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Wavelength Selectivity Using Adaptive Shortest Path Algorithm for Optical Network

Piruthiviraj P*, Preeta Sharan and Nagaraj Ramrao

Department of ECE, The Oxford College of Engineering, Bangalore, Karnataka, India

ABSTRACT

The problem of routing and wavelength assignment is apparent in the dynamic all-optical network that plays an important role in the optical transport layer network. It is solved by minimising the connection blocking since the grooming adaptive shortest path algorithm shows comparably better results in terms of the calculation to find blocking probability. The shortest path algorithm used in this paper contains the present network state information, and each node creates a shortest path tree towards all the other nodes, which form node pairs by connecting each branch in the tree. The adaptive shortest path algorithm will find the shortest path throughout the network path and it chooses the best path from the available source-destination. Considering the number of nodes as 14 and comparing for different topology, it has been observed that the wavelength usage in each node varies with respect to different topology. Additionally, a comparative study of wavelength usage has been achieved for topologies like random, ring and tree.

Keywords: Adaptive shortest path algorithm, blocking probability, topology, wavelength assignment

INTRODUCTION

The problem of routing and wavelength assignment is a crucial issue that has received broad consideration among researchers (Karmi & Chlamtec, 1989). The demand for bandwidth by network users is increasing rapidly. Optical fibre network supports WDM network as its backbone for all solutions related to network issues. Over the decades, Internet traffic has been consistently increasing and has continued to see rapid growth with respect to number of users (Zang, 2000). Internet traffic is due to the huge amount of network capacity that is utilised on bandwidth-demanding networking applications such as IP telephony, video streaming, video conferencing and sharing of the network in peer-to-peer node configuration. The wavelength routed network uses all-optical channel fibre cables for users to communicate with one; this is referred to as

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E-mail addresses:
prithivi.eie@gmail.com (Piruthiviraj P)
sharanpreeta@gmail.com (Preeta Sharan)
nagaraj.ramrao@gmail.com (Nagaraj Ramrao)
*Corresponding Author

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the lightpath (Hurai, 1997). A lightpath utilised in a WDM optical network occupies multiple spans of fibre links. WDM networks without wavelength conversion is assigned as a common wavelength throughout the network and this property is said to be a wavelength continuity constraint.

ROUTING AND WAVELENGTH ASSIGNMENT

Routing Methods

Figure 1 shows lightpaths assigned to all combination pairs of access nodes with different wavelengths, λ1 and λ2. Using a set of connection links, the issues related to lightpaths are carried out through a routing path that is created between the nodes and a wavelength based on wavelength continuity constraint that is assigned, leading to a routing and wavelength assignment (RWA) problem (Kershenbaum, 1995). In general, a connection request in path selection is classified into three types: static routing, incremental and dynamic routing. In static traffic, the network connections (lightpaths) are pre-defined and the issue relates to lightpath connections using this structure (physical topology), resulting in reduction of network resources like wavelength usage in the network.

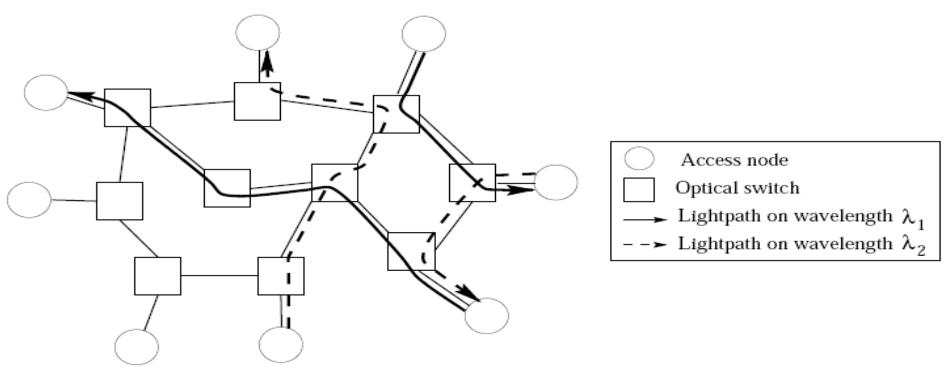

Figure 1. Optical WDM network

Multiple connections can be attempted using static traffic with the given number of wavelengths to minimise blocking ratio. Issues stemming from the RWA problem that are related to static traffic are called static light path establishment (SLE) problems. In a request involving incremental traffic, connection requests arrive in an orderly manner, and the lightpath is assigned for each connection indefinitely. In dynamic traffic, the lightpath assigned to each connection is released after the request is performed within a small interval of time. In both cases, the lightpath setup and wavelength assignment are done to accommodate a multiple number of connections and to reduce blocking that may be arise at any time. This approach is defined as the dynamic lightpath establishment (DLE) problem (Karmi, 1992).

