PERFORMANCE ANALYSIS OF OPTICAL WDM NETWORKS USING MATPLAN WDM

Dissertation submitted in fulfillment of the requirements for the Degree of

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By

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TABLE OF CONTENTS

DECLARATION BY THE SCHOLAR

I hereby declare that the work reported in the Masters Of Technology thesis entitled **"PERFORMANCE ANALYSIS OF OPTICAL WDM NETWORKS USING MATPLAN WDM"** submitted at **Jaypee University of Information Technology, Waknaghat India**, is an authentic record of my work carried out under the supervision of **Dr. Rajiv Kumar and Dr. Neeru Sharma** . I have not submitted this work elsewhere for any other degree or diploma.

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CERTIFICATE

This is to certify that the work reported in the M.Tech project report entitled **"Performance Analysis of Optical WDM Networks Using MatPlan WDM"** which is being submitted by **Swati Bhalaik** in fulfillment for the award of Masters of Technology in Electronics and Communication Engineering by the Jaypee University of Information Technology, is the record of candidate's own work carried out by her under our supervision. This work is original and has not been submitted partially or fully anywhere else for any other degree or diploma.

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ABSTRACT

An optical network system provides a common structure over which a large variety of services can be delivered. The communication between any two end nodes over a WDM network is carried out through a path, called as a lightpath. These lightpaths utilizes a singlewavelength through optical nodes with the help of optical add-drop multiplexers or optical cross-connects withoutconversion on intermediate nodes. These are capable of delivering flexible bandwidth in order to match with the electronic bottle neck of the network.

Optical networks exploit wavelength division multiplexing (WDM) to meet the ever growing bandwidth demands of upcoming communication applications, by dividing the enormous transmission bandwidth of fiber into smaller communication channels that can meet the electronic processing speeds of the users. The major problem with WDM network design is to find an optimal path between two end users and allocate an available wavelength to this chosen path for the successful transmission of data. This communication over a WDM network is carried out through lightpath.

The merging of all these lightpaths in an optical network generates a virtual topology that is suitable for optimal network design and meets the increasing traffic demands. But, this virtual topology design is a NP-hard problem i.e. non-deterministic in polynomial time. This paper aims to explore mixed integer linear programming (MILP) framework to solve this design issue that would result in an optimal virtual topology for various the traffic engineering applications. A comparison with existing mathematical models is carried out and results show that Quality of Service (QoS) is maintained at all cost. The network congestion is seen to reduce marginally which results in overall performance of the network.

The behavior of different topologies is analyzed using MatPlan WDM using various parameters. The parameters that are analyzed in this case are message propagation delays and number of lightpaths per fiber that are desired to be low while the channel utilization and traffic carrying capacity of the network are desired to be high. It is observed that for larger number of nodes the mesh topology is better even with high traffic load but its implementation cost is very high.

This thesis also aims to explore mixed integer linear programming (MILP) framework to solve this design issue. The comparative results of the proposed and existing mathematical models shows that proposed algorithm outperforms with the various performance parameters. Finally, it is concluded that network congestion is reduced marginally in overall performance of the network.

Keywords: Network Design, Mixed Integer Linear Programming, Quality of Service, Virtual Topology

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

ATM–Asynchronous Transfer Mode

CDM - Code Division Multiplexing

D Node - Destination Node

dB/km - Decibels per Kilometer

E/O transmitters - Electrical to Optical Transmitter

FDDI–Fiber Distributed Data Interface

Gb/s - Gigabits per Second

ILP - Integer Linear Programming

ITU - International Telecommunication Union

ISP - Internet Service Provider

MILP - Mixed Integer Linear Programming

NPC - No Problem Complete

OEO - Optics Electronics Optics

O/E receivers - Optical to Electrical Transmitter

QoS - Quality of Services

QoP - Quality of Protection

OXC - Optical Cross Connects

RWA - Routing and Wavelength Assignment

S Node - Source Node

SDM – Space Division Multiplexing

SONET–Synchronous Optical Networking

Tb/s - Terabits per Second

TDM - Time Division Multiplexing

TWC - Tunable Wavelength Converters

VON - Virtual Optical Network

WDM - Wavelength Division Multiplexing

CHAPTER 1
INTRODUCTION

1.1 Introduction

In the present times our communication demands has increased by leaps and bounds from previous ages. A global mesh of communications networks enables us to get this information.Fiber-optics can be considered a savior for meeting this high demand because of the potentially limitless capabilities, very large bandwidth (about 50Tb/s), low signal distortion, low signal attenuation (up to 0.2dB/km) ,low power requirement, small space requirement, low material usage,immunity to electromagnetic interference and low cost.

Optical networking seems to be a promising technology to meet the hugedata bandwidth demand for upcoming networks.For thisoptical fibers aredeployed as physical connection by different network technologies, likeasynchronous transfer mode(ATM), synchronous optical networking (SONET),fiber distributed data Interface(FDDI), etc., due to its large availability of bandwidth withhigh quality signal. Optical networksare designed to fully utilize the fiber'slow attenuation properties. A single fiber has a potential bandwidth of nearly 50 Tb/s, which is about four times higher than the electronic processing data rates of few gigabits per second (Gb/s). This leads to electronic bottle neck in an optical network, where its capabilities are not utilized completely. Therefore to use thishuge bandwidth the channel is divided into smaller bands or channelsconsecutively. This can be achieved by various available multiplexing techniques like code division multiplexing (CDM), time division multiplexing (TDM), and frequency (or wavelength) division multiplexing (WDM), while optical CDM and TDM are technologies for future. WDM is vastly being used as the favorite multiplexing technique of optical networks to meet the electronic equipment bitrate demand wavelength channel that ischosenrandomly.

The network service providers are deploying optical networks along with wavelength division technology all around the world. These can be typically used as backbone network with infrastructure that has up to hundreds of fibersconnecting the core or backhaul network nodes where one singlefibercan have up to hundreds of individual wavelength channels and that single channel that can have a transmission capacity of up to 40 Gb/s.

In current times thewavelength division technology is widely deployed for point to point communicationlinks to connect the electronic nodes or the switching nodes to each other. This is so because in present times the architecture with optical switchesis incapable of interacting with the upper layers to enable flexible, trustworthy and efficient services. Therefore, it is clear that internet protocol with the combination WDM will be the successfulblend for future technologies. This will be achieved by having WDM as a bandwidth rich transport layer and IP as a convergence layer. The major task is to formulate control management system that willsolve issues like lightpath routing with the combination of internet protocol routing, resource management,configurability, monitoring, survivability, etc. The next generation internet over WDM networkswill also be results of efforts to design a common control plane.

Optical networking has mainly two sub divisions of operation i.e.circuit switched networks and packet switched networks where the formerconsists of WDM aware edges and the WDM optical fiberverticesconnecting these edges. The WDM optical node consists oftransmitters, receivers and optical cross connects (OXC) .These nodes are enabled with capabilities to separately rout the given channels in the optical region. For future usage theswitching of optical packet will be seen as a workableoption inarea of networking, because of its switching abilities. As these technologies are still in its early stage of development the future possibilitiescould havevarioushardships from technical point of view. As of now for today'scommunication needs the circuit switched methodlooks like realistic designapproach of optical networks.

The debate about the design of optical cross connects has been going on for a very long time, it is important as these designs have influence the working of whole networks. Where there can be networks that are fully optical and networks with an electronic interface in between known as optics electronics optics (OEO) networks. While in the former optical domain is responsible for all transport layer activities, i.e.at the source node a signal enters the network in an optical domain and then continues to remain in the same domain until it received at its destination node.The latternetworks are equippedwithcross connects that convert theoptical signals into electronic signals at intermediate nodes where they can be multiplexed, routed and de multiplexed. Then the electrical signals will beconverted back to into the optical domain before leaving the node.While the OEO approach has practical applications even the alloptical approach has gainedrapidnessover the last years.

Another issue with thepractical networks is traffic.The traffic rates between given intermediate node pairs vary over a given interval of time. Therefore there is a need to arrange network resources to cater a given traffic matrixbut the traffic matrix changes distinctively over time. This is where a virtual topology optimization comes into picture for a given traffic demand, this is nothing but an impression of the changing traffic demands in form of a matrix. Thus, as the traffic demand changes the virtual topology designalso need changes to meet up with the traffic changes. The virtual topology problem is defined as dynamic allocation of the optical cross connects where the wavelengths are switched input fiber to any output fiber dynamically. Therefore,an optimization problem is important and it needs to be solved along with virtual topology design problem. The general approach to these problems is tosubdivide them into two problems i.e., to design avirtual topology and routing of the lightpaths so thatthe new topologies areformed.

These two subproblems are generally solved individually.Theconventional approach of design the virtual topology problem has several shortcomings. It assumes that the future traffic demands will be known in advance. With this kind of information already in hand, virtual topology is easy because traffic is predicted well in advance .Therefore thecomputation of new topologies are started early , so that there is enough time to complete complex virtual network. This kind ofmethod is similar to off line topology design with the assumption that the traffic demandsare expected.

Whenworkingwith real data,the design approach should to be such that it can deal with unpredictable trafficchanges during the transition phase. The reconfiguration method should be flexible as the logical topology design is closely related to the traffic; it should also be spontaneous to the any new conditions.

Reconfiguration in a network deals with dynamic traffic changes, which can be referred to as an on line methodology in the design oflogical topology. This means that the algorithms should give results in a small duration of time when related to the time at which traffic changes occur. In short the algorithm needs to be fast so as to update the virtual topology in real time frames. As the problem is quite complex thus finding optimal solution is very difficult even when the size of the network is small. Thus we look for good sub optimal solutions with the help of heuristic approaches.

Secondly the simple and fast reconfiguration schemes should also be applicable for large networks. The traffic changes in a network are usuallyincreasing or decreasing slowly. But we have to ask some questions before jumping in designof any such algorithm. How much traffic change is sufficient to cause the reconfiguration event to happen? This is a relativelya complex question to answer, as it consists of optimization problem itself which includes computing a proper trade-off between network resources utilization and the cost of reconfiguration.

The third basis is the elimination of the costly and critical decisions as much as possible. This can be achieved to applying various constraints to the various part of the network i.e. applying constraints of number of hops required, choosing the lightpaths ,continuity of lightpath etc. These help in reducing the size of the network when designing virtual topology. This is achieved by eliminatingsome of the nodes and links so as to make even a large topology effectively small for logical design.

The present day’s communication network can besummarized as a combination ofvarious sizes and scalelike metro, access and backbone networks. Here we want to focus on backbone networks’ and introduce the various technologies for transmission of optical signal in thefiber and also discuss the basic elements ofoptical backbone network. This is desired as optical communication networks find its major application in the back bone networks which connect large areas. The wavelength division multiplexing technique is introduced as present day's communication networks aim to supply communication services to everyindividual and at their disposal.

With the advent of Internet we want to access information at our disposal i.e. when we require it, in whatever ever form we require it and wherever we require it. This information is required at high speed at any given time. The demand of data is growing exponentially with the increase in number of people who can access internet and also with the increase in data hungry services likeworld-wide web, java applications, interactive distant learning, video conferencing, online gaming, etc. This requires high bandwidth networks to support exponential growth of data traffic needs because it is beyond the capabilities of current high speed networks. Fiberoptic technology is capable enough toaccommodate the above mentioned demands, because of its huge bandwidth,low signal attenuation, low power requirements, low cost, lowsignal distortion and otherlimitless capabilities.

Optical networks differfrom the other technologies in terms of application of fiber, and thus the bandwidth that they provide to their users. The present day's communication network can be summarized as a combination ofvarious sizes and scalelike

- Access network varying from 1 to10 km
- Metropolitan network varying from 10 to100 km
- Backbone network extending from 100's to 1000's of km

As shown in Figure 1.1each of these subnetworks has a distinct functional set defined to cope up with technological requirements and research problems.

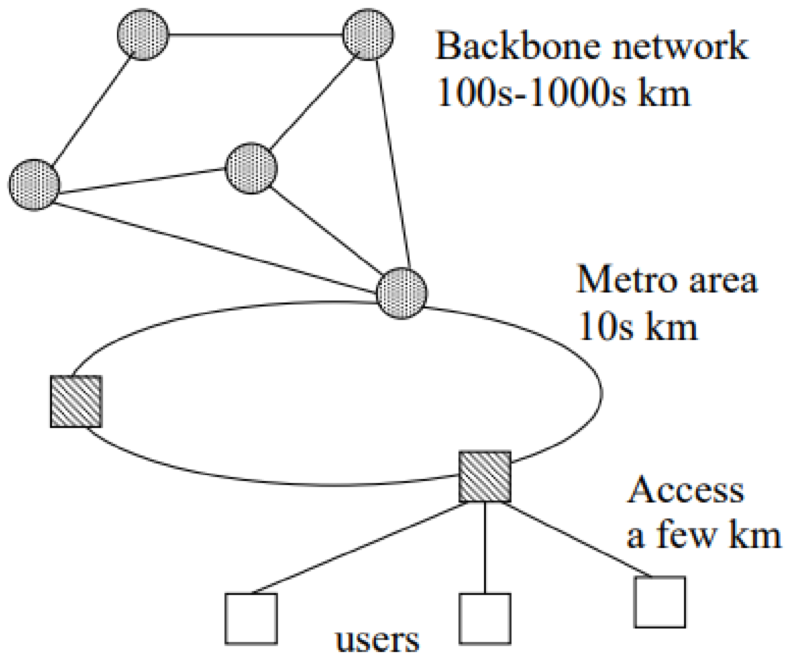

Figure1.1Today's Communication Network Structure [1]

Here the home and business subscribers are connectedto the service providers through access networks i.e.,they serves as theas the first mile as well as last mile communication link in the networks. It is here where we discover the electronic bottleneck in our network infrastructure. The bandwidth problem in access networks can be solved byoptical technology as it can provide at least ten to hundred times more bandwidth.This is also possible even when the area to be covered is large. The next generation access network will deploy to the home (FTTH) and the fiber to the building (FTTB) and alsoproviding Gb/s speeds at low costs.

