Optical WDM Network Reconfiguration Due To Traffic Changes

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Abstract - **This paper studies the virtual topology reconfiguration problem due to traffic changes in optical WDM networks. The reconfiguration problem has twin goals of minimizing the total number of lightpaths changes and optimize an objective function value. An efficient heuristic algorithm for resolving this problem is considered here and applied on a concrete optical WDM network model.** [2]

Keywords – **Reconfiguration, Optical WDM network, Virtual topology, Traffic demands, Traffic changes.**

1. INTRODUCTION

Due to rapid advances in optical technology and components during the last few years WDM optical networks employing wavelength routing are becoming feasible, nowadays. Wavelength Routing Optical Networks, WRON, are composed of one or more wavelength selective elements and fibers connecting them in an arbitrary topology. These wavelength selective elements are totally made up of glass material (i.e. no electro-optical conversions) and they are called wavelength routers. An example of wavelength routing WDM network with four routing nodes is shown in Figure 1.

In this networks routing process is performed on the basis of the optical signal wavelength. A connection from source node to the destination node is established entirely in the optical domain. This connection is also called a *lightpath.* A lightpath is an *all-optical communication path* between two end nodes, established by allocating the same wavelength throughout the route of the transmitted data. The end nodes of the lightpath access the lightpath using optical transmitters/receivers that are tuned to the wavelength on which the lightpath operates.

The set of all established optical lightpaths between the source-destination nodes form the *virtual topology* of the network. The virtual topology design problem is an important and challenging one. It requires such solutions to efficiently utilize network resources (wavelengths, optical transmitters/ receivers) so as to optimize some network performance [1,5].

The virtual topology is usually designed based on the estimated average traffic flow between the node pairs in specific time period. However, the traffic demands between node pairs are not constant with time, but are dynamically changing. Therefore, the virtual topology which is formed for some traffic pattern may not be the optimal one for all the different patterns of traffic flow. Reconfiguring the virtual topology to be in tune with dynamically changing traffic demands would help to maximize network performances [3]. Virtual topology reconfiguration requires that a few lightpaths in the existing topology be removed and some new lightpaths be established to form a new virtual topology. The virtual topology reconfiguration problem due to traffic changes in optical WDM networks is considered in this paper. One heuristic algorithm for resolving this problem is applied and tested on the telecommunication network model with six routing nodes.

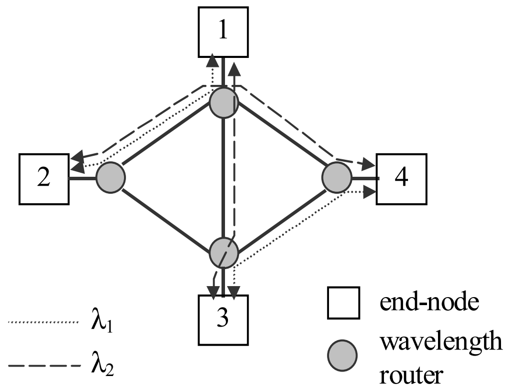

Figure 1. WRON - Wavelength Routed Optical Network

II. VIRTUAL TOPOLOGY RECONFIGURATION

The virtual topology in a transport network consists of a set of lightpaths established between a subset of node pairs in the network. In a virtual topology, a node corresponds to a routing node in a physical topology and an edge between two nodes corresponds to established lightpath through the physical network. The lightpaths can be chosen based on the traffic demands between node pairs.

The virtual topology is designed to optimize an objective function with the traffic demands as input. When traffic demands are changed, the objective function is no longer at an optimal value with respect to the new traffic. Therefore, to keep the network operating in an optimal manner, the underlying virtual topology needs to be reconfigured.

A reconfiguration requirement is also need in a situation when network components, such as physical links or routing

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nodes are failed. A reconfiguration from the current to the new virtual topology is an important and complex problem that has to be performed in situations of traffic changes in a network.

There are a number of issues concerning the virtual topology reconfiguration. Migrating one topology to another topology produce service disruption, which is undesirable. The total number of lightpath changes corresponds to the extent of traffic disruption in the network, while making a transition to the new virtual topology. At the same time, the performance metric needs to be optimized for the new topology. The objective function value decides how best the topology is suited for the given traffic demands. Some of the possible objective functions for the virtual topology design or reconfiguration problem include: minimizing average weighted number of hops, minimizing network congestion, maximizing single-hop traffic, minimizing message delay and others.

