A Survey on Routing and Wavelength Assignment in WDM Optical Networks

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Abstract— The recent advances in the fiber optic technology are strongly affecting network data communications. One of the most promising long-haul communications in optical data communication networks technologies is Wavelength Division Multiplexing (WDM). Wavelength routing in WDM is most important technology for information transport in wide and metropolitan networks. Wavelength routing is used in WDM for realization of future large bandwidth networks. In this paper mainly discussed about routing and wavelength assignment (RWA) research contributions in routing and wavelength assignments problems for both static and dynamic RWA problems. RWA algorithms block calls if continuous wavelength flow from source to destination at that time degrades the network performance. The failure of RWA algorithms to find an available wavelength on all links from source to destination causes congestion resulting in pocket loss.

Key words: WDM, RWA, Routing and Wavelength Assignment, Blocking Probability, Throughput

I. INTRODUCTION

Generalized Multiprotocol Label Switching (GMPLS) control plane plays an important role to address the complexity in the management and operation of highly dynamic, reconfigurable optical networks. For instance, it provides a standardized way to support end-to-end light path provisioning for routing and wavelength assignment (RWA) algorithms. Nevertheless, during lightpath provisioning in wavelength routed networks without conversion capabilities, a lightpath setup can be blocked due to lack of network resources. In addition, when a network failure occurs, an affected lightpath might not be restored if there is insufficient network resources. Based on the order in which the wavelengths are searched, wavelength assignment methods are classified into most-used, least-used, fixed-order and random-order. In the most-used wavelength assignment method, wavelengths are searched in non-increasing order of their utilization in network. This method tries to pack the lightpaths so that more wavelength continuous routes are available for the request that arrives later.

The proposal of this paper is to present an algorithm based on the Least Used Wavelength Conversion. In the least used wavelength assignment method, wavelengths are searched in non-decreasing order of their utilization in the network. This method spreads the lightpaths over different wavelengths. The idea here is that a new request can find a shorter route and a free wavelength on it. This algorithm is an improvement of least used wavelength assignment algorithm. In this algorithm least–used wavelength assignment algorithm is executed until blocking. When the call is blocked wavelength conversion is introduced and hence blocking probability is reduced. If the full wavelength conversion is used after least–used wavelength assignment algorithm the blocking probability is reduced to a very large extent and its value reduces to a minimum possible value. As full wavelength conversion is costlier than sparse wavelength conversion so the sparse wavelength conversion is employed in this proposed algorithm.

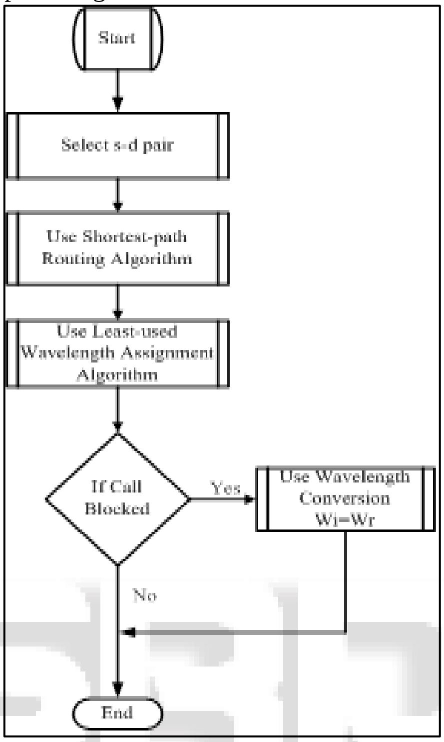

Fig. 1: Least Used Wavelength Conversion Algorithm

Simulations were carried to evaluate the performance of the least use Wavelength Algorithm. The simulation is carried out on simulation software MATLAB 7.2 of Mathworks. The blocking probability of network is compared to a traditional topologically-driven approach with end-to-end re-routing. The remaining of the paper is organized as follows. Firstly, in section II, we briefly discuss some related works and the state-of-the-art in bio-inspired networking. In Section III, we present Routing of Wavelength to different nodes for the RW Algorithm. Then, we discuss Wavelength Assignment and literature survey in Section IV. In Section V, we detail the simulation studies carried out to properly characterize the proposed algorithm. Results obtained are presented and discussed in Section VI. Finally, in Section VII, conclusions are drawn.

