QoS for the Selection of OVPN Connection and Wavelength Assignment

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Communication and Network

by

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Department of Electronics & Communication Engineering

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CERTIFICATE

This is to certify that the thesis entitled, "**QOS FOR THE SELECTION OF OVPN CONNECTION IN WDM NETWORK AND WAVELENGTH ASSIGNMENT**"*submitted by* GYANARANJAN NAYAK *in partial fulfilment of the requirements for the award of Master of Technology degree in* **Electronics and Communication Engineering** *with specialization in* "**COMMUNICATION AND NETWORK**" *during session 2013-2014 at National Institute of Technology, Rourkela (Deemed University) and is an authentic work by him 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

Optical networking is a promising solution to the increasing bandwidth requirements of today's communication networks. The never-ending challenge is to look for the technology which improve network capacity, consistency and cost. So QoS for the optical virtual private network (OVPN) using wavelength-division multiplexing (WDM) is having an important role in telecommunication application. Our proposal deals with a centralized OVPN control manager which can be defined by various network and physical layer parameters. Further these parameters are used by optical virtual private network control manager for the calculation of Q-factor of OVPN connections. Then among them it selects an OVPN connection which is best in quality so that it will satisfy the requirement of client which is attached to the network. The network layer parameters and the physical layer parameters have impact on quality of connection. This is known as physical layer impairments constraints. The effect of them can be analyzed. It is important to consider the process, which provide network and physical layer impairment information to OVPN control manager. In this work, the discussion is based on the improvement in blocking probability with the use of the proposed and the shortest path algorithm and wavelength assignment for routing purpose.

Chapter 1

Introduction

Chapter 1

Introduction

The major demand placed on telecommunications systems is for more information carrying capacity. Because the volume of information produced increases rapidly.

$$C=BW*log_2(1+SNR)$$

C is information carrying capacity (bits/sec), BW is link bandwidth (Hz), SNR is the signal to noise power ratio. The estimated bandwidth of a single fiber optic communication link is far more than that of the coaxial cable or any other available transmission medium. It facilitates the signals to travel long distances with low scale attenuation at high speed. Due to this reason optical fiber communication systems are widely used.

1.1 WDM /DWDM Network

This type of network reduces the burden on the underlying electronics. In recent years the optical networks have provided more functions than point-to-point communication. The supportable bandwidth in an optical network is in the range of Tera bits. Subsequently, it becomes more difficult for the electronics to process the data. In first generation networks, the electronics at a router not only handle the data intended for that but also all the data that has to be passed through that for some other router. Hence burden on the underlying electronics increases. That means we need faster electronic switching circuit, which can operate in the Tera bit range. But electronic circuits have some limitation and till date its maximum speed is in the Giga bit range. Hence 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. Another problem with these networks is that they are not scalable to satisfy future demands. To overcome these drawbacks people go for all optical/transparent networks, which are more scalable, consumes less power and has higher data carrying capacity. The all-optical WDM/DWDM network eliminates [1] the conversions between electricity and light.

DWDM is the most innovative and advanced technology in fiber optic communication system due to its potential ability to provide huge bandwidth over a single fiber channel. The difference between WDM and dense wavelength division multiplexing (DWDM) technology is fundamentally same. In DWDM, the wavelengths are more closer so large number of wavelengths can be multiplexed, and hence overall capacity of fiber will be more. One of the important features of DWDM technology is that it can amplify the entire wavelength simultaneously without converting them to electrical signals and it can carry signal of different speed and type simultaneously through the fiber.

1.2 Quality of Service in OVPN

While making the entire routing decision, network layer assumes that my physical layer is ideal, i.e., it does not have any impairment. But in reality physical layer has a lot of impairments, which significantly affect the signal quality during transmission from source to destination. Hence in order to guarantee a QoT/QoS on the light path, some sort of cross layer optimization methods are followed, where the network layer takes these impairments from physical layer into their consideration. The paper [2] proposed a cross layer model, where the physical layer module model the impairments effects and keep track of them. The QoT/QoS is measured analytically at the physical layer module and this information is provided as a feedback to the network layer module. Network layer after getting the information take the decision for the selection of light-path, whose signal quality is guaranteed. We defined the light-path as OVPN connection (OVPNC).

1.3 Physical Layer Impairments

Impairments in WDM/DWDM networks have been classified into two categories: linear and non-linear impairments [3, 4, 5]. This classification is based on the dependence on intensity of light. Linear impairments are static in nature and 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. So in an optical network, allocation of new light-path affect the existing light-path. Figure 1.1 shows different impairments in WDM/DWDM networks.

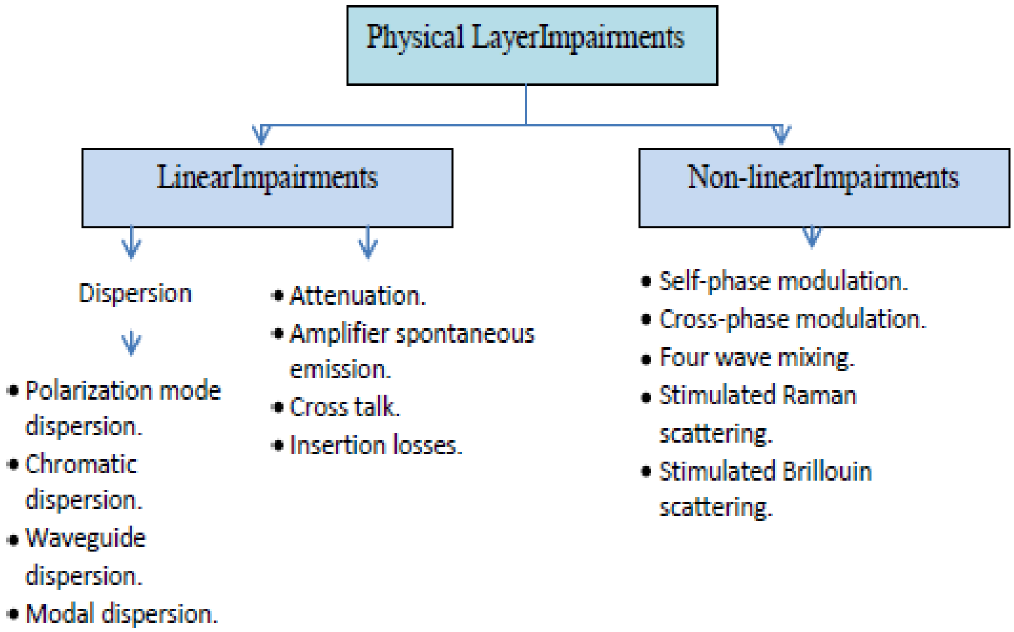


Fig: 1

1-Dispersion in fiber:

In this work, we considered the various types of dispersion in fiber. We have considered the Q-factor in terms of bandwidth and delay which are affected due to different dispersions. The dispersion effect is more at high speed channels. The broadening of pulse is shown in Fig. 2. 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).

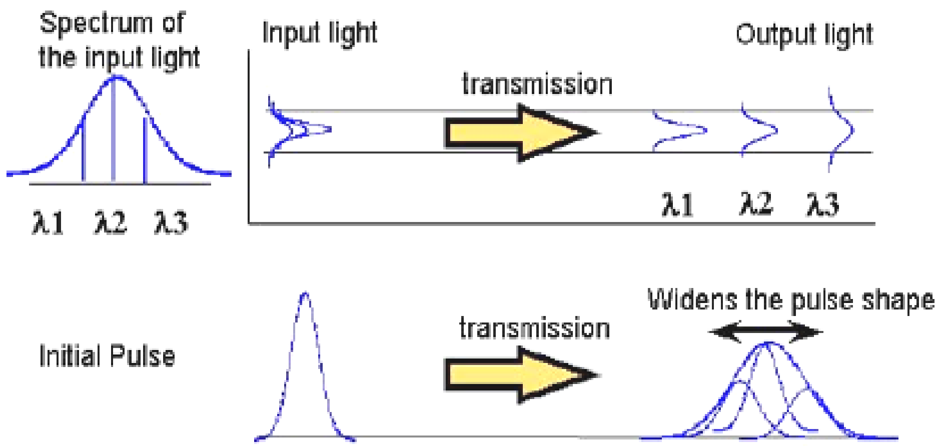


Fig. 2: dispersion in pulse broadening

Chromatic Dispersion (CD):

Intra modal 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 [6]. 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 [6]. The pulse spreading introduced due to chromatic dispersion can be expressed as $TCD=DCD*\lambda*L$ where *DCD* is the dispersion coefficient, L is the 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 [7-9].

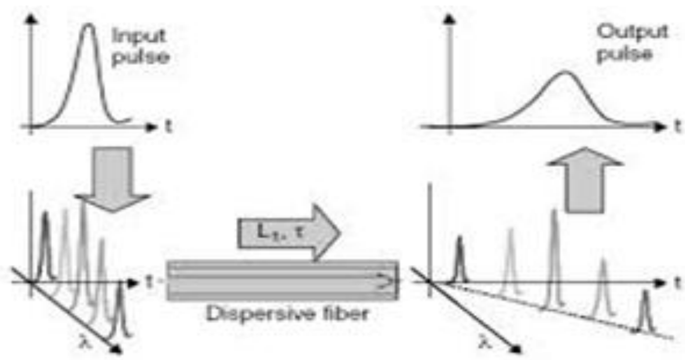


Fig-3

Modal dispersion:

Pulse widening caused by the mode structure of a light beam inside the fiber is called modal dispersion.

Waveguide dispersion:

Another mechanism contributing to intra modal dispersion is waveguide dispersion, which develops when the propagation constant is dependent on wavelength. Waveguide dispersion is caused by the fact that is guided by a structure.This type of dispersion doesn't exist in an open medium.

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.

3-Self phase modulation(SPM):

Another non-linear effect is Self-phase modulation (SPM) which is due to the interaction between light and matter. A short light pulse, which is travelling through a medium, introduces variation in refractive index of the fiber. when pulse travelling through the fiber, the higher intensity portions of a light pulse encounter a higher refractive index of the fiber compared with the lower intensity portions. This refractive index variation 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.

4-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.

5-Four wave mixing(FWM):

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.

6- 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 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. The total impairment factors in optical medium are organized.

Chapter wise contribution of the Thesis

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

Chapter-2

AN INTRODUCTION TO WDM NETWORK

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, each channel in the same fiber can carry any transmission format, may be digital or analog or may be with different bit rates [10].

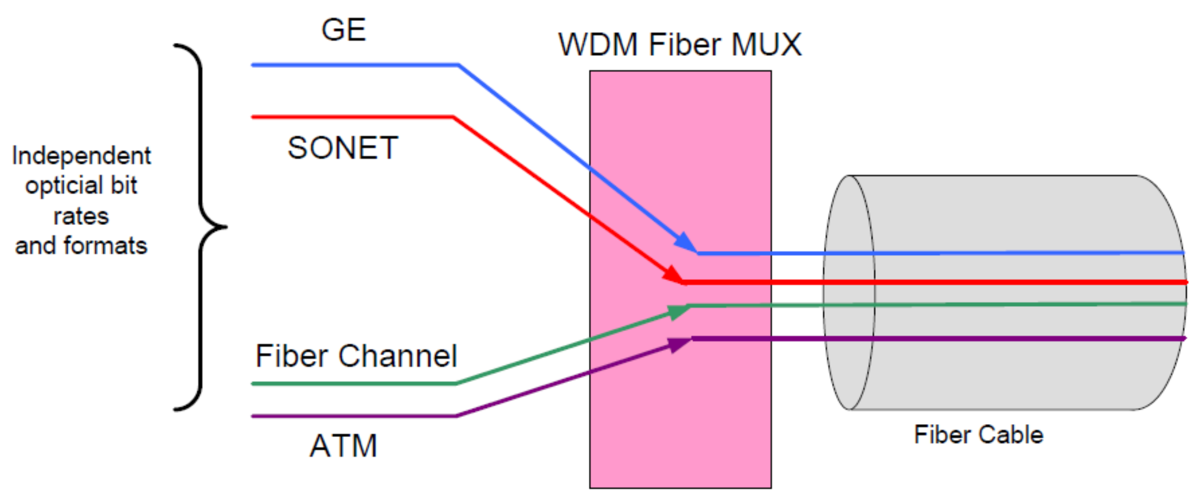


Fig. 3:WDM multiplexing technique

The two most important wavelength gaps are 1310 nm to 1550 nm.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 1

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

Table 1

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 technology the 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 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.

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.

