Literature Review of Virtual Topology Reconfiguration Problem with Traffic Grooming for IP-over-WDM Networks

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ABSTRACT

The demand for bandwidth is growing at a rapid pace, and the Internet data traffic is expected to dominate voice traffic in the near future. With the Internet Protocol (IP) playing a dominant role in wide area networking technology and advancements in wavelength division multiplexing (WDM) technology to provide enormous bandwidth over and above the range of Tera bits per second, the IP-over-WDM networks become the right choice for the next generation Internet networks. Recently Virtual Topology Reconfiguration of IP over WDM networks has received greater attention among researchers. This paper researches the various approaches available in the literature for Virtual Topology Reconfiguration problem with Traffic Grooming for IP-over-WDM networks.

Keywords - **Logical Topology, Traffic Grooming, Virtual Topology Reconfiguration**

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1. INTRODUCTION

In the last decade, WDM techniques and Optical fiber technologies together brought a revolution in high-speed communication networks, which are now able to meet the high bandwidth demands of current voice and data traffic. All optical WDM networks using wavelength routing are considered to be potential candidates for the next generation of wide area backbone networks. In these types of networks, routing and switching are carried out in the optical domain instead of electronic domain.

1.1 IP-over-WDM Networks

The demand for bandwidth is growing at a rapid pace, and the Internet data traffic is expected to dominate voice traffic in the near future. With the Internet Protocol playing a dominant role in wide area networking technology and advancements in wavelength routed WDM technology to provide enormous bandwidth, the IP over WDM networks [1] become the right choice for the next generation Internet networks. The IP over WDM network consists of a set of WDM links and hybrid nodes, each of which consists of electronic IP router part and Optical Cross Connect (OXC) part.

The physical topology [2] consists of optical WDM routers interconnected by point-to-point fiber links in an arbitrary topology. In these types of networks, data transfer carried from one node to another node using lightpaths. A lightpaths 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. This set of pre-established lightpaths is called as Virtual Topology. Virtual Topology [3] is a graph with nodes as routers in the physical network topology and edges corresponding to the lightpaths between them. A virtual topology [4] is a set of lightpaths established to provide all optical connectivity between nodes for a given traffic demand.

1.2 Need for Reconfiguration

The virtual topology designed may need to be changed in response to changing traffic demands or due to failure of network elements This process of changing the current virtual topology to a new one to adapt the dynamic change of traffic or failure of network elements is called Virtual Topology Reconfiguration (VTR) [4]. Reconfiguration is one of the significant characteristics of WDM optical network. As the VTR problem is computationally intractable, heuristic solutions are desired to yield near optimal solution [5].

1.3. Dynamic Reconfiguration

The dynamic reconfiguration of optical networks has been one of the hot topics among the communication research community. There are two different approaches of virtual topology reconfiguration to handle the dynamic traffic. In the first method, a new virtual topology is designed for each change in traffic, giving best performance but number of lightpath changes could be high. In the second method, reconfiguration is done with the objective of minimizing the objective function value and the number of lightpath changes.

The dynamic reconfiguration [11] of virtual topology requires a lot of control overhead and results in network disruption. In the present day WDM networks, a typical reconfiguration process in the order of tens of milliseconds corresponds to tens of megabits of traffic that must be buffered or rerouted at each node that is being reconfigured. If this disruption is not taken care properly, it will result in severe congestion and heavy data loss in the network as the traffic on the lightpaths is order of gigabits per second. This paper researches the various approaches for reconfiguration of virtual topology used for IP-over-WDM networks under dynamic traffic.

This paper is organized as follows. An introduction to IP-over-WDM networks and need for reconfiguration is given in section 1. The VTR problem is described in section 2. Section 3 describes different models for the reconfiguration of virtual topology for IP-over-WDM networks. A survey of various approaches available for VTR for IP/WDM networks is made in section.4. Section 5 describes about various reconfiguration metrics and 6 studies various heuristics for VTR for IP/WDM networks. The challenging research problems for future work are enumerated in section 7. Finally, section 8 concludes the paper.

2. RELATED WORK

There are many researches done earlier in virtual topology design and virtual topology reconfiguration problem with an integral problem of RWA. The basic concepts of WDM optical networks including various approaches for RWA problem are discussed elaborately in [1, 2, and 3]. A detailed study about the various concepts of Dense WDM (DWDM) technology in optical networks including the issues like network control and management is presented in [4]. The authors in [5] presented the several candidate protocols for WDM routing. In addition to the extensions needed to support RWA, the authors also considered the facility with which TE and QoS support could be added to standardize optical extension to Open Shortest Path First (OSPF) protocol.

Many researchers have extensively studied the virtual topology design problem for WDM network. The logical topology for a WDM-based network should be designed based on both the physical network topology and the traffic pattern of upper layers [6]. Linear programming methods for Virtual topology design problem with the objective of minimizing network congestion is proposed [6] [7]. The authors R. Ramaswami and K. N. Sivarajan studied about the lower bounds on congestion in RWA problem for logical topology design in WDM optical networks [6]. Wavelength continuity constraint for the virtual topology design problem has been considered [7], i.e. it is assumed that nodes are not equipped with wavelength converters. Therefore it becomes necessary that a lightpath use the same wavelength on all the physical links. The combined problem of physical topology and virtual topology design has been taken up [8] using genetic algorithm. In particular, some researchers worked earlier in the context of load balancing in RWA problem. The authors Aradhana Narula-Tam and Eytan Modiano had reviewed the previous approaches of load balancing in RWA [9]. The authors Mauro Brunato, Roberto Battiti, Elio Salvadori in [10] developed a heuristic algorithm for load balancing in IP based optical networks, called Reverse Sub-tree Neighborhood Exploration (RSNE) which does at each iteration, a basic change in routing table entry in order to minimize the network disruption. The RSNE algorithm reduces congestion compared to the shortest path algorithm at the cost of increase in path length. The authors in [11,12] proposed three practical adaptive RWA approaches based on Near-maximum Available Wavelengths (NAW), which reduced blocking probability at a smaller cost of path length with reduced time complexity. The authors in [13] reviewed the dynamic lightpaths establishment in wavelength-routed networks for dynamic RWA problem in Virtual Topology Design (VTD).

An efficient approach for RWA algorithm for congested WDM networks was presented already in [14]. A new method [15] for solving RWA problem using optimization principle is described by the authors Xiaohong Guan, Sangang Guo, Qiaozhu Zhai, Weibo Gong and Chunming Qiao. The book [16] published by the authors Rudra Dutta, Ahmed E. Kamal, George N. Rouskas depicts the comprehensive nature of Traffic grooming problem in WDM optical networks. The authors Rudra Dutta and George N.Rouskas have presented a comparative approach of Traffic grooming with reference to past and future in [17].

