

# Polynomial Time Algorithm (PTA) to generate a survivable ring virtual topology for Optical WDM based on the Hamiltonian Circuit Detection Heuristics(HCDH)

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## Abstract

The Routing and Wavelength Assignment (RWA) problem is known to be NP-hard for general Physical Topology (PT) in optical networks. We have analyzed the survivability of the optical network under Survivable Routing and Shared Path Protection (SPP) for various topologies and suggested two survivable RWA algorithms which are shown to perform better under certain performance matrix by simulation. Genetic Algorithms (GA) also provide an attractive approach to solving the challenging problem of RWA in optical Wavelength Division Multiplexing (WDM) networks, because they usually achieve a significantly low blocking probability. Available GA-based dynamic RWA algorithms were designed mainly for WDM networks with a wavelength continuity constraint, and they cannot be applied directly to WDM networks with wavelength conversion capability. The polynomial time wavelength assignment algorithm that maximizes one-hop traffic in a special type of topology called Line Network for multiple wavelengths per link. Since Ring Topology is an important extension to Line Network, we design another algorithm using the previous algorithm, to optimally assign wavelengths in WDM Ring Networks for multiple wavelengths and design Survivable Routing in optical networks.

The failure of a single fiber link may cause the simultaneous failure of several lightpaths in WDM networks, and disconnect the virtual topology. We propose a polynomial time algorithm to generate a survivable ring virtual topology based on the Hamiltonian

Circuit detection heuristics, which acts as the backbone of the virtual topology. Due to establish additional lightpaths in the ring to increase the one-hop traffic enhanced the wavelength utilization. In Shared Path Protection(SPP) approach we find the limitations of the popular Active Path First heuristic and design a new Disjoint Path heuristic, which is proved to provide the disjoint pair, if exists in the network. In RWA environment we use the heuristic, which allocates spare resources for backup path to ensure the failure of active path, we improve the performance of protection of the Path Protection by an Advanced Search method where the routing is integrated with the wavelength assignment part of the RWA algorithm and depends on the network state.

## 1. Introduction

We study the dynamic RWA problem[5] in WDM networks with sparse wavelength conversion and propose a novel hybrid algorithm[9] for it based on the combination of mobile agents technique and GA. By keeping a suitable number of mobile agents[14] in the network to cooperatively explore the network states and continuously update the routing tables, the new hybrid algorithm can promptly determine the first population of routes for a new request based on the routing table of its source node, without requiring the time consuming process associated with current GA-based dynamic RWA algorithms. To achieve a good load balance in WDM networks with sparse wavelength

conversion, we adopt in our hybrid algorithm a new reproduction scheme and a new fitness function that simultaneously takes into account the path length, number of free wavelengths, and wavelength conversion capability in route selection. Our new hybrid algorithm achieves a better load balance and results in a significantly lower blocking probability than does the Fixed-Alternate routing algorithm, both for optical networks with sparse and full-range wavelength converters and for optical networks with sparse and limited-range wavelength converters.

We are moving towards a society, which requires that we have access to information at our fingertips when we need it, and in whatever format we need it. This demand is fueled by many different factors day by day with the networks of higher capacities, at lower cost. The tremendous growth of the Internet and the World Wide Web (WWW) has brought more and more users online, increasing the complexity and data transfer rate, consuming large amounts of bandwidth due to higher data transfer rate. Due to tremendous growth in network traffic and the demand for new services, the world's telecommunication markets are being deregulated. Fiber optics technology can be serving the demand based services due to its potentially limitless capability.

## **2. First Generation Optical Networks(FGON)**

Optical fiber is the preferred medium for transmission of data at anything more than a few tens of megabits per second over any distance more than a kilometer. Optical fiber technology is used in all networks purely as a transmission medium, servicing as a replacement for copper cable, and all the switching and processing of the bits is handled by electronics. Optical networks are SONET (Synchronous Optical Network) and SDH (Synchronous Digital Hierarchy) networks, which form the core of the telecommunications infrastructures in North America and in Europe

and Asia, respectively, as well as a variety of enterprise networks such as FDDI (Fiber Distributed Data Interface).

### **2.1 Multiplexing Techniques**

The increasing demand for bandwidth, along with the fact that is relatively expensive in many cases to lay new fiber, implies that we must find ways to increase the capacity on existing fiber. The fundamental way of increasing the transmission capacity on a fiber is to increase the bit rate, which requires higher speed electronics. Many lower speed data streams are multiplexed into higher speed streams at transmission bit rate by means of higher electronic Time Division Multiplexing (TDM). Optical TDM(OTDM) and WDM is the other approaches that can exploit huge optoelectronics mismatch by requiring that each end user's equipment only operate at electronic rate, but multiple WDM channels from different user may be multiplexed on the same fiber.

