THESIS REPORT ON PERFORMANCE ANALYSIS OF OPTICAL WDM NETWORKS

THIS THESIS IS SUBMITTED IN THE PARTIAL FULLFILMENT OF THE REQUIREMNT FOR THE DEGREE OF
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2012

NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA

CERTIFICATE

This is to certify that the thesis entitled "**Performance Analysis of Optical WDM Networks**" submitted by **Sunil Kumar Kilaka (108EC016)** and **Himansu Sahu (108EC025)** in partial fulfilment of the requirements for the award of Bachelor of Technology Degree in **Electronics And Communication Engineering** at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by them under my guidance during session 2011-2012.

The matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree.

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ABSTRACT

An optical network provides a common infrastructure over which a verity of services can be delivered. These networks are also capable of delivering bandwidth in a flexible manner, supports capacity up gradation and transparency in data transmission. It consists of optical source (LED, LASER) as transmitter and optical fibre as transmission medium with other connectors and photo detector, receiver set. But due to limitation of electronic processing speed, it’s not possible to use all the BW of an optical fibre using a single high capacity channel or wavelength.

The primary problem in a WDM network design is to find the best possible path between a source-destination node pair and assign available wavelength to this path for data transmission. To determine the best path a series of measurements are performed which are known as performance matrices. From these performance matrices, the Quality of Service parameters are determined. Here we have designed four different network topologies having different number of nodes, but each having equal capacity. We have simulated all these networks with different scenario to obtain the performance matrices. Then we have compared those performance matrices to suggest which network is best under the present case..

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ACRONYMS

PON-Passive Optical Network

WDM-Wavelength Division Multiplexing

QoS-Quality of Service

WWC-Wavelength Channel Capacity

‘S’ node-Source node

‘D’ node- Destination node

TD-Traffic Demand

Chapter 1

INTRODUCTION

1. Introduction

In this digital era the communication demand has increased from previous eras due to introduction of new communication techniques. As we can see there is increase in clients day by day, so we need huge bandwidth and high speed networks to deliver good quality of service to clients. Fiber optics communication is one of the major communication systems in modern era, which meets up the above challenges. This utilizes different types of multiplexing techniques to maintain good quality of service without traffic, less complicated instruments with good utilization of available resources .Wavelength Division Multiplexing (WDM) is one of them with good efficiency. It is based on dynamic light-path allocation. Here we have to take into consideration the physical topology of the WDM network and the traffic. We have taken performance analysis as parameter to analyse which type of topology is best suited to implement in real life application without degrading quality of service (QoS).

1.1. WDM

In optical communication, wavelength division multiplexing (WDM) is a technology which carries a number of optical carrier signals on a single fibre by using different wavelengths of laser light. This allows bidirectional communication over one standard fibre with in increased capacity. As optical network supports huge bandwidth; WDM network splits this into a number of small bandwidths optical channels. It allows multiple data stream to be transferred along a same fibre at the same time. A WDM system uses a number of multiplexers at the transmitter end, which multiplexes more than one optical signal onto a single fibre and demultiplexers at the receiver to split them apart. Generally the transmitter consists of a laser and modulator. The light source generates an optical carrier signal at either fixed or a tuneable wavelength. The receiver consists of photodiode detector which converts an optical signal to electrical signal [1]. This new technology allows engineers to increase the capacity of network without laying more fibre. It has more security compared to other types of communication from tapping and also immune to crosstalk [2].

Each wavelength is like a separate channel (fiber)

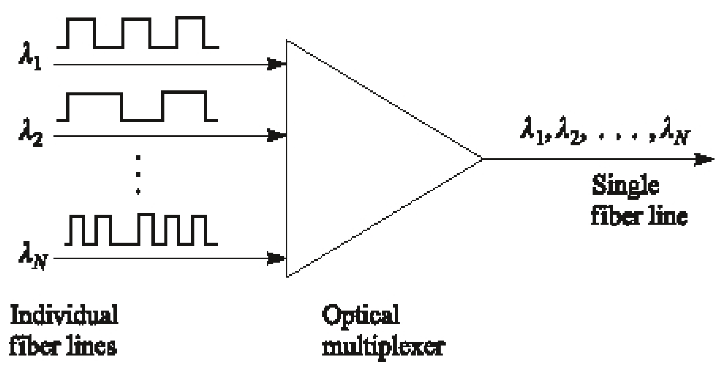

Fig 1.1 Wavelength Division Multiplexing

1.2. Different types WDM network

The optical network has huge bandwidth and capacity can be as high as 1000 times the entire RF spectrum. But this is not the case due to attenuation of signals, which is a function of its wavelength and some other fibre limitation factor like imperfection and refractive index fluctuation. So 1300nm (0.32dB/km)-1550nm (0.2dB/km) window with low attenuation is generally used.

According to different wavelength pattern there are 3 existing types as:-

- WDM (Wavelength Channel Multiplexing)
- CWDM (Coarse Wavelength Division Multiplexing)
- DWDM (Dense Wavelength Division Multiplexing)

Table 1.1 Types of WDM Networks

Parameters	WDM	CWDM	DWDM
Channel Spacing	1310nm & 1550nm	Large,1.6nm-25nm	Small,1.6nm or less
No of base bands used	C(1521-1560 nm)	S(1480-1520 nm)C(1521-1560 nm),L(1561-1620 nm)	C(1521-1560 nm),L(1561-1620 nm)
Cost per Channel	Low	Low	High
No of Channels Delivered	2	17-18 most	hundreds of channel possible
Best application	PON	Short haul, Metro	Long Haul

1.3. Benefits of WDM

Wavelength Channel Multiplexing (WDM) is important technology used in today's telecommunication systems. It has better features than other types of communication with client satisfaction. It has several benefits that make famous among clients such as:

1.3.1. Capacity Upgrade

Communication using optical fibre provides very large bandwidth. Here the carrier for the data stream is light. Generally a single light beam is used as the carries. But in WDM, lights having different wavelengths are multiplexed into a single optical fibre. So in the same fibre now more data is transmitted. This increases the capacity of the network considerably.

1.3.2. Transparency

WDM networks supports data to be transmitted at different bit rates. It also supports a number of protocols. So there is not much constraint in how we want to send the data. So it can be used for various very high speed data transmission applications.

1.3.3. Wavelength Reuse

WDM networks allows for wavelength routing. So in different fibre links the same wavelength can be used again and again. This allows for wavelength reuse which in turn helps in increasing capacity [5].

1.3.4. Scalability

WDM networks are also very flexible in nature. As per requirement we can make changes to the network. Extra processing units can be added to both transmitter and receiver ends. By this infrastructure can redevelop to serve more number of people.

1.3.5. Reliability

WDM networks are extremely reliable and secure. Here chance of trapping the data and crosstalk is very low. It also can recover from network failure in a very efficient manner. There is provision for rerouting a path between a source-destination node pair. So in case of link failure we will not lose any data [19].

1.4. QoS in WDM Network

Quality of Service (QoS) parameters refers to certain parameters which are used to determine performance of a WDM network. To determine QoS first all the possible light paths are found out. Then a number of measurements are performed on these light paths using simulation software, whose results are called performance matrices. From these performance matrices QoS is determined.

Few QoS parameters are Delay, Network Congestion, and Single Hop Traffic/Offered Traffic [7]. For better performance, delay should be low, Network Congestion should be less and Single Hop Traffic/Offered Traffic should be more. So while designing the network, these conditions should be taken into account.

Chapter 2

LITERATURE REVIEW

2. Literature Review

The paper [2] says designed the Mat Plan WDM software for topology design, multi hour analysis & performance analysis. It is a MATLAB-based publicly available network planning tool for Wavelength-Routing (WR) optical networks, and it was fully developed by our research group. His paper describes the multi-hour planning analysis extension included into the Mat Plan WDM version 3.It's novel functionality allows the user to test planning algorithms which react under changes in the traffic demands. Multi-hour traffic patterns appear typically in backbone WR networks that span over large geographical areas, where network nodes are situated in different time zones. A case study example is included to illustrate the merits of the tool.

The articles [16] discuss the routing and wavelength assignment (RWA) problem in optical networks employing wavelength division multiplexing (WDM) technology. Two variants of the problem are studied: static RWA, whereby the traffic requirements are known in advance, and dynamic RWA in which connection requests arrive in some random fashion. Both point-to-point and multicast traffic demands are considered.

Input data for communication network design/optimization problems involving multi-hour or uncertain traffic can consist of a largest of traffic matrices [17]. These matrices are explicitly considered in problem formulations for link dimensioning. However, many of these matrices are usually dominated by others so only a relatively small subset of matrices would be sufficient to obtain proper link capacity reservations, supporting all original traffic matrices. Thus, elimination of the dominated matrices leads to substantially smaller optimization problems, making them treatable by contemporary solvers. In their paper they discussed the issues behind detecting domination of one traffic matrix over another. They consider two basic cases of domination: (i) total domination when the same traffic routing must be used for both matrices, and (ii) ordinary domination when traffic dependent routing can be used. The paper is based on our original results and generalizes the domination results known for fully connected networks.