Routing Sub-Problem

The SLE problem is formulated as two main sub-problems: i) Routing problem; and ii) Wavelength assignment problem. The routing sub-problem arises as three basic approaches: fixed routing, fixed alternate routing and adaptive routing.

Routing Types

Fixed routing is performed by creating a routing path fixed from the given pair of sources to destination connection. This simplest and most straightforward approach is performed as a fixed shortest path routing. The fixed routing uses either the standard shortest routing path algorithm such as Dijkstra's or the Bellman Ford algorithm and the shortest path route is established between the given pair of nodes in the pre-defined routing path. The fixed routing using the shortest path routing is established between Node 0 and Node 2.

Fixed alternate routing is considered to have multiple routes. Every node is assigned with a route according to the routing table, which contains a fixed order of routes to the entire destination node. The routing table is ordered with different shortest path routes as the primary route and secondary route. The primary route is linked between the source node and destination node, while the secondary route acts as a link between the pair of source-destination links, acting as an alternate route without any link to the first route.

Adaptive routing shows the better performance. According to the network state of information, the route is selected dynamically as a route between the source and the destination node. The adaptive shortest path algorithm is well suited for the WDM networks as it calculates the unused links and the used links. When there is a connection request, it calculates the shortest path from the source to the destination node.

Wavelength Assignment Heuristics

In the static wavelength assignment algorithm, based on the given set of lighpaths and routes, a wavelength is assigned to every lightpath; lightpaths do not share a similar wavelength on an optical fibre. The number of lightpaths assigned to any physical fibre link estimates the congestion based on the path selected for each connection. Each lightpath is chosen with the same wavelengths, minimising the number of wavelengths by utilising the wavelength continuity constraint feature.

Lightpaths arriving in incremental or dynamic traffic in an orderly manner should follow the heuristics methods for assigning wavelengths. With static wavelengths, the number of wavelengths assigned is fixed to avoid the dynamic problem and to minimise connection blocking. Although there are 10 wavelength assignment heuristics, the first-fit wavelength assignment technique is commonly used among all the methods as it shows the best performance in terms of blocking probability. In the first-fit scheme, wavelengths are numbered and when there is availability of wavelength, the lowest number of wavelengths is selected rather than the highest number of wavelengths, that is, the initial wavelength available is selected first. Compared with other wavelength assignment techniques, the computation cost is lower as it is not required to search the complete wavelength space for all the routes.

Shortest Path (SP) Algorithm

In Dijkstra's shortest path algorithm (Ribeiro, 2011), the shortest path route is created from every node to its respective destination node in the network. Node pairs are created by connecting the branches of the tree emerging from the individual node. Based on the SP algorithm, only the shortest path route forms a tree between the different node pairs. Topology changes that occur in a dynamic manner give rise to the adaptive shortest path (ASP) algorithm.

Generally, the ASP algorithm, according to the network state information shortest path, is calculated, after which it utilises the wavelengths for the shortest path route. As mentioned earlier, all wavelengths are not available in dynamic systems and they are represented by the traffic grooming method. In turn, they assign the wavelength to the Dijkstra's SP algorithm using the wavelength continuity method so that the connection link and the node pairs of a tree for the new route to be selected are updated.

Three criteria need to be met for the new route:

1) It should have a path that is shorter than available in the previous route.
2) A free wavelength should be available with a grooming wavelength.
3) It should not overrule the traffic constraints.

The first method is the same as the traditional SP algorithm, and a lightpath is assigned to the existing traffic, while the second method keeps a record of current information pertaining to the wavelength assigned, and when a new route is created, it makes sure that there is an available wavelength. The third method involves looking into the TR distance during the last regeneration. When a route is selected using the ASP algorithm, a wavelength is assigned for all the routes using the first-fit algorithm. In the static SP algorithm, the shortest path route is fixed in which a wavelength is assigned to the same, whereas the fixed alternate path algorithm first uses a shortest path and then changes to a second path as an alternative choice (link-disjoint method) if the other is fully occupied due to existing traffic in the network.