II. RELATED WORK

A multi-objective Least Used Wavelength algorithm that took into consideration both hop count and the number of wavelength converters for static routing and wavelength assignment in optical networks was presented in. The commercialization of WDM technology is progressing rapidly. Most important for the development of the WDM technology was the invention of Erbium Doped Fiber Amplifier, (EDFA) an optical fiber amplifier in 1987. The optical fiber amplifier is a component capable of amplifying several optical signals at the same time without converting them first to electrical domain (opto-electronic amplification). Theoretically, fiber has extremely high bandwidth (about 25 THz [terahertz]) in the 1.55 low-attenuation band and this is thousands times of the total bandwidth of radio on the planet Earth [3]. However, only speed of a few gigabits per second is achieved because the rate at which an end user (a workstation) can access a network is limited by electronic speed, which is a few gigabits per second. Hence, it is extremely difficult to exploit all the bandwidth of a single fiber using a single high-capacity wavelength channel due to optical-electronic bandwidth mismatch or “electronic bottleneck.” The recent breakthroughs (Tb/s) are the result of two major developments: WDM, which is a method of sending many light beams of different wavelengths simultaneously down the core of an optical fiber and the EDFA, which amplifies signal at different wavelengths simultaneously regardless of their modulation scheme or speed. Based on the order in which the wavelengths are searched, wavelength assignment methods are classified into most-used, least-used, fixed-order and random-order. In the most-used wavelength assignment method, wavelengths are searched in non-increasing order of their utilization in network. This method tries to pack the lightpaths so that more wavelength continuous routes are available for the request that arrives later. In the least used wavelength assignment method, wavelengths are searched in non-decreasing order of their utilization in the network. This method spreads the lightpaths over different wavelengths. The idea here is that a new request can find a shorter route and a free wavelength on it. In this chapter, we have investigated the analysis and development of wavelength assignment algorithms. The model has also been suggested in this chapter to develop better wavelength assignment strategies. The effective algorithm is proposed in this chapter and the performance of new wavelength assignment algorithm is evaluated in terms of blocking probability and fairness. In the first section of this chapter, the analysis of proposed wavelength assignment algorithms has been discussed. In the second section, proposed wavelength assignment algorithm is compared with conventional wavelength assignment algorithms such as first-fit, best-fit, random and most-used wavelength assignment algorithms. These algorithms are compared on the basis of blocking probability, number of channels and number of links. For the comparison the number of links is kept constant whereas the response of algorithms is calculated by varying load (in Erlangs) per unit link. These simulation results show that the proposed approaches are very effective for minimization of blocking probability of optical WDM networks. Many analytical models have been proposed in the literature but some of them are very complex and lots of simulation statistics are required to evaluate the performance of the system by using these models. The models proposed in literature are such that the mathematical computations used are very complicated. Further, computation time of these models is also quite large. In this chapter, we have identified a low complexity mathematical models which do not require any simulation statistics. These models have low implementation complexity and computation is also quite efficient. These models suggest an optimum path as a solution to routing and wavelength assignment problem.

A. Analysis of Wavelength Assignment Strategies

In this section, conventional wavelength assignment strategies are analysed and compared with each other on the basis of blocking probability and fairness. The performance of conventional wavelength assignment algorithms is calculated in terms of blocking probability and fairness. Erlang’s-B formula is used to compute the blocking probability. We have developed approximate analytical models for clear channel blocking probability of the network with arbitrary topology, both with or without wavelength translations. The goal of our analysis is to calculate and compare blocking probability of different algorithms. In order to do the analysis following assumptions are made:

- The network is connected in an arbitrary topology. Each link has a fixed number of wavelengths.
- Each station has an array of transmitters and receivers, where W is the number of wavelengths carried by the fiber.
- Point to point traffic.
- There is no queuing of the connection request. The connection blocked will suddenly be discarded.
- Link loads are mutually independent.
- Static routing is assumed.

We have considered blocking probability for wavelength non-convertible networks. The two constraints which are followed for the wavelength assignment are:

- Wavelength continuity constraint: a lightpath must use the same wavelength on all links along the path from source to destination edge nodes.
- Distinct wavelength constraint: all lightpaths using the same link must be allocated distinct wavelengths.

