are searched in the order of their index number. The first free wavelength found is reserved for the connection.

2.3. ULW strategy

In the ULW strategy, the process of connection establishment is the same as specified for the VLW strategy except that the weight of every link is taken as unity. If the link weight is taken as unity, then the shortest path algorithm when applied results in finding a route that uses minimum possible hop counts. The route selected will in no case have more number of hops/links along the route than the alternate routes for the same source destination pair and so it uses the minimum possible number of channels to establish the connection.

In the VLW strategy, where the link weights can be non-unity also, it may be the scenario that the shortest route selected traverses more number of hops as compared to the route selected with the ULW strategy for any connection request. With ULW, the route selected will have the lowest weight of the path due to shortest path and the weight of the path in this case will be equal to the number of links along the route. It means that the route selected will traverse minimum links. There could not be any route with lesser weight and lesser number of links because the shortest path algorithm is applied. The lesser the number of links along the route selected with the shortest path, the lesser the number of channels required to accommodate the connection request. For all the given connection requests, the decrease in channel requirement will lead to fewer resource requirement. It may also improve the blocking probability.

3. Results and discussion

No strategy could be validated until it is supported by practical results. In order to demonstrate that the ULW strategy performs better than the VLW strategy and to investigate the performance of strategies, we must resort to simulations. Not able to find a suitable simulator that could support strategies, we designed and developed a simulator to implement provisioning strategies for restorable WDM optical networks for regular and irregular topologies. The simulator is developed in C++ language. It accepts input parameters such as the number of nodes in the network, link weight information, number of wavelengths per fiber, and connection requests. All these parameters can be initialized either before running the simulations to obtain results for a given selection of parameters or at the run time. Some of the calls may be blocked because of the unavailability of free wavelength on links along the routes for working and restoration lightpaths. One output of the simulator is the blocking probability for the specified parameters along with the detailed information of connections for the given resources. Another output of the simulator is the minimum number of wavelengths required to accommodate all the connection requests. Extensive simulations are then carried out to get the results.

Figs. 1 and 2 show the 14 nodes with 21 links NSFNET [6,7] and 11 nodes with 26 links EON [6] standard networks, respectively, taken as sample networks. The nodes are connected together with undirected links and the information on links can flow in both

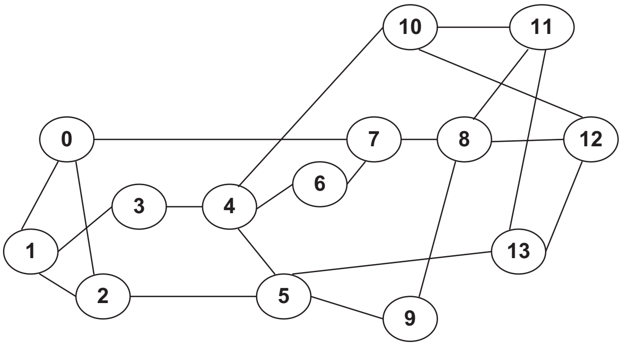

Fig. 1. NSFNET network.

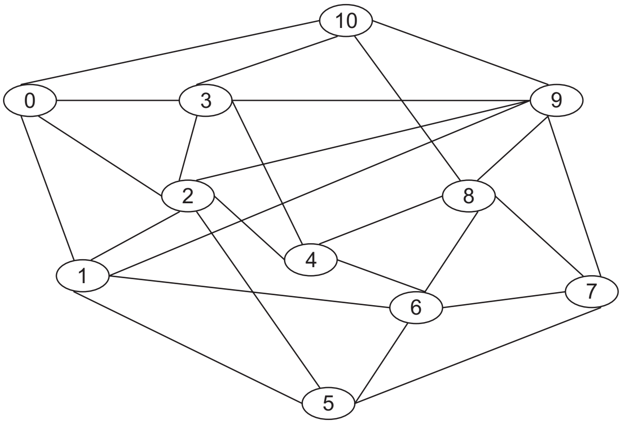

Fig. 2. EON network model.

directions. Let q and h be two different nodes in the network. Due to undirected links, the working routes for q (source) to h (destination) and h (source) to q (destination) will be the same. It will also be the case for their corresponding restoration lightpaths.

Permutation routing has been taken for finding out the sample source destination pairs in which every node in the network acts as the source to every other node in the network simultaneously with the unicasting approach. The total number of source destination pairs in permutation routing depends upon the number of nodes. It is assumed that if a node has to send some data to itself, the data are sent internally and no external links are used for the transfer. So the s–d pairs when $s = d$ are not included during the simulation, as they do not affect the resource requirement and the blocked connections. A dedicated restoration lightpath has been used to handle the failures. An equal number of wavelengths per fiber has been assumed. The alternate shortest path, which is link and node disjoint with working lightpath is used for better provisioning for restoration lightpath. Single link failure model has been assumed. The restoration approach chosen for simulation is a path-based failure-independent proactive approach. The simulations are done with different proportions of resources for working and restoration lightpaths.

Tables 1 and 2 show the link weight information for NSFNET and EON networks, respectively. There is one row in the table corresponding to each link. The first column shows the connecting nodes of the link and the second column represents the weight taken for that link. This link weight is taken when the VLW strategy is applied for obtaining the results. The shortest path for working and restoration lightpaths is calculated according to these weights. In the ULW strategy, the weight of each link is taken as unity. We apply the shortest path according to the link weights mentioned for the EON network and consider a subpath from node number 0 to node number 2. In the VLW strategy, the route will be through node number 1 as it results in subpath weight $1+2=3$ as compared to weight 5, if directly taken from node 0 to node 2. But in the ULW strategy, link weight is treated as unity for each link and the subpath will follow only one link, i.e. from node number 0 to node number 2 because it has weight 1 instead of going through node 1, the subpath in which case will have weight 2. It means that for any connection that requires subpath from node number 0 to node number 2, if the given link weights are applied to find the route, then two channels (one channel along each link) are required along the subpath in VLW strategy, but in the ULW strategy only one channel is required along the subpath. It clearly shows that the ULW strategy may result in lesser channel requirements as compared to the case when the VLW strategy is applied.