Metropolitan area or metro networks serve in regions varying fromtens to few hundreds of kilometers thus covering metropolitan areas. They can be seen as interconnections between access networks and backbone networks. Currently SONET/SDH-based rings form the physical layer infrastructure in these metropolitan networks.

The backbone network varies from several hundred to fewthousands of kilometers and forms the backbone that connects major cities and countries to each other. These also form the undersea networks.

Traffic is collected from the end users by the access networks and fed into the metropolitan network and the further linked to backbone networks. This hugetraffic rate is suppliedto the backbone network by optical communication channels. Management and design of optical backbone networks isa hot research area with many unsolved issues.

1.2 Wavelength Division Multiplexing

The Wavelength division multiplexing (WDM) methods exploits the huge opto electronic mismatched bandwidth, byneeding the enduser's equipment to operate at its own electronic rate, but at the same time having multiple WDM channels from different end-users to be multiplexed on the same fiber.

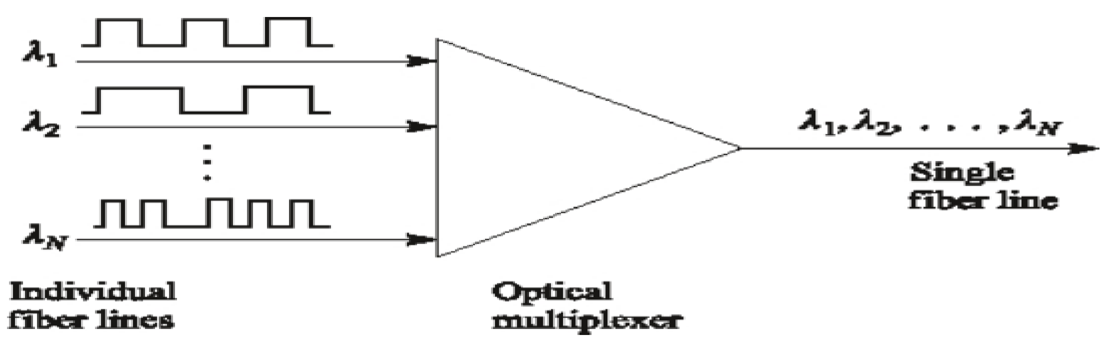

Figure 1.2 Wavelength Division Multiplexing [2]

Thus the WDM, the optical transmission spectrum has a number of non overlapping frequency or wavelengthbands (Figure1.2),where a single wavelength corresponds to a onecommunication channel that operates at a desired rate (peak electronic speed). Therefore if multiple WDM channels can exist together on a single fiber, then the huge fiber bandwidth can be fully used and design appropriate network architectures, algorithms and protocols. WDM devices are easy to implement as allthe components in a

WDM device need to operate at electronic speed as a result, today several WDM devices are available in the marketplace and even more are emerging.

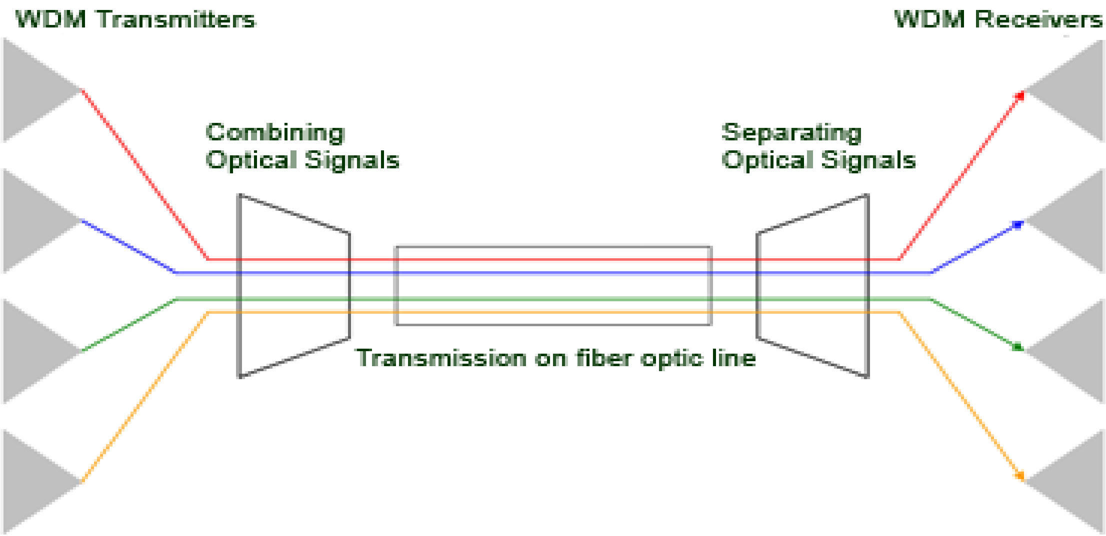

Figure 1.3 Wavelength Division Multiplexing Working Principle[2]

1.3Advantages of Wavelength Division Multiplexing

Wavelength Channel Multiplexing is extensively used in our present day'stelecommunication systems. As it is equipped with features that when compared with other communication networks for client satisfaction point of view. The advantages that make it popular among clients are:

1.3.1 Capacity Upgradation

Optical fiber communicationsupport very high bandwidth capabilities. Here light is the datacarrier. In WDM, multiple lightpaths of different wavelengths are combined into a single fiber. Therefore,the same single fiber isnow capable of transmittingmore data.Thus the capacity of the network increases considerably.

1.3.2 Transparency

WDM networks transmitted data at different bit rates using a variety of protocols. So there is no considerable constraint on how data is send. This can be used for applications where the speed of data keeps on varying.

1.3.3 Reuse of Wavelength

WDM networks allow wavelength routing. Same wavelength can be used again and againin different fiber links. These enables wavelengths reuse which helps in increasing capacity.

1.3.4 Scalability

WDM networks are flexible in nature. One can make changes as per the requirement of the network. Addition and removal of processing unitsat both transmitter and receiver is feasible using WDM. This framework can redesigned to serve the increasing demands of the network.

1.3.5QoS in WDM Network

Quality of Service (QoS) parameters determines the performance of a WDM network using certain parameters. This QoS for an optical network can be a measure of all the possible light paths in a network on which different measurementsare done using different simulation tool e.g. MatPlan WDM. The results are then observed for performance matrices which future determine the QoS. Other QoS parameters likenetwork congestion, delay, single hop and multi hop networksand traffic offered can also be studied.

1.3.6 Reliability

WDM networks are highly secure and reliable. The chance of unauthentic data breach and crosstalk are possible very less. These networks can have efficient failure recovery mechanisms. Rerouting of a path between a given source and destination node pair can be achieved. Therefore in case of link failure data is not lost.

1.4 Optimization of networks

The major goal of any optimization is ensuring an optimal network design with lowest cost with the given set of performance metrics.Optimization is an essential component of effective systems management, asif proper network optimization is not used; the continuous growth of data transfer demand can add strain to the network architecture. The performance metrics governing the overall design of optical networks are:

1.4.1 Delay

In optical networks delay is defined as the customer-specified time, which is a measure of the customer's patience. It is the time a connection request or data transfer that can be held. Link capacities of a networkare inversely proportional to average delays. This can be considered as the sum of the buffering delay T_b, transmission delay T_t , propagation delay T_p

$$T = T_b + T_t + T_p \qquad (1.1)$$

1.4.2 Blocking Probability

Blocking probability evaluation in optical networkis evaluated by the generalizing of approximation techniques of reducing load. It is carried out with the least loading routing and fixed routing. Converter role capabilities are increased with flexibility. Placement issues and routing issues can be solved by having in placenew conversion algorithms.

1.4.3 Average Number of Hops

The optical network aims to minimize theaverage no of hops.$\bar{n}$, Which is average number of hops in a network is a known measure to characterize the routing. It is defined as the average number of links by a given data packet.

$$\bar{n} = \frac{\sum ln}{\sum n} \tag{1.2}$$

Where ‘l’is the number of links in path and ‘n’ is the average number of links crossed till a packet reaches its end/destination node.

1.4.4 Network Congestion

The utilization of link in anetwork is referred to as network congestion.This is the reduction in QoS that occurs when a network node or link is carrying more Information than it can handle. Congestion leads to queuing delays or blocking of new connections which consequently leads to decrease in network throughput.This means that the network is congested with 0.6, and then at least one link has 60% utilization.

1.4.5 Total Network Cost

Totalcost of the network isa contributingfactor in the network optimization.The reduction of overall cost of the network as anticipated is the ultimate goal of optimization. But the cost determination becomes difficult in real life scenarios, and the calculation of the total network cost is not feasible. Here C denote the overall cost of a network, and can be calculated by the sum of a cost at one vertex c(v), and a cost at one edge c(e)

$$C = \sum e\, c(e) + \sum v\, c(v) \tag{1.3}$$

1.4.6 Network Resilience Metrics

The ability of a network to provide decent levels of service even in the presence of attacks and failures is known as network resilience metrics. This is considered as acrucialfeature in the design of networks.Service Level Agreements between service providers and clientsare mostly based on how effective are thenetwork resilience measures of the network. The most desirable among them is the service availability even when the network is under attack or failure.

Further to have a logical topology routing that is sustainable the lightpaths should guarantee corresponding mappings to the entiredisjoint link set. Butdiscovering these disjoint paths between the end node pairs is an NPcomplete problem.Algorithms for theapproximation of lightpath routing will increase the robustness of the networks even after attacks and physical link failures.

The algorithm used to find the above results was an ILP (Integer Linear Programming) approaches which will not produce desirable results when the size of the network increases.Thus heuristic approaches for approximations need to be used.

MatPlan WDM is a reliable simulation tool to analyze various network topologies as it has an inbuilt MILP (Mixed Integer Linear Programming) function.

1.5Motivation

The motivation behind the idea is that as we stepped into an era where the network resources requested to be easily accessible i.e. available instantly without any wait. Due to the massive usage of network resources and increasing demand of everyday applications, the network delay plays a very significant role while considering the major network design components. The major network delay occurred at nodes because resource allocation mechanism takes place at nodes and therefore the nodes gets congested.

The main underlying problem is to optimize the light path creations to minimize the network congestion. It has been considered that the problem of the virtual topology optimization is closely linked to the routing problem. The level of network congestion in a virtual topology is evaluated if there is a set of light paths and specified routing techniques. The main outcomes of the continuity constraint mixed integer linear programming (MILP) are somewhat lies in between efficient resource utilization and enhancing the performance of the network parameters. The main contributions of proposed MILP are listed below which solve the major challenge in WDM:

- The applicability of two constraints of wavelength continuity and light path availability is used to minimize the network congestions.
- Due to the integrity of number of applications and efficient network resource utilization necessitates the reduction in message propagation delay.

1.6 Summary

For today’s fast growing communication networks, optimization of these networks is the key research problem. These can be used to solve the Virtual Topology Design Problem. It allows a number of functions like losses cost per Gbps, with traffic losses/without traffic losses, wavelength conversion/without wavelength conversion, maximum light path distances, cost per electronically switched Gbps and many more.The analysis of larger and complex networks will be done using the MILP function of the software.

CHAPTER 2
LITERATURE REVIEW

2.1 Literature Review

In today's era the communication demand has increased by leaps and bounds from previous ages. A global mesh of communication networks enables us to get the desired information. The evolution of optical networks has enabled us to meet the high-speed present day's communication demands [1].

Wavelength division multiplexing (WDM) thus allows the coexistence of multiple optical channels on a single fiber. Therefore, when fiber-optics is deployed with WDM it can be considered a saviour for meeting this high demand because of the limitless capabilities, very large bandwidth , low signal distortion, low signal attenuation , low power requirement, small space requirement, low material usage, immunity to electromagnetic interference and low cost. WDM has facilitated the efficient use of optical fibers by dividing its huge bandwidth into number of smaller bands where each one supports a different communication channel.

An overview of the development work and the research areas of optical networking is discussed in [2]. The evolution of the WDM networking through point to point system and various components of the WDM system like WADM, fiber and wavelength cross connects are discussed in brief in this paper. It also through light on recent trends those are popular among researchers like network and control management, fault management,multicasting light trees, traffic brushing in WDM ring networks and physicallayer issues.

End to end delay and link approximation are given for networks. Several models are present for calculating blocking probability, network congestion metrics andaverage number of hops. These all combine to form a cost model that captures the scale economies that are present in network design [3].

