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# Traffic Grooming Fault Tolerant Technique for Load-Balanced Routing and Wavelength Assignment in WDM Networks.

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**Abstract:** This problem of traffic grooming, routing, and wavelength assignment (GRWA) is considered with the objective of minimizing the number of transponders in the network. We first formulate the GRWA problem as an integer linear programming (ILP) problem. Unfortunately, the resulting ILP problem is usually very hard to solve computationally, in particular for large networks. To overcome this difficulty, a decomposition method is proposed that divides the GRWA problem into two smaller problems: the traffic grooming and routing (GR) problem and the wavelength assignment (WA) problem. In the GR problem, we only consider how to groom and route traffic demands onto light paths and ignore the issue of how to assign specific wavelengths to light paths. Similar to the GRWA problem, we can formulate the GR problem as an ILP problem. The size of the GR ILP problem is much smaller than its corresponding GRWA ILP problem. Once we solve the GR problem, we can then consider the WA problem, in which our goal is to derive a feasible wavelength assignment solution.

In this paper, we implemented the fault tolerance technique to the load balanced Routing and Wavelength Assignment (RWA) problem in which the wavelength is allocated by using an advanced reservation algorithm. The primary path is set by applying Max-flow and load balancing techniques. A backup path is then computed for handling the failures by checking the class of the request as protection or restoration. Based on the class, we find the available bandwidth for each backup path. An auxiliary graph is constructed based upon the link cost. The backup path is computed using these link costs and the wavelength assignment is performed using the first fit wavelength assignment technique. From our simulation results, we show that by establishing the backup path, fault tolerance in routing and wavelength assignment become effective.

## Keywords

ILP: integer linear programming, RWA: Routing and Wavelength Assignment, GRWA: grooming, routing, and wavelength assignment, GR: grooming and routing, FTPS: Fault Tolerant Path Set, NSF: National Science Foundation Standard network model.

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# 1. Introduction to WDM Routing and Wavelength Assignment:

Wavelength-Division Multiplexing (WDM) is the technology employed in fiber-optic communication, which multiplexes a number of optical carrier signals onto a single optical fiber by using different wavelengths of laser light. Generally, a shared transmission media construction and broadcast-and-select manner operation without switching are performed in a WDM Network .However, switching is vital for data transmission in WDM networks, which is constructed with point-to-point WDM links interconnecting the network nodes. In WDM network, the signals are combined using a multiplexer and separated using a demultiplexer. Both functions can be performed simultaneously with an optical add-drop multiplexer [9]. WDM network enforces the additional constraints on the wavelength assignment. If a switching or routing node is equipped with a wavelength converter, the wavelength continuity constraint will disappear. However, the routing problem remains as in normal circuit-switched networks. If a light path operates on the same wavelength across all fiber links that it traverses, the Routing and Wavelength Assignment (RWA) will satisfy the wavelength continuity constraint. This constraint may cause inefficient utilization of wavelength channels that result in higher blocking probability. For example, a request can be rejected even if a route is available due to the non-availability of the same wavelength on all the links along the route. Therefore, the problem of RWA becomes critical in WDM routing networks where the objective is to maximize the throughput by optimally assigning routes and wavelengths to a given traffic pattern [12].

Fault tolerant wavelength assignment techniques can be classified into dedicated backup, backup multiplexing and primary backup multiplexing. In dedicated backup multiplexing, the backup and the primary paths are set up at the same time. Traffic is routed on both paths by the source. The destination node gets switched to the backup path, when a failure occurs in the primary path. The resources are not shared by the backup paths. In spite of very high network blocking probability, the dedicated backup has a least down time of the connections.

### *1.1 Light-path protection:*

Data are transmitted through lightpaths in WDM optical networks and all optical channels cover multiple consecutive fibers. In the routing and wavelength assignment, the problem is to establish the lightpath for connection request, consists of selecting a route (path) and a free wavelength for serving the connection.[1] When a link or a node fails in the primary, a primary lightpath is selected from the set of candidate lightpaths in order to serve the connection request. For the backup path, a second link disjoint lightpath is selected from the same set to serve the connection in case of node failures [3].A backup lightpath is set up during the call setup of a lightpath, so that all the traffic on the primary lightpath is diverted to the backup lightpath [4].
In order to transfer optical signals from source node to destination node, the lightpath must have same wavelength.

