Wavelength Reassignment Algorithms for Optical WDM Networks

Rajalakshmi P *Ashok Jhunjhunwala*

Telecommunications and Computer Networks (TeNeT) Group,
Department of Electrical Engineering,
Indian Institute of Technology Madras,
Chennai 600 036, India.
[raji, ashok]@tenet.res.in

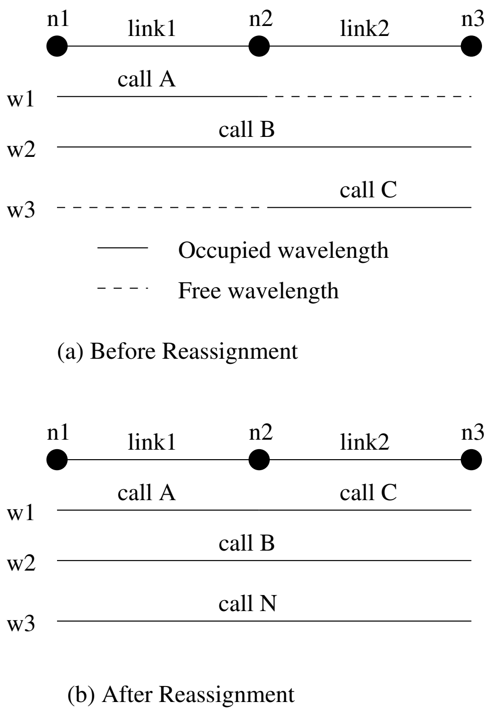
Abstract

In this paper, we have proposed a *wavelength reassignment algorithm* to enhance the blocking performance, in the circuit-switched wide-area optical wavelength division multiplexed (WDM) networks with no wavelength conversion at the nodes. The limitation of such a no conversion network is the ***wavelength continuity constraint*** (wcc). In the wavelength conversion networks, blocking occurs due to capacity exhaustion on the links and not due to wcc. Hence these networks have the *optimal* performance, achieving the lowest possible blocking probability (Pb). Our aim is to see if one can achieve this near optimal blocking performance in no conversion networks by using the ***wavelength reassignment techniques***. We have proposed an heuristic reassignment algorithm namely, **MOLC** and studied the performance on some standard backbone optical networks. Simulation results show that in these example networks, our proposed reassignment algorithm can mostly remove the blocking due to the wcc and achieve the optimal performance.

1. Introduction

Wavelength-division multiplexing (WDM) [1] in optical networks is a promising technology to utilize the enormous bandwidth of opitcal fiber and it offers the capability of building very large wide-area networks with throughputs of the order of gigabits per sec for each node [2]. Lightpaths which is a high-bandwidth end-to-end circuit carries the traffic between nodes. Nodes are equipped with optical cross connects (OXCs) which can selectively drop and add some of the wavelengths locally, switch wavelengths from one input port to another (wavelength routing , WR), and are able to change the wavelength of an incoming lightpath to any of the outgoing wavelengths, called the wavelength conversion capability of the OXCs [3]. No wavelength conversion networks are the one in which the nodes do not possess the wavelength conversion capability. In such a network, a lightpath is established on a route only if there exists atleast one wavelength which is simultaneously free on all the links of that route. This constraint is known as the wavelength continuity constraint (wcc). On the other hand in networks with wavelength conversion, a call is accepted if on all the links of its route there is atleast one free wavelength. Therefore in these conversion networks, a call gets blocked only due to the capacity exhaustion on the links and not due to wcc. Thus, having wavelength conversion is advantageous in that it decreases the blocking probability, Pb and increases channel utilisation [4]. The conversion networks are therefore considered as the **optimal networks**. However, implementing all-optical full wavelength conversion is quite difficult due to technological limiations. Optical wavelength converters are still in the experimental stage. Electronic *wavelength crossconnects* (WXC) are used to realize wavelength conversion at the nodes which involves OEO (Optical-Electronic-Optical) conversions which is considered to be a costlier feature of OXCs [3].

