COMPUTATION OF DISPERSION PENALTY FOR THE ANALYSIS OF WDM LINK QUALITY

A Thesis submitted in partial fulfilment of the Requirements for the degree of

Master of Technology

In

Communication and Networks

by

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CERTIFICATE

This is to certify that the work in this thesis entitled "**COMPUTATION OF DISPERSION PENALTY FOR THE ANALYSIS OF WDM LINK QUALITY**" by Mr. **Narsingrao Ravindra Wakkarlawar** is a record of an original research work carried out by his during 2014-2015 under my supervision and guidance in partial fulfilment of the requirement for the award of the degree of Master of Technology in Electronics and Communication Engineering (Communication and Networks), National Institute of Technology, Rourkela. Neither this thesis nor any part of it, to the best of my knowledge, has been submitted for any degree or diploma elsewhere.

Place: NIT Rourkela

Date: 18th May 2015

Dr. Santos Kumar Das

Assistant Professor

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ABSTRACT

The provisioning of light path over WDM/DWDM network is a challenging factor, which depends on various physical layer impairments such as dispersion in fiber. We proposed a light path provisioning mechanism by considering the effect of dispersion in fiber termed as dispersion penalty, which is the prominent effect at high speed WDM network. In the case of non-ideal filter, light path provisioning without considering the physical layer impairments does not satisfy the signal quality guaranteed transmission. In this algorithm, Quality of Service is described in terms of dispersion penalty values with an assumption that the entire client has a requirement of penalty less than 2 Db. Here we have analyzed the degradation in bit rate due to the effect of dispersion. The maximum possible length of fiber is also reduced due to high dispersion in fiber. Dispersion penalty is the increment in the received power to eliminate the effect of some undesirable distortion in optical fiber. Dispersion penalty is calculated in terms of bit rate and band width for each data path. The proposal of dispersion penalty budgeting is to ensure that the optical power reaching the receiver is adequate under all circumstances. The proposed algorithm defines a mechanism for effective light path provisioning by comparing the requirement of client and the available resources of the network.

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Chapter 1

INTRODUCTION

Chapter 1

Introduction

The fast progression of data exchanges frameworks is always dictated by constantly growing customer solicitations for new applications and perpetual advances in engaging progressions. In the past ten years, we have seen the gigantic accomplishment and unsafe improvement of the web. Particular customers are using the Internet fiercely for information, correspondence, and entertainment, while undertaking customers are continuously relying upon the Internet for there step by step business operations. In this manner, web development has experienced an exponential advancement in the past a quarter century, is using more framework information exchange limit. On the other hand, the ascent of time-essential intelligent media applications, for instance, Internet telephony, highlight conferencing, highlight on hobby, and smart gaming, is also eating up a ton of framework transmission limit. All the sure nesses are constraining a colossal enthusiasm for exchange rate restrain on the fundamental data exchanges establishment. Now a day Optical fiber is used for fast communication. The data is sent through the fiber in the form of light which is formed from core, cladding and outer insulator with more refractive index value of a core than the cladding. Optical fiber faces the problem of dispersion, which is computed. in quality services. In this work, Quality service of the network is closely related to the bandwidth, delay and dispersion penalty factors. In the first part of the work, we have described the Q-Factor (Quality Factor) in terms of bandwidth and delay. Our requirement is high bandwidth and minimum delay. Here the light path provisioning completely depends on the Q-Factor requirement of client which may vary from client to client. But in the second part, Q-Factor is the dispersion penalty which should be less than 2 dB in normal case. In the light path provisioning algorithm, this condition is assumed to be same for all connection requests. The performance of the algorithms is evaluated by computing the possibility of blocking for incoming connection requests over the number of connections established. We have proposed the wavelength number issue that how it improves the blocking probability in all possible paths case for a source destination pair of a network with fewer nodes and links.

1.1 LITERATURE REVIEW

The recent research challenges in Quality of service based routing are described in [1]. This paper surveys the most important issues in terms of Quality of service routing. And also concisely presents some of the proposals and ongoing research efforts in this area. Similarly a delay constraint multicasting algorithm is given [2]. Here the main goal is to allocate a delay constraint multicast tree in WDM network. A Quality of service based algorithm for optical burst switch scheduling on DWDM network is studied in paper [3]. A new optical burst switching protocol for Quality of service satisfied light path provisioning is proposed in the paper [4]. In the paper [5], a new Quality of service provisioning approach which offers loss free transmission in the network is described. The papers [6-11] analyzed the dispersion effect at high speed optical fiber channels. Connection provisioning algorithm considering the Impairment effects such as dispersion and the reduction in bandwidth due to dispersion in optical fiber is described in [8]. Other issues reported in [11], which says how bandwidth splitter works centrally and provides Quality of service to the clients. The paper [12, 21] says about traffic based guaranteed Quality of service which is fully wavelength and number of applicant dependent. The papers [13-16] has studied the various multicasting issues in WDM network. A power efficient multicasting technique is proposed in paper [17]. Different wavelength conversion techniques in WDM network is briefly explained in the paper [18]. For the architectural description of WDM network, we have referred the paper [19]. And computation of blocking probability of WDM network is obtained from the paper [20]. But none of this paper concentrated on the bandwidth and delay based dispersion penalty calculation and the light path connection provisioning mechanism based on the Q-Factor requirement of client. This work develops a new Quality of service guaranteed routing algorithm that ensures better performance.

1.2 LOW LOSS SPECTRUM OF OPTICAL FIBER

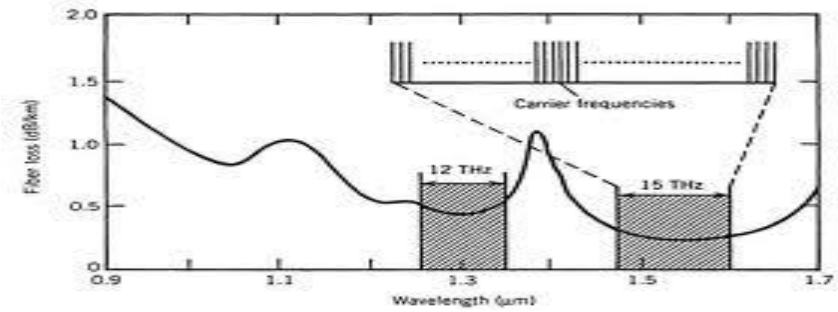

Fig 1.2. Low loss spectrum window for optical fiber

Optical fibers are used for data transmission with higher data rate, which is not possible through normal copper cable and twisted pair. While sending data through optical fibers, certain precautions should be taken. The low loss spectrum of optical fiber is shown in Fig 1.2, where wavelength ranging from 900 nm to 1700 nm. There are two windows ranging from 1270 nm to 1350 nm and 1480 nm to 1600 nm. Total bandwidth including two windows is 30 THz. The optical fiber works with less attenuation and dispersion in this region.

1.3 WDM /DWDM NETWORK

When we having a medium which can support a bandwidth of 30 THz and if we use 1 transmitter and 1 receiver, it will only use 100 GHz bandwidth. That is, we are off by a factor of 1000 in terms of utility of optical fiber. If we use optical fiber medium is just for 1 channel transmission, then the system is highly under-utilized and that essentially the origin of WDM systems.

We divide the signal into multiple channels or we have multiple carriers in optical domain. Each carrier is modulated by data rate (maximum), all carriers are simultaneously transmitted on an optical fiber. The whole multiplexed data on different wavelengths is modulated and given to optical fiber and signal travels through the optical fiber link and reaches to other side where we have a wavelength de multiplexer through that wavelengths are separated.

$\lambda_1, \lambda_2, \lambda_3, \lambda_4 \ldots \ldots \ldots \ldots \lambda_n$ and then you got your signal back which is time multiplexed data. This is all clearly shown in Fig 1.2.1 with multiple transmitters and multiple receivers

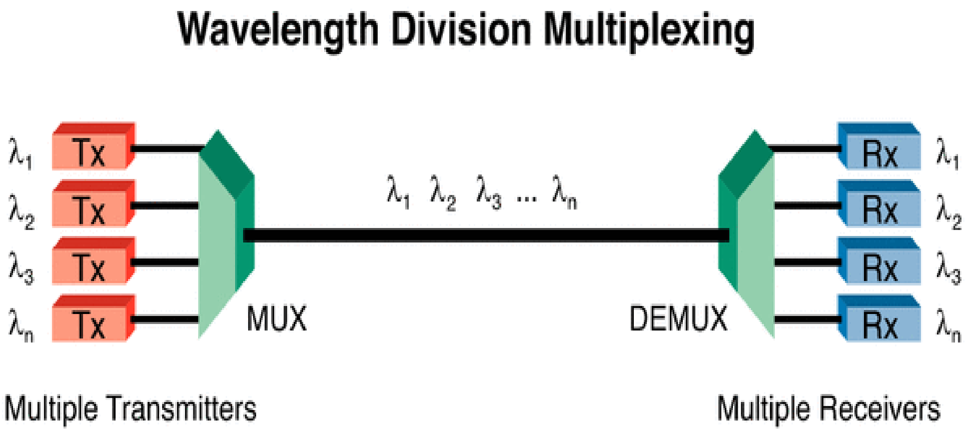

Fig 1.2.1 Wavelength Division Multiplexing (WDM)

WDM/DWDM networks are preferred for the utilization of the enormous bandwidth associated with the optical fiber followed by the reduction of the opto-electronic miss-match. The all-optical WDM/DWDM network eliminates the conversions between electricity and light.

DWDM is the most inventive and propelled innovation in fiber optic correspondence framework because of its potential capacity to give immense data transmission over a solitary fiber channel. The contrast in the middle of WDM and thick wavelength division multiplexing (DWDM) innovation is on a very basic level same. In DWDM, the wavelengths are all very close so substantial number of wavelengths can be multiplexed, and subsequently general limit of fiber will be more. One of the essential highlights of DWDM innovation is that it can increase the whole wavelength all the while without changing over them to electrical signs and it can convey sign of distinctive speed and sort at the same time through the fiber.

1.4 PHYSICAL LAYER IMPAIRMENTS

Optical fiber impairments are the problem faced by the optical fiber during transmission Impairments are classified in two types one is linear and another is non-linear [22-25]. Intensity of light is the major dependency for this classification. Linear impairments are static in nature while nonlinear impairments are dynamic in nature. Linear impairments are independent of signal power and affects each wavelength individually, whereas non-linear impairments depend on signal power and it not only affect the individual channel but also causes disturbance in between the channels. Signal attenuation or loss in the signal as it travels through in optical fiber is one of the major properties of optical fiber which gives us the information of distance between repeaters and amplifiers along with the spacing between transmitter and receiver. Attenuation and Distortion are the major drawbacks of the optical fiber which causes degradation of transmitted signal and pulse spreading respectively. Pulse spreading is purely related to the different types of dispersion, it means distortion is a cause of dispersion. So in an optical network, allocation of new light-path affect the existing light-path. Fig.1.3 shows different impairments in WDM/DWDM networks.

1.4.1 DISPERSION IN FIBER

Dispersion is the internal property of the optical fiber with various types. In this work, we have modeled the Q-factor in terms of band width and delay which are affected due to fiber dispersion. The dispersion effect is more at high speed channels. Due to dispersion pulses are broadened in time when propagating through the fiber, which is a problem at high bit rate over long distances. The broadening of pulse is shown in Fig. 1.3.1.

