ROUTING AND WAVELENGTH ASSIGNMENT IN OPTICAL BURST SWITCHED NETWORK

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This dissertation is submitted to Faculty of Engineering and Technology, International Islamic University Islamabad Pakistan for partial fulfillment of the degree of MS Electronic Engineering at the Department of Electronic Engineering

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MS (Electronics Engineering)

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بسم الله الرحمن الرحيم

In the name of Allah (SWT) the most beneficent and the most merciful.

FORWARDING SHEET

The thesis entitled "Routing and wavelength Assignment in Optical Burst Switch Networks" submitted by Mr. Hanif Ullah Registeration No. 31-FET/MSEE/F-06, in partial fulfillment of Master degree in Electronic Engineering, has been completed under my guidance and supervision. I am satisfied with the quality of student's research work and allow him to submit this thesis for further process of as per Internationl Islamic University rules & regulations.

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Prof. Dr. Zahid Saleem

Date:____________________

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Dr. Ghazanfar Hussain

Thesis Declaration

I certify that except where due acknowledgement has been made the work contained in this thesis entitled ***"Routing and wavelength Assignment in Optical Burst Switch Networks"*** has not been submitted previously, in whole to qulify for any other acadamic award . The content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program.

Hanif Ullah

31-FET/MSEE/F-06

Dedicated to

My Beloved Teachers & Parents

Acknowledgements

In the name of Allah, the Most Gracious and the Most Merciful

All praise and glory to Almighty Allah (Subhanahu Wa Ta'ala) who gave me the courage and patience to carry out this work. Peace and blessings of Allah be upon His last Prophet Muhammad (Sallulaho-Alaihe-Wassalam).

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Abstract

The inherent limitations of optical fiber effect burst transmission and degrade the optical signals. Dispersion and attenuation are important impairment and physical limitations that cause bit-error rate (BER) and signal loss. In this thesis we have analyzed National Science Foundation (NSF) network comprising 14-nodes and 21-edges as an Optical burst switch network (OBS). To combine the merits and advantages of optical circuit switching and optical packet switching techniques, OBS network has been designed. In OBS network a data burst multiple data packets (in a single unit called burst) will be traverse in the optical network all optically. In this network a control packet is sent to reserve bandwidth for the burst (burst header packet PHP or burst control packet BCP), once it reservation completes the data burst then traverses all optically in the optical network. We have analyzed the routing and wavelength assignments in Optical burst switched network. Physical impairments like dispersion, bit error rate and switching-delay in Optical Burst Switch (OBS) and optical communication networks causes to effect both routing and wavelength assignment. We are using the National Science Foundation (NSF) network as a case study. We have found shortest path between any source and destination nodes under a given network condition. We have made adjacency matrix, time delay matrix and length matrix of the network. Analysis of the network is presented for dispersion and time-delay and the results are published.

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CHAPTER 1

INTRODUCTION

1 Optical Fiber

An Optical fiber is a very thin strand of glass or plastic used as a guided communication medium having with huge bandwidth (BW). It is quite like a human hair. It is very long and narrow glass cylinder has special characteristics. It is made up of glass or plastic, works like a glass conduit for light (data), when light entre one end of the fiber, it travel and confined within the fiber until it reach another end. The loss of light in the fiber is very minute, the bit error rate (BER) in optical is very low which contributes towards the data transmission through long distances without deformation. It has many advantages over copper cables like huge bandwidth, online amplification and light weight. Advantages are also listed here.

a. Enormous potential bandwidth:

b. Small size and weight:

c. Electrical isolation:

d. Immunity to interference and crosstalk:

e. Signal security:

f. Low transmission loss:

g. Ruggedness and flexibility:

h. System reliability and ease of maintenance:

i. Potential low cost:

1.1 Optical Fiber Design

Normally optical fiber is made up of glass. It has two parts core part of the optical fiber and cladding part of the optical fiber. The inner portion of the optical fiber with refractive index n_1 is surrounding by the cladding portion with refractive index n_2. Throughout in the optical fiber the ratio of refractive indexes is $n_1 > n_2$.

Once the light pulse inter the core of the fiber, will propagate through the fiber. It is due to the internal reflection of the light beam that confines it in the core. The process is physically termed as *"total internal reflection"*.

As the core and cladding has made up of the same materials with slightly different doping, that makes the refractive index of the core slightly different than that of cladding. The core refractive index is represented by n_1 and the cladding refractive index is represented by n_2, where $n_1 > n_2$.

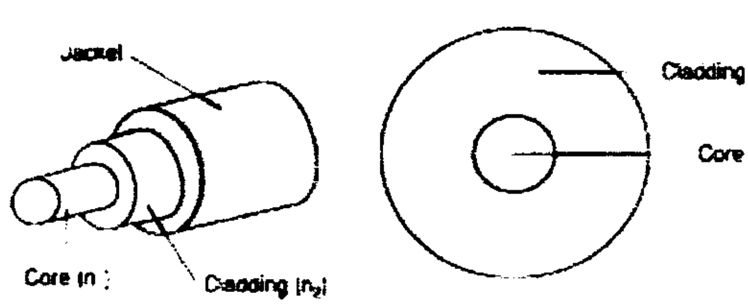

Figure 1: Optical fiber Composition

1.2 Types of optical fiber

Optical fiber has many types.

Single mode, multi mode, step index, graded index optical fibers etc.

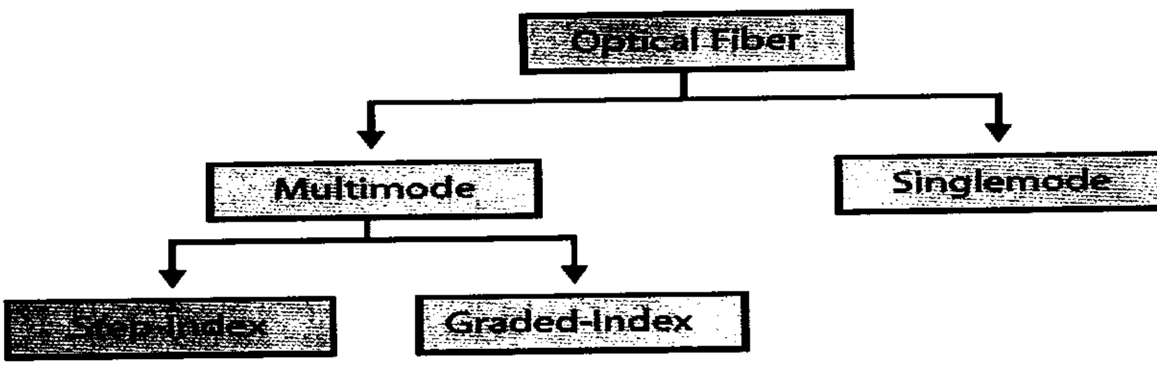

Figure 2: Types of optical fiber

On the bases of index of reflection optical fiber is classified into two types, the step index and the graded index optical fiber. If the index of the core is uniform throughout the radial distance and there is a step change at the core and cladding interface, then this is called step index fiber. If the index of the fiber is a function of the radial distance, and there is a gradual change from the center of the core to its edges is called graded index fiber. Each type of fiber has their importance. Figure 1 gives the geometrical explanation of fibers.

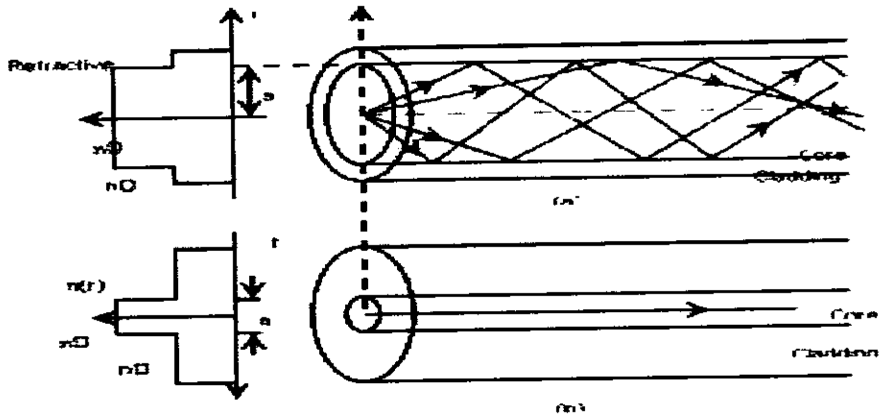

Figure 3: Step Index and Graded Index Fiber

1.2 Types of fiber Based on Modes

On the bases of light modes optical fiber has two types, single mode and multimode fiber.

A single-Mode optical fiber (Mono mode) is a type of fiber carry a single mode/ray of light, the ray travels parallel to the length of fiber. The diameter of the core is $8 - 10\mu m$, where as the diameter of cladding is$125\mu m$.

Step index fiber has a core diameter of $50\mu m$ or 62 μm or 62um, cladding diameter between $100\mu m$ and $140\mu m$ and a numerical aperture between0.2 and 0.5.

Numerical Aperture is $$NA = \sin \alpha o = \sqrt{n_1^2 - n_2^2} \quad (1.1)$$

Similarly refractive index n of the fiber is $$n = c/v \quad (1.2)$$

Here c is speed of light in vacuum $$c = 3 \times 10^8\ m/s$$

A multi-mode optical fiber has core diameter larger than a single mode, it can carry more than one mode/ray of light, hence called multi-mode. It further consists of multi-mode step index and multi-mode graded index fiber. Figure 3 explains the modes propagation in fibers [3].

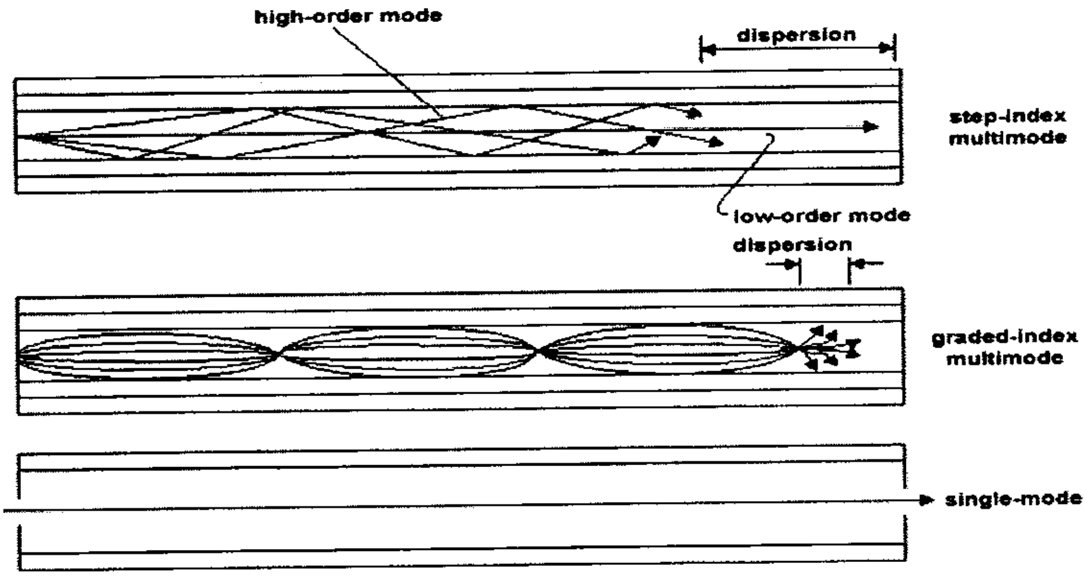

Figure 4: Single mode and multi mode optical fibers

1.2.1 Material used to fabricate Optical fiber.

Normally two types of materials are used for fabrication of optical fiber, glass or plastic. Optical fiber cables mostly mode up of glass materials in which a common type is silica (SiO_2). It is either silica glass or the combination of metal oxide, solenoids or sulfides. In order to produce the slight difference between the refractive indexes of the core and that of cladding various oxides or fluorine are added to the silica. Boron tri oxide (B_2O_3), fluorine andGeO_2, P_2O_5 like materials are used to achieve the difference in indexes. A table is given in which some dopants are used for various fibers.

Table 1: Dopants used in optical fibers

CORE	CLADDING
$SiO2$	$B_2O_3 - SiO_2$
$GeO_2 - SiO_2$	SiO_2
$P_2O_5 - SiO_2$	SiO_2

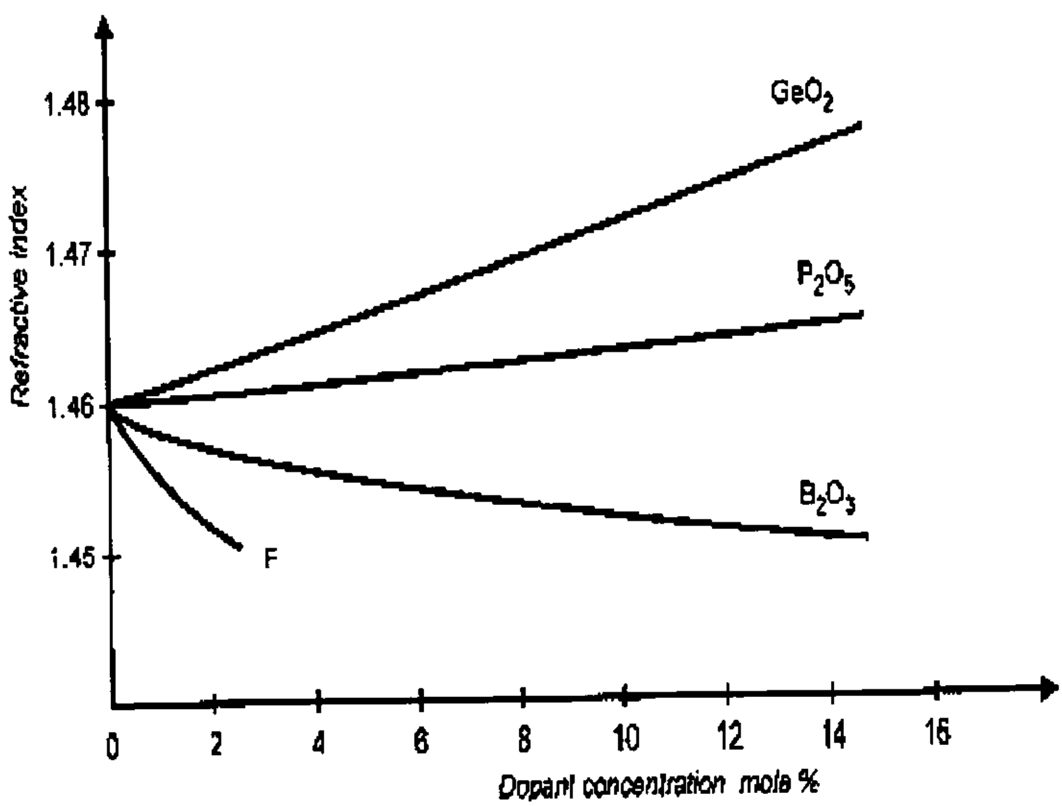

Figure 5: Refractive index verses doping level

Some types of fiber are halide glass fibers. Fluoride glasses have low transmission losses in the range of 0.2 to 8 um wavelength [6]. The minimum attenuation of these materials is about 1dB/m.

Chalcogenide Glass Fiber: The optical fiber made up of group VI elements is termed as chalcogenide fibers. It has long interaction and highly optical nonlinearity, group VI element are arsenic, germanium, sulfur, selenium etc. Its theoretical attenuation has estimated at 1dB/m.

1.2.2 Active Glass Fiber

Some types of element with atomic numbers from 57-71 are used in the manufacturing of active glass fiber. These elements are called Rare-earth elements. The resulting material gives new magnetic and optical properties. When the light is passed through these materials it under goes some basic functions that are attenuation, amplification, and phase retardation. Erbium and neodymium are general materials used for fiber lasers. Erbium doped fiber amplifier (EDFA) in an amplifier used for inline amplification in optical networks.

1.2.3 Plastic Optical fibers

Plastic made optical fibers are useful for short distance (90-100m) purposes applications, medical application and for hazardous environments due to its mechanical strengths and good flexibility and large core. Glass and plastic fiber has the same transmission spectrum. Glass fibers are expensive as well as heavier than plastic fiber. Attenuation in plastic fiber is higher than glass fiber, Operating temperature ranges also limits its uses [6].