We consider the optical backbone network based on a wavelength-routed mesh topology, in which the nodes do not possess the wavelength conversion capability. To remove any blocking due to the wavelength continuity constraint in such a network, we have proposed *wavelength reassignment techniques*. When the new call gets blocked due to wcc, the wavelength reassignment moves some of the already established calls in the network, so as to create a wavelength-continuous route to accommodate the new call. Here, while wavelength reassignment is carried out, the routes for the already established call remains the same i.e. no rerouting is done. Fig. 1. gives an example of the reassignment technique. Let there be three nodes *n1, n2* and *n3* connected with three wavelengths w_1, w_2 and w_3 per link. Figure 1(a) gives the current network status, in which, call *A* between *n1* and *n2* occupying w_1, *B* between *n1* and *n3* occupying w_2 and *C* between *n2* and *n3* occupying w_3. A new call arrival, *N* between *n1* and *n3* is blocked due to wcc. If there exists wavelength conversion, then N can be established in w_3 in link 1 and w_1 in link 2. Since there is no conversion, reassign the wavelength for call *C* from w_3 to w_1. By doing this, w_3 is free on both links 1 and 2, on which *N* can be established as



(a) Before Reassignment

(b) After Reassignment

Fig. 1. Example for Reassignment technique

shown in Fig. 1(b). Thus by wavelength reassignment, the blocked call due to wcc can be established in the no conversion network.

We consider the dynamic version of the circuit switched model, where session requests arrive to the network, based on some stochastic arrival process. Once a connection request arrives between a pair of nodes, the network manager (centralised system), runs the routing and wavelength assignment (RWA) algorithm to establish the lightpath for the connection request. The basic RWA algorithm is, for routing, we use the shortest path finding algorithm such as *Dijkstra's* algorithm and for wavelength assignment, the *First Fit* algorithm which has the lowest computational complexity is used [5], [6]. If the lightpath cannot be established due to wcc, the manager runs the proposed reassignment algorithm to accomodate the call in the network. If the lightpath cannot be established, the call is blocked and is dropped from the network. The reassignment can be activated at a time when the carried traffic is very low (generally late in the night). Care has to be taken so as not to disrupt traffic during the reassignment time.

Simulation based analyses are used to study the improvement in the blocking performance, for the proposed reassignment algorithms. We are particularly interested to know whether one can achieve performance close to that of the full wavelength conversion (optimal) using the reassignment algorithms in no wavelength conversion networks. The simulation results on some standard backbone networks show that, when the call blocking occurs, by employing the proposed reassignment algorithms, performance almost equivalent to full wavelength conversion can be achieved.

2. Critical links of the Optimal Optical network

Uniform traffic distribution (UTD) is used, where there is a call from every node to every node of the network and all these calls are equally likely. Fixed shortest path routing is used to find the path between the source destination pair. In a N node network, for UTD, the number of routes are, $R = (N \times (N-1))$. The number of routes which uses a particular link i, gives the frequency of usage of the link i which is F_i. The carried traffic on link i is dependent on the frequency of link usage F_i. For UTD, the total load on the network, $L_{network}$ is equally distributed on all the routes. Therefore the load on each of the route is given by,

$$L_{route} = \frac{L_{network}}{R} \tag{1}$$

The carried traffic or offered load on the link i which has a frequency of usage F_i is

$$A_i = L_{route} \times F_i \tag{2}$$

The link which has the highest frequency of usage, F_{max}, has the maximum carried traffic which is

$$A_{max} = L_{route} \times F_{max} \tag{3}$$

Thus for an offered load on the network, the link with the highest frequency of usage F_{max}, carries the highest traffic A_{max} and gets congested first than any other link in the network. Hence this link is the *most congested link* or the *critical link* of the network for the UTD. If we consider the congestion level of this most congested link as 1 (100%), then the congestion level of other links in the network can be obtained by normalising their link frequency by F_{max}. Thus, the congestion level of any link i in the network is given by $\frac{F_i}{F_{max}}$.

For the optimal networks, the route of the blocked call will involve the capacity exhaustion of atleast one of the critical or near-critical links in the network. The network without wavelength conversion, has blocking due to the capacity exhaustion of the critical links as well as due to wcc. Hence the blocking probability is high compared to that of the optimal network. The route which get blocked due to wcc may not involve the critical links. By using our proposed wavelength reassignment algorithms, we try to remove any call blocking which occurs due to wcc in the no conversion networks.

3. Proposed Reassignment Algorithms

The wavelength reassignment problem is an *NP complete* problem. Hence, we have proposed an heuristic wavelength reassignment algorithms namely, MOLC - Minimum Overlap to Least congested wavelength. Before getting into the details of these algorithms, let us define some of the parameters which are used in these algorithms.

3.1. Some parameter definitions

1. Wavelength Congestion, of C_{w_i} is the number of links which uses the wavelength w_i. If C_{w_i} = 0, means the wavelength w_i is not used in any of the links in the network or it is the ***least congested wavelength (LC)*** in the network. If C_{w_i} = L, means w_i is used in all the links of the network. This is the most congested wavelength.

