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DIFFERENTIAL TRAFFIC DRIVEN VIRTUAL TOPOLOGY RECONFIGURATION FOR IP OVER WDM NETWORKS FOR DYNAMIC TRAFFIC CHANGES WITH QOS PARAMETERS

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Abstract

The IP (Internet Protocol) over WDM (Wavelength Division Multiplexing) networks will be the best choice for the future generation internet networks as they provide enormous bandwidth satisfying exponentially growing data traffic. Recently Virtual Topology Reconfiguration of IP over WDM networks has received greater attention among researchers. An IP-over-WDM network with dynamic traffic requires the virtual topology reconfiguration based on the traffic load conditions. The existing approaches follow traffic monitoring over an observation period and triggering the reconfiguration based on the threshold level of traffic load. In this paper, we have presented a new approach of differential traffic driven virtual topology reconfiguration for IP over WDM networks with Quality of Service (QoS) parameters and shown that this new approach achieves better QoS performance in terms of blocking probability, throughput and latency.

Keywords: *Differential Traffic, Lightpaths, Virtual Topology Reconfiguration, QoS*

1. Introduction

In the last decade, WDM techniques and Optical fiber technologies together brought a revolution in high-speed communication networks. All optical WDM networks using wavelength routing are considered to be potential 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 WDM technology to provide enormous bandwidth, the IP over WDM networks [1] become the right choice for the next generation Internet networks. 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. Virtual Topology [3] is a graph with nodes as IP routers in the physical network topology and edges corresponding to the lightpaths between them. The 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]. As the VTR problem is computationally intractable, heuristic solutions are desired to yield near optimal solution [5].

The dynamic reconfiguration [11] of virtual topology requires a lot of control overhead and results in network disruption. 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.

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Hence the QoS parameters for the changing traffic to be taken into consideration while reconfiguring the virtual topology for an IP over WDM network.

2. Related Work

Many researchers have extensively studied the virtual topology design problem for WDM network. Virtual topology design problem for 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. 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. The combined problem of physical topology and virtual topology design has been taken up [5] using genetic algorithm.

Reconfiguration of virtual topology for dynamic traffic is carried out with the aim of minimizing one or more objective functions. 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. An adaptive mechanism without prior knowledge of the future traffic pattern is proposed [7]. A two-stage approach of reconfiguration with objective of minimizing average weighted hop count with a tradeoff between the objective function value and the number of changes to the virtual topology is considered [8]. The first stage is reconfiguration stage and the second stage is an optimization stage, which reduces the deviation from the optimal objective function value.

This paper is organized as follows. Section 3 presents proposed work which includes QoS modeling and traffic modeling. Section 4 describes the heuristic algorithm followed by simulation results and discussion in section 5 and section 6 concludes the paper.

3. Proposed Work

3.1. Problem statement

Most of the existing approaches in the literature are triggering the reconfiguration based on the threshold level of traffic load. In our research work, we propose a new idea of reconfiguring virtual topology for IP over WDM networks driven by differential traffic demands for dynamic traffic changes with minimum network disruption and improved QoS performance in terms of network disruption, Blocking probability, Throughput, Delay, etc.

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 R transceivers. 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.

3.3. 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 bits per sec

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iv. Number of transceivers per node = R
v. Average Weighted Hop count for the Topology =AWHT
vi. Number of changes in the topology =Nch
vii. Traffic demand between two nodes =T Mbps or Gbps
viii. Traffic load of the network = A Erlangs

3.4. Mathematical Modeling

In this paper, we have formulated the VTR problem as an optimization problem of minimizing blocking probability, with QoS constraints namely, maximum throughput, minimum number of changes and minimum delay.

3.4.1 QoS parameters

The QoS parameters considered in this research work are blocking probability, message delay and throughput. These parameters are defined as follows.

i. *Blocking Probability(B)*:

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.

ii. *Message Delay(D)*:

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.

iii. *Throughput(τ)*:

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.

3.4.2 Traffic Modeling

A realistic Traffic model is a prerequisite for accurate performance evaluation. The traffic model consists of five layers: physical network, virtual network, call, burst, and packet layers.