Any solution proposed for the reconfiguration problem should optimize chosen objective function value with a minimum number of changes. There are two different approaches concerned to this problem. In the first approach, the reconfiguration problem is formulated as a mixed-integer linear programming (MILP) problem and then it is solved. Linear programming techniques constitute one of the methods which give exact solution to the reconfiguration problem. Here, all possible virtual topologies are computed with optimal objective function values with respect to the new traffic. From this set, one virtual topology is chosen in a such a way that it can be obtained from the old virtual topology with a minimum number of changes. This approach yields the optimum solution but could be computationally demanding. Hence, some heuristic methods could be preferred. Efficient heuristic (approximate) solutions that can give reasonably good performance are the second approach to the virtual topology reconfiguration problem. In this paper, one such heuristic method proposed in [1] is applied for the given optical WDM network model.

III. PROBLEM FORMULATION

In this section, the virtual topology reconfiguration problem is stated formally. The physical network topology is modeled by undirected graph G=(N,L), where N represents the sets of network routing nodes and L stands for the sets of optical fiber links in the network.

The virtual topology can be seen as a directed graph G^*=(N,E), where the subset N is the same as in a graph G, while subset E represent the directed edges between a pair of nodes, which is present if a lightpath has been established between these two nodes. An edge represents the path through the network on which resources, such as transmitter, receiver and wavelength need to be reserved to set up the lightpath. In a WDM network, lightpaths are established between node pairs based on the traffic between them. Hence, the virtual topology graph depends on the traffic matrix. The extent of correspondence between the traffic and the virtual topology obtained is given in terms of certain objective function.

For the given physical optical network topology and the traffic matrix as the inputs, our objective is to obtain such virtual topology so as to minimize objective function given as the *average weighted hop counts*. In a virtual topology that is designed for a particular traffic, node pairs with higher traffic demands may be far apart (in terms of number of hops in virtual topology) when the traffic demands between some node pairs are changed. This would increase routed traffic and so the load on links in the virtual topology may increase. Intuitively, it can be seen that if lightpaths are established between node pairs with high traffic between them, then the average weighted hop count can be reduced.

If by ρ_{total} is denoted the total amount of the offered traffic between all the node pairs in the physical network, then the average weighted number of (virtual) hops, denoted by h_{ave} , is computed as:

$$h_{ave} = \frac{1}{\rho_{total}} \times \sum_{s,d} h_{s,d} \times \rho_{s,d} \qquad (1)$$

where $\rho_{s,d}$ is the offered traffic between an source-destination node pair in physical network and $h_{s,d}$ is the number of hops from node s to node d in the virtual topology. The objective function *F* then is given as

$$F \rightarrow min\ h_{ave} \qquad (2)$$

Reconfiguration problem can now be expressed in terms of this model as follows. For the given network physical topology, available network resources and correspondent virtual topology VT_1 and the new traffic matrix (after traffic changes), the aim is to obtain the new virtual topology VT_2, which fits closest with the new traffic demands and with minimum traffic disruption. These two conflicting objectives can be quantified by the following:

- h_{avg} (for the new traffic) is to be minimized.
- N_{ch} (number of lightpaths added + number of lightpaths deleted) is to be minimized.

IV. HEURISTIC ALGORITHM

The following heuristic, proposed in [1], uses the idea described in section III to find the lightpaths to be established in order to decrease the objective function value. A list of possible topologies with the number of changes within given bounds and the average weighted hop count less than that in the original topology is maintained. Among these, the best candidate is selected as the one with the least average weighted hop count. Algorithm is performed through the next steps:

1. For each source-destination pair (s,d) compute the weighted hop count $whc_{s,d}=\rho_{sad}\times h_{s,d}$, where ρ_{sad} is the (s,d) entry in the new traffic matrix and $h_{s,d}$ is the number of hops from s to d in the virtual topology. Sort $whc_{s,d}$ in decreasing order. Consider the first K pairs.
2. For each (s,d) pair, repeat steps 3 through 8.
3. Find a physical path on the network on which the lightpath for the above (s,d) pair is to be established.
4. To establish a lightpath, at the source a transmitter need to be free and at the destination node one receiver need to be

free. On each link on the path, the same wavelength needs to be free.