Due to power considerations [18], it is possible that not all wavelengths available in a fiber can be used at a given time. In his paper, an analytical model is proposed to evaluate the blocking performance of wavelength-routed optical networks with and without wavelength conversion where the usable wavelengths in a fiber is limited to a certain maximum number, referred to as wavelength usage constraint. The effect of the wavelength usage constraint is studied on ring and mesh-torus networks. It is shown that the analytical model closely approximates the simulation results. It is observed that increasing the total number of wavelengths in a fiber is an attractive alternative to wavelength conversion when the number of usable wavelengths in a fiber is maintained the same.

The paper [19] says while optical-transmission techniques have been researched for quite some time, optical "networking" studies have been conducted only over the past dozen years or so. The field has matured enormously over this time: many papers and Ph.D. dissertations have been produced, a number of prototypes and test beds have been built, several books have been written, a large number of startups have been formed, and optical WDM technology is being deployed in the marketplace at a very rapid rate. The objective of this paper is to summarize the basic optical-networking approaches, briefly report on the WDM deployment strategies of two major U.S. carriers, and outline the current research and development trends on WDM optical networks.

Chapter 3

PROBLEM STATEMENT & NETWORK DESIGN

3. Problem Statement & Network Design

In WDM technology to be deployed we need a physical topology. After topology design we need routing and wavelength assignment to make it fully functional. Here we have taken three problem statements as:

- To design 60 Gbps capacity topology and compare performance matrices.
- To design 100 Gbps capacity topology and compare the performance matrices with 60 Gbps topology.
- To design a network to study the case of link failure and check the performance matrices.

3.1. Routing and Wavelength Assignment

A connection needs to be established in the optical layer in order to carry the information between the clients of the network. The optical connection that is maintained between a source node, s and destination node, d is known as an optical path or light path. The problem of finding a route for a light path and assigning a wavelength to the light path is referred to as the routing and wavelength assignment problem (RWA) [11].

The problem of RWA is divided into two parts:-

- Routing
- Wavelength Assignment

In the traffic model, the RWA problem is considered as two:-

- Static Light path Establishment (SLE): The idea is to reduce the number of wavelengths needed to accommodate the given connection set.
- Dynamic Light path Establishment (DLE): The idea is to reduce the blocking probability.

3.2. Existing Wavelength Assignment Algorithms

There are different types of wavelength assignment algorithms are used in WDM network. It is important task after designing a physical topology upon which whole network quality depends. So the existing wavelength algorithms are follows as:

3.2.1. Random Wavelength Assignment

In this algorithm, first all possible routes between a source-destination node pair is determined. Then all the free wavelengths (which are currently not being used) are found out. Then randomly a wavelength is assigned for data transmission to take place[16].

3.2.2. First-fit Wavelength Assignment

Here, each and every wavelength is numbered. When a connection request is made, the wavelength which is having the lowest assigned number is selected from the available wavelength set.

3.3.3. Most-used Wavelength Assignment

The wavelength that is used by the highest number of links in the network is the most used wavelength. The most used wavelength is selected by the most used algorithm from the available wavelength on the path.

3.3.Constraints

The two fundamental constraints to be followed for the purpose of wavelength assignment are as follows:

3.3.1. Wavelength Continuity Constraint

Along the path from the source to destination nodes, a light path must use the same wavelength on all the links.

3.3.2. Distinct Wavelength Constraint

Within a link all the light paths must be assigned different wavelengths.

3.4.Performance Analysis

The objective is to determine all possible paths from source to destination in WDM optical network. If there is a connection request from a source node to a destination node, first all possible paths are determined, then a series of measurements are performed using a simulation tool. The results are called performance matrices. Then comparing these performance matrices best possible paths is determined [22].

Here we have designed four different network topologies having different number of nodes, but each having equal capacity. Then we have simulated them with different scenarios to obtain the performance matrices. Then we have compared those to suggest which network is best for the present case.

3.5.Network Design

We have designed four different mesh network topologies (fully connected) having 6, 9, 12 and15 nodes. Also we have further designed two 9-nodes networks to analyse the link failure case. We have designed an .xml code to design each network. The .xml contains the list of nodes and fibre links in the network. Per node information is composed by the X and Y coordinates of the node measured in kilometres over a Euclidean plane, number of E/O transmitters, O/E receivers, node population, node type (or node level), number of nodes and the name of each node. Per link information is the maximum number of wavelengths per link and the number of optical fibres.

6-NODE FULLY CONNECTED MESH TOPOLOGY

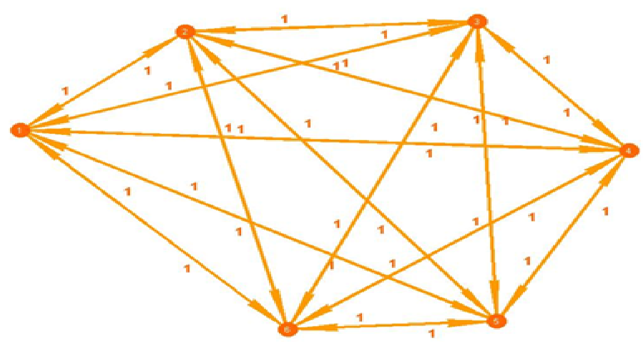

Fig. 3.1: 6-node Mesh Topology

Table 3.1: Physical Information for 6-node network

Number Of Nodes	6
Total Number Of Links	30
Total offered capacity	60Gbps
Number of available wavelengths	40
Type of Connection	Bidirectional

9-NODE FULLY CONNECTED MESH TOPOLOGY

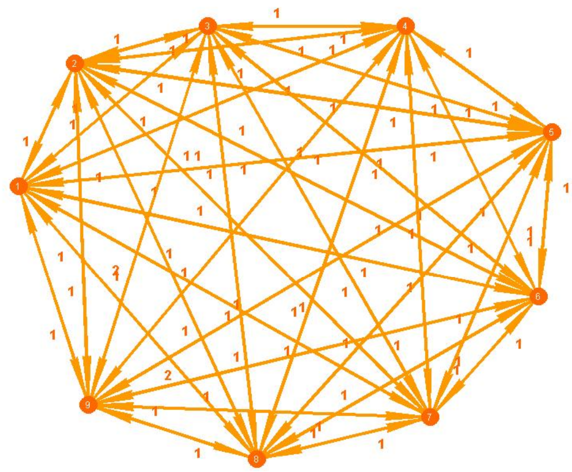

Fig. 3.2: 9-node Mesh Topology

Table 3.2: Physical Information for 9-node network

Number Of Nodes	9
Total Number Of Links	72
Total offered capacity	60Gbps
Number of available wavelengths	40
Type of Connection	Bidirectional

12-NODE FULLY CONNECTED MESH TOPOLOGY

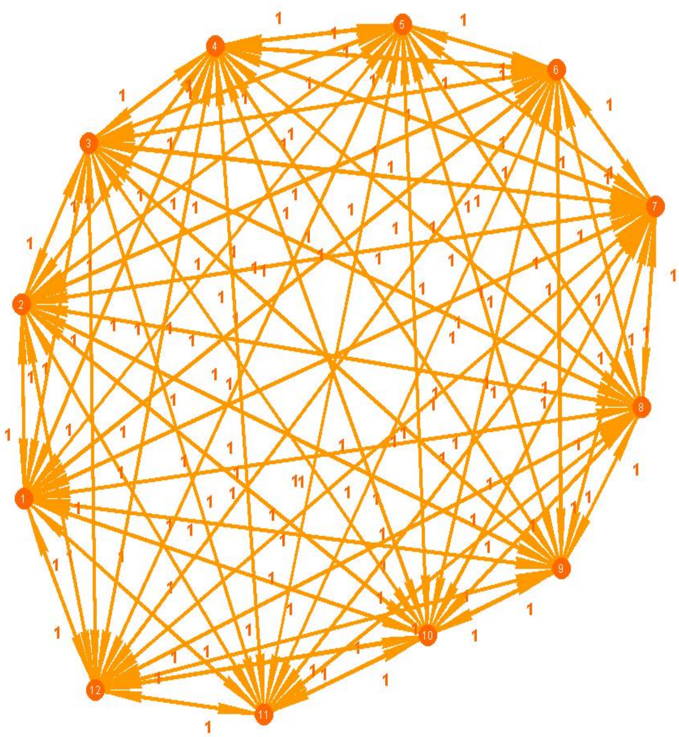

Fig. 3.3: 12-node Mesh Topology

Table 3.3.1: Physical Information for 12-node network

Number Of Nodes	12
Total Number Of Links	132
Total offered capacity	60Gbps
Number of available wavelengths	40
Type of Connection	Bidirectional