1.3 Optical fiber Dispersion

When the light (data) pulse propagates in the fiber it will spread out with time, this spreading out of light pulse is called dispersion. There are many reasons which cause dispersion in optical fiber that may be classified in three types.

a. Model dispersion
b. Material dispersion, and
c. Waveguide dispersion

1.3.1 Model Dispersion

The core of a multi mode optical fiber has a larger size, in which many different rays/modes of light can travel. As these fiber can enter the multi mode fiber at different angles, each mode follows a different path in the fiber have different length, and will reach the destination at different time, which causes spreading of light pulse at the output receiver(Fig-6). Different modes will overlap and will spread along the fiber. The use of single mode fiber will illuminate model dispersion as there is only one mode.

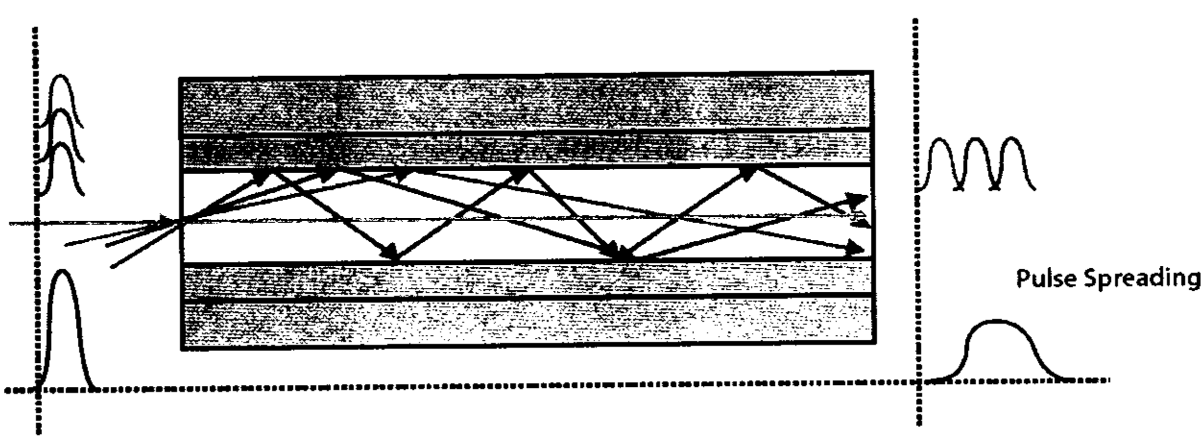

Figure 6: Dispersion in Multi mode fiber

As given in the Fig 6 above, different modes of light travels different paths, then the time taken by each path is, time = velocity x distance.

$$t_1 = \frac{n}{c} \times d_1 \tag{1.3}$$

Similarly for other mode n

$$t_n = \frac{n}{c} \times d_n$$

And time for mode guided straight in the core of the fiber is

$$t_0 = \frac{n}{c} \times d_0 \;\; or \;\; t_0 = \frac{n}{c} \times l$$

Here dispersion in time is

$$\Delta t = t_1 - t_0 \tag{1.4}$$

$$Dispersiont_{time} = \Delta t = NA^2 \times \frac{Length}{2nc} \tag{1.5}$$

Where NA is numerical aperture of the fiber,

t_1, t_0, t_n Are the time duration for mode 1, mode 0, and mode n?

c is velocity of light in free space,

1.3.2 Material Dispersion:

When light consists of a single wavelength then the spreading of light take place due to the material. However generally light consists of a range of wavelengths. Therefore, a corresponding range of wave velocities exists in the fiber which causes chromatic dispersion of light. This phenomenon is called material dispersion. It is a result of the line width of the light source and refractive index of the material.

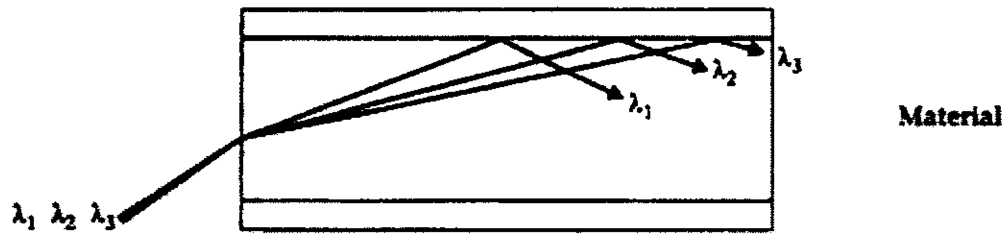

Figure 7: Material or chromatic dispersion

1.3.3 Waveguide Dispersion

For single mode fiber it is important that light pulse propagates faster in cladding as compare to core. It is also a type of chromatic dispersion. The mathematical equation for waveguide dispersion is given.

$$D_W = -\left(\frac{n_1-n_2}{\lambda_c}\right) V \frac{d^2(Vb)}{dV^2} \tag{1.6}$$

where V is the normalized frequency for the fiber $V\frac{d^2(Vb)}{dV^2}$ is the normalized waveguide dispersion coefficient λ_c is the carrier wavelength [12].

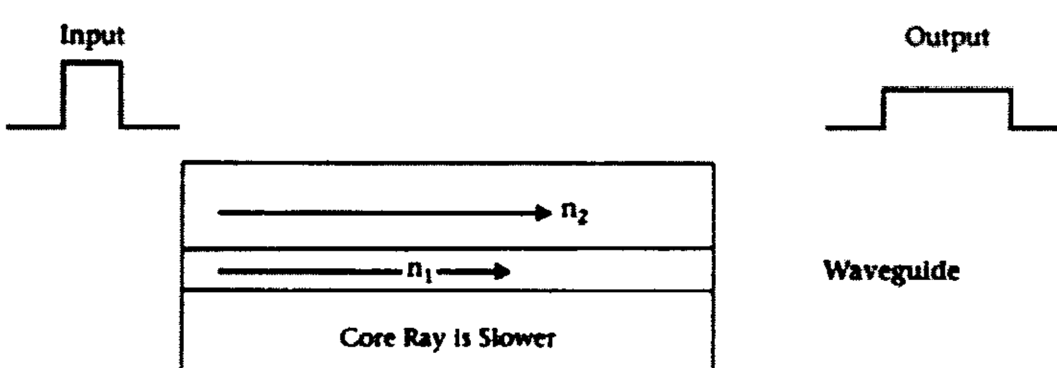

Figure 8: Waveguide Dispersion

1.4 Optical Components

Optical components are devices used in optical network, the function of OC are, transmitting, receiving, shaping, and switching transporting of light signal. These components are grouped in three categories,

Active components: these components are powered electrically, such as modulator, LASERS and wavelength converters or shifters.

Passive components: These are components not generating their own light, and not electrically powered, examples are optical fibers, multiplexer, demultiplexer, isolators, and couplers.

Optical Modules: Modules are the combination of active and/or passive components, performing some special tasks. It include optical switches, optical add/drop multiplexers, EDFAs (erbium-doped amplifiers) and transceivers.

1.4.1 Optical Transmitters

An optical transmitter is a device that accepts an electrical signal as its input, processes it, and uses it to modulate an opto-electronic device, such as a light emitting diode (LED) or LASER diode, to produce an optical signal and transmit it via an optical fiber. These are light sources. Two types of light sources are popular, LASERS and LEDs.

LASERS: Lasers stands for Light amplification by stimulated emission of radiation. Semiconductor laser are used as light source in optical communication, it is used as gain medium. These are the most popular sources of light for communication. These are very compact in size.

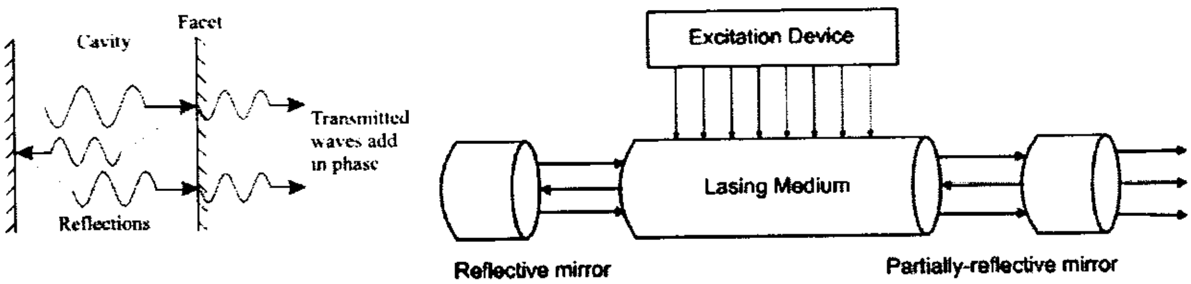

Figure 9: Reflection and transmission at the Facets of a Fabry-Perot cavity

The Figure explains the process of LASER, the general structure that includes the reflective mirrors, lasing medium and the excitation device. One type of LASERs transmitter is the Fabry-Perot laser that consists of a lasing medium, two mirrors and a cavity in between the mirrors. An electrical signal will be applied by the excitation device to the lasing medium; it will cause population inversion (presence of greater number of electron at the excited state than at the stable or ground state). There are two type of emission in LASERS, stimulated emission and spontaneous emission. If a photon in the vicinity of an excited electron causes the jump of electron with emission of same energy of that of photon to the ground level, this process will continue and the photon will reflect from the mirror surface again and again and will cause a Laser.

Vertical Cavity Surface-Emitting Lasers (VCSEL):

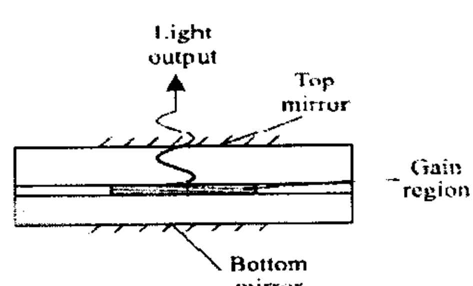

Figure 10: Structure of a VCSEL

By using VCSEL a single – longitudinal mode can be achieved.

1.4.2 Light Emitting Diodes

LED is another common type of light source. It is a p-n junction semiconductor device which emits light when voltage is applied. The emitted light is not monochromatic and coherent like that of LASERS. LEDs have two basic structures, surface emitting and edge emitting LEDs, represented by ELED and SLED. LEDs are mostly used in multimode systems, has a spectral width of about 100nm, can be modulated at bit rates up to 100Mbit/s, LEDs are cheap (inexpensive), are simple to design, produces more power and reliable.

1.4.3 Optical Receivers

Optical receiver or detector: A receiver is a device which converts an optical signal into electrical signal. Basically an optical receiver system consists of optical amplifier, photo-detector, front-end amplifier, and decision circuit. Signal received by optical amplifier will amplify and will guide to detector, the detector will convert optical signal into an electrical signal, the front-end amplifier will increase the power level of the signal and guides the signal to decision circuit, decision circuit will estimate the data will take a proper decision and will give the data.

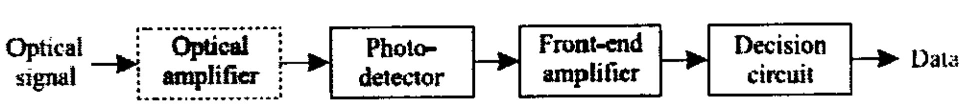

Figure 11: Receiver in a communication system

How a detector works: Photo detector is made of semiconductor materials. When a photon (ray or energy) strikes a semiconductor are absorbed by electron in the valance band. The electron energy will increase due to this photon absorption, and are excited into the conduction band, which cause a hole behind. When external potential are applied, the electron–hole pairs will create electrical current, and this current produce due to the recombination of electron-hole pair is called Photocurrent. Figure given illustrating the process.

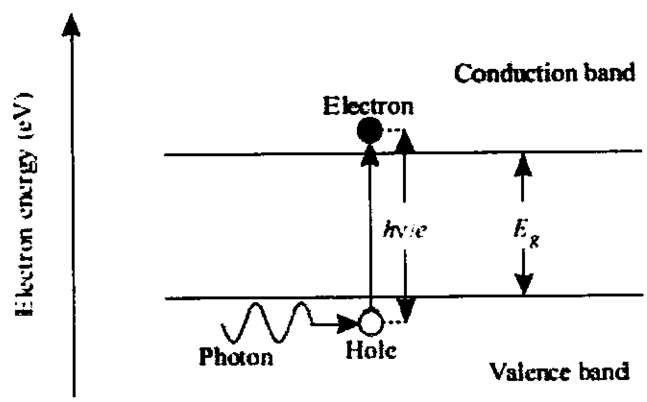

Figure 12: Absorption and emission of photon causes photo current

1.5 Summary of the thesis

In this thesis we have analyzed the optical burst switched network with respect to national science foundation NSF network. Different type of impairments is existing in optical fiber cables; they are attenuation, dispersion and noise. The effects of these impairments on burst communication in OBS network causes blocking. To decrease blocking probability and improve network performance different method have proposed and deployed. We consider time delay, dispersion in single mode fiber, and path selection in this work.

In Chapter No 1 an overview of the optical fiber, its types and classification is described, dispersion types and their effect is presented with mathematical formulation.

In Chapter No.2 we have described optical networks, different generations of optical networks, OBS network, optical packet switch network, optical circuit switch network, and their comparison.

In Chapter No.3 we have discussed Routing and wavelength assignment, Erlang B formula, and blocking probability of OBS network, channel capacity and data variance in networks.

Chapter No.4 is proposed model explains routing and wavelength assignments, different type of routing schemes are given and there detail is also given, wavelength is explained in detail and different techniques for wavelength assignments are given. This chapter is the core of the thesis and is the analysis of OBS network, adjacency matrix and all matrixes which are required for data analysis, traffic calculation, and path selection. Time delay calculation matrix, shortest path and reliability are described.

Effect of impairment is described, dispersion is calculated and graphs are given in the chapter.

Chapter No.5 discusses analysis and conclusion.

CHAPTER 2

BACKGROUND KNOWLEDGE

2 OPTICAL NETWORKS

A historical overview of optical network (ON) is given here. The evolution of optical networks is due to the invention of optical fiber (OF), if there was no optical fiber, there will be no optical network and no optical switches. As being a communication medium optical fiber cable (OFC) provides an extremely huge bandwidth (BW) as compare to other existent transmission mediums. A single optical fiber cable (OFC strand) can provide a bandwidth of 50Tb/s or more. OFC also provides other advantages like low bit error rate (BER) up to a long distance, light weight and immune to the electromagnetic effects.

Optical fiber cable provides huge bandwidth, it is deployed to build optical networks and connect distant and long geographically distributed cities as nodes of a network. In early 1980s, it was used for point-to-point communication link system. It is a very simple system which only used for point-to-point transmission without using any intermediate electronic switch system. It is a first generation of optical network. It mainly consists of transmitter, receiver and transmission medium an OFC cable. It the transmitter side electrical signal is converted into optical signal through electrical –to-optical (E/O) converter, then guided into the core of the optical fiber, at the receiver side the signal will converted back to electrical domain through optical to electrical (O/E) convertor and the data will be delivered.

Similarly to combine more nodes different type (star, ring, mesh networks types) of network can be made from these simple systems. Some broadcast systems were also developed from this system like star coupler etc.

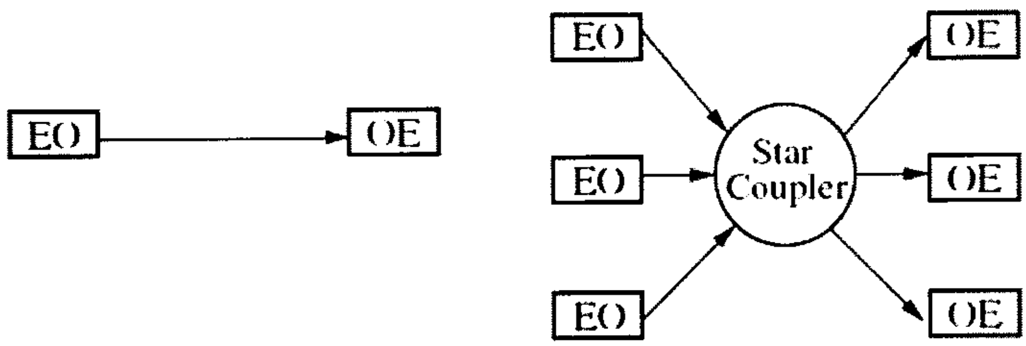

Figure 13: Point -to-point Link Network and star Coupler (Passive Network)

SONET/SDH was the first standards of this network. Synchronous Optical network makes a data frame using time division multiplexing (TDM).