The most challenging problem in an optical network is routing and wavelength assignment (RWA) [5]. Routing i.e. finding an optimal path between the source and destination, has been achieved to some extend by using various algorithms Dijkistra's and Bellman Ford[6] to determine the shortest path while the wavelength assignment problem is to assign wavelengths with and without continuity to the route selected is a logical topology problem. RWA analysis of the network topologies are based on carried/offered network, traffic demand, message propagation delay, wavelength channel capacity[7]-[10].

Bidirectional paths have been used for all the network design and analysis , [11] as the topology with bidirectional paths is more efficient than topology with unidirectional paths in terms of delay, packet lost rate and file transfer time.

However, designing the logical or virtual topologies is a NP-hard problem which means that it is non-deterministic polynomial time. Various offline virtual topology designapproaches have been proposed for optical networks under given periodic traffic conditions [12]. Analysis of distinct optical network attributes with non uniform distances between the end nodes, where the link capacities are chosen in a random.

The virtual topology design have been resolved using MILP (Mixed Integer Linear Programing) to find the various parameters like lightpath routing, wavelength continuity, wavelength assignment, traffic losses and flow routing[15]. Mixed integer linear program can be employed to obtain optimal logical topologies for different traffic demands [13] [14].Various parameters like lightpath routing, wavelength continuity, wavelength assignment and traffic losses can be derived and compared. The main advantage of MILP is to minimize the congestion on a given channel while maintaining the delay in the desired levels of Quality of Service (QoS) parameters [16]. These lead to tolerance against failures, better network reliability, and full utilization of the network resources.

The logical topology routing is an NP complete problem.[17] Proposes method that is based on the idea of preserving spanning tree to set these logical or virtual paths. For agiven a set of virtual spanning trees,some optimization problems were given. To analyze the generalscenario the routing and the tree were determined by MILP formulation.

Multi hour planning is a function of MatPlan WDM used [18] - [20] for dynamic planning of virtual design in wavelength routed networks. In this, the traffic demands of a network are expressed as traffic matrixes that differ in valuesall along the day. The average traffic offered from source node s to destination node dfor any time duration is measured by the activity index of node s and d during that particular time of the day.
This activity index of each node is a factor of node local time, which in turn depends on thetime zone of the node. Thus, this system can be used to find the traffic variation that happen in backhaul/backbone networks of a large geographically distributed network.

Various algorithms are developed for different network topologies that do not have wavelength conversion. The routing and wavelength assignment is developed on scenarios when the connection time for the setup and teardown were known in advance. Here the routing and the wavelength assignment problem are separately studied as spatio-temporal optimization problems. A generalized graph coloring method discussed in [21] is used to determine the wavelength assignment problem. Later on ISP started leasing out spare bandwidth to increase returns by minimizing the cost to run a network. MILP is used in [22] where lightpaths can be added or removed from the ISP's virtual topology. As this method is based on virtual topology the optimization of these topologies in an effective manner holds importance. A cost savings of 21% could be achieved allowing annual savings of millions of dollars. Despite the fact that minimization results in more no of lightpaths to be active, but these lightpaths were shorter and less expensive giving a cost beneficial virtual topology.

Optimization of the virtual topologies also holds applications to guarantee desired levels of quality in service (QoS) in terms of wavelength resource allocation. The problem of the setting up of explicit routing paths and assignment of wavelengths in network is done by MILP formulation in [23]. Even though the virtual topology problem is difficult, still methods provided give fairly good solutions for low optimality gap even for big network.

The latest areas where virtual topology optimization plays a significant role, is for finding energy efficiency of WDM networks through mixed-integer linear programming (MILP). [24] Evaluates the MILP for typical and regular network topologies and the results save up to 37% on the ring topology and 23% on typical topologies in terms of energy efficiency.

MatPlanWDM an educational network planning is the tool used in the current work to determine the results and simulations is discussed in [25],[26] where these papers present a virtual design and a flow routing algorithms can be put together, tested and analyzed with the help of this tool.

The problem of optical grooming and optimal linear programming can also be compared. The tool provides graphical interface that enable it to be used as aneducational tool for evaluating and comparing results. Lightpath mapping over the virtual topology and traffic flow mapping for virtual topology is also explained.

2.2 Related Work

The research area of the MILP is so much attractive and vast that numbers of researchers are involved to enhance the network performance. In this section, the related work has been discussed to firm the base for the proposed system model. The authors in [31] have given the algorithms for the mesh networks that do not have wavelength conversion to derive the routing and wavelength assignment.

The virtual topology adaptation model has been studied by the authors in [32] for the amount of bandwidth required from the network providers to fulfill the traffic needs of the customer. The proposed approach is based on the MILP where lightpaths are added or deletedin the internet service provider'svirtual topology after a given observation time period. The authors used this approach in the dollarcost minimization of the network services to the consumers. The authors in [33] discuss the major problems with the design of virtual topology used for the establishment of explicit routing paths and the allocation of wavelengths in network links to support connections with QoS guarantees. A local-search heuristic algorithm has been proposed for the QoS and gives the solutions of the various network performance factors.

Further, authors in [34] proposed a new infrastructure for the virtual optical network (VON) virtualization to share a common physical infrastructure. The problem of the network virtualization over both WDM and flexible-grid optical networks are formulated as a mixed integer linear programs (MILP). Authors, in this paper [35] have proposed two heuristics approaches as *MaxMapping* and *MinMapping*to solve thequickly but sub optimally. The authors in the [35] shows that the network visualization can advance the utilities of internet and stimulate innovation of new network architectures and applications. The study of energy efficiency using MILP and a heuristic with five operating options has been proposed on the regular network topologies by authors in [36].

2.3 Summary

Various researches related to virtual topology optimization have been discussed. While some focus on wavelength assignment others have considered routing as a problem Wavelength Division Multiplexing is used as a basic underlying principle for all analysis. Dynamic virtual topology design is considered as a NP hard problem in some of problems and various approaches have been proposed for them.

CHAPTER 3

PROBLEM STATEMENT AND SYSTEM MODEL

The objective of the work is to develop a reliable WDM network based on the set of parameters to deliver maximum performance.

3.1 Problem Statement

A physical topology needs to be deployed to develop a WDM network. Before designing the routing and wavelength assignment we will try to find out the best topology network.
Therefore we will try to solve the given objectives

O**bjective1:** Compare the performance matrices for bus, ring, star and mesh topologies

Objective 2: Compare the results of the above topologies for 5node and 11 node networks

Objective 3: Design of optimized virtual topology based on certain constraints to achieve lower transmission delay.

3.1.1 Outcomes

In this thesis, a new technique has been proposed to solve the problem of network congestion and routing problem. The main outcomes of the proposed technique continuity constraint mixed integer linear programming (MILP) are somewhat lies in between efficient resource utilization and enhancing the performance of the network parameters. The main contributions of proposed MILP are listed below which solve the major challenge in WDM:

- The applicability of two constraints of wavelength continuity and light path availability is used to minimize the network congestions.
- Due to the integrity of number of applications and efficient network resource utilization necessitates the reduction in message propagation delay.

3.2 System Model

Let us consider a simplified, geographically distributed optical network$G(N, E)$as shown inthe Figure 1 with N number of nodes with traffic defined for$t = 1, 2, \dots, T$ time intervals and E number of edges(i, j). Each edge (i, j) lies between two nodes $i$and j. Let us consider that any edge (i, j) have a set of wavelengths or light paths $L(i, j)$ each having the capacity $C(i, j)$ i.e. each fiber edge is divided equally according to the wavelength for the transmission of data exploiting thewavelength division multiplexing protocol. It has been considered that traffic is uniformly distributed and for first 1 and last interval of time$t = 1$ and $t = T$can be taken respectively.The traffic demands(Gb/sec)have been considered between nodes i and j are given by$t(i, j)$for the time interval t.

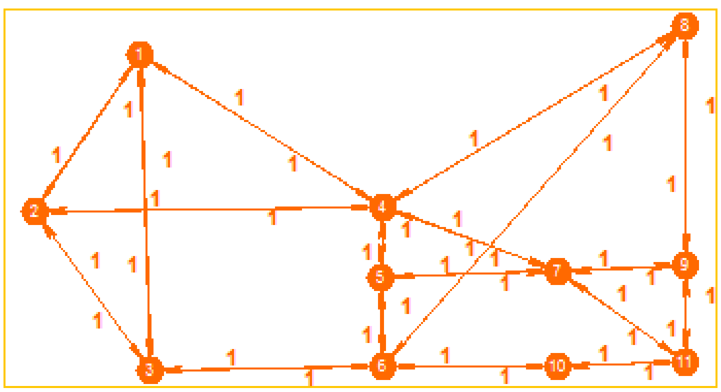

Figure 3.1: Physical Topology Layout of 11 node network

3.2.1 Notations and Assumptions

Notations

$G(N, E)$	An optical networkwith $N$and Enumber of nodes and edges respectively
N	Set of numberof nodes
E	Set of numberof fiber edges
s, d	Source and destination node pair in the optical network
(i, j)	A fiberedge between two consecutive nodes i.e. i and j
$\boldsymbol{e_{in}}, \boldsymbol{e_{out}}$	Incoming link and outgoing link
$C(i, j)$	The uniformly distributed capacity of the edge(i, j)

$L(i,j)$	Light path from node i to node$j$
T	Time interval
$t(i,j)$	Traffic demand from node i to node j in Gb/sec
$f(i,j,s,d)$	Flow of traffic from node s to node d through intermediate node i and node j
C_{TR}	Cost function of transmitter and receiver

Assumptions

Certain assumptions are made to propose the system model:

- In the given optical network, the nodes are represented by $i,j,s,d \in N$ where (i,j) represents the pair of nodes in the given optical network.
- The edges in the optical network are without parallel links to save the resource wastage
- The capacities of different arcs are statistically independent.
- All flows in the network obey the conservation law.
- The traffic between the chosen nodes can be sent on multiple paths.

3.2.2 Constraintsto Objective 3

In the optical networks, the MILP problem considers number of network operation parameters where the main aim is to reduce the overall cost function.

$$\min_{(s,d)} C_{TR} \sum_{i,j \in N} L(i,j) \qquad (3.1)$$

Where $L(i,j) = \{0,1,2 \ldots,\}$ are the lightpaths between any nodes and $L(s,d) = \{0,1,2,\ldots,\}$ are the lightpaths between anysource and destination $\forall\, i,j,s,d \in N$.

The traffic flow $f(i,j,s,d,t) \geq 0 \;\forall\, i,j,s,d \in N$ and $t \in T$ at any instant of time is the data from node s to node d through intermediate node i and node j.

$$\sum_{j \in N} f(n,j,s,d,t) - \sum_{i \in N} f(i,n,s,d,t) = \begin{cases} +ve \; if \; n \; is \; source \\ -ve \; if \; n \; is \; destination \\ otherwise \end{cases} \qquad (3.2)$$

The wavelength continuity constraint is achieved through MILP which means direct establishment of lightpath between the two end nodes. When the outcome is greater than 0 then lightpath is said to be leaving from the node and if the outcome is less than 0 then the lightpath is entering to the node. While, if the outcome is 0 then no new lightpath are said to be established.MILP integer variable will be '1' if lightpath exits between intermediate node i and node j else this will be '0'.

Algorithm 1: Mixed Integer Linear Programming (MILP)

Input: Optical Network $\boldsymbol{G}(\boldsymbol{N},\boldsymbol{E})$, connection request between $\boldsymbol{s}-\boldsymbol{t}$
Output: Continuity Constraint Mixed Integer Linear Programmingor null
Begin{

1. Take a the logical topology as input and then mark all the possible lightpaths as available
2. Employ the routing problem on the derived topology and update the weights with the computed traffic flow for the given lightpaths.
3. Choose the source and destination nodes $\boldsymbol{s},\boldsymbol{d}$ and all the intermediates nodes $\boldsymbol{i}.\boldsymbol{j}$in the topology
4. At each node check the incoming link $\boldsymbol{e_{in}}$ and at the same node check the outgoing link $\boldsymbol{e_{out}}$and according to the equation (2).

If (value isgreater or less than 0)

then a lightpath between the chosen nodes exists

else (value is equal to 0)

no possible lightpath is available.

end

} **End**

3.3 Summary

A new method to solve the problem of network congestion and routing problem is proposed. The main outcomes of the proposed technique continuity constraint mixed integer linear programming (MILP) are somewhat lies in between efficient resource utilization and enhancing the performance of the network parameters.

CHAPTER 4
EXPERIMENTAL SETUP

MatPlanWDM 0.61 an open source educational WDM network planning tool has been used to simulate the results. Virtual topology and flow routing problems can be tested and compared using this tool. This also provides an optimal linear programming option which can be used using externally available solvers like TOMLAB\CPLEX or GLPK.

4.1Network Topology Designing

New networks are designed using '*design virtual topology and flow routing'*mode. Input parameters for simulation like the physical layout file, traffic pattern file and planning algorithm are provided.

