

# Traffic based Virtual Topology Design in a Small WDM Network with Comparative Analysis of Wavelength Dependent Cost of Established Lightpaths

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**Abstract-** In order to establish a virtual topology for a given physical topology, in a small WDM network i.e. with four to six nodes, we are considering traffic as the constraint. Another important factor is the virtual degree constraint, which is equal to the number of transmitters and receivers supported by a node in the network. The virtual topologies are designed using decreasing traffic sequence virtual topology design (DTS-VTD) algorithm and traffic independent virtual topology design (TI-VTD) algorithms, with varying virtual degree value. In the designed virtual topologies, the hops occur without violating the wavelength conflicting constraint. The topologies so designed are compared on the basis of their network traffic load satisfying capability and finally wavelength dependant cost effectiveness of the designed topologies is studied using the joint wavelength route selection algorithm in conjunction with the DTS-VTD algorithm and TI-VTD algorithm.

**Index Terms-** WDM, virtual topology, lightpaths, virtual degree constraint, virtual topology

## 1 Introduction

The virtual topology design is performed with the aim of optimizing the network parameters in such a way so as to improve the networks overall performance. The objective functions which are commonly considered are either optimizing number of wavelengths required to establish a given set of lightpaths, or to establish as many lightpaths as possible for a given set of wavelengths; or to establish lightpaths for a given set of wavelengths to maximize the total traffic throughput of the given network.[1][2][7][8]

Herein we have the objective of establishing lightpaths offering maximum traffic load satisfaction with a wavelength-dependant least cost path. The assumption made is that the traffic offered to a lightpath is independent of that offered to the others.

The constraints like the virtual degree constraint and the wavelength conflicting constraint are useful to help design a close to practically realizable virtual topology. The virtual degree constraint limits the number of lightpaths originating or terminating at a given node, by setting them less than or equal to the number of transmitters or receivers present with a node.

Hence, the value of virtual degree constraint throughout the network remains same, for reducing computational complexity. The wavelength conflicting constraint ensures that no two or more lightpaths are capable of sharing same wavelength on a physical link. The establishment of a virtual topology is dependent on how properly the transmitters, receivers, wavelengths and traffic requests are utilized. In the given physical topology, there exist bidirectional links between the connected node pairs, i.e. say the wavelength constraint is set to 2, which imply that a link is capable of supporting two wavelengths between a given node pair by having two channels or two fibres multiplexed on the same fibre. [2]

The traffic inputs to four and six node networks are different and completely random in nature. The design of the virtual topologies is done considering the traffic.

## 2 Formal Description of the Algorithms

A virtual topology is created over a given physical topology consisting of weighted links, taking into account some important parameters. The parameters like physical links, traffic, distance are input to the design algorithm in the form of matrices, with  $n \times n$  dimensions, where  $n$  denotes the number of nodes in the topology[5]. Considering the given physical topology as the base[10], a virtual topology is designed, taking into consideration the virtual degree (vd) and the wavelength constraints.

(i)Traffic Dependant Algorithm

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The Decreasing Traffic Sequence (DTS) virtual topology design algorithm is aimed at reducing the network load by giving priority to the highest traffic demand. This procedure is followed to minimize large traffic build-ups and hence congestion and propagation delay. The steps for the DTS-VTD algorithm is carried out by arranging the traffic flows in the traffic matrix are sorted in descending order; the highest traffic flow is assigned light path in accordance with the wavelength and vd constraints. The small WDM network, consisting of four to six nodes[4], would adopt different virtual topologies depending on the virtual degree supported. The weights on the links between the nodes are the distances between them.

Table1. Virtual Topology Design for Dts-Vtd Algorithm with vd=1.

Iteration	Light path	Physical Link	Wavelength	Distance (kms.)
1	2-->4	2-->4	1	1
2	4-->3	4-->3	1	2
3	1-->2	1-->2	1	1
4	3-->2	No Rx at 2	-	-
5	1-->4	No Tx at 1	-	-
6	2-->1	No Tx at 2	-	-
7	1-->3	No Tx at 1	-	-
8	4-->2	No Tx at 4	-	-
9	4-->1	No Tx at 4	-	-
10	3-->1	3-->1	1	1

The topology designed with a four node network with one transceiver, is established in accordance with the vd and the wavelength constraints. Due to the violation of the vd constraint, the links from iterations 4 to 9 have not been established, though they stand first in the order of the traffic amount. The links in this case are not considered as the bidirectional ones, i.e. the wavelength constraint has a value equal to 1 here. As the value for virtual degree is increased, more lightpaths can be build. With a vd value equal to 2, more traffic demand can be sorted. The design of lightpath topology is different for different values of the virtual degree constraint. In this design a hop is incorporated in the fourth iteration, in order to meet the aim of the DTS algorithm. Here again the wavelength constraint is unity. Taking wavelength constraint

Table2. Virtual Topology Design for Dts-Vtd Algorithm with vd=2.