To utilize the huge bandwidth of optical fiber cable, different type of multiplexing technique is used. In which the single link will be shared among multiple sources. The process thus introduced was multiplexing and will be define as a technique which allows multiple users (traffic sources) to share a single fiber. For sharing and utilizing a single OFC cable, three types of multiplexing technique were deployed. TDM, SDM, and WDM.

To understand optical burst switched (OBS) Network, the brief introduction of optical network is necessary. Classification of Optical network, component of optical network and architecture is given.

2.1 Optical Network Classification.

a. First generation optical networks

b. Second generation optical networks

c. Next generation optical networks

In the earlier telecommunication network, the medium of transmission was copper cables. Copper cable has limited bandwidth, huge weight and have higher prices and maintenance cost.

2.1.1 First Generation Optical Networks

There are different types of mediums for communication Guided medium, unguided medium etc. Guided medium is further subdivided into low bandwidth and high bandwidth medium. Copper cable is a type of low bandwidth medium. In first generation optical network, copper cable is replaced by optical fiber as a transmission medium. But the rest of the process like switching and bits processing, are however handled in the electronic domain, like an ordinary electronic network. Here the speed and bit error rate (BER) is improved. A large no of E/O and O/E conversions are used. Such type of network uses a single wavelength transmission.

As optical fiber have a huge and a very high bandwidth, low latency and low weight. It has replaced the copper cable.

SONET/SDH networks are the examples of first generation optical networks.

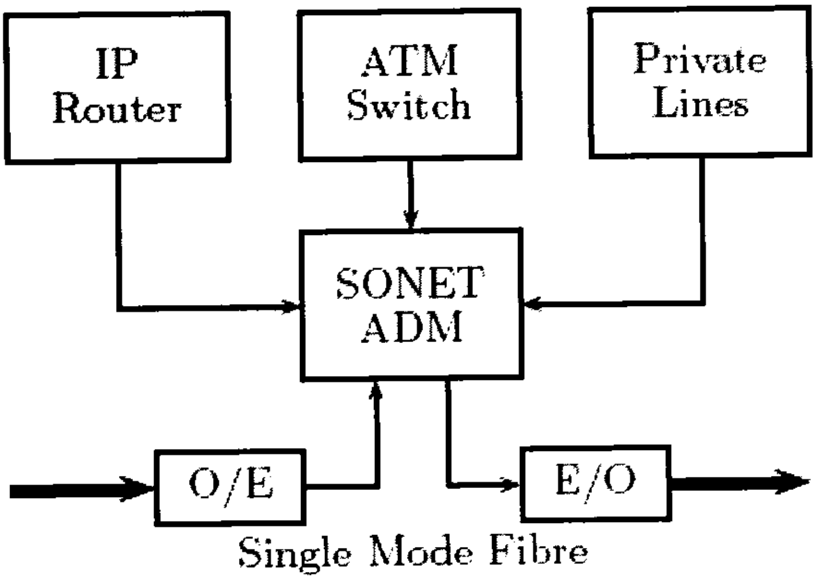

Figure 14: First generation optical network

2.1.2 Second Generation Optical Networks

In second generation optical network traffic can be added and dropped by using wavelength add-drop multiplexers [9] to utilize the maximum bandwidth of optical fiber, multiple carriers wavelengths are used, which will be multiplexed onto a single fiber. The technique is called wavelength division multiplexing (WDM). The primary difference between the second generation optical network and the first generation optical network, as a technological point of view, is the switching and routing functionality is achieved in the optical domain in case of second generation network. The second generation of optical switches is also called optical cross-connects (OXCs). Here electronic switches were replaced by OXCs; therefore the burden on electronic switches was reduced. An OXC is an optical switch capable of individual switching or waveband switching. Figure 15 gives basic idea of optical add/drop multiplexer a type second generation optical networks [10]

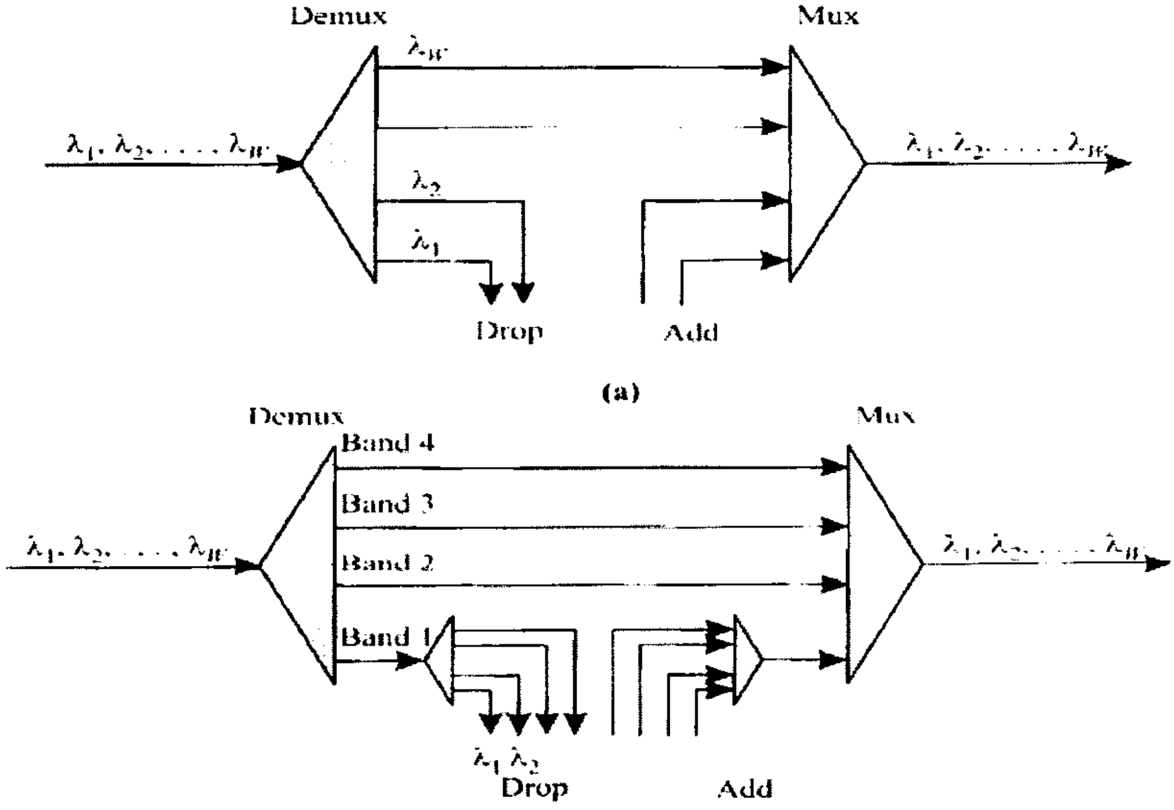

Figure 15: Optical add/drop multiplexer (second generation optical network)

2.1.3 Next Generation Optical Networks

The next generation optical networks involve different types of network parameters, like optical packet switching and all optical networks (AON). In these networks, in a networks node all kinds of switching, routing and buffering are performed optically.

OXCs (Optical Cross Connects), OADMs (Optical Add/drop multiplexing) multiplexer have control on all kinds of parameters like wavelengths, switching and routing. These are like intelligence network; they can connect and regulate it automatically. These devices have full knowledge of the capacities of the nodes and fibers [3]. Figure 15 OADM switch architecture.

The evolution of different methods used in optical network is given in Figure 16, the details also available at [7].

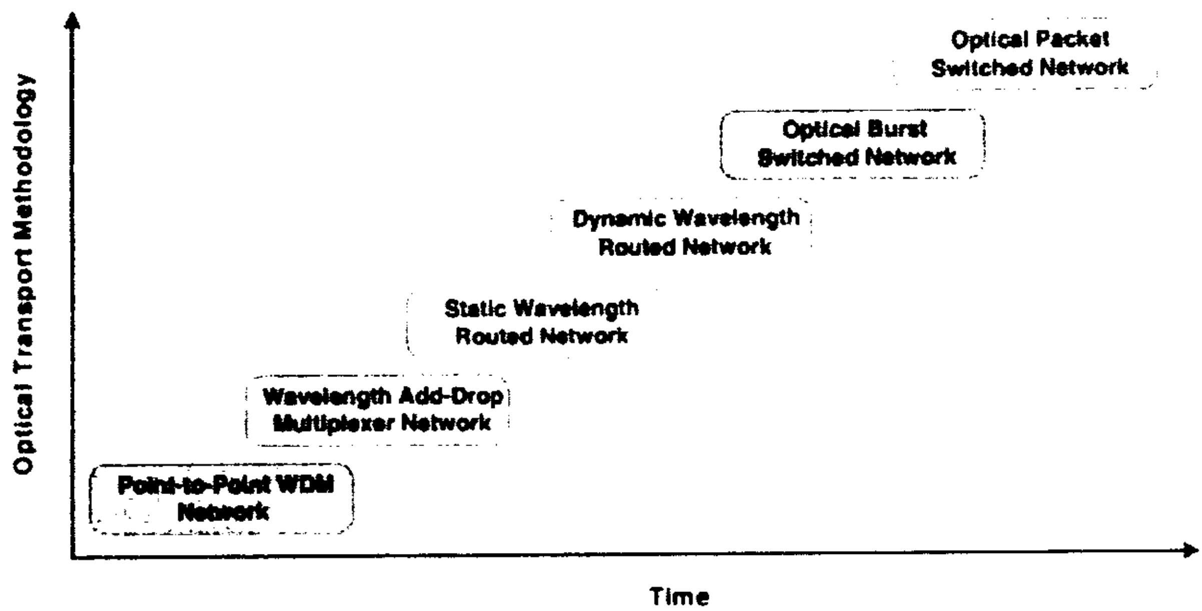

Figure 16: Evolution of optical transport technique.

Different types of multiplexing techniques are used to increase the data rate, like time division multiplexing (TDM), wavelength division multiplexing (WDM) and space division multiplexing (SDM).

2.2 Multiplexing Paradigm

2.2.1 Time Division Multiplexing (TDM)

It is a well known technique which interleaves lower speed streams to obtain a higher-speed stream and is used in many network architecture. Primarily SONET and SDH deployed this technique for fiber link. In high speed optical network, TDM is not so useful due to the E/O and O/E conversion. For the maximum utilization of optical fiber TDM is not an efficient and fast technique. It is due to electro optical conversion. Fig 17 describes two methods for TDM, Static and dynamic [7].

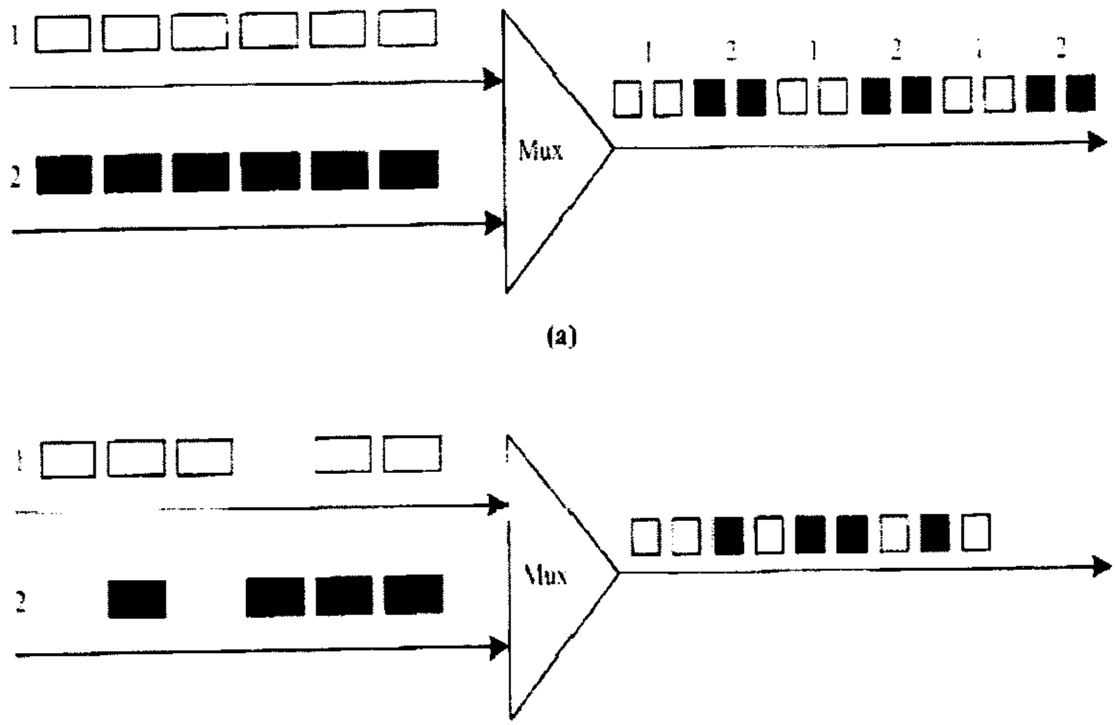

Figure 17: Time Division Multiplexing

2.2.2 Space Division Multiplexing (SDM)

To avoid the electro optical bottleneck then space division multiplexing (SDM) is a simple approach. In SDM multiple fiber are used instead of a single fiber. These fibers are parallel to each other, which can operate at any high data rate efficiently. This is a costly technique for long distance because many fibers are used, but it can be recommended for short distance communication.

2.2.3 Wavelength Division Multiplexing (WDM)

As compare to TDM and SDM, WDM is the best approach to utilize the huge bandwidth of optical fiber. It is similar to FDM (Frequency Division Multiplexing), because each user transmits data at different frequency. Instead of FDM normally WDM terminology is used. In WDM system each transmitter i send data at their own wavelength λ_i, at the multiplexer each wavelength(data) is multiplexed(WDM) and feed onto a single fiber, at the receiver side the reverse process will take place, the demultiplexer will demultiplex the data (wavelength) and forwards the data to the corresponding receiver.

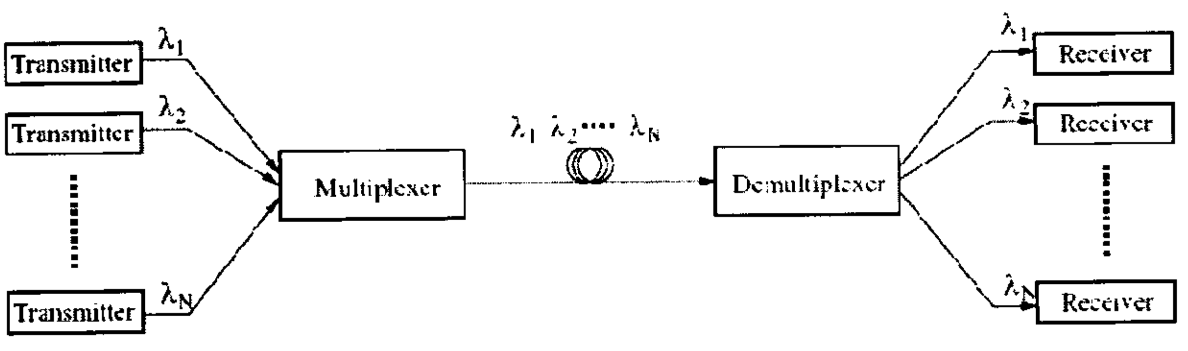

Figure 18: Wavelength Division Multiplexing (WDM)

The evolution of optical networks with time is tremendous. From first generation optical network (Point to point link communication, SDH/SONET technologies) it evaluate to second generation optical network (WDM system, OADMs, OXCs etc were introduced). Further different multiplexing techniques were implemented to increase the maximum bandwidth utilization. Optical Circuit Switching, optical packet switching and then a new paradigm name as optical burst switching (OBS) is now under research and implementation.

2.3 Optical network switching paradigm

2.3.1 Optical Circuit Switching (OCS)

In circuit switch network a dedicated path is first establish between sender (transmitter node) and receiver node. As it routing the wavelength and will refer as wavelength routed networks, it mainly consist of optical cross connect (OXCs) connected by optical fiber links. To switch the data from source to destination nodes a light path will form, the wavelength/frequency of the path for that session will remain the same or will change (Wavelength converter) on traversing on different nodes. There are a number of links in the path which makes the route; the same wavelength will be used by the light path on all the links. The property is known as wavelength continuity constraint (WCC)

OCS perform its functionality on two ways either statically or/and dynamically.