15-NODE FULLY CONNCETED MESH TOPOLOGY

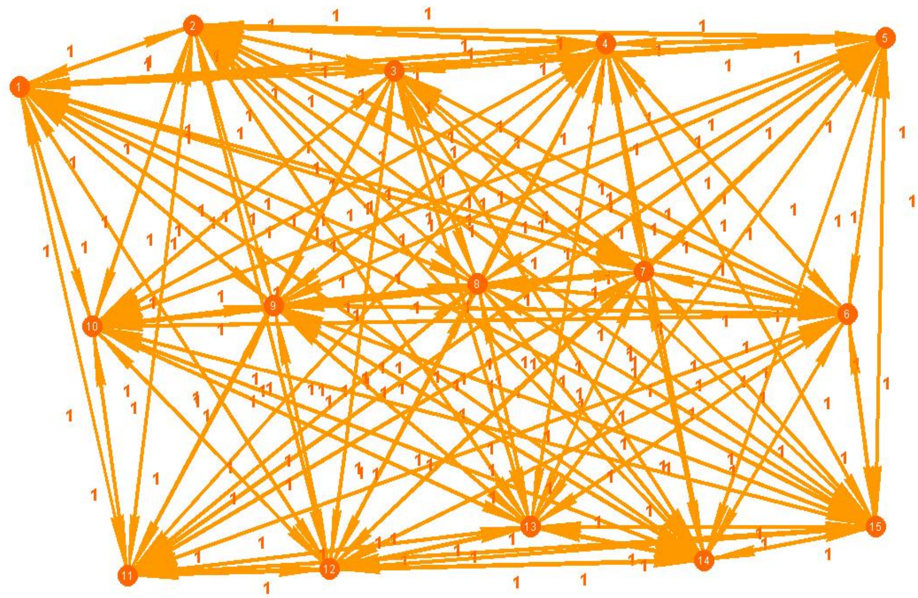

Fig. 3.4: 15-node Mesh Topology

Table 3.4: Physical Information for 15-node network

Number Of Nodes	15
Total Number Of Links	210
Total offered capacity	60Gbps
Number of available wavelengths	40
Type of Connection	Bidirectional

9-NODE TOPOLOGIES TO ANALYZE LINK FAILURE CASE

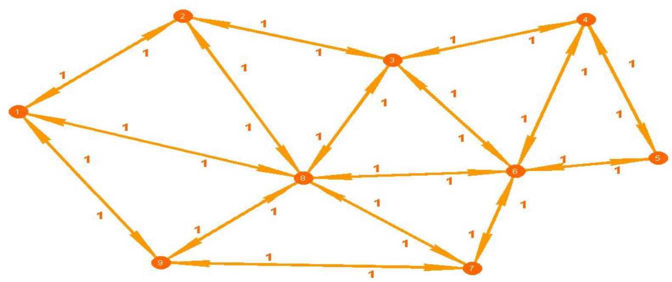

Fig. 3.5: 9-node Topology Before Link Failure

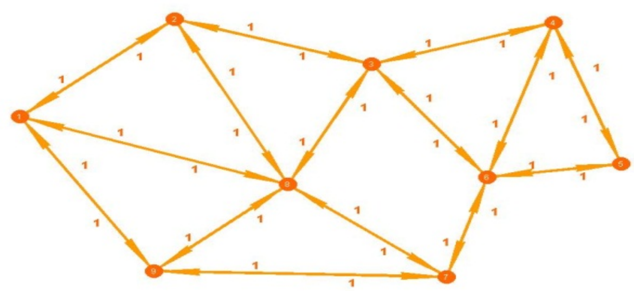

Fig. 3.6: 9-node Topology After Link Failure

Table 3.5: Physical Information for 9-node networks

Parameters	Before Link Failure	After Link Failure
Number Of Nodes	9	9
Total Number Of Links	32	30
Total offered capacity	60Gbps	60Gbps
Number of available wavelengths	40	40
Type of Connection	Bidirectional	Bidirectional

In the above two networks, to analyse the link failure case, we have removed one link. The link removed is between 6-8 node pair. Accordingly the traffic matrix is changed to analyse the link failure case.

Chapter 4

SIMULATION RESULTS AND DISCUSSIONS

4. Simulation Results

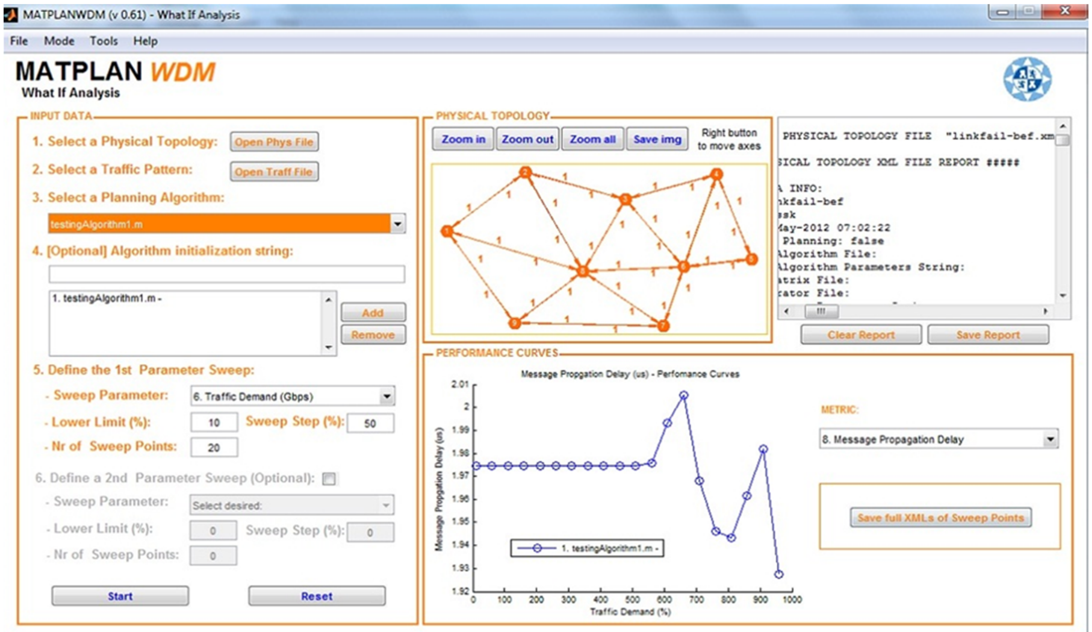

Fig. 4.1: Screen shot of MatPlanWDM (v.061) simulator

Here we have used MatPlanWDM (0.61) as the simulation tool to simulate our topologies. It takes physical topology and traffic data for different network topologies. Here performance analysis of the four topologies has been done using MatPlanWDM0.61 simulator. We have to give topologies in .xml & traffic file in .traff format. The algorithm we used here is a shortest path algorithm. After that we have selected sweep parameters with lower & upper limits and number of sweep points to start simulation.

