DESIGN OF QoS AWARE LIGHT PATH PROVISIONING MECHANISMS IN WDM NETWORK

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Communication and Signal Processing

by

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Roll No: 210EC4082

Department of Electronics & Communication Engineering

National Institute of Technology

Rourkela

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CERTIFICATE

This is to certify that the thesis entitled, "DESIGN OF QoS AWARE LIGHT PATH PROVISIONING MECHANISMS IN WDM NETWORK"submitted by DHANYA V V (210EC4082) in partial fulfilment of the requirements for the award of Master of Technology degree in Electronics and Communication Engineering with specialization in "Communication and Signal Processing" at National Institute of Technology, Rourkela (Deemed University) and is an authentic work by her under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any Degree or Diploma.

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ABSTRACT

In this paper, we explore the issue of connection provisioning and performance analysis in WDM network ensuring the QoS requirement of the connection requests from the client in the network In optical networks. While designing WDM system, we must consider the physical layer impairments (PLIs) incurred by non-ideal optical transmission media, accumulates along the optical path. For high transmission speed Dispersion become a considerable degradation factor and in this work we have concentrated on the effects of dispersion on fiber design parameters such as bandwidth, delay and bit rate. The overall effect of dispersion is described in terms of Q-Factor and dispersion penalty. In this project,we worked on light path provisioning mechanism based on Q-Factor and dispersion penalty. Each path is provisioned satisfying the requirement of client in the network model. This work discusses the improvement in blocking probably for incoming requests while performing routing by proposed algorithm and the traditional shortest path algorithm.

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ACRONYMS

PLI – Physical Layer Impairments

WDM – Wavelength Division Multiplexing

DWDM-Dense Wavelength Division Multiplexing

Q-Factor- Quality Factor

CSN-Connection Serial Number

DJP-Disjoint Path

S-Source node

D-Destination node

STP-Shortest path

SP-Selected Path

QF_R- Required Q-Factor

QF_C-Computed Q-Factor

QF_{SP}-Selected Path Q-Factor

ASE – Amplifier Spontaneous Emission

CD-Chromatic Dispersion

PMD-polarization Mode Dispersion

OSNR- Optical Signal to Noise Ratio

CRS- Connection Request Status

NRSLP-No Requirement Satisfied Light Path

NFLP-No Free light Path

BP- Blocking Probability

Chapter 1

INTRODUCTION

1.1. OVERVIEW

The current research interest mostly concentrated on QoS satisfied connection provisioning in all over the network. WDM is the multiplexing technique which exploits the huge bandwidth capacity of the fiber by the simultaneous transmission of packets of data over multiple wavelength channels. WDM/DWDM network with QoS assurance is the promising technique for the next generation optical communication system. Quality-of-service (QoS) provisioning of light paths in WDM network describes the routing models which facilitate the signal quality guaranteed transmission over the optical fiber for long distance network.

QoS can be defined as the cumulative effect of network performance which determines the level of satisfaction of the clientin the network under consideration [1].

The concern about the ability of the network to provide the minimum signal quality guaranteed transmission resulted in the consideration of QoS parameters such as bandwidth, delay, crosstalk, jitter etc. which are the prominent effect at high speed transmission system. In this work, we have proposed algorithms assuring optimum blocking of connection requests for Quality-of-service transmission over WDM network. In the case of both single mode and multi-mode fiber, degradation in signal strength due to the dispersion is considerable when we are going for high speed transmission. Here our consideration is mainly on various dispersion effects on the fiber which limits the bit rate and length of the fiber due to the introduction of pulse dispersion of the transmitted signals.

In this work, Quality service of the network is closely related to the band width, 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 is completely depending 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. Performance of the algorithms is evaluated by computing the possibility of blocking for incoming connection requests.

1.2. LITERATURE REVIEW

The recent research challenges in QoS based routing is described in [1]. This paper surveys the most important issues in terms of QoS routing. And also briefly presents some of the proposals and ongoing research efforts on this area. Similarly a delay constraintmulticasting algorithm is given [2].Here the main goal is to allocate a delay constraint multicast tree in WDM network. A QoS based algorithm for optical burst switch scheduling in DWDM network is studied in paper [3]. A new optical burst switching protocol for QoS satisfied light path provisioning is proposed in the paper [4]. In the paper [5], a new QoS provisioning approach which offers loss free transmission inside the network is described. The papers [6-11] analyzedthe 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]. Another issues reported in [11], which says how bandwidth broker works centrally and provides QoS to the clients. The paper [12, 21] says about traffic based guaranteed QoS which is fully wavelength and number of applicant dependent. The papers [13-16] has studied the various multicasting issues in WDM network and proposed different algorithms for efficient multicasting in the 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 blocking probability estimation for WDM network is obtained from the paper [20]. But none of this paper concentrated on the bandwidth and delay based Q-Factor calculation and the light path connection provisioning mechanism based on the Q-Factor requirement of client. This work develops a new QoS guaranteed routing algorithm that ensures better performance.

1.3. PROPOSED WORK

In our work, a new algorithm for light path provisioning for high speed WDM network is proposed considering the effect of dispersion in fiber which is a prominent effect at high speed WDM network. In the case of non-ideal fiber, light path provisioning without considering the physical layer impairment does not satisfy the signal quality guaranteed transmission. In the proposed method for light path provisioning, we completely concentrated on the dispersion effects in fiber and the delay introduced due to the effect of various dispersion effects.

1.3.1. Physical Layer Impairments inOptical Fiber(PLI)

Thefiber impairments may be linear or non-linear [22-25]. Some of the important linear impairments in non-ideal fiber are attenuation, component insertion loss, amplifier spontaneous emission (ASE) noise, dispersion and cross talk. Main non-linear impairments are four wave mixing, self-phase modulation, cross phase modulation, scattering etc. The linear impairments such as dispersion and cross talk, degrades the channel length and bit rate. These are completely static in nature. But non-linear impairments are dynamic and results in degradation in signal strength and interference among different modes in fiber. Signal attenuation or signal loss is one of the most important properties of an optical fiber which determines the spacing between repeaters and amplifiers along the fiber length between transmitter and receiver. Attenuation results in the amplitude degradation of transmitted signal. Distortion is of important consideration which causes pulse spreading and hence overlapping between adjacent pulses, hence at the receiver side it become difficult to differentiate pulses and bit error will increases. Attenuation is the main parameter responsible for the degradation of optical power throughout the fiber. Distortion in fiber is a consequence of intermodal dispersion and intermodal delay effects.

a) Dispersion in fiber:

In this work, we considered the various types of dispersion in fiber. 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. 1. There are mainly two classes of dispersion- Intermodal and chromatic dispersion. Different varieties of dispersion we have considered are polarization mode dispersion (PMD), chromatic dispersion (CD), modal dispersion (MD) and waveguide dispersion (WGD).

Polarization mode dispersion: PMD is mainly due to the geometric irregularities present along the optical fiber. Bending, twisting or pinching of the fiber also causes polarization mode dispersion. These irregularities cause different polarizations of the optical signal to travel with different group velocities resulting in pulse spread in the frequency domain, known as PMD. 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 $T_{PMD} = D_{PMD} *\sqrt{L}$, 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. Thenormal PMD value range is in between0.01-10 ps/√km [22-25]. It becomes amajor limiting factor for higher bit rate long distance WDM systems.

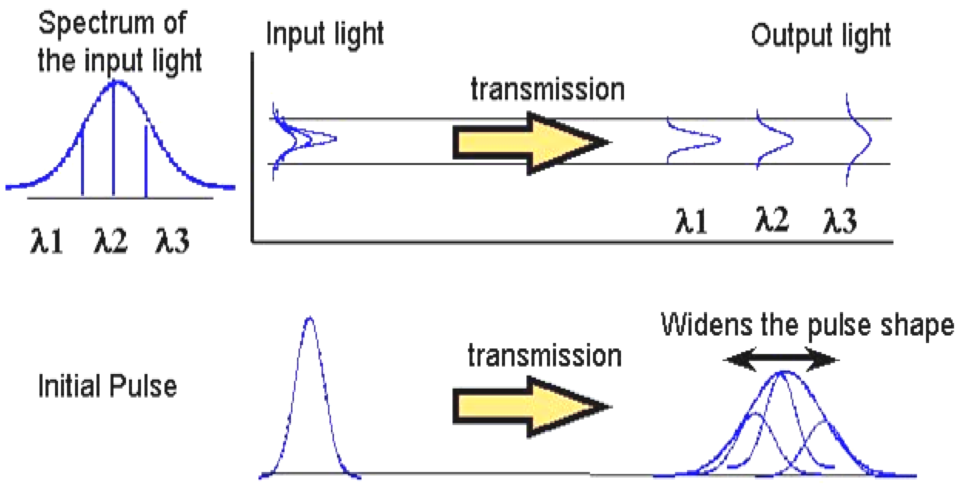

Fig. 1.1: Effect of dispersion in pulse broadening

Chromatic Dispersion (CD): Intramodal dispersion or chromatic dispersion is pulse spreading that occurs within a single mode fiber. The spreading arises because of the finite spectral emission width of the optical source. The pulse spreading of an optical signal is caused by the various spectral components traveling at their own different velocities and is also known group velocity dispersion. 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 $T_{CD}=D_{CD}*\lambda*L$ 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].

Modal dispersion: Model dispersion becomes predominantin multimode fibers.Different modes in the fiber take different path and hence different length while travelling down the fiber. Another factor is that in multimode fiber each mode may be associated with different propagation constant.Model dispersion will result in the time delay between different modes and hence pulse spreading will occurs. In the case of graded index fiber the modal dispersion is less compared to step index fiber of the same size. Effectivemodal dispersion values in graded-index multimode fiber is in the range of 0.2ns*km-1 if we are going for laser light sources and 1.0 ns*km-1 if we choose LED light sources [25].

Waveguide dispersion: Waveguide dispersion is a type of dispersion mainly due to the relationship between the physical dimensions of the waveguide and the light pulse.Single mode fiber is mainly affected due to waveguide dispersion. It is caused by the fact that some light travels, about 20% of total signal power, in the fiber cladding compared to most light travels in the fiber core.In optical fibers, this shows as the propagation constant of a mode being a function of a/λ, where $a$represents the core radius of fiber and λ for the wavelength of the optical signal. For a fiber in whichcore cladding refractive indexes are independent of wavelength, still wavelength dispersion will present in the optical fiber [42].

b) 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.

c) Self-phase modulation (SPM):

Another non-linear effect is Self-phase modulation (SPM) which is due to the interaction between light and matter. A shortlight pulse, which is travelling through a medium, introduces variation in refractive index of the fiber due to the optical Kerr effecti.e. when pulse travelling throughthe fiber, the higher intensity portions of a light pulse encounter a higher refractive index of the fiber compared with the lower intensity portions.Thisrefractive indexvariation produces a pulse phase shift, and hence a change in the pulse's frequency spectrum.SPM is an important effect in optical systems that use small, intense pulses of light, such as lasers and optical fiber communications systems. The effect is shown in Fig. 1. 2.

d) Cross phase modulation (XPM):

A nonlinear optical effect in which one wavelength of light can affect the phase of another wavelength of light through the optical Kerr effect is known as Cross-phase modulation (XPM). Here optical pulse is phase modulated by the effect of neighboring pulse amplitude. XPM causes inter-channel cross talk, amplitude and timing jitter in the fiber medium. When the number of channels is more, then the effect of XPM also increases and it degrades the system performance even more than SPM. But in fiber communication system, XPM is used as a method for addition of information to a light stream by varying the coherent optical beam phase by interacting with another pulse in a suitable non-linear medium. The effect can be understood from the Fig. 1. 2.