4.1.1 Physical File

This is a.xml file which describes the physical topology attributes of a network. It is equipped with a list of edges/nodes and vertices/fiber optical links in the network.For each node X and Y coordinates are taken on the Euclidean plan and the distance measured in kilometers. Number of O/E receivers,E/O transmitters, number of TWCs (Tunable Wavelength Converters), node type, node population, the time zone of each given node and the name for the mentioned node are also given in the physical file. Information for each link in terms ofthe maximum number of wavelengths that can occur in a link and the lightpaths capacity in Gbps is also mentioned.

Lightpaths:The communication between the source and destination nodes or through any intermediate node on a WDM network carried over a path, are referred to as a lightpath. These lightpaths utilizes a singlewavelength through optical nodes with the help of optical add-drop multiplexers or optical cross-connects withoutconversion on intermediate nodes.

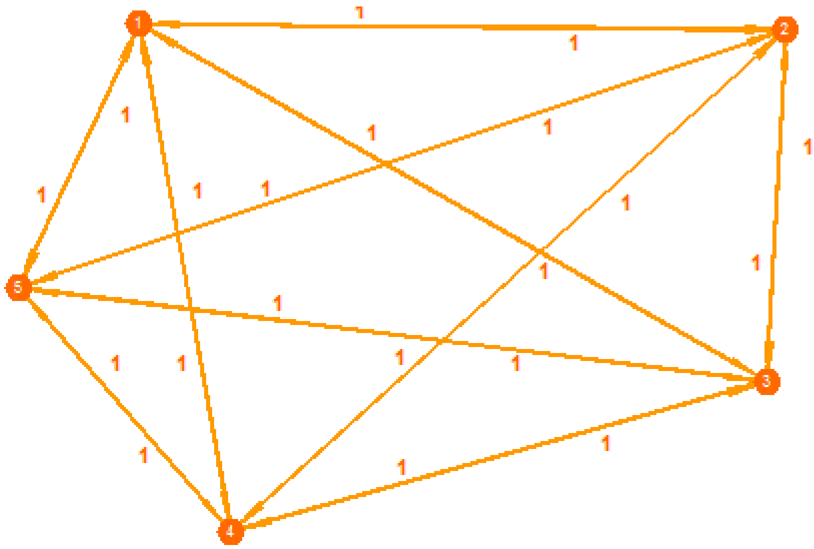

Figure 4.1 - 5 Node Network Physical Topology

Table 4.1 Physical Information for 5 Node Network

Nodes Number	5
Number of Links	20
Number of Available Wavelengths	40
Total Offered Capacity	40Gbps
Type of connection	Bidirectional

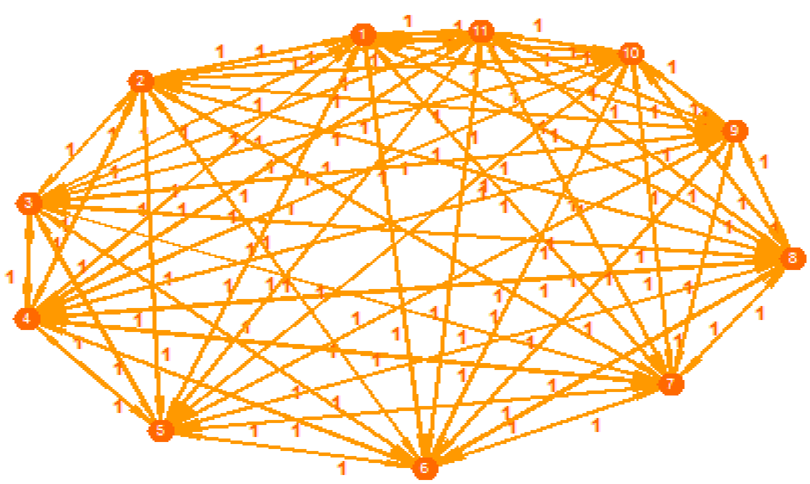

Figure 4.2 - 11 Node Network Physical Topology

Table 4.2 Physical Information for 11 Node Network

Node Number	11
Number of Links	110
Number of Available Wavelengths	40
Total Offered Capacity	40Gbps
Type of connection	Bidirectional

4.1.2 Traffic File

This is a *.traff* file which contains of offered traffic matrix in Gbpsat each ingress and egress node pair. The offered traffic can be row, column or totally normalized.

Traffic Generation is has the following sub parts:

- Input Parameter
- Type of Pattern Generation
- Type of Normalization
- Traffic File

A user starts the process by choosing the number of nodes N in the network. The traffic matrix can be like

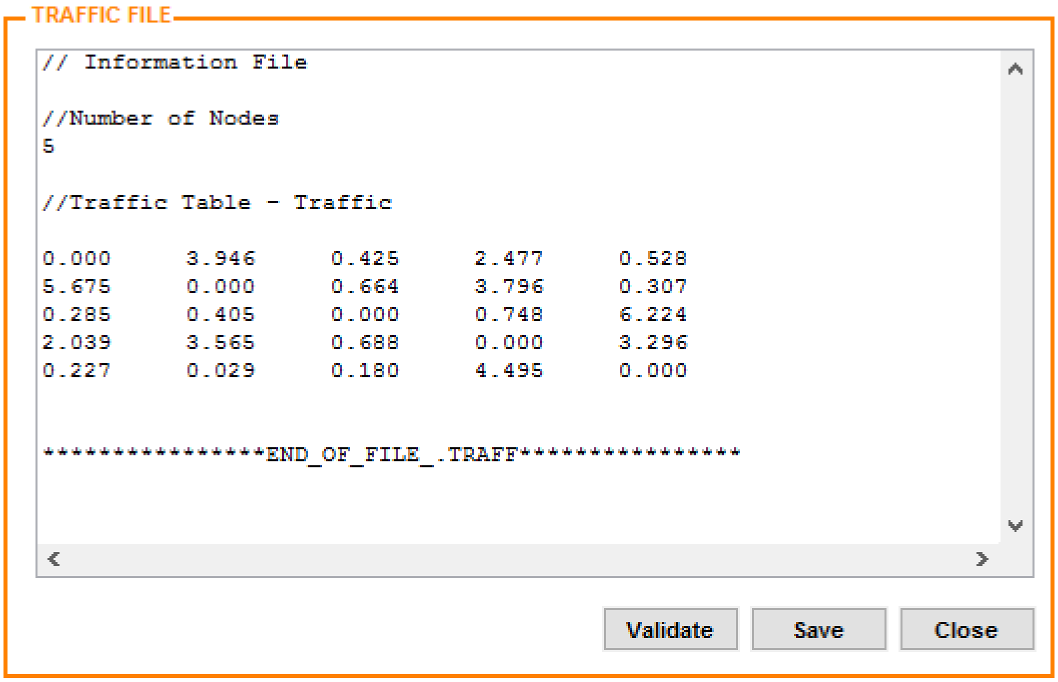

Figure 4.3 Traffic File for 5 Nodes Network

An existing *.traff* file can also be opened and then the desired modificationscan be made. The user may also select the pattern generation option which enablesdifferent ways to generate a traffic matrix.

The distribution in the matrix is based on distances andpopulations. Assume $L \times L$ matrix that allows user to introduce asymmetric traffic.

$L$is the number of levels defined by the user

N is the number of nodes

P_i is the population of the node

P_{max} is the maximum population of the node

Three types of normalization can also be applied to the traffic matrix:

1. Total Normalization: In this the sum of all the matrix elements should be equal to the total traffic that is offered to the network.

Table 4.3 Total Normalization Interface

0.000	0.472	0.900	0.127	0.125	2.187	0.615	0.090	2.335
0.094	0.000	1.259	0.048	0.199	0.116	0.191	1.316	0.112
0.047	2.423	0.000	0.602	0.247	0.153	0.866	0.204	0.210
0.195	0.211	2.315	0.000	0.166	0.466	0.176	0.043	0.208
0.372	0.200	0.131	0.165	0.000	2.001	0.160	0.077	1.487
0.906	0.137	1.070	0.140	0.676	0.000	0.021	0.349	0.338
0.151	0.160	0.225	0.188	0.011	0.079	0.000	2.452	1.255
0.999	0.166	0.620	0.241	0.115	0.285	2.229	0.000	0.130
0.76	1.595	0.316	0.947	0.141	0.004	0.615	0.053	0.000

2. Row Normalization: In this the sum of each row in the matrix should be equal to the value of traffic offered by the user.

Table 4.4 Rowwise Normalization Interface

0.000	2.756	5.255	0.741	0.730	12.769	3.591	0.525	13.633
1.127	0.000	15.100	0.576	2.387	1.391	2.291	15.784	1.343
0.396	20.396	0.000	5.067	2.079	1.288	7.290	1.717	1.768
2.063	2.233	24.497	0.000	1.757	4.931	1.862	0.455	2.201
3.240	1.742	1.141	1.437	0.000	17.427	1.393	0.671	12.950
9.964	1.507	11.768	1.540	7.435	0.000	0.231	3.838	3.717
1.336	1.416	1.991	1.663	0.097	0.699	0.000	21.694	11.104
8.351	1.388	5.183	2.015	0.961	2.382	18.633	0.000	1.087
0.811	17.027	3.373	10.109	1.505	0.043	6.565	0.566	0.000

3. Column Normalization: In this the sum of each column in the matrix should be equal to the value of traffic offered by the user.

Table 4.5Columnwise Normalization Interface

0.000	2.275	3.077	1.280	1.723	12.479	3.432	0.464	11.408
1.652	0.000	8.842	0.995	5.633	1.359	2.189	13.953	1.124

0.580	16.834	0.000	8.756	4.906	1.259	6.967	1.518	1.479
3.024	1.843	14.345	0.000	4.146	4.819	1.779	0.402	1.842
4.749	1.438	0.668	2.483	0.000	17.031	1.331	0.593	10.836
14.606	1.244	6.891	2.661	17.545	0.000	0.221	3.393	3.110
1.958	1.169	1.166	2.874	0.229	0.683	0.000	19.177	9.291
12.241	1.146	3.035	3.482	2.268	2.328	17.807	0.000	0.910
1.189	14.053	1.975	17.468	3.551	0.042	6.274	0.500	0.000

Finally, the generated file can also be verified by the user for its format i.e. *.traff* file.

4.1.3 Planning Algorithm

The planning algorithm is nothing but an algorithm saved asan *.m* file. Built in algorithm can chosenor one can implement an algorithm of their own. The planning algorithm for the design of logical topologies in MatPlanWDM is a testing Algorithm based Dijkistra's Algorithm for Routing.

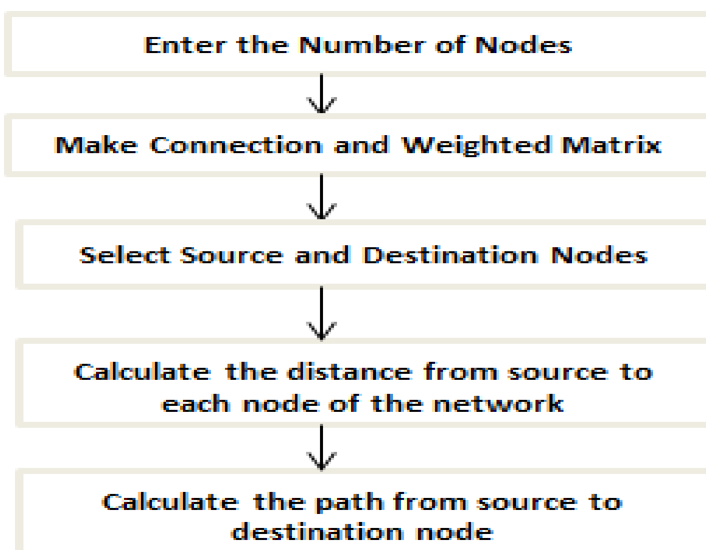

Figure 4.4Flow Chart of the Testing Algorithm

The RWA problem is divided into two parts routing and wavelength assignment, where the routing problem is a request between the source and destination is routed among all the available routes, which can be achieved by using Dijkistra's algorithm to determine the shortest path while the wavelength assignment problem is to assign wavelengths with and without continuity to the route selected by the routing problem.

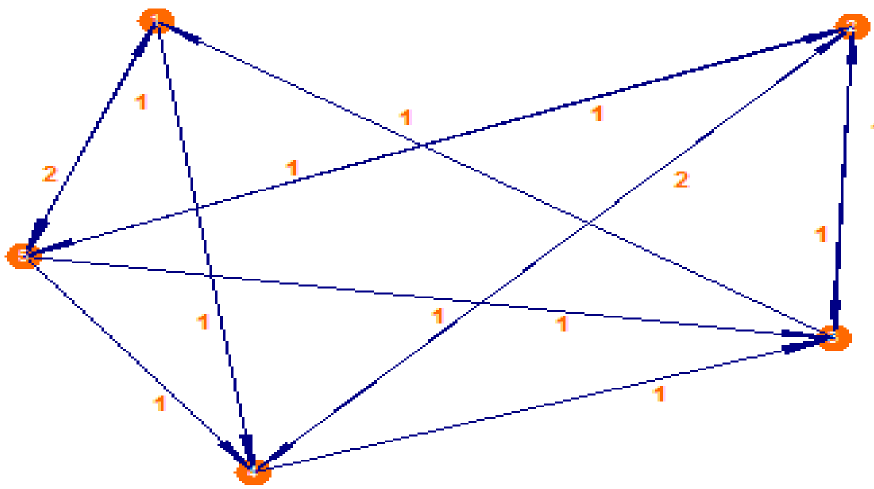

Figure 4.5 Possible Lightpaths or Virtual Paths of 5 Node Mesh Network after Testing Algorithm

4.2 Modes of Operation

MatPlan WDM helps in the study of various network characteristics. They help in design of network topology and user are also able to assign different parameters to network. The main modes of operation are: Topology Designer, Design Virtual and Flow Routing, Multi Hour Analysis, What if Analysis and Dynamic Analysis

4.2.1 Design Virtual and Flow Routing

This mode of operation allows the users to design wavelength and routing in networks. Figure 4.6 shows aMatPlanWDM Graphical User Interface that is used for flow routing and virtual topology design. This is divided into three areas i.e. input data and results report area.