This is referred to as wavelength continuity constraint that leads to high blocking probability and inefficient utilization of wavelength channels [5].

A huge amount of a fiber is segregated into several non-overlapping wavelength channels for independent data transportation, in the optical networks, which employ WDM.The point-to-point optical connections are established using the lightpaths of the wavelength channels. This can cover several fiber links without using routers [6].

### *1.2Problem Identification and Proposed Solution:*

In our previous papers, an adaptive routing and wavelength assignment protocol is proposed, which is based on maximum flow and load balancing.[10][11][13] When a network handles an advance reservation request, the routing is done by means of max-flow algorithm and wavelength assignment is carried out using an advance reservation algorithm. When the network handles an immediate reservation request, routing is done via the traffic load on each link on the paths and wavelength assignment is done by an immediate reservation algorithm.[7] Thus, routing and wavelength assignment is performed adaptively based on the type of reservation request.

When a fault occurs, the network has need of a fault tolerance technique. Based on RWA problem, fault tolerant protection is alienated into fault tolerant routing techniques and fault tolerant wavelength assignment techniques in WDM networks. In order to deal with the problem of routing Fault Tolerant Path Set (FTPS) and the wavelength assignment to FTPS, fault tolerance is essential in WDM networks [8].As an extension to our previous work, we implement fault tolerance in the routing and wavelength assignment of the WDM networks to address the problem of routing FTPS and wavelength assignment to FTPS.

## 2. Traffic grooming in Optical Networks:

The problem of traffic grooming, routing and wavelength assignment (GRWA) is considered with the objective of minimizing the number of transponders in the network [9].We first formulate the GRWA problem as an integer linear programming (ILP) problem. The GRWA problem can be formulated as an integer linear programming (ILP) problem [10].

Let,
*W: the set of wavelengths available on each fiber;*
*D: the set of traffic demands;*
*g: the capacity of a single wavelength;*
$S_d$ *: the size of demand ;* $d \in D$

### a) The GR problem:

Let $t = [t_l]_{l \in L}$ a column vector containing light path capacity decision variable where $t_l = \sum_{w \in W} y_{l,w}$ is the number of wavelengths needed for light path $l \in L$. Then, the GR problem can be formulated as

$$\min \sum_{l \in L} t_l \qquad (1)$$

$$s.t. \quad Axd = u_d \quad d \in D \qquad (2)$$

$$Bt \leq |W| \mathbf{1} \qquad (3)$$

$$\sum_{d \in D} s_d l_{l,d} \leq g t_l \qquad l \in L \qquad (4)$$

### b) The WA Problem

The WA problem of our interest is to find a binary solution y such that

$$\sum_{w \in W} y_w = t \text{ and } By_w \leq \mathbf{1} \text{ for } w \in W \quad (5)$$

where $t$ is a feasible (or optimal) solution of the GR problem.

## 3. Proposed Work in Routing and Wavelength Assignment:

A new adaptive routing and wavelength assignment protocol is proposed [13], which is based on maximum flow and load balancing. The primary paths are created in this phase and a backup path is established to address the problem of faults.

In Fault Tolerance using Backup Path Multiplexing all the requests are assumed to have bandwidth demand of one unit and they are classified into class 1 and class 2.[14]

Class 1: A link disjoint backup path is required along with their primary path,

Class 2: Only the dynamic restoration is enough.

The physical bandwidth of each link is divided into

**P**- Total amount of reserved bandwidth dedicated to primary paths carried by link *l* and it is not allowed to be shared

**B**- Total bandwidth occupied by all backup paths on link *l*, which can be shared by some backup paths, if their associated primary paths are disjoint.

**R**- Residual bandwidth, which is the difference between the physical bandwidth on link *l* and the total consumed bandwidth (P+B).

