

# **Wavelength Assignment Algorithm in WDM Network**

*Thesis submitted in partial fulfillment of the  
requirements for the award of degree of*

**Master of Engineering  
in  
Electronics and Communication Engineering**

*Submitted By*  
**Anuj Singal  
(800961003)**

**Under the supervision of:  
Dr. R. S. Kaler  
Dean (RPG), Sr. Professor  
ECED, TU**



**Department of Electronics & Communication Engineering,  
Thapar University,  
Patiala-147004, Punjab, India  
June 2011**

## CERTIFICATE

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I hereby certify that the work which is being presented in the thesis entitled, "**Wavelength Assignment Algorithms for WDM System**", in partial fulfillment of the requirements for the award of degree of Master of Engineering in *Electronics and Communication Engineering* submitted in Electronics and Communication Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Dr. R. S. Kaler (Sr. Professor)** and refers other researcher's work which are duly listed in the reference section.

The matter presented in the thesis has not been submitted for award of any other degree of this or any other University.

Date :

  
Anuj Singal  
(800961003)

This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

  
(Dr. R. S. Kaler)  
Dean (RPG), Sr. Professor,  
ECED, Thapar University,  
Patiala - 147004

  
Prof. and Head (ECED)  
Thapar University,  
Patiala - 147004

  
(Dr. S. K. Mohapatra)  
Dean (Academic Affairs)  
Thapar University  
Patiala - 147004

## ACKNOWLEDGEMENT

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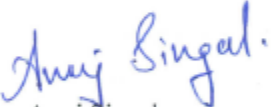
First of all I would like to thank the Almighty, who has always guided me to work on the right path of the life. I am highly grateful to **Dr. A. K. Chatterjee**, Head, Electronics and Communication Engineering Department, for providing this opportunity to carry out the present work.

I would like to express a deep sense of gratitude and thanks to my supervisor, **Dr. R. S. Kaler, Sr. Professor**, Electronics and Communication Engineering Department, Thapar University, Patiala. Without his wise counsel and able guidance, it would have been impossible to complete the present work.

I also express my gratitude to other faculty members of the department for their intellectual support throughout the course of this work.

The copious help received from the technical staff of the department for the excellent laboratory support is also acknowledged.

Finally, I am indebted to all whosoever have contributed to provide help to carry out the present work.

  
Anuj Singal  
(800961003)

## ABSTRACT

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Wavelength assignment is a unique feature in wavelength routed networks that distinguishes them from conventional networks. Wavelength assignment methods are classified into most-used, first-fit, random and wavelength conversion algorithm. In random algorithm a set of wavelengths that can be used to establish the connection is determined. After that wavelength is randomly select with uniform probability distribution from the set. In most-used algorithm selects the wavelength most often used in the network. The objective of this policy is to keep more wavelengths available for calls traveling over long paths. This algorithm requires communication overhead and storage requirements. Further in first fit algorithm numbers all wavelengths, so that when there is a demand for wavelengths available, those of a smaller number are considered first. The first available wavelength is then selected. This algorithm does not require global information system. Its computational cost is lower because no storage is needed to keep the network states and wavelength conversion wavelength assignment algorithm can assigned any incoming light-path to any wavelength on the output side. This eliminates wavelength-continuity constraints.

We analyze the performance of First-fit, Random, Most-used and Wavelength conversion Algorithms for wavelength assignment in WDM unidirectional optical ring network. We compare the blocking probability of various algorithms with the variation in number of events. The performance of the wavelength conversion algorithms is best but there is a burden of using expensive hardware. But without the need of wavelength-convertor most-used algorithm performs better than random and first-fit algorithms. Further we examined the blocking probability of the network for different algorithm based on total number of wavelengths. We show that as we increases the number of available wavelength then blocking probability decreases. In the last, we analyze the blocking probability of the network for wavelength conversion algorithm based on route length in the eight nodes WDM unidirectional optical ring network. Fiber lengths at every link vary one by one and calculate the blocking probability. We show that as we increases the length of route then blocking probability increases.

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## List of Abbreviations

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AON	All-Optical Network
DWDM	Dense Wavelength Division Multiplexing
FFWC	First Fit Wavelength Conversion
FR	Fixed Routing
FTRA	Fault Tolerant Routing Algorithm
FWC	Fixed Wavelength Conversion
RWA	Routing and Wavelength assignment
SLE	Static Lightpath Establishment
WA	Wavelength Assignment
WADM	Wavelength Add-Drop Multiplexer
WAN	Wide Area Network
WDM	Wavelength Division Multiplexer

# CHAPTER 1

## INTRODUCTION

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### 1.1 Optical Fiber System

Development of optical fiber technology is considered to be a major driver behind the information technology revolution and the tremendous progress on global telecommunications that has been witnessed in recent years. Fiber optics, from the point of view of telecommunication, is now almost for granted in view of its wide-ranging application as the most suitable singular transmission medium for voice, video and data signals. Indeed, optical fibers have now penetrated virtually all segments of telecommunication networks, whether transoceanic, transcontinental, intercity, metro, access, campus or on-premise [1].

#### 1.1.1 Evolution of Fiber Optic System

A challenge in using an optical fiber for a communications channel is to have a flexible, low-loss medium that transfers a light signal over long distances without significant attenuation and distortion. One of the first known attempts of using optical fibers for communication purposes was a demonstration in 1930 by Heinrich Lamm of image transmission through a short bundle of optical fibers for potential medical imaging. However, no further work was done beyond the demonstration phase, since the technology for producing low-loss fibers with good light confinement was not yet mature [2]. Further work and experiments on using optical fibers for image transmission continued, and by 1960 glass-clad fibers had an attenuation of about 1 dB/m. This attenuation allowed fibers to be used for medical imaging, but it was still much too high for communications, since only 1 percent of the inserted optical power would emerge from the end of a 20-m-long fiber. Optical fibers attracted the attention of researchers at that time because they were analogous in theory to plastic dielectric waveguides used in certain microwave applications. In 1961 Elias Snitzer published a classic theoretical description of single-mode fibers with implications for information transmission use. However, to be applicable to communication systems, optical fibers would need to have a loss of no more than 10 or 20 dB/km (a power loss factor of 10 to 100) [3]. Prior to 1970 most researchers had tried to purify compound glasses used for standard optics, which are

easy to melt and draw into fibers. In September 1970, they announced the fabrication of single-mode fibers with an attenuation of 17dB/km at the 633-nm helium-neon line (a loss factor of 50 over 1 km). This dramatic breakthrough was the first among the many developments that opened the door to fiber optic communications. Early WDM began in the late 1980s using the two widely spaced wavelengths in the 1310 nm and 1550 nm (or 850 nm and 1310 nm) regions, sometimes called wideband WDM. The early 1990s saw a second generation of WDM, sometimes called narrowband WDM, in which two to eight channels were used. These channels were now spaced at an interval of about 400 GHz in the 1550-nm window. By the mid-1990s, dense WDM (DWDM) systems were emerging with 16 to 40 channels and spacing from 100 to 200 GHz [4]. By the late 1990s DWDM systems had evolved to the point where they were capable of 64 to 160 parallel channels, densely packed at 50 or even 25 GHz intervals as shown in Figure 1.1(a).

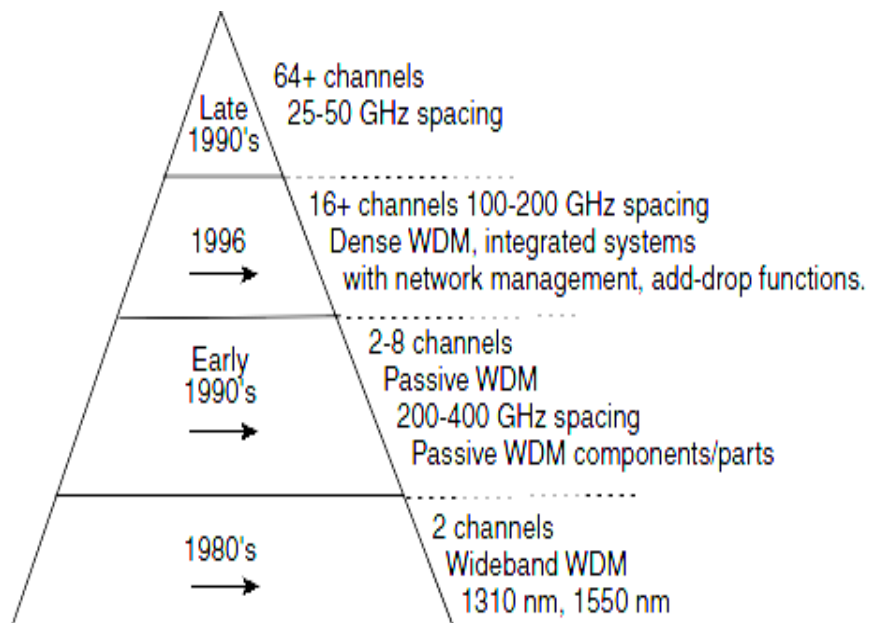


Figure 1.1(a) Evolution of WDM System

Further developments in fiber optics are closely tied to the use of the specific regions on the optical spectrum where optical attenuation is low. These regions, called windows, lie between areas of high absorption. The earliest systems were developed to operate around 850

nm, the first window in silica-based optical fiber. A second window (S band), at 1310 nm, soon proved to be superior because of its lower attenuation, followed by a third window (C band) at 1550 nm with an even lower optical loss. Today, a fourth window (L band) near 1625 nm is under development and early deployment. These four windows are shown relative to the electromagnetic spectrum in Figure 1.1(b).

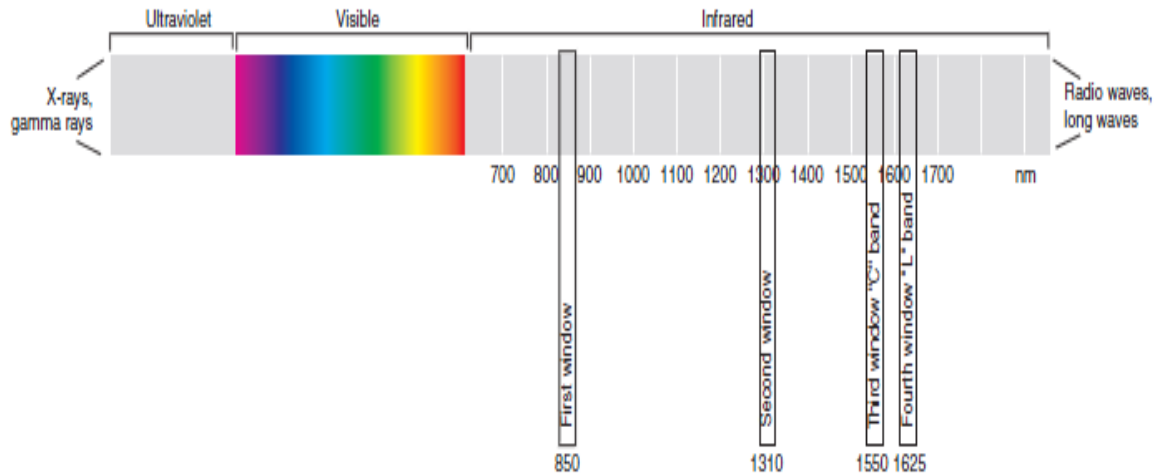


Figure 1.1(b) Wavelength Regions [4].

## 1.2 Wavelength Division Multiplexing

WDM is a method of sending many light beams of different wavelengths simultaneously down the core of an optical fiber, which amplifies signal at different wavelengths simultaneously regardless of their modulation scheme or speed. WDM is essentially same as frequency division multiplexing (FDM), which has been used in radio systems for more than a century. For some reasons, the term FDM is used in radio communication but WDM is used in the context of optical communication, perhaps because FDM was studied by communication engineers and WDM by physicists [5]. The idea is to modulate optical signals at different wavelengths and to transmit the data simultaneously by combining resulting signals over the same optical fiber. WDM systems use a carrier wave which is higher than that of an FDM channel by a million times in frequency. Within each WDM channel, it is possible to have FDM where the channel bandwidth is subdivided into many radio frequency channels each at a different frequency. This is called subcarrier multiplexing.

A wavelength can also be shared among many nodes in a network by electronic time division multiplexing [5].

### 1.2.1 Basics of WDM system

In fiber-optic communications, wavelength-division multiplexing (WDM) is a technology which multiplexes a number of optical carrier signals onto a single optical fiber by using different wavelengths (colors) of laser light as shown in Figure 1.2(a)

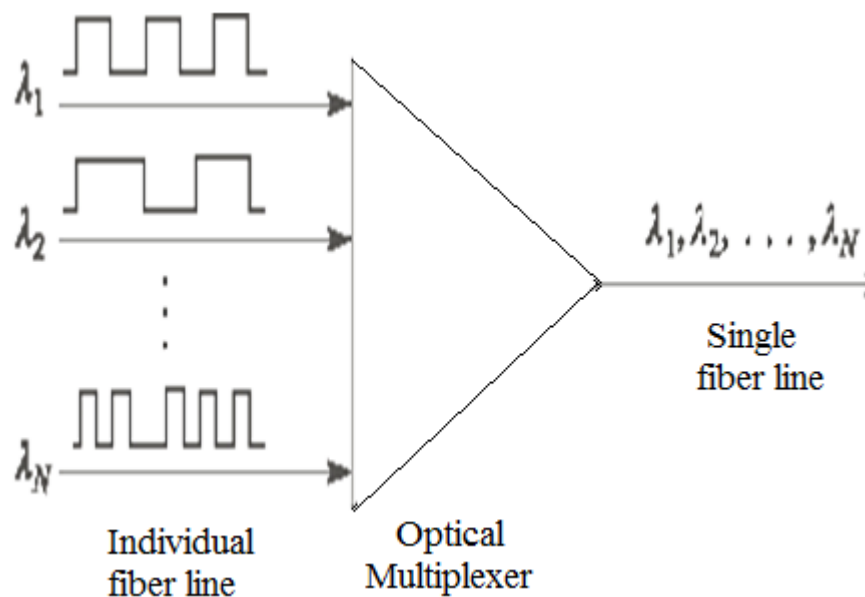


Figure 1.2(a) WDM System

The term wavelength-division multiplexing is commonly applied to an optical carrier whereas frequency-division multiplexing typically applies to a radio carrier. Since wavelength and frequency are tied together through a simple relationship, the two terms actually describe the same concept. WDM systems are divided in different wavelength patterns, conventional or coarse and dense WDM [6].

## 1.2.2 Components of WDM System

In addition to fibers, light sources, and photo detectors, many other components are used in a complex optical communication network to split, route, process, or otherwise manipulate light signals. The devices can be categorized as either passive or active components [6]. Passive optical components do not hum or wink or blink, since they require no external source of energy to perform an operation or transformation on an optical signal. Passive components carry out their unique processes without any physical or electrical action. For example, a passive optical filter will allow only a certain wavelength to pass through it while absorbing or reflecting all others and an optical splitter divides the light entering it into two or more, smaller optical power stream. Active components require some type of external energy either to perform their functions or to be used over a wider operating range than a passive device, thereby offering greater flexibility. The Passive components include optical couplers, isolators, circulators, filters, gratings, and wavelength multiplexers [6].

The most important components are light sources, optical coupler, tunable optical filters, optical switches and of course the fiber. Different components are briefly presented in the following sections

a) Light source is one of the important elements of an optical system is the light source. For communication purpose, a good light source should be quickly tunable with a wide range of wavelengths. To make a component commercially attractive low price and low power consumption are vital parameters. The time scale of tuning depends upon the technique used i.e. with optical packet switching the requirements are somewhere between microseconds and nanoseconds while with circuit switched WDM-networks the time scale is slower. Here is a list of several candidates for light sources [7]:

1. Mechanically tuned lasers
2. Acousto-optically and electro-optically tuned lasers
3. Injection current tuned lasers
4. Switched sources

5. Array sources (using arrayed waveguide gratings (AWG) or distributed feedback (DFB) lasers)

b) Optical couplers perform functions such as splitting a light signal into two or more streams, combining two or more light streams, tapping off a small portion of optical power for monitoring purposes, or transferring a selective range of optical power from one fiber to another as shown in Figure 1.2(b).

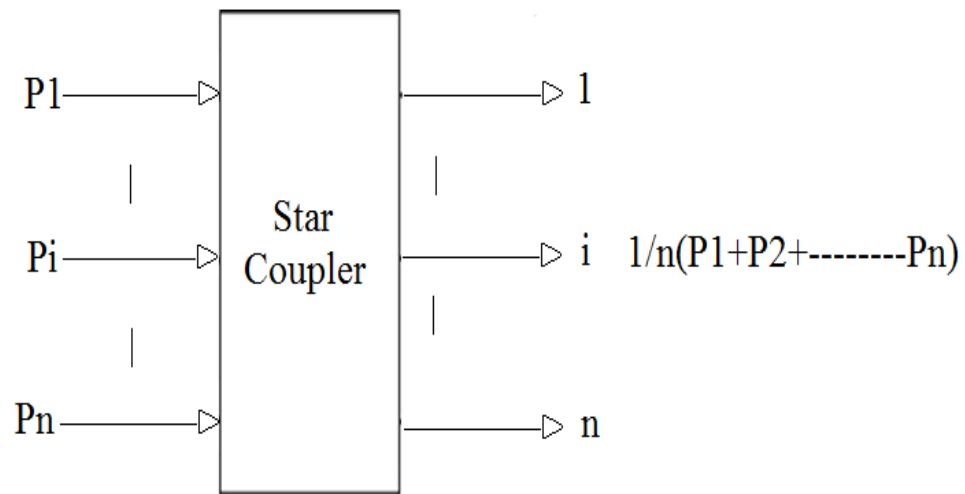


Figure 1.2(b) Star Couple

c) Tunable filters is also one of the important parts of the optical network. Many promising approaches have been studied including Fabry-Perot, acousto-optic, electro-optic and liquid crystal Fabry-Perot filters. A dielectric thin-film filter (TFF) is used as an optical band pass filter [7]. This means that it allows a particular very narrow wavelength band to pass straight through it and reflects all others as shown in Figure 1.2(c).

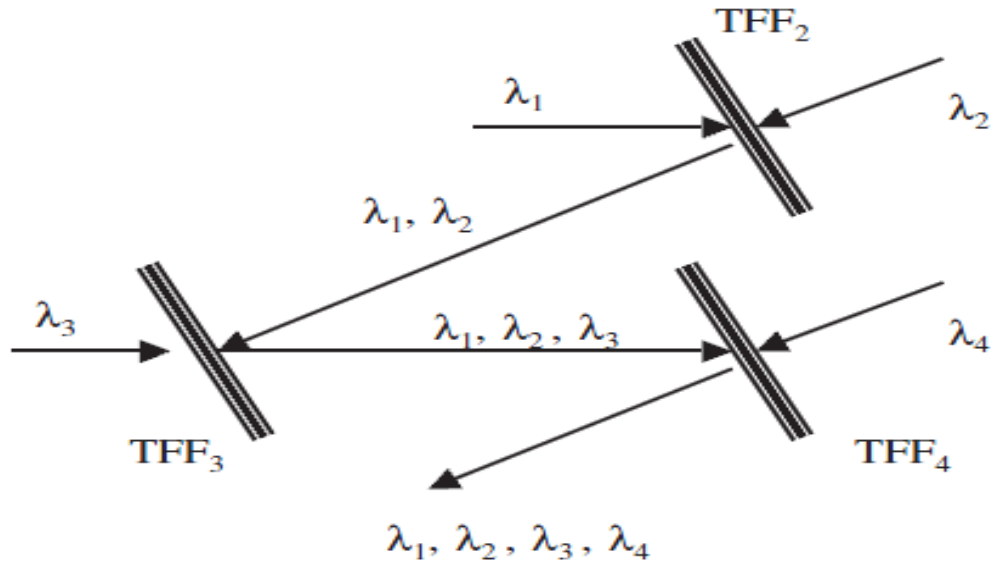


Figure 1.2(c) Dielectric thin film filters

### 1.3 Routing and Wavelength Assignment

RWA is the unique feature of WDM networks in which lightpath is implemented by selecting the path of a physical link between source and destination edge nodes and reserving a particular wavelength on each of these links for the lightpath. Thus for establishment of an optical connection, one must deal with the selection of the path (Routing problem) as well as allocating the available wavelengths for the connections (Wavelength Assignment problem). This resulting problem is known as routing and wavelength assignment problem. We can divide this problem in two problems namely; routing problem and wavelength assignment problem and then we can propose different solutions to this problem.

- Find a route from the source to the destination.
- Assign a wavelength to the selected route.

An end-to-end light path has to be established prior to the communication between any two nodes. To establish a light path, it is required that the same wavelength be allocated on all the links along the path. This limitation is known as the wavelength continuity constraint [8].

