Dynamic WDM Mesh Network Design with Dynamic Optical Path Protection

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Abstract- **A WDM mesh network is planned and designed so that to satisfy all its demands. Each connection has to be protected with the a) dedicated way, b) shared way and c) the benefits of the shared way versus the dedicated way are also showed. The shortest path algorithm is used for all dynamical cases. The network uses wavelength conversion.**

Keywords-**dedicated protection, optical channel layer, shared protection, shortest path, WDM mesh networks.**

I. INTRODUCTION

THE high capacity WDM optical mesh networks that based on optical technologies, provide routing, grooming and restoration at the wavelength level as well as wavelength based services. Research has been done [1]-[10] in relation to the methods and the problems associated with planning, protection and restoration of optical networks. There are several approaches to ensure fiber network survivability [1],[2]. In [3] the author gives a practical guide for network designers and developers. In [4] the authors begin with an overview on the future of optical networking. In the [5] new options and insights are provided about, an existing ring-based network is evolved to a future mesh network. They could be further adapted for use in IP or DWDM layers with GMPLS-type protocols or centralized control plane. In the [6] a perspective on optical layer protection and restoration based on the services offered by carriers using the optical layer, is provided. The [7] looks at several aspects of optical layer protection techniques from an implementation perspective. The authors discuss the factors that affect the complexity of optical protection schemes, such as supporting mesh instead of ring protection, handling low-priority traffic and dealing with multiple types of failures. The [8] provides an overview of some of the optical grooming (aggregation) techniques that have been developed recently with IP as the client layer. The [9] examines different approaches to protect a mesh-based WDM optical network from failures of its elements. The [10] presents that for fault management in optical WDM mesh networks end to end path protection is an attractive scheme to serve customers' connections.

In this paper, a WDM mesh network is planned and designed so that to satisfy all its demands with m:N WDM and optical fiber shared protection, a) each connection has to be protected with the dedicated way and based on the spare capacity which is allocated as a "dedicated" resource for sole use of the connection. b) each connection has to be protected with the shared way and uses the spare capacity as a "shared" resource, where the allocated backup capacity can be shared with other connections. c) the benefits of the shared way versus the dedicated way are also showed. The shortest path algorithm is used for the planning and designing as well as for the dynamic selection of the protection path. The network uses wavelength conversion.

This paper is broken down in the following sections: Section II describes the problem and provides a solution, the method general description and examples. Finally ends with the references.

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II. THE PROBLEM AND ITS SOLUTION

A. *The problem*

The problem deals with the planning and designing a WDM mesh network to satisfy given demands when a) dedicated protection b) shared protection are used for each connection. The results of the comparison of these protection approaches on optical channel layer are showed. For this problem solution the parameters that given are the network topology, the capacity of WDM multiplex system, the number of node pairs and the node pairs that the demands (requests for connection) must be satisfied, the m:N=1:7 optical line shared protection (a practical way to reduce the protection network cost). The network is a circuit switched one with identical nodes. On the network nodes are installed the WDM-OXCs. WDM-OXC does the switching and the routing on the optical channel layer. A lightpath is an optical channel from source node to destination one to provide a circuit switched connection between these nodes.

B. *Symbols*

The following symbols are introduced for the description.

q, p the node and edge number.

G(V,E) , the network graph.

$V(G)=\{v_1, v_2, v_3, \dots , v_q\}$, the network node set.

$E(G) =\{e_1, e_2, e_3,\dots , e_p\}$, the network edge set.

k, the capacity of the WDM and fiber system.

Xn , a column matrix (nx1) with elements the connection group size of the corresponding source-destination node pairs and corresponds to the successful requests for connection.

n is the number of source – destination nodes pairs of the network.

Y, Yw, Ydp, Ysp are the column matrixes (2px1) with the wavelength demands of network links for total, working, dedicated and shared protection respectively.

W, P, T are the column matrixes (2px1) with elements the working, protection and total WDM and optical fiber systems per link respectively.

A, A_w, A_{dp}, are matrixes (2p x n) that present the network active links that pass the total, working and dedicated connections respectively before a link cuts.