## **3. Second Generation Optical Networks(SGON)**

In the recent research, scientists have realized that optical networks are capable of providing more function than just point-to-point transmission. Major advantages are to be gained by incorporating some of the switching and routing function that was performed by electronics into optical part of the network. In the first generation networks, a node must not handle only all the data intended for that node, but also all the data that is being passed through that node onto other node in the network. In the second generation network, this later data pass through the optical domain and significantly reduce the burden on the electronics domain on that node.

### **3.1 Services**

It is useful to think an optical layer that offers services to all the higher layers in the networks. Any network can be visualized as consisting of many layers, with each layer performing possibly different functions. Second generation optical networks may provide three types of services to higher network layers. The first service is a light path service, applicable for WDM networks. In individual wavelengths are

likely to carry data at fairly high bit rates (a few Gb/s), and this entire bandwidth is provided to the higher layer by a light path. Depending on the capabilities of the network, this light path could be set up or taken down upon request of the higher layer. Alternatively the network may provide only permanent light paths, which are set up at the time the network is deployed.

### 3.2 Physical and Logical Topologies

The physical topology of the network is the physical set of routing end-nodes and the fiber-optic links connecting them upon one setup lightpaths between end nodes.

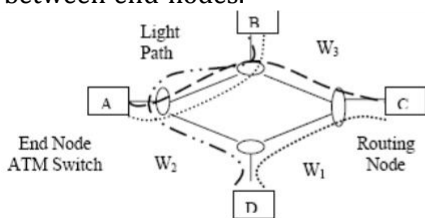


Fig. 1 Physical Topology

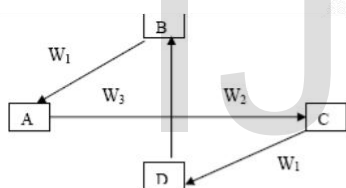


Fig. 2 Logical Topology corresponding to Fig. 1

A light path consists of a path through the network between end nodes and a wavelength on that path. Configuring the routing nodes in the network will set up light paths. Two light paths that share a same link in the network must use different wavelengths. As for example, in the above figure, link between X and Y node shares 3 wavelengths (W1, W2, W3). A light path provides a pipe between end nodes with a bandwidth equal to that of one channel, typically 1-2.4 GB/s. The set of all light paths that have been setup between end nodes constitutes the logical topology. The logical topology is a graph with the nodes corresponding to the end-nodes in the network with a directed edge from node X to node Y if a

lightpath has been set up from node X to node Y. The physical degree of a (routing node) is the number of other (routing) nodes that it is directly connected to by fiber-optic links, e.g., the physical degree of all the (routing) nodes in Fig. 1 is 2. The logical out-degree of an end-node is the number of lightpaths that originate from that end-node and the logical in-degree of an end-node is the number of lightpaths that terminate in that end-node, e.g., in Fig. 2, the logical in-degree and out-degree of every node is 1.

Ideally in a network with n nodes, we would like to set up light paths between all the n (n-1) pairs. However this is usually not possible because of two reasons. First, the number of wavelengths available imposes a limit on how many light paths can be set up. Secondly each node can be the source and sink of only a limited number of lightpaths. This is determined by the amount of optical hardware that can be provided (transmitters and receivers) and by the amount of information the node can handle in total. When it is not possible to establish light paths between all pairs of nodes, node pairs that are not directly connected via light paths must use a sequence of light paths through intermediate nodes to communicate. At each intermediate node, packets coming in on a lightpath must be connected to electronic form, switched electronically and then converted back to optical form and sent out on a different lightpath route to their destinations.

### 4. WDM Architecture

Transmission capacity of a link in today's optical network has increased significantly due to wavelength division multiplexing technology (WDM). Optical wavelength-division multiplexing (WDM) is a promising technology to accommodate the explosive growth of Internet and Telecommunication traffic in wide area, metro area, and local area networks. Wavelength Division Multiplexing (WDM) is a technique to increase the transmission capacity. WDM is essential the same as frequency division multiplexing, which has been used in radio systems for more than a century. The idea is to

transmit data simultaneously over multiple carrier wavelengths (or, equivalently frequencies) over a fiber. WDM provides a way to increase the transmission capacity by using multiple channels at different wavelengths. WDM network architecture can be classified into two broad categories:

**4.1 Broadcast and Select Architecture** – In broadcast and select architecture different nodes transmit at different wavelengths. This form of a network is simple and suitable for use in local or metropolitan area networks, such as access networks. The number of nodes in this network is limited because the wavelengths cannot be reused in the network. [2].

**4.1.1 Wavelength Routing Architecture** -This is a more sophisticated and practical architecture used today. The nodes in this network are capable of routing different wavelengths at an input port to different output port. This enables us to set up many simultaneous using the same wavelength in the network; that is, the capacity can be reused spatially. This architecture also avoids broadcasting the power to unwanted receivers in the network. Thus these networks are suitable for deployment in metropolitan-and wide-area networks, such as local-exchange and inter-exchange networks.