### **1.3.1 Wavelength Routed Constraints**

There are two constraints that have to be kept in mind by the approaches when trying to solve RWA. The first distinct wavelength assignment constraint holds for solving wavelength assignment problem in any wavelength routing network. The second wavelength continuity constraint applies only to the simple case of wavelength routing networks that have no wavelength conversion capability inside their nodes. So brief intro of them is following:-

a) Distinct wavelength assignment constraint: All light paths sharing a common fiber must be assigned distinct wavelengths to avoid interference. This applies not only within the all-optical network but in access links as well.

b) Wavelength continuity constraint: The wavelength assigned to each lightpath remains the same on all the links it traverses from source end-node to destination end-node.

### **1.3.2 Wavelength Assignment algorithm**

Wavelength assignment is a unique feature in wavelength routed networks that distinguishes them from conventional networks. Based on the order in which the wavelengths are searched, wavelength assignment methods are classified into most-used, first-fit, random and wavelength conversion algorithm. So brief intro of wavelength assignment algorithms are following:-

- Random wavelength assignment [8]: In this algorithm a set of wavelengths that can be used to establish the connection is determined. After that wavelength is randomly select with uniform probability distribution from the set.
- Most-used wavelength assignment [8]: The most-used algorithm selects the wavelength most often used in the network. The objective of this policy is to keep more wavelengths available for calls traveling over long paths. This algorithm requires communication overhead and storage requirements.
- Wavelength conversion wavelength assignment [9]: Any incoming light-path can be assigned to any wavelength on the output side. This eliminates wavelength-continuity constraints.
- First-Fit wavelength assignment [10]: This algorithm numbers all wavelengths, so that when there is a demand for wavelengths available, those of a smaller number are

considered first. The first available wavelength is then selected. This algorithm does not require global information system. Its computational cost is lower because no storage is needed to keep the network states. It works well in terms of blocking probability and fairness of allocation. This algorithm is preferred for its small overhead and low computational complexity. The objective of this allocation scheme is to minimize wavelength fragmentation [11-13].

### **1.3.3 Wavelength Routing Techniques**

There are a number of wavelength routing techniques are fixed routing, alternate routing and exhaust routing. In the fixed routing scheme only one route is provided for a node pair. Usually this route is chosen to be the shortest route. When a connection request arrives for a node pair the route fixed for that node pair is searched for the availability of a free wavelength. In the alternate routing scheme two or more routes are provided for a node pair. These routes are searched one by one in a predetermined order. Usually, these routes are ordered in non-decreasing order of their hop length. In the exhaust routing scheme all possible routes are searched for a node pair. The network state is represented as a graph and a shortest-path-finding algorithm is used on the graph. While the exhaust method yields the best performance when compared to the other two methods, it is computationally more complex. Similarly, the fixed routing method is simpler than alternate routing method but it yields poorer performance than the other.

### **1.4 Introduction to Artifex**

Artifex is simulation software for discrete-event systems and is targeted for the engineering of complex discrete-event systems, in a wide range of markets. Artifex is based on high level petri nets and it provides an excellent graphical user interface. This feature is unique and makes it easier for user to model any project required. Artifex being a general purpose simulation tool can be used for a wide range of application design targeting top to bottom layers of the OSI model. Artifex is not only used to design network protocols but also applications like Communication networks, Various algorithms, Switching systems, Network topologies, etc.

### 1.4.1 Artifex Language's Elements

- Places are data stores containing units of information called *tokens*. Tokens are structured data whose type is defined as a record type. Tokens with a void data structure are given the standard type NUL. Each place can contain several tokens at a time, but they must all be of the same type. Places are basically queues of tokens. The queues may be:
  - a) FIFO first in-first out, when a token is put into a place it is added at the end of the queue.
  - b) LIFO last in-first out (type "L"), when a token is put into a place it is added at the beginning of the queue.
  - c) Token delay (type "D"), tokens put into this kind of place are ordered in time units on the basis of their token "delay".
- Transitions are the processing units of the model. They act on the places to which they are connected. A transition models a token-driven computation, where the activation of the computation and the propagation of the information are established by the transition's graphic context. In fact, the necessary condition for a transition to fire is that each of its input places contains at least one token. When a transition fires, it removes one token from each of its input places and adds one token to each of its output places. The default rule is that the transition removes the oldest token from each of its input places, i.e. the one at the head of the queue. The transition has two further timing attributes: the firing delay and the release delay. The firing delay is defined as the delay from the instant at which the transition is enabled to the instant when it fetches the tokens from its input places. This delay may be also linked to the "token delay" of the input place type "D" and the release delay is defined as the delay from the instant at which the transition fetches the tokens from its input places to the instant when it releases the tokens in its output places.
- Arc defines a token path between two graphical elements and is represented by an oriented line. Places that are input and output of the same transition are often connected with a double arrow arc that represents simultaneously the incoming and the outgoing arc.

- Subnets are a way to functionally decompose the Petri-net of a class. Each subnet may represent a specific function to be carried out in order to perform a certain task. A subnet may be made up of other subnets in a hierarchical way thus enabling the top-down specification of a class body. When you create a subnet, Artifex create always a new related page (the physical space where you draw the icons and the connections that define the net). A subnet may contain many pages.
- Page reference is an element that refers to a page that shares some elements with the page in which they are drawn. Info-Arc Page references may be connected to other elements; however these connections, called info-arcs, are only graphical. Info-arcs are used as documentation aids and do not represent a real token path.

## CHAPTER 2

### LITERATURE SURVEY

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#### 2.1 Literature survey

There are a number of models covered in literature for calculation of blocking probability of optical networks.

Suresh Subramaniam et al. [14] examined the effect of topological connectivity and wavelength conversion in circuit-switched all-optical wavelength-routed network and blocking analysis of such network.

Xuehong Sun et al. [15] proposed a new analytical technique for the performance analysis of all optical networks which use the first-fit algorithm for wavelength assignment and analyze the wavelength usage on the links to calculate the blocking probability of a source destination pair, taking into account wavelength correlation and load correlation between Links.

A. Birman et al. [16] noticed that the wavelength converters are very expensive now a days, much research work focuses on sparse wavelength conversion, in which only a part of network nodes have the capability of wavelength. If all the network nodes have the capability of wavelength conversion, this is referred to as full wavelength conversion. There are a number of models covered in the literature for calculation of blocking probability of optical networks. The blocking probabilities of optical network models for the schemes: fixed routing and least-loaded routing are calculated by using generalized reduced load approximation techniques.

Amit Wason et al. [17] proposed algorithm is based on most-used wavelength assignment algorithm and also suggested a mathematical model for WDM optical networks for minimization of blocking probability. The results of proposed algorithm and suggested model are then compared with the conventional wavelength assignment algorithms such as first-fit, best-fit, random and most-used wavelength assignment algorithms. These proposed approaches are very effective for the minimization of blocking probability of optical WDM networks.

Kai-Yeung Siu et al. [18] examined the throughput performance of online algorithms for the problem of routing and wavelength assignment in single-hub WDM ring networks.

Amit Wason et al. [19] proposed a mathematical model to reduce the blocking probability of the WDM optical network. The mathematical model proposed has a closed-form expression and does not require simulated statistics, it has low implementation complexity and the computation is quite efficient. This model suggests us to choose the best path and appropriate number of free wavelengths in the network. We can go for the compromise between the path length and number of free wavelength. The model is also used to evaluate the blocking performance of NSFNet topology and hence used to improve its performance.

Xi Yang et al. [20] measured the network performance in terms of blocking probability, resource utilization and running times under different resource allocation and routing schemes. They addressed the placement of regenerators based on static schemes allowing for only a limited number of regenerators at fixed locations. They further proposed a dynamic resource allocation and dynamic routing scheme to operate translucent networks. This scheme was realized through dynamic ally sharing regeneration resources, including transmitters, receivers, and electronic interfaces between regeneration and access functions under a multi-domain hierarchical translucent network model. An intra-domain routing algorithm, which took into consideration optical-layer constraints as well as dynamic allocation of regeneration resources, was developed to address the problem of translucent dynamic routing in a single routing domain.

Rajneesh Randhawa et al. [21] proposed a new algorithm for wavelength assignment and its performance is evaluated in terms of blocking probability and fairness. It has been shown that the proposed algorithm offers the least blocking probability. The blocking performance of wavelength division multiplexing (WDM) network has been analyzed for the network having 10 nodes and for varying loads. As the load per link (in Erlangs) increases, the blocking probability increases. The result shows that the performance of first-fit algorithm is better than random algorithm whereas the proposed algorithm offers the least blocking.

Anwar Alyatama et al. [22] used random and first-fit wavelength assignment approach for presenting an approximate analytical method and evaluated the blocking probabilities in wavelength division multiplexing networks without wavelength converters. The new approach viewed the WDM network as a set of different layers (colors) in which, blocked

traffic in one layer is overflowed to another layer. Analyzing blocking probabilities in each layer of the network is derived from an exact approach. A moment matching method was then used to characterize the overflow traffic from one layer to another.

Paramjeet Singh *et al.* [23] considered RWA problem on wavelength division multiplexing networks without wavelength conversion. Also, they presented efficient RWA strategies which were used to minimize the blocking probability.

Amit Wason *et al.* [24] developed a simple mathematical model which is used for the calculation of blocking probability of network. A generic routing and wavelength assignment algorithm has also been proposed for the optimization and minimization of blocking probability. The implementation of the proposed model has less complexity and the computation used in this model is quite efficient. This paper suggests an optimum path and assigns wavelength to that path, as a solution to routing and wavelength assignment problem to have least blocking probability. This model can be implemented on different network topologies. Further, the model is also used to evaluate the blocking performance of a 6-node simple network topology and hence used to improve its performance on the basis of blocking probability.

K.R. Venugopal *et al.* [25] attempts to study the impact of wavelength converters in WDM wavelength routed all-optical networks. A new heuristic approach for placement of wavelength converters to reduce blocking probabilities is explored. Multihop virtual topology is designed to minimize the number and overall cost of the converters. Blocking probabilities for Static Lightpath Establishment (SLE) and Dynamic Lightpath Establishment (DLE) are analyzed. In the case of SLE, arranging lightpath in ascending order of their path length reduces blocking probability. Wavelength converters placed at nodes with high nodal degree further reduces the blocking probabilities. Simulation studies performed on 28-node USA long haul network, 20-node arbitrary mesh network, and 19-node EON (European Optical Network) validate the observations made earlier.

Amit Wason *et al.* [26] examined that the blocking probability in wavelength-routed all-optical networks is a very important measure of performance of the network. This blocking probability can be affected by many factors such as network topology, traffic load, number of links, algorithms employed and whether wavelength conversion is available or not and proposed a mathematical model to reduce the blocking probability of the WDM optical

network for both wavelength convertible networks as well as for wavelength non-convertible networks. The model is can be used to evaluate the blocking performance of any network topology also it can be useful to improve its performance of the given network topology.

Chuan-Ching Sue et al. [27] reduced the blocking probability by presenting a wavelength-routing scheme with spare reconfiguration to construct dependable all-optical wavelength-division-multiplexing networks. They developed a Spare Reconfiguration mechanism with Wavelength Reassignment (SR\_WR) and Path Reassignment (SR\_PR) to make the spare dynamic. The proposed wavelength routing with SR proceeds in three stages and has polynomial time complexity. Extensive simulation experiments were conducted on the NSFNet and the K5 fully connected network to investigate the performance of the proposed wavelength routing with SR.

Anwar Alyatama et al. [28] used fixed routing schemes and presented an approximate analytical method to evaluate the blocking probabilities in wavelength division multiplexing networks without wavelength converters. The approach assumed fixed routing with random or first-fit wavelength assignment.

Poompat Saengudomlert *et al.* [29] developed an on-line wavelength assignment algorithm for a wavelength-routed WDM tree network. The algorithm dynamically supports all k-port traffic matrices among end nodes. Implementation of proposed wavelength assignment algorithm was also demonstrated using a hybrid wavelength-routed/broadcast tree with only one switching node connecting several passive broadcast sub-trees.

Abhisek Mukherjee *et al.* [30] proposed a new wavelength conversion algorithm in a DWDM network using online routing. The model for the algorithm has been theoretically developed and the corresponding call connection probability has been calculated. The limitation on the number of wavelength conversions has been addressed by fixing the maximum number of wavelength conversions allowed for the transmissions of a single packet over the network.

Raja Datta *et al.* [31] presented a wavelength assignment algorithm which was used for optimal assignment of a single wavelength to single-hop traffic in a tree topology. The work was further extended for the wavelength assignment in a general graph. This polynomial time algorithm gave an optimal solution to the routing and wavelength assignment problem in a tree topology.

Gaoxi Xiao *et al.* [32] studied blocking probability and proposed a set of algorithms for allocating Fixed Wavelength Conversion (FWC) in all-optical networks. They adopted the simulation-based optimization approach in which utilization statistics of FWC's were collected from computer simulations and then optimization was performed to allocate the FWC's. Extensive computer simulations were conducted on regular and irregular networks under both the uniform and non-uniform traffic.

Jian Liu *et al.* [33] proposed two different wavelength assignment algorithms for the network. These wavelength assignment algorithms were proposed for minimization of blocking probability of the network.

Guangzhi Li *et al.* [34] studied the off-line wavelength assignment problem in star and ring networks for optical wavelength division multiplexed networks. The results showed that the ability to switch between fibers increases wavelength utilization. Additionally, the complexity of the problem was studied and several constrained versions of the problem were also considered for star and ring networks.

Jianping Wang *et al.* [35] studied wavelength assignment for WDM multicast network to cover the maximum number of destinations for minimizing the network cost. The computational complexity of the problem was also studied. Three heuristic algorithms were proposed and the worst-case approximation ratios for some heuristic algorithms were given. They also derive a lower bound of the minimum total wavelength cost and an upper bound of the maximum number of reached destinations. The efficiency of the proposed heuristic algorithms and the effectiveness of the derived bounds were verified by the simulation results.

## 2.2 Objectives of Thesis

The objectives of the thesis are:

- The performance analysis of First-fit, Random, Most-used and Wavelength conversion Algorithms for wavelength assignment in WDM unidirectional optical ring network.
- The blocking probability variation of the network for different algorithm has been studied based on total number of wavelengths variation used in the network.
- Blocking Probability of Wavelength Conversion Algorithm for different route length.

## **2.3 Outline of Thesis**

The thesis is divided into six chapters:

The first chapter includes the introduction of optical networks and wavelength division multiplexing and a brief discussion of routing and wavelength assignment algorithm.

The second chapter includes the literature survey of all routing procedure and wavelength assignment algorithm.

In the third chapter, evaluation of performance of algorithms for wavelength assignment in optical ring network

In the fourth chapter, examined the blocking probability of algorithms for different wavelength assignment in optical ring network

The fifth chapter calculate the blocking probability of wavelength conversion algorithm for different route length.

Finally, the sixth chapter includes conclusion and future scope of the work done.

# CHAPTER 3

## Performance Evaluation of Algorithms for Wavelength Assignment in Optical Ring Network

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### 3.1 Abstract

A new simulating technique for the performance analysis of First-fit, Random, Most-used and Wavelength conversion Algorithms for wavelength assignment in WDM unidirectional optical ring network are being proposed. The blocking probability of various algorithms with the variation in number of events has been compared. The performance of the wavelength conversion algorithms is best but there is burden of using expensive hardware. Without the need of wavelength-converter, most-used algorithm performs better than random and first-fit algorithms. The following approaches are very effective for the minimization of blocking probability of optical WDM networks.

### 3.2 Introduction

The rapid growth of internet traffic has been the driving force for faster and more reliable data communication networks. Wavelength division multiplexing (WDM) is probably the most powerful technique to unlock the enormous bandwidth in optical fiber and thus overcome the electronic bottleneck without laying new fiber. In a WDM network several optical signals are sent on the same fibers using different wavelength channels [36]. The blocking probability of a lightpath request (or a call) is an important performance measure of a wavelength-routed network. This blocking probability is affected by many factors such as network topology, traffic load, the RWA algorithm employed and whether or not wavelength conversion is available. A network equipped with the wavelength converters has a better call blocking performance than a network without wavelength converters. However, since wavelength conversion is an immature extremely costly technology, it may not be economical to install wavelength converters at every node of a network. Rather, it may be more sensible to put wavelength converters at some, but not all, nodes in the network, called sparse wavelength-conversion network [37]. Routing and wavelength assignment problem is

one of the main important problems of WDM optical networks. The existing research demonstrates that an effective routing and wavelength assignment (RWA) algorithm is one of the primary Vehicles for improving blocking performance. An algorithm used for selecting routes and wavelengths to establish lightpath is known as a routing and wavelength assignment (RWA) algorithm. Many problems in wavelength-routed WDM networks have RWA as a sub-problem. The RWA problem can be split into two independent parts:

- 1) Find a route from the source to the destination.
- 2) Assign a wavelength to the selected route.

An end-to-end light path has to be established prior to the communication between any two nodes. To establish a light path, it is required that the same wavelength be allocated on all the links along the path. This limitation is known as the wavelength continuity constraint [38]. This blocking probability can be affected by many factors such as network topology, traffic load, number of links, algorithms employed and whether wavelength conversion is available or not. Blocking is the key performance index in the design of an all-optical network. In simple words the connection is blocked when the network does not have sufficient resources to support a connection. Resources in our case are the available wavelengths in the network. This parameter is dependent on the type of algorithm used to assign the wavelength for communicating nodes in the network. Thus algorithms resulting in minimum blocking have the best performance. Wavelength Assignment algorithms, among possible others, include

- Random wavelength assignment [4]: In this algorithm a set of wavelengths that can be used to establish the connection is determined. After that wavelength is randomly select with uniform probability distribution from the set.
- Most-used wavelength assignment [4]: The most-used algorithm selects the wavelength most often used in the network. The objective of this policy is to keep more wavelengths available for calls traveling over long paths. This algorithm requires communication overhead and storage requirements.
- Wavelength conversion wavelength assignment [5]: Any incoming light-path can be assigned to any wavelength on the output side. This eliminates wavelength-continuity constraints.
- First-Fit wavelength assignment [6]: This algorithm numbers all wavelengths, so that when there is a demand for wavelengths available, those of a smaller number are

considered first. The first available wavelength is then selected. This algorithm does not require global information system. Its computational cost is lower because no storage is needed to keep the network states. It works well in terms of blocking probability and fairness of allocation. This algorithm is preferred for its small overhead and low computational complexity. The objective of this allocation scheme is to minimize wavelength fragmentation

### 3.3 Simulation Setup

The simulation setup for showing the effect of the performance analysis of First-fit, Random, Most-used and Wavelength conversion Algorithms for wavelength assignment in WDM unidirectional optical ring network is shown in Figure 3.3(a) to 3.3(d). WDM ring networks with a single control node that's help in handle the setup request and algorithm selection. Central node contains three transition parts like handle setup request, handle close and discard the message. In the simulation setup we use four different circuit and they are following:

- General circuit.
- Control node circuit.
- Link circuit.
- Node circuit.