If there is no free wavelength available on any link the call will be blocked. In simple terms blocking probability as per Poisson’s formula can be calculated as the ratio of calls blocked to the total number of calls generated as given in equation (4.1).

$$P_{Bavg} = \frac{\text{Total number of calls blocked}}{\text{Total number of calls generated}} \quad (1)$$

Also, the blocking probability on the link can be calculated by famous Erlang-B formula as given by Milan Kovacevic [45] equation (4.2)

$$P_{b(L,W)} = \frac{\frac{L^W}{W!}}{\sum_{i=0}^{W} \frac{L^i}{i!}} \quad (2.2)$$

Where $P_{b(L,W)}$ is blocking probability for L load and W wavelengths.

1) Conventional Algorithms

The algorithms which are used for simulation are conventional algorithms such as first-fit algorithm and random algorithm. These algorithms can be illustrated as below:

- First-fit algorithm: In this algorithm, firstly the wavelengths of the traffic matrix are sorted in non-decreasing order. Then algorithm steps through this sorted list for selecting candidate chains joined. Let u_{ij} be the next highest wavelength element in sorted list. Then, if both nodes i and j are the end nodes of two chains, largest chain is formed by joining two ends, otherwise next highest element is considered. This process is carried on until all chains are considered to form a single chain representing linear topology.

– Random algorithm: In this algorithm, wavelength is selected randomly from available wavelengths. A number is generated randomly and the wavelength is assigned to this randomly generated number.

```
Algorithm First-fit
begin
        sort elements of U in non-decreasing order;
        While (two or more chain exist) do
        begin
        let u_ij be the next highest element in U;
        if (i and j are the end nodes of the two chains 'ij' and 'jl' ) then
                connect i and j to get the chain 'kl';
        discard u_ij ;
end;
```

Fig. 2: First-fit Algorithm

The algorithm for the random wavelength assignment is very simple and is limited to the generation of a random number but algorithm for first-fit is a bit complex. The algorithm for the first-fit wavelength assignment can be illustrated by figure (4.1).

B. *Proposed Least-Used Wavelength Conversion Algorithm*

In this section, we have proposed an efficient wavelength assignment algorithm for dynamic provisioning of lightpath. This proposed algorithm is an improvement of Least-used wavelength assignment algorithm. We have used mathematical model for WDM optical networks for minimization of blocking probability. The results of proposed algorithm and Model given by equation (3.7) are then compared with conventional wavelength assignment algorithms such as first-fit, best-fit, random and most used wavelength assignment algorithms. Simulation results proved that these proposed approaches are very effective for minimization of blocking probability of optical WDM networks.

III. ROUTING

The important routing methods considered in the literature are A) Fixed routing B) Fixed Alternate routing C) Exhaust routing [5].

A. *Fixed routing*

In this method 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.

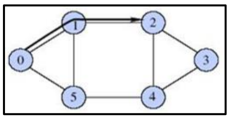

Fig. 3: Fixed routing

B. *Fixed alternate routing*

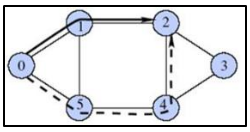

Fig. 4: Fixed alternate routing

In this method two or more rotes are provided for a node pair. Those routes are searched one by one in a predetermined order. Usually these routes are ordered in non-decreasing order of their hop length.

C. *Exhaust Routing*

In this method 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 this method is best among other two.

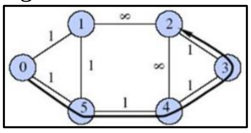

Fig. 5: Exhaust routing

IV. WAVELENGTH ASSIGNMENT

Wavelength assignment methods are classified into many types for static and dynamic traffic.

A. *Random–order(R)*

In this scheme first searched to find out the set of all available wavelengths on the required route. Amongst the available wavelengths, one is selected at random [6].

B. *First-Fit (F)*

In FF scheme, all wavelengths are numbered. While searching for free wavelengths, a lesser numbered wavelength is given priority before a higher-numbered wavelength. The first free wavelength available is then selected. No global information is required in this scheme. The computation cost of this scheme is lower than rando m wavelength assignment, because search for the entire wavelength space for each route is not required. . FF also performs well in terms of fairness and blocking probability [7].