4.1.For 60 Gbps Networks

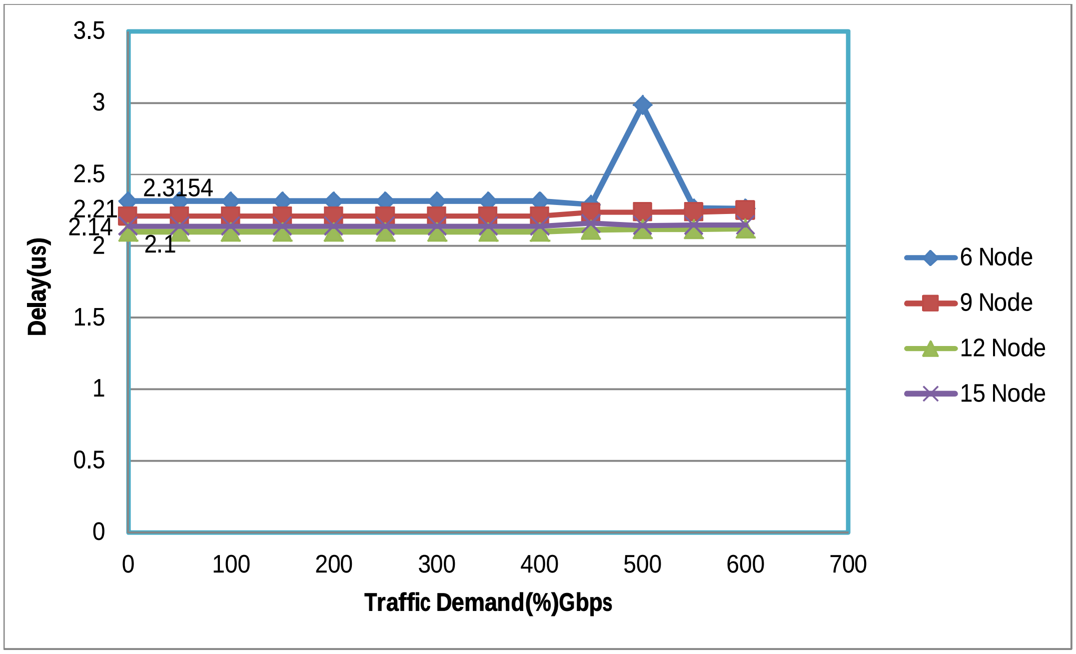

Fig. 4.2: Delay vs Traffic Demand-CASE-1

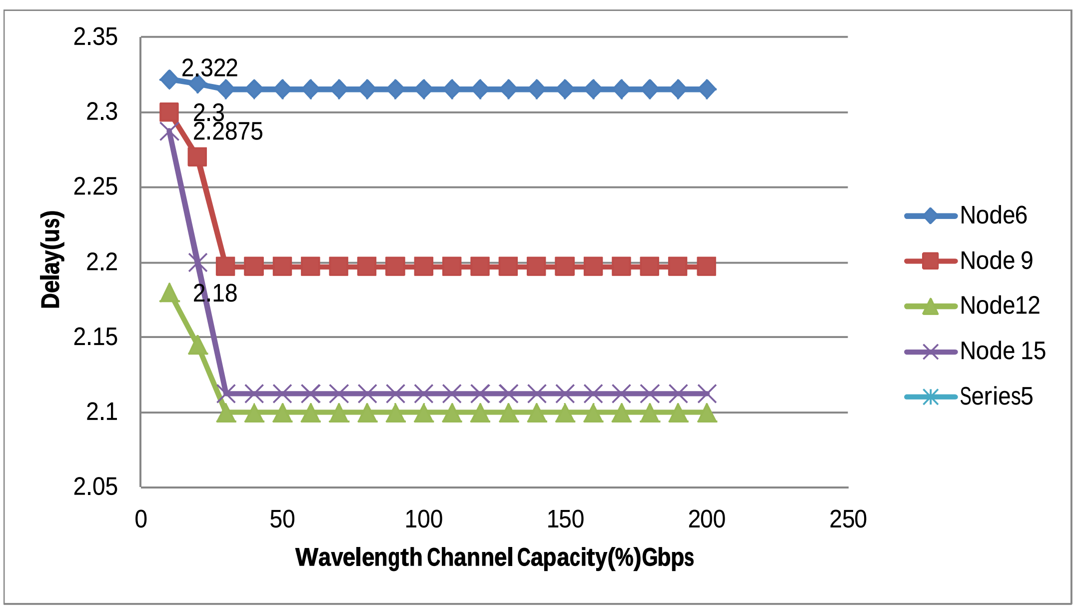

Fig. 4.3: Delay vs WCC-CASE-1

As observed from the above figures delay is increasing with increase in traffic demand, but decreasing with increase in WCC. Also average delay of network is more for 6-node network, whereas least for 15-node network. So more number of nodes is preferable.

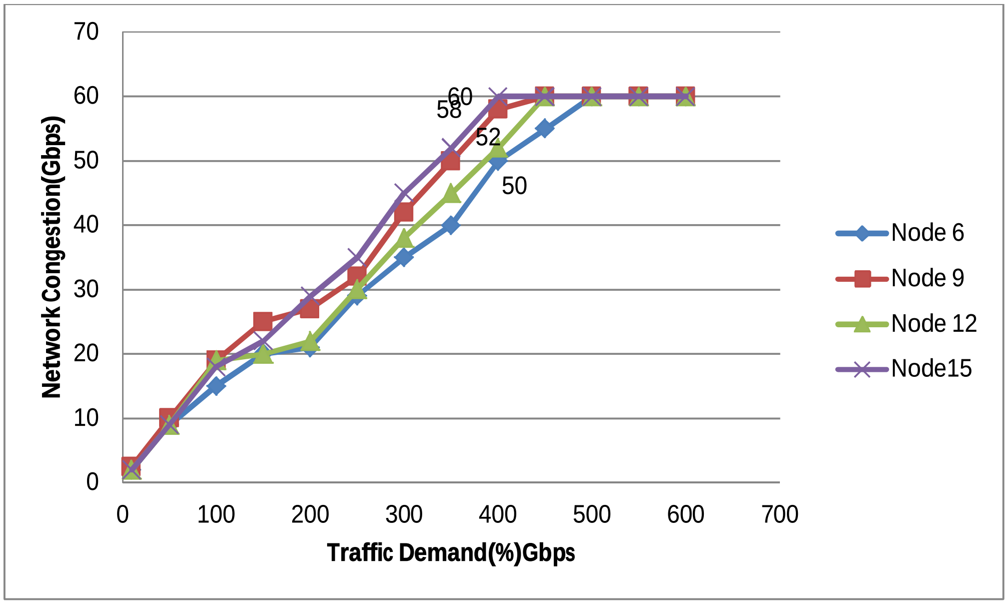

Fig. 4.4: Network Congestion vs Traffic Demand-CASE-1

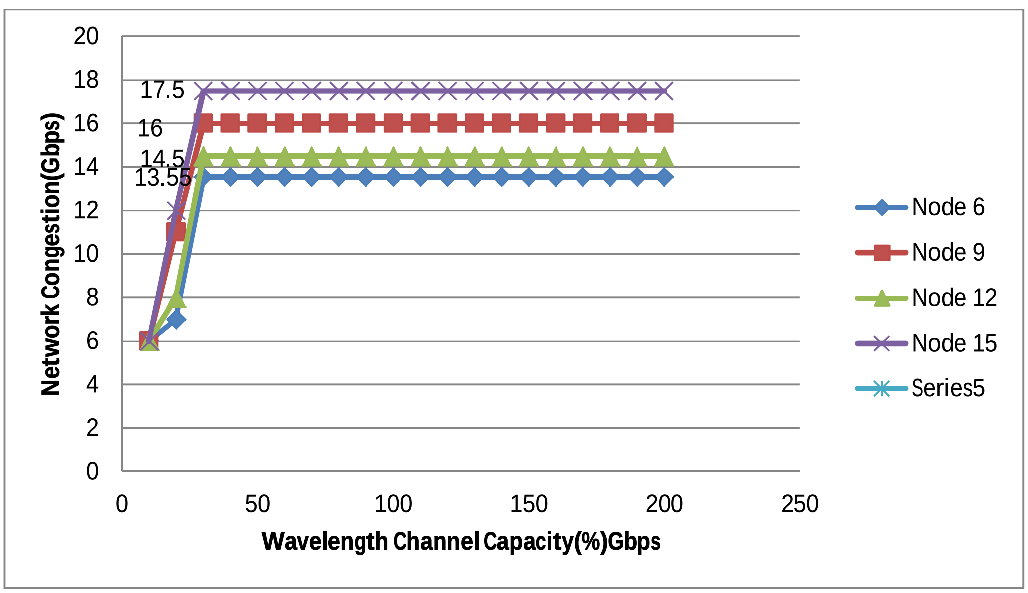

Fig. 4.5: Network Congestion vs WCC-CASE-1

From the above figures we observe that network congestion increase with both increase in traffic demand and WCC. Also network congestion is more for networks having more number of nodes. So network having less number of nodes is preferable.