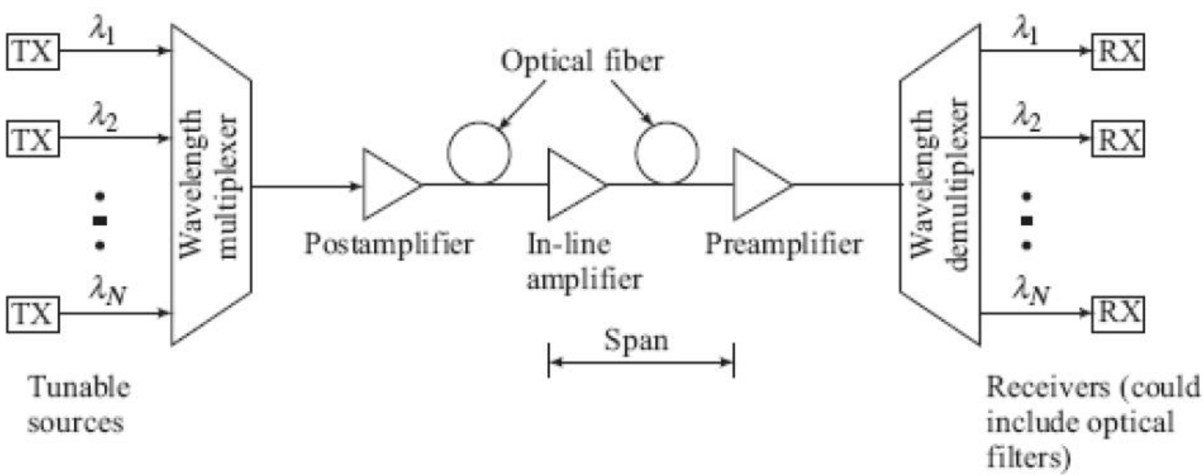


Fig.4: Components of WDM system

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 [11]. 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 [12]. The transponder functioning is given in Fig.

2.2.1. 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.

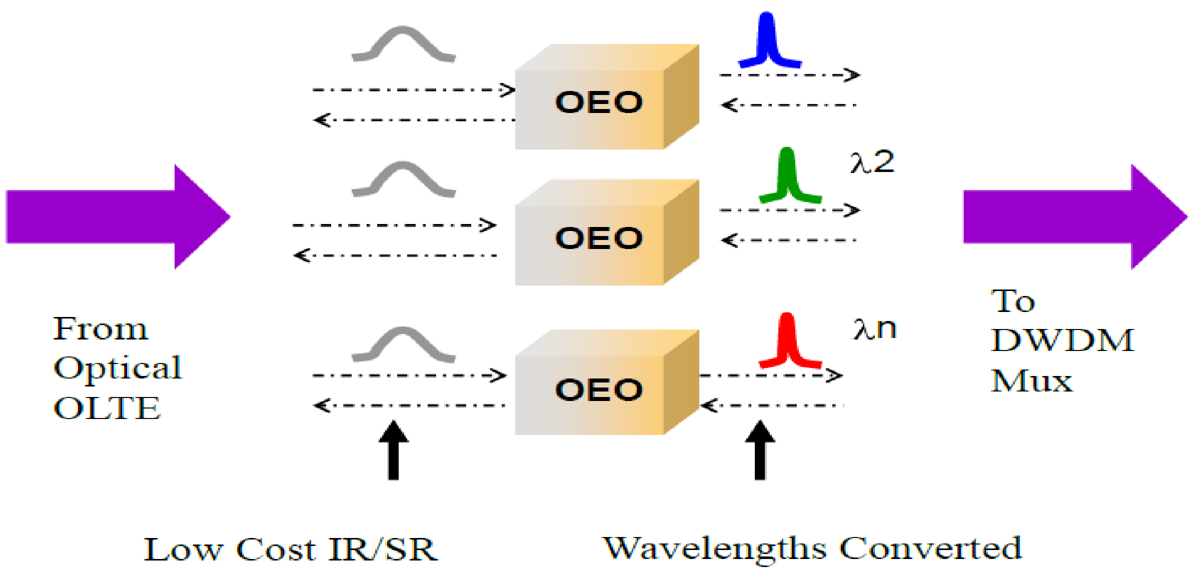


Fig. 5:OEO conversion within the transponder

2.2.2. 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 for several 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

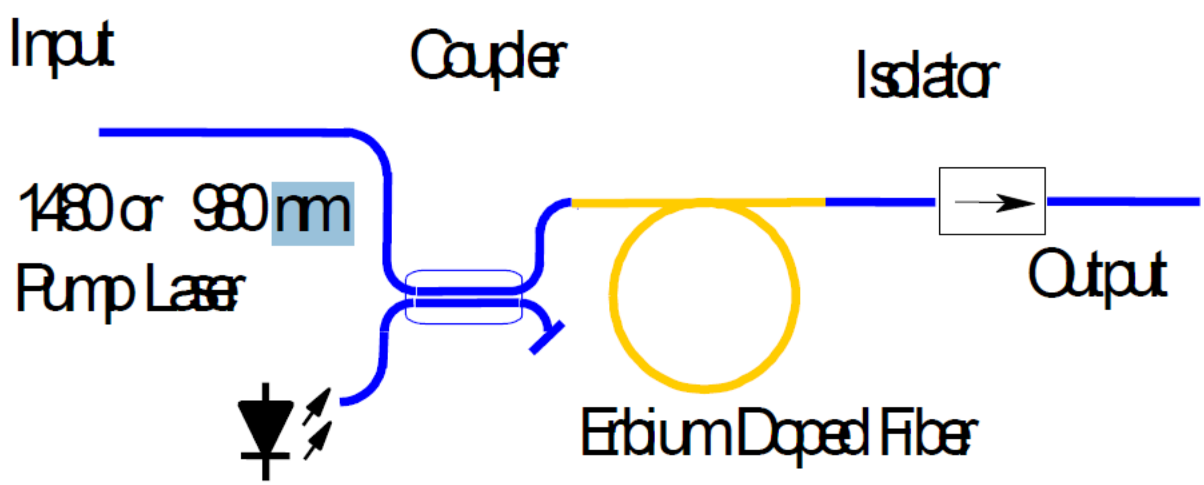


Fig. 6 Erbium doped fiber amplifier

2.2.3. 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. 2.5

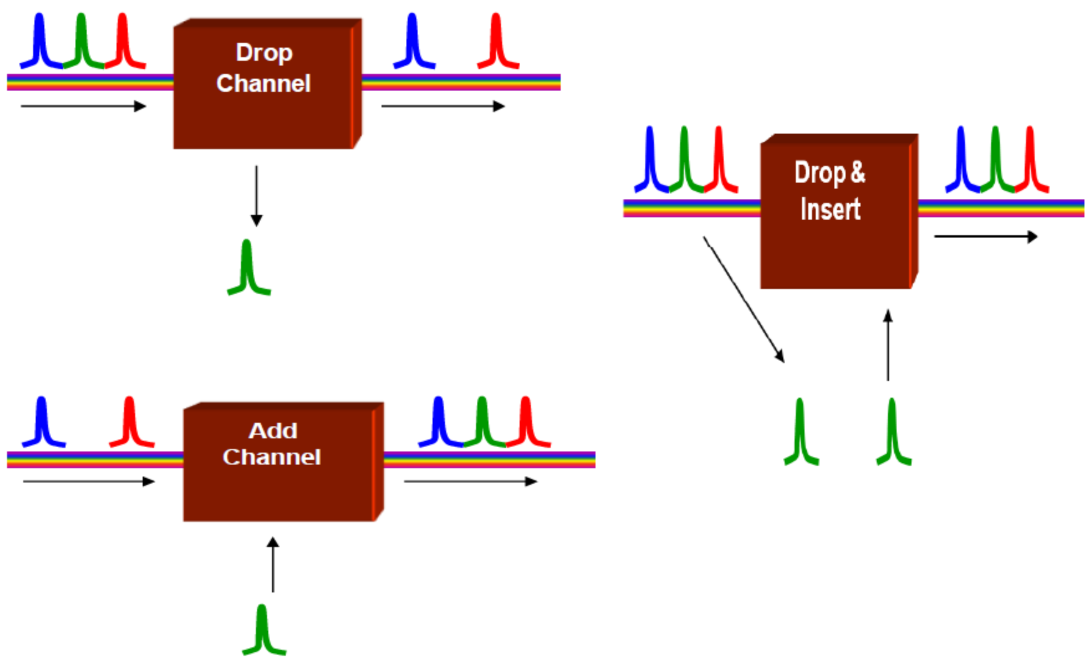


Fig.7:OADM model in WDM system

All-Optical WDM Networks

The WDM technology exploits the bandwidth capacity of optical fibers whereas multiple wavelengths can be transmitted simultaneously over a single fiber. Each wavelength is capable of carrying traffic streams at Gb/s rates, thereby providing a single fiber with a total throughput in the range of Tb/s. In a wavelength-routed optical network, each connection between a pair of nodes is assigned a path and a unique wavelength through the network. A connection from one node to the other, established on a particular wavelength as an all-optical path, is referred to as lightpath and may span multiple fiber links. Connections with paths that share the same link in the network are assigned different wavelengths [13]. Under these conditions, optical cross connects (OXCs) are employed to route and switch different wavelengths from an input port to an output port. A sample topology for a wavelength-routed WDM is shown in Figure.2.6.

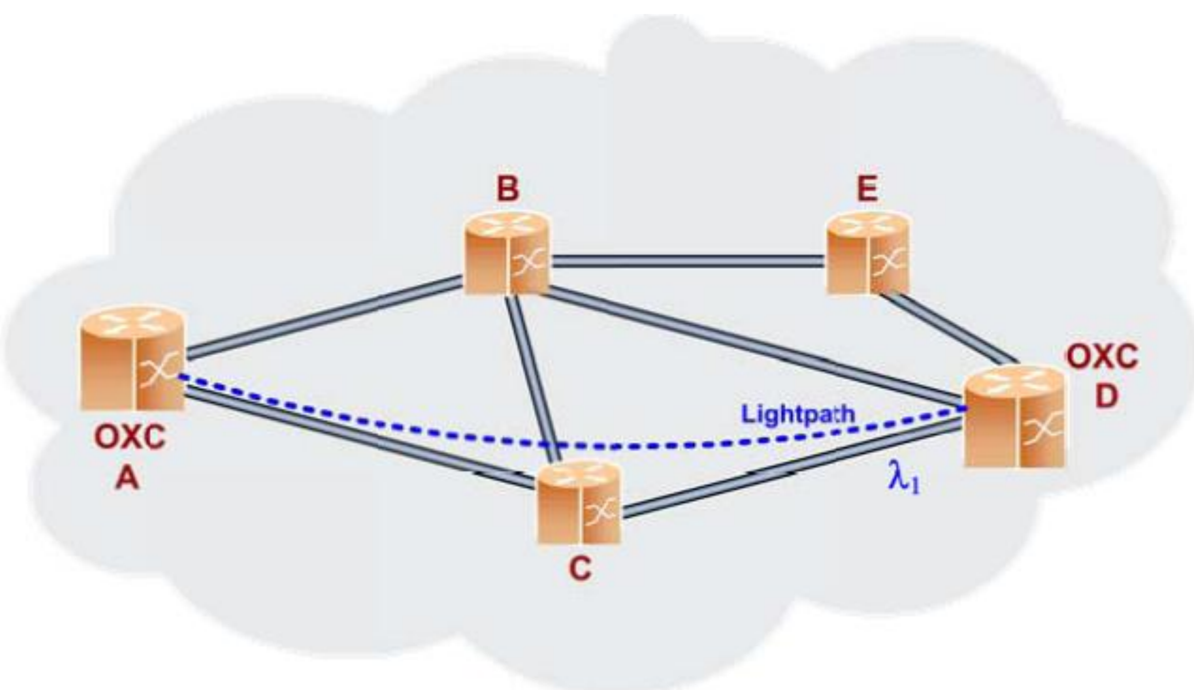


Fig.8 Sample wavelength routed WDM network

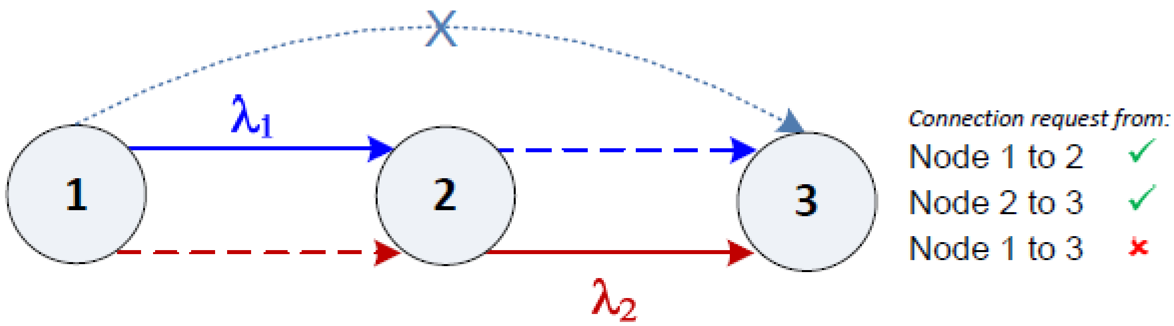


Fig.9 Wavelength continuity constraint

By allowing multiple WDM channels to coexist on a single fiber, the effective establishment of lightpaths in the network becomes crucial and the challenge resides in optimizing resources utilization and network performance.