C. *Least-Used (LU) /SPREAD*

This scheme selects the least used wavelength in the network and tries to balance the load amongst all the wavelengths. The performance of LU is worse than Random, while also introducing additional communication overhead, requiring additional storage and computation cost; thus, LU is not preferred in practice [8].

D. *Most-Used (MU) /PACK*

In this scheme, the most-used wavelength in the network is selected. This scheme performs better then LU and FF. It packs connections into fewer wavelengths and conserves the less-used wavelengths‟ unused capacity [8].

E. *Least-Loaded (LL)*

This heuristic is designed for multi-fiber networks, like MP, It selects the wavelength with the largest residual capacity on the most-loaded link along route. When it is used in single-fiber networks, the remaining capacity is either 1 or 0; thus the lowest-indexed wavelength with residual capacity 1 is selected. Thus LL is reduced to FF in a single fiber networks. LL outperforms MU and FF in terms of blocking probability in a multi-fiber network [8].

F. *Min-Product (MP)*

MP is used in multi-fiber networks. In a single-fiber network, MP becomes FF. The goal of MP is to pack wavelengths into fibers, thereby minimizing the number of fibers in the network Compared to the multi-fiber version of FF in which the fibers, as well as the wavelengths, are ordered MP does not perform well. Its computation costs are also high.

G. Relative Capacity Loss (RCL)

RCL scheme is based on the study that minimizing total capacity loss sometimes does not direct to the best selection of wavelength .Suppose a wavelength i is chosen, that results in blocking one light - path p1 and another wavelength j, if chosen would reduce the capacity of light-paths p2 and p3, but does not block them. In such a case wavelength j would be preferred over wavelength I irrespective of the capacity loss. Thus, RCL computes the Relative Capacity Loss for each path on each available wavelength and then selects the wavelength that minimizes the relative capacity loss sum on all the paths. Both MAX-SUM and RCL can be used for non-uniform traffic by taking a weighted sum over the capacity losses RCL has been observed to perform better than MAX-SUM in most cases.

V. LITERATURE SURVEY

Z. Zhang et. al. [20], presented a heuristic algorithm for effective assignment of a limited number of wavelengths among the access stations of a multi-hop network where the physical medium consists of optical fiber segments which interconnect wavelength elective optical switches.

Poompat Saengudomlert et. al. [21], 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.

Junjun Wan et. al. [22], proposed a wavelength assignment algorithm, which was based on the method called Dynamic Preferred Wavelength Sets (D-PWS). Also, they described the basic architecture of the optical burst switching network based on Dynamic Wavelength Routing (DWR), under which the guarantee of the quality of service in the DWR-OBS network was discussed. Then they focused on two aspects: the transmission latency of the data packets and the blocking probability, which leads to a quantitative description of the transmission latency and the size of the edge node buffer.

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F. Matera et. al. [23], showed how to obtain a wavelength assignment in a wide geographical transport network connecting the main cities of Europe, when all optical wavelength converters are introduced in the network nodes. They also reported an investigation on 40Gb/s transmission performance in the presence of all optical wavelength converters based on four wave mixing in semiconductor optical amplifiers and on different frequency generation in periodically poled lithium niobate waveguides.

Anwar Alyatama [24], 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 (colours) in which, blocked traffic in one layer is overflowed to another layer. Analysing blocking probabilities in each layer of the network is derived from an exact approach. A moment matching method was then used to characterise the overflow traffic from one layer to another.

Raja Datta et. al. [25], 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.

Jianping Wang et. al. [44], 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.

VI. RESULTS AND DISCUSSION

In this section, the simulation results of proposed Least Used Wavelength Conversion algorithm have been shown. Also, the blocking probability of proposed algorithm is compared with the conventional algorithms. The simulation is carried out on simulation software MATLAB 7.2 of Mathworks. The blocking probability of network is compared depending upon number of channels, load and the number of links.

The Least Used Wavelength Conversion algorithm has been proposed for wavelength assignment and the performance of this wavelength assignment algorithm is evaluated in terms of blocking probability and fairness. The results are shown in figure 5.1 – 5.20. In the first phase we have varied the number of wavelengths by keeping the other parameters constant. We have fixed the number of channels to 20; total number of links in the network to 20 and maximum load per unit link to 10 Erlangs and increased the number of wavelengths used from 20 to 50 respectively in figure 5.1 to 5.4.