### Algorithm description

1. For the primary path establishment on a link, the routing and wavelength assignment protocol as described in [17] is used. However, to establish a backup path for a new primary path, the available bandwidth must have the residual bandwidth R and portion of B i.e. Y.

2. Initially the requested class is identified. If the request belongs to class 2, the connection request is again checked. If the request belongs to class 1, find the available bandwidth S for backup paths. The available bandwidth S =R+Y which can be shared. Based upon S, an auxiliary graph is generated, which represents the current network state.

## 3. Calculation of cost value

Cost of primary path = Number of hops or links that they traverse.
Cost of backup path = Number of free wavelengths used by it on each link it traverses.
*Case 1*: When a wavelength is not free as some primary light-path is using it, then the backup path cannot use that wavelength.
*Case 2*: When a wavelength is not free while a set of backup paths are using it, then the new backup path uses the wavelength with no extra cost, only when a primary path is link-disjoint with the primary route of each and every backup light-path in *S*.
*Case 3*: When a wavelength is free, the backup path uses it with a cost value of one.
*Case 4*: When the wavelength belongs to Y, link cost is assigned Zero weight.
*Case 5*: When the wavelength is already allocated by primary path and is not considered in the auxiliary graph, it is not used for backup calculation.

## 4. Backup path computation:

Due to the bandwidth sharing, the path cost of a longer backup path costs less than that of a shorter one. The network performance is improved since more number of wavelengths is available for future requests.
When class-2 traffic is enabled with preemption, the value of B allows sharing of allocated wavelengths from future backup paths of class 1 traffic and can preempt class 2 light-paths. When a backup path is required, backup path computation phase is enabled. The backup paths are computed using the Dijkstra algorithm by selecting the minimum cost paths.

## 5. Wavelength assignment scheme

For each wavelength,
(i) When there is no light-path found, connection is blocked due to backup path blocking and the P and R are updated.
(ii) When multiple backup light-paths are found, only one light-path is assigned based upon the wavelength assignment scheme. Here the First fit algorithm is used for wavelength allocation, which allocates the first one of the minimum costs. This algorithm is briefly described in the flowchart given in Fig. 1.

# 4. Simulation

### *4.1 Simulation Settings*

In this section, we examine the performance of our FT-ARWA protocol with an extensive simulation study based upon the NS-2 network simulator. We use the Optical WDM Network simulator (OWNs) patch in NS-2 to simulate a European NSF network standard model (Fig. 2) of 14 nodes.
In this simulation, a dynamic traffic model is used in which connection requests arrive at the network according to an exponential process with an arrival rate r (call/seconds). The session holding time is exponentially distributed with mean holding time *s* (seconds).
The connection requests are distributed randomly on all the network nodes. In all the simulation, the results of our proposed FT-ARWA are compared with the IA-RWA [2] technique.