**Literature Survey**

**a. Routing and Wavelength Assignment Problem Statement** – From [1], let's give a general RWA problem statement for our works. Let  $T_m = (\lambda^{pq})$  be the traffic matrix, i.e.,  $\lambda^{pq}$  is the arrival rate of packets at p that are destined for q. we assume that traffic is bi-directional and uniformly distributed over multiple shortest paths between a pair of nodes. We seek to create a logical topology  $L_G$  and routing on  $L_G$  that minimizes  $\lambda_{max} = \max_{ij} \lambda_{ij}$ , where  $\lambda_{ij}$  denotes the offer lode on link (i,j) of logical topology.  $\lambda_{max}$  is the maximum offer load to a logical link and is called the congestion. Let  $L_r$  be the given physical topology of the network,  $L_\mu$  the degree of logical topology and M the number of wavelength available. An informal description of the logical topology design problem is as follows:

**Min  $\lambda_{max}$**

Such that –

- Each logical link in  $L_G$  corresponds to a light path and two light path that share an edge in the physical topology are assign different wavelengths,
- The total number of wavelengths used is at most W,
- Every node in  $L_G$  has  $L_\mu$  incoming edges and  $L_\mu$  outgoing edges,
- Traffic is routed so that flow of traffic from each source to destination pair is conserved at each node.

**b. Wavelength Assignment to the Lightpaths** - From [3], we use the following data structures for our RWA algorithms for the ease of implementations. We use a  $M \times N$  matrix called link-state matrix S where M is the set of wavelengths available per link and N is the set of fiber optic links in the physical topology  $L_r$ . The state of a link  $i \in L$  at any time can be specified by the column vector

$$\tau_i = (\tau_i(0), \tau_i(1), (\tau_i(2), \dots, (\tau_i(M-1)))^T$$

where  $\tau_i(j)=1$  if wavelength  $\lambda_j$  is allocated in the link i by some lightpath and  $\tau_i(j)= 0$  otherwise. So the link-state matrix  $U = (\tau_0, \tau_1, \tau_2, \dots, \tau_{L-1})$ . Initially all wavelengths are available in each link. So we initialize the S matrix by 0. An  $N \times N$  matrix VT is maintained which stores the information of the lightpaths already established. The elements of VT are the traffic between the nodes that has been assigned a lightpath. The requests for which the lightpaths cannot be established are stored in another  $N \times N$  matrix BT.

We line up the connection requests for setting up lightpaths using largest-traffic first scheme. This scheme designs the virtual topology by first attempting to set up lightpath between the nodes having the largest traffic. It then attempts to set up lightpath for the nodes having the next largest traffic and so on, the constraints being the physical topology and the limited number of

wavelengths per link. Intuitively, better performance can be achieved if the larger traffic is first allowed to reach the destination in one hop. This is because it is easier and less loading for the intermediate nodes to route small traffic indirectly in multihops. The algorithm is repeated for all the available wavelengths using the first-fit scheme.

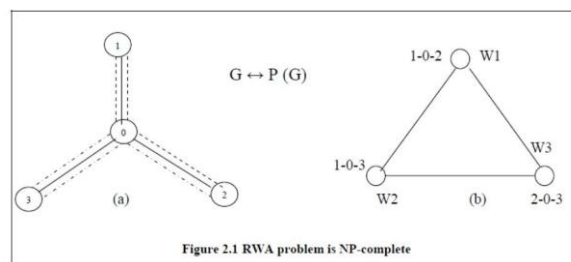
Therefore we sort the traffic matrix in non-increasing order to generate the connection requests for establishing the lightpaths. Let  $Req$  be the ordered set of source-destination pairs so that  $Req = \{(i_1, j_1), (i_2, j_2), \dots, (i_n, j_n) : T[i_k, j_k] \geq T[i_{k+1}, j_{k+1}], 1 \leq i_k, j_k \leq n, 1 \leq k \leq n-1\}$ .

Connection requests will be generated according to this ordered set required.

RWA problem is a NP-hard problem [2] and many researchers have tackled the problem of RWA with a number of efficient heuristic algorithms [1], [3], [4].

### 5. RWA Algorithm using Greedy approach

In [4] it is stated that in case of a greedy RWA in a physical network, the numbers of available wavelengths are given and once a wavelength is assigned to a link it cannot be used again to that link later for another connection. Then we have to check whether there are any available wavelengths or not. If available, then question does not arise, but in case of unavailability the desired connection cannot be established between source and destination node pair. Here a traffic matrix between each node pair is given and we have to arrange the traffic between node pair in decreasing order. Now the link having the highest traffic matrix is assigned the first available wavelength. If the first wavelength is not available then it is trying through next available wavelength otherwise it is left without assigning any lightpath. And the procedure is repeated with the link having the next highest traffic until the all links are assigned or left due to unavailability of resources.



