Restorations for Small Scale WDM Mesh Networks

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Abstract—**This paper presents a WDM (Wavelength Division Multiplex) mesh network planning and designing that satisfies given demands and a restoration approach. This restoration approach is based on the network traffic rearrangement by all source and destination nodes with the shortest path algorithm ignoring the failed link and when a link has inadequate capacity, the problem is solved by both nodes of the problematic link by way of the shortest path algorithm. This restoration approach is compared with another method on optical path layer for a small scale WDM mesh network (few nodes).**

***Index Terms*— optical channel layer, protection, restoration, shortest path, WDM networks**

I. Introduction

THE high capacity WDM (Wavelength Division Multiplex) optical mesh networks is based on optical technologies. Wavelength-division multiplexing (WDM) is the practice of multiplying the available capacity of optical fibres through use of parallel channels, each channel on a dedicated wavelength of light. This requires a wavelength division multiplexer in the transmitting equipment and a demultiplexer (essentially a spectrometer) in the receiving equipment. Arrayed waveguide gratings are commonly used for multiplexing and demultiplexing in WDM. Using WDM technology now commercially available, the bandwidth of a fibre can be divided into as many as 160 channels to support a combined bit rate in the range of Tbit/s. When the WDM systems operate at 100 Gbps per wavelength obtain fibre capacity to 8 Tbps and more. The need of for even greater bandwidths drives, the WDM systems to operate at 1 Tbps per wavelength and obtain fibre capacity to 20 Tbps and more. They transmit large quantities of information due to multiple applications or because they serve large urban areas (big and small local telephone exchanges); need to be maintained fault-free at all times of their operation. Such protection from faults extends to both service providers and end users. To ensure service continuity, service providers plan and design suitable solutions to alleviate such disruptions. These solutions include protection systems and restoration paths. Planning depends on the demands or needs that the network satisfies as well as on the percentage of protection and fulfilment of the network systems. The protection is provided on optical fibre layer or on wavelength layer or combining both of them.

Research has been done [1]-[15] in relation to the methods and the problems associated with planning, protection and restoration of optical networks. In [1] and [12], there are issues of modelling and analysis. In [2], there are software issues. There are several approaches to ensure fiber network survivability [3],[4]. In [5] and [13], authors begin with an overview of the existing strategies for providing transport network survivability and continue with an analysis of how the architectures for network survivability may evolve to satisfy the requirements of emerging networks. In the [6] and [7] addresses issues in designing a survivable optical layer. In [8], addresses issues of protection circles on WDM mesh networks. In [9], the approach of path protection is examined, its wavelength capacity requirements, the routing and wavelength assignment of the primary and backup paths, as well as the protection switching time and the susceptibility of these schemes to failures. In [10] a mesh based hybrid OMS / OCh protection /restoration scheme is suggested. In [11] , two link disjoint paths, a dedicated working path and a shared protection path are computed , for an incoming light path request based on the current network state but the protection approaches to optimize the resource utilization for a given traffic matrix, do not apply because lightpath requests come and go dynamically. In [14] the topic of network disaster recovery is presented with a comprehensive overview of the research, the challenges and opportunities in this area. In [15] the authors present the network architectures that utilize 10Gbps WDM technology with or without Optical Transport Netwok (OTN) switches and compare different options in typical real world networks.

Today installation of WDM networks is based on mesh topologies but the latter are essentially formed by a set of point-to-point links between nodes. Network survivability is an inherent part of the mesh topology because there are usually at least two paths between end nodes. Thus, a network that uses a mesh topology can survive after a single failure. In communications, network survivability defined as the capability of a communication network to resist any link or node interruption or disturbance of service, particularly by warfare, fire, earthquake, harmful radiation or other physical or natural catastrophes.This feature topic will address the various approaches to plan for and recovery following disasters, so that all concerned can mitigate these events effectively.