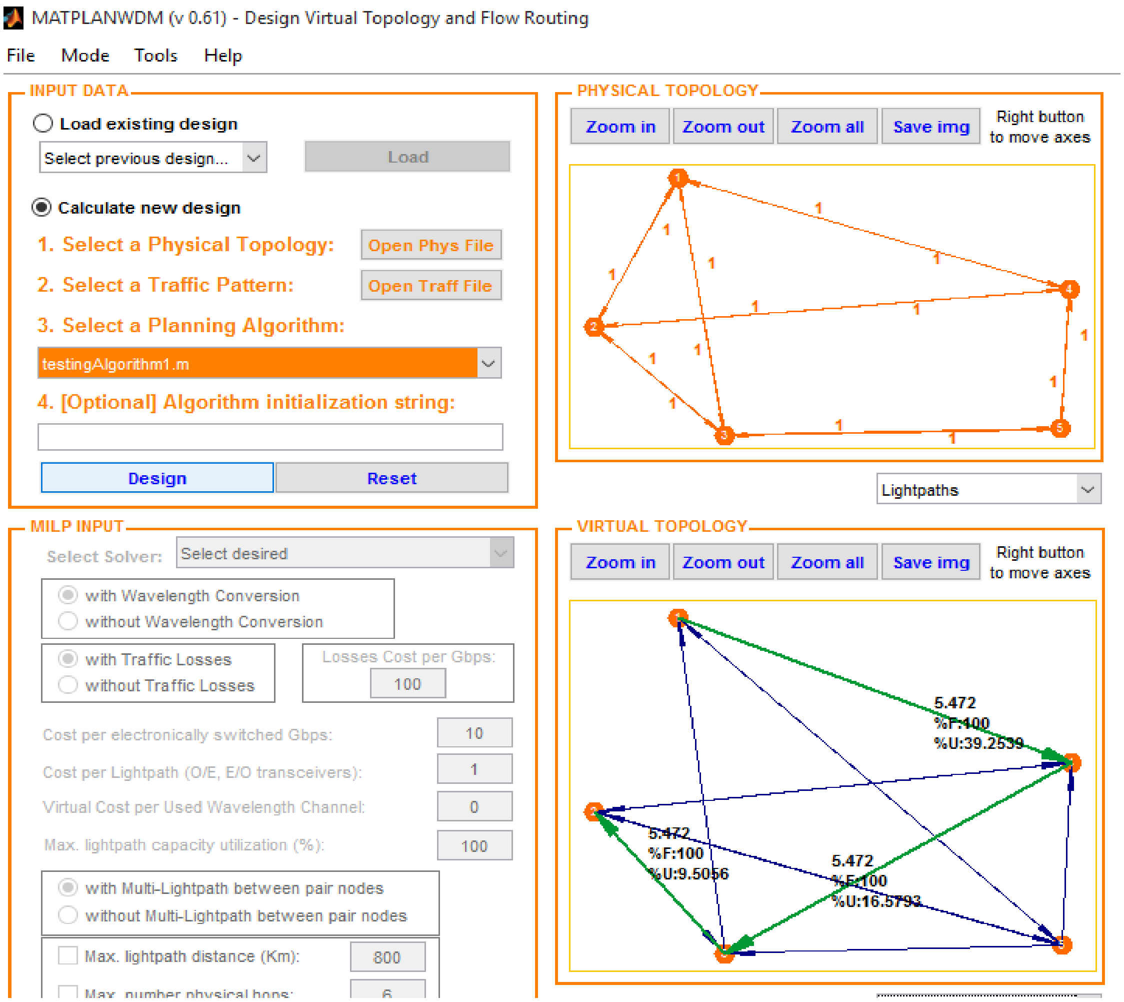

Figure 4.6 Virtual Topology and Flow Routing

The user is required to provide input parameters for the simulation.One can choose to design a topology or select an existing design.

4.2.2 What If Analysis

This function gives user the ability torunmultiple simulations bychoosing any one of the given parameters from the given set ofinput parameters. Fig. 4.7 shows an input data and a physical topology plane that are part of the workspace window. A text report area can also be seen where results are displayed, another area is present that draws the generated performance curves.

In the input parameters area we can define the number of electrical to optical transmitters at each node, number of optical to electrical receivers at each node,wavelengths per fiber,and TWC converters per node, lightpath capacity in Gbps, the traffic matrix, and the planning algorithm that is used. Two different sweep parameters can be defined, where the range of this sweep parameter isgiven byincrease/decrease percentage of a parameter over its current value.

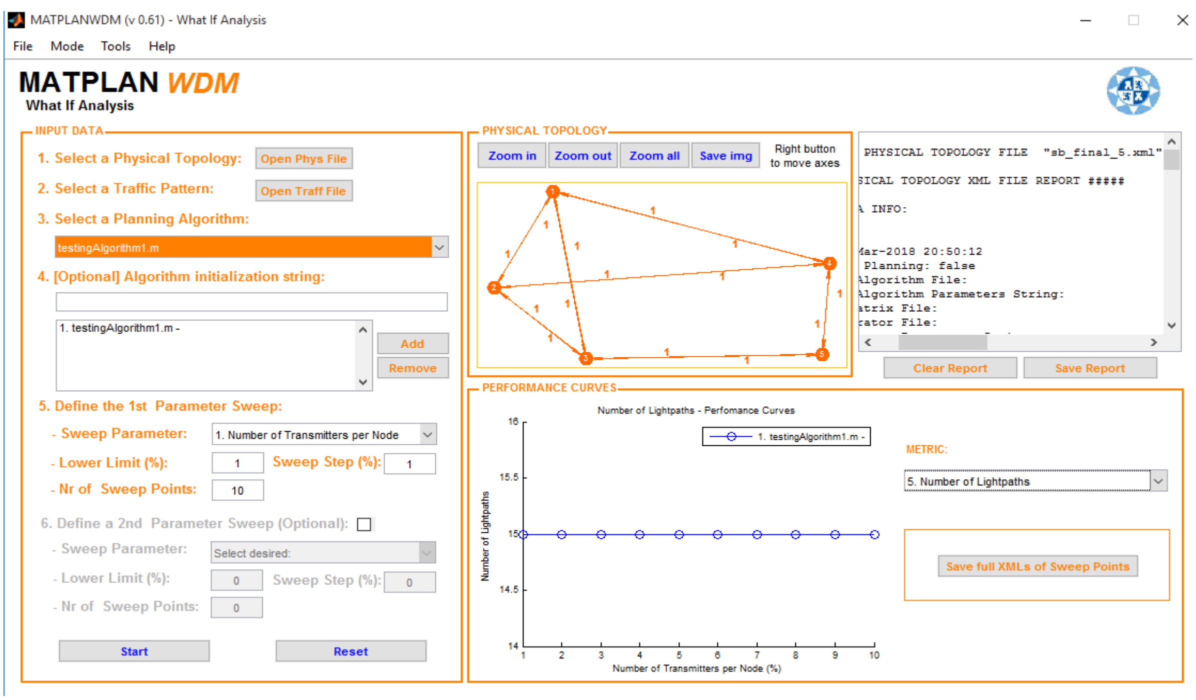

Figure 4.7 What If Analysis

4.2.3 Multi – Hour Analysis

This type of analysis is done where there are time varying traffic demands. It finds major application where the traffic demands in a network is distributed over multiple timezones i.e.the busy hours of the nodes do not coincidence with each other. A new design can be calculated or one can choose to load an existing.

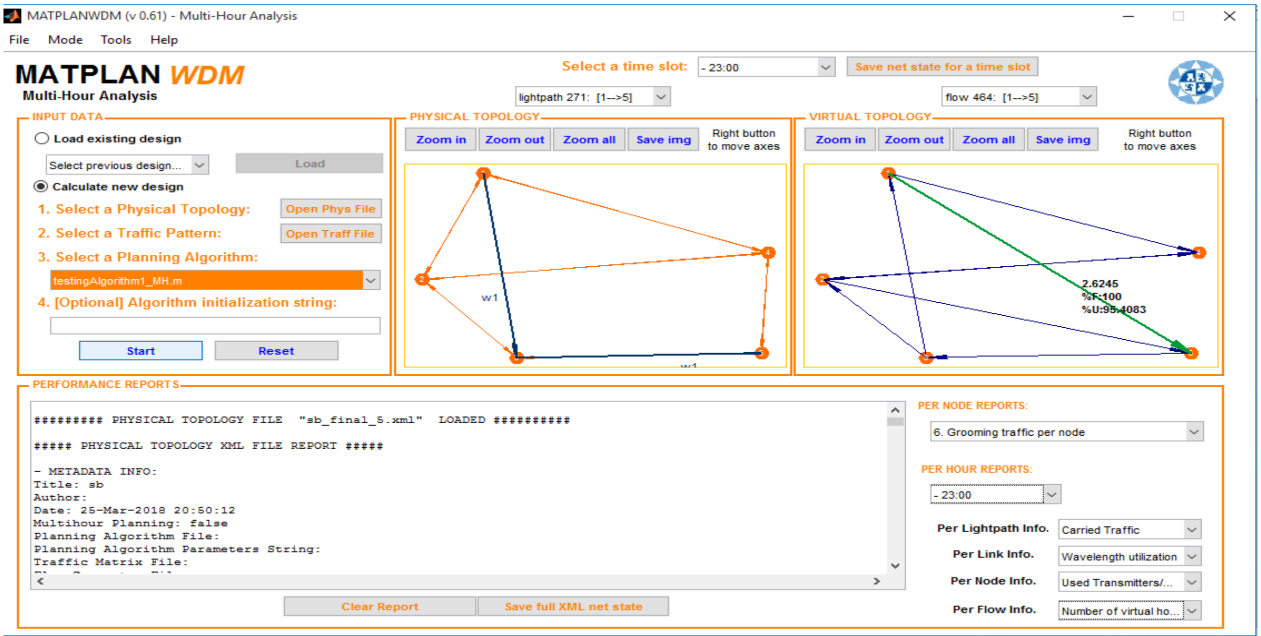

Figure4.8 Multi Hour Analysis

The output of multi hour analysis will be a virtual topology that will be dependent on the hourly changing pattern of traffic.

4.2.4 Dynamic Analysis

The Dynamic Analysis is an online test optimization that can react to very high demands of traffic requests for arrival and termination. This aims to solve the bigger problem of deciding a virtual topology and routs of the flow of traffic. It is achieved by automating the performance evaluation tools with the help of dynamic optimization algorithms in place.

4.2.5 Topology Designer

A user can insert nodes by clicking onright bottom area (a canvas like area) while the Insert Node mode active.

Both unidirectional links and bidirectional links can be inserted to connect the above selected nodesselecting the corresponding buttons.

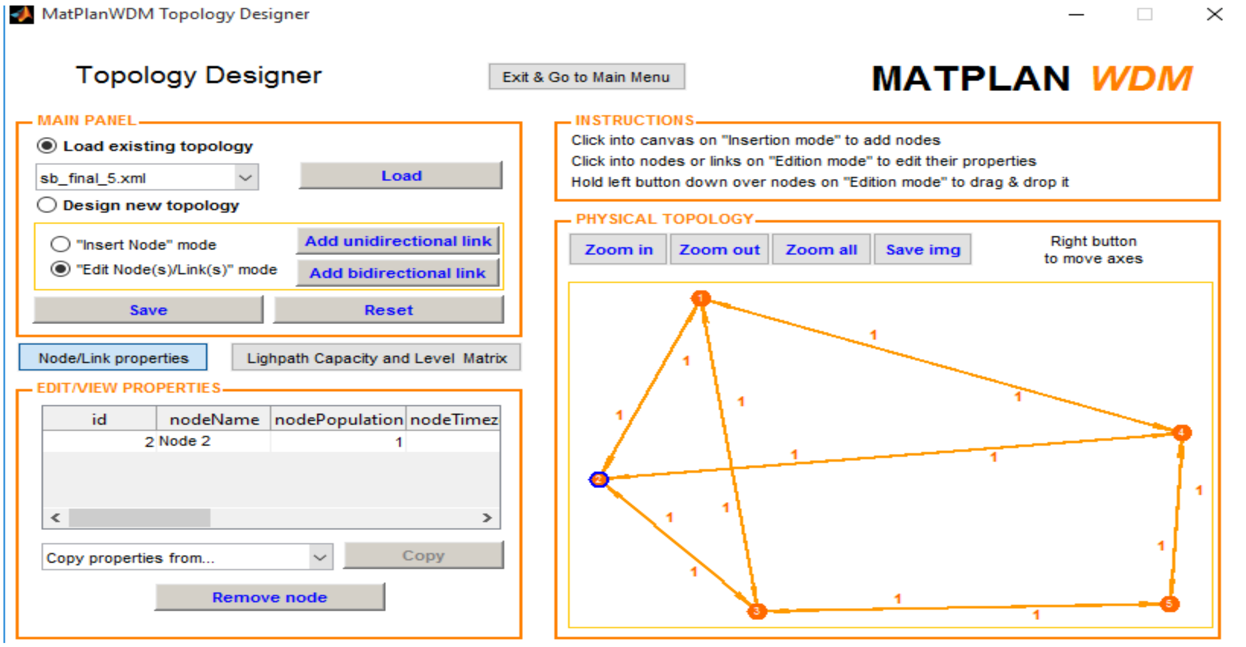

Figure4.9 Topology Designer

After the design of the desired topology one can edit the properties of links and nodes by selecting the Edit Node(s)/Link(s) option. Properties like node population, node time zone, node level, (X, Y) coordinates, and etc. can be changed, while properties like node ID cannot be changed as it is generated internally.

