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Optimization Technique for Virtual Topology Reconfiguration for IP-over-WDM Networks with QoS Parameters

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Abstract

This paper, researches about the application of optimization techniques for the reconfiguration of optical internets using IP-over-WDM technology. Internet Protocol (IP) over Wavelength Division Multiplexed (WDM) networking technology with Terabits per second bandwidth become a natural choice for the future generation internet networks (Optical Internets), wide area network (WAN) environments and backbone networks due to its potential ability to meet rising demands of high bandwidth and low latency communication. Recently Virtual Topology Reconfiguration of IP over WDM networks has received greater attention among researchers. Optimation technique finds many applications in the field of network engineering, which includes linear programming, traffic prediction, network modeling, traffic modeling, etc. In this paper, we have presented a new approach for reconfiguring virtual topology of IP over WDM networks using optimization technique. The computed results show that this new approach achieves better performance in terms of computational accuracy, number of changes and average weighted hop count.

Keywords: Blocking Probability, Lightpaths, Optimization, Virtual Topology Reconfiguration

1. Introduction

In the last decade, WDM Optical fiber networking technologies 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

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candidates for the next generation of wide area backbone 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 IP 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 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 and nodes in an arbitrary topology. In these types of networks, data transfer carried from one node to another node using lightpaths. A lightpath [3] 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.

A virtual topology [4] is a set of pre-established lightpaths established to provide all optical connectivity between nodes for a given traffic demand. The virtual topology is established logically through lightpaths, each identified by an independent wavelength, which provides end-to-end connectivity for transmission over the optical medium. The embedding of virtual topology over a physical topology results in minimizing the number of nodes that were actively involved in network transmission. The Virtual Topology is a graph with nodes as routers in the physical network topology and edges corresponding to the lightpaths between them. A virtual topology is designed with an objective of minimizing certain objective function such as Average Weighted Hop Count of the Virtual Topology (AWHT), congestion, etc. The virtual topology designed initially for a particular traffic may not be optimal for the changing traffic. The virtual topology designed over IP may need to be changed in response to changing traffic demands or due to failure of network elements. Some lightpaths may be heavily loaded and hence new lightpaths to be set up to carry the additional traffic. Likewise, certain other lightpaths may have no traffic at all and such lightpaths to be deleted. 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 [4]. The dynamic reconfiguration of optical networks has been one of the hot topics among the communication research community.

Reconfiguration [5] is one of the significant characteristics of WDM optical network. The reconfiguration [6] is achieved by the fact that WDM optical networks provide an architecture in which logical connections can be embedded over the underlying physical connections. The optical cross connects optical transmitters and receivers and wavelength converters are the components, which enable the network operators to reconfigure the optical network connectivity with the changing traffic conditions. There are two different approaches [7] [8] 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.

Optimization technique finds many applications in the field of network engineering, which includes linear programming, traffic prediction, network modeling, traffic modeling, etc. The methods available in literature follow traffic modeling, which gives only, approximate results. In this paper, we have presented a new approach for reconfiguring virtual topology of IP over WDM networks using optimization technique, which yields more accurate results compared to non-optimization based methods.This paper is organized as follows. A survey of the related work available in the literature is made in the section 2.

Section 3 describes our proposed work. In section.4, the traffic model is described and section 5 and 6 present the optimization model and simulation results respectively. Finally, section 7 concludes the paper.

2. Related Work

Many researchers have extensively studied about optical network and its reconfiguration problem for WDM network. Virtual topology design problem for WDM mesh network with the objective of minimizing average packet delay is given [1]. Linear programming methods for Virtual topology design problem with the objective of minimizing network congestion is proposed [2] [3]. Linear programming for the virtual topology design problem becomes computationally intractable; therefore heuristic approaches are made use of. Wavelength continuity constraint for the virtual topology design problem has been considered [2], 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. An extensive survey of virtual topology design algorithms has been carried out [4]. 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. The combined problem of physical topology and virtual topology design has been taken up [5] using genetic algorithm.

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. An integer linear programming method and resource budget for virtual topology reconfiguration problem with the objective of minimizing average hop distance has been proposed [6]. The authors also discuss on reconfiguration aimed at minimizing the number of lightpath changes for a mesh network. The dynamic reconfiguration for optical networks with trade-off between optimality of the network and network disruption is described in [7]. The reconfiguration problem for wireless optical network is described in [8]. An adaptive mechanism without prior knowledge of the future traffic pattern is proposed [9]. Here the authors consider a slowly varying traffic pattern and consider addition or deletion of one lightpath at a time. A higher and lower watermark level is used to find when to reconfigure the network by adding or deleting the lightpaths. A two-stage approach of reconfiguration with objective of minimizing average weighted hop count with a trade-off between the objective function value and the number of changes to the virtual topology is considered [10]. 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 dynamic reconfiguration 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. The traffic generated belongs to various QoS classes and the service requirement for each QoS class is different. Hence the QoS parameters for the changing traffic to be taken into consideration while reconfiguring the virtual topology for an IP over WDM network.