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Protection and restoration strategies are critical for optical mesh networks. Although dedicated path protection mechanisms are simple and fast, they use 100% or more redundant capacity. Restoration is the method by which backup or spare capacity for the connection is dynamically discovered after connection has failed due to a link or node failure and it is used to provide either more efficient routes and additional resilience against further failures before the first failure is fixed. Restoration is a slower alternative than protection. Complex algorithms can be used to reduce the excess bandwidth required. In this paper a new approach is studied and compared with another method for small scale networks.

TABLE I
THE SYMBOLS

Symbols	Comments
q	The node number
p	The edge number
G(V,E)	The network graph
V(G)	The network node set
E(G)	The network edge set
2p	The number of links
n	The number of source – destination nodes pairs of the network
(S_n,D_n)	The order pairs of the node pairs
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.
k	The number of the wavelengths channels on each fiber that is the WDM system capacity
n(i)	The total number of the connection groups that passes through the fiber (i) and means that each fiber has different number of connection groups pass through it before any failure
Aw	A matrix (2p x n) which shows the network active links that have the fibers with the working lightpaths
Tbi	The busy wavelengths without any failure i=0 and for each restoration method after failure i=1,2

In this paper this problem is solved and the parameters are given such as small 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 node pairs preplanned working optical paths, the 1:1 and the 1:7 (a practical way for reducing the protection costs) optical line shared protection. The solving is the planning and designing a WDM mesh network to satisfy given demands, the restoration capability of this network is calculated when a link cut occurs and the restorations are applied on optical channel layer. The results of the comparison of this restoration approach (first method) versus the restoration of the source destination node pairs ignoring the cut link on optical channel layer (second method) are also showed.

This paper is broken down in the following sections: Section II describes the problem and its formulation, the method general description, an example, discussion and the attributes. Section III draws conclusions and finally ends with the references.

II. THE PROBLEM AND ITS SOLUTION

A. The problem

The following problem is solved and the parameters are given such as small 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 node pairs preplanned working optical paths, the 1:1 and the 1:7 optical line shared protection (a practical way for reducing the protection costs). The solving is the planning and designing a small WDM mesh network to satisfy given demands, the restoration capability of this small network is calculated when a link cut occurs and the restorations are applied on optical channel layer. The results of the comparison of this restoration approach (first method) versus the restoration of the source destination node pairs ignoring the cut link on optical channel layer (second method) are also presented.

At this approach which is the first method (i), the restoration is done with the network traffic to be rerouted by all source destination nodes by the shortest path algorithm ignoring the cut link and if a link has a capacity problem (deficit) it is solved by both its nodes with the shortest path algorithm on optical path layer (Gained dynamic restoration with full rearranging of the existing connections). At the other method which is the second method (ii), the restoration is done by source-destination nodes ignoring the cut link on optical path layer. Using the shortest path algorithm through the network, source-destination nodes of all effected paths discover their restoration paths.

The network is a circuit switched one with identical nodes. On the network nodes are installed the OXCs and the restoration relies on the ability of the latter to execute cross-connections after a failure has occurred in the network. A lightpath is an optical channel from source to destination to provide a circuit switched connection between these nodes. An optical channel passing through a cross-connect node may be routed from an input fiber to an output fiber. It is assumed that different wavelengths are assigned on all links along the route because nodes have wavelength conversion capabilities. Restoration architectures offer either centralized restoration or distributed restoration or some combination of both. The restoration can be applied at the optical path or on optical line layer. This WDM mesh network is a characterized by edges of two links, links of multi optical fibers, multi fibers for working and multi fibers for protection. The number of the connections of each node pair is constant. The connections of the same node pair going by same working preplanned optical paths form a connection group along the network.