OSC has some disadvantages, as it gives a dedicated light path to a user, the resources thus not be fully utilized in case of bursty traffic. The dedicated link might remain unused/idle for a long time. In OCS the link and other resources utilization is not maximum. For full BW utilization the Optical Packet Switch (OPS) paradigm evolved.

2.3.2 Optical packet switching(OPS)

Optical packet switching (OPS) is a switching technique that allows routing and switching of optical data packets. All this process will do in optical domain. Each node will reconfigure on the bases of packets. For packet switch network, if there is contention the data may buffered in storage devices, in OPS fiber delay lines (FDLs) will used. To buffer a burst for a short time (ms) FDLs will be used in kilometers, physical distance limitation limit it uses. Further an OPS node will not properly handle the bursty packets, that are normally produced on browsing internet data [5]. If the intended node is not free, the data can be directed to another free node (deflection routing); it may cause out of order delivery as well as looping of the burst. OPS switches may perform fast in order to synchronize optical bursts to reduce contention and data loss.

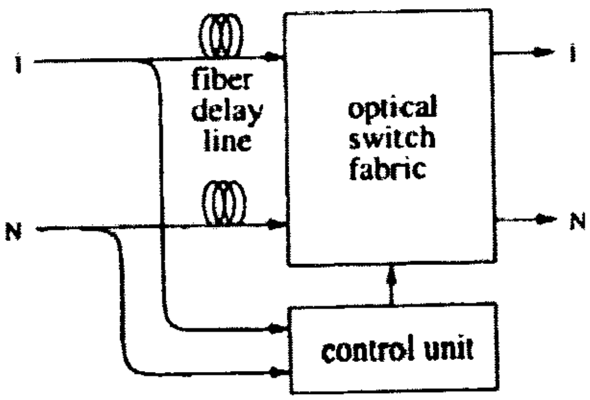

Figure 19: Optical Packet Switching

2.3.4 Optical Burst Switching (OBS)

We have discussed optical circuit switch (OCS) and optical Packet Switch (OPS), both types of switches has their merits and demerits. Tow combine the merits and advantages of both techniques, OBS has been designed [14]. In OBS network a data burst (multiple data packets (in a single unit called burst) will be traverse in the optical network all optically. In this network a control packet is sent to reserve bandwidth for the burst (burst header packet PHP or burst control packet BCP), once it reservation completes the data burst then traverses all optically in the optical network. Different type of reservation protocols is used. Tell-and-go (TAG), just-in-time (JIT), JET, INI scheduling or reservation protocols are used. To know that which scheme is better for optical system depends on their requirements [4]. The signaling technique used is that of out-of-band, means signaling is prior traversing in electronic domain and burst transmission is in optical domain after reservation. The control packet reserve the path and the data burst will guided through the fiber without any buffering at the nodes. The control packet may also specify the burst duration.   Fig 20 explains the offset time require for burst traversing in different nodes.

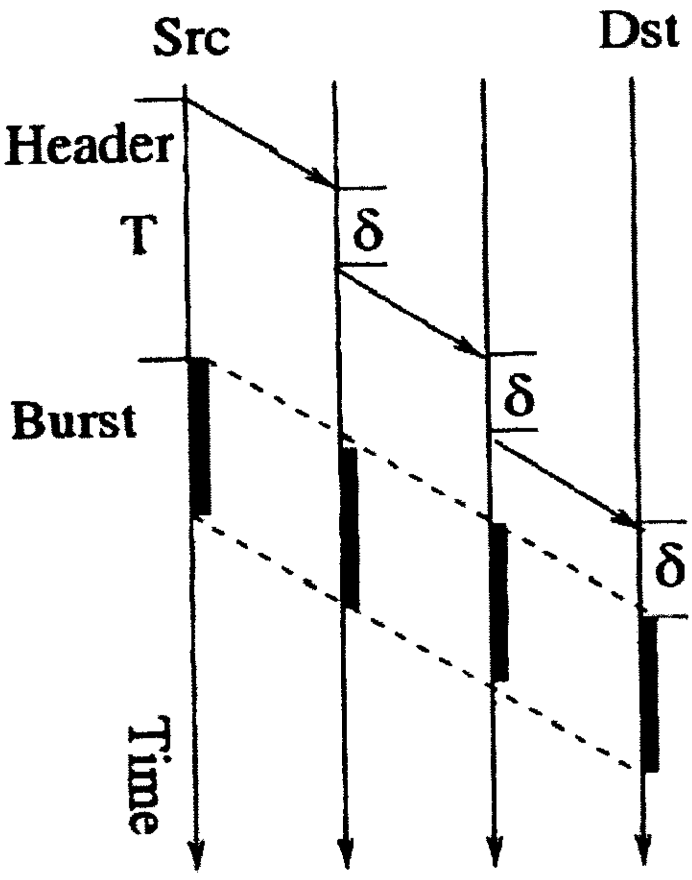

Figure 20: Offset times in OBS network

Table 2: Comparison of OCS, OPS and OBS network technologies

Optical Switches Technique	Switching Speed Required	Traffic Adaptively	Processing/Sync. Overhead	Setup Latency	Bandwidth Utilization
Optical Circuit Switching	Slow	Low	Low	High	Low
Optical Packet Switching	Fast	High	High	Low	High
Optical Burst Switching	Medium	High	Low	Low	High

In OBS technologies the link or light path is reserved for a particular short duration of time(indefinite period) for data bursts and then released for other user unlike OCS network, hence the link utilization is maximum. In optical switching fast switching is required for synchronization but for OBS large burst are transmitted on pre define roots, hence no such fast switching in necessary. The function of OBS can be combine with fast circuit switching, wavelength can be assign and release dynamically having no buffers [17],

Architecture of OBS Network: All types of network switches may consist of some basic elements. OBS network consist of OBS nodes connected by optical fiber. Each link can support multiple wavelengths using WDM. Nodes may be either edge nodes or core nodes. Edge nodes further subdivided as ingress edge node and egress edge node. The optical fiber cable used is bidirectional, have huge BW and support all types of switching techniques. A simple diagram is given (fig 21). Functionalities of nodes are given.

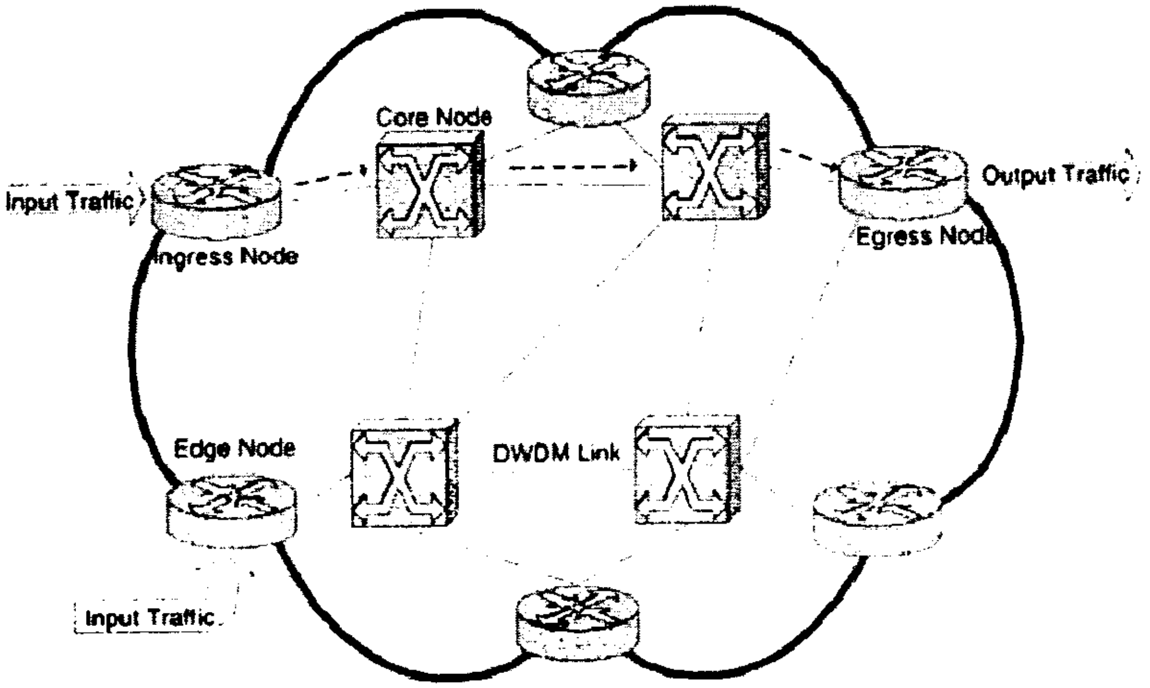

Figure 21: OBS Network Architecture

Edge Node assembles IP packets into bursts, scheduling it for transmission on the outgoing optical fiber channels. The core nodes are switching the burst from input port in to output port based on the header packet of the burst. It also handles contention for burst in the network.

The edge nodes are either ingress nodes or egress nodes [5]. Ingress edge node on receiving the IP packets from different clients assembles into a burst; a burst is the combination of many IP packets varies from a single packet to n packets. The packet may be either from the same client or different clients. Once the burst assembles it will transmit all optically over the OBS network core nodes (routers) without any storage at the core routers. The ingress edge node functionalities are routing, assignment of frequency/wavelength and burst scheduling at the edge.

On receiving the burst on egress edge node the reverse process will take place, the burst will be disassembles into packets and will be routed/forwarded to the destination terminals.

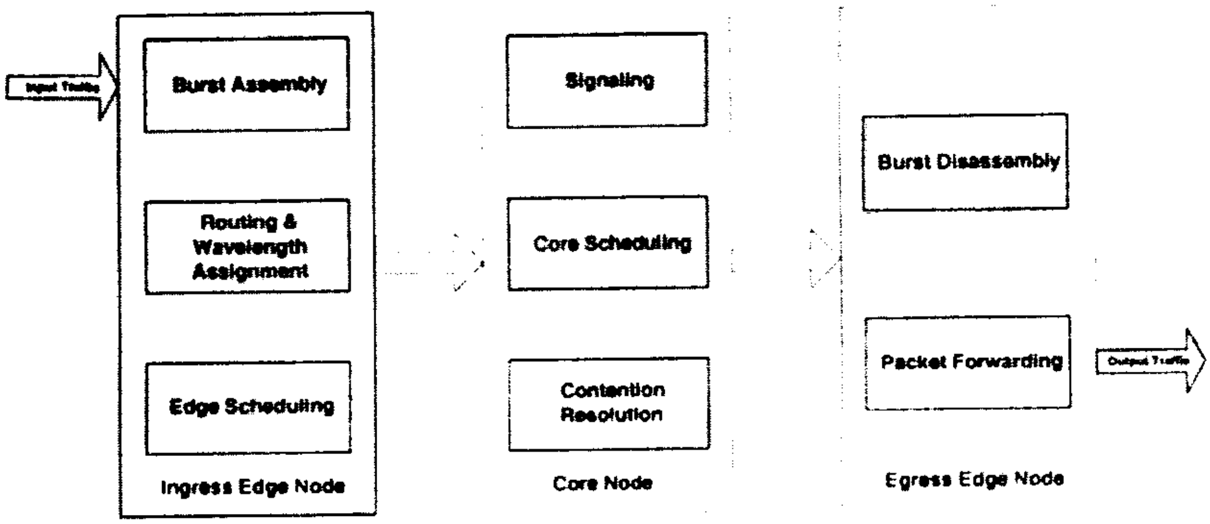

Figure 22: OBS functional diagram

Signaling techniques in OBS network: In OBS network when a burst is transmitted in the optical network, some sort of signaling scheme will be implemented, to reserve the required resources for burst. The process of signaling here is out of band, the header of a burst is transmitted on a different frequency then the burst itself. Header travels along a route establish and reserve a link, informing the nodes to configure their OXCs for incoming burst.

CHAPTER 3

LITERATURE REVIEW

3 Routing and Wavelength Assignment

In communication networks or it any types of communication one (source/transmitter/sender) transmit data and receiver or sink receive that data that is called communication. If there is only one path between source and destination, then it is called point-to-point or peer-to-peer communication. If there is more than one path, then the data will select one of these paths (circuit switching) or data chunks will follow different paths (packet switching) to reach destination. The selection of a path (route) to transmit network traffic is called routing (path selection). As there are many paths, from which one optimal path will be selected, may be based on different criteria. Different type of software program and algorithms are used to select an optimal path which my requires a complex process. The path selection (routing) function may require one or more protocols. These protocols will provide routing information exchange among the routers.

Routing is the process of selecting a path for traffic movement; the path will start from the source and will terminate at the destination. The devices which may perform this functionalities is called router.

3.1 Types of routing

Routing can be classified in different ways like, static (fixed) routing and dynamic (adaptive) routing.

3.1.1 Static routing

This type of routing is also called non adaptive routing, or fixed routing, or deterministic routing, or explicit routing. In this routing the path from source to destination is predetermined. The transmitting node knows about the path by which it transmits all the traffic. It will remain fixed for all communication between these users unless administratively change occurs. Here up-to-date routing information exchange protocols are not required. If there is traffic or topology change in the network it has no measurement and decision making capabilities in static routing. Route will compute in advance, off-line and will upload in the time of network setting up or booted. It has constant routing variables, not changes with time. The techniques used for this routing is almost based on shortest path routing, it will either be due to the length of the path, or based on number of hops in the path [16].

In some types of static routing also called Quasi-static routing- Where one node is dedicated for all routing procedure, it will be a centre for information, will share routing and decision data with other nodes. It example is delta routing.

3.1.2 Dynamic routing

It is also called stochastic or adaptive routing. Unlike static routing, here the routing is hop-by hop. The transmitter node doesn't know about the route, each node uses a routing table which updates periodically, and by the use of that table it will decide for an optimal next hop till destination. Path will be made on per-hop decision bases and no already established path exists. It changes it routing decision if there is a change either in topology or existent traffic scenario. Its algorithms are different from static one. It may have different types depends on decision making criteria.

In some type of routing methods a single node out of the entire network nodes collect information to make decision for an optimal path, it will referred to as a global or centralized routing method. Figure 23 (a) illustrate the centralized method of routing.

In some cases each node may have some contribution by running a local algorithm and find the optimal path on per-hop base decision. It is called local or isolated routing method. Figure 23 (b) illustrate the localized method of routing.

In some cases for high efficiency they may combine both the methods (that are local and centralized) and a third type of method will define which is called a mixed or distributed routing method. Figure 23 (c) illustrate the distributed method of routing.

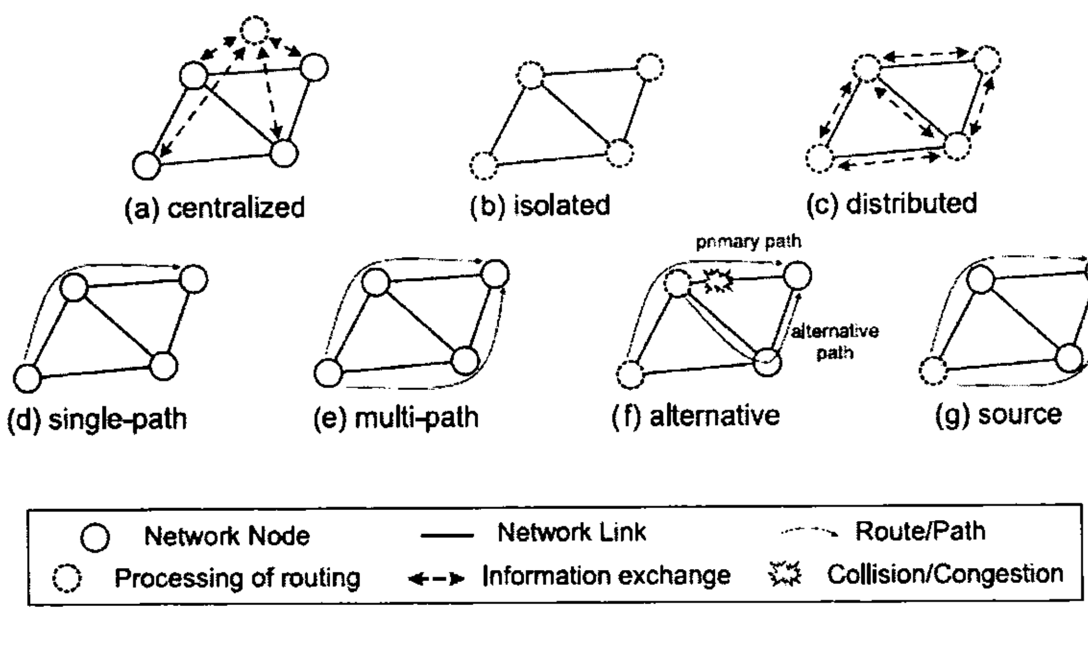

Figure 23: Routing methods in OBS Network ref [16].