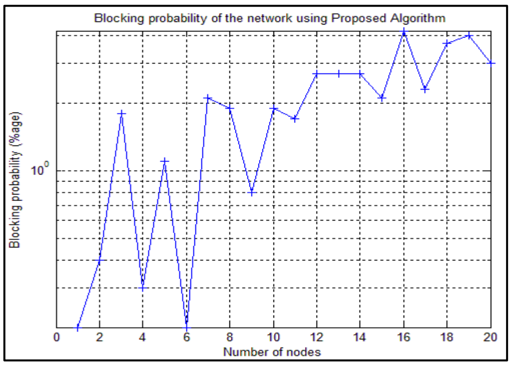

Fig. 5.1: W=10

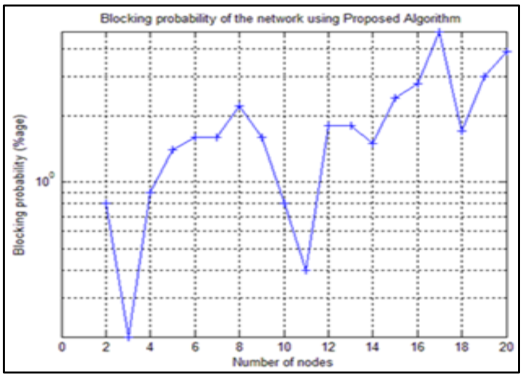

Fig. 5.2: W=20

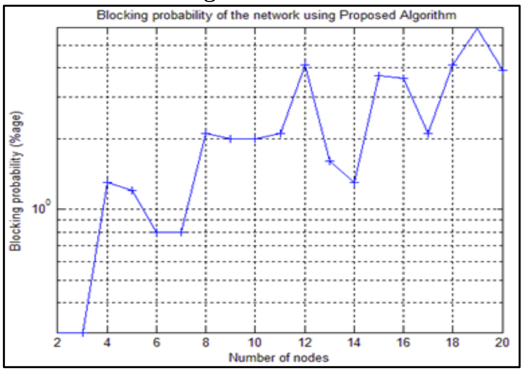

Fig. 5.3: W=30

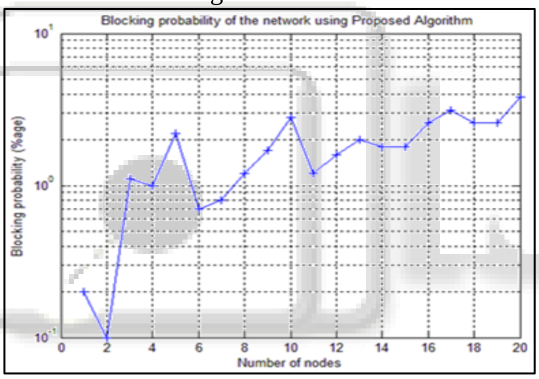

Fig. 5.4: W=40

The results shown in figure 5.1 – 5.4 prove that the blocking probability of the proposed algorithm decreases with the increase in the number of wavelengths. As the number of wavelength is increased the blocking probability is decreased. Further, in figure 5.6 – 5.9 the load per unit link is increased keeping the other parameters constant. The results show that as the load is increased the blocking probability of the network increases for the proposed algorithm keeping other parameters constant.

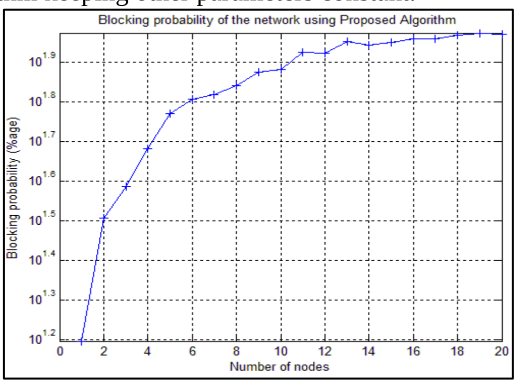

Fig. 5.6: Blocking probability of the proposed Algorithms for load=20 Erl.