B. The formulation

The solution of the planning and designing problem is based on the knowledge of each node pair demands which are its requests for connection and their preplanned working lightpaths create the necessary wavelengths for their satisfaction for each link. From the total working wavelengths of each link the total working WDM and fiber systems as well as the total protection WDM and fiber systems calculated using the capacity of WDM system. So the total WDM systems are also calculated (The capacity of WDM systems is assumed that it is full and there are not free wavelengths-optical channels). The network busy wavelengths for its demands is

$$Tb0=\sum_{i=1}^{2p}\sum_{j=1}^{n(i)} Aw_{i,j}*X_j \qquad (1)$$

Aw is a matrix (2p x n) which shows the network active links that have the fibers with the working lightpaths. The network is planned and designed based on equation (1) and has the following Ts1 wavelengths without any failure

$$Ts_1=\sum_{i=1}^{2p} k\left(\frac{\sum_{j=1}^{n(i)} Aw_{i,j}*X_j}{k}\right)\left(1+\frac{m}{N}\right) \qquad (2)$$

The large parentheses mean the rounding. When there are not protections WDM and fiber systems the term of the m/N is zero in equation (1) and neglected and the available resources are less. In the equation (1) 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 m:N=1:1 is also used. The roundup is always done for the larger integer.

When a failure occurs with a link cut then the the network change and the matrix $Aw_{i,j}$ will be $A_{1w i,j}$. The network has now smaller number of installed wavelengths because a link cut and its capacity is set to zero. The connections that pass through the cut link break and their wavelengths are free and $n_1(i)$ present these changes.

$$Ts_2=\sum_{i=1}^{2p} k\left(\frac{\sum_{j=1}^{n_1(i)} A_{1w i,j}*X_j}{k}\right)\left(1+\frac{m}{N}\right) \qquad (3)$$

A_{1w} is a matrix (2p x n) which shows the network active links that have the fibers with the working lightpaths after a link cut occurs and before restoration. The wavelengths of a link which cut means must be zero. The connections which are passing through it, break.

The number of busy wavelengths for restoration with the first method is the following

$$Tb_1=\sum_{i=1}^{2p}\sum_{j=1}^{n_2(i)} A_{2w\, i,j}*X_j \qquad (4)$$

A_{2w} is a matrix (2p x n) which shows the network active links that have the fibers with the working lightpaths after a link cut occurs and after the first method of restoration.

The number of busy wavelengths for restoration with the second method is the following

$$Tb_2=\sum_{i=1}^{2p}\sum_{j=1}^{n_3(i)} A_{3w\, i,j}*X_j \qquad (5)$$

A_{3w} is a matrix (2p x n) which shows the network active links that have the fibers with the working lightpaths after a link cut occurs and after the second method of restoration. For full restoration, each link must have installed wavelengths more or equal than busy ones. In different case partial restoration is done.

The full present of previous parameters for any case and for any link is too long with a large number of matrixes. So anew parameter is defined and it is called *Capability for Full Restoration*. It means in the network of (*2p*) links, one by one all network links cut and if there is full restoration to be done for any of all links, full restoration is noted for all links and restoration capability equals to (2p). If full restoration is done for another number of link cuts, the restoration capability is equal to this number and so on. With this way the compare is easier for any case.

The symbols of this formulation are showed in the table I. The parameters n(i), Aw, Ts_i and Tb_i change with the network state as no failure , with failure but no any restoration, with failure but with the first method of restoration and with failure but with the second method of restoration. The changes are showed in the formulas.

C. General description of the methods of the planning, designing and restoration

These methods have two parts, the first part or the planning and designing part and the second part or the restoration part. The restoration methods use the shortest path algorithm.

Part I or Planning and designing part

Step 1 Network parameters

Initially the known data as network topology, node number, edge number, link number per edge, wavelength number per WDM and optical fiber system allow the computer to draw a graph and OXCs are on the vertex of the graph. Each edge corresponds to two links with opposite direction to each other. All fibers have the same wavelength number but the links have different fiber number.

Network without failure phase

Step 2 Connection selections

Then, the node pair number, the node pair selection for requests for connection and the constant connection group size are done. The preplanned working optical paths for connections of every node pair are also provided. The planned network is a WDM mesh network.

Step 3 Wavelength allocation

After it, the wavelength allocation starts. A connection starts from source node and progresses through the network occupying a wavelength on each fiber and switches to another fiber on the same or a different wavelength by WDM-OXC of according its preplanned path up to arrive to the destination node. The number of connections of each node pair is equal to its demands (requests for connection).