3. Proposed Work

In this paper, differing from the existing work, a new approach is proposed in the context of virtual topology reconfiguration driven by optimization technique for the IP-over-WDM network.

3.1 Problem Statement

The reconfiguration of virtual topology for optical network using IP over WDM technology is usually handled by modeling it as a Mixed Integer Linear Programming [13] or optimization problem which minimizes the objective function such as Average Weighted Hop Count of the Virtual Topology (AWHT), Congestion, number of lightpath changes, etc. In our research work we propose a new optimization model and a heuristic algorithm for reconfiguring virtual topology for IP over WDM networks for dynamic traffic changes considering QoS parameters namely Blocking probability, Throughput, Delay, etc. The associated sub-problems are as follows.

i. Topology Selection sub-problem
ii. Lightpath establishment sub-problem
iii. Lightpath routing sub-problem
iv. Lightpath wavelength assignment sub-problem
v. Traffic routing sub-problem

The topology selection, lightpath establishment, wavelength assignment sub-problems are using s. The lightpath routing and traffic routing sub-problems are using least congested routing.

3.2 Network Model

We consider a network [6] 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 T transmitters and R receivers. We assume 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. Our network model considers network with an initial traffic matrix and reconfiguration decisions are based on traffic changes whenever such changes are necessary.

3.3 Notations

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

i,j : end nodes

sd: source-destination pair

3.4 Parameters

Listed below are the parameters used in the problem formulation.

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
ix. Network throughput = τ
x. Network Utilization = U

3.5 Variables

We define the variables used in the mathematical formulation.

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 ith node is connected on j^{th} wavelength.
v. Load matrix L, where Lij denotes the load on j^{th} wavelength channel of ith node.
vi. Hop length matrix, H where Hij denotes the hop length for the lightpath between nodes i and j.

3.6 Optimization Problem Formulation

Reconfiguration can be viewed as a process for providing a trade-off between the objective function value and the number of changes to the current virtual topology. The objective function value decides how best the topology is suited for the changed traffic demand. The number of changes decides the amount of network disruption while changing the current virtual topology to a new one. Hence the Virtual Topology Reconfiguration problem can be formulated as a Mixed Integer Linear Programming (MILP) Optimization problem. As the VTR problem is computationally intractable, heuristic solutions are desired to yield near optimal solution [5].

In this paper, we have formulated the VTR as optimization problem of minimizing network congestion, delay, etc with minimizing AWHT & number of changes. The constraints associated with this problem are as follows.

Constraints for Optimization:

i. Maximum load of the network ≤ Congestion threshold
ii. Number of wavelengths ≤ W
iii. Number of changes in the given topology ≤ N_{ch}

The total traffic on the virtual link from node i to j is given by,

$$T_{i,j} = \Sigma_{s,d}\, T_{i,j}^{s,d} \quad (1)$$

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

Congestion is defined as the maximum traffic flow in a lightpath due to all source destination node pairs and is given by,

$$T_{max} = \max_{i,j} T_{i,j} \quad (2)$$

The Average Weighted Hop Count is given by,

$$AWHT = \frac{\Sigma_{s,d}\, T_{i,j}^{s,d} * H_{sd}}{\Sigma_{s,d}\, T_{sd}} \quad (3)$$

where H_{sd} is hop distance between s and d.

The optimization model is as follows.

Objective: Minimize congestion $=\max_{i,j} T_{i,j}$
Constraints: No.of wavelengths $\leq W$
No.of transceivers $= R$
Objective: Minimize Delay =

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

where C is the channel capacity

Constraints: no.of changes $\leq N_{ch}$

Objective:

Minimize $AWHT = \dfrac{\Sigma_{s,d}\, T_{i,j}^{s,d} * H_{sd}}{\Sigma_{s,d}\, T_{sd}}$