1. General Circuit: This contain eight nodes from N00 to N07, Eight links from L00 to L07 and One central node as shown in Figure 3.3(a)

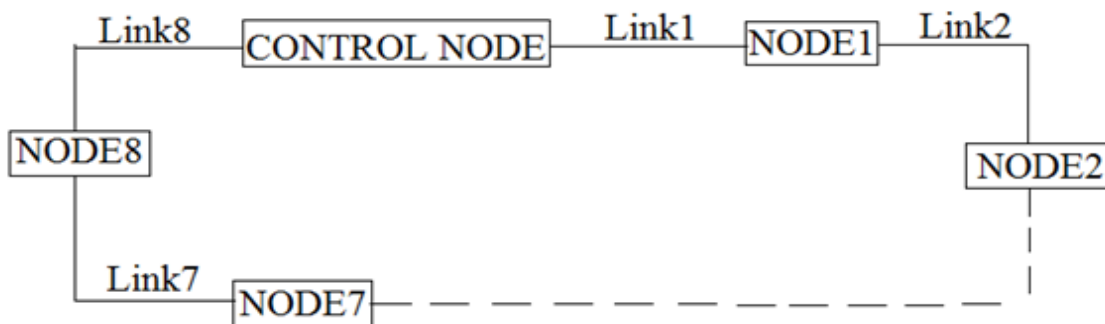


Figure 3.3(a) General circuit of 8 nodes

2. Control Node Circuit: Control node play a very important role here and it help in handle the setup request and algorithm selection. Here there are three transition parts like handle setup request, handle close and discard the message. There is one input and output places as shown in Figure 3.3(b)

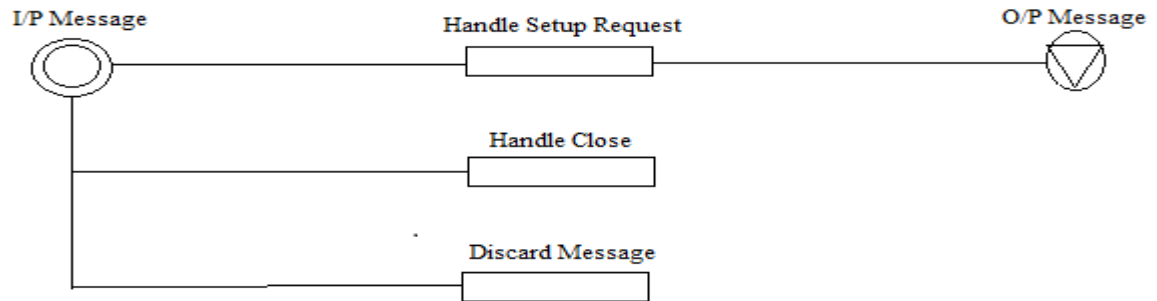


Figure 3.3(b) Control Node

3. Link Circuit: Every link has three part and these are input, output and delay between input and output. But we provide only zero as default delay here so it provide only as a link between input and output without any delay as shown in Figure 3.3(c)

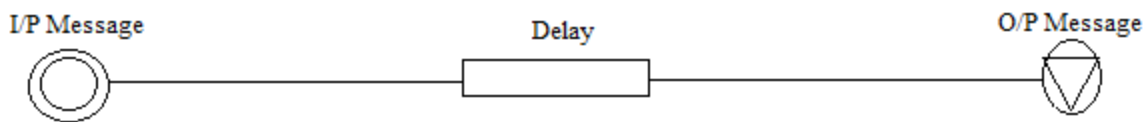


Figure 3.3(c) Link Circuit

4. Node Circuit: Here every node has three paths. First path can send the message directly from one node to other node through I/P message, forward external request, queue for request, send message, O/P Message. Second path can generate the request from request generation point and follow the path request no., request generate, queue for request, send message, O/P Message. Path 3 is use to handle the request when destination node is that node by using the path I/P Message, handle setup acknowledge message and check as shown in Figure 3.3(d)

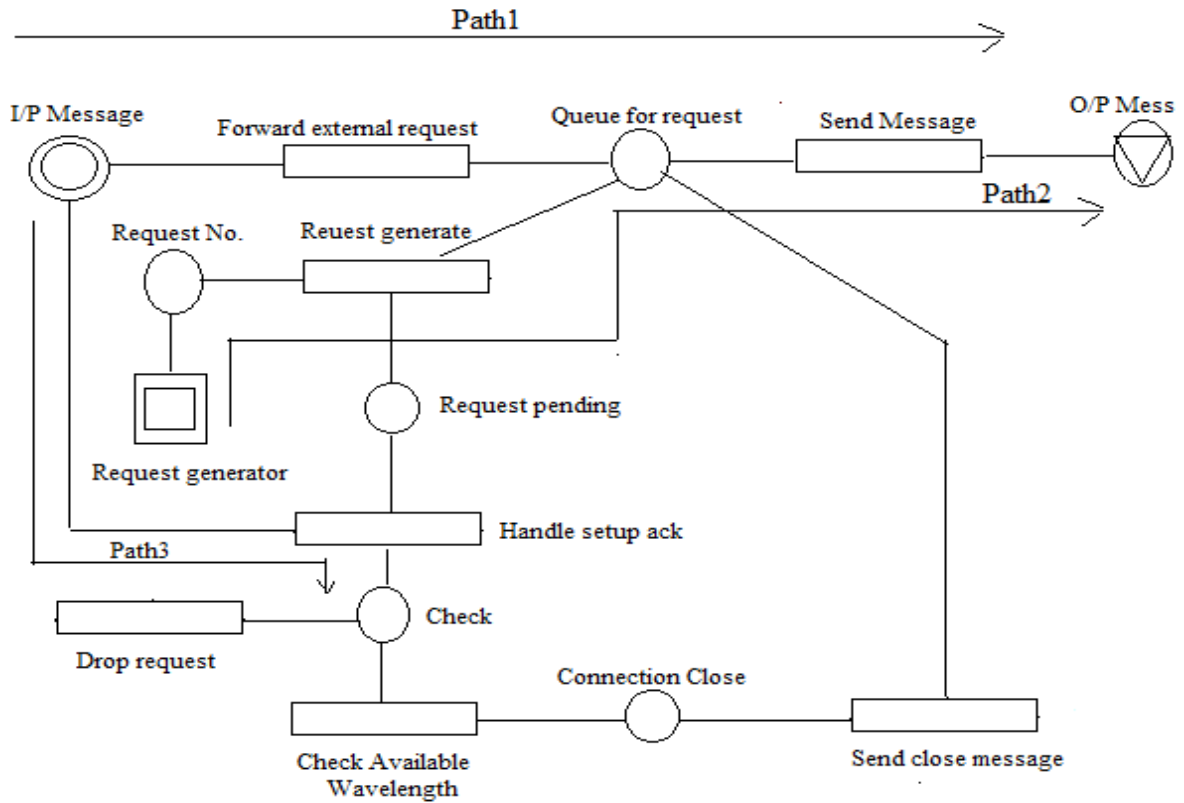


Figure 3.3(d) Node Circuit

### 3.4 Results and Discussion

The blocking probability of the network depends on the number of free wavelengths, number of channels(C) and length of the route. We have fixed 10 channels(C) and 10 numbers of free wavelengths. Here the blocking probability of the algorithm such as first-fit, wavelength conversion, random and most-used algorithm is compared with each other and we obtained the blocking probability with the variation of event on every eight node from N01 to N08 as shown in Figure 3.4(a) to 3.4(h) respectively.