2.3 Routing and Wavelength Assignment (RWA) Problem

Routing and wavelength assignment (RWA) is one of the most important problems in wavelength-routed WDM networks. For a lightpath to be established between a source and a destination node, the network must decide on the physical route and assign an available wavelength on each link before data can be transmitted. However, due to the limited number of wavelengths available on each fiber link as well as the wavelength-continuity constraint [14], the network may not be able to accommodate all connection requests. Therefore, applying an efficient routing and wavelength assignment (RWA) algorithm becomes crucial for achieving good network performance and a lot of work has been carried out on this issue [15]. The problem of establishing lightpaths by routing and assigning a wavelength for each connection request is called the Routing and Wavelength Assignment (RWA) problem [15]. With a good solution to the RWA problem, more connection requests can be accommodated by the network and fewer requests will be rejected during periods of congestion.

We identify two different types of connection requests: static and dynamic [16]. For static network traffic, the set of connections is known in advance and the objective is to establish a set of lightpaths to accommodate all the connection requests while minimizing the number of wavelengths used. Different approaches already exist for the static RWA problem and a summary of schemes and algorithms was presented in [16]. On the other hand, in the case of dynamic traffic, connection requests arrive and depart from the network dynamically in a random manner. A lightpath is set up for each connection request as it arrives and released when data transfer is completed. In this work, we consider dynamic traffic and focus our discussion on the dynamic routing and wavelength assignment problem. The objective of the RWA problem is to route and assign wavelengths while minimizing the blocking probability of incoming requests or maximizing the network throughput. Unlike the static RWA problem, a dynamic RWA should make routing and assignment decisions as connection requests arrive to the network [15]. Due to the complexity of this combined approach and in order to design efficient algorithms, the problem is divided into two sub problems to make it more tractable: the routing and the wavelength assignment sub problems.

2.4 Routing Algorithms

In the routing aspect, there are three basic types of routing approaches: fixed routing, fixed alternate routing, and adaptive routing. The routing algorithms classified as static do not vary with time while the dynamic models referred to as adaptive algorithms use network state information at the time of connection request.

2.5 Fixed Routing

In fixed routing, there is only one fixed route between a source node and a destination node. In Figure 2.8, the fixed-route from Node 1 to Node 4 is illustrated. In general, this path is pre computed using a shortest path algorithm such as Dijkstra's algorithm.

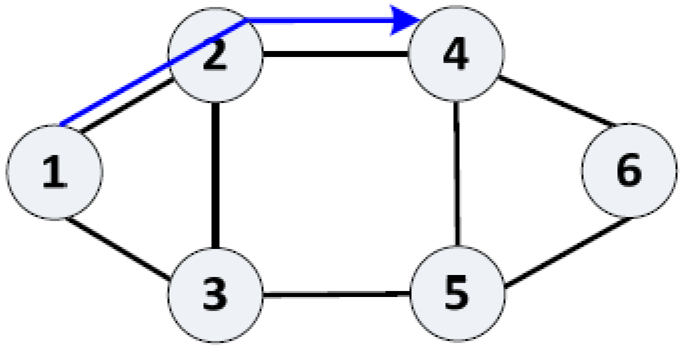


Fig. 10 Fixed routing from node 1 to 4

In this case networks try to found lightpath between two nodes when a request arrives from source node to destination node. If there is no common wavelength present in the link then connection is blocked even though other paths may present.

2.6 Fixed-alternate routing

Fixed-alternate routing is an extension of the fixed path routing. It consists in defining a set of alternate routes for each source-destination pair stored in a routing table - containing fixed routes to each destination node. For instance, Figure 2.9 shows a primary route (solid line) between source node 1 and destination node 4 and an alternate route (dashed line) that does not share any links with the first route. The routing table is ordered by the number of hops to destination, the shortest path being on top.

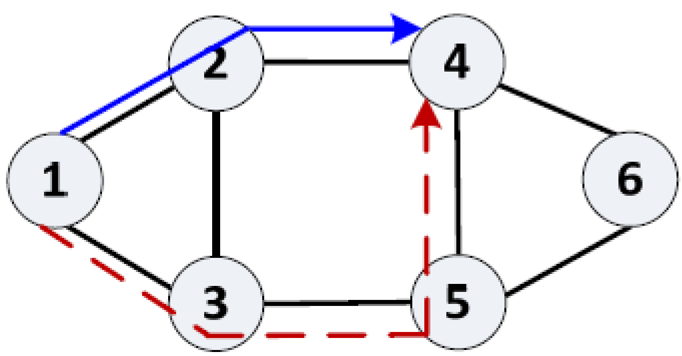


Fig 11 Fixed routing (solide line) and alternate routing(dotted line) from node1 to 4

If the attempt to establish the connection on each of the routes from the routing table in sequence fails, the connection request is blocked. Compared to fixed-routing, this approach reduces the connection blocking probability. The major issue with both fixed routing and fixed-alternate routing is that the current state of the network is not taken into consideration. If predetermined paths are not available, connection requests are blocked even though other paths may exist. For this particular reason, most research conducted on RWA algorithms focuses on adaptive routing techniques.

2.7 **Adaptive routing**

In adaptive routing, there is no restriction on the route selection from a source node to a destination node and routing is based on the current wavelength availability on each link [17]. The route from a source to a destination node is selected dynamically based on the network state, which is determined by the set of all existing active connections. Adaptive algorithms are executed once a connection request arrives and are found to mainly improve network performance [18]. A number of RWA algorithms for dynamic traffic have been proposed [17] including the fixed-shortest-path, the K-shortest-path, the least-congested-path and the least-cost-path routing algorithms. A comparison of these routing algorithms is given in Table 2.2

Routing Algorithm		Advantage	Disadvantage
Fixed-shortest-path	Uses the pre-computed shortest path route	○ Simple implementation ○ Shorter connection setup time	○ Higher blocking probability due to strict restriction on routing ○ Its performance degrades as traffic load increases
K-shortest-path	Uses the first K-shortest path routes	○ Simple implementation ○ Shorter connection setup time	○ Reduced blocking probability compared to Fixed-shortest-path ○ Degraded network performance due to restriction on routing
Least-congested-path	Selects the route with the least congestion (measured in terms of number of wavelengths available on the link)	○ Improves network blocking probability	○ Computational complexity ○ Setup delay
Least-cost-path	Selects the route with the least cost (measured in terms of hop counts)	○ Improves network blocking probability	○ Computational complexity ○ Setup delay

Table-2 Adaptive Routing algorithms

A form of adaptive routing, as shown in table 2, is the Least Congested Path (LCP) routing .

Least Congested Path (LCP) Algorithm

In the Least Congested Path (LCP) algorithm, a lightpath is routed on the least-congested path from among a set of possible routes between a source node and a destination node. The congestion on a link is measured in terms of the number of available wavelengths on the link. As the number of available wavelengths on a link decreases, the more congested it is considered. And the congestion on a route is measured based on the congestion on the most congested link of the route [17]. When a connection request arrives to the network, LCP starts by computing the congestion on all possible routes in the network and selects the least congested one. In case multiple routes have the same congestion level, then the shortest-path is selected. Thus, the wavelength allocated on the least congested path is the first wavelength that is available along all the links in this path. Selection of the least congested path among available paths from source to destination can improve the blocking probability of the network. Let us consider a sample network in Figure 1.5 with a connection request arriving at node A and addressed to node D. And suppose that the wavelength usage on each link is as shown in the figure 1.5. To establish this lightpath, we can identify four alternate routes from source node A to destination node D, denoted as A-B-C-D, A-B-E-D, A-F-E-D and A-F-E-BC-D. The congestion on these routes is given in table 2.3.

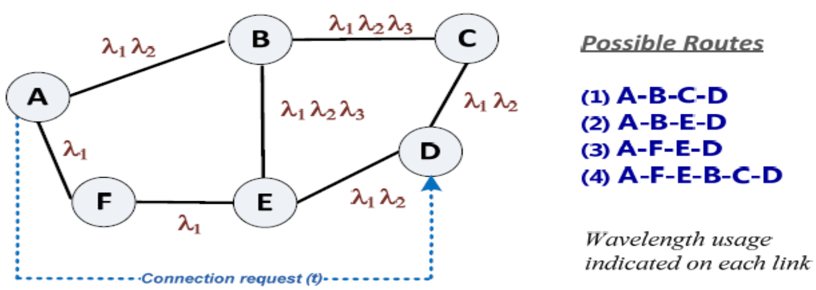


Fig-12

As a result, the connection request will then be established on the path having the largest number of wavelengths available. In this case, the LCP algorithm will select route A-F-E-D for establishing the lightpath as shown in figure

Path	Route Congestion
A-B-C-D	3
A-B-E-D	3
A-F-E-D	2
A-F-E-B-C-D	3

Table 3 Route congestion in sample network for LCP

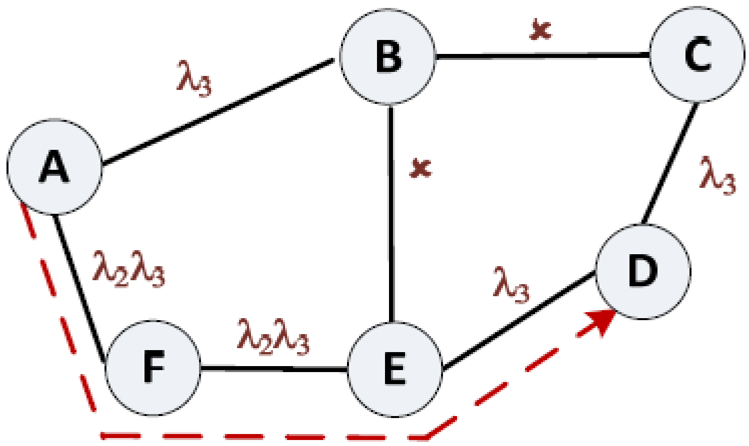


Fig 13 Least congested path. Available wavelengths are shown on each link.

Once the route is selected, a wavelength assignment algorithm is used to assign an available wavelength for the connection. For instance, in our example the selected route A-F-E-D, with available wavelengths as shown on each link in figure 3.1, allows the connection request from A to D to be established on the available wavelength λ_3.

A disadvantage of LCP is its computational complexity as it requires congestion levels to be computed on all possible routes in the network. However, it is also shown [16] that it performs much better than fixed alternate routing in terms of overall blocking probability in the network.

Wavelength Assignment

Numerous wavelength assignment schemes have been devised over the years, from Random to First-Fit, Least Used and Most-Used. Among the four techniques discussed in this section, we will focus on a particular scheme that proved to be effective in studying the RWA problem, the First-Fit algorithm.

– Random Wavelength Assignment (R) searches the network to determine the set of all available wavelengths on the required route for establishing the connection. Next, a wavelength is randomly selected from the set according to a uniform probability distribution.

- Least-Used (LU) selects the wavelength that is the least used in the network, thereby attempting to balance the load among all the wavelengths. The performance of this scheme degrades as additional requests are introduced since it satisfies only connection requests that traverse a small number of links.

- Most-Used (MU), as opposed to LU attempts to select the most-used wavelength in the network. It outperforms LU significantly as it tries to maximize wavelength utilization by packing connections into fewer wavelengths and conserving the available capacity of less-used wavelengths.

Wavelength Assignment Algorithm		Advantage	Disadvantage
Random	Chooses an available wavelength randomly	○ No communication overhead	
Least-Used	Selects least used wavelength in the network		○ Communication overhead ○ Additional storage and computation cost
Most-Used	Chooses the wavelength that is most used in the network	○ Outperforms the Least-Used	○ Communication overhead ○ Additional storage and computation cost
First-Fit	Selects the available wavelength with the lowest index	○ No communication overhead ○ Low complexity ○ Performs well in terms of blocking probability	

Table 4

First-Fit (FF) Wavelength Assignment

In the network, each wavelength is assigned an index from 1 to W, W being the maximum number of wavelengths supported on a single fiber. Whenever wavelength assignment is needed, the search for an available wavelength proceeds. First-Fit is a simple wavelength assignment scheme that requires only knowledge of the links along the route. It searches for available wavelengths starting with the lowest index to the highest index in a fixed order and the first available wavelength found is selected for the lightpath. The main idea behind this scheme is to allow high numbered wavelengths to contain longer continuous paths. In order to illustrate the wavelength assignment schemes, let us consider the sample network given in Figure with four wavelengths (λ1, λ2, λ3 and λ4) on each fiber link. We assume that four connections are already established in the network as shown in the figure A-B-C, B-C-D, B-E and A-B-E.