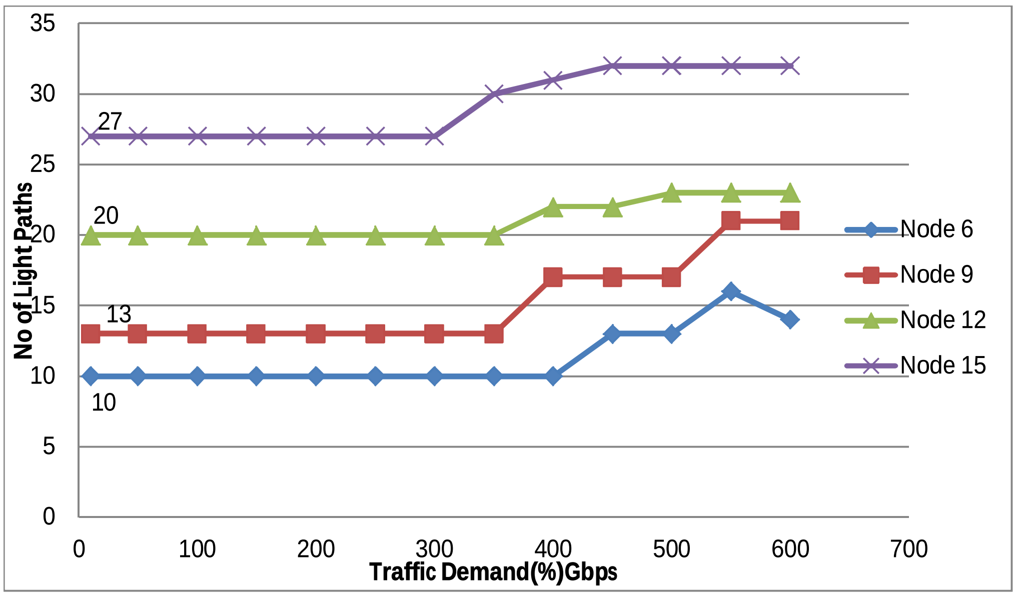

Fig. 4.6: Number of Light paths vs Traffic Demand-CASE-1

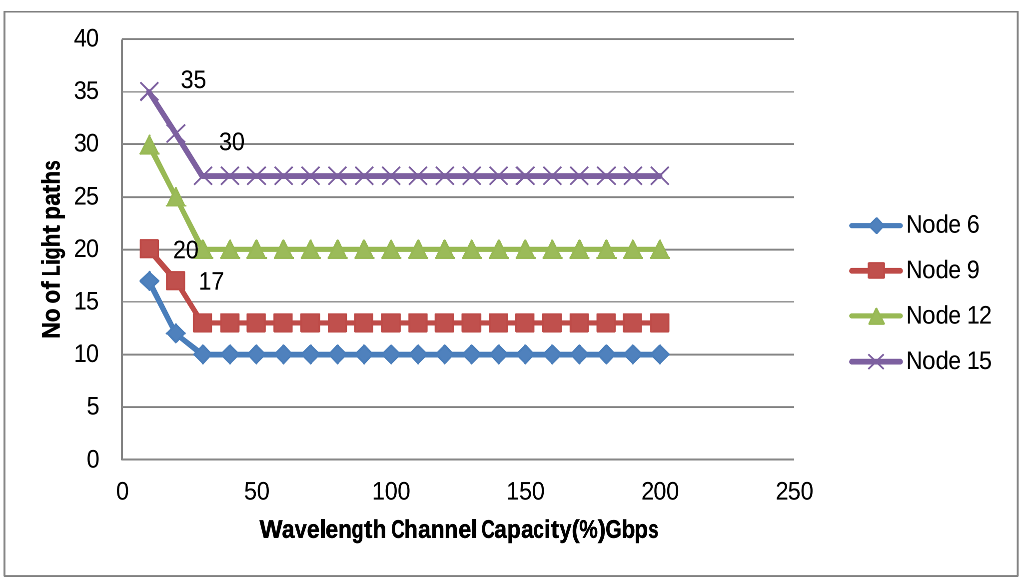

Fig. 4.7: Number of Light paths vs WCC-CASE-1

Number of light path increases with increase in traffic demand as light paths are created as per demand. It decreases with increase in WCC, because as the capacity for each channel increases, the number of light path will decrease to maintain the total offered traffic. More number of light paths are desirable for better routing. Therefore network having more number of nodes is preferable.

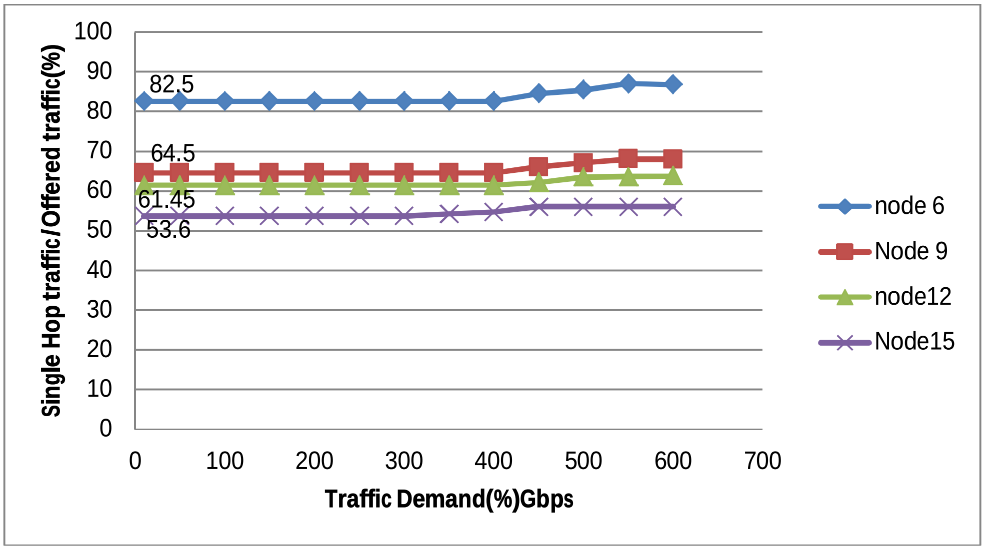

Fig. 4.8: Single Hop Traffic/Offered Traffic vs Traffic Demand-CASE-1

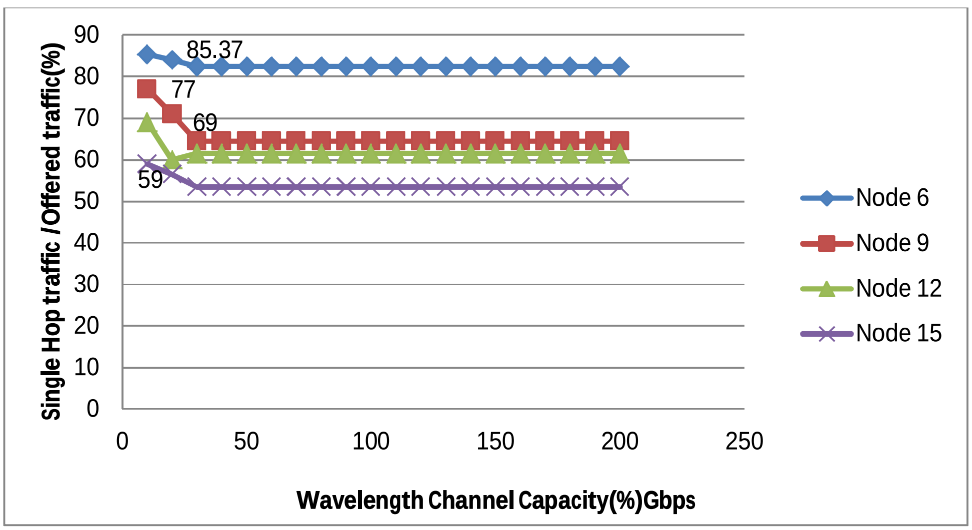

Fig. 4.9: Single Hop Traffic/Offered Traffic vs WCC-CASE-1

Single Hop Traffic/Offered Traffic is more for 6-node network as it has least number of hops. This is desirable. As number of nodes increases Single Hop Traffic/Offered Traffic decreases. So network having less number of nodes is preferable.

4.2.For 100 Gbps Networks

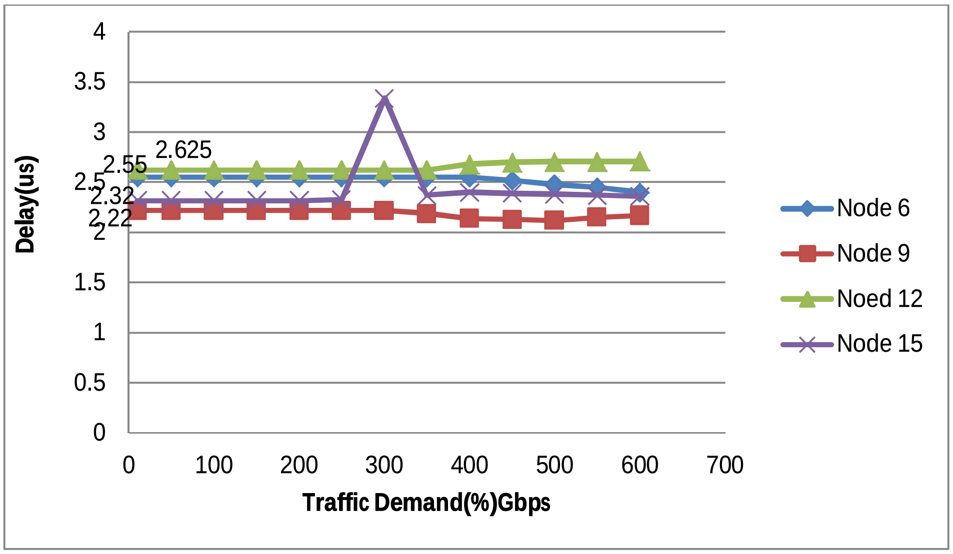

Fig. 4.10: Delay vs Traffic Demand-CASE-2

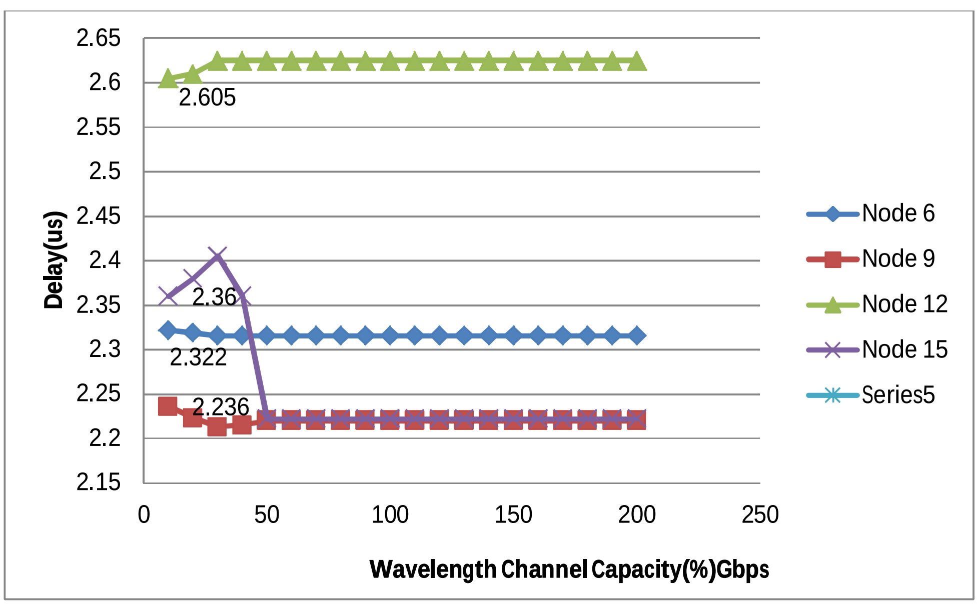

Fig. 4.11: Delay vs WCC-CASE-2

So we can observe that with increase in capacity delay is also increasing with traffic demand, but decreasing with increase with WCC. So it is preferable not to have a very high capacity network. Otherwise QoS will decrease.