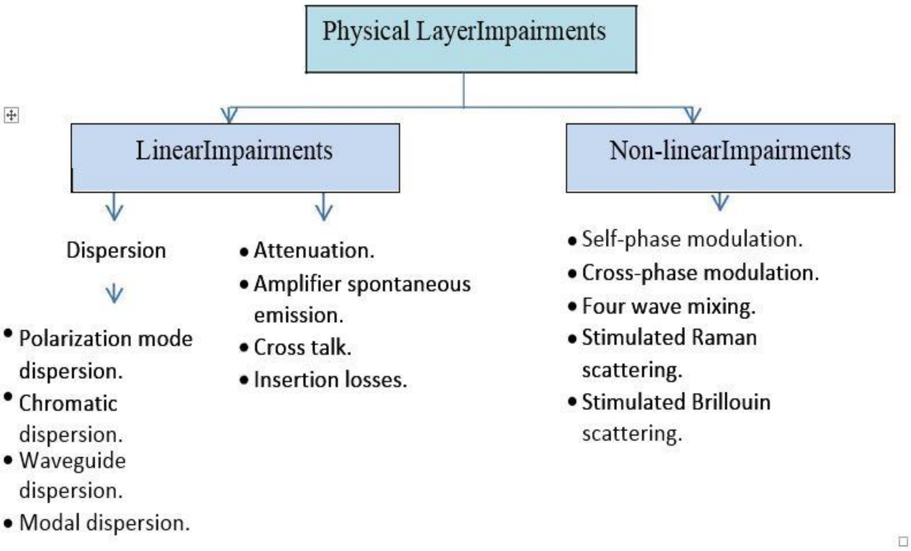

Fig 1.3 Physical layer impairments

Dispersion is the spreading of light pulse as it travels down the length of optical fiber. There are two basic dispersive effects in a fiber: Intermodal dispersion and chromatic dispersion. Intermodal dispersion occurs only in multi-mode fibers. Because a signal pulse propagates in different modes and each mode propagate at a different speed, different modes would arrive at the receiver with different propagation delays and thus results in the pulse spreading out. Obviously, intermodal dispersion is not a problem with

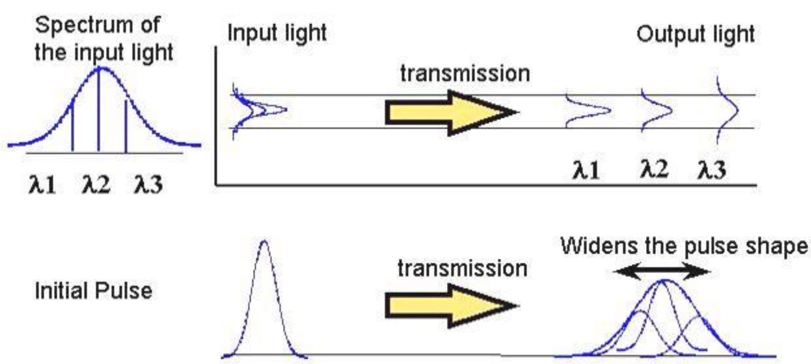

Fig 1.3.1 Pulse spreading as effect of dispersion

single-mode fibers. Different varieties of dispersion we have considered are polarization mode dispersion (PMD), chromatic dispersion (CD). There are two kinds of chromatic dispersion: material dispersion and waveguide dispersion.

a***) Polarization mode dispersion (PMD)***: The electromagnetic waves consist of electric and magnetic fields oscillating at right angles to the direction of travel as shown in Fig 1.3.1.1. The direction of oscillating of electric field, say might be vertical or horizontal. If the direction of electric field of the optical wave propagating in the fiber is aligned with the major axis of ellipse (cross section of non-ideal fiber is elliptical), the major axis component travels slower than that along the minor axis. The direction of the wave oscillation is related to the polarization of the wave, and the differential speed effect is known as polarization mode dispersion (PMD). It is difficult to control the polarization state of the light while it is travelling in the fiber because bends, twits, external pressures on the fiber and random variations in the core shape, composition and strains all conspire to change it as the light progress. Due to the effect of polarization, the two modes processing different polarization level may travel with different velocity hence a differential time delay introduced between this modes. Chromatic dispersion is relatively stable along the fiber length but polarization mode dispersion is completely random in nature. The differential group delay introduced by the non-ideal fiber may be calculated as $T_{PMD}(i,j) = D_{PMD}(i,j) \times \sqrt{L(i,j)}$, where D_{PMD} is the PMD parameter of the fiber and typically measured in ps/√km. Because of the $\sqrt{L}$ dependence, the pulse broadening introduced by PMD is relatively small compared to the effect due to CD. The normal PMD value range is in between 0.01-10 ps/√km [22-25]. It becomes a major limiting factor for higher bit rate long distance WDM systems.

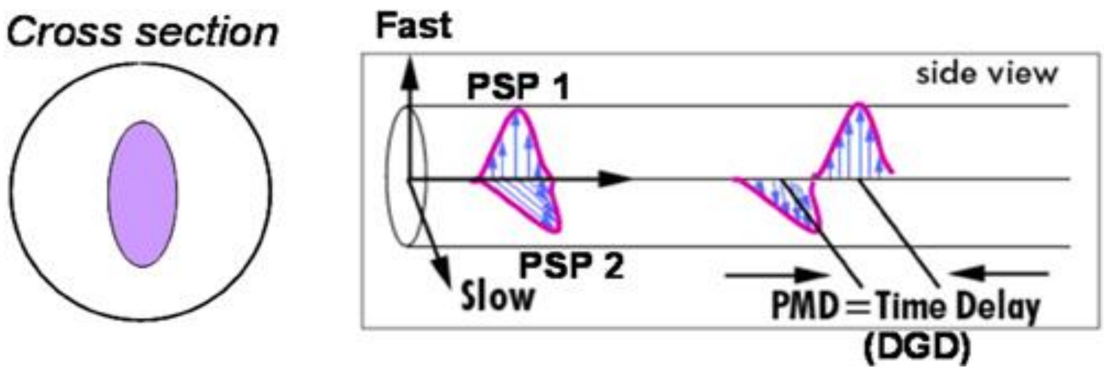

Fig 1.3.1.1 Polarization mode dispersion with cross-section of fiber

***b) Chromatic Dispersion (CD)*:** Chromatic dispersion arises since each wavelength has as slightly different velocity and thus they arrive at different times at the fiber end as shown in Fig 1.3.1.2. Therefore, the range of arrival time at the fiber end of the spectrum of wavelengths will lead to pulse spreading. Chromatic dispersion increases with distance. When the spectral width of the source increases the dispersion also increases [41]. CD causes an optical pulse to broaden such that it spreads into the time slots of the other pulses. It is considered as the most serious linear impairment for systems operating at bit-rates higher than 2.5 Gb/s. CD depends on bit-rate, modulation format, type of fiber, and the use of dispersion compensation fiber (DCF) modules. Chromatic dispersion is sometimes referred to as material dispersion. Material dispersion which is due to the variation in refractive index of the core material is a function of wavelength [41]. The pulse spreading introduced due to chromatic dispersion can be expressed as, $T_{CD}(i,j) = D_{CD}(i,j) \times L(i,j) \times \lambda(i,j)$ where $D_{CD}$is the dispersion coefficient, l length of the fiber link and λ is the wavelength assigned to the fiber link. A typical value of dispersion compensation tolerance in commercial receivers is around ±800 ps/nm for non-return-to-zero (NRZ) 10 Gb/s, while it is ±160 ps/nm for optical duo binary (ODB) 40 Gb/s [23-25].

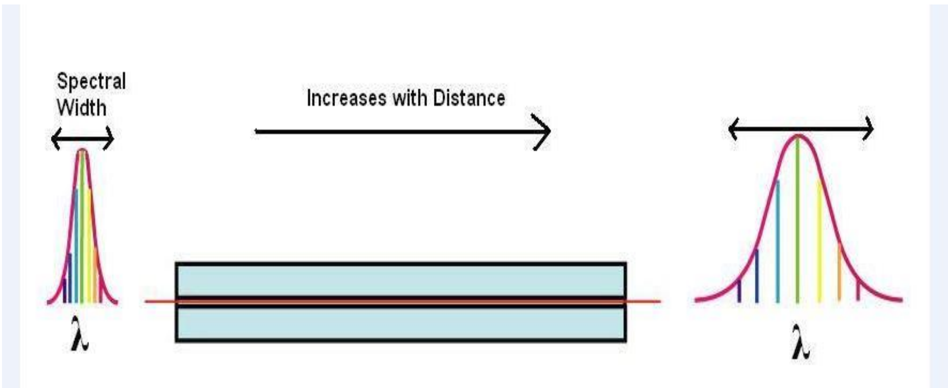

Fig 1.3.1.2 Chromatic dispersion

c) Modal dispersion (MD): In a multimode fiber, different wavelengths travel with different velocities which results in time delay between modes and hence the pulse spreading will occur. Step index fiber has more modal dispersion than graded index fiber. The modal dispersion has a unit ns/km [25]. In modal dispersion, pulse spreading occurs even when different wavelength follows the same path.

d) Waveguide dispersion (WGD): Whenever any optical signal is passed through optical fiber, practically 80% of optical power confined to core and rest 20% optical power into cladding. There are chances of this 20% optical power to escape into outside medium. Thus the information capacity is reduced [42].

1.4.2 DISPERSION PENALTY

In WDM system power budgeting has an important role to ensure that the optical power reaching the receiver is adequate under all circumstances and no components have excessive losses. A receiver in an optical system requires a minimum input power to avoid the possibility of errors. Power budget is the difference between the minimum transmitted output power and the maximum receiver input power. Power penalty is more advanced power budgeting scheme. Typical power penalty can results from various sources like cross talk, dispersion, reflection from components etc. Among this dispersion penalty is much important in the system planning because dispersion effects are high in high speed system. As the result of dispersion, pulse broadening will results and it becomes very difficult at the receiver side to distinguish between ones and zeros. Dispersion penalty is defined as the increase in the receiver input signal power needed to eliminate the degradation in BER due to the effect of dispersion. It is generally measured in dB. Typical value is 2 dB. Dispersion penalty mainly depends on the bit rate and band width of the transmitted data in the optical fiber. Dispersion penalty is used in determining the number of connection accepted for a pair in a network.

1.4.3 SELF PHASE MODULATION (SPM)

Another non-straight impact is Self-stage tweak (SPM) which is because of the cooperation in the middle of light and matter. A short light beat, which is going through a medium, presents variety in refractive record of the fiber because of the optical Kerr effect that is at the point when heartbeat voyaging through the fiber, the higher force parts of a light heartbeat experience a higher refractive record of the fiber contrasted and the lower power portions. This refractive index variation delivers a heartbeat stage shift, and henceforth an adjustment in the beat's recurrence spectrum. SPM is an essential impact in optical frameworks that utilization little, extreme beats of light, for example, lasers and optical fiber interchanges frameworks. The impact is indicated in Fig. 1. 3.1.3.

1.4.4 CROSS PHASE MODULATION (XPM)

A nonlinear optical impact in which one wavelength of light can influence the period of another wavelength of light through the optical Kerr impact is known as Cross-stage tweak (XPM). Here optical heartbeat is stage adjusted by the impact of neighboring heartbeat sufficiency. XPM reasons between channel cross talk, timing jitter in the fiber medium. At the point when the quantity of channels is all the more, then the impact of XPM additionally increments and it debases the framework execution considerably more than SPM. Yet, in fiber correspondence framework, XPM is utilized as a system for expansion of data to a light stream by changing the sound optical pillar phase by interacting with another pulse in a suitable non-linear medium. The effect can be understood from the Fig. 1. 3.1.3.

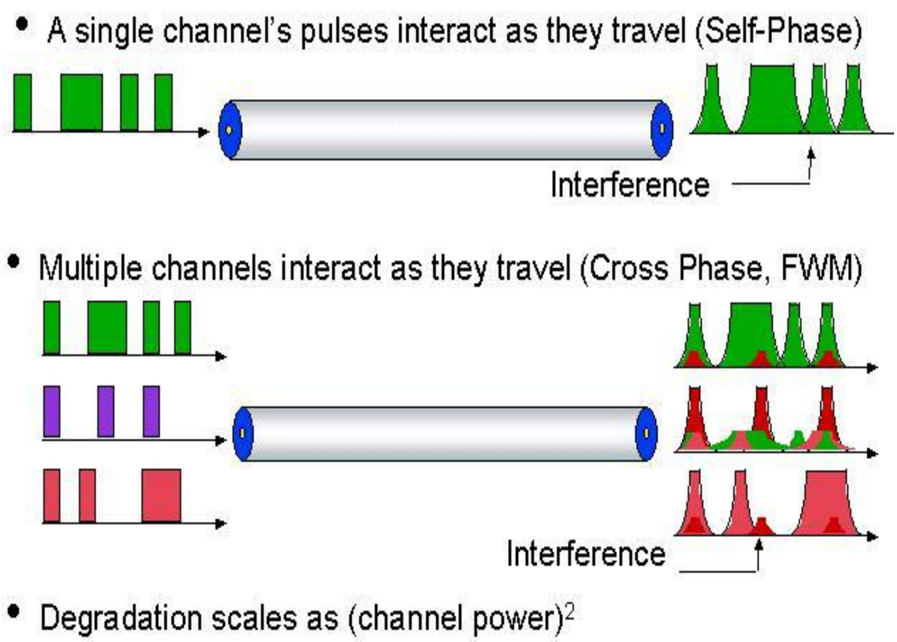

Fig 1.3.1.3 Effect of SPM and XPM in optical pulse

1.4.5 FOUR WAVE MIXING (FWM)

Four wave blending which is an intermodulation marvel in fiber optics, whereby produce two additional wavelengths are created because of the associations between two wavelengths in the transmitted optical signal that is FWM is the era of new optical waves at frequencies which are the blending results of the two approaching signs. In any non-straight medium, three wavelengths cooperation brings about a fourth wavelength and is because of the dispersing of occurrence photon. As the quantity of channels increments or the separating lessens in channel, the impact of FWM gets to be overwhelming in WDM framework. This will prompts cross talk between directs in the system. FWM will be all the more in fiber connected with chromatic scattering.

1.4.6 STIMULATED RAMAN SCATTERING (SRS)

Recreated Raman disseminating impact is a non-direct impact in fiber which brings about the sign corruption of sign at lower wavelength. SRS causes the exchange of force from lower wavelength sign to higher wavelength levels and consequently the sign to clamor apportion of lower wavelength sign diminishes impressively. Be that as it may, in WDM framework, SRS can be abused as favorable element. For actualizing a Distributed Raman Amplifier, we can try for suitable Raman Pumps in the optical fiber. The intensification of the sign can be accomplished in fiber by connecting with EDFA. The pumps are exhausted and the force is exchanged to the sign.