From [2]-Wavelength assignment (WA) problem is closely related to graph coloring problem. In the above graph [Fig. (2.1-a)] is the representation of network  $L$ , where vertices of the graph represents node of network & edge between two vertices represent fiber link between two nodes. The route for each light path correspond to a path in  $L$ , and the set of routes that have been specified for the light paths corresponds to a set of paths, say,  $R$ . Now consider another graph, the path graph of  $L$ , denoted by  $R(L)$ , which is constructed as follows. Each path in  $R$  correspond to a node in  $R(L)$  [Fig. 2.1-b], and two nodes in  $R(L)$  is connected if there two paths in  $R$  share any common edge in  $L$ . Solving the WA problem is equivalent to solving the classical graph coloring problem on  $R(L)$ , that is we have to assign color to each node such a way that two adjacent node must be assigned distinct color and total number of color minimized, which is called *chromatic number* of the graph. Thus minimum number required to solve WA problem is the *chromatic number* of  $R(L)$ . Now in graph  $L$ , given set of node has to be connected by light paths, which routes are uniquely determined? We have light path between two nodes  $1$  and  $2$ ,  $2$  and  $3$ ,  $1$  and  $3$ . Resulting graph  $R(L)$  shown in the graph. The chromatic number of  $R(L)$  is  $3$  and coloring of  $R(L)$  will be in  $3$  colors. Thus we need  $3$  wavelengths to solve the WA problem in this example. Coloring an arbitrary graph is a hard problem that has been intensively studied for several decades. In fact, it is  $n$  NP-complete problem. However there are several special classes of graphs for which first coloring problem have been found. If the  $R(L)$  we are interested in belongs to one of these special classes, then

we can find exact solution to the WA problem. Otherwise, unless  $R(L)$  has only few nodes, we have to content ourselves with finding an approximate solution to the RWA problem. Many fast but approximate algorithms have been devised for general graph coloring problem, and these algorithms can be used to find good but approximate solution to the WA problem. Transformation to a graph-coloring problem does not show that RWA problem is hard or NP complete. To show this, one needs to perform the transformation in the opposite direction, namely, take an instance of a graph-coloring problem and convert it into an instance of the RWA problem. This way we can prove RWA indeed a NP complete problem.

## 6. Design of a Survivable Network

With the integration of computer and communication technologies and rapid maturation of fiber optic communication techniques, today's telecommunication networks can provide fast and high-quality services to end-users. The service type has broadened from voice only to a diverse array of multimedia services. With more and more business users involved, the interruption of service for even short periods of time may have disastrous consequences. As such how to prevent service interruption, and reduce the loss of service to minimum if interruption is inevitable, becomes a critical issue; that is, survivability must be considered in designing telecommunication networks. Optical fiber has become the dominant transport medium in telecommunication systems because of its advantages in capacity, reliability, cost, and scalability. Therefore new multiplexing techniques such as wavelength division multiplexing (WDM) have been proposed in order to utilize fiber capacity more efficiently. The failure of a single physical fiber link in a WDM network may cause the simultaneous failure of several light paths. This may disconnect the virtual topology. In our

attempts we investigate the problem of routing light paths on an arbitrary physical topology, such that virtual topology remains connected even after the failure of a single physical link. We call such a routing as *survivable routing*. To design the algorithms of survivable Virtual Topology Design, we studied and analysis in [11], introduced a heuristic polynomial time algorithm, SemiHam, for finding Hamiltonian cycles in random graphs with high probability. This algorithm assumes unit weight on each link of the given graph. In [12], a new polynomial-time algorithm for finding Hamiltonian circuits in certain graphs. It is shown that the algorithm always finds Hamiltonian circuits in graphs that have at least three vertices and minimum degree at least half the total number of vertices (proving Dirac's sufficiency condition). The algorithm works on graphs with arbitrary weight on each link. In [13], introduced basics of survivable topology design, mathematical formulation of the problem. In [5], introduced about Survivability in Optical Networks. It discussed about the techniques for survivability in optical networks; such as Pre-designed Protection and Dynamic Restoration. It also discussed about the Survivability Techniques in WDM Networks such as Multi-layer protection, Fault detection and localization, protection from single link failures etc and Non-WDM Networks such as automatic protection switching, self-Healing ring etc.