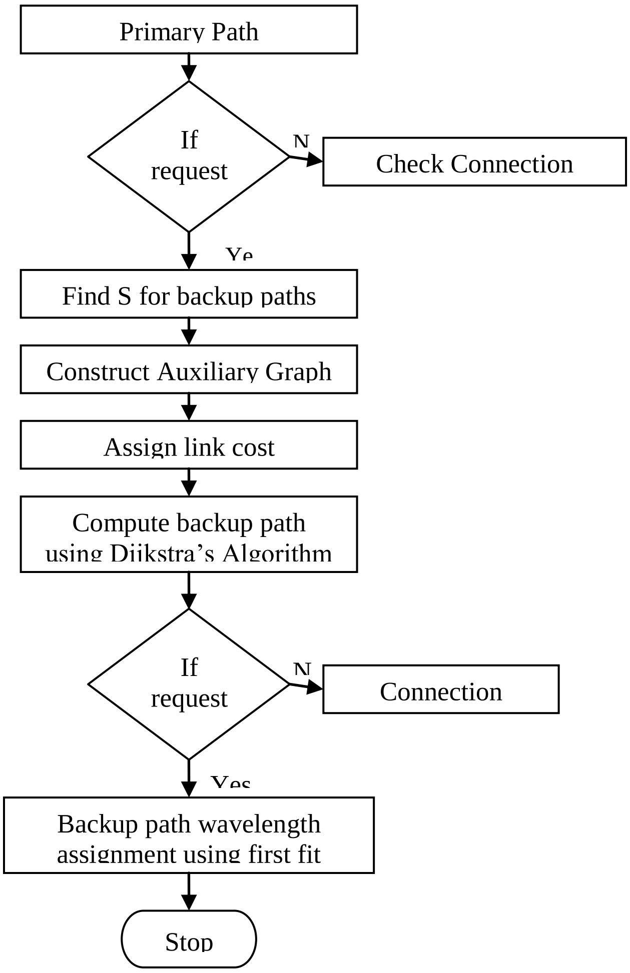


**Fig.1: Flowchart for Backup path multiplexing.**

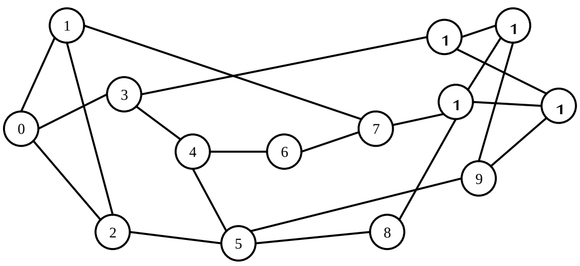


**Fig. 2: NSF network with 14 nodes.**

### *4.2. Performance Metrics*

In this simulation, the bandwidth utilization, Blocking Probability and Packets received are measured.
Bandwidth Utilization: It is the ratio of bandwidth received into total available bandwidth for a traffic flow.
Blocking Probability: It is the ratio between the number of services rejected and the number of services requested.
Packets Received: It is the number of packets received by the receiver during the data transmission.

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**Table 1: Simulation Parameters**.

| | |
|---|---|
| Topology | Mesh |
| Total no. of nodes | 14 |
| Link Bandwidth | 50Mb |
| Link Wavelength Number | 10 |
| Link Delay | 20ms |
| Link Utilization sample Interval | 0.5 |
| Traffic Type | Exponential |
| Traffic Arrival Rate | 0.2 |
| Traffic Holding Time | 0.5 |
| Traffic Packet Rate | 40 to 60 Mb |
| Packet Size | 200 |
| No. of Session-traffics | 1 to 5 |
| Max Requests Number | 50 |

## *4.3 Results*

**A. Effects of Varying Traffic Rate:**

In the initial simulation, the traffic rate is varied as 40Mb, 45Mb, 50Mb, 55Mb and 60Mb.

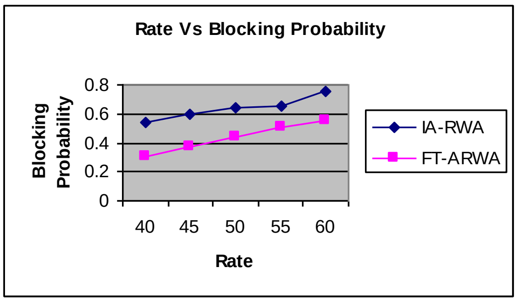


Fig. 3: Rate Vs Blocking Probability

Fig.3 shows the Blocking Probability occurred for both the techniques, when the rate is increased. It shows that the FT-ARWA has 32% lesser significantly Blocking Probability than the IR-RWA, since it uses Max-Flow algorithm for primary path selection and uses bandwidth sharing technique for back up path.

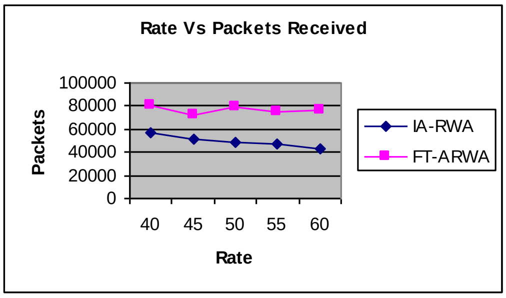


Fig. 4: Rate Vs Packets Received

Fig. 4 shows the average packets received by both the techniques, when the rate is increased. From the figure, it can be seen that the FT-ARWA received 35% more packets when compared to IA-RWA, since it reduces Blocking Probability much.

