

A New Fault Tolerant Approach for Load-Balancing in Routing and Wavelength Assignment in WDM Networks

¹Surendra Bhosale and ²Nisha Sarwade

Abstract: Wavelength Division Multiplexing (WDM) technology is employed in fiber-optic communication systems to multiplex optical carrier signals to a single optical fiber using different wavelengths. Fault tolerance is an important parameter in WDM networks. When a fault occurs the network requires a fault tolerance technique to repair the fault. In this paper, a new fault tolerance technique is proposed for the load balancing routing and wavelength assignment (RWA) problem. In RWA problem the fault protection issue is alienated to fault tolerant routing and fault tolerant wavelength assignment for traffic in WDM networks. The wavelength assignment is done using an advanced reservation algorithm. In routing, the primary path is set by applying max-flow load balancing technique. Then a backup path is computed for handling the link failures based on the class of request. The backup path is used for link restoration when primary path fails. Based on the class, we find the available bandwidth for backup paths. An auxiliary graph is constructed based upon the link cost for the backup path. No backup paths are required to be activated when a single link fails. This provides guarantee that the failed connections can be restored. By establishing the backup path, fault tolerance in routing and wavelength assignment is effective.

Keywords: WDM networks, Fault Tolerance, Routing and Wavelength Assignment (RWA).

1. Introduction

1.1 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. WDM network enforces additional constraints on the wavelength assignment. If a switching or routing node is equipped with a wavelength converter, then the wavelength continuity constraint disappears. However, the routing problem remains as in normal circuit switched networks[12]. If a light path operates on the same wavelength across all fiber links that it traverses, then 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. 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 [13].

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1.2 Challenges in Survivable Routing and Load Balancing in WDM

Achieving survivable routing in WDM is a challenging task. It involves more issues while designing survivable routing mechanism in WDM. Some of the issues are described below,

1. The major problem in providing survivable routing in WDM is routing and wavelength assignment (RWA) problem. It sets up light paths by routing and assigning a wavelength to each connection such that no two light paths use the same wavelength on the same link [1]
- 2 .Due to the lack of optoelectronic regenerators, the impact of a failure propagates without electronic boundary, and a single failure can trigger a large number of redundant alarms.[2]
3. The routing of the light paths on the physical topology can significantly affect the amount of capacity required for network survivability [13].
- 4.The routing and wavelength assignment problems are tightly linked together [3].
5. Since with WDM each physical fiber link can support many lightpaths, once the lightpaths are routed on the physical topology, it is possible that two or more lightpaths would share the same physical link. Hence, the failure of a single physical link, can lead to the failure of multiple links in the logical topology. [4]
6. Load balancing leads to the problem of creating virtual connections by considering both routing and wavelength assignment [13][14]

1.3 Faults in WDM Routing and Wavelength Assignment

Fault tolerant routing or simply routing techniques can be classified into two partitioning techniques *fixed* and *dynamic partitioning*. In *fixed partitioning* techniques, the primary path is partitioned into sub-paths based on fixed pre-determined criteria [8] It can be further classified into two partitioning techniques uniform and non-uniform..In *uniform* partitioning, the primary path is partitioned into sub-paths of constant length with the exception that the last sub-path can have a length less than the constant length. The sub-path length is pre-determined. In a *non-uniform* partitioning technique, the primary path is partitioned into non-uniform sub-paths based on criteria such as existing network partitions. Uniform and non-uniform partitioning techniques can be classified into *sub-path replacement* in which the failed sub-path is replaced by its backup sub-path and *path replacement* in which the whole primary path is replaced by its corresponding end-to-end backup path when a sub-path fails. 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 [9].

Backup multiplexing allows the multiple backup paths to share a wavelength channel as long as no two connections compete for the shared wavelength during the link failure. No backup paths are required to be activated when a single link fails. It provides guarantee that the failed connections can be restored.

