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Node–Arc Link Restoration Model to Optimize Spare Capacity of Optical Networks

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Abstract - *This research work presents simple integer linear program (ILP) formulations for node-arc link restoration model to optimize spare capacity utilization in optical networks. In this paper, the spare capacity utilization is optimized by increasing the backup path of network. It also compares the effect of spare capacity utilized by optical network by increasing the backup path of network. This restoration model provides guaranteed protection against a link failure.*

Key Words: *Node-arc link restoration,* Survivability, Failure, Optical network.

1. INTRODUCTION

Survivability is an ability of any network to continue providing service when a failure occurs. It is one of the most important requirements of the network because today's optical network carries enormous amount of data. If a cut occurs in a fiber it will result in a huge loss of data [1-3]. The techniques that have been used for survivability in optical networks can be classified into two general categories [4]: protection and restoration shown in figure 1.

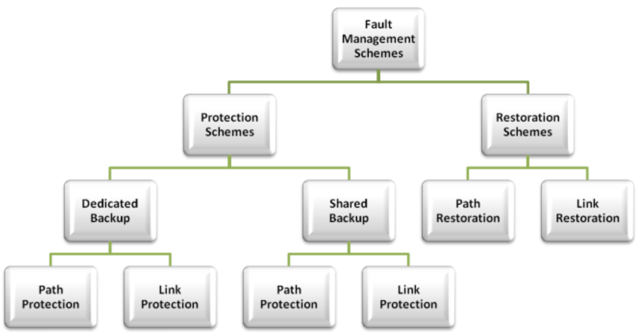

Fig -1: Different protection/restoration schemes

When pre-defined backup-paths and wavelengths are used in case of failure event, it is called network protection. However in network restoration the backup paths and wavelengths are discovered after a failure event. Because protection used pre-defined paths and wavelength its response of recovery is very fast and it does not require any processing. Restoration requires processing and assessment to restore any failure and hence it has slow response to recovery but it is not only cost-efficient but also utilizes resources to the maximum. Restoration requires a post processing unit and algorithm for path and wavelength discovery.

Wavelength division multiplexing (WDM) divides the huge bandwidth of a fiber into many non-overlapping wavelengths, which can be operated at any desirable speed. In a WDM system, a single fiber can carry many channels, and thus total utilized capacity of network can be increased drastically. To establish a connection in the WDM optical network, a route has to be discovered and free wavelengths for all the links are allocated. This is known as the routing and wavelength assignment (RWA) problem [5-7]. The main objective of this manuscript is to optimize the total spare capacity used by network. This paper provides detail study of node-arc link restoration model for spare capacity allocation planning in optical networks. With the help of ILP formulations, the total node-arc spare capacity utilization for NSFNET has been analyzed. Section II, presents the ILP formulations of node–arc link restoration model for spare capacity allocation planning. Section III, presents result analysis of node–arc link restoration model. Conclusions of the paper are described in Section IV.

2. PROBLEM FORMULATION

In this section, an ILP formulation of node-arc link restoration model for spare capacity allocation planning to protect link failure has been discussed [8]. For this model, a link indicates a bi-directional connection between a node pair. A graph is denoted by [N, L], here N is a set of nodes and L shows the link corresponding to the node. The directed graph for the given network is represented by G=[N,E]. Let E be an arc corresponding to the links. In this model, it is assumed that each node has the capability of detecting link failures. The variable c_{ij} denotes the known volume of working traffic on link (i, j) where c_{ij} for all {i, j} ϵ L are fixed. Let the variable h_{ij} denotes the spare capacity assigned to link (i, j) and the variable f_{ij}^{st} denotes the restoration flow on arc (i, j) when {s, t} fails. If link {s, t} fails, c_{st} units of flow must be rerouted from node s to node t and vice versa. In the node-arc model for link restoration, the requirement is given by

$$r_i^{st} = \begin{cases} c_{st}, & if\ \ i = s, \\ -c_{st}, & if\ \ i = t, \\ 0, & \text{otherwise.} \end{cases}$$

The node–arc link restoration model for spare capacity allocation planning is stated mathematically as follows:

Total Working Plus Spare Capacity:

$$\sum_{\{i,j\}\in L} (c_{ij} + h_{ij})$$

Subject to Flow Conservation:

$$\sum_{(k,j)\in E} f_{kj}^{st} - \sum_{(i,k)\in E} f_{ik}^{st} = r_i^{st} \qquad \forall k \in N \quad \forall \{s,t\} \in L,$$