Step 4 Results

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. 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. By m:N (1:1 or 1:7) WDM and optical fiber system shared protection, the protection fibers per link are calculated as well as the total network protection WDM and fiber systems. The number of WDM and fiber system per link and the total network WDM and fiber systems are calculated.

Part II or Restoration part

Network with failure phase

Step 5 Network parameters modifications

When a cut occurs, the network has failure and modifies its parameters according to new conditions. Link cut means that its optical fibres (working and protection) are also cut and the network topology changes. 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 fibres set its wavelengths to zero, the connection groups that passing through the cut link set their using wavelengths to zero and through the others to free, the matrix (Aw) changes as well as the number of the group size that passing through optical fibres.

TABLE II
THE SYNOPTIC PRESENTATION OF THE METHODS

FIRST PART
First step. Network parameters reading
(q, p, V(G), E(G), G(V,E), 2,2p, k)
Second step. Connection selections
(n, (S_n,D_n), Xn, Preplanned working lightpaths)
Failure-free Network Phase
Third step. Wavelength allocation (Routing and wavelength assignment method)
Forth step. Results
(Yw, Wl, Tw,i, Tw, Tp,i, Tp, Ta)
SECOND PART
Network with failure Phase
Fifth step. Network parameter modifications
(cut link, q, p, V(G'), E'(G'), G'(V,E'), 2,2p-1, k)
Sixth step. New Wavelength allocation (Restoration method)
Seventh step. New Results

Step 6 Wavelength allocations for restoration algorithms

After the restoration algorithm or algorithms are activated and the suitable dynamical restoration is carried out if it is possible and after them the method ends. The network has links with a finite, nonzero capacity and the link capacity is not exceeded.

Step 7 New results

At the end of each method the restoration percentage is calculated and the other modified results. The restoration methods are presented below. At the first method (i), the restoration is done with the network traffic to be rerouted by all source destination nodes by the shortest path algorithm ignoring the cut link and if a link has a capacity problem (deficit) it is solved by both its nodes with the shortest path algorithm on optical path layer (Gained dynamic restoration with full rearranging of the existing connections). At the second method (ii), the restoration is done by source-destination nodes ignoring the cut link on optical path layer. Using the shortest path algorithm through the network, source-destination nodes of all effected paths discover their restoration paths.The shortest path algorithm is an algorithm that finds the shortest path between two given vertices in an undirected graph G= (V, E). The table II shows the synoptic presentation of these methods. The symbols with tone mean modifications.

The planning and designing part is common for both methods so the difference of the worst case time complexity of two methods ought to the second part. The worst case time complexity depends of the network topology and the total number of connections. It is for the (i) method about 4* $O(t*q^2)$ and for (ii) method $O(t*q^2)$.

D. Example

For the best presentation of this restoration approach the network here below is studied. 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=4 elements which are V= $\{v_1, v_2, v_3, v_4\}$ and the edge set has p=5 (2p=10) elements which are E= $\{e_1, e_2, e_3, e_4, e_5\}$. Each edge has two optical links of opposite directions with their fibers for each direction. The connections of each node pair form connection groups according to its preplanned path and transverse the network. Figure 1 presents the mesh topology.

Network planning and designing is flexible to meet the needs of the network. The number of node pairs is n=12.These source destination node pairs and their preplanned working paths are showed in the table III. For all node pairs demands equal to 3, the links calculations are showed in the table IV without optical fiber protection for WDM system capacity equal to 8. The m:N WDM and optical fiber system shared protection is studied for two cases, first, 1:1 and second 1:7. A wavelength interchange cross connection is the capability to convert the input wavelength to a same or a different wavelength at the output port.