2. Overlap Degree, O_{w_i}: This gives an overlap count for a wavelength w_i, which is the number of links out of the total links required for the new blocked call, that are occupied by the already established calls, in that particular wavelength. Higher is the overlap, then higher is the O_{w_i}. The wavelength with minimum overlap is called the ***minimum overlapping wavelength (MO)***.

3.2. MOLC - Minimum Overlap to Least Congested wavelength

In this technique, when the call gets blocked, the network manager reassigns the calls from the minimum overlapping wavelength to the least congested wavelength. Once all the links required for the blocked call are freed, establish the call in the freed wavelength. A pseudocode description of the algorithm is given below.
When the new call request gets blocked,

1. *Get the link required for the blocked call*

2. *Calculate C_{w_i} and O_{w_i} for each of the wavelengths w_i, where $i = 1, 2...w$*

3. *Sort the wavelengths in the ascending order of its overlap degree (O_{w_i}) and congestion (C_{w_i}), forming the Overlap array and Usage array.*

4. *For each entry of the Overlap array starting from the first, do*
   For each entry of the Usage array starting from the first, do
   Reassign the already established calls that are occupying the link required from the MO wavelength to the LC wavelength.
   If all the links required are freed in the reassignment process, then
   Establish the blocked call in the freed wavelength. Break from the loop
   end
   end
   end

5. *If the call is not established in step 5 then*
   Drop the call
   end

6. *Go back to basic RWA for the next call request.*

The effect of MO and LC are more evident, when the number of wavelengths (w) and the number of links (L) in the network are large i.e. for large network with higher capacity. Choosing the minimum overlapping wavelength first, from which reassignment is to be done, ensures, smaller number of calls to be reassigned. The chance of finding free links in the least congested wavelength is high, hence the already established calls are reassigned from MO to LC wavelengths.

4. Performance Analysis

We now analyse the performance of the reassignment techniques on some standard backbone networks, such as NSFNET (Fig. 2), INDIANET (Fig. 5) and ARPANET (Fig. 6). The dynamic traffic model is considered where arrivals are Poisson and holding times are exponentially distributed with a mean of h. Uniform traffic distribution (UTD) is assumed, where there is a call from every node to every other node and all these calls are equally likely. The GNU Scientific Library [7] is used for the dynamic traffic generation. The number of wavelengths per link, w=30. The metric used for performance analysis are.

1. G, the percentage gain in the load supported for a particular value of blocking probability (Pb). Load supported, by the no conversion network is L_{noconv}, by the conversion network is L_{conv} and by the reassignment is $L_{reasssn}$. G_{conv} and G_{reassn} gives the percentage extra load that can be supported by the conversion networks and by reassignment respectively, from that of the no conversion networks. Thus

$$G_{conv} = \frac{(L_{conv} - L_{noconv}) \times 100}{L_{noconv}} \quad (4)$$

$$G_{reassn} = \frac{(L_{reassn} - L_{noconv}) \times 100}{L_{noconv}} \quad (5)$$

2. The deviation in the performance of the reassignment algorithm from the optimal performance. The deviation in terms of load, Dev_L is given by

$$Dev_L = \frac{(L_{conv} - L_{reassn})}{L_{conv}} \quad (6)$$

3. Average number of reassigned calls per reassignment process, is the average number of calls that need to be reassigned in the wavelength reassignment algorithm, in order to establish a blocked call in the network. This gives the disturbance caused in the network by the reassignment process.

For simulation, the values are averaged over 100 batches for each load. We present the times taken for computation on the different test networks, for a Pb_{reassn} value of around 0.01 in table I. Note the computation times are on the order of seconds.

Table 1: Times for computation on different networks

Networks	**MOLC** Time (secs)
NSFNET	2.64
INDIANET	3.68
ARPANET	5.3

Let us consider the 14 node, 21 link **NSFNET** for our analysis. For UTD using fixed routing, link 13, 15, 8 and 11 are the critical links whose congestion levels are greater than 0.9 and is marked in Fig. 2. The route of any blocked call in the NSFNET optimal network, will involve the capacity exhaustion of atleast one of these four critical links. By wavelength reassignment algorithm, we try to remove any call blocking due to wcc and would like to ensure only capacity exhaustion blocking of the critical links. Fig. 3 gives Pb Vs Load per node. For