Primary Backup Multiplexing does not allow one or more backup paths to share a channel, since the backup paths are not available for restoring failed connections. Here, no failed connections can be restored upon link failure. It is used to achieve pre-specified network restoration guarantees [6].

1.4 Light-path protection

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. 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 [5]. 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 [6]. 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 [7].

1.4 Problem Identification and Proposed Solution

A new adaptive routing and wavelength assignment protocol is implemented, which is based on maximum flow and load balancing [15]. 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. Thus, routing and wavelength assignment is performed adaptively based on the type of reservation request [15]. When a fault occurs in the network a fault tolerance technique is required.

Based on RWA problem, fault tolerant protection is alienated into fault tolerant routing techniques and fault tolerant wavelength assignment techniques in WDM networks. [10], We have proposed a new 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:

An integer linear program for routing and wavelength assignment problem in WDM optical network with wavelength continuity constraint is a important issue. In this constraint a lightpath must occupy the same wavelength on all the links it traverses. Then, a route must be selected and a wavelength must be assigned to the lightpath [14].

The GRWA problem as an integer linear programming (ILP) problem [11].

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 $d \in D$;

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 lightpath $l \in L$. [11] Then, the GR problem can be formulated as

$$\min \sum_{l \in L} t_l$$

$$\text{s.t. } Axd = u_d \quad d \in D \quad (1)$$

$$Bt \leq |W| \mathbf{1} \quad (2)$$

$$\sum_{d \in D} s_d l_{l,d} \leq g t_l \quad l \in L \quad (3)$$

The WA Problem:

The WA problem of finds a binary solution y such that

$$\sum_{w \in W} y_w = t \text{ and } B y_w \leq \mathbf{1} \text{ for } w \in W \quad (4)$$

Where t is a feasible (or optimal) solution of the GR problem. [11]

3. A New Fault Tolerant Approach for Load-Balancing RWA

A new adaptive routing and wavelength assignment protocol is proposed [15], 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.

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

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

Let **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.

Let **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: The cost calculation is based one the following basis in the network.
 Cost of primary path = Number of hops or links in traverse path.
 Cost of backup path = Number of free wavelengths used by it on each link it traverses.
- There are five different cases arise while carrying out wavelength assignment as listed in Table 1

Case	
1	When a wavelength is not free as some primary light-path is using it, then the backup path cannot use that wavelength.
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.
3	When a wavelength is free, the backup path uses it with a cost value of one
4	When the wavelength belongs to Y, link cost is assigned Zero weight.
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.