The $<V_1, V_2>$ is assumed as a cut link and the effected node pairs that change their lightpaths are presented in the table V. The restoration method (i) is done. In this method all connections are rerouted by shortest path algorithm but only two change their paths. The other preplanned working paths are shortest ones. The shortest path algorithm finds the restoration paths. In the figure 2 the link $<V_1, V_4>$ with its capacity problems (deficit) is presented. This link needs more capacity either by increasing the capacity of multiplex system (16 or more) or by using the protection optical fiber to pass traffic because differently both methods fail. The cut link $<V_1, V_2>$ does not permit to the shortest path algorithm to be used by both nodes of the link $<V_1, V_4>$ and restore the capacity deficit. All connections for the node pair $[V_1, V_2]$ are restored by path V_1, V_4, V_2 and the busy capacity of the corresponded links increase to six (6) wavelengths. But the capacity of multiplex system of eight (8) wavelengths limits the full restoration of the node pair $[V_1,V_3]$ in the link $<V_1,V_4>$ because the full restoration needs nine (9) wavelengths versus eight (8) of the link. So the partial restoration is done.

TABLE III
THE NODE PAIRS WITH WORKING PREPLANNED PATHS

Node Pairs	Working (Main) Paths
$[V_1,V_2]$	V_1,V_2
$[V_1,V_3]$	V_1,V_2,V_3
$[V_1,V_4]$	V_1,V_4
$[V_2,V_1]$	V_2,V_1
$[V_2,V_3]$	V_2,V_3
$[V_2,V_4]$	V_2,V_4
$[V_3,V_1]$	V_3,V_2,V_1
$[V_3,V_2]$	V_3,V_2
$[V_3,V_4]$	V_3,V_4
$[V_4,V_1]$	V_4,V_1
$[V_4,V_2]$	V_4,V_2
$[V_4,V_3]$	V_4,V_3

The $<V_2, V_4>$ is assumed the cut link and the effected node pair that changes its lightpath is presented in the table V. The restoration method (i) is done. In this method all connections are rerouted by shortest path algorithm but only one changes its paths. The other preplanned working paths are shortest ones. For the node pair $[V_2,V_4]$, the changed restoration path is V_2, V_1, V_4. The link $< V_2, V_1>$ can restore two (2) connections and the link $< V_1, V_4 >$ can restore five (5) connections. So the link $< V_2, V_1>$ has a deficit of one (1) wavelength. This deficit is supplied by the path V_2, V_3, V_4, V_1 . This path has not any deficit for one (1) wavelength. So the restoration path is V_2,V_3,V_4,V_1,V_4 with loop back to node V_1 or by the path V_2,V_3,V_4 directly. The second method produces the restoration paths for the node pair $[V_2,V_4]$ of table V restoring two (2) and one (1) paths respectively. So for both methods there is full restoration.

The network of this example has ten (10) links (small network) and the restoration for full restoration (restoration capability) is presented and compared for both methods. So for each value of node pair demands (all node pairs have the same demands) one by one all network links cut and if there is full restoration to be done for any of all links, full restoration is noted for all links and restoration capability equals to ten (10). If full restoration is done for six (6) link cuts, the restoration capability is equal to six (6) and so on. The two methods are compared for WDM system capacity equals to eight (8), each node pair demands increase from one (1) to twenty four (24) (all node pairs have the same demands) for three cases, first case (1) no protection fibers, second case (2) with protection fibers (1: 7) and third case (3) with protection fibres (1: 1), to be used.

TABLE IV
THE NETWORK DEMANDS AND FIBERS

Link	Busy Wavelengths	Fibers
$<V_1,V_2>$	6	1
$<V_1,V_4>$	3	1
$<V_2,V_1>$	6	1
$<V_2,V_3>$	6	1
$<V_2,V_4>$	3	1
$<V_3,V_2>$	6	1
$<V_3,V_4>$	3	1
$<V_4,V_1>$	3	1
$<V_4,V_2>$	3	1
$<V_4,V_3>$	**3**	1

TABLE V
THE EFFECTED PATHS OF CUT LINKS

Cut Link	Node Pairs	Main Paths	Restoration Paths
$<V_1,V_2>$	$[V_1,V_2]$	V_1,V_2	V_1,V_4,V_2
	$[V_1,V_3]$	V_1,V_2,V_3	V_1,V_4,V_3
$<V_2,V_4>$	$[V_2,V_4]$	V_2,V_4	V_2,V_1,V_4
			V_2,V_3,V_4