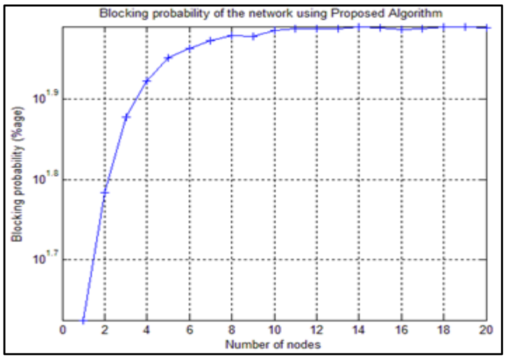

Fig. 5.7: Blocking probability of the Proposed Algorithm for load =30Erl.

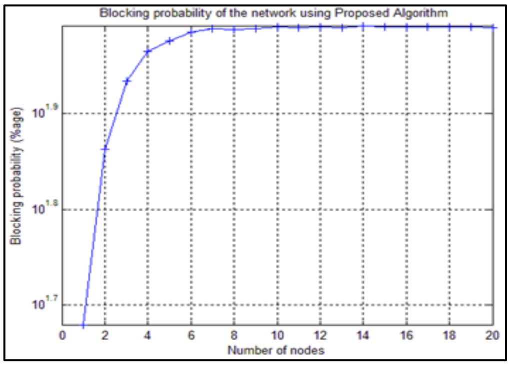

Fig. 5.8: Blocking probability of the proposed Algorithms for load=40 Erl.

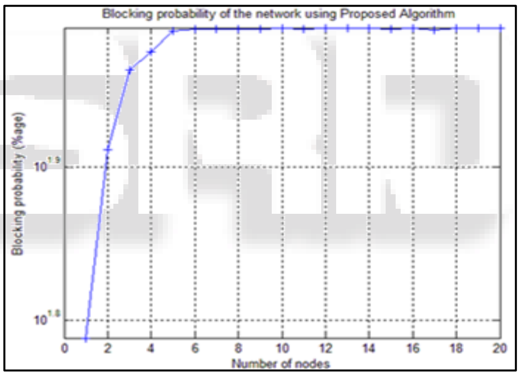

Fig. 5.9:Blocking probability of the proposed Algorithm for load=50 Erl.

The results shown in figure (5.6)-(5.9) shows that as the load in increased the blocking probability of the network is increased.

A. Comparison of proposed wavelength assignment algorithm with the conventional algorithm

Further, the blocking probability of proposed algorithm is compared with algorithms such as first-fit, best-fit, random and most-used wavelength assignment algorithm and are shown in figure (5.10) and figure (5.19). For this comparison we have fixed the number of channels to 20; the total number of links used in the network is also fixed to 20; and the total number of wavelengths used along with the load per unit link is varied. The results shown in figure (5.10) – (5.13) show the results when the other parameters kept constant and number of wavelengths used is 20 and the load per unit link is increased from 10Erlangs to 40Erlangs. The results have shown that as the load is increased keeping all other parameters constant the blocking probability is increased many times but the blocking probability is minimum for the proposed algorithm amongst all the algorithms.

