Virtual Topology Reconfiguration of WDM Optical Networks Using Fuzzy Logic Control

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***Abstract*-Bandwidth requirements of the internet are increasing every day. Wavelength Division Multiplexing (WDM) is the next step towards leveraging the capabilities of the optical fiber, especially for wide area backbone networks. Reconfiguration is a characteristic of WDM optical networks that allows network operators to arrange the networks in response to the changing traffic demands. As a general assumption, reconfiguration studies are based on the idea that the decision of reconfiguration is sudden, i.e. triggered by an event, hence the virtual topology change is an interrupted process. It has two objectives: finding routes that satisfy the wavelength assignment constraints, and making efficient use of network resources. The complexity involved in the networks may require the consideration of multiple constraints to make the decision. In this paper we proposed a new approach using fuzzy logic control on IP over WDM network to reconfigure virtual topology that allows multiple constraints to be considered in a simple and intuitive way. Five fuzzy sets for the number of deleted lightpaths and average utilization for each wavelength are used to divide the variable space: very high(VH), high(H), medium(M), low(L), very low(VL). Simulation shows that this fuzzy reconfiguration algorithm is efficient and promising.**

Keywords: Lightpath, Virtual topology reconfiguration, WDM networks, Fuzzy logic.

I. Introduction

In the recent decades, the growing popularity of the Internet has created unprecedented demand for transport of data. To accommodate this demand optical fiber has emerged as a promising transmission medium in the struggle.

The most important technique that allows expanding the inherent great capacity of optical fibers even more is wavelength division multiplexing (WDM). The idea of WDM is to use several independent lightwaves of different wavelengths on the fiber at the same time, each carrying data at the original bit rate that depends on the fiber quality. By using optical switching devices in the network, an optical signal may be transmitted along several fibers. The resulting optical channel from the transmitter to its receiver is called lightpath. The concept of lightpaths is the main characteristic of all-optical networks [1]. Since optical switches maintain the wavelengths of processed lightwaves, each lightpath operates on exactly one wavelength. This wavelength is used on all optical fibers the signal traverses.

A virtual topology is defined to be a set of all lightpaths in a network. Reconfiguration is one of the most significant characteristics of WDM optical networks, which allows a network to adapt to real-time traffic changes or ensures network survivability during equipment failures. This characteristic is achieved by the fact that WDM optical networks provide an architecture in which logical connections can be embedded over the underlying physical connections.

Reconfiguration management must ensure rearrangement of the network in such a way that traffic disruption is kept to be minimized and remain un-noticeable to the end-user [2].

This paper investigates the use of a method from computational intelligence, such as fuzzy logic, to handle this problem. The fuzzy technology exhibits a solution that often contributes to the decision making for the complex problem. To this end, a fuzzy approach is proposed in order to choose the best topology with the minimum change possible.

The rest of the paper is organized as follows:

Section II, describes the different reconfiguration approaches. Section III describes the proposed algorithm. Section IV presents the simulation results. Finally, section V in which the conclusion of the paper is given.

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II. RELATED WORKS

Reconfiguration capability of wavelength-routed networks has been emphasized as an outstanding characteristic, and several virtual topology reconfiguration schemes have been proposed. In [3] an on-line reconfiguration study is given. The authors proposed a heuristic method based on a two-stage approach. The first stage is reconfiguration where the changes to be made in virtual topology are determined by the aim of minimizing the objective function value. The second stage is optimization aiming to bring the objective function value closer to the optimal point.

A direct technique for reconfiguration optically switched networks is discussed in [4], using Increment Reconfiguration Migration heuristic. This algorithm maintains the lists of two groups of lightpaths those which are to be created and those which remain to be deleted. Each iteration of the algorithm creates as many lightpaths as possible from the list, and then tears down the least loaded lightpaths whose deletion does not disconnect the logical topology. Thus, by postponing lightpath deletion and prioritizing lightpath creation the heuristic reduces network disruption.