Constraints: No.of transceivers $= R$
No.of wavelengths $\leq W$
Objective: Minimize blocking probability $= B = \dfrac{A^C}{C!\sum_{n=0}^{C} \dfrac{A^n}{n!}} + (1 - \dfrac{l_d}{N})^h (1 - P_0) e^{t - t_0}$ (5)

where l_d is the number of lightpaths deleted during reconfiguration, t_0 is the initial time and t is the time of reconfiguration.
Constraints: No.of wavelengths $\leq W$
No.of transceivers $= R$
Objective: Maximize Throughput = Total traffic load in the network
Constraints: No.of changes $\leq N_{ch}$
No.of wavelengths $\leq W$
No.of transceivers $= R$
Objective: Maximize Utilization = $no.\ of\ ,packets*H / L*w*C$ (6)
where L is the number of links

Constraints: No.of changes $\leq N_{ch}$
No.of wavelengths $\leq W$
No.of transceivers $= R$

The above-mentioned set of objectives and their corresponding constraints form the problem of Multi Objective Linear Programming (MOLP) model or Mixed Integer Linear Programming (MILP) model. This model is used to solve the problem of VTR for the IP/WDM networks.

3.7 Traffic Model

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

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

4. Heuristic Algorithm

As the optimization problem grows linearly with the size of the network, it is intractable for larger networks and it is proved as NP-Hard problem. Hence we develop a heuristic for the VTR problem (HVTR). The algorithm is described below.

4.1 Algorithm Description

In the first phase of the heuristic, the WDM network is initialized including its neighborhood structure. Then a random point is generated within the neighborhood structure. For each random point, blocking probability, packet delay and throughput are calculated. If the observed parameter falls below preset critical value, it triggers the reconfiguration phase; otherwise it remains in the traffic-monitoring phase itself. This procedure will be repeated for each and every random point. If the resultant topology is having less computational cost, this will be included under the possible list of virtual topologies. Finally the topology having least cost among the topology list stored will be selected. Thus, the new approach devised leads to less number of changes than existing approaches. Further, it has less blocking as it yields optimal solution, which in turn increases the network throughput.

4.2 Algorithm Description

The heuristic algorithm for VTR problem using optimization technique is presented below.

Input: Physical Topology; Current Virtual Topology, Previous Traffic Demands,
Output: Reconfigured Virtual Topology

Algorithm:

initialise WDM network
initialise network neighbourhood structure
generate a random point in neighbourhood structure
select a structure

```
repeat the following for each structure
 steps:
monitor traffic and predict future traffic with
route traffic over VT using
compute B,D,τ
if (B ≥ B_th)trigger reconfiguration
    if (D ≥ D_th)trigger reconfiguration
        if (τ ≤ τ_th)trigger reconfiguration
        else stop;
trigger reconfiguration:
        for all sd pairs
                compute :  WHT=T_sd*H_sd;
        sort sd pairs  in non-increasing WHTs
        for all sd pairs
                compute shortest paths using all- pair shortest path algorithm
        if no lightpath exists
                if free wavelength available
                if free transceiver available
                establish lightpaths
                else lightpaths deletion:
 find different set of lightpaths to be deleted
 sort lightpaths in non-decreasing order of  load
 delete the first  lightpath in the set
        establish lightpaths
        if the topology is connected then break;
                else continue
        compute N_ch  for the new topology
                if (N_ch< N_th) include the new topology into VT set
                else discard the new topology
        select next   neighbourhood and repeat from  steps
stop:   select the VT with  min N_ch
```

5. Results And Discussion

The MILP optimization problem model was evaluated using MATLAB and then the devised heuristic was heuristic algorithm for VTR is implemented for an IP/WDM network having 14 nodes with NSFNET topology shown in fig 1. The data structures required for simulating this algorithm were written using Java . The traffic source is generated using Fuzzy based prediction method. The performance of the algorithm is measured for the dynamic traffic with the following parameters.

i. Number of nodes, N=14
ii. Number of wavelengths per link, w =10
iii. Capacity of each wavelength C = 1 unit
iv. Cluster size = 10
v. Packet size l = 512 bits
vi. Channel bit rate r = 1Gbps
vii. Propagation delay = 1 μS
viii. Distance between nodes = 1 unit