ADAPTIVE SHORTEST PATH ALGORITHM

The routing algorithm used here selects a route based on the network state information and it is computed after the arrival of a call request. Every router occasionally broadcasts link information to all other routers. This information is utilised to build a perspective view of the topology based on the related connection cost functions. Each router then checks the shortest path from the source to the destination. Topology is represented in the means of a graph G (V, E), in which V indicates the set of nodes and E the set of edges. Every link in the router is connected with a weight, wij, which denotes the cost of that particular link. The cost of the link altered is calculated using the number of wavelengths used.

DESIGN AND SIMULATION

The connection cost function is described as follows.
Given that P = { $e_1,e_2,\ldots e_L$} ∀ e_i ε is a route path composed by L (2) and i= 1, 2, 3,…, M, M therefore indicates the maximum number of links active in network. Then, the total cost of the path, P, is calculated as the sum of all the link costs.

$$C_{T,P} = \sum_{i=1}^{L} Cej\ \ P \tag{1}$$

where, $C_{T,P}$ represents as total cost of the path C_ej as the individual cost of the link e_i ε P. Therefore, cost function is calculated as cost value added when a connection is established and cost value is subtracted when the connection is ended.

$$C^{n}_{i\,j} = \{\ C^{n-1}_{i\,j} + 1,\backslash\ C^{n-1}_{i\,j}\ - 1 \tag{2}$$

The initial cost of all the links is given as:

$$C^{o}_{ij} = 1\ ,\ \forall\ (i,j)\ \varepsilon\ E \tag{3}$$

The connection setup increases the cost value in each connection link and the liberation decreases the cost. It occurs up to a maximum of value $C_{ij} = \infty$, which represents the occupation of all the wavelengths. The cost of a function will increase by excluding the next request if a connection is established in a route that results in an equal load distribution for the network (Humblet, 1996).

Traffic Model

On the assumption of a network topology and traffic load, blocking performance for the SP algorithm is proposed in this paper. Blocking probability is calculated using the adaptive shortest path algorithm and first-fit algorithm (Ribeiro, 2011). Independence models described (Subramaniam, 2014) in the paper use recursive algorithms that are applicable for the dense networks and increase the blocking probability. Some models are assumed to be used for small networks that have an extensive algorithm. The model used in this paper was modified from previous works based on an algorithm that has less computational complexity, which is not suitable for a large number of wavelengths (Wason, 2011). In some models (Sun, 2003), it is proposed that the first-fit algorithm is based on overflow traffic and used as a recursive algorithm, which is suitable for a small number of wavelengths.

In this paper, performance analysis of blocking probability was calculated and analysed using the adaptive shortest path algorithm based on the first-fit wavelength assignment algorithm. The framework used was the adaptive SP algorithm with wavelength assignment algorithm. The network for different topology without a wavelength conversion analytical model is described and simulated using the above algorithm to calculate blocking probability.

Mathematical Model of Blocking Probability

Blocking probability was calculated without wavelength conversion. The wavelength continuity constraints were implemented in assigning the wavelengths. If there is insufficient free wavelength available in the network, blocking probability will be increased. Call blocking is generally calculated as:

$$P_B = (\text{Number of calls blocked})/(\text{Total number of calls generated}) \quad (4)$$

Additionally, blocking probability is calculated using the standard Erlang formula:

$$P_B = L^W / W! \; / \sum_{i=0}^{W} (L^i / i!) \quad (5)$$

where, P_B is the blocking probability with respect to load, L, and wavelength, W. The algorithms used in this paper were the first-fit wavelength assignment algorithm and the adaptive shortest path algorithm, which were compared with Dijkstra's algorithm.

The mathematical model suggested in this paper denoted the routing path in uppercase link parameters in lower case. Prefixes and suffixes used represented links, node and routes. The network was assumed to be without wavelength conversion.

N = number of nodes in the optical network (14 nodes), N ε V.
L = length of the path or number of links or path selected, *r*
r = number of routers; *r* ε R
PB = blocking probability due to insufficient wavelengths
Nλ = free wavelengths available

Algorithm Description

The adaptive shortest path algorithm was computed on the base of the network state information and the wavelength was utilised effectively. The topology structure ring, random and tree are presented in Figures 5, 6 and 7, respectively. Network simulation using MATLAB was performed using a different topology structure that had 14 nodes and 50 wavelengths that were assigned for transmission of data packets.