Generally virtual topology design problem is solved through mathematical methods where the problem is formulated as an integer linear program (ILP) or mixed integer linear program. The Linear programming for the virtual topology design problem becomes computationally intractable and can be easily shown NP-hard and therefore to find realistic solutions, heuristic approaches are made use of. In [18] the authors carried out an extensive literature survey of various heuristic algorithms for logical topology design for WDM optical networks. Linear programming and heuristic methods for different topologies are described and compared. Routing and wavelength problem and reconfiguration of virtual topology have also been dealt with.

There are many research work previously done in the reconfiguration of WDM networks. Reconfiguration of virtual topology for dynamic traffic is carried out with the aim of minimizing one or more objective functions, in order to maximize resource utilization. Some principles for the design of WDM Optical networks using reconfiguration were given in [19]. The authors presented an integer linear programming method and resource budget for Virtual topology reconfiguration problem for a mesh network with the objective of minimizing average packet delay, average hop distance and number of lightpath changes. G.N.Rouskas and M.H.Ammar [20] have proposed dynamic reconfiguration algorithm for WDM optical networks with the assumption of traffic demands are known in advance. Banerjee and Mukherjee [21] have studied the reconfiguration issues for logical topologies in large-scale WDM optical networks. They formulated the reconfiguration problem by using the mixed-integer linear programming (MILP) formulation and proposed a heuristic algorithm to obtain the new logical topology with the minimum cost. They did not mention how to reconfigure the new logical topology. The authors in [22] presented the reconfiguration procedures for torus lightwave networks.

Sreenath *et al.* [23, 24] proposed a two-stage approach to the reconfiguration problem, which follows both optimization and cost based approaches. The first stage is reconfiguration stage and the second stage is an optimization stage, which reduces the deviation from the optimal objective function value. The first step is based on the optimization approach whereas the second step follows the cost based approach. In this approach, the first step computes a limited number of lightpaths that need to be modified. The network is reconfigured to a new topology, which is not fully optimal. The second step performs fine-tuning and brings the topology to the optimal level by maximizing the single hop traffic. This research does not cover the implementation of the reconfiguration process.

Most of the approaches assumed that the traffic-demand is known in advance and based on the known traffic pattern, a new topology is designed. As a result reconfiguration is triggered due to some event rather than considering it an online process. Not many researchers have deliberated on the basic questions of when to reconfigure and how to reconfigure a network; how transition from one topology to another is realized, and how frequently reconfiguration should be performed. Moreover, the emphasis has remained on topology design and reconfiguration algorithms rather than reconfiguration triggering and topology migration mechanisms. In the first stage, the reconfiguration is limited to a few changes in order to speed up the reconfiguration process and reduce the reconfiguration cost. In the second stage, the topology optimization between consecutive traffic changes is performed in order to make the topology close to the optimal one. The reconfiguration methods described above, attempt to limit the differences between the new and the old logical topologies in order to reduce the disruption to the network. However, we still have the problem of how to realize the new logical topology, i.e., how to move the old logical topology to the new one. Some authors focused on the reconfiguration transition approaches. However, their models are limited to small networks like local area networks. Further the authors discuss about integrated services, differentiated services and multi protocol label switching (MPLS) have been discussed and the various possible service classes are also detailed. In differentiated services, packets are marked differently based on the service requirements. Constraint based routing enables determination of routes based on constraints like bandwidth or delay.

Reconfiguration heuristics for logical topologies in wide area networks [25] considered the quantity of disrupted resources as the performance measure and tried to minimize the resource disruption during the reconfiguration process. In the above heuristics the authors considered the topology transition problem from an old topology to its new one, which is determined independently of the old one. Furthermore, it is vital to reconfigure the logical topology according to the changes in traffic pattern. However, the reconfiguration is disruptive to the network under operation. Therefore, it needs to consider a tradeoff between the performance of the new logical topology and the cost of the topology reconstruction [26, 27].

Gencata and Mukherjee [28] proposed an on-line adaptive reconfiguration approach to follow the dynamic changes in traffic patterns without *a priori* knowledge. Their heuristic algorithm reacts promptly to the traffic fluctuation by adding or deleting one lightpath at a time. The problem is then solved for one or more objective functions with a set of constraints. The authors used some monitoring mechanism provides information on the current flow information. In this approach virtual topology dynamically adapts to the changing traffic. The adaptation is realized in real-time by monitoring the changes in traffic volume over each lightpath in topology. At the end of the observation period average lightpath loads are calculated. If a change in traffic intensity is observed, the virtual topology adapts to the change by simply adding or deleting one lightpath at a time. Here the authors consider a single step approach where reconfiguration is performed through changing the topology adaptively with single lightpath addition or deletion. A higher and lower watermark level is used to find when to reconfigure the network by adding or deleting the lightpaths. In this simple approach, reconfiguration algorithm acts as a network controller that regulates the network to deal with traffic changes for an optimal topology. A central manager is responsible for collecting traffic information and lightpath change.

Labourdette *et al.* [29] proposed an efficient reconfiguration method, called the branch exchange, to shift the old topology to the new one in a local area network like a star-coupler configuration. Under their approach, the reconfiguration sequence is determined clearly, and, each time, only one node pair is selected to switch their transmitters and receivers. The author also proposed traffic optimization and reconfiguration management of multi wavelength multihop broadcast lightwave Networks in [30]. Kato and Oie [22] proposed several reconfiguration algorithms that move the old logical topology to the new one for a Torus network. However, their model is based on either star or bus physical networks, i.e., there is no wavelength conflict between the new and old lightpaths. Narula-Tam and Modiano [9] and Mohan *et al.* [31] proposed a reconfiguration method specific to a ring network. Their approach attempts to minimize the disruption to the network and guarantees the connectivity of the network during the reconfiguration process.

The authors I.Baldline and G.N.Rouskas [32] attempted to solve VTR problem along with when to trigger the reconfiguration. In [33] the reconfiguration policy for transition from one topology to another was described. Bala *et al.* [34] proposed a hitless reconfiguration approach for the logical topology. They proposed to first establish all the new lightpaths without removing any old lightpaths. The old lightpaths are removed only when the traffic was rerouted through the lightpaths of the new topology. However, in order to realize their approach, additional spare resources (transmitters, receivers, and wavelengths) are needed to establish the new lightpaths without removing the old lightpaths. Recently, Reddy *et al.* [35] proposed an approach to realize the reconfiguration for a given set of failure lightpaths in large-scale networks. A new lightpath is established for each faulty lightpath with the same starting and ending points. They used the deviation of disrupted time between two faulty lightpaths as their performance measure. The adaptive self reconfiguration scheme described above are using lower and higher threshold values with the assumption of the traffic fluctuations are smooth and follow a pattern, There are, however, certain limitations [36] for selection of values for threshold parameters WH and WL. The adaptive approach might not work for sudden data flooding. In another scenario if a flow rapidly increases and then drops off periodically, the lightpaths would be added and deleted in contiguous "observation-adjustment cycles", producing a flickering effect in the network. Response of this approach under link failures or other equipment failures is questionable as due to limited modification capability per cycle, a significant amount of data can be lost, till the network is restored to acceptable performance level. The static topology reconfiguration problem in [37, 38] is solved as a congestion minimization problem for free space optical networks. In [39], the authors proposed a novel dynamic VTR algorithm, which minimizes the number of wavelength conversions, which in turn reduces wavelength conversion overhead. The traffic based reconfiguration for logical topologies in large-scale WDM optical networks are described in [40]. A heuristic algorithm for virtual topology reconfiguration with successive approximations is given in [41]. The authors Seungyeon You and Sungchun Kim proposed Virtual Topology Reconfiguration controller [42] for WDM networks.