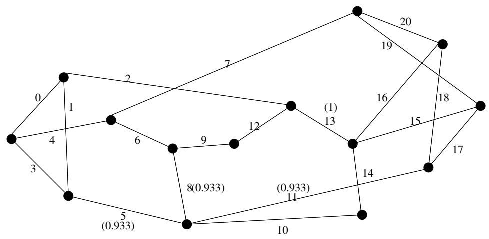


Fig. 2. 14 node, 21 link NSFNET network with the critical links marked

Pb=0.01, L_{noconv} = 8.9285 Erlangs/node, L_{conv} = 9.775 Erlangs/node, L_{MOLC}=9.762 Erlangs/node, the gain in the load for the conversion (optimal) network is around G_{conv} = 9.48% and for reassignment is around G_{reassn} = 9.36% from the no conversion network. The deviation in load for the reassignment algorithm from the optimal performance, Dev_L = 0.0010. Thus the gain in the load attained by using the reassignment algorithm in the no conversion network is almost equivalent to the conversion network with a very negligible deviation. Fig. 4 plots the average number of reassigned calls per reassignment process across different loads for the NSFNET. For the entire range of the load considered for the experiment, the number of calls reassigned in MOLC is less than 2. Thus MOLC technique gives a performance almost equivalent to the optimal causing very less disturbance in the network.

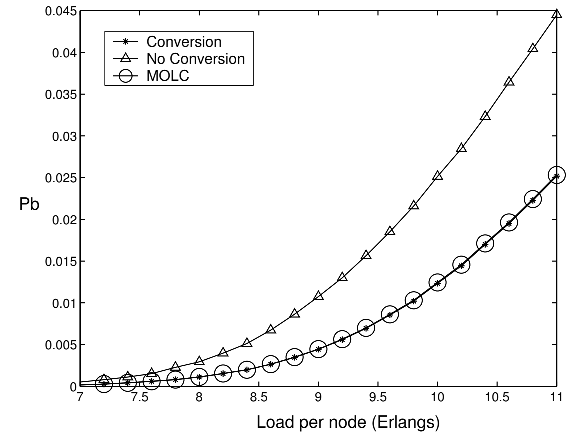


Fig. 3. Blocking Probability Vs Load per node for NSFNET network

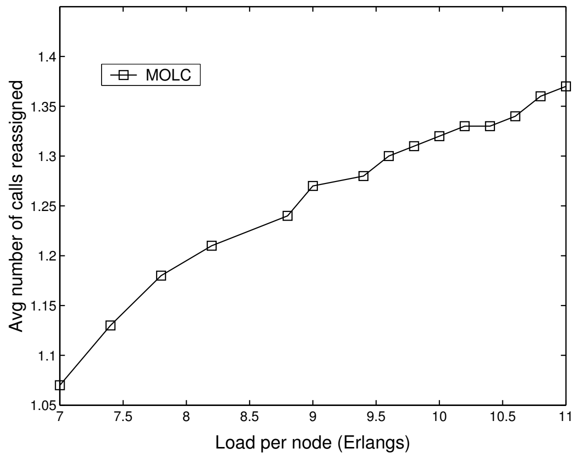


Fig. 4. Average number of calls reassigned per reassignment versus load per node for NSFNET

We would like to introduce the large data network, which is emerging in India, 20 node, 33 link **INDIANET** [8]. Link 10 is the critical link. From Fig. 6 which plots Pb Vs load per node, for a Pb=0.01, the gain in load supported by reassignment is around 7% from no conversion with a very small deviation of Dev_L=0.00028 from the optimal.

Consider the 20 node, 32 link **ARPANET**. Fig. 7 plots Pb Vs load per node, the gain in load supported for conversion is G_{conv}=11.658% and for reassignment is G_{reassn}= 9.08% from no conversion. There is a deviation of around 2.3% in the performance achieved by reassignment from the optimal performance. In this test network, ARPANET, the reassignment could not remove all the blocking due to wcc. We are in the process of identifying *features* of the network, which prevents the reassignment to totally remove wcc blocking. We are also examining how even in such networks one can get the same performance as that in the wavelength conversion