4.3Summary

Virtual topology and flow routing problems can be tested and compared using this tool.What- if- analysis is selected torundifferent kinds of simulations by varying any one of the given parameters. Results are obtained for further comparison using this function.

CHAPTER 5

SIMULATION RESULTS

Comparison is dome for parameters wave length channel capacity and traffic demands. These are plotted against message propagation delay, number of wavelengths used, etc.

5.1 Simulation Results

Comparison is done for various performance parameters and the results of objective 1 and 2 are analyzed.The basic four topologies (bus, ring, star, mesh) are considered and various parameters are compared to have a topology that outcomes all other topologies.

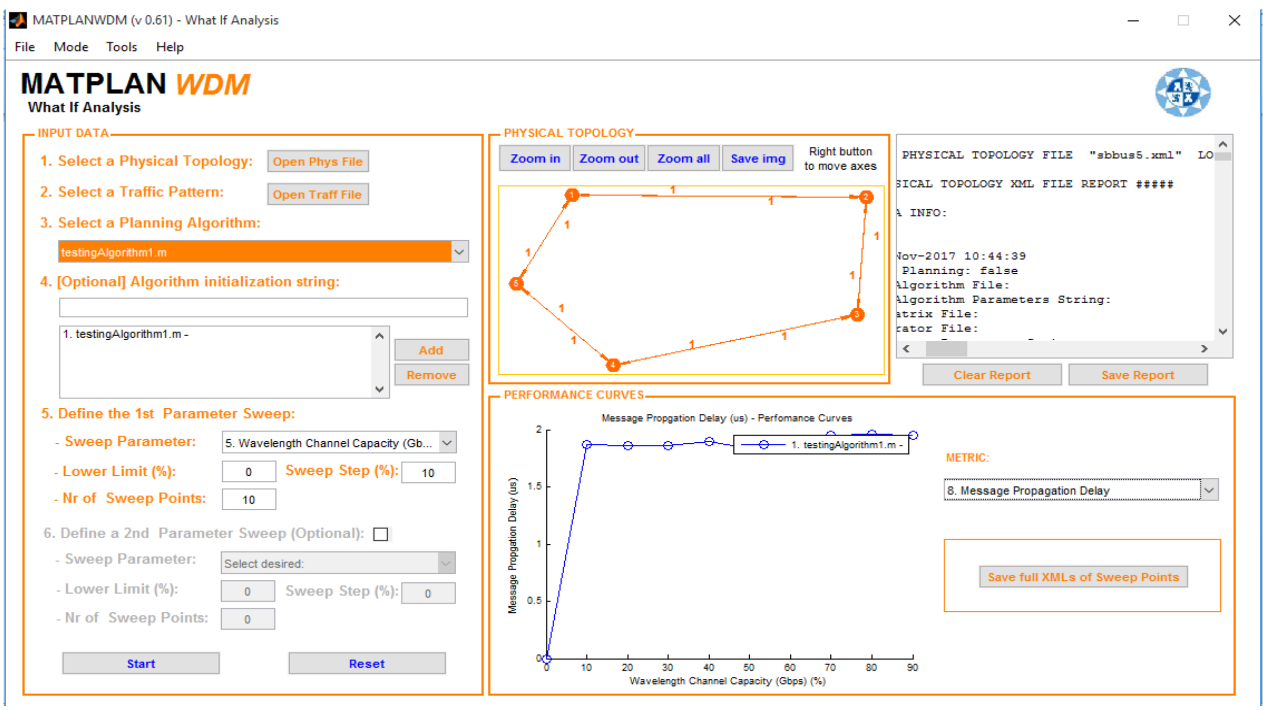

Figure 5.1 Message Propagation Delay (μS) VS Wavelength Channel Capacity (%Gbps)

5.1.1 Comparison of Wavelength Channel Capacity:

Comparison analysis is done with wavelength channel capacity as its utilization impacts the overall performance of a network.

With the increase in wavelength channel capacity the number of wavelength channels that are used in a network will decrease as availability of bandwidth will be more. It is clear from the observations that mesh topology is not a good performer in this scenario for the initial usage of the bandwidth.

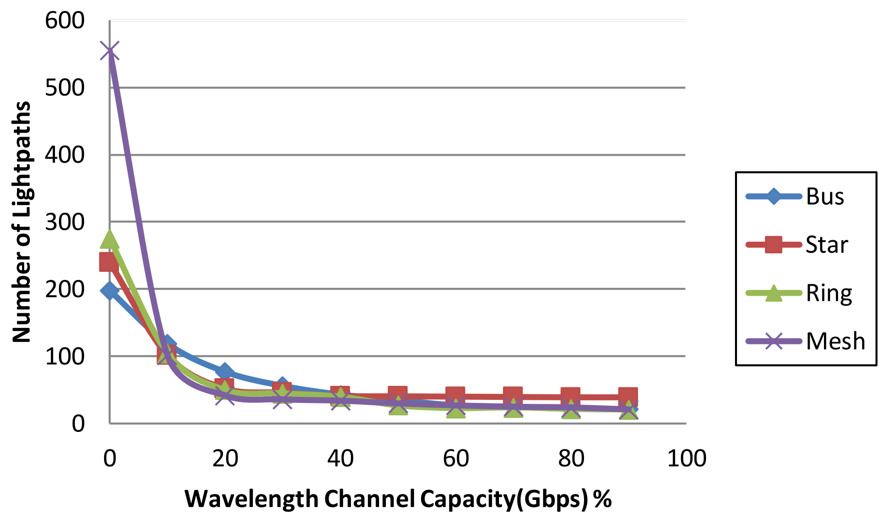

Figure 5.2 Number of Lightpaths VS Wavelength Channel Capacity (%Gbps) for 5 Node Network

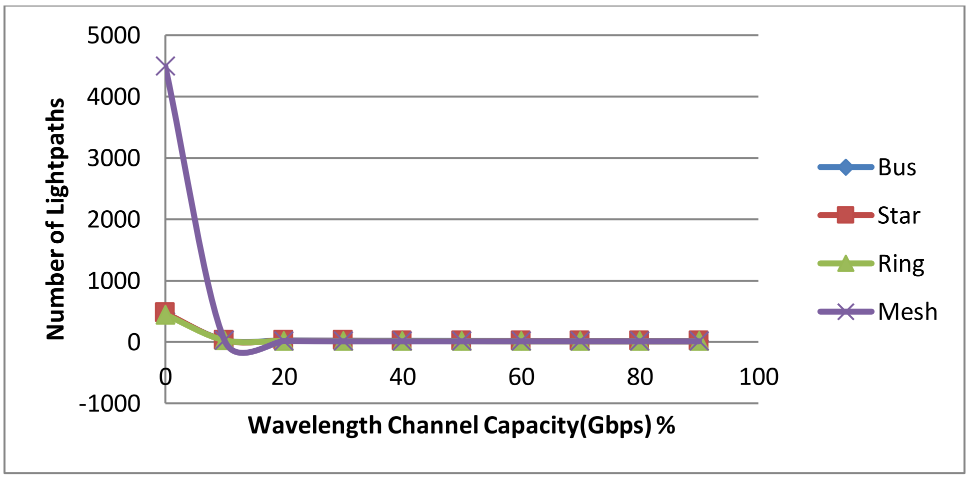

Figure 5.3 Number of Lightpaths VS Wavelength Channel Capacity (%Gbps) for 11 Node Network

The analysis of message propagation delay and wavelength channel capacity is carried out to findthe problems that arise with the advantages of topologies. For example in the case of star topology scalability and initialization are advantages but network's traffic passes through a centrally located connecting device, creating a bottleneck which leads to poor results in terms of propagation delay .While same is not the case for mesh topology as there aremultiple cable which efficiently manage the load.

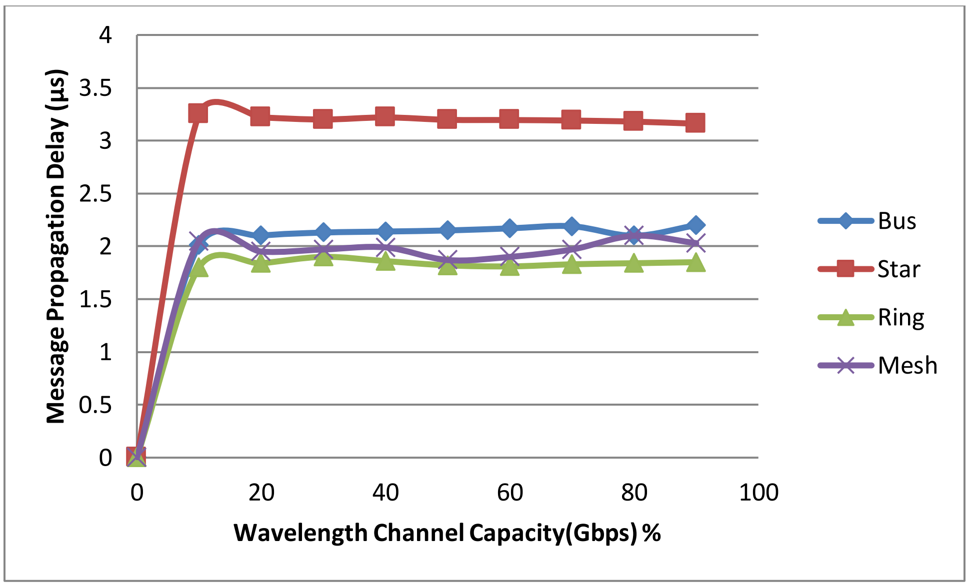

Figure 5.4Message Propagation Delay(µs)VS Wavelength Channel Capacity (%Gbps) for 5 Node Network

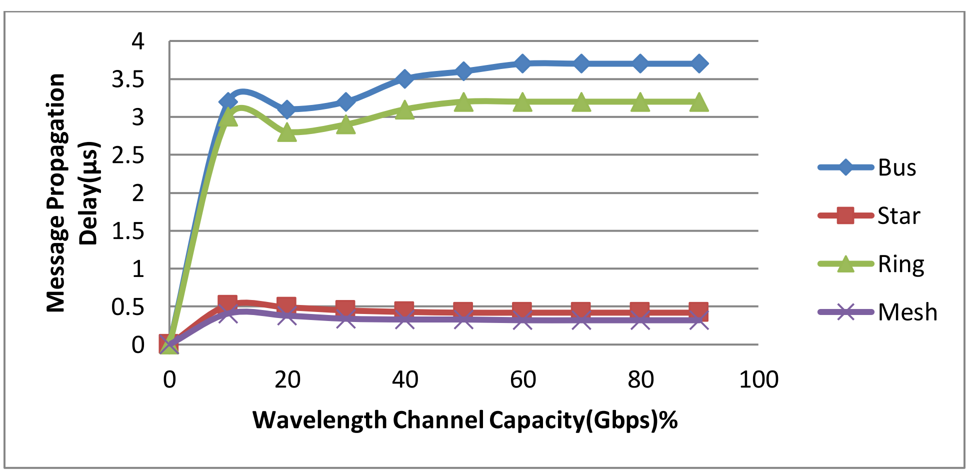

Figure 5.5 Message Propagation Delay (µs) VS Wavelength Channel Capacity (%Gbps) for 11 Node Network

5.1.2 Comparison of Traffic Demand:

From these analyses it is concluded that different topologies show variable nature when they undergo different trafficdemands.

The network congestion reduces the quality of service as it refers to a node or link is carrying more data it can handle.

The analysis show that for lesser number of nodes the congestion is less for bus topology but as the number of nodes increase the congestion for ring, mesh and star falls to the level of bus i.e. it improves.