C. The formulation

The solution of the planning and designing problem is based on the following equations.

$$Yw = Aw * Xn \quad (1)$$

It means that the knowledge of each node pair demands which are its requests for connection and their shortest working lightpaths create the necessary wavelengths for their satisfaction for each link. The total working wavelengths of each link are

$$Y_{w,i} = \sum_{j=1}^{n} A_{w\,i,j} * X_j \quad (2)$$

The knowledge of each node pair demands which are its requests for connection and their shortest full disjoint dedicated protection lightpaths create the necessary wavelengths for their satisfaction for each link.

$$Ydp = Adp * Xn \quad (3)$$

The total dedicated protection wavelengths of each link are

$$Y_{dp,i} = \sum_{j=1}^{n} A_{dp\,i,j} * X_j \quad (4)$$

For the matrix the following equation is valid

$$A = A_w \cup A_{dp} \quad (5)$$

The total wavelengths for dedicated protection the following

$$Y = Yw + Ydp \quad (6)$$

The total wavelengths for the corresponded shared protection are the following

$$Y = Yw + Ysp \quad (7)$$

Ysp contains the total wavelengths that are reserved for sharing protection of working lightpaths.

The working WDM and fiber systems are

$$W = Y/k \quad (8)$$

This equation means that dividing the number of the necessary busy wavelengths of each link with the capacity of the multiplex system creates the necessary working WDM and optical fiber systems for each link. The roundup is done for the larger integer.

$$P = W*(m:N) \quad (9)$$

This equation means that multiplying the number of the necessary working WDM and optical fiber systems of each link with the m:N ratio creates the necessary protection WDM and optical fiber systems. The m:N=1:7 shared protection WDM and optical fiber systems of each link means that the maximum number of working WDM and optical fiber systems that sharing a protection WDM and optical fiber system is seven. It is a practical way to reduce the cost of the protection network. The roundup is always done for the larger integer.

$$T = W + P \quad (10)$$

T presents the total network WDM and fiber systems per link with protection. The available wavelengths Ta for protection are the following

$$Ta = \sum_{i=1}^{2p} (kT_i) - \sum_{i=1}^{2p} Y_{w,i} \quad (11)$$

For dedicated protection Ti is written as Tdi and for shared protection it is written as Tsi. The analytical format of Tdi for dedicated protection and Tsi for shared protection, are more analytical written below when the optical channels of WDM and fiber systems of protection are used.

$$T_{di} = \left[\frac{Y_{w,i} + Y_{dp,i}}{k}\right] + \left[\frac{m}{N}\left[\frac{Y_{w,i} + Y_{dp,i}}{k}\right]\right] \quad (12)$$

$$T_{si} = \left[\frac{Y_{w,i} + Y_{sp\,i}}{k}\right] + \left[\frac{m}{N}\left[\frac{Y_{w,i} + Y_{sp\,i}}{k}\right]\right] \quad (13)$$

The parentheses mean the rounding. When the protection network is not used the term which multiplied with (m/N) is neglected and the available resources are less.

The protection ratios for dedicated and shared protection are more analytical written below

$$PR_d = \frac{\sum_{i=1}^{2p} Y_{dp,i}}{\sum_{i=1}^{2p} Y_{w,i}} \quad (14)$$

The protection ratio for shared protection is the following

$$PR_s = \frac{\sum_{i=1}^{2p} Y_{sp,i}}{\sum_{i=1}^{2p} Y_{w,i}} \quad (15)$$

$Y_{w,i}$, $Y_{dp,i}$, $Y_{sp,i}$ the elements of the corresponded matrixes.

Optical fiber spare capacity for connection protection $Y_{sp,i}$ is calculated assuming that a sub-network protects each optical fiber.