## 8. Path Protection in WDM Networks

Survivability of high bandwidth optical networks has emerged as an important area of research in recent years due to tremendous importance as a national and international infrastructure for moving large volumes of data. Failure of any part of this infrastructure, either due to national causes or malicious attacks is bound to have a large adverse impact on economy and security of country [8]. In WDM networks, end-users can

communicate with each other via all-optical WDM domain called lightpaths. Because of the high traffic (up to 50 Tbits/s) a fiber carries (because many lightpaths can route through same fiber and each lightpath is expected to operate at a few Gb/s [15]), it's imperative to develop appropriate protection and restoration schemes to prevent or reduce data loss [5].

### 9. Survivability Mechanisms

The main goal of a survivable network is to be able to perform a rapid restoration at as small cost as possible (i.e. using minimum resources). For this, we have two different survivability mechanisms:

i) Pre-designed protection where redundant protection capacity is pre-allocated for use when a link fails [14]. Usually it relies on resources (fibers, wavelengths, switches, etc.) dedicated to protection purposes from failures at either connection setup or network design time [7].

ii) Another survivability mechanism, Dynamic restoration, implies the discovery of spare capacity dynamically in the network to restore the affected services; i.e. the protection is not pre-computed but chosen from available resources when failure occurs [7].

In pre-designed protection, protection resources are kept idle when there is no failure. So, the use of capacity is not very efficient. On the other hand, resource utilization is very efficient in restoration.

#### 9.1 Link and Path Protection

Protection mechanisms are broadly classified into path protection and link protection, depending on where the protection switching is done.

i) In Link protection (also called loopback protection), alternate paths (distinct paths for each wavelength, in general), called backup or protection paths between the end points of each link are pre-computed. Upon a link's failure, all of the lightpaths using the link (called primary or working lightpaths) are switched at the end-nodes of the links to their corresponding backup lightpaths. The portion of the working lightpaths excluding the failed link remains the same [14].

ii) Path protection entails the end-to-end rerouting of all working lightpaths that use the failed link along pre-computed back-up lightpaths. Here the entire route of working lightpaths may be changed [14]. In an optical network without wavelength conversion capability, the establishment of a lightpath is subject to wavelength continuity constraint i.e. a lightpath is required to be on same wavelength channel throughout its path in the network [5].

#### 9.2 Dedicated and Shared Protection

Protection schemes can further be divided into two sections based on whether backup resources are shared by more than one connection:

i) In Dedicated protection, each node or link can be reserved as a backup resource for at most one connection [5]. In Fig. 2.3, we have two working paths, 4-5-6 (connection 1) and 1-2-3 (connection 2), both using .1. The protection path for connection 1 is .2 on 4-1-2-6 and for connection 2 is 1-5-2-6-3.

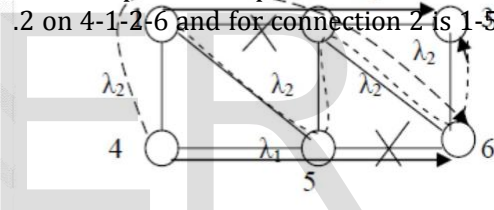


Fig. 2.3: Shared path protection Constraints

Since these two protection paths have the common link 2-6, and .2 is assigned to protection path 1, protection path 2 has to be assigned a different wavelength (e.g. .1). [7].

ii) In Shared protection, a link or node can be reserved as a backup resource for multiple connections, as long as those connections do not fail simultaneously [5]. Again, dedicated protection requires more network resources but is simpler to implement, while shared protection is more resource efficient but requires more complex signaling and network management [5].

#### 9.3 Shared Path Protection Problem Statement

In our work, we have assumed that we have a connected graph  $G$ , i.e. number of edges  $\geq n-1$ . We study the problem in the following way: Consider a WDM network where each fiber can carry  $W$  wavelengths  $\Lambda = \{\lambda_1, \lambda_2, \dots, \lambda_W\}$ . A lightpath is established between a source-destination node pair when a request for such a node pair arrives and appropriate resources are available. For reasons of survivability, following the shared path protection strategy, we try to establish a primary (active) path and a secondary (backup) path. If sufficient resources are available at the time of request arrives, the active-backup paths are established; otherwise the call request is blocked. Thus our algorithm provides WDM protection. We assume that both active and backup paths follow *Wavelength continuity constraint*, but they can have different wavelengths individually. A path that carries 1 traffic under normal operation is known as a *working or active path (AP)*. When a working path fails, the traffic is rerouted through *protection or backup path (BP)*.

#### 9.4.1 HCDH Algorithms:

##### Hamiltonian Circuit Finding Algorithms(HCFA) 1:

In the algorithm is  $n$  vertex in the undirected graph  $G(v,e)$ , where vertices are numbered 0 to  $n-1$ . It performs  $n$  number of iterations and each iteration program performs to extend the path construction. In the  $i^{th}$  iteration, algorithm creates  $i-1$  edges with path of length  $i$  edges, when it complete the iteration cycle and extend the path. On Completion of  $n^{th}$  successful iteration, Hamiltonian Path generated in the graph and the next iteration it close the path which is called a Hamiltonian circuit. If it unable to extend the path due to failure of further iteration ( $n+1$ ), the proposed algorithm declare that no Hamiltonian circuit exist and no survivable routing path found in the physical topology.