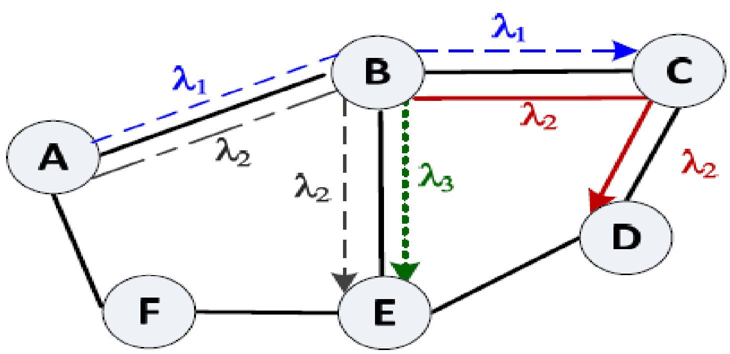


Fig-14

A connection request arrives at node A to be routed to node D, and the path A-F-E-D is selected. Thus, each of the wavelength assignment algorithms presented in this section will search the wavelengths in a different order and select a different wavelength for the lightpath as explained in table 2.5

WA Algorithm		Selected Wavelength
Random	Searches in random order, for example: λ_3, λ_2, λ_1,λ_4	λ_3
Least-Used	Searches in the order: λ_4, λ_3, λ_1,λ_2	λ_4
Most-Used	Searches in the order: λ_2, λ_1, λ_3,λ_4	λ_2
First-Fit	Searches in the order: λ_1, λ_2, λ_3,λ_4	λ_1

Table 5

Chapter-3

System Design

3.1 SYSTEM MODEL

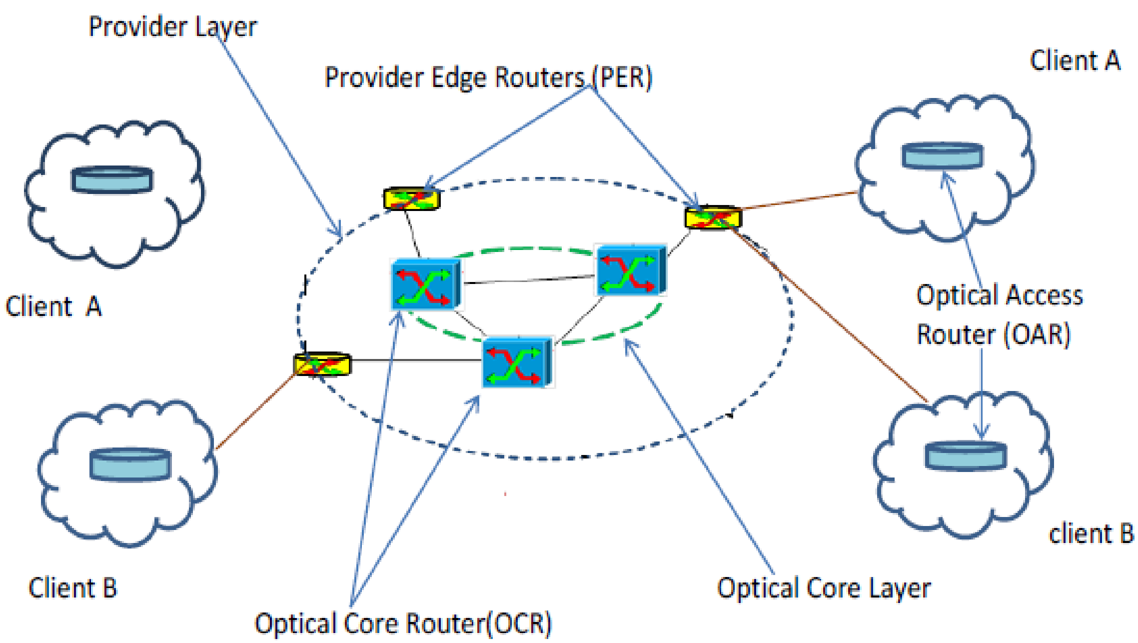


Fig-15 Physical Topology

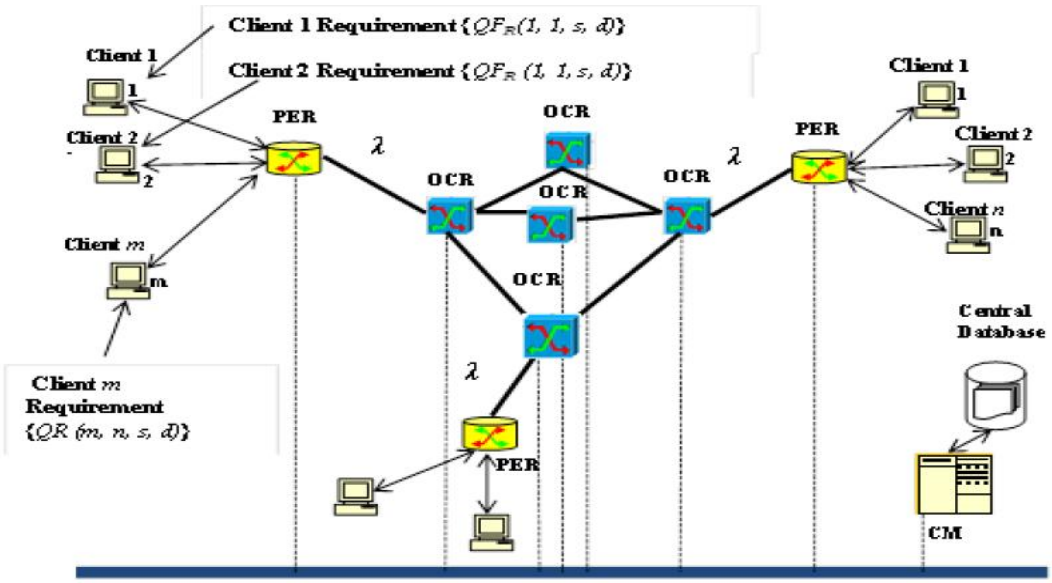


Fig-16

Connectivity in a system:

Assuming the network has R number nodes/routers. The connectivity is the connection between two nodes and is also known as a link. If there is a link present, then the connectivity is taken as '1' otherwise it is taken as '0'. Using this connectivity matrix, OVPNC can be computed using standard routing algorithms. If (i, j) is the node/router pair, then the connection metrics.

$T(i,j)$ can be represented as

$$T(i,j) = \begin{cases} 1 & \text{If link exist between link } (i,j); \\ 0 & \text{Otherwise.} \end{cases}$$

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

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

3.2 PROBLEM FORMULATION

Assume every client end point is attached to at most one PER. In Fig., 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 QFR (m, n, s, d)is the required Q-Factor, then, it can be formulated as follows [19].

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

Bandwidth for a link (i , j):

Assume the physical layer constraints are dispersion coefficient and link length. If DPMD (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].

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

Where σ represents the pulse broadening factor

Time Delay for a link (i, j):

Delay due to the effect of polarization mode dispersion:

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

Where DPMD (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:

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

Where DCD(i, j) is the dispersion coefficient and λ(i, j) is the wavelength assigned for the link with length L(i, j).

Delay due to modal dispersion:

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

V is the cut off wavelength and can be calculated using the expression given below

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

Total Delay:

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

Total Delay:

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

Q-Factor :

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

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 [20] as follows.

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

If

$$QF_R(m, n, s, d) \leq QF_C(m, n, s, d)$$

Then the connection request will be blocked

Chapter-4

Simulation Results and Discussions

4.1 Simulation Results and Discussions

We use MATLAB for all over the simulation work. This section explains the simulations for 1) Q-Factor and wavelength assignment mechanism and 2) performance analysis in terms of blocking probability.

4.2 Assumptions

1)NSFNet topology of 10 nodes and 16 links, shown in Figure

2) Parameters mentioned in Table

Parameters Used for Simulation

Parameters	Values
Maximum number of wavelengths	8
Wavelength (λ) ranges in nm	12080 to 1360
One fiber span	70 Km
Pulse broadening factor (δ)	0.1

Table-6

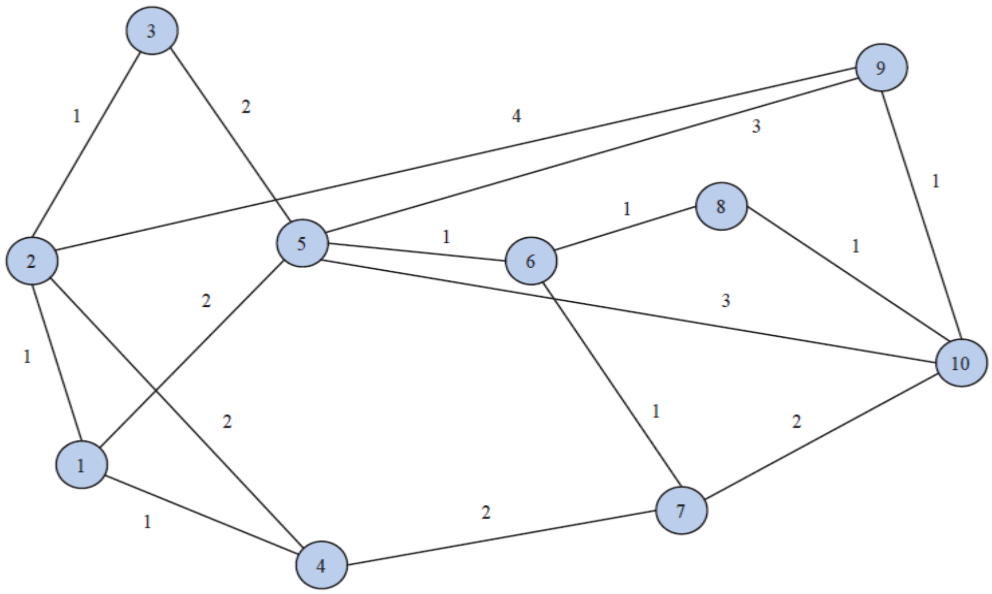


Fig-17 NSFNet Topology Used for Simulation, the number represents the number of spans, one span is 70km

The simulation work presented few results for the selection of OVPNCs with Q-Factor or wavelength assignments for a single or group of connection request. The proposed mechanism is analyzed by as all possible, shortest and disjoint OVPN. The result shows how the OVPNSWA algorithm can help to assign a Q Factor or wavelength and calculate the blocking probability for a given network. In-order to get the best suitable connection, all the cases of OVPNC type uses Q-Factor as a quality parameter, which. The Q-Factor is nothing but a numerical value in percentage, which represents the quality of the connections.