The following procedures were followed:

1) Initial creation of nodes was carried out and the nodes were placed in the structure according to the topology.
2) Wavelength to be assigned was defined.
3) Source and destination nodes in the structure were defined.
4) The algorithm was used to compute and find the available path in the network.
5) The initial shortest path was calculated using Dijkstra's algorithm.
6) The wavelength from the table for the best path chosen was assigned.
7) Bandwidth constraints were used to ensure that data transmission followed the best path to avoid loss of data and that connection was available.

8) If data transmission is completed, the total number of data transferred in the network is calculated.

9) If data transmission is not completed, the number of data packets are calculated and free wavelength available in the network is assigned.

10) After the completion of data transmission, blocking probability in the network was estimated.

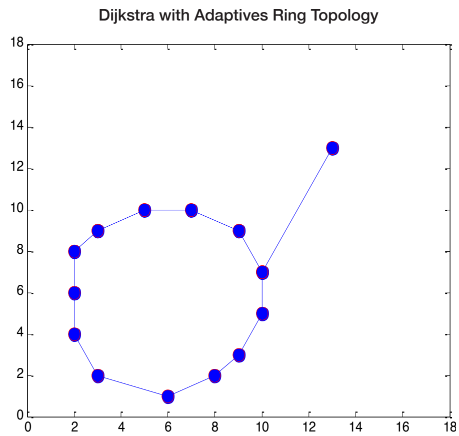

Figure 2. Ring topology with 14 nodes

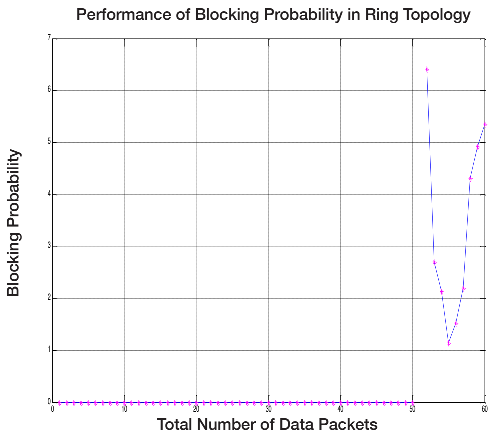

Figure 3. Blocking probability analysis

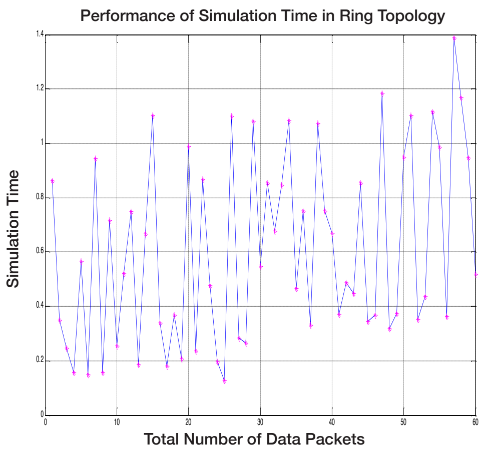

Figure 4. Simulation time

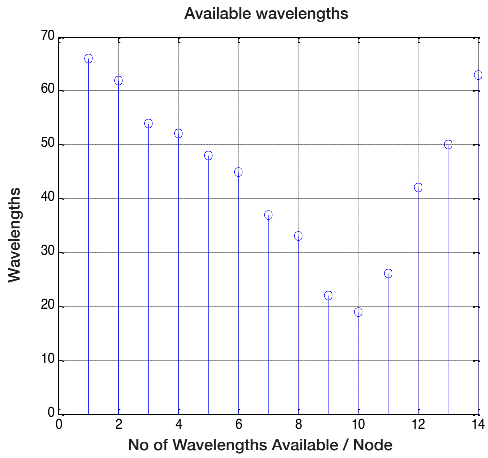

Figure 5. Wavelength utilisation

SIMULATION RESULTS AND DISCUSSION

Figure 2 represents the structure of ring topology in the network. Nodes were placed according to the ring structure as defined in the programme. The advantage of ring topology is that it enhances data transmission throughout the nodes in the network. Figure 3 shows the estimation of blocking probability, which increased after the transmission of 50 data packets due to the non-availability of wavelengths from the wavelength table. Data packets are transmitted once a free wavelength is assigned. Figure 4 shows the calculation of the simulation time, which varied accordingly with respect to the data packets to be transmitted. The graph showed increases and decreases in time since the data transfer took place once the free wavelength was available in the network. Finally, the estimation of wavelength usage is shown in Figure 5; the number of wavelength utilisation varied with respect to the nodes as the nodes came one after another. Wavelength was therefore assigned to the individual combination of source and destination nodes.