We define a structure with an array  $v[n]$  that identifies the number of vertices in the path and it stores  $v[0]$  head to  $v[n-1]$ ,tail. Every vertex has a smallest external neighbor to the

We illustrate the *shared path protection constraints* with an example with the Fig. 2.3.

According to C5, APs 4-5-6 and 1-2-3 don't share any link. According to C3, link 2-6 is shared by two BPs 4-1-2-6 and 1-5-2-6-3 having same wavelength  $\lambda_2$ . Again, following C4, AP 1-2-3 and BP 4-1-2-6 with two different wavelengths, share link 1-2. Two APs have same wavelength  $\lambda_1$  as per C6. Also, each of the

path and if a vertex has no external neighbor then the entry is -1 and if vertices not in the path then it is undefined.

We assume initialize Edge  $(f,t)$ ,  $E$  where  $f$ = head and  $t$ = tail of the path. Then  $v[0]=f$ ,  $v[1]=t$  and  $length=2$ , update store path accordingly.

Repeat the following steps for  $(n-2)$  times.

Steps:

- a. If external neighbor of the head is not then extend the path along the head to the given external vertex  $p$ .
  - b. The new head generated from the external vertex complete the current iteration otherwise goto step 2
2. If tail not -1 then extend the path along the tail to the given external vertex  $p$ . The external vertex  $p$  becomes the new tail and complete the current iteration otherwise go to step 3.
  3. If head and tail are joined by an edge, then cycle exist in the current path  $v$ . We examine the path vertices until find a vertex  $v[i]$  whose external neighbor entry is  $p \neq -1$ . Such a vertex is guaranteed to exist. Otherwise our path would be disconnected from the rest of the graph. If step 3 is successful to extend the path, and then complete the currents iteration, otherwise go to step 4. Path extension using step 1 and step 2 is called simple extension and step 3 is called cycle extension.

To build a new paths we apply steps 4 to 6, by rotations to the original path until find a path either simple simple extension or cycle extension in different order. The size of the allocation path is the size of  $n^2$  and at the beginning size is 0. We calculate the storage and number of paths from the list which are



calculated by applying the step 4 to 6.

4. Evaluating the all the vertices to find the successive path from the list to established the new link with iterating the vertices, established path included in the list and verify path extension through previous steps.

5. Repeat the step 4 to add the new path and increment the length list and check the path is extended or not through step 2/3 and complete the iteration and go to next step 6.

6. Extending the path and increment the present list.

### G. Hamiltonian Circuit Finding Algorithms(HCFA) 2:

We apply heuristic based nearest neighborhood approach in the graph G with n number of vertices and considering each node as a starting node for Hamiltonian circuit for maximum cost for all the vertices else minimize the degree of the vertices and perform the following steps:

Step1: Consider a vertices which are visited and consider  $v_i = p_i$ , apply iteratively visited all the vertices and calculate each unvisited neighbors with minimum  $\eta(c)$  and extend the path until iteratively it visits last vertex. Finally it generate a path  $p_0$  with vertices which has no unvisited neighbors.

## 10. Shared Path Protection Constraints

In our algorithm, the working lightpath  $l_w$  and backup lightpath  $l_b$  satisfy the following *shared path protection constraints* with respect to existing lightpaths [6].

• For same request:

C.1  $l_w$  and  $l_b$  are link disjoint.

C.2  $l_w$  and  $l_b$  may have same or different wavelengths.

• For different requests:

C.3  $l_b^i$  and  $l_b^{i+1}$ , where  $1 \leq i \leq W-1$ , can share both links and wavelengths on the common link they traverse.

C.4  $l_w^i$  and  $l_b^i$ , where  $1 \leq i \leq W$ , can share only links but not any wavelength on the common link they traverse.

C.5  $l_w^i$  and  $l_w^{i+1}$ , where  $1 \leq i \leq W-1$ , do not share any link between them as we want only one request to be affected by a single fiber-cut.

C.6  $l_w^i$  and  $l_w^{i+1}$

AP-BP pair follows C1 and C2.

## 10.1 Disjoint Path Algorithms

In order to find two link-disjoint lightpaths for multiple wavelengths, we may consider the intuitive two-steps well-known Active Path First (APF) algorithm of complexity  $O(n^2)$ . Even if we have a polynomial time disjoint pair algorithm (Suurballe's algorithm). In APF, graph G and (s,d) pair between which disjoint pairs will be found, Active Path (AP) and Backup Path (BP), if exist.