The authors in [5] presented a Virtual Topology Reconfiguration (VTR) controller for WDM networks. First, VTR controller decided when current virtual topology is reconfigured, and then the controller creates the target topology. The inform they used to reconfigure were such as: the traffic that travel with single hop lightpaths and the others, and the amount of traffic. The increase in the amount of traffic serviced through multi-hop lightpath, shows that current virtual topology is not adequate for traffic demands.

In [6], another reconfiguration algorithm, called Minimal Disrupted Lightpath First (MDPF) , attempts to shift from current virtual topology to a new one, while keeping the network availability as much as possible. An objective of the reconfiguration algorithm is to arrange a reconfiguration sequence with the minimum disruption to the network. To this end, MDPF create the auxiliary graph Ga(Ea,Va), where Va is new and old lightpaths as vertices and Ea is the conflict relation between old and new lightpaths as edge.

In reconfiguration procedure, the auxiliary graph is created first. For each new lightpath the cost is defined as the number of old lightpaths disrupted by the new lightpath. By sorting the costs, the minimum value is defined. The lightpath with minimum cost is established. The operation is repeated until the list of new lightpaths be empty. Since our objective function of our algorithms is similar to MDPF, we compare the performance of our algorithms with MDPF.

In most approaches it is assumed that the traffic demand is known in advance and based on the known traffic pattern, a new topology is designed.

In our previous work [7] we have developed a reconfiguration algorithm, called Protected Reconfiguration Algorithm (PRA) that used backup path to protect the main lightpaths. The lightpaths that are currently used will be lost after freeing their resources, so they use backup paths to preserve their data.

Using backup paths has another privilege to this algorithm and that is the ability of error recovery. This algorithm controls the network situation in an alternative time. If an error occurs in the network, the traffic loss is stopped by changing the path from the primary to the backups.

The following steps describe the proposed reconfiguration algorithm.

Step 1: Try to setup the new lightpath using the available resources. If the process is not successful go to step2 otherwise go to step12.
Step 2: Create the conflict list for every wavelength on which a new lightpath can be setup.
Step 3: Sort the list in ascending order based on the **minimum** number of backup lightpaths which new lightpath has conflict with them and **maximum** backup path hop counts.
Step 4: Select the wavelength so that the minimum lightpath deletion is occurred.In this step only backup lightpaths are selected.
*Step 5***:** Delete backup lightpaths and make their resources free.
Step 6: If recourse allocation is possible go to step 12 otherwise go to next step.
Step 7: Sort the conflict list in an ascending order, based on the **minimum** number of current lightpaths and **minimum** primary path hop counts.
Step 8: Release the resources of the selected lightpaths.and switch their traffics to their backups. In this phase only the primary paths that have backup are chosen.
*Step 9:*If recourse allocation is possible go to step 12 otherwise go to next step.
Step 10: Sort the conflict list in an ascending order, based on the **minimum** number of current lightpaths. The lightpath omission may be occur in this phase.
Step 11: Release the resources of the selected lightpaths
Step 12: Set up the new lightpath.
*Step 13***:** Set up the backup path for new lightpath.

III. THE PROPOSED ALGORITHM

In real networks, the traffic rates between node pairs distinguishably fluctuate over time. Because of the traffic fluctuates, reconfiguration of the virtual topology would be needed; since the virtual topology optimized for a specific traffic demand would lose its optimality with changes in the traffic pattern. During reconfiguration, packet loss may occur due to the deletion of older lightpaths. Therefore, there is a trade-off in the reconfiguration between improved network performance obtained from reconfiguration itself, and the traffic loss penalty due to the lightpath during the reconfiguration. Accordingly, it's necessary to have an effective transition method to shift current topology to the new one so as to minimize the effect of the reconfiguration on the upper layer traffic.

The fuzzy sets provide us with a theoretical framework to solve a wide range of problems in different research areas [8] with a high degree of efficacy and efficiency.

We proposed a two step reconfiguration algorithm in which the network traffic flows are continuously observed and the updates to the virtual topology are made when necessary.

