Distributed Traffic Adaptive Wavelength Routing in IP-Over-WDM networks

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Abstract

In Wavelength Routed Wavelength Division Multiplexing (WR-WDM) networks, a set of lightpaths (all-optical communication paths) defines the virtual topology. Internet Protocol (IP) makes use of virtual topology to route its traffic in the optical form. The virtual topology is designed with an aim of minimizing certain objective function value. In the event of changes in traffic demand at the IP layer, the objective function value of the network (virtual topology) may be affected leading to decreased network performance. Thus, the underlying virtual topology needs to be changed in response to the changing traffic patterns in the IP layer. This process of changing the virtual topology to meet the traffic requirement is called as reconfiguration. As distributed networks like IP over WDM networks demand a fully distributed process for reconfiguration, we view the reconfiguration as an on-line distributed process that provides a trade-off between the objective function value and the number of changes commited to the virtual topology. The objective function value decides how best the topology is suited for the given traffic demand. The number of changes decides the extent of traffic disruption in the network while making a transition to the new virtual topology. The performance of the proposed methodology is studied through extensive simulation experiments in terms of objective function value of reconfigured topology and the number of changes performed to get the reconfigured topology.
Keywords: IP-Over-WDM Networks, Distributed protocol, Virtual Topology Reconfiguration.

1.Introduction

With the Internet Protocol (IP) playing a dominant role in wide area networking technology and advancements in wavelength-routed wavelength division multiplexing (WDM) technology to provide huge bandwidth, the IP-over-WDM technology becomes the right choice for next generation Internet networks [1]. In these networks, messages are carried from one node to another node using *lightpaths*. A *lightpath* is an all-optical path established between two nodes in the network by the allocation of same wavelength on all links of the path. In IP-over-WDM networks, lightpaths are established between IP routers. The problem of establishing lightpaths statically (*a priori*) is referred to as static lightpath establishment (SLE) problem. IP-over-WDM networks make use of these lightpaths to transfer data. This set of pre-established lightpaths is called as *virtual topology.* Virtual topology is a graph with nodes as the routers in physical network (IP-over-WDM network) and edges corresponding to the lightpaths between them. A node pair may not have a lightpath due to non-availability of wavelengths between them or transmitters at the source or receivers at the destination. Traffic between a node pair *sans* a lightpath, is routed using multiple lightpaths (logical hops). A virtual topology (which is a graph) is said to be *connected*, if every node in the virtual topology can communicate either using single lightpath (single hop) or using multiple lightpaths (multihop) to every other node. A virtual topology may be designed with an objective of minimizing certain metric (objective function) such as maximum congestion on a lightpath [3], average packet delay [4], or average weighted hop count [5].

The set of lightpaths (virtual topology) designed as above may need to be changed in various situations. This process is referred to as *reconfiguration*. The first situation which calls for reconfiguration is when the network components such as links and nodes fail. The lightpaths which are affected by such a failure need to be restored[7]. The second situation arises when the traffic demand changes at higher layer. Due to the change in traffic, the objective function value of the network may not be at the optimal point. Hence, a set of lightpaths needs to be changed to reflect the new traffic. In IP-over-WDM networks, the traffic on a lightpath connecting two routers can be monitored continuously and appropriate changes can be made to the virtual topology. In this paper, we consider the reconfiguration problem that arises due to the changing traffic demand. The number of lightpaths added or removed during the reconfiguration process defines the total number of changes to the existing virtual topology. Changing the current virtual topology will incur control overhead and traffic disruption. It may also require rerouting the existing traffic. Since the traffic on the lightpaths is of the order of gigabits per second, the disruption in traffic needs to be minimized. The traffic disruption may be more when more lightpaths are changed. Hence, the number of changes needs to be minimized.

The reconfiguration can be performed in a centralized or a distributed manner. In the centralized process, a single node maintains the information of all lightpaths that are existing in the network. In the event of changes in traffic, this node collects the traffic information from the various nodes. It then finds out the set of new lightpaths to be established and the set of lightpaths that are to be deleted. Since the total information about the traffic topology and the resources available at each node are known to the central node, the reconfigured topology may be very close to the optimal point. However, with a distributed process this may not be achievable since every node takes care of the reconfiguration process on its own and the total information about the network is not known to the individual nodes. Hence a distributedly reconfigured topology may not be as close to the optimal point as the one that is obtained through centralized reconfiguration.