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

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

3.4.2.1 Poisson iid model

The probability function of a random variable *X,* which follows Poisson distribution is given by, $P(X = x) = \frac{e^{-\lambda}\lambda^{x}}{x!}$, $0 \le x \le \infty$ -------(1)

The important characteristics of Poisson process are:

i. The packet arrivals are uniform and Poisson distributed at a rate of λ
ii. The packet inter-arrival times are exponentially distributed
iii. Packet service rate is μ.
iv. Forward-recurrence time is exponentially distributed (i.e., memoryless property)
v. Number of arrivals in non-overlapping time intervals is independent random variables (i.e., independent-increments property.

The independent and identically distributed (i.i.d) traffic model assumes uniform distribution between 0 and a maximum traffic density. The example traffic matrix [5x5] generated using the iid model is given below.

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[T]=

0	7	38	3	24
1	0	2	22	47
12	10	0	3	4
3	14	1	0	2
44	1	32	13	0

3.4.2.2 Poisson Traffic cluster model

Acting one particular node as source or destination for a group of destination or source nodes model the traffic cluster. The particular node acting as source or destination for the group of nodes is called cluster head which depends upon the traffic pattern. 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]=

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

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 5 as the destination for the group of nodes 1,2,3 and 4. Note that the traffic between source destination pairs other than these two clusters is negligible.

3.4.3 QoS Modeling

The QoS models for the VTR for IP over WDM network are described as follows.

3.4.3.1 For 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

The blocking probability model for the network using Erlang loss formula [12] is given by,

$$P_0 = \frac{A^C}{C!\sum_{n=0}^{C}\frac{A^n}{n!}} , \qquad (2)$$

where C is the channel capacity of one wavelength. Including the blocking due to reconfiguration, the total blocking probability is written as follows

$$B = \frac{A^C}{C!\sum_{n=0}^{C}\frac{A^n}{n!}} + (1-\frac{l_d}{N})^h (1-P_0)e^{t-t_0} , \qquad (3)$$

which gives the blocking probability model for the IP over WDM network, where l_d is the number of lightpaths deleted during reconfiguration interval (t,t_0).
The throughput of the network is estimated by the formula given by,

$$\text{Throughput} = \frac{\textit{No. of packets received}}{\textit{No. of packets sent}} . \qquad (4)$$

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

$$\text{Latency} = D_q + D_p + D_t + D_r \ , \qquad (5)$$

where,

$$D_q\text{: Queuing delay} = \sum_{ij} \sum_{sd} T_{ij}^{sd} \frac{1}{\left(C - \sum_{sd} T_{ij}^{sd}\right)} \ , \qquad (6)$$

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

$$D_p\text{: Propagation delay} = \sum_{ij} T_{ij}^{sd} d_{ij} p_{ij} \ , \qquad (7)$$

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

$$D_t\text{: Transmission delay} = \frac{\textit{packet length } l}{\textit{channel bit rate } r} \qquad (8)$$

$$D_r\text{: Processing delay} = \frac{1}{\left(\Re - \left(T_{sd} + X_i\right)\right)} \ , \qquad (9)$$

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

$$X_i = \left[\sum_j T_{ji} + \sum_j T_{ij} + \sum_j T_{sd} \beta_{ij}^{sd} \right] - T_{ij} \qquad (10)$$

D_{rc}: Reconfiguration delay.

3.4.3.2 For Traffic cluster model

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, except with the multiplication factor called, cluster size.

4. Heuristic Algorithm

The new approach for differential traffic driven Virtual Topology Reconfiguration (VTR) considering QoS parameters is described as follows. For each sd pair, differential traffic is calculated, which is positive for increased traffic and negative for decreased traffic. The increased traffic with more difference is to be reconfigured first, which gets the highest priority in the VTR list. For example, consider a first case of sd pair with previous traffic 128 and current traffic increased to 130. Second case of sd pair, had previous traffic 75, but increased to 108, is having more priority for VTR in this new approach. The first case of sd pair with only 2 units of traffic increase is having less priority, since the routing of increased 2 unit traffic, may not need reconfiguration. Hence the sd pair which has more traffic for routing than previous instant of time is reconfigured first, avoiding unnecessary and frequent reconfiguration just based on the higher traffic values. In other words, the new approach devised leads to less number of changes than existing approaches. Further, it has less blocking as it considers more traffic difference at first, which in turn increases the network throughput. The heuristic algorithm for the differential traffic driven VTR is presented below.