3. VIRTUAL TOPOLOGY RECONFIGURATION PROBLEM

In this section, we define some terminology generally used in the context of virtual topology reconfiguration and then virtual topology reconfiguration problem.

3.1. Terminology

Physical Topology**:** Physical topology is a graph in which each node in the network is a vertex, and each fibre optic link between two nodes is an arc. Each fibre link is also called a ***physical link***, or sometimes just a link.

Virtual Topology**:** Virtual topology is a graph in which the set of nodes is the same as that of the physical topology graph, and each lightpath is an arc. It is also called the ***logical topology.***

Lightpath: A lightpath is a clear optical channel between two nodes. (also called ***Logical link***)

Physical Degree**:** The number of physical links that are directly connected to a node is called physical degree of the node..

Virtual Degree**:** The number of lightpaths or logical links that are originating from or destined to anode is called virtual or logical degree of the node.

Physical Hop Length**:** The number of physical links that make up a lightpath is called the physical hop length of that lightpath.

Virtual Hop Length**:** The number of lightpaths a given traffic packet has to traverse, in order to reach from source to destination node over a particular virtual topology, is called the ***virtual or logical hop*** *length* of the path from that source to that destination in that virtual topology.

Traffic Matrix**:** A matrix, which specifies the average traffic between every pair of nodes in the physical topology. If there are N nodes in the network, the traffic matrix is an NxN matrix $T = [t(sd)]$, where $t(sd)$ is the average traffic from node s to node d in some suitable units, such as arriving packets per second.

Traffic Load*:* The aggregate traffic routed over a lightpath in a virtual topology for different source-destination pairs is called the ***virtual traffic load*** of the lightpath. The sum of traffic load carried by all the lightpaths in the virtual topology is called the ***total load*** of the network.

Congestion: Congestion is defined as the maximum virtual load among all the lightpaths due to all possible source destination pairs in a virtual topology.

Weighted Hop Count: Weighted hop count is the traffic demand between a source-destination pair multiplied by hop length for the light path between the pair.

3.2. Virtual Topology Reconfiguration Problem

The virtual topology reconfiguration problem has the following sub-problems.

i. Topology Selection Sub problem**:** Determine the logical topology to be imposed on the physical topology, that is, determine the lightpaths in terms of their source and destination edge nodes.

ii. Lightpath Routing Sub problem**:** Determine the physical links, which each lightpath consists of, that, is, route the lightpaths over the physical topology.

iii. Wavelength Assignment Sub problem**:** Determine the wavelength each lightpath uses, that is, assign a wavelength to each lightpath in the logical topology so that wavelength restrictions are obeyed for each physical link.

iv. Traffic Routing Sub problem**:** Route packet traffic between source and destination edge nodes over the logical topology obtained.

3.3. Notations

The following are the notations used in the VTR problem formulation and in the algorithm.

i,j : end nodes of lightpath

sd: source-destination pair

3.4. Variables

We define the following variables used in the virtual topology reconfiguration problem.

i. Physical topology matrix P, where P_{ij} denotes the presence of fiber link between i and j.
ii. Traffic matrix T, where T_{ij} denotes the expected maximum rate of traffic flow from node i to node j, in bits per sec.
iii. Virtual Topology: The variable Vij denotes the number of lightpaths from node i to node j in the virtual topology. There may be multiple lightpath between the same sd pair.
iv. Wavelength Assignment matrix W, where Wij denotes the node to which the i^{th} node is connected on j^{th} wavelength.
v. Load matrix L, where Lij denotes the load on j^{th} wavelength channel of i^{th} node.
vi. Hop length matrix, H where Hij denotes the hop length for the lightpath between nodes i and j.
vii. P^{ij}_{mn}, denotes the number of lightpaths between nodes i *and* j being routed through the fiber links between m and n.

3.5. Parameters

Listed below are the parameters used in the virtual topology reconfiguration problem.

i. Number of nodes in the network = N
ii. Number of wavelengths per fiber = w
iii. Capacity of each wavelength channel = C bps
iv. Number of transceivers per node = R

v. Average Weighted Hop count for the Topology =*AWHT*
vi. Number of changes in the topology =N_{ch}
vii. Blocking probability =*B*
viii. Network latency =*D*

3.6. QoS Parameters

In addition to the parameters defined above, the following QoS parameters are considered in this research work.

i. *Blocking Probability*:
Blocking probability of a network at a particular instant of time is defined as the ratio of number of traffic calls blocked to the total number of traffic requests.

i. *Message Delay*:
Message delay in a network at a particular instant of time is defined as the average delay incurred for a message to travel from a source node to destination node.

ii. *Throughput*:
Throughput of a network is defined as the ratio of number of packets received at the destination node to the number of packets transmitted from the source node.

4. MODELS FOR RECONFIGURATION

For the reconfiguration of WDM networks, researchers developed different models considering various parameters and related constraints.

4.1. Linear Programming Model

Generally virtual topology reconfiguration problem for IP-over-WDM networks is modeled as a mixed integer linear programming (MILP) model. In this model, the multi-commodity flow problem is used to solve VTR, where a commodity refers to a lightpath between a source-destination pair and flow on an edge corresponds to traffic flow offered onto the edge. The inputs to the problem include the traffic matrix, the physical topology, the number of available wavelengths per fiber, and the number of available transceivers at the nodes. This model aims to optimize certain objective function under a set of constraints. The possible objective functions may be minimizing average weighted number of hops, minimizing average weighted hop count of the virtual topology (AWHT), minimizing network congestion, maximizing single-hop traffic, minimizing network delay, maximizing throughput, etc. The various constraints, that could be used in the linear programming model may be virtual degree constraints, traffic flow constraints, and wavelength constraints, hop constraint, etc. The linear-programming model finds a set of possible solution satisfying the given objective function under the given constraints and the best one will be selected which is the optimal. The most of the models available in the literature are in this category.

4.2. Cost based model

This model aims to solve the virtual topology reconfiguration problem at minimum cost, given that the current topology, traffic demand matrix and physical topology. The reconfiguration cost can be calculated using certain objective functions such as AWHT, number of changes, packet delay, etc. The reconfiguration cost plays an important role in deciding the specific need and the frequency at which the reconfiguration must be performed. The cost may be in the form of number of lightpath changes, packet loss, message delays, throughput gain and other related factors used in the reconfiguration problem. There are few researchers considered the cost based model for the reconfiguration of IP-over-WDM networks.