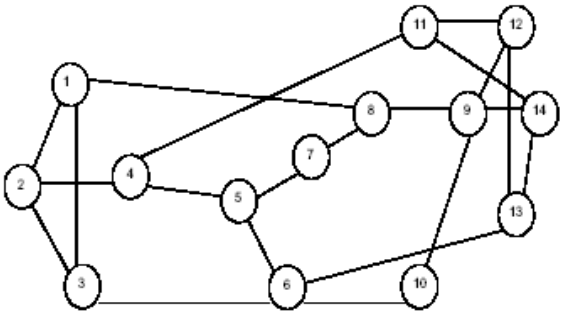

Fig 1. NSF Network with 14 nodes

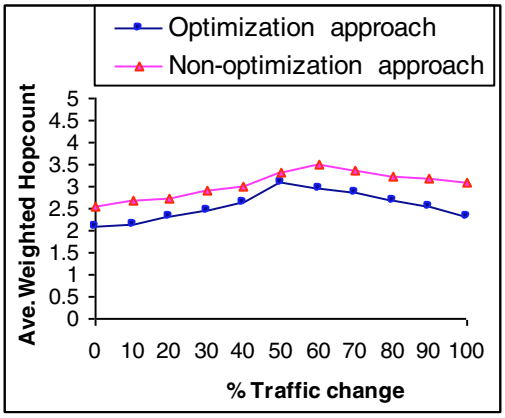

Fig 2. AWHT vs % Traffic change

The Average Weighted Hop Count measured by varying % of change in traffic for dynamic network with i.i.d traffic model is plotted in the fig. 2. From this graph, it is observed that the AWHT is minimal compared to the two-stage reconfiguration approach given in [10]. The reduction in AWHT is due to the optimal path found by the RWA algorithm. The optimization approach has minimal AWHT while compared to the existing non-optimization fuzzy approach for IP/WDM networks.

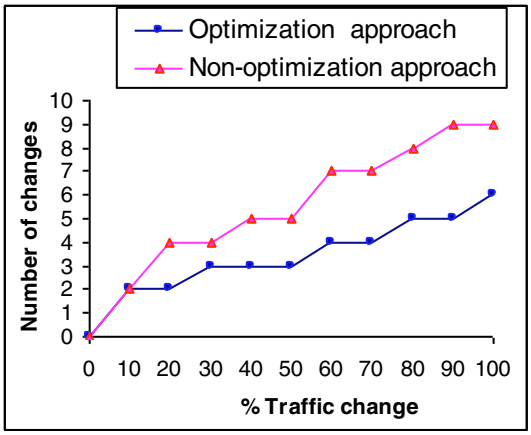

Fig 3. Number of changes vs % Traffic change

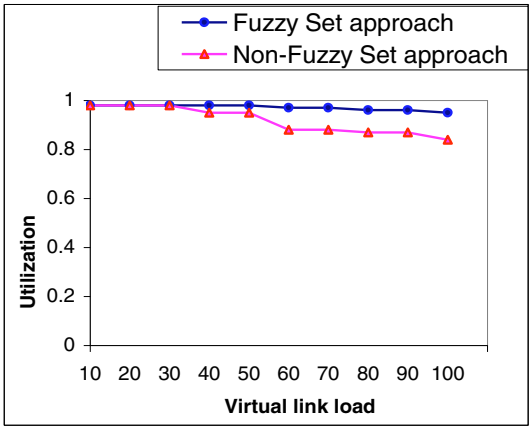

Fig 4. Throughput vs Virtual link load

The Average Weighted Hop Count measured by varying % of change in traffic for dynamic network with i.i.d traffic model is plotted in the fig. 3. From this graph, it is observed that the AWHT is minimal compared to the two-stage reconfiguration approach given in [10]. The reduction in AWHT is due to the optimal path found by the RWA algorithm. The number of changes measured by varying % of change in traffic for dynamic network with i.i.d traffic model is plotted in the fig. 4. From this graph, it is observed that the number of changes is minimal compared to the two-stage approach given in [10]. The reconfiguration cost is greatly reduced in the optimization approach compared to the non-optimization

method. Further, due to the above results, the resource utilization is also improved better than the existing non-optimization methods. The graph depicting network resource utilization versus virtual link load is shown in fig 4. The resource utilization for optimization approach is more than 90% while compared with non-optimization based approach, which yields only around 80% at heavy load conditions. Thus, optimization method maximizes the network resource utilization and it gives an optimal solution for VTR problem.

6. Conclusion

In this paper, it is proposed a new approach using optimization technique for Virtual Topology Reconfiguration (VTR) for Multihop IP over WDM optical networks with i.i.d traffic model. The proposed heuristic approach was implemented and s computed using Java and validated using optimization model in MATLAB. The obtained results show that the new optimization approach achieves better performance in terms of AWHT, computational cost, resource utilization and number of changes for dynamic IP over WDM networks, compared to the existing non-optimization approach. Further, the i.i.d traffic modeling and Fuzzy based traffic prediction gives more accurate estimation of future traffic, compared to non-optimization Fuzzy prediction methods, which leads to optimal reconfiguration of the given topology for the future traffic demand set.

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