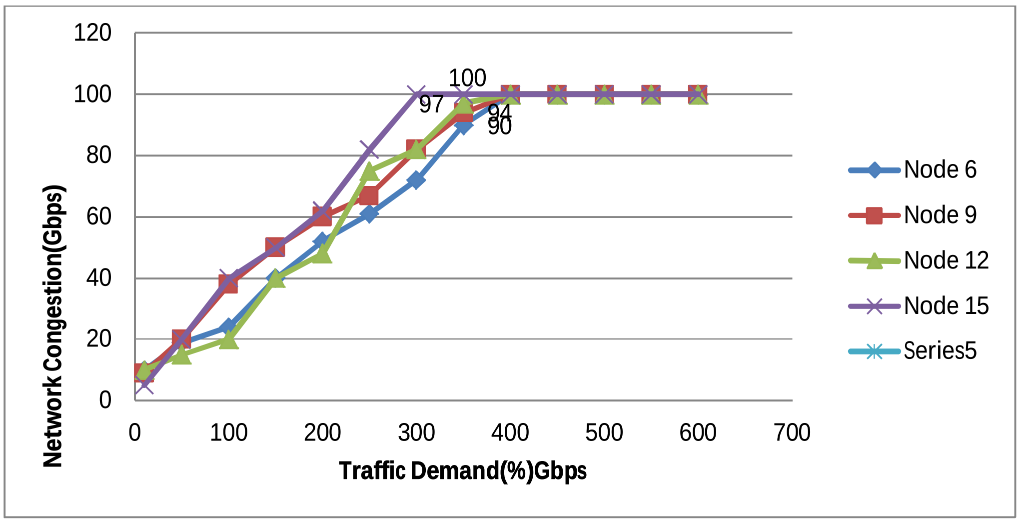

Fig. 4.12: Network Congestion vs Traffic Demand-CASE-2

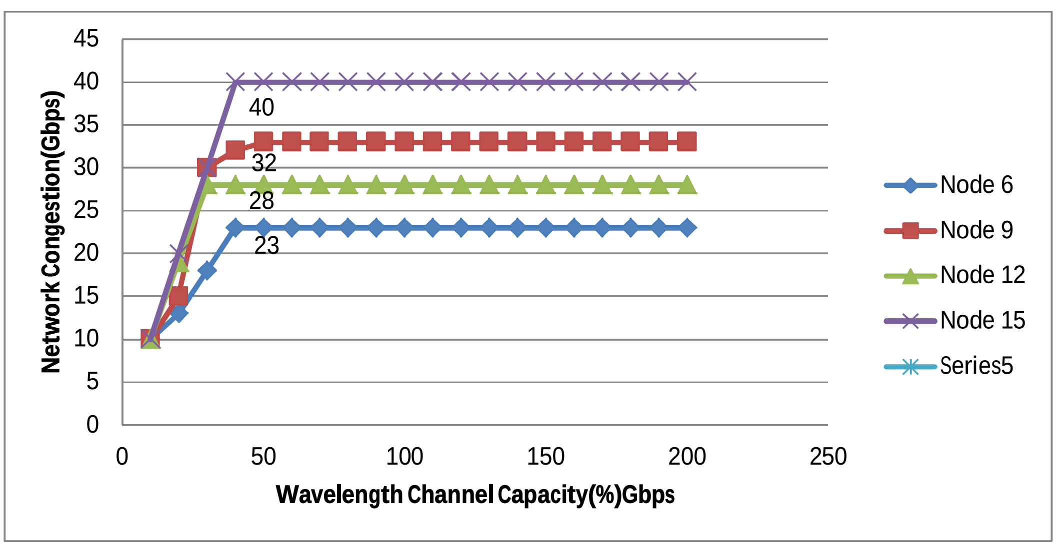

Fig. 4.13: Network Congestion vs WCC-CASE-2

We can observe from these above graphs that network congestion is increasing with increase in overall capacity of the network. So capacity should be as low as possible maintaining the QoS.

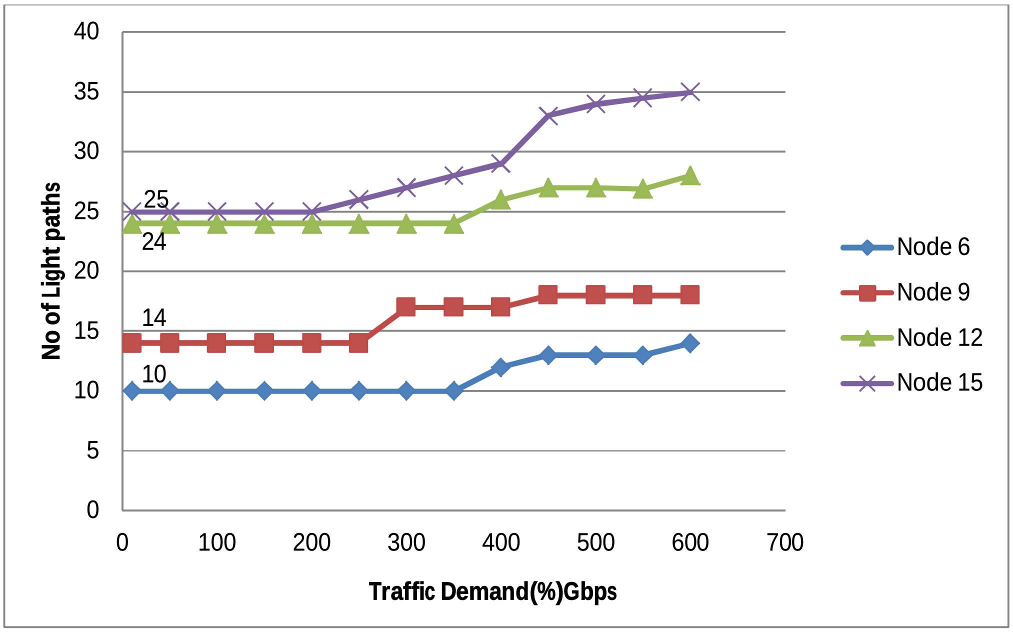

Fig. 4.14: Number of Light paths vs Traffic Demand-CASE-2

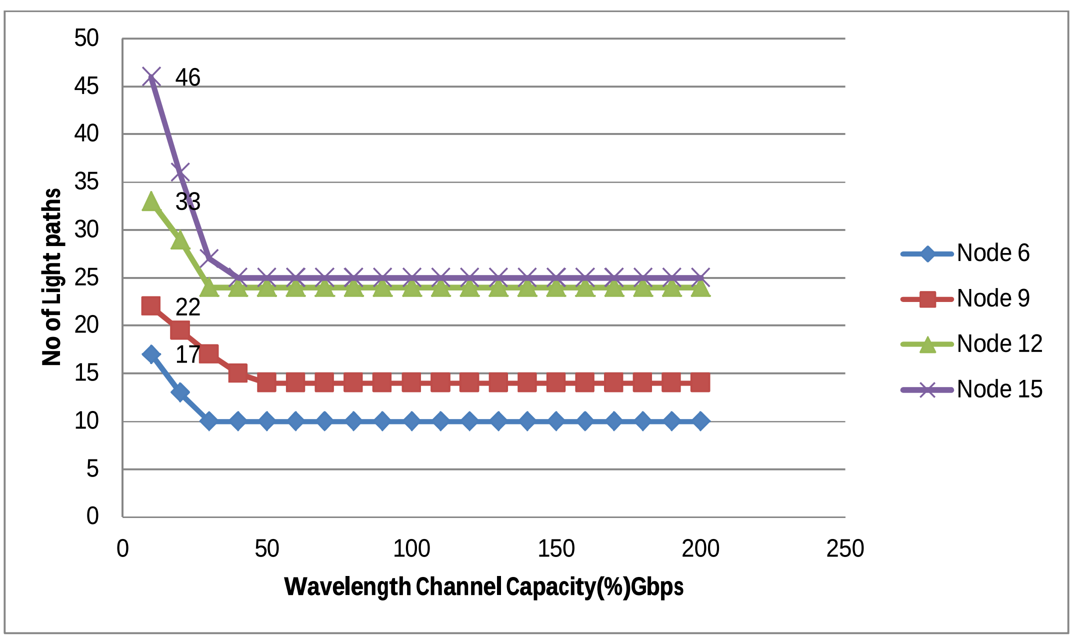

Fig. 4.15: Number of Light paths vs WCC-CASE-2

The number of light paths is increasing with increase in overall capacity of the network. This is because, as the capacity increases to maintain it, more number of light paths are created.