Iteration	Light path	Physical link	Wavelength	Distance (kms.)
1	2-->4	2-->4	1	1
2	4-->3	4-->3	1	2

3	1-->2	1-->2	1	1
4	3-->2	3-->4-->2	1	3
5	1-->4	No Rx at 4	-	-
6	2-->1	2-->1	1	1
7	1-->3	1-->3	1	1
8	4-->2	No Rx at 2	-	-
9	4-->1	No Tx at 4	-	-
10	3-->1	3-->1	1	1
11	1-->2	No Tx at 2	-	-
12	3-->1	No Tx at 3	-	-

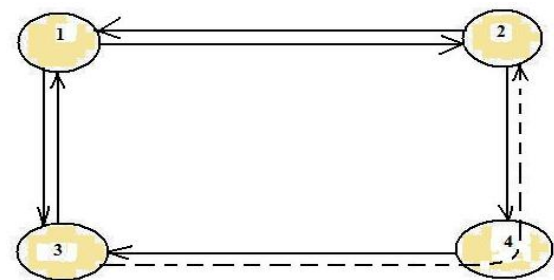


Fig.1. Lightpath topology for DTS-VTD with vd=2

as unity means no bidirectionality in links. though the lightpath topology looks the same, it actually consists of two counter clockwise flowing topologies forming a sort of dual ring structure. The virtual topology can be depicted by using ones to signify a virtual connection between nodes, and a zero for no virtual link. For a virtual degree 3 value the virtual topology designed can be represented as:

VT: 0111 1011 1101 1110

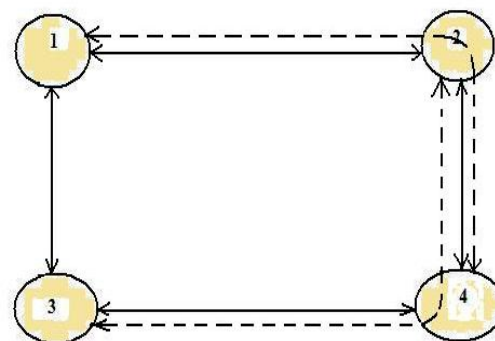


Fig.2. Lightpath topology for DTS-VTD with vd=3

Also the wavelength constraint is taken as 2,

Depicted by double arrowheaded link.

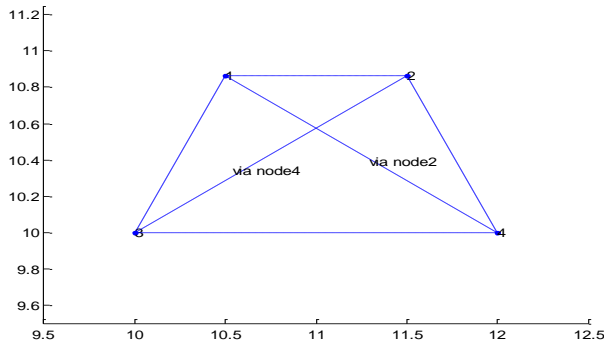


Fig.3. Virtual topology Design with DTS-VTD for vd=3, showing the link length between nodes(in kms)

Table3. Virtual Topology Design for Dts-Vtd Algorithm with vd=3.

It.	Light path	Physical link	Wavel ength	Dist. (km.)
1	2-->4	2-->4	1	1
2	4-->3	4-->3	1	2
3	1-->2	1-->2	1	1
4	3-->2	3-->4-->2	2	3
5	1-->4	1-->2-->4	3	2
6	2-->1	2-->1	1	1
7	1-->3	1-->3	1	1
8	4-->2	4-->2	1	1
9	4-->1	4-->2-->1	3	2
10	3-->1	3-->1	1	1
11	2-->3	2-->4-->3	2	3
12	3-->4	3-->4	1	2

In this case, hops are present and are possible via intermediate node 2 and 4. This node performs the opto-electronic and electro-optical routing. [2] In vd=3, all the traffic demands arising are satisfied. Now, if a six-node network is considered, new physical link, traffic and distance matrices are taken. With virtual degree value equal to 2, and taking the value of wavelength constraint as 1, which means a link is capable of supporting only one wavelength between a node pair. The virtual topology is simple and is given as:

