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Modeling and Simulation of Wavelength-Routed optical Networks

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Abstract

All-optical Wavelength Division Multiplexing (WDM) networks providing extremely large bandwidths are among the most promising solutions to the increasing need for high-speed data transport. A lightpath has a specific route and one or more wavelengths through which the information is routed from the source to the destination node. In wavelength-routed optical networks, data are transmitted solely in the optical domain along lightpaths from source to destination without being converted into the electronic form and each lightpath is allowed to use the same wavelength on all the links along its path. This restriction is known as the wavelength continuity constraint. And it leads to an issue called as blocking in networks. Optical wavelength conversion with suitable Routing and wavelength assignment (RWA) can increase the performance and capacity of optical networks by eliminating this restriction and relaxing the wavelength continuity constraint. In this research, we analyze the problem of placing a limited number of wavelength converters in a mesh network using Weighted Maximum Segment Length (WMSL) converter placement algorithm. It employs Least-Loaded Routing and First-Fit (LLR-FF) RWA algorithm. It is tested on varying number of nodes in network and its respective blocking probabilities are calculated. The proposed algorithm provides the minimum blocking probability on optimal wavelength converters placement.

Keywords: *Wavelength Division Multiplexing (WDM), Wavelength-Routed Networks, Wavelength Continuity Constraint, Routing and Wavelength Assignment (RWA), Optical Network, First-Fit (FF),*

I. Introduction

The advantages of optical fiber communication lead to a technology called as Wavelength-Division Multiplexing (WDM) which multiplexes the multiple signals onto a single optical fiber. WDM in optical fiber networks has been rapidly gaining acceptance as a means to handle the ever-increasing bandwidth demands of network users. A wavelength-routed all-optical WDM network comprises of optical wavelength routing nodes that is wavelength routers interconnected by optical fiber links. A lightpath is to be set up before any communication between any two wavelength routers. These light paths need to be set up dynamically by determining a path across the network connecting the source to the destination is called as routing. Allocating the free wavelength on each fiber link along the chosen path is called as wavelength assignment [1]. Routing and Wavelength Assignment (RWA) is a fundamental problem in the engineering, control, and design of all-optical networks and it arises in most network design applications, including traffic grooming, survivability design, and traffic scheduling. There are various routing algorithms in all–optical networks using WDM and wavelength routing in Wide Area Networks (WAN). This study aims to highlight the RWA problems in WDM optical networks. The RWA algorithm plays a role of selecting the path and assigning a wavelength to it called as lightpath. Generally RWA algorithms block the call requests if a continuous or same wavelength from source to destination cannot be found. This drawback is known as Wavelength Continuity Constraint (WCC). This failure of RWA algorithm to find available wavelengths on all the links in network from source to destination results into congestion or blocking. This blocking causes loss of signals [2]. Blocking or congestion is a major challenge in the design of WDM networks. Wavelength conversion is used to eliminate wavelength blocking in optical networks. Hence, RWA and Wavelength Conversion (WC) are the techniques to improve the blocking performance. The existing research has proved that these are two techniques to be considered together to solve the blocking problem in networks [3].

II. Literature Survey

2.1. RWA algorithms

Routing is the process of selecting best paths in a network. In the past, the term routing was meant to forward network traffic between networks. It is also described as forwarding. The routers are used mainly by connecting several networks and providing packet forwarding to different networks. The main idea for routing protocols is to establish the best path from the source to the destination [4]. The routing algorithm is a major factor in the performance of the routing environment. The purpose of the routing algorithm is to make decisions for the router concerning the best paths for data. The router uses the routing algorithm to compute the path from the source to the destination. There are three basic approaches of routing in networks such as fixed routing, fixed-alternate routing and adaptive or dynamic routing [2]. In fixed routing, all the paths are fixed for source-destination pairs. Standard Shortest path algorithms (SPA) are used to calculate the shortest path route for each source-destination pair. Predetermined routes are used for the connection between the specified pair of nodes using these algorithms. This routing has the disadvantages such as it is unable to handle the fault situations where more number of links are failing and it results into the large number of wavelengths if the resources are not available for the particular path. In fixed-alternate routing (FAR), every node in the network is required to maintain the routing table that contains an ordered list of numbers of fixed paths to each and every destination node. Alternate-shortest path (ASP) algorithms are used to calculate the multiple shortest paths. These alternate paths do not share any common link between source and destination pair. If no path is available from the routing table, then the connection is blocked or lost. The network state information is not considered in fixed and fixed-alternate routings [2]. In adaptive or dynamic routing, the path is selected dynamically from a source to a destination node, depending on the network state. And the network state is determined by all the set of connections that are currently in progress [2]. Hence dynamic routing approaches are more efficient than static routing approaches [5].