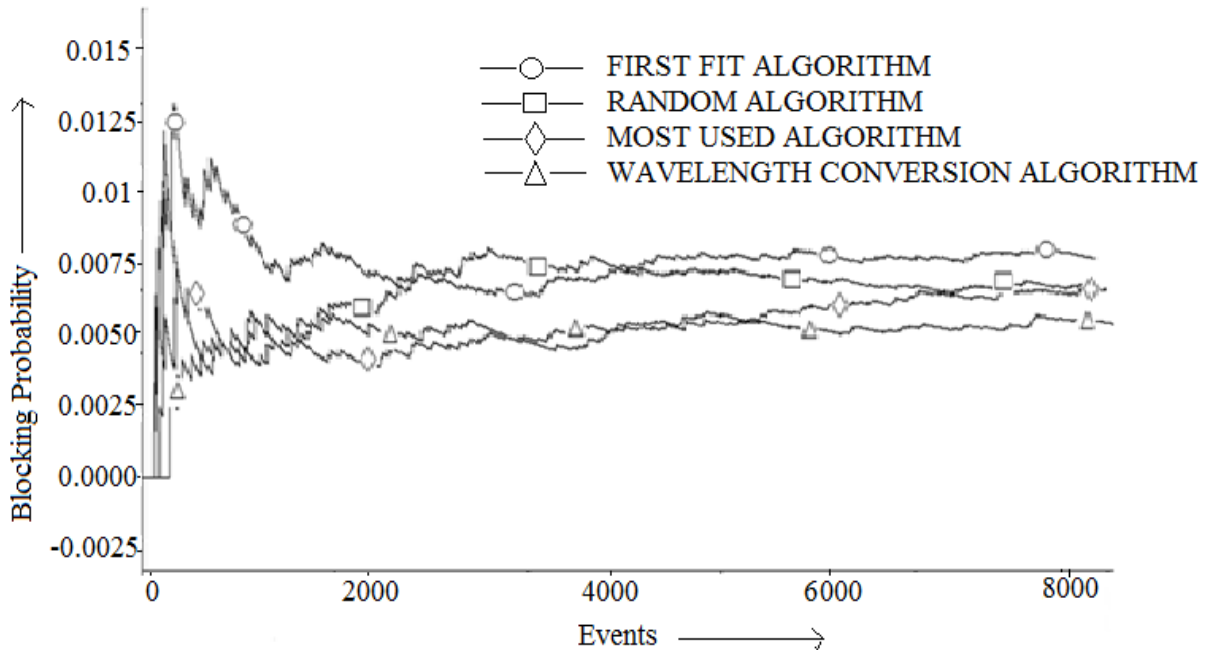


Figure 3.4(a) Blocking probability v/s events at node 1

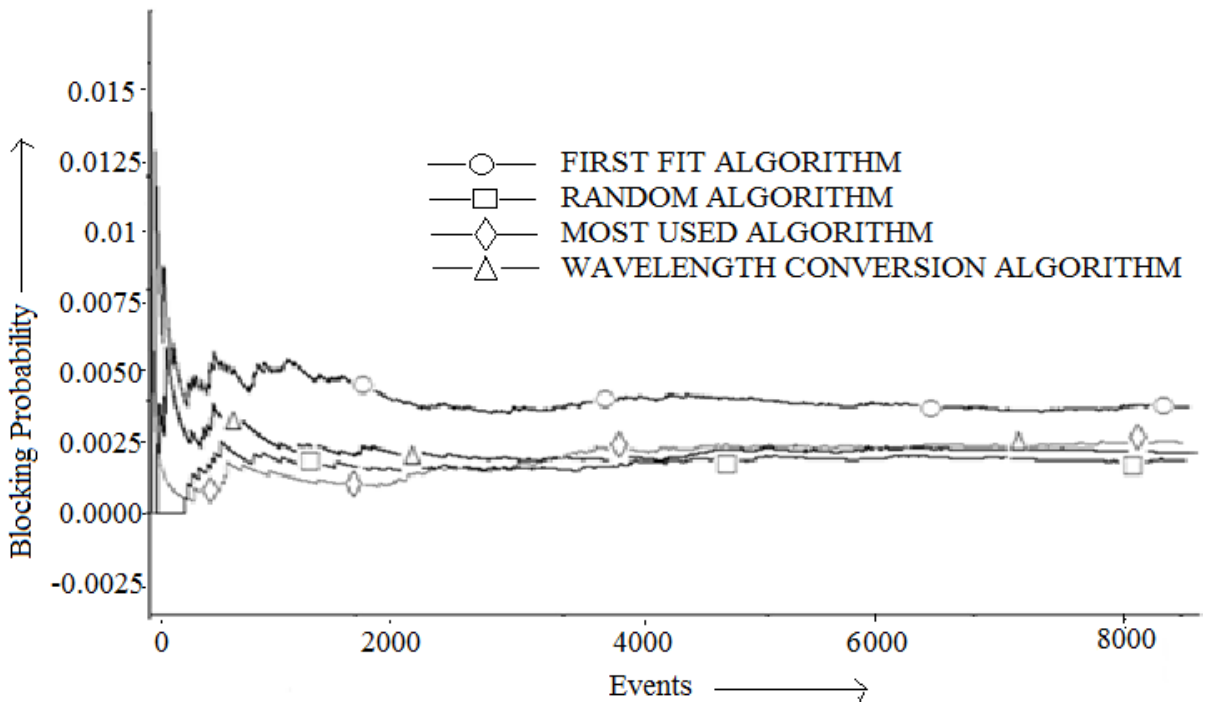


Figure 3.4(b) Blocking probability v/s events at node 2

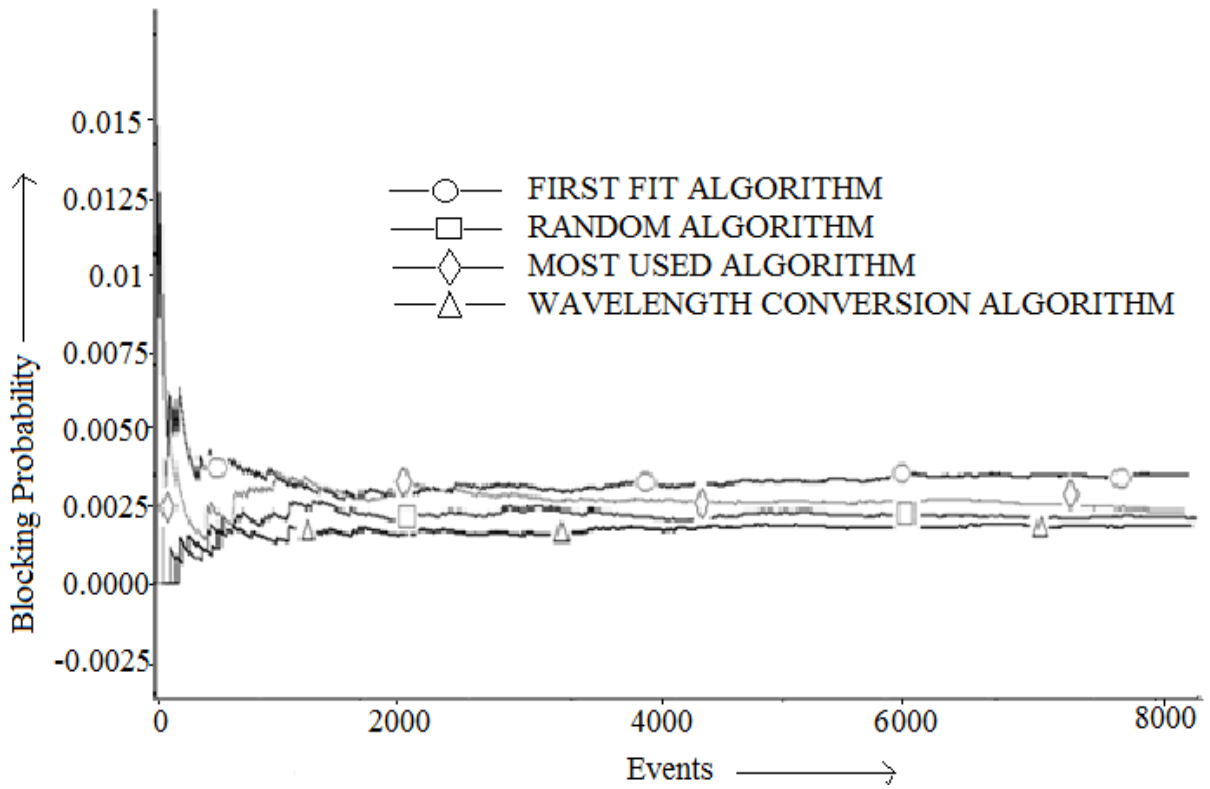


Figure 3.4(c) Blocking probability v/s events at node 3

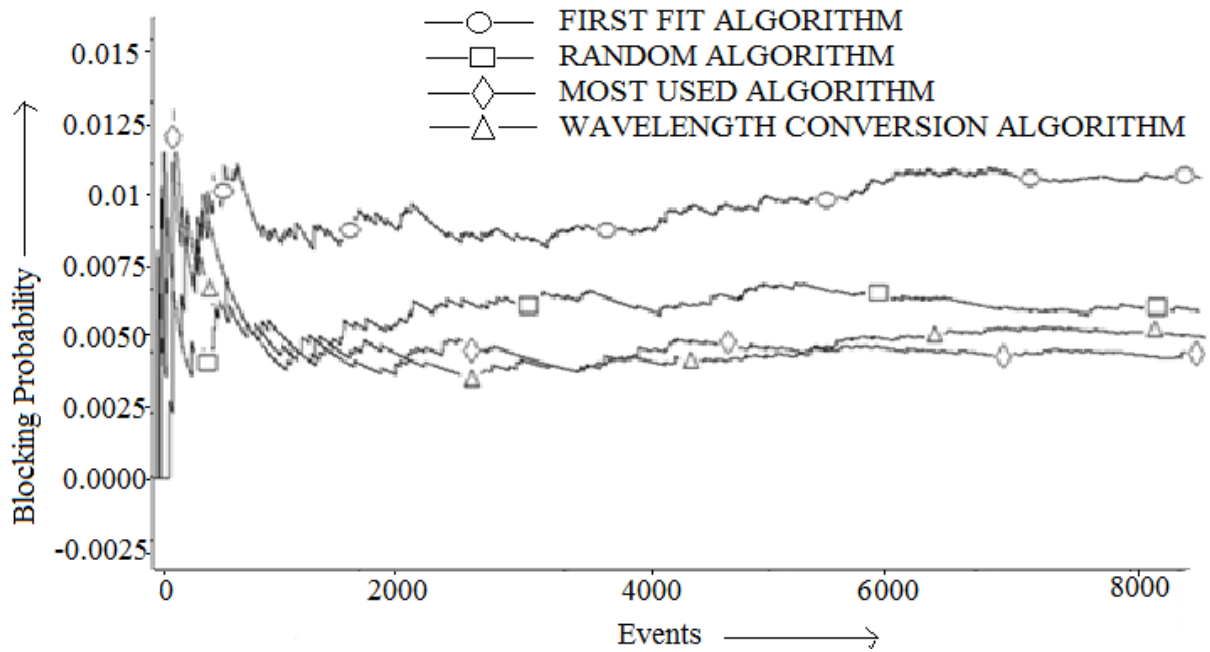


Figure 3.4(d) Blocking probability v/s events at node 4

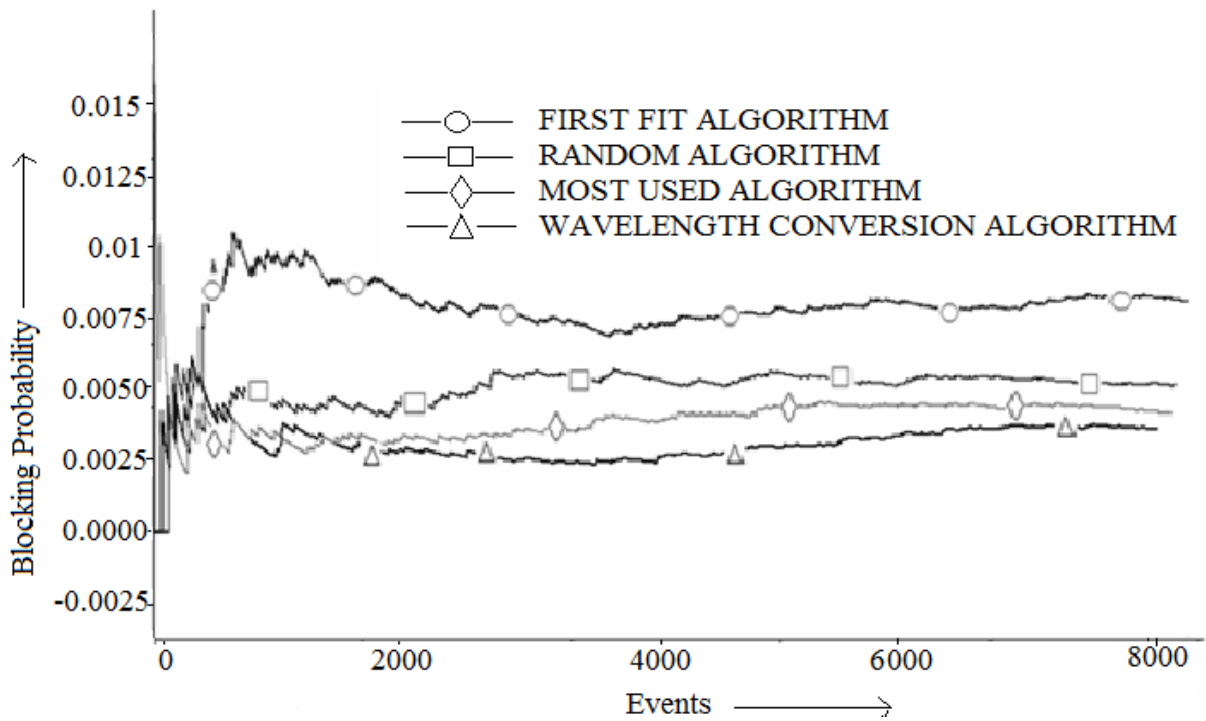


Figure 3.4(e) Blocking probability v/s events at node 5

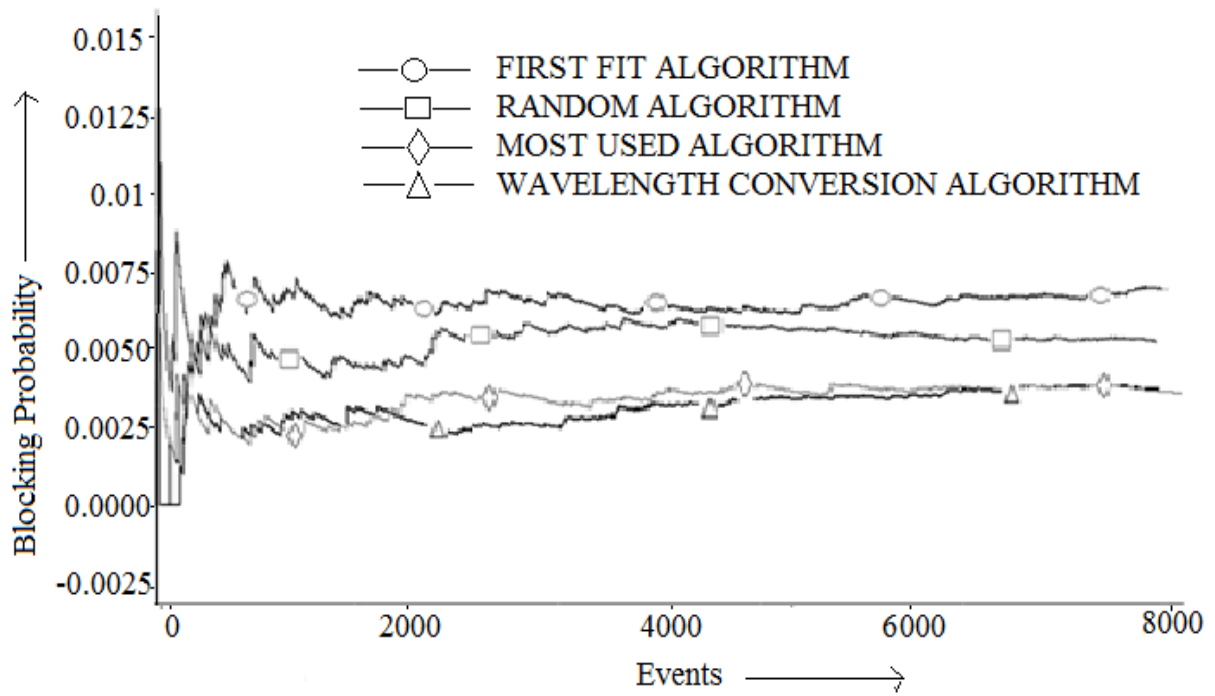


Figure 3.4(f) Blocking probability v/s events at node 6

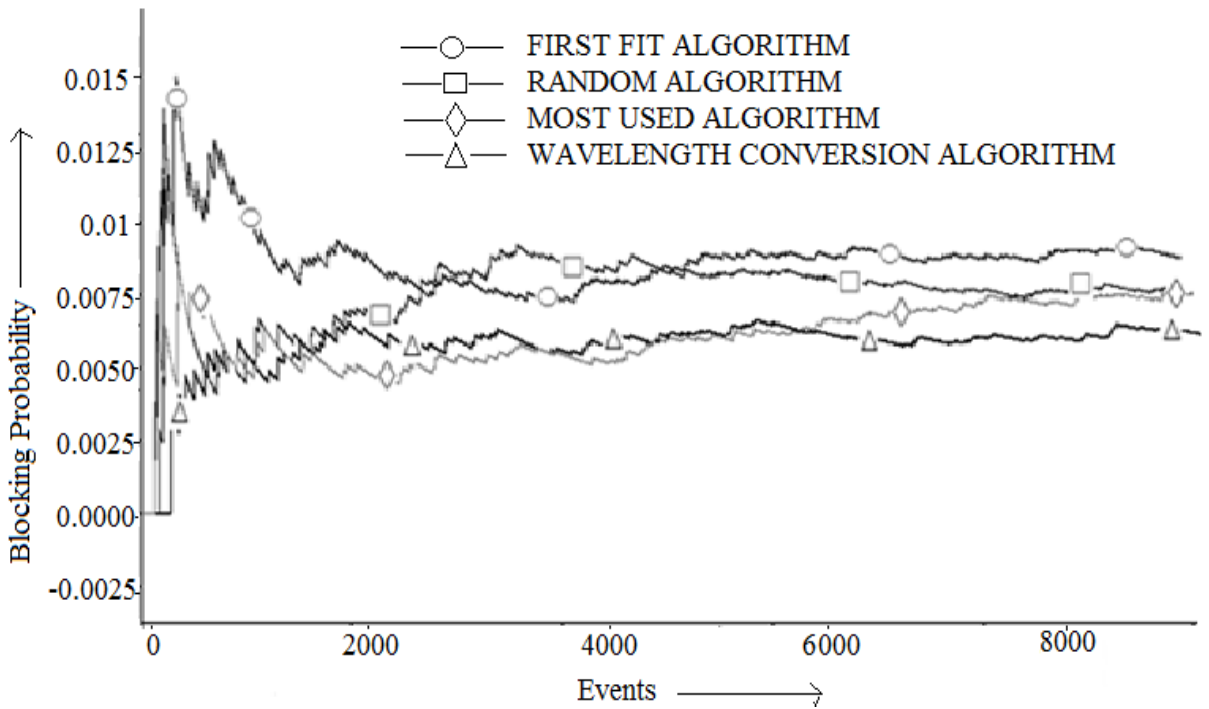


Figure 3.4(g) Blocking probability v/s events at node 7

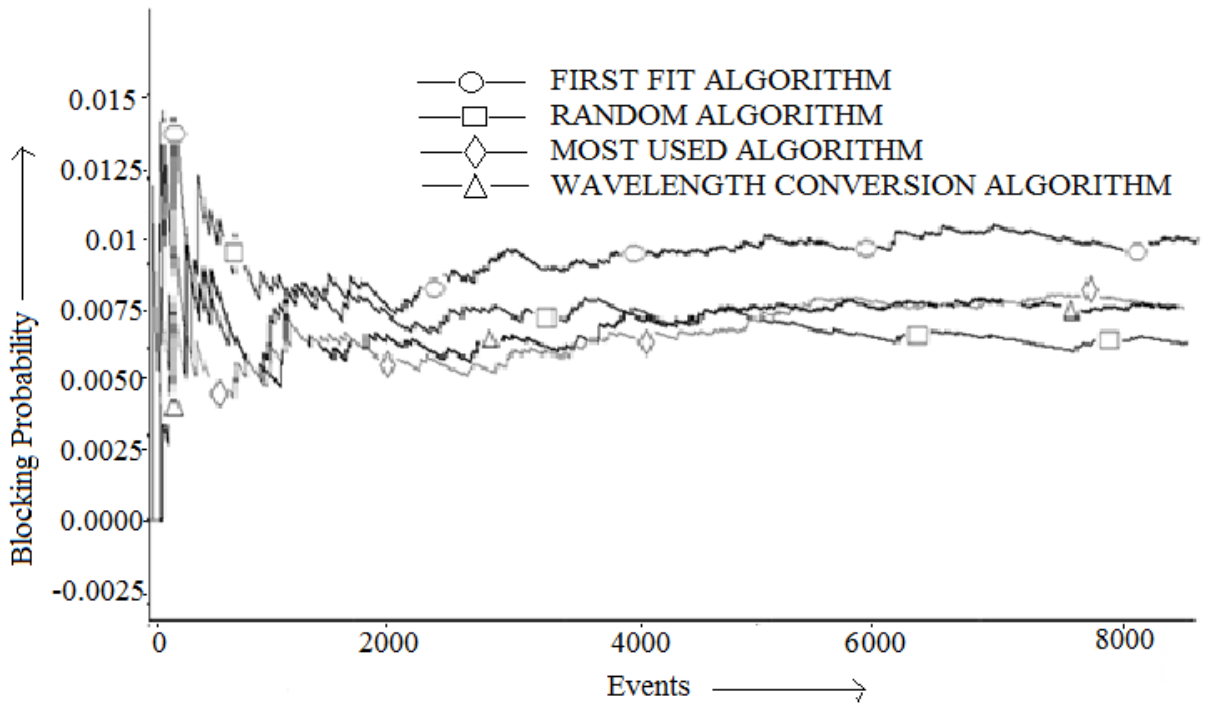


Figure 3.4(h) Blocking probability v/s events at node 8

In the above graphs, node 1 to 8 shows average blocking probability of first used algorithm and random algorithm is always large as compared to most used and wavelength conversion algorithms. We also examined that wavelength conversion algorithm perform better in all of algorithms since blocking probability is the ratio of the number of lightpath requests rejected to the number of lightpath connections requested. Fig. 3.4(i) shows the lightpath established between nodes 1-2, 2-3 and 1-3. Each fiber supports two wavelengths,  $\lambda_1$  and  $\lambda_2$ . A connection request is set up between nodes 1-2 on  $\lambda_1$  and between nodes 2-3 on  $\lambda_2$ . A next connection request between nodes 1-3 is set up only on a two-hop path; i.e. node 1-2 on  $\lambda_2$  and node 2-3 on  $\lambda_1$ . This is possible only if the optical switching node has a wavelength converter at 2, otherwise, the call is blocked (Fig. 3.4(i)). Thus nodes with wavelength conversion capability reduce blocking probability.

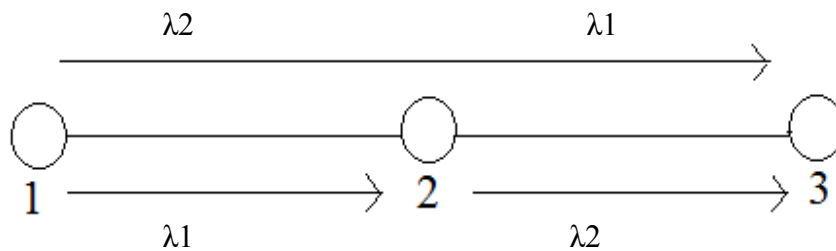


Figure 3.4(i) Wavelength conversion

### 3.5 Conclusion

This result presents a simulating technique for performance analysis of optical network using First-fit, Random, Most-used and Wavelength conversion algorithms. The Simulation results obtained for calculating the blocking probability for each of this algorithm has been compared and we conclude that using wavelength convertors in the network results in best performance of the network but there is burden of using expensive hardware. The most-used algorithms perform better than the random and the first-fit algorithms without the need of wavelength convertor.

## CHAPTER 4

# Blocking Probability of Algorithms for different Wavelength Assignment in Optical Ring Network

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### 4.1 Abstract

The blocking probability of the network for different algorithm based on total number of wavelengths in the eight node WDM unidirectional optical ring network is being proposed. As the number of available wavelength increases the blocking probability decreases. As compared to most used algorithm the performance of the wavelength conversion algorithms is best but there is burden of using expensive hardware. The simulation setup is accurate even in a system with large number of wavelengths. The following approaches are very effective for the minimization of blocking probability of optical WDM networks.

### 4.2 Introduction

Wavelength division multiplexing (WDM) optical networking is enabled by a range of technologies. Optics is clearly the preferred means of transmission, and WDM transmission is now widely used in the network. In recent years, the people have realized that optical networks are capable of providing more function than just point to point transmission. Major advantages are to be gained by incorporating some of the switching and routing functions that were performed by the electronics into the optical part of the network. In the first generation optical networks, the electronics at a node must handle not all the data intended for that node but network. If the latter data could be routed through in the optical domain, the burden on the underlying electronics at the node would be significantly reduced. This is the one of the key driver for the second generation optical networks. The optical networks based on this paradigm are now being deployed. We call this network as wavelength-routed network [39]. Routing and wavelength assignment problem can be defined as; given the network topology and a set of end-to-end light path requests, determine a route and wavelength(s) for the requests, using the minimum possible number of wavelengths. Routing and wavelength assignment problem is one of the main important problems of WDM optical

networks. In literature there are a number of methodologies proposed to tackle the RWA problem. One method is to consider the RWA problem as a coupled RWA problem (single compete problem) and the other method is to divide this RWA into the two sub problems i.e. Routing problem and wavelength assignment problem. The solution obtained by dividing this problem in sub problems is suboptimal but is practical to use. The RWA problem can be split into two independent parts, first is find a route from the source to the destination and second is assign a wavelength to the selected route. An end-to-end light path has to be established prior to the communication between any two nodes. To establish a light path, it is required that the same wavelength be allocated on all the links along the path. This limitation is known as the wavelength continuity constraint [40]. In WDM optical networks, there are three main constraints related with wavelength assignment: wavelength continuity constraint (WCC), distinct wavelength assignment constraint (DWAC), and nonwavelength continuity constraint (NWCC). In WCC, the same wavelength should be used on all the links along the selected route. In DWAC, two light paths cannot be assigned the same wavelength on any fiber and in NWCC; different wavelengths can be used on the links along the selected route but the nodes should have wavelength conversion capability. Wavelength conversion is the ability to convert the data on one wavelength to another wavelength. Eliminating wavelength conversion significantly reduces the cost of the switch, but it may reduce network efficiency because more wavelengths might be required. But several studies reported that the increased efficiency by using wavelength conversion is small as compared to the cost increase [41]. The blocking probability of a lightpath request (or a call) is an important performance measure of a wavelength-routed network. This blocking probability is affected by many factors such as network topology, traffic load, the RWA algorithm employed and whether or not wavelength conversion is available. A network equipped with the wavelength converters has a better call blocking performance than a network without wavelength converters. However, since wavelength conversion is an immature extremely costly technology, it may not be economical to install wavelength converters at every node of a network. Rather, it may be more sensible to put wavelength converters at some, but not all, nodes in the network, called sparse wavelength-conversion network [42].

### 4.3 Simulation Setup

The simulation is done with the help of Artifex tool. The simulation setup for showing the effect of the performance analysis of Most-used and Wavelength conversion Algorithms for different wavelength assignment in WDM unidirectional optical ring network is shown in Figure 4.3(a) to 4.3(c). The simulation setup is made of 8 nodes transmitting packets on WDM unidirectional optical ring network. WDM ring networks with a single control node helps in handling the setup request, algorithm selection as well as to vary the number of available free wavelength. Central node contains three transition parts like handle setup request, handle close and discard the message. In the simulation setup we have used three different circuit and they are following:

- Optical Ring of 8 nodes with control node.
- Link circuit.
- Control node circuit.

1. Optical Ring: This contain eight nodes from N00 to N07, Eight links from L00 to L07 and One central node as shown in Figure 4.3(a)

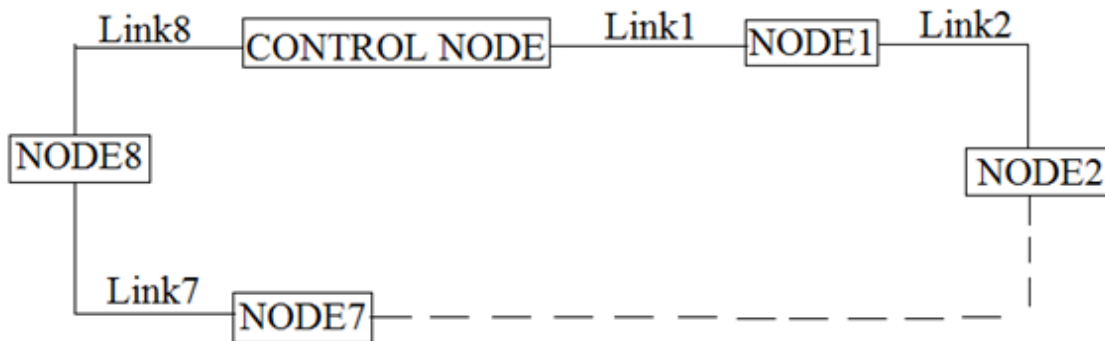


Figure 4.3(a) Ring of 8 nodes

2. Link Circuit: Every link has three part and these are input, output and delay between input and output. But we provide only zero as default delay here, so it provide only as a link between input and output without any delay as shown in Figure 4.3(b)

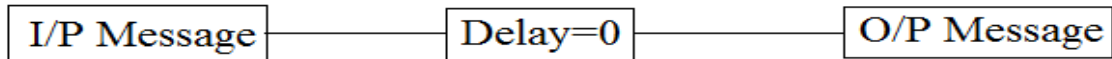


Figure 4.3(b) Link Circuit

3. Control Node Circuit: Control node play a very important role and it helps in handling the setup request and algorithm selection. Here there are three transition parts like handle setup request, handle close and discard the message. There is one input and output places as shown in Figure 4.3(c)

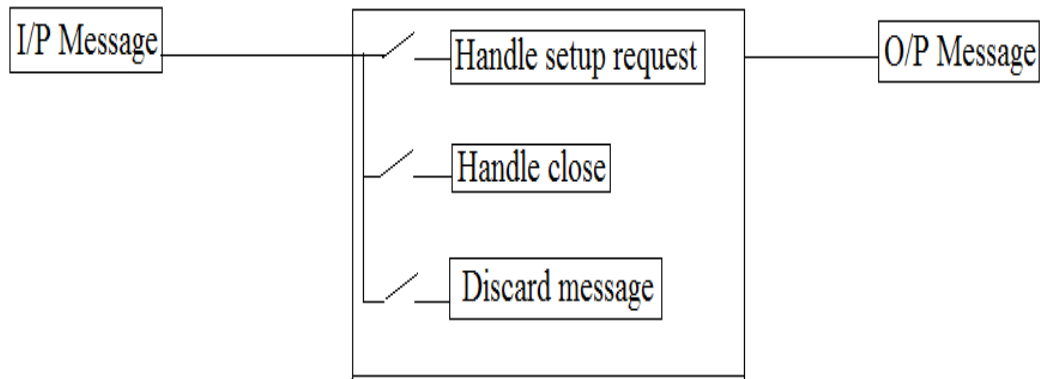


Figure 4.3(c) Control Node

#### 4.4 Results and Discussion

We designed and developed a simulator to implement routing and wavelength assignment in all-optical networks for regular and irregular topologies. The simulator is developed in C++ language. It accepts input parameters such as the number of nodes in the network, link information with weight, number of wavelengths per fiber, connection requests. Some of the calls may be blocked because of the unavailability of free wavelength on links along the route from the source to the destination. The ratio of the total number of calls blocked to the total number of lightpath requests in the network is defined as the blocking probability. The output of the simulator is the blocking probability for the specified parameters along with the detailed information of connections. All these parameters can be initialized before running

the simulations to obtain results for a given selection of parameters. Extensive simulations are then carried out for every combination of parameters of interest. The blocking probability of the network depends on the number of free wavelengths, number of channels(C) and length of the route. We have fixed the number of channels(C) to 10 and vary the number of free wavelengths from 1 to 10.

Firstly we obtained the blocking probability with the variation of event on every eight node from N01 to N08 for most used algorithm as shown in Figure 4.4(a) to 4.4(h) respectively.