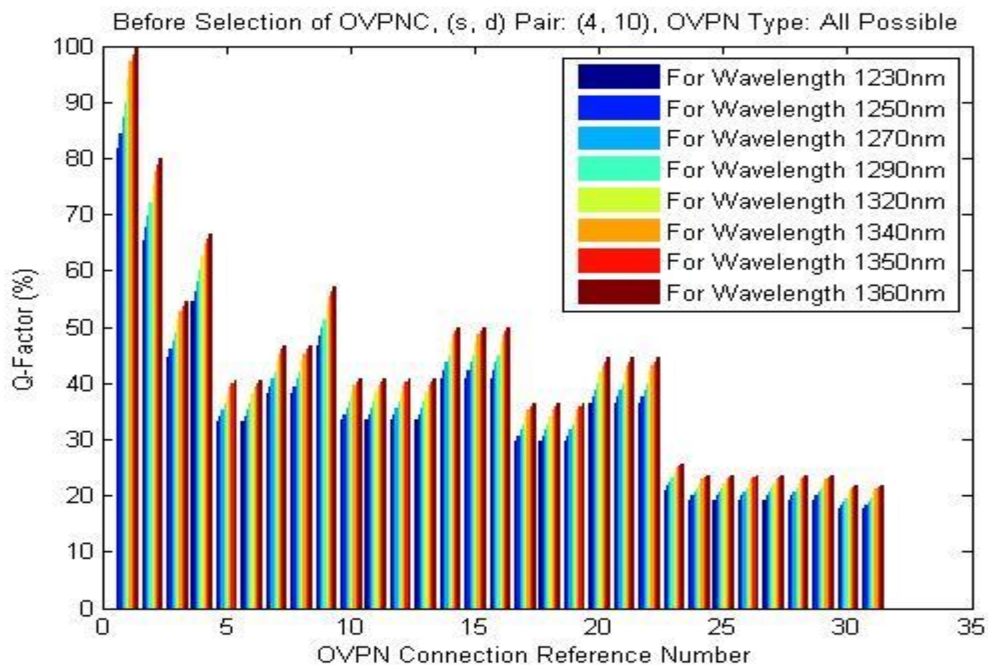
Q-Factor and Wavelength Assignments

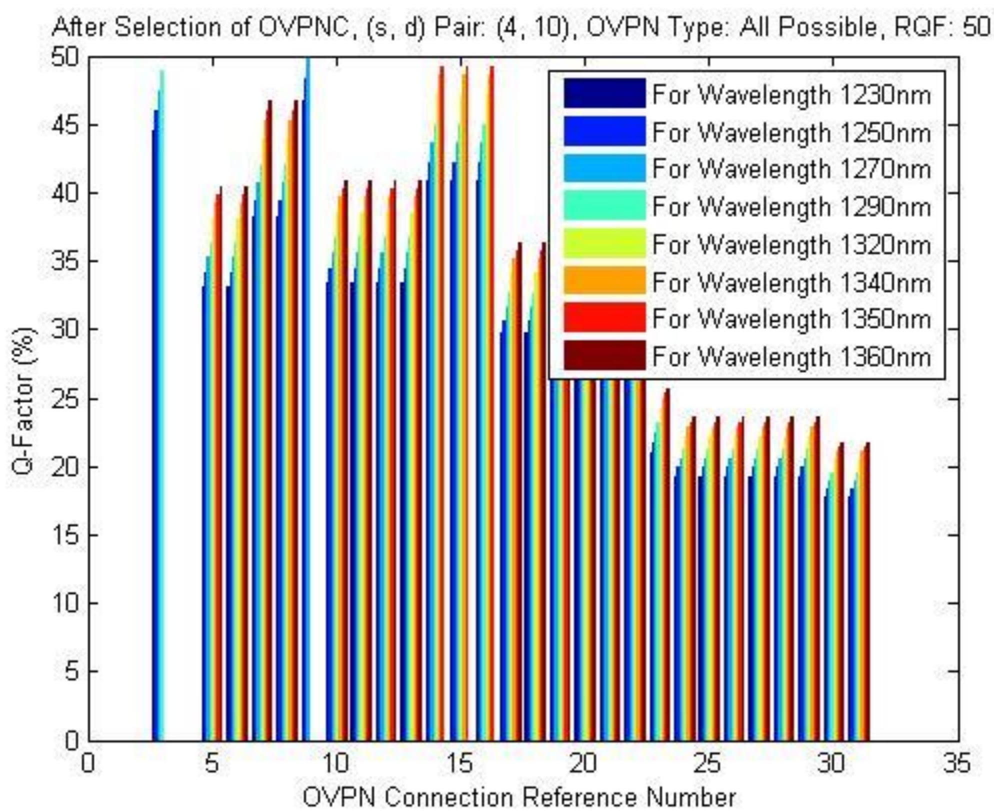
The Figures show the simulation results for Q-Factor with respect to OVPNC reference number of a OVPN client source-destination pair (4, 10) with required Q-Factor for all the OVPNC types such as all possible, shortest and disjoint. In case of all possible OVPNC, we found total of 31 connections, out of which three are disjoint. All the connections are represented as OVPNC reference number. The results are obtained by taking different wavelengths per connections. The OVPNC reference number is an index assigned for a OVPNC. All the plots say about the OVPNC quality in terms of Q-Factor values before and after OVPNC wavelength assignments. The Q-Factor and wavelength assignment to a OVPNC request is done by considering 8 number of OVPN connection request groups starting from group 1 to group 8, where group 1, group 2, group 3, group 4, group 5, group 6, group 7 and group 8 containing 1, 15, 25, 50, 100, 150, 200 and 250 number of connection requests respectively. Let us take the example for the case of all possible OVPNC type by taking 8th group containing 250 connections requests with required Q-Factor of 50, where each OVPNC request will be assigned only one wavelength. The available Q-Factor values before connection requests and after connection requests are presented in Figure . It is clear from these plots that out of 250 connection requests only 10 are assigned with wavelengths and Q-Factor values and the remaining connections are blocked. In this case, the blocking probability will be (250 - 10)/250 i.e., 0.96, which is 96 in percentage. Here we are taking different plot for different required Q-factor(RQF).

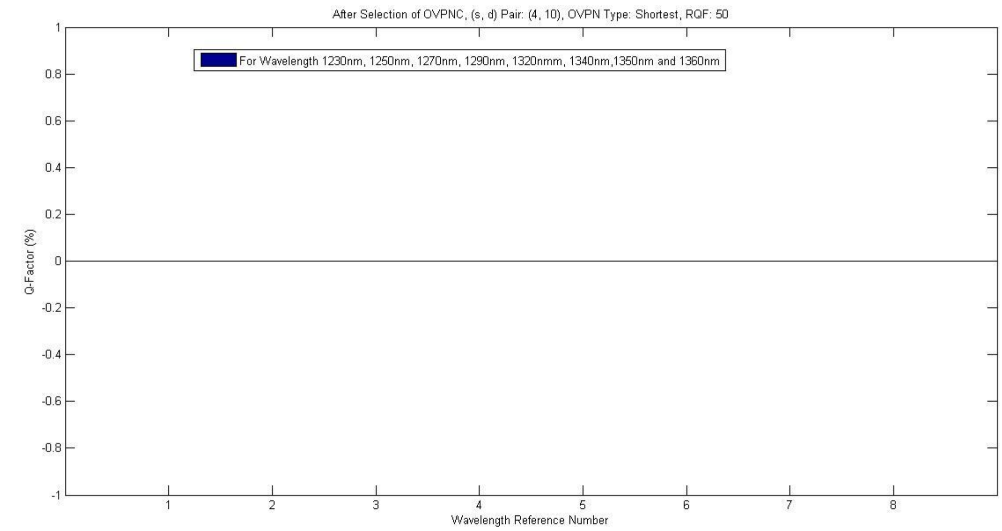
No. of links	Source node	Destination node	Distance
1	1	2	70
2	1	4	70
3	1	5	140
4	2	3	70
5	2	4	140
6	2	9	280
7	3	5	140
8	4	7	140
9	5	6	70
10	5	9	210
11	5	10	210
12	6	7	70
13	6	8	70
14	7	10	140
15	8	10	70
16	9	10	70

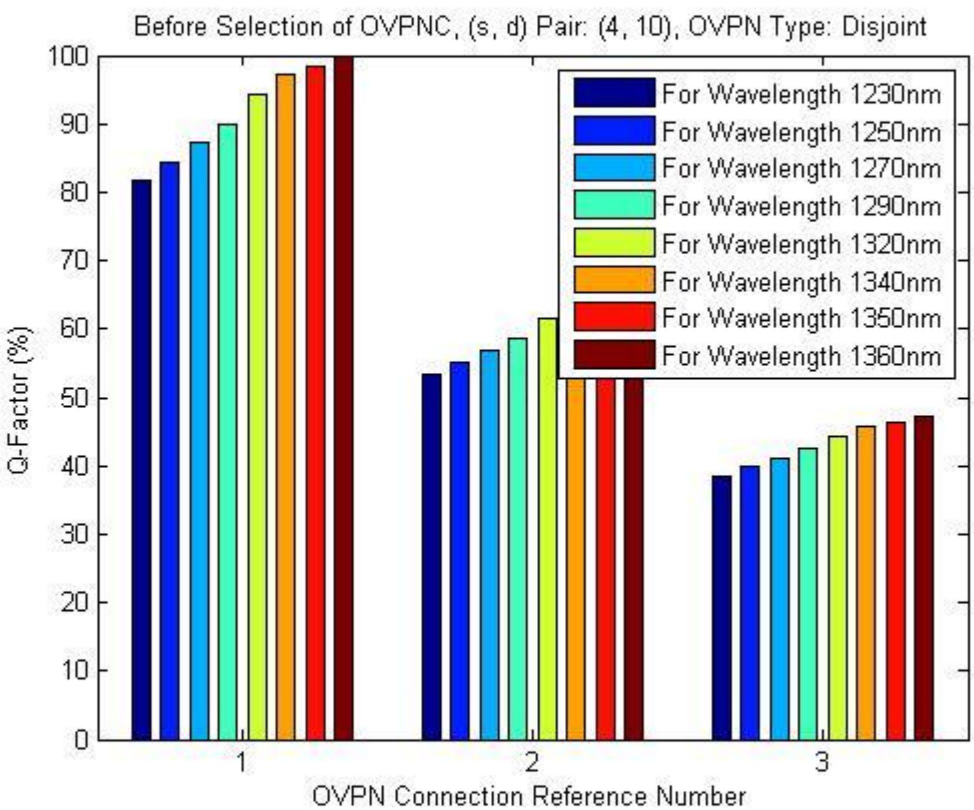
Table-7

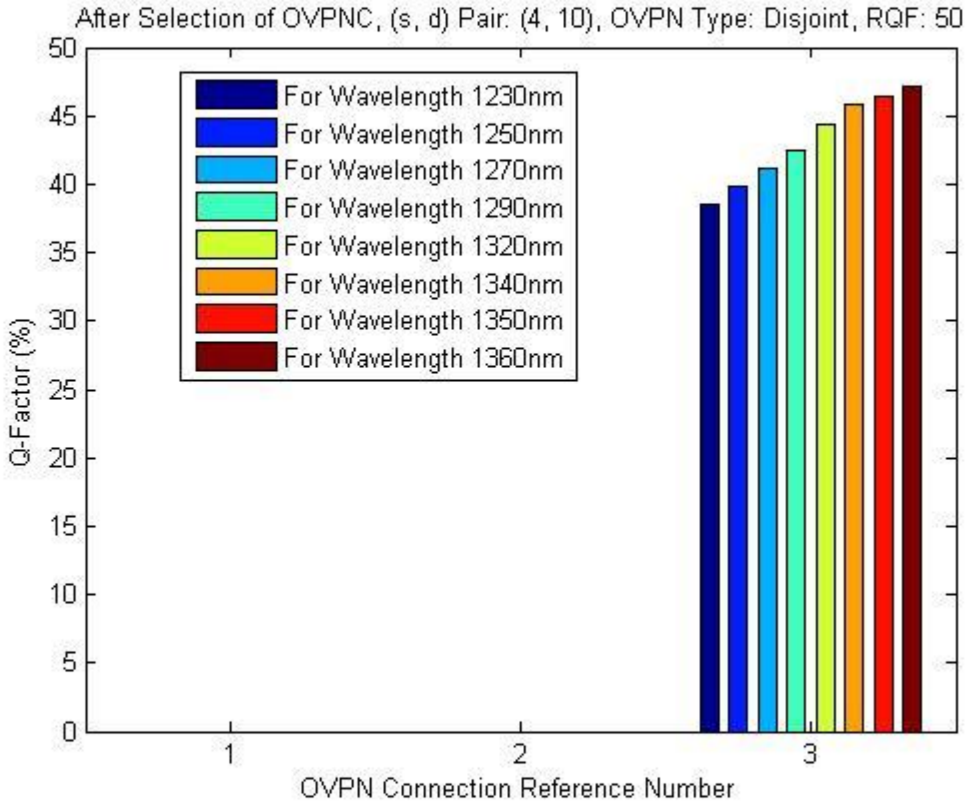
For required quality factor 50

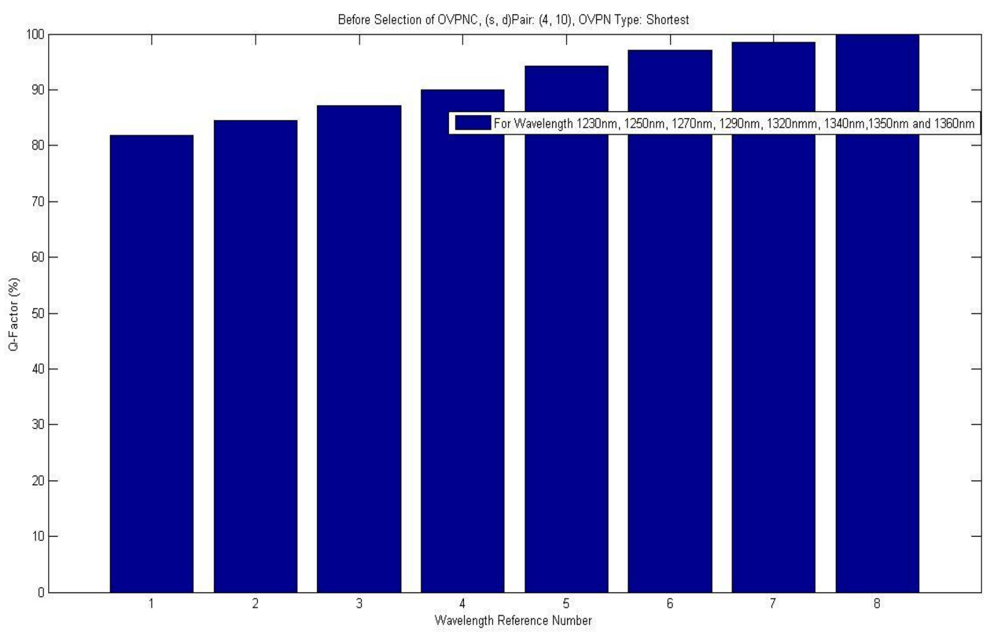





After Selection of OVPNC, (s, d) Pair: (4, 10), OVPN Type: Shortest, RQF: 50
For Wavelength 1230nm, 1250nm, 1270nm, 1290nm, 1320nmm, 1340nm,1350nm and 1360nm
Q-Factor (%)
Wavelength Reference Number