1.4.7 STIMULATED BRILLOUIN SCATTERING

Stimulated Brillouin Scattering occurs in the optical signal in fiber due to the interaction with the density variations such as acoustic phonons and hence a changes in its path. In SBS, the scattering process is stimulated by photons which are associated with higher wavelength than the wavelength of the incident signal. It is one of the most dominant fiber non-linear scattering effects. SBS limits the upper optical power level that can be launched into an optical-fiber.

1.5 ORGANISATION OF THE THESIS

This thesis is sub-divided in five chapters, Starting with introduction and explaining the impairments of optical fiber in first chapter. We have given the detailed description on quality of service based data path provisioning mechanism for WDM network along with introduction about WDM network model, routing and wavelength assignment issues. System design for the algorithm which is proposed is explained in chapter 3 which also includes different numerical formulae. Chapter 4 discusses the simulation results and some conclusion is drawn in 5th chapter.

Chapter 2

AN INTRODUCTION TO WDM SYSTEMS

2.1 OVERVIEW

One of the critical issues in correspondence framework today is the gigantic increment in the data transmission necessity because of the rising application like interactive media, feature and other propelled procedures in correspondence in the realm of correspondence. Wavelength Division Multiplexing (WDM) is one of the answers for this issue subsequent to WDM innovation redesign the data transfer capacity limit of the optical system without including more strands. In WDM system, we can make diverse diverts in the same optical fiber allocating distinctive wavelengths to every channel all the while. Wavelength Division Multiplexing multiplexes numerous optical transporter motions on a solitary optical fiber by utilizing distinctive wavelengths of laser light to convey diverse signs. To evade obstruction between channels, the wavelengths in fiber ought to be dispersed legitimately in WDM framework. WDM multiplexing is indicated in Fig. 2.1. In WDM innovation, which is a piece of third era system, both information transmission and exchanging is done in optical area just. Straightforwardness i. e., every direct in the same fiber can convey any transmission configuration, may be digital or analog or may be with different bit rates [26].

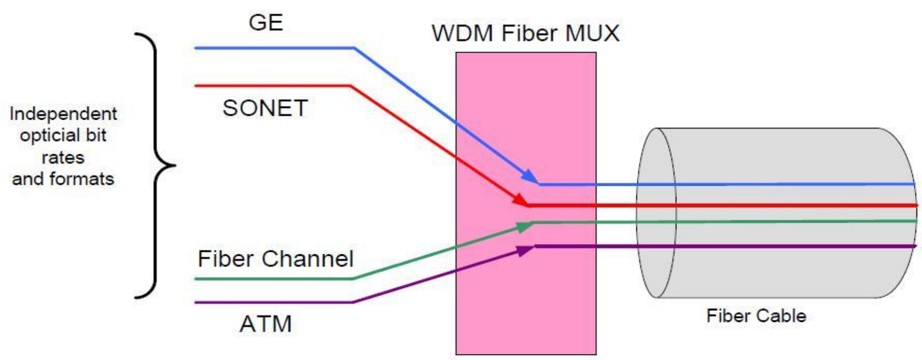

Fig 1.2 WDM multiplexing technique

The two most important wavelength gaps are 1310 nm to 1550 nm. Transmission using 1310 nm is most common for metropolitan short range transmission because of their lower cost. 1550 nm is usually preferred over long distance transmission.

The advanced WDM technologies are

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

A brief overview of CWDM and DWDM is shown in Table 2.1

Table 2.1: Features of CWDM and DWDM

Feature	CWDM	DWDM
Wavelengths per fiber	8-16	40-80
Wavelength spacing	2500GHz	100 GHz
Wavelength capacity	Up to 2.5 Gbps	Up to 10 Gbps
Aggregate fiber capacity	20-40 Gbps	100-1000 gbps
Overall cost	Low	Medium
Applications	Enterprise, metro access	Access, metro-core, regional

i) CWDM, which speaks to coarse wavelength-division multiplexing, is an optical innovation for transmitting various channels, every direct in an alternate wavelength over the same optical fiber. Not at all like thick WDM (DWDM), have which transmitted 32 or more channels on the same fiber by hard pressing them, CWDM multiplexing innovation on a more extensive separating between channels. This more extensive separating multiplexing technique makes CWDM a moderately economical innovation for transmitting multiple data with diverse information rate on a solitary optical fiber, as contrasted and DWDM and WDM. The multiplexing is attained to in optical correspondence framework with the assistance of multiplexers and de-multiplexers connected with the system. The channels in optical correspondence framework works as steering lights from numerous approaching/active strands to a typical transmit/get trunk port. Coarse WDM (CWDM), then again, utilizes a much more extensive wavelength run (1200 to 1600 nm) with a base 20-nm wavelength hole between any two channels. Optical segments utilized for CWDM are less exact and in this way less lavish as a result of the 20-nm wavelength crevice. CWDM cannot maintain the strength of signal for long distances because the signal is not amplified. It can support from 50 to 80 kilometers. CWDM has very less capacity for wavelength, it hardly contain eight active wavelengths per fiber so the wavelengths are spread far apart from each other with wide range frequencies.

ii) DWDM, which is a latest fiber optic multiplexing innovation because of its potential capacity which gives huge data transmission over a solitary fiber channel. This Dense Wavelength Division Multiplexing (DWDM) innovation is in a general sense the propelled rendition of WDM innovation. In DWDM the wavelengths are all the more closer so extensive number of wavelengths can be multiplexed, and subsequently over all limit of fiber will be more. On account of DWDM innovation the whole wavelength can be enhanced all the while in the optical area itself i.e. transformation to electrical flags not needed. What’s more, it can convey sign of distinctive speed and arrangement all the while through the single optical fiber.

The other important features behind the wide acceptance of DWDM technology are given

Transparency: DWDM is physical layer architecture and it can support TDM and data format such as ATM, ETHERNET etc.

Scalability: DWDM can exploit the abundance of optical fiber in many metropolitan area and make the networks to quickly meet band width demand on fiber channels and on spans of existing SONET/SDH rings.

Dynamic data path provisioning: DWDM supports dynamic data path provisioning which supports efficient routing mechanism and results improved blocking performance of the network.

DWDM network normally uses the wavelength in the range of 1530-1560 nm with very high laser accuracy.

2.2 BASIC COMPONENTS OF WDM SYSTEM

A feature of WDM is that the discrete wavelengths form a set of light signal carriers that can be multiplexed, routed, and switched independent to each other. WDM networks require a variety of passive and active devices to combine, distribute, isolate, and amplify optical power at different wavelengths.

Fig 2.2 shows the important components of a basic WDM system of this section.

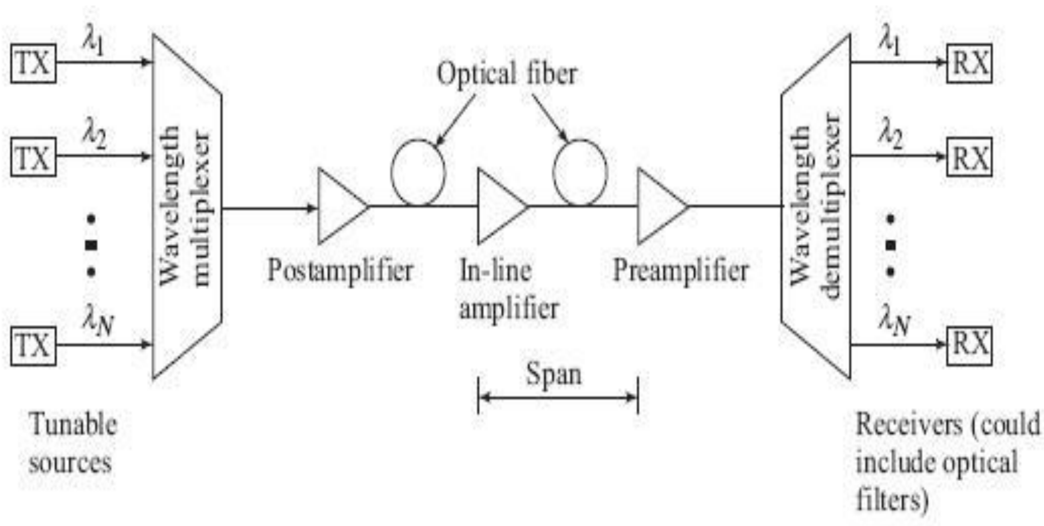

Fig 2.2 Components of WDM System

2.2.1. TRANSPONDERS

In fiber communication, transponder is the basic element for transmission and reception of optical signal from the channel. A transponder is generally characterized by the maximum bit rate it can handle with and the maximum distance the optical pulse can travel without degradation. Transponders convert an optical signal from one wavelength to an optical pulse with another wavelength [27]. Another important function of transponder device is the conversion of broadband signal to a signal associated with specific wavelength by optical to electrical to optical conversion [28]. The transponder functioning is given in Fig. 2. 3.

2.2.2. WAVELENGTH CROSS CONNECT

Wavelength cross associate is an exchanging gadget whose capacity is to switch or join any wavelength from the information port to any of the out port in the fiber. The working is totally in optical area. An OXC with N information and N yield ports fit for taking care of W wavelengths every port can be thought as W autonomous N×N optical switches. A 2 layer 9×9 OXC is given in Fig. 2.4.

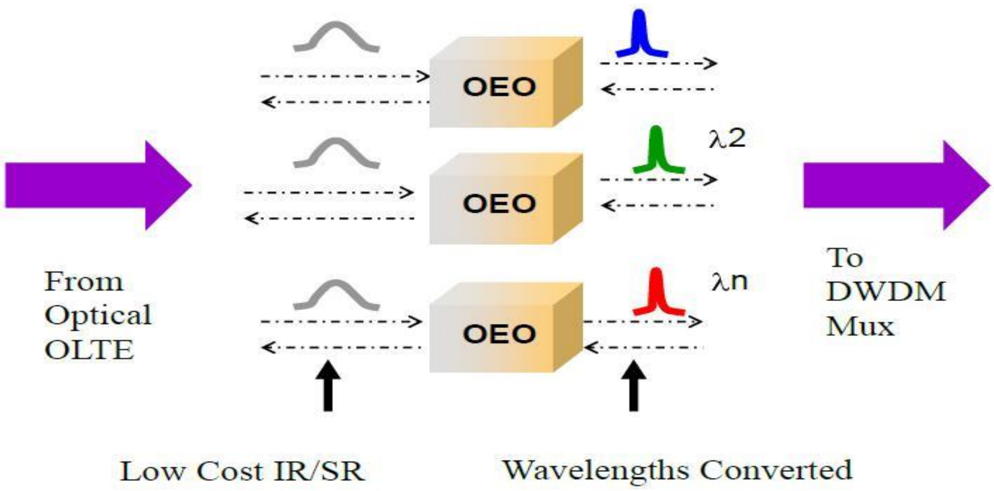

Fig 2.3 OEO conversion with the transponder

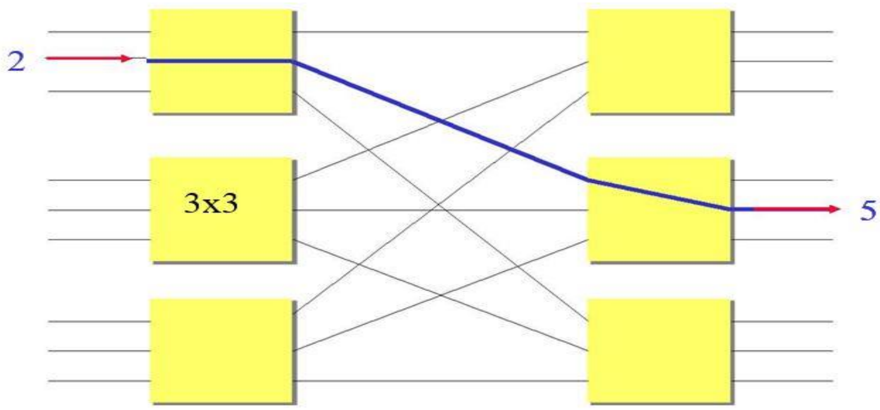

Fig. 2.4: Two layer 9×9 OXC

2.3 ROUTING AND WAVELENGTH ASSIGNMENT (RWA) ISSUES IN WDM SYSTEM

In WDM, different channels are established simultaneously in a single fiber and large numbers of wavelengths are used for implementing separate channels [29]. With WDM a single fiber can accommodate 120 channels now days and more in future [30]. Efficient routing and wavelength assignment is an important issue in the WDM system. RWA is a unique feature of WDM network in which the process of data path selection i.e., the selection of path for a particular connection request with specified source destination edge nodes and then then reserving one particular wavelength for the selected path occurs. For establishing a connection in the WDM network, we should consider both selection of data path i.e. routing and wavelength assignment for the selected route.