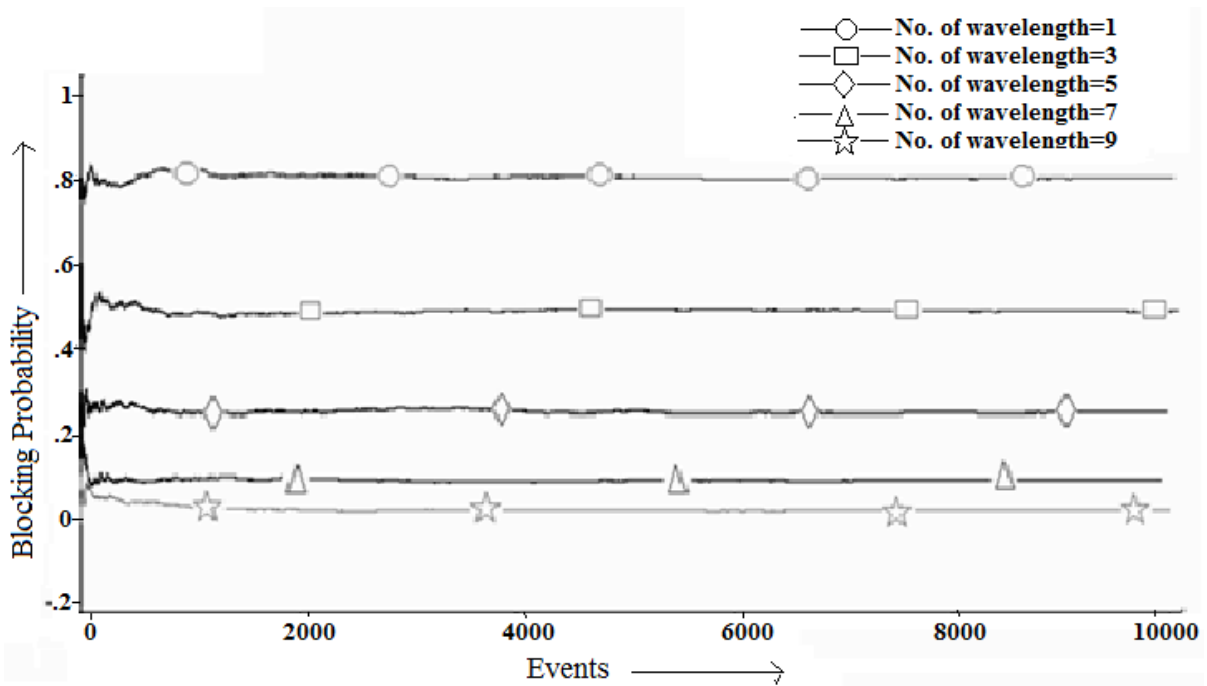


Figure 4.4(a) Blocking probability of node 1

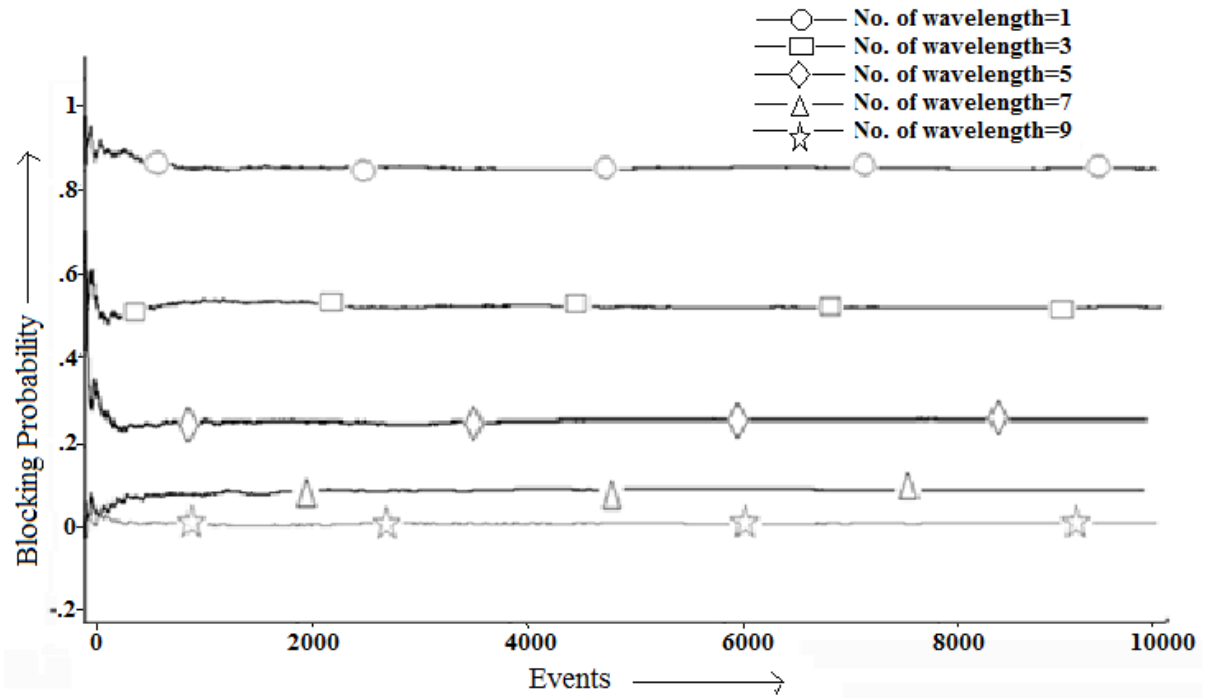


Figure 4.4(b) Blocking probability of node 2

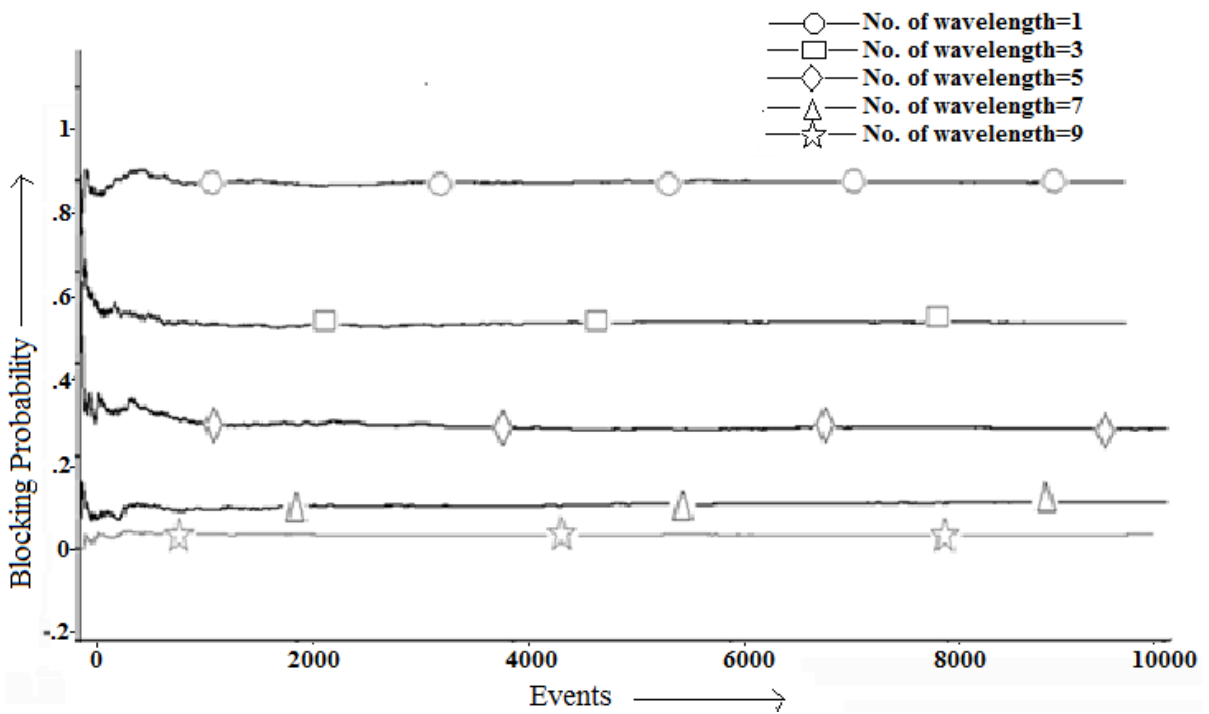


Figure 4.4(c) Blocking probability of node 3

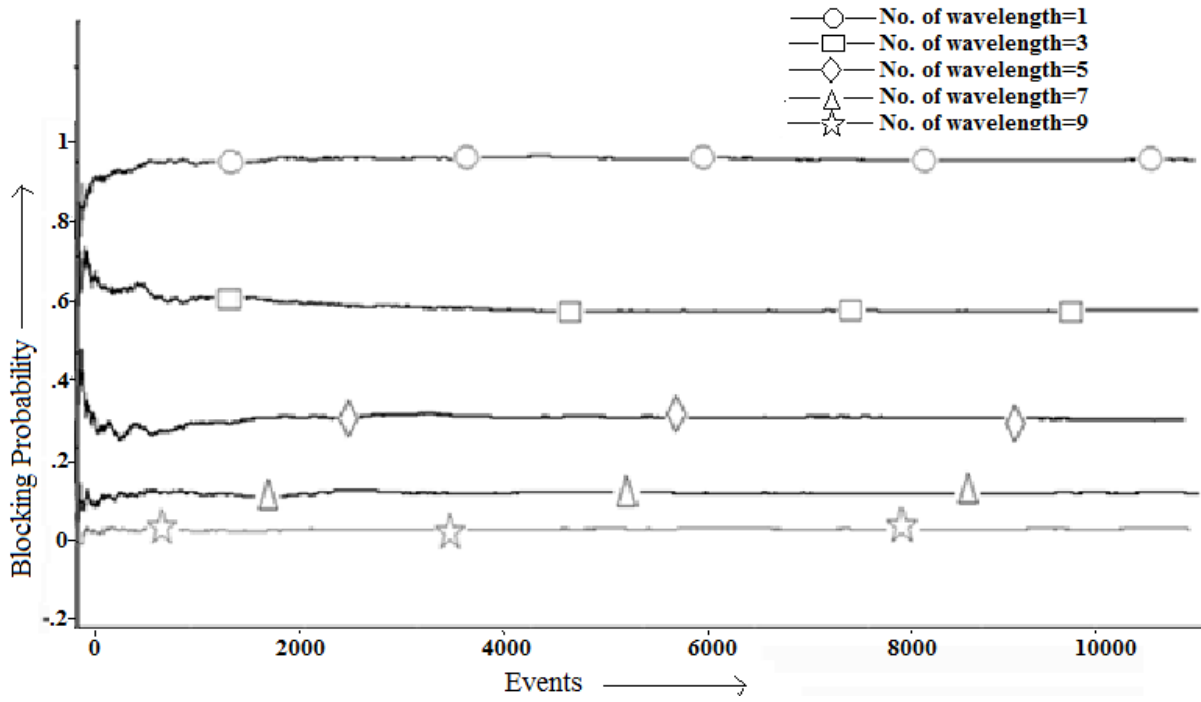


Figure 4.4(d) Blocking probability of node 4

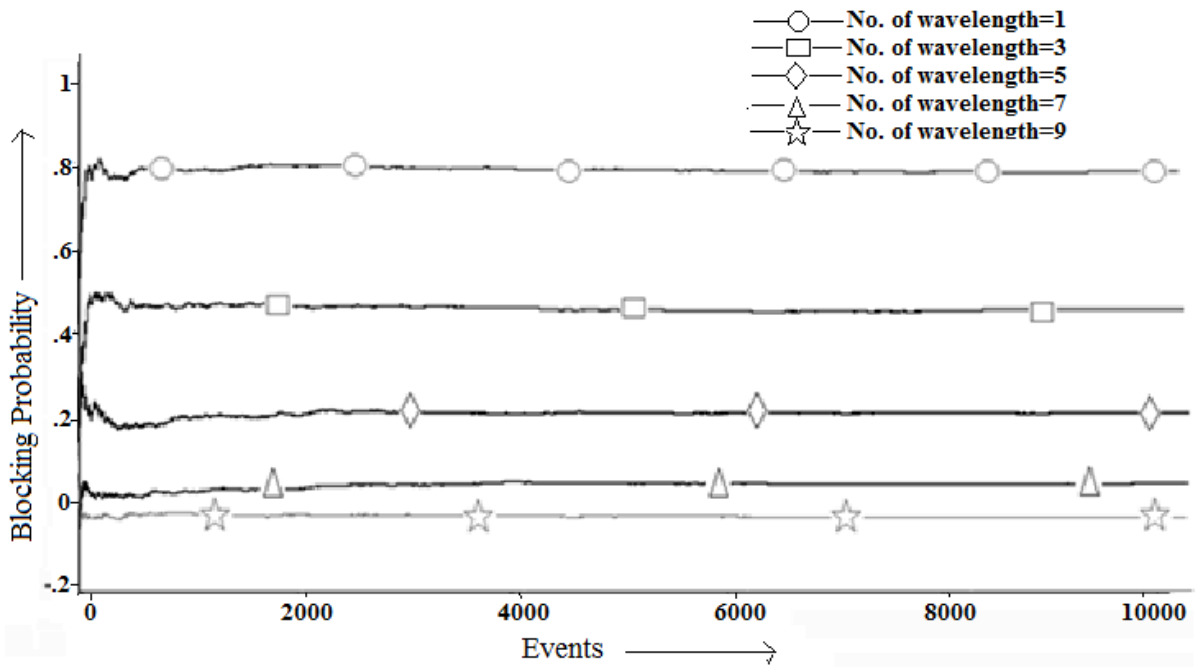


Figure 4.4(e) Blocking probability of node 5

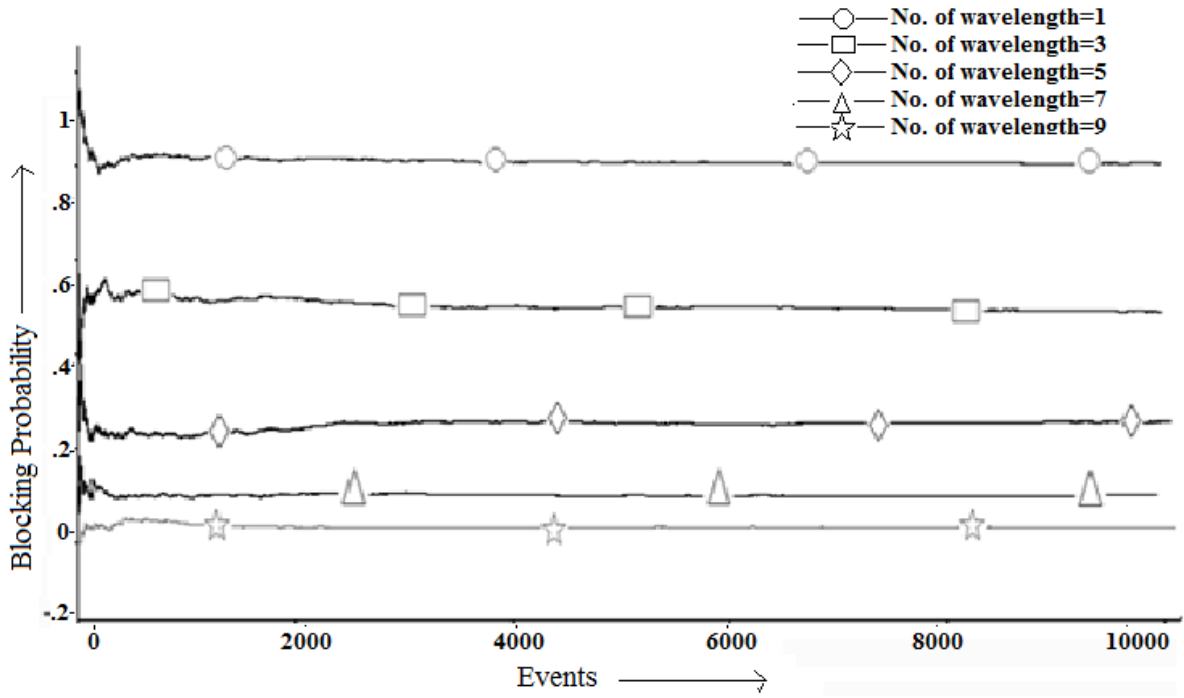


Figure 4.4(f) Blocking probability of node 6

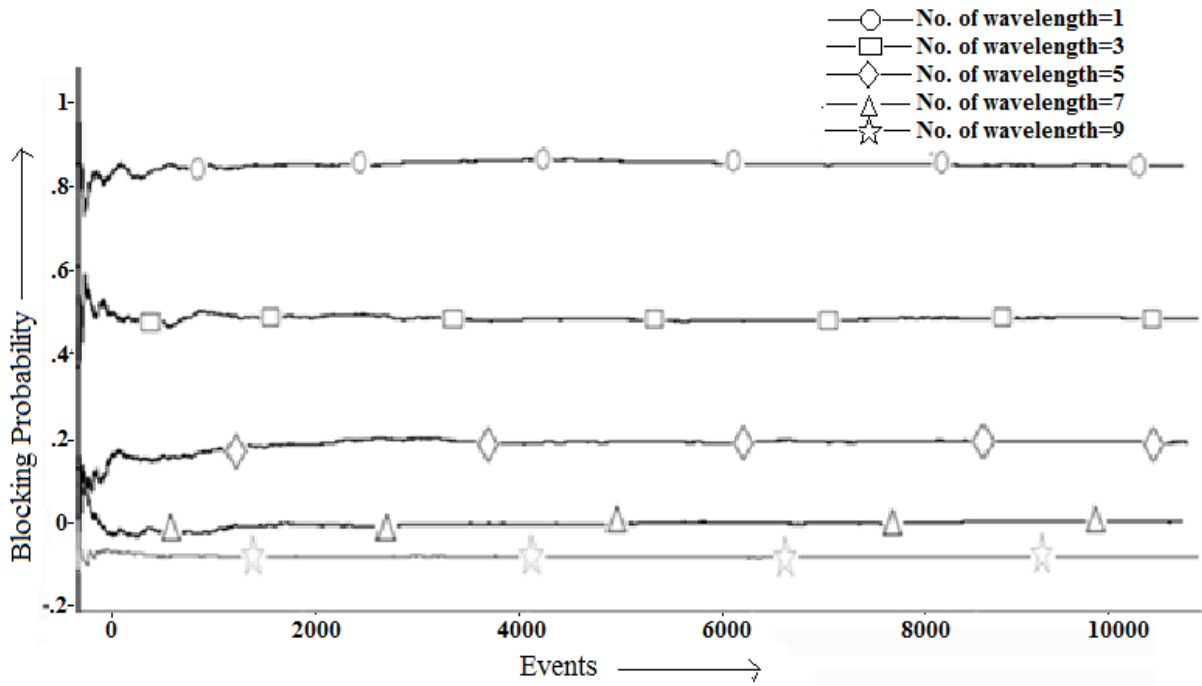


Figure 4.4(g) Blocking probability of node 7

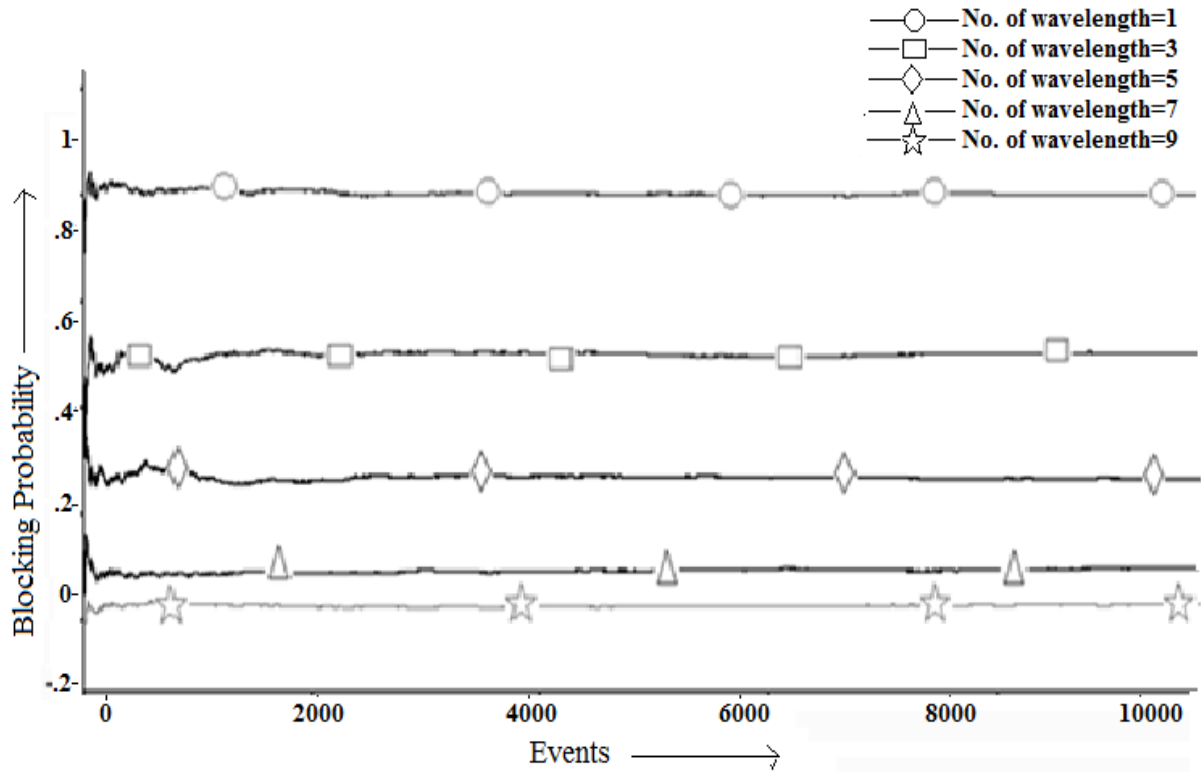


Figure 4.4(h) Blocking probability of node 8

In the above graph for node 4 to 11 we noticed that as we increase the number of available wavelength then blocking probability decreases.

- Secondly we obtained the blocking probability with the variation of event on every eight node from N01 to N08 for wavelength conversion assignment algorithm as shown in Figure 4.4(i) to 4.4(p) respectively.