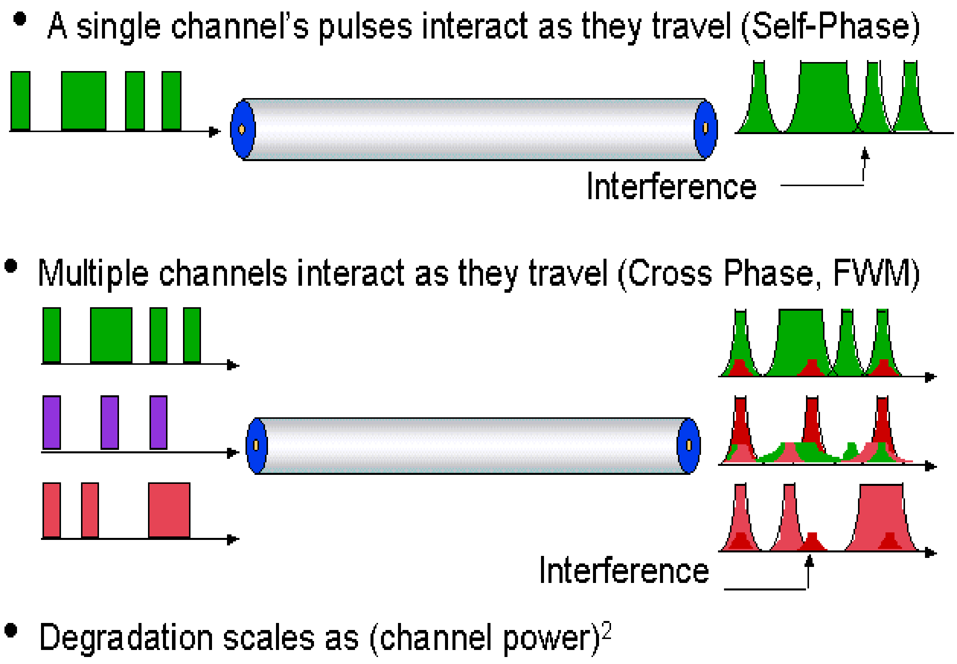

Fig. 1.2: Effect of SPM and XPM in optical pulse

e) Four wave mixing (FWM):

Four-wave mixing which is an intermodulation phenomenon in fiber optics, whereby produce two extra wavelengths are produced due to the interactions between two wavelengthsin the transmitted optical signal.i.e.,FWM is the generation of new optical waves at frequencies which are the mixing products of the two incoming signals. In any non-linear medium, three wavelengths interaction results in a fourth wavelength and is due to the scattering of incident photon. As the number of channels increases or the spacing reduces in channel, the effect of FWM becomes dominant in WDM system. This will induces cross talk between channels in the network. FWM will be more in fiber associated with chromatic dispersion.

f) Stimulated Raman scattering (SRS):

Simulated Raman scattering effect is a non-linear effect in fiber which results in the signal degradation of signal at lower wavelength. SRS causes the transfer of power from lower wavelength signal to higher wavelength levels and hence the signal to noise ration of lower wavelength signal reduces considerably. But in WDM system, SRS can be exploited as an advantage. For implementing a Distributed Raman Amplifier, we can go for suitable Raman Pumps in the optical fiber. The amplification of the signal can be achieved in fiber by associating with EDFA. The pumps are depleted and the power is transferred to the signal.

g) Stimulated Brillouin scattering:

SBS 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 higherwavelength 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.

The total impairment factors in optical medium are organized in Fig. 1. 3.

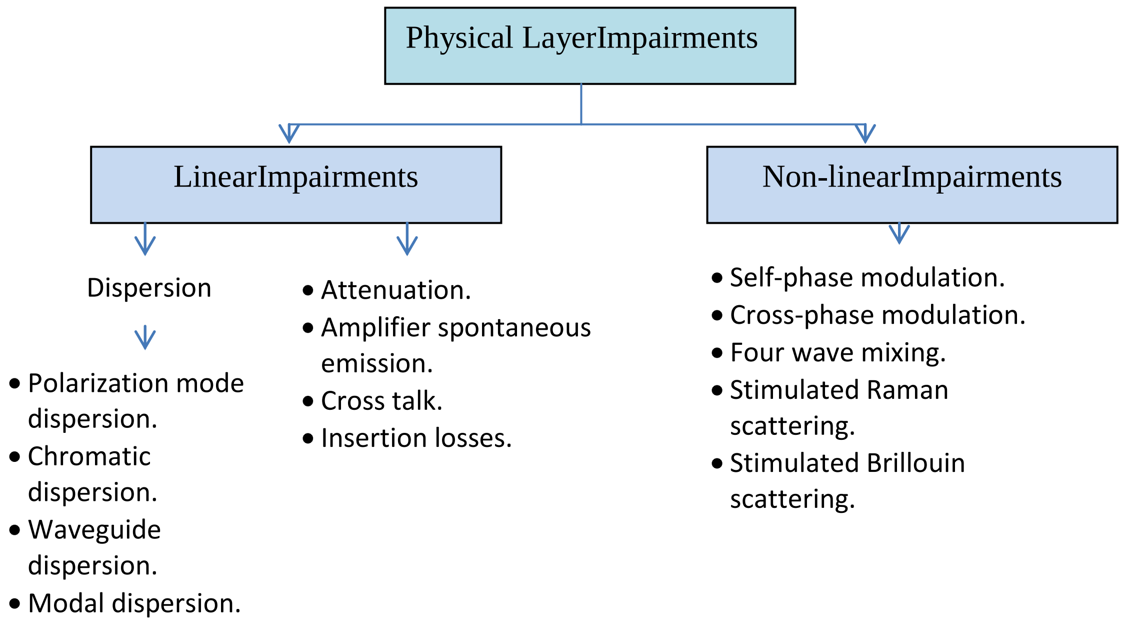

Fig. 1.3: Impairment factor effecting Optical fiber

1.4. Q-FACTOR AS THE COST OF THE WDM NETWORK

We have defined Q-Factor as the cost of the network. In the proposed algorithm, we modeled the QoS requirement considering the bandwidth for each path and delay in the fiber due to the pulse broadening due to dispersion. The main goal of the project is the data path provisioning with optimum drop offs. We define Q-factor in terms of bandwidth and delay in the fiber. The light path provisioning is done considering the Q-Factor requirement of the client in the network. In the second part of the work, the light path provisioning is done by estimating the dispersion penalty for all light paths for a particular connection request. In this case the optimum value of dispersion penalty is taken as 2 dB for light path routing. In both the cases, provisioning is done satisfying the network cost or Q-Factor requirement of client.

1.5. ORGANIZATION OF THESIS

In the coming chapters, we have explained the modeling and QoS based data path provisioning mechanism for WDM network. In the 2^{nd} chapter a general introduction about WDM network model, routing and wavelength assignment issues in the same is included. A detail description for the system design for the proposed algorithm is given in chapter 3. Chapter 4 discusses the simulation results and some conclusion is drawn in 5^{th} chapter.

Chapter 2

AN INTRODUCTION TO WDM SYSTEMS

2.1 OVERVIEW

One of the important issues in communication system today is the tremendous increase in the bandwidth requirement due to the emerging application like multimedia, video and other advanced techniques in communication in the world of communication. Wavelength Division Multiplexing (WDM) is one of the solutions for this issue since WDM technology upgrade the bandwidth capacity of the optical network without adding more fibers. In WDM network, we can establish different channels in the same optical fiber assigning different wavelengths to each channel simultaneously. Wavelength Division Multiplexing multiplexes multiple optical carrier signals on a single optical fiber by using different wavelengths of laser light to carry different signals. To avoid interference between channels, the wavelengths in fiber should be spaced properly in WDM system. WDM multiplexing is shown in Fig. 2.1. In WDM technology, which is a part of third generation network, both data transmission and switching is done in optical domain only. Transparency i. e., each channel in the same fiber can carry any transmission format, may be digital or analog or may be with different bit rates [26].

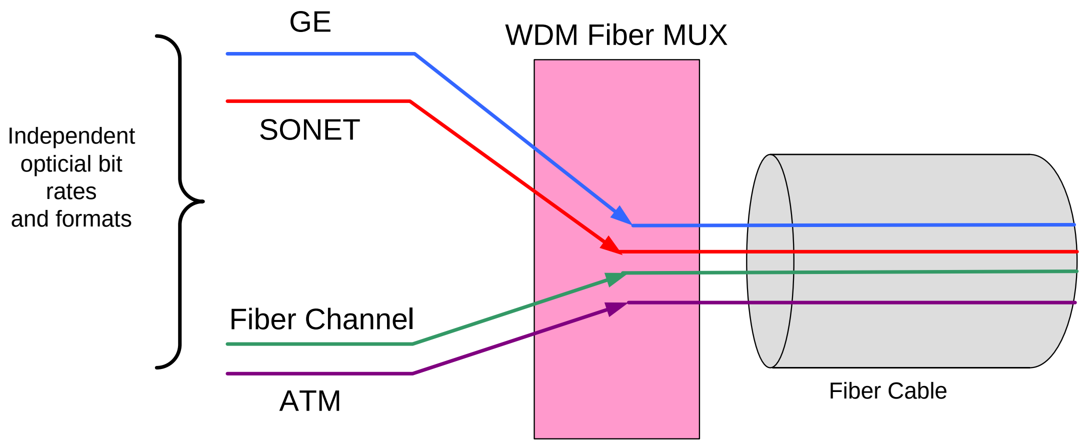

Fig. 2.1:WDM multiplexing technique

The two most important wavelength gaps are 1310 nm to 1550 nm. Transmission using 1310nm 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

DWDM is the most recent fiber optic multiplexing technology due to its potential ability to provide enormous bandwidth over a single fiber channel. Dense Wavelength Division Multiplexing (DWDM) technology is fundamentally the advanced version of WDM technology. In DWDM the wavelengths are more closer so large number of wavelengths can be multiplexed, and hence over all capacity of fiber will be more. In the case of DWDM technologythe entire wavelength can be amplified simultaneously in the optical domain itself i.e., conversion to electrical signals not required. And it can carry signal of different speed and format simultaneously through the single optical fiber.

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

Transparency:DWDM isphysical 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 andmake 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.

CWDM, which represents coarse wavelength-division multiplexing, is an optical technology for transmitting multiple channels, each channel in a different wavelength over the same optical fiber. Unlike dense WDM (DWDM), which can transmit 32 or more channels on the same fiber by tightly packing them, CWDM multiplexing technology on a wider spacing between channels. This wider spacing multiplexing method makes CWDM a relatively inexpensive technology for transmitting multipledata with different data rate on a single optical fiber, as compared with DWDM and WDM. The multiplexing is achieved in optical communication system with the help of multiplexers and demultiplexers associated with the system.The filters in optical communication system functions as: routing lights from many incoming/outgoing fibers to a common transmit/receive trunk port.Coarse WDM (CWDM), on the other hand, uses a much wider wavelength range (1200 to 1600 nm) with a minimum 20-nm wavelength gap between any two channels. Optical components used for CWDM are less accurate and thus less expensive because of the 20-nm wavelength gap.

2.2. BASIC COMPONENTS OF WDM SYSTEM

A feature of WDM is that the discrete wavelengths form an 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.

The important components of a basic WDM system are briefly explained in this section.

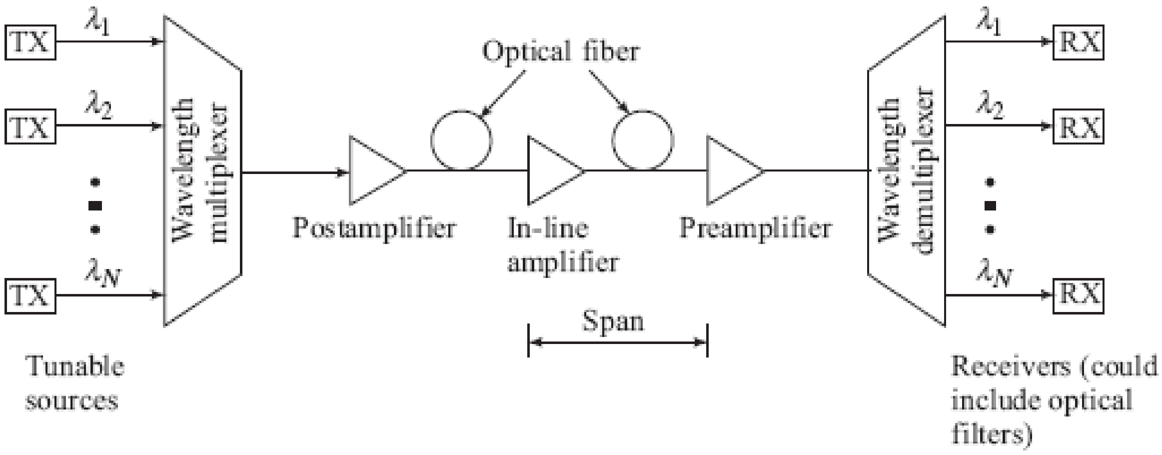

Fig. 2.2: Components of WDM system

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. 2.

2.2.2. Wavelength cross connect

Wavelength cross connect is a switching device whose function is to switch or connect any wavelength from the input port to any one of the out port in the fiber. The functioning is completely in optical domain. An OXC with N input and N output ports capable of handling W wavelengths per port can be thought as W independent N×N optical switches. A 2 layer 9×9 OXC is given in Fig. 2.3.