For each request of a new lightpath, the shortest path is selected as the route. However, the needed wavelength may currently be occupied by another lightpath(s) on some links of the path. In this case, the algorithm which is called, Fuzzy Metric Reconfiguration Algorithm (FMRA), defines the second shortest path and the wavelength availability in each fiber. Using the second shortest path, when wavelength allocation on the shortest path is failed, causes load balancing, so it can postpone the reconfiguration time. If it can successfully define a route and assign wavelength, the process stop, otherwise it goes to second step.

In second step, to establish a new lightpath, first the conflict list is created according to the conflict relation between the new and the old topology, and then the Fuzzy algorithm is used to select a new virtual topology that yield the least effect on the network availability. For example, for a physical network shown in Fig. 1, the new and current lightpaths are given in Table1, which leads to a conflict list as shown in Table 2.

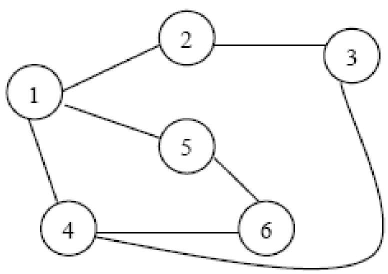

Fig. 1 Physical topology

Table 1 Current and new lightpaths with their paths and wavelength

Current lightpaths		
Path	Wavelength	Current lightpaths
1-2-3	W2	L1
6-5-1	W2	L2
2-3	W1	L3
5-1-4-3	W1	L4
2-1-5	W1	L5
New requested lightpath		
Path	New lighpath	
4-3-2	NL1	

Table 2 The conflict relations between current and new lightpaths

Wavelength	Conflict link	Conflict lightpath
W1	3-2	L3
	4-3	L4
W2	3-2	L1

To indicate the order of preference of the wavelength, based on the conflict list, FMRA assigns a value between 0 and 1 for each wavelength based on a fuzzy membership function, which shown in Fig. 2,. Five fuzzy sets for the number of deleted lightpath and average utilization for each wavelength are used to divide the variable space: very high (VH), high(H), medium(M), low(L), very low(VL). FMRA found a path with a minimum number of lightpath to be deleted and a maximum average of free resources, to set load balancing. One of the objectives of this study is to distribute traffic load among all links, which causes load balancing. If the traffic load distribute among the links, the need for reconfiguration is become lessened. By reducing the reconfiguration process, the traffic disruption decreases remarkably. For this reason, average utilization of the wavelength is considered in fuzzy algorithm to define the proper wavelength. The Fuzzy algorithm tries to select the wavelength that causes a few lightpaths to be deleted and the free resources on their paths are scant. So by deleting those lightpath, which is indispensable for establishing a new lightpath, more resources will be available on the links and the traffic loads on those links reduces.

The fuzzy interference system is based on the linguistic approach that depends on linguistic variables whose values are words and sentences in natural or artificial language rather than numbers. Mamdani minimum interference engine, triangular fuzzifier and center average defuzzifier were used in this fuzzy system.

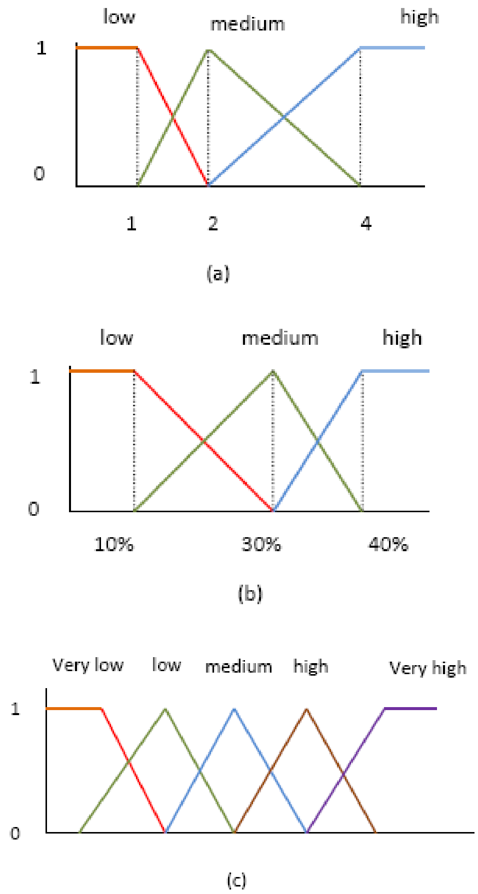

Fig. 2 a) Fuzzy Membership function of deleted lightpaths b) Fuzzy Membership function of average used resources c) Fuzzy output

To define the relationship between the inputs and outputs, our fuzzy-based reconfiguration algorithm is based on nine fuzzy rules, as shown in Fig. 3.