Before Selection of OVPNC, (s, d) Pair: (4, 10), OVPN Type: Disjoint
For Wavelength 1230nm
For Wavelength 1250nm
For Wavelength 1270nm
For Wavelength 1290nm
For Wavelength 1320nm
For Wavelength 1340nm
For Wavelength 1350nm
For Wavelength 1360nm
Q-Factor (%)
OVPN Connection Reference Number





Required QF:50

Number of Connection Accepted: 16

Number of Connection Accepted is: 16

Number of Connection Blocked: 234 for OVPN Type (1: All, 2: Shortest, 3: Disjoint):3 of group 6

Blocking probability for Connection group:6 is 9.360000e+001

Blocking probability =

0	28.0000	64.0000	76.0000	82.0000	85.6000
0	84.0000	92.0000	94.6667	96.0000	96.8000
0	68.0000	84.0000	89.3333	92.0000	93.6000

For required quality factor 80

Required QF: 80

Number of Connection Accepted: 8

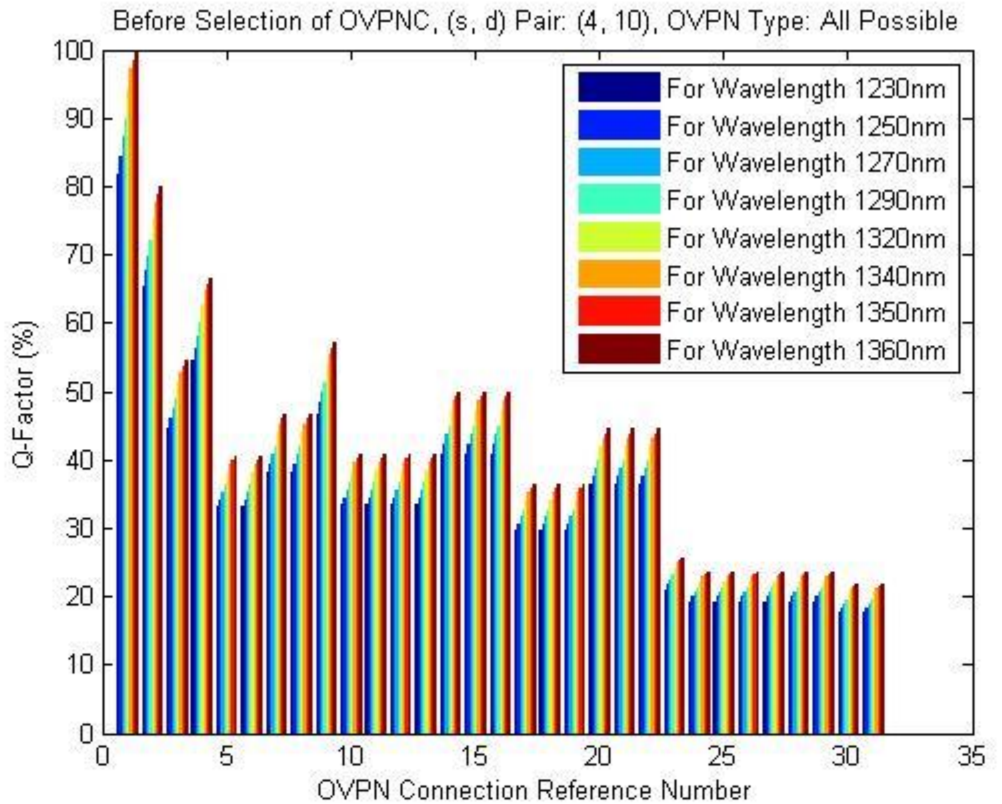
Number of Connection Accepted is: 8

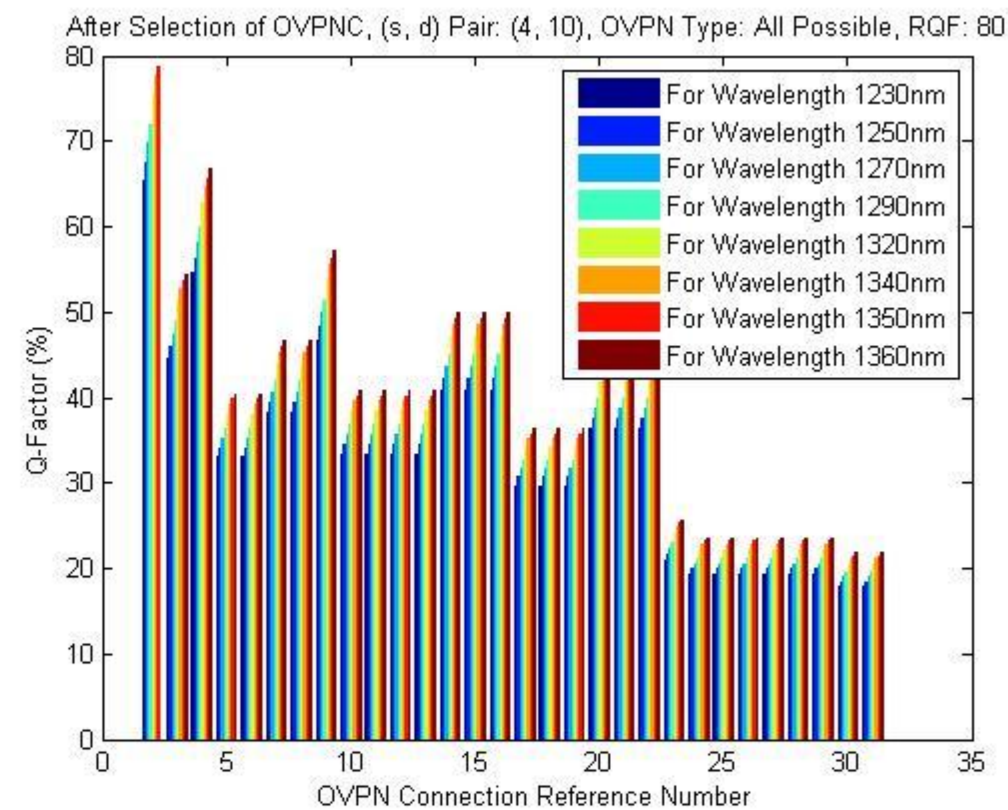
Number of Connection Blocked: 242 for OVPN Type (1: All, 2: Shortest, 3: Disjoint):3 of group 6

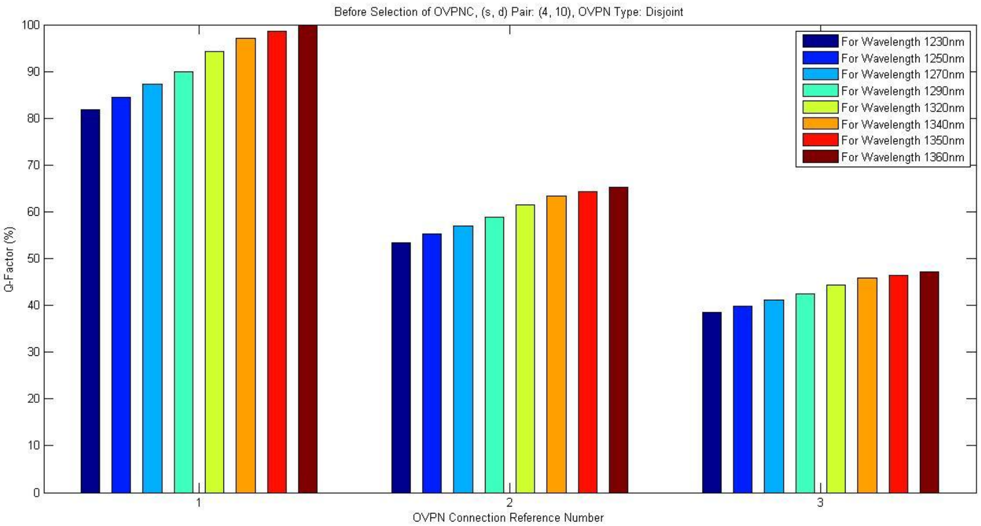
Blocking probability for Connection group: 6 is 9.680000e+001

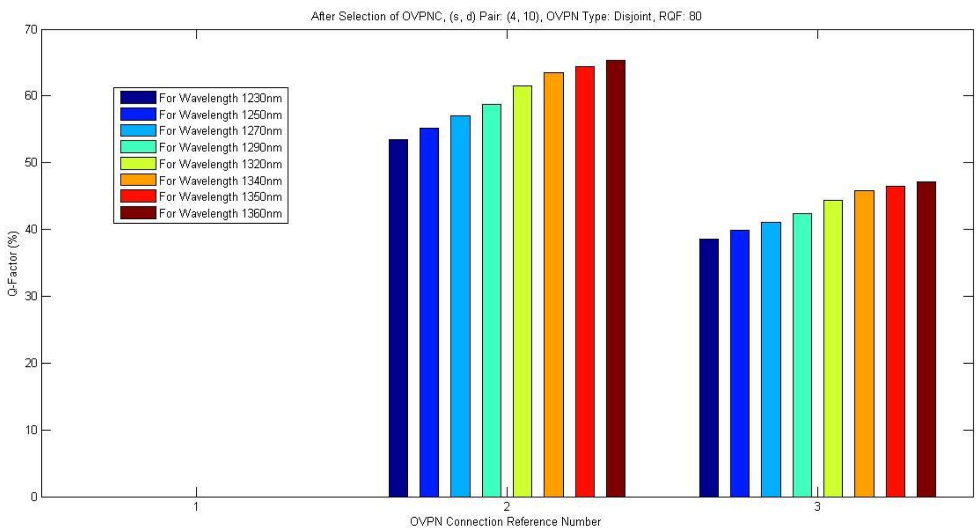
Blocking probability =

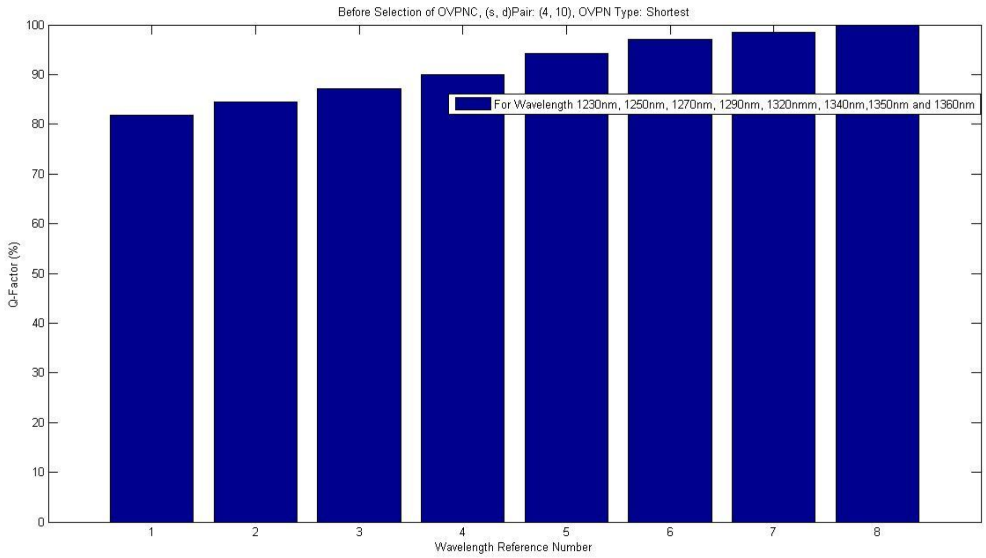
0	82.0000	91.0000	94.0000	95.5000	96.4000
0	84.0000	92.0000	94.6667	96.0000	96.8000
0	84.0000	92.0000	94.6667	96.0000	96.8000