Figs. 3 and 4 show the comparison of the two strategies for the applications that require 100% degree of restoration, when applied on NSFNET and EON networks,

Table 1. Link weight for NSFNET

Link	Weight
0–1	67
0–2	100
0–7	173
1–2	38
1–3	61
2–5	118
3–4	42
3–10	130
4–5	91
4–6	40
5–9	58
5–13	114
6–7	43
7–8	39
8–9	55
8–11	25
8–12	27
10–11	38
10–12	49
11–13	29
12–13	14

Table 2. Link weight for EON

Link	Weight
0–1	1
0–2	5
0–3	4
0–10	1
1–2	2
1–5	8
1–6	7
1–9	4
2–3	3
2–4	2
2–5	6
2–9	7
3–4	1
3–9	9
3–10	2
4–6	2
4–8	3
5–6	1
5–7	1
6–7	1
6–8	2
7–8	3
7–9	2
8–9	2
8–10	4
9–10	5

respectively. Let $e{:}f$ represent the proportion of resources allocated for working and lightpaths. It means that the wavelengths that can be used by working lightpaths are $(e/(e+f))\times$ total number of wavelengths in the system. The wavelengths for the restoration lightpaths are the remaining $(f/(e+f))\times$ total number of wavelengths in the system. The proportion of resources for working and restoration lightpaths is shown along the X-axis. The minimum number of wavelengths required to accommodate all the connection requests is shown along the Y-axis.

The VLW strategy shows the results when varying weights are taken for the links as given in Tables 1 and 2. The ULW strategy shows the results when the weight of every link is taken as unity. The connections accepted are those that lead to 100% degree of restoration in the event of failure so that these can be used for critical applications. Simulation results show that the ULW strategy performs better than the VLW strategy in terms of resource requirement.

Fig. 5 is the comparison graph for the EON network. The X-axis represents the number of wavelengths. The wavelengths are divided into two equal sets: one for working and another for restoration lightpaths, i.e. 1:1 proportion is taken. The Y-axis represents the blocking probability. The graph clearly shows that the blocking probability with the ULW strategy is less than the VLW strategy.

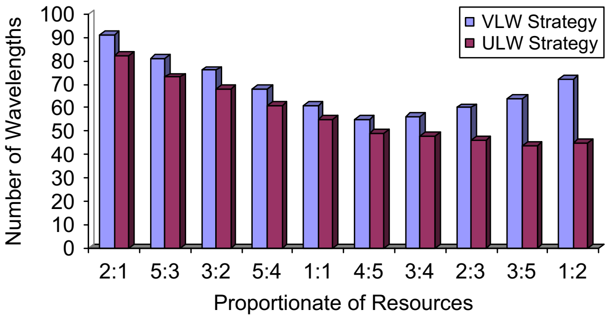

Fig. 3. Comparison chart for NSFNET.

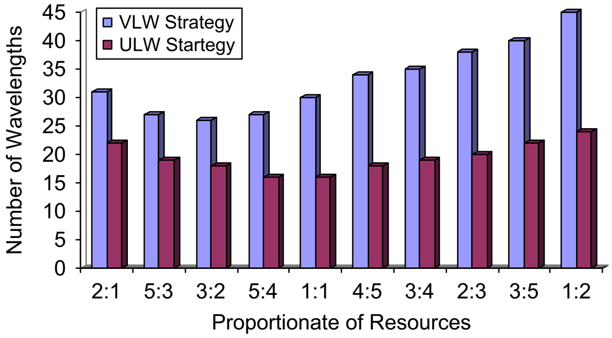

Fig. 4. Comparison chart for EON.

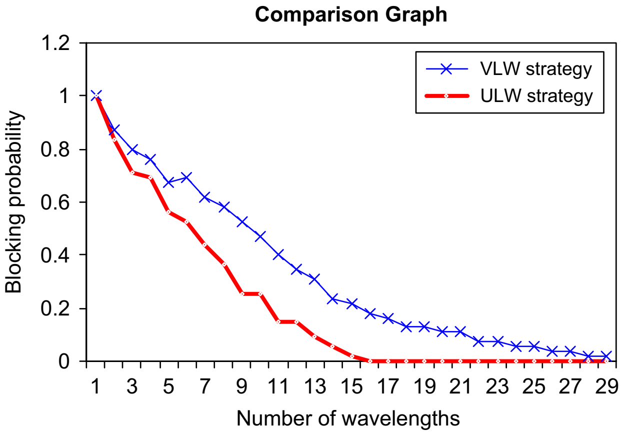

Fig. 5. Comparison graph for EON.

4. Conclusions

An efficient provisioning strategy handles the resources efficiently. In this paper, two provisioning strategies for restorable WDM optical networks have been covered: VLW and ULW strategies. These strategies are experimented on two standard networks for critical applications: NSFNET and EON. Critical applications require resources reserved for both working and restoration lightpaths to attain 100% degree of survivability in the event of failure. The simulated results are taken for different proportions of resources for working and restoration lightpaths. The results show that the blocking probability with ULW is less as compared to the VLW strategy. Also, the resources required with ULW are always less than with the VLW strategy to accommodate all the connection requests.

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