Subject to Capacity in Normal Direction:

$$f_{ij}^{st} \le h_{ij} \qquad \forall \{i, j\} \in L \quad \forall \{s,t\} \in L,$$

Subject to Capacity in Reverse Direction:

$$f_{ji}^{st} \le h_{ij} \qquad \forall \{i, j\} \in L \quad \forall \{s,t\} \in L,$$

Subject to Link Failures:

$$f_{st}^{st} + f_{ts}^{st} = 0 \qquad \forall \{s,t\} \in L$$

Subject to Non-negativity:

$$h_{ij} \ge 0 \qquad \forall \{i, j\} \in L,$$

$$f_{ij}^{st} \ge 0 .$$

The given node–arc link restoration model has been performed with the help of 6-node optical networks shown in figure 1, it consist of 6 numbers of node and 9 links. Table 1 represents demand matrix corresponding to 6-node network.

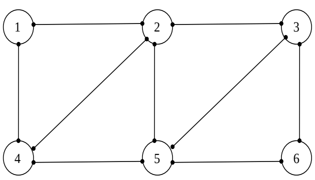

Fig -2: 6-node network

Table -1: Demand matrix for network

Node	1	2	3	4	5	6
1	---	10	0	10	10	0
2	0	---	10	10	10	10
3	0	0	---	0	10	10
4	0	0	0	---	10	0
5	0	0	0	0	---	10
6	0	0	0	0	0	---

3. RESULTS AND DISCUSSIONS

'AMPL' language with CPLEX 12.2 solver is used to solve the ILPs formulation for given example networks. An optimal solution of node–arc link restoration model of network A for |T| = 60 is illustrated in figure 3. In this case 60 backup paths are assigned in the data file. For network A, 125 units of spare capacity are required to protect 130 units of working capacity. The capacity utilized by each link of problem network A has been analyzed. For |T| = 60, the total capacity utilized by network A is 255. On increasing the backup path from |T| = 60 to |T| = 120, 105 units of spare capacity are required to protect 130 units of working capacity. An optimal solution of node–arc link restoration model of network A for |T| = 120 is illustrated in figure 4. For |T| = 120, the total capacity utilized by network A is 235.

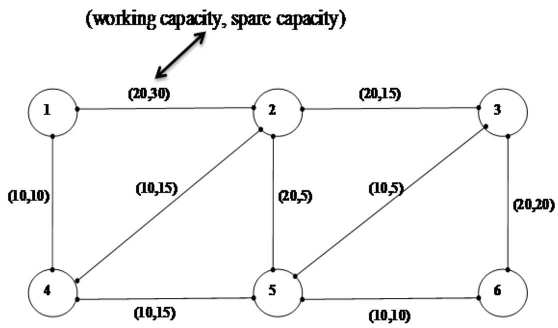

Fig -3: Solution of node–arc link restoration model of network A for |T| = 60
(working capacity = 130 and spare capacity = 125)

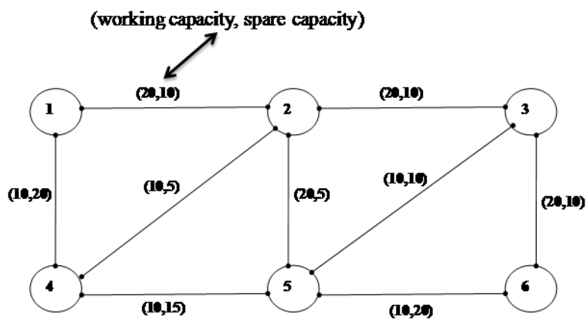

Fig -4: Solution of node–arc link restoration model of network A for |T| = 120
(working capacity = 130 and spare capacity = 105)

3. CONCLUSIONS

In this paper, node–arc link restoration model is used to optimizing spare capacity utilization in survivable WDM network. In this research paper it is found that 16% less spare capacity is required for network A, if backup path is increased from 60 to 120. The spare capacity required for each link of optical network has been also analyzed. The paper proves that network requires less spare capacity on increasing the backup path. This restoration model provides guaranteed protection against a link failure.

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BIOGRAPHIES

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