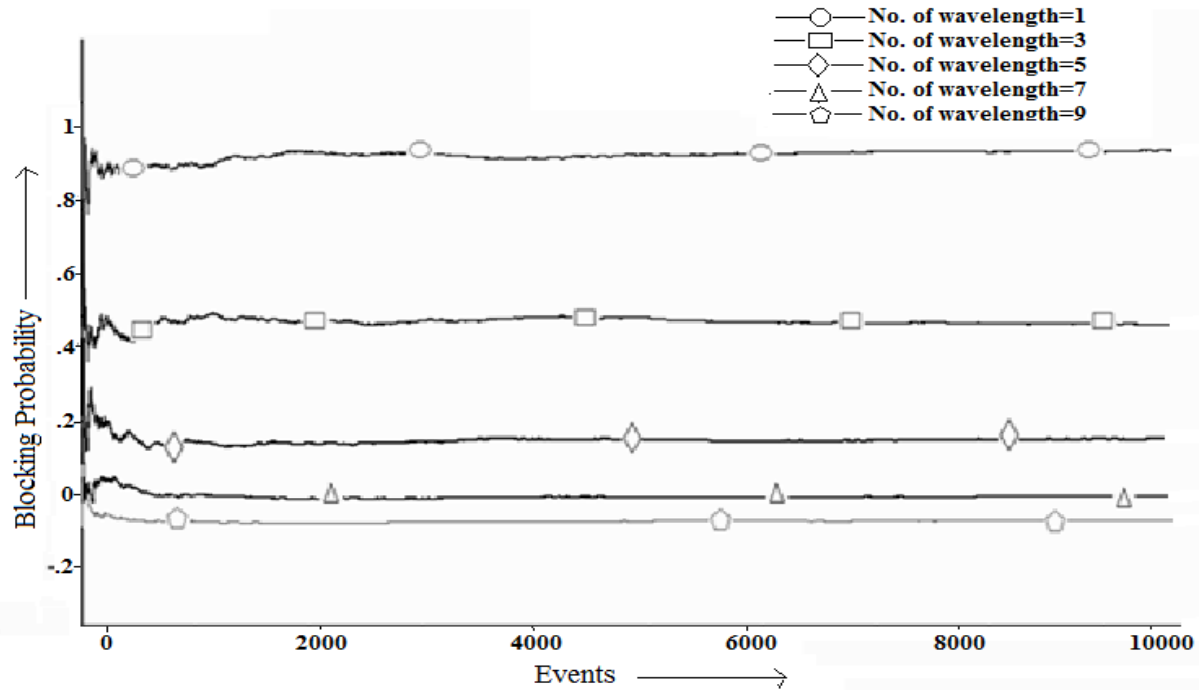


Figure 4.4(i) Blocking probability of node 1

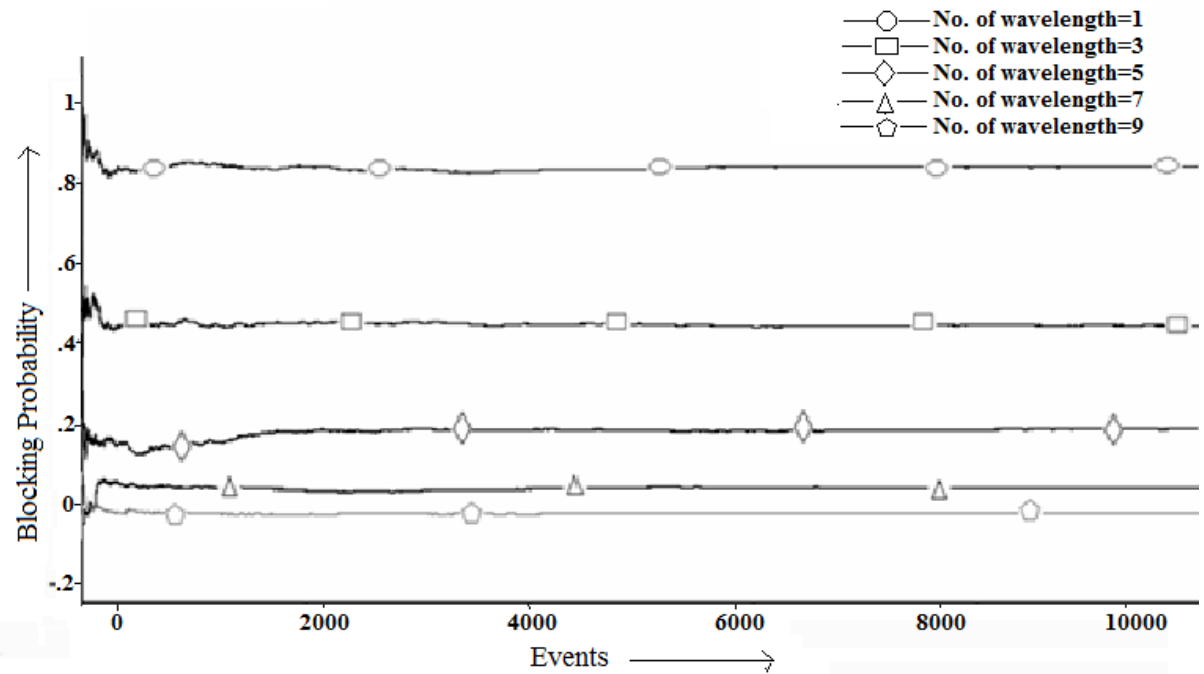


Figure 4.4(j) Blocking probability of node 2

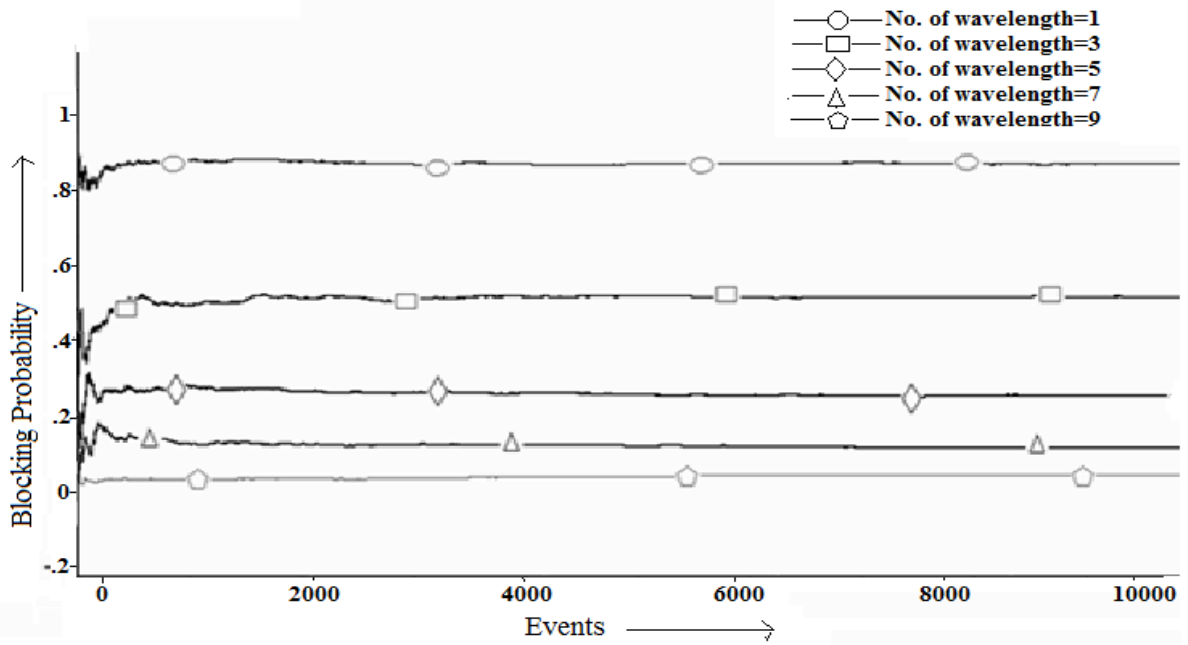


Figure 4.4(k) Blocking probability of node 3

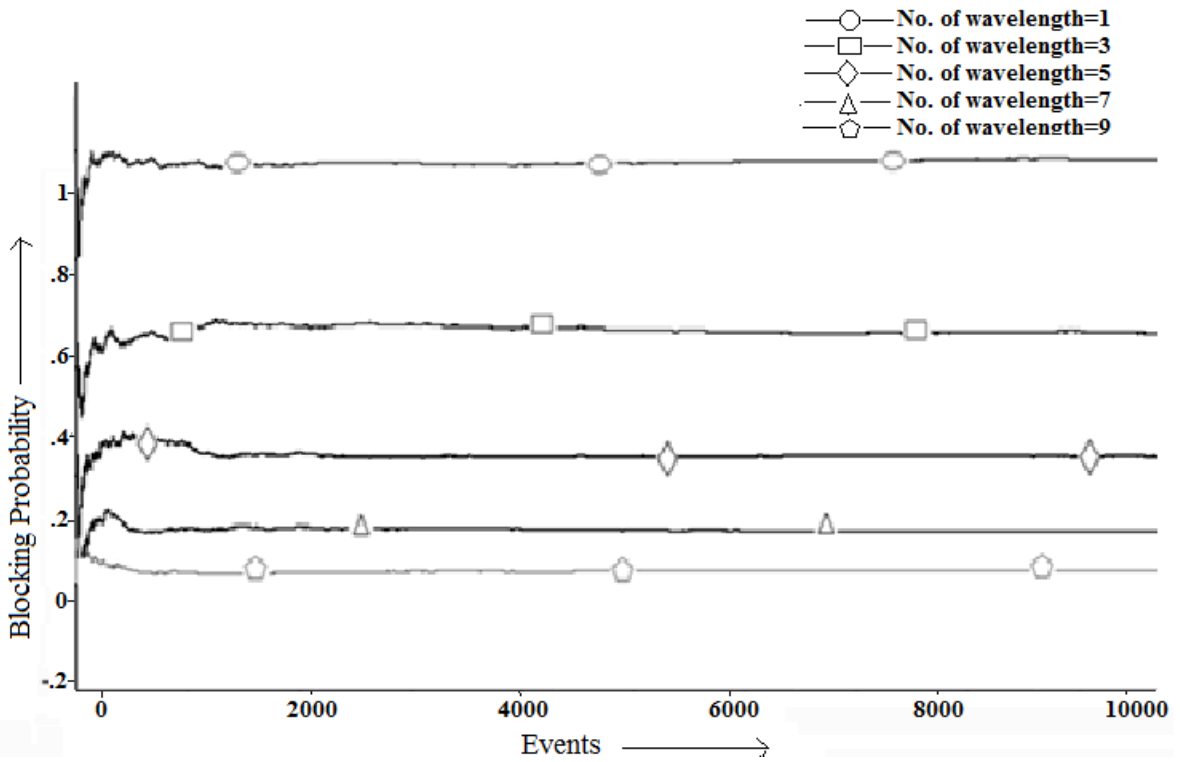


Figure 4.4(l) Blocking probability of node 4

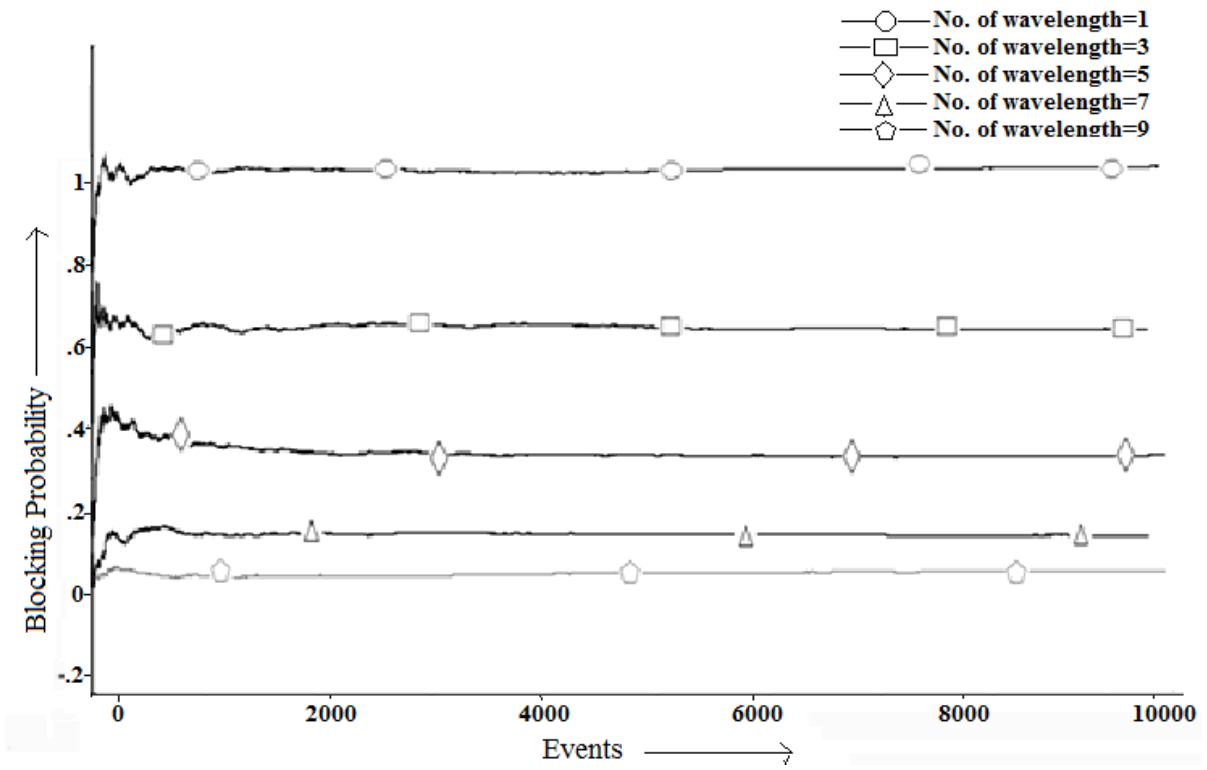


Figure 4.4(m) Blocking probability of node 5

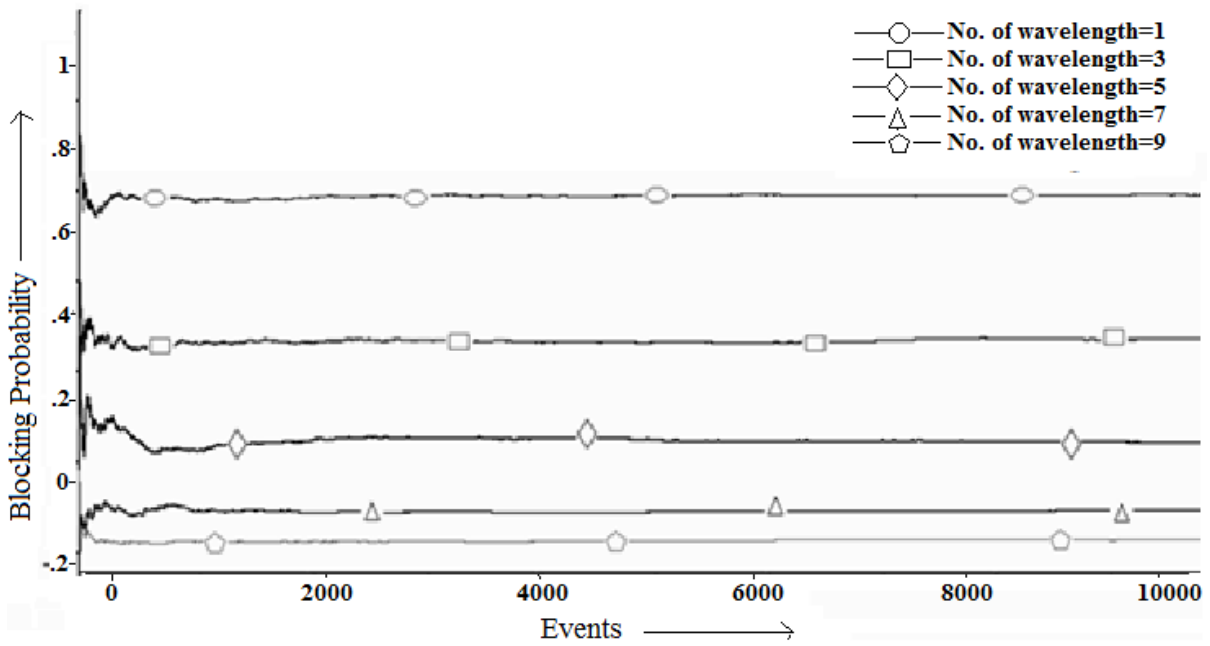


Figure 4.4(n) Blocking probability of node 6

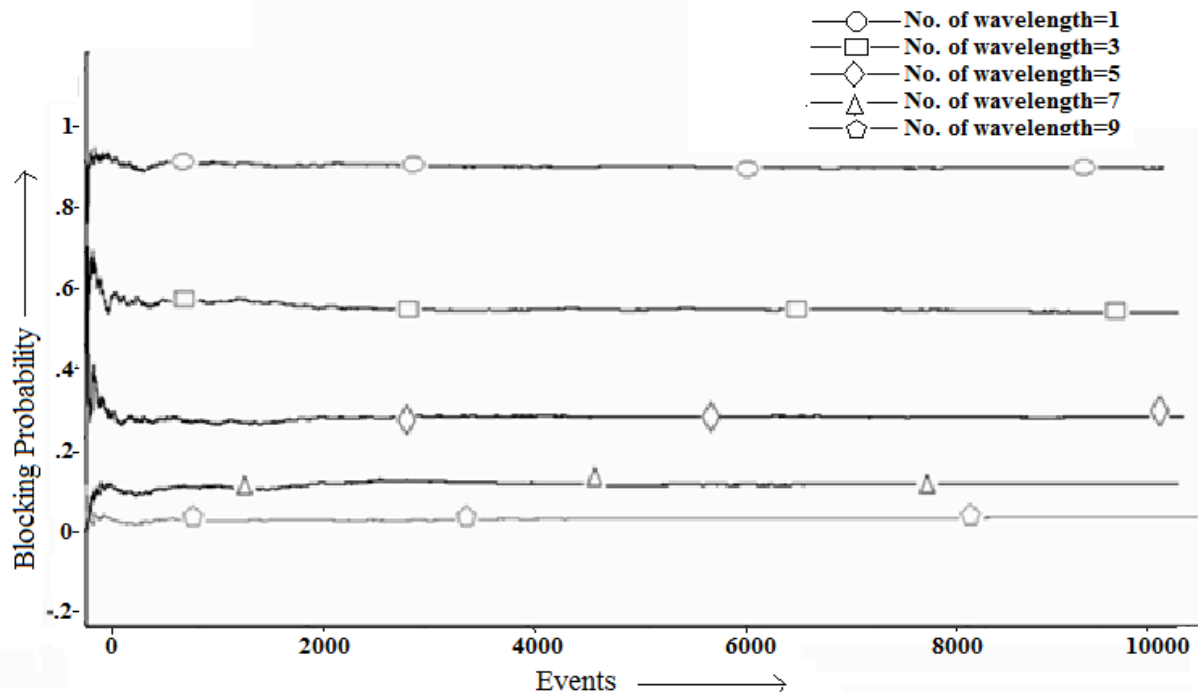


Figure 4.4(o) Blocking probability of node 7

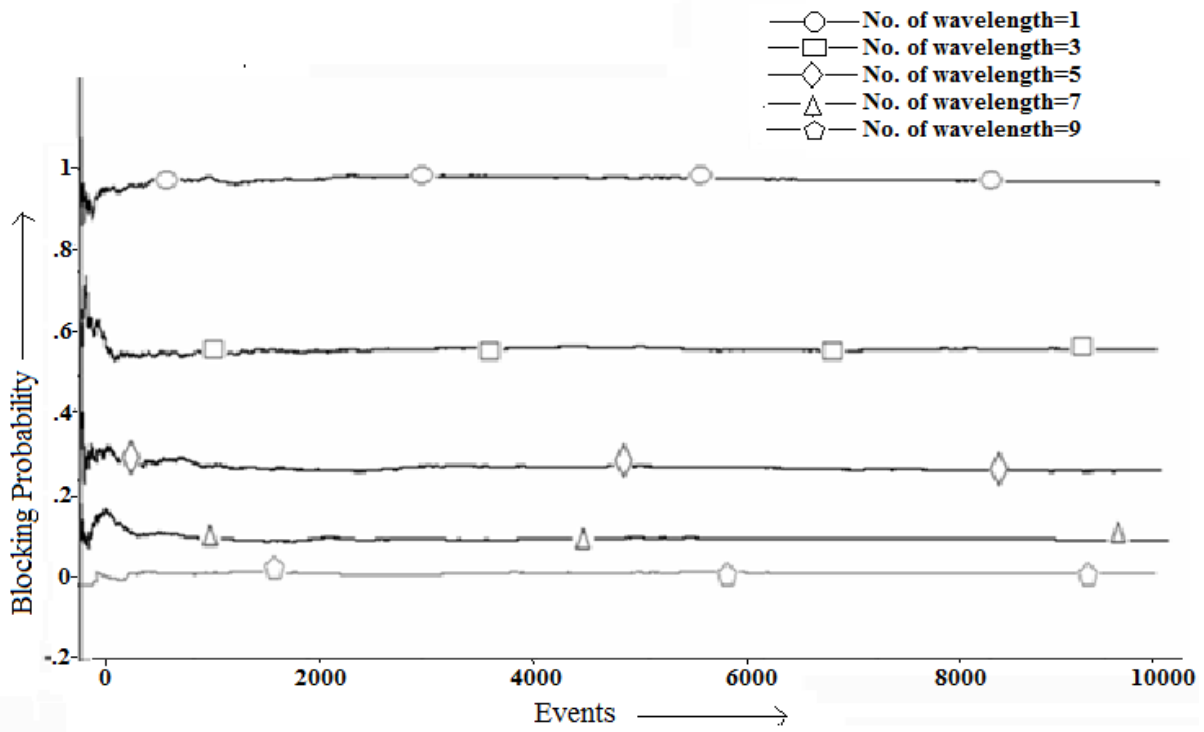


Figure 4.4(p) Blocking probability of node 8

In the graph for node 12 to 19 we noticed that as we increase the number of available wavelength then blocking probability decreases. Now we compare the blocking probability of both algorithms for different wavelength assignment and noticed that the performance of wavelength conversion algorithm is better than most used algorithm.

## **4.5 Conclusion**

The blocking performance of the WDM network analyzed for the network having 8 nodes and for varying available wavelength. So this chapter presents a simulating technique for examining the blocking probability of algorithms for different wavelength assignment in optical ring network. Firstly we obtained the blocking probability with the variation number of available free wavelength on every eight node from N01 to N08 for most used algorithm and we see that as we increase the number of available wavelength then blocking probability decreases. Similarly for wavelength conversion algorithm as we increase the number of available wavelength then blocking probability decreases. After that we compare the simulation results obtained for calculating the blocking probability for each of this algorithm and It is analyzed that most algorithm offers the most blocking probability and the wavelength conversion algorithm offers the least blocking probability. We conclude that using wavelength convertors in the network results in best performance of the network but there is a burden of using expensive hardware.

# CHAPTER 5

## Blocking Probability of Wavelength Conversion Algorithm for different route length

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### 5.1 Abstract

Blocking probability of the network for wavelength conversion algorithm based on route length in the eight nodes WDM unidirectional optical ring network is being proposed. We vary fiber length at every link one by one and calculate the blocking probability. As we increase the length of route the blocking probability increases. These following approaches are very effective for the minimization of blocking probability of optical WDM networks.