2.3.1 ROUTING ALGORITHM

The following section explains some of the important routing algorithms

a) Fixed routing

In this algorithm method, the way for the source destination pair is ascertained utilizing calculations, for example, Dijkstra calculation or Bellman-Ford calculation [31]. Most limited way technique is an illustration of Fixed directing where the briefest way in the middle of source and destination is registered logged off and this light way is utilized for the association making for all association demand with this predetermined source destination pair i.e., same settled way is utilized for a given source and destination. It is a straightforward calculation, however the accessibility of viable light ways in the system is least subsequently blocking will be more. Thus it is not an asset productive used directing strategy.

b) Fixed alternate routing

Here a few other ways are figured logged off for a source destination pair [32, 33]. For a source destination match a few courses are registered and all may be masterminded in some need request, ordinarily the most brief course is the most organized course. A few cases the quantity of connections in the light way is likewise a criteria for organizing the ways. At the point when association appeal arrives, the source hub seeks a light way to destination until it discovers a course with a free wavelength for association foundation. On the off chance that no accessible course is found among every single conceivable way, then the association solicitations will be blocked. This system for directing gives substitute ways to an association ask for subsequently connect disappointment issue can be tackled. The blocking likelihood additionally lessens in the event that we strive for settled substitute directing system.

c) Adaptive routing

In this strategy, ways are ascertained internet relying upon system state and accessibility of assets in the system [34]. Here a course in the middle of source and destination is adjusted alertly relying upon system state. Consider the instance of most brief versatile steering. At the point when an association solicitations arrives, the most limited way in the middle of source and destination is resolved. In the event that more way with same separation present, one is taken haphazardly. Here both wavelength persistent and wavelength particular ways are considered. The call will be blocked if there is no course accessible in the middle of source and destination. This is the most productive steering calculation for WDM system.

2.3.2 WAVELENGTH ASSIGNMENT METHODS

The present existing methods of WDM are explained below

a) Random wavelength assignment

This method is very simple. By only selecting a random wavelength which is available [34]. A random number is generated and wavelength assigned to the randomly generated number.

b) First fit wavelength assignment

In this technique, every accessible wavelength are masterminded in the climbing request and a wavelength framework is framed. At that point all the wavelengths are numbered and the minimum numbered wavelengths are doled out for the first light way [33, 35]. More need is given to the lower numbered wavelength. Calculation expense of this plan is less since no compelling reason to hunt down all wavelengths. The execution well as far as blocking likelihood decency and computation unpredictability likewise less in this technique.

In a wavelength-routed network, the traffic may be static or dynamic.

Static pattern: In a static pattern, a set of connection request are provisioned at a time and it remain for a period of time. Here we have assumed that all light paths are establishing simultaneously. This provisioning mechanism is known as static light path establishment problem.

Dynamic pattern: In this mechanism, each light path is established as it arrives and it is released after a period of time. This method considers the current traffic state of the network and according to that only light path provisioning is done. As the growth in the communication system, the bandwidth demand also increases. For satisfying this, dynamic light path provisioning or on-demand light path established is preferred over static methods.

2.3.3. WAVELENGTH CONSTRAINTS METHODS

The two important wavelengths constraints that we followed for our work are

a) Wavelength continuity constraint

Here all the connections in a light way is must be doled out with the same wavelength. The wavelength coherence limitation recognizes the wavelength consistent system from a circuit exchanged system which pieces calls just when there is no limit along any of the connections in the way allocated to the call. This method is more precisely used over the other method which explained below Wavelength persistent system endures all the more blocking comparer to circuit exchanged system. To dodge this debase execution we can strive for wavelength transformation systems which is clarified underneath.

b) Wavelength distinct constraint

In this case, the links in the light path may assign with different wavelength [34].Here we are able to convert the signal arriving at one wavelength to another wavelength at an intermediate router and then this converted data is forwarded through another link of the same data path. This technique is almost used in all WDM network and is known as wavelength conversion method for wavelength assignment. Wavelength convertible network, in which all the nodes capable to do wavelength conversion is almost similar to a circuit switched network which blocks the call only if there is no available links carrying the capacity to forward the data [18]. Here the effective resources i.e. the total effective light path for routing will be more, hence the probability of blocking for incoming connection request is less.

Chapter-3

SYSTEM DESIGN

3.1 SYSTEM MODEL

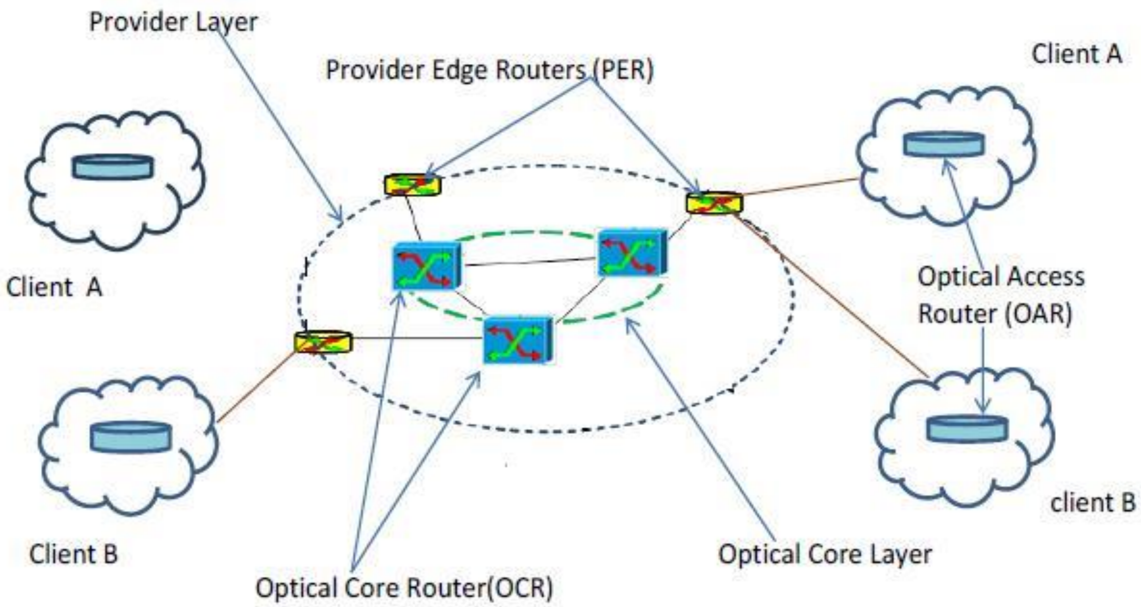

Fig 3.1. SYSTEM MODEL

This framework model comprising of two layers- the Provider edge layer (PER) and the Optical center layer (OCR). As indicated in the model, supplier edge switch (PER) has a place with light way customer which gives light way administration and interface in the middle of customer and optical center switch (OCR). An OCR is not associated with a customer straightforwardly. The provisioning of light way is the foundation of the passages, which may be built at layer 1 and layer 2.

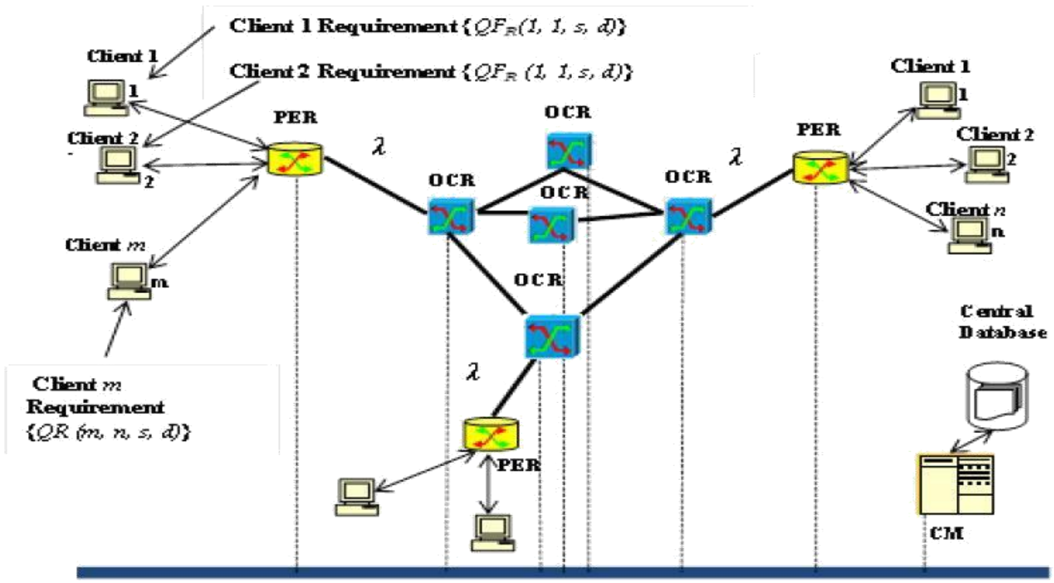

Fig 3.2 Network Architecture

3.2 PROBLEM FORMULATION

The problem of light path provisioning can be based on the Q-Factor requirement of the client and the existing traffic in the network in terms of computed Q-Factor. For the formulation of Q-Factor, we assumed dispersion parameter. We have formulated few things such as i) Required Q-Factor on client point of view, ii) Computed Q-Factor on System/network point of view. iii) Blocking probability, iv) Optimal light path connection setup.

3.2.1 Connectivity in a system

For the connection between two nodes/routers there should be connection called connectivity. If there is a link present between two nodes connectivity is taken as '1' otherwise it is taken as '0'. Using this we can form the connection matrix from that we can determine whether the light path connection can takes place or not.

If *i* and *j* are the node/router pairs, then the connection matrix (i, j) can be as follows

$$C\,(i,j) = \begin{cases} 1 & \text{if link between i and j exists} \\ 0 & \text{otherwise} \end{cases}$$

If the λ(i, j) is the wavelength matrices between *i* and *j*, then, it can be represented as follows

$$\lambda(i,j) = \begin{cases} 1 & \text{if wavelength is available between i and j} \\ 0 & \text{otherwise} \end{cases}$$

3.2.2 Q-Factor Estimation Model

While computing the Q-Factor of light path, we have considered the bandwidth associated with the optical link and the total delay in the fiber due to various types of dispersion effects in the fiber link. Following are the description of our proposed system model parameters

3.2.1.1 BANDWIDTH COMPUTATION

Assume the physical layer constraints are dispersion coefficient and link length. If D_{PMD} *(i, j)* is the dispersion of the fiber and L (i, j) is the length of the fiber link pair (i, j), the bandwidth matrix can be defined as [8]

$$BW(i,j) = \frac{\sigma}{D_{PMD} \times \sqrt{L(i,j)}} \qquad [3.1]$$

Where σ represents the pulse broadening factor should typically be less than 10% of a bit time slot for which polarization mode dispersion can be tolerated.

If *p(s, d)* is the light path connection path for a source (*s*) and destination (*d*) pair, then computed band width for the path can be formulated as follows

$$BW(S,D) = Min\{BW(i,j)\}, \forall (i,j) \in p(s,d) \quad [3.2]$$

3.2.1.2 BIT RATE COMPUTATION

The maximum possible bit rate for a light path with source destination pair *(s, d)* can be computed as [42].

$$BR(S,D) = \frac{\varepsilon}{10^{-6} \times T_{total}(s,d)} \quad [3.3]$$

Where ε is the pulse broadening ratio,

$T_{total}(s,d)$ *is* the total dispersion in the light path and can be computed as follows.

3.2.1.3 DELAY COMPUTATION

For delay computation for fiber link we have to consider the pulse spreading due to various types of dispersion in fiber mentioned below

e) ***Delay due to the effect of polarization mode dispersion***

The differential time delay between the two modes in fiber due to the effect of polarization mode dispersion link can be calculated as [23, 24, 25].

$$T_{PMD}(i,j) = D_{PMD}(i,j) \times \sqrt{L(i,j)} \quad [3.4]$$

Where D_{PMD} *(i, j)* is the polarization mode dispersion coefficient associated with the optical link and *L (i, j)* is the length of the link. The unit of dispersion coefficient is ps/$\sqrt{km}$. This is the most important delay which causes spreading of the pulse.

f) ***Delay due to the effect of chromatic dispersion***

The time delay introduced in optical fiber due to chromatic dispersion can be calculated as follows [23, 24].

$$T_{CD}(i,j) = D_{CD}(i,j) \times L(i,j) \times \lambda(i,j) \quad [3.5]$$

where $D_{CD}(i,j)$ is the dispersion coefficient and $\lambda(i,j)$ is the wavelength assigned for the link with length *L (i, j)*.

g) ***Delay due to modal dispersion***

The delay in a fiber link due to modal dispersion can be calculated using the equation given below [23, 24].

$$T_{MD}(i,j) = \frac{L(i,j) \times (\eta 1 - \eta 2) \times (1 - \frac{\pi}{V})}{C} \quad [3.6]$$

Where $\eta 1$ is the refractive index of core of the fiber and $\eta 2$ is the refractive index of cladding. V is the cut off wavelength and can be calculated by using the expression given below

$$V(i,j) = \frac{2 \times \pi \times a}{\lambda(i,j)} \sqrt{{\eta_1}^2 - {\eta_2}^2} \quad [3.7]$$

Where 'a' is the diameter of the core.

h) ***Delay due to waveguide dispersion***

Time delay due to waveguide dispersion is given below.

$$T_{WGD}(i,j) = \frac{L(i,j) \times \eta_2 \times \Delta \times \nabla\lambda}{C \times \lambda} \times V \frac{d^2(b(V))}{dV^2} \quad [3.8]$$

Where $\nabla\lambda$ is the spectral width of light source.