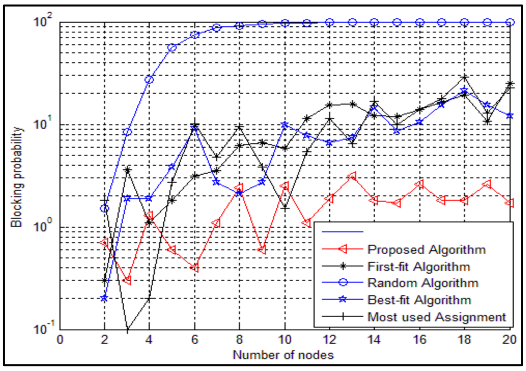

Fig. 5.10: Comparison of the algorithm for load=10 Erlangs; W=20

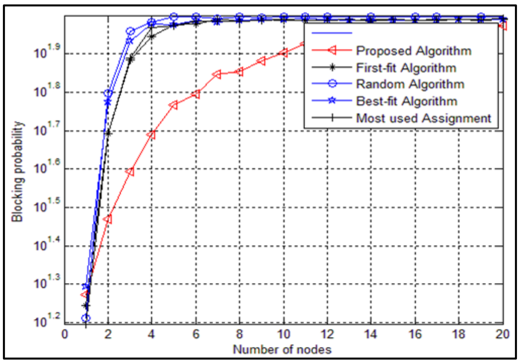

Fig. 5.11: Comparison of the algorithm for load=20 Erlangs; W=20

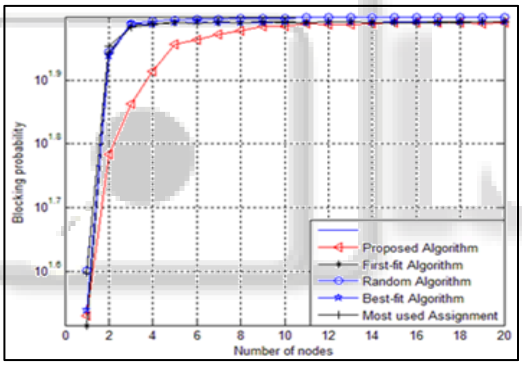

Fig. 5.12: Comparison of the algorithm for load=30 Erlangs; W=20

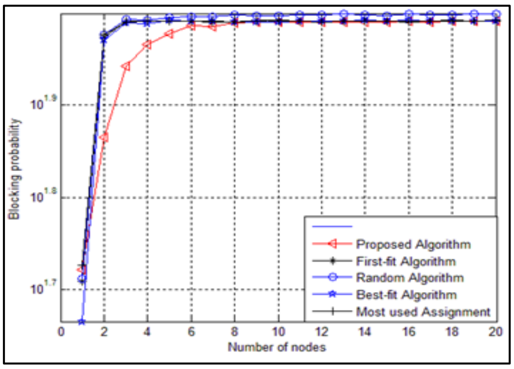

Fig. 5.13: Comparison of the algorithm for load=40 Erlangs; W=20

The results shown in figure (5.14) – (5.19) show the results when the other parameters kept constant and load is fixed to 10 Erlangs and the number of wavelengths used is increased as 10, 20, 30, 40, 50 and 100 respectively. The results have shown that as the number of wavelength is increased keeping all other parameters constant the blocking probability decreases very small for the conventional algorithm but this decrease is significant for the proposed algorithm. The results have shown that value of blocking probability is minimum for the proposed algorithm amongst all the algorithms.