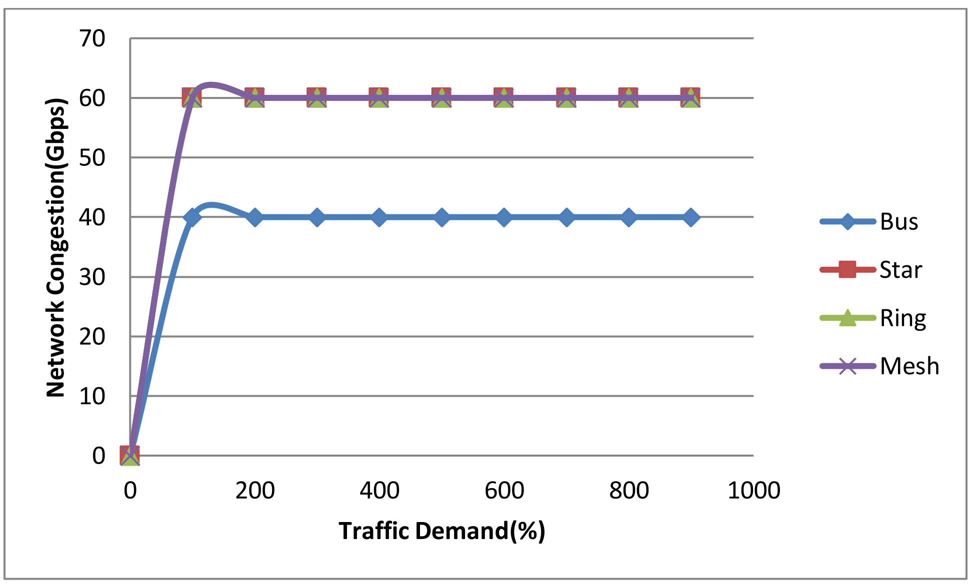

Figure 5.6 Network Congestion (Gbps) VS Traffic Demand (%) for 5 Node Network

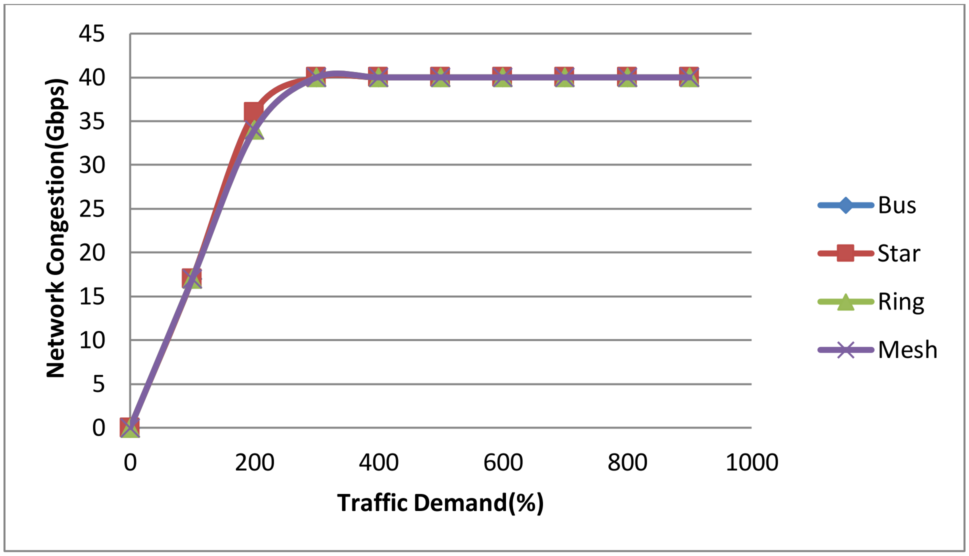

Figure 5.7 Network Congestion (Gbps) VS Traffic Demand (%) for 11 Node Network

It is clear from the analysis that for all topologies the numbers of lightpaths per fiber are directly proportional to the increase in traffic. But they are highest for bus topology asall the nodes share a single link. Mesh clearly comes out as the best performer and the number of lightpaths is further reduced as we keep on increasing the number of nodes.

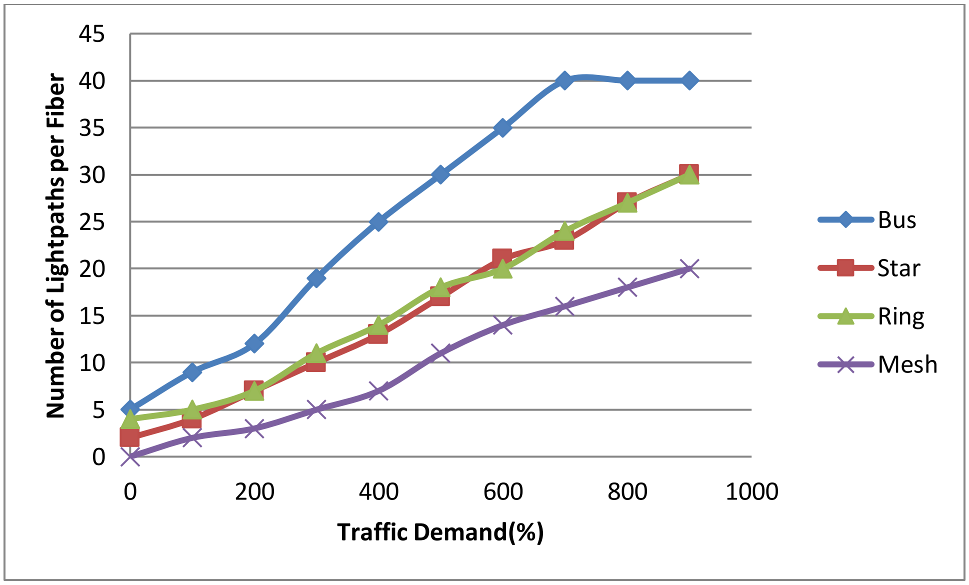

Figure5.8 Number of Lightpaths per Fiber VS Traffic Demand (%) for 5 Node Network

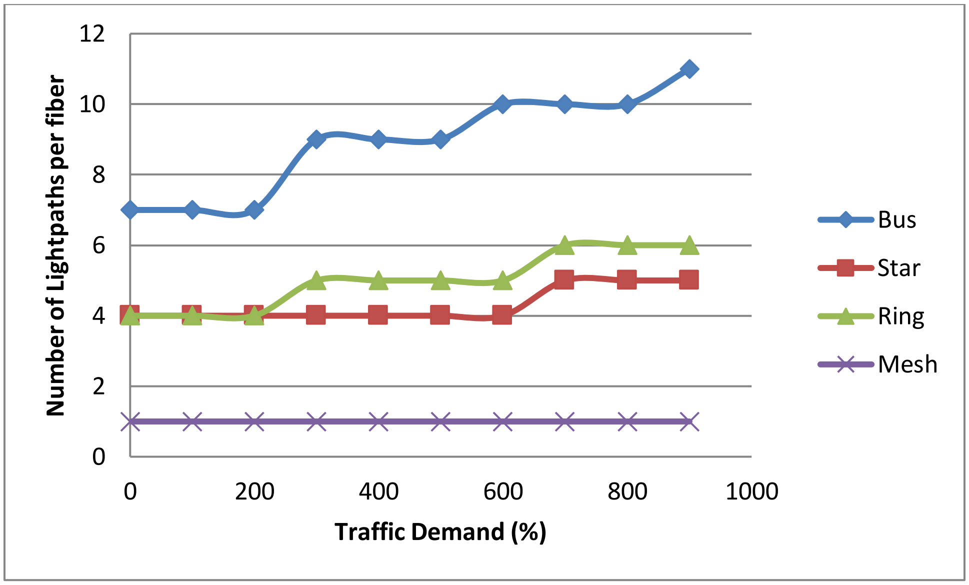

Figure 5.9 Number of Lightpaths per Fiber VS Traffic Demand (%) for 11 Node Network

The message propagation delay plays an important role in the design of high speed networks.

As the star topology has one central node through which all the data passes the delay in this topology is maximum. Also as the number of nodes increase it becomes clear that mesh topology has the least delay.

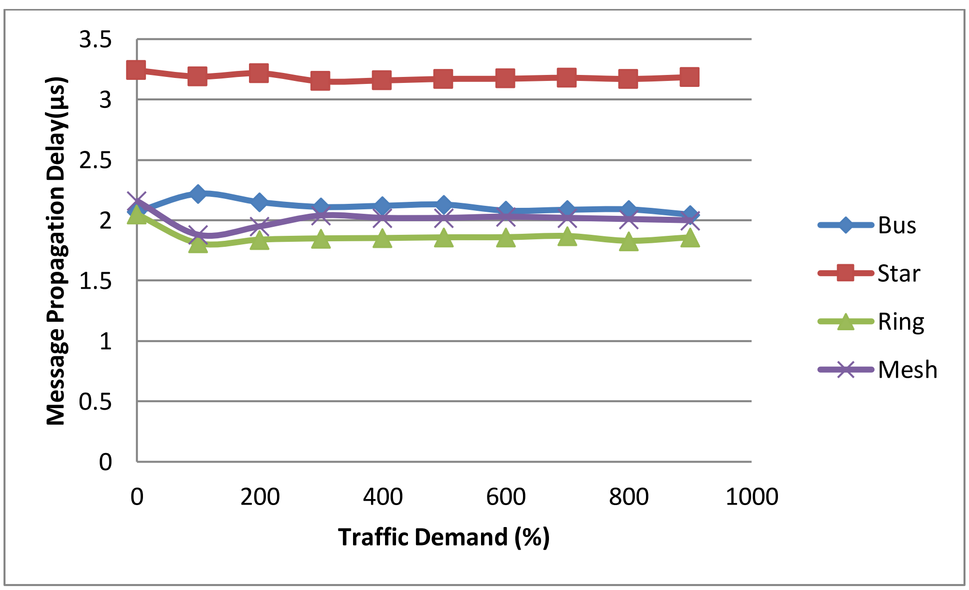

Figure5.10Message Propagation Delay (µs)VS Traffic Demand (%) for 5 Node Network

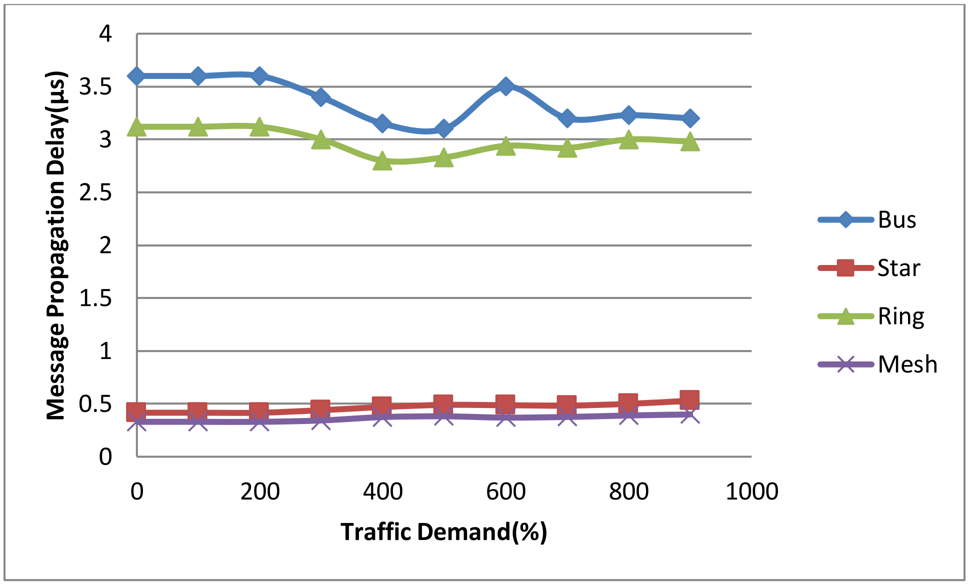

Figure 5.11 Message Propagation Delay (µs) VS Traffic Demand (%) for 11 Node Network

Table 5.1 Simulation Summary

Performance Parameters	**5 Nodes**				**11 Nodes**				**Comments**
	Bus	**Ring**	**Star**	**Mesh**	**Bus**	**Ring**	**Star**	**Mesh**	
No. Of Lightpaths per Fiber vs Wavelength Channel Capacity	1	3	2	4	2	1	3	4	The number of lightpaths should be less of any given network to be efficient. Clearly mesh topology is the worst performer for this analysis for both less and more number of nodes.
Message Propagation Delay vs Wavelength Channel Capacity	3	1	4	2	4	3	2	1	Message propagation delay is of the order of 2µs for mesh topology with 5 nodes and reduces further to the order of 0.3 µs for the same topology with 11 node network.

Network Congestion vsTraffic Demand	1	2	2	2	1	1	1	1	Bus topology is the best performer in terms of network congestion as is does not have a routing overhead.
No. Of Lightpaths per Fiber vs Traffic Demand	4	3	2	1	4	3	2	1	Mesh topology has the best performance with respect to number of lightpaths used per fiber.
Message Propagation Delay vs Traffic Demand	3	1	4	2	4	3	2	1	Message propagation delay is of the order of 2μs for mesh topology with 5 nodes and reduces further to the order of 0.3 μs for the same topology with 11 node network.

5.1.3 Comparison Based on MILP

Objective 3 deals with the comparison of two algorithms i.e. the testing algorithm and MILP based on the same performance parameters that were analyzed for the above objectives.