Δ is given as

$$\Delta = \frac{\eta_1 - \eta_2}{\eta_1}$$

b(V) is a function of V and can be expressed as

$$b(V) = \frac{1-(1+\sqrt{2})^2}{\sqrt{1+(4+V^4)}} \quad [3.9]$$

3.2.1.4 TOTAL DELAY COMPUTATION

Total delay of the fiber link (i, j) can be expressed as

$$T_{total}(i,j) = \sqrt{T_{PMD}(i,j)^2 + T_{CD}(i,j)^2 + T_{MD}(i,j)^2 + T_{WGD}(i,j)^2} \quad [3.10]$$

Total delay for the light path with source destination pair *(s, d)* can be calculated as

$$T_{total}(s,d) = L(s,d) \times T_{total}(i,j) \quad [3.11]$$

3.2.1.5 DISPERSION PENALTY COMPUTATION

Dispersion penalty for light path can expressed as

$$P_D(s,d) = C \times \frac{BR(s,d)^2}{BW(s,d)^2} \quad [3.12]$$

Where C is a constant taken as 0.5, $BW(S,D)$ is the bandwidth of the light path and can be computed from equation [3.2] already given.

Q –Factor or Dispersion penalty can be expressed in dB as

$$Q - Factor = D_P(dB) = 10\ logP_D \quad [3.13]$$

Required Dispersion Penalty for any path is less than or equal to 2 dB

Bandwidth, delay and bit rate are the important factors for computing dispersion penalty.

Dispersion penalty less than 2 dB are considered for light path provisioning.

3.2.3 Blocking Probability Computation

Assume *TNCR (s, d)* is the aggregate number of association asked for a source (s) and destination (d), *TNCB (s, d)* is the aggregate number of association blocked, then the blocking probability *BP(s, d)* can be characterized [30] as takes after.

$$BP(s,d) = \frac{TNCB(s,d)}{TNCR(s,d)} \quad [3.14]$$

3.3 ALGORITHM AND FLOWCHART

As we stated before that the required Dispersion Penalty for any path is less than or equal to 2 dB so we are considering those paths for light path connection.

$$D_P(s,d) \leq 2\ dB \quad [3.15]$$

There are two cases in which the connection request can be blocked are

Case 1:

$$D_P(s,d) > 2\ dB \quad [3.16]$$

Case 2:

$$\lambda(s,d) = 0 \quad [3.17]$$

In the proposed algorithm, we have computed all possible paths and among them paths providing dispersion penalty less than or equal to 2 dB is considered for light path provisioning. Here Dispersion penalty is considered as the Quality factor and all the connections are established ensuring minimum received power at the receiver side.

The main steps in the algorithm are given below:

STEP 1: Compute all possible path matrixes and the dispersion penalty matrix for the same.

STEP 2: Check the condition [3.15] from the dispersion penalty matrix, if it satisfies check the availability of wavelength. If wavelength is available, establish the connection. If wavelength is not available, then check for the condition [3.15] again for next paths in the matrix.

STEP 3: If condition is not satisfied, go for the other paths in the matrix, if no path satisfying the condition, connection request is blocked. The algorithm can be easily explained with the help of flowchart given below Fig 3.3 Flowchart

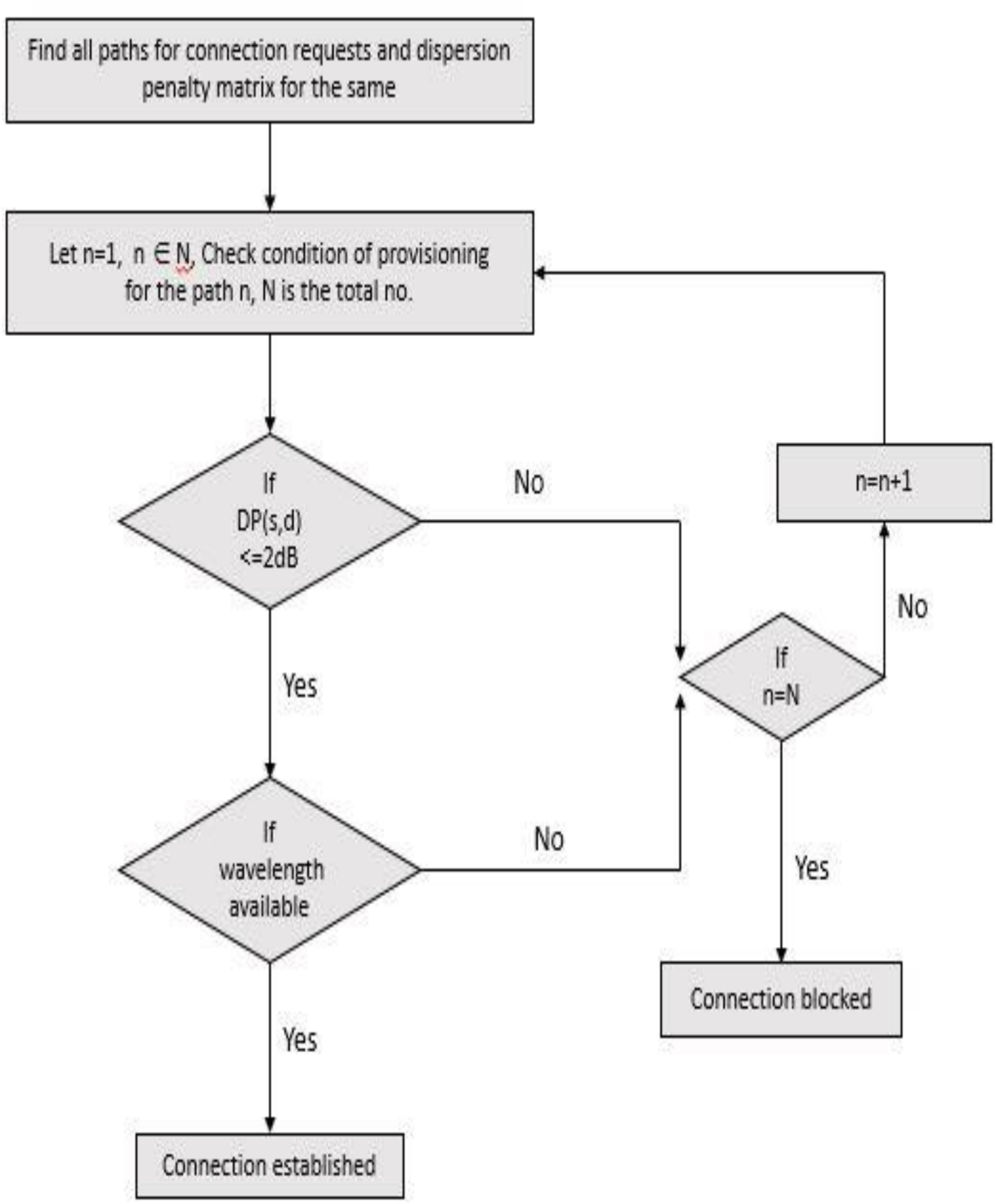

Fig 1.3 Flowchart

Chapter 4

SIMULATION RESULTS

A. Simulation Results

First we done simulation for Quality of Service (Qos) for light path provisioning. In that we have computed Bandwidth associated with each path, Time delay for each path and then Q-factor in percentage for a given network model. All this simulation is done using MATLAB. Results are divided in two categories

1. Quality of service (Dispersion penalty)
2. Blocking Probability

4.1. Network Model

For analyzing and computing the light path provisioning the network model is given in fig 4.1.1. The network model consists of 10 routing nodes and 16 connecting links.

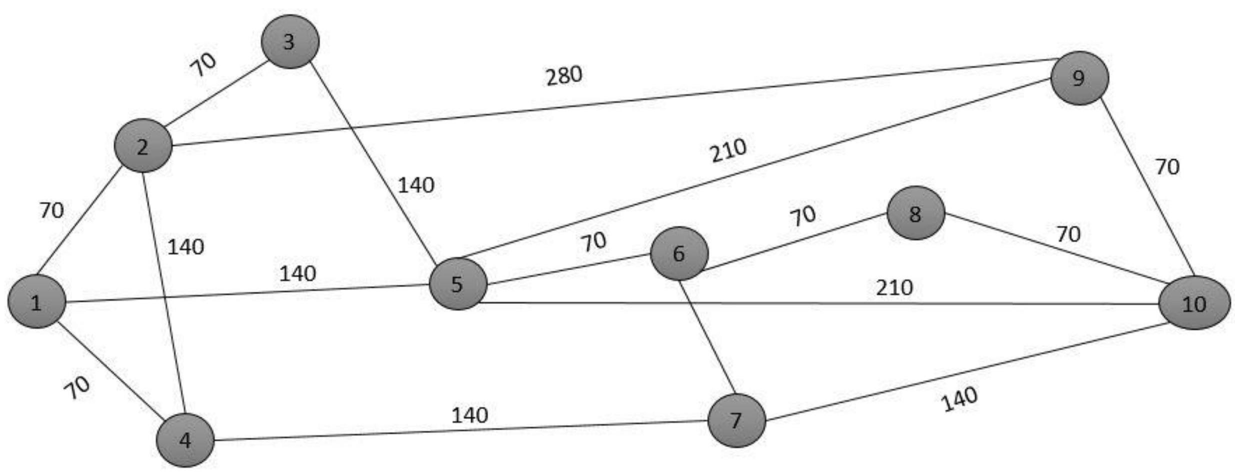

Fig 4.1.1. Network Model (all distances are in kilometers)

In this simulation, we have assumed that all the connection requests have to be establishing simultaneously defined dynamic traffic model. The network model given in fig 4.1.1 having all the distances in kilometers. In our simulation work, there are few pre-defined parameters related to various dispersions in fiber, which are described in Table 4.1.2

Table 4.1.2 Simulation Parameters

Parameter	value
ε , pulse spreading ratio	.115 (for 1dB), .182 for 2 dB
σ, pulse broadening factor	0.1
PMD coefficient(ps/√km)	0.5
CD coefficient (ps/nm-km)	2.7
MD coefficient (ps/km)	18
WGD coefficient (ps/ km)	2
λ, Wavelength(nm)	1300-1600

4.2 RESULTS OF BAND WIDTH, DELAY AND Q-FACTOR COMPUTATION

We have assumed that the network under consideration is a high speed WDM network. Consider the source destination pair (1, 7). We have computed all possible paths between the source and destination. The bandwidth, delay and Q-factor associated with each path are calculated and plotted as shown in Fig. 4.2.1, Fig. 4.2.2 and Fig. 4.2.3.

Bandwidth associated with each path is calculated using the equations [3] and [4]. For computing the bandwidth for a light path, first we have computed the bandwidth for each link in the light path and then the minimum value is taken as the resulting bandwidth of the light path. Likewise bandwidth is computed for all possible paths for source destination pair (1, 7).

Bandwidth v light path index number is shown in Fig 4.2.1. The light path which gives the maximum bandwidth, the optimal path. Here light paths containing minimum distance links gives the maximum bandwidth and the paths with maximum distance links gives the minimum bandwidth(Bandwidth is inversely proportional to square root of length).

Using equations [6-13] we have calculated the total time delay associated with each path for source destination pair (1, 7). From the Fig 4.2.2 we can understand that the light paths having minimum length links will give rise to minimum delay (as delay is directly proportional to square root of distance). Path with index number 3 is the optimal path which is associated with minimum delay. By analyzing Fig. 4.2.1 and Fig. 4.2.2, it is clear that the path with minimum delay provides maximum bandwidth also.

For simulating Q-Factor, we have used equation [16] and the results are plotted in Fig. 4.2.3. Q-Factor is the resultant of bandwidth and time delay. The light path with maximum bandwidth and minimum delay will be the path with maximum Q-Factor. The Q-factor value is decided as per the client's requirement and we have to select the path which satisfies the value of Q-factor in which client's requirement is fulfilled. For source destination pair (1, 7), light path with index number 3 is the optimal path.