4.3. Traffic Engineering Based Model

This model is based on the traffic engineering criteria such as fault tolerance, network surveillance, network provisioning, Quality of reliability, QoS, etc. This model addresses the issues of end-to-end QoS in IP-over-WDM-networks in terms of differentiated optical services, grades of services, classes of services, priotorized traffic, etc. There are few models available in the literature following this traffic engineering principle.

3.4 Analytical Model

Analytical model is a mathematical one and based on several concepts and factors, which affect the performance of the optical network during the process of reconfiguration. This model mathematically analyzes the relationship between several factors involved in the reconfiguration. There are some analytical models available for the virtual topology reconfiguration for WDM optical networks.

3.5 Practical Model

The practical model considers the possible factors, which are affecting the implementation of virtual topology reconfiguration of IP-over-WDM networks. The possible factors, which could be considered in this model, are traffic parameters, type of the nodes, number of transceivers, capacity of links, channel capacity, number of changes from the initial virtual topology. This model also considers the time to reconfigure and the practical method of reconfiguration.

3.6 Network Model

Generally, the network model given below is considered for the reconfiguration of WDM networks. Consider a network of N nodes connected by bi-directional optical links forming an arbitrary physical topology. Each optical link supports w wavelengths, and each node is assumed to have R transceivers. Further it is assumed that each node is equipped with an optical cross connect (OXC) with full wavelength conversion capability, so that a lightpath can be established between any node pair if resources are available along the path. Each OXC is connected to an edge device like an IP router, which can be a source, or a destination of packet traffic and which can provide routing for multi hop traffic passing by that node. This network model considers network with an initial traffic matrix and reconfiguration decisions are based on traffic changes whenever such changes are necessary.

3.7 Traffic Models

The traffic models used for simulation of the VTR algorithm for IP over WDM network are:

i. independent and identically distributed (i.i.d.) traffic model
ii. traffic cluster model

3.7.1 i.i.d. Traffic Model

The independent and identically distributed (i.i.d) traffic model assumes uniform distribution between 0 and a maximum traffic density. It uses Erlang B traffic model with the following assumptions for calculation of blocking probability.

i. The packet arrivals are uniform and Poisson distributed at a rate of λ
ii. The packet lengths are fixed and exponentially distributed.
iii. Blocked calls are cleared

Following the above assumptions, the Erlang loss formula [12] is given by,

$$B = \frac{A^C}{C!\sum_{n=0}^{C}\frac{A^n}{n!}} \quad \text{--------- (1)}$$

which gives the blocking probability model for the IP over WDM network, where A is the traffic load and C is the channel capacity of one wavelength.
The throughput of the network is estimated by the formula given by,

$$\text{Throughput} = \frac{\text{No. of packets received}}{\text{No. of packets sent}} \quad \text{-------- (2)}$$

The latency of the network is delay incurred by the data packet from a source node to a destination node and is given by,

Latency = $D_q + D_p + D_t + D_r + D_{rc}$ -------- (3)
where,
D_q: Queuing delay =

$$\sum_{ij} \sum_{sd} T_{ij}^{sd} \frac{1}{\left(C - \sum_{sd} T_{ij}^{sd}\right)} \quad \text{--------(4)}$$

where, T_{ij}^{sd} is the traffic demand between a source destination pair using the link ij.

D_p: Propagation delay = $\sum_{ij} T_{ij}^{sd} d_{ij} p_{ij}$ -------- (5)

where, d_{ij} is the distance between physical end points i and j
p_{ij} is the physical link between end points i and j.

$$D_t\text{: Transmission delay} = \frac{\text{packet length } l}{\text{channel bit rate } r} \quad \text{--- (6)}$$

$$D_r\text{: Processing delay} = \frac{1}{\left(\Re - \left(T_{sd} + X_i\right)\right)} \quad \text{-----(7)}$$

where,
$\Re$ is the processing capability of router in Mbps
T_{sd} is the traffic demand between a sd pair
X_i is the sum of traffic routed by router i except the traffic originating at the node i., and is given by,

$$X_i = \left[\sum_j T_{ji} + \sum_j T_{ij} + \sum_j T_{sd} \beta_{ij}^{sd}\right] - Tij \quad \text{-----(8)}$$

D_{rc} is the delay due to reconfiguration

3.7.2 Traffic Cluster Model

The traffic cluster is modeled by acting one particular node as source for a group of destination nodes or the particular node acting as destination for a group of source nodes. The particular node acting as source or destination for the group of nodes is called cluster head which depends upon the traffic pattern. Assuming the Poisson distribution for the uniform nature of the traffic and other assumption as made in the previous section, the QoS parameters will have the expressions as given earlier.
In this model, the cluster size varies based on the number of nodes actively participate within the group of nodes. The example traffic matrix [5x5] generated using the traffic cluster model is given below.

$$T = \begin{array}{|ccccc|} 0 & 1 & 2 & 3 & 40 \\ 1 & 0 & 2 & 3 & 40 \\ 20 & 10 & 0 & 30 & 40 \\ 3 & 4 & 1 & 0 & 20 \\ 4 & 1 & 2 & 3 & 00 \end{array}$$

From the above traffic matrix for the traffic cluster with 5 nodes cluster, observe that node 3 is the source node for the group of nodes 1, 2, 4 and 5. Further, with another cluster having the node 4 as the destination for the group of nodes 1, 2, 3 and 5. Note that the traffic between source destination pairs other than these two clusters is negligible.

4. METHODS OF RECONFIGURATION

Reconfiguration is one of the significant characteristics of IP-over-WDM optical network, which allows a network to adapt to real time traffic changes or due to the failure of optical links or nodes. This characteristic is due the fact that the IP logical connections can be embedded over the WDM physical layer using the optical cross connects (OXC), optical transceivers and wavelength converters. Generally the virtual topology reconfiguration problem can be solved by the following approaches.

i. ***Direct approach***: In this approach, whenever the traffic changes or network element fails, the virtual topology is completely redesigned from the scratch. The input for this approach will be physical topology and new traffic matrix. This approach has the inherent drawback of maximum disruption to the network due to the reconfiguration but the solution is optimal one. But this approach does not achieve a good tradeoff between optimality and cost.
ii. ***Optimization approach***: In this approach, virtual topology reconfiguration problem is modeled as a mixed integer linear programming (MILP) model. In this model, the multi-commodity flow problem is used to solve VTR, where a commodity refers to a lightpath between a source-destination pair and flow on an edge corresponds to traffic flow offered onto the edge. The inputs to the problem include the traffic matrix, the physical topology, the number of available wavelengths per fiber, and the number of available transceivers at the nodes. This model aims to optimize certain objective function under a set of constraints. The linear-programming model finds a set of possible solution satisfying the given objective function under the given constraints and the best one will be selected which is the optimal solution. The virtual topology reconfiguration problem modeled using MILP model grows intractable with increasing size of the network and hence this problem is treated as NP-hard. Thus, for networks of

moderately larger size, it is impractical to solve this VTR problem using MILP model.