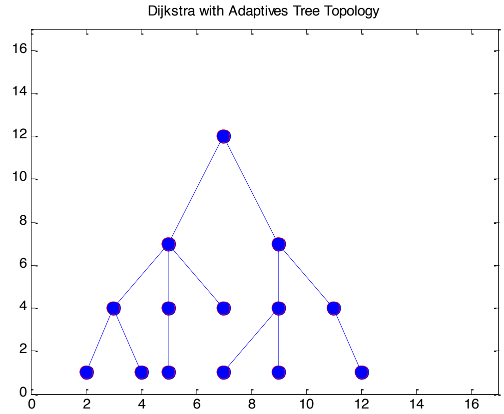

Figure 6. Tree topology with 14 nodes

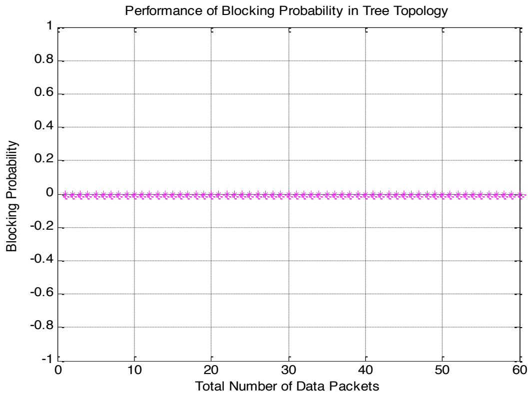

Figure 7. Blocking probability analysis

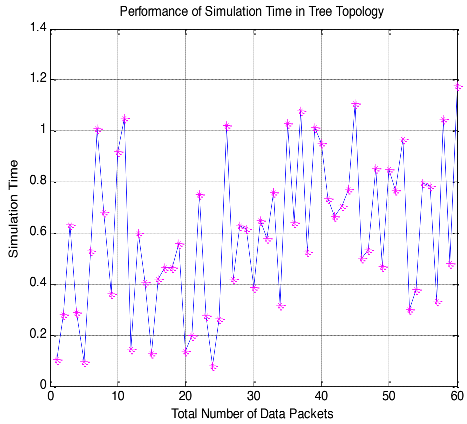

Figure 8. Simulation time

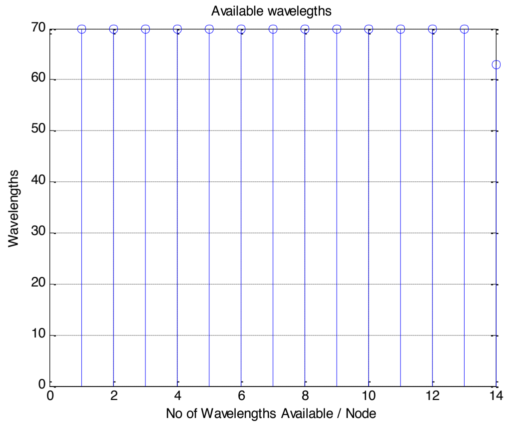

Figure 9. Wavelength utilization

Figure 6 shows the tree topology of the network. The node structure indicates that there were multiple links placed in between the different pairs of nodes. Figure 7 indicates zero blocking probability, but due to the multiple links placed between the nodes, connection cost may have been increased, as is the case with wavelength converters if different wavelengths are used in the programme. Figure 8 shows the simulation time obtained during the transmission of data in the ring topology. Simulation time was calculated as CPU time as it showed how fast the data packets were transmitted through the network. Figure 9 shows the estimation of the blocking probability node by node. The tree structure created multiple pairs of nodes in the network. It had various branches in the network structure so it assigned the required wavelength and lightpath to individual pairs of nodes. Wavelength was utilised effectively throughout the network structure.