VT: 0 1 0 0 0 1; 1 0 1 0 0 0; 0 1 0 1 0 0; 0 0 1 0 1 0; 0 0 0 1 0 1; 1 0 0 0 1 0

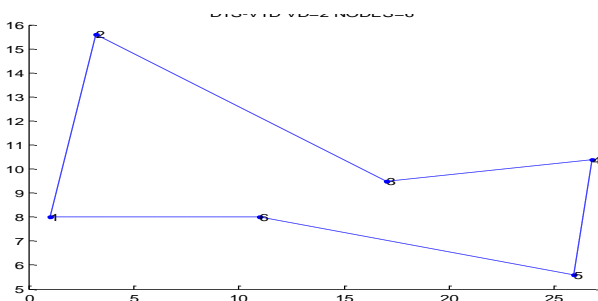


Fig.4. Virtual topology Design with DTS-VTD for vd=3, showing the link length between nodes(in kms)

In the figure 7, the actual light path connectivity between the nodes is shown. The links are capable of handling one wavelength per fiber, hence both the lightpaths i.e. 1->2->3->4->5->6->1 and 1->6->5->4->3->2->1 exist on two separate fibres. For the same case, considering the value of wavelength constraint to be 2, a totally different virtual topology is obtained which has hops in it.

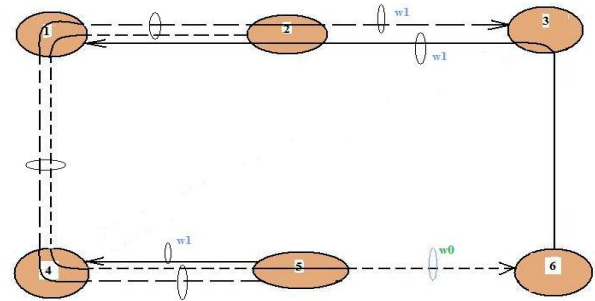


Fig.5. Lightpath topology for DTS-VTD with vd=2,M=2,maximum hops=4

This is realizable when the link is able to handle two wavelengths per fiber. The maximum hop length consisting of four hops is needed to channelize the traffic. A limit can be imposed on the maximum number of hops between the node pairs, using a virtual hop matrix.[6]

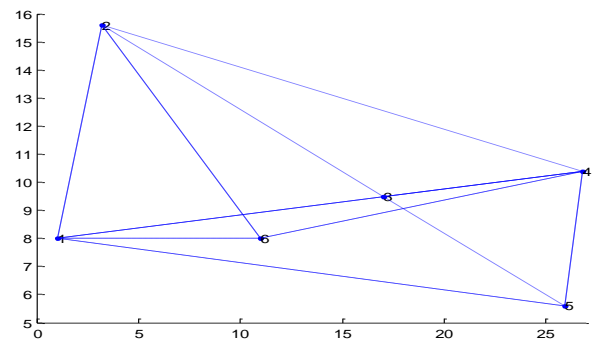


Fig.6. Virtual topology Design with DTS-VTD for vd=3, showing the link length between nodes(in kms)

The realised virtual topology can be considered for cost effectiveness by the Joint Wavelength Routing (JWR) Algorithm. Lightpaths have an important role in the cost effective management of network resources [9].The algorithm is applicable to the node pairs with two or more than two lightpaths between the nodes.

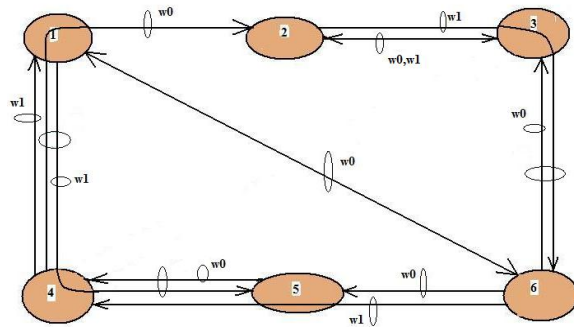


Fig.7. Lightpath topology for DTS-VTD with  $vd=2, M=2$

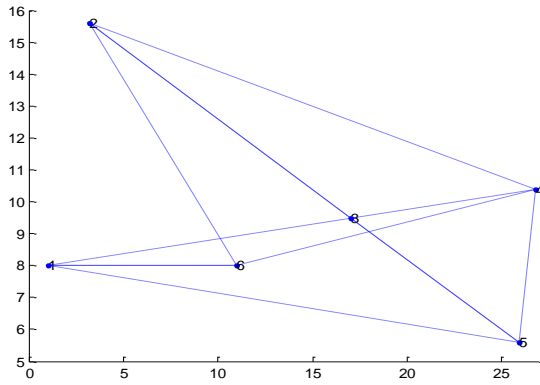


Fig.8. Virtual topology Design with DTS-VTD for  $vd=2$ , showing the link length between nodes (in kms)