The allocation of free wavelength on each link along the selected path is called as wavelength assignment. Heuristic methods are used to assign wavelengths to the lightpaths when arrive one at a time. Random wavelength assignment heuristic performs well in the low traffic network. First-Fit (FF) performs better in high traffic network to assign free wavelengths to the paths. Most used heuristic also achieves the same performance as that of FF, but FF is simple and easy to implement [6]. Hence dynamic routing together best wavelength assignment scheme works much better than any other static algorithms. So dynamic RWA algorithms are developed to improve the overall blocking performance of the wavelength-routed optical networks. The existing research shows the dynamic RWA with FF algorithms are the best suitable wavelength assignment algorithms [2], [3].

2.2. Wavelength Conversion

Today wavelength-routed all optical networks are considered as the best candidates for the next generation networks [3]. The wavelength conversion plays an important role in improving the fiber link utilization. It also reduces the blocking probability of the optical networks [7]. A wavelength converter is used to convert one wavelength to another wavelength by placing it on the nodes in the networks. As it is observed in literature survey that sparse wavelength conversion and full wavelength conversion can be implemented to eliminate the wavelength continuity constraint in wavelength-routed optical networks. Since wavelength converters are expensive. Hence, they cannot be used at every node in the network. When it is used on every node of the network for conversion, then it is called as full wavelength conversion and when it is used at particular nodes in the networks then it is called as sparse wavelength conversion [8]. Most of the research work has focused on sparse wavelength conversion as it is achieving satisfactory performance with a small number of converters.

2.3. Issues related to sparse wavelength conversion

RWA and Wavelength Conversion (WC) can be used together to improve the blocking performance. Specially, sparse wavelength conversion can be used to improve the overall blocking performance of the networks than full wavelength conversion as it uses small number of converters. The wavelength converter placement problem is not considered as critical as placing the wavelength converters in the network in order to minimize the blocking probability. The placement of optimal wavelength converters on appropriate nodes is very important to reduce the blocking in networks. The existing research has considered this as an individual issue and this can be solved by using wavelength converter placement algorithms in networks. The wavelength converter placement algorithms are already existing for the topologies like ring, bus [9]. The development of converter placement algorithms for an arbitrary network such as mesh is very difficult. Hence number of converter placement algorithms are developed. All are assumed suitable for static networks [10-13].

In literature study, it is seen that for mesh networks, the dynamic RWA algorithms with wavelength conversion has to be designed. A well designed wavelength converter algorithm for a particular RWA algorithm might not work well with different RWA algorithms. So it is necessary to design RWA algorithm with its suitable wavelength converter placement algorithm. In the proposed work, the problem of placing the limited wavelength converters on appropriate nodes in network is investigated and the blocking performance is observed by calculating the blocking probabilities of the paths. The Least-Loaded Routing With First-Fit wavelength assignment algorithm (LLR-FF) is used. Under LLR-FF RWA, the heuristic algorithm called as Weighted Maximum Segment Length (WMSL) for wavelength converter placement is employed.

III. Implementation of Converter Placement Algorithm under LLR-FF RWA Algorithm

2.4. LLR-FF RWA algorithm with sparse wavelength conversion

The LLR algorithm is a commonly used dynamic routing algorithm which achieves better performance than static routing algorithms in terms of blocking probabilities. Sparse wavelength conversion is used in LLR-FF RWA algorithm to place limited number of wavelength converters. The analytical model includes the LLR-FF with sparse wavelength conversion which is given in [3]. This analytical model includes the path-blocking analysis and link-traffic analysis. The mesh network consists of *N* nodes and *J* fiber links. Each link has *W* wavelengths that are labeled from 1 to *W*. The call holding time is exponentially distributed with one unit time. The *M* number of wavelength converters are used in the networks. This LLR-FF RWA algorithm is used to set up lightpaths in networks. The following are the steps to determine the overall blocking probabilities:

1. Initialize all the blocking probabilities of the paths, $B_{R_a^{(t)}}$ as zero where $R_a^{(t)}$ is the path passing through the node pair *a*.
2. The m_j is the available wavelengths on link *j*. Let $q_j(m_j)$ denote the probability that m_j wavelengths are free on link j. So $q_j(0)$ is initialized as zero for all links.
3. Determine $\propto_j$ for all links where $\propto_j$ is the rate at which call requests arrive at link j which follows Poisson distribution.
4. Calculate $B_{R_a^{(t)}}$ for all the paths. If new values of $B_{R_a^{(t)}}$ are converged then iteration is terminated otherwise go to step 2 again.
5. Finally, determine the overall blocking probability.
   The above steps are performed using the analytical equations given in [3]. When a call request arrives for node pair a, it selects a path and assign wavelength to that path. The states of the number free wavelengths on the M_a paths are examined. The M_a are the paths passing through the node pair *a* where wavelength converters are placed. The path with the maximum free wavelengths is selected for connection. Call request gets blocked if there is no free wavelength on the path. The path with the smallest label is selected if two paths are having same number of free wavelengths. FF is used to assign wavelengths to the paths.

2.5. WMSL algorithm for wavelength converter placement

The heuristic algorithm called as WMSL for wavelength converter placement employs the LLR-FF RWA algorithm in mesh network. The WMSL algorithm places the converters sequentially one by one on nodes. The nodes which give less blocking probabilities than other nodes are found. These nodes give less blocking probabilities after placing the wavelength converter on them. The approach is to assign a weight value to each and every node present in the network. These weight values are used to decide the significance of the node for reducing blocking probabilities. The most important factor affecting the blocking probability of the path is length of the path. When there is no wavelength conversion then length of the path affects the blocking probability significantly [14]. Since wavelength converters divide the length of the path into segments or links. So it eliminates the issue called as wavelength continuity constraint. Hence blocking probabilities of the paths are directly related to the maximum segment length of that path. This WMSL algorithm is employed to minimize the sum of the maximum segment length of the paths over the network. The following are the steps of WMSL algorithm to place the wavelength converters in the network in order to reduce blocking probability and avoid of loss signals:

1. Once the wavelength is blocked due to wavelength continuity constraint then calculation is made for the blocking probability.
2. The weight values are calculated for each node present in that path in terms of blocking probabilities.
3. The maximum length of path is calculated among the paths passing through each and every node of the path.
4. Again the maximum length is calculated for each node after placing a wavelength converter on them. And difference between these two maximum lengths (step 3 and step 4) is multiplied with the offered traffic to that path
5. The maximum value of the node is selected to place a wavelength converter.
6. The number of wavelength converters can be placed till it reaches the acceptable value for blocking.

In this way the proposed WMSL algorithm is executed to find the suitable nodes to place the wavelength converters in networks.

IV. Results and analysis

The proposed WMSL algorithm for wavelength converter placement is simulated using MATLAB software. The simulations are done for different number of nodes in the network. In proposed work, the mesh network consists of *N* number of nodes which is varying as 9- Nodes and 16-Nodes respectively. The number of wavelengths in networks used are five that is *W*= 5. In simulations, the call requests arrived to the networks are following a Poisson distribution and the call holding time is exponentially distributed. Then according to the nodes and offered traffic to the network, carried traffic 'L' is calculated. The results are observed using MATLAB software which are significantly reducing the blocking probabilities by using wavelength converters for 9-nodes and for 16-nodes respectively.

4.1 Simulation results for 9-Nodes

Here the mesh network of 9-nodes is simulated where the nodes are placed randomly as shown in Figure 1.

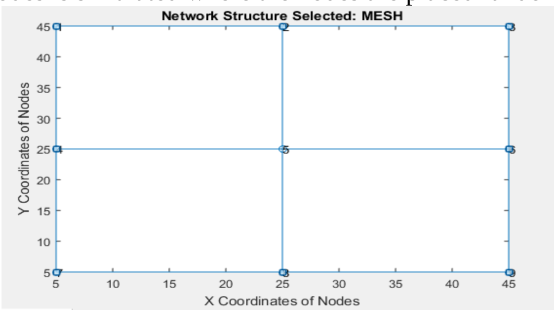

Figure 1. Network Structure for 9-Nodes

Here the routing is done using SP algorithm to decide the best path for a particular source and destination nodes. The number of links present on the path are giving the maximum number for wavelength converter placement. Three links or segments are included in the shortest path for Node- 2 as source and Node- 9 as destination. So the maximum three wavelength converters can be used in the network to minimize the blocking probability as shown in Figure 2.