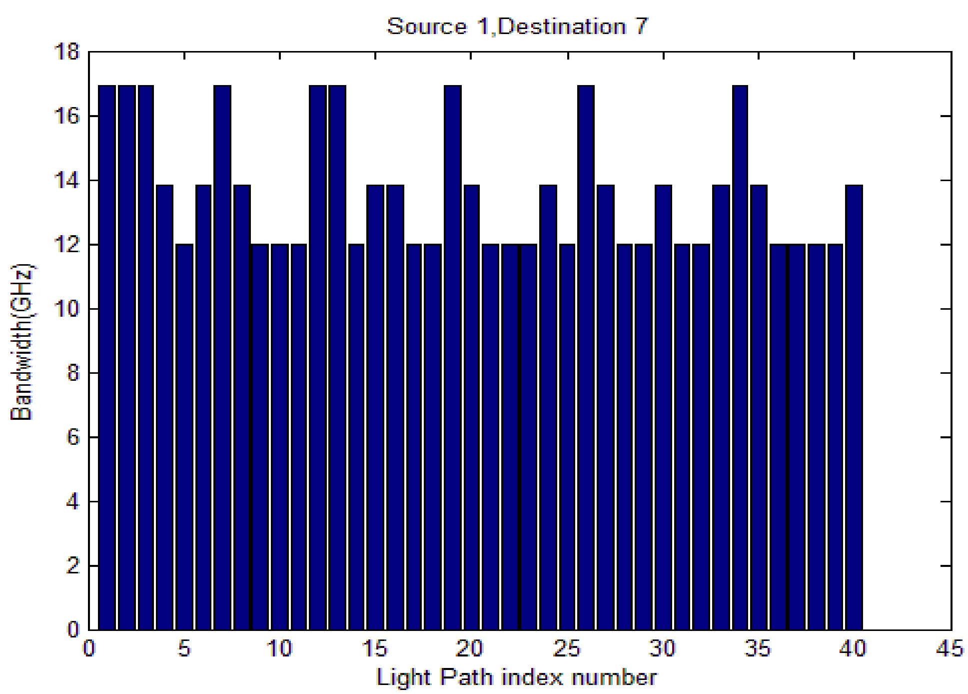

Fig 4.2.1: Bandwidth plots of all light paths of source destination pair (1, 7)

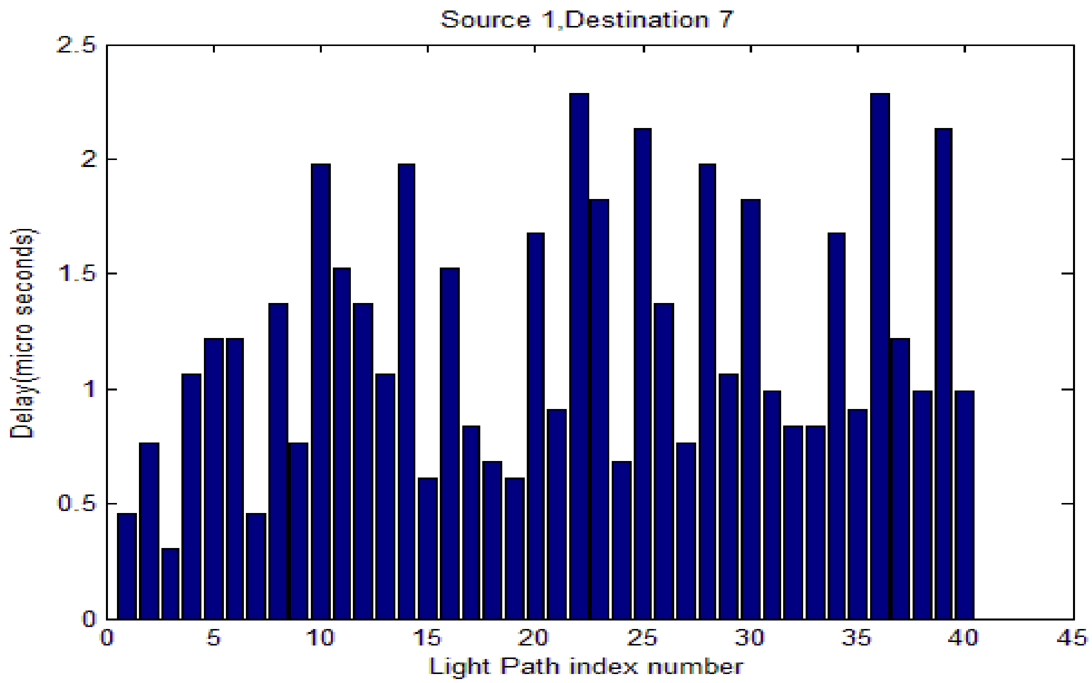

Fig. 4.2.2: Delay plots of all light paths of source destination pair (1, 7)

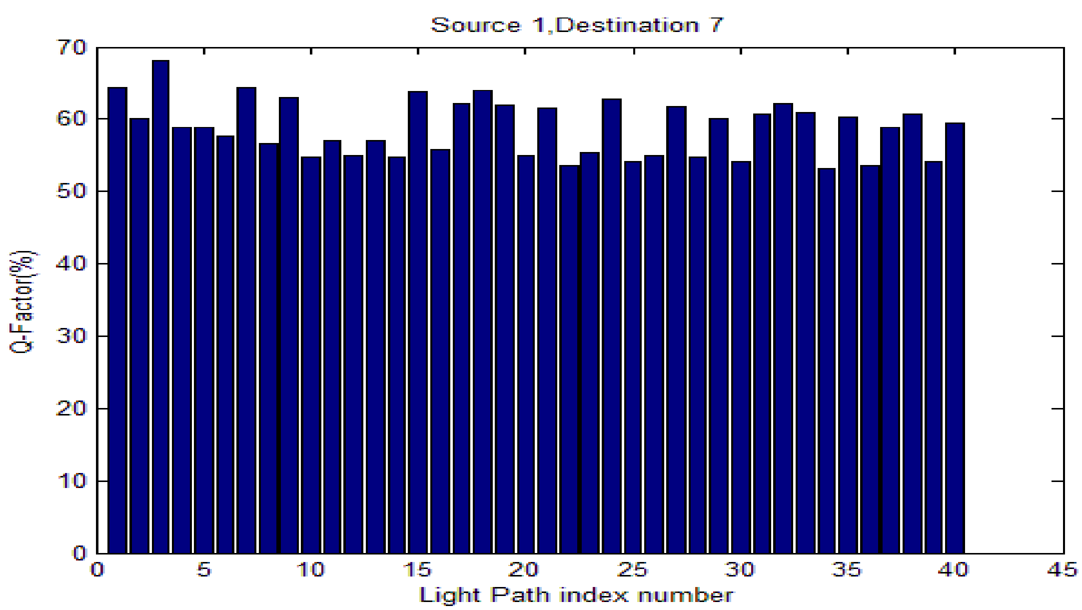

Fig 4.2.3: Q-Factor plots of all light paths of source destination pair (1, 7)

The all three figures of Bandwidth, Delay and Q-factor given in fig 4.2.1, fig 4.2.2, fig 4.2.3 shows total 41 paths which are avalaible in the soure destination pair (1,7). There will be different number of paths for different pairs that is going to be discussed in next section.

4.3 PLOTS OF ALL POSSIBLE PATHS, DISJOINT PATHS, SHORTEST PATH

For any pair (source to destination), there are particular no. of paths those are called all possible paths. For light path provisioning, these all paths may or may not satisfy the conditions to be required for transmission but few of them definitely satisfies the required conditions that we are going to check in our next section. Disjoint paths and shortest path are the subset of all possible paths. Each network has disjoint paths between source node and destination node. What is mean by disjoint path?

The paths having no common edge (link) between them called as edge-disjoint paths. Let us understand this disjoint paths between pair (1, 5), (3, 8). Reference is taken from Fig 4.1.1

THE DISJOINT PATHS IN SORTED ORDER FOR PAIR (1, 5)

1	5	0	0	0	0	0	0	0	0
1	2	3	5	0	0	0	0	0	0
1	4	7	6	5	0	0	0	0	0

THE DISJOINT PATHS IN SORTED ORDER FOR PAIR (3, 8)

3	5	6	8	0	0	0	0	0	0
3	2	9	10	8	0	0	0	0	0

From the above results it is clear that there is no any node is repeated amongst the paths except source node and destination node. Shortest path is nothing but the path with minimum distance between the source node and destination node.

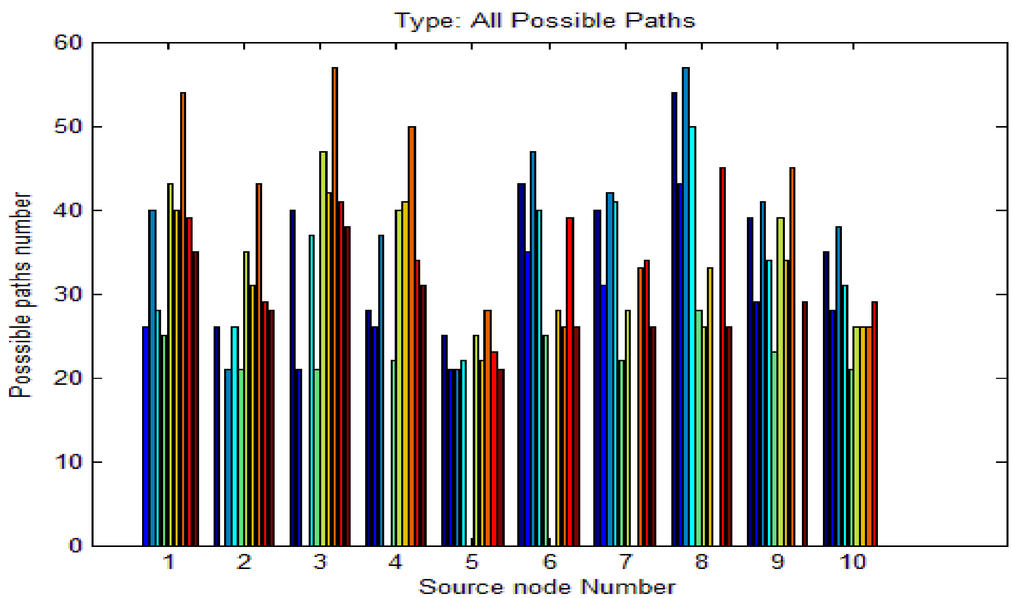

Fig 4.3.1 All possible paths plot for source destination node pair(s,d)

Table 4.3.1 All Possible Paths for pair(s, d)

Source Destination	1	2	3	4	5	6	7	8	9	10
1	0	26	40	28	25	43	40	54	39	35
2	26	0	21	26	21	35	31	43	29	28
3	40	21	0	37	21	47	42	57	41	38
4	28	26	37	0	22	40	41	50	34	31
5	25	21	21	22	0	25	22	28	23	21
6	43	35	47	40	25	0	28	26	39	26
7	40	31	42	41	22	28	0	33	34	26
8	54	43	57	50	28	26	33	0	45	26
9	39	29	41	34	23	39	34	45	0	29
10	35	28	38	31	21	26	26	26	29	0

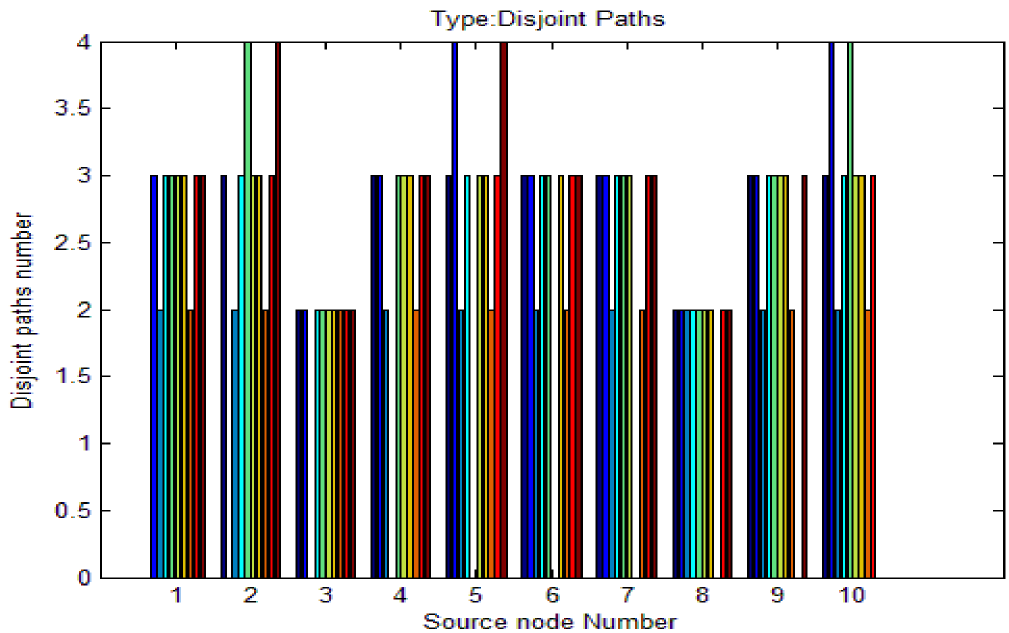

Fig 4.3.2 Disjoint paths plot for source destination node pair(s,d)

Table 4.3.2 Disjoint Paths For Pair (s, d)

Source Destination	1	2	3	4	5	6	7	8	9	10
1	0	3	2	3	3	3	3	2	3	3
2	3	0	2	3	4	3	3	2	3	4
3	2	2	0	2	2	2	2	2	2	2
4	3	3	2	0	3	3	3	2	3	3
5	3	4	2	3	0	3	3	2	3	4
6	3	3	2	3	3	0	3	2	3	3
7	3	3	2	3	3	3	0	2	3	3
8	2	2	2	2	2	2	2	0	2	2
9	3	3	2	3	3	3	3	2	0	3
10	3	4	2	3	4	3	3	2	3	0

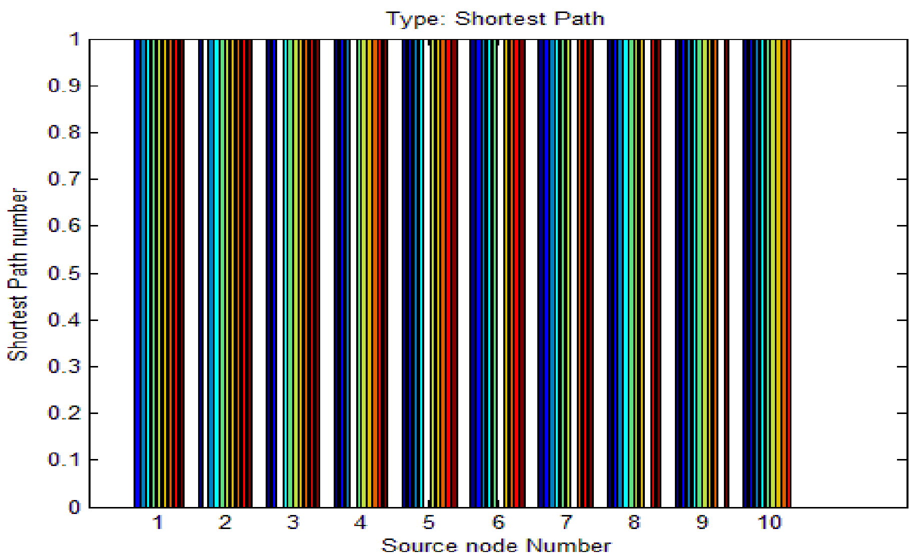

Fig 4.3.2 Shortest path plot for source destination node pair(s,d)

About the shortest path, there is only one shortest path for any pair as shown in Fig 4.3.2. The shortest path may or may not satisfies the requirements for light path provisioning.