The rest of the paper is organized as follows. Section 2 illustrates the need for reconfiguration. Section 3 explains our distributed reconfiguration methodology. Section 4 discusses performance study of our method. Section 5 concludes the paper.

2.Virtual Topology Reconfiguration

In this paper, we consider the reconfiguration problem that arises due to the changing traffic demand at the IP layer. There are different approaches to handle the changing traffic. In the first approach, the virtual topology once designed for a particular traffic, is used for any other traffic demands. Here, lightpaths are permanent at the WDM layer and will not be changed with change in the traffic. In the second approach, whenever the traffic demand changes at the IP layer, a new virtual topology is designed at the WDM layer ignoring the current virtual topology. The virtual topology thus designed, yields the best performance in terms of objective function. However, the number of lightpaths that need to be changed to make a transition from the current virtual topology to the new virtual topology could be very high. We refer this method as centralized new-design method. In the third approach, the virtual topology is reconfigured at the WDM layer with the objective of minimizing an objective function value and the number of lightpaths that need to be changed.

The problem of designing virtual topology for a given static traffic demand is computationally intractable[2]. In reconfiguration problem, apart from minimizing the objective function, it is required to minimize the number of changes. Hence, the problem of reconfiguration is also computationally intractable. Therefore, efficient heuristic solutions that can yield reasonably good performance are preferred. In [5, 8, 9, 10,11], different algorithms for reconfiguration due to traffic changes were proposed. These are centralized algorithms that involve huge control traffic to and from the central node. Although centralized algorithms are well-suited for country wide networks, they do not scale well for world wide networks like the Internet. Distributed networks like IP over WDM network demand a fully distributed process for reconfiguration. Also, the central node in these algorithms is a single point of failure. In [12], the authors have proposed a distributed protocol for restoring the connectivity of the virtual topology after a link failure. The protocol tries to reconfigure the virtual topology inorder to restore the failed connectivity. However, there is no provision in this protocol for bringing down the objective function value in the event of traffic changes. The major thrust behind the current work is to provide a distributed reactive solution to the problem of virtual topology reconfiguration in the event of traffic changes.

3.Distributed Reconfiguration methodology

The various control messages used by our protocol are sent through the control channel. The control channel is established by duplicating the physical topology on the virtual topology using the wavelength W_0. Every node is assumed to know the following details: All lightpaths emerging from it, all lightpaths incident on it, load on each lightpath associated with that node and route of each lightpath. A lightpath is considered for deletion only when its deletion does not affect the connectivity of the network. Such lightpaths are referred to as *non-critical lightpaths*. The lightpaths whose deletion disconnects the virtual topology are referred to as *critical lightpaths*. Criticality of a lightpath is verified by flooding a control packet on the virtual topology. If the source of the lightpath receives an acknowledgement from the other end node of the lightpath, then it concludes that the lightpath is non-critical. We use average weighted hop count Havg [5] as the objective function which is defined as the average number of hops on the virtual topology traversed by an unit traffic.

Every node is assumed to know the traffic from that node to various other destinations, and watermark levels (W_{cong}, $W_h$and W_l) for every destination. A lightpath is said to be overloaded or congested if it carries load greater than W_{Cong}. It is said to be underloaded it the load carried by it is less than W_l. In addition to this every node keeps a set of candidate routes for each destination. At regular intervals of time, every node runs the reconfiguration procedure to add or delete lightpaths associated with it. If a node finds that the traffic to a particular destination is greater than the watermark level W_h or if a lightpath to a destination is congested (carrying load greater than W_{cong}), it tries to establish a new lightpath to that destination node. If there exists a lightpath to that destination, the new lighptath shares the traffic of the previously existing lightpath. This avoids any lightpath getting overloaded. In turn it improves the objective function value and thereby the network performance. If there exists no lightpath to that destination previously then the traffic to the destination is carried by the newly established lightpath.