Table-1

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

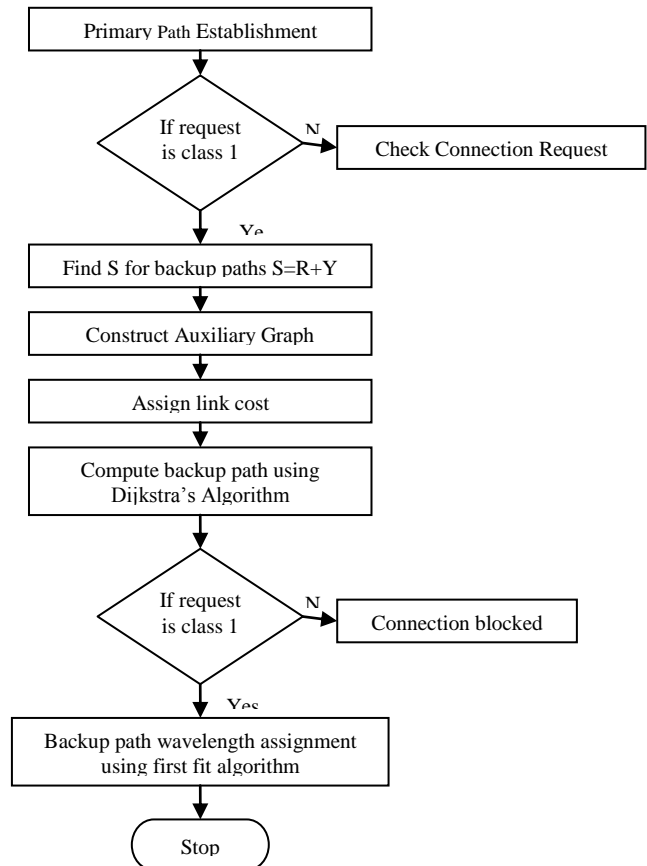


Fig 1

4. Simulation Results

4.1 Simulation Settings

The performance of a new FT-ARWA protocol is tested with the Optical WDM Network simulator (OWNs) patch in NS-2 to simulate a NSF network (Fig.2) of 14 nodes. The results are compared with our earlier protocol ARWA.[15] 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 ARWA [15].

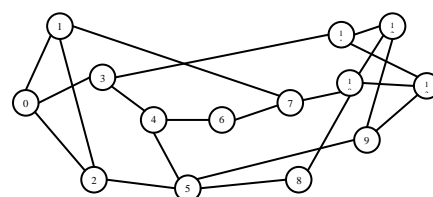


Figure 2: NSF network with 14 nodes.

Topology	Mesh
Total no. of nodes	14
Link Bandwidth	50Mb
Link Wavelength Number	10 to 25
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	5Mb
Packet Size	200
No. of Session-traffics	1 to 5
Maximum Requests	50

Table 2: Simulation Parameters

4.2. Performance Metrics

The Performance metrics namely 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.

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.

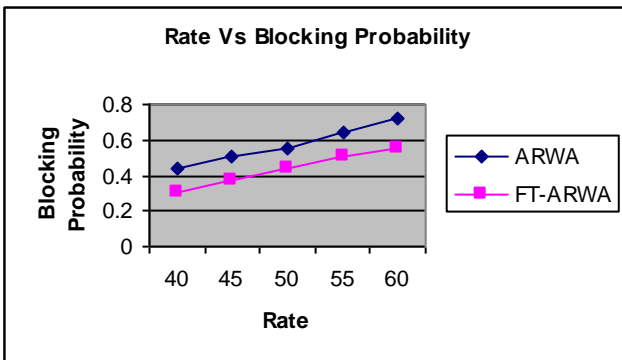


Fig 3: Rate Vs Blocking Probability

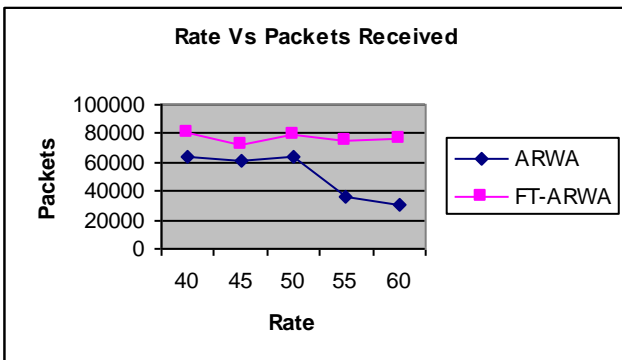


Fig 4: Rate Vs Packets Received

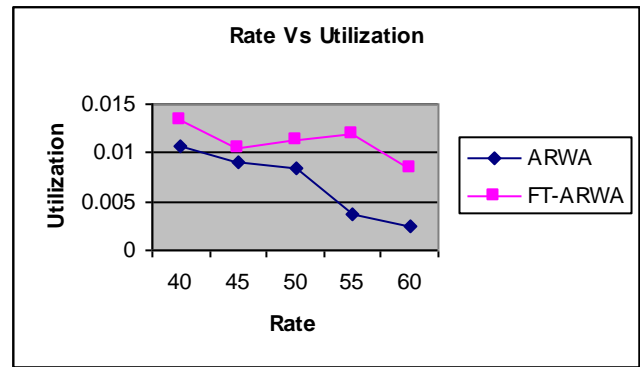


Fig 5: Rate Vs Utilization

Fig.3 shows the Blocking Probability occurred, when the rate is increased. It shows that the FT-ARWA is significantly higher than the ARWA.