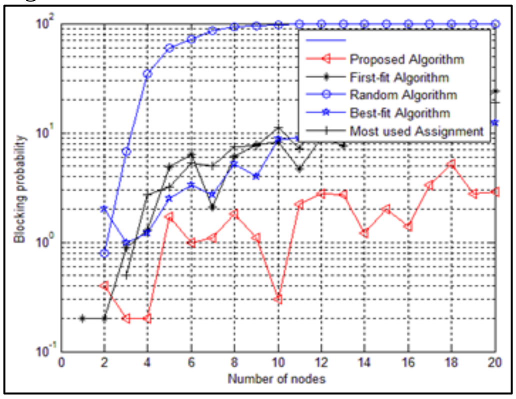

Fig. 5.14: Comparison of the algorithm for load=10 Erlangs; W=10

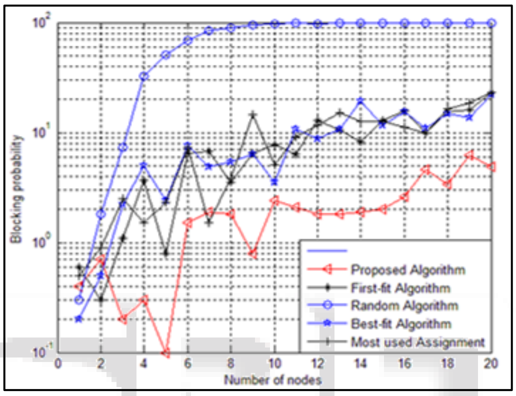

Fig. 5.15: Comparison of the algorithm for load=10 Erlangs; W=20

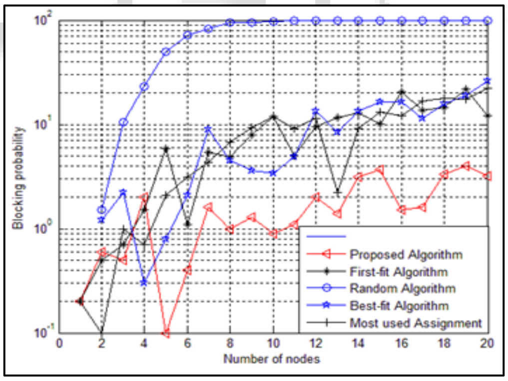

Fig. 5.16: Comparison of the algorithm for load=10 Erlangs; W=30

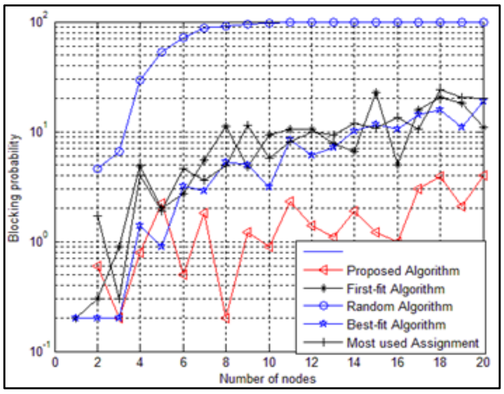

Fig. 5.17: Comparison of the algorithm for load=10 Erlangs; W=40

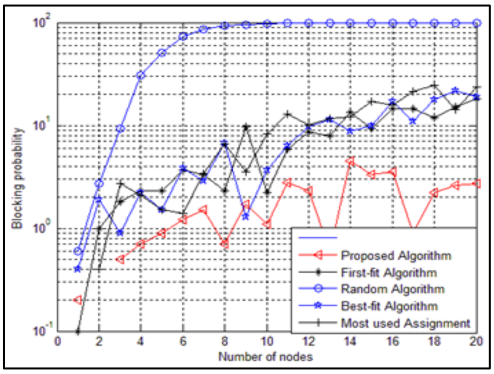

Fig. 5.18: Comparison of the algorithm for load=10 Erlangs; W=50

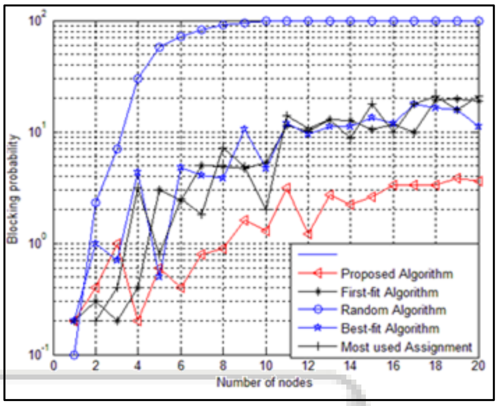

Fig. 5.19: Comparison of the algorithm for load=10 Erlangs; W=100

The results have proved that blocking probability of network is highest for random wavelength assignment algorithm and is lowest for the proposed algorithm. The blocking probability of proposed algorithm is low in comparison to the conventional algorithms. Thus, in situations where the algorithm of the given system can be changed then the proposed algorithm can be used. Also, the simulation results proved that blocking probability (%age) increases with increase in the number of nodes.

VII. CONCLUSIONS

In this thesis the Least Used Wavelength Conversion algorithm has been proposed for wavelength assignment and the performance of this wavelength assignment algorithm is evaluated in terms of blocking probability and fairness. In the first phase we have varied the number of wavelengths by keeping the other parameters constant. We have fixed the number of channels to 20; total number of links in the network to 20 and maximum load per unit link to 10 Erlangs and increased the number of wavelengths. The results prove that the blocking probability of the proposed algorithm decreases with the increase in the number of wavelengths. As the number of wavelength is increased the blocking probability is decreased. In the second phase, the load per unit link is increased keeping the other parameters constant. The results show that as the load is increased the blocking probability of the network increases for the proposed algorithm keeping other parameters constant.

Further, the blocking probability of proposed algorithm is compared with algorithms such as first-fit, best-fit, random and most-used wavelength assignment algorithm. For this comparison we have fixed the number of channels to 20; the total number if links used in the network is also fixed to 20; and the total number of wavelengths used along with the load per unit link is varied. The results have shown that as the load is increased keeping all other parameters constant the blocking probability is increased many times but the blocking probability is minimum for the proposed algorithm. This algorithm proposed gives the blocking free environment.

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