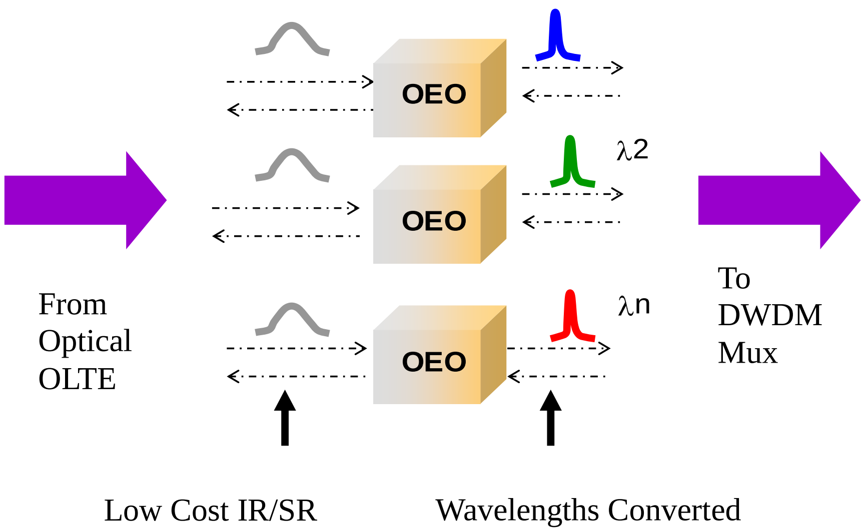

Fig. 2.3:OEO Conversion within the transponder

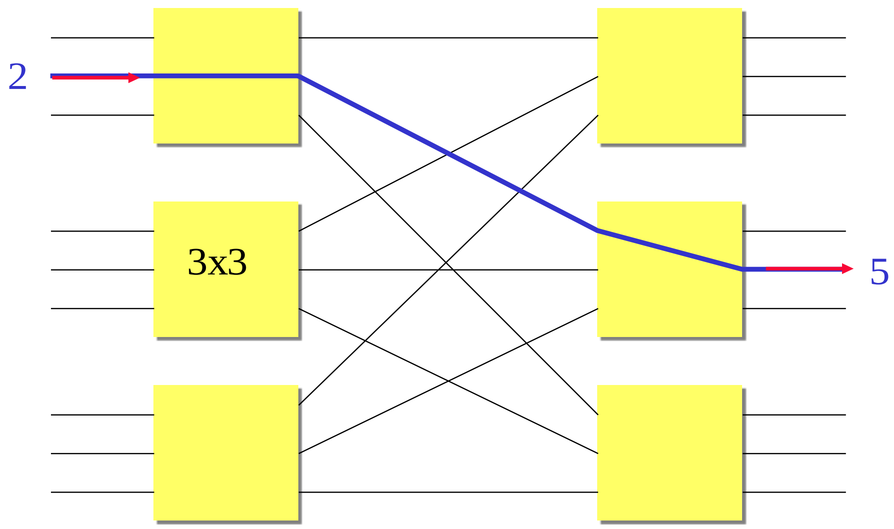

Fig. 2.4: Two layer 9×9 OXC

2.2.3. Optical amplifiers

For optical communication, which is generally meant for long distant communication, the possibility for signal degradation is high which reduces the signal strength as it reaches the receiver side.Hence regeneration of the light signal becomes essential especially over large distances forseveral thousand kms. Optical amplifiers are introduced in the system to solve this problem. An optical amplifier is a device which amplifies the optical signal directly without optical to electrical conversion i.e., all functions occurs in optical domain.In optical fiber, the light pulse itself is amplified. Optical amplifiers provide high gain and low noise for the optical signal; it has importance in the overall bandwidth provided by WDM system.

Variety of optical amplifier types exists, including:

- Semiconductor optical amplifiers
- Optical fiber amplifiers (Erbium Doped Fiber Amplifiers)
- Distributed fiber amplifiers (Raman Amplifiers)

The erbium doped fiber amplifier (EDFA) operating at 1540 nm region has proven to be an excellent choice for the WDM systems which completely operating in optical domain, no signal conversion is required. Other important types of amplifiers used in WDM system are Raman amplifier and Laser amplifier.Erbium doped fiber amplifier (EDFA) is shown below

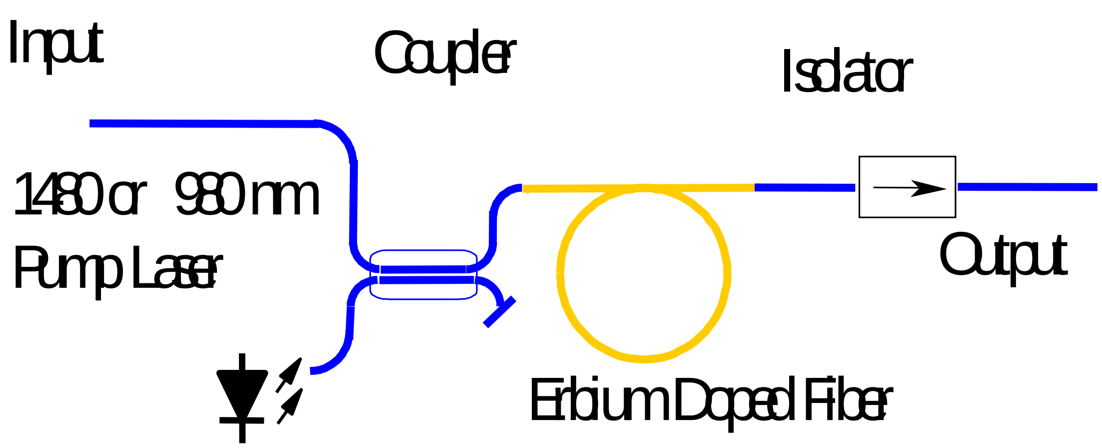

Fig. 2.5: Erbium doped fiber amplifier (EDFA)

2.2.4. Optical Add-drop multiplexer

Optical Add-Drop multiplexer is a device which is capable to add or drop one or more wavelengths from the existing WDM system. There are three important domains for an OADM- optical multiplexer, de multiplexer and a method to reconfigure the path between multiplexer and de multiplexer. The operation of OADM can be modeled as given in Fig. 2. 4

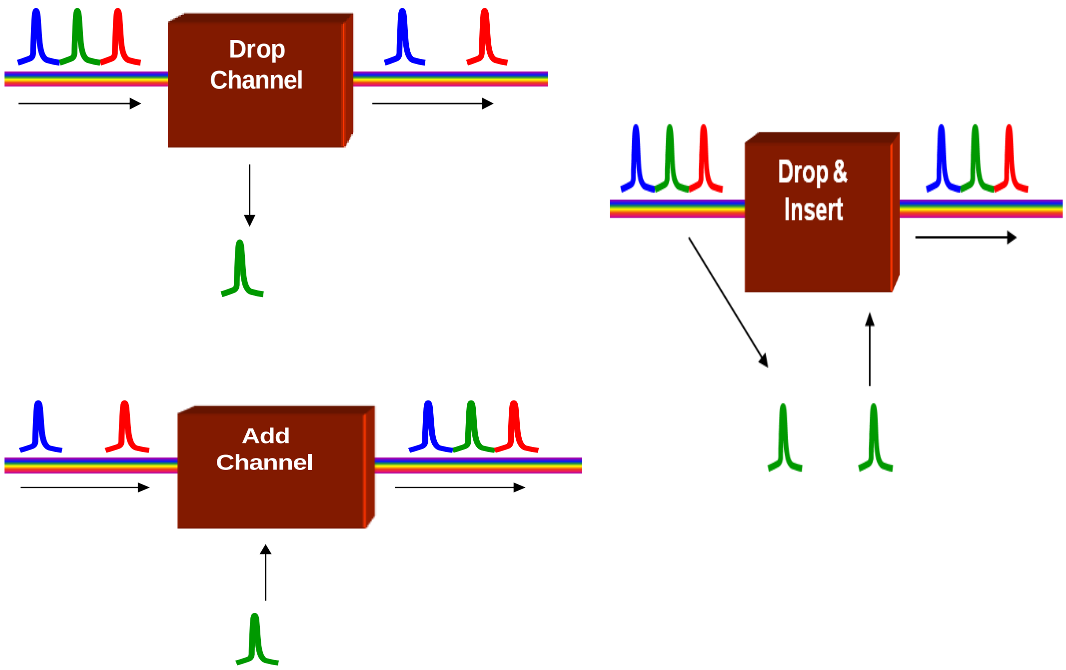

Fig. 2.6:OADM model in WDM system

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 Algorithms

Some of the important routing algorithms are given below

a) Fixed routing

In this algorithm, the path for the source destination pair is calculated using algorithms such as Dijkstra algorithm or Bellman-Ford algorithm [31]. Shortest path method is a an example of Fixed routing where the shortest path between source and destination is computed offline and this light path is used for the connection establishing for all connection request with this specified source destination pair i.e.,same fixed path is used for a given source and destination. It is a simple algorithm, but the availability of effective light paths in the network is minimum hence blocking will be more. Hence it is not a resource efficient utilized routing technique.

b) Fixed alternate routing

Here several alternate paths are calculated offline for a source destination pair [32, 33]. For a source destination pair several routes are computed and all may be arranged in some priority order, normally the shortest route is the most prioritized route. Some cases the number of links in the light path is also a criteria for prioritizing the paths. When connection request arrives, the source node searches a light path to destination until it finds a route with a free wavelength for connection establishment. If no available route is found among all possible paths, then the connection requests will be blocked. This method of routing provides alternate paths for a connection request hence link failure problem can be solved. The blocking probability also reduces if we go for fixed alternate routing technique.

c) Adaptive routing

In this method, paths are calculated online depending on network state and availability of resources in the network [34]. Here a route between source and destination is adapted dynamically depending on network state. Consider the case of shortest adaptive routing. When a connection requests arrives, the shortest path between source and destination is determined. If more path with same distance present, one is taken randomly. Here both wavelength continuous and wavelength distinct paths are considered. The call will be blocked if there is no route available between source and destination. This is the most efficient routing algorithm for WDM network.

2.3.2. Wavelength assignment Methods

The existing wavelength assignment methods in WDM systems are

a) Random wavelength assignment

Here a wavelength is selected randomly from the available [34]. A random number is generated and wavelength assigned to the randomly generated number.

b) First fit wavelength assignment

In this algorithm, all available wavelengths are arranged in the ascending order and a wavelength matrix is formed. Then all the wavelengths are numbered and the least numbered wavelengths are assigned for the first light path [33, 35]. More priority is given to the lower numbered wavelength. Computation cost of this scheme is less since no need to search for all wavelengths. The performance well in terms of blocking probability fairness andcomputation complexity also less in this algorithm.

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 links in a light path is must be assigned with the same wavelength.The wavelength continuity constraint distinguishes the wavelength continuous network from a circuit switched network which blocks calls only when there is no capacity along any of the links in the path assigned to the call. Wavelength continuous network suffers more blocking comparer to circuit switched network. To avoid this degrade performance we can go for wavelength conversion techniques which is explained below.

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.

2.4. QOS SATISFIED ROUTING

In our work, we defined the QoS in terms of Q-Factor which is computed in terms of bandwidth and delay associated with the optical fiber light path.Here Quality of Service is defined in the client requirement base and the light path routing is done assuring the Q-Factor requirement of the client and considering the availability of resources in the network. The maximum value for Q-Factor is the optimum requirement for the connection request.

While calculating Q-Factor, we have considered the linear impairment factor dispersion, which causes considerable pulse spreading and hence delay for the transmitted signal. The light path/ route with minimum delayare the optimum path for routing. But for the bandwidth, the optimum path is the path which provides maximum value. Out of all possible paths, the paths which satisfy the Q-Factor requirement of client only considered for light path provisioning. Dispersion penalty is another QoS parameter which we have considered. Dispersion penalty is computed for all possible paths in terms of bandwidth and bit rate associated with the light path. In this case paths with penalty less than 2 dB are the desirable paths for provisioning. In both the method, the algorithm is simple, efficient and it ensures the client requirement which is an important factor in the future communication systems.