APF is simple to implement, runs fast [8] and successfully works in almost all dense graphs which we consider in DWDM. But the solution fails in *trap topologies* [5], i.e. it fails to find AP-BP pair even if there is some. In real life, *trap topology* is of less importance when we

are dealing with MAN. But in the midst of wavelength assignments to different requests, the intermediate graph may look like one of trap topologies.

## 10.2 Path Protection Mechanism

In recovery process for WDM shared path protection. Upon detecting a fiber failure the end nodes of the failed fiber send alarm messages to the source node and destination node of the connection. Then the source node sends a set-up message to the destination node along the backup route (which is determined at the time of call setup) and configures the cross-connects at each intermediate node. The destination node, upon receiving the setup message, sends a

where  $1 \leq i \leq W-1$ ,  
can have same or  
different wavelengths.

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node,

thus completing the recovery process [9][15].

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A good estimate of recovery time complexity is provided in [9].

## 11. Wavelength Assignment to Disjoint Paths

We are concentrating on shared path protection with multiple wavelengths. For single wavelength networks, a feasible solution can be found using Suurballe's algorithm [10]. The total cost of the resulting two link-disjoint lightpaths is minimal among all such path pairs. The algorithm runs in  $O(n^2 \log n)$  time, where  $n$  is the number of nodes. For networks with multiple

**Algorithm.** In the first algorithm, two disjoint routes are found using Suurballe's algorithm and then wavelengths are assigned to them. In the second algorithm, first scan through each wavelength to find a pair of link-disjoint lightpaths using Suurballe's algorithm. If Suurballe's algorithm fails search through each pair of wavelengths for a pair of link-disjoint lightpaths on different wavelengths using a two step approach.

In [8], a heuristic called *Enhanced Active Path First (APFE)* is discussed where a big weight  $M$  is assigned to the Active path (AP) when corresponding Backup path (BP) is not found. Then cost(AP) is found and compared to cost which is initialized as zero. If it's less, then the BP is taken as AP and newer BP is found by shortest path algorithm. It continues until exit condition achieves.

But none of the above papers provide guarantee to success. In [9],[10],[15], different RWA heuristics are presented with path protection. All of them have tried to avoid the most general but erroneous *Active Path First algorithm* and so either the solution has become critical or can't provide solutions to each possible case of disjoint pair. Along with that, [16] provides some conditions on mesh network to get disjoint paths with some modifications to mesh network itself.

wavelengths, we can apply this algorithm on every wavelength to find the same lightpaths on the same wavelength. However, if such paths do not exist, the problem is to find two link-disjoint lightpaths on two different wavelengths [5]. In [5], it's proven that irrespective of total cost of the two lightpaths, the problem is NP-complete. Also, when we work on shared path protection, we'll have two separate graphs on which AP and BP will be found. So, Suurballe's algorithm will not work again, since it works on single graph.

In [5], two RWA algorithms are discussed: *Route-First algorithm* and *Wavelength-Scan*

## 12. Greedy Algorithm for Ring Networks

### Algorithm :

Choose an initial two-dimensional State matrix ( $S\_MAX [n][w]$  where  $n$  and  $w$  signifies edge and wavelength) whose all elements are zero. Where one dimension is the node & another dimension is wavelength. Take a two dimensional traffic matrix ( $T\_MAX [n][n]$ ) whose elements are generated randomly keeping all the diagonal element zero and upper diagonal element are same with the lower diagonal corresponding element. Take a liner array named Max Traffic ( $T\_ARRAY$ ) Array whose elements are arranged in descending order. We have to assign these weights to the free path using any free wavelength and assign 1 to the corresponding path of the State matrix.

**1:** Repeat up to step 3 for each element of  $T\_ARRAY$ .

**2:** Repeat the loop up to step 3.

**3:** Check the shortest path and assigned 1 to the corresponding position of state matrix in which each link of the path is free. If there is no such path go to step 2 to check with the next wavelength. Otherwise go to step 1.

4: If there is no element in array then stop.

### Dynamic Programming Approach

Here connection requests are initiated in some random fashion. At the time of request depending upon the availability of the resources it may or may not be sufficient to establish a lightpath between source-destination edge node pair. Each time a request is made it should be examined whether the request is feasible to accommodate the request, if so, to perform routing and wavelength assignment. If a request cannot be accepted because of lack of resources, it is blocked. A typical approach to designing an efficient algorithm is to decompose the problem into two sub-problems: the routing problems and wavelength assignment problem. Consequently, most dynamic RWA algorithms for wavelength routed network consist of the following general steps:

1. Compute a number of candidate physical paths for each source-destination edge node pair.
2. Order all wavelengths in a wavelength list.
3. Starting with the path and wavelengths at the top of the corresponding list, search for a feasible path and wavelength for the requested lightpath.