Fig. 4 shows the Packets receives ratio occurred, when the rate is increased. From the figure, it is proved that the FT-ARWA has high ratio when compared to ARWA

Fig.5 shows the channel utilization obtained, when the rate is increased. FT-ARWA shows better utilization than the ARWA scheme.

B. Effect of Varying the Flows

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

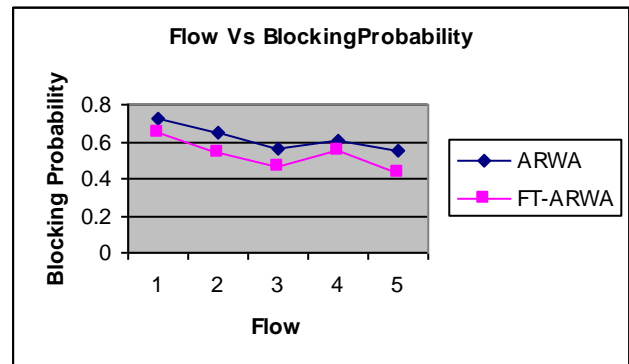


Fig 6: Flow Vs Blocking Probability

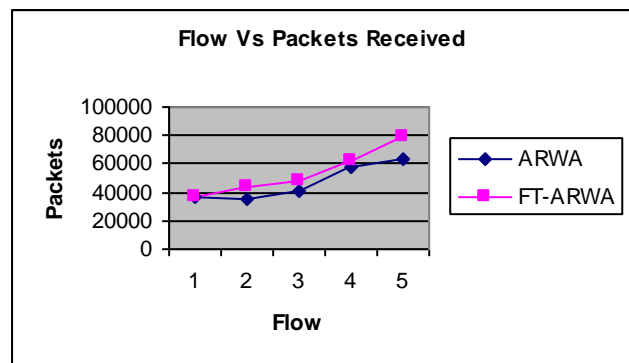


Fig 7: Flow Vs Packets Received

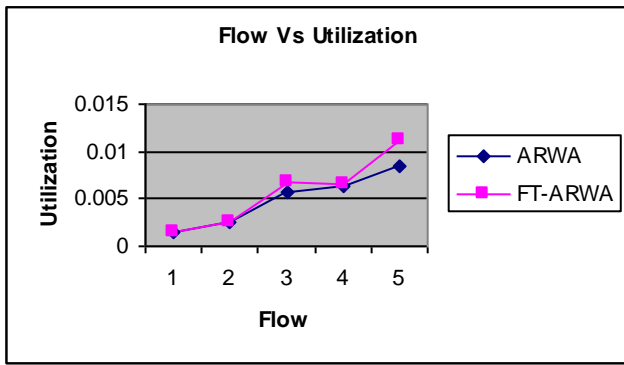


Fig 8: Flow Vs Utilization

Fig.6 shows the Blocking Probability occurred, when the rate is increased. It shows that the FT-ARWA is significantly higher than the ARWA.

Fig. 7 shows the Packets receives ratio occurred, when the rate is increased. From the figure, it is proved that the FT-ARWA has high ratio when compared to ARWA

Fig.8 shows the channel utilization obtained, when the rate is increased. FT-ARWA shows better utilization than the ARWA scheme

5. Conclusion:

A new fault tolerance technique is implemented in Routing and Wavelength Assignment problem. The primary path is set by applying Max-flow and load balancing techniques and wavelength is allocated using an advanced reservation algorithm. A backup path is then computed to handle the failures by verifying the class of the request as protection (Class 1) or restoration (Class 2). According to the class, we find the available bandwidth for backup paths. In Class 1, a link disjoint backup path is required along with their primary path and in Class 2, only the dynamic restoration is enough. The link cost is calculated to construct an auxiliary graph. The backup path is computed using these link costs. The wavelength assignment is performed using the First fit wavelength assignment technique. From our simulation results, we show that by establishing backup path fault tolerance in routing and wavelength assignment is effective.

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