iii. ***Minimizing objective based approach:*** This approach follows the reconfiguration process with minimizing certain objective such as delay, number of hops, number of changes or disruption, etc.

iv. ***Heuristic approach:*** To avoid the problems encountered by the optimization approach, heuristic approach is used to solve virtual topology reconfiguration problem for networks of larger size.

v. ***Meta-heuristic approach:*** Meta-heuristics are a class of approximate methods, which are designed to attack hard combinatorial optimization problems where classical heuristics have failed to be effective and efficient. This approach is based on a partial exploration of the space of admissible solutions, finalized to a good solution. The soft computing approaches such as genetic algorithms and simulated annealing are under this category. The other examples are local search (LS), tabu search (TS) algorithms, etc. The reconfiguration algorithms based on this approach are such as simulated annealing (SA), threshold acceptance (TA), multistart local search (MLS), etc.

a. Local search Heuristic approach: In this approach, a set of neighboring configurations is exhaustively searched and the best on e will be taken as the solution. The configuration neighborhood is defined as the set of configurations reachable by as single branch-exchange operation. This method is less flexible but very simple to apply.

b. Simulated annealing (SA) is another kind of meta-heuristic algorithm, following the partial exploration of possible solution space**.** It is based on indirect neighborhood discovery such as wide indirect neighborhood discovery (WIND) and new swap node pair list approach (Xswap). But for there is no search memory, so it cannot be avoided to revisit the space, which has been explored in the previous searches.

c. Tabu search (TS) is one of the well-known meta-heuristics used to solve the hard combinatorial optimization problems. The problem found in the SA is avoided by using TS. Since this method explores the solution space, a FIFO limited list is built to keep track of the solutions, which had been searched in before, this list is called Tabu list, which is used to avoid cycling search.

vi. ***Partial Reconfiguration approach:*** This approach performs only a part of the reconfiguration process, which provides cushions to accommodate only the traffic changes. This approach is based on the tradeoff between the optimality of the new configuration and the degree of network disruption incurred during the migration phase. The basic principle of this method is to identify the most loaded logical links and perform operations that redistribute the load in these links. This approach is more flexible in terms of the ability to control the running time and degree of network disruption through input parameters.

vii. ***Reconfiguration policies:*** The reconfiguration policies are concerned with the process of deciding when configuration updates should be performed and how it is applied to a network. Of those works that do not ignore this important sub-problem, most indicate one of three types of rudimentary approaches.

viii. ***Automated Regression based approach***: In this approach, the selection of parameters used for reconfiguration is based on a mathematical formulation, where a performance metric such as the rate of traffic loss is modeled as a differentiable function of multiple variables, including the parameters under consideration. The optimization technique applied to this function is based on the steepest descent method.

ix. ***Intelligent approach***: This artificial intelligent approach is based on optical agents within the optical transport network. This method can be used for solving multi-layer problems related to reconfiguration for IP-over-WDM network survivability.

x. ***Information Theoretic approach:*** This method uses probabilistic prediction of future traffic sequences and the number of times the reconfiguration policy is re-determined. This approach has the sub-problems namely, pre-planning, prediction, Re-prediction and universality.

xi. ***Model based Reconfiguration:*** This method is based on modeling the desired experimentation scenarios and then processing models with automatic tools that deploy the desired configuration in the testbed. This method is used for GMPLS based optical testbeds in order to allow experimental performance evaluation of real GMPLS based networks under various topologies and configurations.

xii. ***Resource Budget based approach:*** This approach follows minimization of the resource budget. This may be achieved if the target topology is nearly similar to the current topology.

xiii. ***Load balancing based approach:*** This approach treats the reconfiguration problem itself as a kind of load balancing with minimization of network congestion by establishing new lightpaths along the heavily loaded links, and deleting the lightpaths, which are lightly loaded, to balance the load.

xiv. ***Single step and multi step approaches:*** In the single step approach, the entire process of reconfiguration of the topology is done in a single step. But in the multi-step approach, only limited number of nodes or links is reconfigured and hence the entire network reconfiguration needs several incremental changes.

xv. ***Adaptive approach:*** This approach automatically adopts with the dynamic traffic changes by monitoring the traffic patters periodically. This adaptive reconfiguration is considered to be an online and continuous process in which network transformation is performed when a change is observed in the traffic flow.

xvi. ***Autonomic Reconfiguration***: This type of reconfiguration is an intelligent approach, which is capable of knowing when to reconfigure and how to reconfigure independently without the intervention of an external control for the virtual topology reconfiguration. The process of reconfiguration is autonomous.

xvii. ***Centralized Reconfiguration:*** This approach is reconfiguring the topology with a centralized control. The traffic monitoring, lightpath establishment, lightpath deletion, etc are done centrally by a single node. This method overloads the central node.

xviii. Distributed Reconfiguration: This approach is reconfiguring the topology with a distributed control. The traffic monitoring, lightpath establishment, lightpath deletion, etc are done in a distributed way by different nodes in different regions. Passing messages from one node to another carries out the updation of information available at different nodes. This method balances the load among all the nodes in the network, but it suffers from the problem of message overloading.

xix. Adaptive Self-Reconfiguration: This approach introduces a reflective process into the virtual topology reconfiguration agent.. This method efficiently handles the problems of parameter reconfiguration and adapting with the dynamically changing traffic requirements and other network circumstances like failure of nodes or links. The reconfiguration agent with a network model and the incremental process will allow for automatic detection and correction of failures in the reactive process.

xxx. Agent based Reconfiguration: This approach introduces optical agent, which can provide an appropriate way for solving the multi-constraint problems such as mixed integer linear programming.

xxxi. Traffic Engineering based Reconfiguration: This approach is based on the traffic engineering concepts to initiate virtual topology reconfiguration. It uses traffic monitoring, multiprotocol label switching, generalized multiprotocol label switching, differentiated services, and QoS, based on which the reconfiguration process is triggered.

xxxii. Reconfiguration with Divide and Conquer This approach decomposes the virtual topology reconfiguration problem into two sub problems at the first level and further sub-problems in the subsequent levels. Since the VTR problem is treated as NP-hard, the divided sub problem can be solved easier than the original VTR problem. After solving the independent sub problems, the solutions will be combined to get the final solution of the VTR problem.

5. RECONFIGURATION METRICS

The following metrics are used to analyze the performance of reconfiguration algorithms. They are listed as follows.

i. Average Weighted Hop Count
ii. Number of changes
iii. Average number of hops
iv. Degree of Load Balance
v. Blocking probability
vi. Message delay
vii. Throughput
viii. Network Utilization
ix. Reconfiguration cost
x. Reconfiguration gain
xi. Speed improvement factor
xii. Network Availability

The performance metrics used for studying the reconfiguration strategies are defined as follows.