#### Using Single Wavelength

It is a special case of line network using multiple wavelengths stated below. In case of multiple wavelengths the number of wavelengths is  $w$ , but in case of single wavelength, the value of  $w = 1$ . Hence the algorithm is also same as the multiple wavelengths algorithm excepting the parameter  $w$  having the fixed value 1.

#### Using Multiple Wavelengths

In line network, we have set of nodes such as  $P_1, P_2, P_3, \dots, P_n$ . We have to establish light path between  $P_1$  to  $P_n$  using intermediate nodes. We take traffic matrix  $T$  of order  $n \times n$ ,

which holds all the traffic between each edge. At each step to establish light path between a pair of node we take the maximum traffic between this nodes directly from the traffic matrix or sum up the traffics of the intermediate edges. And we take the maximum of these two values. To store the light paths already established, we take a state matrix  $S$  with  $w \times e$ , where  $n$  denotes number of nodes in the network,  $w$  denotes number of wavelengths available and  $e$  denotes the number of edges.

#### Algorithm 1

- 1: For each wavelength, do the Step 2 and Step 3.
- 2: Establish light path between  $P_1$  and  $P_j$ , where  $1 < j \leq n$ ; To establish the light path we take  $\max \{T(1,j), T(j,j-1) + T(j-1, j-2) + \dots + T(2,1)\}$ . If  $T(1,j)$  is maximum then store this information in the matrix  $S$  only the edge  $(1,j)$  in the corresponding row specifying the wavelength current wavelength usage. If the sum of traffics among intermediate nodes is the maximum, then store this information in the matrix  $S$  for all intermediate edges.
- 3: Update the traffic matrix corresponding to the edges such it will not be considered for next wavelength.
- 4: If all wavelengths exhausted or all edges assigned with light path, then stop.

### Application of the Algorithm for Ring Network

Here we propose an algorithm that optimally establish lightpaths in an optical ring network using a single wavelength  $\lambda$ . Assume that  $Q = p_1, p_2, \dots, p_i, p_{i+1}, \dots, p_n, p_1$  is a ring network of  $n$  nodes where  $P$  is the set of nodes in the network, traffic matrix is  $T$  and a single wavelength  $\lambda$  is available per link. We have to determine a virtual topology that optimizes the one hop traffic. We further extend our algorithm for multiple wavelengths per link. Let the set of wavelengths available per link of the ring network is  $M = \{\lambda_1, \lambda_2, \dots, \lambda_w\}$ . So the

number of wavelengths available per link is  $|M|=w$ . Assume that the ring network is  $Q$  and the traffic matrix is  $T$ .

### Using Single Wavelength

In case of a ring network using single wavelength is a special case of multiple wavelengths stated below. In case of multiple wavelengths, the number of wavelengths is  $w$ , but in case of single wavelength, the value of  $w = 1$ . Hence the algorithm is also same as the multiple wavelengths algorithm excepting the parameter  $w$  having the fixed value 1.

### Using multiple Wavelengths

In ring network we have a set of nodes  $P_1, P_2, P_3, \dots, P_n$  where  $P_1$  connected to  $P_2, P_2$  connected to  $P_3$  and so on and lastly  $P_n$  connected to  $P_1$  form the ring. Here we use the algorithm 4.2. For each wavelength we split each node  $P_1$  through  $P_n$  to make it a linear network and apply the algorithm 4.2. We note the total one hop traffic for each iteration and finally we consider the assignment of light path for which one hop traffic is maximum. We iterate the above procedure for each wavelength and ultimately sum up maximum traffics. To design the algorithm we take all the assumption of algorithm 1.

#### Algorithm 2

- 1: For each wavelength, repeat up to Step3.
- 2: For each node  $i$ , split the node and make it a linear network with  $n+1$  number of nodes, where  $n$  denotes the number of nodes in the network.
- 3: Call algorithm 4.2 with number of nodes  $n+1$ . Make a record of the assignment of wavelength and one hop traffic. Go to Step2.
- 4: Take the maximum one hop traffic and update the information into  $S$  matrix.
- 5: If all wavelengths are exhausted, then stop. Sum up the one-hop traffics for each wavelength.

## Conclusions

Our RWA algorithm using dynamic programming for ring network to maximize one-hop traffic and the simulation results have shown that our algorithm indeed provides optimum one-hop traffic. Then we provided survivability to a network by two approaches: one by designing a survivable virtual topology and another by shared path protection mechanism. We also provide necessary and sufficient conditions both for the existence of survivable virtual topology and alternate backup path for path protection, on which we design survivable RWA algorithms. Optical network is mainly used in WAN network, which operates under DWDM methodology. This type of network suffers from multiple fiber links failure simultaneously in practical. So our future work consists of designing a survivable RWA algorithm, which provides continuous service even after multiple fiber links failure.

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