4.4 DISPERSION PENALTY COMPUTATION RESULTS

The network model used for simulation is same as given in Fig 4.1.1. Assume that we have a connection request with *(s, d)* pair (4, 7). For this calculation, we have taken all possible routes available between source and destination in the given network model. For computing dispersion penalty values of this entire path, first we have to calculate the bandwidth and bit rate associated with each of the path. In the given network model, we have got 41 possible paths between (4, 7) and the bandwidth associated with this paths is shown in the form of bar graph in Fig 4.2.1. Bandwidth is given in GHz. We have plotted the dispersion penalties for all the possible paths available in the source and destination pair (4,7) shown in fig 4.4.1 Out of 41 paths in the pair (4, 7) there are 27 paths with dispersion penalty more than 2 db. These paths are not used for routing.

The paths with required dispersion penalty are shown in Fig. 4.4.2. It contains 14 paths which are used for the routing purpose. While calculating dispersion penalty we have considered only one wavelength (1230 nm) as wavelength only shows effect in delay due to chromatic dispersion (equation [3.5]).If we are considering more wavelengths the overall effect on dispersion penalty will be same.

Similarly, we have computed the dispersion penalty plots for all possible case and required dispersion penalty plots among those all possible paths case for the pairs(2,8) and pair(5,9)

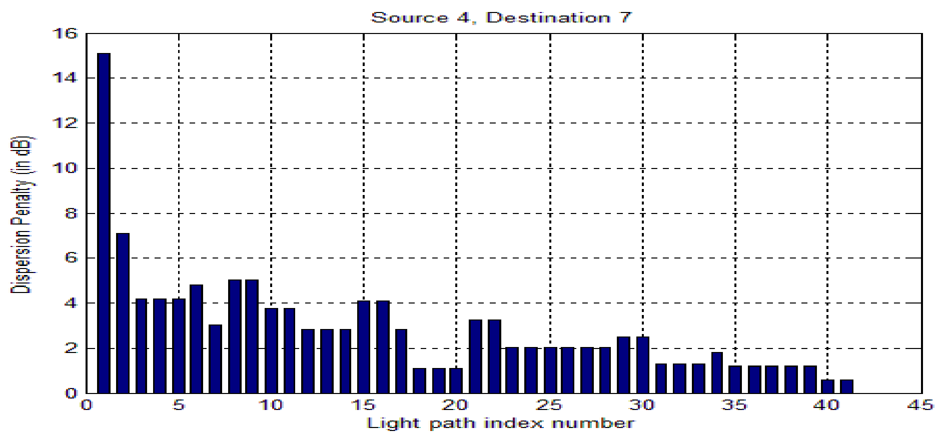

Fig 4.4.1 Dispersion penalty plot for pair (4,7)

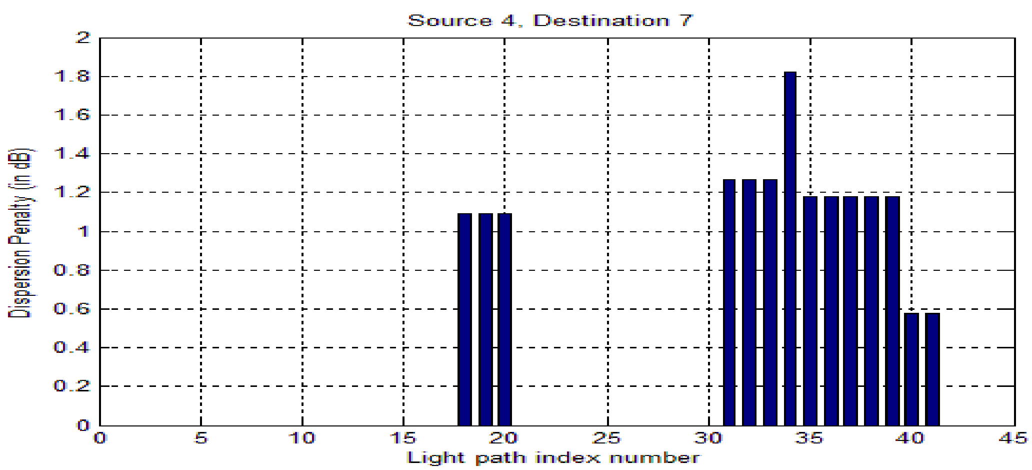

Fig 4.4.2 Required Dispersion penalty plot for pair (4,7)

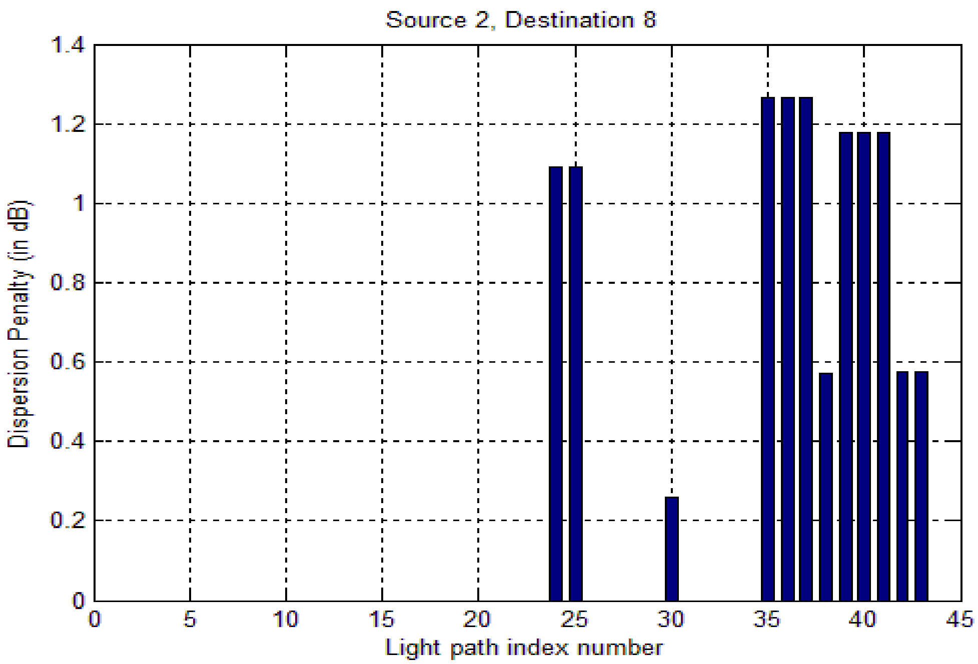

Fig 4.4.3 Dispersion penalty plot for pair (2, 8)

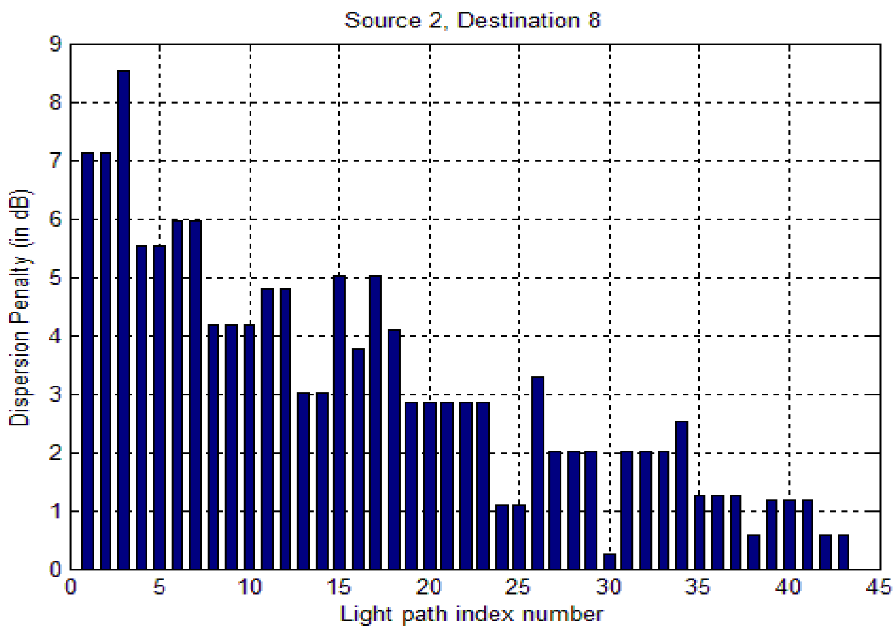

Fig 4.4.4 Required Dispersion penalty plot for pair (2, 8)

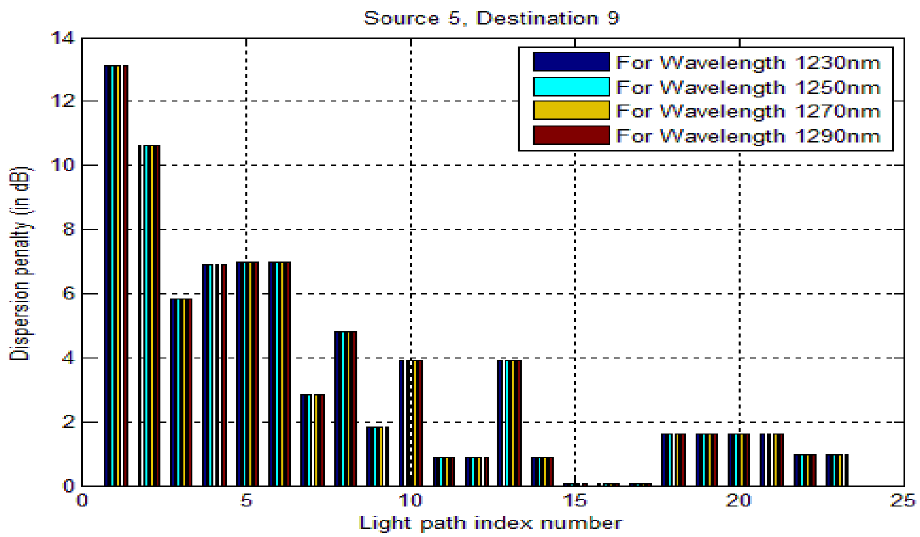

Fig 4.4.5 Dispersion penalty plot for pair (5, 9)

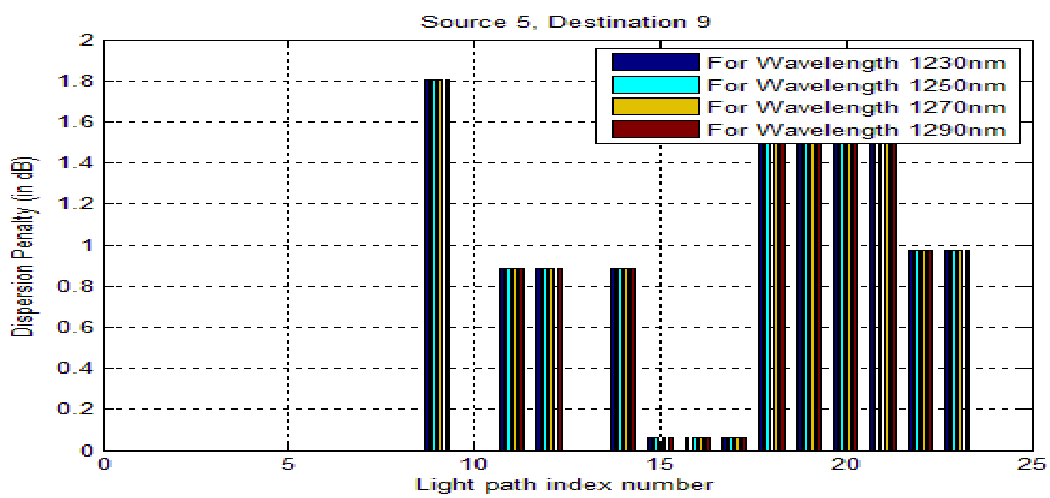

Fig 4.4.6 Required Dispersion penalty plot for pair (5, 9)