D. General description

These methods have two parts. The first part or the planning and designing part and mean network without failure and the second part or network with failure. The allocation path algorithm uses the shortest path algorithm because is a dynamical way to do it and TURBO PASCAL is used to program the model. At first step (network parameters) initially the following data are known network topology, node number, edge number, link number and wavelength number per WDM and fiber system. This information allows the computer to draw a graph with WDM-OXCs are on the vertex of the graph. Each edge corresponds to two links with opposite direction to each other. The computer reads the adjacency matrix and is informed about the network topology. At second step (connection selections), the connection node pair number and the connection node pair selection for connections are done. The connection group of each node pair reads its size. The size is constant. At third step (wavelength allocation-Failure-free Network Phase), wavelength allocation is initiated. A working connection starts from the source node and progresses through the network occupying a wavelength on each optical fiber and switch to another fiber on the same or other wavelength by OXC, according to its shortest working optical path up to arrive at the destination node. Then, the protection lightpath of the connection starts from the source node and progresses through the network occupying a wavelength on each optical fiber and switch to another fiber on the same or other wavelength by OXC, so another full disjoint protection optical path is obtained. It is full dedicated protection for this connection. The same procedure is repeated for the shared protection but each wavelength is reserved to share by others connections. The number of connections of each node pair is equal to its connection group size. At forth step (Results), having the connection group size the total results are computed. After the wavelength allocation has been completed, the wavelengths that each link needs for the full satisfaction of network demands are known and WDM and optical fiber system calculation starts with all fibers have the same wavelength number. The working WDM and fiber system calculation per link is implemented using the WDM capacity as well as the total network working WDM and fiber systems. The m:N(1:7) shared protection WDM and fiber systems per link are calculated by multiplied with m:N(1:7) the working ones. Then the total network protection WDM and fiber systems are calculated. At the end, the number of WDM and fiber system per link and the total network WDM and fiber systems are calculated. If there is no failure, the method is terminated. This network have been planned and designed so that all requests for connection have been satisfied and formed connections. So there is not any connection blocking. At network with failure phase, when a failure occurs and a link is cut, the working and protection optical fibers of this link are also cut and the network topology change. The connection groups that passed through the cut link are also cut. The computer is informed of the cut link and modifies suitably the network parameters. The cut optical fibers sets their wavelengths to zero, the connection groups that passing through the cut link are noted and set their using wavelengths to zero and through the others to free, the matrix A changes as well as the number of the group size that passing through fibers. Protection paths pass the traffic.

Its worst case time complexity depends of the network topology and the total number of connections. *It is $O(t*q^2)$ where t the total number of the connections*. In the examples, the shared protection method needs about 16 100^{th} of the second time to consume but the corresponded dedicated protection method needs 11 100^{th} of the second. The time difference of these protection methods is small but the dedicated protection method is faster than the shared one because a special procedure is used to transform the dedicated protection to the shared protection.

E. Examples

For the best presentation the network here below is studied for a simple example and for a more complex one. It is assumed that the topology of the network is presented by the graph G(V,E). This mesh topology is used because it is a simple, palpable and it is easy to expand to any mesh topology. The vertex set has q=11 elements and the edge set has p=20 elements. Each edge has two optical links of opposite directions with their fibers for each direction. The connections of each node pair form connection group according to its shortest path and transverse the network.

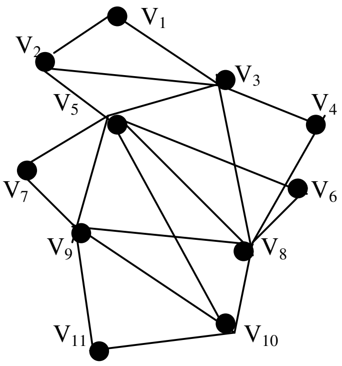

Fig.1.The mesh topology of the network

For the simple example, network planning and designing is flexible to meet with the needs of the network. The capacity of WDM optical fiber system is 16 OChs (wavelengths). The number of node pairs is n=11*(11-1)=110. Each source destination demand is constant and equal to one. The working and protection lightpaths are not showed because their matrixes are large. The m:N WDM and optical fiber system shared protection is 1:7, which is a practical way to reduce the protection network. No further calculations and results are presented for the network planning and designing because their matrixes are very large. A wavelength conversion cross connection is the capability to convert the input port wavelength to a same wavelength or a different one at the output port. So a connection wavelength of the link $<V_1,V_2>$ routes at the same wavelength or different one to the link $<V_2,V_3>$ by WDM-OXC of node V_2 and thus, it is written V_1-> V_2-> V_3 (optical channel layer, OCh layer).

The dedicated protection and shared protection are done during the planning and designing step. When a failure occurs the infrastructure will change and the protection lightpaths pass the traffic. The capacity of the WDM system is 16 optical channels and each node pair has one connection. The total working wavelengths are 202. The total dedicated protection wavelengths are 278. So the total busy wavelengths are 480. The protection ratio is 1.37. The working WDM and fiber systems are 44, the protection one are 40 and the total 84. The table 1 shows here below the node pairs connections that pass the traffic when the link **$<V_1,V_2>$** cuts. The bold lightpaths are cut.