When there is a single path between source and destination (or any pair of nodes), then the traffic will definitely use that single path and the phenomenon is called as single path routing (or peer-to-peer routing). Figure 23 (d) illustrate the single path method of routing. But normally there are many (more than one path) between pairs of nodes might be equally proper and good for communication and transmission of traffic. By using any single path out of that will not be proper and efficient and it will desire to use multi paths for better communication. It will reduce the load on the single path by splitting the traffic; this type of routing will be referred as multi-path routing. Different type of data can be transmitted on different paths, the reliability of the network will also be improved, which the advantage of multi-path routing over single path is routing. Figure 23 (e) illustrate the multi-path routing. A special case of multi-path routing called alternative routing or deflection routing in which if one link fails it deflect to an alternate path and then traverse till destination. Figure 23 (f) illustrate it.

3.2 Route managements in OBS

Routing methods also classified based on place where routing decision take place. Whilst many routing algorithms can perform and each and every node of the network, in source routing the routing decision node is the source node or the source node is the routing decision node which decide all or most of the routing decision. Similarly destination routing will do vice versa.

Comparison of different features and characteristics of dynamic and static routing can be tabulate and summarize in a table given below [17].

Table 3: Comparison of static and dynamic routing

Static routing	Dynamic routing	Feature
No	Yes	Automatic reaction to OBS network changes
High	Low	Administrative involvement in (Re)Configuration
High	Low	Human and administrative supervision of available routes and paths.
No	Yes and necessary	Exchange of routing information
Low	High	Impact on router's processing capacity
Low	Medium - High	Memory consumption
None	Medium (at regular operation) to high	Network routing overhead load

3.3 Routing and wavelength assignment

Wavelength assignment is basically the assignment of a frequency (wavelength in OBS network) to each burst between two nodes. If the burst has assigned the same wavelength between source to destination and there is no Electrical-to-Optical-to-Electrical (E/O/E) conversion is called wavelength continuity constrains (WCC), and the whole system is called as transparent optical network. Different type of methods are used for wavelength assignments are given.

3.3.1 Static routing and wavelength assignments

In this method requests for light path are know in advance.

3.3.2 Dynamic routing and wavelength assignment

It has no prior information about light path request exist. When a burst is arrived it will assign a wavelength dynamically.

3.3.3 RWA with wavelength conversion

When wavelength convertor is used then WCC (wavelength continuity constraint) is removed. The purpose of all these techniques is to enhance the performance of the OBS network and to reduce the burst loss probability due to contention at the core node. How to reduce the contention? The mechanisms will be either implement at core nodes or at edge nodes. At the core nodes additional hardware and software components will be used (for buffering etc) which are cost effective and will make the system expensive. At the edge nodes proper routing as well as wavelength assignments will solve the contention problem effectively [93]. It is also possible to route on a per burst basis, but this type of routing will cause delay. If each burst select shortest path on per hop bases the propagation time will might be decreased but the possibility of contention on the core node will cause data loss due the bottleneck occur. To solve this alternate path routing concept may helpful [15].

3.4 *Wavelength assignment heuristics*

Different heuristics for wavelength assignments may be used.

3.4.1 Random wavelength assignments

There is a set of wavelengths from which any wavelength can be selected randomly; the process will be termed as random wavelength assignments. Which wavelengths are available and then chooses one of them randomly amongst them.

3.4.2 First-Fit

The wavelengths will be arrange in a set like {0, 1, 2,}, out of it the smallest numbered wavelength (wavelength with the lowest index) will be selected. Higher numbered wavelengths will be available for future light path requests.

3.4.3 Least used

As a number of wavelengths can be select in the routing process, the least selected wavelength will be found to use.

3.4.4 Most used: The most used wavelength can be selected out of that set

An example is given in figure 24 for wavelength routed networks

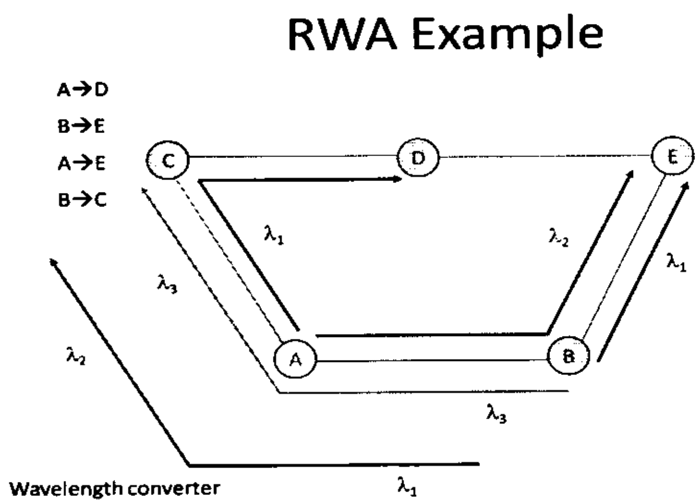

Figure 24: Wavelength Routed Networks

Path between different pairs of nodes is given by different colors (wavelength),

Path from A→D is represented by λ_1,

Path from B→E is represented by λ_2,

Path from A→E is represented by λ_1,

Path from B→C is represented by λ_3, As there is no wavelength converter , if one can use a wavelength converter, the number of wavelength used will be reduce, as given in the figure. λ_3 Will be replaced by λ_1, and λ_2 . Wavelength heuristics as first-fit or random can be assigning like that in [18].

3.5 *Erlang B Formula*

Erlang B formula was developed by Agner Krarup Erlang, who was a Danish mathematician; the formula was mainly design for blocking probability. It calculates the probability that a caller finds all of the circuits busy, the formula is given as [10].

$$P_B = \frac{\left(\lambda/\mu\right)^m / m!}{\sum_{n=0}^{m} \left(\lambda/\mu\right)^n / n!}$$

Or simply

$$P_B = \frac{(A)^m / m!}{\sum_{n=0}^{m} (A)^n / n!}$$

(3.1)

where $A = \frac{\lambda}{\mu} = \rho$

The mathematical expression 3.1 is generally related with load, capacity and blocking probability The parameter given in the formula is described below in detail.

λ : Arrival rate per unit time. 120 calls per hour, means 2 calls per minutes.

μ: Service rate that gives the number of events that can be handled in a unit time, the concept of service time will be used.

ρ: total system utilization, and is the ratio of arrival rate λ **to** service rate μ, as mention in the above equation, $\rho = \lambda / \mu$

The arrival rate λ and service rate μ are important, to find how much servers are required.

Example 1

if

$\lambda = 1.2$ per minute, and

$\mu = 0.5$ per minute

then for, 72 calls/hours: $\lambda = 72/60(\text{min}) = 1.2$ calls per minutes= λ

and for 2 minutes service time = 60(min)/2 = 30 per hours / 60 = 0.5 per minutes

Rho = lambda/Mu $\rho = \lambda/\mu = 1.2/.5 = \rho = 2.4$

In a network the user are in whole numbers, n=0, 1, 2, n we do not have 2.4 users, and then here the minimum number of servers required would be 3 instead of 2.4.

The utilization per server is 2.4/3= 0.8, or 80%.

in expression 3.1

A is Offered load

m is Number of servers (lines)

P_B is Probability for blocking

Here for traffic arrival some assumption will be made. That are,

- Poisson arrival (traffic is random).
- Call holding time of fixed length or exponentially distributed.
- Blocked calls are cleared.

Let take some values as an example.

A=3

m= 6

Then by using formula II, we will calculate Pb = 0.0522, 5% of callers would be blocked, other description can be find in ref [17].

3.5.1 Erlang B Results Table

These are some calculated results by using Erlang B formula. The relation is given in table 3, blocking probability is calculated for different channels/lines and the codes for figure 25 are given[1].

Table 3: Blocking probability for different-channel system

Busy Hour Traffic(B.H.T)	Blocking Probability	Lines/channels
3.000	0.052	6
1.000	0.001	6
1.000	0.500	1
1.000	0.200	2
3.000	0.052	6

6.000	0.590	3
60.000	0.837	10
2.000	0.211	3
1.000	0.500	1
1.500	0.600	1
2.000	0.667	1
3.000	0.750	1
5.000	0.833	1
6.000	0.857	1
7.000	0.875	1
8.000	0.889	1

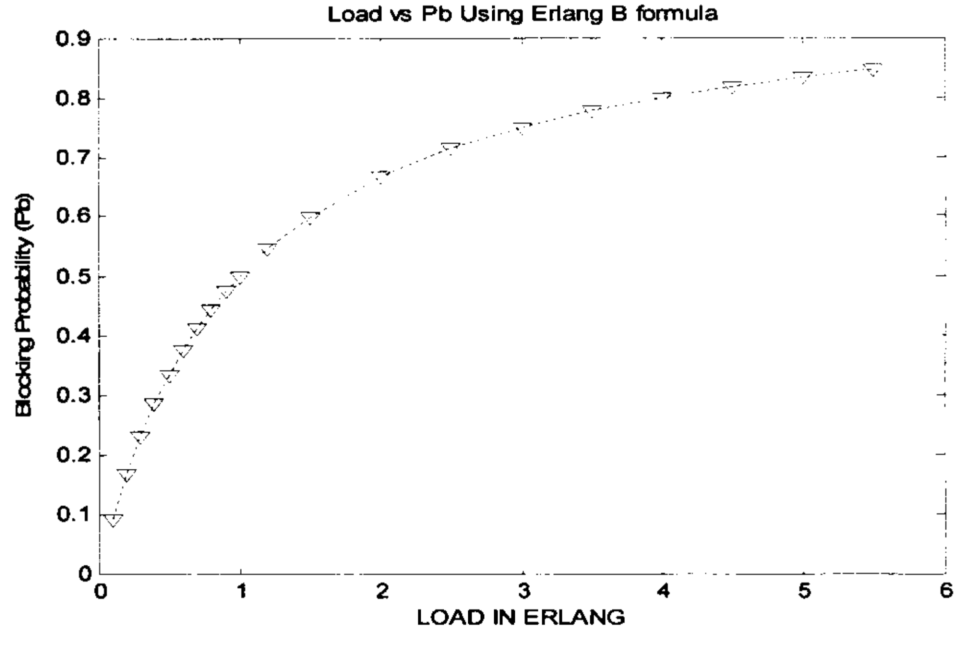

Figure 25: Load verses blocking probability

[1] Mat lab codes are given in Appendix A1

3.5.2 Erlang B Results Table

There are some results of the Erlang B formula. The unknown blocking probability is calculated and the results are given in table 4.

Table 4: Blocking probability for a given load

Busy Hour Traffic(B.H.T)	Blocking Probability (Unknown)	Lines/channels
0.100	0.005	2
0.200	0.016	2
0.300	0.033	2
0.400	0.054	2
0.500	0.077	2
0.500	0.077	2
0.700	0.126	2
0.800	0.151	2
0.900	0.176	2
1.000	0.200	2
1.500	0.310	2
2.000	0.400	2
2.500	0.472	2
3.000	0.529	2
3.500	0.576	2
4.000	0.615	2
4.500	0.648	2
5.000	0.676	2
5.500	0.699	2
6.000	0.720	2

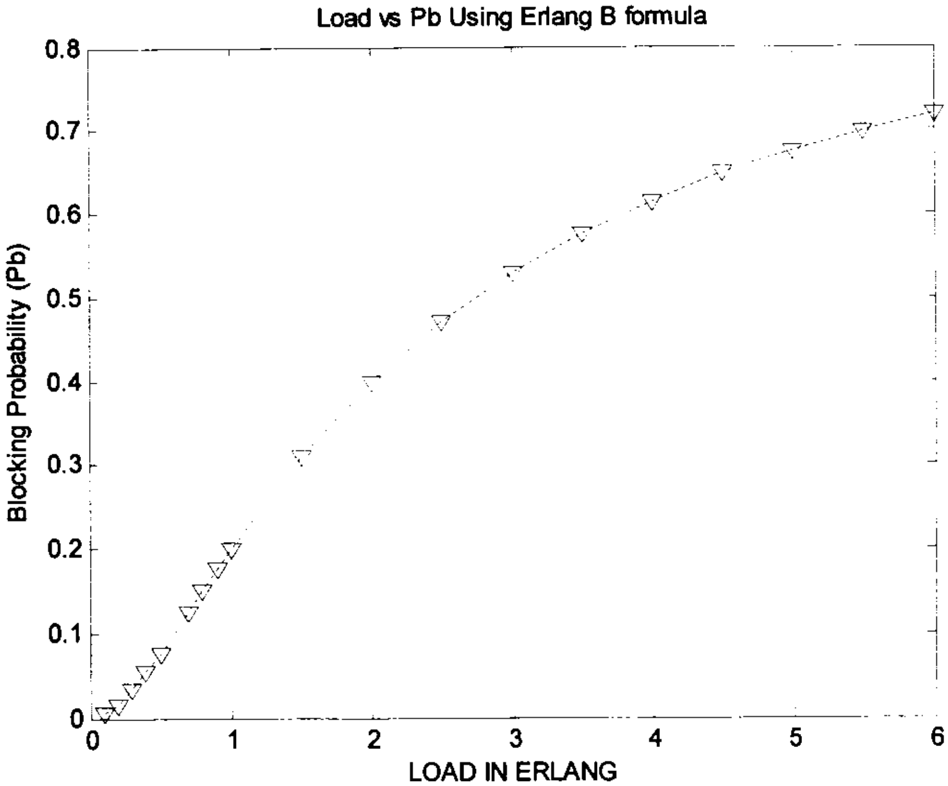

Figure 26: Load (Erlang) verses blocking probability

For known values of input (bursty) traffic, the relation for channel capacity and blocking probability is inverse. If we increase number channel for the same input traffic the blocking probability will decrease and vice versa.

3.5.3 Erlang B Results Table

Here are the results of the Erlang B formula. The unknown values are shown.

Busy hours traffic is from 0.1 to 6 Erlang, lines or channels are taken fixed (here 3).

Table 5: Blocking probability for 3-channnel system

Busy Hour Traffic(B.H.T)	Blocking Probability (Unknown)	Lines/channels
0.100	0.000	3
0.200	0.001	3
0.300	0.003	3
0.400	0.007	3
0.500	0.013	3
0.500	0.020	3
0.700	0.029	3
0.800	0.039	3
0.900	0.050	3
1.000	0.063	3
1.500	0.134	3
2.000	0.211	3
2.500	0.282	3
3.000	0.346	3
3.500	0.402	3
4.000	0.451	3
4.500	0.493	3
5.000	0.530	3
5.500	0.562	3
6.000	0.590	3

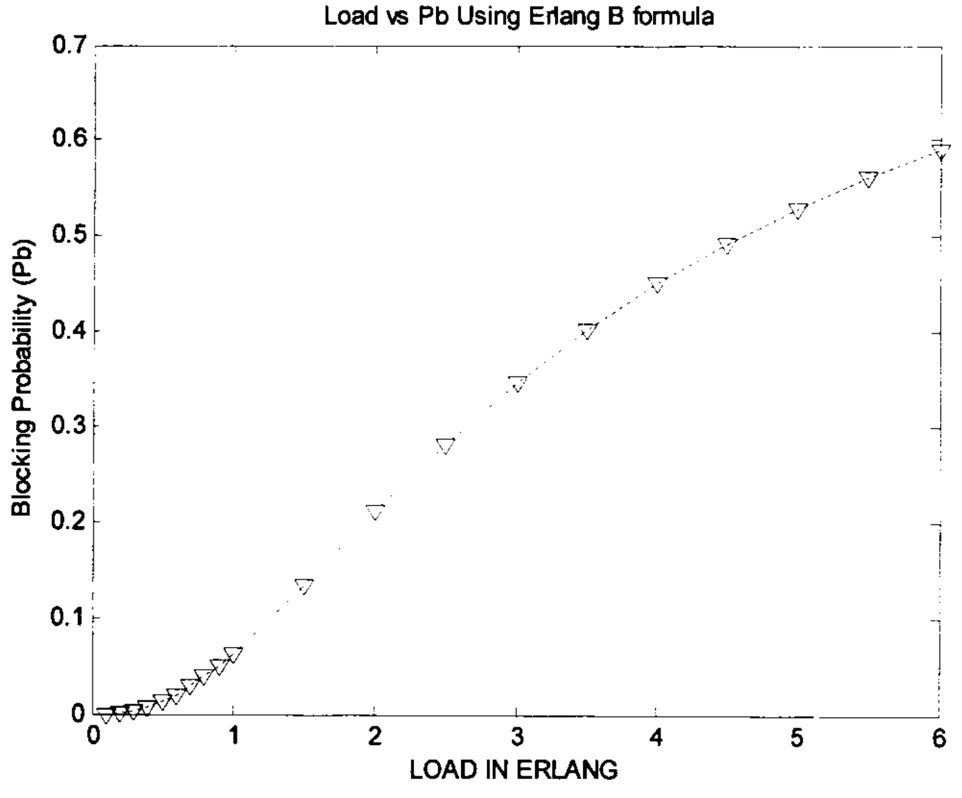

Figure 27: Load verses blocking probability

For known values of input (bursty) traffic, the relation for channel capacity and blocking probability is inverse. If we increase number channel for the same input traffic the blocking probability will decrease and vice versa.