The parameters needed to search for the wavelength dependant least cost lightpath are:

$A(w_i)$ : number of links on which wavelength  $w_i$  exists

$L(R_{p_i})$ : denotes the hop length

$F(R_{p_i})$ : denotes the free wavelengths on  $R_{p_i}$

$$C(w_i, R_{p_i}) = \alpha_1 \cdot A(w_i) + (1 - \alpha_1) \{ \alpha_2 [w - F(R_{p_i})] + (1 - \alpha_2) \cdot L(R_{p_i}) \}$$

where  $\alpha_1$  and  $\alpha_2$  are variables such that  $\alpha_1 \geq 0$  and  $\alpha_2 \geq 1$ . [3]

Every lightpath has a particular wavelength associated with it.

For DTS with  $vd=3$ , the complexity in wavelength assignment and hop length increases.

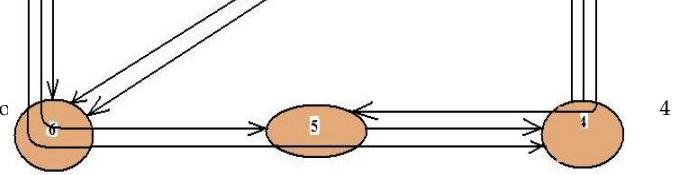


Fig.9. Lightpath topology for DTS-VTD with  $vd=3, M=2$

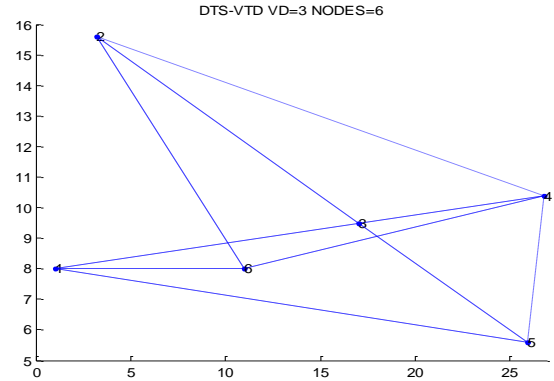


Fig.10. Virtual topology Design with DTS-VTD for  $vd=3$ , showing the link length between nodes (in kms)

The routes depicted in the figure 14, are  $R_0: 1 \rightarrow 5, R_2: 1 \rightarrow 4, R_4: 4 \rightarrow 2, R_6: 3 \rightarrow 5, R_7: 4 \rightarrow 6$  depending on the wavelength used there is a variation in the cost associated.

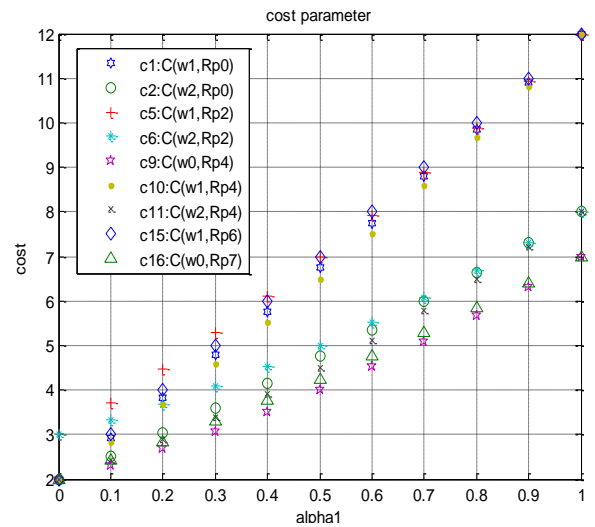


Fig. 11. Wavelength dependant cost of lightpaths in DTS-VTD with  $vd=3, M=2$ .