Before Selection of OVPNC, (s, d) Pair: (4, 10), OVPN Type: All Possible
Q-Factor (%)
OVPN Connection Reference Number
For Wavelength 1230nm
For Wavelength 1250nm
For Wavelength 1270nm
For Wavelength 1290nm
For Wavelength 1320nm
For Wavelength 1340nm
For Wavelength 1350nm
For Wavelength 1360nm

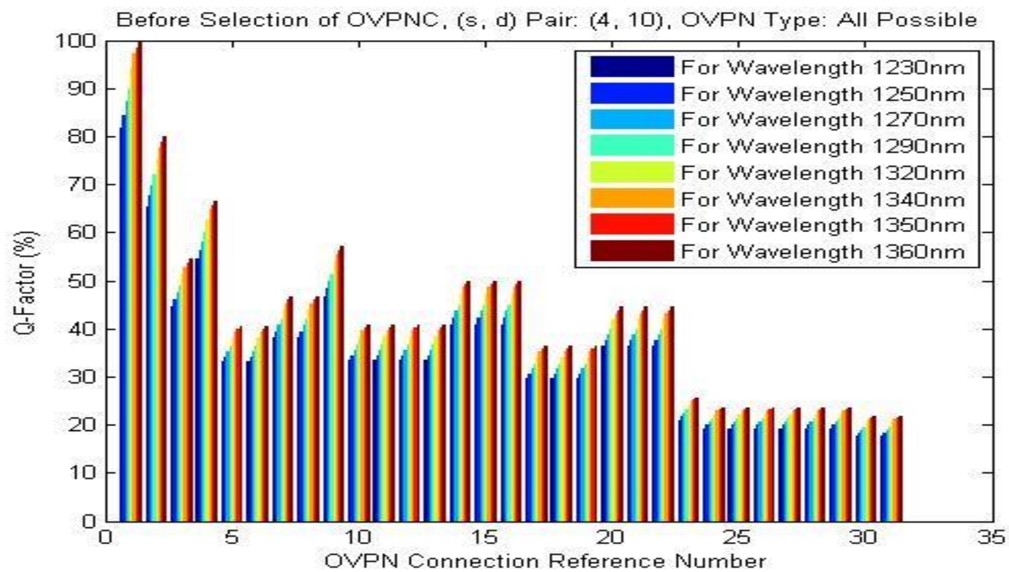

After Selection of OVPNC, (s, d) Pair: (4, 10), OVPN Type: All Possible, RQF: 80
Q-Factor (%)
OVPN Connection Reference Number
For Wavelength 1230nm
For Wavelength 1250nm
For Wavelength 1270nm
For Wavelength 1290nm
For Wavelength 1320nm
For Wavelength 1340nm
For Wavelength 1350nm
For Wavelength 1360nm


Before Selection of OVPNC, (s, d) Pair: (4, 10), OVPN Type: Disjoint
Q-Factor (%)
OVPN Connection Reference Number
For Wavelength 1230nm
For Wavelength 1250nm
For Wavelength 1270nm
For Wavelength 1290nm
For Wavelength 1320nm
For Wavelength 1340nm
For Wavelength 1350nm
For Wavelength 1360nm

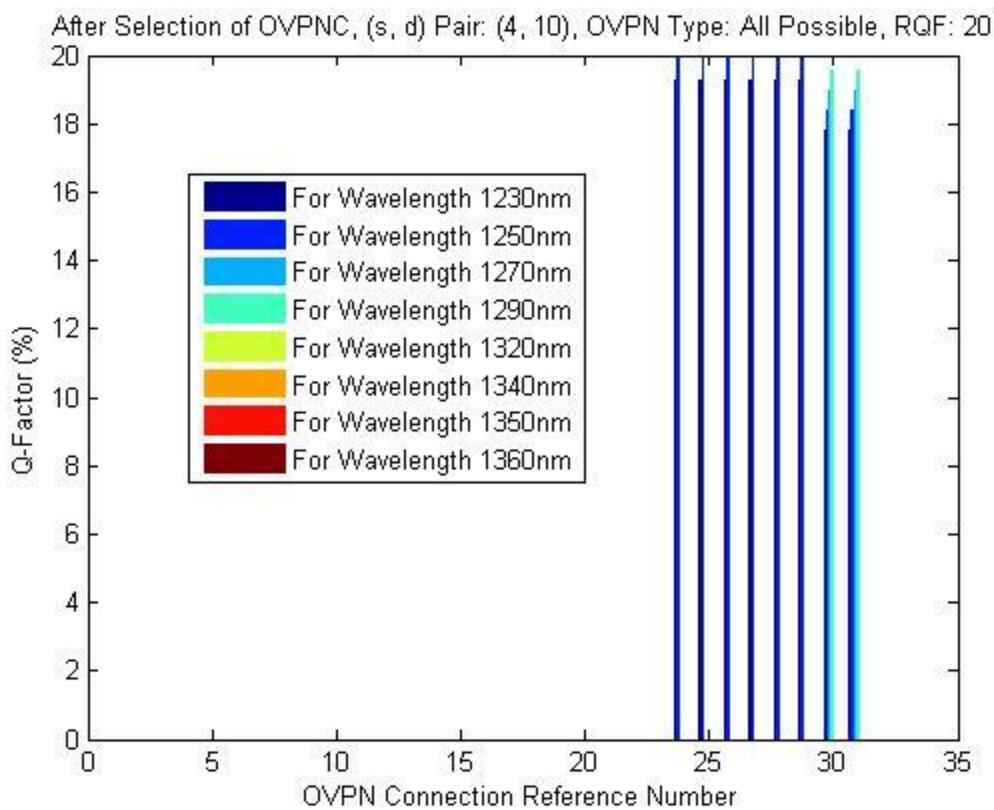

After Selection of OVPNC, (s, d) Pair: (4, 10), OVPN Type: Disjoint, RQF: 80
Q-Factor (%)
OVPN Connection Reference Number
For Wavelength 1230nm
For Wavelength 1250nm
For Wavelength 1270nm
For Wavelength 1290nm
For Wavelength 1320nm
For Wavelength 1340nm
For Wavelength 1350nm
For Wavelength 1360nm



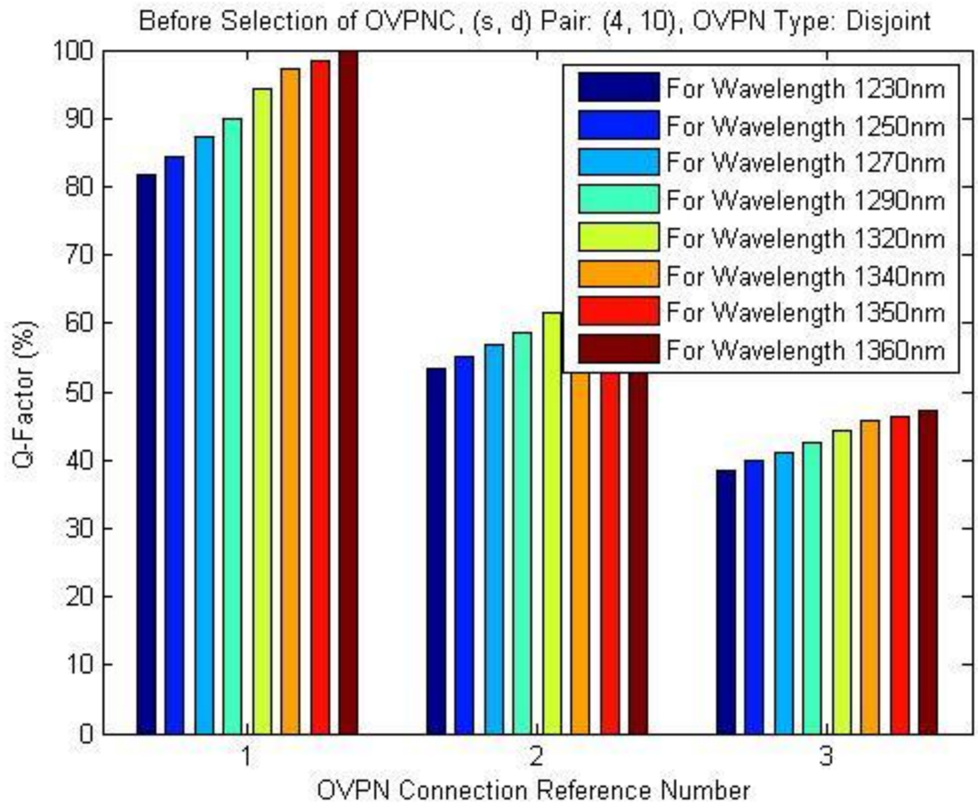
For required quality factor 20

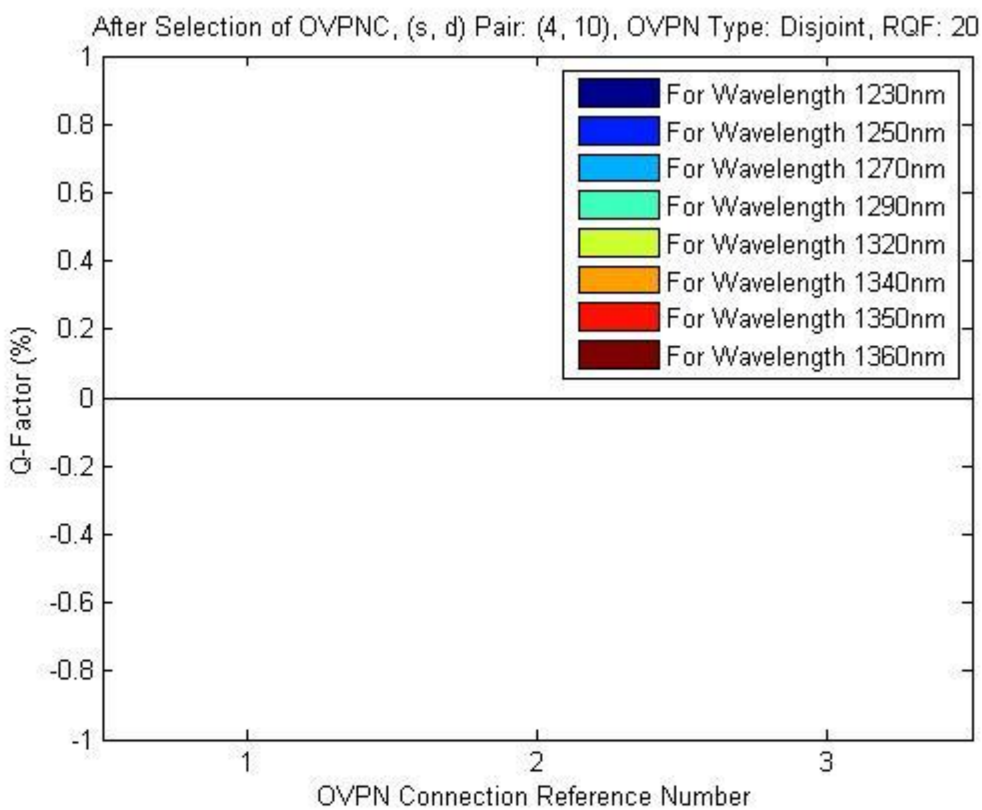


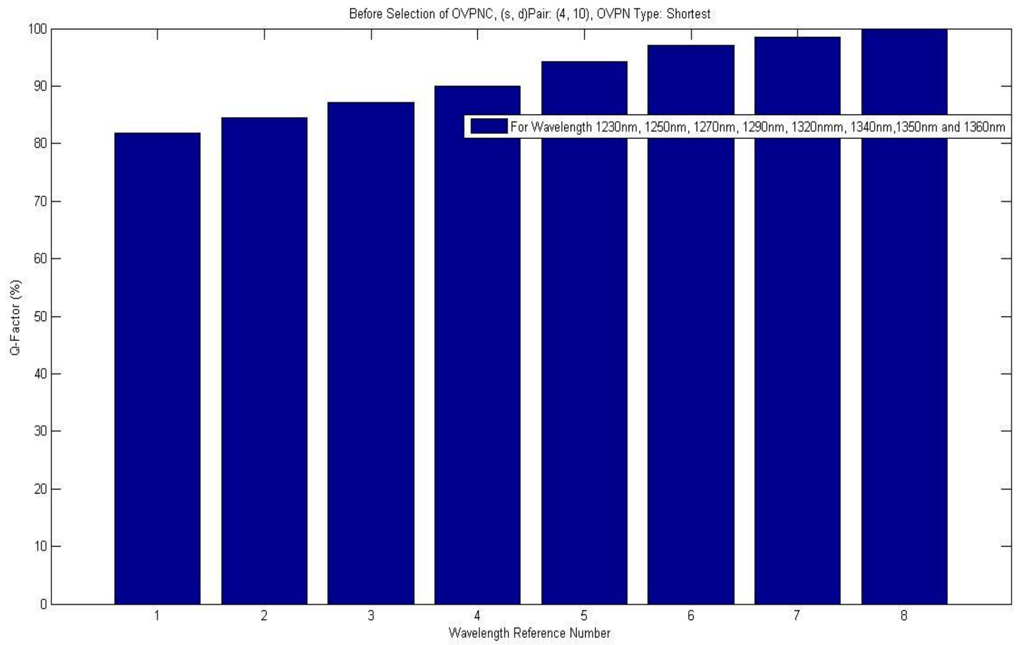
Before Selection of OVPNC, (s, d) Pair: (4, 10), OVPN Type: All Possible
Q-Factor (%)
OVPN Connection Reference Number
For Wavelength 1230nm
For Wavelength 1250nm
For Wavelength 1270nm
For Wavelength 1290nm
For Wavelength 1320nm
For Wavelength 1340nm
For Wavelength 1350nm
For Wavelength 1360nm