Chapter 3

SYSTEM DESIGN AND PLANNING

A. Q-FACTOR BASED LIGHT PATH PROVISIONING ALGORITHM

In the algorithm, we have considered various QoS parameters such as bandwidth, differential time delay, physical layer impairment (PLI) constraints, dispersion, spectral width and wavelength of light and formulated Q-Factor model for the light path connection setup. We also estimated the QoS requirement such as bandwidth and delay from the client for a light path connection in terms of Q-Factor. In the second part, we have proposed a mechanism for light path provisioning based on the dispersion penalty of each light path. The proposed algorithm defines a mechanism for effective light path provisioning by comparing the requirement of client and the available resources of the network.

3.1 SYSTEM MODEL

The WDM system model which we have followed throughout the work is shown in Fig. 3. 1.

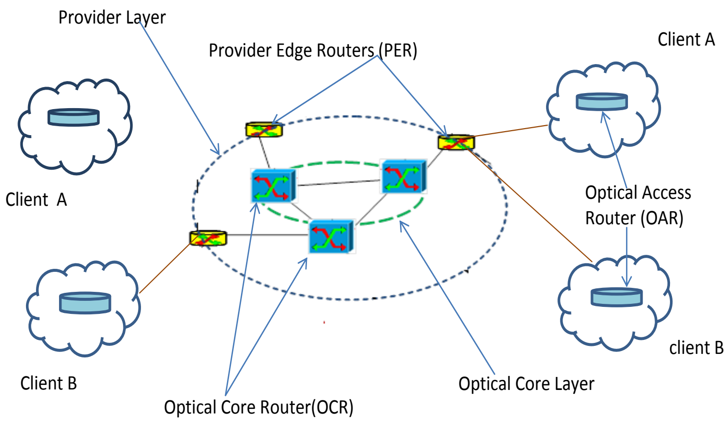

Fig. 3.1: System Model

This system model consisting of two layers- the Provider edge layer (PER) and the Optical core layer (OCR) [36, 37]. As shown in the model, provider edge router (PER) belongs to light path client which provides light path service and interface between client and optical core router (OCR). An OCR is not connected to a client directly. The provisioning of light path is the establishment of the tunnels, which may be constructed at layer 1 and layer 2.

The optical layer provides point-to-point connectivity between routers in the form of fixed bandwidth circuits, which is termed as light-paths. The collection of light-paths therefore defines the topology of the virtual network interconnecting routers. In provider layer the PER are responsible for all the non-local management functions such as management of optical resources, configuration and capacity management, addressing, routing, topology discovery, traffic engineering, and restoration etc. The provider layer controls all the traffic corresponding to both client and optical layers. PER maintains a traffic matrix (TM) for all the connected clients within its domain of control. The TM maintains the network as well as physical layer impairment (PLI) constraints such as bandwidth, delay, dispersion and Q-Factor matrices for all the possible light path connection in the network, belonging to all the layers. In the following sections we outline our algorithms that carry out the computations necessary for the decisions that lead to provisioning/de-provisioning of light path connection.

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 various QoS parameters such as bandwidth and time delay. In the following section we 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.

Network may be modeled [38, 39] using nodes/routers and links, which provides the layout pattern of interconnections of the various elements like links, nodes, etc. of a network system which is shown in Fig. 3. 2. In a network, a node is a connection point, either a redistribution point or an end point for data transmissions. Link in a network is a connection through optical fiber link between two nodes.

Connectivity in a system: Connectivity is determined by the connection between two nodes/routers. If there is a link present between two nodes connectivity is taken as ‘1’ otherwise it is taken as ‘0’. Using this connectivity matrix, light-path can be determined.

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

$$C(i,j) = \begin{cases} 1 \; if \; link \; between \; i \; and \; j \; exists \\ 0 \; otherwise \end{cases} \quad [3.1]$$

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

$$\lambda(i,j) = \begin{cases} 1 \; if \; \lambda \; is \; available \; between \; i \; and \; j \\ 0 \; otherwise \end{cases} \quad [3.2]$$

3.2.1 Estimation of Required Q-Factor

We consider the virtual topology shown in Fig. 3. 2.

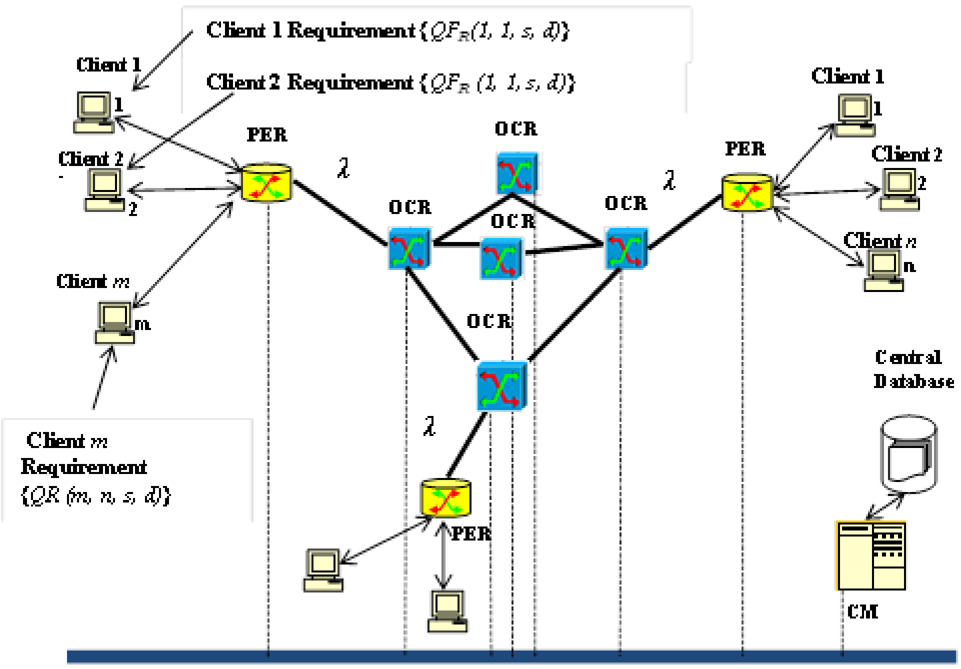

Fig. 3.2: Network Architecture

In this model, a number of connection request for different applications are multiplexed at the source PER *i* to destination PER *j* for a light path. This formulation is for the provisioning and de-provisioning of light path based on the client requirements and available resources.

The problem formulations are based on different QoS parameters such as, bandwidth and delay in terms of required Q-Factor, which are explained in following sections. We defined the link cost as the ratio of bandwidth and delay, which is termed as Q-Factor.

Assume every client end point is attached to at most one PER. In Fig. 3.2, suppose a flow for client m and n with light path from source s to destination d has bandwidth requirement *BW (m, n, s, d)* and the delay requirement of flow for *(m, n)* client pair from source *s* and destination *d* is *T (m, n, s, d).*

If QF_R *(m, n, s, d)*is the required Q-Factor, then, it can be formulated as follows [40]

$$QF_R(m,s,s,d) = \frac{BW(m,n,s,d)}{T(m,n,s,d)} \quad [3.3]$$

3.2.2 Estimation of Computed Q-Factor

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.

***a) Bandwidth Computation for a link (i, j)*:**

Assume the physical layer constraints are dispersioncoefficient 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 follows [8].

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

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.

***b) Time Delay Computation for a link (i, j)*:**

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

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 follows [23, 24, 25, 41].

$$T_{PMD}\,(i,j) = D_{PMD}\,(i,j) \times \sqrt{L(i,j)} \qquad [3.5]$$

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.

Delay due to the effect of chromatic dispersion: Thetime delay introduced in optical fiber due to chromatic dispersion can be calculated as follows [23, 24, 41].

$$T_{CD}(i,j) = D_{CD}(i,j) \times L(i,j) \times \lambda(i,j) \qquad [3.6]$$

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

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, 41].

$$T_{MD}\,(i,j) = \frac{L(i,j) \times (n_1 - n_2) \times (1 - {}^{\pi}/_{V})}{C} \qquad [3.7]$$

Where n_1 is the refractive index of core of the fiber and n_2 is the refractive index of cladding V is the cut off wavelength and can be calculated using the expression given below

$$V(i,j) = \frac{2 \times \pi \times a}{\lambda(i,j)} \sqrt{({n_1}^2 - {n_2}^2)} \qquad [3.8]$$

Where $a$is the diameter of the core.

Delay due to waveguide dispersion: Time delay due to waveguide dispersion is given below [41].

$$T_{WGD}(i,j) = \frac{L(i,j) \times n_2 \times \Delta \times \nabla\lambda}{C \times \lambda} \times V \times \frac{d^2(b(V))}{dV^2} \qquad [3.9]$$

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

Δ is given by

$$\Delta = \frac{(n_1 - n_2\ )}{n_1} \quad [3.10]$$

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

$$b(V) = \frac{1 - (1 + \sqrt{2}\ )^2}{\sqrt{1 + (4 + V^4})} \quad [3.11]$$

Computation of Total Delay: Total delay for a fiber link *(i, j)* can be computed as

$$T_{total}(i,j) = \sqrt{(T_{PMD}\ (i,j)^2 + T_{CD}(i,j)^2 + T_{MD}\ (i,j)^2 + T_{WGD}(i,j)^2)} \quad [3.12]$$

c) Bandwidth for a light path with source destination pair (s, d)

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

$$BW(m,n,s,d) = Min\{BW(i,j)\}, \forall(i,j) \in p(s,d) \quad [3.13]$$

d) Total Delay for a light path with source destination pair (s, d):

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

$$T_{total}\ (m,n,s,d) = L(i,j) \times\ T_{total}(i,j) \quad [3.14]$$

e) Q-Factor for a light path with source destination pair (s, d)

$$QF_C(m,n,s,d) = \frac{BW(m,n,s,d)}{T_{total}(m,n,s,d)} \quad [3.15]$$

3.2.3 Estimation of Blocking Probability

Assume *TNCR (m, n, s, d)* is the total number of connection requested for a source (*s*) and destination (*d*), *TNCB (m, n, s, d)* is the total number of connection blocked, then the blocking probability *BP (m, n, s, d)* can be defined [30] as follows.

$$BP(m,n,s,d) = \frac{TNCB(m,n,s,d)}{TNCR(m,n,s,d)} \quad [3.16]$$

3.3 LIGHT PATH CONNECTION SETUP MECHANISM

In this section the light path connection set up mechanism has been mentioned, which means the provisioning light path connection request depending on the required and computed Q-Factor. If the required Q-Factor is satisfied by one of the computed connections, then that connection will be fixed for a client, otherwise the request will be blocked. Assume $QF_R(m, n, s, d)$ is the required Q-Factor for a connection request for a source destination pair *(s, d)* and $QF_C(m, n, s, d)$ is the computed Q-Factor, which are explained in previous section, then, this mechanism of light path provisioning can be explained mathematically as follows.

$$QF_R(m,n,s,d) \leq QF_C(m,n,s,d) \quad [3.17]$$

The connection request will be blocked for the following two cases.

Case 1:

$$QF_R(m,n,s,d) > QF_C(m,n,s,d) \quad [3.18]$$

Case 2:

$$\lambda(s,d) = 0 \quad [3.19]$$

Where, λ *(m, n)* is the status of available wavelength at any of the connections for *(s,d)* pair

3.3.1 Algorithm and flowchart

In our proposed work, we considered two algorithms such as i) Conventional Shortest path Algorithm (STP algorithm), iii) Proposed Disjoint path Computation (DJP algorithm). Both the algorithm has been evaluated considering both wavelength conversion mechanism and without wavelength conversion mechanism. The proposed algorithms provide a light path connection to the client depending on their QoS requirement.

The main steps in the algorithm is given below

STEP 1: Compute all disjoint path and the Q-Factor matrix for all these paths and then arrange them in the ascending order of Q-Factor.

STEP 2: Compare the required Q-factor of client to the Q-Factor matrix of disjoint path.

STEP 3: If condition [3.17] is satisfied, then checks the availability of wavelength, if free wavelength available, establish the light path. Otherwise check for another path from the disjoint path matrix. For shortest path matrix only shortest path is taken for consideration.

STEP 4: If condition [3.17] is not satisfied for any path in the disjoint path matrix or free wavelength is not available for any satisfied path, the connection request will be blocked.

The algorithm can be understood from the Flowchart given below Fig. 3.3 Flowchart 1.