### 5.2 Introduction

Wavelength Division Multiplexing (WDM) wavelength routed all-optical WANs have emerged as the most efficient means to meet the ever increasing integrated demands of the communication applications. The advantages of WDM optical networks over conventional networks are large bandwidth, scalability, low power loss, modularity, reliability, reconfigurability and protocol transparency. Wavelength division multiplexing (WDM) enables optical networks to divide the enormous bandwidth of an optical fiber into non-overlapping wavelength channels, which can be operated in parallel. Hence, wavelength routed optical networking has been considered as a promising approach for the realization of next generation large bandwidth networks. In wavelength routed WDM networks, traffic is carried over optical paths (light paths) between source and destination nodes. In the absence of wavelength converters, a lightpath occupies the same wavelength channel on all the fiber links along its path and it is optically switched at intermediate node [43]. The routing and wavelength assignment (RWA) is the problem of selecting a path and wavelength for each of the given connection demands, subject to the constraint that no two paths sharing a link are assigned the same wavelength and this limitation is known as the wavelength continuity constraint. Two light paths cannot be assigned the same wavelength on any fiber. This

requirement is known as distinct wavelength assignment constraints. However, two light paths can use the same wavelength if they use disjoint set of links. This property is known as wavelength reuse. Wavelength reuse in wave length routed network makes them more scalable networks than other networks. The performance of the routing and wavelength assignment algorithms is calculated in terms of blocking probability and fairness. We can also have wavelength conversion if we have wavelength converters as a part of the network. Wavelength conversion can eliminate the wavelength continuity constraint and can thus improve the blocking performance significantly. Since the wavelength converters are very expensive now a days, much research work focuses on sparse wavelength conversion, in which only a part of network nodes have the capability of wavelength. If all the network nodes have the capability of wavelength conversion, this is referred to as full wavelength conversion [44]. The blocking probability of a lightpath request (or a call) is an important performance measure of a wavelength-routed network. This blocking probability is affected by many factors such as network topology, traffic load, the RWA algorithm employed and whether or not wavelength conversion is available. A network equipped with the wavelength converters has a better call blocking performance than a network without wavelength converters. However, since wavelength conversion is an immature extremely costly technology, it may not be economical to install wavelength converters at every node of a network. Rather, it may be more sensible to put wavelength converters at some, but not all, nodes in the network, called sparse wavelength-conversion network [42].

### **5.3 Simulation Setup**

The simulation setup shows the performance analysis of Most-used and Wavelength conversion Algorithms for different wavelength assignment in WDM unidirectional optical ring network is shown in Figure 5.3(a) to 5.3(c). This setup is made of 8 nodes transmitting packets on WDM unidirectional optical ring network. WDM ring networks with a single control node helps in handling the setup request, algorithm selection as well as vary the number of available free wavelength. Central node contains three transition parts like handle setup request, handle close and discard the message. This simulation setup use three different circuits and they are as follows:

- Optical Ring of 8 nodes with control node.

- Link circuit.
- Control node circuit.

1. Optical Ring: This contains eight nodes from N00 to N07, eight links from L00 to L07 and one central node. There is a link between any two node and we vary the fiber length at every link one by one as shown in Figure 5.3(a)

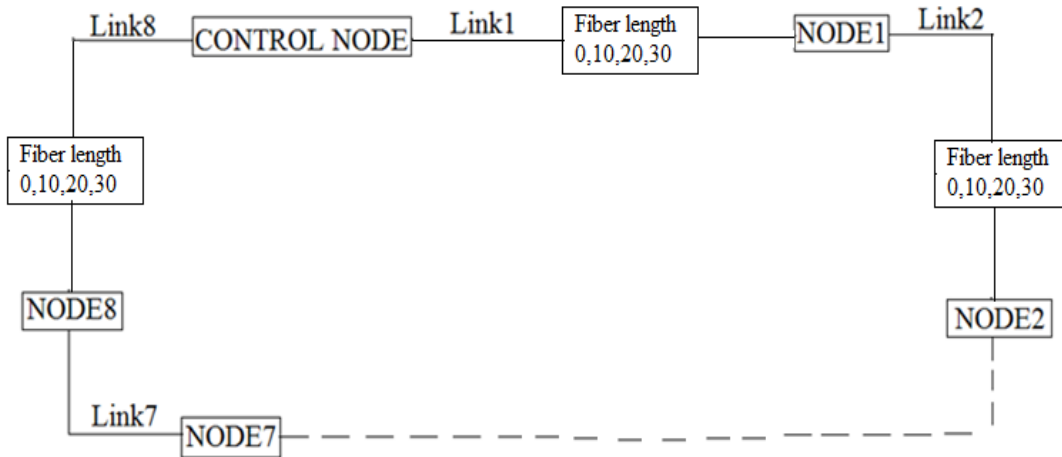


Figure 5.3(a) Ring of 8 nodes.

2. Link Circuit: Every link has three parts and these are input, output and delay between input and output. But we provide only zero as default delay here so it provide only as a link between input and output without any delay and we vary the fiber length at every link one by one as shown in Figure 5.3(b)

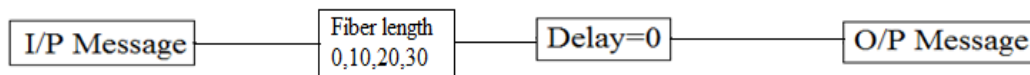


Figure 5.3(b) Link Circuit

3. Control Node Circuit: Control node plays a very important role and it helps in handling the setup request and algorithm selection. There are three transition parts like handle setup request, handle close and discard the message. There is one input and output places as shown in Figure 5.3(c)

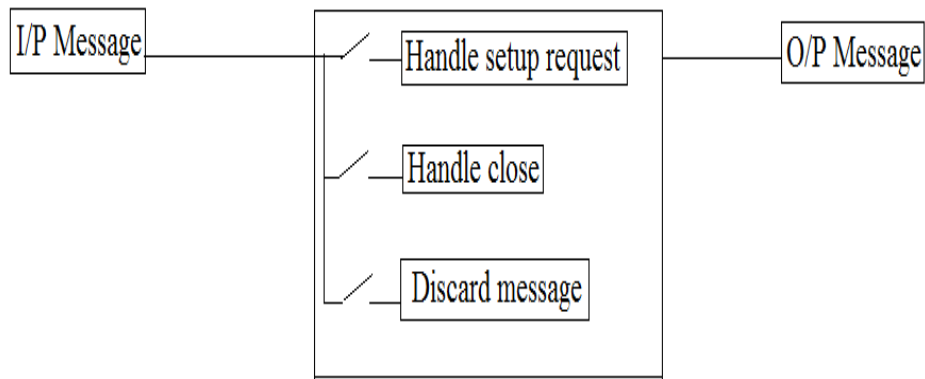


Figure 5.3(c) Control Node

## 5.4 Results and Discussion

We designed and developed a simulator to implement routing and wavelength assignment in all-optical networks for regular and irregular topologies. The simulator is developed in C++ language. It accepts input parameters such as the number of nodes in the network, link information with weight, number of wavelengths per fiber, connection requests. Some of the transmission may be blocked because of the unavailability of free wavelength on links along the route from the source to the destination. The ratio of the total number of calls blocked to the total number of lightpath requests in the network is defined as the blocking probability. The output of the simulator is the blocking probability for the specified parameters along with the detailed information of connections. All these parameters can be initialized before running the simulations to obtain results for a given selection of parameters. Extensive simulations are then carried out for every combination of parameters of interest. The blocking probability of the network depends on the number of free wavelengths, number of channels(C) and length of the route. We have fixed the number of channels(C) to 10 and the number of free wavelengths to 10. So we calculate blocking probability of wavelength conversion algorithm for different route length as shown in Figure 5.4(a) to 5.4(h)