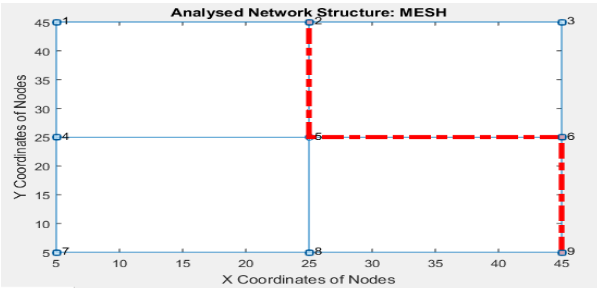

Figure 2. Shortest Path for 2-9 Nodes

After selecting the source and destination nodes, the blocking probabilities of all the links present in that shortest path are calculated using the steps explained in Section 3. The following table gives the blocking probabilities for Node-2 as source and Node-9 as destination.

Table 1. Blocking Probabilities for 2-9 Nodes with no, one, two and three wavelength converters

Number of Nodes in Network	Source-Destination Nodes	Blocking Probabilities with No Converter	Blocking Probabilities with Wavelength Converter =1	Blocking Probabilities with Wavelength Converters =2	Blocking Probabilities with Wavelength Converters =3
9-Nodes	2-9	0.0003	0.0003	-	-
		0.0089	0.0065		
		0.0098	0.0099		
		0.0020	-	0.0005	-
		0.0072		0.0055	
		0.0096		0.0090	
		0.0005	-	-	0.0000
		0.0044			0.0009
		0.0090			0.0051

Figure 3 shows the comparative difference between the blocking probabilities for no wavelength converter and after placing one wavelength converter in the network. The blocking probabilities with no wavelength converter can block the traffic. So to avoid such congestion or blocking, wavelength converters are used. The wavelength converter is placed on a node that from there the blocking probability is minimum. So with one wavelength converter again blocking probabilities are calculated showing the significant difference.

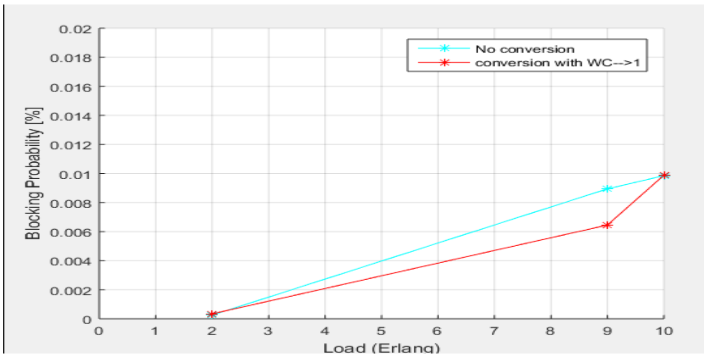

Figure 3. Blocking Probabilities for no converter and for one converter placement

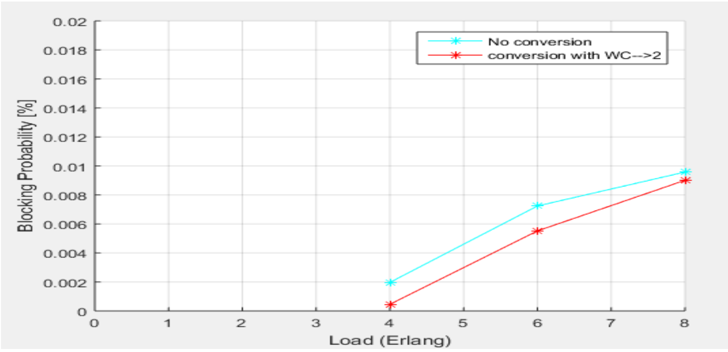

Figure 4. Blocking Probabilities for no converter and for two wavelength converters placement

Figure 4 and Figure 5 show the comparative difference between the blocking probabilities after placing two and three wavelength converters for 2-9 Nodes in network. As the number of wavelength converters increases the blocking probability decreases. It is observed that with only a few wavelength converters the blocking probability can be decreased by a large margin. Once the number of wavelength converters is beyond some threshold then blocking probability decreases very slowly. When there is no conversion in network the blocking probability for 2-9 nodes is 0.0190 (in percentage). When one and two wavelength converters are used, the total blocking probabilities are 0.0167 and 0.0150 (in percentages) respectively. When three wavelength converters are used then blocking probability is 0.0060 (in percentage). It is showing that it is reducing as number of wavelength converters are increased. So the optimal number of wavelength converters for 2-9 nodes are three.