5. Find the different combinations of lightpaths to be deleted. Choose L sets of lightpaths to be deleted by which the transceivers and wavelengths are freed. For every set of lightpaths to be deleted, repeat steps 6 through 8.
6. Free the resources by deleting the lightpaths. Establish a lightpath from s to d. If the resultant topology is not connected, then consider subsequent (s,d) pairs in the sorted order and establish lightpaths until topology is connected. For establishment of these lightpaths, no further resources are released.
7. Find average weighted hop counts for the topology so obtained. If it is less than that for the original topology and the number of changes from the original topology falls within the given bounds, then add this to the list of possible.
8. If all L sets of lightpaths are checked as in the steps 6 and 7, then go to step 9. Otherwise, consider the next set of lightpaths and go to step 6.
9. Of all the topologies obtained in the above procedure, consider the one with the minimum h_{avg}. If it is less then the h_{avg} for the current topology, then the current topology is updated to the topology so found. If none of the topologies is found to be fit, then select the next K (s,d) pairs and go to step 2.
10. Continue with step 1 until all (s,d) pairs have been considered and discarded.

V. NETWORK MODEL

The observed all-optical WDM network model with six wavelength routing nodes interconnected by bi-directional fiber links is shown in Fig.2.

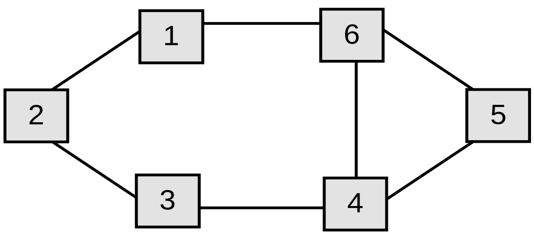

Figure 2 Optical WDM network model with 6 nodes

For this network model, it is assumed that all routing nodes are equipped with two optical transmitters and two receivers. Except of all is the routing node 1 which have 4 transmitters and 4 receivers. Each physical link contain one optical fiber in each direction between two nodes. Two wavelengths are available on each fiber.

A . Traffic demands

For the network physical topology, shown in Fig.2 it is assumed that the traffic demands between node pairs are as shown in Table 1.

Table 1. Traffic matrix

s \ d	1	2	3	4	5	6
1	0	10	11	20	8	12
2	15	0	8	7	4	5
3	16	6	0	8	3	4
4	18	8	9	0	6	6
5	12	6	4	14	0	8
6	17	3	2	7	6	0

B. Virtual topology

For the given physical network topology (Fig.2) and traffic demands given in Table 1, Heuristic Logical Topology design Algorithm (HLDA), described in [2] is used to create the virtual topology. When the HLDA algorithm is performed, obtained virtual topology VT_1 is shown in Fig.3.

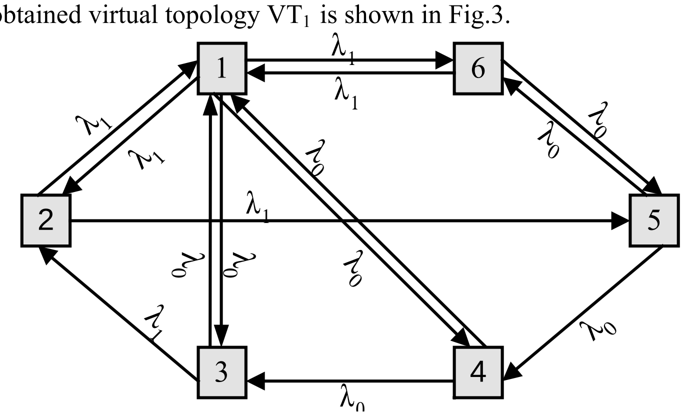

Figure 3 Virtual topology VT_1 for given traffic

The established lightpaths through the network are given in Figure 3. For this virtual topology the average weighted hop count is computed to be h_{ave}=1,564.

VI. RECONFIGURED VIRTUAL TOPOLOGY

If the traffic, given in Table 1 is changed with time the reconfigured virtual topology is obtained by using the heuristic algorithm, described in section IV. Let a new traffic demand matrix is given by Table 2.

Table 2. Changed traffic matrix

s \ d	1	2	3	4	5	6
1	0	3	14	20	8	12
2	15	0	12	14	4	10
3	8	14	0	2	3	4
4	18	8	9	0	10	6
5	12	6	4	7	0	8
6	3	17	18	7	2	0

Now, if a new virtual topology is constructed for changed traffic demands without taking the current virtual topology into consideration, new virtual topology shown in Figure 4 is obtained. The average weighted hop count for this topology is 1,690. As can be seen by comparing the lightpaths set up to make a transition from the old virtual topology to this topology, 8 lightpaths have to be deleted and 4 new ones have to be set up. The total number of changes is therefore 12.