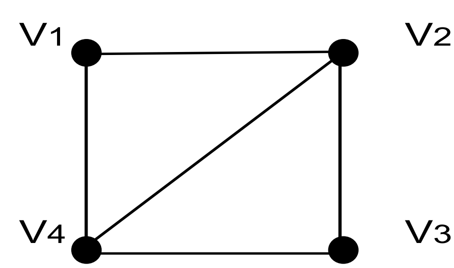

Fig.1. The mesh topology of the network

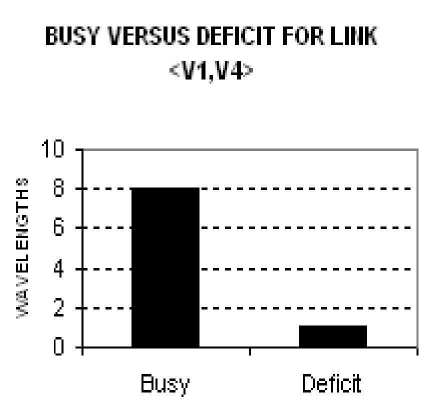

Fig. 2. The busy and deficit capacities in wavelengths of link $<v_1,v_4>$

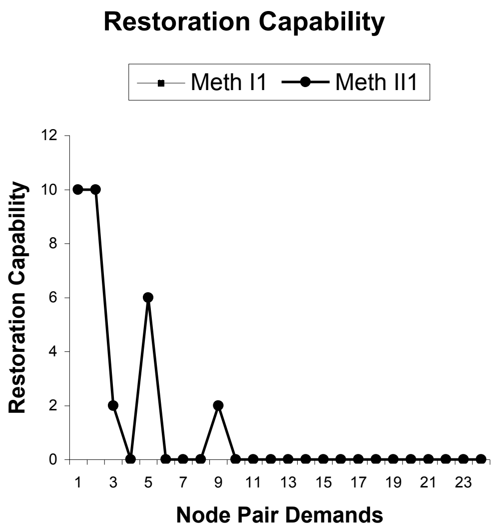

Fig. 3. The restoration capability for two methods, MethI1 means method (i) no protection fibres, MethII1 means method (ii) no protection fibers.

For large values of node pair demands of 1000 and 10000 requests for connection, the restoration capability of two methods (I1, I2) and (II1, II2) is zero. When the protection increases as the case third (protection fibres 1: 1), the restoration also increases to the 60% for both methods (I3 and II3). It means, for six (6) links cut, the restoration is full and for the other four (4) links cut the restoration is partial.

D. Discussion and Proposals

Typically, larger scale networks are built by smaller scale networks. The study of the protection systems will start from small networks as the stand alone point to point systems and proceed to more complex systems as rings and finish to the core network. When a network carries enormous information a best way for its protection is the dedicated protection 1+1 or 1:1 with or no diversity protection. The maintenance is realized more easy when protection is used. This network planning and designing is implemented from the start and no add at the end. So the protection architecture is designed correctly. In this paper the protection architecture of a small network is studied and searched its full restoration capability after a link failure occurs.

The suitable network planning and designing uses extra capacity for its protection network to supply to its customer high quality services with protection. The most common failure in the optical networks is the cable cut and attention is paid for their protection from several failures. The interconnection between OXC is implemented by multifiber links. When a link cut occurs and the link fails, the failure event is passed to the control system and new routing paths are calculated. These paths are downloaded to the nodes and new routing decisions are executed either preplanned or a dynamic way. It means for the link failure that the traffic is passed through the other links and the restoration is searched by alter paths. If an alter path exists, the restoration is done, if does not exist the connection breaks. In this paper the lightpaths for restoration are discovered by the shortest path algorithm. This done for three cases, first the multifibre links of the network have not any protection (there is not any protection network) and in the second and third cases, the m:N protocol is used for the protection network. In the second case each multifibre link has a protection for its fibers with m:N=1:7 and in the third case, each multifibre link has a protection for its fibers m:N=1:1. The full restoration capability for any link cut is searched for each restoration method. The results are showed in the figures 3,4 and 5.