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

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Algorithm:

1. *for all sd pairs, compute, differential traffic* $T^{diff}_{sd} = (T_{sd}(t) - T_{sd}(t\text{-}1))$
2. *for all sd pairs, compute,differential weighted hop count:* $DWHT= T^{diff}_{sd} * H_{sd};$
3. *Sort all sd pairs in non-increasing order of their DWHT*
4. *for the given VT, Compute* $AWHT=Sum (T_{sd}*H_{sd})/Sum(T_{sd})$
5. *for each sd pair in the sorted list, compute shortest paths*
6. *if lightpath exists on the path found, check if free wavelength and transceiver available.*
7. *if yes, then establishes lightpaths and goto step 9.*
8. *else, find different set of lightpaths to be deleted; sort lightpaths in non-decreasing order of load delete the first lightpath in the set and establish lightpaths.*
9. *if the topology is connected then compute AWHT for the new topology*
10. *if* $(AWHT_{new}<AWHT_{old})$ *and if* $(N_{ch}<N_{th})$, *include the new topology in to VT set*
    else discard the new topology
11. *repeat this procedure for all the sorted sd pairs*
12. *select the VT with minAWHT*

5. Results and Discussion

The heuristic algorithm for differential VTR is implemented for an IP/WDM network having 14 nodes with NSFNET topology [13][14] shown in fig 1. The data structures were written using Java [15] and simulated using the tool, GLASS [16]. The performance of the algorithm is measured for the dynamic traffic with the following parameters.

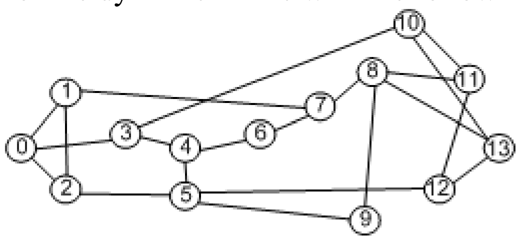

Fig 1. NSF Network with 14 nodes

Parameters:

i. Number of nodes, N=14
ii. Number of wavelengths per link, w =10
iii. Capacity of each wavelength = 1 unit
iv. High Load Threshold, α = 6 wavelengths.
v. Low Load Threshold, β = 1 wavelength
vi. Cluster size = 10
vii. Packet size = 512 bits
viii. Channel bit rate = 1Gbps
ix. Propagation delay = 1 µS
x. Distance between nodes = 1 unit

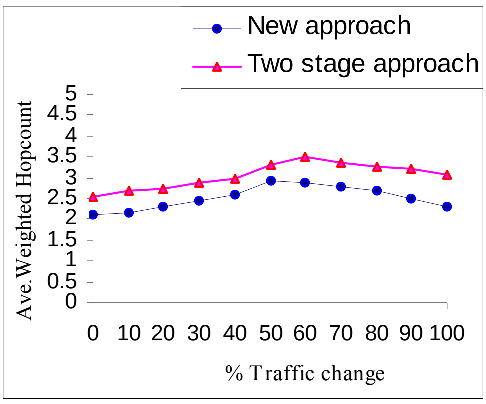

Fig 2. AWHT vs % Traffic change

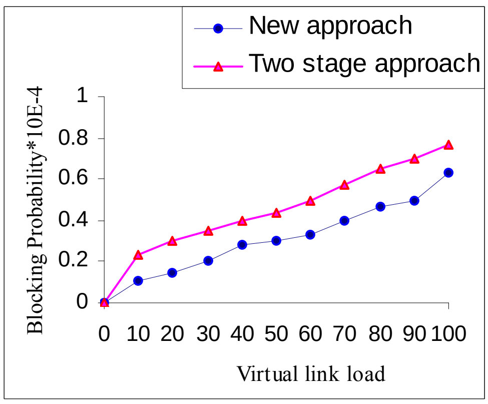

Fig 3. Blocking probability vs Virtual link load

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. 2. From this graph, it is observed that the AWHT is minimal compared to the two-stage reconfiguration approach given in [8]. The reduction in AWHT is due to the optimal path found by the RWA algorithm, which was proposed by the same author and described in detail [17].