If NDL is low and NUW is low then output is **Very low**
If NDL is low and NUW is medium then output is **Low**
If NDL is low and NUW is high then output is **Medium**
If NDL is medium NUW is low then output is **Low**
If NDL is medium and NUW is medium then output is **Medium**
If NDL is medium and NUW is high then output is **High**
If NDL is high and NUW is low then output is **Medium**
If NDL is high and NUW is medium then output is **High**
If NDL is high and NUW is high then output is **Very high**

Fig.3 Fuzzy rule base with two parameters: number of deleted lightpaths (NDL) and average used wavelength (AUW)

The main idea is to provide a proper virtual topology under dynamic traffic condition, by keeping the lightpath load balanced and by changing the virtual connectivity only when it is necessary with minimum of changing and disruption. Fig. 4 describes the proposed reconfiguration algorithm.

Given :

- Virtual topology
- Number of wavelength (Total_Wvlen)
- The traffic matrix
- A new lightpath request (NLP)

Find :

- A new virtual topology with minimum disruption

variables:

- VT: virtual topology,
- CLP: current lightpath,
- succ is a boolean variable which shows the function is done successfully or not
- TotalLP ={CLP1,CLP2,…CLPn) //Total number of lightpaths
- Conflict_list //the list that shows the conflict relation of new and current lightpaths

Algorithm :

```
//Route traffic using shortest path routing and finds the shortest path for
the new lightpath
Find_Path(NLP,shorthest_path)
//Try to alssign needed wavelength to the new lighpatht.
Succ = Alooc_Wvlen(NLP,shortest_path)
If succ = TRUE then
   Establish NLP on the shortest path
   TotalLP = TotalLP+{NLP}
else
  //Route traffic using shortest path routing and finds the second
shortest path for the new lightpath
  Find_Path(NLP,second_shortest)
 //Try to alssign needed wavelength to the new light.
Succ = Alooc_Wvlen(NLP,second_shortest)
If succ = TRUE then
     Establish NLP on the second shortest path
     TotalLP = TotalLP+{NLP}
else
     For every w εTotal_Wavlen  do
     If w is not available in all link of the path then
     // add the wavelength and the CLP which has conflict to NLP
      Add_conflict_List(w,CLP)
      endif
     endfor
     //use fuzzy algorithm to find the wavelength with minimum number
of disruption based on conflict list
    Fuzzy_alg(conflict_list)
   //sort the conflict list in ascending order of fuzzy metric value
    Sort_Fuzzy(conflict_list)
   //select the wavelength so that the minimum lightpath deletion is
occurred, which is in the beginning of the list.
  //conflict_list[w] has the current lightpaths that should be deleted
  While (conflict_list [w] is not empty) do
       Tear_Down(CLP)
       TotalLP = TotalLP-{CLP}
  endwhile
   Establish NLP on the  path and assign w to it
   TotalLP = TotalLP+{NLP}
endif
endif
```

Fig. 4 Pseudocode of the proposed algorithm

IV. SIMULATION RESULTS

In this section, we present some simulation results using NS2 simulator. The NS2 is a discrete event simulator widely accepted and used for the analysis of the computer networks. The Information Science Institute makes the whole package available in their site www.isi.edu.