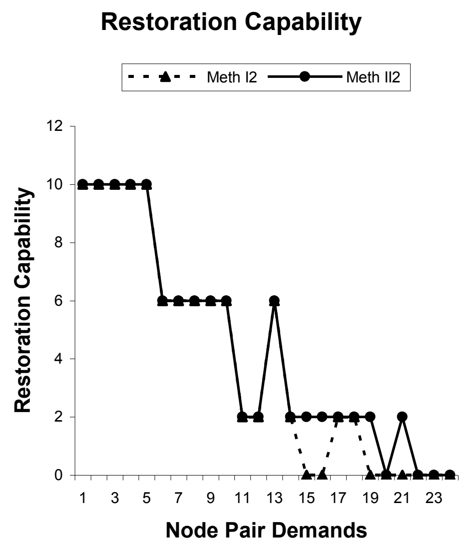

Fig. 4. The restoration capability for two methods, MethI2 means method (i) with protection fibers (1: 7), MethII2 means method (ii) with protection fibers (1: 7).

It is showed from the figures 3,4 and 5 that the restoration approach (i) has good results versus the other method (ii). When the node pair demands are low the restoration capability of both methods is very good because the number of paths which must be restored is small. When the demands increase then method (ii) has light better results. For large values of demands the full restoration capability is zero without protection increment because there are a lot of connection paths and it is difficult their full restoration. For the third case the restoration is better. For small networks the restoration capability is about the same for both methods but in larger and more complex networks the second (ii) method has better full restoration capability by the (i). To obtain full restoration for every of above cases, extra protection capacity must be use of the protection network or the protection network must plan and design with a more efficient way.

The speed requirement is significant for the completion of restoration, so the running time for ten thousands experiments is for this restoration approach (i) about five minutes and the other algorithm (ii) about three minutes. It is because (ii) algorithm is faster, simpler, uses the shortest path algorithm for less times and effects to less paths than (i).

In real time, the restoration schemes require longer restoration times because they need to compute the backup path after failure detection and the backup path establishes by using some kind of signaling mechanism. All these steps take seconds or minutes to complete. This restoration approach (i) takes longer consuming time because does all network traffic rerouting for completion and remains limited to small networks. The restoration speed is faster in low coverage network*s*.

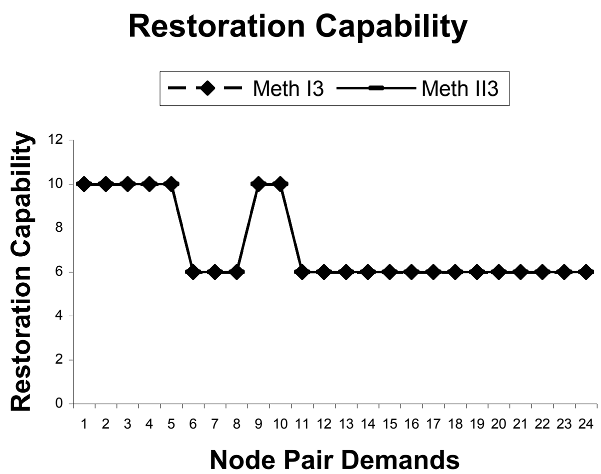

Fig. 5. The restoration capability for two methods, MethI3 means method (i) with protection fibers (1: 1), MethII3 means method (ii) with protection fibers (1: 1).

III. CONCLUSIONS

The transport capability of WDM optical networks is enormous. The optical supporting technology is more advanced and provides an important platform of rapid evaluation and introduction of advanced technologies in the manufacture, maintenance of the network elements as well as to increase the possibility and improvement of the service providing. This paper is a contribution for them.

So this restoration approach have been compared and studied versus another method (the restoration of the source destination node pairs ignoring the cut link on optical channel layer) for small networks. The conclusion is that all two are suitable for the telecommunication traffic restoration when a failure occurs. The selection of the suitable method depends on the failure site, restoration layer, demands, protection protocol, and requirements for fast restoration, network size (small or large networks), topology and coverage as well as availability of multiplex systems.

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