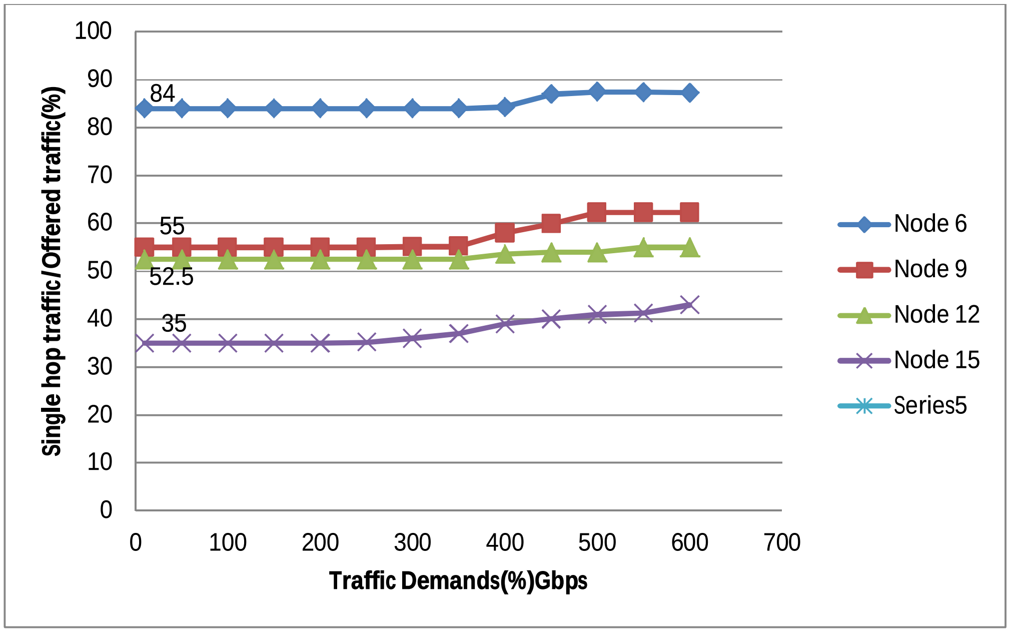

Fig. 4.16: Single Hop Traffic/Offered Traffic vs Traffic Demand-CASE-2

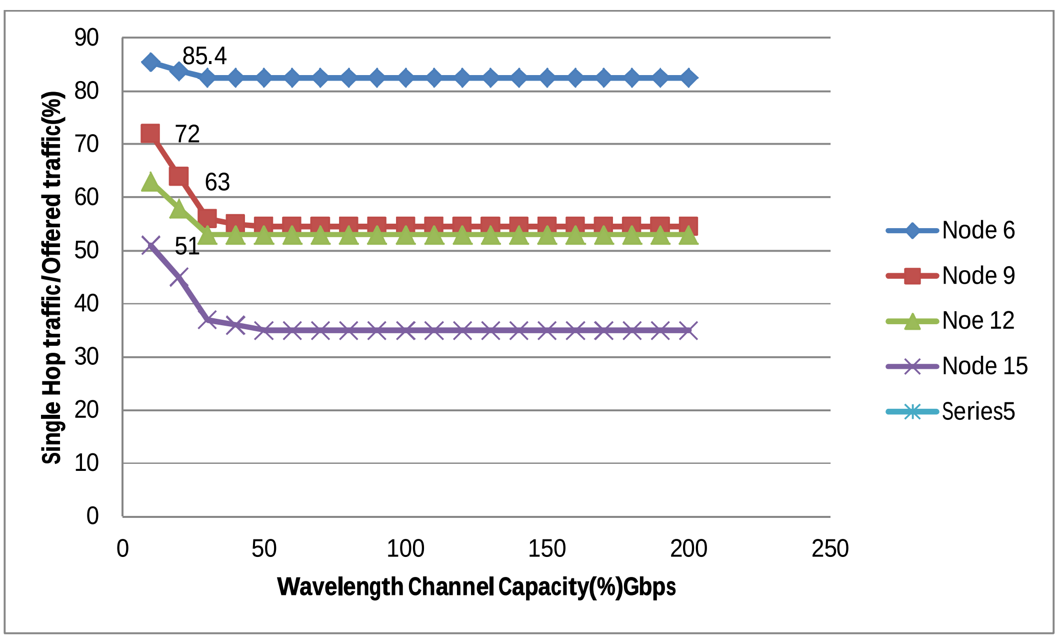

Fig. 4.17: Single Hop Traffic/Offered Traffic vs WCC-CASE-2

As the number of nodes in a network increases in a network as does the number of single hops. So single hop traffic/offered traffic will decrease if the capacity remain constant. If two networks have same architecture, but different capacities, then the network having higher capacity will have higher value of single hop traffic/offered traffic. This is observed from the above figures.

4.3.For the Case of Link Failure

To Study the case of link failure, we have designed a two 9-node network topologies. In the second network we have removed one connection from the first network. Then we have simulated them with different scenarios to obtain the performance matrices and observe the difference.