In the last two figures (Fig 4.4.3 and Fig 4.4.4) we have plotted dispersion penalty plot for all possible paths and required dispersion penalty plot for pair (5, 9) respectively. Here we have taken four wavelengths (1230 nm, 1250 nm, 1270 nm, 1290 nm) but in previous case we have computed the dispersion penalties by considering only one wavelength(1230 nm) for pairs(4, 7) and pair(2,8). From Fig 4.4.3, it is clearly seen that there is no change in dispersion penalty values as we changed the wavelength values. The wavelength only effects in delay calculation due to chromatic dispersion (as stated in equation [3.5]),

Table 4.4.1 Dispersion penalty values for pair (5, 9)

Path number	Dispersion penalty for pair(5, 9) with multiple wavelengths		
	1230 nm	1250 nm	1270 nm
1	13.1073	13.1073	13.1073
2	10.6085	10.6085	10.6085
3	5.8372	5.8372	5.8372
4	6.9093	6.9093	6.9093
5	6.9971	6.9971	6.9971
6	6.9971	6.9971	6.9971
7	2.826	2.826	2.826
8	4.8142	4.8142	4.8142
9	**1.8039**	**1.8039**	**1.8039**
10	3.8990	3.8990	3.8990
11	**0.8887**	**0.8887**	**0.8887**
12	**0.8887**	**0.8887**	**0.8887**
13	3.8990	3.8990	3.8990
14	**0.8887**	**0.8887**	**0.8887**
15	**0.0608**	**0.0608**	**0.0608**
16	**0.0608**	**0.0608**	**0.0608**
17	**0.0608**	**0.0608**	**0.0608**
18	**1.6201**	**1.6201**	**1.6201**
19	**1.6201**	**1.6201**	**1.6201**
20	**1.6201**	**1.6201**	**1.6201**
21	**1.6201**	**1.6201**	**1.6201**
22	**0.9764**	**0.9764**	**0.9764**
23	**0.9764**	**0.9764**	**0.9764**

so the overall effect get neglected in the computation of dispersion penalty due to variation in wavelength.

In the table 4.4.1 we have plotted the values of dispersion penalty for all possible paths of source destination pair (5, 9) with three different wavelengths 1230 nm, 1250 nm, 1270 nm respectively and we have observed that the dispersion penalty values are nearly equal for all the cases. The paths with required dispersion penalty (less than or equal to 2 dB) are highlighted in the given table 4.4.1. The paths can only be used for light path provisioning.

4.5 BLOCKING PROBABILITY COMPUTATION RESULTS

Blocking probability is computed on the basis of number of connection accepted over the number of connection requested for a particular pair(s, d) in all cases like all possible paths, disjoint paths and shortest path (equation [3.14]). Wavelength number plays the key role in the blocking probability calculation. We have computed blocking probability for pair (5, 9) in all three cases (all possible, shortest and disjoint). Here we observed the blocking probability is high for shortest path case, moderate for disjoint path case and it is very less for all possible path cases shown in Fig 4.5.1.

Number of connection established (for all possible paths) = 30

Number of connection established (for shortest path) = 3

Number of connection established (for disjoint paths) = 9

Total number of connection requested = [1 15 25 50 100 150 200 250]

$$Blocking\ probability = \frac{number\ of\ connections\ blocked}{number\ of\ connection\ requested}$$

$$Blocking\ probability = \frac{number\ of\ connection\ requested - number\ of\ connection\ established}{number\ of\ connection\ requested} \times 100$$

Blocking probability =

0	0	0	40.0000	70.0000	80.0000	85.0000	88.0000
0	80.0000	88.0000	94.0000	97.0000	98.0000	98.5000	98.8000
0	40.0000	64.0000	82.0000	91.0000	94.0000	95.5000	96.4000

The first row gives the values for all possible paths case and the second row gives the values for shortest path case and third row shows the values for disjoint path case. The each column represents the values for the connection request 1,15,25,50,100,150,200,250 respectively. The blocking probability values are going on decreasing in a row as the number of connection request increasing. This is obvious as the number of connection request increases means the load on the network increases so the traffic increases. This results in decrease of blocking probability because the number of connection established is fix in all 8 connection requests for a fixed wavelength number. Here in this case we assumed only three wavelengths.

In Fig 4.5.2 we have plotted blocking probability in percentage for five pairs like (1, 7), (2, 8), (3, 10), (4, 10), (5, 9) verses number of connection request and they are shown in five different colors.

For first few number of connection request, the blocking probability percentage is less and it goes on increases as the number of connection request increases for all pairs.

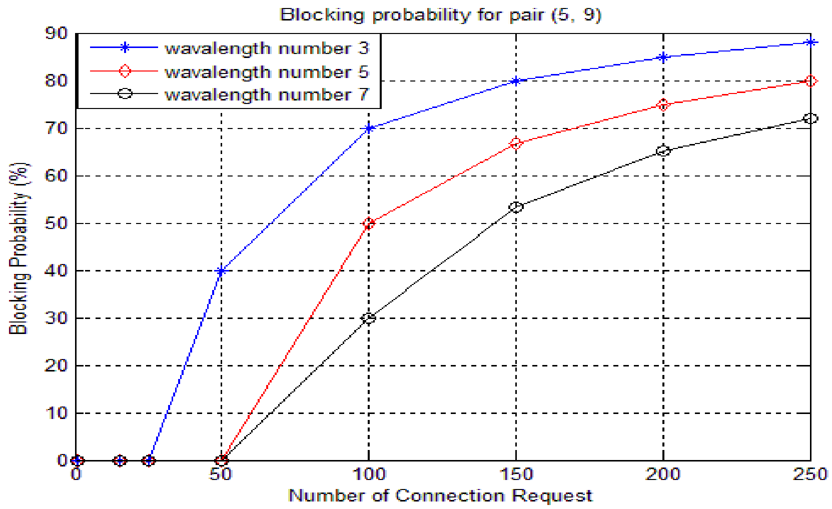

Fig 4.5.1 Blocking Probability plot for pair (5, 9) with 3 wavelengths

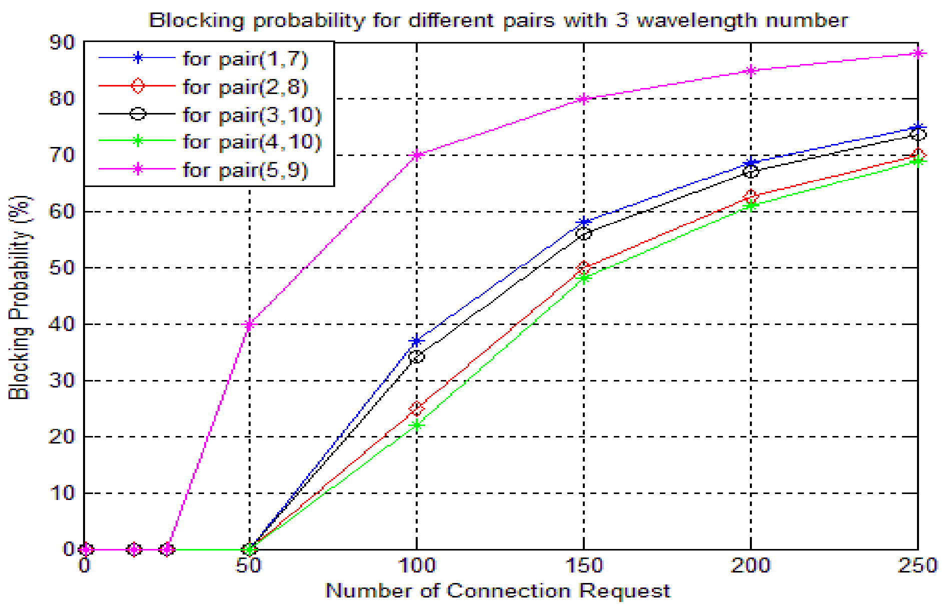

Fig 4.5.2 Blocking Probability plot for different pairs in all possible paths case

We have assumed three different wavelength numbers for our blocking probability computation to study the effect of wavelength number on it. As we increasing the wavelength number, it is been observed that blocking probability gently decreasing. Availability of connection establishment will be more for higher wavelength numbers. The blocking probability verses number of connection request for three different wavelength numbers (3, 5, 7) for a pair (5, 9) are plotted in Fig 4.5.3 as given below. We considered only all possible paths case.

Number of connection established (for wavelength number 3) = 30

Number of connection established (for wavelength number 5) = 50

Number of connection established (for wavelength number 7) = 70

Total number of connection requested = [1 15 25 50 100 150 200 250]

Blocking probability=

0	0	0	40.0000	70.0000	80.0000	85.0000	88.0000
0	0	0	0	50.0000	66.6667	75.0000	80.0000
0	0	0	0	30.0000	53.3333	65.0000	72.0000

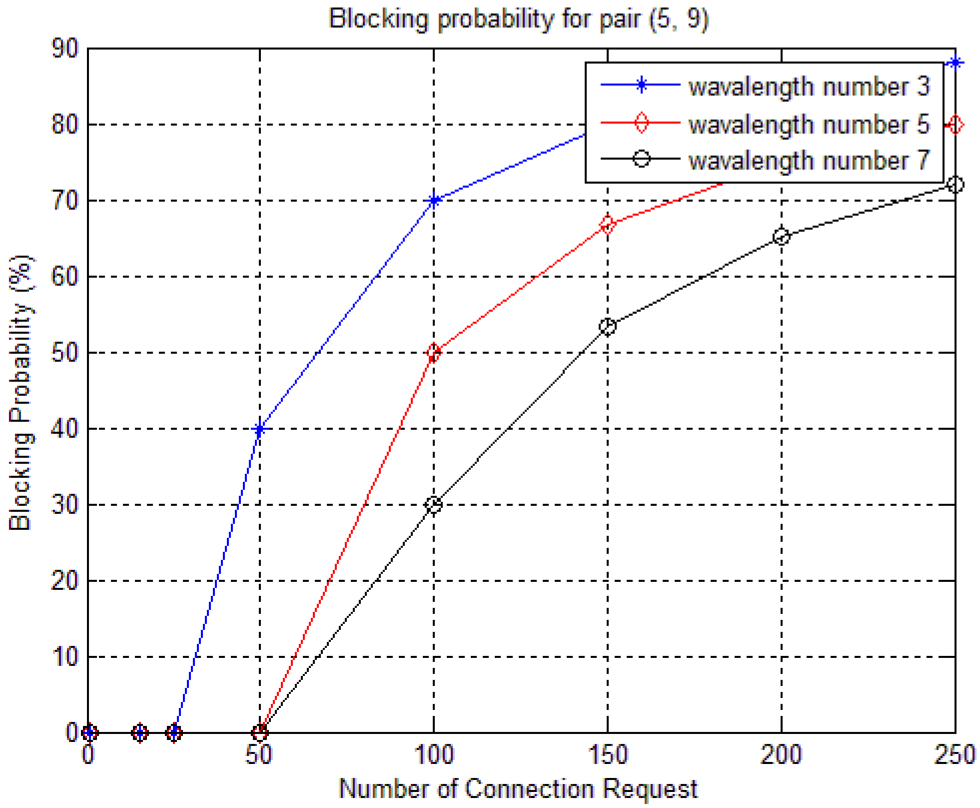

FIG 4.5.3 Blocking Probability in three different wavelength numbers

Chapter 5

CONCLUSION

5.1 CONCLUSION

In this work, we have done a study on physical layer impairments and their effects on optical fiber transmission. Optical fiber transmission is badly affected by two things one is attenuation and other is dispersion, we mainly focused on dispersion related effects on it because attenuation can be controlled by using proper amplifiers while dispersion is the internal property of fiber and cannot be controlled by external devices. We concentrated on dispersion penalty for the WDM link quality which we have considered as $2dB$. This work contains the computation of dispersion penalty and blocking probability. The dispersion penalty completely depends upon the different types of delays, bandwidth and bitrate. Dispersion penalty is being key factor for determining the number of connections established for a WDM link as we observed. We followed the algorithm for computing blocking probability. By using constant wavelength number we got better results in all possible paths case which gives less blocking probability than in case of disjoint paths and shortest path. Next we have gone for the varying wavelength number effects on blocking probability and we observed that as wavelength number increases the blocking probability continuously decreases.

5.2 FUTURE WORK

This work can be extended and can be computed with different blocking probability calculation methods such as Erlang method. The combination of different method will improve the performance over this WDM link.

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