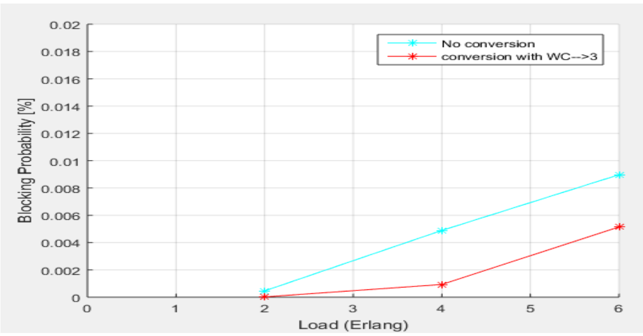

Figure 5. Blocking Probabilities for no converter and for three converters placement

Therefore, the sparse wavelength conversion is very meaningful for arbitrary networks where traffic is nonuniform and independent. A 35% investment of wavelength converters for 2-9 Nodes has achieved better blocking performance up to 75%.

4.2. Simulation results for 16-Nodes

Here the mesh network of 16-nodes is simulated where the nodes are placed randomly as shown in Figure 6

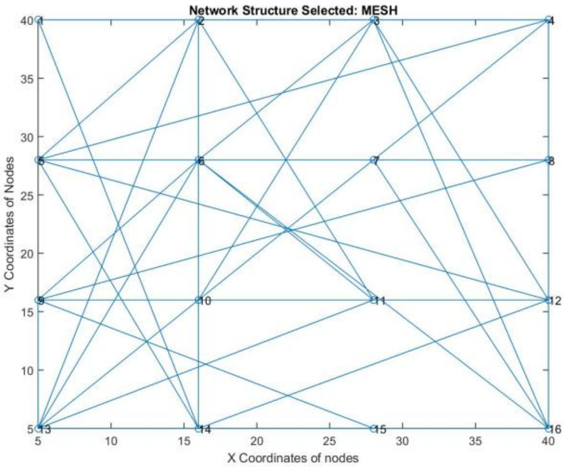

Figure 6. Network Structure for 2-15 Nodes

The Figure 7 shows the shortest path selected for 2-15 nodes using SP algorithm where 2 is source node and 15 is destination node. The number of links involved in the shortest path are three. So maximum three wavelength converters can be used for wavelength conversion for 2-15 nodes in network.

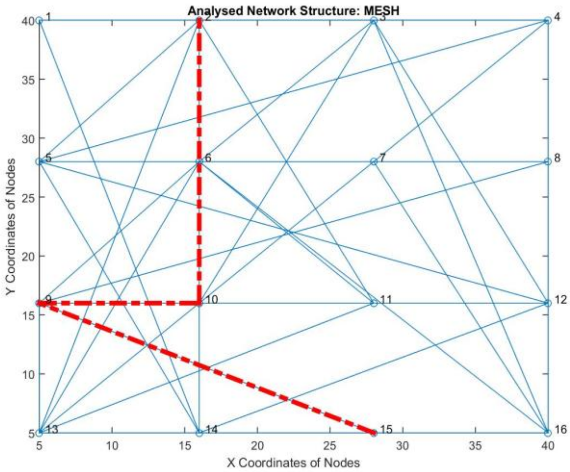

Figure 7. Shortest Path for 2-15 Nodes

The

Table 2 gives blocking probabilities for 2-15 Nodes. It is efficiently showing the reduction in blocking probabilities when wavelength converters are used.

Table 2. Blocking probabilities for 2-15 Nodes with no, one, two and three wavelength converters

Number of Nodes in Network	Source-Destination Nodes	Blocking Probabilities with No Converter	Blocking Probabilities with Wavelength Converter =1	Blocking Probabilities with Wavelength Converters =2	Blocking Probabilities with Wavelength Converters =3
9-Nodes	2-15	0.0004	0.0001	-	-
		0.0082	0.0065		
		0.0098	0.0099		
		0.0003	-	0.0001	-
		0.0089		0.0065	
		0.0098		0.0099	
		0.0010	-	-	0.0002
		0.0087			0.0053
		0.0098			0.0079

Figure 8 shows the comparative difference between the blocking probabilities for no wavelength converter and after placing one wavelength converter in the network. The blocking probabilities with no wavelength converter can block the traffic. So the wavelength converters are used on appropriate nodes to reduce it.