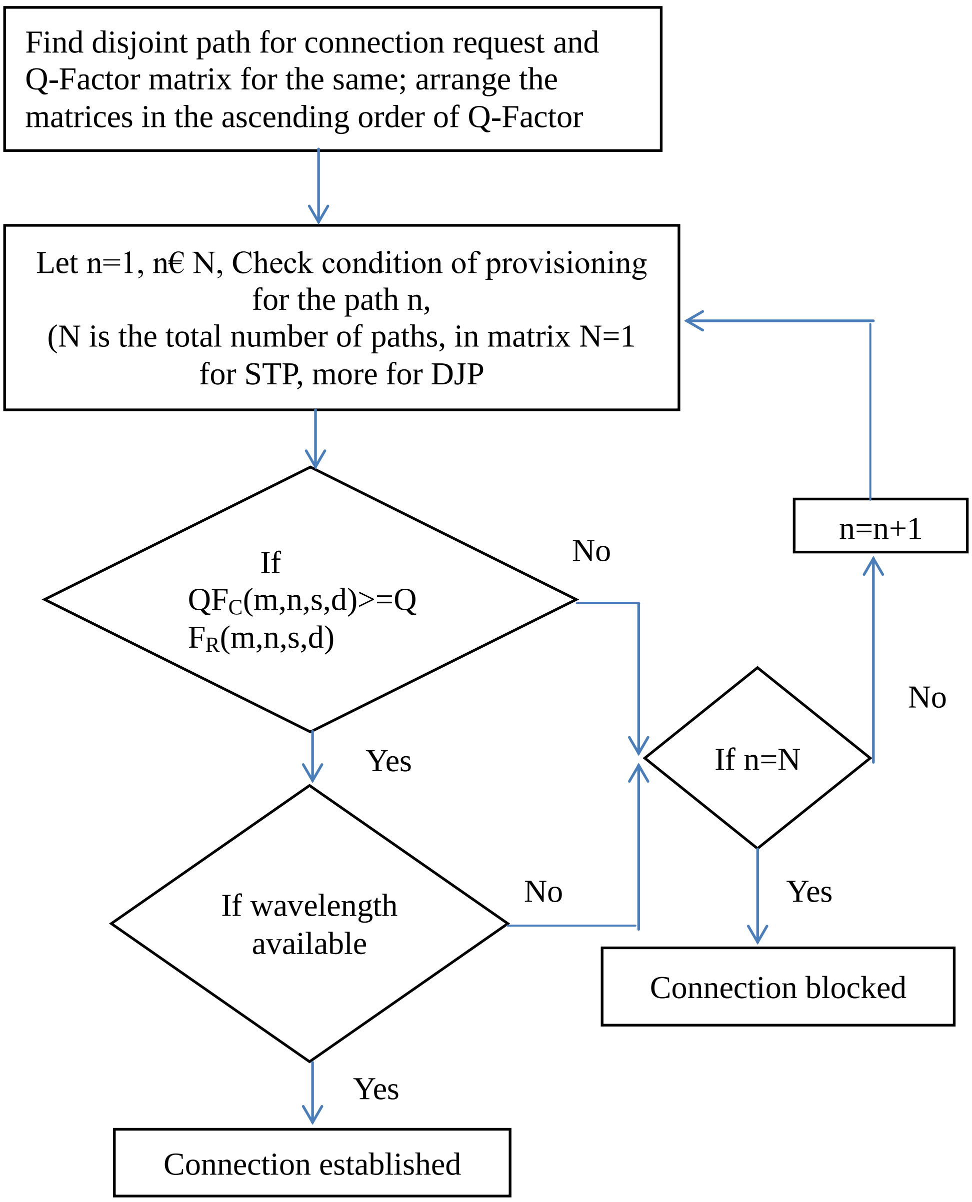

Fig. 3.3: Flowchart 1

B. DISPERSIONPENALTY BASED LIGHT PATH PROVISIONING ALGORITHM

In this section, we have explained an efficient light path provisioning algorithm based on the dispersion penalty of each possible light path. In this algorithm, QoS 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 of 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 the optical fiber. Dispersion penalty is calculated in terms of bit rate and band width for each data path.The purpose of dispersion penalty budgeting is to ensure that the optical power reaching the receiver is adequate under all circumstances. Normal value of dispersion penalty is taken as 2 dB.

3.4 PROBLEM FORMULATION FOR DISPERION PENALTY DESIGN

3.4.1 Dispersion penalty Computation

a) Computation of Maximum possible Bit rate:

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

$$BR(m,n,s,d) = \frac{\varepsilon}{10^{-6} \times T_{total}(m,n,s,d)} \quad [3.19]$$

Where ε is the pulse broadening ratio, $T_{total}(m,n,s,d)$ is the total dispersion in the light path and can be calculated using the equation [3.14].

b) Computation of Maximum possible length of the data path:

For data path with source destination pair *(s, d)*, maximum possible length is computes as [40]

$$L(m,n,s,d) = \frac{104000}{BR(m,n,s,d) \times T_{total}(m,n,s,d)} \qquad [3.20]$$

Where $BR(m,n,s,d)$is the maximum bit rate in the data path and $T_{total}(m,n,s,d)$ is the total pulse spreading due to dispersion.

c) Computation of Dispersion penalty for the light path:

Dispersion penalty for light path can be calculated as [40]

$$P_D(m,n,s,d) = C \times \left(\frac{BR(m,n,s,d)}{BW(m,n,s,d)}\right)^2 \qquad [3.21]$$

Where C is a constant taken as 0.5, $BW(m,n,s,d)$ is the bandwidth of the light path and can be computed using equation [3.13].

Dispersion penalty can be expressed in dB as

$$P_D\,(dB) = 10\ \log P_D \qquad [3.22]$$

3.5 LIGHT PATH PROVISIONING CRITERIA

Here all paths having dispersion penalty less than or equal to 2 dB is considered for light path provisioning.

$$D_P(m,n,s,d) \leq 2dB \qquad [3.23]$$

The two cases for a connection request to be blocked are

Case 1:

$$D_P(m,n,s,d) > 2dB \qquad [3.24]$$

Case 2:

$$\lambda(s,d) = 0 \qquad [3.25]$$

Blocking probability is calculating using equation [3.16].

3.5.1 Algorithm and Flowchart

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 [3.23] 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 [3.23] 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 3.4 Flowchart 2

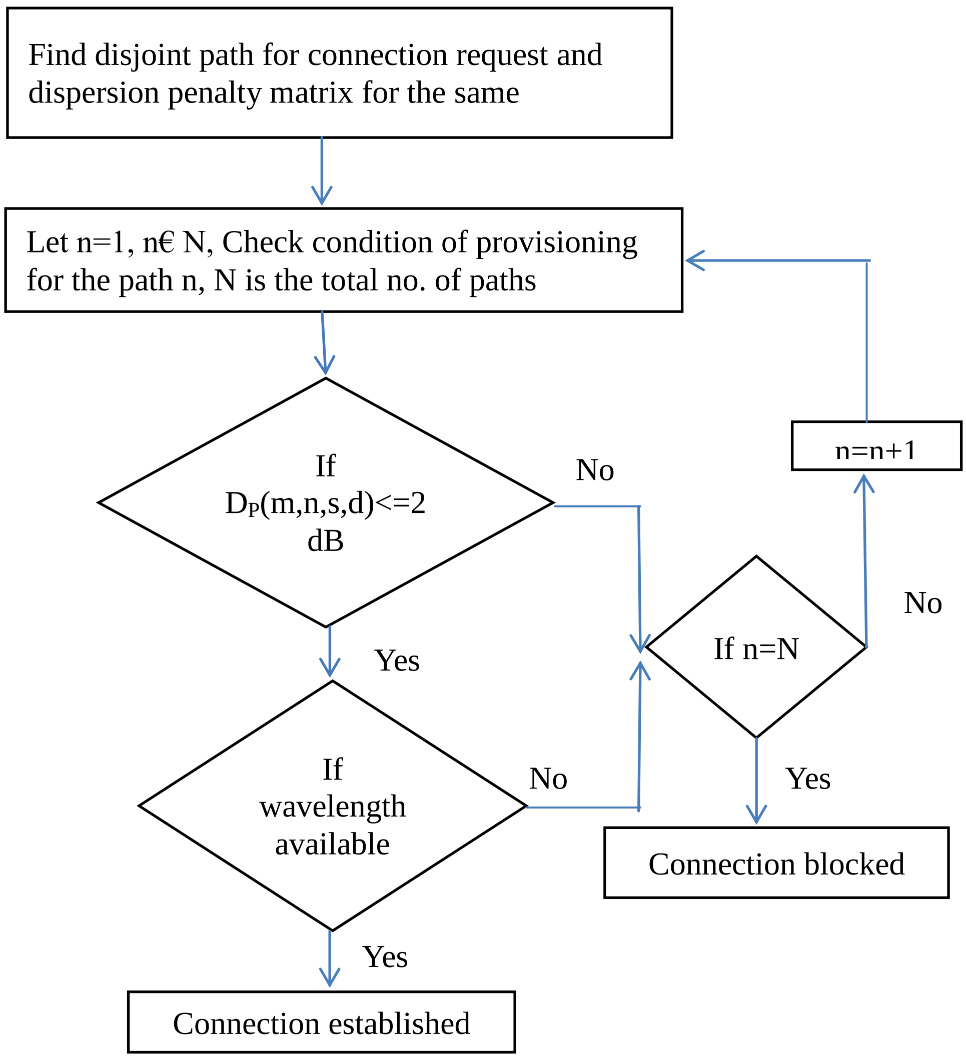

Fig. 3.4: Flowcharts 2

Chapter 4

SIMULATION RESULTS

A. SIMULATION FOR Q-FACTOR BASED LIGHT PATH PROVISIONING

In the first section of this chapter, we examine the performance of our new QoS aware light path provisioning algorithm with an extensive simulation. Here we compute the optimal light path connection for each connection request. In both DJP and STP algorithms we have calculated the time delay, bandwidth and finally Q-Factor associated with all possible light paths for a connection requests with specified edge nodes. In both cases of both DJP and STP, the light path connection selection mechanism considers quality parameters such as bandwidth, delay in terms of Q-Factor for finding the best suitable connections. The Q-Factor is nothing but a nominal value in percentage, which represents the quality of the connections.

4.1 NETWORK MODEL

The NSF network model used for simulation is given as Fig. 4.1. The network model consists of 10 nodes and 16 links. In our simulation, we use a dynamic traffic model in which we have assumed that all the connection requests have to be establishing simultaneously.

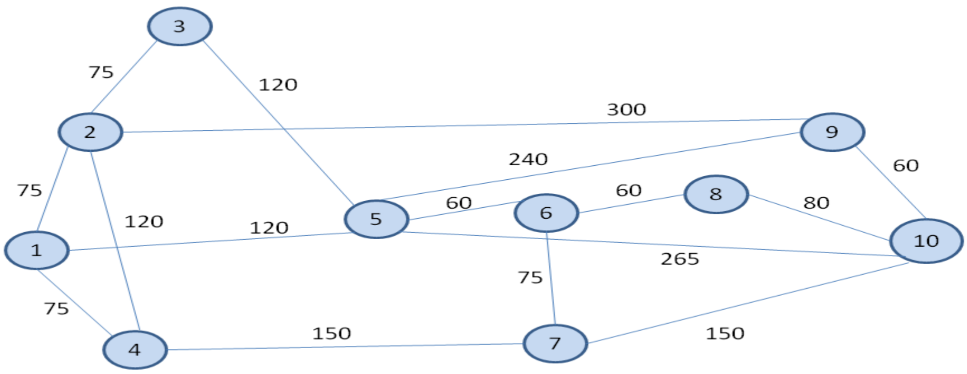

Fig. 4.1: Network Model(Note: All distance in km)

In our simulation, we use a dynamic traffic model in which we have assumed that all the connection requests have to be establishing simultaneously. In our simulation work, we use few of the pre-defined parameters, which are mentioned in Table 4.1.

Table 4.1: 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-FACTORCOMPUTATION

Assume 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, Fig. 4.3 and Fig. 4.4.

Bandwidth associated with each path is calculated using the equations [3.4] and [3.13]. 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 reference number is shown in Fig 4.2. The light path which gives the maximum bandwidth, the optimal path, is clearly marked in the plot. Here light path with reference number 8 gives the maximum bandwidth and light path 7 gives the minimum bandwidth.

Using equations [3.9-3.12] and [3.14] we have calculated the total time delay associated with each path for source destination pair (1, 7). From the Fig 4.3 we can understand that a light path 8 is the path with minimum delay. Path with reference number 8 is the optimal path which is associated with minimum delay.By analyzing Fig. 4.2 and Fig. 4.3, it is clear that the pathwith minimum delay provides maximum bandwidth also.