The network congestion in Gbps is plotted against the traffic demand. As the percentage of traffic increases these is an increase in the network congestion also as the nodes become loaded with traffic. However, it can be seen that the congestion is significantly reduced using MILP. This is achieved by having wavelength continuity constrain that reduces the congestion at the nodes.

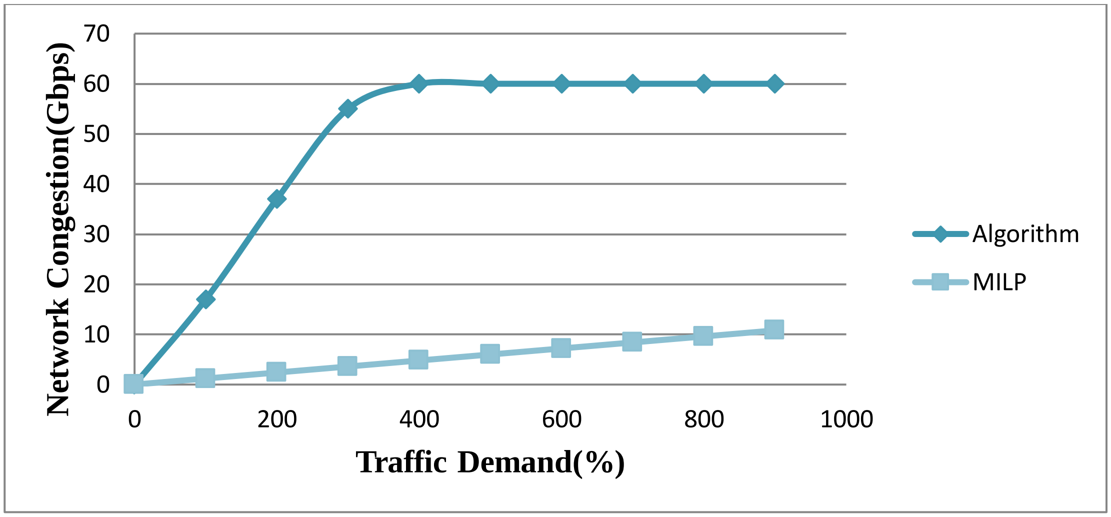

Figure 5.12 Traffic Demand VS Network Congestion for 11 Node Network

With decrease in the congestion these can also be seen a very small change in the overall propagation delay of the system. Where propagation time is a function of taken to reach from source to destination node. This considerable fall in network congestion and the propagation delay leads to improvedQuality of Service (QoS), while maintaining other parameters like wavelength channel capacity, number of wavelengths assigned per fiber,etc. in desired level of QoS.

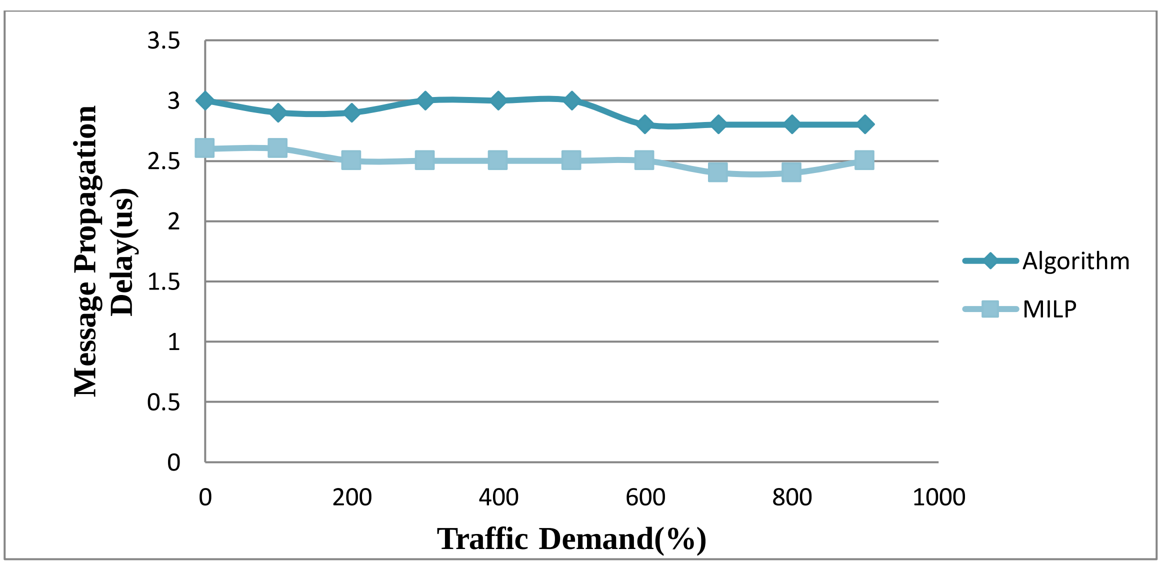

Figure 5.13 Traffic Demand VS Message Propagation Delay(us) for 11 Node Network

It is desirable to have more number of lightpaths in a network as they enable better possibilities of routing in a virtual topology network. Thus a network with more number of paths will be more preferred. It can be observed from the Fig. 5.14 that the number of lightpaths increases with the increase in the traffic demand. It can also be seen that the number of lightpaths generated using MILP are higher than the other algorithm.

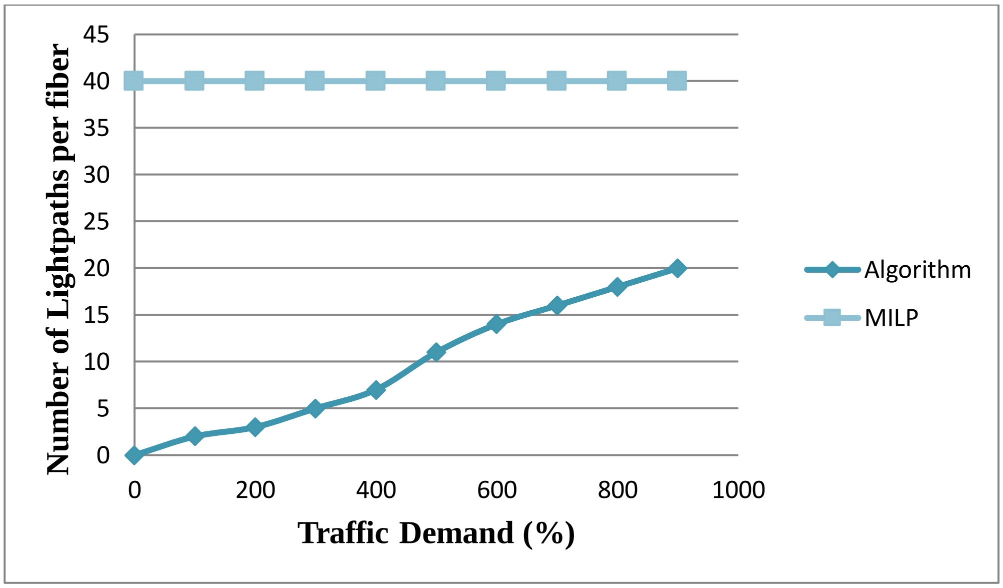

Figure 5.14 Traffic Demand VS Number of Lightpaths per Fiber Capacity for 11 Node Network

With the increase in the channel capacity of the given network there can be seen a fall in the number of lightpaths when using simple algorithm, this is so because when the capacity of a network increases less number of lightpaths will be required to maintain a given traffic. But with MILP we can see that there is a constant value in the number of lightpaths generated. This can be observed as an added advantage from routing point of view in a virtual topology network.

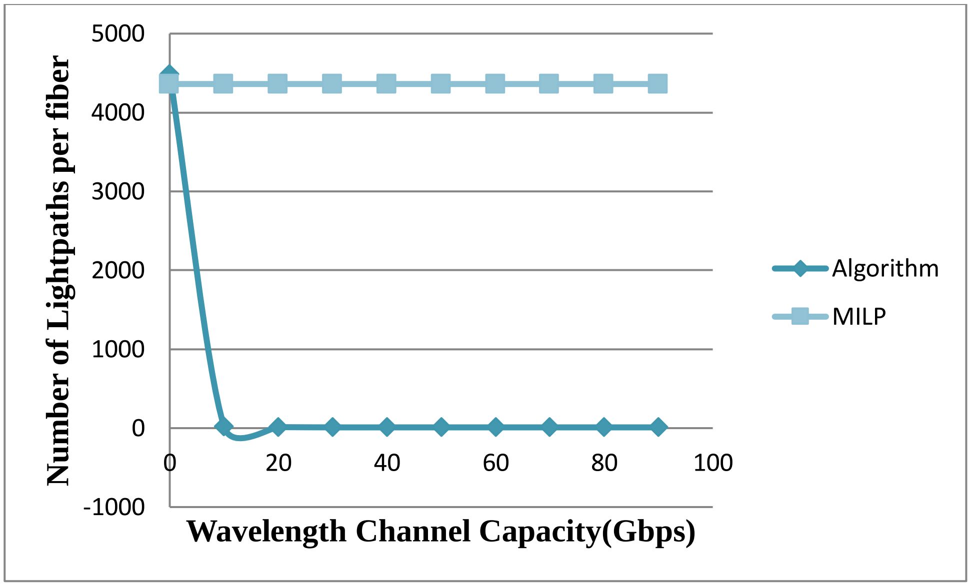

Figure 5.15 Number of Light Paths VS Wavelength Channel Capacity for 11 Node Network

The increase channel capacity of a given network is will result in overall decrease in the message propagation delay. The delay when compare to traffic demand is significantly less as in Fig. 5.16 full utilization of channel seen.

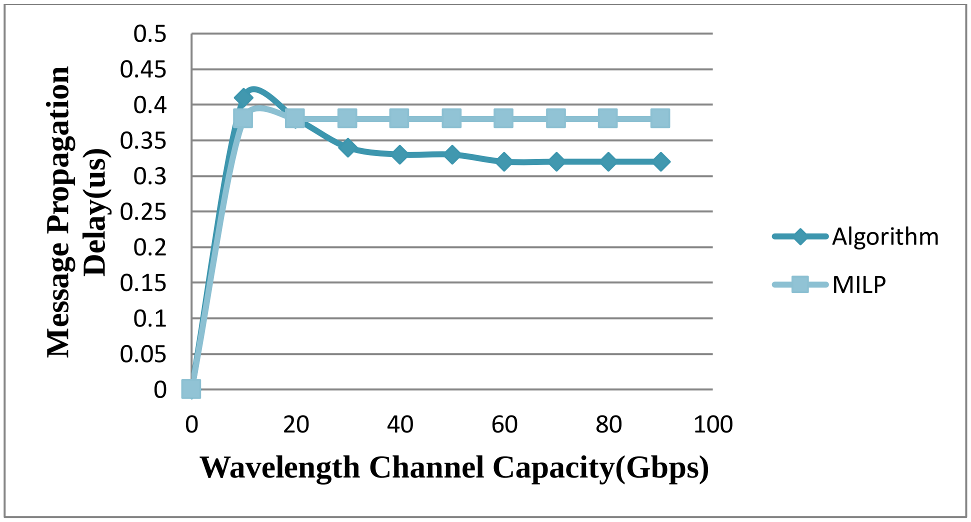

Figure 5.16 Message Propagation Delay VS Wavelength Channel Capacity for 11 Node Network

Discussion made with using all these parameters when compared and placed together leads to the desired value of quality of service (QoS).

5.2 Summary

The mixed integer linear programming has been proposed for efficient virtual optical topology design. The simulated result suggests the competency of the proposed work. The analyzed results for different algorithms observe that fraction of latency and congestion is lesser in MILP.

CHAPTER 5
CONCLUSION AND FUTURE WORK

5.1 Conclusion

Practical implementation of wavelength division multiplexed networks has gained importance with the recent developments in optical communication networks. Determining the Quality of Service is a major issue as it depends on performance matrices.Therefore the network architecture has a vital role to play while designing networks. So different networks were designed, simulated and analyzedfor various set of performance matrices, which are also referred to as QoS (Quality of Service) parameters.It can be concluded that mesh topology is better when compared to various other topologies under heavy traffic andthe performance further increases in terms of lesser delay even when the number of nodes are also increased. The only disadvantage being that the cost of laying a mesh network is very high. Thus one can select the performance matrices required select the topology that suits the best for their set of requirements.

The mixed integer linear programming (MILP)is proposed for efficient virtual optical topology design. The simulated result suggests the competency of the proposed work. The analyzed results for different algorithms observe that fraction of latency and congestion is lesser in MILP. So, if the objective of the application is message propagation delay then MILP can be used. In other words, the accomplishment of any algorithms is based upon parameters that are under consideration.

MatPlanWDM0.61 is used as simulation tool, to study the various WDM networks and their performance.This is open source software which is an open source tool. Itis equipped with different features for deployment and designing of topology.

5.2 Future Work

Approximately a 30% rise in optical network traffic has been experienced worldwide. This growth is a result of upcoming technologies cloud computing, real time gaming, video streaming and big data analysis etc. With us moving into an era of internet of things from internet of information, millions of machines and smart devices will want to communicate with each other. The question arises that can the current network technologies cope up with these needs. The throughput can be enhanced by space division multiplexing (SDM) [37] with mixed integer linear programing (MILP) that will be used to increase the data rate.

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