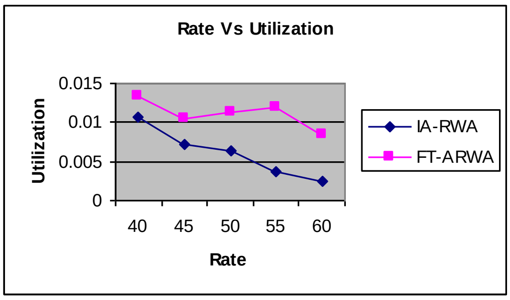


Fig. 5: Rate Vs Utilization

Fig.5 shows the bandwidth utilization obtained for both the technique when the rate is increased. Cleary FT-ARWA shows 47% better utilization than the ARWA scheme, since it uses the shared bandwidth assignment technique for backup paths.

**B. Effect of Varying the Flows**:

In this simulation, the number of flow is varied as 1, 2, 3, 4 and 5.

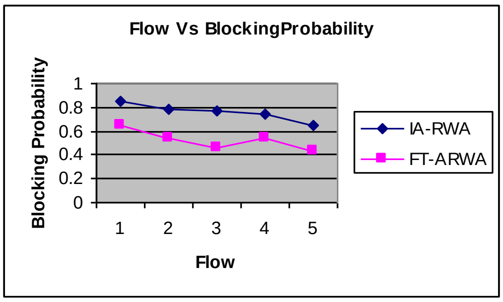


Fig. 6: Flow Vs Blocking Probability

Fig. 6 shows the Blocking Probability occurred for both the technique, when the number of flows is increased. It shows that the FT-ARWA has 30% less Blocking Probability when compared to IA-RWA, since it uses Max-Flow algorithm for primary path selection and uses bandwidth sharing technique for back up path.

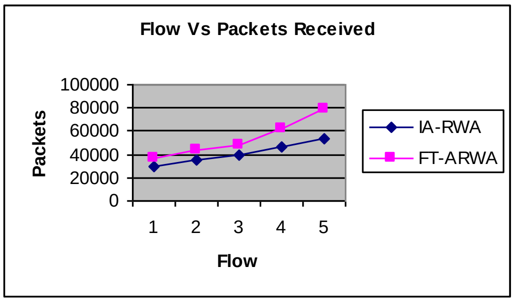


Fig. 7: Flow Vs Packets ReceivedFig.7 shows the average packets received by both the techniques, when the number of flows is increased. From the figure, it can be seen that the FT-ARWA received 22% more packets when compared to IA-RWA, since it reduces Blocking Probability much.

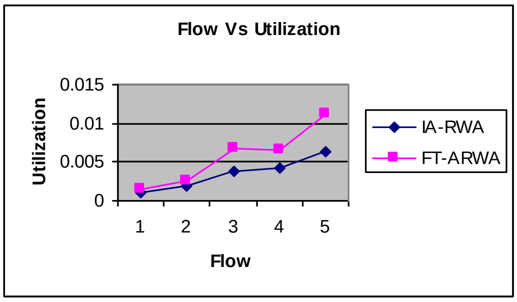


Fig. 8: Flow Vs Utilization

Fig.8 presents the bandwidth utilization obtained for both the technique when the number of flows is increased. Cleary FT-ARWA shows 35% better utilization than the ARWA scheme, since it uses the shared bandwidth assignment technique for backup path

# 5. Conclusion

In this paper, we implemented fault tolerance technique to the load balanced Routing and Wavelength Assignment (RWA) problem. By using Max-flow and load balancing technique and advanced reservation algorithm, the primary path is established and the wavelength is allocated to it. A backup path handles the failures by verifying the class of the request as protection (Class 1) or restoration (Class 2). In case of Class 1 request, a link disjoint backup path is required along with their primary path whereas in Class 2, only the dynamic restoration is enough and the connection is blocked. The link cost is calculated to construct an auxiliary graph based on which the backup path is computed. First fit wavelength assignment technique is performed for wavelength assignment. From our simulation results, we show that fault tolerance in routing and wavelength assignment becomes effective by establishing backup path.

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