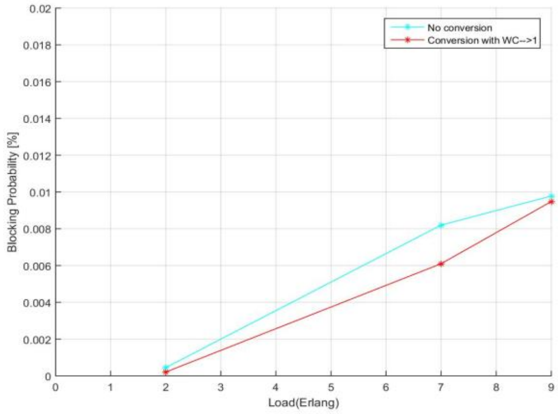

Figure 8.Blocking Probabilities for 2-15 Nodes for no converter and for one converter placement

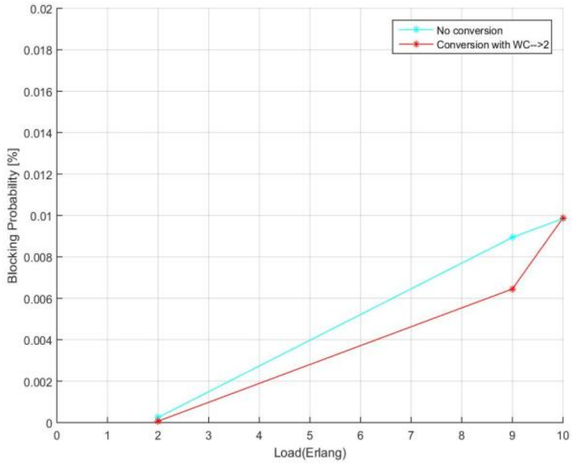

Figure 9.Blocking Probabilities for 2-15 Nodes for no converter and for two converters placement

Figure 9 and Figure 10 show the comparative difference between the blocking probabilities after placing two and three wavelength converters for 2-9 Nodes in network. When there is no conversion in network the blocking probability for 2-15 nodes is 0.0190 (in percentage). When one and two wavelength converters are used, the total blocking probabilities are 0.0158 and 0.0165 (in percentages) respectively. When three wavelength converters are used, the total blocking probability is 0.0134(in percentage). Hence it is reducing the blocking in network efficiently as number of wavelength converters are increased. So the optimal number of wavelength converters for 2-9 nodes are three.

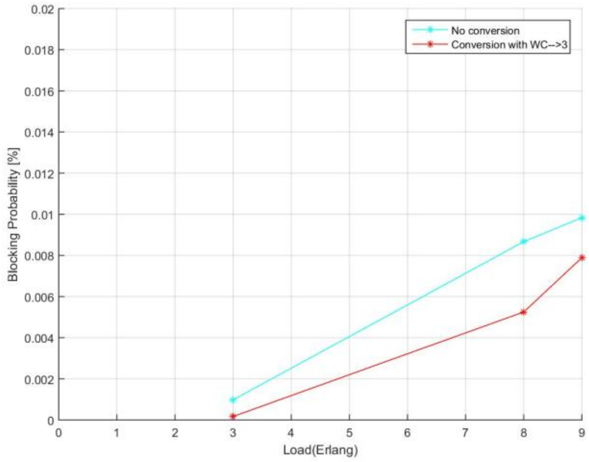

Figure 10. Blocking probabilities for 2-15 Nodes for no converter and for three converters placement

Therefore, a 19% investment of wavelength converters for 2-15 nodes has achieved the better performance up to 75%.

V. Conclusion And Future Scope

The proposed work has modelled, simulated and analysed the dynamic RWA algorithm with wavelength conversion. This work deals with the following analysis of reduction in blocking probabilities and usage of optimal number of wavelength converters. It is concluded that sparse wavelength conversion can improve the blocking performance efficiently in mesh networks with non-uniform traffic. An investment of 15%-40% (overall) of wavelength converters can improve the blocking performance in network. Hence the cost of using more number of wavelength converters is avoided. It has been observed that the proposed work reduces the number of wavelength converters in networks according to the traffic given. And it achieves the performance as that of the full wavelength conversion. So it is concluded that the proposed algorithm is efficient for minimizing the blocking probabilities in wavelength–routed optical networks. The study can be extended in the future in following possible directions:

1. A single generic RWA algorithm for all the types of optical networks can be designed so that there will be no issue related to the routing and wavelength assignment of different topology
2. The algorithm can be designed with fast computations
3. These algorithms can be designed by taking different metrics like delay, jitter.

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