The blocking probability measured for different virtual load of the dynamic network for i.i.d traffic model is plotted in the fig. 3. From this graph, it is observed that the blocking probability is much less than that of two-stage approach. Thus, the blocking rate of the proposed VTR heuristic is considerably less than that of the existing approach.

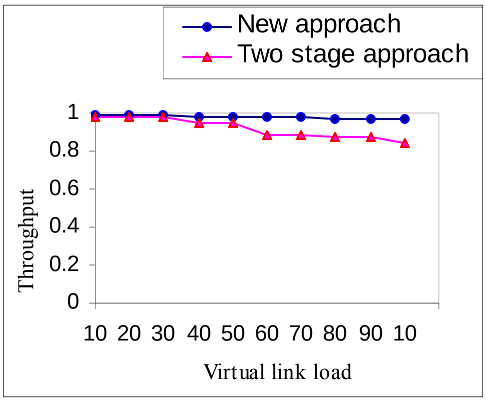

Fig 4. Throughput vs Virtual link load

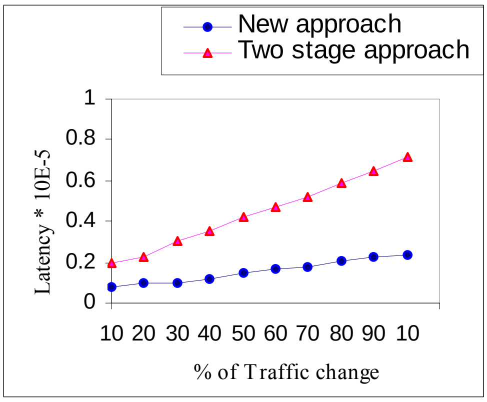

Fig 5. Latency vs % Traffic change

The network throughput measured for different virtual load of the dynamic network for i.i.d traffic model is plotted in the fig. 4. From this graph, it is observed that the network throughput is maximal for the new heuristic approach till the virtual link load is 50. After that a slight decrease in throughput and reaches a steady state value at the load value of 100.But for the same case, the existing two-stage approach has network throughput, which is much less than that for new approach. The network latency measured by varying % of change in traffic for dynamic network with i.i.d traffic model is plotted in the fig. 5. From this graph, it is observed that the network latency is minimal compared to the two-stage approach given in [8]. 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.6. From this graph, it is observed that the number of changes is minimal compared to the two-stage approach, since the new approach avoids unnecessary (reconfiguration) addition or deletion of lightpaths.

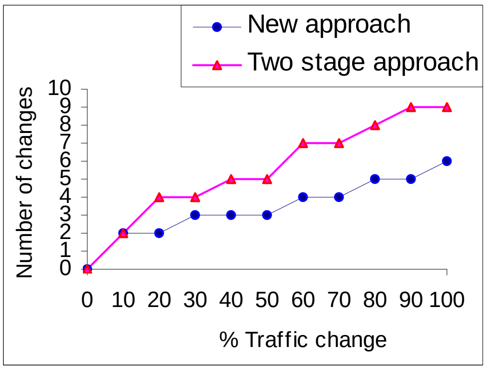

Fig 6. Number of changes vs % Traffic change

6. Conclusion

In this paper, it is proposed an algorithm for Differential Virtual Topology Reconfiguration (VTR) algorithm with considering QoS parameters for Multihop IP over WDM optical networks with i.i.d. traffic model and cluster traffic model. The proposed heuristic approach was validated using simulation. The simulation results show that the new approach achieves better QoS in terms of blocking probability; throughput and latency for i.i.d. traffic model for dynamic IP over WDM networks, compared to the existing two stage approach.

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