3.6 Poisson formula

This is the contribution of Simeon Denis Poisson, a French mathematician, which state that for some events, arriving at an average rate (λ), the probability of x arrivals in time t is given

$$P(k) = \frac{(E(n) * t)^k e^{-E(n)*t}}{K!}$$

3.2

Where P (k) = Probability of arrivals,

E (n) = Average Arrival Rate,

t= Average Holding Time, and

e= 2.71828.

it will be used for the calculation of the probability of n arrival, during some time interval.

CHAPTER 4

PROPOSED METHODOLOGY

4 NSF Network

The National Science Foundation (NSF) Network is taken as a case study for our research and simulation. This network consists of 14-Nodes and 21-Edges. Node-to-node distance (length in km) is given in the diagram, reliability values are also given on each edge, time delay will be calculate from velocity of light in the fiber have refractive index of η [2].

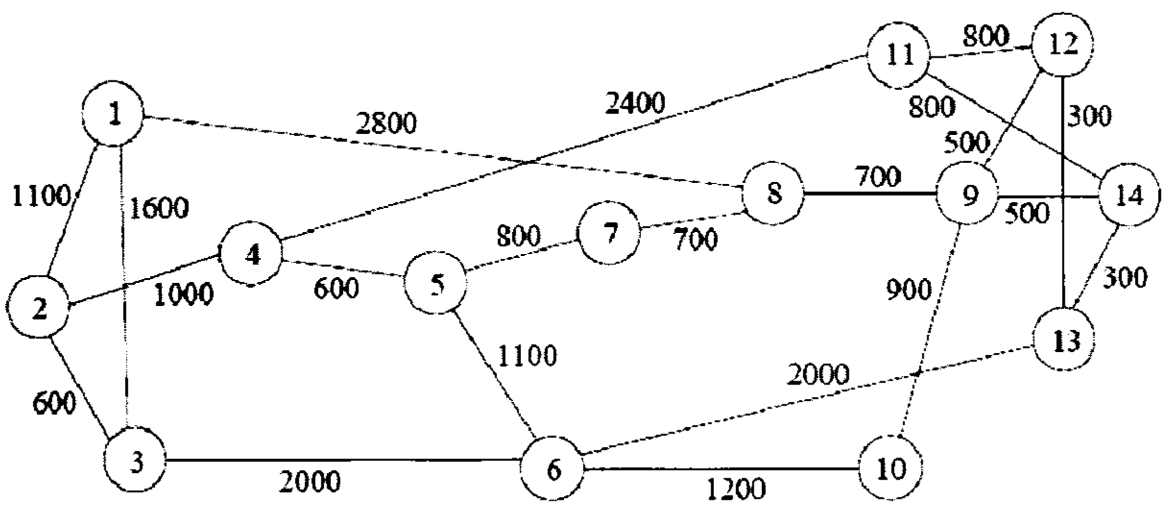

Figure 28: National Science Foundation Network (14-Nodes and 21-Edges)

4.1 Problem formulation

To transmit data from source to destination (from node 1 to node 14, or between any two nodes) in which the path consists of links. There could be many paths between source and destination.

Like shortest path, longest path, and a number of other paths between shortest and longest. Which path is to be selected depends upon the environment and algorithm used by the researcher. Here we will select the shortest path between source and destination. We will calculate the time required for the path and reliability factor of the path.

For the above mathematical purposes we will find

a. Adjacency matrix of the network,
b. Weight/Length matrix of the network,
c. Reliability matrix of the network,

4.1.1 Adjacency Matrix

It is a N x N matrix consist of '1', and zero '0', if $A_{i,j}$ of the network are connected then

$A_{i-j} = 1$, otherwise 0.

Adjacency matrix for NSF network is a 14 x 14 matrix, where **i** represents that node i and j are connected through an edge, and **0** represent that no edge is present. Table for adjacency matrix of NSF network is given as follow

Table 6: Adjacency matrix for NSF network

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	1	1	0	0	0	0	1	0	0	0	0	0	0
2	1	0	1	1	0	0	0	0	0	0	0	0	0	0
3	1	1	0	0	0	1	0	0	0	0	0	0	0	0
4	0	1	0	0	1	0	0	0	0	0	1	0	0	0
5	0	0	0	1	0	1	1	0	0	0	0	0	0	0
6	0	0	1	0	1	0	0	0	0	1	0	0	1	0
7	0	0	0	0	1	0	0	1	0	0	0	0	0	0
8	1	0	0	0	0	0	1	0	1	0	0	0	0	0
9	0	0	0	0	0	0	0	1	0	1	0	1	0	1
10	0	0	0	0	0	1	0	0	1	0	0	0	0	0
11	0	0	0	1	0	0	0	0	0	0	0	1	0	1
12	0	0	0	0	0	0	0	0	1	0	1	0	1	0
13	0	0	0	0	0	1	0	0	0	0	0	1	0	1
14	0	0	0	0	0	0	0	0	1	0	1	0	1	0

ADJACENCY MATRIX FOR NSF Network

The adjacency matrix is given .

$$A=\begin{pmatrix}
0&1&1&0&0&0&0&1&0&0&0&0&0&0\\
1&0&1&1&0&0&0&0&0&0&0&0&0&0\\
1&1&0&0&0&1&0&0&0&0&0&0&0&0\\
0&1&0&0&1&0&0&0&0&0&1&0&0&0\\
0&0&0&1&0&1&1&0&0&0&0&0&0&0\\
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0&0&0&1&0&0&0&0&0&0&0&1&0&1\\
0&0&0&0&0&0&0&0&1&0&1&0&1&0\\
0&0&0&0&0&1&0&0&0&0&0&1&0&1\\
0&0&0&0&0&0&0&0&1&0&1&0&1&0
\end{pmatrix}$$

4.1.2 Length Matrix

This matrix gives the values of the length (in km) between connected nodes in the NSF network. If node i and j are connected then A_{i-j} = km otherwise if I and j are not connected then $A_{i-j} = 0$ zero '0'. [1].

Table 7: Length matrix of NSF network

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	1100	1600	0	0	0	0	2800	0	0	0	0	0	0
2	1100	0	600	1000	0	0	0	0	0	0	0	0	0	0
3	1600	600	0	0	0	2000	0	0	0	0	0	0	0	0
4	0	1000	0	0	600	0	0	0	0	0	2400	0	0	0
5	0	0	0	600	0	1100	800	0	0	0	0	0	0	0
6	0	0	2000	0	1100	0	0	0	0	1200	0	0	2000	0
7	0	0	0	0	800	0	0	700	0	0	0	0	0	0
8	2800	0	0	0	0	0	700	0	700	0	0	0	0	0
9	0	0	0	0	0	0	0	700	0	900	0	500	0	500
10	0	0	0	0	0	1200	0	0	900	0	0	0	0	0
11	0	0	0	2400	0	0	0	0	0	0	0	800	0	800
12	0	0	0	0	0	0	0	0	500	0	800	0	300	0
13	0	0	0	0	0	2000	0	0	0	0	0	300	0	300
14	0	0	0	0	0	0	0	0	500	0	800	0	300	0

4.1.3 Reliability Matrix

Reliability of the link is important for the QoS, Reliability is represented by γ where $0 \leq \gamma \leq 1$ it gives the percentage of the reliability. A random variable will be generated, which will be uniform $U[0.6, 1]$ for each link in the NSF network, corresponding values are given in the diagram [13].

Table 8: Reliability matrix of NSF Network

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	0.99	0.99	0	0	0	0	0.9	0	0	0	0	0	0
2	0.99	0	0.99	0.98	0	0	0	0	0	0	0	0	0	0
3	0.98	0.99	0	0	0	0.92	0	0	0	0	0	0	0	0
4	0	0.98	0	0	0.99	0	0	0	0	0	0.8	0	0	0
5	0	0	0	0.99	0	0.8	0.86	0	0	0	0	0	0	0
6	0	0	0.92	0	0.8	0	0	0	0	0.83	0	0	0.94	0
7	0	0	0	0	0.86	0	0	0.82	0	0	0	0	0	0
8	0.9	0	0	0	0	0	0.82	0	0.8	0	0	0	0	0
9	0	0	0	0	0	0	0	0.8	0	0.75	0	0.95	0	0.99
10	0	0	0	0	0	0.83	0	0	0.75	0	0	0	0	0
11	0	0	0	0.8	0	0	0	0	0	0	0	0.9	0	0.83
12	0	0	0	0	0	0	0	0	0.95	0	0.9	0	0.83	0
13	0	0	0	0	0	0.94	0	0	0	0	0	0.83	0	0.66
14	0	0	0	0	0	0	0	0	0.99	0	0.83	0	0.66	0

R=

$$
\begin{pmatrix}
0 & 0.9900 & 0.9900 & 0 & 0 & 0 & 0 & 0.9000 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.9900 & 0 & 0.9900 & 0.9800 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.9800 & 0.9900 & 0 & 0 & 0 & 0.9200 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0.9800 & 0 & 0 & 0.9900 & 0 & 0 & 0 & 0 & 0 & 0.8000 & 0 & 0 & 0 \\
0 & 0 & 0 & 0.9900 & 0 & 0.8000 & 0.8600 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0.9200 & 0 & 0.9900 & 0 & 0 & 0 & 0 & 0.8300 & 0 & 0 & 0.9400 & 0 \\
0 & 0 & 0 & 0 & 0.8600 & 0 & 0 & 0.8200 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.9000 & 0 & 0 & 0 & 0 & 0 & 0.8200 & 0 & 0.8200 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.8000 & 0 & 0.7500 & 0 & 0.9500 & 0 & 0.9900 \\
0 & 0 & 0 & 0 & 0 & 0.8300 & 0 & 0 & 0.7500 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0.8000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.9000 & 0 & 0.8300 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.9500 & 0 & 0.9000 & 0 & 0.8300 & 0 \\
0 & 0 & 0 & 0 & 0 & 0.9400 & 0 & 0 & 0 & 0 & 0 & 0.8300 & 0 & 0.6600 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.9900 & 0 & 0.8300 & 0 & 0.6600 & 0
\end{pmatrix}
$$

These matrixes are the basic matrices; from these matrixes we will be able to find other different type of values. Like length of shortest path, time delay for shortest path, reliability values for shortest path.

4.2 Time delay Matrix

The time taken by the burst to reach from one (source) node to another (destination) node is the delay time. It depend upon the length of the link, if the route (path between source s and destination d) consist of more than one link, the total delay is the sum of links delay. As the length is given in km, and refractive index of the fiber core is given it is easy to calculate the time delay between source and destination. The value of refractive index is from 1.46 to 1.56 in practical Optical cables.

Time delay is equal to distance times the velocity of light.

Here, distance is in km and velocity of light is 250 km/ms given in

As velocity of light is $3 \times 10^8\ m/s = 3 \times 10^8 km/s\ = 300 \times km/ms$

Comparing both will give n=1.2

As $D = V \times T$

$T = D/V,$

Table 9: Time-delay between connected nodes of NSF network

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	4.40	4.0	0	0	0	0	11.200	0	0	0	0	0	0
2	4.40	0	2.4	4.0	0	0	0	0	0	0	0	0	0	0
3	4.40	2.40	0	0	0	8.oo	0	0	0	0	0	0	0	0
4	0	4.00	0	0	2.4	0	0	0	0	0	9.600	0	0	0
5	0	0	0	2.4	0	4.40	3.200	0	0	0	0	0	0	0
6	0	0	8.0		4.4	0	0	0	0	4.800	0	0	8.000	0
7	0	0	0	0	3.2	0	0	2.800	0	0	0	0	0	0
8	11.2	0	0	0	0	0	2.800	0	2.800	0	0	0	0	0
9	0	0	0	0	0	0	0	2.800	0	3.600	0	2.00	0	2.00
10	0	0	0	0	0	4.80	0	0	3.600	0	0	0	0	0
11	0	0	0	9.6	0	0	0	0	0	0	0	3.200	0	3.200
12	0	0	0	0	0	0	0	0	2.00	0	3.200	0	1.200	0
13	0	0	0	0	0	8.00	0	0	0	0	0	1.200	0	1.200
14	0	0	0	0	0	0	0	0	2.00	0	3.200	0	1.200	0

From the above table (length L) we will find the matrix for time delay between nodes, the total time delay from one node (source) to another node(destination) will be the sum of the time 't' for the links.

Table 10: Some paths, path length and time delay

S.N0	Path	Nodes	Total path length (km)	Time-delay (ms)	Reliability
1	P1	1→ 8→ 9→ 14 (3-Links)	4000	16	0.7128
2	P2	1→2→3→6 →13→ 14 5-L	5800	23.2	0.55940
3	P3	1→ 2→ 4→ 11 →14 4-L	5300	21.2	0.6507
4	P4	1→ 2→ 4 →5→ 6→ 10→ 9→ 14 7-L	6400	25.6	0.4735

- DG =

- (1,2) 1100
- (1,3) 1600
- (2,3) 600
- (2,4) 1000
- (4,5) 600
- (3,6) 2000
- (5,6) 1100
- (5,7) 800
- (1,8) 2800
- (7,8) 700
- (8,9) 700
- (6,10) 1200
- (9,10) 900
- (4,11) 2400
- (9,12) 500
- (11,12) 800
- (6,13) 2000
- (12,13) 300
- (9,14) 500
- (11,14) 800
- (13,14) 300

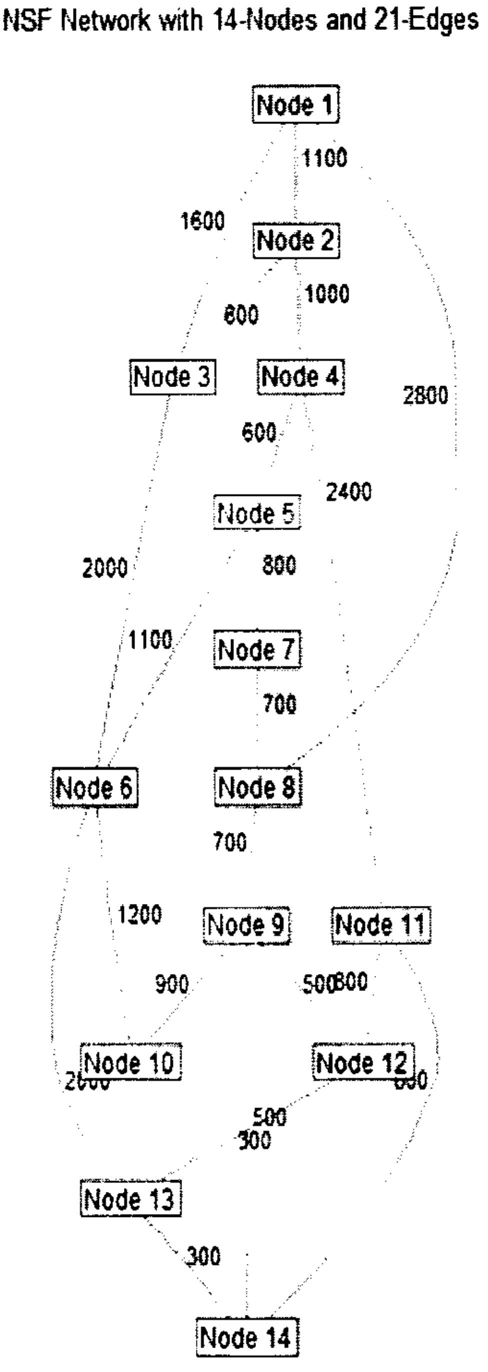

Figure 29: NSF Network and corresponding Edge length

Matlab codes are given A2

The following table is for path length matrix of the network in killo meters km.