The Average Weighted Hop Count is given by,

$$AWHT = \frac{\Sigma_{s,d}\, T_{i,j}^{s,d} * H_{sd}}{\Sigma_{s,d}\, T_{sd}} \quad \text{------- (9)}$$

where $T_{i,j}^{s,d}$ gives the traffic from node s to d that employs the virtual link i to j.

H_{sd} denotes the hop length for the lightpath between the pair.

The number of changes during the reconfiguration process is the number of lightpaths added and the number of lightpaths deleted.

The average number of hops is the average value of number of hops traversed for all the sd pairs and is given by,

$$Ave.Hop = \frac{\Sigma_{s,d}\, H_{sd}}{N\,(N-1)} \quad \text{------ (10)}$$

where $N\,(N-1)$ is the number of sd pairs, as N sis the number of nodes in the network.

The degree of load balance describes the extent at which the load is balanced between the most loaded lightpaths and the least loaded lightpaths after reconfiguration.

The QoS parameters namely blocking probability, throughput and message delay were defined already in section 4, under the models of VTR problem.

The network utilization *(U)* is defined as the percentage of utilization of network resources practically with respect to the available resources theoretically and is given by,

$$U = \frac{\text{Resources used}}{\text{Resources available}} \times 100 \quad \text{---------- (11)}$$

Reconfiguration cost is the cost incurred due to the process of reconfiguration in terms of packet loss, etc. Reconfiguration gain is the improvement in the performance of the network after reconfiguration.

The speed improvement factor *(S)* is defined as the improvement in speed due to reconfiguration and is given by,

$$S = \frac{\text{Message delay after reconfiguration}}{\text{Message delay before reconfiguration}} \quad \text{----(12)}$$

The network availability *(A)* is defined as the percentage of time the network is available, considering reconfiguration time, failure time, etc.

$$A = \frac{MTBR}{MTBR + T_R} \times 100 \quad \text{--------- (13)}$$

where,
MTBR – Mean Time Between Reconfiguration
T_R – Reconfiguration time

6. STUDY OF HEURISTIC ALGORITHMS

In this section, we study some of the heuristic algorithms proposed in literature.

6.1 VTR with minimum number of changes

The authors [21] developed virtual topology reconfiguration algorithm with minimizing the number of changes for WDM optical networks. The results show that the heuristics minimizes number of lightpaths added and lightpaths deleted. Further the virtual topology reconfigured by this heuristics is close to optimal one.

6.2 VTR with optimization stage

The authors [23] developed a two-stage approach for virtual topology reconfiguration of WDM optical networks. The first stage is the usual reconfiguration process followed by the second stage, which is the optimization stage, which is used to get fine tune the solution obtained near optimal. The heuristic developed provides the tradeoff between the number of changes and the objective function value. The objective value decides how best the virtual topology reconfigured is suited for the changed traffic, and the number of changes limits the disruption to the network operation. The optimization stage fine tunes the approximation done in the reconfiguration stage and hence leads to near optimal solution. The simulation results showed the effectiveness of the heuristics with changing the frequency of optimization. Similar approach developed by the authors [24], called two-phase approach, the first phase is for reconfiguration and second phase for fine-tuning to get optimal solution. Further this approach minimizes the number of changes to get optimal one.

6.3 VTR Based on Heuristics

The heuristics for the reconfiguration of logical topologies in wide area networks were developed [25]. The heuristics include longest lightpath forest, shortest lightpath first, minimum disruptive lightpath first and Tree Search algorithms. Among these algorithms tree search algorithm provides very good performance with large computational complexity. The minimum disruptive lightpath first algorithm is a simple one with moderate performance and reasonable computational complexity. But the longest lightpath first and the shortest lightpath first algorithms perform poor with low computational complexity. The incremental reconfiguration migration heuristic algorithm for IP over WDM networks was developed in [56]. The simulation results showed that the proposed reconfiguration heuristic improves the network throughput and reduced average hop distance over the fixed topology. An efficient heuristic for virtual topology reconfiguration in Optical WDM networks was proposed in [57]. The proposed heuristic tears down the under utilized lightpaths without increasing tht load of maximally utilized lightpath. Further, the heuristic has low computational complexity. A new heuristic approach for logical topology reconfiguration in IP over WDM networks was developed in [58]. The proposed heuristic monitors the network traffic for long term and obtains relatively stable virtual topology.

6.4 VTR Based on Meta-Heuristics

The authors [51] developed virtual topology reconfiguration algorithm based on meta-heuristics for multihop WDM lightwave networks. The heuristics developed include simulated annealing, threshold acceptance and multistart local search for multihop WDM networks with regular topology. The authors compared the performance of these heuristics in terms of their computation time. The results show that the heuristics based on threshold acceptance and tabu search combined with random sampling method, which is used for generating initial solutions, showed better performance than other algorithms with the random sampling method. Further, the performance of all algorithms improves with using Greedy method for generating initial solutions.

A two stage simulated annealing logical topology reconfiguration in IP over WDM networks is given in [59]. The authors proposed a meta-heuristic approach using simulated annealing which trades off between the network performance and computational complexity. The congestion parameter was taken as the performance metric and obtained the optimal performance by tuning the congestion threshold value. This two-stage approach optimizes multiple objectives.

A simulated annealing based heuristic algorithm for solving VTR problem of higher complexity was proposed in [65]. The methodology given tries to optimize the dual objective functions namely minimizing reconfiguration cost and maximizing network performance. The results showed that the simulated annealing heuristic approach can be applied to solve the problem for medium to larger instances of network size with complex traffic demand sets, to arrive at near optimal solution. Further, this proposed approach is highly inexpensive, fast and can be used for all backbone networks.

6.5 Policy Based Reconfiguration

The authors [52] [64] designed the dynamic reconfiguration policies for broadcast WDM networks. The design objectives considered are degree of load balancing and number of retuning needed. The VTR problem is formulated as a Markovian Decision Process and a framework for dynamic reconfiguration policies was developed. The results obtained from the Markovian Decision Process theory applied to get optimal reconfiguration policies even for networks of larger size. Further the optimal reconfiguration policies performed better than the threshold based reconfiguration policies.

6.6 VTR Based on Automated Regression

The WDM optical network reconfiguration using automated regression – based parameter value selection is given in [53]. It considers the problem of automatic and dynamic reconfiguration of WDM optical networks, by using a reconfiguration policy decision, selecting the new virtual topology and then migration from the old topology to new one. The authors developed a technique, which automatically selects the values for parameters used in the reconfiguration algorithm, with the objective of maximizing the long-term reconfiguration gain The results showed the effectiveness of the proposed method in the context of a threshold based reconfiguration policy. This new technique relatively simplifies the task of performance management by selecting appropriate parametric values for the reconfiguration process.