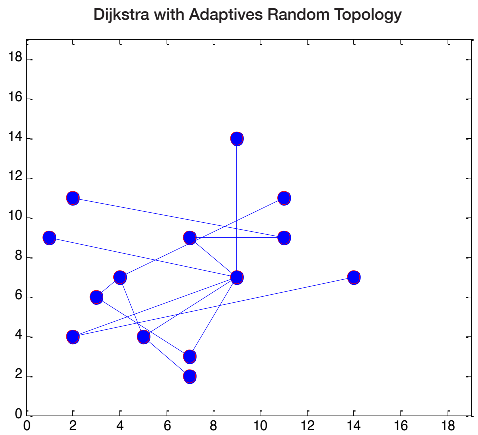

Figure 10. Random topology with 14 nodes

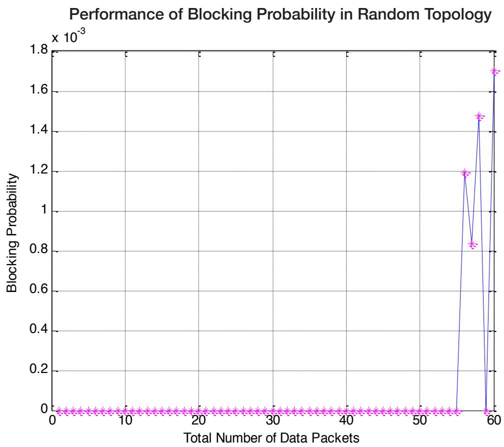

Figure 11. Blocking probability analysis

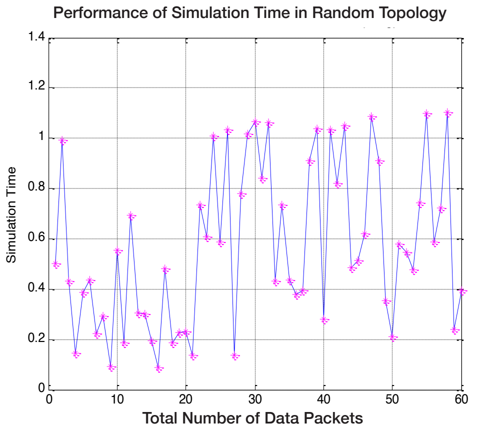

Figure 12. Simulation time

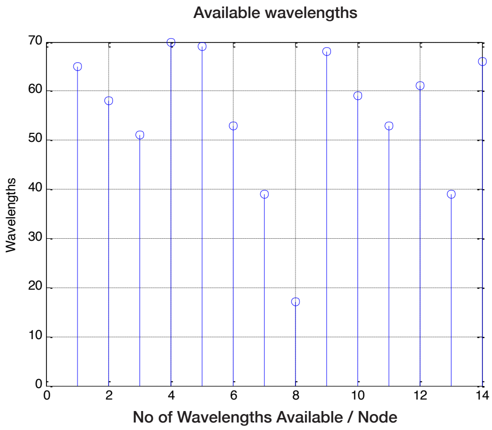

Figure 13. Wavelength utilisation

The random topology shown in Figure 10 indicates that the nodes were placed invariably in the network. This created multiples of node pairs. Figure 11 shows the simulation of the random topology as the same mesh network structure in which wavelength was initially assigned to all the nodes. After the number of data packets reached 50, blocking probability was increased due to the non-availability of wavelengths. Once free wavelength was released, the remaining data packets were transferred. The graph shows that the blocking probability was increased. Figure 12 shows the estimation of the simulation time required for the completion of the transmission of the data packets. Wavelength usage was calculated for the random topology. The study showed that the wavelength utilisation was non-uniform as there was mixing of the routing path in the network. The shortest path network was attended to as soon as there was a wavelength available for the service.

CONCLUSION

In this paper, various approaches of routing algorithms were explained to route the path and assign wavelength in the optical fibre network. The different routing types studied were the fixed, fixed alternate and adaptive algorithm. The algorithm implemented in this work showed better performance in the aspect of blocking probability. Simulation time, packets transferred and traffic load were the design parameters that justified the performance level of blocking probability. The node structure was obtained for ring, random and tree topology using 14 nodes as defined in the NSFNET structure.

The results stated that the usage of the ASP routing algorithm enhances the performance analysis of the RWA algorithm by reducing the usage of wavelengths for the corresponding level of blocking probability based on the adaptive routing when compared to other two routing algorithms. However, this is limited only with respect to the routing technique implemented in different topologies compared with the use of adaptive routing in various topologies like tree, ring and random. Tree topology had reduced wavelength utilisation compared with the other two since it had multiple links and wavelengths were assigned to the corresponding node pairs so it had no blocking probability due to the effective utilisation of wavelengths. We conclude that the use of adaptive algorithm showed better performance in choosing the best path and in lower blocking using tree topology.

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