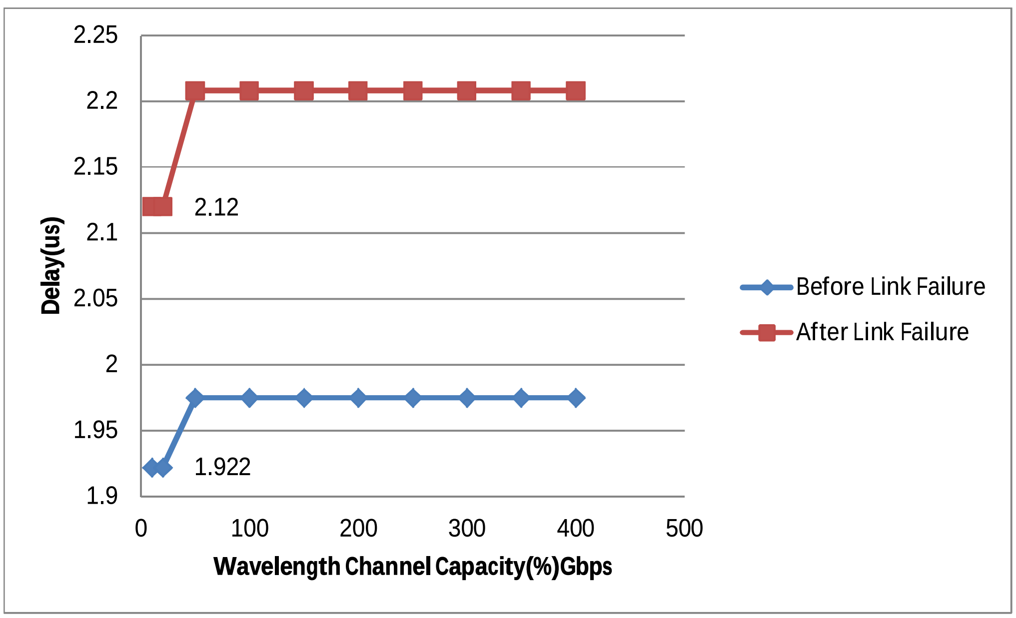

Fig. 4.18: Delay vs WCC-CASE-3

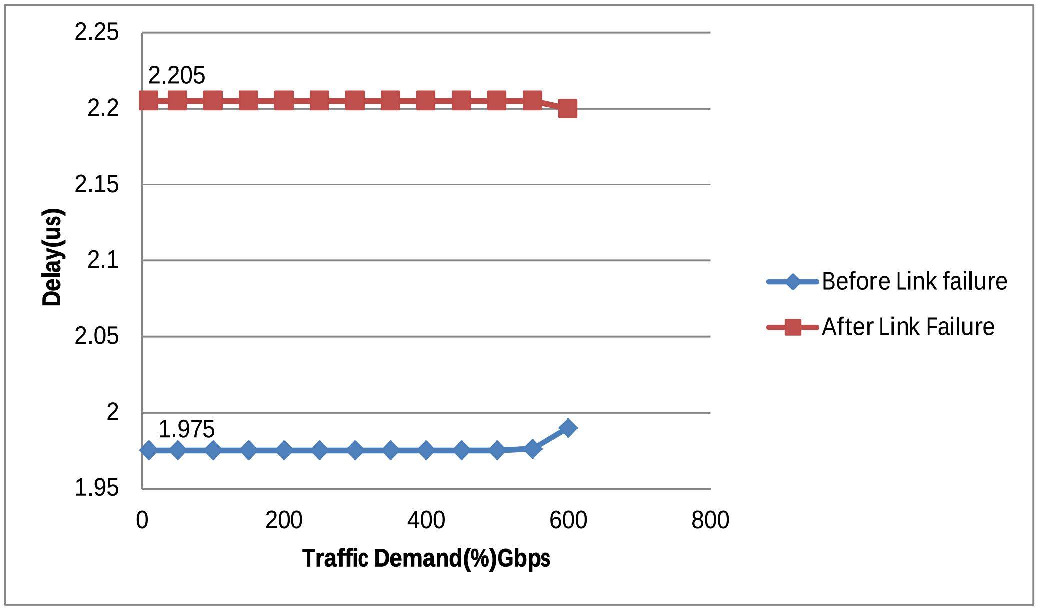

Fig. 4.19: Delay vs Traffic Demand-CASE-3

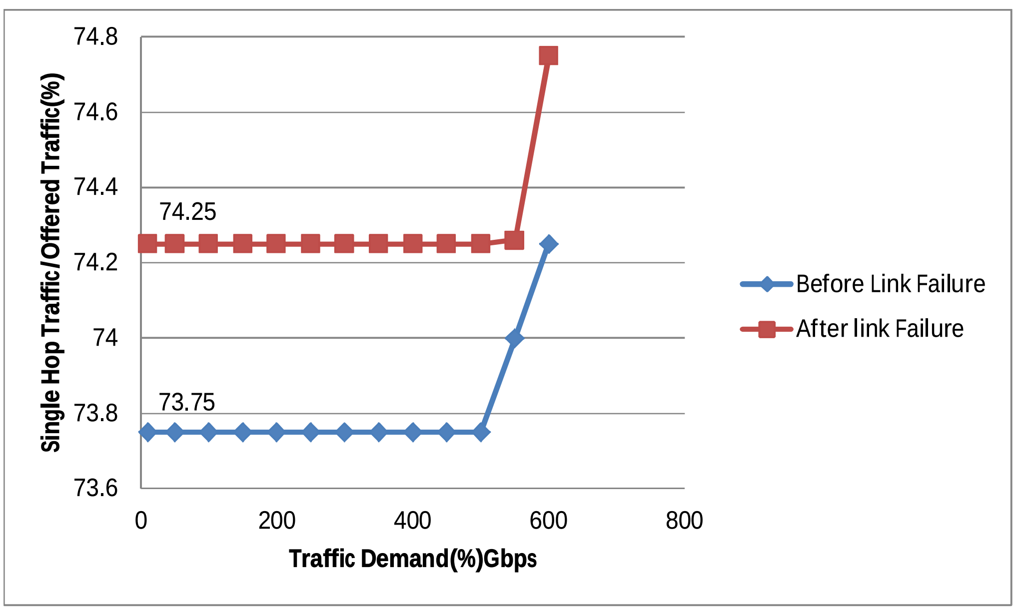

Fig. 4.20: Single Hop Traffic/Offered Traffic vs Traffic Demand-CASE-3

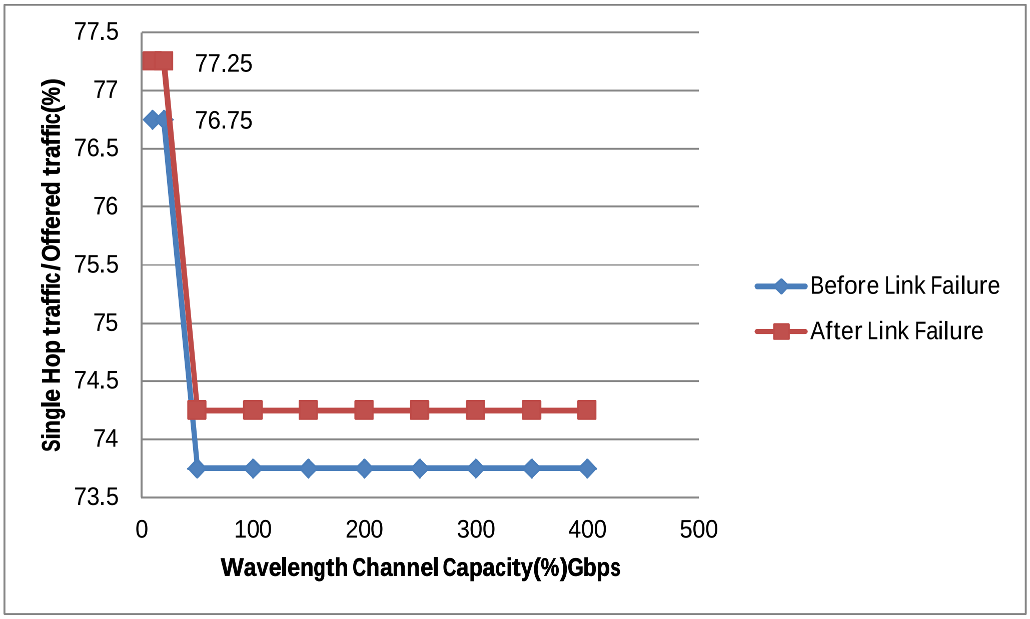

Fig. 4.21: Single Hop Traffic/Offered Traffic vs WCC-CASE-3

Table 4.1: Comparisons of Results of link failure

Parameters	Delay(us)	Single Hop Traffic/Offered Traffic (%)
Traffic Demand(TD) Before Link Failure After Link failure	1.975 2.205	73.75 74.25
Wavelength Channel Capacity(WWC) Before Link Failure After Link Failure	1.922 2.12	76.75 77.25

From above table, we can see that the delay increases after link failure. Due to link failure we lose a path from source to destination in shortest path algorithm. Hence distance from ‘s’ to ‘d’ node increases and to maintain minimal previous data rate the delay increases. In case of single hop traffic/Offered traffic, it also increases after link failure to maintain minimal traffic to avoid congestion.

Table 4.2: Comparison of Results for the four 60 Gbps Network Topologies

Number of Nodes	Average Delay (us)	Average Network Congestion (Gbps)	Average Number of Light paths	Single Hop Traffic/Offered Traffic (%)
6-node TD WWC	 2.3154 2.322	 50 13.55	 10 17	 82.5 85.37
9-node TD WWC	 2.21 2.3	 52 14.5	 13 20	 64.5 77
12-node TD WWC	 2.14 2.2875	 58 16	 20 30	 61.45 69
15-node TD WWC	 2.1 2.18	 60 17.5	 27 35	 53.6 59

For a topology to be implemented in real life application it has to have minimum delay, low network congestion rate, maximum number of possible light paths and high Single Hop Traffic/Offered Traffic. In case of normal assumption one can think that delay will increase with increase in number of nodes. But from above performance analysis table we can see that with increase in node the delay decreases (2.3154us to 2.1us).It depends upon number of light paths. So with increase in number of nodes, the number of light paths increases from source node to destination node in shortest path algorithm. So the queuing delay decreases, decreasing the overall delay. Since we can get more light paths, so delay decreases with increase in nodes. We can see the network congestion, number of light paths, single hop traffic/offered traffic increases with increase in number of nodes.

Chapter 5

CONCLUSION

5. Conclusion

Recent advances in the field of optical communication have opened the way for the practical implementation of WDM networks. After going through several papers we have found out that for determining Quality of Service the effect of network architecture is not taken into account. So we have designed four different networks and simulated them with different scenario to determine the performance matrices, which are called QoS (Quality Of Service) parameters.

In this work, we have used the simulation tool MatPlanWDM0.61, to study WDM networks and their performance analysis, which is freely available. It is an excellent framework for designing & development of topology with various features. We have concluded that if there is less number of nodes with high capacity, then delay will be more. If number of nodes is more as well as high capacity then network congestion will be more. So we have to choose a minimized output so that a better QoS is maintained.

So after simulation we have found out that 12-node network is the best for present case. We can generalize this to suggest that for very high capacity networks number of nodes in network should be moderate.

In case of link failure, we found that the delay will be more after link failure in networks and also the single hop traffic/offered traffic. So for survivability of WDM network, it is important to find the optimal routes through the network in case of link failure to maintain minimum delay and desired traffic. So it assures a god QoS.

5.1.SCOPE OF FUTURE WORK

MatPlanWDM is a good simulation tool to analyse different network topologies and performance matrices. With this we can use different types of designing algorithm like MILP (Mixed integer Linear Programming). For this we need TOMLAB(require registration) which allows many more functions like wavelength conversion/without wavelength conversion, with traffic losses/without traffic losses, losses cost per Gbps, cost per electronically switched Gbps, maximum light path distances.

Its GUI (Graphic User Interface) allows the user to carry out full multi-hour test for a pre-built or user defined multi-hour planning algorithm and virtual topology analysis. We can work towards dynamic Analysis which allows GUI (Graphic User Interface) to test online optimization algorithms to react to high level traffic connections arrivals, terminations and to do high level of performance analysis with good accuracy.

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