6.7 Traffic Prediction Based Adaptive VTR

An adaptive VTR policy [54] using multi-stage traffic prediction in optical internet was developed. The authors formulated optimal reconfiguration policy as a multi-stage decision making problem to maximize the expected reward and cost function over an infinite horizon. The continual approximation problem in the several VTR heuristics was avoided by using optical internet traffic prediction. The proposed Traffic prediction based multi-stage VTR algorithm, realized the optimal reconfiguration policy. The simulation results showed the proposed method performs better than the conventional one without traffic prediction.

6.8 Cost Based Reconfiguration

Virtual Topology Reconfiguration with minimum cost was developed in [55]. The algorithm proposed uses the concept of splitting and merging of the existing lightpaths as well as cost-benefit analysis to reduce the reconfiguration cost.

Topology reconfiguration with successive approximations [41] was proposed. This method of reconfiguration uses packet drops as the reconfiguration cost which is to be minimized. It was shown that the reconfiguration cost was minimum if the target topology was implemented in series of reconfiguration steps with successive approximations. It was also shown that including the reconfiguration cost along with the objective function of minimizing congestion could minimize the packet drops during the process of reconfiguration. The simulation carried out for other heuristic algorithms combined with successive approximations yielded reduced packet drops and fewer topology reconfigurations with time varying traffic demand.

6.9 Dynamic Reconfiguration Heuristic

A dynamic reconfiguration [60] heuristic for dynamic traffic changes with a tradeoff between number of retuning and the degree of load balance. The most and least loaded channel balance algorithm performed better in terms of the number of retuning and degree of load balance.

Another heurists developed by authors in [61] for dynamic reconfiguration for WDM optical networks. This heuristic works with a trade off between the optimality of the solution and the network disruption. The proposed algorithm also minimizes number of physical resources used, number of retuning required and number of hops.

The authors [63] devised algorithms for joint WDM layer dynamic reconfiguration and Ip-layer routing in IP-over-WDM networks. The single hop algorithm – Maximum Weighted Matching and multihop algorithm- Differential Backlog, are asymptotically throughput optimal. The frame-based algorithms mitigate the optical layer overhead due to the reconfiguration delay. The algorithms show that the control decisions made at each slot at the IP and WDM layers, with the Differential Backlog in general making use of both IP-layer multihop routes and WDM reconfiguration. The results showed that the WDM reconfiguration is preferred when the additional load from the multihop IP-layer routing is high and multihop IP-layer routing is preferred when the additional load incurred is sufficiently small.

A dynamic reconfiguration heuristic algorithm [70] was proposed for hybrid wireless optical networks, by addition /deletion of lightpaths, to cater bandwidth on demand. This type of reconfiguration is used for sharing of network resources by different service providers and for differentiation of service-by-service providers.

A heuristic algorithm for dynamic reconfiguration of WDM optical networks was developed in [73]. This heuristic assigns the priority to the lightpaths based on the type of the traffic carried on them. During the reconfiguration process in response to the connection requests, the priority level of the lightpath to be deleted is compared to that of the new lightpath to be established. Deletion of lightpath is done only if it is of low priority. Thus, the lightpaths carrying higher priority traffic are not disrupted and hence the network throughput is not degraded. The performance of the heuristic was studied in terms of congestion performance for dynamic traffic changes.

Another heuristic [74] was proposed by the same authors with the objective of minimizing congestion in WDM optical networks for dynamic traffic changes. The congestion performance of the heuristic was analyzed for dynamic traffic with and without considering AWHT.

6.10 Distributed Virtual Topology Reconfiguration

A distributed virtual network topology reconfiguration method for IP-over-WDM network under dynamic traffic was proposed in [62]. The proposed heuristic for distributed VTR employs GMPLS based routing protocol for fast reconfiguration by setting up or tearing down lightpaths. In this paper, GMPLS routing protocol is extended to carry the traffic demand over label switched paths so that each node can share the same traffic demand information. Identical information on both topology and traffic demand are shared by all nodes. Each node autonomously calculates a new virtual network topology by adding / deleting LSP in a distributed manner. The performance of the proposed heuristic was studied under variable traffic model.

The authors [66] devised an online distributed virtual topology reconfiguration protocol with a trade off between objective function value and the number of changes. Simulation experiments were conducted to investigate about the above-mentioned trade off parameters.

6.11 Reconfiguration with Information Theoretic Approach

A framework for evaluating the reconfiguration policy was developed [65] with the objectives of maximizing resource utilization and minimizing network disruption. An incremental Clustering Algorithm was proposed to pre-plan the reconfiguration policy with fully predictable finite sequence of traffic pattern. The predictability of traffic sequences and the number of times the reconfiguration policy is re-determined are based on information theoretic approach. Further, an Universal Reconfiguration Management System was proposed with Prediction base Incremental Clustering Algorithm to predict the reconfiguration policy. The simulation results showed that the performance of the proposed heuristics approaches near to the fully predictable ones.

A two-phase distributed reconfiguration algorithm for node failures in IP-over-WDM networks was developed in [75]. The heuristic restores the network connectivity in the first phase and improves the network performance in the second phase. The performance of the algorithm was studied in terms of number of disconnected topologies, average number of components formed, average hop count, number of changes, number of transceivers used and number of messages used in response to node failures in IP-over-WDM-networks.

6.12 Reconfiguration due to Failures

The authors developed heuristic algorithm [68] for virtual topology reconfiguration due to node failure with a trade off between the objective function value and the number of changes. The heuristic developed maintains the connectivity in the virtual topology as well as improves the performance of the network.

Similar heuristic [69] for the virtual topology reconfiguration due to link failure was developed with the same trade off parameters. The results showed that the network connectivity and performance were improved because of the reconfiguration heuristic.

6.13 Autonomous Reconfiguration

The autonomous reconfiguration of backbones in free space optical networks is found in [71]. FSO networks consist of high data rate and narrow beam FSO links between wireless nodes. The authors presented algorithms and heuristics for the dynamic and autonomous reconfiguration processes of Free Space Optical sensor networks with the goal of optimizing performance based on network layer parameters. The objective is to form a bi-connected topology with minimum congestion, given the traffic patterns in the network in the form of a traffic matrix.

The autonomous reconfiguration of free space optical sensor networks is found in [72]. It is feasible to reconfigure network topologies through intelligent and dynamic rearrangement of fixed and mobile backbone nodes in high data rate, optical wireless networks. The use of scalable heuristics can effectively compute new topologies in response to degradation in one or more links in the network. The authors adapted the well-known techniques of “multihop,” “rollout,” and “branch exchange” for the reconfiguration heuristics, and investigated their performance in ring topologies. Based on simulations, the average performance improvement and running times of such heuristics were investigated. The simulation results showed that the better performance could be expected at the expense of large computational complexity. Further, the effectiveness of topology control on the network shown that the network layer performance was significantly improved when reconfiguration heuristics were used. The total results suggest that performance in TCP/IP networks, which have degraded topologies, can be improved as a result of the introduction of dynamically reconfigured topologies, which lower aggregate costs.