For simulating Q-Factor, we have used equation [3.15] and the results are plotted in Fig. 4.4Q-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. For source destination pair (1, 7), light path with reference number 8 is the optimal path.

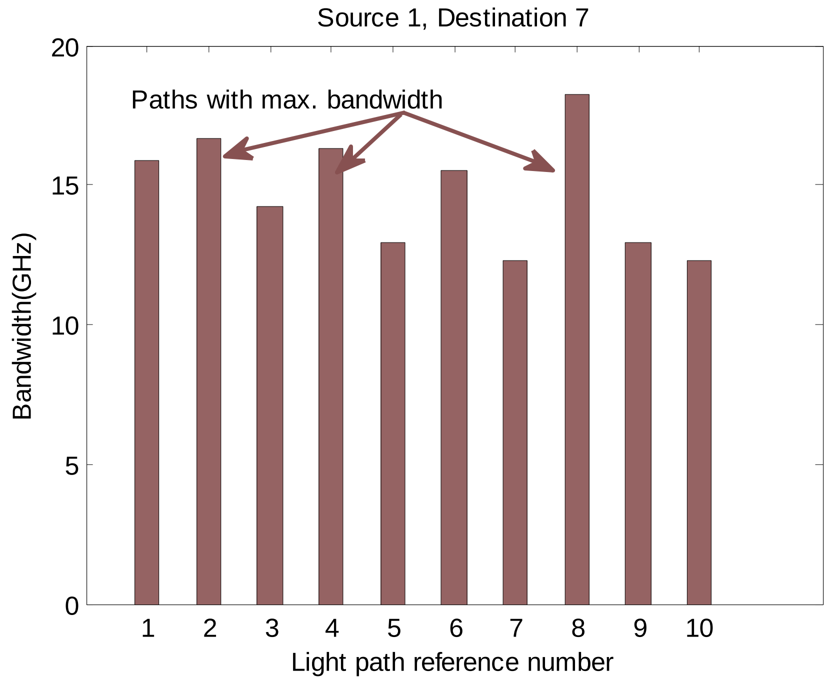

Fig. 4.2: Bandwidth plots ofall light paths of source destination pair (1, 7)

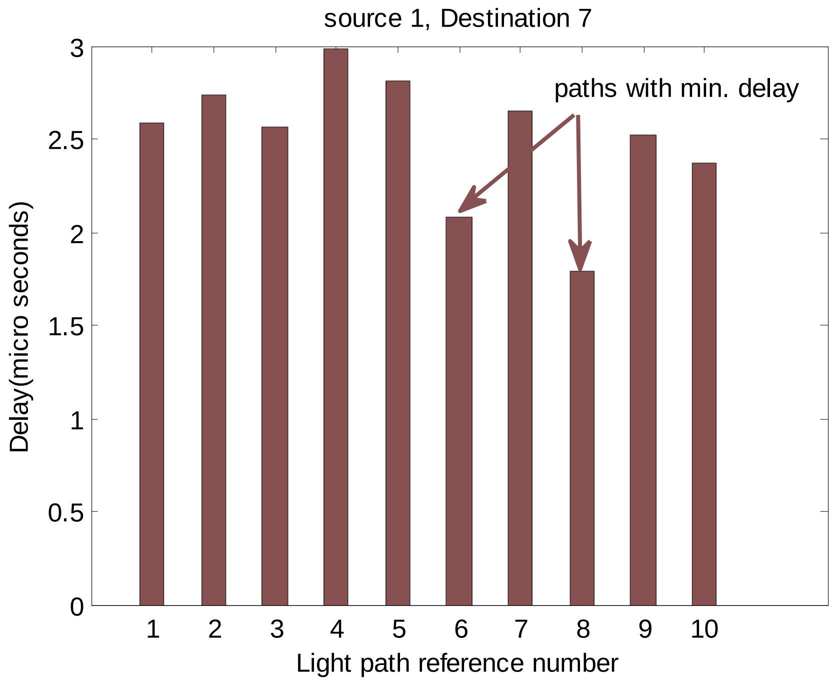

Fig. 4.3: Delay plots of all light paths of source destination pair (1, 7)

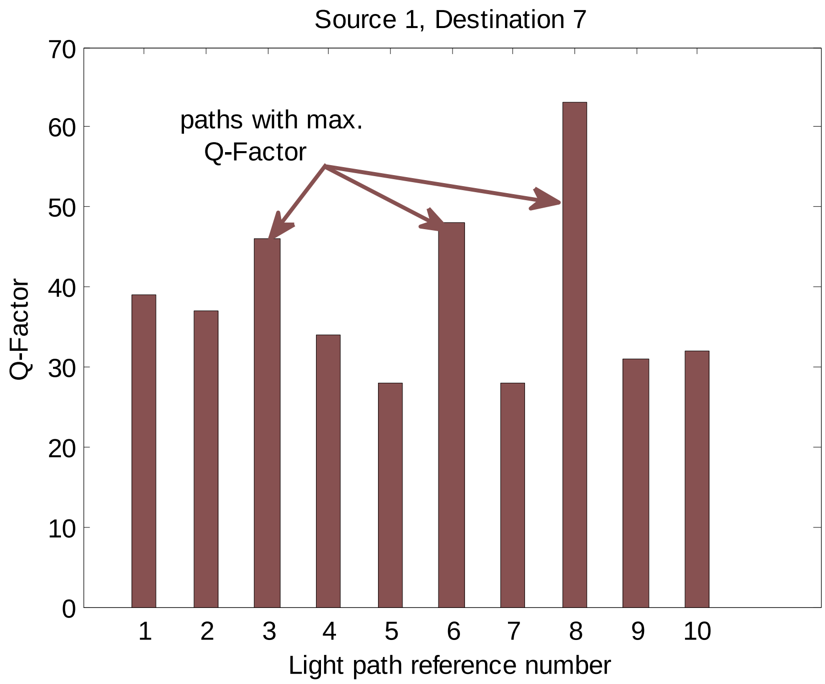

Fig. 4.4:Q-Factor plots of all light paths of source destination pair (1, 7)

4.3 RESULTS OF DISJOINT PATHS Q-FACTOR COMPUTATION

Here we have done the light path provisioning by both Disjoint Path Algorithm (DJP) and Shortest Path Algorithm (STP). In the case of DJP algorithm, we have considered all the disjoint paths for routing. STP is the traditional algorithm in which only the shortest path among all possible paths is used for light path provisioning. Consider three pairs of source and destination nodes (1, 5), (3, 8) and (5, 9). We have computed disjoint paths for all this pairs and then the Q-factor associated with all this computed disjoint paths. The computed bandwidth, delay and Q-Factor for this disjoints paths are given in Table 4.2.

For source destination pair (1, 5), there is three disjoint path 1-5, 1-4-7-10-5 and 1-2-9-5. For the light path 1-5, 12.23 GHz is the bandwidth, 0.531 μs is the delay and the normalized Q-Factor is 73. As the length of the path increases, delay increases and hence Q-Factor decreases. For DJP algorithm, all the three paths is considered for provisioning but for STP only the shortest path 1-5 used for light path provisioning. Similar is the case of other connection pairs (3, 8) and (5, 9).

Table 4.2: Computed Bandwidth, delay and Q-Factor for disjoint paths

Source	Destination	Disjoint paths	Delay(µs)	Bandwidth(GHz)	Q-Factor
1	5	1 - 5	.531	12.23	73
		1 - 4 - 7 – 10 - 5	1.03	12.23	48
		1 - 2 - 9 - 5	2.72	11.51	12
3	8	3 - 5 - 10 - 8	2.05	13.56	62
		3- 2 -9 -10- 7 - 6 -8	3.186	12.14	38
5	9	5 - 9	1.03	22.53	48
		5 - 10 - 9	1.44	15.87	35
		5 - 6 - 7 - 4 - 2 - 9	3.12	11.24	16

4.4 RESULTS OF OPTIMAL LIGHT PATH SELECTION

In our proposed algorithm, the connection corresponding to the Q-Factor greater than or equal to the required Q-Factor is the optimal light path connection for any connection requests. Table 4.3 shows the computed Q-Factor and the selection of light path by proposed DJP algorithm. We assume there are three connection requests with their Q-Factor requirements for different (*s*, *d*) pair. According to our algorithm, all possible disjoint light path connections, light path connection serial number, computed Q-Factor, required Q-Factor and optimal connection are shown in this table. From this tabular form, it will be easy to say that which one will be the optimal light path for a source-destination pair of a client based on their required Q-Factor.

Consider the first connection request with *(s, d)* pair (3, 8) with a Q-Factor requirement of 43. For this *(s, d)* pair, two disjoint paths 3-5-10-8, 3-2-9-10-7-6-8 with computed Q-Factor 62 and 38 respectively are available. Among these two paths, only the first path 3-5-10-8 satisfies the client requirement, hence this path is provisioned for the first connection request. By STP algorithm, only the shortest path, here 3-5-10-8 is taken into consideration. In the case of this connection request, the shortest path satisfies the client requirement. Hence the path 3-5-10-8 is taken for light path routing.

Table 4.3: Light path selection by DJP and STP algorithm

CSN	S	D	QF_R	Using DJP algorithm				Using STP algorithm	
				DJP	QF_C	SP	QF_{SP}	SP	QF_{SP}
1	3	8	43	3-5-10-8	62	3-5-10-8	62	3-5-10-8	62
				3-2-9-10-7-6-8	38				
2	5	9	39	5-9	48	5-10-9	40	5-9	48
				5-10-9	40				
				5-6-7-4-2-9	16				
3	2	7	64	2-9-10-7	16	NRSLP	_	NRSLP	_
				2-4-7	44				
				2-3-5-6-7	40				

(Note: CSN- Connection Serial Number, S-Source, D- Destination, QF_R- Required Q-Factor, DJP- Disjoint paths, QF_C- Calculated Q-factor, SP-Selected Path, QF_{SP}-QF of selected path, NRSLP-No Requirement Satisfied Light Path)

Similarly for the second connection request with *(s, d)* pair (5, 9), the optimal path is 5-10-9. Here in DJP algorithm, the two disjoint paths 5-9 and 5-10-9 satisfies the client required Q-Factor, but 5-10-9 is the optimal path. For the third connection request Q-Factor requirement is 64, but among the disjoint paths, no path available with a satisfying Q-Factor. Hence in the given network model, the connection request can't be established.

4.5 RESULTS OF BLOCKING PROBABILITY COMPUTATION

Here we have done the performance analysis of both DJP and STP algorithm by calculating the probability of blocking after establishing light path connections for a number of connection requests. Assume that we have eight connection request to be established with different *(s, d)*pair and Q-factor requirement. With the help of Table 4.4, we can explain the blocking probability computation by DJP and STP algorithms. Blocking probability is simply the ratio of total number of calls blocked to the total number of calls expressed in percentage. Minimum blocking is always the desired condition for provisioning.

Table 4.4: Blocking probability computation for connection request

DJP	QF_C	STP	CSN	QF_R	Using DJP algorithm			Using STP algorithm		
					SP	CRS	BP(%)	SP	CRS	BP(%)
1-5	73	1-5	1	44	1-4-7-10-5	1	25	1-5	1	63
			2	53	1-5	1		1-5	1	
			3	70	1-5	1		1-5	1	
1-4-7-10-5	48		4	40	1-4-7-10-5	1		NFLP	0	
			5	50	1-5	1		NFLP	0	
1-2-9-5	12		6	48	1-4-7-10-5	1		NFLP	0	
			7	55	NRSLP	0		NFLP	0	
			8	48	NFLP	0		NFLP	0	

(Note: DJP-Disjoint paths, QF_C – Computed Q-Factor, STP- Shortest Path, QF_R- Required Q-Factor, SP- Selected Path, CRS- Connection Request Status, BP- Blocking Probability, NFLP-No Free light Path)

Assume that we have to establish eight connections from source 1 to destination 5. We have calculated all disjoint paths for the pair(1,5) and then the Q-Factor associated with each of this light path. The light path provisioning depends of both the Q-Factor requirement of client and the availability of wavelength for assigning wavelength to the routed path. In our simulation, we have assumed that each fiber link multiplexed with three different wavelengths. A connection requests can be blocked either due to the availability of QoS satisfied path or due to the absence of free light path. Simulation results are given in

Table 4.4. In this example, by DJP algorithm all the first six connections are established. Seventh call blocked because of the absence of Q-Factor satisfied light path and eighth call is blocked due to the lack of free wavelengths in the network. By STP algorithm, only one light path 1-5 which is the shortest path is considered for light path provisioning. In this case only first three calls established. All other calls except seventh call are blocked because of the lack of free wavelength. But in the case of seventh connection request, call blocked because the light path 1-5 can't satisfy the Q-Factor requirement of the client.