## (ii). Traffic Independent Algorithm

Another algorithm doesn't take into consideration the traffic, hence the name Traffic Independent (TI) Algorithm. For a four node network, with different  $vd$  values, it establishes all possible lightpaths. VT: 0100 0001 1000 0010; 0010 1000 0001 0100

Lightpaths:  $1 \rightarrow 2 \rightarrow 4 \rightarrow 3 \rightarrow 1$  via  $W_0$ ;  $1 \rightarrow 3 \rightarrow 4 \rightarrow 2 \rightarrow 1$  via  $W_1$

In case the virtual degree value is 2, then:

VT 0110 1001 1001 0110

RWA  $1 \rightarrow 2 \rightarrow 4 \rightarrow 3 \rightarrow 1$  and  $1 \rightarrow 3 \rightarrow 4 \rightarrow 2 \rightarrow 1$  via  $W_0$

In case the virtual degree value is 3, then:

VT 0111 1011 1101 1110

RWA VD=2 case plus 1-->4, 4-->1 via W1; 2-->3, 3-->2 via W1

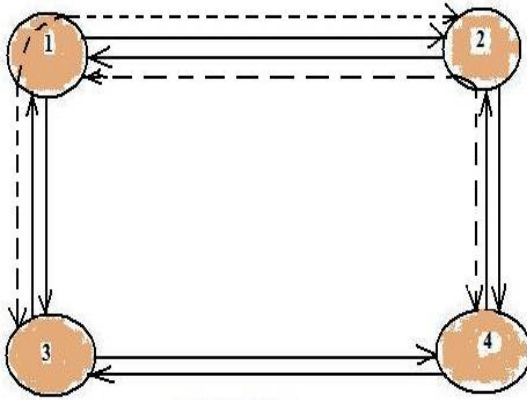


Fig.12. Lightpath topology for TI-VTD with vd=3,M=2

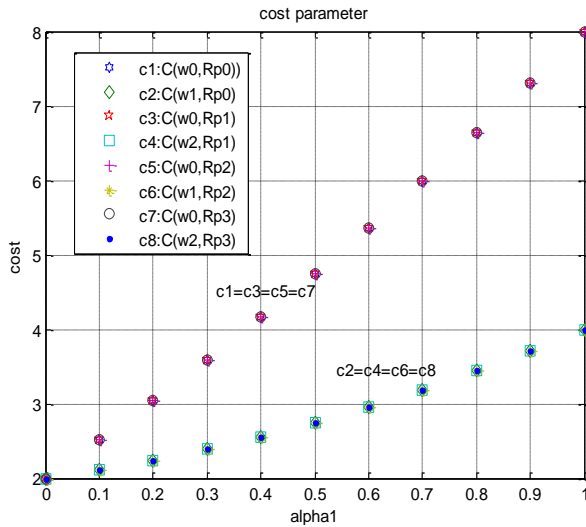


Fig. 13. Wavelength dependant cost of lightpaths in TI-VTD with vd=3,M=2.

The routes depicted in the figure 17, are R0: 4->1,R1:2->3,R2:1->4,R3:3->2 depending on the wavelength used there is a variation in the cost associated.

For a six node network, taking M=1, ie each fiber link supports single wavelength value, the vd 2 virtual topology is:

VT:[0 1 0 1 0 0;1 0 1 0 0 0;0 1 0 0 0 1;1 0 0 0 1 0;0 0 0 1 0 1;0 0 1 0 1 0]

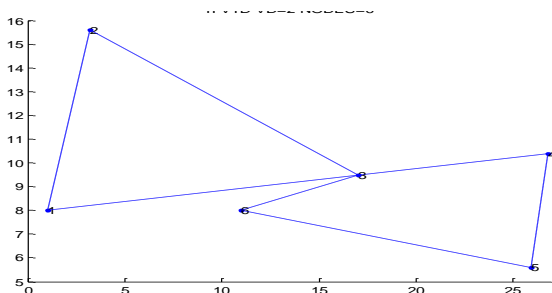


Fig.14. Virtual topology Design with TI-VTD for vd=2, showing the link length between nodes(in kms)

VT:[0 1 1 1 0 0;1 0 1 1 0 0;1 1 0 0 0 1;1 1 0 0 1 0;0 0 1 1 0 1;0 0 0 0 0 0]

This is the virtual topology configuration for vd value 3. The routes depicted in the figure 21, are R0: 2->4,R1:4->2,R2:3->1,R3:5->3 depending on the wavelength used there is a variation in the cost associated.