6.14 Traffic Engg based Reconfiguration

The authors [40] proposed several heuristic algorithms namely, fixed most benefit first, adaptive most benefit first, and minimal average packet hop distance lightpath first that take into account of the traffic demand of upper layers. The heuristic algorithms, move the current virtual topology efficiently to the given target virtual topology in large-scale wavelength routed optical networks. In these proposed algorithms, the performance improvement/degradation of data transmission in terms of transmission delay or distance between s-d pair caused by a new lightpath is considered as benefit for establishing the new lightpath. The proposed algorithms construct the new virtual topology starting from a lightpath with the largest benefit to the user traffic. Simulation results showed that the proposed algorithms perform with shorter average hop distance less number of mean disrupted transceivers than the existing algorithms.

Topology reconfiguration mechanism for traffic engineering in WDM optical network was proposed in [41]. The authors presented an adaptive reconfiguration mechanism for WDM optical networks and heuristic algorithms namely combination algorithm and multi lightpath change algorithm (MLPC). The algorithms considered all ranges of traffic flows and element failure scenarios to evaluate the performance of the heuristic approach proposed. The new approach incurred very less traffic loss with more lightpaths under extreme load conditions than single lightpath change (SLPC) algorithm Performance of the new approach steadily improves as simulation progresses over longer duration, for other loading conditions ranging from low to high.

Traffic driven virtual network topology reconfiguration for GMPLS network was developed in [76]. This scheme uses a statistical traffic processing which makes virtual network topology (VNT) reconfiguration depend on average traffic value for the generalized multi-protocol label-switching (GMPLS) network. The traffic engineering involved in this new method including traffic measurement, calculation of traffic shape parameter, computing EWMA parameter and smoothing measured traffic. Based on the burst nature of the traffic, this new reconfiguration scheme dynamically changes the smoothing traffic value. The proposed method of reconfiguration reacts to the dynamic traffic changes with minimal delay and suppressing erroneous reactions to spikes by smoothing the traffic appropriately. Further, the authors analyzed the possibility of implementation of this traffic engineering based reconfiguration using GMPLS router and showed that the system worked properly.

6.15 Load Balancing based Reconfiguration

The virtual topology reconfiguration problem with load balancing in broadcast WDM networks. The proposed approach reconfigures single hop WDM networks for dynamic traffic changes with a tradeoff between two conflicting objectives namely degree of load balancing and number of transceivers that need to be retuned. This new approach leads to scalable with the number of WDM channels.

6.16 Hop Distance based Reconfiguration

The virtual topology reconfiguration controller for WDM networks was proposed in [42]. The proposed reconfiguration controller works based on the average weighted hop count. If the AWHT value exceeds certain threshold, the reconfiguration process is triggered. In other words, most of the traffic carried through multi hop lightpaths means that the network to be reconfigured. This method establishes less number of lightpaths with discontinuous wavelengths so as to reduce the amount of blocking. The simulation results showed that the amount of single hop lightpaths increased and this reconfiguration controller maintained the average single hop WDM network.

6.17 Reconfiguration with Traffic Grooming

The virtual topology reconfiguration algorithms were proposed for groomed WDM networks in [78]. A simple framework was given to evaluate the reconfiguration gain in terms of the objectives namely maximal throughput and minimal network disruption. Two heuristic algorithms namely incremental add algorithm with forward approach and incremental add algorithm with backward approach, were proposed for the adaptive reconfiguration for the dynamic traffic. The simulation results demonstrated the flexibility and robustness of the proposed algorithms.

Under this category, an alternate approach was presented [79] for the reconfiguration of WDM optical network with traffic grooming. The authors used the approach of divide and conquer to solve the problem of VTR, by dividing it into two independent sub problems namely VTR triggering policy and VTR algorithm. A new multi-objective VTR algorithm called integrated reconfiguration algorithm was proposed, which combined three main factors namely, traffic load, and traffic grooming ratio and route length of lightpaths into a single objective and considers them all when reconfiguring. The simulation results showed that the proposed VTR policy, periodic VTR triggering policy with integrated reconfiguration algorithm, achieved better VTR performance, compared to the existing approaches. Further, the different VTR algorithms had tradeoffs between resource utilization and network disruption.

7. CHALLENGING RESEARCH PROBLEMS

In this section, we present the future directions for open research problems in the field of virtual topology reconfiguration for WDM networks. Certain important VTR problems to be focused in near future are listed below.

i. The existing analytical models not taken different parameters on IP and WDM layers, which affect the performance of the reconfiguration process. An analytical model for VTR problem on IP-over-WDM network, considering parameters related to IP and WDM layers and traffic engineering is an open issue.
ii. Most of the VTR problems assumed traffic pattern was known in advance. VTR problem for dynamic traffic, by predicting the future traffic without prior knowledge and adapting it in an intelligent way is a challenging one for the IP-over-WDM networks.
iii. Most of the VTR problems assumed the traffic distribution as Poisson process, which is failed to model the real time traffic on a long run basis. Thus, VTR problem for IP-over-WDM networks with traffic modeled other than Poisson distribution is another problem to be solved for the real time traffic.
iv. The blocking models available for the WDM networks considered Poisson traffic model. The blocking model for IP-over-WDM networks with non-Poisson traffic model and computation of relevant parameters is another open problem.
v. Queueing analysis for VTR problem in IP-over-WDM networks with non-Poisson distribution of traffic and preemptive queue.
vi. The blocking analysis of VTR problem in IP-over-WDM networks for WDM networks may consider the blocked packets are buffered in the queue.
vii. The introduction of optical agents within the transport network can provide an appropriate way of solving multi-constrained problems related to optical network management and survability. The challenging research problem is to use optical agents for the virtual topology reconfiguration for IP-over-WDM networks.
viii. Autonomous networks of different regions, of different service providers may share the network resources globally. In this global sharing, the global network topology need to be reconfigured depending upon the traffic requirements for the different autonomous networks. In this problem of virtual topology reconfiguration, protecting the data and information between one network to another, while sharing information related to topology and traffic demands globally is an important security problem for IP-over-WDM networks.
ix. The future work includes devising VTR algorithms for Traffic Engineering & Traffic Grooming capable GMPLS over IP over WDM networks using the simulator GLASS.
x. Devising VTR algorithms for distributed GMPLS networks with QoS parameters and implementing the algorithms for the above stated GMPLS networks using the simulator GLASS is also another open research problem.

8. CONCLUSION

In this paper, the problem of virtual topology reconfiguration with Traffic Grooming for IP-over-WDM network is reviewed in the current literature up to date. The various approaches existing for the VTR problem are discussed in elaborate including the design concept and their significant contribution to the research community working in this problem. A detailed study was made over different approaches and heuristic algorithms devised by several authors in the past research work carried out, including essential investigations, observations and conclusions made. Finally, a set of challenging research problems for further research work is given for the problem of virtual topology reconfiguration in IP-over-WDM networks.

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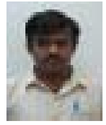

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