TABLE 1

A /A	NODE PAIR	WORKING LIGHTPATH	PROTECTION LIGHTPATH
1	[V_1,V_2]	**V_1->V_2**	V_1-> V_3->V_2
2	[V_1,V_3]	V_1->V_3	**V_1-> V_2-> V_3**
3	[V_1,V_4]	V_1-> V_3-> V_4	**V_1-> V_2-> V_5-> V_8-> V_4**
4	[V_1,V_5]	**V_1-> V_2-> V_5**	V_1-> V_3-> V_5
5	[V_1,V_6]	**V_1-> V_2-> V_5-> V_6**	V_1-> V_3-> V_8-> V_6
6	[V_1,V_7]	**V_1-> V_2-> V_5-> V_7**	V_1-> V_3-> V_8-> V_9-> V_7
7	[V_1,V_8]	V_1-> V_3-> V_8	**V_1-> V_2-> V_5-> V_8**
8	[V_1,V_9]	**V_1-> V_2-> V_5-> V_9**	V_1-> V_3-> V_8-> V_9
9	[V_1,V_{10}]	**V_1-> V_2-> V_5-> V_{10}**	V_1-> V_3-> V_8->V_{10}
10	[V_1,V_{11}]	**V_1-> V_2-> V_5-> V_9 -> V_{11}**	V_1-> V_3-> V_8-> V_{10}-> V_{11}
11	[V_3,V_2]	V_3-> V_2	**V_3-> V_1-> V_2**

The total shared protection wavelengths are 184. So the total busy wavelengths are 386.The protection ratio is 0.91. The working WDM and fiber systems are 40, the protection one are 40 and the total 80. The advantages of the shared protection are obvious than the dedicated protection because the shared protection has less protection ratio (0.91 vs 1.37) and less number of WDM and fiber systems (80 vs 84).

For the more complex example, the two approaches are studied by calculation the corresponded protection percentages of fully protected cut connections when the number of connections of each node increase up to maximum value which is 64. All node pairs have the same number of connections. The capacity of WDM optical fiber system is 32 OCh (wavelengths). The procedure is executed calculating the protection ratio and the number of WDM and fiber systems that are saved by shared method versus dedicated method *without* using the capacity of the protection WDM and fiber systems and the results are showed in the figures 2 and 3. It is also showed in fig. 3 the best fit curve. It is a linear curve of $y=3.4075*x$, (y, the benefits and x the connections per node pair) that is produced by the best fit procedure.

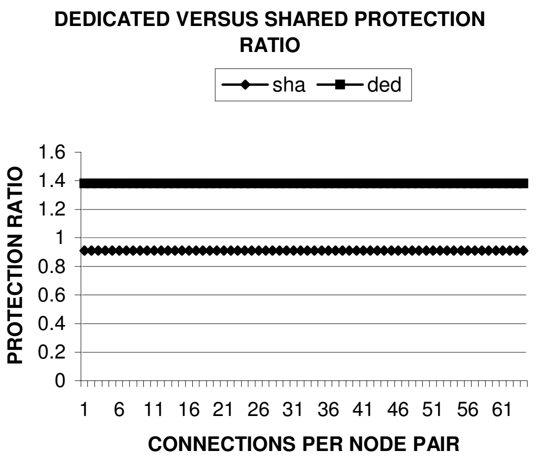

Fig.2.The shared versus dedicated protection ratio, when WDM system has 32 O C h.

The results of the comparison show that the number of WDM and fibers systems that are saved when the shared protection is used versus the dedicated one is significant so it is worth to use this protection method. These results are expected by previous equations.

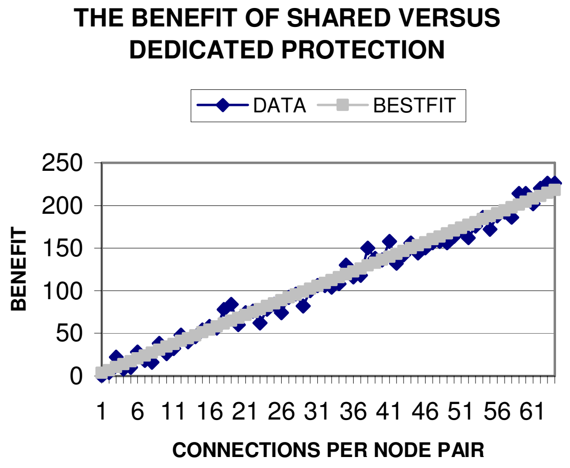

Fig.3. The shared versus dedicated benefit at WDM systems, when WDM system has 32 O C h (DATA means the curve of calculated data by model and BESTFIT means the curve of best fit procedure).

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