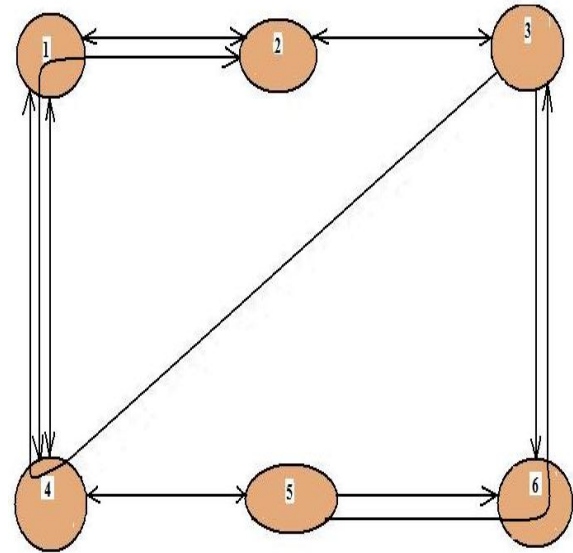


Fig. 15. Lightpath topology for TI-VTD with vd=3,M=2

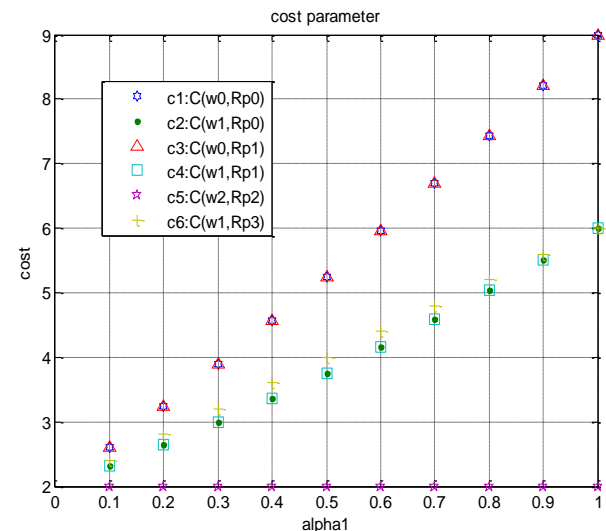


Fig. 16. Wavelength dependant cost of lightpaths in TI-VTD with vd=3,M=2.

## COMPARATIVE ANALYSIS

The virtual topologies designed by the algorithms already discussed can be analysed based on their network load reducing capability. The traffic requests entering a network must be entertained in such a way so as to prevent congestion and delay from occurring. Thus the traffic can be handled as it comes, which is applied with the help of TI-VTD algorithm or it can be dealt with based upon its bulkiness, which is applied with the help of DTS-VTD algorithm. Both these approaches are equally relevant. TI-VTD algorithm is computationally fast as it need not look for the highest traffic demand through out the network, whereas DTS-VTD helps get rid of large traffic demands first leading to lower risk of network congestion.

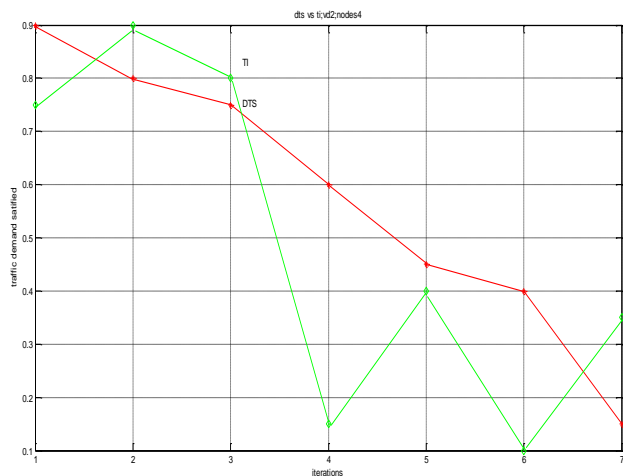


Fig. 17. Traffic Demand satisfied versus Iterations for DTS and TI; vd=2; nodes=4.

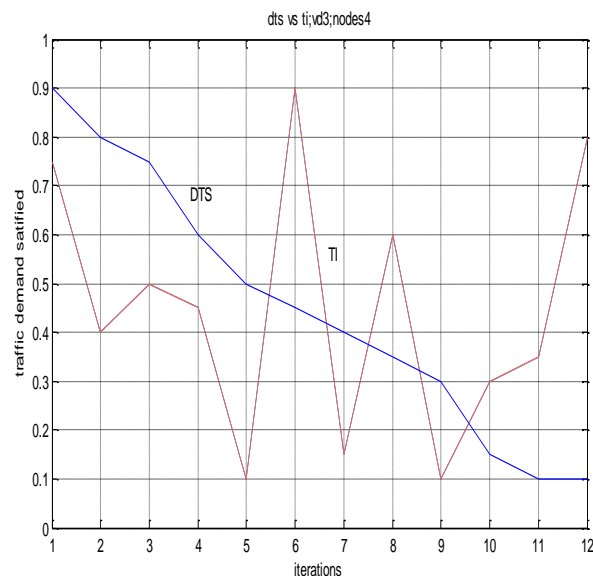


Fig. 18. Traffic Demand satisfied versus Iterations for DTS and TI; vd=3; nodes=4.