After Selection of OVPNC, (s, d) Pair: (4, 10), OVPN Type: All Possible, RQF: 20
Q-Factor (%)
OVPN Connection Reference Number
For Wavelength 1230nm
For Wavelength 1250nm
For Wavelength 1270nm
For Wavelength 1290nm
For Wavelength 1320nm
For Wavelength 1340nm
For Wavelength 1350nm
For Wavelength 1360nm


Before Selection of OVPNC, (s, d) Pair: (4, 10), OVPN Type: Disjoint
Q-Factor (%)
OVPN Connection Reference Number
For Wavelength 1230nm
For Wavelength 1250nm
For Wavelength 1270nm
For Wavelength 1290nm
For Wavelength 1320nm
For Wavelength 1340nm
For Wavelength 1350nm
For Wavelength 1360nm


After Selection of OVPNC, (s, d) Pair: (4, 10), OVPN Type: Disjoint, RQF: 20
Q-Factor (%)
OVPN Connection Reference Number
For Wavelength 1230nm
For Wavelength 1250nm
For Wavelength 1270nm
For Wavelength 1290nm
For Wavelength 1320nm
For Wavelength 1340nm
For Wavelength 1350nm
For Wavelength 1360nm



Required QF: 20

Number of Connection Accepted: 24

Number of Connection Accepted is: 24

Number of Connection Blocked: 226 for OVPN Type (1: All, 2: Shortest, 3: Disjoint):3 of group 6

Blocking probability for Connection group:6 is 9.040000e+001

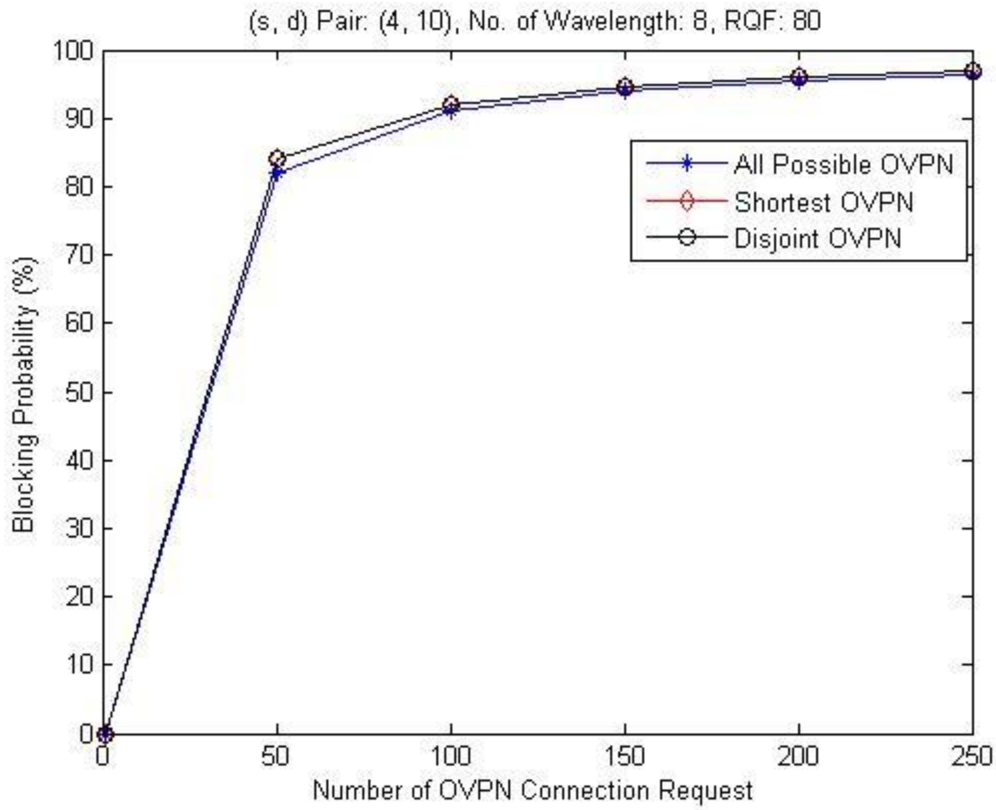
Blocking probability =

0	0	0	0	0	8.8000
0	84.0000	92.0000	94.6667	96.0000	96.8000
0	52.0000	76.0000	84.0000	88.0000	90.4000

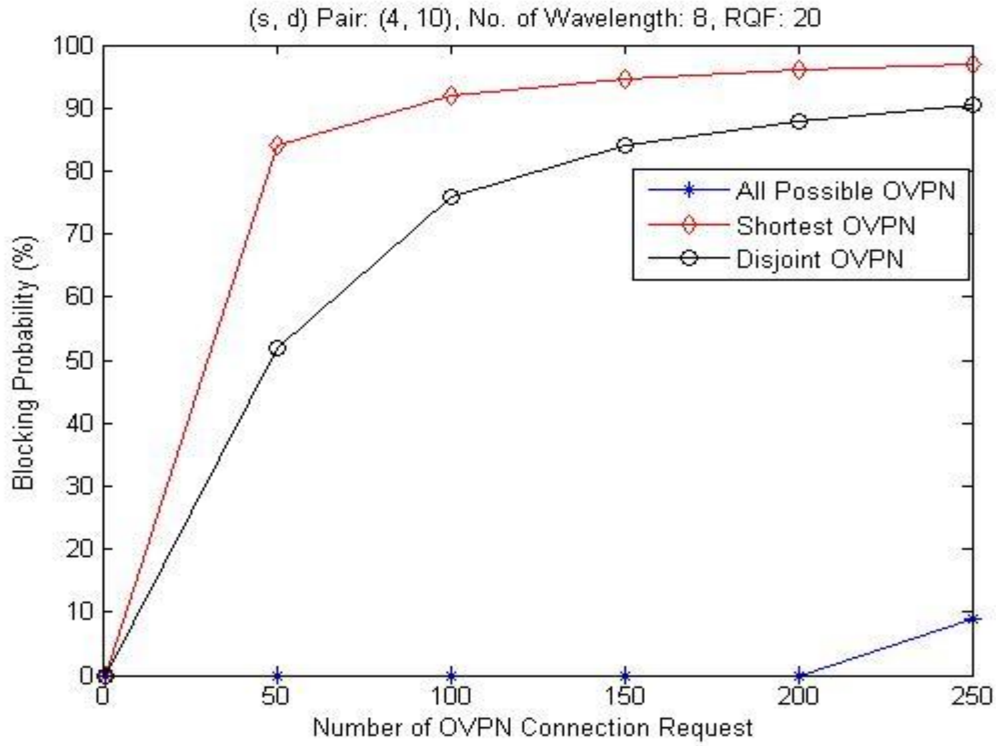
Blocking probability

The Figures shows the simulation results for the connection blocking probability with respect to number of OVPNC requests for a source-destination pair (4, 10) with different wavelengths and for different required Q-factor. All the plots show the comparison of OVPNC types such as all possible, shortest and disjoint OVPNs. It is clear from the plots that the blocking probability for the case of all possible OVPNCs is lowest as compared to other cases. The plots also say that for all the cases, when the number of wavelength increases the blocking probability decreases and when the required Q-factor is more the blocking probability is near about same in all cases. When the required q-factor is less than the calculated Q-factor the blocking probability is less in case of All possible OVPN. Here we calculated the blocking probability for the First Fit and Random wavelength assignment.In this case we get blocking probability is less in First Fit wavelength Assignment.

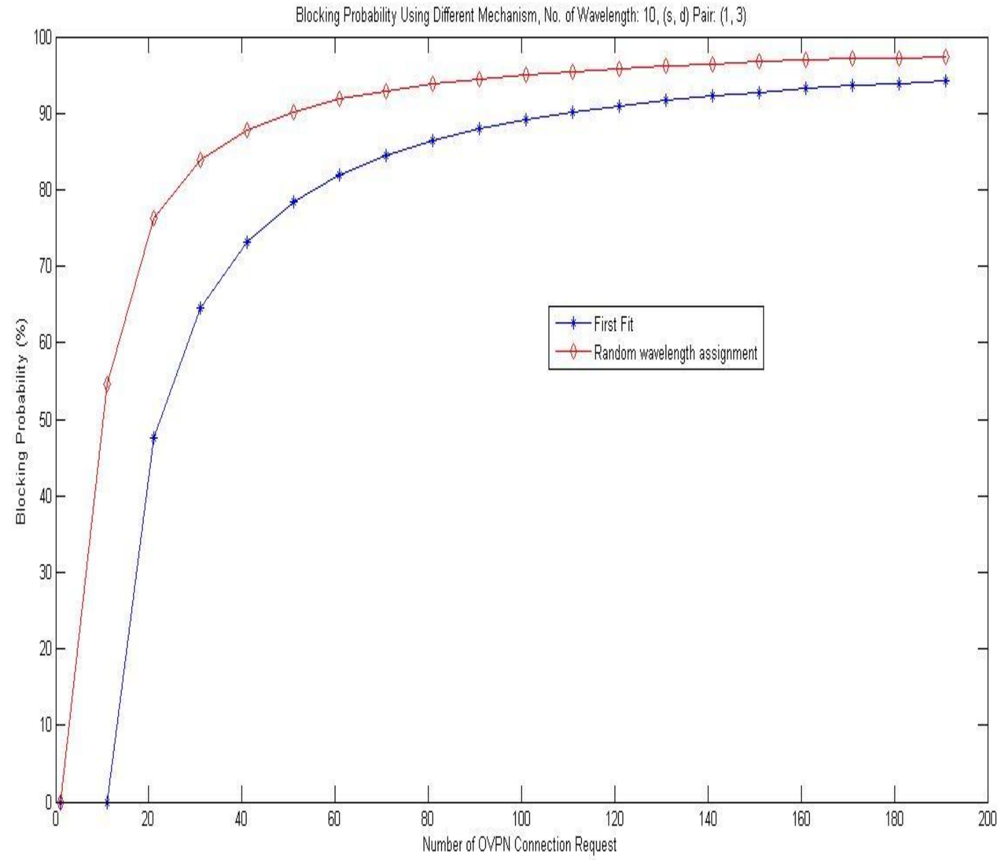
For required quality factor 80



For required quality factor 20



Blocking Probability for the First Fit and Random wavelength Assignment


Blocking Probability Using Different Mechanism, No. of Wavelength: 10, (s, d) Pair: (1, 3)
Blocking Probability (%)
Number of OVPN Connection Request
First Fit
Random wavelength assignment
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
120
140
160
180
200

Chapter-5

Conclusion and Future Work

Conclusion

This work presents the analysis of QoS and performance analysis in terms of blocking probability for the selection of OVPNC over WDM/DWDM network by considering the changes of transmission date rate and delays due to the effect of dispersion . We mixed the network and physical layer concept and proposed a OVPN selection and wavelength assignment mechanism in order to provide the end-to-end guaranteed OVPNC. This mechanism has been evaluated for OVPNC setup by using three different OVPN type: shortest OVPN, disjoint OVPNs and all possible OVPNs. In case of shortest OVPN type, it uses only one connection, which leads to high blocking probability of OVPN client requests. The disjoint OVPN type has more number of connections and provides the client with more available resources. That is the reason, this method can provide more OVPN connections and hence blocking probability is less as compared to shortest OVPN type. But in case of all possible OVPN type, it provides more connections and accordingly more number of wavelengths are available, which can lead to less blocking probability for a single or group of OVPNC request as compared to the other two OVPN types. The proposed mechanism for the selection of OVPN is based on the required Q-Factor of the clients and the computed Q-Factor of the computed connections, which can provide a guaranteed OVPNC to the end clients.

Future work:

This project work can be done through different other topologies of WDM network by considering other Quality factor like Fragmentation cost of a connection link. We can use different routing algorithm for optimize the blocking probability

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