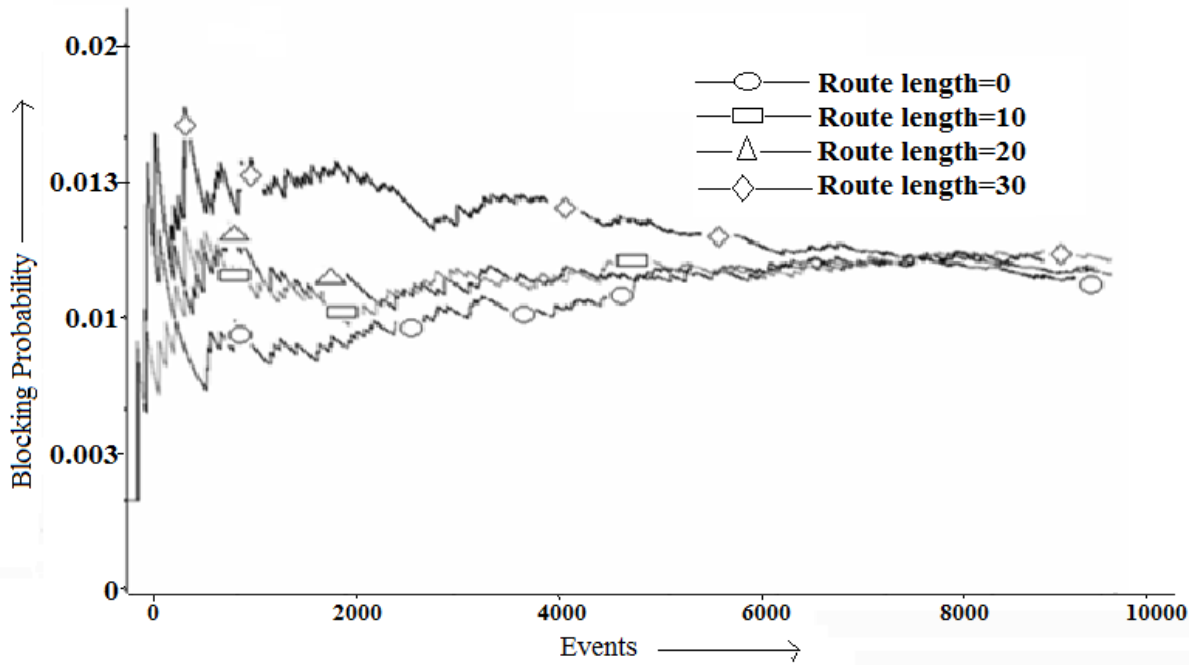


Figure 5.4(a) Blocking probability of node 1

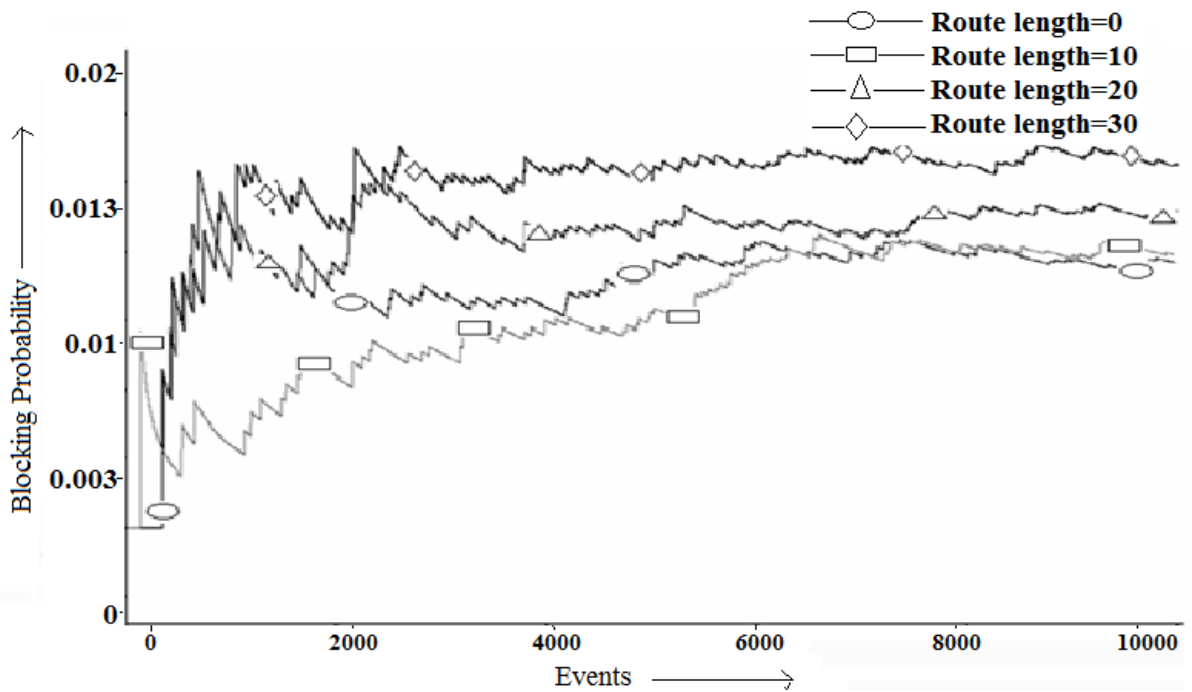


Figure 5.4(b) Blocking probability of node 2

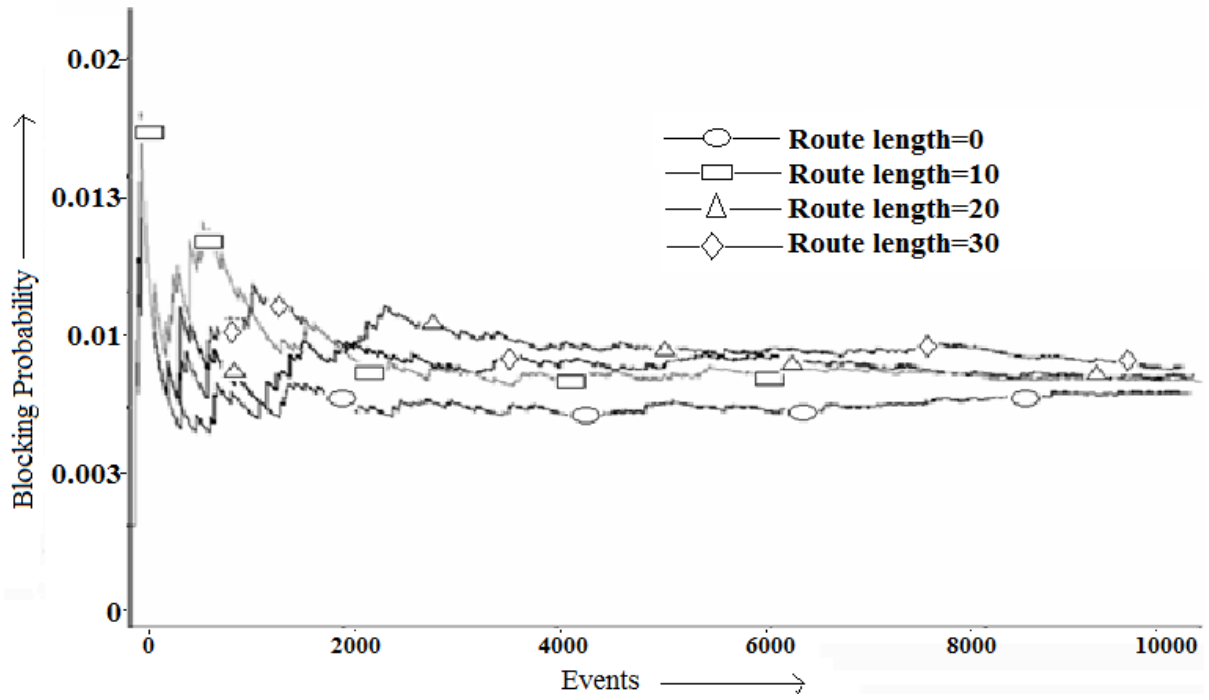


Figure 5.4(c) Blocking probability of node 3

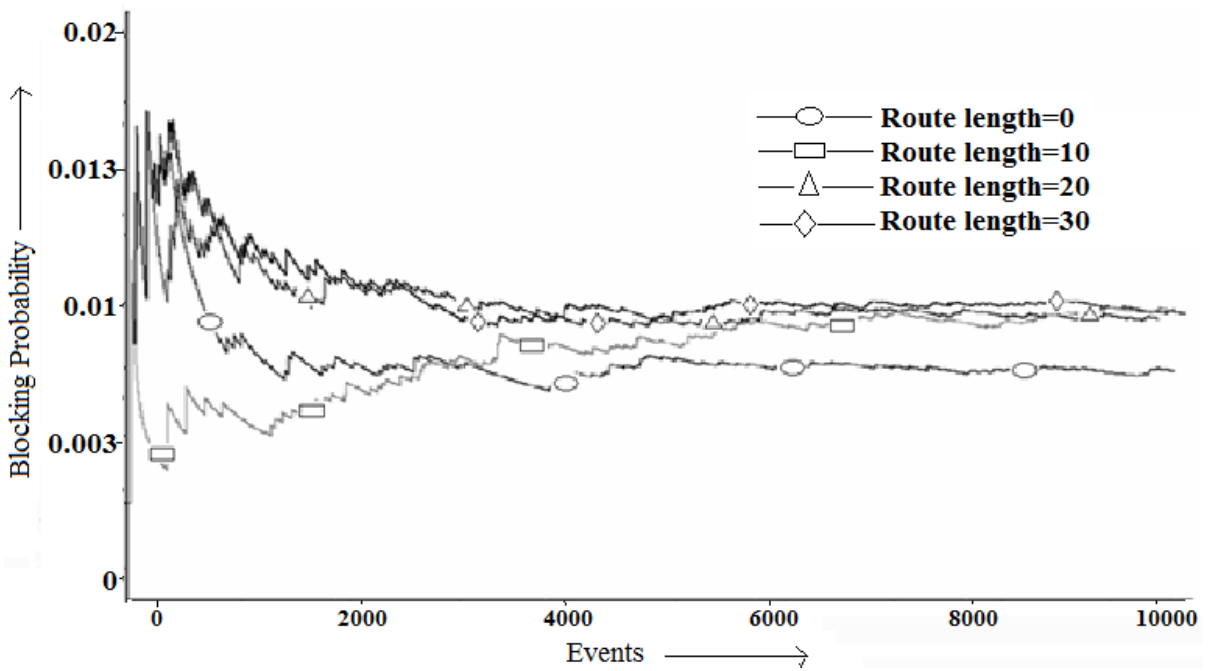


Figure 5.4(d) Blocking probability of node 4

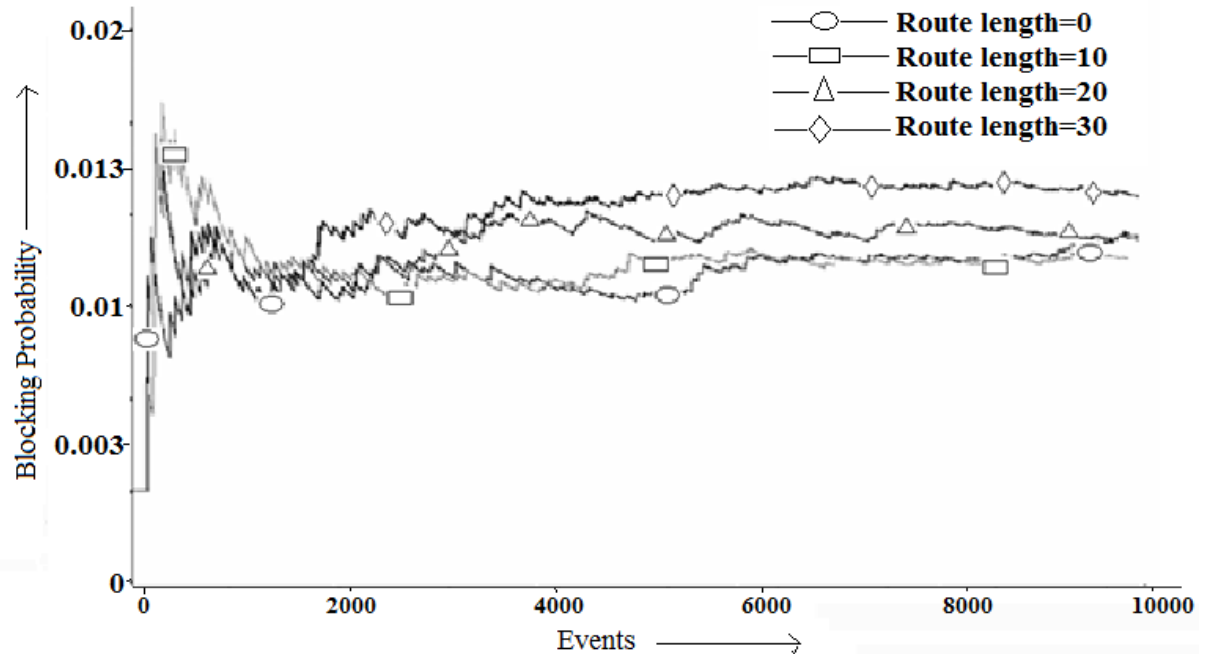


Figure 5.4(e) Blocking probability of node 5

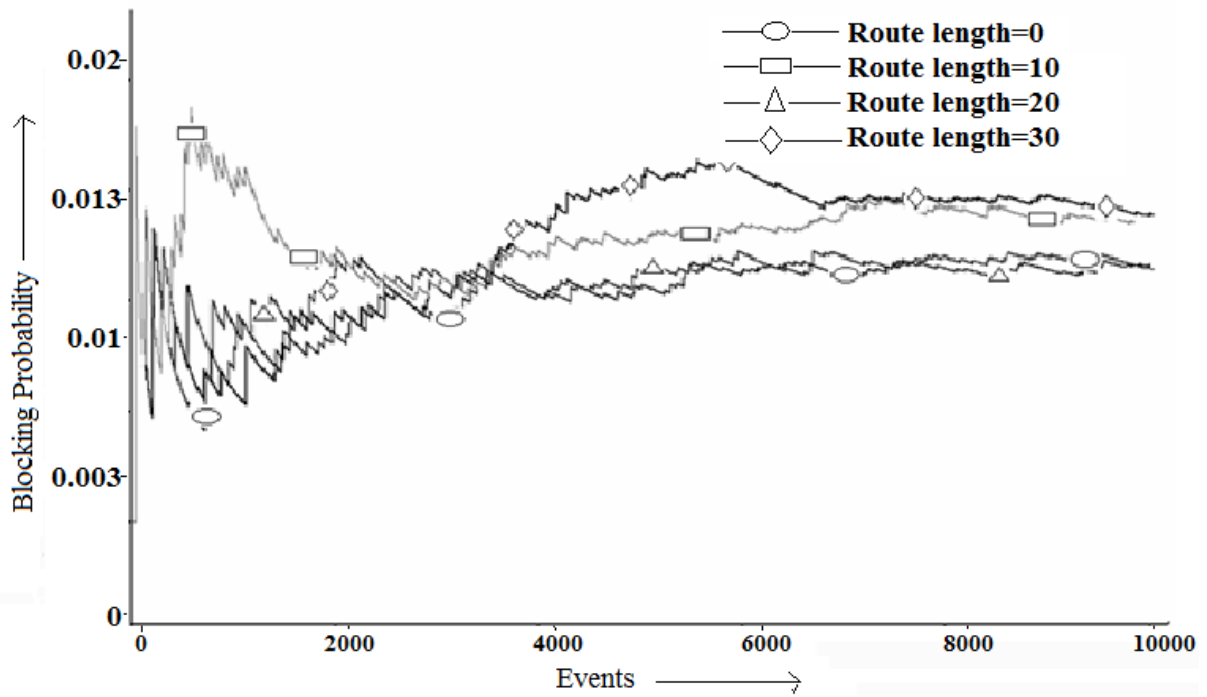


Figure 5.4(f) Blocking probability of node 6

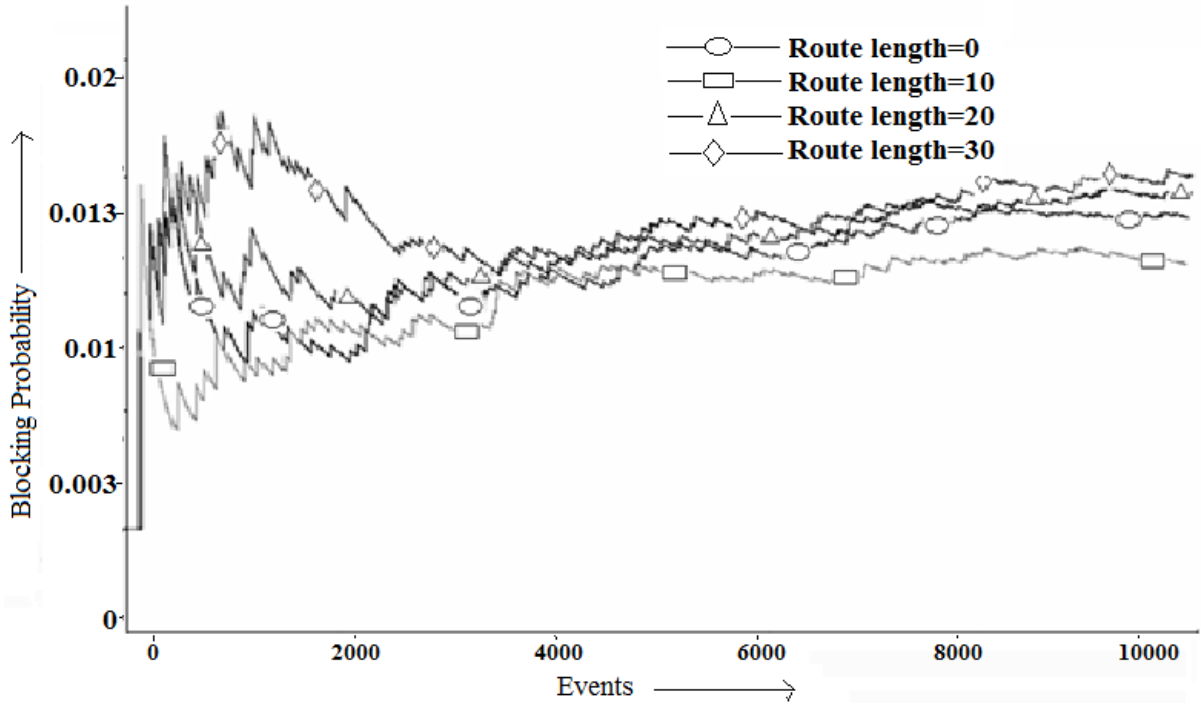


Figure 5.4(g) Blocking probability of node 7

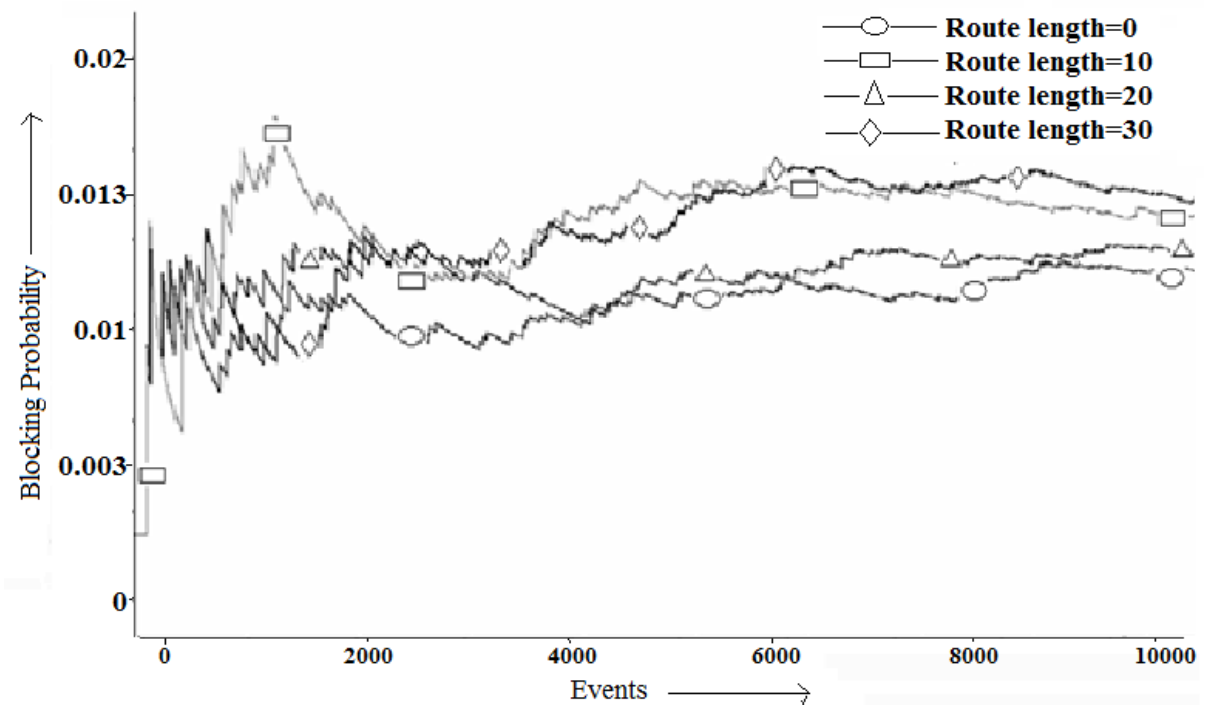


Figure 5.4(h) Blocking probability of node 8

In the above graphs for node 1 to 8, we noticed that as we increase the length of route then blocking probability increases.

## **5.5 CONCLUSION**

The blocking probability of the WDM network was analyzed having 8 nodes and for varying route length. The blocking probability of the network depends on the number of free wavelengths ( $N\lambda$ ), number of channels( $C$ ) and length of the route ( $L$ ). We have fixed the number of free wavelengths ( $N\lambda$ ) to 10, the number of wavelength conversion to 10 and calculated results for blocking probability for different route lengths. Here we provide only zero as default delay so it provide only as a link between input and output without any delay and we vary the fiber length at every link one by one. We noticed that as we increases the length of route the blocking probability increases.

# CHAPTER 6

## Conclusion and Future Work

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### 6.1 Conclusion

Optical wavelength routed network offer huge capacity with high scalability which makes them a very attractive choice for the next generation optical networks. The wavelength division multiplexing technique is considered to be one of the best possible techniques in optical network to enhance the capacity of optical fiber. Wavelength assignment problems are the major problems of WDM networks. Wavelength assignment is a unique feature in wavelength routed networks that distinguishes them from conventional networks. So we analyze the performance of First-fit, Random, Most-used and Wavelength conversion Algorithms for wavelength assignment in WDM unidirectional optical ring network. We compare the blocking probability of various algorithms with the variation in number of events. The following conclusions are based on the results achieved in the individual chapters of the thesis.

1) The result in Chapter 3 presents a simulating technique for performance analysis of optical network using First-fit, Random, Most-used and Wavelength conversion algorithms. The Simulation results obtained for calculating the blocking probability for each of this algorithm has been compared and we conclude that using wavelength convertors in the network results in best performance of the network but there is burden of using expensive hardware. The most-used algorithm performs better than the random and the first-fit algorithms without the need of wavelength convertor.

2) The blocking performance of the WDM network was analyzed for the network having 8 nodes and for varying available wavelength. So Chapter 4 presents a simulating technique for examining the blocking probability of algorithms for different wavelength assignment in optical ring network. Firstly we obtained the blocking probability with the variation number of available free wavelength on every eight node from N01 to N08 for most used algorithm and we see that as we increase the number of available wavelength then blocking probability decreases. Similarly for wavelength conversion algorithm as we increase the number of

available wavelength then blocking probability decreases. After that we compare the simulation results obtained for calculating the blocking probability for each of the algorithm and it is analyzed that most algorithm offers the most blocking probability and the wavelength conversion algorithm offers the least blocking probability. We conclude that using wavelength convertors in the network results in best performance of the network but there is a burden of using expensive hardware.

3) The blocking probability of the WDM network was analyzed having 8 nodes and for varying route length. The blocking probability of the network depends on the number of free wavelengths ( $N\lambda$ ), number of channels( $C$ ) and length of the route ( $L$ ). We have fixed the number of free wavelengths ( $N\lambda$ ) to 10, the number of wavelength conversion to 10 and calculated results for blocking probability for different route lengths. Here we provide only zero as default delay so it provide only as a link between input and output without any delay and we vary the fiber length at every link one by one. We noticed that as we increases the length of route the blocking probability increases.

## **6.2 Future Scope**

There are a couple of areas where future work is needed. This wavelength assignment schemes can be modified to increase the capacity of the optical networks and can be proposed for fault detection and recovery in WDM optical networks for better performance. The fault tolerant schemes proposed in this thesis can be enhanced for restoration and fault recovery.

We can also use different routing protocol, different rerouting algorithm with different wavelength assignment schemes and we can also work to wavelength colouring problem in WDM network. Also this work can be extended for traffic grooming and colouring.

Here we work only on different algorithms; number of wavelength used in the network, used different routing length so we can also work on different number of nodes and calculates the blocking probability for different node. Here we used zero as a default delay in the link circuit between the two nodes but we can also calculated the blocking probability for this different delay.

## REFERENCES

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- 1) Bishnu P. Pal, “Guided Wave Optical Components and Devices”, Elsevier academic Press, 2006.
- 2) Ajoy Ghatak and K.Thyagarajan, “Introduction to Fiber Optics”, Cambridge University Press, 1995.
- 3) Govind P. Agrawal, “Light wave technology telecommunication systems”, A John Wiley & Sons, Inc., Publication, 2005.
- 4) Stamatios V Kartalopoulos , “Introduction to DWDM Technology”, IEEE Computer Society Press, June 4, 2001.
- 5) C. Siva Ram Murthy and Mohan Gurusamy, “WDM optical networks -Concepts, Design and Algorithms”, Prentice Hall of India Pvt. Limited, 2002.
- 6) Jean-Pierre Laude, “DWDM Fundamentals, Components and Applications”, Artech House Publishers, Jan 2002.
- 7) M. H. E. Jaafar and T. M. Hussein, “Technologies and Architectures for Scalable Dynamic Dense WDM Networks”, IEEE Communication Magazine, vol. 38, no. 2, pp.58– 66, February 2000.
- 8) Biswanath Mukherjee, Optical Communication Networks, McGraw-Hill series on computer communications, McGraw-Hill, 1997.
- 9) Suresh Subramaniam, Arun K. Somani “All-optical networks with sparse wavelength conversion”, IEEE/ACM Transactions on Networking 4 (4) (1996) 544–557.
- 10) Xuehong Sun', Yunheo Lit, Ioannis Lambadarist and Yiqiang Q. Zhao' “Performance Analysis of First-Fit Wavelength Assignment Algorithm in Optical Networks”, *IEEE*, pp. 403-409 June 11-13, 2003.
- 11) D. Banerjee and B. Mukherjee, “A Practical Approach to Routing and Wavelength Assignment in Large WDM Routed Networks,” *IEEE Journal on Selected Areas in Communications*, vol. 14, pp. 903-908, June 1996.

- 12) T. E. Stern, D. Simchi-Levi and K. Bala, "Routing in a linear light wave network," IEEE/ACM Transactions on Networking, vol. 3, no. 4, pp. 459–460, 1995.
- 13) Zhang and A. S. Acampora, "A Heuristic Wavelength Assignment Algorithm for Multi-hop WDM Networks with Wavelength Routing and Wavelength Re-use," IEEE/ACM Transactions on Networking, vol. 3, no. 3, pp. 281-288, June 1995
- 14) Suresh Subramaniam, Arun K. Somani "All-optical networks with sparse wavelength conversion", IEEE/ACM Transactions on Networking 4 (4) (1996) 544–557.
- 15) Xuehong Sun', Yunheo Lit, Ioannis Lambadarist and Yiqiang Q. Zhao' "Performance Analysis of First-Fit Wavelength Assignment Algorithm in Optical Networks", IEEE, pp. 403-409 June 11-13, 2003.
- 16) A. Birman, "Computation approximation blocking probabilities for a class of all-optical network", IEEE J. Select. Areas Commun. 14 (5) (1996) 852–857.
- 17) Amit Wason, R.S. Kaler, "Wavelength assignment algorithms for WDM optical networks" Optik 122 (2011) 877-880.
- 18) Kai-Yeung Siu, Ching Law, "Online Routing and Wavelength Assignment in Single-Hub WDM Rings", IEEE, pp. 2111-2123, vol. 18, October 2000.
- 19) Amit Wason, R.S. Kaler, "Blocking probability calculation in wavelength-routed all-optical networks", Optik 122 (2011).
- 20) Xi Yang and Byrav Ramamurthy, "Dynamic Routing in Translucent WDM Optical Networks: The Intradomain Case," Journal of Light wave Technology, vol. 23, no. 3, pp. 955-971, March 2005.
- 21) Rajneesh Randhawa, J.S.Sohal, "Blocking probability analysis of survivable routing in WDM optical networks with/without sparse-wavelength conversion", Optik 121 (2010) 462-466.
- 22) Anwar Alyatama, "Wavelength decomposition approach for computing blocking probabilities in WDM optical networks without wavelength conversions," Computer Networks, vol. 49, pp. 727–742, 2005.
- 23) Paramjeet Singh, Ajay K. Sharma, Shaveta Rani, "Routing and wavelength assignment strategies in optical networks," Optical Fiber Technology, vol. 13, pp. 191–197, 2007.
- 24) Amit Wason, R.S. Kaler, "Generic routing and wavelength assignment algorithm for a wavelength-routed WDM network", Optik 122 (2011) 1100-1106.

- 25) K.R. Venugopal, E. Ezhil Rajan, P. Sreenivasa Kumar, "Impact of wavelength converters in wavelength routed all-optical networks", *Computer Communications* 22 (1999) 244–257.
- 26) Amit Wason, R.S. Kaler, "Blocking in wavelength-routed all-optical WDM network with or without wavelength conversion", *Optik* 121 (2010) 2162-2165.
- 27) Chuan-Ching Sue, "Wavelength Routing With Spare Reconfiguration for All-Optical WDM Networks," *Journal of Light wave Technology*, vol. 23, no. 6, pp. 1991-2000, June 2005.
- 28) Anwar Alyatama, "Wavelength decomposition approach for computing blocking probabilities in WDM optical networks without wavelength conversions," *Computer Networks*, vol. 49, pp. 727–742, 2005.
- 29) Poompat Saengudomlert, Eytan H. Modiano and Robert G. Gallager, "Dynamic Wavelength Assignment for WDM All-Optical Tree Networks," *IEEE/ACM Transactions on Networking*, Vol. 13, No. 4, pp. 895-905, August 2005.
- 30) Abhisek Mukherjee, Satinder Pal Singh, V.K. Chaubey, "Wavelength conversion algorithm in an intelligent WDM network," *Optics Communications*, vol. 230, pp. 59–65, 2004.
- 31) Raja Datta, Bivas Mitra, Sujoy Ghose, and Indranil Sengupta, "An Algorithm for Optimal Assignment of a Wavelength in a Tree Topology and its Application in WDM Networks," *IEEE Journal on Selected Areas in Communications*, vol. 22, no. 9, pp. 1589-1600, November 2004.
- 32) Gaoxi Xiao and Yiu-Wing Leung, "Algorithms for Allocating Wavelength Converters in All-Optical Networks," *IEEE/ACM Transactions on Networking*, vol. 7, no. 4, pp. 545-557, August 1999.
- 33) Jian Liu and Gaoxi Xiao, "Efficient Wavelength Assignment Methods for Distributed Lightpath Restorations in Wavelength-Routed Networks," *Journal of Lightwave Technology*, vol. 27, no. 7, pp. 833-840, April 1, 2009.
- 34) Guangzhi Li and Rahul Simha, "On the Wavelength Assignment Problem in Multifiber WDM Star and Ring Networks," *IEEE/ACM Transactions on Networking*, vol. 9, no. 1, pp. 60-68, February 2001.

- 35) Jianping Wang, Xiangtong Qi, and Biao Chen, "Wavelength Assignment for Multicast in All-Optical WDM Networks With Splitting Constraints," *IEEE/ACM Transactions on Networking*, vol. 14, no. 1, pp. 169-182, February 2006.
- 36) Amit Wason, R.S. Kaler, "Blocking in wavelength-routed all-optical WDM network with wavelength Conversion" *Optik* 122 (2011) 631–634.
- 37) S. Subramaniam, M. Azizoglu, A.K. Somani, "Connectivity and sparse wavelength conversion in wavelength – routed networks", *Proc. IEEE INFOCOM-96* (1996) 148–155.
- 38) Amit Wason, R.S. Kaler, "Blocking in wavelength-routed all-optical WDM networks", *Optik* 121 (2010) 903–907.
- 39) Ramaswami, K.N. Sivarajan, *Optical Networks: A Practical Perspective*, second ed., Morgan Kaufmann Publishers, An imprint of Elsevier, 2004.
- 40) A. Wason, R.S. Kaler, Blocking performance analysis of wavelength assignment algorithm in WDM networks, *Int. J. Microw. Opt. Technol.* 3 (1) (2008) 54–61.
- 41) Y. Zhang, O. Yang, H.A. Liu, "A Lagrangean relaxation and subgradient framework for the routing and wavelength assignment problem in WDM networks", *IEEE J. Select. Area Commun.* 22 (9) (2004) 1752–1765.
- 42) S. Subramaniam, M. Azizoglu, A.K. Somani, "Connectivity and sparse wavelength conversion in wavelength – routed networks", *Proc. IEEE INFOCOM-96* (1996) 148–155.
- 43) R. Dutta, A. E. Kamal, and G. N. Rouskas, Eds., "Traffic Grooming in Optical Networks: Foundations, Techniques, and Frontiers", Springer, 2008.
- 44) Amit Wason, R.S. Kaler, "Blocking probability calculation in wavelength-routed all-optical networks", *Optik* 121 (2010).