Table 11: Values of shortest path length between nodes

0	1100	1600	2100	2700	3600	3500	2800	3500	4400	4500	4000	4300	4000
1100	0	600	1000	1600	2600	2400	3100	3800	3800	3400	4200	4500	4200
1600	600	0	1600	2200	2000	3000	3700	4100	3200	4000	4300	4000	4300
2100	1000	1600	0	600	1700	1400	2100	2800	2900	2400	3200	3500	3200
2700	1600	2200	600	0	1100	800	1500	2200	2300	3000	2700	3000	2700
3600	2600	2000	1700	1100	0	1900	2600	2100	1200	3100	2300	2000	2300
3500	2400	3000	1400	800	1900	0	700	1400	2300	2700	1900	2200	1900
2800	3100	3700	2100	1500	2600	700	0	700	1600	2000	1200	1500	1200
3500	3800	4100	2800	2200	2100	1400	700	0	900	1300	500	800	500
4400	3800	3200	2900	2300	1200	2300	1600	900	0	2200	1400	1700	1400
4500	3400	4000	2400	3000	3100	2700	2000	1300	2200	0	800	1100	800
4000	4200	4300	3200	2700	2300	1900	1200	500	1400	800	0	300	600
4300	4500	4000	3500	3000	2000	2200	1500	800	1700	1100	300	0	300
4000	4200	4300	3200	2700	2300	1900	1200	500	1400	800	600	300	0

Time delay matrix is

Rows start from 1→14

Columns start from 1→14

Diagnal values are all zeros, indicate that there is no self loop in the network.

Row1, column14 is 4000, means there are 4000 km destance of the link inbetween source s (1) and destination d (14) given as

1→ 8→ 9→ 14, the total length is

2800 + 700 + 500 = 4000 km given by row 1 column 14 (R1, C14) of above Matrix-5.

From the above time delay Matrix we will find the total delay time between different nodes,

MATLAB codes[2] will be used for calculations

UG =

(2,1)	4.4000
(3,1)	6.4000
(8,1)	11.2000
(3,2)	2.4000
(4,2)	4.0000
(6,3)	8.0000
(5,4)	2.4000
(11,4)	9.6000
(6,5)	4.4000
(7,5)	3.2000
(10,6)	4.8000
(13,6)	8.0000
(8,7)	2.8000
(9,8)	2.8000
(10,9)	3.6000
(12,9)	2.0000
(14,9)	2.0000
(12,11)	3.2000
(14,11)	3.2000
(13,12)	1.2000
(14,13)	1.2000

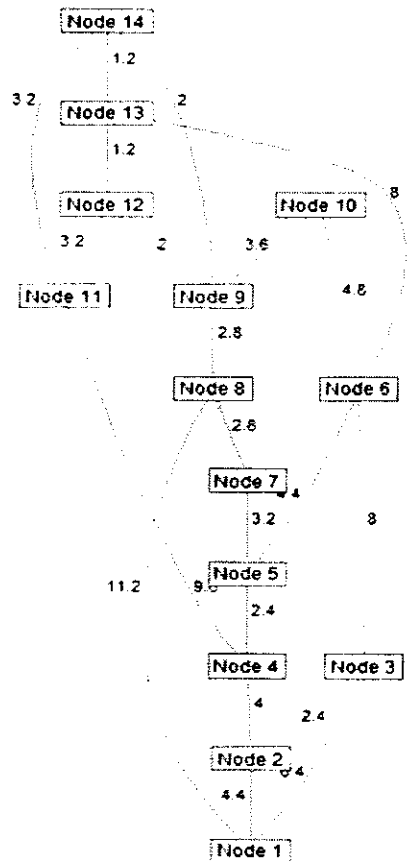

Figure 30: Time-delay for each edge and path delay per edge bases

[2] MATLAB codes are it A2

Table 12: Time-delay matrix for shortest path

Nodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	4.4	6.4	8.4	10.8	14.4	14	11.2	14	17.6	18	16	17.2	16
2	4.4	0	2.4	4	6.4	10.4	9.6	12.4	15.2	15.2	13.6	16.8	18	16.8
3	6.4	2.4	0	6.4	8.8	8	12	14.8	16.4	12.8	16	17.2	16	17.2
4	8.4	4	6.4	0	2.4	6.8	5.6	8.4	11.2	11.6	9.6	12.8	14	12.8
5	10.8	6.4	8.8	2.4	0	4.4	3.2	6	8.8	9.2	12	10.8	12	10.8
6	14.4	10.4	8	6.8	4.4	0	7.6	10.4	8.4	4.8	12.4	9.2	8	9.2
7	14	9.6	12	5.6	3.2	7.6	0	2.8	5.6	9.2	10.8	7.6	8.8	7.6
8	11.2	12.4	14.8	8.4	6	10.4	2.8	0	2.8	6.4	8	4.8	6	4.8
9	14	15.2	16.4	11.2	8.8	8.4	5.6	2.8	0	3.6	5.2	2	3.2	2
10	17.6	15.2	12.8	11.6	9.2	4.8	9.2	6.4	3.6	0	8.8	5.6	6.8	5.6
11	18	13.6	16	9.6	12	12.4	10.8	8	5.2	8.8	0	3.2	4.4	3.2
12	16	16.8	17.2	12.8	10.8	9.2	7.6	4.8	2	5.6	3.2	0	1.2	2.4
13	17.2	18	16	14	12	8	8.8	6	3.2	6.8	4.4	1.2	0	1.2
14	16	16.8	17.2	12.8	10.8	9.2	7.6	4.8	2	5.6	3.2	2.4	1.2	0

If we draw the graph for time delay verces length , on x-axis we take the length of the path in km, and on y-asix delay time in milli second (ms). The graph will be of edge link verses delay time is shown in figure 31. The programing codes are given at [3]

[3] MATLAB codes are given at A3

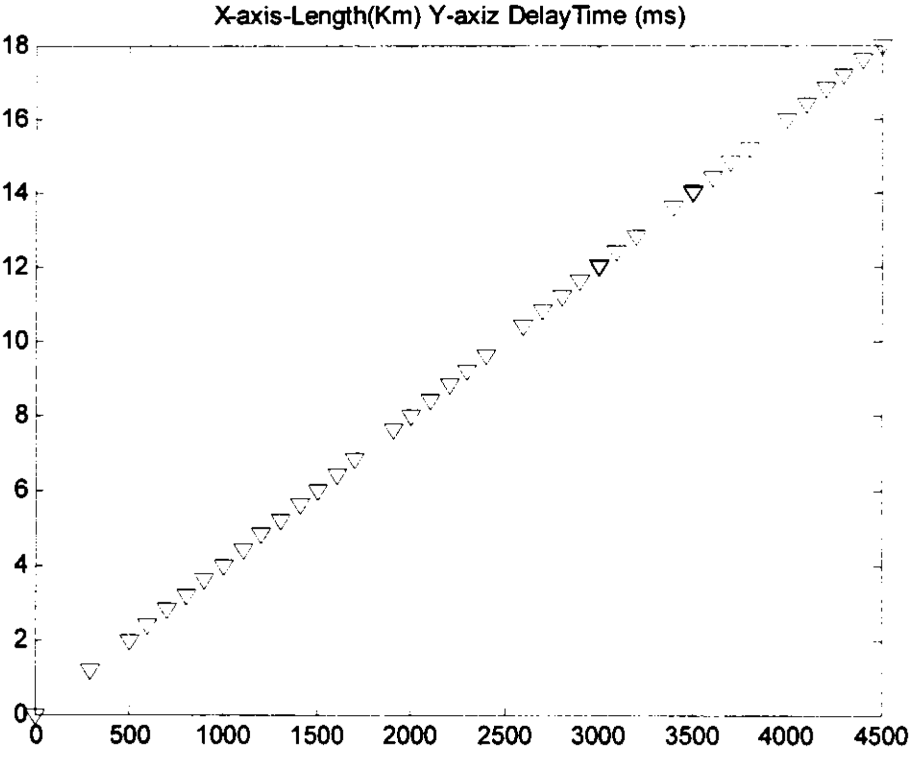

Figure 31: X-axis distance (km) verses Y-axis time delay (ms)

MATLAB Codes Used for making NSF Network, with given specification, measuring shortest path as well as link delay time is given in A3.

In figure 31 as the length of the line increases, time delay will also increase.

We will select one path (shortest path) out of a number a paths, for that path we will keep the values for the link taken, and will be replace all other values of link by zero. It will elliminate the other paths from the graph.

Adjacency matrix for shortest path, will be represented by S and is given below

$$S=\begin{pmatrix}0&0&0&0&0&0&0&1&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0&0&0\\1&0&0&0&0&0&0&0&1&0&0&0&0&0\\0&0&0&0&0&0&0&1&0&0&0&0&0&1\\0&0&0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&1&0&0&0&0&0\end{pmatrix}$$

Table 13: Adjacency matrix for shortest path of the NSF network

Nodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	1	0	0	0	0	0	0	0	1	0	0	0	0	0
9	0	0	0	0	0	0	0	1	0	0	0	0	0	1
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	1	0	0	0	0	0

Length matrix for shortest path represented by Ws.

$$
Ws=\begin{pmatrix}
0&0&0&0&0&0&0&2800&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
2800&0&0&0&0&0&0&0&700&0&0&0&0&0\\
0&0&0&0&0&0&0&700&0&0&0&0&0&500\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&500&0&0&0&0&0
\end{pmatrix}
$$

Table 14: Length matrix for shortest path of NSF network

Nodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	0	0	0	0	0	0	2800	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	2800	0	0	0	0	0	0	0	700	0	0	0	0	0
9	0	0	0	0	0	0	0	700	0	0	0	0	0	500
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	500	0	0	0	0	0

Reliability matrix for shortest path is is represented by Rs,

$$
Rs=\begin{pmatrix}
0000000.90\ 0\ 0\ 0\ 0\ 0 \\
000000000\ 0\ 0\ 0\ 0\ 0 \\
000000000\ 0\ 0\ 0\ 0\ 0 \\
000000000\ 0\ 0\ 0\ 0\ 0 \\
000000000\ 0\ 0\ 0\ 0\ 0 \\
000000000\ 0\ 0\ 0\ 0\ 0 \\
000000000\ 0\ 0\ 0\ 0\ 0 \\
.90000000.8\ 0\ 0\ 0\ 0\ 0 \\
0000000.80\ 0\ 0\ 0\ 0\ .99 \\
000000000\ 0\ 0\ 0\ 0\ 0 \\
000000000\ 0\ 0\ 0\ 0\ 0 \\
000000000\ 0\ 0\ 0\ 0\ 0 \\
000000000\ 0\ 0\ 0\ 0\ 0 \\
00000000.99\ 0\ 0\ 0\ 0\ 0
\end{pmatrix}
$$

Table 15: Reliability matrix for shortest path of NSF network

Nodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0.9	0	0	0	0	0	0	0	0.8	0	0	0	0	0
9	0	0	0	0	0	0	0	0.8	0	0	0	0	0	0.99
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	500	0	0	0	0	0

Time-delay matrix for shortest path,

$$
Ts=\begin{pmatrix}
0&0&0&0&0&0&0&11.2&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
11.2&0&0&0&0&0&0&0&2.8&0&0&0&0&0\\
0&0&0&0&0&0&0&2.8&0&0&0&0&0&2.0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&2.0&0&0&0&0&0
\end{pmatrix}
$$

Table 16: Time-delay matrix for shortest path of NSF network

Nodes	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0	0	0	0	0	0	0	11.2	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	11.2	0	0	0	0	0	0	0	2.8	0	0	0	0	0
9	0	0	0	0	0	0	0	2.8	0	0	0	0	0	2
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	2	0	0	0	0	0

4.4 Dispersion consideration for NSF Network

When the light (data) pulse propagates in the fiber it will spread out with time, this spreading out of light pulse is called dispersion. There are many reasons which cause dispersion in optical fiber, and it classified mainly in three types.

a. Intermodal Dispersion,
b. Intra modal or Chromatic Dispersion, and
c. Waveguide Dispersion

The core of a multi mode optical fiber has a larger size, in which many different rays/modes of light can travel. As these fiber can enter the multi mode fiber at different angles, each mode follows a different path in the fiber have different length, and will reach the destination at different time, which causes spreading of light pulse at the output receiver. Different modes will overlap and will spread along the fiber. The use of single mode fiber will illuminate model dispersion as there is only one mode for long distance communication

Material Dispersion: if light consist of a single mode, which have a single wavelength, then the spreading of light will be minimum. But normally the light is not exactly monochromatic, it consist of different chromes, having different velocities and wavelength which causes spreading of light. This type of dispersion is called chromatic dispersion which is a type of material dispersion. It is a result of the line width of the light source; it also depends on refractive index of the material.

Waveguide dispersion is important in single mode fiber. The fiber consist of core and cladding, core is denser than cladding. Light pulse will propagate faster in cladding as compare to core. It is also a type of chromatic dispersion.

4.4.1 Dispersion in Single-mode fiber

If single mode fiber used in a communication system intermodal dispersion can be illuminate. The broadening of light pulse in a single mode fiber will still persists due to intramodal or chromatic dispersion. It is dispersion o ccurs due to the group velocities of a light source. Dispersion in Single mode fiber is also due the index difference of fiber and profile of the fiber. That is called Waveguide, and profile dispersion. The total dispersion in single mode fiber is given in the equation [12].

The total chromatic dispersion in a single mode fiber is given as;

$$D_T(\lambda) = \frac{\lambda S_o}{4}\left(1 - \left(\frac{\lambda_o}{\lambda}\right)^4\right)$$

Where λ is operating wavelength 4.1

S_o is zero dispersion slopes,

λ_o is Wavelength of minimum intermodal dispersion.

If we consider waveguide and profile dispersion for the fiber, then total dispersion is given as.

$$D_T = D_M + D_W + D_P$$

4.2

4.4.2 Parameter of SMF-28e Optical fiber

For a single mode optical fiber made by corning SMF-28e, the dispersion

parameter are given as,

Table 17: Parameter of SMF-28e Optical fiber

Wavelength (nm)	Dispersion Value [ps/(nm.km)]
1550	$\leq$ 18.0
1625	$\leq$22.0

Zero Dispersion Wavelength (λ_o): $1202 \text{ nm} \leq \lambda_o \leq 1322 \text{ nm}$

Zero Dispersion Slope (S_o): $\leq 0.089 \ [\text{ps/nm}^2.\text{km}]$

The formula for dispersion is

$$Dispersion\ D(\lambda):=\frac{S_o}{4}\left[\lambda-\frac{\lambda_0^4}{\lambda^3}\right]\ ps/(nm.km) \quad 4.3$$

for operating wave length: $1200 \leq \lambda \leq 1625$

These values (parameter) will use for NSF (National Science Foundation) network.

As there are different paths in the NSF network.