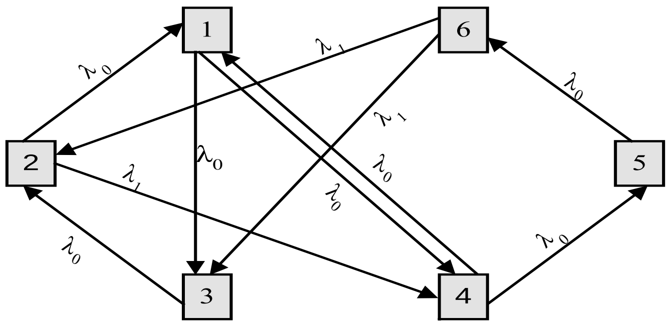

Figure 4. Virtual topology VT_1' for changed traffic

The solution may admit less number of changes if a higher objective function value is admissible. Taking this consideration, now the reconfiguration process is performed with the new traffic demands and the old virtual topology, as inputs to obtain the new virtual topology which has less average virtual hop count than virtual topology VT_1 and less number of changes than virtual topology VT_1'.

For the new traffic matrix, given in Table 2, the weighted hop count for all node pairs is calculated with respect to the current virtual topology VT_1.

The highest weighted hop count is for the node pair (6,3), the shortest path between which is 6→4→1. A new lightpath for wavelength λ_1 is tried, since this wavelength is available on both links on the shortest path from node 6 to node 1. There is no transmitter free at node 6. So in the first combination, path 6→5 is deleted to free one transmitter. To free one receiver at node 3, the lightpath from node 4 to 3 is deleted. The obtained virtual topology can become connected by adding new lightpath 4→5 through the link between nodes 4 and 5 on wavelength λ_0. The resulting virtual topology is now connected and has an average weighted hop count of 1,489. Since this is less than the value for the current topology, this virtual topology is taken as a possible solution This virtual topology is shown in Figure 5. As can be seen the number of lightpath changes is only 3, compared with the old virtual topology. So the traffic disruption is reduced by this topology. Also, other combinations for deleted lightpaths have to be considered, but no one give better results. The procedure is continued to the next iteration.

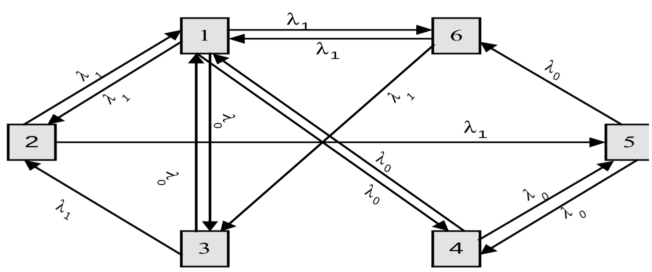

Figure 5. Virtual topology at first iteration

The next node pair in the sorted list of weighted hop count is (6,2). By deleting the lightpaths 6→1 and 1→2, both on wavelength λ_1, one transmitter, the wavelength λ_1 and one receiver become free on the shortest path 6→1→2 between nodes 6 and 2. So the lightpath between this node pair can be established. The resulting virtual topology in this iteration has the average weighted hop count of 1,568 which is more than the value for the current virtual topology. So this solution is discarded.

This process is continued, but no one of the obtained virtual topology in the next few iteration can give the better solution than in the first iteration. So the virtual topology shown in Fig.3 is taken as the final solution obtained by this heuristic algorithm. This topology has the minimum weighted hop count and also the number of changes is less, compared with the virtual topology VT_1'.

VII. CONCLUSION

Optical networking has remained as the most important transmission medium and enabled the explosive growth of communications networking for many years. The optical transmission properties (large bandwidth, low error rate, low attenuation), and transport networking functions supplied by SONET/SDH delivered major improvements in capacity, reliability, and efficiency. Introduction of WDM has also played an important role in satisfying the growing bandwidth demand in last years.

One of the important problems that have to be resolved in optical WDM routing networks is the virtual topology designing in situations of traffic changes. There are different approaches to handle traffic changes in optical WDM network. In the first approach, the virtual topology, once designed for a particular traffic is used for any other traffic demands. Here, established lightpaths are permanent and don change with changes in traffic. Thus the network may not be operating at optimal point. In the second approach, whenever the traffic demands changes, a new virtual topology is designed, without consider the current virtual topology. This can bring the best objective function, but the number of lightpath changes may be very high. In the third approach, the new traffic demand and the old virtual topology are taken as inputs to obtain a new topology with the aim of minimizing the objective function value and the numbers of lightpaths that need to be changed. This approach is considered in the paper.

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