For better understanding of the light path provisioning mechanism, the Table 4.4 is represented in the form of a bar graph as shown in Fig 4.5.

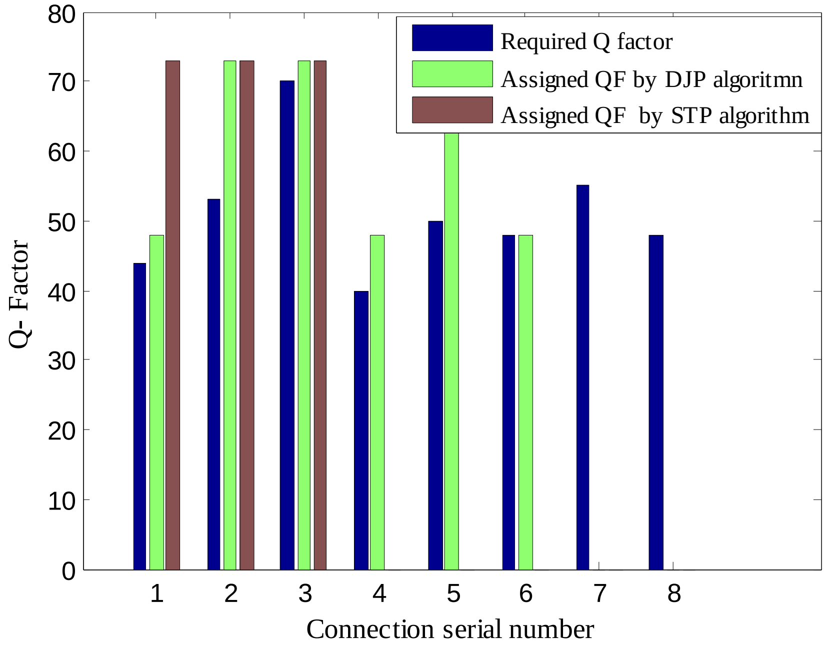

Fig. 4.5: Q-Factor assignment by DJP and STP algorithm

The performance of algorithms is analyzed by calculating blocking probability with wavelength conversion and without wavelength conversion while wavelength assignment for the selected optimal light path. Fig 4.6 shows the plot of blocking probability with the variation of number of connections requests for different source destination pair. Blocking probability is calculated from the number of calls blocked and the total number of calls generated as given in equation [3.15]. A significant improve in blocking probability is achieved using DJP algorithm, which is our proposed mechanism for light path provisioning. Here our algorithm helps to analyses both bandwidth and delay constraints and determine the best possible path between source destination pair for each connection request. The best path has been selected based on the requirement of the client. Her we have considered all disjoint paths between source and destination instead of the traditional shortest distance concept, hence resources is more in DJP algorithm. Hence improved blocking probability is obtained by DJP algorithm as compared to STP algorithm.

We analyzed and compared the two methods by introducing wavelength conversion and without wavelength conversion. In the case of wavelength conversion method more resources are available for light path provisioning since single light path can be assigned with different wavelengths for the links within that light path. But for provisioning without wavelength conversion, wavelength continuity constraint has to be maintained throughout the light path. Hence effective light path available of provisioning is less in this case, that is the reason why DJP algorithm with wavelength conversion blocking probability is less as compared to the same algorithm without wavelength conversion.

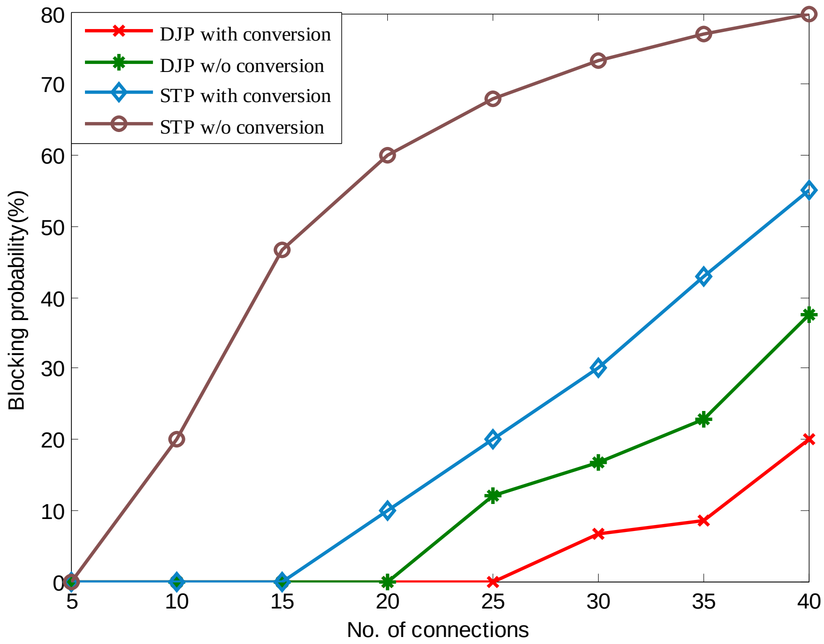

Fig. 4.6: Blocking probability plot for DJP and STP algorithm

Simulation for light path provisioning has been done by DJP algorithm done with different number of wavelengths (3, 6, 8) in the same network model. The blocking probability for different network load is plotted as shown in Fig 4.7. The result shows that by increasing the number of wavelength in the network, the blocking probability can be reduced as the number of wavelengths increases the effective number of light paths also increases.

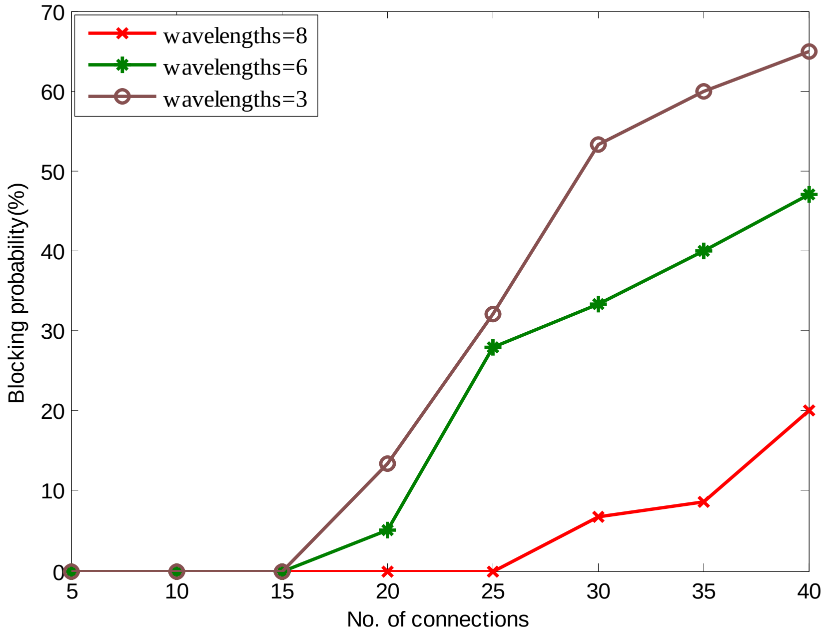

Fig. 4.7: Blocking probability for different number of wavelengths

B. SIMULATION FOR PENALTY BASED LIGHT PATH PROVISIONING

In this section, we have described the simulation work for dispersion penalty based light path provisioning algorithm. Here QoS of the system is defined in terms of the dispersion penalty of the light path. Light path provisioning based on the dispersion penalty ensure that all the path/connection we are establishing in a network carry signal with a minimum quality which is expected at reach the receiver side. We have assumed that all the connection requests demands a dispersion penalty which is less than or equal to 2 dB which is the normal value for penalty. Here we have considered all possible paths between a source and destination corresponding to the connection request for light path provisioning.

4.6 ANALYSIS FOR MAXIMUM POSSIBLE BIT RATE AND LENGHT

The maximum bit rate for data path is degraded due to the dispersion effect in fiber. Maximum bit rate is calculated using equation [3.19] for a penalty of 1 dB and 2 dB. The plot for bit rate is shown in Fig 4.8. Here bit rate is expressed in Mb/s and dispersion in ps.

From the figure, it is clear that as dispersion increases maximum possible bit rate decreases and the rate is different for different dispersion penalty. Here we have done the simulation for two normal penalty considerations 1 dB and 2 dB. If we go for 1 dB penalty, i.e. the maximum dispersion penalty allowed is 1 dB, and then the maximum value of bit rate is less compared to the value corresponding to a 2 dB penalty case.

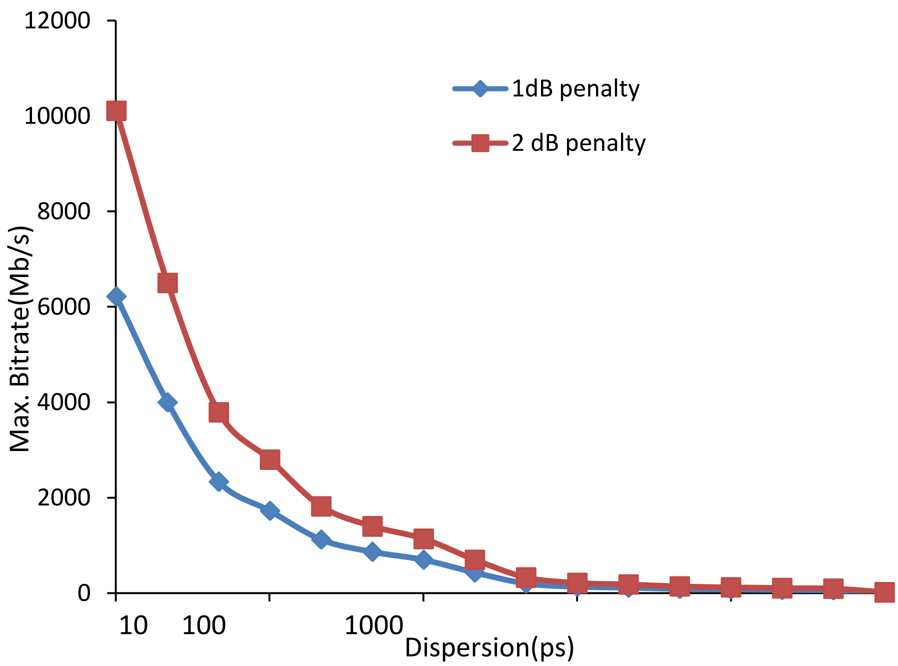

Fig. 4.8: Max. Bit rate v Dispersion for different penalties

We have plotted bit rate for various dispersion values and from the figure it is clear that as dispersion increases beyond 100 ps, then the maximum possible bit rate reduces abruptly.In the similar way, maximum possible length of the fiber without degradation of the signal also reduces due to dispersion effect. As dispersion increases, signal degradation will be more in the fiber and hence maximum length of the fiber reduces. The effect can be more clearly understood from the plot given as Fig 4.9. Even in the case of dispersion compensated fibers, a minimum dispersion is present, i.e. we can’t eliminate the dispersion completely from the fiber. Here for simulation dispersion values from 2 ps to 250 ps is considered and the length of the fiber is represented in km. for a fiber with dispersion 30 ps, the maximum possible length the fiber can carry data without considerable degradation is around 800 km.