DTS algorithm lowers the network traffic load considerably for the same number of iterations as compared to TI algorithm. The slope varies abruptly in the TI algorithm. The second highest traffic demand value of 0.8 that is

entertained in the second iteration in DTS whereas in TI it gets satisfied in the last iteration.

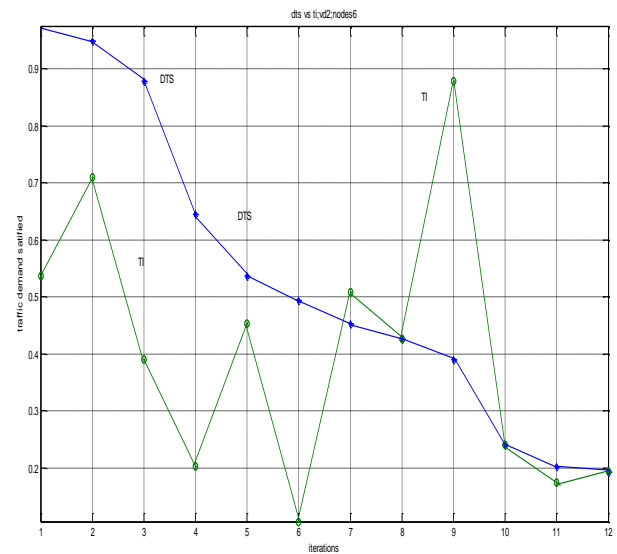


Fig. 19. Traffic Demand satisfied versus Iterations for DTS and TI; vd=2; nodes=6.

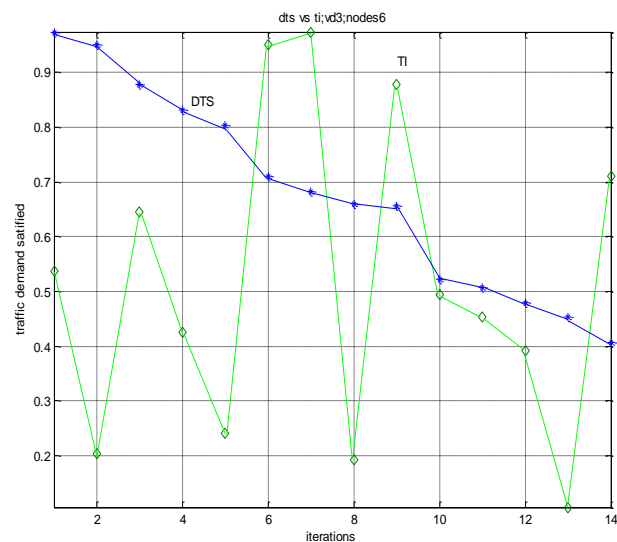


Fig. 20. Traffic Demand satisfied versus Iterations for DTS and TI; vd=3; nodes=6.

Similar outcomes hold when number of nodes in the network are increased to six. The network load reduction is related to the networks virtual degree value in DTS algorithm and is totally independent in TI algorithm. This holds true even when the number of nodes is increased to six, in a small scale WDM network.



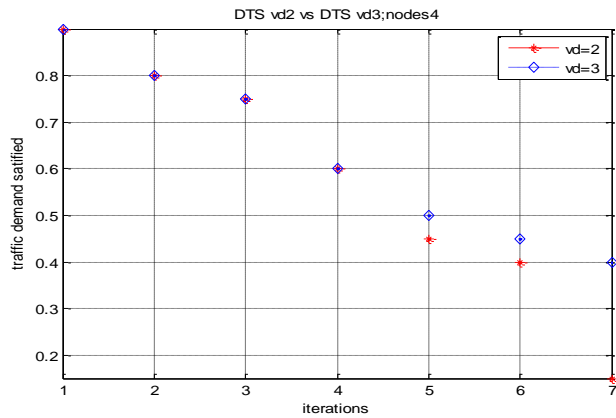


Fig. 21. Traffic Demand satisfied versus Iterations for DTS; when vd is varied; nodes=4.