We have used version ns-allinone-2.1b6for linux with the addition of OWns patch to simulate the WDM features. NS2 has been integrated with the OWns patch. The Optical WDM Network Simulator (OWns)[9] has been developed to extend the NS2 capabilities with the primary purpose of developing a simulator that makes it possible to simulate various WDM applications. We implemented the FMRA algorithm in OWns. We implement FRMA, our proposed approach, FRA, Our previous work, and MDPF algorithms in Owns simulator to compare their performance. In this simulation there is no wavelength convertor. The traffic flow between node pairs is randomly created. It is assumed that each node in the network has the same number of transceivers, and the new topology is built on the current topology and traffic requests. To evaluate the performance of the proposed algorithm, the following metrics are considered:

- The number of deleted lightpaths,
- The number of dropped packet,
- The average hop count,
- The link utilization
- Blocking percent

We used NSFNet topology with 14 nodes and 21 links which is shown in Fig. 5.

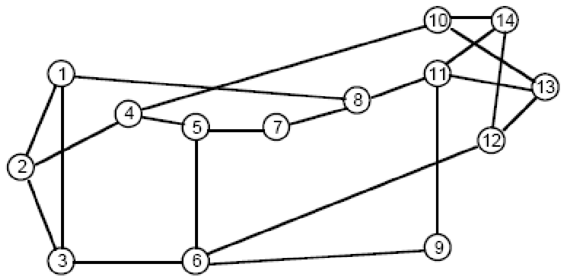

Fig. 5 The NSFNet topology which is used in simulation

In Fig. 6 the number of deleted current lightpaths is plotted versus the number of traffic requests. As can be seen in Fig. 6 in MDPF with an increase in the number of traffic flows, and a decrease in free wavelength, the number of deleted lightpaths is grown. The total number of deleted lightpath is reduced remarkably, since the PRA method uses backup paths. The main idea of using backup paths is to protect traffic flows. When the primary path, which the data transmit on it, has to tear down the traffic switches to its backup path therefore the data will be preserved. In FMRA algorithm, using the second shortest path, when wavelength allocation on the shortest path is failed, causes load balancing, so it can postpone the reconfiguration time. Moreover, by using the two metrics fuzzy algorithm, in reconfiguration process, the optimal new virtual topology will be gained with less disruption. The number of deleted ligthpath is decreased by two reasons in FMRA. First, when we can't assign wavelength to a new lightpath setup request on the shortest path, the second shortest path is selected so the traffic load reduces in the shortest path. Second, one of the main factors of fuzzy algorithm in reconfiguration process is the minimum number of deleted lightpath. Moreover average used wavelength which is used in fuzzy algorithm influences on selecting the path with less traffic and more free resources. Load balancing causes the traffic distribution in the network and the reconfiguration process delayed; subsequently the number of deleted lightpath is reduced.

The total packet drop versus total traffic requests is shown in Fig. 7. Since lightpaths are like a channel for transmitting data packets, whenever the path between two nodes tears down, due to a reconfiguration process, packet loss will occur. In MDPF the number of deleted lightpaths is great; therefore, we have an increase in the number of packet loss. PRA uses backup paths to protect the primary paths. Even if the primary path is forced to tear down, by reconfiguration, it's packets switch to the backup path, therefore, the packet loss in PRA is decreased. In FMRA because of the minimum number of deleted lightpath, we have less packet drops than the MDPF and PRA. There is a relationship between the number of deleted lightpath and drop packets so that the number of drop packets is decreased by reducing the number of deleted lightpath,

Fig. 8 denotes the average of hop counts versus total traffic requests. By selecting the second shortest path, the path can become longer and this may have a negative effect on the number of hops and delays but as seen in Fig. 8 the first and second shortest paths are almost the same. Since there is a little difference between the second and first shortest path in the number of hops, the second shortest path doesn't make a big difference and can be ignored.

Fig. 9 shows the link utilization versus total traffic requests. As PRA reserves resources for both backup path and primary path, the link resources are more used: and we can see why PRA has a better performance than MDPF and FMRA.

Blocking occurs when the requested wavelength is not available on all the links from the route. Even though we try to assign wavelength carefully and without any disruption during reconfiguration process, blocking may happen. As shown in Fig. 10, with increase in traffic flows, the number of free resources reduces, therefore the blocking percent grows. The reconfiguration algorithms can allay the excessive growth of the blocking. The blocking percent is reduced, when the reconfiguration algorithm causes less disruption in the network. That is why we have less blocking percent in FMRA rather than the two others.