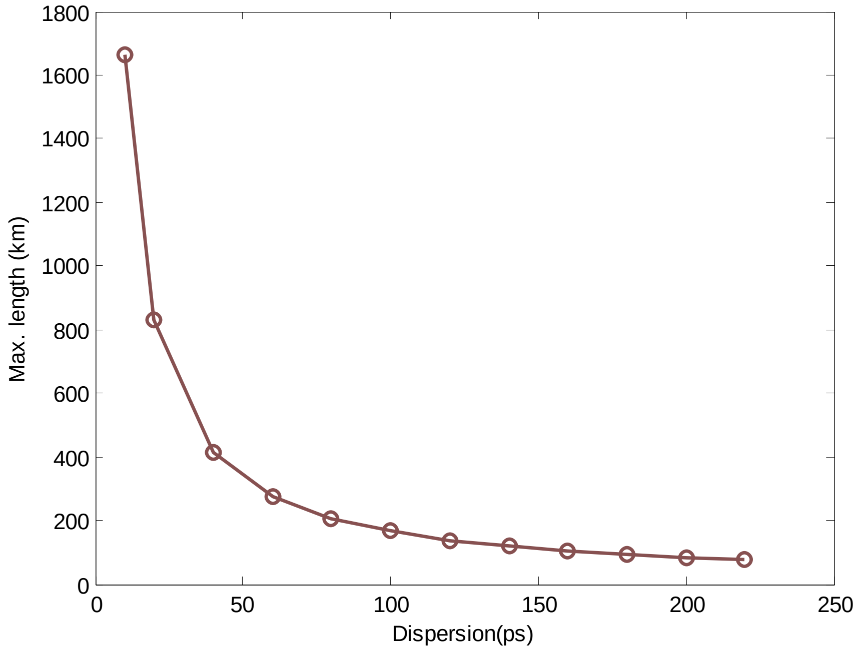

Fig. 4.9: Max. Length of fiber for different dispersion values

Dispersion penalty v fiber length for different bit rate is plotted as shown in Fig. 4.10. Here three bit rate is used for simulation. .79 Gb/s, 1.56 Gb/s and 2.11 Gb/s. Dispersion penalty corresponding to the length of the fiber is shown. Minimum penalty is the optimum case. For a bit rate of .79 Gb/s, penalty reaches a value of .7 dB at a length of 160 km only. So more length can be established with this bit rate before attaining a penalty of 2 dB. In the case of path with bit rate 1.56 dB, 2db penalty is reached after 130 km only. But for bit rate 2.11 Gb/s, the path reaches 2 dB penalties at 60 km itself. From this it is clear that as penalty requirement decrease the possible length of the fiber and the bit rate reduces. Here for light path provisioning, we have assumes that all the light path should have a penalty less than 2 dB which ensure signal quality guaranteed reception at the receiver side of the optical system.

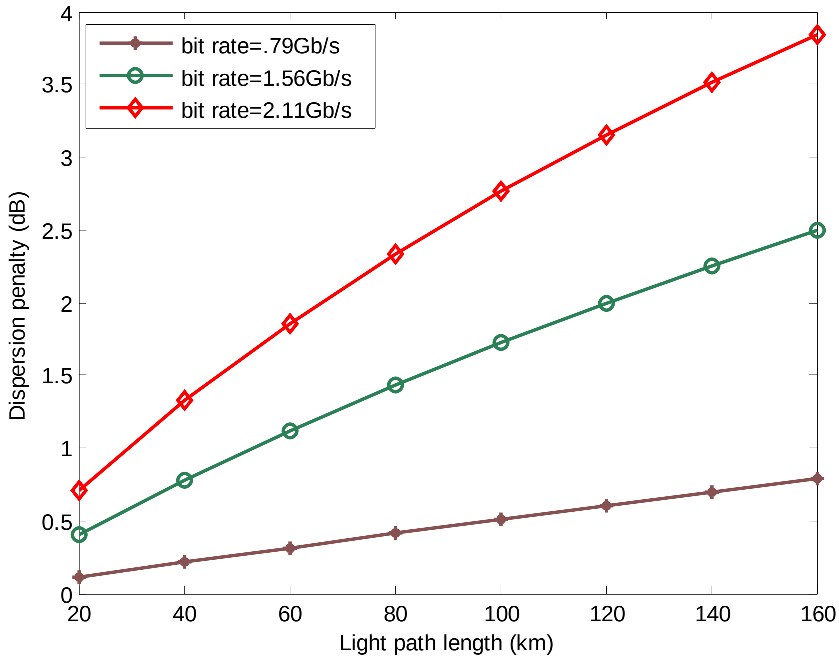

Fig. 4.10: Dispersion penalty for different bit rate

4.7 RESULTS OFDISPERSION PENALTY COMPUTATION

The network model used for simulation is same as given in Fig 4.1. Assume that we have a connection request with *(s, d)* pair (4, 7). In this work, we have considered all possible paths available between source and destination in the given network model. For computing dispersion penalty values foe 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 11 possible paths between (4, 7) and the bandwidth associated with this paths is shown in the form of bar graph in Fig 4.11. Bandwidth is given in GHz. From the plot, we can understand that the light path with reference number 1 is the path with maximum bandwidth which is the optimal condition. This is the shortest path among all possible path and for the longest path, i.e. with reference number 11, bandwidth is minimum. Paths with reference number 2 and 3 also provide considerable bandwidth.

The computed dispersion penalty in dB is plotted as shown in Fig 4.12. The path with penalty less than or equal to 2 dB only taken for provisioning. Here for *(s, d)* pair (4, 7), only path satisfies the dispersion requirement hence only one path is available for routing.

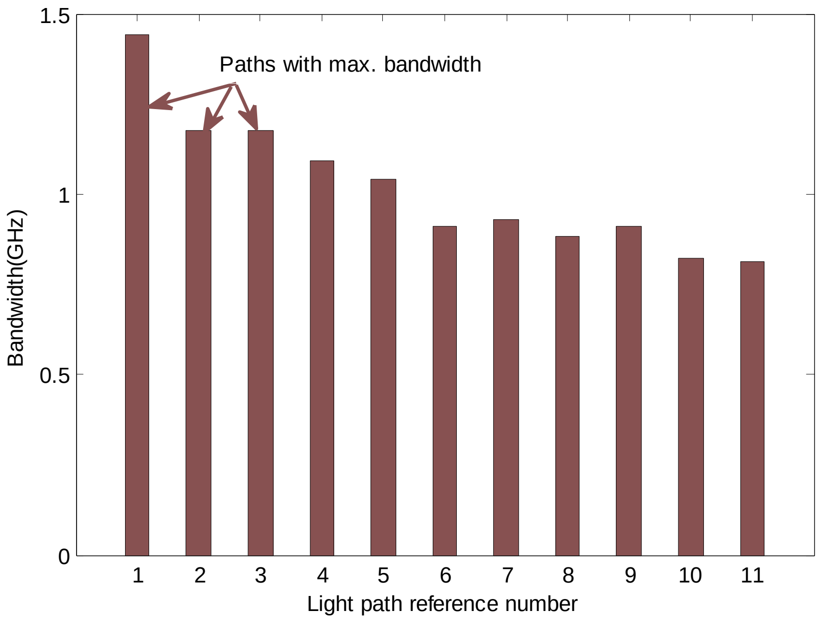

Fig. 4.11: Computed Bandwidth for all possible paths of (s, d) pair (4, 7)

4.8 RESULTS OF BLOCKING PROBABILITY COMPUTATION

The performance of the algorithm is analyzed by calculating blocking probability for the incoming connection requests. Assume that we have to establish eight connection requests from source 4 to destination 7. We got 11 possible paths for this *(s, d)* pair. But we have only one path available for light path provisioning satisfying the penalty requirement. We have multiplexed each link with six different wavelengths. Hence six connections can be established in the above example by considering single light path for routing. Remaining two

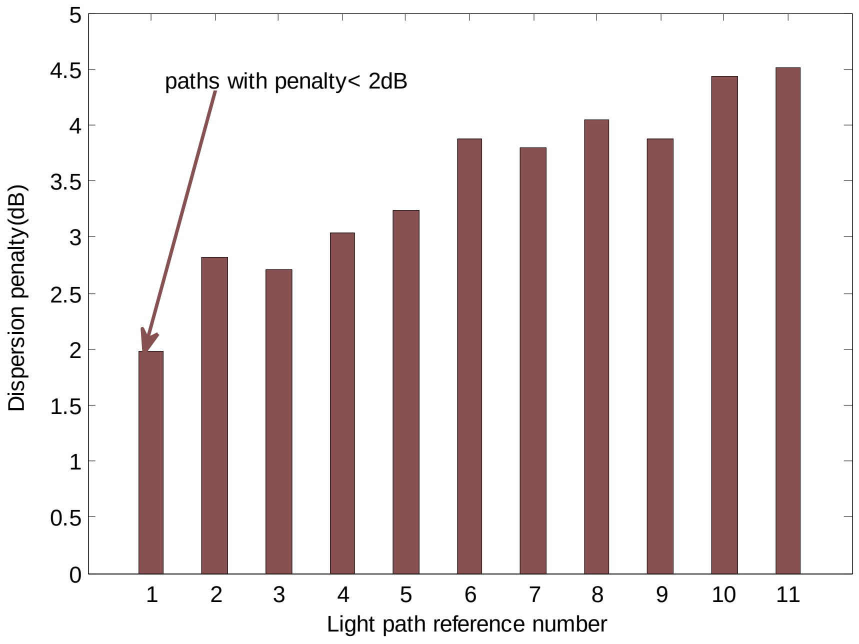

Fig. 4.12: Computed penalty for all possible paths of (s, d) pair (4, 7)

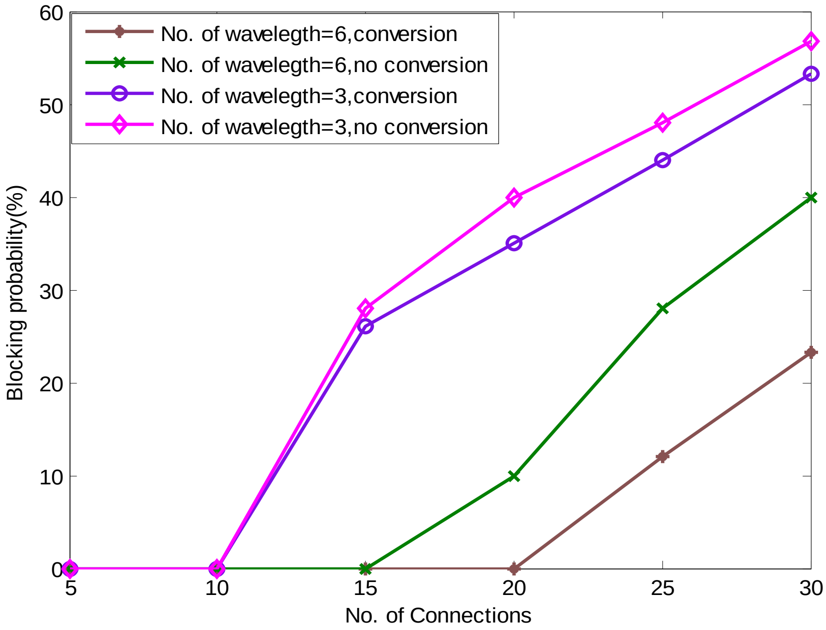

Fig. 4.13: Blocking probability plot for various no. of connections

connection request are blocked. We have repeated the simulation using three wavelengths for multiplexing. In this case five calls are blocked and blocking probability is more i.e. when the number of wavelength increases the effective number of possible data path increase and then blocking reduces.

Here simulation repeated for two different wavelength assignment methods-with wavelength conversion and without wavelength conversion. We have taken connection requests from with different *(s, d)* pair but all have same dispersion penalty requirement. When we include wavelength conversion technique, blocking for incoming connections reduces because of the availability more effective light paths in the network. Here provisioning is done considering the penalty requirement and the present traffic in the network.

Chapter 5

CONCLUSION

5.1 CONCLUSION

We have presented a dynamic light path provisioning algorithm that determines the condition when to provision light path connections or remove existing ones in a WDM network. Here we have considered both Q-Factor and dispersion penalty based mechanism for the provision of an optimal light path connection as per the client requirements. By principle, if the light path connection is provisioned by Q-Factor mechanism, we can ensure a QoS satisfied light path for the connection request.If we are going for the provisioning based on dispersion penalty, it guarantees signal quality guaranteed received signal for the system. What makes the algorithm unique is the fact that it performs traffic engineering at the provider edge router of provider layer, which manages the provisioning and de-provisioning of light path connection by traffic control manager (TCM). This TCM performs a global optimization based upon two criteria namely *i*) Q-Factor requirements, ii*)* Dispersion penalty for the light path.We have considered a 10 node network topology as per our convenience and simulated our mechanisms. We have compared the simulation results for both the cases of traditional shortest distant and the proposed disjoint path method. In the case of disjoint path algorithm the availability of resources is high, so the blocking probability for the connection requests is significantly improved compared to the shortest distance method. The proposed mechanisms for light path provisioning are based on the quality requirement of the client and the available resources, which can provide a guaranteed source to the end customer.

5.2 SCOPE OF FUTURE WORK

The proposed algorithm can be extended for route restoration during link failure time. In future we are planning to extend our work for the enhancement of light path application during link/path failure conditions and for dead line driven request light path provisioning. In the work, we have considered static light path provisioning technique; we can extend the work for dynamic light path provisioning.

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