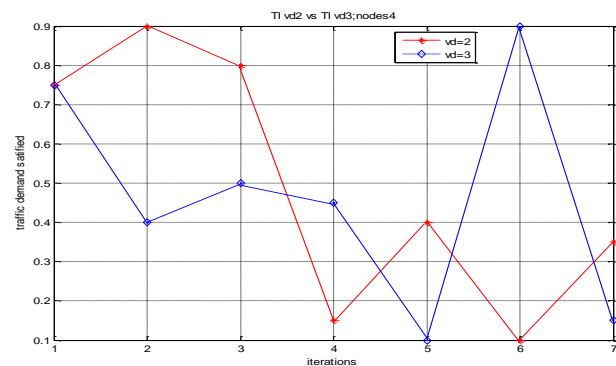


Fig. 22. Traffic Demand satisfied versus Iterations for TI; when vd is varied; nodes=4.

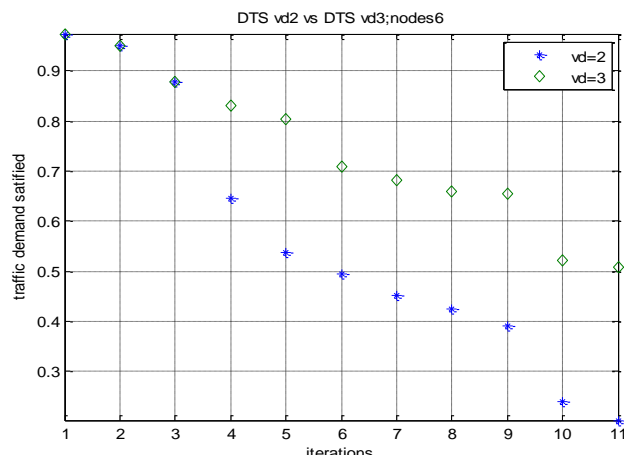


Fig. 23. Traffic Demand satisfied versus Iterations for DTS; when vd is varied; nodes=6.

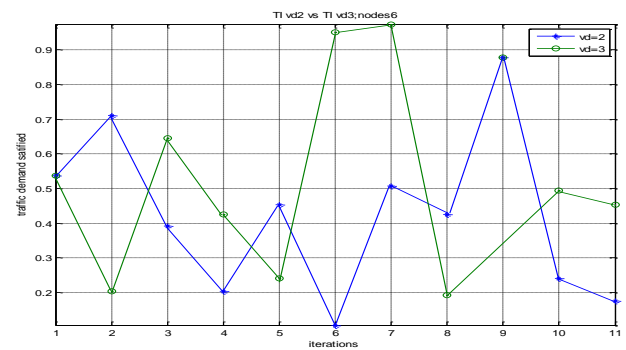


Fig. 24. Traffic Demand satisfied versus Iterations for TI; when vd is varied; nodes=6.

The cost effectiveness of the lightpaths established via varying the virtual degree and the number of nodes can be used to analyse the best possible lightpaths. All the wavelength dependant least cost lightpaths from different nodes and virtual degree values of the two algorithms are used for the comparative analysis. There is a comparative increase in the cost of the lightpaths with higher value of the virtual degree constraint. The cost is wavelength dependant, hence there is a direct relation between the number of wavelengths utilised and the virtual degree value.

For the same number of nodes and virtual degree value, the cost for DTS algorithm is slightly higher than the TI algorithm, which can be compromised with the better traffic handling capability of DTS algorithm. Another observation shows that the cost can be equalised by creating an inverse relation between the number of nodes and the virtual degree value. The wavelength dependant cost for DTS with six nodes and virtual degree value 2 is the same as that of TI algorithm with four nodes and virtual degree value 3, hence creating an inverse relation.

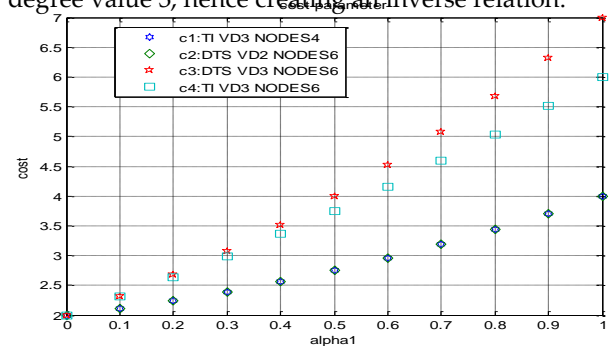


Fig.25. Cost versus alpha1 for different values of vd constraint and number of nodes for DTS, TI algorithms.

## CONCLUSION

In this paper, we have designed virtual topologies for a given physical topology, for a small WDM network containing four to six nodes, by varying the virtual degree constraint. Two approaches are adopted : traffic dependent

and traffic independent approach. These are analysed by the wavelength dependent cost effectiveness of the established individual lightpaths. By this analysis, lightpaths relation to the number of nodes and virtual degree is made, taking wavelength dependant cost as the parameter.

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