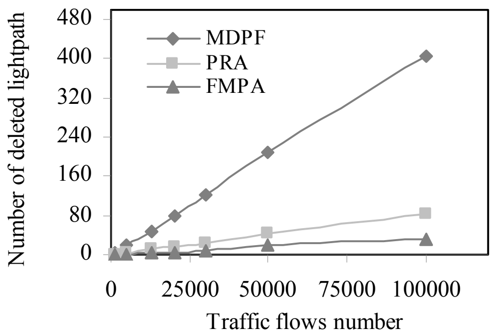

Fig. 6 The number of deleted lightpaths versus the number of traffic flows

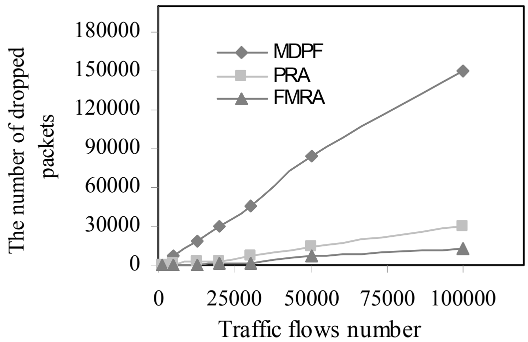

Fig. 7 The number of dropped packets versus the number of traffic flows

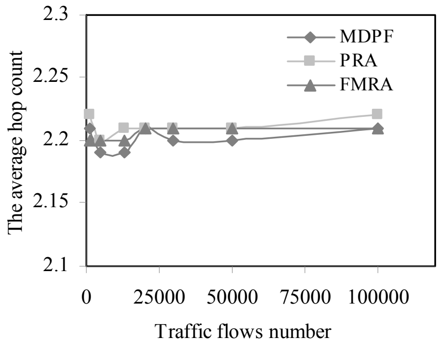

Fig. 8 The average hop count versus the number of traffic flows

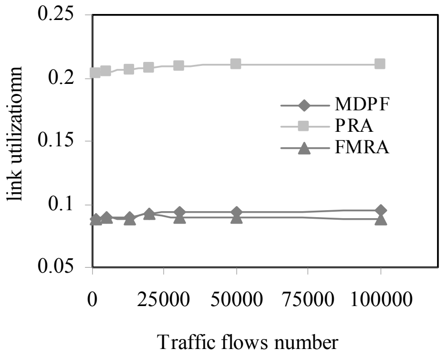

Fig. 9 The link utilization versus the number of traffic flows

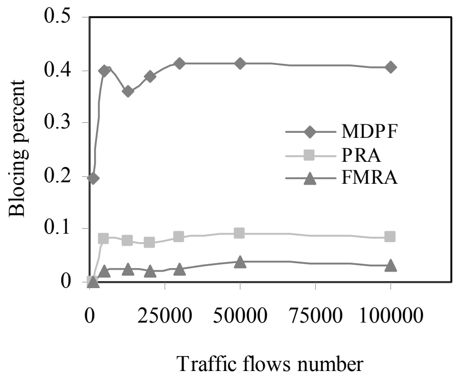

Fig. 10 The blocking percent versus the number of traffic flows

V. CONCLUSION

In this paper we focused on the design and evaluation of fuzzy algorithm for reconfiguration of virtual topology in an optical network. For large networks, simple and effective algorithms are needed to provide on-line reconfiguration of the optical layer. In this procedure we first attempt to assign wavelength to the shortest path and if for some reason, the needed resources are not available on this path, we use second shortest path. Moreover if the algorithm is unable to allocate the needed free wavelength again, the two metric fuzzy algorithm is used to select the best new virtual topology with minimum disruption. FMRA defines wavelength with minimum number of deleted lightpath and the path with maximum average of free wavelength for new request. Experimental results showed that the deleted lightpaths and packet loss of our algorithm is less than others.

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