To establish a lightpath, every node makes use of the following protocol which is similar to the backward reservation protocol for dynamically establishing a lightpath. The protocol reserves free wavelengths as in backward reservation protocol. But in addition to that, it deletes some underloaded (<WL) lightpaths whose resources are necessary to the establishment of the new lightpath. Since the lightpaths with low load are selected for deletion, it may not affect the objective function value significantly. The resources released after the deletion of a lightpath are used for establishing a new lightpath which will carry higher traffic. Hence the overall objective function value of the network may be minimized. An underloaded lightpath is deleted only when it is a non-critical one.

In this protocol, all wavelengths (free wavelengths and wavelengths that can be made available by deleting underloaded lightpaths) for establishing the new lightpath are collected during forward transversal of the control message along the candidate route. This set of wavelengths is referred to as *candidate wavelengths.* Inorder to establish a new lightpath, the source verifies if it has a free transmitter or if it can get a transmitter by deleting some underloaded lightpath. It sends a control message across the candidate route to collect all candidate wavelengths for establishing the new lightpath. The candidate wavelengths are collected but not reserved during the forward traversal. Once this message reaches the destination, the destination node knows the set of candidate wavelengths, it verifies if it has a free receiver or a receiver can be made free by deleting some underloaded lightpath. It prepares another control message containing a subset of candidate wavelengths. This message traverses backward from the destination to the source node reserving potential wavelengths that are selected on the links. When it reaches the source node, one wavelength is selected and the other wavelengths are released. The source sends an *estab_lp* message to establish the lightpath. Since our protocol tries to establish new lightpaths only for those source-destination pairs with high traffic, the number of changes made to the virtual topology is considerably less and hence it does not cause much traffic disruption in the network during the reconfiguration process.

4.Discussion of the results

In this section, the performance of the proposed methodology is studied. Extensive simulation experiments are conducted on NSFNET T1 backbone network. To design a virtual topology, wavelength continuity constraint is enforced, and it is assumed that only one lightpath may exist between a node pair, and the lightpath is chosen on the shortest path between source-destination pairs. We use the model given in [5] to simulate the time variation of traffic values of traffic matrix. Traffic is measured between all pairs of nodes and is given as an N x N matrix, say Traffic, where $Traffic_{i,j}$ represents the average traffic from node i to node j. It is to be noted that $Traffic_{i,j}$ may not be the same as $Traffic_{j,i.}$ The objective of the reconfiguration process is to improve the objective function value with minimum number of changes N_{ch} and minimum message overhead.

The parameters with respect to which these metrics can be studied are the number of transceivers T, the number of wavelengths W and the percentage of traffic change P. In our experiments, we observed the values for performance metrics such as Average weighted hop count $H_{avg,}$ Number of messages sent and $N_{ch,}$ number of changes made to the virtual topology.

Fig 1. Effect of No. of Resources on No. of Messages sent when P=40

These observations are made while fixing one of the parameters. It is observed that the increase in number of resources causes increase in the number of messages that are to sent. It is evident from figure 1. It is because of the existence of more number of lightpaths in a topology designed with more resources. Here, the number of Transceivers T is taken to be equal to the number of wavelengths W. The percentage of traffic change P is taken as 40.