Table 18: Some paths, their length and dispersion

S.No	Path	Nodes	Total path length (km)	Time-delay (ms)	Dispersion $ps/(nm.km)$
1	P1	1→ 8→ 9→ 14 (3-Links)	4000	16	88,000
2	P2	1→2→3→6 →13→ 14 5-L	5800	23.2	127,600
3	P3	1→ 2→ 4→ 11 →14 4-L	5300	21.2	116,600
4	P4	1→ 2→ 4 →5→ 6→ 10→ 9→ 14 7-L	6400	25.6	140,800

Dispersion will be find either by using formula 4.1 or 4.3. Data releted to single mode fiber are given, calculating the dispersion, the graph of length (shortest path) vs dispersion is given in figure 32. path is node 1→ 8→ 9→ 14 (3-Links)

Note. Programing code is given A3

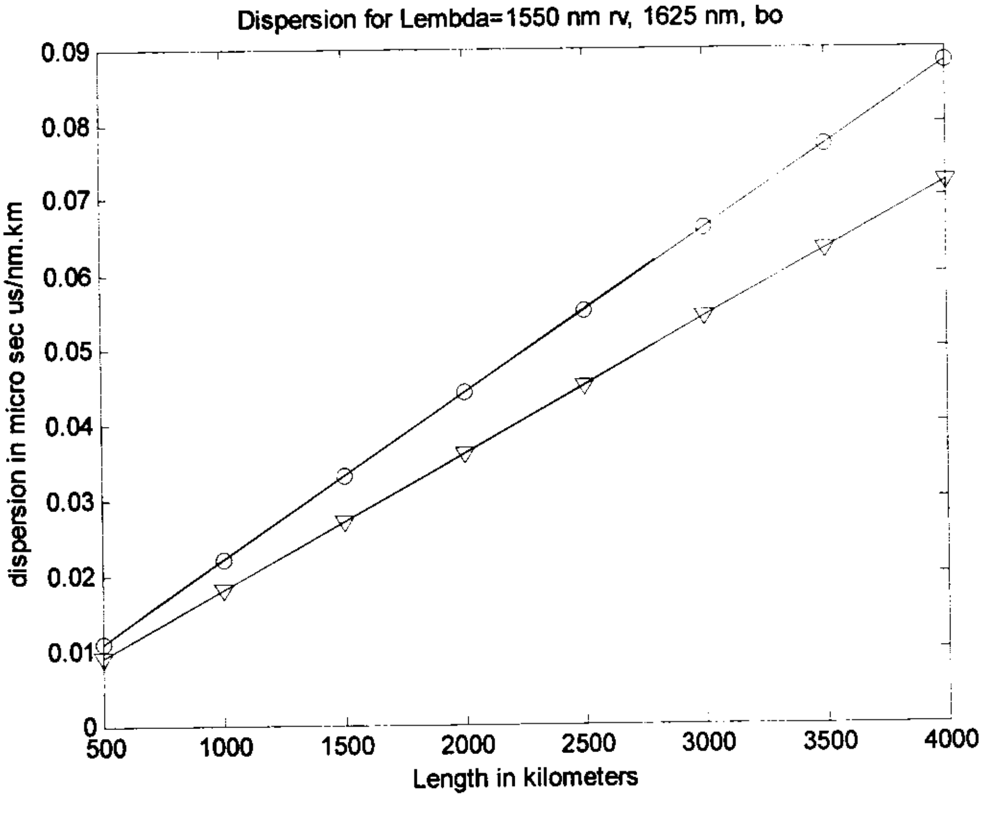

Figure 32: Graph for link length verses dispersion for λ= 1550 nm 'rv 'line, and for λ= 1625nm 'bo' line

Graph in figure 32 gives two results for the same shortest path. Line with small circles (bo) given dispersion for 1625nm wavelength and line with small triangles (rv) give dispersion for 1550 nm wavelength. Both results are impesise that dispersion is a function of length and increases with decreasing the wavelength for a transmission window (wavelength).

Graph for path 2,

Path is Node 1→2→3→6 →13→ 14 (5-Links)

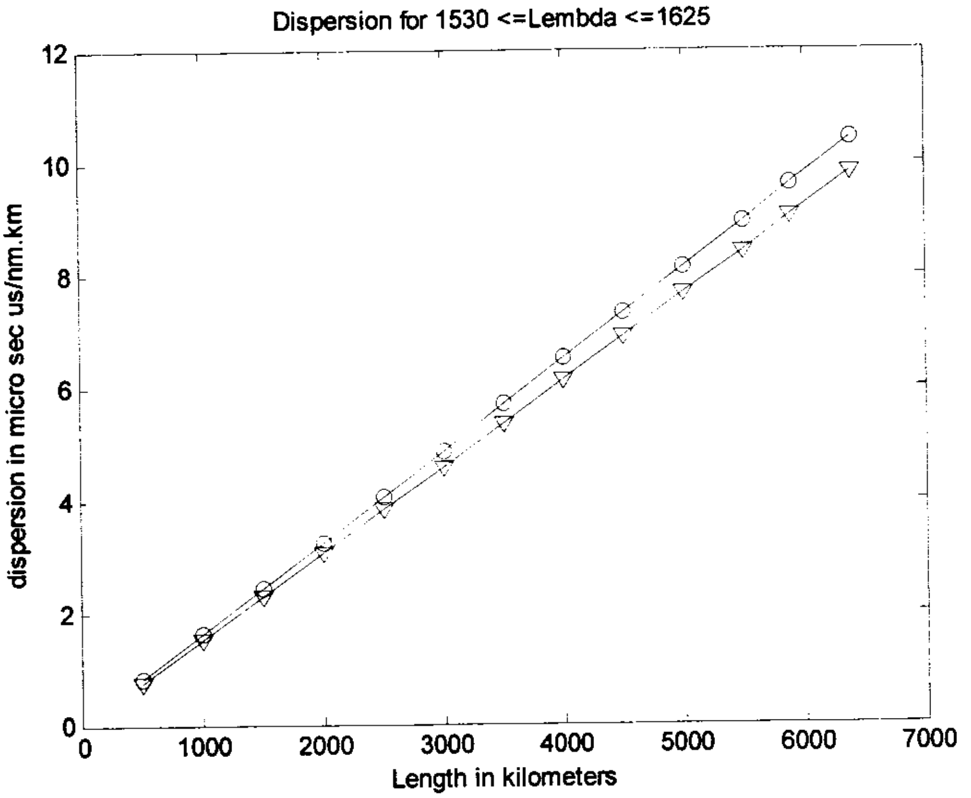

Figure 33: Graph for Length verses dispersion for λ= 1525 nm ---red line, and for λ= 1625nm

In figure 33 the graph is given for a second (long) path with length 5800km. The dispersion increases if we increase the optical fiber length. If dispersion increases the bit-error-rate will increase which will cause data loss and blocking.

A comparison of wavelengths from 1530 nm ≤ λ ≤ 1625 nm on path 2 is given as

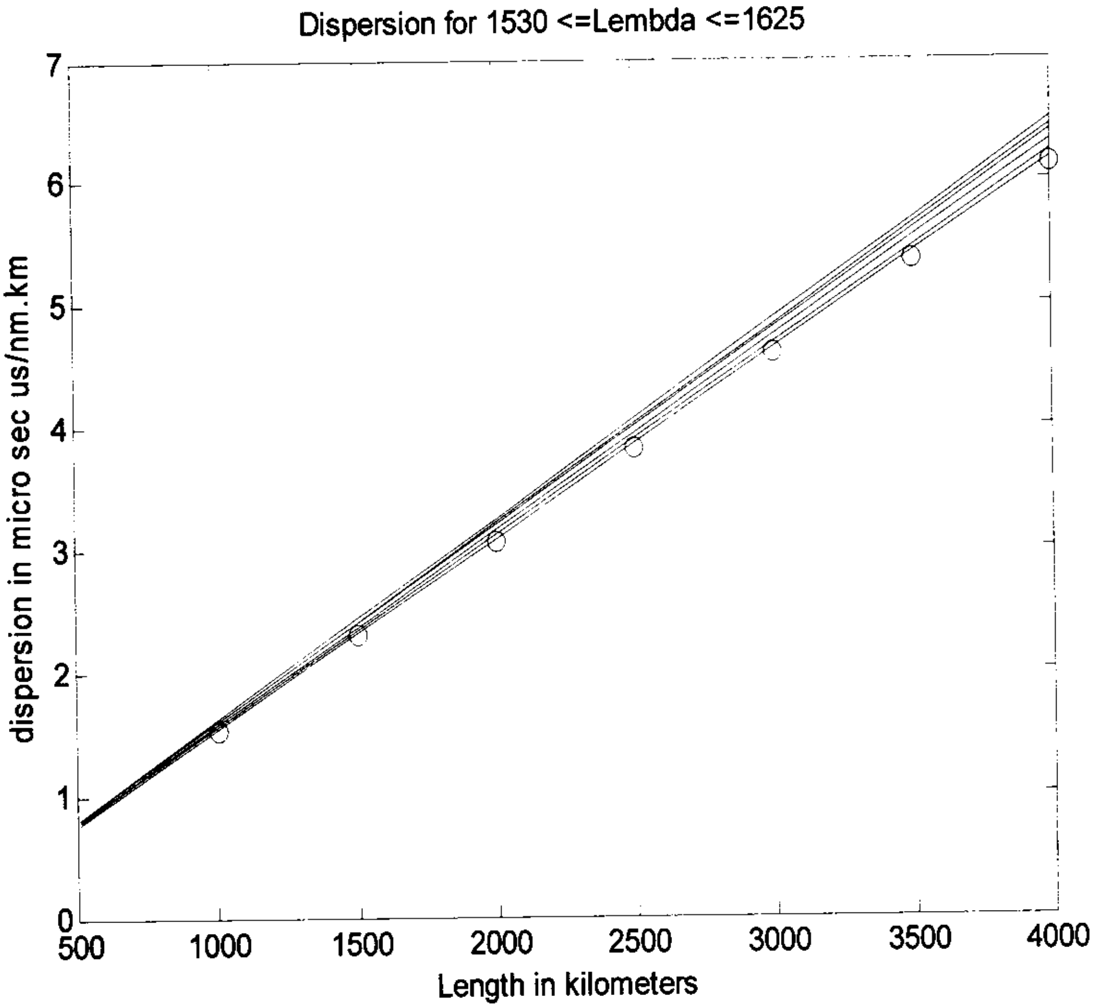

Figure 34: Comparison of different wavelengths on the same path

A general graph is given for NSF network in figure 34. Wavelength for different communication is changed between 1530 nm and 1625 nm. Path is taken as shortest path and the results are given in the graph. When length increases dispersion also increases, if dispersion increase bandwidth of the channel will decrease, this will limit the bandwidth of the optical fiber. If the profile of the optical fiber is improved and dispersion are decreased then the bandwidth utilization increases.

CHAPTER 5

CONCLUSION AND FUTURE WORK

The summary of the work carried out for the thesis presented in this part with some future research plans based on the results is discussed. A brief introduction to optical fiber is given, types of optical fibers, impairments in optical fibers like dispersion, optical components are addressed in the beginning of the thesis. A background knowledge is given next to the introduction section where we have discussed optical networks, network classification and multiplexing paradigm for optical networks.

Some brief literature review related to the work is discussed. Here we have discussed routing and wavelength assignments, types of routing, routing managements in OBS network, wavelength assignments heuristic like random wavelength assignments, first fit, and least used, most used etc are discussed. Blocking probability is discussed and calculated by using Erlang B formula, Poisson formula is also defined.

Core of the thesis where proposed methodology is discussed, here we have find and calculate path (routes) for traffic routing. We have analyzed the theory and mathematic on National Science Foundation (NSF) network and find some useful results. Optical impairments are discussed and simulation results are calculated for a single mode fiber SMF-28e optical fiber, here we calculated the shortest path for NSF network, for this purpose we have calculated and create matrixes, adjacency matrix, time delay matrix, length matrix for the whole NSF network, then we have calculated shortest path for the network. Time-delay was calculated for the paths, dispersion was also calculated and the simulation results are obtained. The process can be applied and used for any type of network.

5.1 Conclusion

The amount of traffic being transmitted over existing networks is rising at an unprecedented rate, and telecommunication and data communications companies are racing to provide the means for meeting these demands.

Optical Burst Switching (OBS) are the engines for high speed Internet transport on optical networks. Optical burst switching combines the advantages of packet switching and circuit switching in a single network. Data and control information are sent through different wavelength channels in a WDM system, new analyses and research are necessary to avoid traffic degradation, burst loss probability and system failure. New protocol and their proper implementation are needed. In this work we have analyzed different routing schemes and optical impairments. We have analyzed NSF network architecture for our consideration.

5.2 Future Work

Optical fiber communication is broad and waist field and a number of considerations can be taken. We have discussed only shortest path routing and the system used was NSF network. Least used path can also be considered to reduce blocking probability and improve traffic transmission. Locally WATEEN network can also be consider for optical measurements. Signal to Noise Ratio (SNR) and Bit error ratio (BER) can also considered and calculated for the said networks. The research can be extended for blocking probability, Q.o.S and many-casting.

5.3 Limitations

Optical fiber has natural qualities and properties. For different transmission windows it dispersion characteristics are changed. It some wavelength it offer zero dispersion but will cause other impairments to increase.

Appendix

A1

Implementation of Erlang B formula. Traffic is from 0 to 6 E and cannel is % taken as 1, the probability will find by the following matlab codes.

```
BHT1= [0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.2 1.5 2 2.5 3 3.5 4 4.5 5 5.5]

BLCK1= [0.091 0.167 0.231 0.286 0.333 0.375 0.412 0.444 0.474 0.5

        0.545 0.6 0.667 0.714 0.75 0.778 0.8 0.818 0.833 0.846]

plot(BHT1,BLCK1, 'rv:')

xlabel(' Load in Erlang ')

ylabel(' Blocking probability (Pb)')

title(' Load vs Pb using Erlang B formula')
```

A2

NSF network can be formed by using the code given below.

```
W1=[11 16 28 10 6 20 6 24 8 11 12 20 7 7 9 5 5 8 8 3 3]*100;

DG1=sparse ([1 1 1 2 2 3 4 4 5 5 6 6 7 8 9 9 9 11 11 12 13],[2 3 8 4 3 6 5 11 7 6 10 13 8 9 10
12 14 12 14 13 14],W1,14,14)

h=view (biograph(DG1,[],'ShowArrows','off','ShowWeights','on'))

title( ' NSF Network With 14-Nodes and 21-Edges')
```

A3

NSF network, shortest path can be find by using.

```
W1=[11 16 28 10 6 20 6 24 8 11 12 20 7 7 9 5 5 8 8 3 3]*100;
DG1=sparse([1 1 1 2 2 3  4 4 5 5 6 6 7 8  9 9 9 11 11 12 13],
[2 3 8 4 3 6 5 11 7 6 10 13 8 9 10 12 14 12 14 13 14],W1,14,14)
h=view(biograph(DG,[],'ShowArrows','on','ShowWeights','on'))
 title( ' NSF Network With 14-Nodes and 21-Edges')
 graphallshortestpaths(DG)
 W2=[11 16 28 10 6 20 6 24 8 11 12 20 7 7 9 5 5 8 8 3 3]*0.4;
DG2=sparse([1 1 1 2 2 3  4 4 5 5 6 6 7 8  9 9 9 11 11 12 13],
[2 3 8 4 3 6 5 11 7 6 10 13 8 9 10 12 14 12 14 13 14],W2,14,14)
 UG1=tril(DG1+DG1')
 UG2=tril(DG2+DG2')
 view(biograph(UG1,[],'ShowArrows','off','ShowWeights','on'));
 A1=graphallshortestpaths(UG1,'directed',false)
 view(biograph(UG2,[],'ShowArrows','off','ShowWeights','on'));
 A2=graphallshortestpaths(UG2,'directed',false)
 xlabel('Path lenght (Km)')
 ylabel(' time delay (T)')
 plot(A1,A2, 'rv')
 title( 'X-axis-Length(Km) Y-axis Delay Time (ms)  ')
```

A4

Dispersion verses path length can de find by using,

```
W1=[11 16 28 10 6 20 6 24 8 11 12 20 7 7 9 5 5 8 8 3 3]*100;
DG1=sparse([1 1 1 2 2 3  4 4 5 5 6 6 7 8  9 9 9 11 11 12 13],
[2 3 8 4 3 6 5 11 7 6 10 13 8 9 10 12 14 12 14 13 14],W1,14,14)
W2=[11 16 28 10 6 20 6 24 8 11 12 20 7 7 9 5 5 8 8 3 3]*0.4;
DG2=sparse([1 1 1 2 2 3  4 4 5 5 6 6 7 8  9 9 9 11 11 12 13],
[2 3 8 4 3 6 5 11 7 6 10 13 8 9 10 12 14 12 14 13 14],W2,14,14)
h=view(biograph(DG1,[],'ShowArrows','on','ShowWeights','on'))
 title( ' NSF Network With 14-Nodes and 21-Edges')
 graphallshortestpaths(DG)
UG1=tril(DG1+DG1')
UG2=tril(DG2+DG2')
view(biograph(UG1,[],'ShowArrows','off','ShowWeights','on'));
A1=graphallshortestpaths(UG1,'directed',false)
view(biograph(UG2,[],'ShowArrows','off','ShowWeights','on'));
A2=graphallshortestpaths(UG2,'directed',false)
xlabel('Path lenght (Km)')
ylabel(' time delay (T)')
plot(A1,A2, 'rv')
title( 'X-axis-Length(Km) Y-axis Delay Time (ms)  ')
```

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