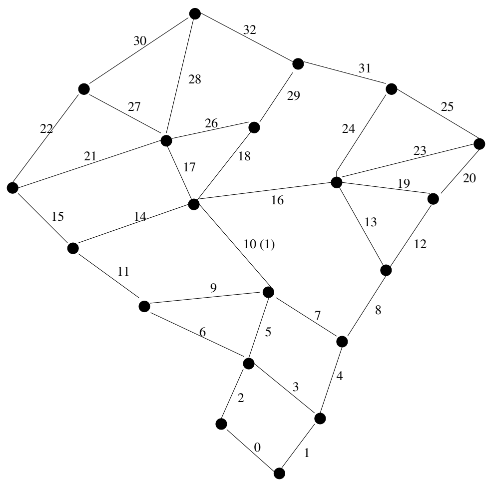


Fig. 5. 20 node, 33 link INDIANET with critical links marked

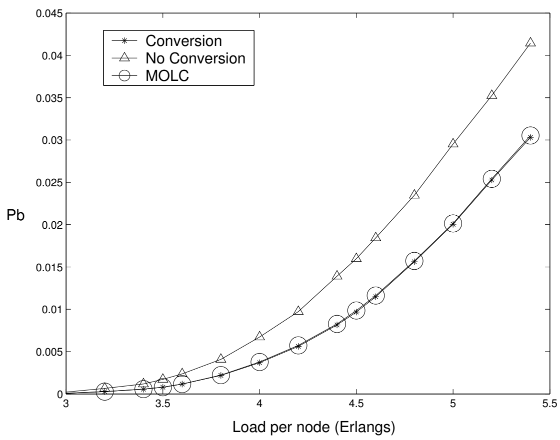


Fig. 6. Blocking Probability Vs Load per node for INDIANET

networks by appropriately modifying the routing and reassignment techniques.

5. Conclusion

In this paper, we have proposed an heuristic algorithm for the wavelength reassignment problem, to improve the call blocking probability in no wavelength conversion optical networks. We have done the performance analysis of the proposed algorithm, MOLC, on the standard backbone networks. The simulation results on the networks NSFNET and INDIANET, show that by using the reassignment techniques, the wcc blocking is almost removed and blocking occurs only due to capacity exhaustion of the critical links of the network, which is equivalent to the optimal network performance (full wavelength conversion). MOLC wavelength reassignment technique also causes minimum disturbance in the network. In one of the test networks (ARPANET), there is a slight deviation in the performance of the reassignment from the optimal performance. The detailed analysis on the features of such networks is under study.

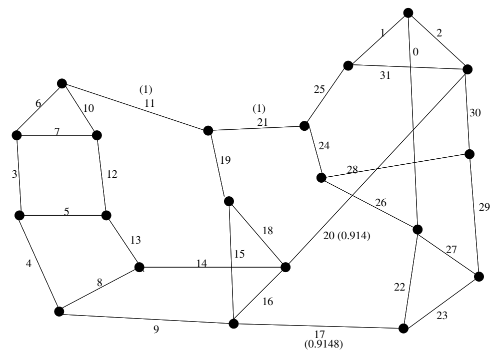


Fig. 6. 20 node, 32 link ARPANET with critical links marked

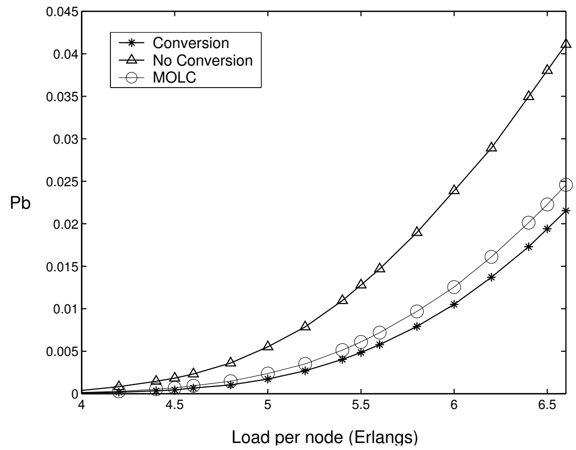


Fig. 7. Blocking Probability Vs Load per node for ARPANET

6. References

[1] C. A. Brackett, "Dense wavelength division multiplexing network principles and applications," *IEEE Journal on Selected Areas in Communicatinos*, vol. 8, pp. 948-964, Aug. 1990.

[2] R. Ramaswami, "Multi-wavelength lightwave networks for computer communication,"*IEEE Communications Magazine*, vol. 31, pp. 78-88, Feb 1993.

[3] R. Ramaswami and K. N. Sivarajan, "*Optical Networks: A Practical Perspective*," Morgan Kaufmann Publishers, San Francisco, 1998.

[4] B. Ramamurthy and B. Mukherjee, "Wavelength conversion in WDM networking," *IEEE Journal on Selected Areas in Communications*, vol. 16, pp. 1061-1073, Sept. 1998.

[5] H. Zang, J. P. Jue, and B. Mukherjee,"A review of routing and wavelength assignment approaches for wavelength-routed optical WDM networks," *Optical Networks Magazine*, vol. 1, no. 1, pp. 47-60, Jan. 2000.

[6] R. Ramaswami and K. N. Sivarajan, "Routing and wavelength assignment in all-optical networks," *IEEE/ACM Transactions on Networking*, vol. 3, pp. 489-500, Oct. 1995.

[7] "*GNU Scientific Library – Reference Manual*"

[8] "*www.tenet.res.in/graph/indianet.html*"