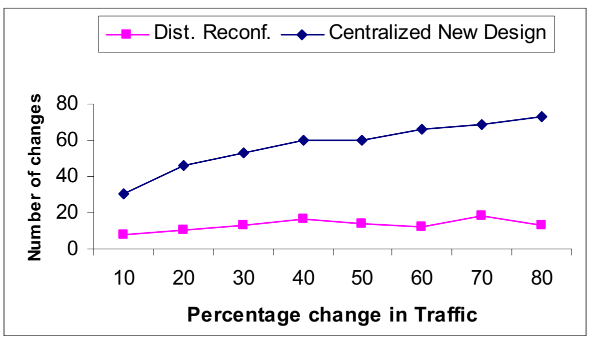

Fig 2. Effect of Percentage of Traffic change on No. of changes when T=W=7

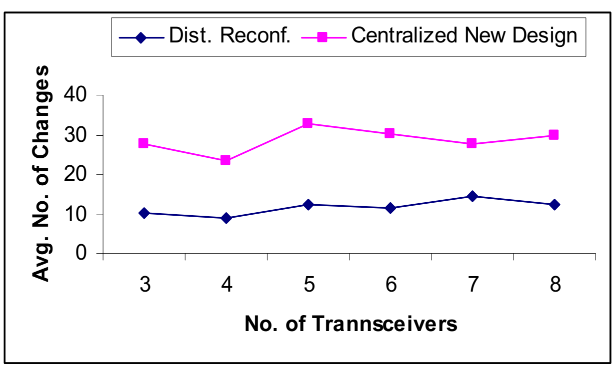

Fig 3. Effect of No. of Transceivers on No. of changes when W= 4 and P=40

Figure 2 shows the effect of the percentage of traffic change on the number of changes that are to be made. Here the number of transceivers T and wavelenghts W are taken to be 7. It is evident from the figure that the number of changes for distributed reconfiguration is very less compared to that of the centralized new design method. Figure 3 shows the effect of the number of transceivers on the average number of changes to be made. Here the number of wavelengths W is taken as 4 and the percentage traffic change P is assumed as 40. Here again the number of changes is less for the distributed reconfiguration method. Figure 4 shows the effect of the number of transceivers on average weighted hopcount Havg. The number of wavelengths W is assumed as 4 and percentage of traffic change P is taken as 40. Figure 5 shows the effect of number of wavelengths on the average weighted hopcout Havg. Here also the percentage of traffic change P is taken as 40 and the number of transceivers as 4. From figure 4 and figure 5, it is evident that the value of average weighted hopcount Havg after the reconfiguration process is almost equal to that of a newly designed virtual topology.

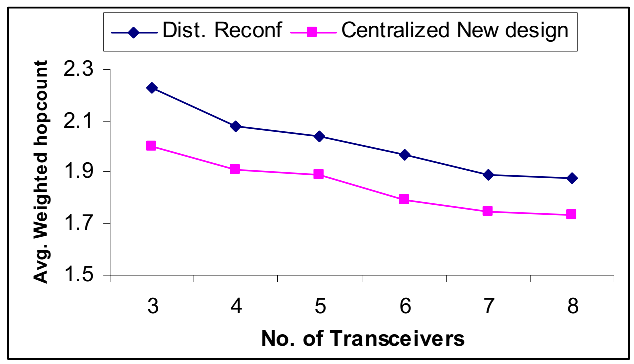

Fig 4. Effect of No. of Transceivers onAverage weighted hopcount Havg when W= 4 and P=40

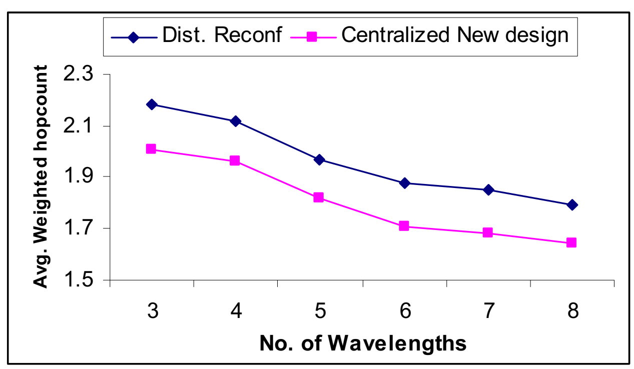

Fig 5. Effect of No. of Wavelengths onAverage weighted hopcount Havg when T= 4 and P=40

5.Conclusions

In IP-over-WDM networks, the IP traffic may make use of a set of lightpaths that are already established (virtual topology). In the event of traffic changes at the IP layer, the virtual topology needs to be reconfigured. This is because, the change in traffic increases the objective function value of the virtual topology leading to decreased network performance. In this paper, we made an attempt to device distributed protocols for improving the performance of the network in the event of traffic changes. Our reconfiguration protocol tries to bring down the objective function value with minimum number of changes to the existing virtual topology. Extensive siimulation experiments are performed on NSFNET to support our results empirically. In our work, we assumed wavelength continuity constraint for a lightpath. However, the constraint can be relaxed if the nodes have wavelength conversion capability. In future, we intend to devise distributed protocols for virtual topology reconfiguration in networks having sparse wavelength conversion capability wherein only a few nodes in the network are equiped with wavelength convertors.

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